RECLAIMING ECOLOGICAL SUSTAINABILITY OF URBAN STREAMS BY USE OF GREEN INFRASTRUCTURE TECHNIQUES

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfilment of the Requirements for the Degree of

MASTER OF SCIENCE

in Urban Design

by
Selçuk AKSOY

July 2016
İZMİR

We approve the thesis of **Selçuk AKSOY**

Examining Committee Members:

Assist. Prof. Dr. Nicel SAYGIN
Department of City and Regional Planning, İzmir Institute of Technology

Prof. Dr. Adnan KAPLAN
Department of Landscape Architecture, Ege University

Assist. Prof. Dr. Nursen KAYA EROL
Department of City and Regional Planning, İzmir Institute of Technology

25 July 2016

Assist. Prof. Dr. Nicel SAYGIN
Supervisor, Department of City and Regional Planning,
İzmir Institute of Technology

Prof. Dr. Serdar KALE
Deputy Head of the Department of City and Regional Planning,

Prof. Dr. Bilge KARAÇALI
Dean of the Graduate School of Engineering and Sciences

ACKNOWLEDGMENTS

I would like to extend my sincerest gratitude to my supervisor Assistant Professor Dr. Nicel Saygın for her excellent guidance, friendly support and encouragement. I would also like to thank Professor Dr. Adnan Kaplan and Assistant Professor Dr. Nursen Kaya Erol for their significant criticisms of my research.

Finally, I offer my deepest thanks to my dear family, friends and colleagues for their patience and support.

ABSTRACT

RECLAIMING ECOLOGICAL SUSTAINABILITY OF URBAN STREAMS BY USE OF GREEN INFRASTRUCTURE TECHNIQUES

Ecological sustainability of urban streams has been significantly reversed from the last quarter of the 20th century onwards. This reverse has occurred as a result of increasing urbanisation and human activity, including construction in floodplain areas, relocation and culverting of streams, channelization, riparian clear-cut, and discharge of wastewater into streams. However, on comprehending the significance of urban streams, ecologically-based stream rehabilitation projects have been preferred to hard engineering solutions. These rehabilitation projects not only restore stream ecosystems but also reclaim their contribution to urban landscapes through the provision of ecological, social, and cultural assets.

Based on the above, this study sets out to examine urban stream rehabilitation in the context of sustainable water management. In that regard, this research suggests an integrated and holistic approach through green infrastructure tools which can compensate for misguided human interventions on nature, and reclaim ecological sustainability of urban streams and their environs. In line with ecological sustainability, best practices from various countries and the case study of the research evidenced how the degraded stream ecosystem could be rehabilitated by using green infrastructure techniques.

The research methodology used in the study involves analysis of the theoretical literature on green infrastructure and stream rehabilitation, best practice analysis, and case study analysis to develop a rehabilitation guideline for Arap Stream and its surroundings. In this sense, the research presents urban-scale, district-scale and neighbourhood-scale rehabilitation strategies for the case study. Finally, the study delivers the rehabilitation plan for Arap Stream that includes in-stream and green infrastructure techniques.

Keywords: *Stream rehabilitation, green infrastructure, sustainable water management, Arap Stream and its surroundings, urban streams, ecological sustainability*

ÖZET

YEŞİL ALTYAPI TEKNİKLERİ KULLANIMI İLE KENTSEL AKARSULARIN EKOLOJİK SÜRDÜRÜLEBİLİRLİĞİNİN YENİDEN SAĞLANMASI

Kentsel akarsular, son yıllarda yanlış müdahalelere maruz kalarak ekolojik işlevselliklerini yitirmişlerdir. Taşkın alanlarındaki yerleşimlere tehdit oluşturmaması açısından kentsel akarsuların güzergâhları değiştirilmiş, beton kanallara alınmış veya yer altına alınarak "ıslah" edilmişlerdir. Akarsu ekosistemlerinin zarar görmesi yalnızca ekolojiyi tahrip etmemiş, ayrıca kent kimliklerinin ve değerlerinin de yitirilmesine sebep olmuştur. Zaman içerisinde yapılan müdahalelerin daha yıkıcı etkilere sebep olduğunun anlaşılması ile akarsuların ekolojik rehabilitasyonu tüm dünyada gündeme gelmiştir. Bu yaklaşım akarsuların yalnızca ekosistemini iyileştirmemiş, aynı zamanda kent peyzajına da önemli katkı sağlamıştır.

Bu çalışma, sürdürülebilir su yönetimi çerçevesinde kentsel akarsuların ekolojik ıslahını ele almaktadır. Bu bağlamda, çalışma yeşil altyapıyı bir araç olarak kullanıp kentsel akarsularda yanlış müdahalelerin etkisini azaltan ve aynı zamanda akarsu ıslahını sağlayan bütüncül ve entegre bir anlayışı ön plana çıkarmaktadır. Çalışma farklı ülkelerde uygulanmış pek çok başarılı örneğin yanı sıra, Arap Deresi ve çevresi için hazırlanan ıslah projesini de sunarak bu sorunlara nasıl çözüm getirilebileceğini ortaya koymaktadır.

Çalışmada kullanılan metoda göre, ilk olarak teorik literatür değerlendirilmiş, daha sonra uygulanmış projeler irdelenmiş ve en son Arap Deresi ve çevresinin analizi yapılmıştır. Tüm elde edilen bulgular ile Arap Deresi ve çevresi için şehir, bölge ve mahalle ölçeğinde ilkeler geliştirmiştir. Çalışma aynı zamanda bu yeşil altyapı temelli ilkeleri kullanarak hazırladığı öneri projesini sunmaktadır.

Anahtar Kelimeler: *Dere ıslahı, yeşil altyapı, sürdürülebilir su yönetimi, Arap Deresi ve çevresi, kentsel akarsular, ekolojik sürdürülebilirlik*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1. Problem Definition

Natural water resources such as rivers, streams, lakes, wetlands and wildlife habitats have constantly been subjected to modification. Flowing freshwater has, to a large degree, undergone significant changes over the past centuries as a consequence of the conventional approach at the time, which claimed that the stormwater and flooding issue in urbanised environments could be overcome through channelized streams.

In line with the conventional approach and urbanisation, urban streams have been straightened, altered, deepened and converted into concrete channels to mitigate flood risk. Naturally-vegetated floodplains have been replaced by dwellings and impervious surfaces such as concrete, asphalt roadways and other paved areas. Since these surfaces are unable to absorb stormwater during heavy rains, the replacement has resulted in further degradation, including increased velocity of urban streams, excessive erosion, pollution and uncontrolled runoff on impervious surfaces. Furthermore, urban streams have also been heavily polluted by stormwater and wastewater.

On the other hand, the transformation of natural watercourses into artificial channels not only resulted in the loss of wildlife habitat and decreased biodiversity, but also increased the distance between people and natural spaces, and changed the spirit of certain places. Even though urban streams were once offering ecosystem goods and enhancing the social life of cities, they have been abandoned to their fate.

After all the misguided human interventions on nature, stream rehabilitation projects have been initiated in different parts of the world with the aim of recovering the degraded stream ecosystem, decreasing negative impact on the overall environment, re-naturalizing stream beds, improving water quality and riparian vegetation, enhancing biodiversity and wildlife habitat, and controlling runoff from rainfall. Additionally, several buried streams are daylighted again, not only to restore their ecosystem but to reclaim their contribution to the urban landscape, and to provide recreational opportunities.

Despite the popularity and success of the concept of “ecological rehabilitation”, urban streams in Turkey are still being regulated in a conventional way in the name of “stream rehabilitation”. For that reason, urban streams, many of which act as wastewater carriers, can often be faced with the possibility of being buried underground or rerouted. To protect permanent settlements in floodplains from flood damage, pure engineering solutions are still carried out in Turkey, but have resulted in further degradation and fragmentation of urban streams and landscapes. Accordingly, urban streams that have lost their natural characteristics are no longer being recognised as part of the urban landscape, since they have been isolated from cities and urban life.

It is the intention of recent stream rehabilitation projects across the world with an emphasis on ecological sustainability to show how natural resources, which have been influenced by human impact, could be saved and reclaimed for public use. Thus, this study criticises conventional approaches towards urban streams, introduces innovative rehabilitation approaches, including ecological rehabilitation and green stormwater infrastructure, and proposes a holistic rehabilitation plan for the case study of the research: Arap Stream and its surroundings in İzmir, Turkey.

1.2. Study Objectives

For the purpose of this study, green infrastructure and stream rehabilitation techniques are presented within a holistic and integrated framework which can reverse misguided human impact on stream ecosystems, and reclaim ecological sustainability of urban streams and their surroundings. In that sense, this study offers an ecologically-based rehabilitation approach towards urban streams, instead of conventional engineering solutions.

The main question of the study is; “How can urban streams, which have been dramatically altered by human intervention, be rehabilitated by using innovative approaches such as green infrastructure and in-stream techniques?”. In light of the main question, the sub-questions to be examined are listed in Table 1.1.

Table 1.1. The need for the study

• To show the ecological stream rehabilitation as an urgent need for cities. • To explore the integration of green stormwater infrastructure techniques and urban stream rehabilitation. • To compare the conventional stream rehabilitation techniques with the alternative and innovative solutions in terms of environmental performance.	Theoretical-Scale
• To examine urban stream rehabilitation perspectives in Turkey. • To guide future stream rehabilitation practices in Turkey.	Country-Scale
• To develop a rehabilitation guideline for Arap Stream. • To propose a holistic stream rehabilitation plan for Arap Stream and its surroundings.	Urban-Scale

1.3. Methodology

The method of the study consists of three main phases: evaluation of the theoretical literature; analysing best practice; and the case study analysis. From the findings of these steps, the study develops a rehabilitation guideline for the case study of the research, Arap Stream and its surroundings. Moreover, it presents a sustainable rehabilitation plan for the case area through utilising rehabilitation strategies (Figure 1.1).

The first phase of the study is based on an extensive literature review focused on urban streams, stream rehabilitation, green infrastructure, sustainable water management, and ecological sustainability. This phase is to find a link between green infrastructure and stream rehabilitation. For this purpose, journal articles, book chapters, research reports, electronic documents, dissertations and city maps were reviewed. In addition, numerous academics from İzmir in Turkey, and Prague in the Czech Republic, who specialise in stream rehabilitation, were consulted.

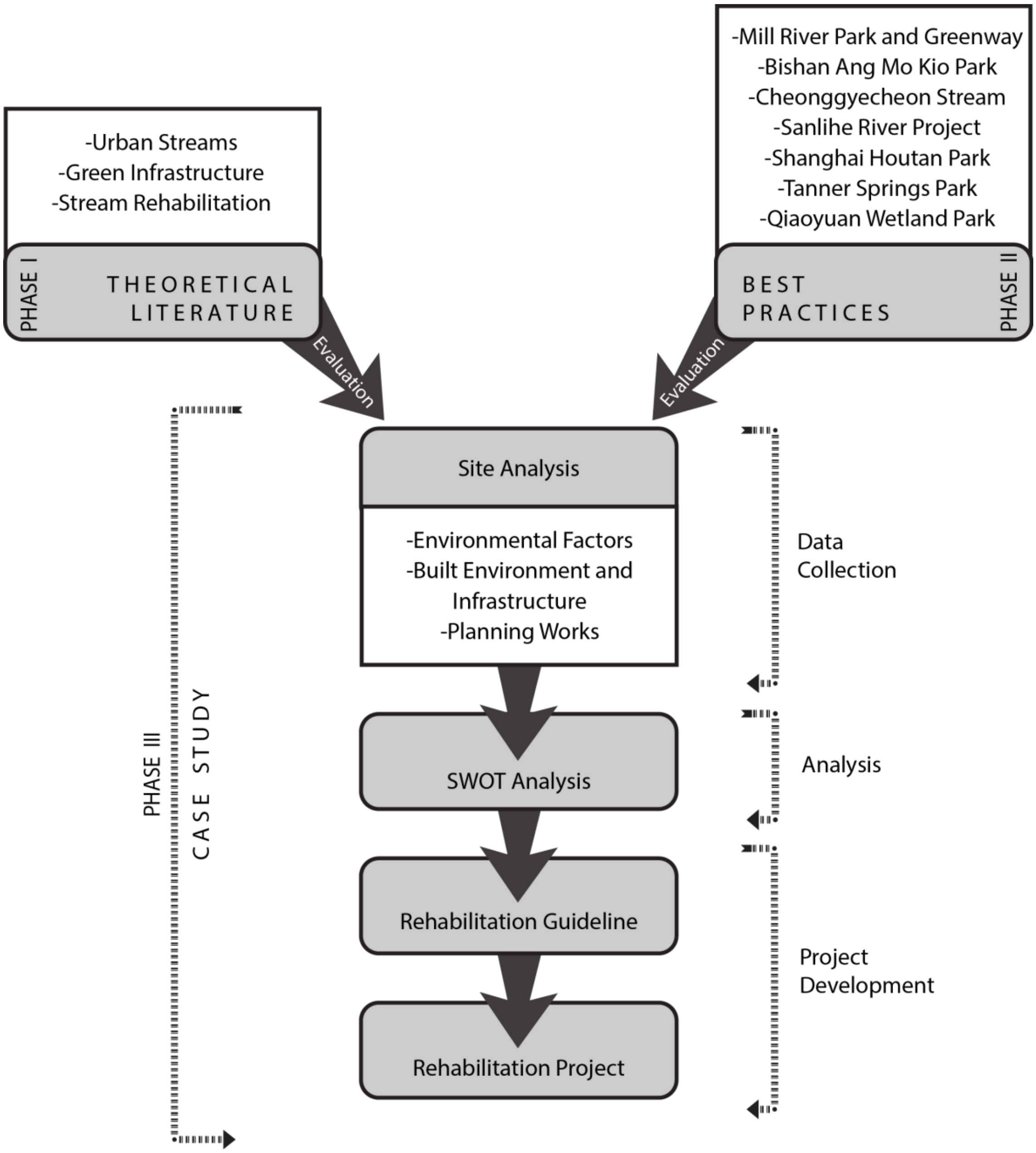

Figure 1.1. Layout of the methodology

In addition to the theoretical literature review, seven best practice projects from different parts of the world were examined to obtain more detailed information about stream rehabilitation. These projects - Mill River Park and Greenway, Bishan-Ang Mo Kio Park, Cheonggyecheon Stream, Sanlihe River Project, Shanghai Houtan Park, Tanner Springs Park, and Qiaoyuan Wetland Park - are included in this research, as they include not only stream rehabilitation approaches, but also green infrastructure approaches. All of these projects, located in city centres, lost their hydrological characteristics after urbanisation and human intervention, making them very suitable for inclusion in the study. Nevertheless, all of them have been rehabilitated through ecologically-based design solutions, and have been transformed into appealing urban landscapes. As the historical development of these projects suffers the same fate with Arap Stream, examining their design and planning processes would contribute to the rehabilitation of the subject of the case study.

Theoretical literature and best practice were evaluated separately with the aim of helping to develop a rehabilitation guideline for the case study. Once the result from these phases is obtained, the case study can be tackled. The research methodology used in the case study is divided into three groups: data collection, analysis and project development.

As the case study of the research, Arap Stream and its surroundings located within an industrial district is selected due to its exposure to severe urbanisation pressures and major human interventions. It held a significant place in the history of İzmir since it was once a freshwater resource and place for recreational activities. However, it has lost its characteristics and identity as a result of the influence of the conventional approach on urban streams, as well as uncontrolled urban development. Thus, Arap Stream and its surroundings was studied to reclaim ecological sustainability, and to reconstruct its significance in the collective memory of the community.

With regard to the collection of data about Arap Stream and its surroundings, the study first analysed the historical overview of the case area. Subsequently, environmental factors including hydrography, geology, geomorphology, climate, and vegetation were examined. Lastly, Arap Stream and its surroundings was evaluated based on built environment, infrastructure and planning works. All findings from the site survey, theoretical literature and best practice were assessed in the following part of the research.

On the other hand, the study also encountered a range of limitations that needed to be considered. One of the main limitations was data collection from the related organisation regarding the case study of the research, Arap Stream. Since data sharing from administrative structures, even to researchers, is not permitted, the case study was conducted with a lack of hydrological data. For that reason, it was impossible to appropriately determine both the limits of the 100-year and 500-year floodplain of Arap Stream and also the hydrological constraints. Moreover, stream rehabilitation needs an interdisciplinary approach from several professions; the study, however, was accomplished within the limitation of individual research.

In relation to the analysis of the data and information, a SWOT analysis - which helps to explore strengths, weaknesses, opportunities and threats - was conducted to establish the main advantages and disadvantages of the case area. Upon receipt of the findings from the site survey, best practice and the literature review on green infrastructure and stream rehabilitation, missing or altered features of Arap Stream were identified. The main problems listed among weaknesses and threats include the content of the rehabilitation brief in Arap Stream and its surroundings. Also, strengths and opportunities include positive aspects that help in the process of rehabilitation.

In the last part of the case methodology, outputs achieved from the SWOT analysis were used to develop a rehabilitation guideline for Arap Stream and its surroundings in terms of sustainable water management. Accordingly, urban, district and neighbourhood-scale strategies were staged. These strategies primarily aim to solve the main problems of Arap Stream, to reconnect the community with their lost nature, and equally importantly to reclaim ecological sustainability. Finally, an integrated and holistic rehabilitation plan was prepared for Arap Stream by utilising these rehabilitation strategies. In this manner, sustainable stormwater techniques and in-stream techniques were rendered in the study area.

1.4. Structure of the Thesis

This thesis consists of five chapters, each with a different focus. The first chapter presents the establishment of theoretical frameworks that includes the statement of the problem, study objectives, and methodology. The second chapter not only introduces general hydrologic terms and current problems related to urban stream but also contains an extensive literature review on green infrastructure and stream rehabilitation. Chapter 3 presents the best practices on urban stream rehabilitation and green infrastructure from various countries. Chapter 4 handles the case study of the research: Arap Stream and its surroundings. Finally, the main conclusions, recommendations, and discussions are included in the last chapter.

CHAPTER 2

STREAM REHABILITATION FROM A HOLISTIC PERSPECTIVE

This chapter presents an overview of the basic concepts related to urban streams to find out which components are necessary for stream rehabilitation and green infrastructure. Since stream rehabilitation is the main aim of the study, as a holistic framework, the concept of 'green infrastructure' was reviewed. Then elements, components, and various practices of green infrastructure were clarified. Later, the concept of stream rehabilitation was introduced. After presenting a rehabilitation outline for streams, finally, keys steps of the stream rehabilitation process were explained while discussing failures in the projects and implementations.

2.1. Urban Streams and Hydrology

2.1.1. Definitions

Water is significant for all living creatures and it has no substitute. As is commonly known, three-quarters of the Earth is covered by water. Even though water seems abundant, the real issue is that all of this water is not available for human use. Most of Earth's water is saltwater in the oceans. The amount of freshwater, which is commonly found in glaciers, lakes, ponds, rivers, streams, and wetlands, is limited. Only 2.5% of all of the water on Earth is freshwater that people can use. The other part consisting of saltwater can also be turned into drinking water with desalination, but this process is considered difficult and expensive. As rivers and streams are significant components of freshwater systems, they are considered vital to life.

A **river** and a **stream** both refer to moving bodies of water; but a river, in literature, is generally considered to be larger, deeper and longer than other watercourses. River is defined as a large natural system of flowing freshwater along a defined course (Standop, 1988). However, the Geographic Names Information System defines all linear flowing bodies of water as streams in its database (U.S. Geological Survey, 2013a). A stream might sometimes be as short as a brook, or it might also be as large as a river (Collins, 2008). Therefore, stream is a general term, which refers to any natural running watercourse (U.S. Geological Survey, 2013b). It is clear that the terms river and stream are very interchangeable, but the term stream seems more appropriate to use in this study because the aim of this thesis is to analyse ecological-based approaches for urban water bodies, which are affected by human interactions, regardless of their size. Since the term stream refers to any kind of watercourse, the use of the term "urban stream" fits the aim of this research.

Surface runoff and **precipitation** are the primary suppliers of streams. When the amount of surface water from rainfalls exceeds the soil's saturation rate, runoff occurs. The greater part of surface water eventually runs into the oceans, via connected running freshwaters, like streams. Then, the water gets heated and evaporates back into the atmosphere. Some water enters into the soil by infiltration and this leads to the formation of groundwater, much of which turns back into running water. This continuous movement of water is defined as a hydrologic cycle.

Rivers and streams are very significant elements of the **water cycle**. To understand how water moves around the world, it is necessary to review the steps of the hydrologic cycle. In the water cycle, there is not specific start or end point. Liquid water is evaporated from the oceans into the atmosphere. Then, the atmospheric humidity comes back to the earth in the form of snow or rain (Figure 2.1). According to Walter & Alberto (2000), almost a quarter of the overall annual precipitation can fall onto the lands of the world. The liquid fresh water flows over the land surfaces, on its journey back towards the ocean. As a result, lakes, rivers, wetlands, and groundwater aquifers are formed and created (Walter & Alberto, 2001).

This research intends to examine urban streams and the case study from **a holistic perspective**, which entails a watershed-scale approach. In this regard, the research criticises particular land uses, such as municipal or industrial sites, which might contaminate natural systems in the catchment area. In this sense, the study's aim is to develop a broad rehabilitation framework in the light of green infrastructure. Even though the study offers holistic and integrated approaches, which can be carried out in watersheds, some limitations led to the shift of focus to district and neighbourhood scales.

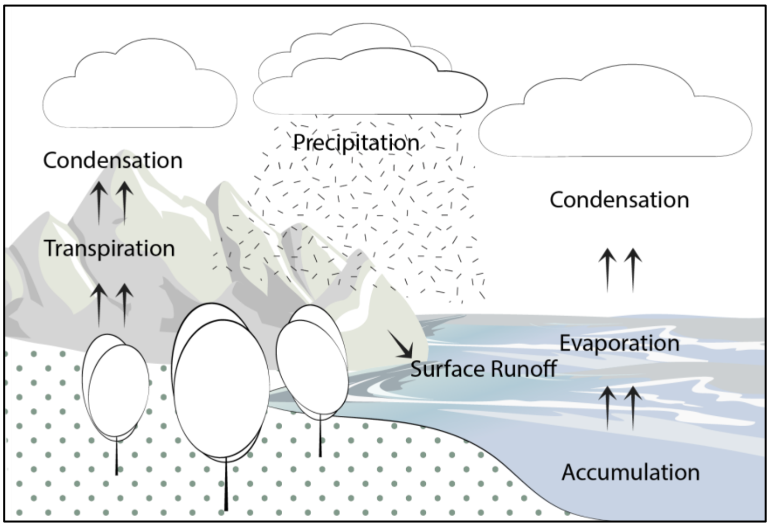

Figure 2.1. Water cycle

A **watershed**, also known as a drainage base, is defined as an area of land where all water falls in and drains off. A river basin and a watershed can make up a river system (Teclaff, 1987). A **basin** is usually surrounded by a natural boundary called the watershed or drainage divide. A water basin can be classified as basin, sub-basin, watershed, subwatershed, and catchment (Reimold, 1998).

Each river basin has its particular characteristics. Abiotic factors of the ecosystem, such as climate, geology, topography, soil, flora, and fauna, all interact with the river basin. If there is a change in any of these factors, the stream is affected for this reason; therefore, planning and management of streams is better held in the watershed-scale, considering characteristics of the stream (Uysal, 2005). However, human activities in a watershed are the main threats that determine the quality and quantity of water that is usable. Walter & Alberto (2001) describe a continuing cycle, where humans extract water, afterwards use it, and then damage it; finally, they have to restore the resources with the aim of re-using. As humans keep polluting and abusing their natural resources, the cycle can become increasingly difficult to maintain.

Sustainable water resource management is a key component of sustainable development, with the aim of meeting increasing water demands. In this regard, it is intended to provide efficient management of water resources by reusing greywater and decreasing potable water use (Saygın & Ulusoy, 2011). In urban stream rehabilitation practices, sustainable water resource management should be adopted as a principle that requires watershed-based restoration. Thus, river basin planning and river basin management gain more significance as an ecological approach.

A **floodplain** is a land area adjacent to a running freshwater source. Due to its nature, a floodplain is extremely productive for agriculture because it contains fertile soils carried by watercourses. Periodic floods cause accumulation of sediments on the floodplain, which makes floodplain vegetation one of the richest habitats for wildlife, regarding diversity. Therefore, humans choose these kinds of places for purposes such as settlement, recreation, or agriculture, and this creates a change of water level that reaches the flood stage. As a result of development near water systems, floodplain limits have declined and channelized streams have appeared (Figure 2.2). The runoff from rainfall, which used to soak in by the natural ground, cannot be absorbed in urban settlements where nature was replaced by a large amount of impervious pavement. Therefore, excessive runoff directly reaches to the urban streams, which causes flooding.

Figure 2.2 shows an approach to the stream and its floodplain and emphasises the difference of floodplain limits between pre-development and post-development.

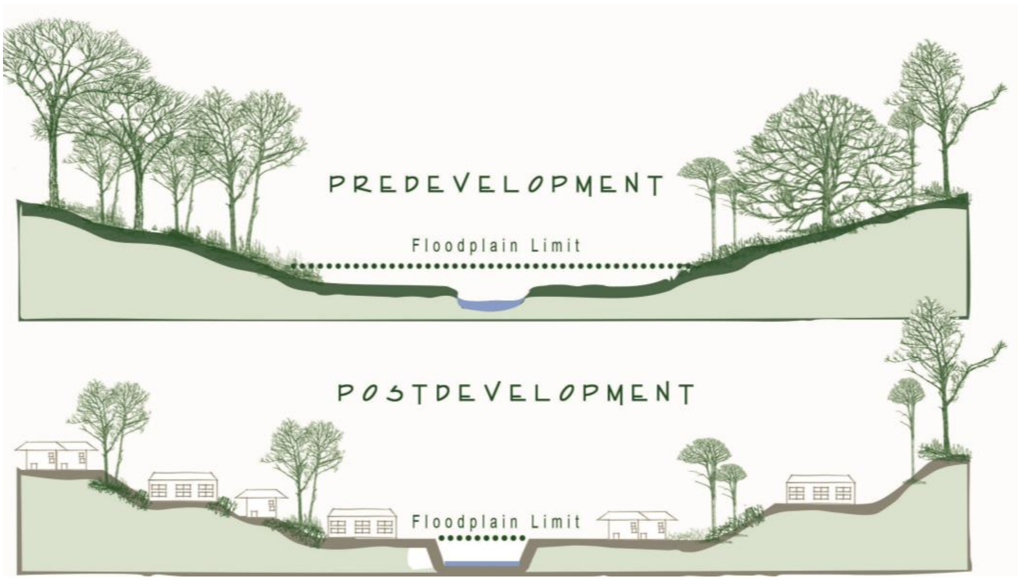

Figure 2.2. Channelization and floodplain limit

Velocity is one of the main determinants of hydrological characteristics. The velocity of a stream can be defined as the rate of water movement, given as metre/second. The velocity changes along the course of any stream due to factors such as the slope, the shape of the river channel, and the channel's roughness. All of these factors determine the stream's flowing speed. The velocity also changes according to the type of gradient, due to gravitational force pulling the speed of the streams.

Therefore, a steep gradient has faster velocity than a gentle gradient. A rough channel, which has rough boulders at the bottom of the stream bed, has a slower velocity than a smooth channel, which has more small pebbles at the bottom. The velocities of a narrow channel and a wider channel are also different.

The **discharge** of a stream is the volume of water passing through a cross-section in a unit of time, which is usually expressed as m^3s^{-1} (Meybeck, Friedrich, Thomas, & Chapman, 1996).

The velocity of a stream can be different across a channel because the depth of a stream also can be different across its width. So, measurements must be taken at more than a few points across the channel for better results. Kuusisto (1996) defines a useful method to divide the cross section of any stream into several vertical pieces (Figure 2.3).

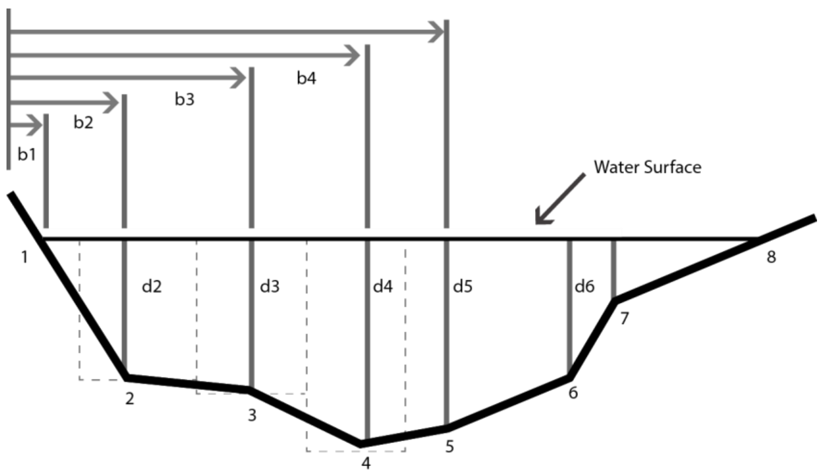

Figure 2.3. Multiple measurement method
(Reproduced from Kuusisto, 1996)

2.1.2. Classification of Streams

Streams can be classified according to some of their features such as topography, the type of flow regime, ordering, discharge capacity, and velocity; with the aim of discovering their similarities and differences. There are many classification systems, but currently, there is no universal stream classification system. Because of this, no classification system is applicable to every stream. The Strahler, Leopold and Wolman, and the Montgomery and Buffington can be considered as the most used methods (Erskine, 2005). Rosgen listed four reasons for classifying streams:

1) To anticipate the behaviour of the river regarding its physical characteristics.

2) To create connections for given stream regarding hydraulics and sediment.

3) To extrapolate information particularly to the site and apply it to comparable streams.

4) To order a stream is to give a predictable reference for portraying the stream's morphology (Rosgen, 1994).

Strahler’s method, being one of the earliest and most used methods, basically aims to determine the order of streams (Figure 2.4). The method begins with the shortest ones and they are considered first-order-streams. When two of the shortest tributaries meet, they create second-order-streams; when two second-order-stream tributaries meet, they create third-order-streams, and so on. Since same-order-streams have similar characteristics, such as average discharge, velocity, and drainage area, Strahler’s method is significant in places which do not have hydraulic data. According to the classification system of Meybeck et al., a stream has three to six tributaries; a river has six to nine tributaries (Table 2.1).

Figure 2.4 represents a stream network and its streams orders. In this method, first-order streams, the shortest tributaries, are shown as number 1; second-order-streams are shown as number 2, and so on.

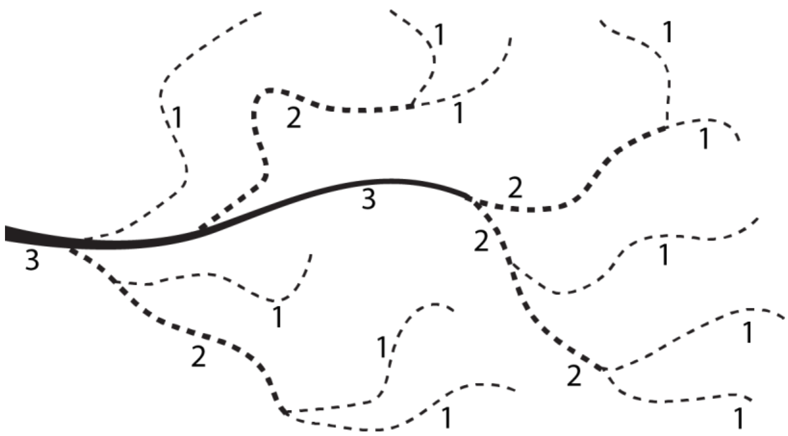

Figure 2.4. Strahler’s Classification Method

Although the classification of streams by their discharge is more agreed upon throughout the world, it is not accepted as one which can be used for all streams. In any case, various specified discharge rates are broadly used to determine the discharges and annual varieties of streams (Meybeck et al., 1996). While stream discharge, especially in dry and tropical districts, might be zero in hot seasons, it could also be a considerable amount in rainy seasons.

Even though the term stream means any flowing freshwater system, these systems can also be categorised by other authors based on average discharge, drainage area, and river width (Table 2.1). According to Meybeck et al., streams have less drainage area and discharge capacity than rivers. Nevertheless, the term stream in this research is used regardless of its discharge capacity, drainage area, width, or stream order.

Table 2.1. Classification of flowing freshwater
(Source: Meybeck et al., 1996)

A River Size	Average Discharge (m3/s)	Drainage Area (km2)	River Width (m)	Stream Order
Very Large Rivers	> 10,000	> 10^5	> 1,500	> 10
Large Rivers	1,000 – 10,000	100,000 - 10^5	800 – 1,500	7 to 11
Rivers	100 – 1,000	10,000 – 100,000	200 – 800	6 to 9
Small Rivers	10 – 100	1,000 – 10,000	40 – 200	4 to 7
Streams	1 – 10	100 – 1000	8 – 40	3 to 6
Small Streams	0.1 – 1.0	10 – 100	1 – 8	2 to 5
Brooks (or creeks)	< 0.1	< 10	< 1	1 to 3

Furthermore, streams can also be grouped into the following three categories according to the timing of flow in the year:

- ***Ephemeral streams:*** Flowing only occurs during precipitation or after precipitation. Therefore, these streams are also called rain-dependent streams and they do not usually flow more than 30 days per year. It is common to see ephemeral streams in arid regions.
- ***Intermittent streams:*** They flow seasonally when small upstream waters flow and enough water for stream flow is provided by groundwater. Seasonal flow in intermittent streams, also called seasonal streams, usually lasts longer than 30 days per year.
- ***Perennial streams:*** Also known as year-round streams, they flow continuously during all seasons. In other words, the water from perennial streams is always available in

stream beds, even on hot summer days (Figure 2.5). Most of the water from perennial streams comes from upstream water and runoff from base flow (USEPA, 1998).

Figure 2.5. A perennial stream from Turkey: Stream of Bıçkı, Sakarya
(Source: Sivil ve Ekolojik Haklar Derneği, 2016)

2.1.3. Changing Functions of Streams

Throughout their history, streams have maintained their importance in human history. However, in parallel to urbanisation and population growth, the natural cross-section of urban streams started to change gradually. This change also brought new functions to streams and their surroundings. Natural lands adjacent to urban streams were replaced by impermeable lands. This transformation is considered one of the most significant impacts of urbanisation on urban streams, since it leads to a fall in infiltration and a rise in surface runoff. When impermeable surfaces increase to 10-20%, runoff increases more than twofold, to 35-50%; and when impervious surfaces increase to 75-100%, surface runoff increases more than fivefold (Arnold & Gibbons, 1996).

In this regard, the destruction of stream ecosystems by land transformation has resulted in hydrologic changes and habitat changes. A significant number of riparian areas were destroyed due to new land uses for retail, residential, and commercial purposes. Then the negative effects of the transformation became more visible because of the interrelation of streams with human settlements. After having destroyed riparian areas for new settlements, unregulated streams in urbanised cities brought about several problems, including floods, and accordingly, they became a threat to communities settled near urban streams.

Due to increasing ecological awareness worldwide, various urban streams have been re-designed within their floodplains since the 1980’s (Table 2.2). In this respect, green infrastructure and stream rehabilitation techniques have been implemented in many cities to improve the relationship between people and their community.

Table 2.2. Stream Rehabilitation Practices
(Source: Şimşek, 2011)

Period	**Transition of Rehabilitation Practices**
Before 1850s	Many streams were untouched.
1850s-1960s	A small number of artificial structures, such as sewers, were constructed.
1970s	A significant number of urban streams were channelized to control rainfall.
1980s	Many city parks were designed within floodplains of urban streams in the context of green infrastructure.
1990s	Ecological river restoration techniques were implemented to reclaim ecosystems.
2000s	The relationship between urban streams and people has been improved.

In Table 2.3, Şimsek (2011) identified the changing functions of streams from ancient times to the present. Until the 1850s, urban streams were in their natural conditions and they were a source of fresh water and a place of recreational activities. However, between the 1850’s and the 1990’s, they were seen as a flood threat. For this reason, municipalities and developers targeted riparian communities and urban streams. This resulted in urban streams losing their environmental functions. Since degradation of natural systems in cities became a significant problem for communities, restoration efforts of these systems, including stream rehabilitation and habitat rehabilitation, were initiated in the 1990’s.

Table 2.3. Changing Functions of Streams
(Source: Şimşek, 2011)

Function	In Ancient Times	Until 1850s	Between 1850s and 1950s	Between 1950s and 1990s	Since 1990s
Potable Freshwater	√	√			
Water for Domestic Use	√	√		√	√
Water for Industrial Use			√	√	√
Sewage Disposal Area			√	√	
Converted to Concrete Channels			√	√	
Covered up			√	√	√
Source of Irrigation	√	√	√	√	√
Object of Rehabilitation				√	√
Transportation	√	√	√	√	√
Navigation	√	√	√	√	√
Boating, Canoeing etc.		√	√	√	√
Fishing	√	√			√
Recreation	√	√		√	√
Washing up along the River	√	√			
New Approaches for Urban Rivers					√
Waterfront Design Innovations					√
Environmental Concern					√
Considering with Green Infrastructure					√

2.2. Green Infrastructure

Green infrastructure (GI) is an ecological framework for holistic planning and design, which also provides social and economic sustainability. For future generations, natural resources can be preserved by using green infrastructure techniques that enhance environmental quality and provide utility services such as improved water quality and vegetation, which can control erosion and stabilise the soil at steep slope. Even though the term green infrastructure sounds new, the idea developed out of the discipline of proper planning of the environment (McDonald, William, Benedict, & Keith, 2005). Green infrastructure is seen as a strategy to conservation planning that brings together the initiatives of previous planning strategies and practices in the world into a regular structure, which can include larger scenery and wider planning goals (McDonald et al., 2005).

All elements of the landscape, which have the functional attribute of linking various ecological features to form larger networks, are called ecological networks (Liu & Taylor, 2002). Even though not all environments function under the same principles, we can easily identify some themes that can connect ecological networks to the advantages that they can bring for green infrastructure. The organisation of connective networks is, practically, one of the most significant attributes of ecological networks. By linking a particular number of supporting systems within a polycentric hub, these supporting systems allow migration and movement (Farina, 2006). The way these ecological networks can be utilised to connect various ecological elements is similar to the manner in which grey infrastructure has been used to connect people and urban services.

Green infrastructure as a phrase has several explanations according to literature. The concept of green infrastructure has been used in urban design and planning terminology. The same way a functional support system is described by grey infrastructure, the term green infrastructure, used as a noun, represents the life support system of nature (McDonald et al. 2005). Used as an adjective, it stands for a strategy to conservation planning which is landscape-scale, which has an extensive public coverage range. This leads to an execution plan to guide a network of ecology for conservation lands (McDonald et al. 2005). According to the US Environmental Protection Agency, the term green infrastructure is used for natural systems, to decrease adverse effects of urban development (USEPA, 2014b).

To establish urban space networks, green infrastructure uses public spaces, such as parks, squares, water bodies, green roofs, avenues, and shorelines, as elements (Kaplan, 2012). Green infrastructure aims to physically connect networks of natural and cultural landscape areas to provide a wide range of benefits for people. For instance, in contrast to grey infrastructure, using green infrastructure techniques can decrease energy and wastewater treatment costs. Reducing energy use and improving available water supply can be considered significant economic benefits of green infrastructure.

In addition to the environmental and economic benefits of green infrastructure, it is also important to point out the social benefits of green infrastructure. To put it simply, the use of green infrastructure techniques improves the livability of communities by amending social conditions. In this regard, its fundamental aims are to enhance the level of physical activities and to facilitate social interactions in interconnected urban spaces. Thus, green infrastructure promotes psychological health and welfare for communities.

A connective system is formed by combining these elements to create a network of multi-functional open spaces. The broad objectives of creating a network of public spaces are listed by Benedict & Mcmahon (2002), as follows;

a. To link parks and other green spaces for people
b. To connect natural areas to treat fragmentation and to preserve biodiversity
c. To protect interconnected systems for environmental, economic, and social benefits, which provides a sustainable future for all
d. To build upon the greenbelt movement

Similar to the present attempt to attain sustainable development in urban centres, a similar approach with green infrastructure and ‘technological infrastructure’ has existed in traditional planning for urban spaces (Sandström 2002). The focus for landscape planning is, as is the root of green infrastructure, a strategic conservational planning approach that develops on the approach made for conservation planning of recent years (McDonald et al., 2005). The scientific analysis and planning, often called “reserves” that has stood as the foundation of regional biodiversity networks are the source of the green infrastructure approach (McDonald et al. 2005).

Green infrastructure was recently defined by researchers as a connection of multipurpose public spaces, so as to be a tool for more efficient and sustainable land use. Green infrastructure not only contributes to the protection of built environment but also delivers life for new and existing realms (Kambites & Owen, 2006). In an urban setting, green infrastructure contributes dramatically to urban services by reducing grey infrastructure and water treatment needs.

On the other hand, green infrastructure provides not only green networks including green spaces but also provides blue networks including rivers and streams. Benedict & McMahon (2002), in the surrounding of the United States, defines green infrastructure as interconnected public spaces including all of the open spaces, parks, squares, wildlife habitats, and other natural areas that sustain clean water and air and enhance the quality of life. Their belief was that it originates from the idea that people benefit from linking parks and green space and that the ecosystem benefits from preserving and connecting natural places. Therefore, green infrastructure is regarded as a life support system for cities by several researchers.

Randolph (2004) depicts the types of planning efforts for green fields in a different time range by explaining the primary objectives and conservation tools. Table 2.4 represents an increasing complexity in the planning of green fields, and therefore shows that green infrastructure has recently been used with many conservation tools and objectives.

Table 2.4. Evolving Nature of Local Government Land Conservation in the US (Source: Randolph, 2004)

Period	**Type**	**Conservation Tools**	**Primary Objectives**
Until 1980	Parks and Recreation Planning	Land acquisition; park planning and management	Active recreation, scenic amenity
1980s	Open Space Planning	Land acquisition and easement; park planning and management	Active recreation, scenic amenity, farmland protection, urban forestry
1990s	Greenways and Open Space Planning	Land acquisition, easement, floodplain zoning, park and greenway planning and management	Active and passive recreation, scenic amenity, farmland protection, urban forestry, urban wildlife

(cont. on next page)

Table 2.4. (cont.)

2000	Green Infrastructure	Land acquisition, easement, floodplain management, smart growth management tools, conservation land development, partnerships with landowners, land trusts	Hubs and links for active and passive recreation, scenic amenity, farmland protection, urban forestry, urban wildlife, regional and state ecological systems, integration of conservation and growth management.

For this study, green infrastructure can be defined as functional wetlands, wildlife habitats, interconnected stream networks, squares, avenues, and the rest of the natural areas; woodlands, public parks, and gardens, and the rest of the conservation lands. All of these promote natural ecological process, sustain natural resources, and provide environmental, economic, and social benefits to both people and environments. For any rehabilitation project to be regarded as successful, it would need to combine the guiding knowledge of green infrastructure.

2.2.1. Elements and Components of Green Infrastructure

It is important to be clear about the definitions of cores, hubs, and corridors, which are the components of green infrastructure. The principles to make up a green infrastructure network are quite simple. An isolated patch cannot contribute to an ecosystem as much as connected hubs can. Therefore, an individual fragmented area cannot join the network system. Understanding the components of green infrastructure may reveal how a green network works.

Cores can be defined as pure natural areas that provide connectivity of the ecosystem and also reduce the amount of fragmentation. Cores can be rivers, streams, wetlands, woodlands, or meadows. The size of a core can be various; sometimes as big as a forest, other times as small as a garden. According to Matlock & Morgan (2011a), a big core is always better than a small one, rounder is more preferred than a linear, connected is better than isolated, closely linked cores are healthier than widely linked cores, and connected cores in the form of a cluster are much better than segmented cores in a linear form. Since cores provide habitat conditions, the size of cores should be large.

As shown in Figure 2.6, a hub is quite larger than a core in size and can contain multiple cores and surrounding areas as a block of natural areas. They can act as buffer zones in commonly undeveloped areas, such recreational lands. A hub provides space where plants, animals, people, water, nutrients, and wildlife exist and it contributes to the biodiversity of the region.

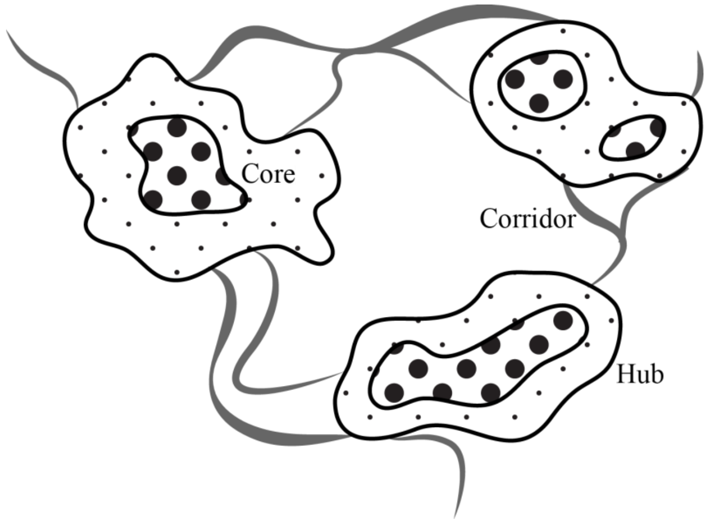

Figure 2.6. Green infrastructure networks

After examining the various sources of green infrastructure, the threshold size of a hub can be considered in the range of 20 to 40 hectares (Matlock & Morgan, 2011a). Smaller hubs than the threshold, generally fail. Therefore, it needs to be as large as possible.

Cores and hubs are the main components of green infrastructure. Native species living in these areas can spread into the surrounding areas thanks to the links between hubs. These connections between the hubs in green infrastructure are called corridors. They fundamentally facilitate the movement of people and animals between the hubs. Matlock and Morgan (2011a) articulate that the width of a corridor should be longer than 200 meters for effective practice. Riparian corridors should be considered with the floodplain and some connected upland areas.

There are also numerous ideas included in this literature that encourage the green infrastructure concept. These ideas sustain the fact that these networks can minimise landscape fragmentation by linking smaller networks and supporting the connective nature of larger networks, such as Patch-Corridor-Matrix (Figure 2.7).

The networks of corridors, hubs, and cores provide habitat and connectivity, which is needed to conserve biodiversity. These networks additionally provide water supply, climate regulation, recreational opportunities, and pollution management for a sustainable practice that can be used in ecological restoration projects.

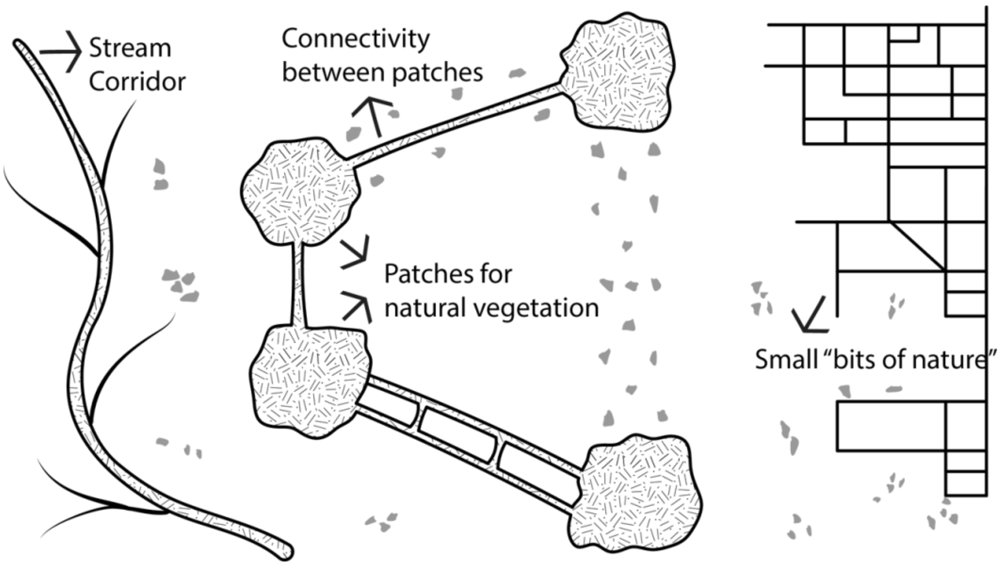

Figure 2.7. Forman's Pattern
(Reproduced from Forman, 1995)

Forman (1995) defines the three fundamental landscape elements as patch, corridor, and matrix. A patch can be regarded as a hub in green infrastructure terminology, which provides several functions including fauna, flora, and sources for species. Patches are described relatively as nonlinear areas. Corridors as linear areas provide habitat for wildlife, and pathways for species. Matrixes are considered the dominant land cover types, with respect to area and connectivity.

As shown in Table 2.5, in an urban setting, patches, corridors, and matrices as landscape elements are exemplified by Ahern and Forman.

Table 2.5. Types of Urban Landscape Elements
(Source: Ahern, 1995; Forman, 1995)

URBAN PATCHES	URBAN CORRIDORS	URBAN MATRIX
Parks	Rivers	Residential Neighbourhoods
Sport fields	Canals	Industrial Districts
Wetlands	Drainage ways	Waste Disposal Areas
Community Gardens	Roads	Commercial Areas
Cemeteries	Power lines	Mixed Use Districts
Campuses		
Vacant Lots		

Also, green infrastructure systems can be grouped into three broad categories based on several types of green infrastructure elements (Table 2.6).

Table 2.6. Green Infrastructure Elements and Systems
(Source: Kamalludin et al., 2014)

GREEN INFRASTRUCTURE SYSTEMS	GREEN INFRASTRUCTURE ELEMENTS
Open Space Systems	Public spaces Recreational parks Green roofs Street Trees Eco-industrial parks
Transportation Systems	Boulevards, streets, and alleys Green roads Walking and cycling pathways Porous Pavement Abandoned railways
Stormwater Management Systems	Streams Bioswales Constructed wetlands Rain Gardens

Various natural and cultural assets, which are significant to metropolitan regions, have been preserved by conventional methods. These open spaces have been perceived as a vital core to a particular developmental pattern. The need for a pattern and network of open spaces for development has been highlighted by Forman (1995), Benedict (2001), McDonald (2005), and other experts. This development needs to be planned regarding the maximum preservation of natural and cultural processes and amenities. In this regard, green infrastructure offers various benefits and opportunities.

Several benefits surrounding this process have been analysed to measure their value in sustainable life and landscape resources. As shown in Table 2.7, Abrahams (2010) listed the essential components of green infrastructure by different researchers. According to Abrahams' matrix, Benedict and Sandstöm are on the same line about green infrastructure. However, the criterion of Tzoulas et al. are mainly based on green fields' protection and development.

Table 2.7. A comparison of Green Infrastructure Criteria
(Source: Abrahams, 2010)

Green Infrastructure Criteria	McHarg (1969)	Sandström (2002)	Weber et al. (2005)	Benedict et al. (2006)	Tzoulas et al. (2007)
Ecosystem Services	X	X	X	X	X
Environmental quality & aesthetics	X	X	X	X	
Natural solutions to technical problems	X	X	X	X	
Awareness of the history of the city		X		X	
City structure		X		X	
Recreation	X	X	X	X	X
Integration of the city with nature	X	X	X	X	X
Maintains integrity of habitats	X	X	X	X	X
Preserves lands for food and forest products	X	X	X		

Furthermore, Sandström (2002) states that some criteria that were determined by Swedish institutions related to environment and planning have been used for seven Swedish cities for effective land use and urban health.

2.2.2. Green Infrastructure Practices for Stormwater Management

Green infrastructure can advance at different spatial scales based on the subject of connectivity. Landscapes should not be viewed as being independent of each other, since they are connected through their functions, structures, and interactions (Farina, 2006; Forman, 1995). On the other hand, they can be considered networks of interacting spaces, which may be connected to green infrastructure resources.

One of the most significant characteristics of the concept is the ability of green infrastructure to exist as pavement greenery, street plants, and wetlands, furthermore allowing it to deliver benefits to different spatial scales (Mell, 2010). This approach may also be employed to spread the significance of green infrastructure as a multi-scaled natural resource for maintaining large or complex systems.

The way in which spaces are organised may range from the smallest areas with communal or neighbourhood level benefits to urban-wide spaces. Each scale will offer the welfare of green infrastructure, although all of the spatial variations could be any size. As a result, in case the natural or cultural (man-made) green spaces are a significant step to a better environment, then green infrastructure may be regarded as a process of providing a better urban space for public uses.

Successful stormwater management is obtained from a management approach, which is different from the approach that focuses on practices from individuals (Droguett, 2011). That is, the management of pollution, which can be achieved by any given management system, is considered the sum of its parts, a reference to the range of efficiency associated with each single exercise, the costs of each exercise, and the resulting total cost and efficacy (USEPA, 2014b).

The Best Management Practices are classified into structural and non-structural, by the United States Environment Protection Agency (USEPA). However, BMP's are differentiated into filtration, infiltration, retention/detention, and innovative systems.

The Center for Watershed Protection (2010) defines infiltration, filtration, retention, and innovative practices as follows:

Infiltration practices: Treatment of urban runoff discharge is dependent on water absorption. Water is moved through the soil. During this process, filtration and biological action eliminate pollutants. For this technique to work effectively, the soil must be a deep permeable soil at separate distances, a minimum of 120 cm between the root of the structural and groundwater levels during the season.

Filtration practices: Sheet flow is treated by using sand or vegetation to filter and settle the pollutants. The treated water can be routed into drainage channels, streams, or other water bodies, evaporated, or percolated into groundwater after it has passed through the filtration media. Infiltration and treatment in the subsoil may also occur in some cases; i.e. bio-retention or rain gardens.

Retention practices: Runoff is temporarily impounded by retention practices, also known as detention practices, to control the rate of runoff and settle and retain the stormwater deposit and associated pollutants. Constructed stormwater wetlands are an advanced method because it removes pollutants by detaining flows that result in sedimentation and gravitational settling of suspended soils.

Innovative practices: They may integrate some or all of the above and include vegetated roofs and urban forestry.

2.2.2.1. Rain Garden

Rain gardens can also be identified as infiltration or retention gardens. Rain gardens as bio-retention areas capture rainfall and surface runoff from rooftops and impervious surfaces (Figure 2.8). They work best if consisting of plants with long roots like native grasses (Wise et al., 2010).

Figure 2.8. A rain garden in Portland, Oregon, USA
(Source: ASLA, 2016)

Rain gardens are usually found inside small pockets of lands for residential purposes, according to the United States Environment Protection Agency (USEPA, 2014a). They are installed in gardens with the aim of infiltrating rainfall and runoff biologically through the filter media and plants. In urbanised areas, rain gardens can easily prevent excessive surface runoff from precipitation. As a result of infiltration, sediments and pollutants are easily removed from the water and then the purified water evaporates back into the air after waiting for a while in soil. Alternatively, in some cases, filtered water is collected in pipes or retention areas for re-use and evapotranspiration.

Since surface runoff can consist of petroleum products, such as oil, gas, or other harmful substances like pesticides, they become a significant threat when they are carried into streams, lakes or other natural reserves. Therefore, a rain garden is a small but efficient tool to absorb rainfall and surface runoff.

2.2.2.2. Bioswale

Bioswales, also known as vegetated swales, convey rainfall and surface runoff within shallow channels for multiple purposes (Figure 2.9). Just as a rain garden aims, a bio-swale also seeks to filter and slow surface runoff from rainfall. The difference between a bio-swale and a rain garden is that rain gardens are usually installed into small-scale lands, like residential areas. However, bioswales in urbanised cities are installed into larger areas, such as parking lot islands or roadways; therefore, they filter water from a larger amount of impervious surfaces.

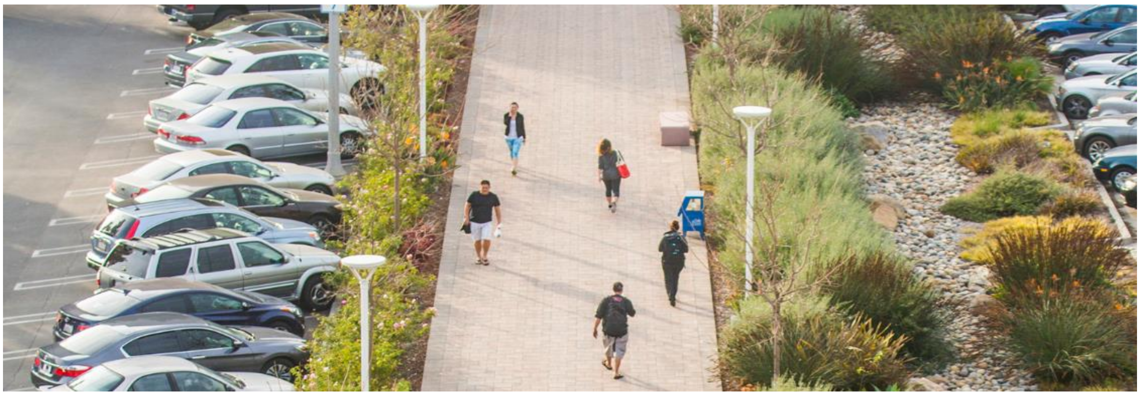

Figure 2.9. A bioswale in a parking lot
(Source: http://news.fullerton.edu/2014sp/images/Swale-hr.jpg)

Bioswales as open drainage channels, promote natural treatment and infiltration and they commonly take place in lands where stormwater is transported slowly (Droguett, 2011). Bio-swales are commonly formed in linear shapes; therefore, it is more efficient when they are parallel to roads and sidewalks.

In situations with soils, topography, drainage areas, safety, and permit slope concerns, vegetated swales can be of use in the right-of-way streets and on sites that are being developed to transport and treat stormwater from roads, sidewalks, and other impermeable surfaces (Center for Watershed Protection, 2010).

2.2.2.3. Green Roof

A green roof, also known as a vegetated roof, is another technique to harvesting rainfall. A green roof is defined as a roof which has partially or wholly been covered with a growing medium and vegetation that has been planted over an impermeable membrane (Droguett, 2011). In addition to rainwater harvesting, green roofs provide several benefits; such as improvement of water and air quality, reduction of heat island effects, infiltration of pollutants, recreational opportunities, energy conservation, and aesthetic value.

A green roof may also include extra layers, such as a root barrier and irrigation and drainage systems. Based on the depth of growth medium, green roofs are considered extensive or intensive. For an extensive system, the depth of a growing media is considered between 5-15 cm (Center for Watershed Protection, 2010). Green roofs with an extensive system are not commonly used for recreational purposes (Figure 2.10). These techniques are recognised by lower investment cost and lower weight. Therefore, extensive systems should be used in small places where other stormwater techniques cannot be easily applied.

Figure 2.10. An extensive green roof from Singapore
(Source: http://www.elmich.com.au/marina-barrage-extensive-greenroof/)

As seen in Figure 2.11, green roofs with intensive systems, which are appropriate to use for recreational purposes, are recognised by a layer of soil that has deeper growing media than intensive systems, with higher investment cost, greater weight, more maintenance requirements, and improved plant diversity (Center for Watershed Protection, 2010).

Figure 2.11. An intensive green roof from Baltimore, USA
(Source: http://www.greenroofs.com/projects/pview.php?id=1337)

Green roofs are mainly appropriate for redevelopment or retrofit tasks, or also for structures that are still new and can be set up in car parks which are small or bigger commercial, industrial, and public structures (Droguett, 2011).

2.2.2.4. Tree Planting

Trees as vertical structures in landscapes have a significant influence on stormwater management. Not only do they provide habitats for wildlife species in urbanised areas, but they can also intercept rainfall before becoming surface runoff (Figure 2.12). Therefore, tree planting is an efficient tool to reduce stormwater runoff, especially in new developments or redevelopment areas. In these areas, open spaces are designed through minimising impervious surfaces. Protecting existing trees or the planting of new ones can decrease the occurrence of stormwater runoff, increase evapotranspiration and the rate of nutrient uptake, offer covering and heat reduction, provide bank stabilisation, and provide a habitat for wildlife (Droguett, 2011).

Figure 2.12. Urban street trees
(Source: https://media.licdn.com/mpr/mpr/p/5/005/064/3bf/1cf9990.jpg)

The tree planting method is just like riparian restoration, but this usually takes place on a compact sized scale. Another difference is that shrubs and low growing ground that covers plants are vital elements in riparian restoration.

The Center for Watershed Protection (2010) suggests the following practices for stormwater management:

- During construction, existing trees in an urban environment should be conserved when they are non-invasive and healthy. Also, transplanting can be another option to move a tree to another location, if conserving is infeasible.
- New native trees that require low-cost maintenance should be integrated into all stormwater practices.
- Tree planting in a tree pit is suggested along sidewalks, roads, or other permeable areas situated in redevelopment sites that are highly impervious.

2.2.2.5. Constructed Wetland

Wetland stormwater treatment can be carried out by restoring natural wetlands or constructing new ones. In urban settings where the environment can drastically change the natural hydrological cycle, constructed wetlands are used to employ wetland plants to treat wastewater in a more controlled atmosphere than in natural wetlands (Pasi & Smardon, 2011).

Wetlands are defined as transitional areas where aquatic and terrestrial systems meet. In wetlands, the ground is commonly covered by shallow water or the water table is close to the surface (Pasi & Smardon, 2011). Wetland ecosystems, which include streams, lakes, marshes, and coastal regions, are estimated to cover 1,200 million hectares (Springate-Baginski, Allen, & Darwall, 2009), which is 50-fold larger than the total area of the United Kingdom, 15-fold larger than Turkey, and 1.5-fold larger than the United States. However, a significant degree of wetlands have been destroyed as a result of human interference, and constructed wetlands have had to be implemented.

Wetlands can be naturally formed in various ways, according to their water source (Figure 2.13). The amount of groundwater, precipitation, and surface water determine types of wetlands. For instance, if a source of a wetland is predominantly fed by groundwater, then it is either a spring-fed wetland or fen.

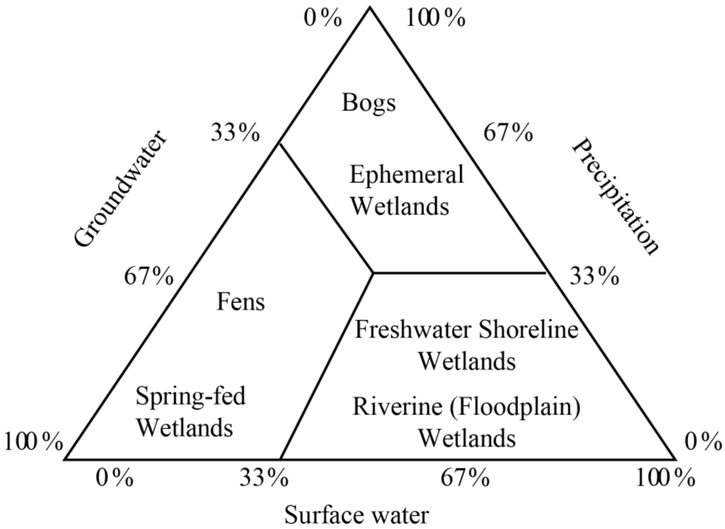

Figure 2.13. Wetlands according to water source
(Developed from Brinson, 1993)

Constructed wetlands, also known as man-made or engineered wetlands, are artificial wetlands, which are built within controlled environments especially to filter and store stormwater runoff. They are the largest infiltration stormwater technique both in areas and in-depth (Wise et al., 2010). According to the Ramsar Convention, wetlands in which the water level does not exceed six meters, are defined as areas of fens, marshes, or water, whether natural or man-made, intermittent or permanent (Ramsar Convention Secretariat, 2006). Constructed wetlands take all advantages of natural wetland systems to improve water quality. This treatment method is carried out by restoring natural wetlands or constructing new ones in an urban environment in which the hydrological cycle is drastically changed (Figure 2.14).

Figure 2.14. The 1.5-hectare constructed wetland located in Cambridge
(Source: http://cenews.com/large-engineered-wetland-combines-form-and-cso-function)

In this process, pollutants held in stormwater are removed by wetland plants. In the long run, hydrocarbons from petroleum carried in stormwater runoff from roads, parking lots, and driveways are broken down by microorganisms (Droguett, 2011). Additionally, metals that settled out of stormwater into sediments are taken up by wetland plants. As infiltration time of water within the wetlands increases, the effect of biological and non-biological processes are improved (Droguett, 2011).

According to Pasi and Smardon (2011), the reasons to construct a wetland are listed as follows:

- Constructed wetlands compensate the community for their lost wetlands.
- Constructed wetlands improve water quality by filtering out pollutants and reducing N concentration through wetland vegetation.
- Constructed wetlands provide flood control for heavy rainfall and urban runoff.
- Constructed wetlands supply food and fibre.

On the other hand, constructed wetlands may have potential hazards if not properly managed. These may cause undesirable consequences, such as breeding of mosquitoes. Also, constructed wetlands may not be economical for drainage areas of less than four hectares (Droguett, 2011). According to Pasi and Smardon (2011), the main disadvantages of constructed wetlands are the availability of suitable location, grading site, the cost of plant harvesting and disposal, and habitats for insects or diseases. Disadvantages of wetlands may result in public views or misunderstandings, which decrease the practicality and feasibility of wetland projects (Smardon, 1989).

2.2.2.6. Porous Pavement System

The Porous Pavement System is an alternative to conventional impervious paving. The general principle behind the Permeable Pavement System is essentially the collection, treatment, and free infiltration of any surface runoff to support groundwater recharge (Droguett, 2011). Permeable pavement improves stormwater retention, reduces ground conductivity, and noise pollution is also cut down in contrast to the conventional pavement (Wise et al., 2010). Through porous pavement systems, rainwater and urban runoff can be infiltrated easily and harmful pollutants can be removed without being carried anywhere. Also, another advantage of using porous paving is erosion prevention.

Porous pavements are used in several public spaces including driveways, sidewalks, and parking areas. Since permeable paving allows surface runoff to drain easily, they should also be used near natural reserves such as rivers, streams, and lakes, to prevent the harmful effects of runoff.

Porous pavement is also known as permeable pavement, which includes porous asphalt, porous concrete, plastic grids, permeable turf, porous interlocking paving, and permeable clay bricks. As seen in Figure 2.15, porous asphalt or concrete pavement is similar to conventional asphalt or concrete, but the difference is that it is partially porous (Droguett, 2011). It consists of open-graded roads and the concrete is situated above the well-drained soil. Porous concrete pavement mainly consists of cement binder and aggregate (Droguett, 2011). It is porous because the fine aggregates are omitted.

Figure 2.15. Porous concrete pavement
(Source: https://upload.wikimedia.org/commons/Permeable_paver_demonstration.jpg)

These products made of concrete can also serve as a basin for pollution, due to their ability for particle retention during purification. As a result of the high porosity of this unique concrete, it leads to proper air exchange rates and good infiltration. Pollutants that have filtered out can sometimes be removed after the cleaning of the pavement (Droguett, 2011).

In addition to controlling runoff from rainfall and infiltration of pollutants, a porous pavement system also provides benefits for vegetation by giving enough space to the root systems of plants; therefore they can grow to full size without any obstacles, even on paved surfaces.

2.3. Stream Rehabilitation

Rehabilitation efforts of urban streams aim at treating a number of components of the degraded stream ecosystem, decreasing of negative impacts on the overall environment, improving water quality, enhancing riparian vegetation, controlling runoff from rainfall, and managing water resources for sustainability. Therefore, it is important to clarify concepts related to rehabilitation of streams.

There are several different terms about the treatment of urban streams, such as restoration, rehabilitation, re-naturalization, and reclaiming. The literal meaning of restoration is to return to former conditions. When used for stream ecosystems, this definition can be unclear. Because of this, there might be some conflict in determining what precisely “former conditions” means (Ortiz & Merseburger, 2009). In addition, some streams are always changing due to natural conditions; therefore, a former condition could refer to many different states of streams at various times. Restoration of a stream can also be regarded as an intervention in physical, chemical, and biological states of a stream (Interagency Workgroup on Wetland Restoration, 2003). By definition, rehabilitation means repairing natural and historical functions of the degraded aquatic ecosystem to improve ecological functions, according to the Interagency Workgroup on Wetland Restoration (Figure 2.16). Another term related to the treatment of a stream is reclamation, defined as the process of altering an area to bring it to a healthy state, unlike the original ecosystem.

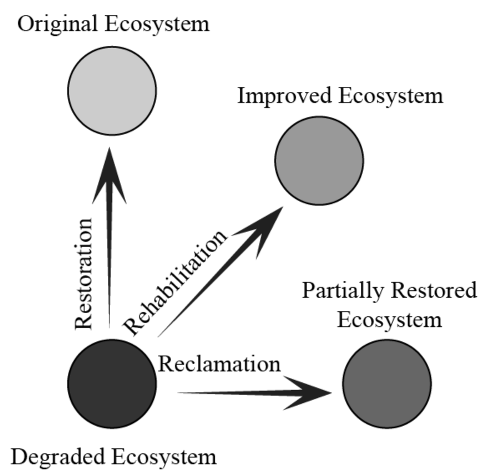

Figure 2.16. The distinction between the terms of "Stream Restoration" and “Stream Rehabilitation"

There are numerous terms related to rehabilitation of urban streams. All of them aim to minimise man-made and adverse effects in the context of ecosystem recovery. In the United States, the term restoration is more common than the term rehabilitation; in the United Kingdom, the term reclamation is the preferred term (Şimşek, 2011). However, reclaiming is a less preferred concept for streams, compared to restoration and rehabilitation. Improving water quality, designing stream banks to provide values and services, and to support urban health such as wildlife habitat, groundwater recharge, recreational use, and flood control, are also the components of the process of all of these terms.

Roni & Beechie (2012) developed a matrix, shown in Table 2.8, defining the terms related to stream rehabilitation; such as protection, restoration, improvement, reclamation, creation, and mitigation.

As shown in Table 2.8, some of the terms mentioned above are interchangeable. Throughout the study, the concept of rehabilitation is used, since it refers to bringing the healthy state back and minimising human effects on streams. Even though the term restoration is employed in many cases, full restoration does not look possible for degraded stream ecosystems in urbanised cities. Therefore, the term stream rehabilitation is more appropriate for the aim of this study and the case study.

Table 2.8. Terminology related to Stream Intervention
(Source: Roni & Beechie, 2012)

Term	Definition
Protection	Creating laws or other mechanisms to safeguard and protect areas of intact habitat from degradation.
Restoration	Returning an aquatic system or habit to its original, undisturbed state. This is sometimes called ‘full restoration,’ and can be further divided into passive (removal of human disturbance to allow recovery) and active restoration (active manipulations to restore process or conditions).
Rehabilitation	Restoring or improving some aspects or an ecosystem but not fully restoring all components. It is also called ‘partial restoration’ and may also be used as a general term for a variety of restoration and improvement activities.
Improvement	Improving the quality of a habitat through direct manipulation (e.g. placement of instream structures) or enhancing productivity (e.g, addition or nutrients). Sometimes referred to as habitat enhancement and sometimes also considered as ‘partial restoration’ or rehabilitation.
Reclamation	Returning an area to its previous habitat type but not necessarily fully restoring all functions (e.g. removal of fill to expose historic estuary, removal of a levee to allow river to periodically inundate a historic wetland). Sometimes referred to as compensation.
Creation	Constructing a new habitat or ecosystem where it did not previously exist (e.g. creating new estuarine habitat, or excavating an off channel pond). This is often part of mitigation activities.
Mitigation	Taking action to alleviate or compensate for potentially adverse effects on aquatic habitat that have been modified or lost through human activity (e.g. creating of new habitats to replace those lost by a land development).

2.3.1. Rehabilitation Outline

Urban streams have been subjected to rehabilitation and in this regard, it is important to have guidelines showing the steps of the rehabilitation process. A number of ecological rehabilitation frameworks for different types of streams have already been projected by various researchers and they have fundamentally defined key processes for ecological stream restoration. One of these outlines was proposed by Kovar (2013) for Czech water systems, which can be broken down into the following guidelines: (1) water quality needs to be improved by providing self-purification process, efficiency of water purification plant; (2) biological regime should be regulated by species, tropical structure, interconnection of zones, and riparian vegetation; (3) diversification needs to take place in a meandering route, in a longitudinal profile (pools and rapids), and in a cross-section profile, as non-symmetrical in a curve (Figure 2.17); (4) discharge capacity should be calculated also considering re-evaluation of the change of land use along a river route, local obstacles, polders, and dikes; (5) a movable bottom should be created by bottom zoology, bottom morphology, and bed load movement.

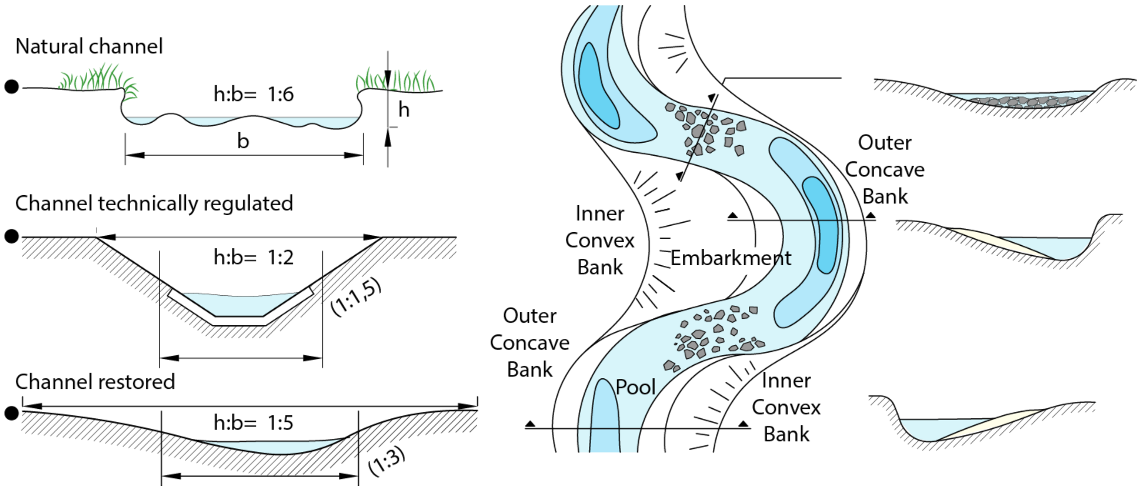

Figure 2.17. Shapes of channel in meanders
(Reproduced from Kovar, 2013, Class lecture for course, Czech University of Life Sciences Prague, Czech Republic)

Furthermore, these kinds of frameworks focus primarily on biological systems. Given that the urban landscape is a combination of dynamic, overlapping social systems, ecological systems, and management or institutional systems, these frameworks are inadequate for addressing the multidisciplinary challenges of urban stream rehabilitation. These documents provide theory, but their focus is primarily on design techniques, with no detailed discussions on how to integrate urban elements into rehabilitation approaches. These kinds of studies and projects can be implemented in some countries, but in Mediterranean countries, these outlines could be different because of different regional and climatic contexts for their dry creeks.

Since urban runoff is a significant source of pollution, it generates uncontrolled velocities, which causes erosion. To prevent negative impacts of floods and erosion, green infrastructure techniques can also be used in Mediterranean countries. In this respect, green infrastructure techniques and stream rehabilitation techniques can be implemented, even on dry creeks, to revitalise and prevent the risk of floods in built environments. Since green infrastructure techniques are represented in the previous section, only selected stream rehabilitation techniques are analysed in this section. Discussed concepts focused on the Mediterranean region are also applicable to all regions and various ecosystems.

Correspondingly, after a detailed literature review, the rehabilitation outline of this study for streams in Mediterranean regions is determined as follows: (1) water quality and climate settings, (2) in-stream habitat techniques, (3) riparian vegetation, (4) connectivity, (5) natural channel design: daylighting.

2.3.1.1. Water Quality and Climate Settings

Poor quality of water and numerous extreme quantity issues, like flood and scarcity, are the most obvious threats posed to humans by stream ecosystems worldwide. Discharge from a stream can vary, depending on the region. Particularly in the Mediterranean Region, the climate is characterised by dry summers and wet winters. Correspondingly, streams in this region are shaped by their unique hydrologic regime due to extreme flooding and extended dry periods.

As seasonality and variability are the main attributes of the Mediterranean climate, approximately 80% of precipitation in Mediterranean countries falls only during the three months of winter (Matlock & Morgan, 2011b). As a result, flooding often occurs during winter in this region. Annual rainfall in the Mediterranean Region usually ranges between 270-900 mm (Matlock & Morgan, 2011b).

While streams of the Mediterranean regions, in wetter areas, hold surface water throughout the year, in drier areas, streams cannot carry water in dry seasons because of climate conditions. They are characteristically composed of isolated pools (Matlock & Morgan 2011a). In İzmir, drying of the headwater tributaries is considered a typical attribute of streams.

As another extreme quantity issue of streams, floods have several impacts on their ecosystems, some of which are losing accumulated sediment, moving organic matter, changing of channel morphology, damaging riparian zones, and impairment of water quality (Matlock & Morgan, 2011b).

Agricultural land use and urban sewages can also be regarded as primary causes of water quality degradation. Pollutants can bring about serious damages to the running water ecosystems, but the most popular are those of organic matter and nutrients, which can cause severe impairment in stream ecosystems through extreme pH changes, organic pollution, salts or heavy metals, among other components. Excess of these compounds can lead to eutrophication, having harmful effects on the aquatic ecosystems and limiting their suitability for human consumption and use (Paul & Meyer, 2001). Before redirecting urban runoff from urban areas into the streams, it is important to provide a self-purification system in floodplain areas by using green infrastructure techniques, because urban runoff is contaminated with some materials, which has a toxic impact on aquatic ecosystems.

While natural places do not produce as much runoff due to easy infiltration, in urban areas even a small rainfall can cause intense runoff because of impervious surfaces. Therefore, cities need treatment of polluted stormwater runoff to avoid the undesirable impacts. However, measures of pollution in the aquatic ecosystem on a large scale often inevitably fail because the diffuse sources tend to increase due to surges of agricultural and urban activities and then subsequent rise in the pollution of the aquatic ecosystem (Moerke, Gerard, Latimore, Hellenthal, & Lamberti, 2004).

One of the techniques that can easily be used in the treatment of wastewater is phytoremediation, which is the direct use of plants to reduce contamination in soil, water, and sediment (Figure 2.18). Phytoremediation is increasingly recognised as improving wastewater quality due to its advantages such as cost effectiveness, environmental friendliness, and the possibility of biodegrading some contaminants, such as metals (Wang, Zhang, & Cai, 2011).

Figure 2.18. Phytoremediation technique depicting use of aquatic plants to clean water (Source: http://www.linternaute.com/savoir/grands-chantiers/06/dossier/seine-arche-nanterre/images/11.jpg)

Native plants in phytoremediation have more advantages than other species in restoring biodiversity and enhancing wildlife. Unlike other treatment methods, it is possible to save money. Because of this, these native plants do not require fertiliser or water.

Some plants from the Lemnaceae family, such as *Lemna minor* and *Lemna gibba*, also live in places having eutrophication issues, low O_2 and high CO_2 rates, can reduce about 95% of N components and 85% of P components (Saygıdeğer, 1996). The General Directorate of State Hydraulic Works (DSİ) identified the plants in aquatic systems in Turkey. All of these plants, including Lemna species, are seen as a threat to both humans and animals because of their 'harmful impacts,' which are summarised as restricting discharge in a channel, causing floods, and damaging structures by DSİ (General Directorate of State Hydraulic Works, 2000). Since any chemical, physical, or biological treatment methods do not offer the same performance, ignoring the capability of plants in regard to biodegraded pollutants would clearly be a mistake. Public awareness programs directed at the ever growing population, regarding water consumption and the need for increased wastewater treatment plants are considered the most effective means by which the pollution of the aquatic ecosystems could be alleviated (Ortiz & Merseburger, 2009). Therefore, many restoration efforts have recently been initiated to enhance water quality naturally.

Areas of low population densities and limited economic conditions where treatment plant installation could be difficult are encouraged to use wetlands or septic systems to prevent direct inputs of crude wastewater and subsequent degradation of aquatic quality (Kivaisi, 2001). One of these kinds of implementations is establishing Natural Treatment Facilities, where phytoremediation techniques are implemented, such as in 2004 in Haymana, Ankara (Figure 2.19).

Figure 2.19. First constructed wetland in Turkey
(Source: Yurtseven & Çakmak, 2007)

Constructed Wetlands provide filtration of wastewater with the help of plants. The Republic of Turkey Ministry of Environment and Urbanisation projected 43 constructed wetlands in several villages (Center For Middle Eastern Strategic Studies, 2011) after several researches proved the undisputed benefits of phytoremediation, including creating wildlife, balancing O_2-CO_2 rate, minimising toxic impacts of pollutants, and enhancement of riparian vegetation. However, once the sources of the compounds causing pollution are mitigated, the ecosystem rapidly recovers from their effects. This is because the hydrologic forces are continuously working on cleaning the system of its pollutants. Flooding and drying also play a major role in accelerating these self-purifying processes, therefore acting as a kind of reset mechanism (Ortiz & Merseburger, 2009).

Overexploitation of the aquatic system by human activities, causing dryness of the water, courses more often than natural conditions and affect their natural states strongly. Most Mediterranean countries have developed policies to provide water in streams for inhabitants, but even the most environmentally friendly governments cannot totally prevent the dryness resulting from natural reasons (Ortiz & Merseburger, 2009). To avoid human-caused water shortages, various green infrastructure techniques are being put in place that will ensure safety in the discharge by redirecting urban runoff and rainfall into stream ecosystems. Relative to this point, Matlock & Morgan (2011a) listed the components of the treatment of water quality as follows: minimization, natural filtration, constructed filtration, evaporation, and pollution prevention. All of these steps of water treatment require green infrastructure techniques, including rain gardens, bio-swales, green roofs, wetlands, and more.

Consequently, an effective restoration plan with innovative techniques would require actions, especially at the catchment level. However, these projects are hardly ever successful because of the effort and economic implications they often entail (Allan, 1996). Among these measures, the most supported by agriculture practitioners is the application of the latest technologies and strategies for the increase of efficiency of agricultural products and fertilisers (Ortiz & Merseburger, 2009). Procedures such as the establishment of constructed wetlands, riparian vegetation, or avoidance of excessive farming are not generally considered within this context, even though there are several effective practices of green infrastructure in the world to enhance water quality. The innovative solutions discussed earlier, rather than conventional methods, would provide more benefits and enhance environmental quality, without a doubt. Hence, the benefits that are supposed to be achieved by these so-called ecosystem services are often neglected (Ortiz & Merseburger, 2009).

2.3.1.2. In-stream Habitat

Urbanisation has impacts on the fluvial system as a result of flood management and land use planning. Several interventions to streams caused by development are called channelization, referring to converting streams into concrete channels. These actions include straightening, widening, deepening, and reshaping of channels, as well as clearing up riparian vegetation and removing boulders and logs. This kind of projects cause significant alteration of the aquatic ecosystem, resulting from loss of in-stream habitat (Woodcock & Huryn, 2007).

These actions have primarily been implemented with the aim of reducing flood risk, facilitating navigation, and creating more geometric lands. All of these interventions can cause irreversible impacts on stream ecosystem: (1) increased stream velocities and bank erosion, (2) destruction of aquatic life, (3) creating impervious surfaces, (4) decreased biodiversity and water quality. Removing riparian vegetation causes increasing temperatures in water, indirectly, which results in impairment of water quality. In addition, constructing concrete channels and floodwalls prevent bio-infiltration, sediment carrying into other connected tributaries, and makes navigation difficult for both animals and people. All of these cause growing problems of pollution, water quality, and aquatic life.

Ortiz & Merseburger (2009) do not oppose that dwellings located within floodplains of streams have to be protected from flooding by contention walls. According to the researchers, it is a very reasonable solution for safety, if they do not criticise the policies and regulations of streams. However, building concrete channels and altering of stream morphology have clearly adverse effects on the aquatic ecosystems.

The first principle of in-stream habitat improvement should be removing concrete channels, which prevent the natural meandering of streams and damage stream ecosystems. As discussed earlier, a significant degree of streams in Turkey were converted into artificially built channels in the name of so-called 'Stream Rehabilitation.' While European countries implement projects to rehabilitate channelized streams with the aim of bringing natural conditions back, urban streams in Turkey are still being regulated through engineering measures only.

Natural streams have been converted into artificial channels with the aim of protecting settlements from floods through redirecting water flow toward downstream areas. Even though concrete streambeds allow water to flow quickly, according to Farassati (2007), after some interventions to streams, people realised their mistakes, because the water flows through the concrete channels more rapidly than expected without plants, rocks, and stones, and this results in erosion in downstream areas. During heavy rain and flooding, rapid water flow in channelized streams can create other problems and cause more damage than a natural stream might be able to cause.

Some innovative companies offer to use gabions, terramesh, or geomat instead of concrete in stream banks. This may offer more advantages than concrete with their natural appearance and supporting wildlife through vegetation application along the banks.

As seen in Figure 2.20, Batch River does not look natural or attractive as a public space in the city centre. After losing its natural characteristics as a consequence of channelization, the distance between inhabitants and Batch River was dramatically increased. Then the rehabilitation process of Batch River was initiated with the aim of returning it to its natural conditions and re-connecting people with their lost nature. In addition, it was designed within a broad floodplain to provide sustainable urban drainage as a hotspot to install green infrastructure and in-stream techniques.

Figure 2.20. Before and after images of Batch River Rehabilitation Project in Japan (Source: http://image.slidesharecdn.com/narbowada-120920133055)

In-stream projects, in the context of stream rehabilitation, aim to add structures mimicking nature with the help of wood and rock materials. These structures provide housing for water species, decrease water temperature, facilitate wildlife passage, and prevent bank erosion.

Riparian vegetation, examined in the next section, as a shelter for living creatures, provides bank stabilisation. Similarly, fallen leaves, branches, trees, logs, and boulders provide a complex matrix, which serve as food sources and refuges for most aquatic organisms. However, the relevance of fallen trees in the aquatic ecosystems could easily be misunderstood by inexperienced water managers who may cut trunks into smaller logs with the aim of increasing in-stream habitat (Ortiz & Merseburger, 2009). As a result, smaller logs can easily be moved downstream by water flow. Therefore, it is significant to put structures together in a big group, like logjams (Figure 2.21). Some of these techniques to enhance in-stream habitats are listed in Table 2.9.

Table 2.9. Common types of in-stream improvement techniques
(Source: Roni, Pess, Hanson, & Pearsons, 2012)

Type of In-stream Rehabilitation	Definition	Typical Purposes
Log Structures and Boulder Structures (e.g. logs, log jams, weirs, sills, deflectors)	Placement of log structures and boulder structures into the channels	Create pools and holding and rearing areas for fish, trap sediment, prevent channel migration, restore floodplain, and side channels.
Gabions	Wire mesh baskets filled with gravel and cobble	Trap gravel and create pools or spawning habitat
Rubble matts or boulder additions to create riffles	Addition of boulders and cobble to create riffles	Increase riffle diversity (velocity and depth) create shallow water habitat
Cover Structures (Lunker structures, rocks or log shelters)	Structures embedded in stream banks	Provide fish cover and prevent erosion
Brush bundles/ root wads	Placement of woody material in pools or slow water areas	Provide cover for juvenile and adult fish, refuge from high flows, substrate for macro-invertebrates
Gravel additions and spawning pads	Addition of gravels or creation of riffles	Provide spawning habitat for fishes
Channel re-meandering	Alter channel morphology by excavating new channel to restore meander patterns or return to historic channel	Restore meander patterns, increase habitat complexity and pool-riffle ratio, reduce channel width, reconnect floodplain

Figure 2.21. Large woody debris as an in-stream improvement technique
(Source: http://america.pink/large-woody-debris_2542573.html)

2.3.1.3. Riparian Vegetation

Riparian vegetation directly affects aquatic organisms and plays a significant role in the process of stream rehabilitation. The roles of the riparian buffers include nutrient retention, purification, erosion protection, decreasing of flood impacts, increasing water quality, regulating of eutrophication through canopy shadow, and supporting wildlife (Ortiz & Merseburger, 2009). Removal of riparian vegetation may cause several problems to stream ecosystems; therefore it is important to clarify some benefits of riparian vegetation. First of all, vegetation near a stream provides shadow in the stream and reduces temperature, which is a necessity for aquatic life. Otherwise, as a result of removing riparian vegetation, stream habitats can be exposed to high temperatures in the especially hot summer climate of the Mediterranean region. Moreover, as leaves, branches, and other organic materials from riparian plants fall into streams, the amount of carbon increases in the streams. However, the situation is not the same for channelized streams, especially if the streams were converted into concrete blocks.

According to Ortiz and Murseburger (2009), riparian vegetation is the main factor that is commonly considered in most stream rehabilitation and restoration projects, because working with visible objects is considerably easier than the other components of the aquatic ecosystem. These projects intend to plant cultivated trees and remove exotic species. Fischenich and Allen (2000) articulate that narrow buffers less than 5-10 m require riparian vegetation recovery projects. A riparian corridor as an element of the green infrastructure network, examined earlier, should be wider for efficient management practices. Since the banks of some streams were transformed into concrete blocks to avoid flooding and erosion, they require entirely riparian vegetation recovery in a broader context with various experts, including ecologists, landscape architects, and biologists. Therefore, we can classify riparian vegetation efforts into two groups: (1) partial rehabilitation, (2) entire rehabilitation.

In the process of improving riparian habitat, the planting of trees, shrubs, and live stakes and removing non-native plants are the most common methods in which some factors (e.g. geographic area, climate) determine the success of planting. Various plants can be used in riparian buffers, but factors influencing the selection of plants are as follows: (1) availability; (2) suitability and durability for climatic conditions; (3) root systems; (4) physical appearance; (5) plant sociology; (6) other ecological features such as infiltration capability, purification attribute.

One of the criteria for plant selection should be the roots of plants, to provide stabilisation. As larger plants have larger root systems, plants with big canopy diameters may be more preferred to prevent erosion and flooding in stream ecosystems. Moreover, phreatophyte species, which have deep root systems, can also be used in the planting process. Since native plants, which can be found easily for plantation, do not require water or fertiliser as much as other plants, it is important to determine the native plants in the region. Correspondingly, appropriate plants, native plants, and especially fast-growing species, e.g. willows, should be used in riparian buffers instead of exotic plants, due to their advantages.

Invasive plants as introduced species threaten aquatic ecosystems because they cannot be controlled easily. Therefore, it is important to know the attributes of species and relations with other species for effective plantation. These plants, for instance, *Phragmites australis* (Common Reed) and *Arundo donax* (Giant Cane*)*, can spread so rapidly and suppress other species because of food and water competition. Hence, invasive plants can affect stream ecosystems negatively through decreasing a number of natural resources, threatening native species, and spreading randomly, which results in drought in stream ecosystems. Therefore, in many riparian vegetation improvement projects, invasive plants are targeted for removal.

Re-vegetation (or re-colonization) in a riparian buffer is a vital stage of stream rehabilitation. Nevertheless, the expansion and subsequent colonisation of new areas by living species may cause some problems. Ortiz and Merseburger (2009) listed these problems as major habitat alterations, species extinction, resource depletion, and damages to human infrastructures. As a result of using exotic species instead of native species, in a few years, invasive plants damage the entire ecosystem, since they often exceed the natural dispersal capacities for the species. Therefore, conventional methods in stream rehabilitation bring about the elimination of existing invasive species from the riparian buffer. However, these efforts are hardly successful, since they require high economic budget and great human effort.

Invasive species are not only composed of plants, but also animals, like fishes. Some invasive species seen in Mediterranean regions are *Ailanthus altissima* (tree of heaven), *Robinia pseudoacacia* (black locust), *Arundo donax* (giant cane), and flora species *Procambarus clarkii* (red crayfish), *Dreissena polymorpha (*zebra mussel), and *Amerulus melas* (catfish) (Ortiz & Merseburger, 2009).

On the other hand, invasive plants can be native plants in other regions, since some factors control the growing and spreading of these plants. Thus, an understanding of plant sociology in the stream ecosystem and avoiding the use of exotic species should be significant principles in riparian rehabilitation projects and before the re-colonization stage in rehabilitation projects, the risk of invasive plants should be evaluated very well. Otherwise, all investments could be wasted within a few years.

Medicago sativa (lucerne) and *Spartium junceum* (Spanish broom) are some of the most significant plants that can be used in the sloped zones in Mediterranean countries, to provide slope stability. They can grow in wet and moderately fertile soils. It is crucial for riparian vegetation to have a tolerance of gently flowing water and drought.

Riparian vegetation enhances interactions amongst organisms of the habitat, ensures high-quality water and habitat, and implies the prevalence of innocuous insects, such as caddisflies, mayflies, and stoneflies, instead of the dangerous ones like midges, mosquitoes or blackflies (Ortiz & Merseburger, 2009). Riparian buffers along streams should be rehabilitated as zones; therefore, several plants that can be used in these zones are listed in Table 3.7.

As shown in Figure 2.22, the proximity of each zone to the stream determines the vegetation types and species. Herbaceous perennial plants are placed in Zone C, (i.e. located on the water's edge) with the aim of providing stabilisation on the steep slope. *Iris* and *Carex* species are often seen in this zone. Next, shrubs stand between trees and low-growing plants. Then, trees are placed in the following zone.

Table 2.10. Riparian Buffer Vegetation
(Developed from Güney, 2011 and Cooke, 1997)

Riparian Trees (Zone A)	**Riparian Shrubs (Zone B)**	**Low Growing Plants (Zone C)**
Acacia sp.	*Lonicera japonica*	*Cartex sp.*
Acer sp.	*Origanum smyrneum*	*Carpobrotus acinaciformis*
Alnus glutinosa	*Pistacia lentiscus*	*Gazania rigens*
Chamaecyparis lawsoniana	*Prunus spinosa*	*Iris sp.*
Eucalpytus viminalis	*Rhododendron occidentale*	*Lampranthus sp*
Fraxinus excelsior	*Rosa sp*	*Lonicera carifolius*
Populus alba	*Rubus sp.*	*Lotus corniculatum*
Populus nigra	*Salix purpurea*	*Mesembryanthemum barbarus*
Salix alba	*Salix viminalis*	*Scirpus sp*
Sequoia sempervirens	*Spartium junceum*	*Thymus serpyllus*
Ulmus minor	*Spiraea douglasii*	*Typha sp*
Tilia cordata	*Tamerix sp.*	*Verbana repens*

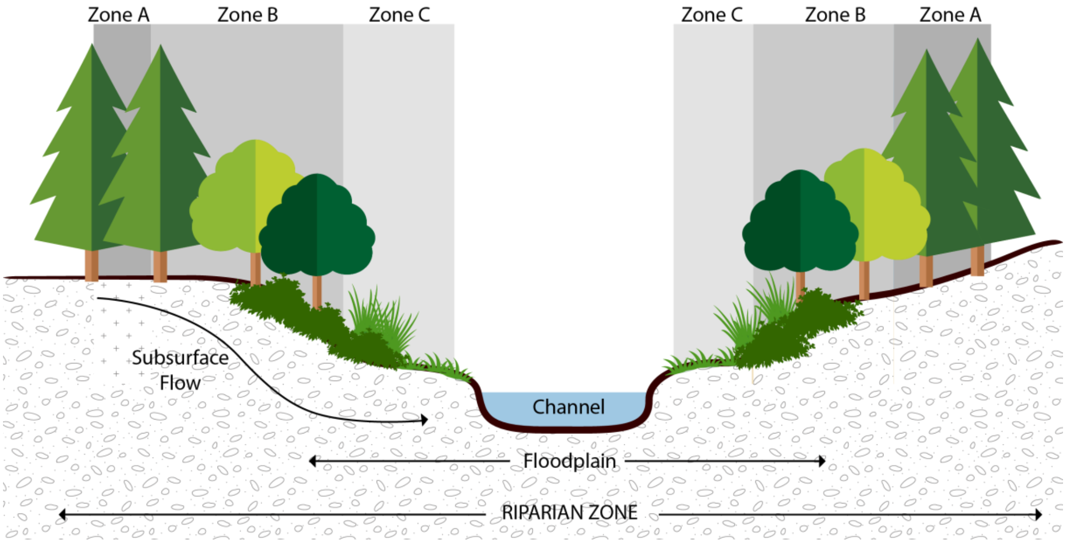

Figure 2.22. Riparian zone cross-section

2.3.1.4. Stream Connectivity

Connectivity is of great significance to streams. Many stream rehabilitation projects fail because they have not been implemented at the catchment level. Therefore, it is important to clarify the term of connectivity and its components for streams. Aquatic beings, organic matter, and nutrients can move easily due to the presence of connectivity in watershed. Connectivity in a stream exists as longitudinal, lateral, and vertical ways. While the longitudinal dimension of connectivity refers to the connection from downstream to upstream (Figure 2.23), lateral connectivity, also known as a transversal, relates to the connectivity of the stream to the floodplain and riparian buffer (Roni et al., 2012). Vertical connectivity in a stream is identified as the linkage between the hyporheic zone and stream channels (Boulton, 2007); i.e. the connection between atmosphere and groundwater.

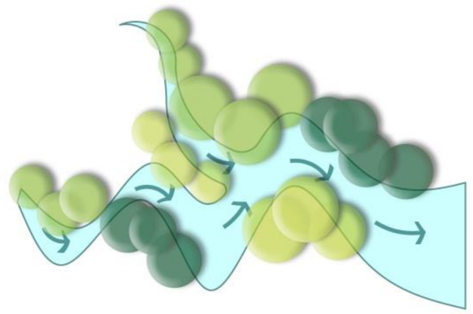

Figure 2.23. Longitudinal connectivity of a stream

Some structures in a stream ecosystem cause boundaries that threaten the aquatic fauna and damage the longitudinal connectivity of a stream. Longitudinal connectivity is of great importance for fish species to positively complete their life cycles (Ortiz & Merseburger, 2009). Rehabilitation of longitudinal connectivity often requires the removal of dams and artificial structures including weirs, culverts, and pipelines (Roni et al., 2012). Since the removal of structures and rehabilitation of riparian buffer increases the connectivity (Kondolf et al., 2006), the first goal should be supporting longitudinal connectivity in a watershed context. In some restoration projects, instead of dam removal, fish passages are built. However, only those that meet the objective of passage for migratory fish (Roni et al., 2012). Removing of dams and structures like culverts would be aimed in the longitudinal connectivity process for more efficient results (Figure 2.24).

Figure 2.24. Removal of dam and road culverts
(Source: Aadland, 2010)

In this context, Ortiz & Merseburger have some recommendations to support the longitudinal connectivity, some of which are listed below.

- Reservoirs and ponds can be substituted for dams in cases they are replaceable.
- A gauging station in a stream ecosystem could be replaced by another efficient technique of flow measurement, even though it is essential and significant for people.
- If the destruction of the structures in a watershed is not possible, fish passages should be established to decrease the negative impacts of boundaries.
- Less expensive and aggressive structures like bridges can be substituted for road culverts.

Streams, especially channelized ones, may call for the rehabilitation of lateral connectivity in order to improve floodplain functions and to create a linkage between stream channels and floodplains (Figure 2.25). Lateral connectivity concerning nutrients and organisms is established between a stream channel and its adjacent floodplain. Some factors affecting lateral connectivity in a watershed are as follows: (1) frequency; (2) duration of surface flooding; (3) seasonality; (4) groundwater; (5) channel water levels and (6) water management (Rouquette et al., 2011).

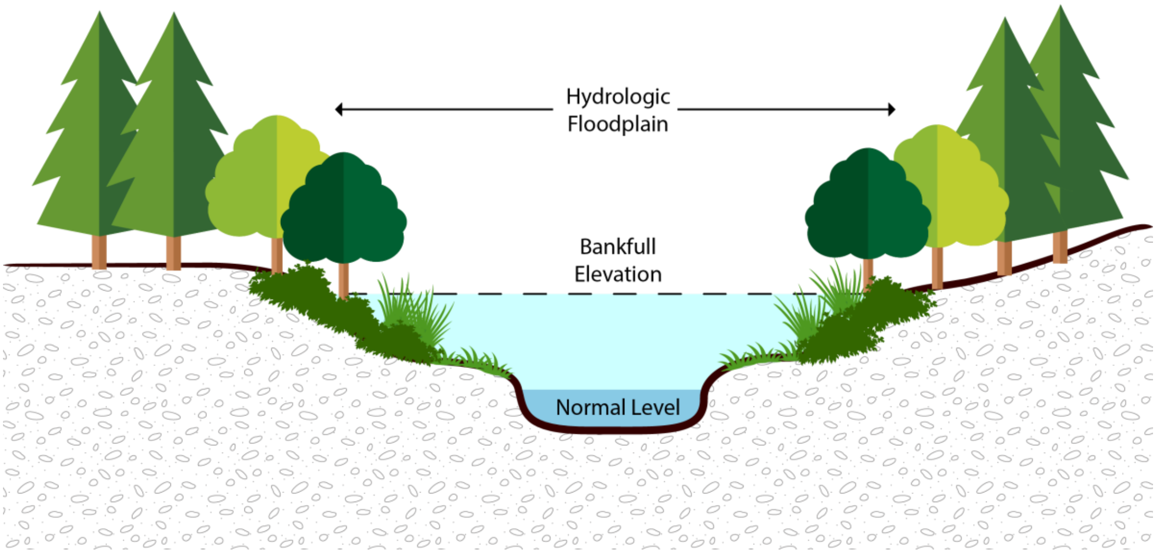

Figure 2.25. Lateral connectivity of a stream

Floodplain can be disconnected from a stream for months or even years as a result of hot climate conditions or some human intervention. Water from lakes or swamps isolated near streams may not reach to the main channel during this period. Correspondingly, primary productivity and nutrient levels may decrease in the floodplain (Tockner, Lorang, & Stanford, 2010). This is the reason why lateral connectivity is also regarded by some authors as the connection of streams to other wetlands, but lateral connectivity refers to the linkage of streams with floodplains. However, it is important to underline that the connection of isolated wetlands to streams is vital since natural wetlands have high nutrients and organic matter. If possible, restoration projects should be targeted to the isolated patches, to reconnect them.

Restoration of lateral connectivity gives the stream a chance, which permits overbank flooding. Therefore, the first aim should be the removal of bank revetments, if any exist. In this regard, organic materials and nutrients can be transported during floods or heavy rains, which provides productivity and diversification in stream ecosystems. Through the elimination of lateral boundaries, aquatic biota could be more homogeneous and species could spread easily (Rahel, 2007). After the removal of structures preventing connections between streams and floodplains, the next step is to reconnect isolated floodplain wetlands.

One approach can be used in this context; channelized streams need to mimic natural streams that meander through landscapes (Figure 2.26) since straightened channels cause several problems including the disconnection of floodplains (Roni et al., 2012).

Figure 2.26. Natural meandering and connected tributaries
(Source: http://nwrm.eu/measure/restoration-and-reconnection-seasonal-streams)

As Figure 2.27 indicates, vertical connectivity of a stream is the relationship between the streambed and ground water. Stream-bed channelization can be the most significant cause of vertical disconnection. Concrete stream-beds disrupt the interaction between the water's surface and the hyporheic zone. Even though the vertical connectivity is ignored in restoration projects (Jansson, Nilsson, & Malmqvist, 2007), it should be on the to-do list in the rehabilitation process. Another reason for disrupted vertical connectivity is clogging by organic matters and sediments from agricultural activities and urban wastewater (Ortiz & Merseburger, 2009).

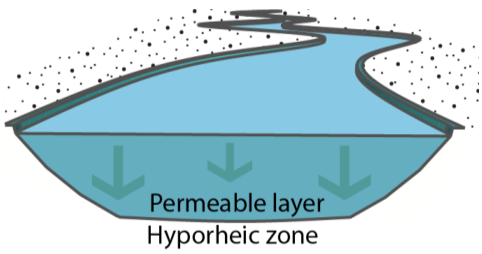

Figure 2.27. Vertical connectivity of a stream

Longitudinal, lateral, and vertical connectivity in a stream ecosystem should be considered together, since restoring one of the connectivity dimensions would help to improve the others. Therefore, the pros and cons should be listed first and then alternative solutions for the current problems should be represented, which will provide the connectivity in a watershed context. In addition, landscape connectivity, as discussed in the previous section, not only supports this idea and enhances functions of stream ecosystems, but also provides a healthy urban environment.

2.3.1.5. Stream Daylighting: Natural Channel Design

As mentioned earlier, the modern era has caused many problems for streams including changing their natural courses underground. Since people have enlarged their agricultural areas and built structures and transportation networks within floodplains, streams confined in pipes and concrete walls are polluted. In addition, running waters are also exposed to straightening and being put into culverts. With increasing awareness about the significance of running water, the term of stream daylighting aims to restore buried waterways and bring daylight back. The main goal of daylighting is to rehabilitate streams for more natural conditions through improving riparian environments. Therefore, it is important to clarify natural channel design techniques to be able to understand which methods are required in this process.

Re-naturalization of streams results in several benefits, including slowing velocity, flood control, removal of water from combined water systems, and ecological revitalization (Trice, 2013). Natural channel design helps to manage stormwater by slowing the flow, reducing impervious surfaces, increasing green areas, improving water quality, enhancing urban health, and using porous paving. In the following chapter, the focus will be on implementing practices to be able to understand the main purpose of each technique.

Daylighting efforts offer not only ecological benefits, but also recreational opportunities. For instance, these kinds of projects may have enriched recreational space by linking communities to the environment, providing land where students can learn the basis of the environment and creating a corridor with walking and bike paths (Trice, 2013). According to Vought and Lacoursiere (2010), the main points of daylighting are listed below:

- Rehabilitation of streamflow regulation
- Providing self-cleaning of streams

- Reclaiming streams to functional ecosystems

Moreover, in conventional methods, urban runoff mixes with sewage, but daylighting removes stormwater from combined sewer systems, referring to the system carrying sanitary sewage and storm runoff together (Pinkham, 2000). Another reason daylighting is considered an applicable technique is that it is cost-effective, especially when compared to a damaged culvert. For instance, when a culvert collapses, repairing or reinstalling a new culvert could be more expensive than replacing a stream into an open waterway (Trice, 2013). Correspondingly, since the monitoring of open streams for any damage is easier, this system can work more efficiently in the process of stream rehabilitation. Some rehabilitation projects will be examined in detail in Chapter 3, representing various practices related to urban streams from various countries.

As shown in Figure 2.28 and Figure 2.29, meanders, pools and riffles need to be created to control the velocity after streams are unearthed from culverts. In-stream habitat techniques mimicking the functions of nature can be applied in these practices to provide more natural conditions. Riffles and pools not only help to regulate and control the water flow, but also filter urban runoff and improve water quality. Other techniques which can be applied in urban streams to create more natural watercourses will be examined in the following section.

Figure 2.28. Natural channel design in Dortmund, Germany
(Source: Prominski, Stokman, Zeller, Stimberg, & Voermanek, 2012)

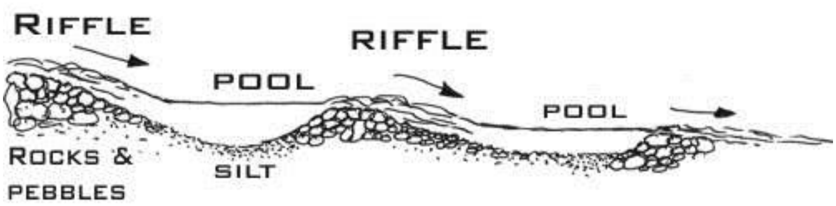

Figure 2.29. Natural channel design cross-section
(Source: http://www.lifeinfreshwater.org.uk/Web%20pages/Rivers/Channels.htm)

2.3.2. Stream Rehabilitation in Turkey

Since Turkey is located in a semi-arid region, it is not a country rich in freshwater resources. Insufficient water availability is a serious problem in the region of Turkey. Therefore, it is appropriate to point out that sustainable water management comes to the forefront as a solution to the water problem. In this regard, the treatment and reuse of wastewater should be common methods, which could be used in basins of urban streams.

Riverfronts in Turkey have been key components of open space systems, which act as socio-cultural centres of urban life by welcoming people of all ages, social statuses and educational backgrounds, since the Ottoman Period (Türer Başkaya, 2013). However, as a result of the factors that led to the emergence of the conventional approach, several urban streams in Turkey have been exposed to interventions on such a scale. This resulted in urban streams in parts of riverfronts in Turkey dramatically being transformed and detached from urban life.

It is important to underline that the conventional approach to urban streams affected the entire world in the 1900’s. Therefore, urban streams are not only being channelized in Turkey for stormwater management, but also in other countries. However, after having noticed the effects of all of the interventions on urban streams, recovery efforts brought to the forefront the concept of stream rehabilitation. Nevertheless, hard engineering solutions of the conventional approach are still carried out in Turkey. These implementations, which are seen as infrastructure projects, are temporary solutions to the conventional approach to controlling stormwater, whereas the term stream rehabilitation requires a more extensive approach, not only to improve stream ecosystems, but also to contribute to urban life and landscapes. Therefore, the perception of stream restoration in Turkey should be changed based on ecology principles.

On the other hand, since boundaries of watersheds extend beyond city limits, stream rehabilitation requires an integrated and holistic approach, with the collaboration of local governments. Nevertheless, each local government in Turkey may approach each stream which passes through more than one city, in a different way, due to uncooperative bureaucracy and the lack of laws and regulations ensuring collaboration and information sharing among the administrative bodies.

Another reason for the failure of stream rehabilitation in Turkey is the lack of infrastructure; therefore, urban streams as existing lines connecting districts are used to reduce infrastructure costs. Consequently, many urban streams in Turkey carry wastewater without any filtration and discharge into the seas, due to financial and infrastructure problems.

Exceptionally, the Porsuk River, which flows through the city of Eskişehir in Turkey is the only river that has been ecologically rehabilitated in Turkey. Even though it was once a river where inhabitants of Eskişehir had fun, it was converted into an open sewer like many watercourses in Turkey. Rehabilitation of the Porsuk River consists of three steps: preventing floods, renewing its channel, and improving a tramway network. This project is considered the most significant river rehabilitation project in Turkey, since it not only improves the water system of Eskişehir, but also contributes to the urban life of the city. However, as with the deficiencies (Şimsek, 2011), and through increased awareness of ecological restoration, this project has become a focal point in Turkey due to its attempts.

Interventions on floodplains, rapid urbanisation, uncooperative bureaucracy, inappropriate land uses, destruction of vegetation in the basin, faulty spatial perceptions, the lack of infrastructure and environmental awareness, financial problems, and water structures such as dams and culverts have caused serious urban problems. For all these reasons, urban streams in Turkey urgently need ecologically based rehabilitations.

All of this points to the fact that sustainable development cannot be achieved without sustainable urban approaches. In this respect, urban streams in Turkey should be perceived as vital components of natural resources. Clearly, they have a duty to be rehabilitated ecologically so that every person can have the right to access healthy and safe water.

2.3.3. Key Steps for Stream Rehabilitation

In spite of enormous financial investments to the stream rehabilitation, they may fail because of mistaken scales, inappropriate technique selection, or skipping some steps in the rehabilitation process. As mentioned before, rehabilitation efforts always require a watershed or basin scale approach by various techniques. However, in some cases, they are only rehabilitated on the floodplain scale due to financial problems. Some of the common mistakes causing failures are listed by Roni & Beechie (2012) as follows:

- Not addressing the essential causes of degradation
- Ignorance of connectivity linking upstream and downstream
- Inappropriate technique selections
- Incoherent approaches
- Insufficient projects design
- Failure to get adequate support from public and private organisations
- Not monitoring after implementations to check effectiveness

It is essential to underline the significance of developing projects in accordance with the 'adaptive management approach,' (Ortiz & Merseburger, 2009). Stream rehabilitation has a need for an experimental approach, requiring feedback in order to improve the effectiveness of the project. Even though monitoring and evaluation are also vital phases of this process, this thesis is not intended to explain all of the steps of stream rehabilitation. The goals in any rehabilitation project can be achieved by various techniques; we only represent selected innovative techniques instead of conventional techniques in order to reduce negative impacts upon the environment. However, this does not mean that all innovative techniques can be used in any stream restoration. Inappropriate technique selections can also fail. Therefore, a group of consultants including hydrologists, landscape architects, urban designers, engineers, and ecologists should decide together on an appropriate technique selection.

2.4. Evaluation

This chapter points out the environmental measures that can be implemented in urban streams to provide urban health. In this sense, the study calls these kinds of endeavours Stream Rehabilitation. While the concept stream refers any flowing freshwater, including rivers or creeks, the term rehabilitation means an improvement instead of full restoration. In an urban context, flowing freshwater cannot be restored to its original state due to financial and organisational problems, like the ownership dilemma. On the other hand, the case study of this research is situated in an urbanised area, which needs rehabilitation to heal as much as possible. Thus, the research focuses on stream rehabilitation approaches.

In this context, green infrastructure is an environmental and planning approach to catalyse sustainable urban development. In the light of green infrastructure framework, this research emphasises the techniques that can ensure urban river health. In-stream and green infrastructure practices and approaches, therefore, stand out to be adopted for the Arap Stream on a catchment scale. However, a significant part of the Arap Stream was destroyed or buried underground, which calls for daylighting not only for ecological concerns, but also for social and economic assets in terms of maintenance. As discussed in previous chapters, an open waterway is considered more cost-effective than an artificial stream buried underground. Therefore, Arap Stream should be rehabilitated in its catchment area through bioengineering techniques that mimic nature, with the goal of providing water balance in (un)built environment. In this regard, sustainable stormwater management techniques such as rain gardens, bio-swales, green streets, and constructed wetlands play a noteworthy role in the rehabilitation process.

CHAPTER 3

BEST PRACTICES

This chapter presents Best Practices, which have been implemented in different parts of the world, and that integrate green infrastructure and some innovative techniques into urban streams. Among numerous rehabilitation projects, this chapter examines seven selected case studies with the aim of demonstrating innovative techniques on urban streams and analysing how an urban stream and its surroundings can be turned into an ecologically and socially functioning whole, through innovative approaches.

Additionally, it is also crucial to mention hydrological park projects, which can be a guide for the ecological design of urban landscapes. Hydrological park projects are commonly considered in cities where hydrologic and environmental problems exist. These problems can provide opportunities for the cities to be redeveloped ecologically. Therefore, this chapter also discusses hydrological parks that were modified by human impact and then redesigned using an ecology-oriented approach.

3.1. Mill River Park and Greenway (Stamford, USA)

Mill River Park, located in the heart of Stamford, is a major park that maintains the ecological and social fabric of the city (Figure 3.1). Mill River Park was designed on 13 hectares of waterways and greenery, by the Olin Partnership in collaboration with the Mill River Collaborative, between 2007 and 2012. The main objective of the project was to build the park for ecological, economic, and social sustainability through green infrastructure techniques (Olin Partnership, 2007). Also, another objective was to connect Stamford with the waterfront and to offer revitalization to the district as a whole. The first phase of the rehabilitation project was implemented in 2013. Future phases will be carried out once funding becomes available.

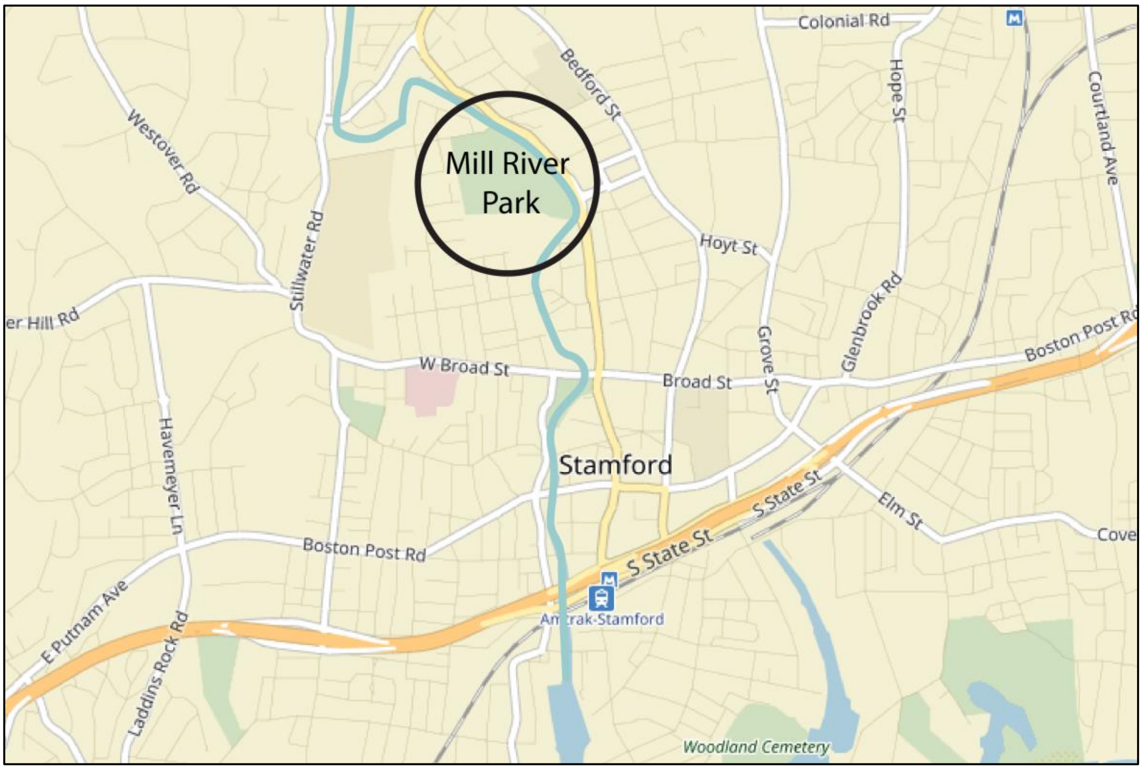

Figure 3.1. Mill River Park in Stamford
(Source: Yandex Map)

The historical context of the rehabilitation project of River Mill reaches back to the floods and hurricanes that frequently happened in the region. Not only were there natural disasters in the district, but the channelized and polluted Mill River also played an important role for the derelict riverfront (Figure 3.2). To mitigate this threat, the City of Stamford hired landscape and urban design firm Olin Partnership, in 2005, for a rehabilitation project. In this regard, an interdisciplinary team, including landscape architects, urban designers, ecologists, and engineers designed a “self-regenerating” landscape project, in order to reclaim water and land habitats, allow the watercourse to flow freely, remove concrete dams and residential dwellings from the floodplain, and decrease the flood risk (ASLA, 2015). According to the project, numerous walking paths along Mill River connect neighbourhoods to a vibrant and verdant landscape, which offers active and passive recreation opportunities to the community.

Figure 3.2. Mill River before the rehabilitation project
(Source: ASLA, 2015)

Regarding the realisation of the Mill River Park and Greenway, it was divided into three stages. River Restoration Project, Stage I, and Stage II, which will be completed over the course of 40 years (Olin Partnership, 2007). River Restoration Project provides places including the great lawn, fountains, grand steps, riparian edge, main street bridge, porch, carousel, sculpture garden, playground, piers, amphitheatre, basketball court, historic cemetery, kayak area, sensory garden, butterfly garden, and scent garden for active and passive recreation (Figure 3.3). In this sense, Stage I includes the restoration of the riparian zone, the transformation of the concrete channel into a naturalised river bed, and implantation of most of the design elements, including the pathway system. As the first step of construction, a playground was built in 2006. Then, the Pulaski Street Dam and the Mill Pond Dam were demolished in 2009. Also, five hectares of landscape area were created in 2013 as part of Stage I. According to Landezine (2014), the budget of the project is $11.8 million, excluding Stage II. As the last step of the development plan, Stage II includes improvement of some land uses and expansion of greenway paths along Main Street (Olin Partnership 2007). However, the funding for Stage II is still in the process of being secured.

Figure 3.3. Mill River Park and Greenway
(Source: ASLA, 2015)

The edges of the Mill River today have a protective floodplain that eliminates adverse impacts of stormwater from surrounding neighbourhoods (Figure 3.4). Supporting native wildlife communities and creating a variety of habitats also enhanced the biodiversity of Mill River. The interdisciplinary team designed some meanders, pools, and riffles in order to mimic the natural morphology of waterways (ASLA 2015). Almost 500 native plants, including shrubs and trees, were installed along the watercourse. Since many historic cherry trees existed in the project area, during construction they were held in a nursery with the aim of saving as many as possible. According to Verel (2010), visible design process, non-profit collaboration, and private funding are the key elements for the development of the project.

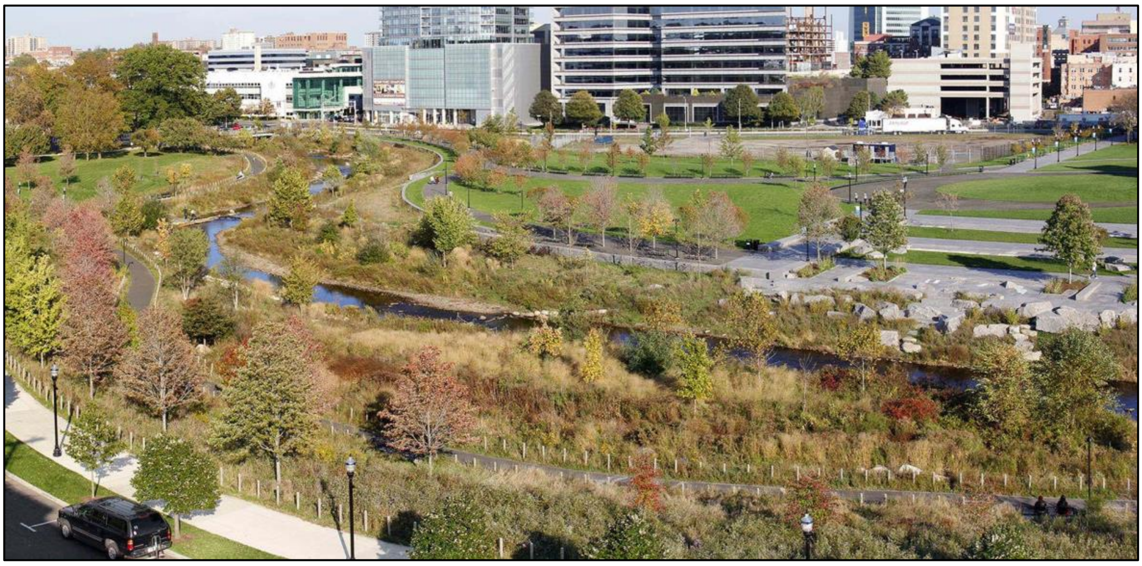

Figure 3.4. Mill River Park and Greenway after the rehabilitation project
(Source: ASLA, 2015)

3.2. Bishan-Ang Mo Kio Park (Bishan, Singapore)

Bishan Park, with more than three million visitors each year, holds a significant role in the heartlands of Singapore (Landezine, 2014). The longest river in Singapore, Kallang River, flows for about ten kilometres through the city centre (Figure 3.5). The 62-hectare park was designed between 2007 and 2010 by Ramboll Studio Dreiseitl. The main aim of the project was to improve the capacity of the concrete canal and to transform the existing park into a functional park, which is fully integrated with nearby neighbourhoods, with a water-sensitive urban design approach (Ramboll Group, 2012).

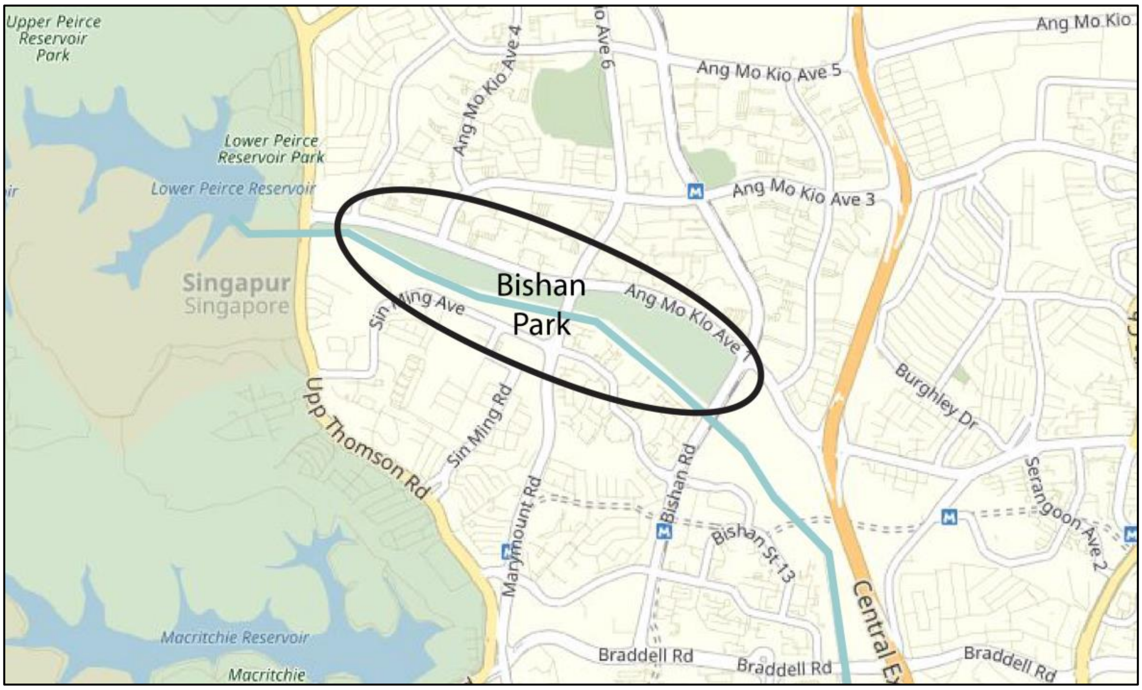

Figure 3.5. Bishan-Ang Mo Kio Park in Singapore
(Source: Yandex Map)

Before the restoration project, Kallang River, like many waterways around the world, was forced into a concrete channel to reduce the impacts of extensive flooding (Figure 3.6). The existing park around the river, which could receive some migratory birds due to its geographical location, had wide lawn areas which did not function ecologically. The urban park, with randomly located trees, did not have considerable biodiversity value. Also, the population of the district increased dramatically after the district was completely urbanised.

Figure 3.6. Kallang River before the rehabilitation project
(Source: Ramboll Group, 2012)

As a part of the Active, Beautiful, Clean Waters Programme (ABC Waters), which was launched in 2006 to transform water bodies in the country into vibrant and clean streams and lakes with new spaces and amenities, Ramboll Studio Dreiseitl was commissioned to provide design projects for Kallang River and Bishan Park. In this regard, the existing park was extended, with an additional ten hectares of waterways and greenery for drainage as well as recreation. Also, as seen in Figure 3.7, a three km length of the straight concrete channel was converted into a vegetated, natural, and meandering water system (Landezine, 2012). Many city designers, stakeholders, and agencies were involved in the process from beginning to end.

Figure 3.7. Kallang River after the rehabilitation project
(Source: Ramboll Group, 2012)

In addition to a new design process and new technological techniques, a natural cleansing system and a soil bioengineering technique were also key elements in the rehabilitation project of Kallang River (Figure 3.8). Since the bioengineering system had not been used before in a tropical climate, people living close to the park did not support the construction of the project, even though it offered many solutions. After a test area was built in order to show its reliability and effectiveness, the rehabilitation project was implemented successfully in 2012.

Figure 3.8. The rehabilitation plan of Kallang River and its surroundings
(Source: Ramboll Group, 2012)

With regard to the construction of the project, costing $60 million to build, stormwater networks were integrated with the creation of a new meandering river. In this regard, the undulating terrain of the district is used to capture stormwater from higher areas and to retain it in Kallang River, which meanders through the park. Some recycled materials and natural materials, like rocks and gravel, were used in the process of construction. The non-flood zones in the riparian areas were developed as a recreational site, with a range of activities and amenities including event lawns, recycle hills, viewing points, riverside gallery, playgrounds, bio-swales, and ponds. Also, riffles, rocks, and pools in the new riverbed were designed to reduce velocity for flood protection. On the other hand, a biodiversity monitoring system was integrated into the district, so as to understand the changes in water quality and biodiversity. According to the monitoring result, biodiversity in the park has increased by 30% since the rehabilitation project completed (Landezine, 2014). Also, the heat island effect in the district has drastically been reduced.

The rehabilitation of Kallang River and its surrounding area is one of the most significant projects, which shows how natural resources, which have been influenced by human impact, can be saved again. Also, reconnection of the community members with their lost nature is one of the most significant outcomes.

3.3. Cheonggyecheon Stream (Seoul, South Korea)

The Cheonggyecheon Stream flows for about 11 kilometres through downtown Seoul (Figure 3.9). The Cheonggyecheon Stream Rehabilitation Project, covering 40 hectares of land and water, transformed an urban highway between two central business districts into a pedestrian area. The rehabilitation project of Cheonggyecheon not only aimed to revitalise the district, but also sought to recover the history and culture. The project was designed by Mikyoung Kim Design Team and was implemented between 2003 and 2005.

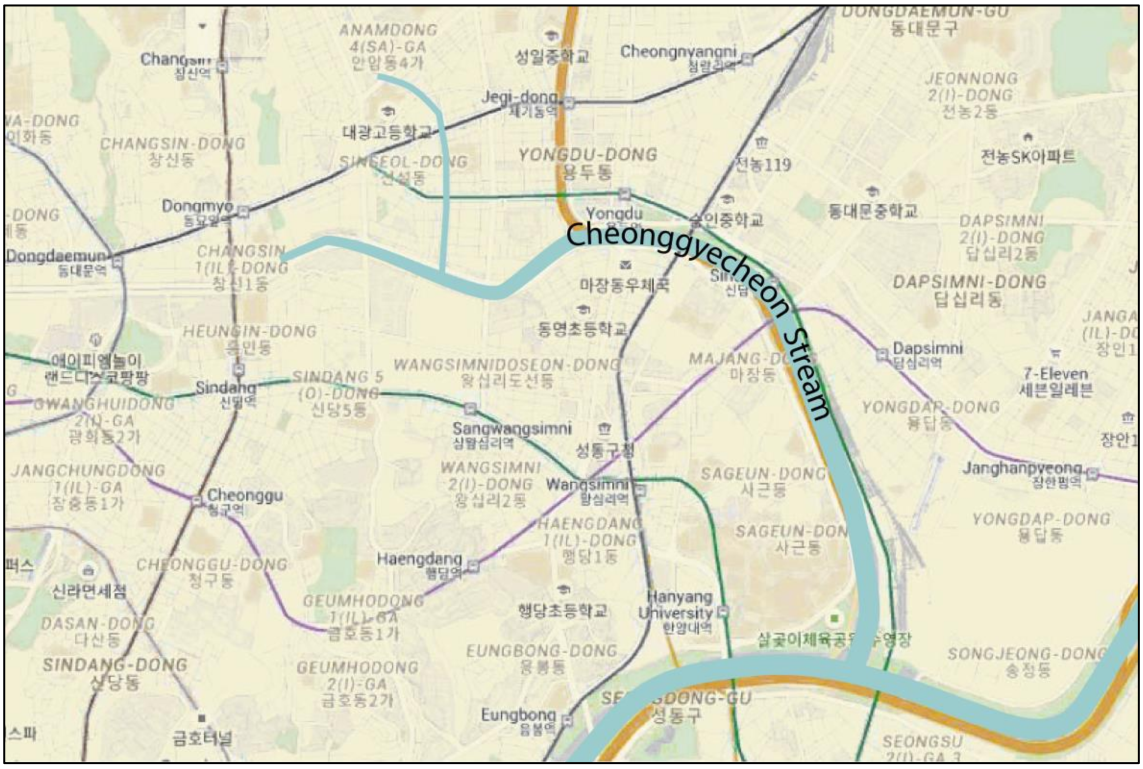

Figure 3.9. Cheonggyecheon Stream in Seoul
(Source: Google Map)

Historically, the stream was a natural watercourse of Seoul that collected drainage from the surrounding highlands. As a result of population increase in Seoul, raw sewage and waste water drained directly into Cheonggyecheon, which became a source of health concerns as well as a sign of poverty for the city (ASLA, 2009). After the construction of an elevated highway over the stream in the 1960's, it was completely abandoned. Since heavy traffic caused serious problems, including safety issues, the city government of Seoul decided to demolish the expressway and rehabilitate the district in 2002 (Bocarejo, LeCompte, & Zhou, 2012). In this regard, Seoul Municipality held an international design competition, primarily to highlight the future reunification of South and North Korea, and to transform the urban fabric of the city. The winning project came up with a master project for rehabilitation of the Cheonggyecheon Stream, which used local materials from each province of South and North Korea to symbolise this political effort (Mikyoung Kim Design, 2009).

On the other hand, the surroundings of Cheonggyecheon include several private properties. Since the expropriation process requires an enormous budget and a long time to deal with administrative issues, the Municipality of Seoul decided that the project would only cover public lands near Cheonggyecheon, to make the project more feasible (Metropolis Policy Transfer, 2015). Therefore, a master plan for stream rehabilitation was prepared in 2003, which considered public properties (Figure 3.10).

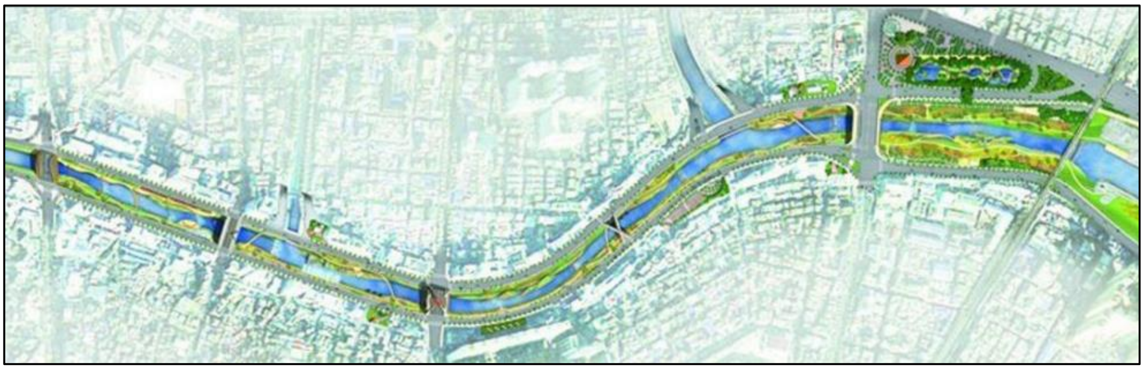

Figure 3.10. Conceptual site plan represented in 2002 by Seoul Development Institute (Source: Landscape Architecture Foundation 2010)

The rehabilitation process of Cheonggyecheon, which cost $281 million (Bocarejo et al., 2012), consisted of four phases: (1) removal of the road structures; (2) stream design; (3) water supply; (4) construction of landscape elements and pathways. In this regard, the first phase of the implementation, the demolition process, started in 2003. Then, the existing canal was rerouted and enlarged to the terraces, which are lower than the ground level. After the construction of the water recycling system and landscape elements - including waterfalls, sidewalks, squares, and fountains – the implementation of the project was completed in 2005. Thus, the district with the elevated highway was transformed into a pedestrian-friendly open space (Figure 3.11).

Figure 3.11. An elevated highway ran through the centre Seoul before the rehabilitation of Cheonggyecheon Stream (Source: Landscape Architecture Foundation, 2010)

After the construction, lost animal and plant species have reappeared and habitat has almost returned to its former state. Also, Cheonggyecheon Stream has become one of the main tourist attractions in Seoul (Figure 3.12).

Figure 3.12. Today's Cheonggyecheon Stream
(Source: Mikyoung Kim Design, 2009)

According to monitoring results of Seoul Development Institute (2006), the outcomes of the implementation of the Cheonggyecheon Stream Rehabilitation Project can be categorised into three distinct groups of environmental, social, and economic. For environmental benefits, the project protects the district with up to 200-years of flood, which mitigates flooding issues dramatically. Biodiversity was increased by 63% between 2003 and 2008. Urban heat island effect along the stream was reduced about five °C, compared to surrounding neighbourhoods. Fresh and healthy air was provided for the community by reducing air pollution by 35%. Also, social interaction has drastically increased in the district. Since the project completed, it attracts about 65,000 visitors daily, which contribute up to about two million USD for the Seoul economy. In addition, the price of properties rose by 30-50% after the rehabilitation of the stream.

3.4. Sanlihe River Project (Qian'an, China)

Sanlihe River, one of the tributaries of the Yongding River, flows through the City of Qian’an in China (Figure 3.13). The rehabilitation project prepared by Turenscape in 2007 transformed 135 hectares of a garbage dump into a vibrant new public realm. The project not only aimed to rehabilitate the district ecologically, but also to catalyse sustainable urban development in Qian’an through landscape guides.

Figure 3.13. Sanlihe River in Qian’an
(Source: Yandex Map)

Formerly, the Sanlihe River was known for its clear water until the 1970s. However, as a result of industrial development and population growth in the city, the river was polluted by waste and sewage. In 2006, Turenscape was commissioned for a landscape planning and design project that reclaimed ecological sustainability of the district. The project of Turenscape proposed a greenway as an ecological corridor with a length of 13 km, varying 100 to 300 m in width, in Qian'an City, China (Figure 3.14).

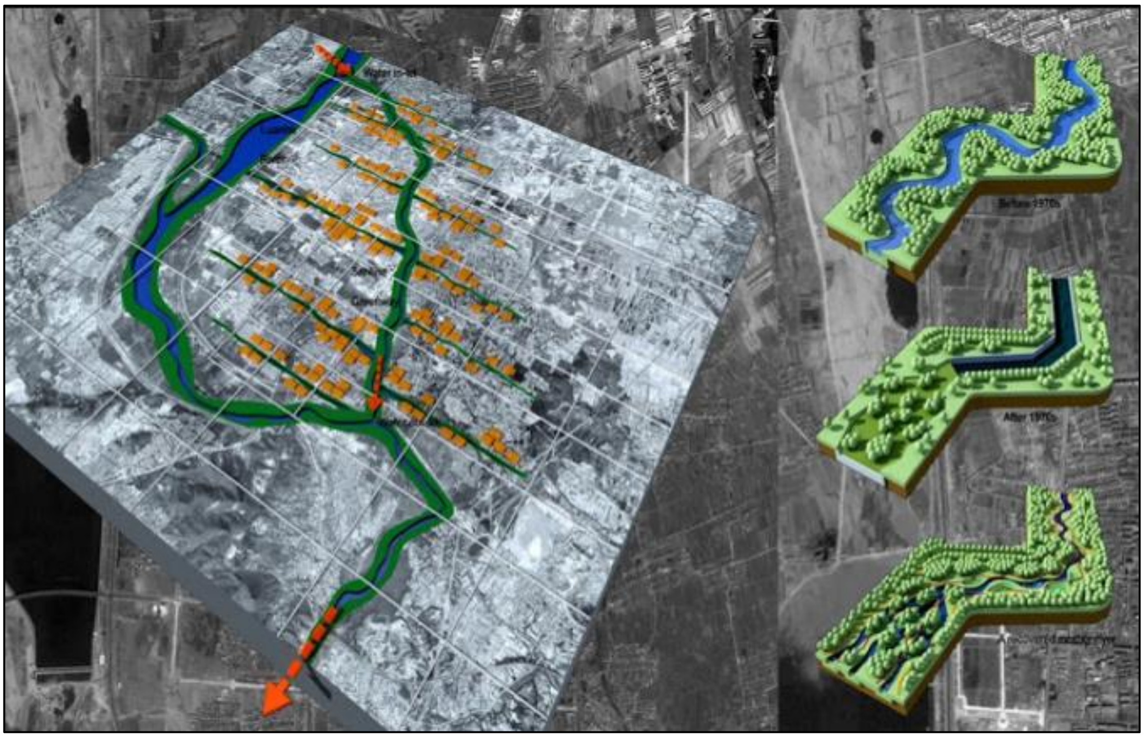

Figure 3.14. Planning and design concepts of the project
(Source: Turenscape, 2010)

Furthermore, the rehabilitation project was inspired by art. Paper cutting as one of the local arts in the region influenced the concept of the landscape. Red Folding paper, which serves as a shading canopy, outdoor furniture, bicycle shed and art, make the greenway a vibrant and attractive destination (Turenscape, 2010).

During the rehabilitation process of Sanlihe, a series of strategies were developed across scales. These comprehensive strategies included urban design, water management, and ecological restoration along the Sanlihe River Greenway, based on the site's social, historical, and cultural background. Firstly, sewage pipes discharging directly into the river were redesigned to separate urban stormwater and wastewater. Then organic garbage from adjacent neighbourhoods was collected with the aim to shape landforms. Also, industrial waste was cleaned from the site and its impact on the urban environment was minimised. The concrete embankment along the river was removed without harming the willows. A new wetland was constructed, which kept the existing trees on the site. Also, a new waterway and greenway in Qian'an were created by using the natural elevation difference between the river and city, so that inhabitants could use a scenic water byway. After two years of construction, Sanlihe River was opened to the public in 2010 (Turenscape, 2010).

After construction of the greenway, an enormous amount of investment in commercial and residential land use was attracted, and it entirely changed the urban fabric of Qian'an. Preserving the current vegetation and planting new native plants provided low maintenance. The existing dried channel was turned into a flower bed, which included native wild chrysanthemums (Turenscape, 2010).

The rehabilitation project of the Sanlihe River is considered as one of the best exemplary landscape projects of how a neglected landscape can be rehabilitated by using green infrastructure techniques (Shannon & Yiyong, 2013). Eventually, this rehabilitation project turned this profoundly polluted and forgotten landscape back to its natural conditions with a scenic greenway (Figure 3.15). Restoring the local system by reversing the human impacts on the environment with sustainable strategies and integration of art were the vital elements of this project.

Figure 3.15. Sanlihe River was transformed from a garbage dump into a vibrant landscape (Source: Turenscape, 2010)

3.5. Shanghai Houtan Park (Shanghai, China)

Houtan Park is considered one of the best rehabilitation projects, not only for its design, but also for its regenerative living landscape and natural purification system. This park was intended to be an innovative demonstration of the ecological culture for scores of visitors during the 2010 EXPO. In this manner, the project transformed a brownfield into an attractive public waterfront park, which was also used after the exposition (Yu, 2011).

Shanghai Houtan Park, designed by Kongjian Yu of Turenscape, is located along the Huangpu River waterfront in Shanghai (Figure 3.16). The 14-hectare park was developed in 2007-2009 as an innovative demonstration of the ecological culture for scores of visitors during the 2010 EXPO. In this regard, the project transformed a brownfield into an attractive public waterfront park, which was also used after the exposition (Yu, 2011). Houtan Park is considered one of the best rehabilitation projects, not only for its design, but also for its regenerative living landscape and natural purification system.

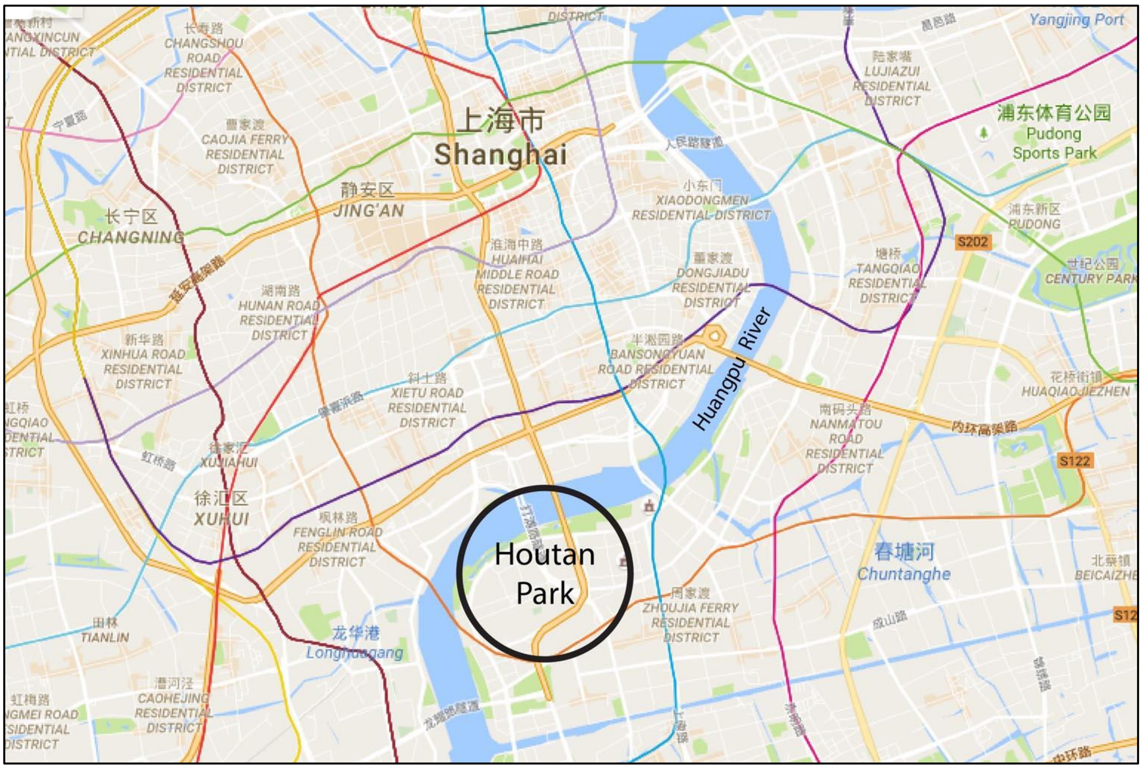

Figure 3.16. Houtan Park in Shanghai
(Source: Google Map)

Historically, Houtan Park was an industrial site where a steel factory and a shipyard existed. The presence of the industrial site near the river affected the fate of the district. Firstly, the water of the river was highly polluted by the industrial site and then the district was considered unsafe for recreational use. Since the organising of an EXPO brings innovative approaches to the districts, which had infrastructure problems, local government administrators used this chance to impressively construct new wetlands, reclaim industrial materials and structures, provide ecological flood control, treat polluted water, and rehabilitate the degraded waterfront in an innovative way. In this regard, Turenscape was commissioned to design a rehabilitation project in 2007. Kongjian Yu and his team used regenerative design strategies to turn this site into a living system. In the centre of the park, a linear constructed wetland was designed to create a living waterfront that treats polluted water from the Huangpu River (Figure 3.17). Wetland plants chosen from different species also help to absorb pollutants. In addition, the existing concrete floodwalls were replaced by riprap, which lets flora and fauna grow along the river.

Figure 3.17. Planning and design concepts of the project
(Source: ASLA, 2010)

Furthermore, Turenscape designed terraces to break down the elevation change that refers to China’s 5000 years of agricultural history (Figure 3.18). In this context, an urban farm with crops and wetland plants offers experiences to its guests for observation, education, and aesthetic enjoyment. Regarding the industrial spirit of the district, industrial structures and materials were reclaimed. Transformation of these structures into overlook platforms and hanging gardens evoked the memories of people, places, and times. Also, some of the industrial materials that remained on the site were converted to artful forms and new paving material. The construction, which cost about $16 million, was completed in 2009, and Houtan Park was opened to the public in 2010 (Yu, 2015). Figure 3.19 depicts the transformation of Houtan Park.

Figure 3.18. The terraced wetland
(Source: ASLA 2010)

Figure 3.19. Before and after images of Houtan Park
(Source: Landscape Architecture Foundation 2013)

Monitoring results prove that 2,400 cubic meters of water are purified per day in this way (Yu, 2011). Purified water can also be used throughout the site, except for potable use. This natural purification system saves a half million US dollars compared to conventional water treatment (Yu, 2011). Also, wetlands as a flood protection buffer minimises the flood risk.

Houtan Park, designed with the principles of low maintenance and high performance, is one of the best rehabilitation projects, which shows that green infrastructure techniques can provide multiple services for people and nature. Natural water purification system, flood control methods, and transformation of a brownfield into an appealing landscape provide contribution to the content of the project

3.6. Tanner Springs Park (Portland, USA)

Tanner Springs Park, located in downtown Portland, is an urban wetland park where stormwater is treated and managed efficiently (Figure 3.20). Tanner Springs Park was designed on one of the downtown blocks, 60x60 meters, by Atelier Dreiseitl in collaboration with local landscape architects from Greenworks PC in 2005 (Ramboll Group, 2010). The main objective of the project was not only to provide stormwater management, but also to restore the wetland characteristics of the site.

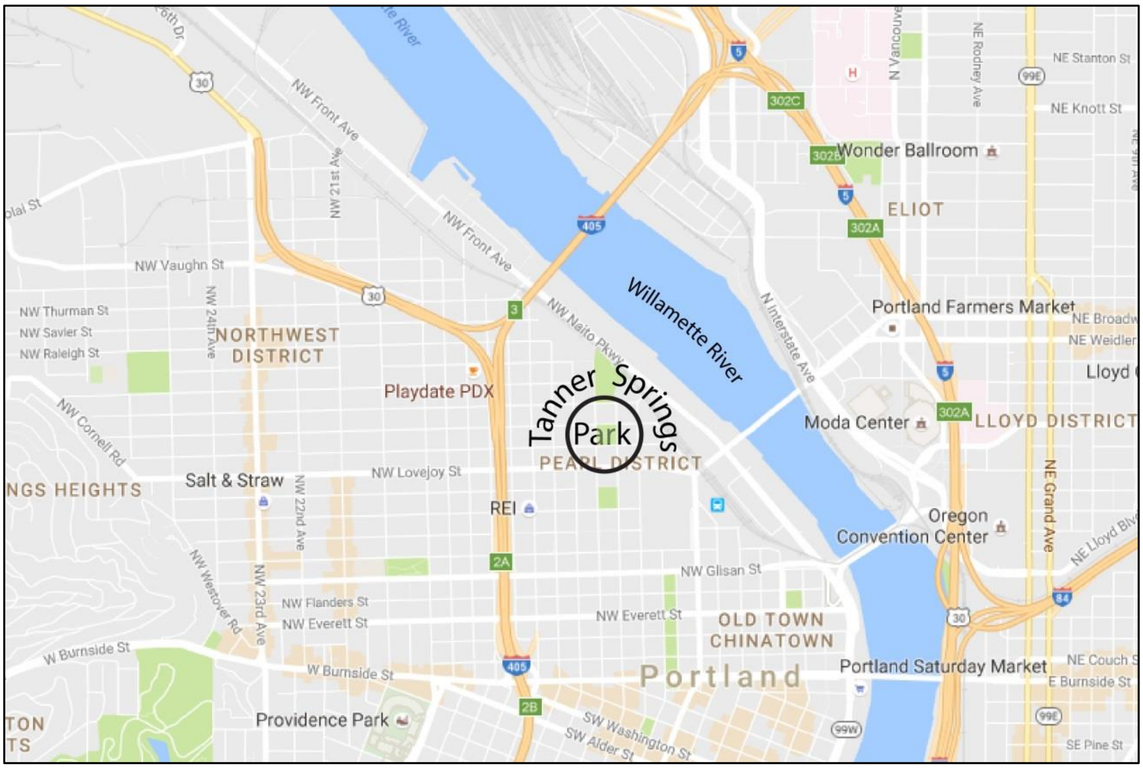

Figure 3.20. Tanner Springs Park in Portland
(Source: Google Maps)

Historically, it was once a wetland fed by streams. As a result of the population growth in Portland, Tanner Creek was rerouted underground into pipes. Then the wetland and its surroundings, including Couch Lake, were replaced by residences, warehouses, and a rail yard. In 1999, the City of Portland, Oregon engaged Peter

Walker & Partners, a landscape architecture firm, to develop a design framework for three neighbourhood parks in the district (Senville, 2013). According to Walker's plan, drawn in 2001, each of the sites was designed to have a unique feature (Figure 3.21). In this regard, they were designed as a neighbourhood park, a wetland park, and a spring plaza, respectively. The first site, Jamison Square, was opened to the public in 2002. As the second phase of the master plan, the City of Portland hired Atelier Dreiseitl in 2002 for their design services for the second site, which was offered as a wetland park (ASLA, 2006). Thus, the design process of the Tanner Spring Park was officially started.

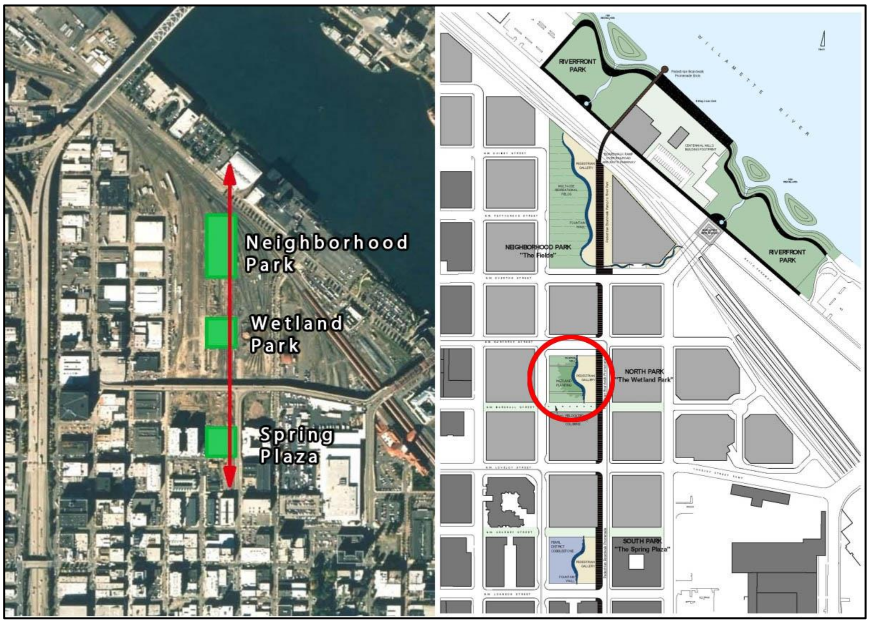

Figure 3.21. Walker's urban design framework for three neighbourhood parks (Source: Senville, 2013)

According to the plan of Atelier Dreiseitl, Tanner Springs Park was redesigned as an urban wetland park through the creative use of green technology (Figure 3.22). Stormwater management was considered the key feature of the proposed project. The new design for Tanner Springs Park not only reflected its history, but also infiltrates rainwater into a biotope for a natural cleansing system, which allows pure, clean water to bubble up through the springs. However, Atelier Dreiseitl did not attempt to replicate the former wetland. Instead, the new design aimed to peel back the urban fabric through urban landscapes. Also, during the design process of Tanner Springs Park, numerous workshops were organised to bring residents and local businesses together. The desire of residents for the park was to create a calm, natural, and restorative place. In 2005, the park was opened to the public as the first block of the city that was designed, so that impervious surfaces of surroundings paths drained into the park rather than into the streets (Senville, 2013). The total construction cost for Tanner Springs Park was $3.6 million (Landscape Voice, 2012).

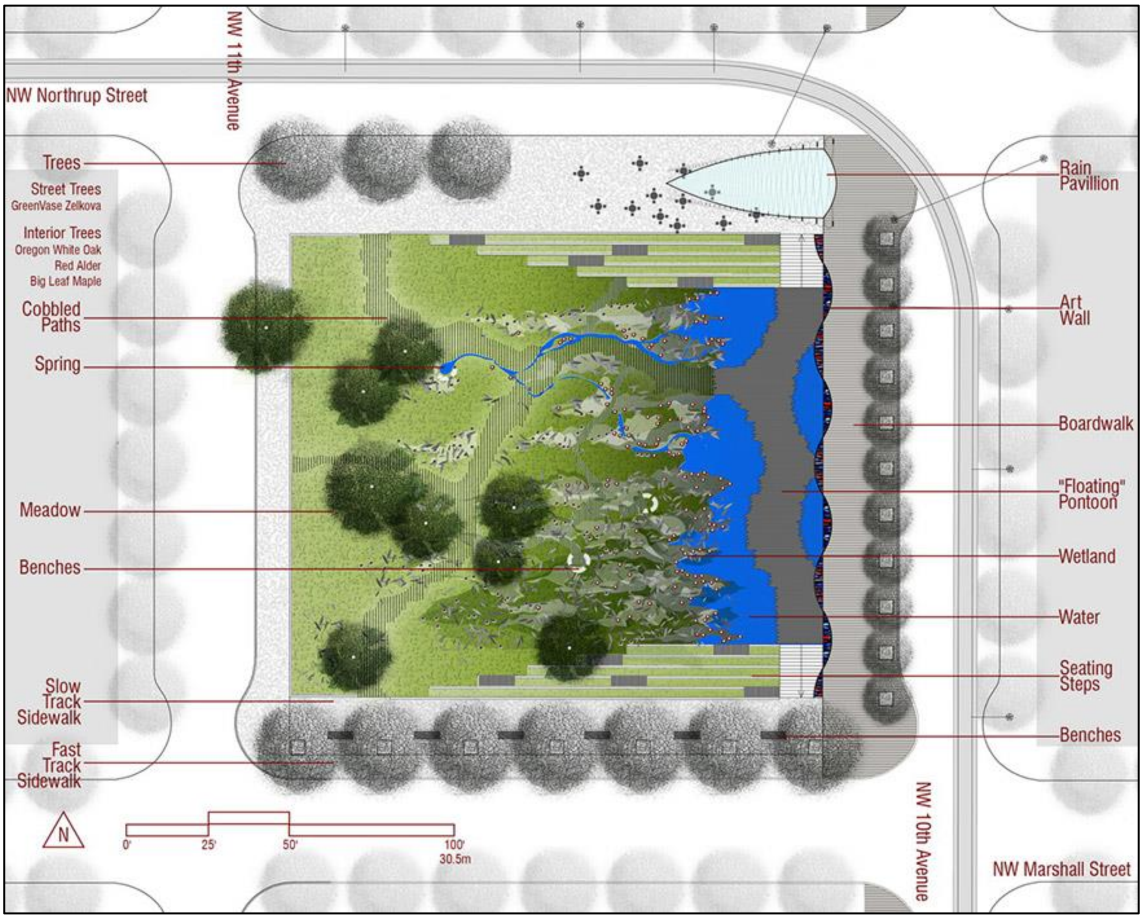

Figure 3.22. The project of Tanner Springs Park
(Source: Ramboll Group 2010)

Since its opening in 2005, Tanner Springs Park has been embraced by inhabitants. Transformation of the district brought not only social and ecological benefits, but also economic benefits (Figure 3.23). Tanner Springs Park saves half the cost of the filtration and irrigation annually. (Ramboll Group, 2010). Also, the city organised public tours to inform park users about the characteristics of the site. After the third site was opened in 2013 as a neighbourhood park, The Fields, revitalization of the Pearl District has been completed.

Figure 3.23. Before and after images of Tanner Springs Park
(Source: Ramboll Group 2010)

3.7. Qiaoyuan Wetland Park (Tianjin, China)

Qiaoyuan Park is a wetland park of 22 hectares in the northern part of the city of Tianjin (Figure 3.24). Turenscape, a landscape architecture studio, transformed a former garbage dump and military shooting range into a low maintenance park in 2008, with the goal of purifying stormwater, naturalising channelized Shuicheng River, improving soil, enhancing biodiversity, creating an aesthetic experience, and providing opportunities for recreation and education (Turenscape, 2008).

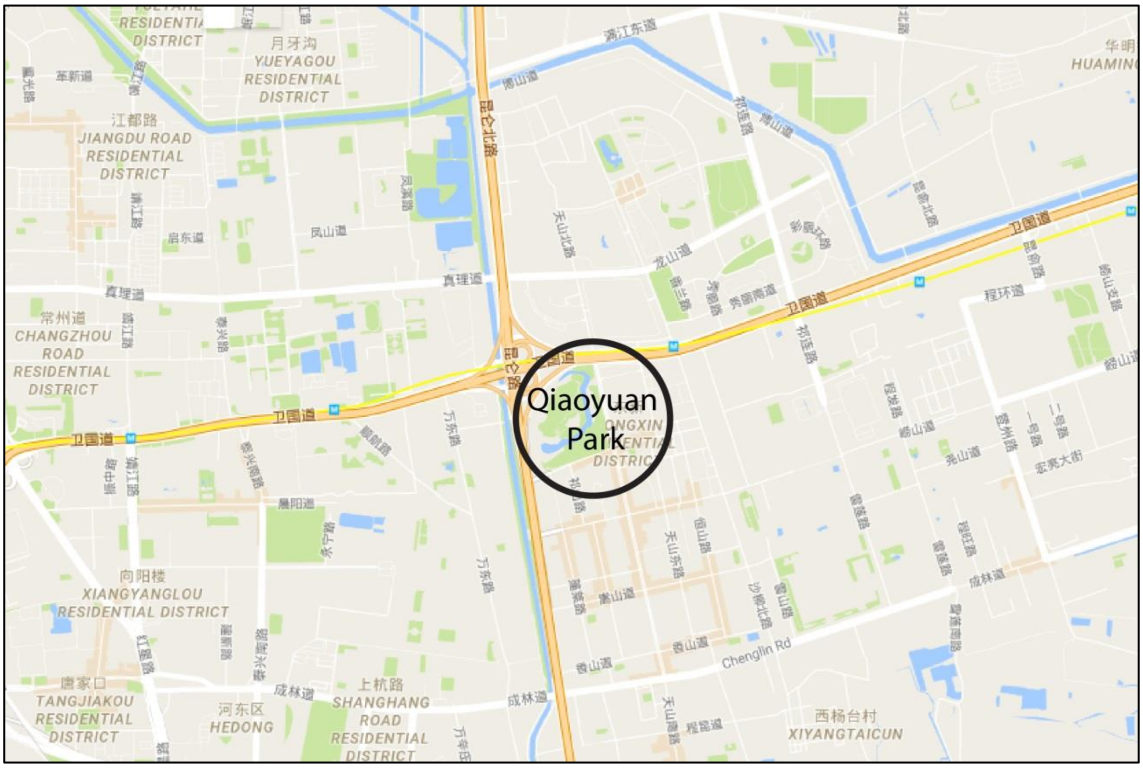

Figure 3.24. Qiaoyuan Wetland Park in Tianjin
(Source: Google Maps)

Rapid urbanisation affected the wetlands of Tianjin adversely; therefore the project area was dramatically polluted and isolated from city life. Saline-alkaline soil also caused problems for vegetation. The community living close to the project area had economic problems as well (Busch, 2012). In 2006, the City of Tianjin contracted Turenscape to reclaim the site, in response to the call of its inhabitants (Turenscape, 2008). The proposed project was based on a regenerative design, aiming to recover the wetland ecosystem. As shown in Figure 3.25, the design consists of twenty-one pond cavities, measuring about 10-40 meters in diameter and 1-5 meters in depth. These artificial ponds, which concentrate water in various locations and provide phytoremediation, imitate the ecological interactions that existed before the development (Busch, 2012). Also, the new design allows park users to experience the wetland ecosystem in wooden platforms, which are connected to each other through red coloured asphalt pedestrian paths (Figure 3.26).

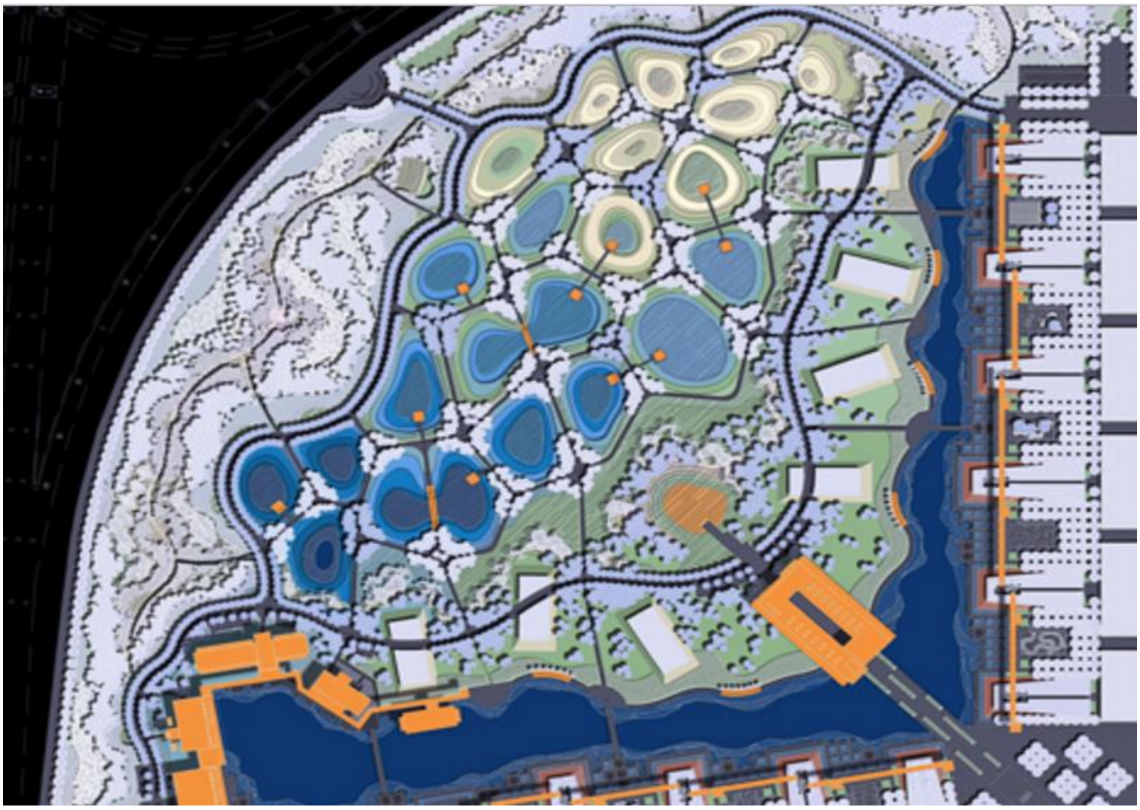

Figure 3.25. Rehabilitation Project of Qiaoyuan Wetland Park
(Source: Turenscape 2008)

Figure 3.26. Pedestrian networks of Qiaoyuan Wetland Park
(Source: Turenscape 2008)

The construction of Qiaoyuan Wetland Park, which cost $14.1 million, was completed in 2008, and the park opened its gates to the public in 2008 (Landscape Performance, 2014). Accordingly, the site was transformed into a vibrant landscape where natural systems function (Figure 3.27). Today Qiaoyuan Wetland Park attracts thousands of people from around the world. Since the park is visited by 350,000 people every year, it contributes positively to the economy and society. Also, according to monitoring results, soil and water pH dropped from 7.7 to around 7 after the rehabilitation project was implemented. Not only have plant species increased, but also animals including ducks, foxes, weasels, and rats have dramatically increased in the park. According to Landscape Performance (2014), the noise level was also reduced from 70dB outside of the project area to 50dB. Therefore, this project is considered to be one of the best rehabilitation projects of natural water systems.

Figure 3.27. Before and after images of Qiaoyuan Wetland Park
(Source: Turenscape 2008)

3.8. Evaluation

This chapter presents seven successful rehabilitation projects: Mill River Park and Greenway in the USA, Bishan-Ang Mo Kio Park in Singapore, Cheonggyecheon Stream in South Korea, Sanlihe River, Shanghai Houtan Park in China, Tanner Springs Park in the USA, and Qiaoyuan Wetland Park in China. In all of these cases, the sites were influenced by urban expansion and human interference. Therefore, they were redesigned with the purpose of lessening human impact on water systems and returning to natural conditions as much as possible.

These Best Practices helped to develop rehabilitation guidelines for Arap Stream and its surroundings. The main criterion, which serves as the basis for evaluation of these projects, are in relation to the larger context (1), design approach (2), type of action (3), ownership (4), and outcomes (5).

1. *Relation within a larger context:* When considering the relation of the case studies within their broader context, some of the studies were developed as part of a former large-scale plan. In this sense, Mill River Park and Bishan Park continued to be urban parks (Table 3.1). However, other projects were created as single projects specific to particular sites, with the goal of bringing back former hydrological characteristics. Regarding the size of the studies, Sanlihe River covered 135 hectares of land to rehabilitate its site in the watershed context, while other projects were only interested in some specific portions of waterways and lands. Only Tanner Springs Park was redesigned within an urban block in a different way due to its own nature.

Table 3.1. Former Land Uses of Best Practises

Project Name	**Area**	**Former Land Use**
Mill River Park and Greenway	13 ha	Urban Park
Bishan-Ang Mo Kio Park	62 ha	Urban Park
Cheonggyecheon Stream	40 ha	Urban Highway
Sanlihe River	135 ha	Garbage Dump
Shanghai Houtan Park	14 ha	Brownfield
Tanner Springs Park	0.4 ha	Industrial Site
Qiaoyuan Wetland Park	22 ha	Garbage dump and military shooting range

2. *Design approach:* In accordance with the project reports, it can be said that all selected Best Practices are based on sustainable and ecological principles. While some of the projects, e.g. Mill River Park, aimed to reclaim environmental, economic, and social sustainability, others were designed with an emphasis on ecological sustainability. On the other hand, it can also be said that all the projects were implemented in the early 2000's through a water-sensitive urban design approach; therefore, their rehabilitation contents are quite similar. The common point of these projects is that green infrastructure and in-stream techniques are the key elements of rehabilitation. Also, it was seen that low-maintenance and high performance are essential principles of landscape design.
3. *Type of action:* Commonly, these rehabilitation projects offer removal of concrete channels, embankment walls, and dams, to enhance riparian vegetation, to re-

naturalize their water bodies and their surroundings, to adopt sustainable water management and water-centric planning for development, to separate stormwater and wastewater, and to provide pedestrian-friendly public spaces and self-generating landscapes.

4. *Ownership:* Some of the projects, for instance, the Cheonggyecheon Stream, were developed only on public lands, since there was no need to challenge the property issue. While some of them, e.g. Mill River Park and Greenway Project, have long term rehabilitation strategies to expand the parks and greenways beyond their current boundaries in the future.

5. *Outcomes:* According to the monitoring results of the projects, they have commonly minimised the risk of flooding and negative impacts of stormwater. Also, enhanced biodiversity and wildlife habitats are other substantial results. On the other hand, since these projects were embraced by the community, a significant degree of investment in commercial and residential real estate was attracted. All of these point to the fact that Best Practices are some of the notable exemplary projects that show how bioengineering systems can be used more efficiently and economically, instead of conventional techniques.

CHAPTER 4

THE CASE OF ARAP STREAM AND ITS SURROUNDINGS

This chapter presents Arap Stream and its surroundings as the case study of the thesis. The chapter aims to apply the techniques represented in the previous chapters to create ecologically and socially functioning landscapes. Accordingly, Arap Stream and its surroundings is studied with the aim of providing sustainability in the local context, improving some land uses nearby the stream, turning the site into a living system with self-regenerating landscapes, enhancing biodiversity and riparian vegetation, keeping the collective memory of the community alive for Halkapınar’s natural life, and bringing back the natural features as much as possible.

In this sense, firstly, Arap Stream is analysed regarding its historical, climatic, topographic, geologic and hydrological characteristics. Secondly, a series of rehabilitation strategies, based on Halkapınar’s social, historical and cultural background, are developed across scales. Lastly, a green infrastructure plan for Arap Stream and its surroundings is delivered with the aim of showing how Arap Stream can be ecologically rehabilitated within a green infrastructure framework.

4.1. Characteristics of the Case Area

4.1.1. Location

İzmir, one of the biggest metropolitan cities of Turkey, is located around the Gulf of İzmir, on co-ordinates 38° north, 27° east. It is the largest city in the Aegean region of Turkey and is the third most populous metropolis in the country with about four million inhabitants. The study area, Arap Stream and its surroundings is located in the centre of İzmir (Figure 4.1).

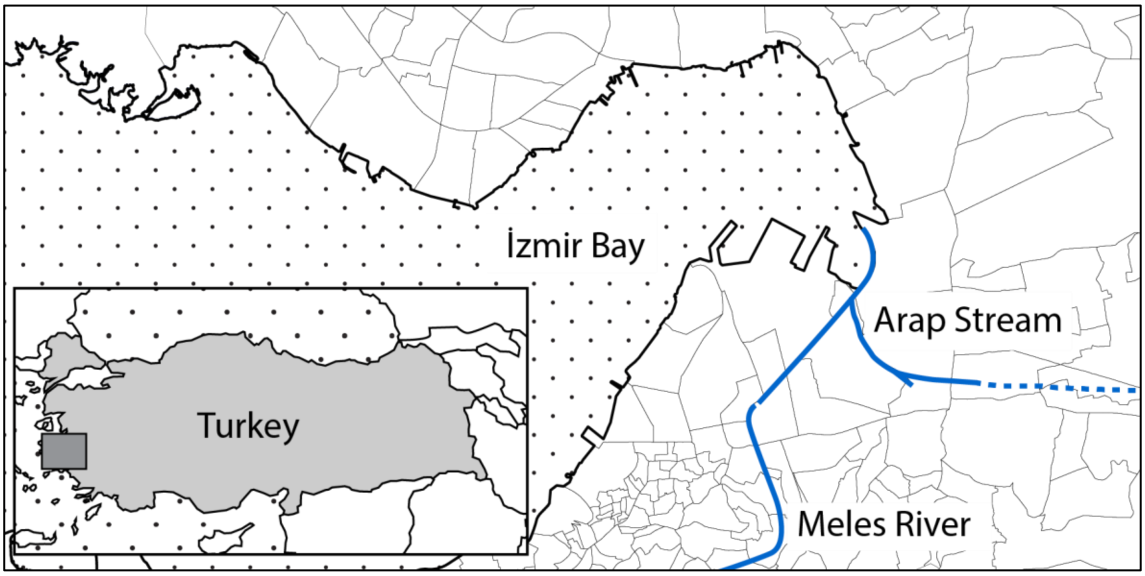

Figure 4.1. Location of Arap Stream in İzmir, Turkey

Arap Stream, one of the major streams of İzmir, is also known as Gökdere and Halkapınar Stream. It originates from the south-east of İzmir, navigates to the districts of Altındağ and Çamdibi, passes from the industrial site and connects to the Meles River near the İzmir Harbour (Kılıçaslan, 2004). As it is in the city centre and flows through Halkapınar and connects to the Meles River, Arap Stream is therefore centrally a significant ecological unit. However, after human intervention to Arap Stream, it was buried underground. In addition, the downstream part of Arap Stream was channelized by İZSU (İzmir's Water and Sewerage Agency) like all streams in the city centre of İzmir. For that reason, by 2016, it has a length of around two kilometres. The only open and visible part, which passes from the industrial site and connects to the Meles River as polluted, is the scope of this case study.

İzmir New City Centre Master Plan offers a new central business district for 2030, which is also known as a high-density skyscraper area, as well as the focus of foreign and local investors. Since the study area is located between the old city centre and the new business centre, it can be called a transition zone (Figure 4.2). Also, Manda Stream, Bornova Stream, and Laka Stream flow through the centre of İzmir.

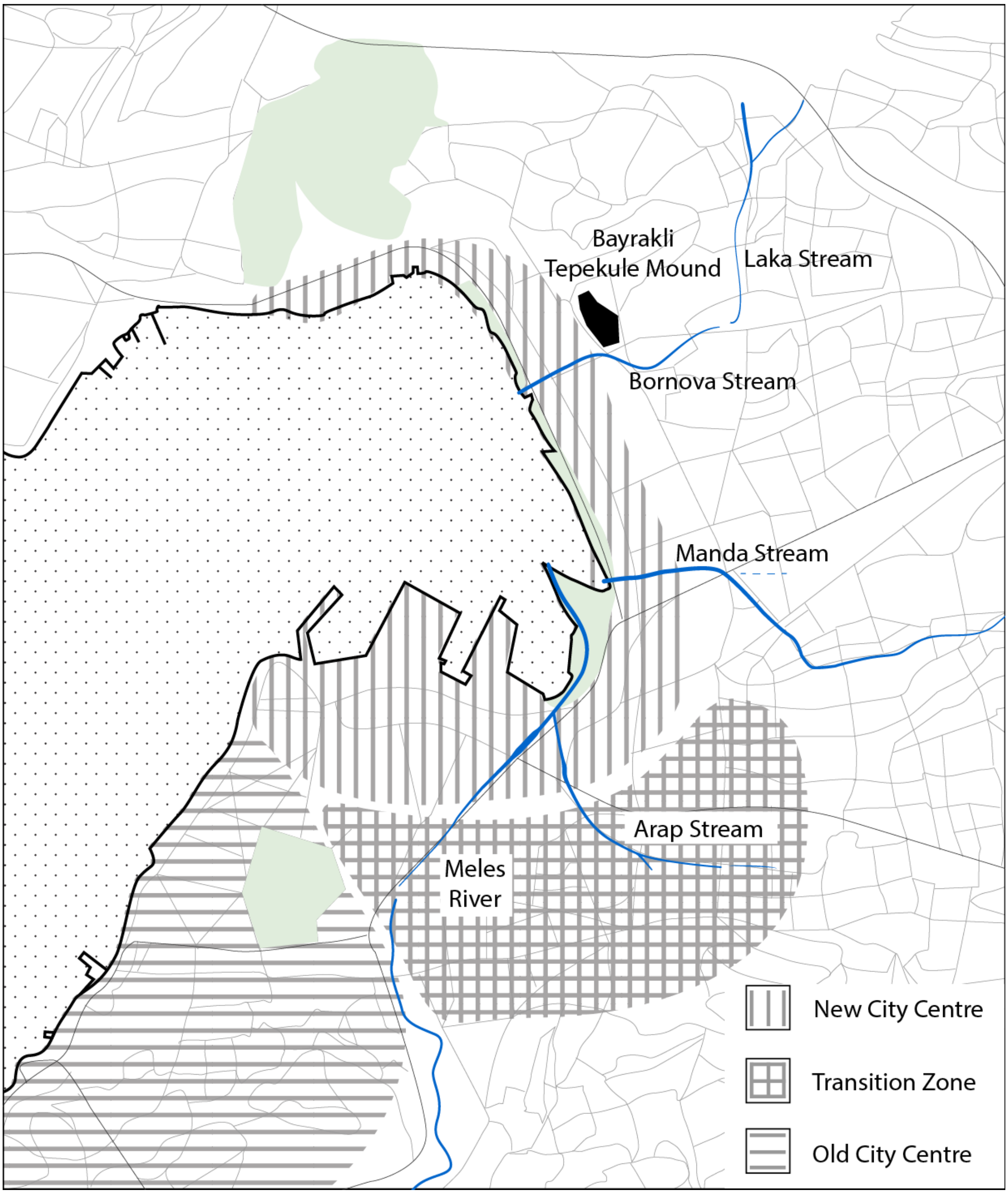

Figure 4.2. Arap Stream flowing through a transition zone between the old city centre and new city centre

Figure 4.3 shows a broader view of the open part of Arap Stream with its surroundings, including Atatürk Football Stadium, an industrial site, and the Halkapınar Transportation Hub adjacent to Arap Stream.

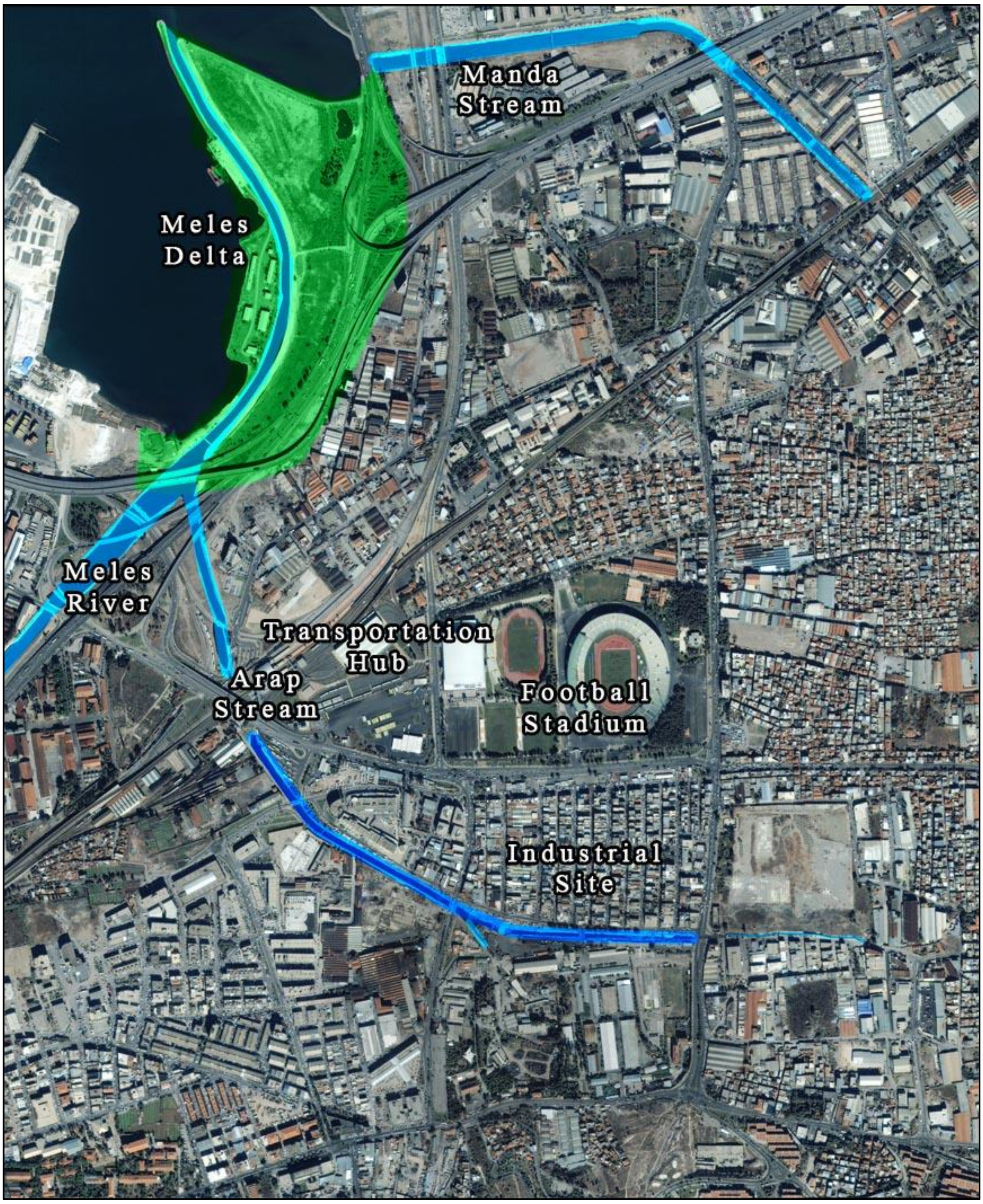

Figure 4.3. Aerial view of the open part of Arap Stream in 2008
(Anonymous, 2008)

4.1.2. History

Arap Stream is a relatively short water body which is connected to the Meles River that can be considered one of the most vital streams of İzmir due to its location and mainly history. Today, the northern part of the Meles River flows directly into the

Gulf of İzmir. However, the Meles with its tributaries was formerly draining in a larger area (Figure 4.4). As seen in Cadoux's Map (1938), there was previously a stream that originated from a place named Diana's Baths (Halkapınar Lake). This stream in Halkapınar is currently a part of Arap Stream. Also, the course of Arap Stream was different than it is today.

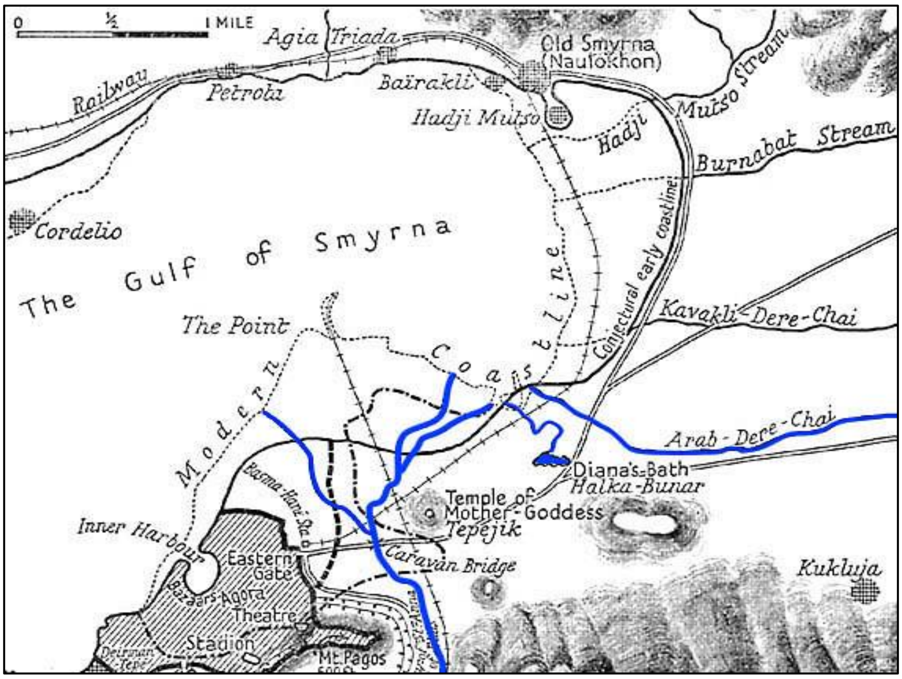

Figure 4.4. Cadoux's map of Ancient Smyrna
(Source: Cadoux, 1938)

The exact location of Meles is unclear, as researchers define its course differently. According to Calder (1906), Malay (2010), and also several other researchers, the Meles River forms a lake near the İzmir Bay and it carries the water from the springs to the sea. However, the description, which is not relevant to today's Meles, exactly corresponds with the course of Halkapınar Stream. For this reason, it can be said that Halkapınar Stream was called the Meles River a hundred years ago.

On the other hand, many researchers frequently mention the Meles River since it was the legendary and main river of Smyrna (the ancient name of İzmir), which is one of the twelve Ionian cities. In this period, the Meles was illustrated in a human form worshipped as the River God. Figure 4.5 represents the River-God Meles holding a reed in right hand, and leaning left while water flows.

Figure 4.5. Old Smyrna Coins in Ionia (AD 100-200)
(Source: Asia Minor Coins, 2009)

According to one legend, Homer (the author of the Odyssey and Iliad) was born on the banks of the Meles in Ionia. Therefore, Homer is also known as ‘Melesigenes', which means ‘son of Meles’ (West, 1999). Even though Homer did not mention Meles frequently in his epic poems, he stated that the sparkling water of the holy Meles flows through Smyrna (Kılıçaslan, 2004). Meles was seen as holy by Homer and others; therefore, it is called the River-God. A poem about Meles found in Bornova is as follows:

"I say my prayers to Meles (River-God) who is my saviour and who has protected me from dangers and epidemics" (Translated by Republic of Turkey Ministry of Culture and Tourism, 2016).

On the other hand, throughout history, Halkapınar Lake was a popular recreational area for citizens and even emperors. Macrides (1978) states that in the 12th century, Byzantine Emperor Manuel I Komnenos and his wife Empress Eirene were staying in their imperial residence near Halkapınar which is surrounded by many springs. Also, the Meles River was famous for its clarity and beauty. Greek historian and geographer, Strabo stated that the Meles River washes the walls of Smyrna since it flows very near the city walls but the Smyrnians made a mistake: While paving the streets, engineers neglected to build a sewage system under the stones. Therefore, the dirty water covers all streets of Smyrna on rainy days (Republic of Turkey Ministry of Culture and Tourism, 2016). Even though almost two thousand years have already passed, İzmir still suffers from infrastructure problems.

As illustrated in Figure 4.6, urban streams in the study area have drastically been altered from the 1800s to the present. According to the 1817 İzmir map (Beyru, 2011), the Meles River with its tributaries was draining into a large area. However, most of the northern portion of the basin was gradually replaced by shops and residences. Another significant difference between the 1800s and 2000s is the presence of Halkapınar Stream and the lake (Figure 4.8). Even though there is no clear information when Halkapınar Stream was channelized, a glance at the maps of Captain Richard Copeland from 1834 and 1860 shows the change of Halkapınar Stream (Levantine Heritage Foundation, n.d.). Although Halkapınar Stream was flowing in its natural course in 1834 map (Figure 4.7), it started flowing in an artificial channel according to the 1860 map. To confirm this information, Calder (1906) mentioned Halkapınar Stream in the late 1800s as an artificial channel which carried a body of running water from the springs to the sea. Calder's description coincides exactly with the course of Halkapınar Stream.

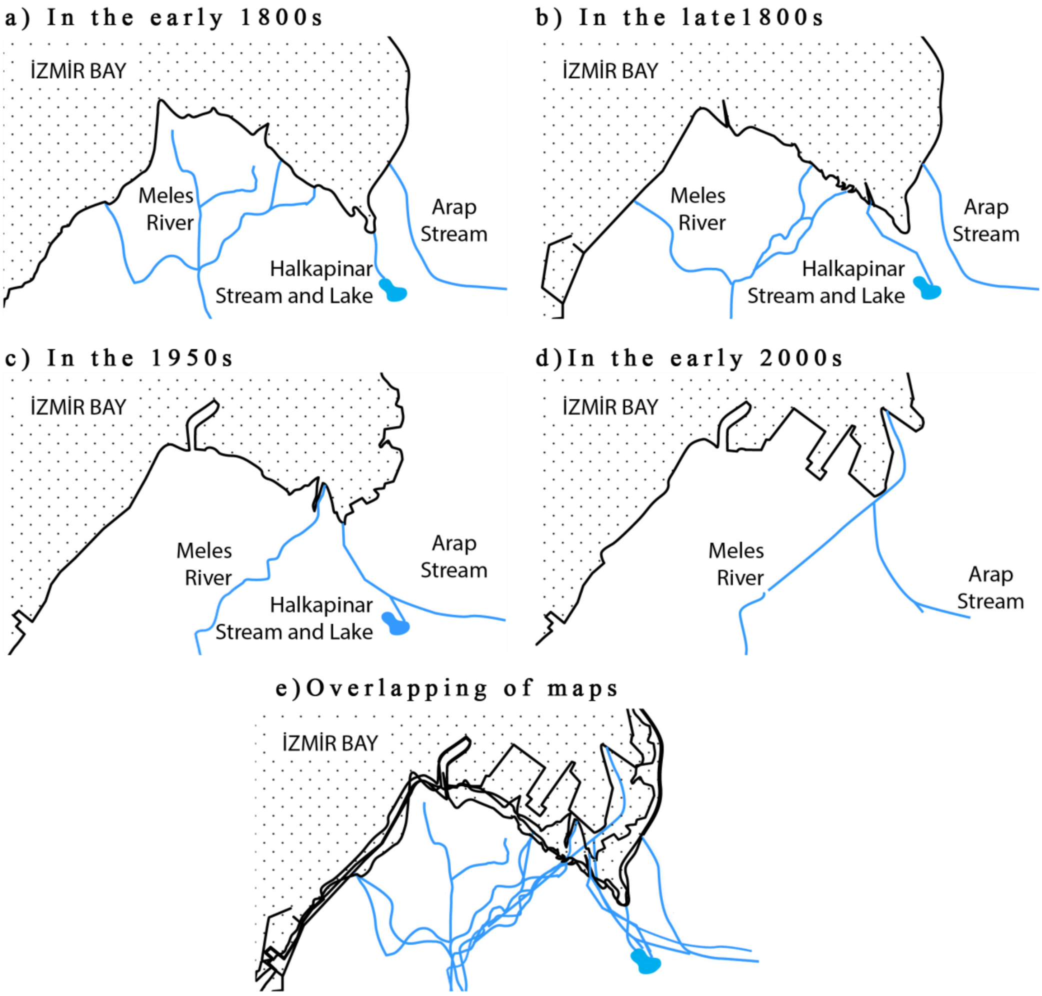

Figure 4.6. The change of Arap Stream throughout history
(Developed from Cadoux 1938; Beyru 2011; City Surf)

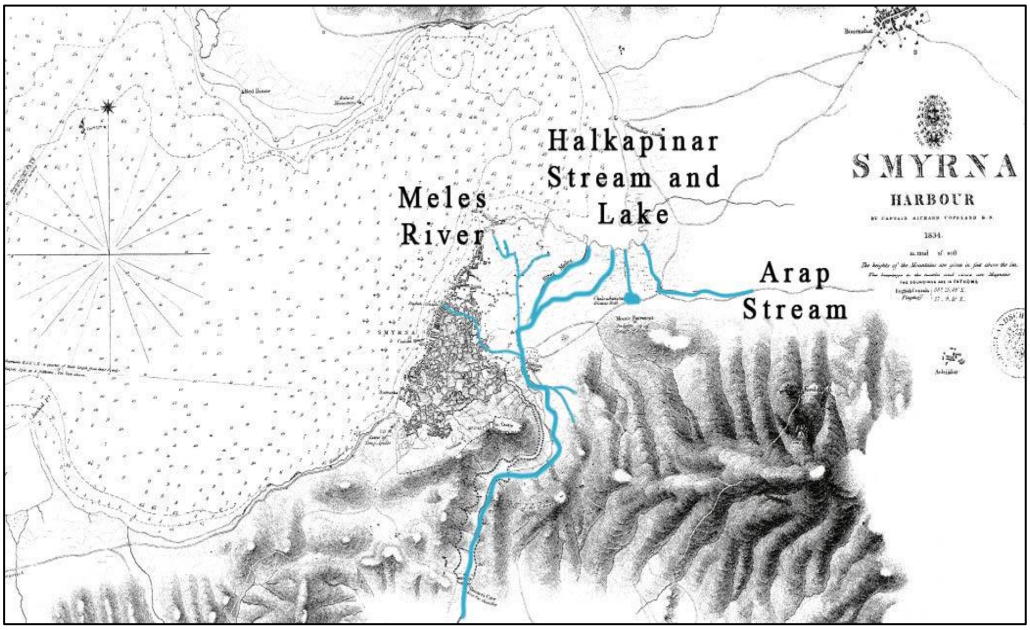

Figure 4.7. A Smyrna map in 1834 by Captain Richard Copeland
(Source: Levantine Heritage Foundation, 2016)

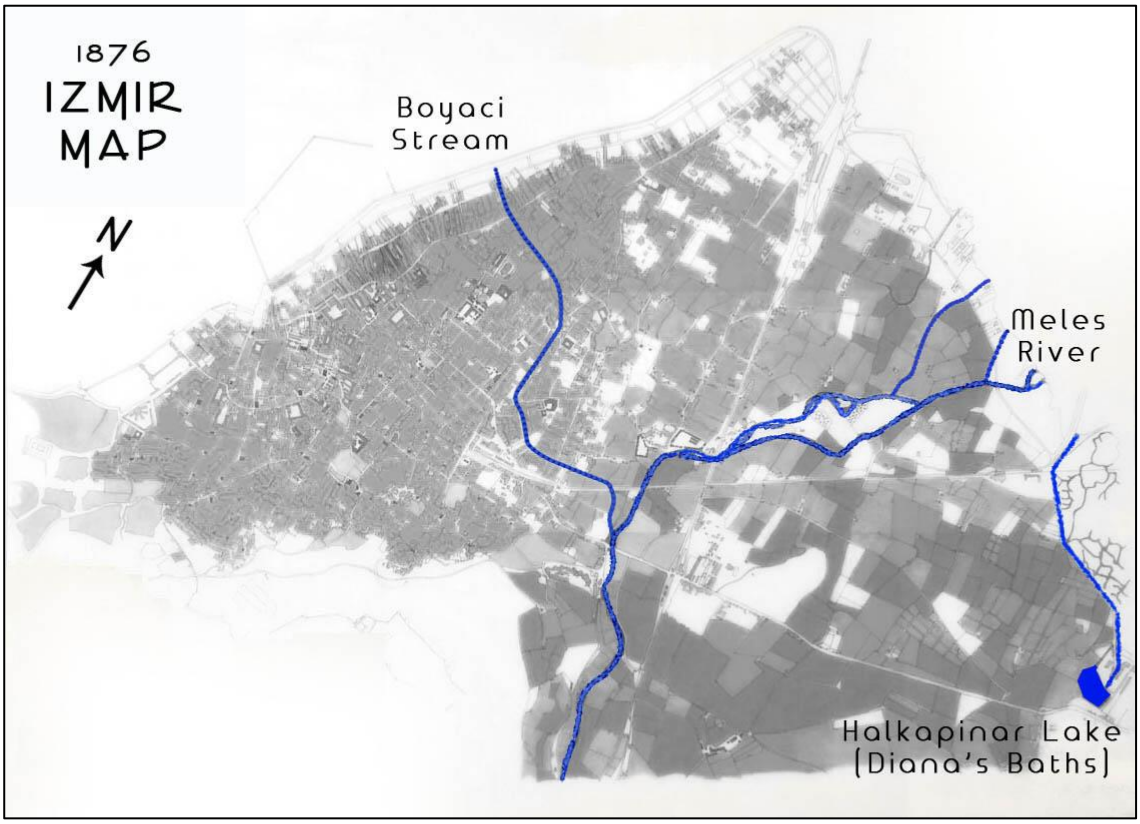

Figure 4.8. Old İzmir Map of Lamec Saad in 1876
(Source: Beyru, 2011)

Moreover, Halkapınar means Circular Springs in Turkish. Calder (1906) also stated that the upper part of the watercourse was shaped like a necklet, and that is why it is called the Circular Springs.

From the descriptions of many authors, the Meles River was born from multiple water sources, which formed a lake - called Halkapınar Lake today - close to İzmir Bay (Fidanoğlu, 2014). As shown in Figure 4.9, in these times, there were some structures made of marble around the lake, some of which still exist in the property of İZSU (İzmir's Water and Sewerage Agency) which are not used for recreational purposes. Moreover, according to one legend, there was a bath, which was dedicated to Goddess Diana in the 19^{th} century, which is why there are many remaining structures made of marble in this district (Fidanoğlu, 2014). Therefore, many documents also call the lake Diana's Baths.

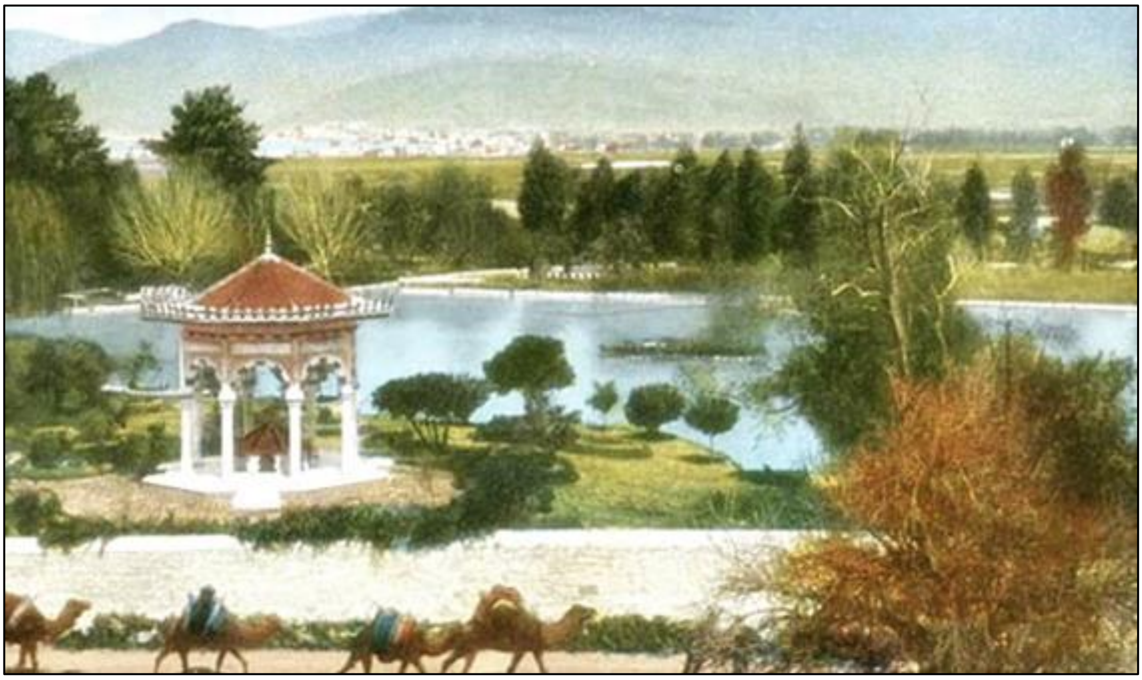

Figure 4.9. A postcard of Halkapınar Lake depicting Diana's Baths and a cistern in the 19th century (Source: Levantine Heritage Foundation, 2015)

By the end of the 19^{th} century, a water company, which was a joint-venture between Turkey and Belgium, was established to provide potable water from freshwater sources of Halkapınar. A cistern, a water pumping station and a water storage unit were built from 1886 to 1897 (Fidanoğlu, 2014). While the cistern and water pumping station still exist in the study area, a storage unit stands in Selvilitepe near Mount Pagos and

Kadifekale (Figures 4.10 and 4.11). After the foundation of Turkish Republic, İzmir Municipality took over the water system.

Figure 4.10. A remaining structure on site: A cistern
(Source: İZSU, 2016a)

Figure 4.11. The water pumping station providing potable water for the city from 1897 to 1988 (Source: http://www.panoramio.com/photo/64907133)

The Meles River with its surrounding area has preserved its importance for hundreds of years. In the 20th century, the region suffered from urbanisation, squatter settlements, industrial buildings and natural hazards. Arap Stream and also the other watercourses have been channelized, water has been polluted by industrial waste, and the natural attributes of the region have totally disappeared.

As shown in Figure 4.6, another notable change is the rerouting of Arap Stream in the mid-1900s and the connection with Halkapınar Stream. Arap Stream was flowing through the site where the football stadium exists today (Figure 4.12), but its stream bed had been completely changed.

Figure 4.12. İzmir in the 1920s
(Source: Atay, 1998)

Previous floods in the district of Halkapınar caused serious hazards to life. For example, as seen in Figure 4.13, when heavy rainfall continued nonstop for 36 hours in 1930, not only did 117 people drown but more than 2000 people were displaced due to extensive property damage (Levantine Heritage Foundation, 2011). Also, a repeat flood occurred in November 1995, and that resulted in the death of 61 people and $50 million of property damage in İzmir (Kömüşçü, Erkan, & Çelik, 1998). During the heavy rains, it was observed that more than 20 streams, many of which were channelized, caused flooding in İzmir.

Figure 4.13. The 1930 İzmir Flood
(Source: Levantine Heritage Foundation, 2011)

According to Fidanoğlu (2014), in the 1950s Halkapınar had a spectacular lake where many people swam during hot summer days. Also, the lake was surrounded by reeds where a significant number of ducks lived. People still went hunting and fishing in Halkapınar Lake until the 1970s. In Fidanoğlu's article (2014), it is explained that Halkapınar Lake was the largest freshwater resource in the district from Prehistoric Ages.

The absence of natural embankment and riparian vegetation not only harmed the Arap Stream's ecosystem but also affected urban health and quality of life. Historically, the surroundings of Arap Stream comprised gardens and vineyards, according to the map of Lamec Saad (Beyru, 2011). There had once been a big pine grove near the site of the stadium. However, a significant part of the grove was burned in a fire at the end of the 1960s, and was gradually lost as a result of urbanisation (Figure 4.14). Today, there is almost no remarkable vegetation in the district and its surroundings, excluding the Park of Culture.

Figure 4.14. Depicting a pine grove near Arap Stream in 1970
(Source: http://wowturkey.com/t.php?p=/tr390/Hudai_Halkapınar_Stadi.jpg)

In 1965, a small industrial site was established along Arap Stream. This industrial development would have a detrimental impact on the ecosystem of Arap Stream. Furthermore, one of the significant decisions in 1971 for the Mediterranean Games was to build a football stadium. Also, in 1975, the Halkapınar Bus Terminal was situated in an area that has wetland characteristics. During construction of the industrial area, bus terminal and football stadium, the wetland area was affected, and the spirit of the place was completely changed.

At the end of the 1970s and the beginning of the 1980s, the water level of the source was reduced dramatically, since the water company overused its source for the water supply of the Bornova District of İzmir Province. New facilities then had to be established (Fidanoğlu, 2014). In other words, the water pumping station served the city for 91 years from 1897 to 1988 as the most significant water resource of İzmir (Atış, 2009). Thus, overuse of freshwater sources resulted in shortages and desiccation of the lake in Halkapınar. In this respect, after losing the traces of Diana’s Bath, the district not only lost its natural wetland characteristic and missed opportunities for recreation, but saw the disappearance of a significant collective memory element.

The Halkapınar district today embraces an industrial neighbourhood of İzmir, and it is extremely polluted (Figure 4.15).

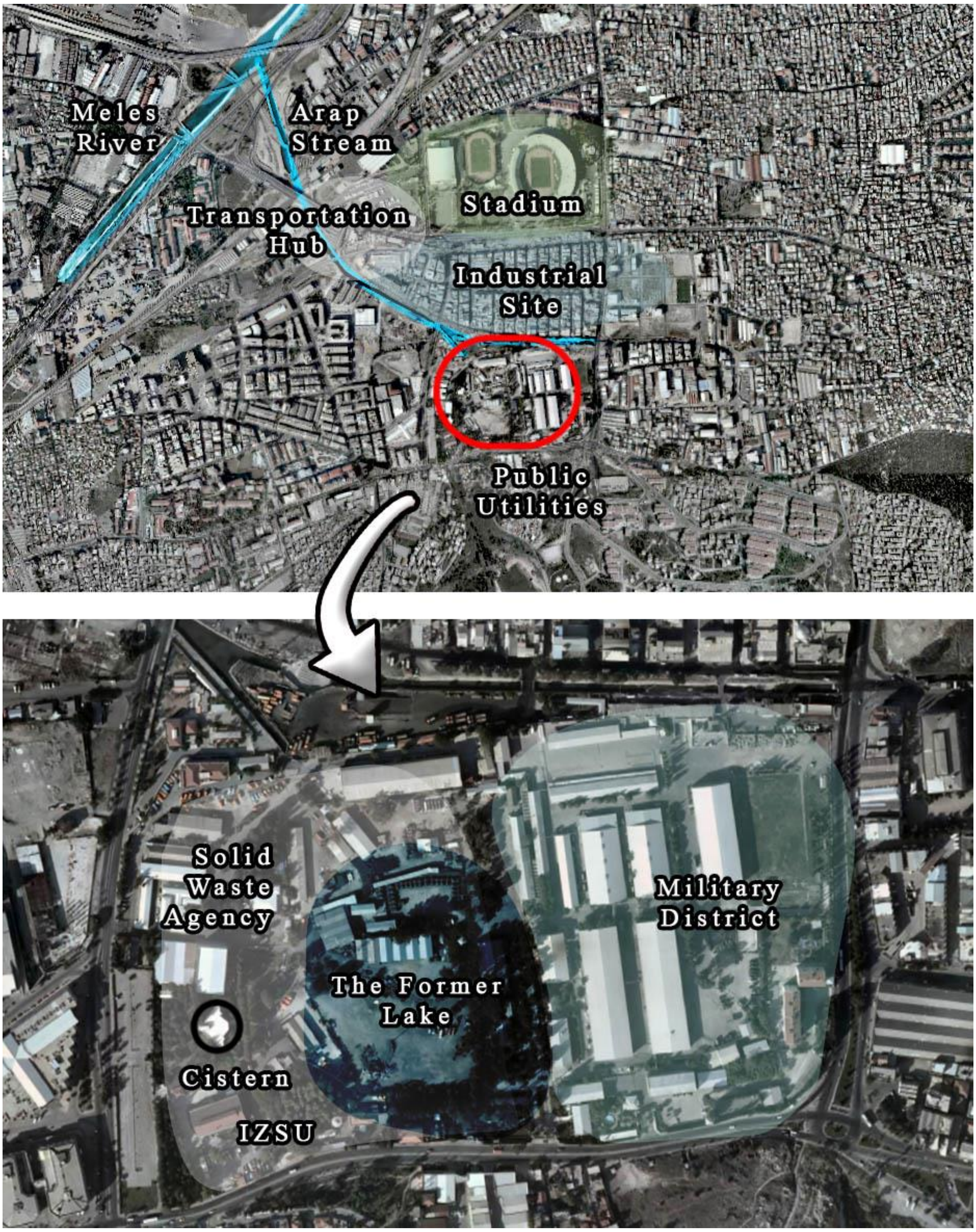

Figure 4.15. The current situation around the Halkapınar Lake which dried up in the 1970s (Source: Citysurf İzmir)

Figure 4.16 depicts that the İzmir coastline has been gradually changed since 1817 due to human modifications. Moreover, an earlier conjectural coastline, referring to ancient Smyrna, is illustrated based on Cadouex's map. Also, the original Smyrna settlement in the 30th century BC is shown in Bayraklı. Even though some new programs across the coastline have had some positive impacts on community and economy, these interventions bring about changes in the courses of urban streams that are connected to the bay.

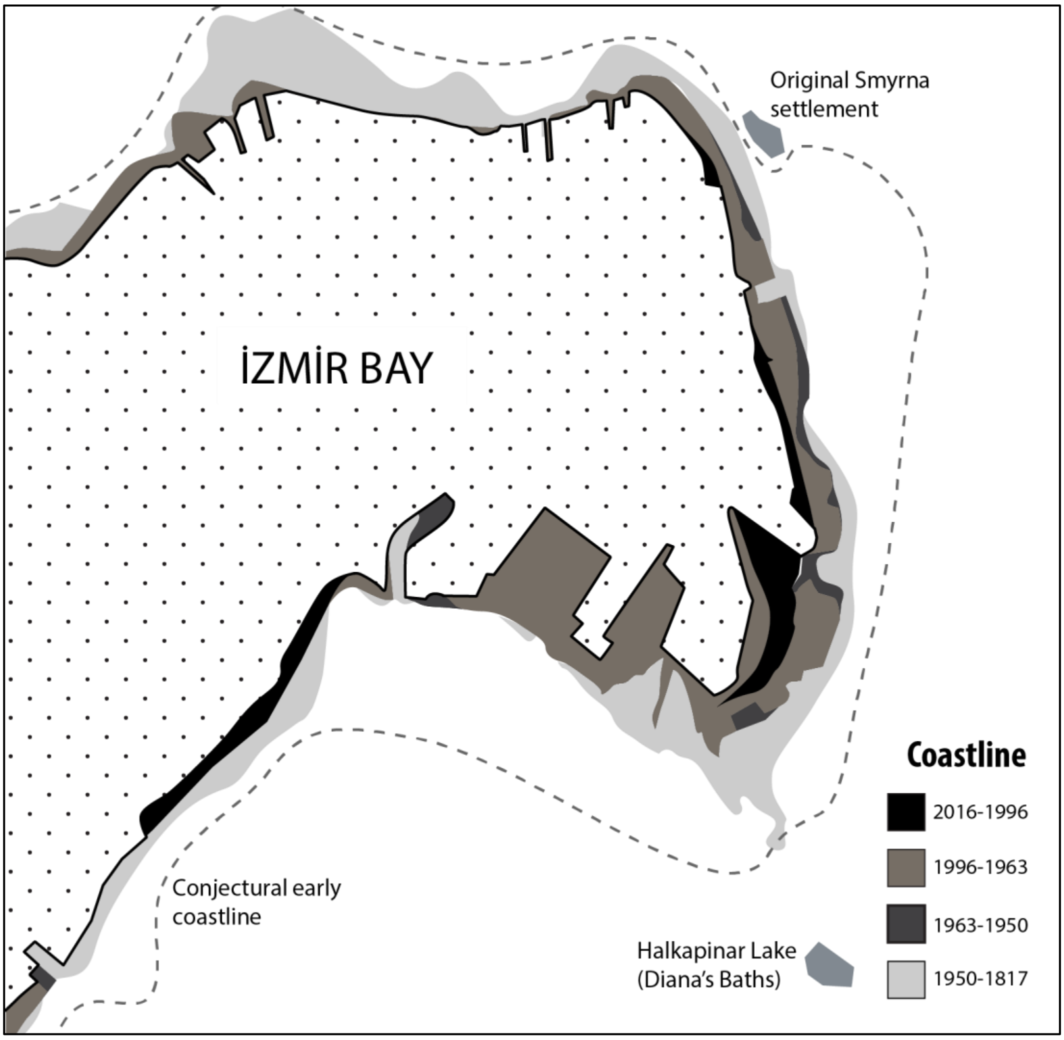

Figure 4.16. Change of İzmir's coastline throughout history
(Developed from Beyru, 2011; City Surf; Cadoux, 1938)

4.1.3. Existing Conditions

In this section environmental factors, built environment, infrastructure, planning works and land use, all of which influence Arap Stream and its surroundings, are analysed. The findings of this section will form the basis of rehabilitation strategies that will be represented in the following section.

4.1.3.1. Environmental Factors

4.1.3.1.1. Climate

To understand the dynamics of Arap Stream, it is significant to know about climate in its region. The study area is in the west of Turkey, and has a typical Mediterranean climate, characterised by hot, dry summers and mild, rainy winters.

Precipitation consists mainly of rainfall and snow. Even though it is occasional, snow can fall in İzmir during the winter months. Annual average rainfall in İzmir is about 650 mm (Figure 4.17).

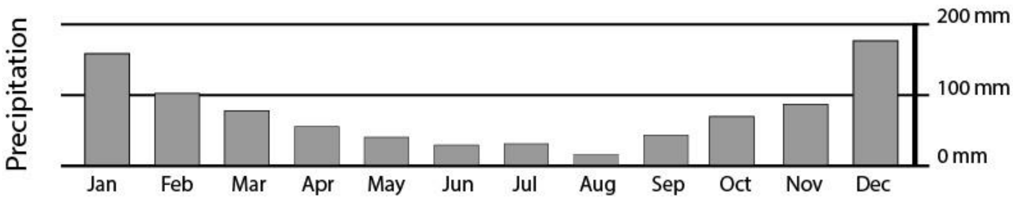

Figure 4.17. Average monthly precipitation over the year (including rain, snow, etc.) (Reproduced from World Weather and Climate Information, 2015)

The rainiest days in İzmir are seen in the month of December. On the other hand, İzmir has very dry periods in the summer months. On average, there are only a few rainy days in summer (Figure 4.18). Therefore, natural streams in İzmir, most of the time, are dried in hot summer days of İzmir. Exceptionally, in some cases when heavy rainfall occurs in a short period of time, many urban streams in İzmir cause damaging flooding. Also, the annual average wind speed across İzmir is approximately 2.5 m/s (Figure 4.19).

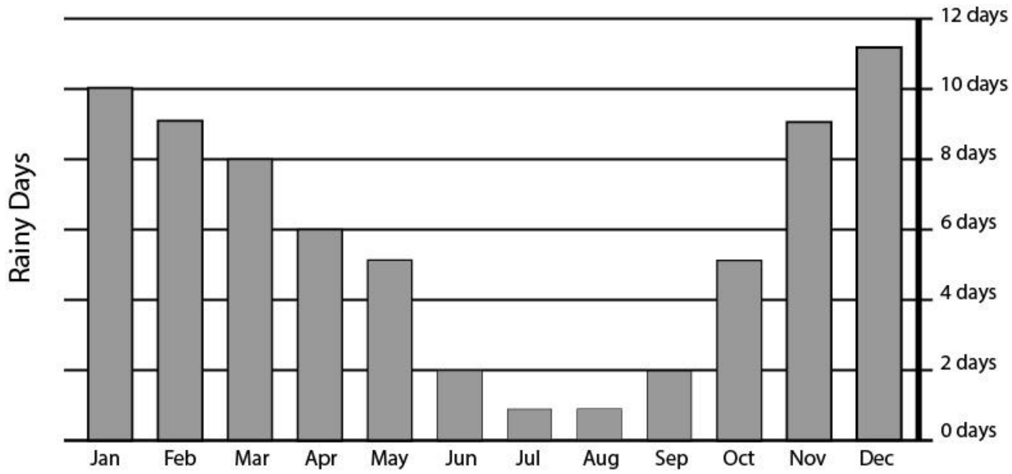

Figure 4.18. Average monthly rainy days over the year (including rain, snow, etc.)
(Reproduced from World Weather and Climate Information, 2015)

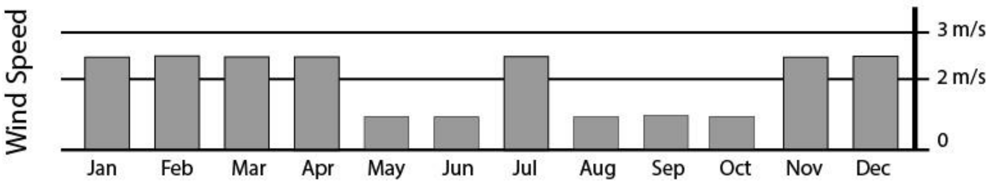

Figure 4.19. Average wind speed over the year (meters per second)
(Reproduced from World Weather and Climate Information, 2015)

According to World Weather and Climate Information (2015), the average temperatures during the summer range from 25 to 28 °C, while the winter months experience moderate temperatures, between 9 and 11 °C. The average maximum temperature is 22 °C during the year and 32 °C during the summer (Figure 4.20).

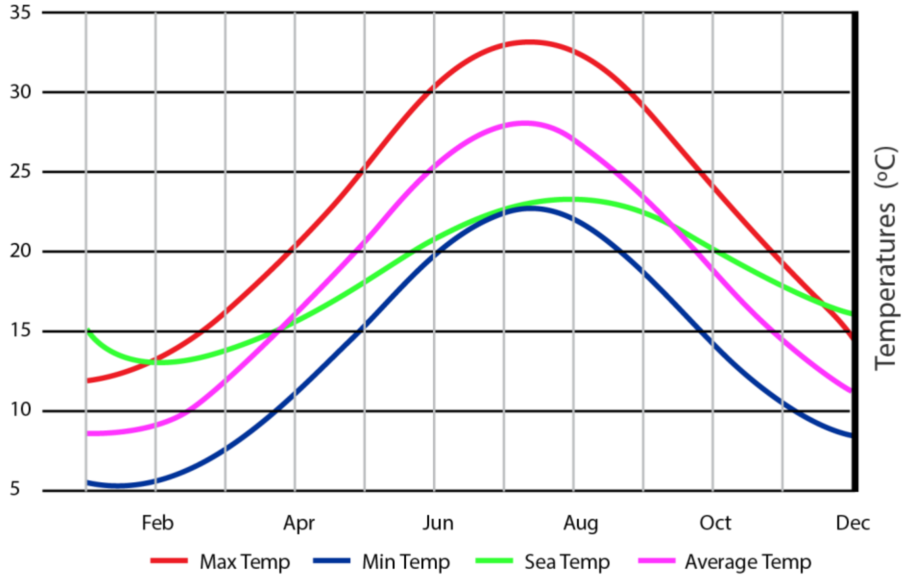

Figure 4.20. Temperature graph of İzmir
(Reproduced from World Weather and Climate Information, 2015)

Thus, Arap Stream in İzmir is shaped by its unique hydrologic regime due to heavy rains in winter and drying periods in summer. Since streams in this region cannot carry water in dry seasons, purified waste water should be allowed to flow through especially in summer months.

4.1.3.1.2. Geology and Geomorphology

Throughout history, İzmir has experienced many strong earthquakes, since it is located on fault lines. İzmir's city centre was predominantly founded on deep alluvial soils which also include Arap Stream's above-ground channel. According to Koçman's geologic map of İzmir (1991), Arap Stream originates from the flysch zone, navigates to the area of massive limestone, and finally passes through the alluvium zone before connecting to İzmir Bay (Figure 4.21). The existing part of Arap Stream today is located in alluvial soils.

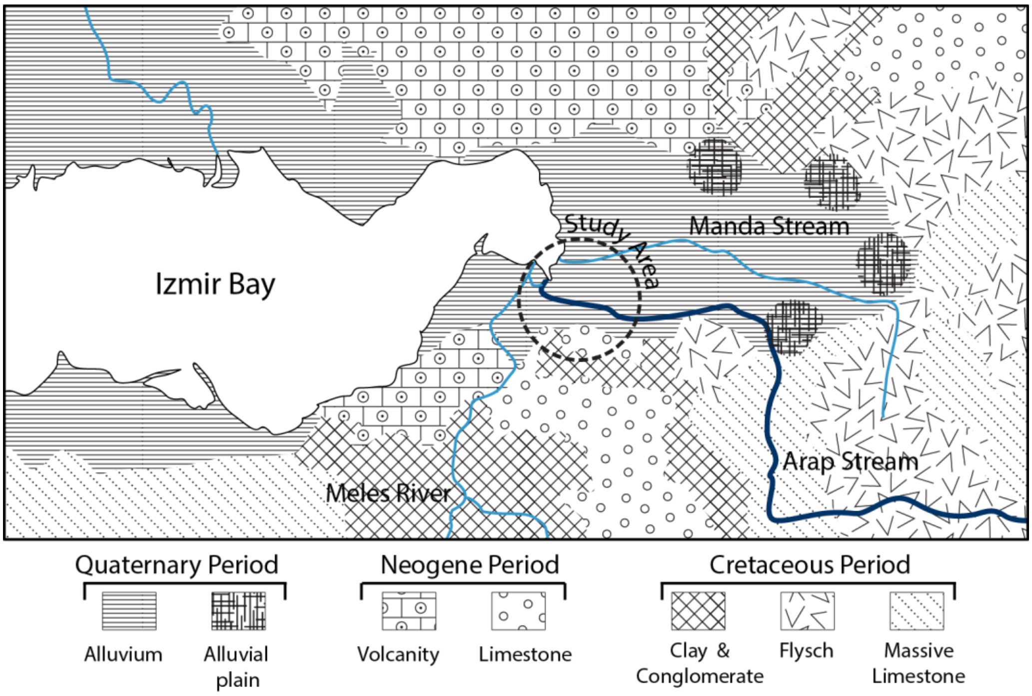

Figure 4.21. Geologic map of the study area
(Reproduced from the map of Koçman, 1991)

With regard to the geomorphological process, there are basically three major formations that affect the settlement in İzmir: Foothill plains in Balçova and Narlıdere; alluvial plains in Bornova; and hillside areas surrounding the bay (Koçman, 1991). The settlement in the district of Halkapınar, where Arap Stream flows through, was set up on the alluvial plain of Bornova (Figure 4.22).

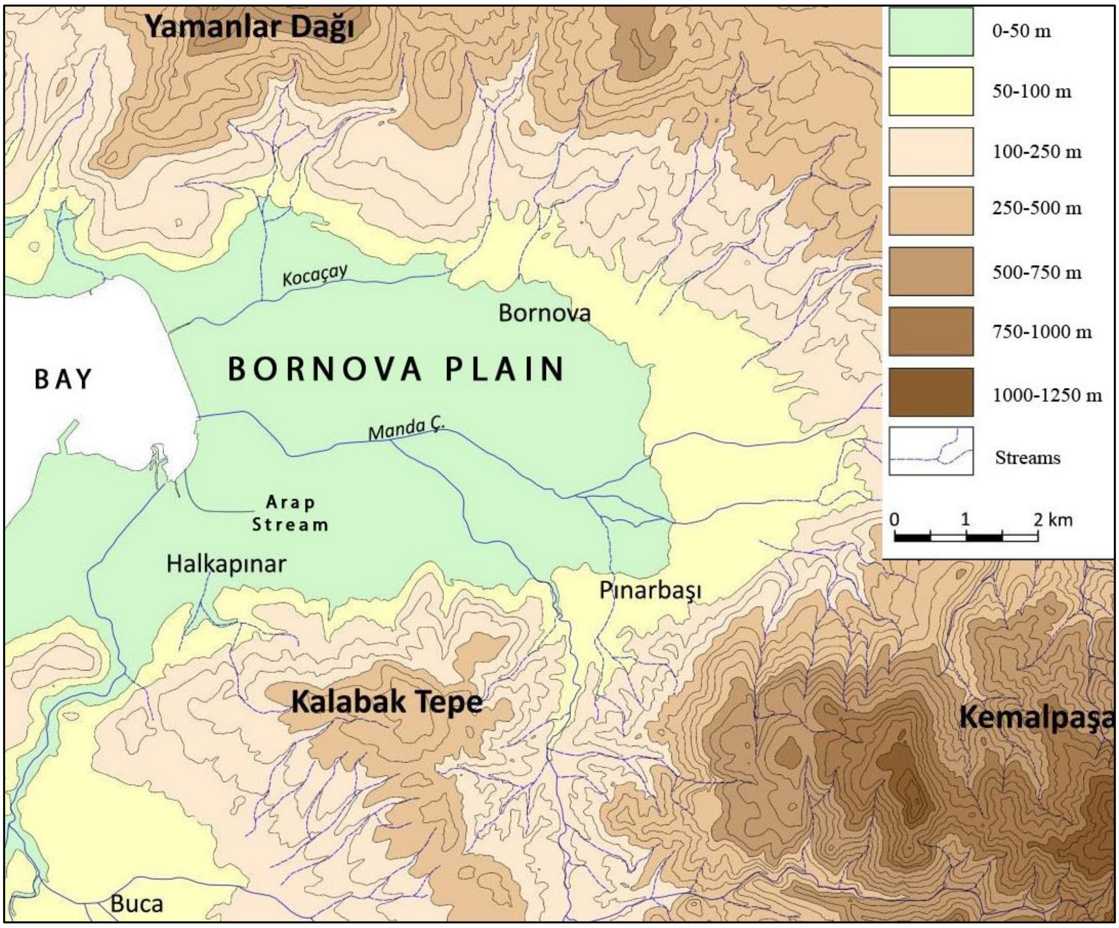

Figure 4.22. Hypsometric map of Halkapınar and its surroundings (Developed from Karadaş, 2014)

Since Arap Stream, Manda Stream and the Meles River brought organic materials to the mouth of the bay, the delta had problems with the accumulation of gravel, sand, silt and clay. Therefore, they were regulated through hard engineering solutions. In this manner, their original riverbeds were changed by considering the development in surrounding neighbourhoods. For that reason, damaging floods can occur in the district due to the shifts in the geomorphology pattern.

On the other hand, the slope in Halkapınar is reasonably gentle in downstream parts of the Meles River and Arap Stream (Figure 4.23). However, the southern part of the stream has a steep slope, since it is situated in a hillside location. With heavy rain, the district can receive surface runoff from higher elevations; therefore, it is essential to eliminate the flooding risk through minimising impervious surfaces and maximising green spaces.

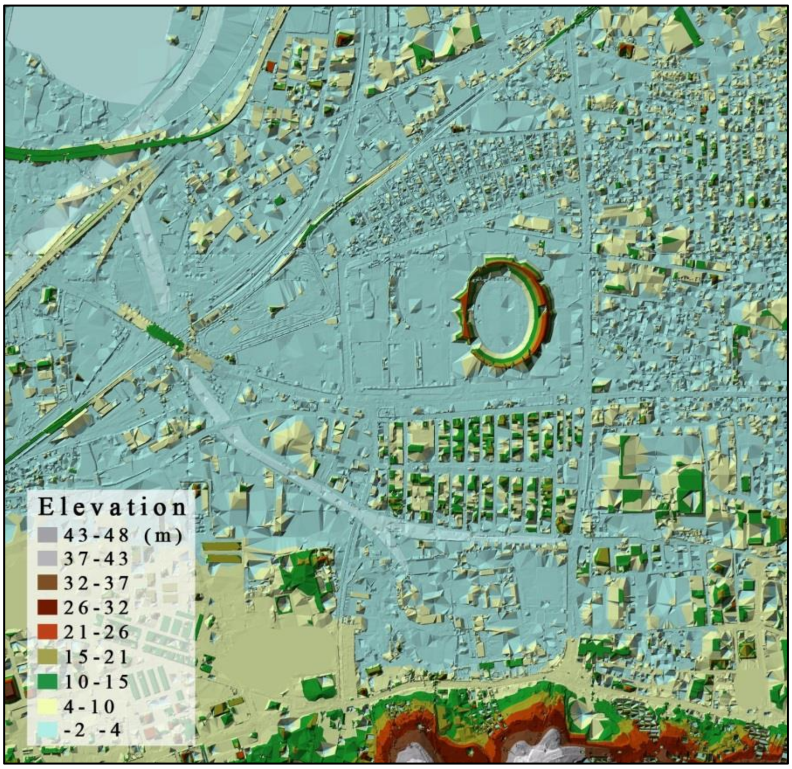

Figure 4.23. Elevation map

4.1.3.1.3. Hydrography

A functional flow requires reflecting patterns of nature. In this regard, it is essential to interact in three dimensions (longitudinally, laterally and vertically). Intervened streams, therefore, do not have the functional flow regime.

Many urban streams in İzmir, including Arap Stream, are intermittent streams that flow seasonally. Formerly, Arap Stream was a watercourse fed by springs, discharging into the bay. Presently, the hydrography of Arap Stream is artificially maintained as a straight line. Wastewater, rainfall and surface water are the primary water sources for the stream. The open part of Arap Stream is connected to neither the hyporheic zone nor the upstream part of Arap Stream. Since the south branch of the stream was buried under the ground, only a 2 km length of the concrete channel serves the city as an infrastructural system (Figure 4.24)

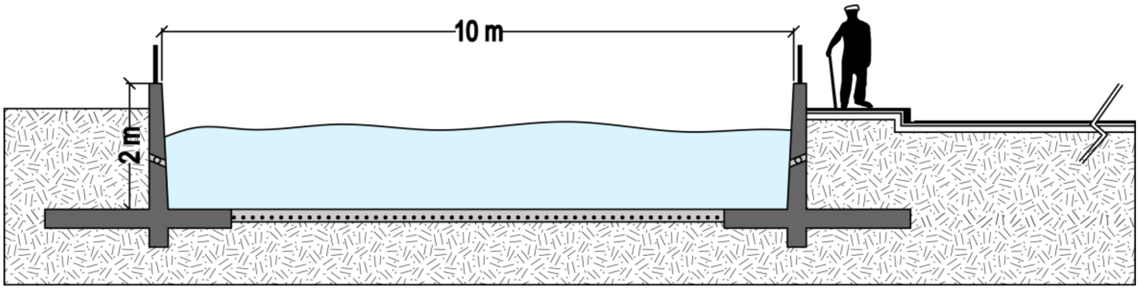

Figure 4.24. The cross-section of Arap Stream, which was channelized into a concrete channel, from the 2821st St

On the other hand, Arap Stream does not look natural at all since it was channelized in the mid-1900s. After the Large Canal Project, which integrates several collector networks for sewer and stormwater with the aim of maintaining İzmir Bay, which was carried out by İzmir Municipality and The General Directorate of State Hydraulic Works (DSI) in 2002, Arap Stream had to be connected to one of the main collectors of the Large Canal. Accordingly, Arap Stream, as an open channel, is charged with carrying waste water and stormwater to the collectors of the water treatment plant. Even though it works sustainably in general, it has no natural features on the local scale. Instead of having natural streams, the community has to live with channelized streams carrying wastewater only.

Based on the map of İZSU (2001), the watershed boundaries of the Meles River, Arap Stream, and Manda Stream are illustrated in Figure 4.25. Even though the focus is on the open part of Arap Stream, the scope of this research covers the watershed of Arap Stream. Since some parts of the watercourses are destroyed, Figure 4.25 is illustrated to display the whole of the urban stream network within the city boundary. Also, some first and second order tributaries are shown in the same figure by using a river classification system, which is presented in Chapter 2. In this regard, while the main branch of the Meles River is a third order tributary, the main branches of the former Arap Stream and former Manda Stream are second order tributaries.

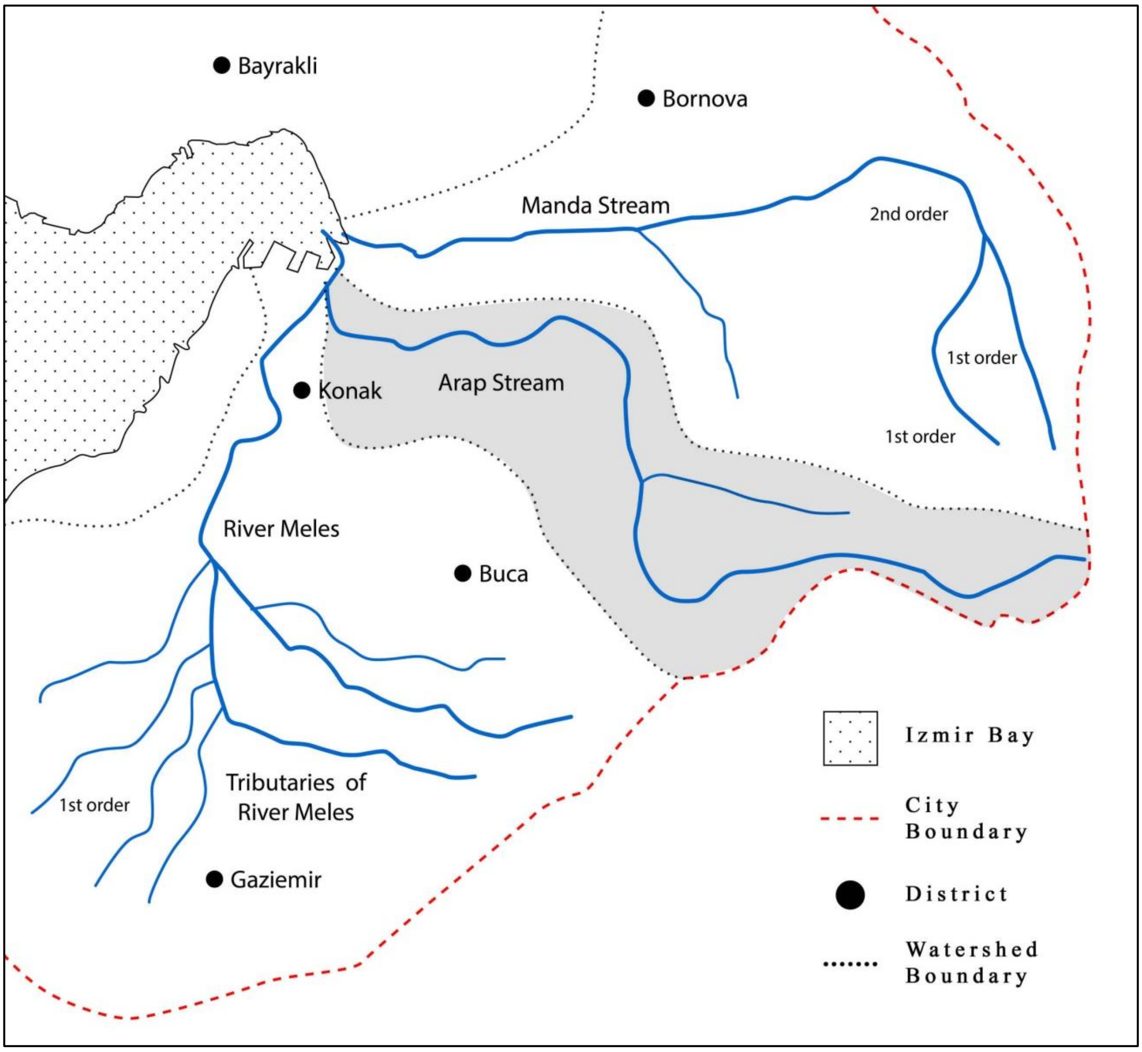

Figure 4.25. Watershed boundaries of Arap Stream, Manda Stream, and River Meles within the boundary of İzmir (Developed from İZSU's map, 2016)

Figure 4.26 demonstrates the locations of the following photographs on the map (Figures 4.27 to 4.35). As seen in the following figures, Arap Stream is a water body which is surrounded by tall fences and fragmented by the transportation network. Despite its existence in the city centre, it is not a stream used for recreational purposes by the community.

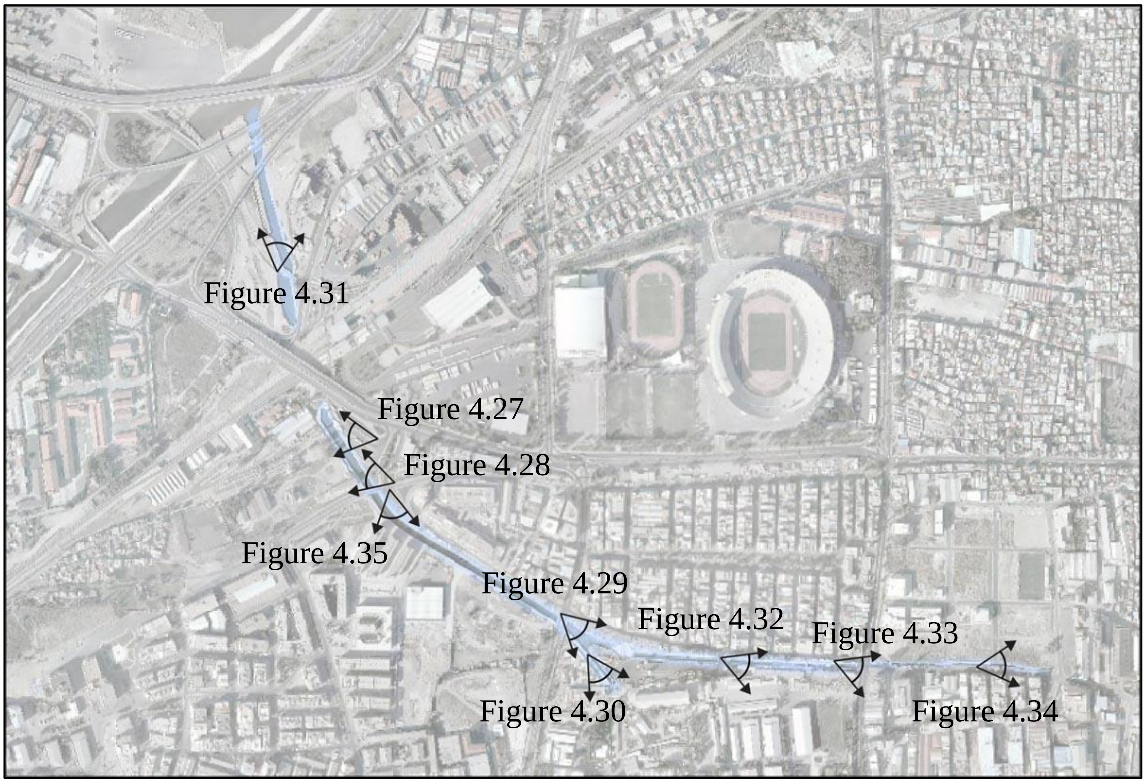

Figure 4.26. Locations and viewpoints of the photographs on map
(Developed from Google Maps)

While the water level of Arap Stream decreases dramatically in summer days due to the climatic characteristics of İzmir, it does not threaten the community with its increased water level in winters (Figures 4.27 and 4.28). Since the Turkish State Railway is located on one side of the stream, it is surrounded by walls and fences. Even these fences can be taller in other portions of the stream (Figure 4.34). Also, Halkapınar Transportation Hub is situated exactly in the location where these pictures were taken. Therefore, pedestrians can only walk on the side of the bus terminal. Also, Arap Stream has concrete embankment walls except for this part of the stream. As seen in Figures 4.27 and 4.28, stone floodwalls are placed partially in front of the transportation hub.

Figure 4.27. Arap Stream in the winter (February 2016)

Figure 4.28. Arap Stream in the summer (June 2016)

Originally, Arap Stream did not have any tributary before its artificial creation for the purpose of conventional stormwater management. After a short length of Halkapınar Stream was connected to Arap Stream, it gained its present appearance (Figures 4.29 and 4.30). Presently, İzmir Solid Waste Agency, which discharges its wastewater into the stream, is situated in the location where the small tributary joins the main course.

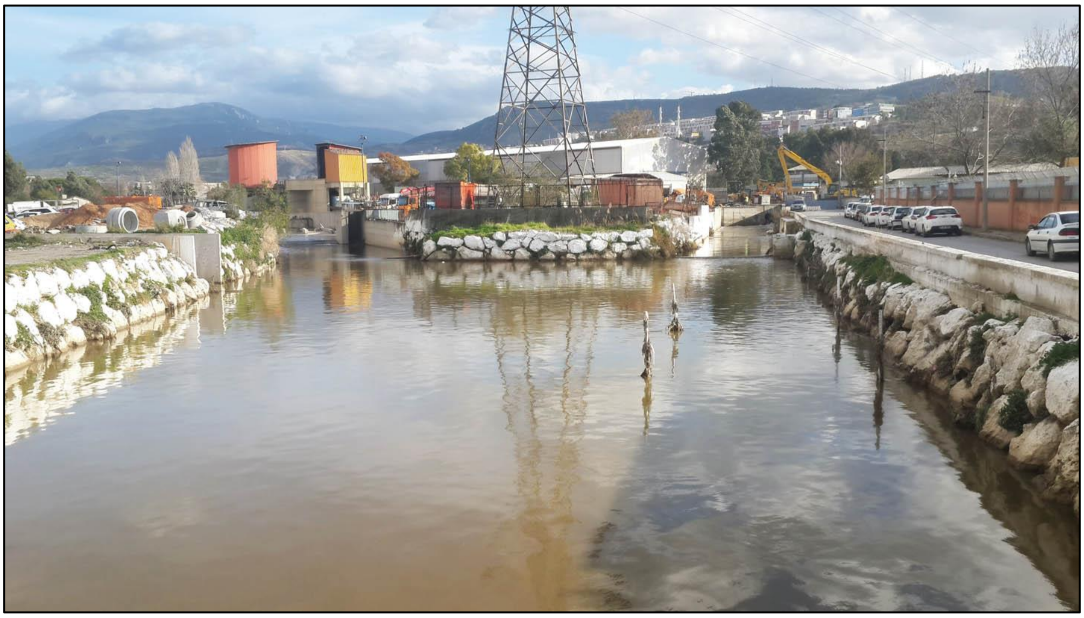

Figure 4.29. Tributaries of Arap Stream (December 2015)

Figure 4.30. Discharging into the short tributary of Arap Stream (December 2015)

Figure 4.31 shows one of the elevated highways, passing over Arap Stream. Additionally, pedestrian access is not possible in this part of the stream. Municipal utilities on the opposite side of the stream are also isolated from Arap Stream. Despite the existence of a green area, it is not used by the community (Figure 4.32). Neglected river banks, therefore, do not have any influence on recreational purposes.

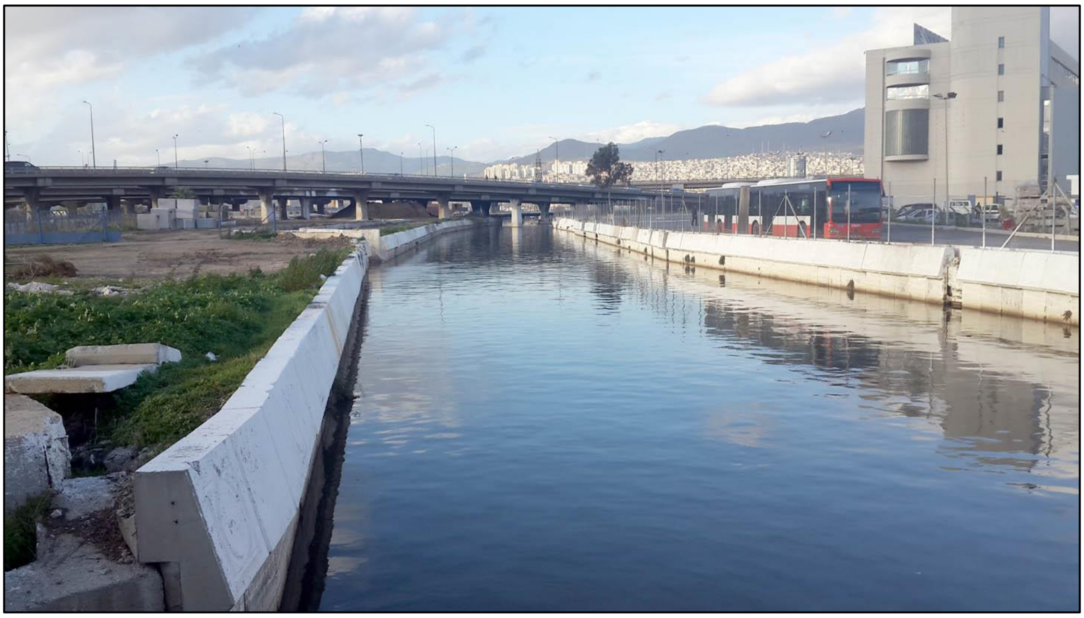

Figure 4.31. Arap Stream passing underneath the elevated highways (December 2015)

Figure 4.32. The banks of Arap Stream (December 2015)

Arap Stream is fragmented several times by transportation infrastructure (Figure 4.33). As the current plans of İzmir do not take into consideration the presence of water systems in general, urban streams in this district are crossed by several roads and railways. Thus, each intersection not only leads to environmental unbalance but also damages the integrity of aquatic systems.

The only improvement for Arap Stream in recent years was to install tall fences for pedestrian safety (Figure 4.34). However, this obstacle shows us that the local government perceives Arap Stream as a potential threat to the community. Thus, isolating streams is the best solution of the current water management system to make them inaccessible.

Figure 4.33. The intersection of Arap Stream and Fatih Street (December 2015)

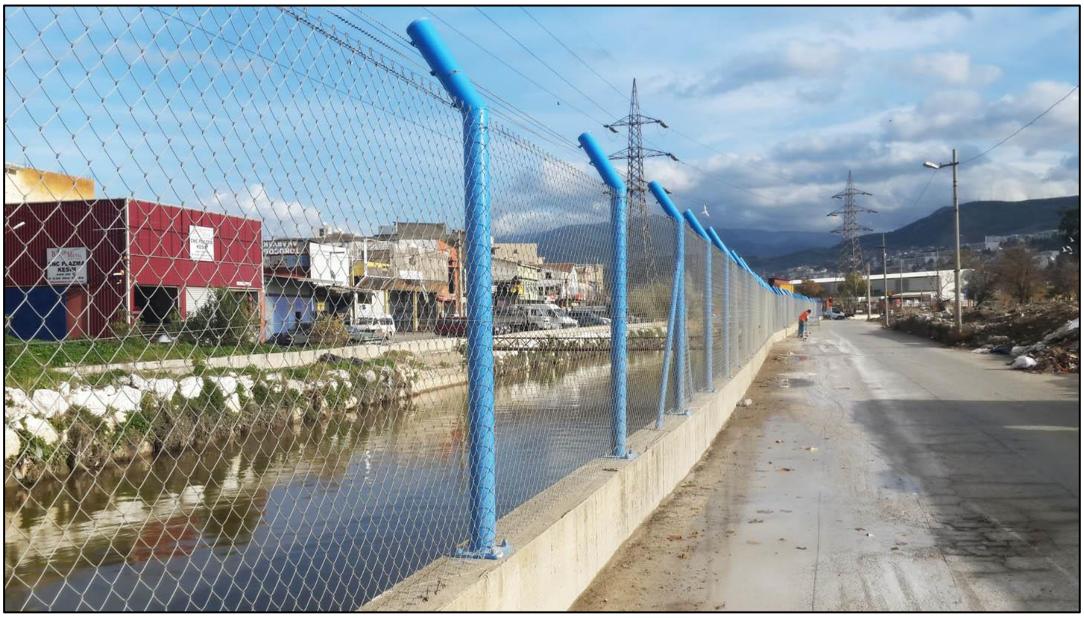

Figure 4.34. Arap Stream surrounded by tall fences (December 2015)

4.1.3.1.4. Vegetation

The flora of İzmir is mainly covered by Mediterranean vegetation dominated by maquis shrubland. The climax tree of the region is considered as *Pinus brutia* (Turkish red pine). Red pine forests in natural lands of İzmir are frequently accompanied by *Pistacia sp*. and *Quercus coccifera* (kermes oak). Also, *Olea europea* (olive), *Laurus nobilis* (bay laurel), *Spartium junceum* (Spanish broom) and *Nerium oleander* (oleander) are some of the most significant plants for natural and cultural landscapes in İzmir.

The edges of Arap Stream do not include any native species (Figure 4.35). Narrow lawn areas along the stream do not function ecologically. Even though eucalyptus trees, which are generally used to dry out wetlands, are non-native species in İzmir, they are currently the most common tree species along the stream. This proves that they were planted to dry out the wetland area in the past. Since using native plants are low-maintenance, the trees listed above are of great significance to the process of riparian zone restoration.

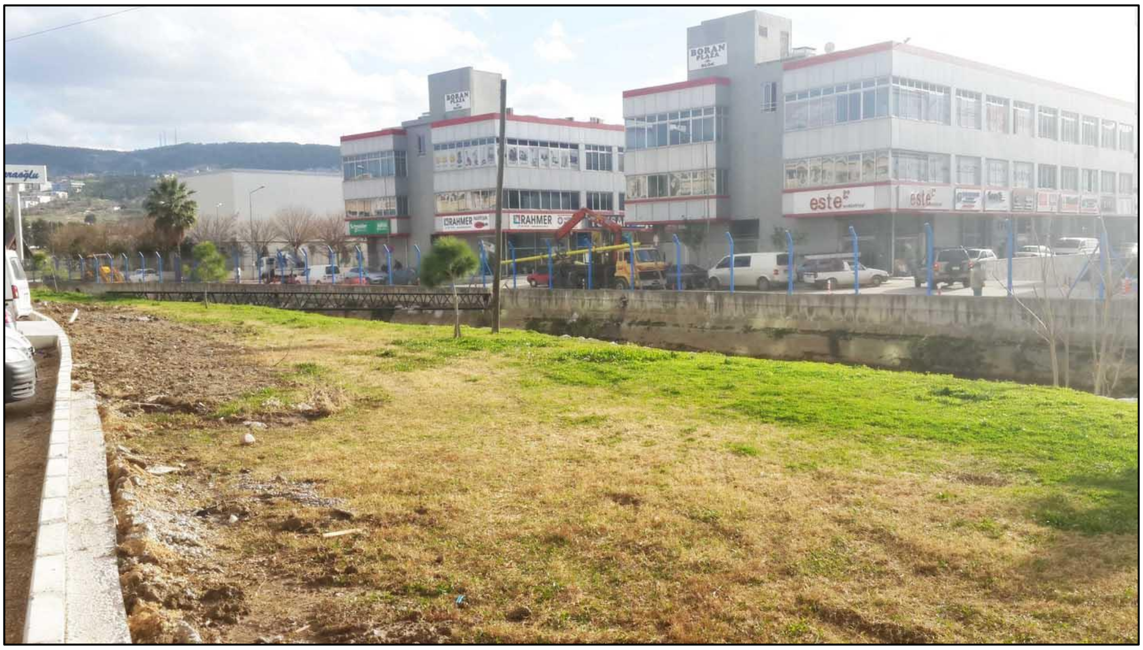

Figure 4.35. The edge of Arap Stream

Surrounding streets adjacent to Arap Stream have low vegetation density (Figure 4.36). As the urban heat island effect in urbanised cities has an adverse impact upon the environment, particularly during summer days, more urban trees should be considered along Arap Stream as a part of the urban infrastructure.

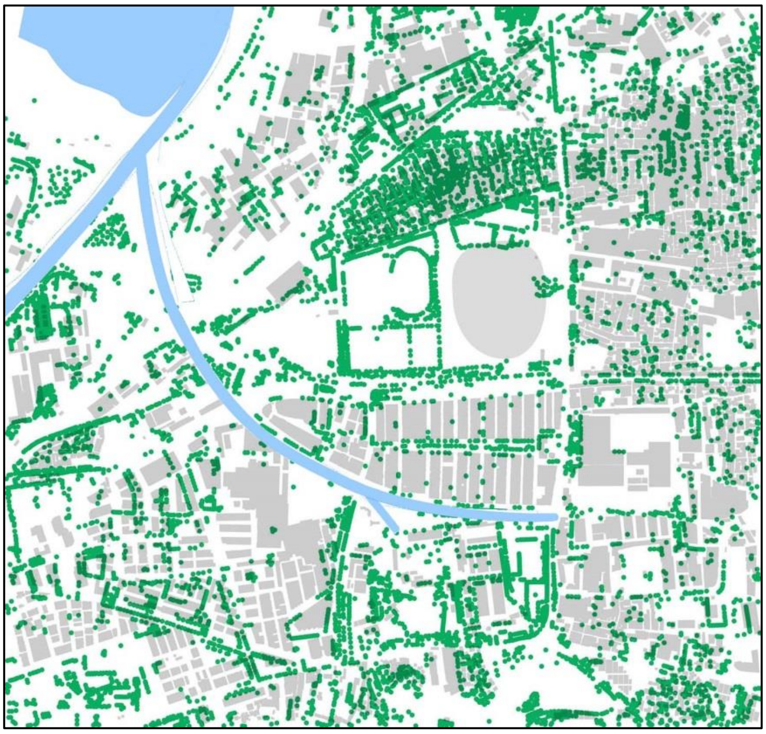

Figure 4.36. Urban street tree density

4.1.3.2. Built Environment and Infrastructure

The study area is located near İzmir Harbour which has the highest real estate values in İzmir. Since the whole district is urbanised, there is no natural landscape within the surroundings of Arap Stream. The most significant urban landscape in the nearby districts can be considered as the Park of Culture (Kültürpark), also known as the International Fair Centre, that was designed on the area of 42 hectares in the 1930s.

On the other hand, the Meles Delta is one of the significant ecological assets of İzmir not only providing recreational opportunities to the community but it also having a unique hydrologic regime. Meles River, Manda Stream and Arap Stream meet in the delta before discharging into the bay (Figure 4.37 and 4.38). However, in spite of the existence of the delta, its surroundings have experienced several flooding events. Since the delta was only planned as an urban green space which does not have any bioengineering solutions, its engineering structure needs to be improved (Özeren & Kaplan, 2013).

Figure 4.37. Meles Delta in the early 2000s
(APİKAM, 2015a)

Figure 4.38. Arap Stream meets Meles River in the early 2000s
(APİKAM, 2015b)

Figure 4.39 is illustrated with the aim of displaying morphological characteristics (openness, enclosure, containment, etc.) of the district. In this regard, the district has a complex structural pattern. The riverfront development along both the Meles River and Arap Stream does not reflect the existence of the natural water systems; therefore, this has resulted in decreasing the legibility of the district.

Figure 4.39. Mass-Space analysis

The study area is highly accessible since it is near the Halkapınar Transport Hub where passengers can easily transfer between public buses and metro lines (Figure 4.40). However, Arap Stream is frequently cut into fragments by numerous crisscrosses of primary and secondary arteries, especially in the district where Arap Stream meets the Meles River. Since there is no safe walking path close to the stream, pedestrians have to track the rail trail and pass under the elevated highways if they want to reach the coastline from Arap Stream.

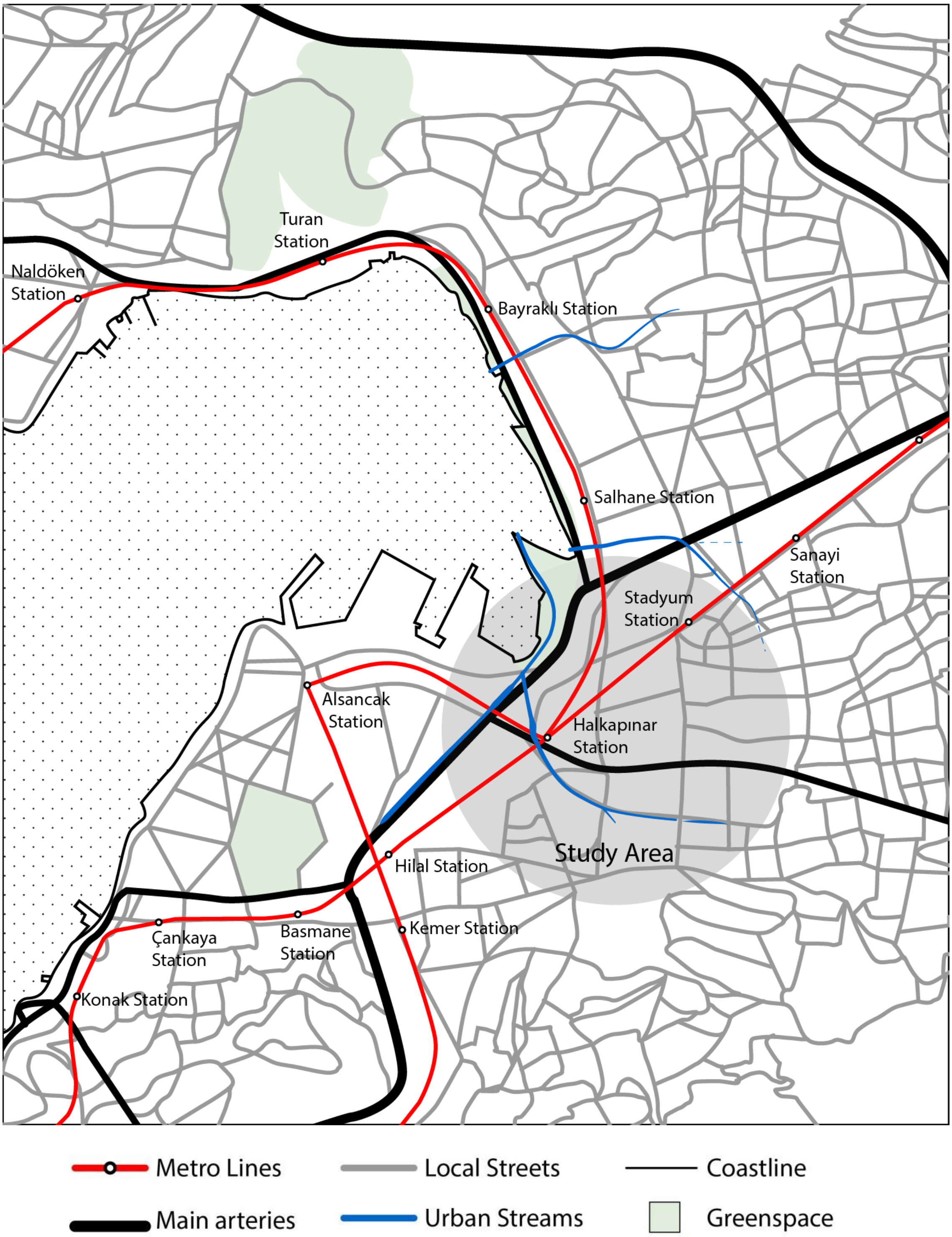

Figure 4.40. Transportation network around Arap Stream

Figure 4.41 demonstrates that the buried south branch of Arap Stream, carrying waste water, connects effectively to the main collector of Large Canal. However, the rest of the stream, which is the open part of Arap Stream, does not work with this canal project even though İzmir's Water and Sewage Agency stated that currently there is no stream directly flowing into the İzmir Bay (İZSU, 2015). As shown in Figure 4.40, the northern parts of the Meles River and Arap Stream can flow directly into the İzmir Bay.

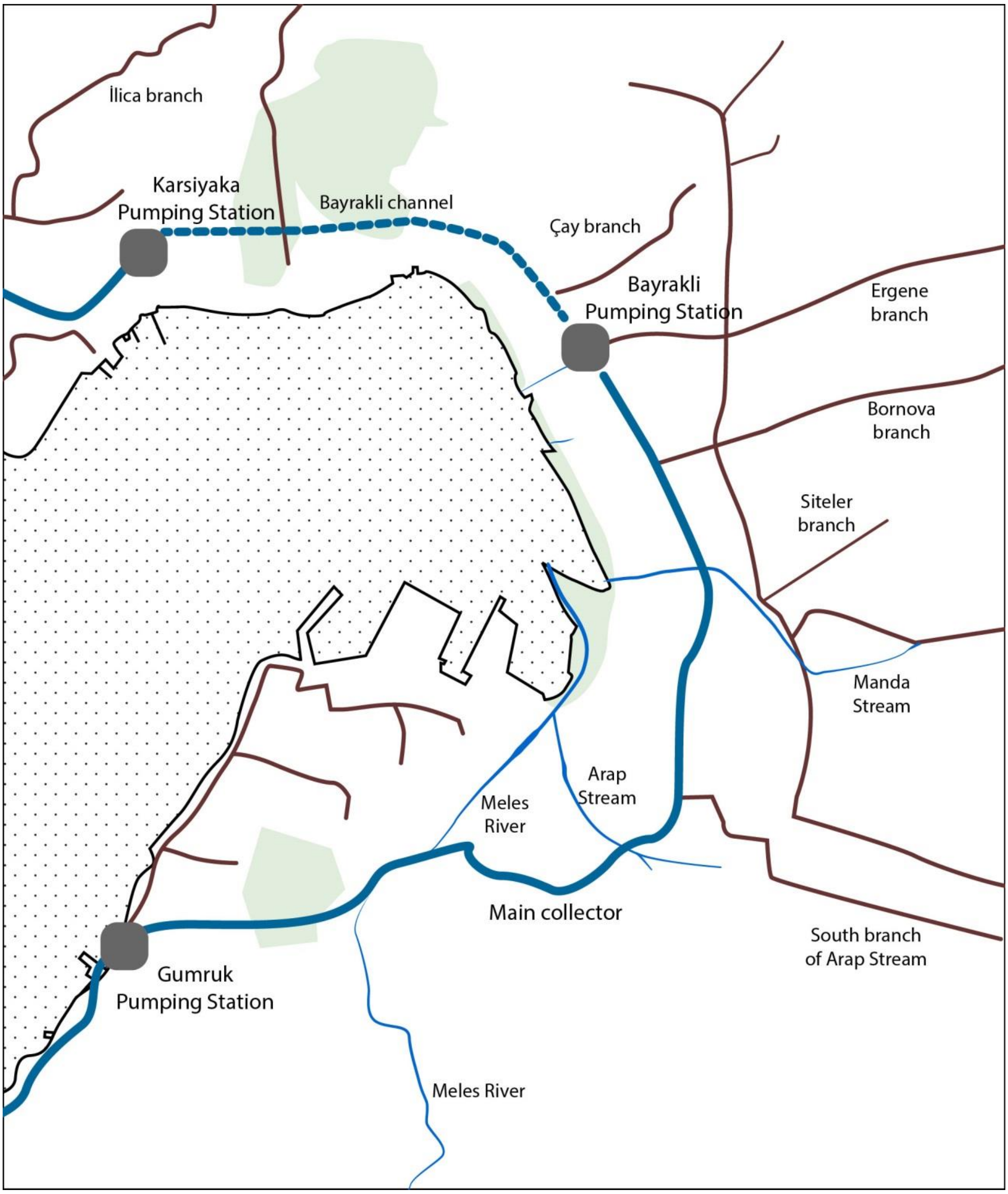

Figure 4.41. The relationship of urban streams in İzmir with the Large Canal

Despite the existence of the Large Canal Project, Arap Stream is still subjected to pollution problems. According to Kılıçaslan (2004), based on types of pollution, including land, noise, visual and water pollution, Arap Stream is the most polluted urban stream among six urban water bodies in İzmir.

As seen in Figure 4.42, only private properties are situated along Arap Steam, except the area where the Solid Waste Agency and İzmir's Water and Sewerage Agency exist. Even though properties of Halkapınar Metro Station and the Bus Transfer Station are also public, these areas cannot be used to integrate Arap Stream with its surroundings. Moreover, rerouting of the course or creating a wide riparian buffer would require the expropriation of a considerable amount of properties in the district. In this regard, it is significant to have feasible and long term rehabilitation strategies. Also, the only public property near the stream should be considered as the key area of the short term rehabilitation process.

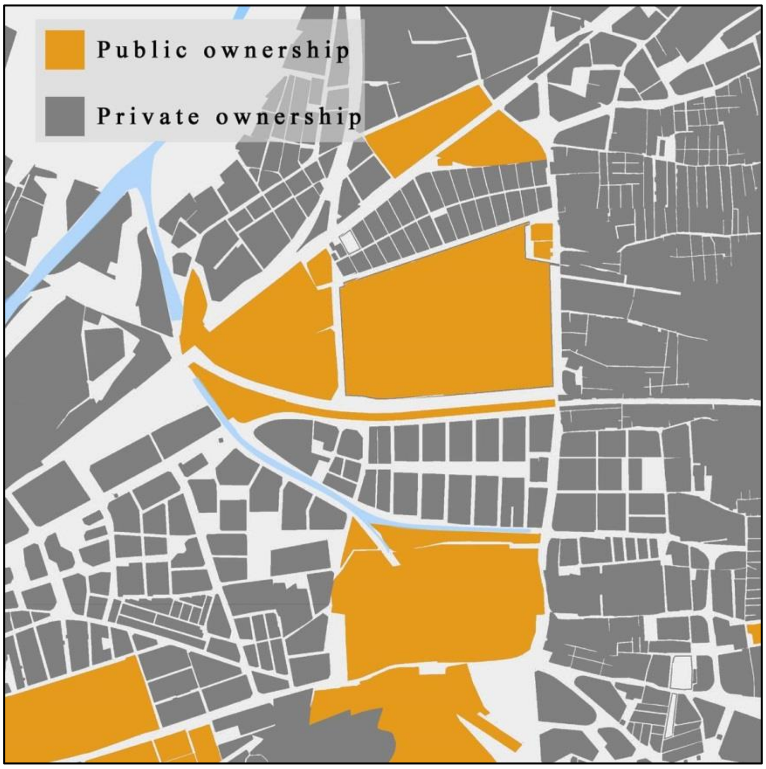

Figure 4.42. Ownership analysis

With regard to the existing land use, the study area mainly consists of commercial and industrial buildings (Figure 4.43). Along Arap Stream, many small industrial buildings, including auto galleries and manufacturing factories, are located. Halkapınar Metro Station, İzmir's Water and Sewerage Agency and Solid Waste Agency are major public facilities in the study area.

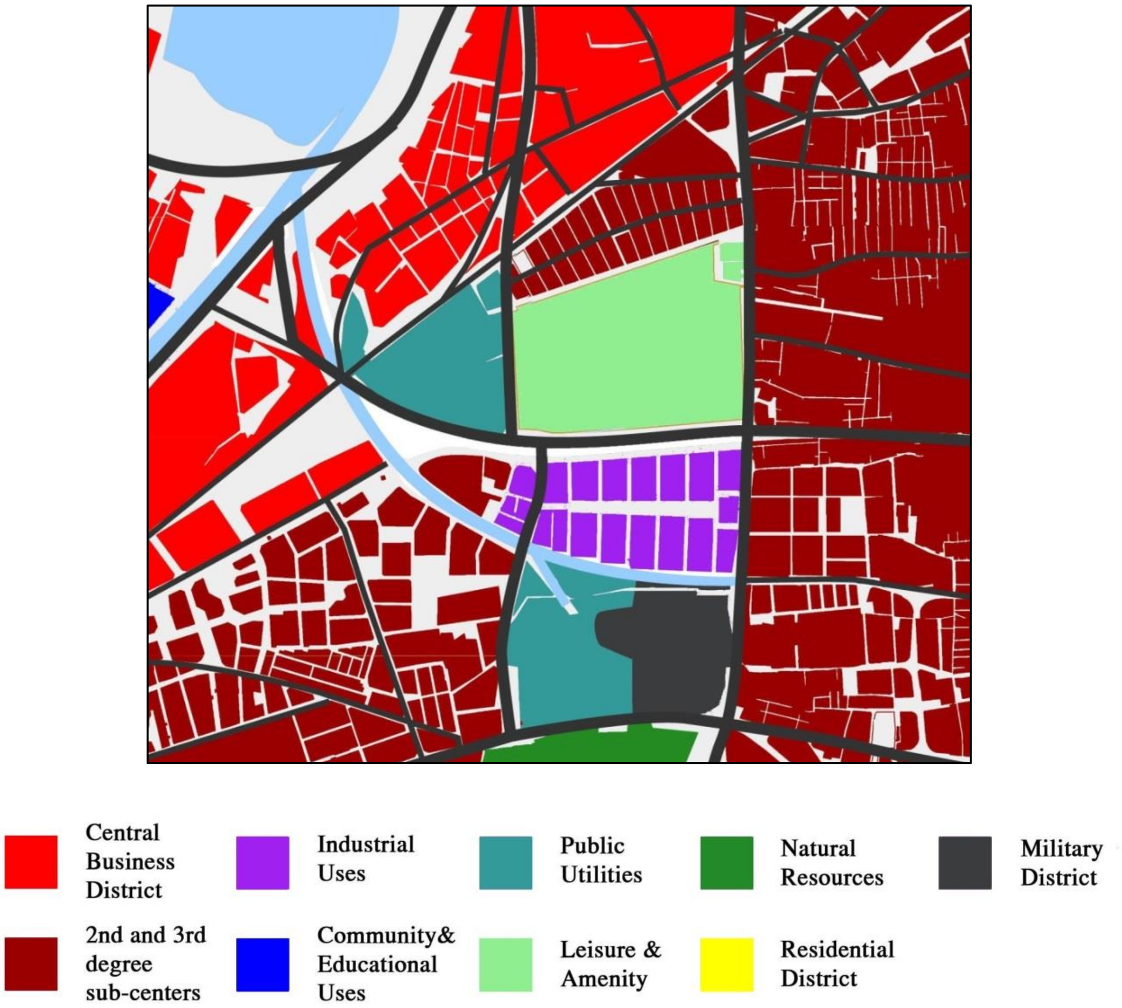

Figure 4.43. Existing Land Use

4.1.3.3. Planning Works

The basic decisions of the Environmental Plan on scale 1/25000 about the study area continue the industrial site and central business district land uses (Figure 4.44). According to the plan, only municipal uses can be located in the area where Halkapınar Lake once existed. There is no concern related to Arap Stream's course such as a green corridor along its banks. On the other hand, according to the İzmir New City Centre Master Plan (1:5000) for 2030 and also other city plans, there is likewise no change in the land use of the industrial area which is the primary source of pollutants of Arap Stream (Figure 4.45 and 4.46).

Rather than a wide riparian zone, central business district and industrial land uses along Arap Stream have an adverse impact on the urban quality of life. Also, municipal land uses affect not only the historical character of the district but also the ecological structure of the district with its wastewater. For that reason, land uses in this district do not reflect the spirit of the place. In this regard, Arap Stream should be integrated with its surroundings through waterways and greenery. Accordingly, new compatible land uses should be considered.

Apart from ecological concerns, the industrial area will have to be relocated from central areas of İzmir to the periphery because of increased property values. Therefore, this study provides not only ecological sustainability but also brings visionary approaches to revitalise the whole district.

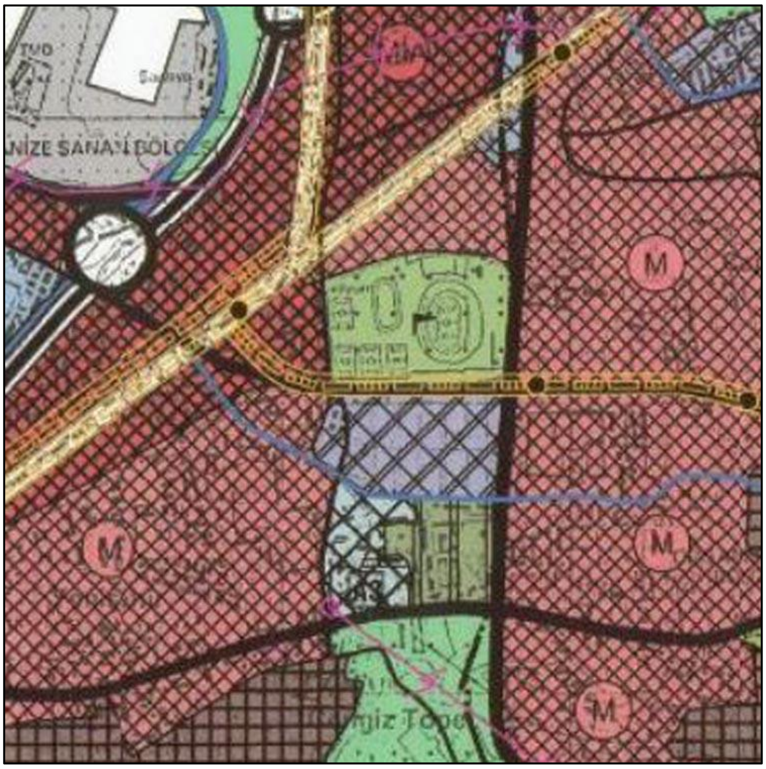

Figure 4.44. 1/25000 Scaled Environmental Plan approved in 2009
(Source: İzmir Metropolitan Municipality, 2016)

Figure 4.45. İzmir New City Centre Master Plan for 2030
(Source: İzmir Metropolitan Municipality, 2016)

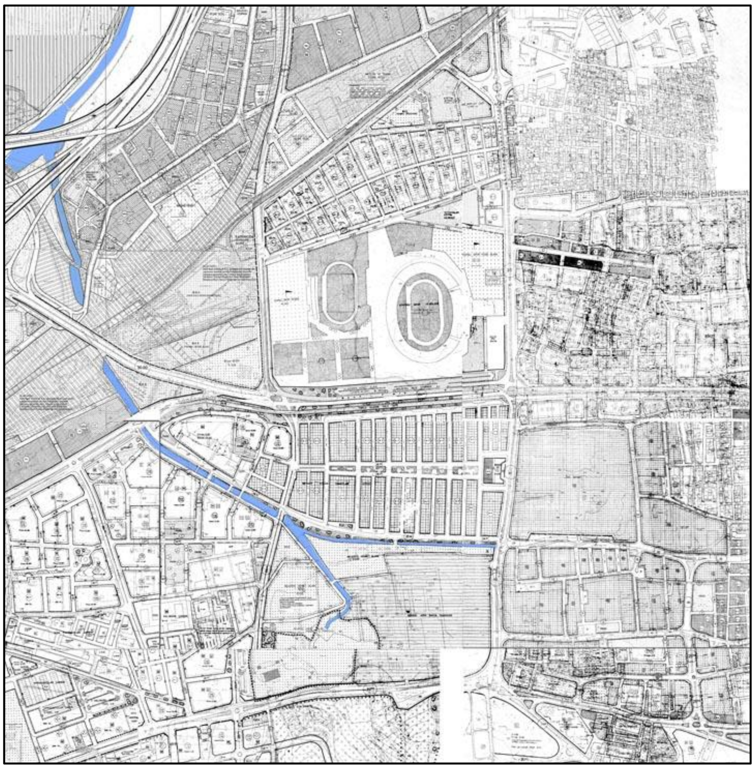

Figure 4.46. 1/1000 Scaled Master Plan approved in 1970
(Source: İzmir Metropolitan Municipality, 2016)

Figure 4.47 not only demonstrates types of existing buildings in the district but also demonstrates land use clusters within a five-minute walk or 400-metre radius.

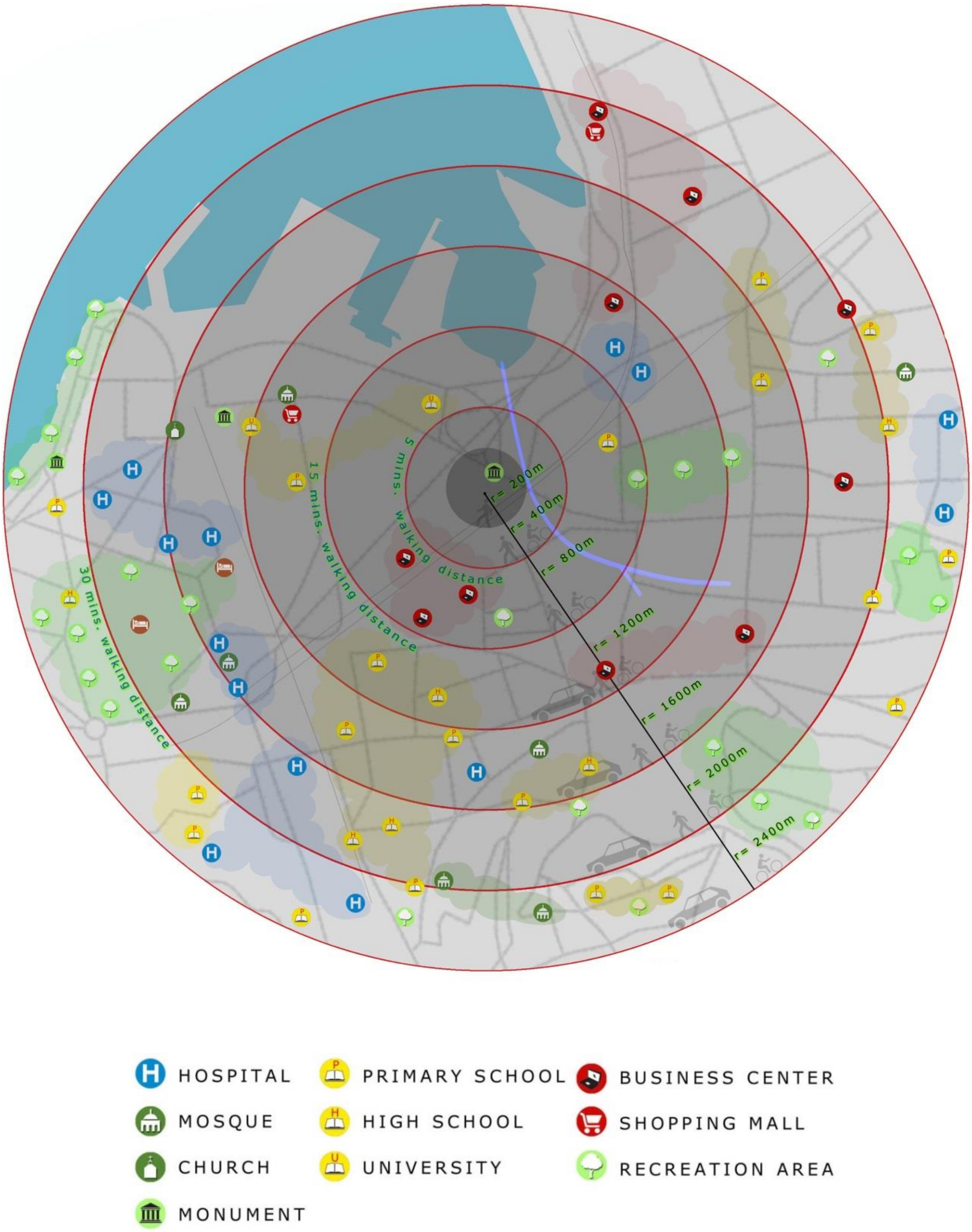

Figure 4.47. Land use clusters near Arap Stream

4.2. SWOT (Strengths, Weaknesses, Opportunities, and Threats) Analysis

As shown in Table 4.1, a SWOT analysis is conducted to analyse the weaknesses, strengths, opportunities and threats that show all the main disadvantages and advantages of Arap Stream and its surroundings. The result of the analysis is to determine the criteria for the rehabilitation of Arap Stream.

Table 4.1. The SWOT Analysis for Arap Stream and its surroundings

Strengths	• Availability of historically rich underground water resources • Providing an historical focus on urban identity • Being in the heart of the city and easily accessible by public transportation, including metro lines and public buses
Weaknesses	• Polluted water bodies flowing into İzmir Bay despite the presence of the Large Canal Pattern • The existence of an industrial area near Arap Stream • Surrounded by elevated highways and poor quality of urban fabric • Fragmented sites and water bodies isolated from the city centre • Lack of riparian zone and of continuous public ownership around the stream • Current institutional arrangements on stream management • Safety issues and lack of pedestrian environment.
Opportunities	• A new city centre development adjacent to the study area • Need to revitalise the brownfield, old Tekel Factory, near Arap Stream that requires a comprehensive rehabilitation project for the entire district including the natural ecosystem • Presence of wetlands and historical trails • Recreational opportunities, local economic regeneration, investment and job creation

(cont. on next page)

Table 4.1. (cont.)

Threats	• Existence of industrial use on the edge of Arap Stream • New urban development and redevelopment projects in İzmir • Channelization and water pollution from the industrial site, human activities and decreased natural purification services as wetlands in the district destroyed • Limited environmental awareness • Perceiving water bodies as sources of threats as well as parts of sewage systems • Lack of new and ecologically-driven land-use decisions, which are compatible with the new city centre, to the industrial site in the projected master plans of İzmir for 2030

Strengths: Historical significance, hydrological features, and the location of Arap Stream are some of the strengths of the watercourse. Healing Arap Stream and its surroundings, which will recall the natural beauty of the district, is to provide a compatible urban identity with the history. Since Halkapınar Transportation Hub exists near the stream, actions to be taken will ensure a contribution not only to the local community but also to the entire city of İzmir.

Weaknesses: The major weaknesses of Arap Stream are the presence of the artificial canal, which flows through an industrial site, and wastewater discharge. Additionally, the ecological integrity of Arap Stream was disrupted by fragmental infrastructure. As the physiological structure of Arap Stream has a resemblance to other urban streams of İzmir, it is proved that the perception of the current water management in İzmir plays a primary role in the ecological destruction of urban streams.

Opportunities: New emerging city centre in Bayraklı attracts large volumes of investment in nearby districts. The proximity of Arap Stream to the new centre that has economic attractiveness would facilitate the rehabilitation process. Additionally, the presence of the brownfield, which calls for revitalization, can be seen as another significant asset in the district. When taken together, these assets would provide an integrated and holistic approach to the recuperation of the vicinity.

Threats: Some inputs listed in weaknesses can simultaneously be threats. For instance, the current water management in İzmir and the presence of the industrial site provides threats to Arap Stream and its surroundings. Also, the combined sewage system not only damages urban health but also the ecological balance. Since urban regeneration and redevelopment endeavours are considered regardless of urban water systems, Arap Stream might be able to face a threat that can destroy the rest of the stream.

The historical and ecological significance of Arap Stream is one of the reasons why Arap Stream needs regeneration. However, some constraints, including ownership and governance issues, cause infeasible full rehabilitation in the short term. Moreover, the newly emerging city centre in Bayraklı and the presence of brownfields in the district provide opportunities for the stream and its surroundings. Due to the techniques that can be implemented in the short term, a partial rehabilitation of the stream can relieve the problems of the district.

4.3. Guidelines for Rehabilitation of Arap Stream

After examining the inputs of the SWOT analysis, it can be seen that the rehabilitation of Arap Stream calls for different types of rehabilitation strategies, some of which can be short term while others may be appropriate for the long term. Therefore, rehabilitation approaches will be discussed under the following headings: urban-scale decisions, district-scale decisions, and neighbourhood-scale decisions respectively.

This chapter, therefore, aims to present the rehabilitation of Arap Stream and its surroundings by recovering natural systems, changing the land use of the surroundings in the catchment area, providing green and water networks and using innovative approaches such as green infrastructure techniques, natural cleansing systems and soil bioengineering techniques.

As discussed in the previous chapters, after realising the significance of the existence of urban streams, daylighting projects have been initiated all over the world. Even though this study partially deals with the above-ground channel of Arap Stream, it is important to underline that it still requires a watershed-based approach for rehabilitation. This study, therefore, criticises and focuses on the faulty implementation on the existing part of the stream, and also presents rehabilitation on a larger scale by considering its buried parts beneath sewers and culverts.

Also, in this chapter, a series of guidelines are developed across scales in order to reclaim the ecological sustainability of Arap Stream and its surroundings. These comprehensive strategies include sustainable water management and ecological rehabilitation along Arap Stream as well as urban design based on Halkapınar's historical, social and cultural backgrounds.

4.3.1. Urban-Scale Rehabilitation

Urban-scale rehabilitation offers stream rehabilitation strategies on the urban scale. However, they are pointless without institutional structure, administrative decisions, and proper related governing laws and regulations. Stream rehabilitation requires an integrated and holistic approach from several professions working together including ecologists, hydrologists, landscape architects, community members, biologists, construction contractors and local managers. However, presently, several administrative bodies are involved in the management of water resources and each of them have different goals that cause a conflict of interest. Since there is a need for collaboration and information sharing among the administrative bodies, it is essential that all of these organisations and professions should be working together towards the common goal of recovering Arap Stream and its surroundings.

Table 4.2 demonstrates urban-scale strategies that need to be adopted in the long term to minimise human impact on stream ecosystems.

Table 4.2. Urban-Scale Rehabilitation Strategies

Urban Planning Strategies
• Citywide planning efforts should approach the urban streams at watershed scale. • Not only urban streams but also other natural resources should be considered as a single interrelated system at watershed scale. • Particular land uses, which cause pollution from agricultural, industrial, and municipal sources, should be limited within watershed areas. • Watershed areas need to be planned as low-density development. • City planners need to consider the hydrologic regime of urban streams, the ecological needs of wildlife habitats, and features of watersheds. • Construction within floodplains needs to be restricted. • Fragmentation of natural water systems by infrastructure should be minimised. • Urban streams should be considered as urban corridors with their greenways. Correspondingly, numerous riverfront parks should be planned. • Riverfront developments need to be planned with a water-centric approach which preserves the ecological integrity of natural water resources. In this sense, floodplains should be preserved while simultaneously enhancing riparian vegetation.

(cont. on next page)

Table 4.2. (cont.)

• Riverfronts should provide recreational uses as well as physical and visual connections to urban streams. • Riverfronts need to be planned as part of nature, which evoke their districts' character and history.
Governance and Regulation
• Citywide sustainable water resource management should be adopted. • All urban streams connected to the İzmir Bay should be ecologically rehabilitated with the aim of reconnecting inhabitants to their lost nature. • As watershed area extends out of the city limit, collaborative rehabilitation attempts should be undertaken among relevant organisations. • Long term rehabilitation management and maintenance plans should be developed. • Local planning ordinances and state laws should preserve riparian buffers through development regulations (Otto, McCormick, & Leccese, 2004). • Wastewater should not be combined with stormwater and should not discharge into the İzmir Bay through urban streams. In this regard, all wastewater of İzmir needs to be collected by the Large Canal with the goal of treatment. • Floodplain violations through administrative decisions should be eliminated. • Only clean or cleansed water should be carried through urban streams for urban health. Therefore, bioengineering techniques and natural cleansing systems should be installed in the watershed areas of İzmir. • Setback distance between watercourses and proposed new developments should be determined considering minimum 100-year floodplains with the aim of preventing floods and preserving natural habitats. • A various range of stakeholders and community members need to be included in rehabilitation processes to identify restrictions and opportunities. • Not only environmental education should be conducted in educational facilities, environmental seminars should be held to raise awareness of ecology also.
Stream Engineering Strategies
• Soft engineering techniques, also known as nature-based solutions, should replace conventional hard engineering techniques on streams. • Sustainable infrastructure and stormwater master plans should be prepared for the entire city of İzmir. • Rather than artificial canals, new meandering stream courses, which closely resemble their original shapes, should be considered. • A stormwater master plan of the study area should be coherent with the city's stormwater strategies.

4.3.2. District-Scale Rehabilitation

District-scale rehabilitation offers some strategies which can be applied in the catchment area of Arap Stream in the long term, in order to recover its ecosystem that has been damaged, degraded, and partly destroyed because of human interference. These strategies can be used to develop a master plan for addressing the route of the new stream channel, land use near Arap Stream and other issues listed in Table 4.3.

Table 4.3. District-Scale Rehabilitation Strategies

Socioeconomics and Land Use
• 550 hectares of urban area in İzmir are planned as a new city centre for 2030. Therefore, the study area with the industrial site remains as a transition zone between the existing and planned city centres. However, there is no land use change in the transition zone according to projected master plans. Therefore, a new land use plan, which is also compatible with the history and character of the district as well as the new city centre, should be considered. • Concerning creating a greenway and riverfront parks along Arap Stream, new plans need to be developed to guide land use decisions along the riverfront. • The industrial use should be relocated from the wetland area near Arap Stream to move out of the city. • Rehabilitation of Arap Stream should not only aim for ecological restoration but also should consider local businesses in the district.
Sociocultural Structure
• The Halkapınar area was once a wetland offering a range of recreational activities and freshwater resource until the middle of the 20th century, but it has lost its characteristics and identity after a significant degree of construction in the district. Therefore, it needs to be rehabilitated to re-connect the city's past to its present by re-constructing the wetland area and collective memory of inhabitants. • Since community life of the district is isolated from the city, the social structure needs to be renovated with the goal of providing social and cultural opportunities.
Ecological Structure
• Even though this study is concerned with the open air part of Arap Stream, passing from the industrial site and its surroundings, it is essential to approach Arap Stream at the catchment level. Therefore, the rest of Arap Stream should be unearthed in the concept of daylighting by rediscovering the stream and its riparian habitat. • As Arap Stream passes through a heavily urbanised area, green retrofitting the built environment in the basin as a cost-effective strategy towards sustainable development should be considered not only to improve air and water quality but also to reduce demand on grey infrastructure. • Green corridors should be linked along Arap Stream in its watershed as a recreational amenity. • Green infrastructure does not only aim to create green networks, but also to build blue networks, regarding water bodies. Therefore, a water system network should be established at catchment level for stormwater management. In this sense, urban ponds and lakes need to be formed with the Meles River, Arap Stream, and Manda Stream, especially in the Meles Delta where urban streams can naturally be filtered through plants and soil to remove pollutants before discharging into the bay. • A sustainable stormwater and wastewater management plan, associated with the stream, should be designed for the whole catchment area of Arap Stream to create an urban drainage hotspot by installing sustainable landscape infrastructure. • Impervious surfaces of hardscape in the catchment area should be reduced to control stormwater runoff, and also to decrease the urban heat island effect. In this regard, the total length and width of residential streets should be reduced to the minimum needed. • Parking lot design should be based on urban green space structure throughout the Arap Stream basin. • Detention measures such as rainwater cisterns, ponds and constructed wetlands should be considered in the catchment area to filter stormwater.

4.3.3. Neighbourhood-Scale Rehabilitation

Neighbourhood-scale rehabilitation offers innovative techniques that can be implemented practically within the floodplain of Arap Stream in the short term. To be able to reclaim the ecological sustainability of Arap Stream, primarily urban-scale and district-scale rehabilitation strategies should be adopted. Otherwise, short term rehabilitation strategies only aim to improve the ecological status of Arap Stream within its floodplain and to partially recover wetland characteristics.

In this context, green infrastructure and in-stream techniques can be design guidelines that provide social, economic, and environmental benefits. A number of approaches to solving the problem which concerns Arap Stream and its surroundings are listed in Table 4.4.

Table 4.4. Neighbourhood-Scale Rehabilitation Strategies

Urban Design
• The open part of Arap Stream with its immediate surroundings should be designed as a riverfront park which provides natural drainage for the district. • Some buildings in the floodplain of Arap Stream and public facilities, like Solid Waste Agency, in the place where Diana's Baths and the lost lake once existed, should be removed. • The presence of the industrial heritage next to Arap Stream should be involved in the revitalization process of the district that serves to transform abandoned brownfields into ecological and socially appealing urban landscapes. • The new design of Arap Stream and its surroundings should consider the social, cultural and economic needs of the district. In this regard, the Halkapınar Transportation Hub welcomes thousands of people every day. It needs not only a recreational park where visitors can breathe in the fresh air near the stream but also a learning laboratory where people of all ages can experience wetland ecology. • Arap Stream is frequently fragmented by multiple road crossings. A continuous pathway system passing through riparian zones should be developed to create a safer place for pedestrians and cyclists. • An Environmental Centre of İzmir, including enclosed buildings, can benefit the community, provide an experience-based learning environment, and serve multiple purposes such as research laboratories and classrooms. • The community should be connected to Arap Stream and its riparian buffer in allowed locations for recreational use such as wading, sitting on the banks, fishing, and so on.

(cont. on next page)

Table 4.4. (cont.)

In-Stream Techniques
• The existing concrete channel should be transformed into a naturalised stream. Instead of flowing in a straight line, a new meandering stream bed should be created that allows Arap Stream to flow naturally. • Since the concrete embankment along Arap Stream harms the environment, new spaces on the edges of Arap Stream should be designed for drainage and recreation. • As Arap Stream, channelized into concrete ditches, poses a risk to community safety, it should be restored by providing lateral and vertical connectivity. Arap Stream needs access to its floodplain, for the reason that water bodies can rise dramatically within a few hours in the case of heavy rain. In this sense, vertical connectivity would work efficiently between the groundwater and atmosphere. Therefore, a new channel with permeable surfaces would work more efficiently in its floodplain rather than be restricted into the stream bed. • In-stream rehabilitation techniques, such as log structures, rocks, gabions, channel re-meandering and gravel additions, which are already presented in Chapter 2, ought to be applied for Arap Stream. • Since Arap Stream is polluted by industrial wastewater despite the Large Canal Project, it is essential to improve the water and soil quality within the floodplain of Arap Stream through natural cleansing and bioengineering systems, also known as bioremediation and phytoremediation techniques. • Ripraps should be naturalised through planting live stakes of willows, and simultaneously using geotextile fabrics to prevent erosion. • A riparian buffer should be created with native vegetation. In this regard, existing vegetation should be preserved and enhanced. However, invasive species should be removed. • Low growing plants characterised by aquatic species should be included in the floodplain zone while trees and shrubs are in the riparian margin.
Green Infrastructure Techniques
• Constructed wetlands that provide natural treatment and infiltration should be designed to highlight the significance of the site’s history and characteristics. Concerning filtering stormwater, numerous rain gardens, bioswales and green roofs should be considered. • A greenway should be designed that connects the ecological assets of the district for each other along the course of Arap Stream. • Vegetated spaces should be maximised, while simultaneously minimising impervious surfaces. In this sense, only permeable pavements such as porous concrete, pervious asphalt, and porous interlocking paving should be used in the surroundings of Arap Stream. • Appropriate plants and organic materials like dead brushes, or tree stumps, should be used to provide bank stabilisation of Arap Stream. • Tree choices must be made in accordance with the land use. While the surroundings of the Halkapınar Transportation Hub are appropriate for a recreational site that may have a sustainable and aesthetically appealing urban landscape where the species can be planted in groupings, the district, where Arap Stream and the Meles River meet needs more drought-tolerant plants since highways surround it.

4.4. The Rehabilitation Proposal of Arap Stream

Considering all these above, this section aims to present a rehabilitation project for Arap Stream and its surroundings. One of the main goals of the project is to reflect on how to approach Arap Stream and its surroundings rather than determining the exact location and size of the proposed elements since it can be designed effectively in many ways. Therefore, it aims to show how the natural resources of Halkapınar, which have been influenced and devastated by human effects, could be saved again. It is important to note that this project presumably offered strategies for the city which will adopt sustainable water management policy.

As discussed earlier, Arap Stream, polluted by industrial wastewater, flows into İzmir Bay after its confluence with the Meles River. To rehabilitate Arap Stream and its surroundings, some objectives of the project based on green infrastructure criteria of different researchers (Abrahams, 2010) are listed in Table 4.5. Accordingly, a rehabilitation project, which reflects on these objectives and criteria, will be presented in the following section.

Table 4.5. Arap Stream Rehabilitation Objectives

Criteria	Arap Stream Rehabilitation Objectives
Ecosystem Services	• Water pollution treatment • Regulation of the hydrological regime
Environmental quality & aesthetics	• Improved aesthetics and amenity values
Natural solutions to technical problems	• Prevention of floods • Low-cost maintenance with its self-regenerating landscape • Runoff reduction from impervious surfaces and provision of sustainable urban drainage
Awareness of the history of the city	• Reconnection of the community with their lost nature • Provision of a historical focus and positive contribution to the collective memory of İzmir
City structure	• Pedestrian-friendly public space • Revitalised riverfront properties within a water-centric planning approach • Separation of stormwater and wastewater
Recreation	• Recreational and educational opportunities through a riverfront park

(cont. on next page)

Table 4.5. (cont.)

Integration of the city with nature	• A new meandering stream channel contained within a broad floodplain • Enriched human interaction with nature
Maintains integrity of habitats	• Enhancement of the district's biodiversity

Regarding the green space concept, it is significant to link green corridors along the stream to the Meles Delta as an ecological and recreational amenity as well as an economic development strategy. Since the Meles Delta is only reserved for urban greening, it is essential to extend the current wetland systems to the delta with the aim of integrating bioengineering techniques (Kaplan, Velibeyoğlu, Kılıçaslan, Özeren, & İnce, 2013). Green infrastructure techniques help to enhance the habitat and biodiversity of the area, as well as revitalising the district. Therefore, the project proposes a wide riparian zone instead of concrete blocks on the banks of Arap Stream in order to decrease the risk of flood. Also, Arap Stream needs to interact with people rather than be covered up. Instead of being hidden by concrete walls and culverts, wildlife refuges near Arap Stream are proposed, not only to offer recreational opportunities to the community but also to become buffer zones in case of heavy rains.

The surroundings of Arap Stream are divided into three zones regarding its historical and spatial features (Figure 4.48). The first zone, called Zone I, is the place where Diana's Baths existed in the past, but it is replaced by public facilities that do not offer much to the community in terms of ecosystem goods and services. As a result of a significant number of constructions in the district, it lost its wetland characteristics. Therefore, it is proposed that it should be a recreational site with constructed wetlands and bioswales to regain its historical identity. Also, it is proposed to move the industrial area - between the two significant centres - out of the city. While some of the new areas are offered as both commercial and mixed-use development, the rest is involved in the urban park. The second zone, next to the metro transfer and bus stations is known as a transportation hub, hosting many people every day. Accordingly, it needs to be welcoming and accessible to everyone with its amenities. The third zone, next to an abandoned industrial site, is surrounded by elevated highways where Arap Stream also meets the Meles River. This brownfield area will be turned into a knowledge hub that interacts with both the Meles River and Arap Stream.

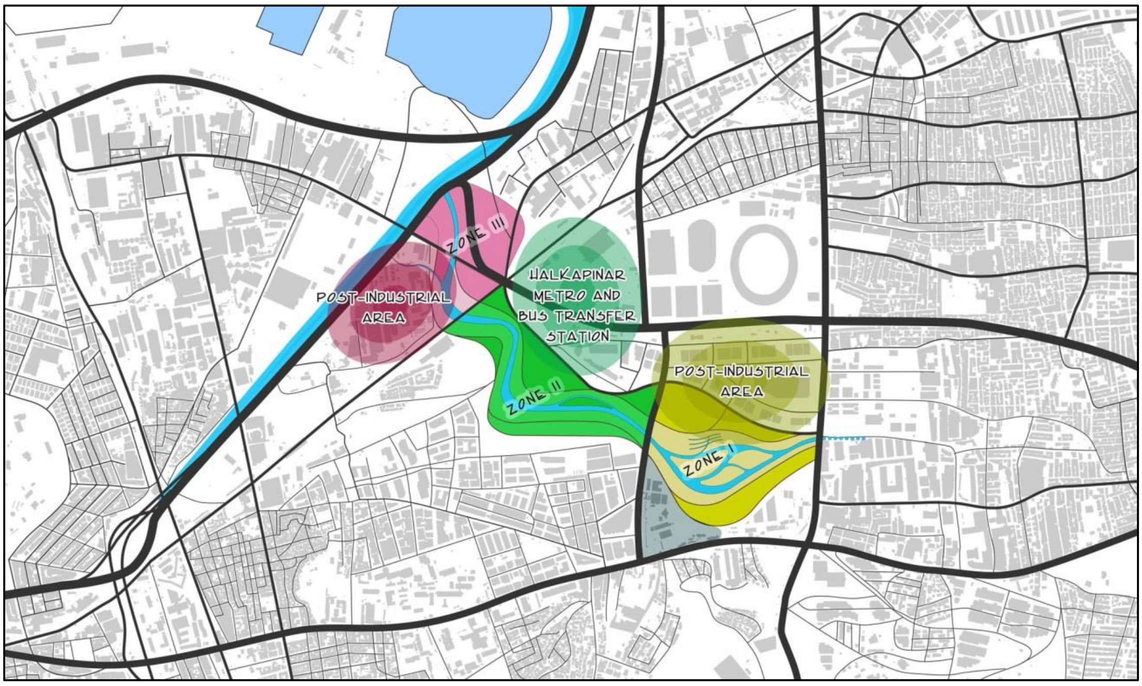

Figure 4.48. Location of three zones in İzmir city centre

In the past, during the construction of the stadium and other blocks near Arap Stream, some techniques were implemented to dry out the wetlands in Halkapınar. In spite of all attempts, Halkapınar still has rich groundwater resources (İZSU, 2001). Zone I, therefore, is re-designed with constructed wetlands, bioswales and bio-retention areas with the purpose of highlighting its distinguishing feature. Retrofitting existing buildings and their surroundings is offered for both the commercial and mixed-use development area. Permeable pavements such as pervious concrete, permeable asphalt, and porous interlocking pavement are integrated into the surroundings of Arap Stream. A green network along the stream is established to manage stormwater sustainably. Zone I offers recreational opportunities for the community following its ecological restoration.

The project approaches Zone II as a recreational wetland that visitors can enjoy since it welcomes thousands of people every day. It offers several recreational activities for amusement, enjoyment and pleasure. The presence of a big urban park in a transitional zone would bring social, economic, health and environmental benefits to İzmir and its people. In this context, Arap Stream and its surroundings would be one of the focal points of İzmir with its appealing urban landscape.

Zone III next to İzmir Harbour includes an urban brownfield embracing a rich industrial heritage. One of the tributaries of Arap Stream is redirected to flow through the site of an abandoned factory, Tekel, which is more accessible for pedestrians and cyclists. Thus, it is offered as the starting point to enter the site rather than the district surrounded by elevated highways. Since an old flour mill, built in 1908, is considered one of the landmarks of the district, it is being restored for new use by the İzmir Metropolitan Municipality. Also, this zone includes another wetland near the facilities of the Turkish State Railways. Therefore, the project in Zone III covers all these sites for a revitalization plan with a focus on the relation of water bodies and the brownfield.

While the current situation of Arap Stream is illustrated in Figures 4.49 and 4.50, proposed approaches are depicted in Figures 4.51 and 4.52 that present a concept stormwater plan for Arap Stream and its surroundings. Moreover, the detail of phytoremediation technique, which is one of the main keys of the rehabilitation process, is presented in Figure 4.53.

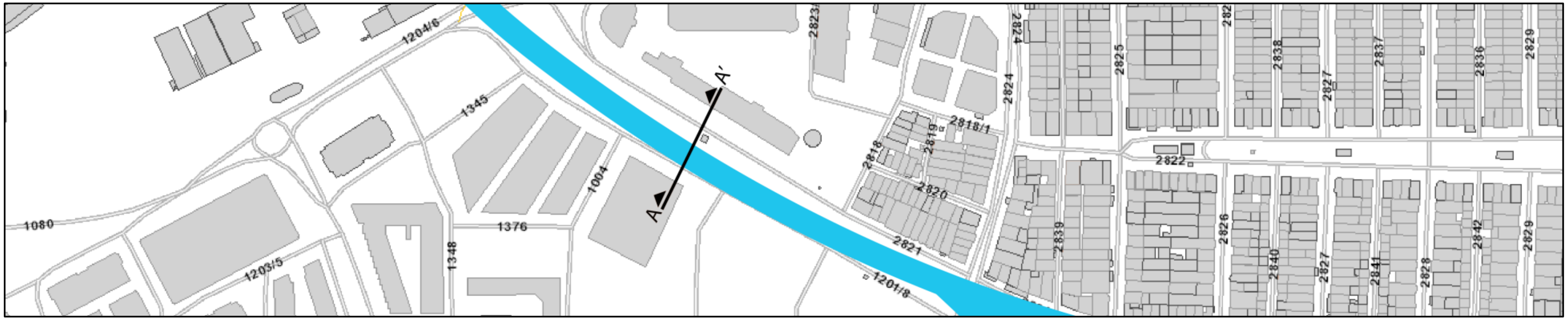

Figure 4.49. The current site of Arap Stream

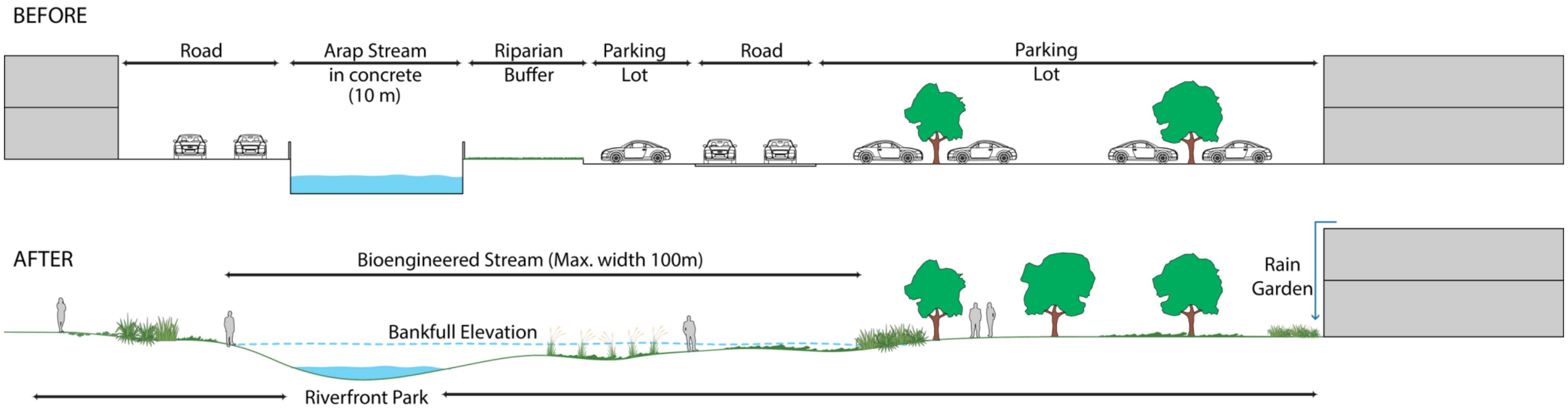

Figure 4.50. Existing and proposed site cross-sections (Sections A-A')

Figure 4.51. Concept plan of the case study

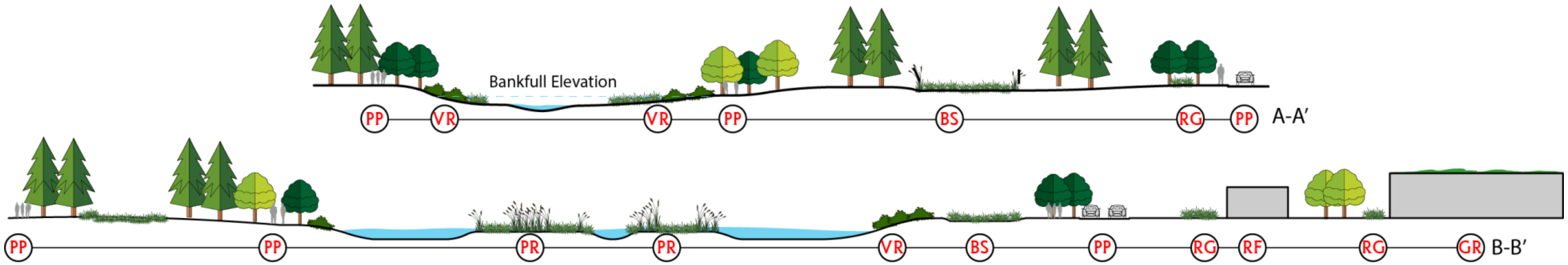

Figure 4.52. A-A’ and B-B’ Sections

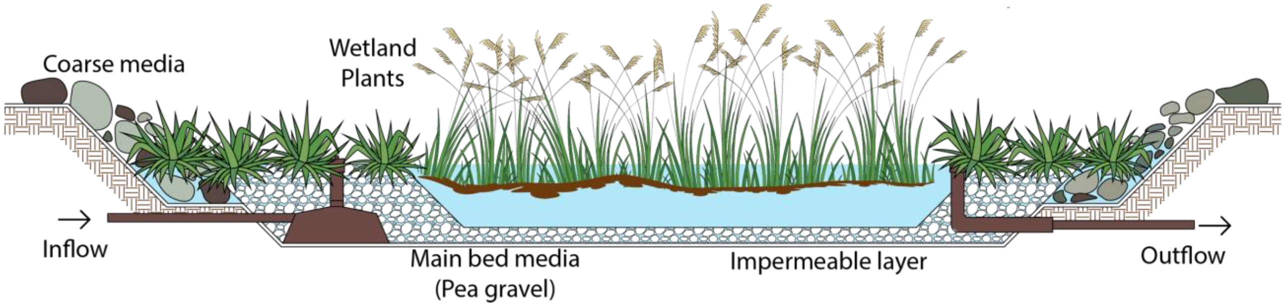

Figure 4.53. Phytoremediation technique for cleaner water

Several green infrastructure and stormwater techniques are proposed based on the characteristic of each zone. Table 4.6 demonstrates three zones in the matrix, showing additional techniques.

Table 4.6. Additional techniques in zones

Techniques	ZONE I	ZONE II	ZONE III
Bioswale	X	X	X
Green roof	X	X	X
Porous Pavement	X	X	X
Phytoremediation	X	X	
Green retrofit	X	X	X
Rain garden	X	X	X
Vegetated riprap	X	X	X
Water reservoir	X		

Even though the transformation of a brownfield is not in the scope of this study, it is involved in the process of the revitalization of the district in the proposed Arap Stream rehabilitation project. As seen in municipal planning and design projects, urban brownfields in the district are almost neglected. Therefore, these places as an ecological entity need to be merged with a green infrastructure framework (Kaplan et al., 2013). For that reason, the post-industrial area in Zone 3 is turned into a knowledge hub, where inhabitants can share their insights and gain a deeper understanding of wetland ecosystems, by using abandoned buildings and creating a centre between water systems.

Figure 4.54 depicts the existing situation of the brownfield in Zone III. The old flour mill, marked as the landmark, has been converted into the City College by the Municipality to bring some institutions and community together for improving the projects and ideas. The existing Halkapınar Square next to the old flour mill is re-designed within a larger area to attract more people. The rest of the buildings between Arap Stream and the Meles River are rehabilitated in the concept of a knowledge hub. In addition to all these approaches, sustainable stormwater techniques for Zone III are illustrated in Figure 4.55.

Figure 4.54. Existing situation in Zone III
(Source: Google Earth)

Figure 4.55. A proposed knowledge hub in Zone III

The proposed rehabilitation project includes not only public properties but also contains private properties. Therefore, some private parcels within the border of the project need to be expropriated for public use. Since expropriation is a long and challenging process to handle, it is important to have long term strategies. In this respect, Figure 4.56 is illustrated with the goal of demonstrating the private properties, which needs to be expropriated. While the orange colour shows public ownerships, the grey colour depicts private ownerships. The other two different colour tones show the intersection areas between the ownerships and project.

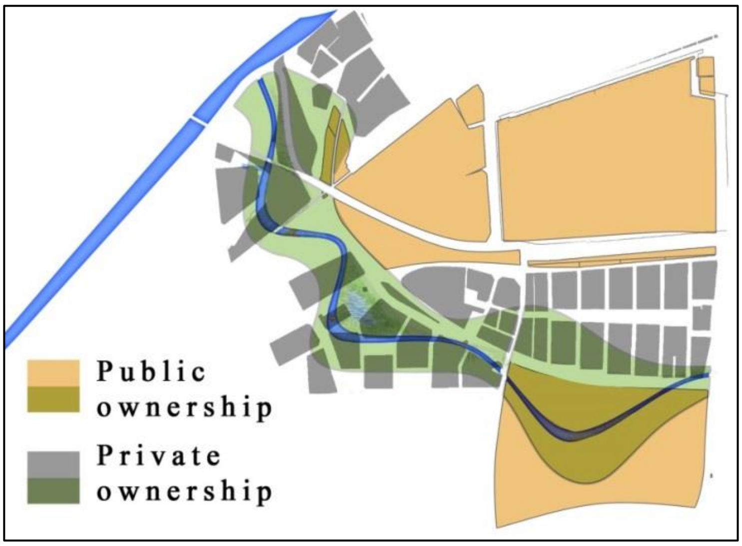

Figure 4.56. An ownership analysis on the proposed project
for Arap Stream and its surrounding

Green retrofit practices should be implemented throughout the watershed of Arap Stream. This approach should be placed not only on sites near the stream but also several locations within the catchment area. Green retrofit practices such as sustainable stormwater infrastructure, including porous surfaces, green streets, green parking, rain gardens, bioswales, and green roofs can simply be implemented into existing landscapes to absorb surface runoff and offer retrofit opportunities. Through these practices, surface water and stormwater can be simply intercepted before they pose threats to the nearby districts or neighbourhoods. However, the ownership issue limits the feasibility of integrated watershed management. Regarding improving quality in private properties, local governments should motivate property owners to install stormwater retrofit projects either voluntarily or mandatorily. Thus, watersheds can easily be transformed into ecologically sensitive landscapes that simultaneously provide urban river health.

Details of the all stormwater infrastructure and in-stream techniques that have already been proposed in the rehabilitation of Arap Stream are illustrated in Figures

4.57 to 4.61. In this regard, these techniques are drawn considering Arap Stream and its habitat; therefore, these systems can be used in several locations throughout the watershed of Arap Stream.

Figure 4.57 illustrates the existing channel, which currently has 2m depth and is 10m wide, and the proposed channel with vegetated riprap that allows vegetation to grow on rocks. Gabion baskets, also known as wire meshes, provide not only slope stabilisation but also observation terraces to connect the community with Arap Stream.

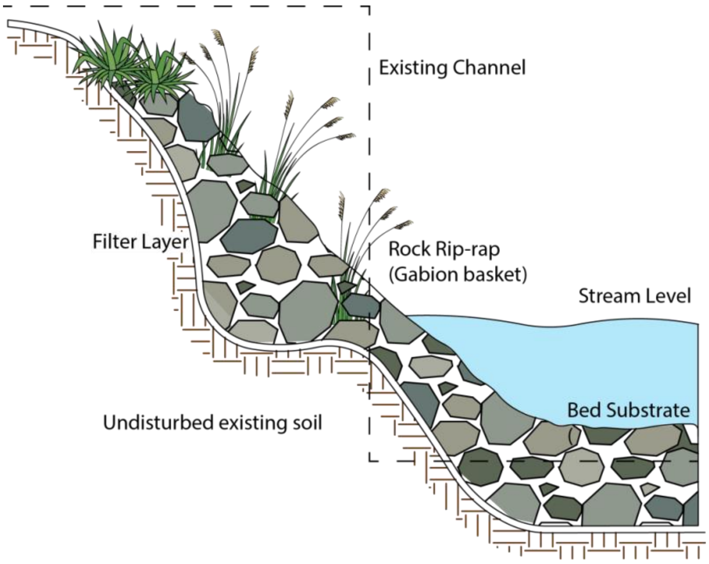

Figure 4.57. Proposed channel with the vegetated riprap

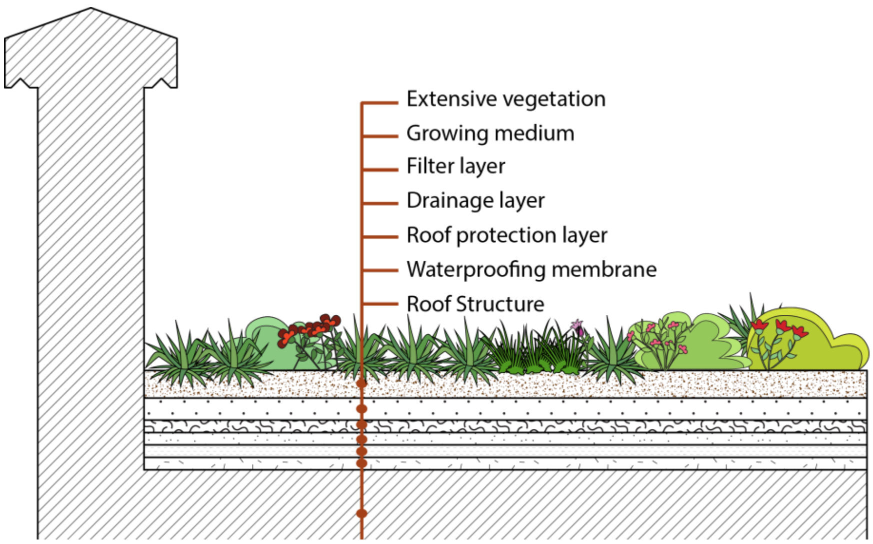

Figure 4.58. Proposed green roof

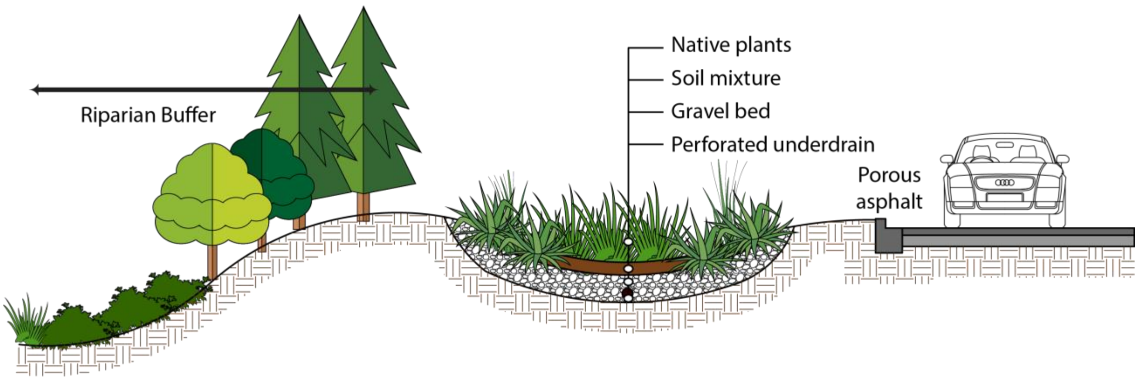

Figure 4.59. Proposed bioswale

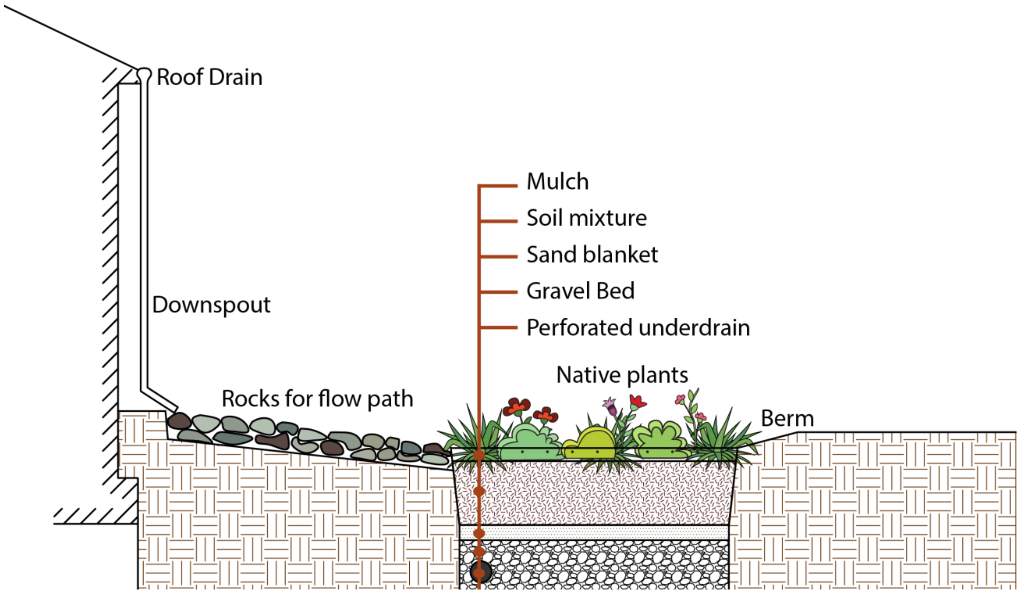

Figure 4.60. Proposed rain garden

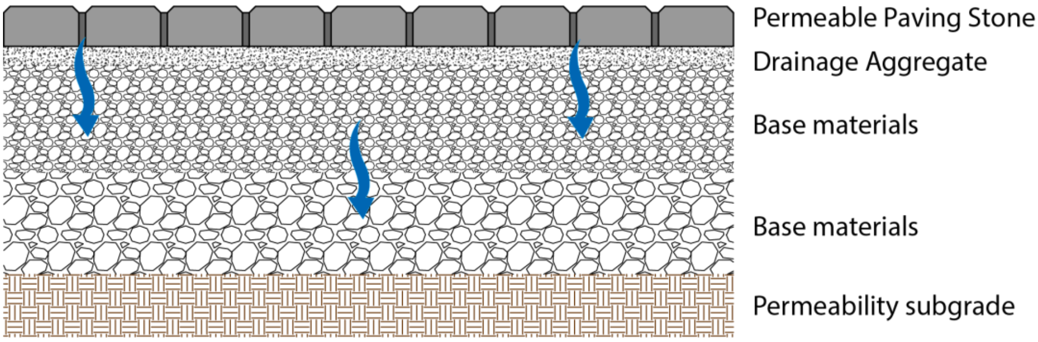

Figure 4.61. Porous Pavement System

CHAPTER 5

CONCLUSION

Green infrastructure as a holistic and integrated framework suggests the achievement of stream rehabilitation. This study has presented an evaluative perspective on stream rehabilitation and was conducted in an urban setting through sampling various practices and introducing the case study, Arap Stream and its surroundings.

The study sets out to promote innovative approaches, such as green infrastructure and in-stream rehabilitation techniques, particularly in a case study in İzmir to guide future stream rehabilitation practices and to reclaim lost assets of İzmir inhabitants. To answer the main research question of the study, “How can urban streams, which have been dramatically altered by human intervention, be rehabilitated by using innovative approaches such as green infrastructure and in-stream techniques?”, all of these techniques are introduced and illustrated throughout the study.

This chapter mainly concludes all findings from the research obtained in the three main groups as follows: theoretical literature findings, best practice findings, and the case study findings. The first group primarily outlines a rehabilitation framework for urban streams through ecologically-based approaches. The second group evidences ecological, social and economic outputs of the rehabilitation projects, which have already been carried out. Lastly, the case study findings reveal not only what Arap Stream needs but also what constraints hinder the feasibility of the project.

Theoretical literature: The conventional approach on urban streams has been replaced by green solutions in various countries. Stream rehabilitation endeavours are often carried out in watershed areas. However, reconstructing natural attributes of streams in highly altered urban centres is almost impossible due to some constraints, such as financial and ownership issues. Therefore, the objective of stream rehabilitation should be minimising human impacts on the environment, while simultaneously developing long-run plans. In this regard, green infrastructure offers an agenda for future connections of projects. To rehabilitate urban streams ecologically, not only should in-stream and sustainable stormwater techniques be installed into urban streams and their immediate surroundings, but it is also essential to spread an ecological virus outward from the urban corridors (i.e. streams and greenways). In this sense, greenways should connect nearby neighbourhoods to each other with the aim of providing healthier riverfronts which enable stream ecosystems to function successfully.

Moreover, sustainable stormwater practices have an important place in the stream rehabilitation process. In this sense, surface runoff is intercepted by riparian corridors or retention practices like constructed wetlands. Therefore, sustainable green infrastructure should be considered in suitable sites throughout the watersheds of urban streams. Also, green infrastructure retrofitting enables the expansion of practices such as green streets, rain gardens, porous surfaces, green parking, green roofs, and bioswales. In various countries, some local governments encourage the community to become part of rehabilitation projects. In this manner, sustainable stormwater techniques can be installed into private properties, and rehabilitation on a watershed-scale can be partially achieved through the inclusion of communities.

Best practices: As already discussed, these projects are considered as some of the best rehabilitation practices due to their contributions. According to the monitoring results of best practices, which was represented in Chapter 3, these projects brought significant ecological, social and economic benefits to the communities. In this sense, a significant improvement in landscape performance of the selected best practices has been observed. Many neglected landscapes have been transformed into self-regenerating urban landscapes with two major principles: low-maintenance and high-performance. This resulted in a reduction in air pollution, urban heat island effect, and noise level; and an increase in biodiversity, fresh and healthy air, and quality of soil and water.

With regard to economic benefits, these rehabilitation projects save millions of US dollars in comparison with conventional rehabilitation techniques. A large portion of water is purified due to these innovative techniques, and this dramatically decreases the cost of irrigation and filtration. Moreover, rehabilitation projects converted troubled riverfronts into points of attraction. Since thousands of local and foreign tourists visit these sites, they contribute to the local economy, generate employment, and revitalise the districts by integrating the economic value of rehabilitation.

What is more, according to rehabilitation reports of best practices, social interaction has considerably improved in rehabilitated riverfronts. Various events and festivals are organised in these places. Also, stream ecosystems offer people of all ages outdoor discovery opportunities. For that reason, it can be said that these places not only function ecologically but also serve as economic and social centres.

Case Study: A large tract of Arap Stream and its surroundings has been altered by the end of the twentieth century due to urban development and human interference on nature. Therefore, all pros and cons of Arap Stream are already listed in the site analysis of Chapter 4. This study presents a rehabilitation guideline for Arap Stream by using outcomes from theoretical literature, best practice, and site analysis of the case study. In this sense, urban-scale, district-scale, and neighbourhood-scale rehabilitation strategies are developed to be adopted in long term or short term.

Even though the research approaches Arap Stream at watershed-level, more focus is placed on district-scale and neighbourhood-scale approaches due to some restraints, which limited the study to work on a large scale. Realising primary principles of stream rehabilitation in heavily urbanised areas requires a large amount of financial support and a radical modification in urban morphology. To put this plan into practice, the local government need to deal with a long expropriation process. Despite watershed strategies of the research regarding Arap Stream, organisational and urban patterns of İzmir decrease the feasibility of the integrated project. Therefore, short term ecological measures, which are more applicable, are highlighted in the proposed rehabilitation project to mimic nature.

On the other hand, in Turkey, stream rehabilitation is only charged by the General Directorate of State Hydraulic Works, whose perception is simply based on hard engineering solutions. Therefore, concrete stream beds and embankment walls are the typical features of all urban streams in İzmir. Also, some land uses, which are caused by faulty spatial perceptions, like industrial and municipal sites in watersheds, are not appropriate for healthy riverfronts, since they contaminate urban streams and their environs. Regarding another problem of governance, urban streams are seen as corridors, which connect neighbourhoods to each other. Accordingly, they are used as wastewater carriers due to the lack of infrastructure. Unless the current perception on urban streams is changed in Turkey, this rehabilitation project cannot achieve any success.

The surroundings of Arap Stream contain many private properties. To mitigate the effect of the ownership problem, the research offers some ways forward. As with the project of Seoul - Cheonggyecheon Stream Project - rehabilitation measures should be taken in public lands along Arap Stream to lessen adverse effects. Therefore, neighbourhood-scale strategies, which can be applied in the short term, are placed in Chapter 4. However, just as with the Mill River Park Project, it is also essential to prepare long term strategies to expand green corridors to the city centre. In this sense, it is important to develop private-public partnerships, which can fund the park.

Moreover, the district of Halkapınar experienced damaging flooding in its history. In relation to the creation of an urban drainage hotspot, it is essential to design low-maintenance and high-performance landscapes near the stream. In this regard, the community should be a part of the rehabilitation project. Also, local government should promote sustainable infrastructure. Accordingly, some meetings should be organised to bring the community together, and to discuss the advantages and disadvantages of the project. In certain sites, which urgently need a recovery, green infrastructure retrofitting application should be mandatory. All of these measures can increase environmental awareness in the district while solving the stormwater problem on the local scale.

To generate sustainable policies and practices concerning stream rehabilitation, there is an urgent need for more collaboration and an integrated rehabilitation framework at the city level to allow further assessment of urban streams in İzmir. In this research, there are a set of gaps that need to be filled, due to some constraints which have been stated previously. Therefore, further studies will reconstruct new perspectives to Arap Stream (Figure 5.1).

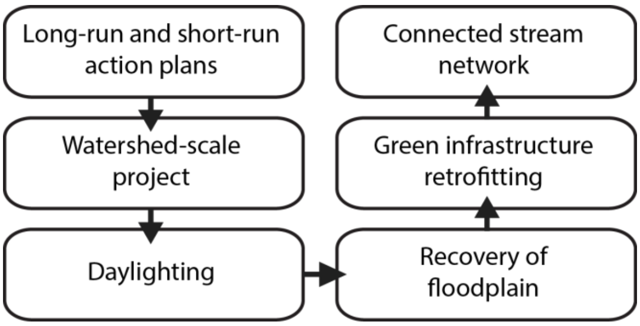

Figure 5.1. Further studies

In this regard, initially, short-run and long-run action plans should be studied in collaboration with stakeholders, community members and agencies. Short-run actions should be carried out once funding is available. Also, private funding should be considered with the aim of increasing the possibility of long-run actions. Then, watershed areas of Arap Stream should be studied based on sustainable water management. Stormwater infrastructure practices should be projected for the entire watershed of Arap Stream. According to new plan and policies, the rest of Arap Stream should be uncovered and be functioning ecologically. Not only should hydraulic calculations of Arap Stream be determined, so also should 100-year and 500-year floodplain limits. Accordingly, some buildings in the floodplain should be removed. Moreover, green retrofitting projects should be designed for the surroundings of Arap Stream. In this regard, certain sites should be determined, and landowners should be encouraged. Last but most certainly not least, the Meles River, Meles Delta and Manda Stream also need to be studied. Thus, the district can be transformed into an ecologically functioning whole.

REFERENCES

Aadland, L. P. (2010). Reconnecting Rivers: Natural Channel Design in Dam Removal and Fish Passage. *Minnesota Department of Natural Resources Division of Ecological Resources Stream Habitat Program.*

Abrahams, P. M. (2010). *Stakeholders Perceptions of pedestrian accessibility to green infrastructure: Forth Worth's urban Villages*. *Landscape Architecture*. The University Of Texas At Arlington.

Ahern, J. (1995). Greenways as a planning strategy. *Landscape and Urban Planning*. Landscape and Urban Planning 33. http://doi.org/10.1016/0169-2046(95)02039-V

Allan, J. D. (1996). Stream Ecology: Structure and Function of Running Waters, *77*(6). http://doi.org/10.2307/2265800

APİKAM. (2015a). *Islah çalışmaları öncesi Meles Deltası'nın durumunu gösteren hava fotoğrafı*. İzmir: İzmir Büyükşehir Belediyesi Basın ve Yayın ve Halkla İlişiler Müdürlüğü.

APİKAM. (2015b). *Meles Deltasını Kuşatan Ulaşım Ağı*. İzmir: İzmir Büyükşehir Belediyesi Basın ve Yayın ve Halkla İlişiler Müdürlüğü.

Arnold, C. L., & Gibbons, C. J. (1996). Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association, 62*(2), 243–258. http://doi.org/10.1080/01944369608975688

Asia Minor Coins. (2009). Ancient Greek and Roman coins from Asia Minor. Retrieved January 4, 2016, from http://www.asiaminorcoins.com/gallery/displayimage.php?album=139&pid=5904

ASLA. (2006). Peeling Back the Surface. Retrieved May 2, 2016, from https://www.asla.org/lamag/lam06/april/feature3.html

ASLA. (2009). ChonGae Canal Source Point Park: Sunken Stone Garden, Seoul, Korea. Retrieved February 1, 2015, from https://www.asla.org/2009awards/091.html

ASLA. (2010). Shanghai Houtan Park: Landscape as a Living System. Retrieved April 2, 2016, from https://www.asla.org/2010awards/006.html

ASLA. (2015). Mill River Park and Greenway. Retrieved February 1, 2016, from https://www.asla.org/2015awards/95842.html

ASLA. (2016). Designing Our Future : Sustainable Landscapes, Mount Tabor Middle School Rain Garden. Retrieved February 22, 2016, from https://www.asla.org/sustainablelandscapes/raingarden.html

Atay, Ç. (1998). *Osmanlı'dan Cumhuriyet'e İzmir Planları*. İzmir: Yaşar Eğitim ve Kültür Vakfı.

Atış, İ. (2009). İzmir'in Gelecekteki Su Kaynakları. In *TMMOB İzmir Kent Sempozyumu* (p. 315). İzmir. Retrieved from http://www.tmmobizmir.org/wp-content/uploads/2014/05/200828.pdf

Beyru, R. (2011). *19. Yüzyılda İzmir Kenti*. İzmir: Literatür Yayıncılık.

Bocarejo, J. P., LeCompte, M. C., & Zhou, J. (2012). Case Study: Cheonggyecheon, Seoul, South Korea. In *the Life and Death of Urban Highways* (p. 27). Institute for Transportation & Development Policy and EMBARQ. Retrieved from http://www.wrirosscities.org/sites/default/files/Life-Death-Urban-Highways-EMBARQ.pdf

Boulton, A. J. (2007). Hyporheic rehabilitation in rivers: Restoring vertical connectivity. *Freshwater Biology*. http://doi.org/10.1111/j.1365-2427.2006.01710.x

Brinson, M. M. (1993). A Hydrogeomorphic Classification for Wetlands. *Wetlands Research Programm Technical Report WRP-DE-4*, *WRP-DE-4*(August), 101. http://doi.org/10.2134/agronj2001.931131x

Busch, E. L. (2012). *From Brownfield to Greenfield: A Social and Environmental Remediation Project*. Ball State University. Retrieved from https://core.ac.uk/download/files/209/5014222.pdf

Cadoux, C. J. (1938). *Ancient Smyrna: A History of the City From the Earliest Times to 324 A.D.* Oxford: Blackwell. Retrieved from http://digital.library.stonybrook.edu/cdm/ref/collection/amar/id/123934

Calder, W. A. (1906). Smyrna as Described by the Orator Aelius Aristides. In *Studies in the history and art of the eastern provinces of the Roman Empire* (p. 110). Scotland: Aberdeen University Press.

Center For Middle Eastern Strategic Studies. (2011). *Constructed Wetlands and Re-use of Waste Water for the Irrigation in Turkey and Israel*. Ankara: Orsam. Retrieved from http://www.orsam.org.tr/eski/tr/trUploads/Yazilar/Dosyalar/2011127_orsam_reportt_78_tr.pdf

Center for Watershed Protection. (2010). Green Infrastructure Practices. In *New York State Stormwater Management Design Manual* (pp. 1–116). Ellicott City, MD 21043. Retrieved from http://www.dec.ny.gov/docs/water_pdf/swdm2010entire.pdf

Collins. (2008). *Collins concise English dictionary. 175 Years Of Dictionary Publishing*. HarperCollins Publishers.

Cooke, S. S. (1997). *A field guide to the common wetland plants of western Washington & northwestern Oregon*. Seattle, Washington: Seattle Audubon Society.

Droguett, B. R. (2011). *Sustainability Assessment of Green Infrastructure Practices for Stormwater Management: A Comparative Emergy Analysis*. State University of New York. Retrieved from http://gradworks.umi.com/15/00/1500785.html

Erskine, W. D. (2005). Stream Classification. *Water Encyclopedia*, (Figure 1), 217–250. http://doi.org/10.1002/047147844X.sw966

Farassati, A. (2007). A project report: Las Virgenes Creek Restoration Project. Retrieved from http://www.cityofcalabasas.com/environmental/las-virgenes-creek-restoration-project.html

Farina. (2006). Methods in landscape ecology. In *Principles and methods in landscape ecology* (pp. 313–391). Retrieved from http://link.springer.com/chapter/10.1007/978-1-4020-5535-5_8

Fidanoğlu, İ. (2014). Once upon a time in İzmir. *İzmir Culture & Tourism Magazine*, 75–81.

Fischenich, J. C., & Allen, H. (2000). *Stream Management*. Vicksburg: US Army Corps of Engineers. Retrieved from http://www.engr.colostate.edu/~bbledsoe/CIVE413/Stream_Management.pdf

Forman, R. T. T. (1995). *Land Mosaics*. *The Ecology of Landscapes and Regions*. Cambridge: Cambridge University Press.

General Directorate of State Hydraulic Works. (2000). DSİ Teknik Bülten, (94), 33. Retrieved from http://www2.dsi.gov.tr/kutuphane/dsi_teknik_bulten/94.pdf

Güney, A. (2011). Onarım Tekniği. In *Unpublished Lecture Note*. İzmir: Ege University, Landscape Architecture Department.

Interagency Workgroup on Wetland Restoration. (2003). An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement. *Environmental Protection*, 1–102.

İzmir Metropolitan Municipality. (2016). İzmir 2030 Yeni Kent Merkezi Bayraklı. Retrieved January 1, 2016, from https://www.izmir.bel.tr/HaberDetay/16018/tr

İZSU. (2001). 2001 Yılı Faaliyet Raporu. Retrieved February 2, 2016, from https://www.izmir.bel.tr/Dokumanlar/350/tr

İZSU. (2015). Kanalizasyon Şebekesi. Retrieved February 2, 2015, from http://www.izsu.gov.tr/Pages/standartPage.aspx?id=199

İZSU. (2016a). İzmir Tarihi Su Yapılarının Restorasyonu. Retrieved March 1, 2016, from http://www.izsu.gov.tr/Pages/simplepage.aspx?page=13

İZSU. (2016b). Kent Merkezindeki Büyük Dereler. Retrieved January 1, 2016, from http://www.izsu.gov.tr/Pages/standartPage.aspx?id=205

Jansson, R., Nilsson, C., & Malmqvist, B. (2007). Restoring freshwater ecosystems in riverine landscapes: The roles of connectivity and recovery processes. *Freshwater Biology*. http://doi.org/10.1111/j.1365-2427.2007.01737.x

Kamalludin, B., Hishammudin, M. A., Sipan, I., & Nurlaila, A. (2014). A Review on for Green Infrastructure to be Adopted by Local Authorities. *International Journal of Public Policy and Administration Research*, *1*(1), 1–11.

Kambites, C., & Owen, S. (2006). Renewed prospects for green infrastructure planning in the UK. *Planning Practice and Research*, *21*(4), 483–496. http://doi.org/10.1080/02697450601173413

Kaplan, A. (2012). “Green Infrastructure” Concept as an Effective Medium to Manipulating Sustainable Urban Development. In O. Y. Ercoskun (Ed.), *Green and Ecological Technologies for Urban Planning: Creating Smart Cities* (pp. 234–254). Gazi University: IGI Global. http://doi.org/10.4018/978-1-61350-453-6.ch013

Kaplan, A., Velibeyoğlu, K., Kılıçaslan, Ç., Özeren, M., & İnce, İ. (2013). Revisiting Urban Brownfield Regeneration and Beyond within the Lens of Green Infrastructure-based Design and Management. In Fábos, M. Lindhult, R. Ryan, & M. Jacknin (Eds.), *Proceedings of Fábos Conference on Landscape and Greenway Planning 2013: Pathways to Sustainability* (pp. 109–117). Amherst: University of Massachusetts.

Karadaş, A. (2014). Holocene Palaeogeographies and Coastline Changes of the Bornova Plain. *Aegean Geographical Journal*, *23*(2), 37–52.

Kılıçaslan, Ç. (2004). Akarsuların Kentsel Gelişme Dönüşüm Süreci İçinde Çeşitli Kullanımlar Yönünden Etkileşimlerinin İzmir Kenti Örneğinde Ortaya Konulması. In *Unpublished doctoral thesis* (pp. 97–102). İzmir: Ege University.

Kivaisi, A. K. (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: A review. *Ecological Engineering*, *16*(4), 545–560. http://doi.org/10.1016/S0925-8574(00)00113-0

Koçman, A. (1991). İzmir’in Kentsel Gelişimini Etkileyen Doğal Çevre Faktörleri ve Bunlara İlişkin Sorunlar. *Coğrafya Araştırmaları Dergisi*, *3*, 102. Retrieved from http://tucaum.ankara.edu.tr/wp-content/uploads/sites/280/2015/08/cadata3_7.pdf

Kondolf, G. M., Boulton, A. J., O'Daniel, S., Poole, G. C., Rahel, F. J., Stanley, E. H., … Nakamura, K. (2006). Process-based ecological river restoration: Visualizing three-dimensional connectivity and dynamic vectors to recover lost linkages. *Ecology and Society*, *11*(2). http://doi.org/5

Kovar, P. (2013). River Restoration. In *Class Lecture for Course*. Prague: Czech University of Life Sciences Prague.

Kömüşçü, A. Ü., Erkan, A., & Çelik, S. (1998). Analysis of meteorological and terrain features leading to the İzmir flash flood, 3-4 November 1995. *Natural Hazards*, *18*(1), 1–25. http://doi.org/10.1023/A:1008078920113

Kuusisto, E. (1996). Hydrological Measurements. *Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes*. Retrieved from http://www.who.int/water_sanitation_health/resourcesquality/wqmchap12.pdf

Landezine. (2012). Bishan Park. Retrieved June 1, 2016, from http://www.landezine.com/index.php/2012/06/kallang-river-at-bishan-ang-mo-kio-park-by-atelier-dreiseitl/

Landezine. (2014). A Restorative Landscape for Stamford. Retrieved June 1, 2016, from http://www.landezine.com/index.php/2014/01/mill-river-park-and-greenway-by-olin/

Landscape Architecture Foundation. (2010). Cheonggyecheon Stream Restoration Project. Retrieved March 1, 2015, from http://landscapeperformance.org/case-study-briefs/cheonggyecheon-stream-restoration

Landscape Architecture Foundation. (2013). Shanghai Houtan Park. Retrieved January 3, 2016, from http://landscapeperformance.org/case-study-briefs/shanghai-houtan-park

Landscape Performance. (2014). Tianjin Qiaoyuan Park: The Adaptation Palettes. Retrieved February 2, 2015, from http://landscapeperformance.org/case-study-briefs/tianjin-qiaoyuan-park-the-adaptation-palettes

Landscape Voice. (2012). Tanner Springs Park. Retrieved from http://landscapevoice.com/tanner-springs-park/

Levantine Heritage Foundation. (n.d.). Old Maps of Smyrna. Retrieved February 2, 2016, from http://www.levantineheritage.com/data8a.htm

Levantine Heritage Foundation. (2011). Flood. Retrieved from http://www.levantineheritage.com/flood.htm

Levantine Heritage Foundation. (2015). Water works. Retrieved January 5, 2016, from http://www.levantineheritage.com/waterworks.htm

Liu, J., & Taylor, W. W. (2002). *Integrating Landscape Ecology into Natural Resource Management*. *Science*. http://doi.org/10.1017/CBO9780511613654

Macrides, R. J. (1978). *A Translation and Historical Commentary of Georpe Akropotes History*. King's College London. Retrieved from https://kclpure.kcl.ac.uk/portal/files/2932523/DX187399.pdf

Malay, H. (2010). Smyrna, Meles ve Halkapinar. In G. Gokcay (Ed.), *DR. Eren AKÇİÇEK'E Armağan* (p. 134). İzmir. Retrieved from http://yesilova.ege.edu.tr/arsiv/Eren_Akcicek_Armagan yesilova.pdf

Matlock, M. D., & Morgan, R. A. (2011a). Green Infrastructure Design. In *Ecological Engineering Design: Restoring and Conserving Ecosystem Services* (pp. 267–282). New Jersey: John Wiley & Sons, Inc. http://doi.org/10.1002/9780470949993

Matlock, M. D., & Morgan, R. A. (2011b). Stream Restoration Design. In *Ecological Engineering Design: Restoring and Conserving Ecosystem Services* (pp. 222–243). New Jersey: John Wiley & Sons, Inc.

McDonald, L. A., William, L. A., Benedict, M., & Keith, O. (2005). Green Infrastructure Plan Evaluation Frameworks. *Journal of Conservation Planning*, *1*(1), 6–25. Retrieved from http://www.journalconsplanning.org/2005/volume1/issue1/allen/manuscript.pdf

Mell, I. C. (2010). *Green infrastructure : concepts , perceptions and its use in spatial planning*. Newcastle University. Retrieved from https://theses.ncl.ac.uk/dspace/bitstream/10443/914/1/Mell10.pdf

Metropolis Policy Transfer. (2015). Seoul Urban Renewal: Cheonggyecheon Stream Restoration. Retrieved from http://policytransfer.metropolis.org/case-studies/seoul-urban-renewal-cheonggyecheon-stream-restoration.pdf

Meybeck, M., Friedrich, G., Thomas, R., & Chapman, D. (1996). Chapter 6 - Rivers. *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring*, *5*.

Mikyoung Kim Design. (2009). ChonGae Canal Restoration. Retrieved from http://myk-d.com/projects/chongae-canal-restoration/

Moerke, A. H., Gerard, K. J., Latimore, J. A., Hellenthal, R. A., & Lamberti, G. A. (2004). Restoration of an Indiana, USA, stream: bridging the gap between basic and applied lotic ecology. *Journal of the North American Benthological Society*. http://doi.org/10.1899/0887-3593(2004)023<0647:ROAIUS>2.0.CO;2

Olin Partnership. (2007). Mill River Park & Greenway Master Plan Master Plan for Mill River Park & Greenway in Stamford. Retrieved from https://issuu.com/niarhodesjackson/docs/mill_river_masterplan_final_111109

Ortiz, J. D., & Merseburger, G. (2009). Restoration, Rehabilitation and Gardening in Mediterranean Stream Ecosystem. In P. George & O. Thomas (Eds.), *Ecological Restoration*. Nova Science Publishers.

Otto, B., McCormick, K., & Leccese, M. (2004). Ecological riverfront design: Restoring rivers, connecting communities. *APA Planning Advisory Service Reports*, (518-519), 1–170.

Özeren, M., & Kaplan, A. (2013). Yeşil Altyapı Sistemi Kapsamında Meles Deltası ve Çevresinin Kurgulanması. In *Peyzaj Mimarlığı 5. Kongresi Bildiriler Kitabı* (pp. 278–290). Adana.

Pasi, N., & Smardon, R. (2011). *Urban and Rural Treatment Wetlands Manual*. Retrieved from http://efc.syr.edu/wp-content/uploads/2015/03/Wetlands_Final-WebOptimized.pdf

Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. *Annual Review of Ecological Systems*, *32*, 333–365. http://doi.org/10.1146/annurev.ecolsys.32.081501.114040

Pinkham, R. (2000). Daylighting: New Life for Buried Streams. Rocky Mountain Institute. Retrieved from https://www.downtowndevelopment.com/pdf/W00-32_Daylighting.pdf

Prominski, M., Stokman, A., Zeller, S., Stimberg, D., & Voermanek, H. (2012). *River.Space.Design Planning Strategies, Methods and Projects for Urban Rivers*. Berlin: Birkhäuser.

Rahel, F. J. (2007). Biogeographic barriers, connectivity and homogenization of freshwater faunas: It's a small world after all. *Freshwater Biology*. http://doi.org/10.1111/j.1365-2427.2006.01708.x

Ramboll Group. (2010). Tanner Springs Park. Retrieved April 2, 2015, from http://www.ramboll.com/projects/germany/tanner-springs-park

Ramboll Group. (2012). Bishan Ang Mo Kio Park. Retrieved March 1, 2016, from http://www.ramboll.com/projects/singapore/bishan-park

Ramsar Convention Secretariat. (2006). The Ramsar Convention Manual: A guide to the Convention on Wetlands (Ramsar, Iran, 1971). *Ramsar Convention Secretatriat, Gland, Switzerland, 4th Editio*.

Randolph, J. (2011). *Environmental land use planning and management*. Washington, DC: Island Press.

Reimold, R. J. (1998). Watersheds-an Introduction. In Robert J. Reimold (Ed.), *Watershed Management, Practice, Policies, and Coordination* (pp. 1–5).

Republic of Turkey Ministry of Culture and Tourism. (2016). The Poet Homeros and the Meles River. Retrieved January 2, 2016, from http://www.kultur.gov.tr/EN,34494/the-poet-homeros-and-the-meles-river.html

Roni, P., & Beechie, T. (2012). Introduction to Restoration: Key Steps for Designing Effective Programs and Projects. In P. Roni & T. Beechie (Eds.), *Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats* (pp. 1–8). Chichester, UK: John Wiley & Sons, Ltd. http://doi.org/10.1002/9781118406618

Roni, P., Pess, G., Hanson, K., & Pearsons, M. (2012). Selecting Appropriate Stream and Watershed Restoration Techniques. In P. Roni & T. Beechie (Eds.), *Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats*. Chichester, UK: John Wiley & Sons, Ltd.

Rosgen, D. L. (1994). A classification of natural rivers. *Catena*. Elsevier B.V. http://doi.org/10.1016/0341-8162(94)90001-9

Rouquette, J. R., Posthumus, H., Morris, J., Hess, T. M., Dawson, Q. L., & Gowing, D. J. G. (2011). Synergies and trade-offs in the management of lowland rural floodplains: an ecosystem services approach. *Hydrological Sciences Journal*, *56*(8), 1566–1581. http://doi.org/10.1080/02626667.2011.629785

Sandström, U. G. (2002). Green Infrastructure Planning in Urban Sweden. *Planning Practice and Research*. http://doi.org/10.1080/02697450216356

Saygıdeğer, S. (1996). Lemna gibba l. ve Lemna minor l., (Lemnacea)'nin Morfolojik Anatomik, Ekolojik ve Fizyolojik Özellikleri. *Ekoloji Çevre Dergisi*, *Ocak-Şubat*(18), 8–11.

Saygın, N., & Ulusoy, P. (2011). Stormwater Management and Green Infrastructure Techniques for Sustainable Campus Design Sürdürülebilir Kampüs Tasarımı için Yağmursuyu Yönetimi ve Yeşil Altyapı Teknikleri. *Journal of Polytechnic*, *14*(3), 223–231.

Senville, W. (2013). A Tale of Three Parks. Retrieved May 1, 2016, from http://plannersweb.com/2013/08/a-tale-of-three-parks/

Seoul Development Institute. (2006). *Monitoring study of Cheonggyecheon Restoration Project*. Retrieved from http://worldcongress2006.iclei.org/uploads/media/K_LEEInKeun_Seoul_-

_River_Project.pdf

Shannon, K., & Yiyong, C. (2013). (Recovering) China's urban rivers as public space. *Footprint*, (12), 27–44. Retrieved from http://footprint.tudelft.nl/index.php/footprint/article/view/760

Sivil ve Ekolojik Haklar Derneği. (2016). Sakarya Bıçkı Deresi. Retrieved April 4, 2016, from http://www.suhakki.org/wp-content/uploads/2014/11/sakarya-akyaz%C4%B1-kiral%C4%B1k-dere

Smardon, R. C. (1989). Human Perception of Utilization of Wetlands for Waste Assimilation, or How Do You Make a Silk Purse Out of a Sows Ear. *Constructed Wetlands for Wastewater Treatment*, 287–295.

Springate-Baginski, O., Allen, D., & Darwall, W. (2009). *An integrated wetland assessment toolkit. A guide to good practice*. Retrieved from https://portals.iucn.org/library/efiles/edocs/2009-015.pdf

Standop, E. (1988). *Collins COBUILD English language dictionary*. *System* (Vol. 16). http://doi.org/10.1016/0346-251X(88)90082-6

Şimşek, G. (2011). *An Approach to Urban River Rehabilitation for Coexistence of River and its Respective City: Porsuk River Case and City of Eskişehir*. Middle East Technical University. Retrieved from http://etd.lib.metu.edu.tr/upload/12613339/index.pdf

Teclaff, L. A. (1987). Evolution of the River Basin Concept in National and International Water. *Natural Resources Journal*, *36*, 77–78. Retrieved from http://lawschool.unm.edu/nrj/volumes/36/2/07_teclaff_basin.pdf

Tockner, K., Lorang, M. S., & Stanford, J. A. (2010). River flood plains are model ecosystems to test general hydrogeomorphic and ecological concepts. *River Research and Applications*, *26*(1), 76–86. http://doi.org/10.1002/rra.1328

Trice, A. (2013). Daylighting Streams: Breathing Life into Urban Streams and Communities, 23. Retrieved from http://www.americanrivers.org/assets/pdfs/reports-and-publications/daylighting-streams-report.pdf

Turenscape. (2008). Tianjin Qiaoyuan Wetland Park. Retrieved October 4, 2015, from http://www.turenscape.com/english/projects/project.php?id=339

Turenscape. (2010). The Red Folding Paper in the Greenway. Retrieved February 3, 2015, from http://www.turenscape.com/english/projects/project.php?id=4554

Türer Başkaya, F. A. (2013). Urban stream enhancement - Revisiting urban streams of Istanbul. *A/Z ITU Journal of the Faculty of Architecture*, *10*(2), 148–160.

U.S. Geological Survey. (2013a). Geographic Names of Individual U.S. States. Retrieved May 30, 2015, from http://geonames.usgs.gov/domestic/faqs.htm

U.S. Geological Survey. (2013b). How urbanization affects the hydrologic system. Retrieved May 2, 2015, from http://ga.water.usgs.gov/edu/urbaneffects.html

USEPA. (1998). Stream Corridor Structure. *Watershed Academy Web*, 1–49. Retrieved from http://www.epa.gov/watertrain

USEPA. (2014a). Bioretention (Rain Gardens). Retrieved April 5, 2015, from https://www.epa.gov/soakuptherain/rain-gardens

USEPA. (2014b). What is green infrastructure? Retrieved March 2, 2015, from http://water.epa.gov/infrastructure/greeninfrastructure/

Uysal, A. B. (2005). *A Method For Sustainable Development In A River Basin: Game Theory*. İstanbul Technical University. Retrieved from https://polen.itu.edu.tr/bitstream/11527/8108/1/4501.pdf

Vought, L. B. M., & Lacoursiere, J. O. (2010). Restoration of streams in the agricultural landscape. In M. Eiseltova (Ed.), *Restoration of Lakes, Streams, Floodplains and Bogs in Europe* (pp. 225–243). Prague: Environment and Wetland Centre Public Association. http://doi.org/10.1007/978-90-481-9265-6

Walter, R., & Alberto, C. (2001). *Lakes and Reservoirs The Watershed: Water from the Mountains into the Sea*. (W. D. Williams, Ed.). Retrieved from http://www.ilec.or.jp/en/wp/wp-content/uploads/2013/03/Vol.21.pdf

Wang, H., Zhang, H., & Cai, G. (2011). An application of phytoremediation to river pollution remediation. *Procedia Environmental Sciences*, *10*(PART C), 1904–1907. http://doi.org/10.1016/j.proenv.2011.09.298

West, M. L. (1999). The Invention of Homer. *The Classical Quarterly*, *49*(2), 364–382. http://doi.org/10.2307/639863

Wise, S., Braden, J., Ghalayini, D., Grant, J., Kloss, C., MacMullan, E., … Yu, C. (2010). Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits. *Low Impact Development 2010: Redefining Water in the City*, 1–18. http://doi.org/10.1061/41099(367)98

Woodcock, T. S., & Huryn, A. D. (2007). The response of macroinvertebrate production to a pollution gradient in a headwater stream. *Freshwater Biology*, *52*(1), 177–196. http://doi.org/10.1111/j.1365-2427.2006.01676.x

World Weather and Climate Information. (2015). Average Weather in Izmir, Turkey. Retrieved December 21, 2015, from https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Izmir,Turkey

Yu, K. (2011). Landscape as a Living System: Shanghai 2010 Expo Houtan Park. In *Applied Urban Ecology: A Global Framework* (pp. 186–192). http://doi.org/10.1002/9781444345025.ch14

Yu, K. (2015). City Green: Landscape As a Living System Shanghai 2010 Expo Houtan Park. Retrieved May 1, 2016, from http://www.turenscape.com/english/news/view.php?id=327

Yurtseven, E., & Çakmak, B. (2007). Tarımsal atık suların sulamada yeniden kullanılması. *Türkiye Ziraat Mühendisliği VII. Teknik Kongresi*. Ankara: Özdoğan Matbaa Yayın Hed. Eşya San. Tic. Ltd. Şti. Retrieved from http://www.zmo.org.tr/resimler/ekler/4e299e28c5847ef_ek.pdf