The Relationship between Policy, Program, and Implementation in Sustainable Urban Water Management

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Dedication

This thesis is dedicated to my beloved parents, Soodabeh and Bagher, who assisted me without any expectations, in all stages of my life.

Abstract

This thesis examines the relationship between the policies, programs, and implementation in facing today's urban water issues. Our current way of life has resulted in separation of the built environment from the nature and degradation of natural processes. In addition, climate change phenomenon adversely affects local water cycles. In order to ensure our continuous existence on this planet we have to rethink our approach toward urban water. I have investigated how some pioneering cities are addressing their current urban water issues by sustainably managing their surface waters and by bringing the natural balance back to local hydrological systems. I also have exploited their strong and weak points. After that, I have categorized the urban water issues based on their source of creation, extracted some common connections and disconnections (gaps) between policies, programs, and implementations, and discussed the role of these gaps in functionality and efficiency of municipalities' approaches. This is followed by a framework to fill out these gaps between policies, programs, and implementation.

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1. Introduction

Within the past decades, water has been increasingly recognized as a limited and precious resource. Some of the most detrimental factors contributing the present day water crisis are its overuse, continued pollution and the change in natural water cycle. Moreover, the effects of climate change will further aggravate the water crisis. Finally, current urbanization policies are altering the urban water cycles, and hence, increasing pollution, changing groundwater level and destroying habitat. These conventional developments and city planning result in urban runoff phenomena and manipulated water streams inside the boundaries of cities [1].

The emergence of this water crisis has forced cities in some areas of the world to rethink their approach to urban water. In order to create workable solutions that combine “blue and green” strategies to make cities livable and sustainable, we should consider the approach of the integration of urban and natural systems. This combined approach allows us to move past the current unsustainable practices and insufficient preservation policies [2]. I argue that one of the most effective ways to achieve this approach is by managing stormwater runoff in a sustainable manner.

Rain water that becomes stormwater is now being used as an important source of water in cities. Recent research has shown that this approach has a lot of environmental, social and urban benefits. Stormwater should no longer be considered as a dire consequence of urban landscape that has to be removed from cities as fast as possible [3]. However, there currently are not sufficient or effective strategies for urban designers and policy makers to create reasonable solutions to use stormwater as an urban resource.

Holistic sustainable stormwater management can be essentially seen in three major parts; creation of the “Policy”, development of the appropriate “Design response” and ensuring proper “Implementation” to meet the policy goals. Currently, there are gaps and disconnects between these three parts. In other words, there are disagreements between the concerns of policy makers; planners; designers; developers; and the public. The question I will address is how to convince all of these stakeholders to give up the conventional relationships between policy, program, and design, and come up with creative and effective alternatives for better blue and green cities.

In my thesis, I will attempt to find answers to critical questions of: what are the current urban water issues and in what ways they are different from conventional water issues? Why should we rethink our approach toward water in urban environment? Why our conventional approach cannot guarantee our current and future urban living? What opportunities sustainable stormwater management creates for municipalities? Is it possible to create an urban habitat in which urban environment and nature integrate? How can municipalities help their residents to help them back in dealing with current water issues? And most importantly, how we can create an integrated system of policies, programs, and implementation to achieve water sustainability in cities?

My thesis is composed of three main chapters. In the first chapter, I will examine the current trends in sustainable stormwater management. In order to do so I will present eight case studies about cities from different parts of the world to compare and contrast their policy, design and implementation strategies. Sustainable approaches can be seen both as a cultural and technical process, which differ from country to country, and city to city. The aim of these case studies will be to analyze the connection between policy, design and implementation of stormwater management systems by studying strengths and weaknesses of each city's program.

In Europe, I studied three pioneer cities in sustainable urban water practices. Firstly, the historical story of the City of Berlin and its cultural background is studied to find out how it achieved a closed water cycle and self-sufficiency [4]. Secondly, the unique challenges of the City of Rotterdam in dealing with sever climate change effects is studied [5]. And finally, the city of Malmo's adaption of one of Berlin's programs is studied [6]. I also chose to study Australia, due to its vulnerability to climate change and recent decade-long drought which has become the main driver of national change. Within Australia, Melbourne and Sydney were chosen, because although there are similarities between their policies' targets, their programs and the method of implementation of these programs are different [7], [8]. In the USA, I chose three cities, Portland [9], Seattle [10], and Austin [11].

In the second chapter, I will analyze the importance of connections between policy, design and implementation and to address the interconnected challenges of sustainable urban water management. I observed connections and disconnects between policy, program and implementation in the case studies to develop an understanding of how to create strong bonding between the urban water policies, programs and implementation phases.

Moreover, I will develop an informative framework as a matrix which includes three major parts; Policy making guidelines, Program Design guidelines, and the Implementation of the programs guidelines. These three components ensure that cities can utilize a sustainable, effective, and realistic approach to urban water management. Additionally, the components of the proposed framework are flexible enough to be applied to cities with different water issues, climates, social compositions, and vulnerability of climate change. The framework's aim is to achieve a closed/sustainable urban water cycle in cities by addressing the major issues of overuse, pollution, and changes in natural water cycle, as well as to mitigate the effects of climate change. Addressing these issues will reveal the importance of altering our conventional methodologies toward water management in favor of sustainable approaches.

In the last chapter, I will assay the proposed framework by applying it to the case of Minneapolis, MN. The City of Minneapolis is currently facing challenging water issues in a relatively complex geological, hydrological, and social context [12]. For this purpose, I will investigate how this framework can improve the existing relationships of policy, program, design and implementation within an existing city wishing to create sustainable water strategies for their future development.

2. Case Studies

2.1. Berlin

Berlin has been one of the first cities that have a sustainable approach toward urban water management. The isolation of West Berlin created a situation whereby half of the city was reliant on water resources within its administrative boundaries. This forced the City to adopt a closed water cycle approach. Today, the City of Berlin has implemented an integrated urban runoff management, and it is known as a forerunner for its innovative and holistic urban water management.

Berlin has been chosen as a case study because of its self-sufficiency in water supply and its outstanding achievements in many different aspects of managing urban water, including demand management initiatives, stormwater infiltration and the construction of green roofs. In this section, I will present the story of Berlin to demonstrate the development of an integrated approach to urban water management.

2.1.1. Background and Major Issues

During the Cold War era, Berlin was divided into two physically separated nations. As a result, West Berlin was surrounded on all sides by East Germany. Hence, West Berlin was reliant on water resources from within its administrative boundaries. This situation revealed the true value of water to the City of West Berlin and forced it to develop a closed water cycle. In order to achieve a closed water cycle, demand for potable water had to be reduced and innovative methods of water provision had to be developed [1].

In addition to the historical scarcity of water in Berlin, the activities of environmentally conscious citizens plays a key role in shaping Berlin's current approach toward urban sustainability. These activities started in 1970s by forming an urban greening campaign [2]. Consequently, Berlin is in exemplar with its pioneering green infrastructure [3].

Berlin is located in a relatively dry area of Germany with an annual precipitation of 24 inches. The rivers Spree and Havel flow through Berlin. Moreover, Berlin is surrounded with a chain of slow flowing lakes. As these rivers and lakes are slow-flowing, they are not sources for potable water. The soil in Berlin consists of sand gravel, till, and clay and provides good quality groundwater. Therefore, the water utility in Berlin, Berlin Wasserbetriebe (BWB) relies exclusively on groundwater for its water supply operations. The raw water is extracted from depths of between 30 and 170 meters through 800 deep wells and is then transported to the waterworks [4].

Berlin's city centre is characterized by high density development. This development pattern influences environmental conditions, resulting in a high degree of soil sealing, inadequate replenishment of groundwater due to the rapid runoff of rainfall into the sewage system, lack of humidity and the resultant urban heat island effect, and biodiversity pressures due to inadequate green space cover [5].

The quality of water in Berlin exceeds the requirements of the German drinking water ordinance. However, repeated fish kills have been observed in the Spree and Havel in Berlin after heavy rainfall events. The reason is treatment plants discharge the excessive sewer to the water bodies without any pre-treatment. This untreated stormwater contains pollutants such as nitrates, heavy metal and hydrocarbons washed away from impervious roads and pavements which is a considerable threat to the ecology of the rivers. This excessive amount of sewer mostly comes from the inner city of Berlin where the mixed sewer networks were built during the 1950s [6].

Berlin has a unique administrative condition. It is the capital city of Germany and one of its 16 federal states. The Senate acts as the main authority for the City as a whole which is divided into different administrative departments. The reunification of Germany reinstated Berlin as the country's capital. The city also received considerable financial support for the reunification. This opportunity provided a unique testing ground for innovative ideas to be put into practice in the form of large-scale development projects not only in water management but also in the field of ecological construction [7]. The unique opportunity to develop the vast central area of the city after the reunification of East and West Berlin provided a testing ground for innovative large-scale green infrastructure projects [2].

2.1.2. Policy

Before the fall of The Wall in 1989, the first priority of West Berlin was to reduce its dependency on East. Shouting off the water supplies from East in 1952 revealed that the wells within the city's borders could not meet the demand quantities of the city. After this event, the authorities of West Berlin concentrated on increasing water supply capacity to achieve self-sufficiency. Their solution was extensive forms of groundwater replenishment by bank filtration and rainwater infiltration, reducing pipeline leakages, and reducing domestic water consumption. As a result, the supply capacity was increased by 227% by 1978 [8].

Despite the fall of the Berlin Wall, the city has continued to promote the sustainable use of the city's own resources. In 2000, the Senate passed new legislation which required the city to abstract all is water use within its boundaries and to promote a more responsible and sustainable use of its water resources. This was established to keep the existing supply and treatment infrastructure functioning and also to protect the BWB workers from unemployment [9].

Hence, the city has accumulated considerable expertise in sustainable water solutions, including [10]:

- The extraction of water had to occur within the confines of the city's boundaries;
- The quantity of water used for various purposes needed to be minimized;
- The withdrawal of groundwater had to be proportional to replenishment and recharge;
- The city's water bodies had to be protected from pollution as strictly as possible;
- The treated wastewater was useful for boosting the flow rate in the water bodies; and
- The retention of stormwater was a given in order to complement the limitations of the other resources.

In 2000 the SenGUV - under the Berlin Water Act - introduced the 'rainwater management at source' strategy. The strategy promotes disconnection of rainfall runoff collected by impervious surfaces to urban drainage systems and provides infiltration at source. Two main reasons led to the promotion of this system: first, the increase of rainwater infiltration and, second, the economic benefit associated with reducing infrastructural and operational costs that are linked to treating polluted rainwater at a centralized location [11].

Although the urban greening campaign by city administration intended to improve urban biodiversity and reduce soil sealing in densely populated areas, the campaign indirectly affected the city's water management strategies by improving replenishment of groundwater [2]. By the time the Landscape Program for West Berlin was introduced in 1984, all political parties had developed nature conservation priorities. The main policies of the Landscape Program focus on the protection of nature and wildlife, natural resources, landscape, and recreation areas [2]. The environmental quality goals of the City can be summarized as [12]:

- Safeguarding and improving the microclimate and atmospheric hygiene,

- Safeguarding and developing soil function and water balance,
- Creating and enhancing the quality of plant and animal habitats,
- Improving the residential environment

2.1.3. Design Standards

The policies and Berlin's unique cultural background has resulted into the development of cutting edge programs by the City of Berlin. In this section, I will study these programs.

2.1.3.1 Bank filtration in conjunction with wastewater reclamation

In order to boost the groundwater resources, city administrators in Berlin have extensively applied riverbed/bank filtration in conjunction with wastewater reclamation and artificial aquifer recharge. Riverbank filtration is the process of collecting water from wells or infiltration galleries located near the bank of a river. In this process, the river water is allowed to pass through the riverbed/bank into the aquifer. Thus, the riverbed/bank acts as a natural filter that removes most organic particles and pathogenic microorganisms [13]. Also, treated wastewater is pumped back up-stream to replenish surface water which in turn recharge aquifers and replace the quantity of water withdrawn from the city's groundwater sources [14]. This vast and expensive process is illustrated in Figures 1 & 2.

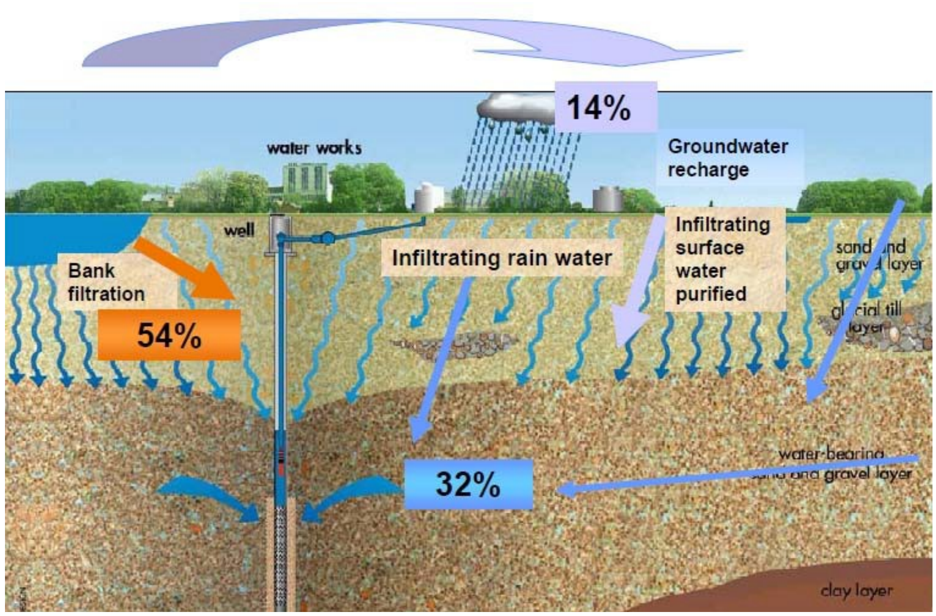

Figure 1 Bank Filtration technique in Berlin [9].

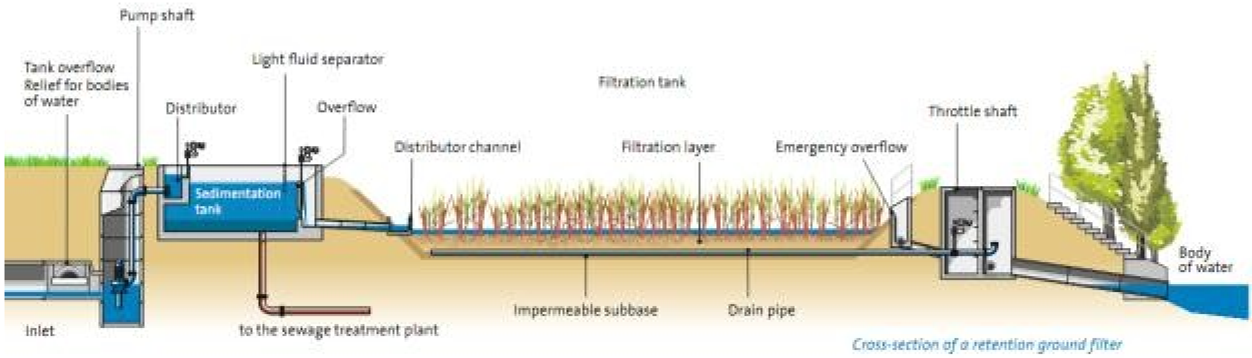

Figure 2 an example of retention ground filters in Berlin [15]

2.1.3.2. Sustainable rainwater management

Sustainable rainwater management for artificial groundwater recharge is an important requisite of water resources management in the Berlin area. The relatively moderate annual precipitation of 24 inches can only support the natural groundwater recharge rate of up to 8 inches, which is not sufficient to maintain groundwater resources for the city. The public water companies have established three groundwater recharge plants in order to increase groundwater quantities. For this purpose, the collected surface water is discharged in the vicinity of groundwater abstraction wells, into shallow earthen basins, ponds, or pits for percolation into the groundwater. By infiltrating rain water the remaining deficit of groundwater is thus attenuated [9].

In recent years, rainwater harvesting, retention and use as service water has become popular in Berlin. Many new commercial centers as well as residential areas in Berlin have installed innovative concepts in stormwater retention and reuse.

2.1.3.3. Biotope Area Factor (BAF)

Originally, the BAF is a part of a larger suite of documents relating to landscape planning, landscape design and species protection. The concerns of the BAF are atmospheric hygiene, soil function and water balance, plant and animal habitat, and residential environment. It also addresses climate changes such as high temperatures and urban flooding [5].

The BAF sets minimum standards for all forms of new development. All potential green areas such as courtyards, roofs and walls are included in this program. It only specifies the targets for developers and not the means. Hence, the developers are provided with a wide range of options for achieving the required standard. The BAF and it success due to internal collaboration and its generation based on sound evidence has lead to global attention and many cities such as Seattle and Malmo are using the outcomes of the BAF to prepare their own GSFs [5].

BAF= Ecologically Effective Surface Areas/ Total Land Area

An "ecological value" is given to each type of surface which has to be applied in the formula. This weighting factor differs from complete 1 for surfaces with vegetation which are connected to the soil below to 0 for the sealed surfaces. For each type of development (e.g. residential units, public facilities, etc.) a BAF target has been proposed and the developments should achieve them by applying a combination of different types of green spaces. Tables-1 and 2 in the appendix depict different ecological values and BAF targets for different types of development projects [5].

2.1.3.4. Green roofs

A green roof is a conventional roof that is covered with a layer of vegetation planted over a waterproofing membrane. Green roofs provide several advantages for buildings, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, increase humidity and helping to lower urban air temperatures and combat the heat island effect [16].

The introduction of green roofs in Berlin formed, along with community gardens and green facades, part of an urban development project which was aimed at increasing the green spaces in high density districts in Berlin [2]. In the 1970s, researchers from the Technical University of Berlin were experimenting with green roofs in the city with respect to an ecological approach. Green roofs provided multiple benefits such as water purification, runoff delay as well as increasing urban biodiversity. It is an approach effective to address a large number of problems in Berlin.

At the same time, there was also a growing demand from the citizens for a more environmentally-friendly standard of living. This motivated the landscape planners in the city administration [7] to follow up on the research made on green roofs and to implement them through the city's urban plans during 1984 to 1994 [2]. The urban development program was aimed at mitigating the following concerns:

- Hydraulic stress on existing stormwater drains.
- Lack of humidity and excess warming of the surrounding areas.
- Decrease of flora and fauna due to inadequate green spaces.
- High degree of soil sealing in densely populated areas.

- Inadequate replenishment of groundwater which resulted from rapid draining of rainfall run-off into the drains.

Through the greening program, approximately 710,000 square feet of green roofs were installed. Berlin's residents received 25 to 60 Euros /m² in subsidies for their investment in green roofs. Direct financial incentives were a common practice throughout from the 1980s until the 1990s. The incentives were gradually reduced and a more voluntary approach to green roofs was adopted as Berlin faced economic deficits. In spite of the reduction in incentives, 14% of all new urban developments in Berlin are installed with green roofs [16].

2.1.3.5. Demand management

The water authorities in West Berlin introduced a water demand management strategy to curb per capita consumption during the 1980s. The demand management strategy mainly focused on the following measures:

- Higher tariffs for water to encourage customers to adopt a more economical use of water.
- Effective publicity campaigns and well-organized public relations and instructions for water saving (in the 1980s first in West Berlin, later in the 1990s in the former Eastern sector of Berlin).
- Temporary subsidies for the purchase and installation of water saving equipment.
- Strong efforts to diminish leakages and losses due to pipe breakages.

As a result of such measures, the overall consciousness of water related-issues in Berlin tangibly improved. In addition, there were also numerous technological innovations implemented in the field of leakage detection in pipes to reduce losses in water supply. The result was that Berlin's pipe breakage rate was dramatically reduced in a span of ten years.

These measures have succeeded in reducing Berlin's per capita water consumption from 66 to 30 gallons/ person/ day. In 2003, the consumption of water for the whole city had dropped by 45% over the previous two decades [17].

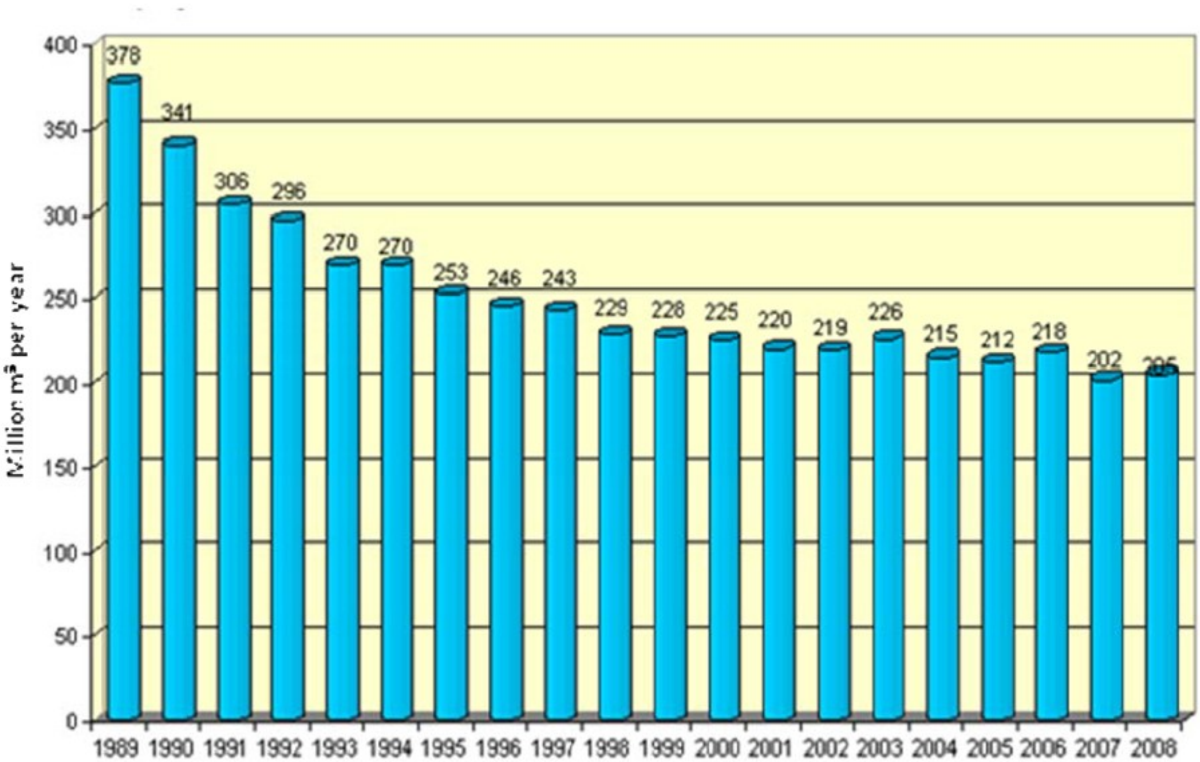

Figure 3 Reduction of water consumption in Berlin [17].

2.1.4. Efficiency of the Design

It is important to mention that although Berlin does not follow a citizen involved approach for their stormwater management planning and decision making, a well developed plan has resulted to one the most successful and meaningful integrations between human and nature.

The key here is the balance they city has made between their demands and water resource exploitations. By the above programs with a Promethean approach, the city discharges more water to the groundwater than it abstracts from. It demonstrates how an integrated human-nature approach works with no pressure on the natural resource. Hence, they have achieved the resilience to ensure future excessive demand for water resources. In addition, Berlin has been successful in water consumption reduction through:

- Modifying citizens' consumption patterns
- Using water efficient fixtures

Moreover, city planners received positive feedback from architects and residents because of the implementation of the BAF, which indicates that the BAF is easy to use. Another positive feature of the BAF is that it allows room for individuality, creativity, and flexibility for designers. In general I assume that the success of the BAF is highly related to its simple structure and its similarity to other established planning ratios. The success of the BAF has encouraged other cities to implement similar planning tools. Malmo and Seattle have adapted modified versions of BAF in their spatial planning systems [5].

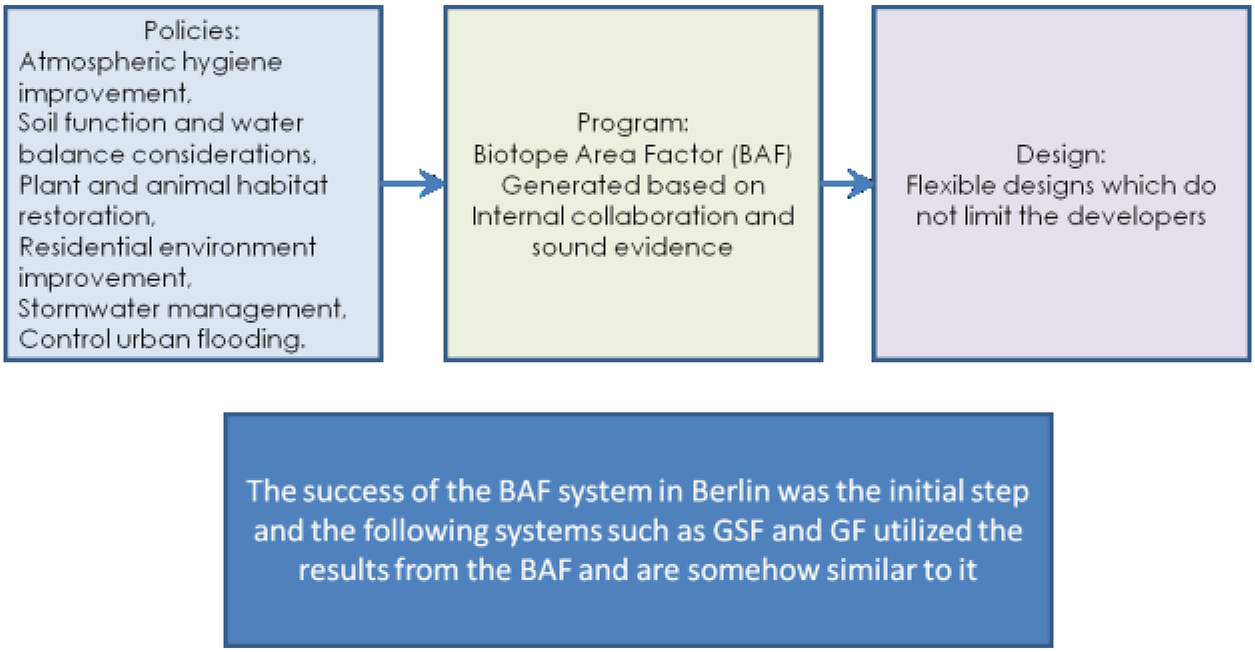

Figure 4 Drivers of the BAF and its success

As mentioned, there are still reports about overflow of combined sewer system in Berlin during heavy rain events. This is partly because some parts of city are still served by a combined sanitary and stormwater sewer network. Changing the sewer system to one where stormwater is separated from domestic and industrial waste would require considerable investment from the state. As of 2009, no plans had been drawn up to tackle the problem [6].

A summary of Berlin's achievements can be classified as:

- Reduced per-capita water consumption
- Reduced pollutions in discharged treated wastewater
- Innovative concepts for collecting and treating wastewater
- Abstracted groundwater is less than the amount discharged (ability to sustain future increases in water demands)
- Closed water cycle approach realized at urban level

- The introduction of the BAF and its reputation which has made other cities like Malmo and Seattle to implement similar programs

The disadvantages of this approach are:

- The BAF program does not applied feedback strategies, so it has not been evolved.
- The BAF is exclusively focused on the quantity of green spaces and not the quality of green spaces. For example, ordinary lawns provide smaller biodiversity opportunities than bushes, but both of these green covers are weighted equally. Hence, there are still considerations about effectiveness of BAF in enhancing biodiversity.
- This program has a top-down approach, and non-official public and NGO's don't play role in this program.
- The artificial infiltration of water has High costs.
- There are still combined sewer networks in the city.

2.1.5. Conclusion

The overall success of the City of Berlin in addressing urban water issues is related to its cultural background. The key factors are: compelling political necessity to achieve water self-sufficiency, environmentally concerned citizens and political parties, and high levels of financial support after the unification of Berlin. Most of cities have not experienced political extremes similar to Berlin, or they do not have access to such amount of funding. In general, the overall success of Berlin manifests the possibility of addressing urban water issues through revitalized natural systems and local hydrological regimes without degrading them.

2.1.6. Appendix

Table 11 Types of surfaces and weighting factors for Berlin BAF [5]

Type of surface	Description of surface types	Examples	Weighting
Sealed	Air and water impervious surfaces	Concrete, asphalt, sealed tiles/paving, water proof plastic coating	0.0
Partially sealed	Air and water impervious surfaces, permit infiltration to a certain extent, do not permit plant growth	Large and small stone pavements, clinker, mosaic paving, wooden pavement, sandy areas, crushed stone, heavily compacted soil …	0.3
Semi- enclosed	Air and water impervious surfaces that permit both	Pavement with grass joints, wooden pavement with high	0.5

	infiltration and plant growth	percentage of joints, grass paver …	
Vegetation- not connected to surrounding soil	Less than 80 cm of soil application	-	0.5
Vegetation- not connected to surrounding soil	More than 80 cm of soil application	-	0.7
Vegetation- connected to surrounding soil	-	-	1.0
Rainwater infiltration	Each square meter of roof area on which the surface water is drained off to a vegetation surface		0.2
Green walls	Green vertical surfaces on windowless external walls. Planting up to a height of 10 m is weighted.	The surface which can be covered by self-climbing vegetation such as vines …	0.5
Green roofs	No difference between intensively or extensively greened roofs	-	0.7

Table 12 The overall BAF target for different developments [5]

Type of development	Description	BAF target
Residential	Site occupancy index of up to 0.37	0.6
	Site occupancy index of 0.38 up to 0.49	0.45
	Site occupancy index of 0.5 and over	0.3
	New development	0.6
Businesses and Commercial Premises / Service Providers	All types	0.3
Public Facility and Public Service Sites	Schools providing general education, centers for education and training with undeveloped space per student of	
	25 m^2 and above	0.5
	15 m^2 and below 25 m^2	0.4
	< 15 m^2	0.3
	New development	0.4
	Nursery schools and day care centers with site occupancy index level up to 0.29	0.6
	Nursery schools and day care centers with site occupancy index level of 0.3 up to 0.49	0.45

	Nursery schools and day care centers with site occupancy index levels of 0.5 and over	0.30
	New development child-care facilities	0.6
	Cultural amenities and other public facilities- site occupancy index level up to 0.34	0.6
	Cultural amenities and other public facilities- site occupancy index level of 0.35 up to 0.49	0.45
	Cultural amenities and other public facilities- site occupancy index level of 0.50 and over	0.3
	Existing public administration facilities- site occupancy index level up to 0.29	0.5
	Existing public administration facilities- site occupancy index level of 0.30 up to 0.39	0.40
	Existing public administration facilities- site occupancy index level of 0.40 and over	0.3
	Public service sites	0.3

2.2. Rotterdam

The Rotterdam's Waterplan 2 is one of the most cutting edge stormwater management programs which go further than only integrating the urban spaces in nature. It tries to develop an artificially sustainable urban space.

2.2.1. Background and Major Issues

Rotterdam is the second largest city in the Netherlands and the lowest lying delta metropolis in Europe. It also has one of the largest ports in the world. It is situated 2 meters below sea level and the city is surrounded by dykes and has a complex pumping system that protects the city from flooding. Rotterdam's primary problem is flooding caused by heavy rain supplemented by the rising sea level that threatens the dykes and the fact that the stormwater cannot be drained away due to local hydrology. In the long run, the low-lying delta city will also be confronted with rising sea levels and fluctuating river discharge; both as consequences of climate change [1]. Hence, the water issues in Rotterdam can be classified as:

- Higher water level: There is a risk of flooding in areas outside the dykes.
- Flooding caused by increasing rainfall: Due to the changing climate, a lot of rain can fall in a short space of time.
- Stringent demands on the quality of water.

Figure 5 Rotterdam, biggest European port, [3].

Figure 6 Flooding water issue in Rotterdam, [3].

Figure 7 Water challenges in Rotterdam, [3].

2.2.2. Policy

Until 2007, water management strategies viewed water primarily as an invasive threat, focusing on safety, quantity and quality issues. This changed in 2007, when it became increasingly clear that Rotterdam will be seriously affected by climate change (higher water level due to rising sea levels; flooding caused by increased rainfall) [2].

As the vulnerability of Rotterdam to climate change effects became more and more clear, *Rotterdam Climate Initiative* (RCI) was launched in 2007. The RCI attempts to mitigate the climate change effects and requires the Rotterdam City Council, the Port of Rotterdam, DCMR, and Deltalinqs to reduce their carbon dioxide emission by50% by 2025 based on 1990 baseline levels. However, the climate change effects take time to manifest themselves, any reductions in emissions will inevitably be unable to prevent the climate from undergoing considerable changes.

Hence, the *Rotterdam Climate Proof* (RCP) was launched in 2007 to complement the RCI. The RCP attempts to adapt to the climate change and aims to reduce the vulnerability to climate change and for make use of the opportunities that it presents [3]. The RCP has three main policies:

- Adaptation to make Rotterdam protected
- Adaptation to make Rotterdam strong economically
- Adaptation to make Rotterdam attractive

the City of Rotterdam responded to Rotterdam's main concept to face the local water issues is using water as an opportunity to make a city more attractive by creating and implementing new solutions for stormwater storage in densely built urban areas and by following an integrative approach.

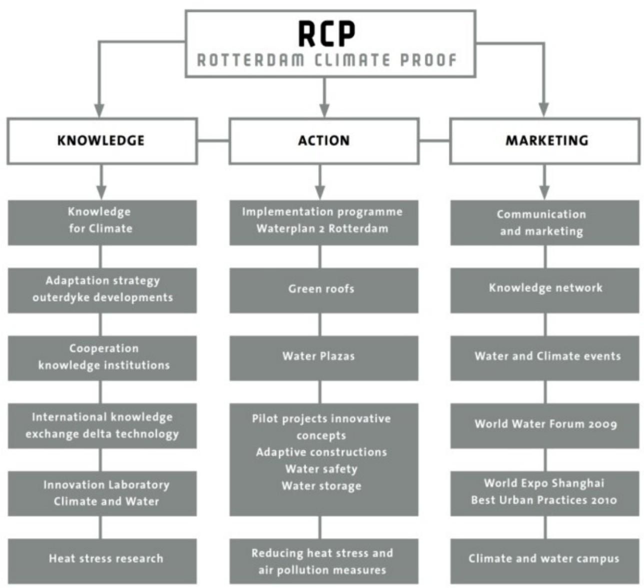

Figure 8 Rotterdam Climate Proof, [3].

2.2.3. Design Standards

2.2.3.1. Waterplan 2

Rotterdam developed Waterplan 2 in 2007, a comprehensive joint approach to spatial planning and water management. Rotterdam's Waterplan 2 created strategies to raise the dykes but also to build facilities for temporary water storage within the city. The aims are [1]:

- Protection against flooding

- Ensure water quality requirements
- Integrate urban planning with water management to solve water problems and enhance the city's attractiveness as a place to live, work and relax.
- Reorganize stormwater runoff via decentralized innovative solutions that perfectly match the specific area.

The Waterplan 2 is a city planning project. The development of goals and strategies of water management and planning were integrated as these two fields were jointed from the beginning of the project. After developing broad city-wide strategies, they were divided into district and then individual neighborhoods. Individual solutions therefore reflect the master plan, while at the same time responding to individual community needs. It also followed an integrative approach. Water management planners worked together with urban development planners and landscape architects to communicate competing concerns and interests, provide feedback, solve conflicts and optimize synergies.

The Rotterdam's Waterplan 2 has made the whole city water sensitive by building facilities for temporary water storage. Innovative solutions were presented such as green roofs, water squares, water gardens, and innovative water detention areas (temporary stormwater storage on streets and multipurpose underground parking garages that can store stormwater). In addition, a map was developed for the places where these measures should be put into practice. Moreover, all new developments in the outskirts have to be built with large water buffers and/or other alternative forms of water storage.

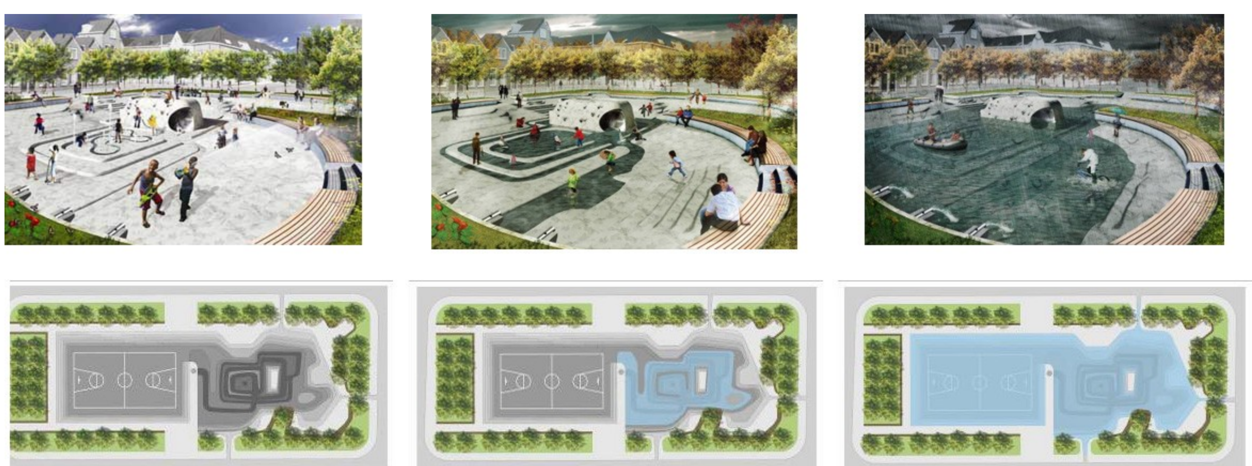

Figure 9 Water Squares and their multi-functionality during different seasons and conditions, [1].

The innovative water square contributes to the quality in public space and uses multifunctional technical systems to manage stormwater. During dry periods, it is an open recreational public space. During the heavy rains, the square is used for temporary rainwater storage.
The Waterplan 2 used intensive pre-implementation steps such as height measurements, flow-off simulations, and calculated water detention capacities. These steps were taken on a site specific basis. The cityscape was studied to identify buildings suitable for green roofs [2].
There are two levels of public involvement [1]:

- During planning phase. The meetings were open to public. The contents of the plan were issued in newspapers and the ideas of citizens were questioned.
- During implementation, workshops are held to motivate citizens to participate in design and planning process for specific measures.

2.2.3.2. Rotterdam Climate Proof

The RCP consists of five substantive themes which focus on knowledge development and implementation: flood management, accessibility, adaptive building, the urban water system, the urban climate. The Rotterdam Climate Proof program serves as an invitation to public and private parties to come up with innovative and effective contributions that can help realize these goals [3]:
Flood mitigation: In collaboration with the government and a number of regional partners, various scenarios are explored for the future structure of water management. Rotterdam wholeheartedly embraces the Veerman Committee conclusion that by 2050, the layout of the Rijnmond region should be designed to withstand the impact of storms and extreme river discharges, and considers this a condition for the further development of the city and port [3]. The proposed alternative of a ‘Lockable Open Rijnmond region’ seems to offer opportunities for spatial planning along the river and nature development, as well as to strengthen Rotterdam’s position as an innovative delta city and world port. For this reason, the City of Rotterdam is collaborating with Delft University of Technology and ‘HKV Lijn in Water’, conducting research into the possibilities of this lockable alternative. In addition, other alternatives are studied as well, including one that relies even more heavily on levee strengthening. In addition to the pivotal role of research, various means of communication are used to convince the local residents and the corporate sector, on a local as well as an international level, of the adequacy of flood protection in

the city and port, and to make them aware of what they, themselves, can do to contribute to the safety of the city and port.

Accessibility: Sustainable solutions for the future in the area of infrastructure in and around the city incorporate climatic effects. This requires research, first of all, as knowledge on the actual consequences is lacking. Based on the outcome of this research, the measures will be defined that are necessary at least to preserve the existing network. Some measures will be easy to implement, but some consequences will necessitate adjustments. New mobility issues as a result of climate change will also need to be taken into account in this respect. The concept of living on water, for example, will obviously also increase the demand for transport by water.

Adaptive buildings: For an optimal approach of adaptive building in the areas outside the levees, the subject is addressed from various angles, including the aspects of urban planning and construction method, access structure, mains services design, the organization of the public space, and legal measures (such as area-specific regulations on the method of construction and use). Key elements in this respect are permanent protection against flooding, and the development of a sustainable and attractive environment. Adaptive building thus offers opportunities for the realization in Rotterdam of new residential and business environments. Rotterdam has ambitious plans to build floating urban districts. The Stadshavens (city ports) district offers space for 1600 hectares of sustainable area development. Until 2040, some 13,000 climate change resilient homes will be built here, approximately 1,200 of which will be built on water.

Urban Water System: Developing a proper adaptation strategy requires more in-depth insight into the solution avenues available to prevent flooding and water shortages. The task at hand is to devise measures that will solve future bottlenecks while at the same time contributing to the economic strength and attractiveness of the city. For this reason, water storage in Rotterdam is integrated in the urban environment wherever possible. Against this backdrop, Rotterdam Climate Proof and the water boards collectively encourage the installation of green roofs, for example. During heavy rainfall events, these green roofs are a highly valuable solution for temporary water storage. In addition, the City is studying possible locations for the construction of water plazas. These water plazas – a Rotterdam invention – fill up in a controlled manner during heavy rainfall, preventing surrounding streets from flooding. In dry periods, the plazas serve as children’s playgrounds. Other storage applications involve multifunctional car parks.

2.2.4. Efficiency of the Design

Because predicted affects of climate change are severe, Rotterdam has invested more heavily than other cities in research and development for climate change adaptation. As a result, pilot projects and unconventional solutions for urban stormwater management have been developed. These results are adaptable to other cities and situations but more importantly, other cities can learn from the experienced integration of water management and spatial planning. Waterplan 2 demonstrates what is possible when stakeholders cooperate, interdisciplinary teams are coordinated, and when there is a general willingness to experiment and not to shy away from unproved solutions that can cause difficulties. Although other cities may not have the resources available to Rotterdam for this critical research, much can be learned and applied in other contexts [1].

The city did not just solve its stormwater problem. It also aimed for at improving its livability and appearance. This was done by introducing novel methods, such as water square, which expand upon existing techniques to create aesthetically pleasing, environmentally responsible, and user friendly public spaces.

All the concepts help to design usable and livable public spaces. The water squares are attractive places to play, sit, and linger. Planners have developed ideas for these spaces even when they are filled with water as well. They can be used as water playgrounds or even for boating. Green roofs fulfill their function of storing water and provide spaces of nature. Water streets act as normal public traffic areas for 90% of the year and hold rainwater during heavy rains.

The Waterplan 2 presented different solutions for different city areas. So the designs were based on the surrounding areas. It is well suited for changing conditions. The future security of city is ensured by linking very different solutions [1]. Each kind of solutions will be managed by a different department. However, responsibility for some measures has not yet been clarified [1].

2.2.5. Conclusion

Rotterdam has secured its position as a leading city in the field of sustainability by altering its approach toward water in urban environment and making comprehensive solutions besides strengthening its dams and levees. This approach is substituted by a collaborative approach between different stakeholders and research institutes to innovate the best way to increase the resiliency of their vulnerable city against climate change. Although their multifunctional innovative facilities and programs might be inefficient in other cities in different contexts, strong connections they have made between their policies, programs, and implementation can aid other cities in developing appropriate approaches toward urban water issues.

2.3. Malmo

2.3.1. Background and Major Urban Water Issues

Malmo is a European city in Sweden which is built on former agricultural land with no hills, forests or other natural obstacles to dense development. Due to Malmo's geographical location on flat, former agricultural land, many parts of the city lack natural channels for stormwater. This doesn't affect the city districts closer to the sea, but in large areas elsewhere small creeks receive more stormwater than their capacity, leading to flooding and erosion problems. Moreover, there is little green land available for recreation in Malmo compared to other Swedish cities [1].

Figure 10 West Harbor Malmo [2].

2.3.2. Policy

An international housing exposition, called Bo01, and also referred to as 'The Sustainable City of Tomorrow', was held in Malmo in 2001. It consisted of two parts: a temporary exhibition area of buildings surrounded by gardens and art forms; and a new housing district of 500 dwellings, mostly apartments. The new housing district was the first development in the former industrial area of the Western Harbor and was an important step in Malmo's journey from industrial city in deep economic crisis to a modern, sustainable city with a knowledge-based economy. This change was driven partly by a visioning process led by the city administration during the 1990s [1].

Major efforts were made to produce a district that reflected the Bo01 expo's 'Sustainable City of Tomorrow' theme. Most importantly, the area is supplied with 100% locally produced renewable energy, with electricity generated from wind, heat from the sun and from sea water, which is seasonally stored in underground aquifers [1].

The environmental schemes as well as aesthetics are described in the *Quality Program Bo01*, a document co-created by the city and the expo company, with representatives from the developers giving their views throughout the process. The Quality Program set out ambitious instructions for the aesthetic quality as well as the biodiversity of the public space, not least the parks [3].

The objective of creating new, high-quality green space incurred a breakthrough when the City Council agreed to use a 'Green Space Factor' and a 'Green Points System' to achieve a minimum level of greenery, and special green and blue qualities for the courtyards [3].

The most important goals when implementing the green planning instruments were: to present an attractive, healthy environment for people; to promote biodiversity; and to minimize stormwater run-off.

2.3.3. Design Standards

In order to apply green planning instruments City Council agreed to use a Green Space Factor (GSF) and a Green Points System (GPS) for the courtyards. By GSF, the developers were required to allocate a predefined percentage of each site's area for green space cover. By GPS, they were required to enhance the biodiversity by building different features I their buildings such as birds nesting, biotopes, and animal habitat. The system was adapted from the Biotope Area Factor (BAF) land use planning tool used in Berlin and Hamburg [1].

The developers had to describe in their detailed plans how they would achieve the requested Green Space Factor of 0.5. The plan was then checked by landscape architects at the City Planning Office, and the developers were asked to improve it if necessary [1].

The GSF alone could not fully fulfill the program's initial ecological demands. The reason for this is that different surfaces in the same category have different ecological functions. For example a mown lawn scores as same as a more natural meadow which supports greater biodiversity. Due to this shortcoming a green points system (GPS) was implemented. By the GPS, the developers were provided by a checklist of 35 measures and they have to implement 10 of them. These measures covered a vast variety of ecological aspects and ranged from implementation of bird nests to stormwater management measures [4].

2.3.4. Programs

2.3.4.1. Green Space Factor

Malmo's GSF is calculated by multiplying the area of each space by an assigned score for different surface types. The results of each individual surface then add up and the result is divided by the total area of the site. The assigned scores range from 0 to 1 and represent how much the surface contributes to the GSF goals [4].

$$GSF = \frac{(area\ A\ \times Factor\ A) + \ (area\ B\ \times Factor\ B) + \ etc.)}{Total\ area}$$

As the program proved its applicability in Western Harbor, it was generalized from being practiced only in Western Harbor, to being included in Malmo's building code and practiced in all sites and even in the neighboring city of Lund. This was done through modifying the factors associated to each surface type to achieve a balance between the requirements of policies and the experiences the planners gained from discussion with developers during previous phases. This involved a process of creative dialogue' among stakeholders to reach achievable environmental goals at a realistic cost based on four aspects of sustainability [1]:

- high quality architecture
- social sustainability
- economic sustainability
- ecological sustainability

The current weighting factors of the GSF (GSF Version 3) are presented in table 1 [4].

Table 13 current GSF values for each surface type, GSF Ver.3

Surface type	GSF
Vegetation on ground	1
Vegetation on trellis or façade	0.7
Green roofs	0.6
Vegetation on beams, soil depth between 200 millimeters and 80 millimeters	0.7
Vegetation on beams, soil depth more than 800 millimeters	0.9
Water surfaces	1
Collection and retention of stormwater	0.2
Draining of sealed surfaces to surrounding vegetation	0.2
Sealed areas	0
Paved areas with joints	0.2

Areas covered with gravel or sand	0.4
Tree, stem girth 16-20 centimeters (20 square meters for each tree)	20
Tree, stem girth 20-30 centimeters (15 square meters for each tree)	15
Tree, stem girth more than 30 centimeters (10 square meters for each tree)	10
Solitary bush higher than 3 meters (2 square meters for each bush)	2

2.3.4.2. Green Pointing System

The Green Pointing System aims to enhance the quality of green spaces and increase biodiversity. In its first version, developers were given a list of 35 Green Points and were required to choose and practice 10 of them in their new developments. The chosen 10 Green Points had to be described in the detail plans. Among the points, some aimed to aid biodiversity such as the inclusion of bat boxes and wild flowers in the courtyards, whilst others were included to improve the architectural qualities of the yard or help with stormwater management [1].

Although the first version was quite successful, in the second phase, the checklist was dismissed and was replaced by a list of biotopes out of which at least one should be built, a number of animal housing or habitats of which three should be built and a request that plant species should be rich in nectar and or berries, seeds and nuts [4]. However, due to general disappointment and lack of acceptable examples of success the city is now developing a more comprehensive environmental building program. In general, this program aims to include biodiversity in the GSF and in return there will be no need for the GPS anymore. For example, meadows or other biotopes will score better than mown lawns; animal housing will give additional points and so on.

2.3.5. Efficiency of Designs

The GSF and GPS programs have been revised three times before reaching their current form. Each version was evaluated one year after the implementation and the outcomes were used to measure the success or failure of the program and determine the acceptance of the program among developers. The lack of resources for evaluation is a common problem with local authorities demanding special development qualities.

After evaluation of the first version of GSF and GPS by the City of Malmo, it was concluded that [4]:

- most developments achieved the GSF that had been sought
- all detailed plans had shown how a GSF score of at least 0.5 could be achieved

- In most cases where the actual GSF was lower than the planned one, climbing plants had died and not been replaced
- very high GSF scores of 0.84 were achieved in two cases where landscape architects had been hired to compete for the best result
- local residents ranked the green and blue aspects of the development very highly
- the outcomes were judged to be slightly disappointing from a biodiversity perspective but much more could have been achieved through little effort and at very low cost
- an important first step in green and blue planning had been achieved that could be further developed in the future

Outcomes of the evaluation of second versions included [4]:

- there was general disappointment with the development in terms of its green spaces
- not a single developer was judged to have achieved an acceptable result in terms of biodiversity

It is important to note that the GSF alone cannot fully fulfill the program's initial ecological demands. The reason for this is that different surfaces in the same category have different ecological functions. For example, a mown lawn scores as same as a more natural meadow which supports greater biodiversity. In another example, an extensive green roof with a thin growing substrate for vegetation is of equal value to an intensive green roof with a thicker substrate which supports increased biodiversity and can help to intercept more rainwater [4].

The interesting point here is that the GSF planning tool is very adaptive, just like its predecessor; the BAF. It allows the developers to design freely. It also resembles ordinary land use planning tools and ratios which the developers are familiar with. Hence, it does not result in confusion among developers.

However, both versions of the GPS include highly professional requirements. These requirements include building habitats, bird nesting, and biotopes. Meeting such highly professional requirements is outside the abilities of ordinary developers who prefer simple construction schedules. I believe this is the main reason for failure of the GPS program.

Importantly, the program has been evolving for more than a decade and is now implemented in two cities of Malmo and Lund. If the program is implemented on a wider scale, it can help us adapt to climate change, manage temperature extremes, reduce flood risks, and help other species adapt to changed conditions.

The instrument used in Malmo and later implemented in Lund is an example of the interaction between three levels of policy, programs, and implementation (see figure 2). GSF has been revised three times to fulfill both policy requirements and realistic designs. Moreover, the unsuccessful program designs in the second phase of GPS have lead to the dismissal of it and forced the system to re-adapt. The environmental building program plays the role of the system in this case study. The system in Malmo and Lund is now evolving in a manner to fulfill biodiversity policies at the same time it tries to be realistic and implementable.

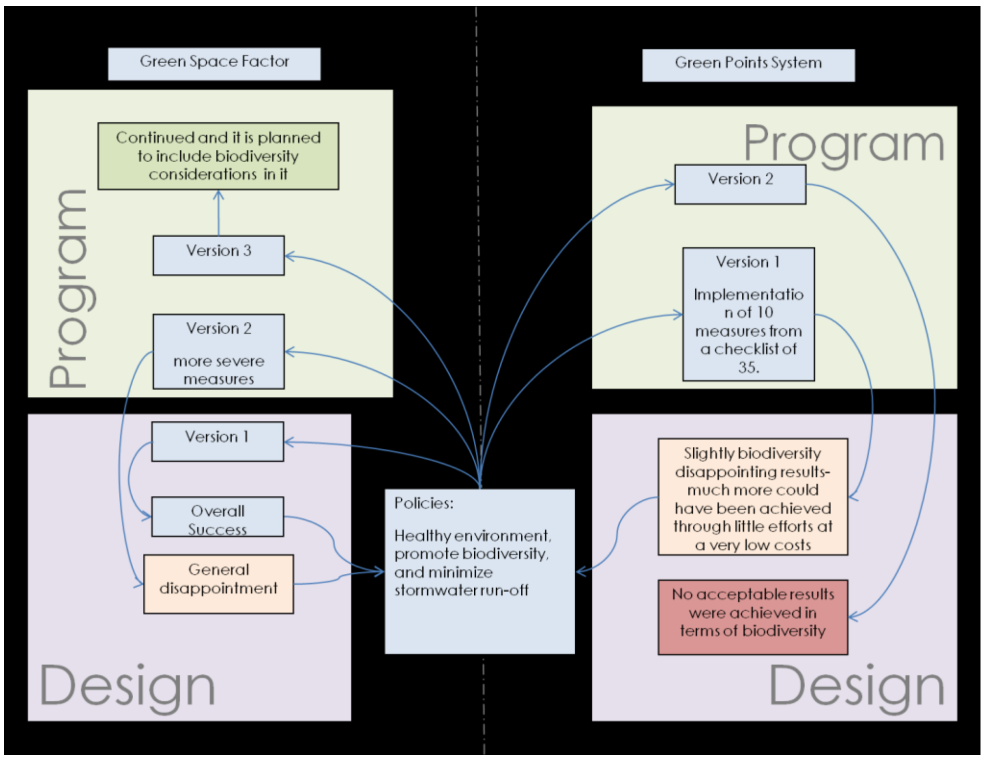

Figure 11 Summary of interrelations between policies, Program design, and programs in Malmo.

2.3.6. Conclusion

In order to achieve an attractive, healthy environment for people, promote biodiversity, and minimize stormwater run-off, the city of Malmo has developed two green infrastructure planning tools: green space factor (GSF) and green points system (GPS). These planning tools are very adaptive, and they have evolved three times since their first application. In addition, local consideration was considered to reach achievable environmental goals at a realistic cost. The planning tools may also differ for different parts of the city.

2.4. Melbourne's WSUD Program

2.4.1. Background and Major Water Issues

Australia has been suffering from long lasted drought for over a decade. Melbourne in Australia is one the most vulnerable cities to the climate change. The most important factors that have forced the city to rethink its water strategies are:

- Population growth
- Adverse effects of climate change
- Environmental concerns

Melbourne has a relatively dry-climate. Its average precipitation is approximately 25 inches with a remarkably even rainfall pattern throughout the year. Due to the current drought a large part of Victoria has struggled with rainfall significantly below long-term average. Its severity has been unprecedented, and its impact has been widespread across the State. This has resulted in a significant reduction in inflows into Melbourne's storages over the recent years. The city was benefited from reliable rain and water resource until 1990s (the basis for confident planning of future water supplies). However, the recent sustained drought has chained the condition of Melbourne's water resources. As it is a long-term drought, it is possible that Victoria is suffering a step-change in water availability due to climate change [1]. Other key climate risks include: extreme heat waves and bushfires, intense rainfall and wind storms, and sea level rise [2].

Greater Melbourne had the largest growth of any capital city in Australia between June 2011 and June 2012. Australia experienced 1.6% population growth between 2011 and 2012. Population growth between 2011 and 2012 was most prominent in outer suburbs, inner cities, urban infill areas and along the coast. Areas that have seen decline include well-established suburbs within capital cities, and inland rural areas [3].

The demand for water is increasing with population growth. This growth is in contrast with water supply patterns which are affected by climate change and could reduce water abundance. In addition, the adjacent Bays' aquatic ecology is inherently linked to the City's discharged stormwater and wastewater.

Melbourne's water is sourced from catchments to its north and east. The water quality of these catchments is high because the area is filled with natural forests. To meet drinking water standards, 90% of this water needs minimal treatment and the remaining 10% needs filtering. Importantly, only about 4% of this treated water is used for human consumption. A separate wastewater network is responsible for collecting the wastewater. The collected wastewater is treated and then discharged to the ports and bays to Melbourne's south and east. By 2010, 20% of all effluent had to be recycled by the aim of Melbourne Water. Hence, recycling schemes had to be developed to minimize effluent discharge to the bay. In addition, the stormwater is collected by another separate network of pipes and is discharged directly to the boundaries of Melbourne's catchment, bays, and pipelines which are illustrated in figure 1 [1].

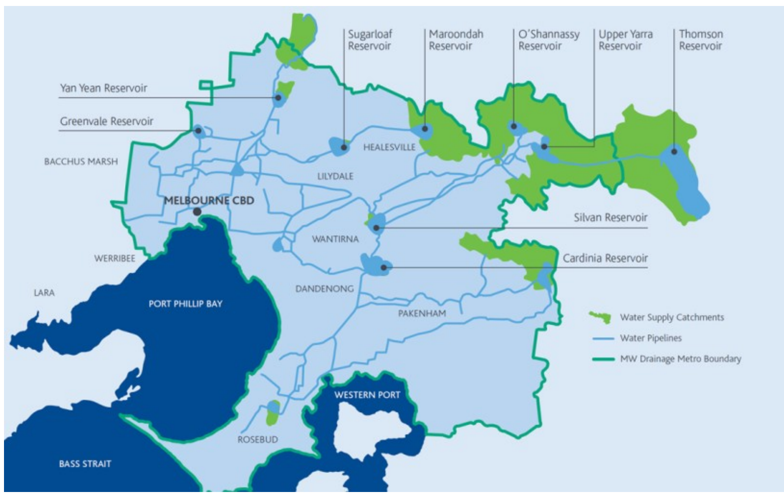

Figure 12 Water supply catchment and main water pipelines for the City of Melbourne [4].

The conventional urban water management is composed of three separate water networks, including: the potable water supply (piped system treating and delivering drinking water quality from catchments outside of urban area), the sewerage system, and the stormwater system.
The primary priorities of such system can be classified as [1]:

- Quickly moving urban stormwater to the nearest natural waterway for flood protection
- Safely removing and treating wastewater through centralized infrastructure
- Supplying safe and good quality drinking water through the centralized piped infrastructure

The Melbourne's geology does not allow a suitable groundwater extraction. This is because the geology is primarily a basalt shelf and the water quality and quantity of groundwater is typically saline and low. In addition, as the City of Melbourne is located at the bottom of the catchment, waterways are saline, groundwater is shallow, and pollution occurs from upstream sources. The

City seeks ways to improve the water quality of the whole catchment and improve the water bodies on a regional scale [1].

The City of Melbourne's rivers and creeks and the Port Phillip Bay are confronted by pollution issues caused by the following problems:

- Pollution from urban stormwater run-off
- Channelization of water bodies due to prior inappropriate land use and water management practices
- Erosion of banks caused by loss of vegetation alongside waterways

New and long-term management approaches are needed to improve waterway health. Macro invertebrate populations and diversity in the Yarra River are poor. An assessment of vegetation and stream flow in 2004 demonstrated that the Yarra River, Maribyrnong River and Moonee Ponds Creek all rated 'poor'. [1].

Integrated water management solutions are needed to keep the ecosystem healthy through secure and reliable water supply and appropriate water control and treatment [5].

Current and future key issues for sustainable water management practices are:

- Protection of public health when people come into contact with water bodies, and water treatment and reuse schemes
- Protection of the environment, with a specific emphasis on the aquatic ecosystem including rivers, riparian zones and wetlands
- Ensuring reliable provision of water services to the community including:
  - sustainable water supply
  - safe and reliable wastewater disposal
  - landscape amenity supplied by irrigation, with a preference for alternative water supplies
- Reduction of the City's environmental footprint. Being efficient with our energy, materials, oil, and other resources at the same time as meeting our sustainable water objectives.

Figure 13 three major water sources in Melbourne [1].

2.4.2. Policy

In Melbourne, drivers for the sustainable water resource management are inter-related. However, water supply, demand, quality and transport are all influenced by:

- Population
- Climate change and human health
- Environmental impacts

The population growth means more water demand. Hence, the City of Melbourne has released the Total Watermark City as a Catchment policy that has also the purpose of demand reduction for different sectors. The goals of this policy are presented in Table 1 [1].

Table 14 *Total Watermark City as a Catchment* target goals, adapted from [1].

Field	Goals by 2020	Relevant year of base levels
Water conservation	40% reduction in water consumption	2000
	50% reduction in water consumption per employee	
	90% reduction in total water consumption by Council	
Stormwater management: non-Council land	20% reduction in total suspended solids (TSS)	2005
	15% reduction in total phosphorus (TP)	
	40% reduction in total nitrogen (TN)	
	30% reduction in litter	
Stormwater management: Council land	20% reduction in total suspended solids (TSS)	2005
	15% reduction in total phosphorus (TP)	
	30% reduction in total nitrogen (TN)	
	30% reduction in litter	
Alternative water source targets	30% of Council's water needs to be sourced from alternative water	NA

	9% of non-Council water needs to be sourced from alternative water	
Wastewater reduction target	30% reduction in wastewater across the municipality	2000
Groundwater quality target	Where groundwater needs to be re-injected to prevent land subsidence, it needs to be of equal or better quality to the water in the aquifer	

A goal of 20% of waste water at the treatment plants is to be recycled by 2010. Over the past few years, the stormwater industry has increasingly been encouraging and regulating for each development site to treat stormwater. These policies aim to achieve [5]:

- 80% reduction in total suspended solids (grit, tyre and car residues etc)
- 45% reduction in total phosphorus (fertilizer, detergent)
- 45% reduction in total nitrogen (airborne pollutants, fertilizer)
- 70% reduction in litter

These strategies are part of City of Melbourne's work to become one of the world's most sustainable cities. They believe that a successful future depends on understanding the risks that climate change poses, reducing the urban and human impacts, and becoming more resilient. As part of this, the goal is for Melbourne to be carbon neutral by 2020, as outlined in the Zero Net Emissions by 2020 – 2014 update. Other key strategies referenced in Total Watermark – City as a Catchment including Climate Change Adaptation Strategy, Urban Forest Strategy, Open Space Strategy, Urban Ecology and Biodiversity Strategy and the Municipal Strategic Statement [5]. The Total Watermark City as a Catchment is aligned with community objectives set out in the Eco-City section of the Future Melbourne plan. The section requires the city to deliver a range of sustainable water management goals, indicators, and outcomes [1].

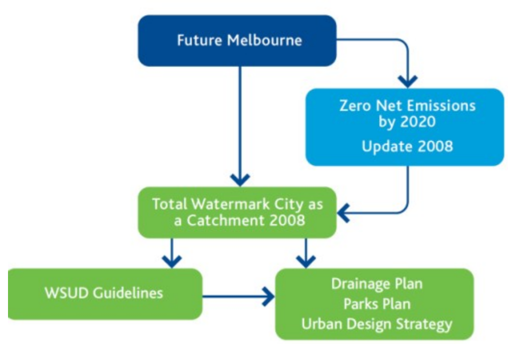

Figure 14. Water policy for the City of Melbourne [1]

The policy makers tried to consider local issues and understand the impacts of their decisions on water flows. The Total Watermark City as a Catchment policy is a short-term 12 year program that sets water management goals for the Council.

By The City of Melbourne's Total Watermark City as a Catchment policy, the city is considered as a catchment. This means that all city sites, including buildings, roads, footpaths, and open spaces can contribute to sustainable water resource management across the municipality and the water can be increasingly managed from the local catchment and rely less on external catchments. Over time, this approach will build the resilience of water resources and aquatic environments under the pressures of urban consolidation and climate change. In addition, community engagement is an integral component of all projects from the project conception onwards. Incorporating local, decentralized solutions that are 'sensitive' to the issues of water and energy sustainability for environmental protection is a fundamental part of achieving community engagement [1]. This was considered in policy making stage when the City ran a six-week community consultation, during which community members had the opportunity to provide feedback on the draft document of the Total Watermark City as a Catchment policy [5].

The City of Melbourne is committed to a triple bottom line approach to its decision making, incorporating consideration of [1]:

- Environmental issues: water quality, stormwater harvesting integration and river health
- Social issues: community awareness, education potential, internal capacity and involvement across Council departments
- Economic issues: costs of a WSUD project, relative to an alternative project

In general, policies of the City of Melbourne focus on:

- Climate change mitigation and adaptation,
- Capacity building for water supply system by demand reduction and finding alternative 'fit to purpose' water resources,
- Managing water cycle as means for enhance health, wellbeing, and enjoyment of the residents,
- Environment by water managed for biodiversity, healthy public open spaces, and clean waterways

2.4.3. Design Standards

City of Melbourne practices an integrated water cycle management. This is the coordinated management of all components of the water cycle including water consumption, rainwater, stormwater, Greywater (water from the bathroom taps, shower, and laundry), wastewater (blackwater from toilet and kitchen and water mining from sanitary sewer system) and groundwater, to secure a range of benefits for the wider catchment [5].

To incorporate the above mentioned policies The City has applied the Water Sensitive Urban Design (WSUD) programs. The WSUD marks a shift in thinking towards an integrated water management where all water streams are considered one resource. The WSUD is benefited from a wide perspective which focuses on the integration between different stakeholders [1]. Its objectives include:

- Potable water demand reduction
- Stormwater quality or flow discharge objectives
- Landscape amenity
- Ecosystem value
- Minimizing change to existing topography
- Preserving the natural drainage systems

The WSUD seeks to achieve an integrated water management by:

- Reducing potable water consumption
- Maximizing water reuse
- Reducing wastewater discharge
- Minimizing stormwater pollution before it is discharged to the aquatic environment
- Maximizing groundwater protection

The Water Sensitive Urban Design (WSUD) is often confused with the terms ‘Ecologically Sustainable Development (ESD)’ and ‘Water Cycle Management’ (WCM). The three terms are distinct but linked, as shown in Figure 2.

ESD is the environmental component of sustainable development that maintains and protects ecological processes. The WSUD sits under the ESD as an application of its themes into the urban design area. The WSUD is considered in the area of urban design to integrate and protect all aspects of the urban water cycle [1].

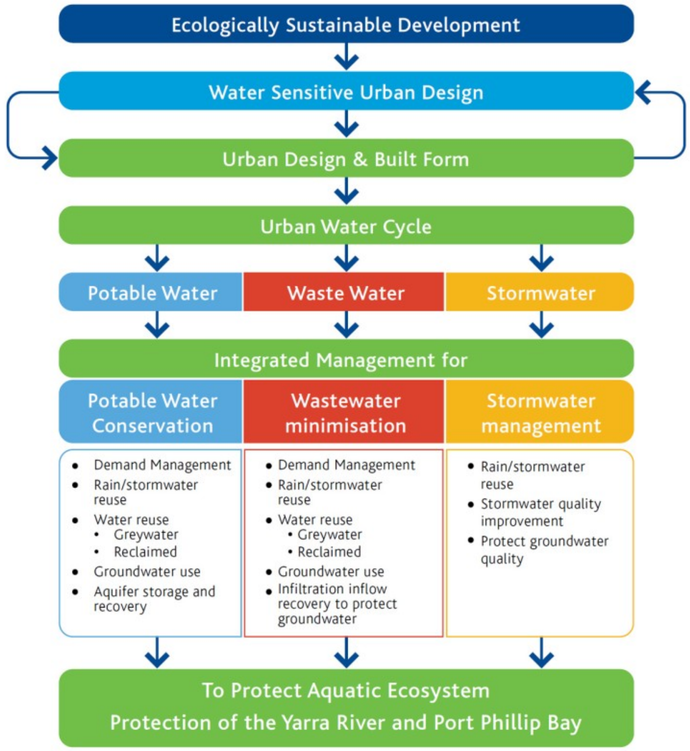

Figure 15 Interactions between ESD, WSUD and the Urban Water Cycle [1]

Adaptation of each element often leads to considerable outcomes for other elements as well because such efforts positively affect the urban water cycle and hydrology. For example rainwater harvesting will conserve potable mains water and reduce stormwater discharges [6].

The guiding principles promote the adoption of sustainable water management practices across council managed assets, residential, and commercial/industrial land uses [1].

While drinking water is not needed for irrigation and toilet flushing, alternative sources should be found for these purposes. The integrated water cycle management matches available water sources with the most appropriate uses (“fit-to-purpose”). By this manner, the demand for potable water reduces and sources such as greywater or stored stormwater can be reused and less discharged directly to the environment [5].

There are numerous ways to incorporate the WSUD in a redevelopment project to meet water targets. Strategies depend on the following factors [1]:

- Individual site conditions (e.g. location, geography)
- Building function and occupancy (e.g. residential, commercial, industrial)
- Development or redevelopment scale

- Water use and demand (e.g. garden irrigation demand, industrial use)
- Water sources available, including local climate (rainfall seasonality)
- On-site catchment area (roof and surface)
- Urban landscape design (architectural and landscape)

To produce an innovative and optimal solution, the WSUD approach needs input from a range of disciplines, including architects, landscape architects, engineers, planners, regulators, maintenance personnel and local community members with an appreciation of the WSUD [1]. In general The principles of WSUD are achieved through:

- Managing the demand for water by reducing it
- Assessing the appropriate potable or alternative supply of water for the end purpose
- Applying best practice to stormwater management

2.4.4. The WSUD program description

The WSUD program is executed through development of WSUD options. There are three steps in development of these options [1]:

- Step 1: Find ways to reduce water consumption. This step focuses on managing water demand. The reduction in water demand is done through: behavior change, regulation, technology, and design. Behavior change is an important part of this step. For this purpose, the City has visualized the local water issue of resource shortage and the current drought through a meaningful figure in the WSUD Guidelines. This figure is presented in figure 5. As this figure clearly states, the City is facing severe difficulties in meeting the water demand. Such visualizations of local water issues viscerally affect residents and inform them about the severity of the resource shortage problem.

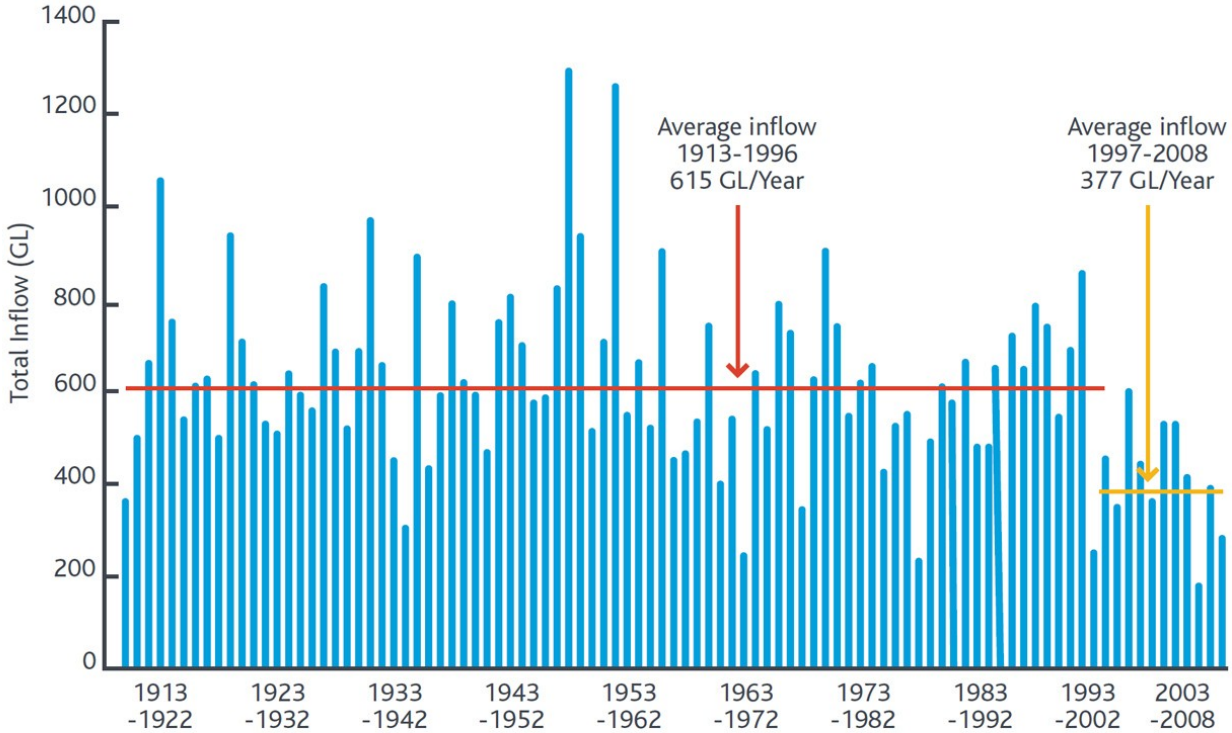

Figure 16 Figure 2 Melbourne Average Annual Inflows 1913 to 2008

- Step 2: Replace drinking water with an alternative source. A strong emphasis of the WSUD program is on the fact that different water usages require different water quality levels. For example, we should not use potable water for purposes that require lower water quality levels. This fit-to-purpose strategy seeks alternative water sources for non-drinking purposes. These resources include:
  - Alternative water sources from within the local catchment, including: rainwater harvesting, stormwater harvesting and water recycling
  - Alternative water sources from beyond the local catchment, including: wastewater from sewerage transfer network, stormwater from rivers, creeks and groundwater

The WSUD also presents guidelines for the water quality of any type of reused water. In order to reuse water in building, additional piping systems are needed. An example for using grey water within a multi-family residential is illustrated in figure 6. The City has also developed a new scheme to incorporate alternative water resources in the urban water cycle. This fit to purpose scheme is illustrated in figure 7.

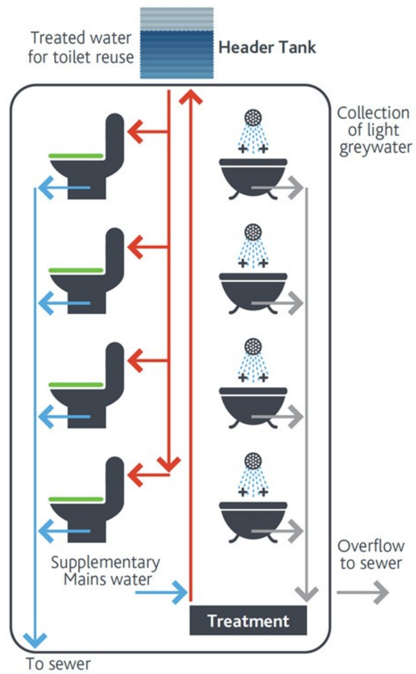

Figure 17 Greywater system within a multi-storey residential development [1].

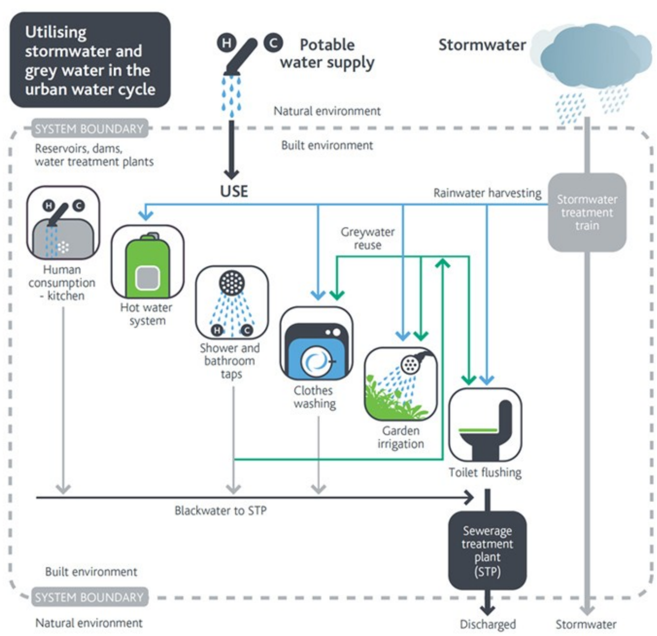

Figure 18 Utilizing stormwater and grey water in the urban water cycle

- Step 3: Treat stormwater before discharge into water bodies Best practice urban stormwater management aims to meet multiple objectives including:
    - Providing flood conveyance to reduce flow volumes and velocities (safe transport of floodwaters
    - downstream that reduces risk to humans, riverine habitat and infrastructure)
    - Removing contaminants to protect downstream aquatic ecosystems.
    - Providing for infiltration to groundwater and base flow
    - Promoting WSUD elements as part of the urban form.

A summary of these structural BMPs are presented in table 2.

Table 15 Site conditions and benefits of stormwater treatments

Treatment Measure	Potential benefits	Suitable site conditions	Unsuitable conditions
Gross pollutant traps	Reduces litter and debris Can reduce sediment Pretreatment for other measures	Conventional drainage systems	Sites larger than 100 ha Natural channels
Sediment basins	Coarse sediment capture Temporary installation Pretreatment for other measures	Need available land area	Proximity to airports because of bird presence
Rainwater tanks	Storage for reuse Sediment removal in tank	Proximity to roof Suitable site for gravity feed Incorporate to urban design	Non-roof runoff treatment
Vegetated swales	Medium and fine particulate removal Streetscape amenity Passive irrigation	Mild slopes (<4%)	Steep slopes
Buffer strips	Pretreatment of runoff for sediment removal Streetscape amenity	Flat terrain	Steep terrain
Raingardens	Fine and soluble pollutants removal Streetscape amenity	Flat terrain	Steep terrain High groundwater table
Ponds	Storage for reuse Fine sediment settling Flood retardation Community & wildlife asset	Steep terrain with confined valleys	Proximity to airports, landfill
Wetlands	Community asset Medium to fine particulate and some soluble pollutant removal Storage for reuse Wildlife habitat	Flat terrain	Steep terrain High groundwater table Acid sulphate soils Proximity to airports because of bird presence
Retarding basins	Flood retardation Community asset	Available space	Limited available space Very flat terrain

In order to define WSUD project objectives, WSUD projects consider:

- Water sensitive urban design principles
- Energy and climate impacts
- Social considerations
- Life cycle costs
- Technology selection

Objectives should as much as possible:

- Reduce potable water demand
- Meet stormwater water quality or flow discharge objectives
- Maintain or enhance landscape amenity and ecosystem value
- Minimize changes to existing topography
- Preserve and maintain the natural drainage system
- Ensure adequate provision for access and maintenance to all services

The WSUD program addresses climate change issues. The WSUD guidelines include a well developed chapter about this topic such as greenhouse gas emissions, material analyses, and renewable energy in water treatment. One of the most interesting efforts that the City has done in this regard is that the WSUD guidelines have measured the amount of greenhouse gas emissions from different WSUD treatments. This is shown in figure 8. This comparison links the demand reduction and water reuse goals of the City with the climate change issues.

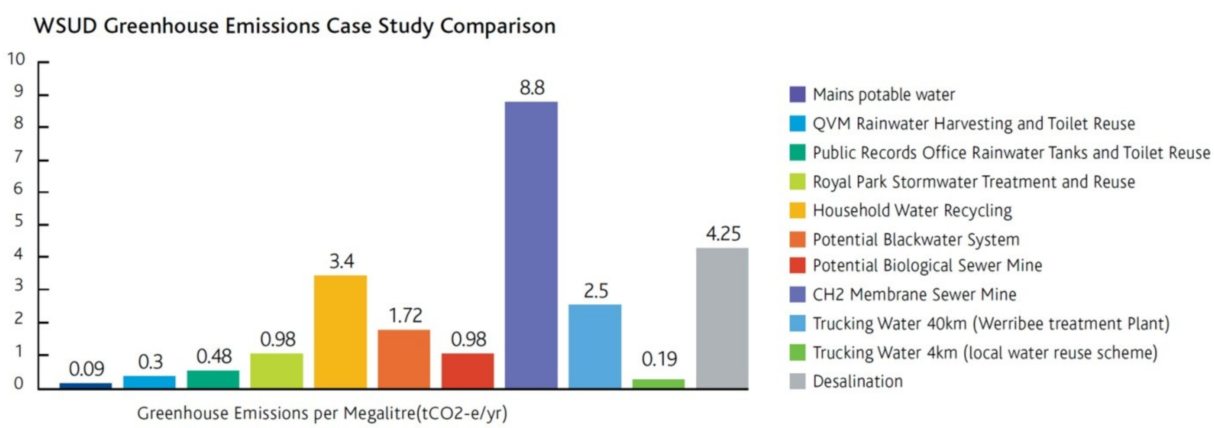

Figure 19 Case study comparison of greenhouse emissions from different WSUD treatments [1].

2.4.5. Implementation

The Council is the link between the existing policies and the WSUD program. Moreover, the Council evaluates the feasibility WSUD projects and incorporates considerations about environmental, social, and economic issues in their evaluations before the implementation phase [1].

One important factor in the Melbourne's program is that before implementation, it collects information background of the sites [1] such as information about the ownership, community issues, topography, geology, catchment boundaries, natural features, heritage, etc. Through this process, stockholder fights, community issues, and institutional barriers can be avoided or at least considered from the beginning. Hence, the best solution for these challenges can be found with lowest possible costs.

The WSUD Guidelines includes a project check-list and flowchart that help Council officers with key steps for implementation.

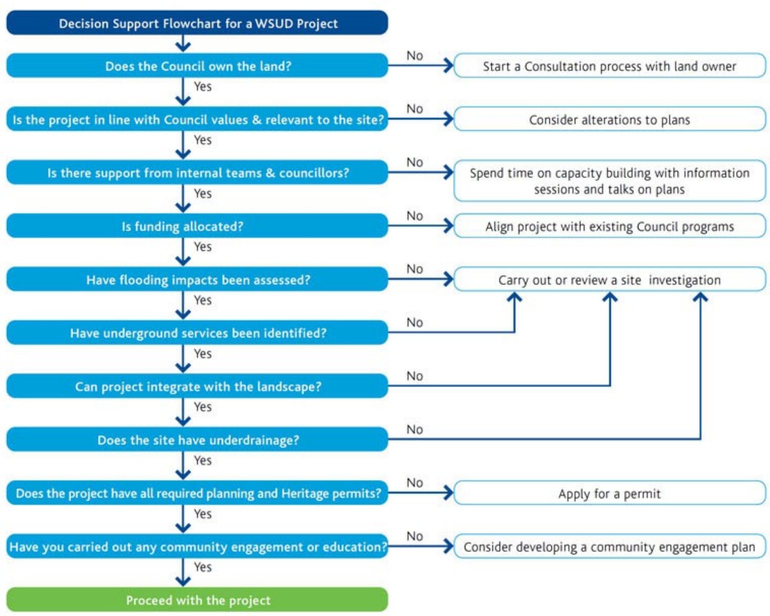

Figure 20 WSUD Flow Chart [1]

All city sites, planning or building proposals and council managed projects need to:

- Identify a site as a water source or sink (that is, a site water budget) and identify opportunities on the site itself and on nearby sites that could use surplus water or provide deficit water

- Account for costs and benefits of decentralized water options in terms of water, energy, building materials/infrastructure/technology, and risks
- Consider habitat enhancement for biodiversity, birdlife and microclimate benefits

One of the prioritized factors of WSUD is the public involvement and education. Through consultation, the ideas, innovations and concerns of a community can be incorporated into the decision making process. It develops open communication early and a design solution that have ownerships within the community. Community consultation also increases public awareness of water-related issues and results in positive behavior change with better environmental outcomes [1].

2.4.6. Efficiency of the Design

Since 2002, the municipality of Melbourne has made a significant progress in integrated water cycle management practices. The 2009 edition of Total Watermark was developed while Melbourne was in the middle of the drought, so the strategy primarily focused on reducing both overall water consumption and reliance on potable water network. At that time, many other organizations in Melbourne's water sector also focused on the water conservation [5].
This agenda was highly successful. Residential water consumption in the municipality of Melbourne has reduced 58 per cent since 2000, and is down 48 per cent per worker. The City of Melbourne has also achieved a 26 per cent reduction in its own water use during this period [5].

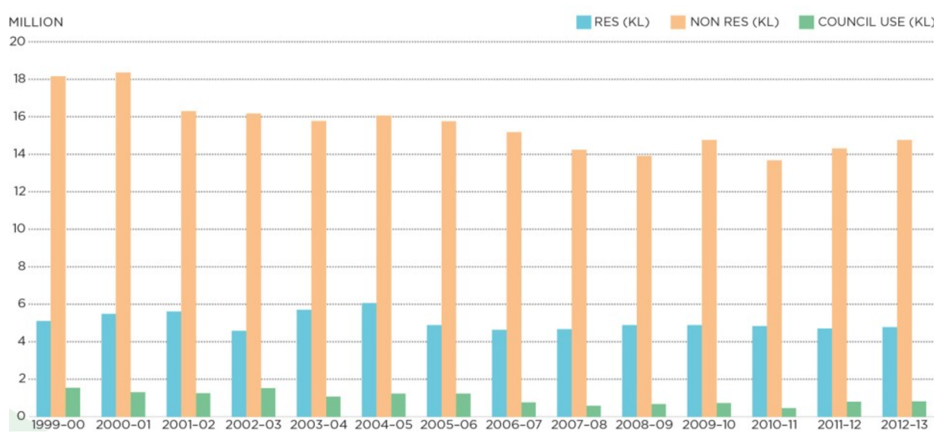

Figure 21 Total water consumption in the municipality of Melbourne since base year 1999-2000 [5].

Melbourne is now successfully moving toward its goals for the demand reduction and water reuse. A summary of its current progress is presented in table 3. Moreover, as figure 11 shows, the inflows of Melbourne are recovering from the 13 year millennium drought over the recent three years and the water storage levels are assessed as being in the high zone now (see figure 12).

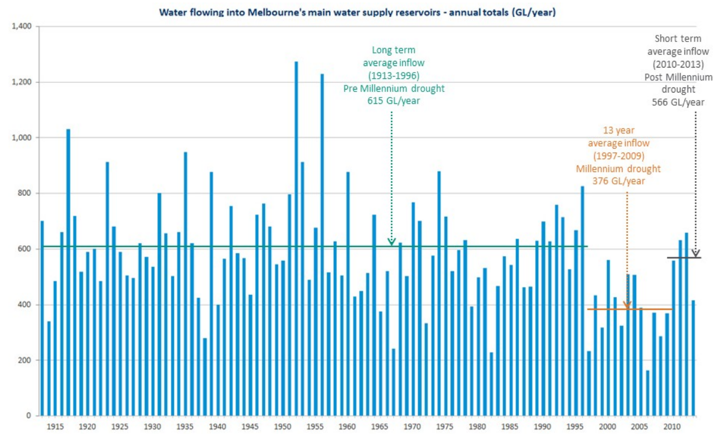

Figure 22Current Inflows stating recovery from Millennium Drought [7].

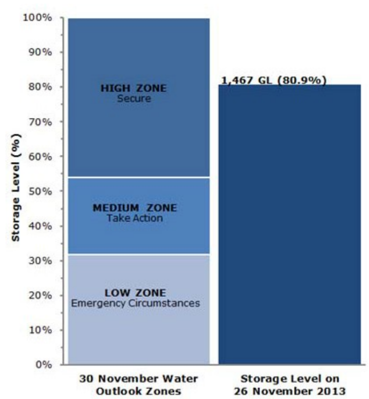

Figure 23 Storage levels on 26 November 2013 [8].

Table 16 Summary of water consumption for the City of Melbourne [1].

Base Year	Water Saving Targets (Total Watermark – City as a Catchment)	Progress	Comments
99/00	50% reduction in potable water consumption *per employee* by 2020	48% reduction per employee. Water use down from 181 litres/person/day to 109/p/d. 20% reduction in commercial water use from 18,243 ML/yr to 14,593 ML/yr.	Target recently increased as previous target of 40% has been exceeded.
99/00	40% reduction in potable water consumption *per resident* by 2020	45.5% reduction per resident. Water use down from 296 l/p/d to 161 l/p/d. 0.5% reduction in residential water use from 5,541 ML/yr to 5,087 ML/yr.	Previous target retained due to uncertain impact of water restrictions being lifted.
99/00	90% reduction in potable water consumption *by Council* by 2020	70% reduction in Council use. Water use down from 1,544 megalitres per year to 458 ML/yr.	Changes in watering patterns will occur again with lifting of restrictions due to horticultural needs. Commitment to zero potable water use in parks.
99/00	25% 'absolute' water saving target by 2020	15.5% absolute water saving.	The challenge remains to keep absolute savings while the population grows by 120%.

The WSUD has the environmental benefits such as [1]:

- Increased water conservation
- Improved stormwater quality, therefore improved water quality in waterways, bays and catchments
- Improved habitat and biodiversity through the establishment of wetlands and other 'natural' treatment alternatives
- Reduced greenhouse gas emissions by reducing water consumption and increasing rainwater harvesting and 'natural' treatment alternatives.
- Providing an adoption measure to address climate change impacts such as flooding and heat island effect.

The urban setting also benefits in a number of ways including:

- Replacement of pipes with natural elements for drainage, such as wetlands
- Enhanced aesthetics through increased vegetation, aquatic elements and landscaping
- 'Visible infrastructure' combining functionality and natural elements
- Linked urban and natural environments

- Flood mitigation by slowing down water movement through urban areas to streams.

2.4.7. Conclusion

The City of Melbourne creates a public will to understand local water issues and to represent them viscerally for residents. This will plays an important role in the implementation phase. However, most parts of Melbourne's program are only guidelines with the absence of mandatory regulations.

Moreover, the policies of the City of Melbourne are all aligned to achieve the goal of being globally an example of sustainability, climate change resiliency and a livable city. These policies are not fragmentally addressing individual water issues but aim to bring back the natural balance to the local hydrology through an integrated water cycle management. As a result, these policies have not negative impacts on each other.

As author Brown [9] argues, the City of Melbourne is in a transition phase from a city that addresses the issue of limited resources by an integrated water cycle management, to a city with a wider perspective that relates the health of residents to the health of their surrounding environment.

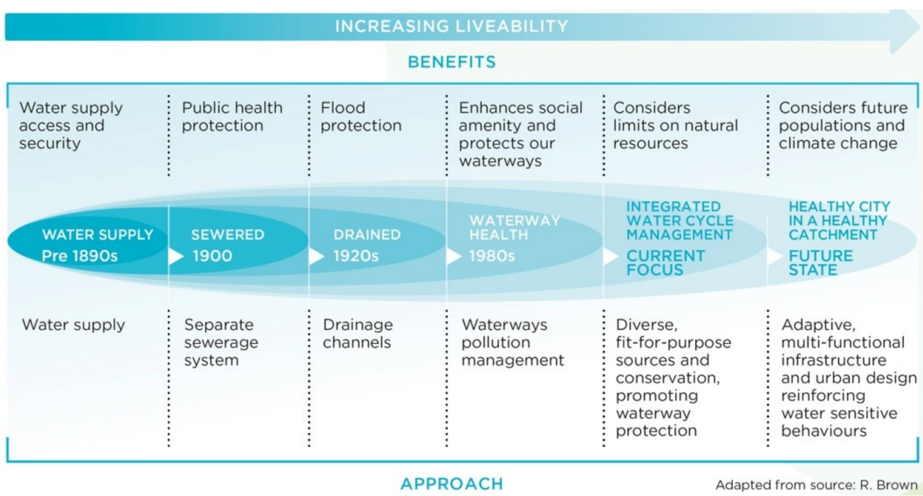

Figure 24 Historical progress of the City of Melbourne in addressing the water issues [9].

The City of Melbourne has addressed all of its policies through a single, yet integrated, WSUD program. This comprehensive approach has resulted in a steady progress to achieve the goals of the policies without creating additional water issues.

Interestingly, the WSUD program attempts to link the local water issues. For example, it justifies the need for demand reduction and water reuse by framing its reasons in term of greenhouse gas emission terms (figure 8). In addition, the severity of the local water issues is visually represented for the residents (figure 5).

By The City of Melbourne's Total Watermark City as a Catchment policy, the city is considered as a catchment. This enables the water management decision-makers to make policies with comprehensive hydrological and geological understanding of the city. Hence, it is important for water policies to consider local water issues based on local geological studies.

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2.5. Sydney

2.5.1. Background and Major Issues

Sydney is the most populous Australian city [1]. In addition, the first British penal colony was formed in Sydney [2]. Hence, the effects of modern civilization are highlighted more in this city than other Australian cities. Trough the development of the city, the stormwater runoff resulted in flooding. To address this issue and enable more land to be developed, the City of Sydney's forefathers followed a "Streamlining" scheme of channelization and piping of natural rivers and removing the water as fast as possible to Sydney Harbor and Botany Bay. Toward the end of the 20th century, the impact of development and channelization on biodiversity and downstream pollution of Sydney Harbor and Botany Bay was recognized. The early 1990's attempts to address these issues through better waste management, street cleaning, separation of sewerage and stormwater systems, development controls and an investment in stormwater quality improvement devices by the City of Sydney and Sydney Water. However, the adverse effects of non-visible pollutants continued and risked algal blooms and marine life [3].

The nationwide Australian drought at the dawn of the 21st century has highlighted the importance of considering stormwater as a potential water resource. This has lead to the wide implementation of rainwater tanks and small scale stormwater harvesting schemes that can be used in gardens and open space irrigation. Moreover, Sydney is experiencing extreme population growth like other major Australian cities.

As Melbourne and Sydney have similar urban water issues, I conduct a comprehensive comparison between two cities with the same nationwide federal policies. The results will show the efficiency of these federal policies.

2.5.2. Policy

In general, the most important drivers of change in Sydney are the following factors:

- Climate change and the need for alternative water resources
- The Importance of the Sydney Harbor and Botany Bay to the City of Sydney and the necessity of stormwater pollution control

Major issues such as population growth and climate change are similar between Sydney and Melbourne, and only the expression of these issues is different in these cities. These issues emphasize on the importance of alternative water resources.

Water consumption in the City of Sydney is not limited to water used by urban residents. The centralized, coal fired, energy power stations are considerable water consumers. There are three Master Plans responsible for the goal of water consumption reduction:

- *Decentralised Water Master Plan*
- *Green Infrastructure Master Plan*
- *Decentralised Energy Master Plan*
  - Trigeneration
  - Renewable Energy

The Decentralised Energy Master Plan will displace equivalent to a 22% reduction in the City of Sydney's overall 2030 water demand. The targets in the Decentralised Water Master Plan are in addition to, and not part of the Decentralised *Energy Master Plan- Trigeneration* and further reductions are considered in Decentralised Energy Master Plan- Renewable Energy published in 2013.

Regarding the recycled water, a 30% recycled water target (of the wastewater collected) is set for the capital cities by Federal Government in 2007. However, 2010 status report shows Sydney has achieved only 7% of this target (p.27 of [4]). While, the city of Brisbane has achieved 37%, Adelaide has achieved 30%, and Melbourne has achieved 20%.

In order to provide a strong backbone data for the program, multilayered maps are prepared based on data collected from the City of Sydney and Sydney Water [4]. These maps can be used for different purposes. For example, the infrastructure maps are useful in estimating and mapping the potential fraction of wastewater and stormwater harvested for producing recycled water. These maps include:

- Base layer: boundaries and context

  Sydney's 11 sub-catchments that drain to three receiving waters
- Layer A: Land use and floor space
- Layer B: Water consumption data
- Layer C: Growth in water demand by 2030

Water demand growth was estimated and mapped based on projected increase in demand due to population growth and urban development.

- Layer D: D1=Stormwater, D2= Groundwater and seepage water
- Layer E: Wastewater volume and sewer pipe network
- Layer F: Land use and surface type

Figure 25 Spatial layers that assisted in determining decentralized water solutions

2.5.2.1. Sydney Water

Sydney Water is the water utility responsible for water provision, distribution infrastructure, and wastewater treatment in Sydney. In Sydney Water's 5 years servicing strategy, they investigated the water and wastewater infrastructure and concluded that water and sewage infrastructure are in good conditions and decentralized recycled water schemes will not result in any significant reductions in the avoided costs [4]. Moreover, Sydney Water is neither encouraged nor required by regulations to invest in decentralized recycled water schemes. The only relevant regulation is the *Water Industry Competition Act (WICA) 2006* which is introduced by New South Wales (NSW) government. Under this legislation, Sydney Water has obligations to facilitate access to stormwater drainage network and sewer mains for those agencies that may choose to develop and operate decentralized water schemes.

However, to identify its need to provide customers with solutions that they value, and to support its key role in contributing to Sydney as a livable city, they have recently adopted a new

Corporate Strategy. By this strategy, responding to costumer's expectations plays a key role in shifting the focus from traditional water supply to a greater range of fit to purpose sources and services that support affordability, urban amenity, protection of waterways, energy and resource recovery, and resilience in the face of weather extremes and emergencies. These goals require the integration of water management with urban planning, and collaboration with Council, developers, government agencies and other stakeholders.

2.5.3. Design Standards

Based on comprehensive analysis of data specific to the city and across elements of urban water cycle, decentralized water solutions are proposed which focus on all three elements of water cycle: water, sewage and stormwater [4].

2.5.3.1. Water Efficiency Solutions:

Improving water efficiency will lead to water demand reduction and therefore sewage volumes. Based on evidence based robust analysis, a water efficiency target of 10 percent in 2006 demand by 2030 is set. This is the realistic approach and based on these analyses, almost a quarter of annual water demand in the city could be reduced by switching to water efficient devices and operations.

2.5.3.2. Water Recycling Solutions:

Local water resources such as rainwater, stormwater, groundwater, sewage, and sea water are recovered and captured to match the demand. The recycled water can be used for non-drinking demands. These demands include:

- Demand within existing properties: toilet flushing, cooling towers, irrigation, washing bays, industrial processes, etc.
- Demand within new development: toilet flushing, cooling towers, irrigation, washing bays, laundry, etc.
- Demands by Trigeneration energy plants

Over 50 percent of the city's water demand in 2030 could be supplied with recycled water. Resources for water recycling include: roof water, stormwater, groundwater, sewage and blackwater, greywater, and sea water. Regional demands are calculated for each catchment and fractions of these demands by each source are determined.

2.5.3.3. WSUD Solutions:

Best Management Practices (BMPs) are implemented solely for reducing pollution. For each of the 11 sub-catchments in Sydney, WSUD solutions are mapped for: redevelopment WSUD, Renewal WSUD, Retrofit WSUD, Recycle/Reuse. Other benefits of implementing WSUD solutions are considered as side-benefits and are not included in cost-benefit evaluations. These benefits include:

- Improved aesthetics and amenities
- Enhancement of biodiversity
- Greener and cooler microclimate within the city
- Additional sources of water for irrigation and other non-drinking uses
- Relief from unnatural and nuisance flooding
- Celebration of water by making it more visible and appealing part of the urban landscape

To understand how much potential is existed in which locations opportunities are first mapped. Then, solutions are designed to capture practicable opportunities.

2.5.4. Program Description

2.5.4.1. Water Efficiency Solutions

The water efficiency programs focus on sectors with high water-saving potential. These solutions could use one or a combination of instruments such as [4]:

- Education
- Metering and Reporting- Providing the consumers with information on the amount of consumption for water saving actions and behavior by providing a feedback loop
- Providing consumers with water audits and low- or no-cost water efficient equipment
- Recognition and Reward
- Financial Assistance such as low interest loans

The design and development of water efficiency solutions is done through a collaborative work with the following groups:

- Existing partners
- New partners who are strategic and relevant to the targeted end use or sector
- Government and agencies

- Sydney Water

2.5.4.2. Council Water Demand

The water saving actions by the council include (p49):

- Retrofit of top ten water consuming Council sites with water efficient fixtures and appliances
- Installation of smart water meters on 23 high water using sites to enable real-time metering that is valuable in responding to any leakage in the system
- Installation of rainwater tanks to substitute mains water use by toilet flushing, irrigation, and washing bay areas
- Implementation of small scale park-based stormwater harvesting schemes to provide alternative water sources for irrigation

2.5.4.3. Recycled Water Solutions

Water-recycling solutions replace the demand for potable water with recycled water from locally available water resources for non-drinking water demand. The program consists of assessing local water resources and mapping supply and demand to map these resources for appropriate demands. These resources include:

- Roof water
- Stormwater
- Groundwater (including tunnel seepage water)
- Sewage and Blackwater (Sewer Mining)
- Greywater
- Sea water (Thermal Desalination)

This mapping is a complex procedure of Multi Criteria Analysis (MCA) which is illustrated in figure 2 and the filtering procedure described in table 1.

Figure 26 Process for filtering preliminary opportunities

Table 17 Considerations used to filter preliminary opportunities

Local Characteristics

- Target larger residential and commercial buildings with fewer connections and higher demand
- Avoid older areas and terraced properties requiring multiple connections with low demand
- Target new developments to include third pipe and plumbing during construction
- Consider topography to avoid pumping and energy costs

Synergies

- Synergies with existing and proposed infrastructure and initiatives
- Utilise existing infrastructure including sewerage pumping stations and collection networks
- Co-location of infrastructure to minimise disruption and avoid costs e.g. trigeneration network
- Minimise energy use and carbon emissions and reduce waste e.g. utilise waste heat from trigeneration to distil seawater

Reliability and Effectiveness

- Reliability of supply e.g. stormwater and roof water reliability is driven by yield and storage
- Sewer mining is more cost effective with increase in scale. Small opportunities were clustered to improve economies of scale
- Small opportunities targeting only a few properties suit lot-scale solutions
- Network effectiveness targets clusters of high recycled water demand and minimises length of supply network

2.5.4.4. WSUD Solutions

The City of Sydney is the home to one of the first developments that incorporated the WSUD in new development in Australia. However, the pollution control is the main driver for the City to incorporate WSUD solutions into its master plans. Hence, only the performance of WSUD solutions for the pollution reduction are included in reports and other ecological benefits such as provision of biodiversity are considered as secondary benefits and, they are not properly assessed. Apart from this difference in assessment and planning, the WSUD measures are similar to those described in Melbourne case study.

Key criteria in determining of pollution reduction solutions are:

- Contribution to total suspended solids (TSS)reduction target
- Contribution to total nitrogen (TN) reduction target
- Cost per kilogram of total suspended solids and total nitrogen removed.

The City's pollution reduction targets are set to be (by 2030):

- Achieving 50% reduction in total suspended solids (sediments)
- Achieving 15% reduction in total nitrogen (nutrient) being discharged to the waterways

The City tries to achieve these targets by:

- Mandating WSUD in all new developments- the result is expected to be 21% reduction in current sediment load and 11% reduction in nutrient load
- Retrofitting of the drainage network with gross pollutant traps into the existing drainage network- this would result in 15% reduction in sediment load with no reduction in nutrient load
- Retrofitting of public open spaces in at least 10% of opportunities- 9% reduction in sediment and 3% reduction in nutrient load
- Incorporating WSUD during at least 10 per cent of opportunities presented by renewal of road and other streetscape projects can provide a 5 per cent reduction in current sediment load and 1 per cent reduction in current nutrient load.

2.5.5. Implementation

Water efficiency program is implemented via the incorporation of water efficiency solutions targeting different water consumer sectors. There are two versions for each program. In one version only the city resources are assumed to fund the program. A higher level of investment is assumed as a second version with the presumption that the City seeking support and resource from NSW Office of Environment & Heritage and Sydney Water [4].

2.5.6. Efficiency of the Programs

- Based on the analysis in the Decentralised Water Master Plan, the City has set a water efficiency target of achieving 10 percent reductions on 2006 demand levels by 2030 through water efficiency [4].
- Despite an increase in the number of its buildings, the Council has managed to reduce its mains water demand between 2006 and 2012 by 3.6% (p49).

With the presumption of 'business as usual' the Council's water demand is expected to increase 30% on 2006 levels by 2030 (p40). The council has set itself a target of 10% demand reduction of 2006 levels by 2030. The Council intends to achieve this target through water efficiency, recycling, and alternative sources.

Based on the data presented in the *Decentralised Water Master Plan*, I conclude that retrofitting of the WSUD into public open spaces is more profitable in financial terms than retrofitting it into private spaces. Importantly for the City of Sydney, the implementation costs include both the construction costs and ongoing maintenance costs. Similar to some previous case studies, maintenance costs are considered as a secondary priority, and this fact reduces the effectiveness of those programs.

The performance of recycled water solutions is a complex task to because several criteria have to be considered. Moreover, factors such as the source of water used and location of the recycled water scheme add to the complexity of such assessment. There are four major solutions for recycled water in Sydney: Thermal desalination, sewer mining, stormwater harvesting, and roof water harvesting. Here, for the sake of avoiding any technical complexity, only conclusions that can be made out of data presented in the *Decentralised Water Master Plan* [4] are presented.

Potential volumes and costs:

- Thermal desalination and sewer mining have high potential to satisfy the demand for recycled water in terms of volume, and stormwater and roof water have relatively lower potential.
- Collecting roof water seems to be the most expensive way to produce recycled water. Thermal desalination, stormwater harvesting, and sewer mining have lower costs, respectively. However, thermal desalination and sewer mining is considerably more reasonable source of producing recycled water.

Multi-criteria analysis (MCA):

- In terms of resilience and reliability, sewer mining and thermal desalination show great performance, stormwater harvesting shows good performance, and the performance of roof water harvesting is considerable.
- In terms of environmental impact, due to their processes, sewer mining and thermal desalination are not beneficial at all. In contrast, stormwater harvesting and roof water harvesting are beneficial in this regard.
- In terms of net carbon intensity, sewer mining shows no contribution but in this regard, the performance of the other three solutions is extremely great.

- In terms of distribution network effectiveness, the position of sewer mining facility (water treatment plant) plays a key role and if the facility is positioned in the right location (not far from the consumers) the produced recycled water can be consumed effectively. In addition, considering the location of a thermal desalination plant, they can perform yet more effectively than stormwater and roof water harvesting solutions.
- Stormwater harvesting schemes do not perform as well on network/supply effectiveness, but perform very well on net carbon intensity and environmental impact (benefit).
- Sewer mining schemes, on the other hand, perform well on network/supply effectiveness but perform poorly on net carbon intensity due to the energy intensive treatment process the scheme relies on.
- Thermal desalination process performs well on net carbon intensity a synergistic use of resources, as the scheme will make use of the zero carbon waste heat from Trigeneration plant.

2.5.7. Conclusion

Here, I present the differences between the outcomes of Sydney and Melbourne in a relatively similar context:

- In contrast to Melbourne which executed one integrated program to simultaneously address all of its urban water issues, Sydney has presented fragmented and exclusive programs to separately address its individual water issues. This separation of programs has resulted in loss of potential contribution opportunities between these programs. For example, retrofitting WSUD measures in single family residential is considered economically least beneficial whereas they provide resource opportunities of stormwater for water reuse and demand reduction programs.
- Both water recycle and demand reduction programs rely on federal requirements, which has resulted in an improper backbone for these programs. In other words, local evidences are needed to support these programs, because without such evidences the residents will not understand why they have to contribute to these programs. Moreover, the lack of emphasis on the local water resource shortage and also the conclusion of Sydney Water that presents water recycle schemes are not beneficial has resulted in achieving only 7% of its 30% target for

water reuse. Figure 3 illustrates the current progress of major Australian cities toward achieving the federal recycled water target.

The collaborative action toward the design and development of water efficiency programs can be seen from two perspectives. From the City's point of view, this is a unique approach that is in contrast with the traditional demand management (conventionally the responsibility of the water service provider). So, the City believes that the water conservation and efficiency is promoted and facilitated to residents and businesses as a social and environmental imperative, and the collaboration between Sydney Water and NSW Government can deliver water savings results greater than each agency can deliver on its own. From another perspective, as the number of stakeholders or collaborators increase, the confusion increases as well.

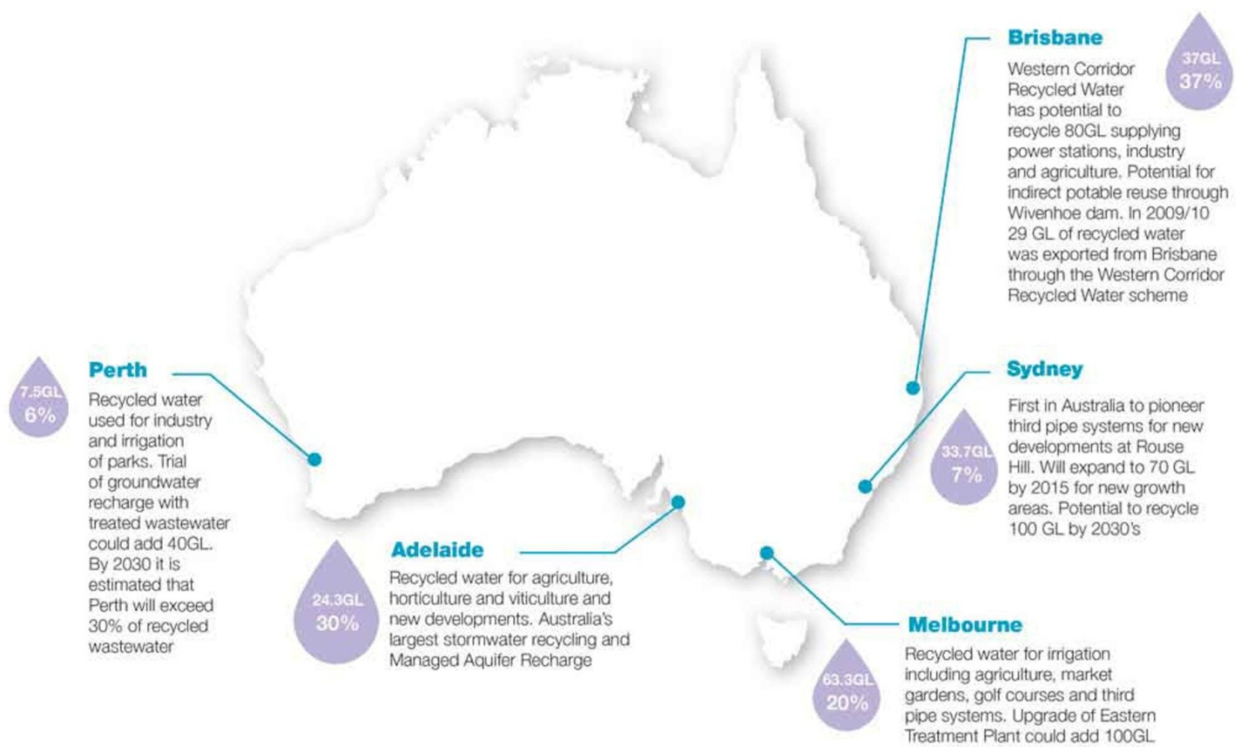


Figure 27 Recycled water (percentage of wastewater collected) in 2010 [4]

2.6. Austin

Local politics in Austin are often characterized by simplistic dichotomies of preservation versus growth, local versus outsiders, and environmentalists versus developers. But, local water issues transcend these categories to reveal the tensions between culture and nature, built and un-built, past and future.

Austin is reputed as a progressive leader in the environmental protection. However, their approach toward addressing their local water issues is like patchwork efforts which try to link Austin's long tradition of protection with novel and more up-to-date sustainable approaches. The insufficiency in their approach indicates the necessity of changing the point of view from environmental protection to integrative restoration.

In this section, I review the story of the City of Austin in dealing with its local water issues. These issues have been divided into two categories: the City of Austin's efforts to conserve its natural and beautiful features of Barton Springs, and stormwater management efforts in Austin's inner-city.

2.6.1. Background and Major Issues

The environmental condition in Austin is strikingly different from the dry landscape devoid of vegetation stereotype of Texas portrayed in Western movies. The city receives 32 inches of rain annually and the region is subject to some of the largest flood producing storms in the US. This has resulted in devastating flood experiences in Austin; the most recent is the Memorial Day flood in 1981. Moreover, as the regional topsoil is very thin, there is always risk of erosion due to these flooding [1]. Hence, the major topic in Austin is keeping the exceptional beautiful natural landscape while harnessing its extremes. Past practices to achieve this were highly dependent on purely civil engineering means that attempted to either protect the nature or administer total control over it.

The municipality of Austin's reputation is largely founded on their activities to protect undeveloped land upstream of Barton Springs (mostly with rural or undeveloped land use) [2], and their urban stormwater management programs in the inner-city [1]. The Barton Springs protection activities are done through strict water quality ordinances and conservation land development practices. The urban stormwater management includes comprehensive monitoring activities, the early adoption of BMPs for new urban development, and the retrofit of previously developed areas of the city with water quality controls.

Austin has experienced a considerably high rate of population growth over recent decades. Its population in 2013, of about 843000, has almost tripled in the recent 40 years; with an increase of 100000 over the recent seven years [3].

2.6.1.1. Saving Barton Springs

The focal point of environmental politics in Austin is Barton Springs, a cluster of four freshwater springs at the mouth of the Barton Creek watershed in the heart of the city. Owned by the City of Austin, Barton Springs is used to create Barton Springs Pool which attracts a wide range of residents and visitors (figure 1). Barton Springs are often referred as the "soul of Austin" because they provide a direct connection among residents, their community, and the landscape [2]. The water of Barton Springs comes from sensitive Edwards Aquifer which is replenished from subsurface and groundwater of Barton Springs Zone watershed in the Hill Country (figure 2). Hence, a particular focus of Austin residents, regional politics, and urban growth is the land to the west of the city known as Hill Country. This area comprises an area spanning several counties and hundreds of square miles of largely rural area characterized by rolling landscape, massive oak trees, and picturesque views.

Figure 28 Barton Springs Pool Attracts residents [4].

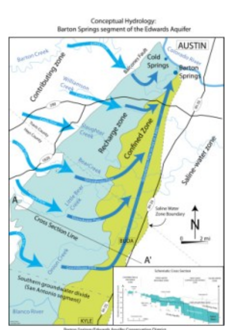


Figure 29 Hill Country and the Barton Springs Zone watershed [5].

Early land use in the Hill Country consisted largely of cattle ranching and cotton farming. These activities have devastating effects on soils and vegetation by compacting the land and producing polluted stormwater runoff during storm events; similar to urbanization effects. Today, the area continues to support cattle ranching but the region as a whole is increasingly characterized by single-family residences in suburban subdivisions.

The land development activities in the Hill Country would affect not only surface waters but also groundwater and underground water flows. This is because the subsurface of the region is a vast underground storage vessel of permeable limestone characterized by caves, sinkholes, and other conduits. Due to its landscape features and porous character, the aquifers do not filter groundwater and the groundwater is directly connected to the surface water. This makes the Edwards Aquifer the most environmentally sensitive subsurface waterbody in Texas. Barton Springs Zone division of the Edwards aquifer directly discharges at Barton Springs. Hence the Barton Springs Pool acts as an indicator of environmental impacts of land development activities upstream.

The porous characteristics of Edwards aquifer has resulted in a direct interaction between activities on land and the groundwater quality. Therefore, soil erosion in hill country not only affects the local landscape and surface waters, but the groundwater, aquifers, and potentially Barton Springs. This sensitive underground network of water flows connects land development in upstream hill country to Austin culture downstream.

2.6.1.2. Inner-city Stormwater Management

Austin's inner-city is located on a land with numerous creeks and highly erosive soil. The increase in urban land use has resulted in larger volumes of urban runoff. Additionally, a considerable percentage of its area is always at risk of flooding. These frequent flooding has resulted in efforts by municipality to secure human lives and properties. Their solution to this problem includes widening of creek beds and securing them trough highly engineered measures. Unfortunately, Austin implemented its solutions long before sustainability topics. Today, insufficiencies of Austin's programs have become evident to the municipality and they are facing difficulties in passing the protection-restoration boundary.

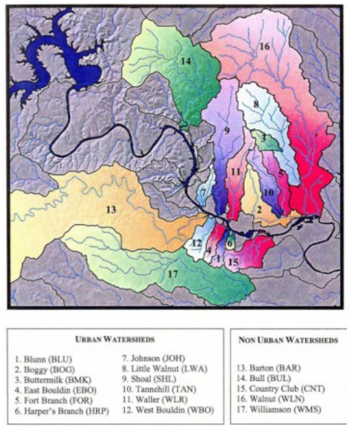


Figure 30 Major watersheds in Austin, City of Austin Watershed Protection Master plan Phase I [6]

The inner-city challenges of urban runoff can be classified as:

- Protection of residents and property from flooding and erosion
- Meeting water quality goals in a highly impervious landscape

High frequency of devastating floods is a major issue in Austin. The risk of flooding is a consequence of the collision between impervious surfaces of urban development and the violent hydrologic regime. This threat has resulted in a municipal strategy with a primary goal of protecting lives and property from periodic storm events. The severity of the problem is apparent in eroded and heavily armored creek edges with large concrete cobbles. In other words, the concrete impervious cover from roofs and paved surfaces, which is 50%, does not allow for natural infiltration and contribution to groundwater. Hence, the creeks are drying up, eroding, and the channels are widening because of runoffs at a higher volume and velocity. This also has resulted in lower water quality. For example, Little Walnut Creek expanded about sixty-five feet in width, (see figure 4) between 1962 and 1997 [2].

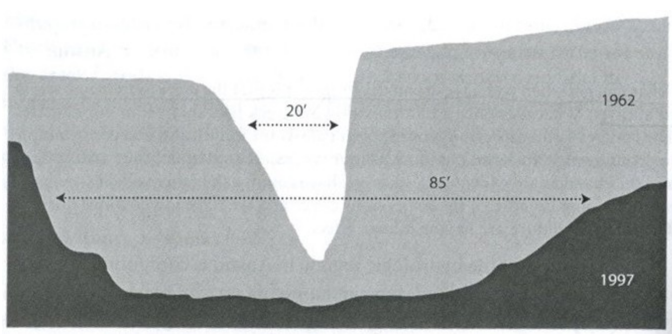


Figure 31 Cross-sectional diagram of Little Walnut Creek illustrating erosion over time, illustration by Shawn Kavon [2].

The condition of the creeks is highly affected by the past activities. As these creeks are at the lowest elevation, they served as the open sewer for both sanitary and stormwater flows in the early twentieth century. Today, the stormwater flow mix with the creek water and the sanitary waste is carried trough a subsurface piping system to the wastewater treatment plant downstream and east of the city [2].

2.6.2. Policy

There have been two types of perspectives about environmental governance in Austin: a) Due to economic development ideas, the urban development was prioritized and landscape was perceived as a bundle of resources to be harnessed for human ends. b) The unique natural culture of Austin indicates the need of protection from future development. As a result of conflicts between these two urban water approaches, nature could be revered or it could be exploited; but not both [1].

The *Austin Tomorrow Plan* policy was adapted by the city council in 1980 and focused on limiting development in environmentally sensitive areas of Barton Springs Zone and in areas next to waterways. However, the desire to steer the growth away from Barton Springs Zone to protect the aquifer was not realized, because there was a strong market force for development and people wanted to live in the hill country.

The population growth was fueled by high-tech industry in hill country and its exceptional natural beauty. This resulted in suburban development in Hill Country which was in a direct contradiction with the *Austin Tomorrow Plan*. These developments were supported by frequent municipal government's exemptions to subdivisions and land use regulations and state law that allowed developers to create Municipal Utility Districts (MUDs) [3].

Long local tradition of encouraging municipalities to govern themselves and the Texas Law of Extraterritorial Jurisdictions (ETJs) that enable municipalities to exercise subdivision and infrastructure regulations up to five miles beyond their corporate limits has resulted in different types of land development in the geographic areas between municipalities. Therefore, it is hard to redirect the developments into less water sensitive areas.

Regulatory attitudes of the State of Texas follows an economically rationalist approach that ties societal progress to property development and sees dense human settlement in Hill Country inevitable. In contrast to the State of Texas and the neighborhood municipalities, the City of Austin is one of the first US municipalities that showed commitment to protecting water quality.

For example, the Lake Austin Growth Management Plan of 1976 is one of the first examples of water quality planning in the United States. Measures include development density limits and construction bans on steep slopes, near watercourses, and sensitive environmental features. Table 1 presents a list of watershed management policies in Austin.

Table 18 Summary of past watershed ordinances.

Policy	year	Brief description
Lake Austin Watershed Ordinance	1980	impervious cover limits, structural controls, an erosion sedimentation control plan, and prohibition on building in the floodplain around Lake Austin
Comprehensive Watershed Ordinance	1986	extended environmental protection to watersheds that did not provide drinking water for Austin residents
Urban Watershed Ordinance	1991	required water quality control structures on new development in urban watersheds, recognizing that built-up areas also needed to protect natural resources

However, environmental and community groups felt that these measures were insignificant to protect Barton Springs from impairment, because although, ordinances were on the books, their existence did not always translate into rigorous enforcement. Hence, they formed Save Our Springs Alliance (SOS Alliance) to focus specifically on protecting Barton Springs and all of the Edwards Aquifer contributing watersheds. The SOS Alliance codified their desire to protect the Barton Springs and wanted to institute stringent municipal regulations to permanently prohibit large developments over the aquifers areas in the City's jurisdictions. The result was the SOS Ordinance which was voted into law.

Today, the environmental politics in Austin has evolved to a collaborative approach between environmentalists and developers. Major reasons for this change in environmental politics are: The SOS Alliance like every other social movement was weakened over time and its oppositional approach was not a reliable long-term political strategy. Moreover, the singular focus on protecting the springs has gradually been supplanted by other issues such as air quality, urban gentrification, affordable housing, and energy use; all emerged by sustainable development ideas gaining momentum in recent years.

Protection of urban creeks in inner-city Austin can be dated to its early settlements in 1839 when the idea of a greenbelt city captured the imagination of Austenites. Such plans and concepts of greenbelts or linear parks along inner city creeks can be observed in 1928 City Plan, 1961 Master Plan, bicentennial project of 1976, and civic improvement projects in 1970s and 1980s. however, such efforts has remained limited to short stretches of creeks, and construction continues on these areas to undo damages of the Memorial Day (major 1981 flood which took thirteen lives and caused a property damage of over $35 million, see figure 5) flood.

Figure 32 Memorial Day flood, Austin History Center.

Between 1981 and 1984, $75 million was approved by voters for capital improvement flood protection projects. The result has been armored creek banks that prevent erosion. Early methods for such activities involved dumping concrete onto the banks. This practice has been modified to include formed concrete walls, gabion walls, and geo-synthetic fabrics that mimic vegetated creek banks. Vegetated walls are aesthetic and provide at least a modest amount of riparian habitat, and in most successful instances, it is difficult to recognize that the bank has been stabilized [2]. Residents of Austin value the creeks with an emphasis on water quality. This is a product of the historical importance of the creeks to early residents, evolving knowledge about the state of the environment, and environmental degradation concerns emerged in the 1970s. The issue of water quality has been a central target of urban planning since the *Austin Tomorrow Comprehensive Plan* in 1970s [2].

Austin's approach to water quality activities has experienced its greatest transition only in the last two decades. Hence, the municipality has had a long history of flood and erosion control before starting a meaningful water quality improvement program. In 1996, the government brought flood and erosion control together with water quality protection as part of a series of departmental reorganizations to form a new department of Water Protection Department. The erosion and flood control personal were engineers from Public Works Department, and water quality staffs was from the Environment Management group in the planning Department. The department has adopted an integrated environmental management approach that recognizes the interrelation between various drainage mandates of the municipality. The collision between two cultures has resulted in collaborative efforts which produce integrated projects as opposed to single mission projects. The main reason for such reorganization was because many solutions to flood problems became environmental problems. This integrated approach of finding common grounds between different missions has resulted in a transition from rationalist model of environmental management into a multidisciplinary collaboration that requires cross-pollination to find optimal scientific, technical, and economic solutions [2].

In 2001, the newly formed department published its ambitious *Watershed Master Plan*. The plan addresses the flood, erosion, and water quality conditions in seventeen watersheds in the municipality's jurisdiction. The study includes detailed analysis of the watersheds and overlays these analyses to produce an integrated prioritization of service needs. It was estimated that the plan required $800 million over the next forty years. This is equivalent to about twice the historical capital spending rate [p76]. Hence, achieving the triple goals of flood control, erosion control, and water quality simultaneously requires substantial financial commitment.

By the plan, the watersheds are divided into three groups of urbanized, developing, and rural. The urbanized watersheds are those with greater than 50 percent impervious cover with creeks that are more than doubled in size. Channel enlargements in these watersheds are not expected due to the presumption that these systems have already expanded and are relatively stable. The activities in these watersheds would include channel restoration, property buyouts, and upgrade of existing flood control and water quality ponds. In contrast, the majority of change is expected to occur in the rural and developing watersheds. In these watersheds, impervious surface coverage and cleaning waterflows are expected to increase dramatically [2].

2.6.3. Design Standards

In order to conserve Barton Springs, The SOS Ordinance requires the impervious cover of developments in Barton Springs Zone to be 15-25%. It also requires the implementation of Best Management Practices (BMPs) to ensure that the average annual loading of common stormwater pollutants such as suspended solids and nutrients do not increase between pre- and post development conditions. The ordinance also required building setbacks of two hundred feet from major waterways and four hundred feet from main channel of the Barton Creek. Later, protection of Barton Springs became simultaneously a local issue of cultural preservation and a national issue of biodiversity protection, when Barton Springs Salamander (see figure 6) was granted protection under the federal Endangered Species Act.

Figure 33 Endangered Barton Springs Salamander Specie [9]

Today, the City embarks on an ambitious conservation land development program. In 1998, $65million in municipal bonds was approved to purchase fifteen thousand acres of undeveloped land for water quality protection in Barton Springs Zone. This approach is continued, and as of 2007 the City of Austin's *Water Quality Protection Land Program* managed about twenty thousand acres of land and put it under conservation easements. These lands serve as enormous stormwater BMPs to protect water quality. An unintended consequence of this approach is the fact that the land purchases for conservation inflate property values and make further conservation purchases more expensive [1].

In the case of inner-city's stormwater management, flood control strategies and armoring the creek banks reflects the ideas of economic development. Economic development needs a stable and predictable foundation for its economy to grow on. Such approach follows the Promethean approach and creates a sharp distinction between the built environment and predevelopment hydrologic flows. A good example of coupling water control with business development is the Waller Creek Tunnel Project. The $127 million project is the improvement of the channelized creek of 1970s. The project is a tunnel which will accommodate the majority of flows in the creek and protect the surrounding buildings and streets. Moreover, the project will create an amenity for downtown businesses to attract tourists and shoppers [2].

Figure 34 Channelized section of Boggy Creek in East Austin [2]

The municipality has developed two internationally recognized approaches to protect and enhance urban water quality. Both of these activities rout back in time, and in time of initiation, were ahead of most of the American cities. These two can be recalled as monitoring activities, and end-of-pipe urban runoff BMPs requirements from new developments. The monitoring activities was initiated in the mid- 1970s. The activities included longstanding monitoring of water quality conditions for watersheds throughout the city. Austin had automated samplers on many urban creeks in the 1970s and by the time they joined the federally funded National Urban Runoff Program in 1981, they had already ten years of data. The monitoring activities alone do not have any altering effects on creek water quality, but it recognizes the value in tracking how environmental conditions change over time [2].

In addition, Austin instituted water quality regulations that were performance- based and requires high levels of treatment with cost-effective sand filters in early 1980s. The sand filters provide high level of treatment in a small footprint, as well as modest long-term maintenance requirements and represent a strong commitment to protecting waterways from urban runoff impacts. However, the municipality has regulated strict rules about these end-of-pipe BMPs and the rules call for sand filter or equivalent. This has resulted in limited innovation. More recent source control strategies face difficulties in proving equivalence and therefore have not been adopted. The municipal regulations rely on proven technology which created a “technological momentum” to continue stormwater management in the established manner. In the mid 2000s, the Environmental Criteria Manual was updated and a handful of source control measures such as vegetated filter strips, rain gardens, rainwater harvesting, porous pavements, and biofiltration were included. However, these measures are not utilized by the majority of new development projects. These projects continue to rely on conventional strategies with established performance records [2].

The municipal water quality activities, both the monitoring and the BMPs regulations, can be seen at two levels. The regulations, which reflect the water quality interests of Austin residents, stabilize the nature-society network via well-established technological strategies. The codes translate regulations into material practices for developers. Although the establishment of the water quality program could be interpreted as a significant achievement in the 1980s, the resulting system of regulations resists modification and circumvention by newer strategies. Hence the evolution of the program largely fails to reflect new approaches to stormwater management [2].

2.6.4. Efficiency of the Design

The Edwards Aquifer is spread beyond the fragmented jurisdictional authorities, and the neighboring municipalities and ETJs do not follow an environmentally concerned approach similar to the City of Austin. 72 percent of the area of Barton Springs Zone is located outside the Austin's jurisdiction. Although SOS Ordinance was effective in controlling development within the City of Austin's jurisdiction, the unregulated growth over parts of the aquifer area outside the Austin's jurisdictions are still contributing to the Aquifers degradation.

Austin has successfully translated its cultural appreciation of Burton Springs into stringent water quality ordinances. However, this approach frames the nature as outside of human world which has to be protected from human influence and preserved in its original state. This method of environmental governance totally denies the human's ability to live in fragile landscapes and does not present solutions for such scenarios. Hence, emerging notions of Low Impact Development (LID) and source control strategies are totally denied because all forms of urbanization are interpreted harmful.

Furthermore, municipality's efforts to address flood and erosion problems usually conflict with water quality improvement efforts because stabilizing the channel for flood protection and erosion control is in direct opposition to restoration activities and the creation of biological habitat [2].

Moreover, the problem regarding monitoring and maintenance of BMPs is another problem with Austin's program. The municipality is responsible for monitoring of all BMPs. However, the maintenance of BMPs in commercial and multifamily residential buildings is the responsibility of the owner. To identify the deficiency, the municipality has to inspect every BMP and maintain BMPs for an ever increasing number of single-family residential. This requires annual increase in municipality budget, and result in uncertainty about the proper maintenance of some of the commercial and multifamily residential buildings. The situation degrades since the municipality does not even know the location of more than half of these structures. To remedy the situation, in 2005 the department began a comprehensive field survey to identify all BMPs in the municipality's jurisdiction and construct a database to manage them efficiently and effectively. As of November 2007, the database contained about 4,700 commercial BMPs and 860 residential ponds and was about 85 percent complete [2].

The above mentioned items highlight the municipality's challenges in managing a complex and continually expanding technological network. Municipal staff is charged with managing the network using the latest scientific expertise within a bureaucratic hierarchy. But, the municipality does not have the capacity to fulfill and maintain the ambitious goal of greening up the Promethean infrastructure of the past while maintaining the existing system. Ultimate control of nature requires energy and finances that are beyond most of the contemporary governmental bureaucracies [2].

Furthermore, Austin's inner-city activities are dominated by Watershed Department staff members that rely on scientifically proven and cost-effective rational environmental strategies. Hence, the inner-city is considered "unworthy of environmental protection" and the most significant issue here has become the issue of flood treat to property and human life [2].

The newly formed department finally came to the conclusion that environmental flows cannot be effectively managed in a segmented fashion because this merely pushes the problem from one geographic region to another or solves a flooding problem while creating a water quality problem [2].

In general, the Watershed Master Plan aims to first gradually approach address areas that are more problematic. There are not similar planning visions with previous greenbelt proposals, and the application of small-scale source control strategies is briefly addressed. Moreover, the plan emphasizes on the evolution of the existing drainage network, but the authors of the Master Plan are not enthusiastic about the outcomes of the water quality mission in the urban core. The reason is there are not enough regional retrofit opportunities in urban watersheds and inadequate regulatory controls in areas outside of the City's jurisdiction. Furthermore, they have concluded that the notion "returning the waterways to predevelopment conditions" is far from reach and in many cases, channelization is the best and the only option. Hence, the vision of restoring a natural system is declined and they are not going back to nature [2].

Although Austin's municipality is internationally reputed among water quality professionals and it has a newly integrated department for stormwater management, these interesting facts have not resulted in groundbreaking water quality project throughout the city. Municipality's efforts beyond the scattered network of sand filters and significant changes in bank stabilization approaches show its commitment to water quality mission are few.

The wet pond program is one of the most visible examples of Watershed Department means of retrofitting the central core. Wet ponds are highly engineered structures that act like natural water filters. Unlike sand filters that are not effective in removing dissolved contaminants, wet ponds are composed of a permanent pool as well as wetland plants that remove both nutrients and dissolved contaminants from urban runoff. In contrast to other efforts by the City such as channelization's, which create a distinct boundary between nature and urban areas, wet ponds have the ability to blur the boundaries between technical, natural, and social systems. The ponds act as flood control devices, water quality filters and aesthetic amenities. Such controls can be considered as aesthetically pleasing Stromwater treatment facilities. They are used to treat water from a large area of landscape. However, they are very costly in both construction and maintenance and need a large land area. Hence, they have to be implemented in private and public lands such as parks with the collaboration of Watershed Department [2].

Figure 35 Few examples of completed wet ponds in Austin, top: Oak Springs, middle: Conventional Center, bottom: Central Park [7].

Importantly, initial efforts by The City for significant setbacks from creeks would have been a better solution. But unfortunately, these regulations are neglected and considerable amount of buildings are built over creeks. It is very costly for the municipality to purchase such structures to allow urban waterways more room and freedom. These purchases are done in limited instances and are urban equivalent to conservation land purchases in the rural Hill County. Here the problem is the municipality comforts a complexly tied network of built environment and nature of the past century. This built environment resists the large-scale changes which is necessary for the improvement of water quality [2].

2.6.5. Conclusion

In general, the Austin case study highly shows the inefficiency of the Promethean approach that tries to control the nature, and draw a distinctive boundary between it and the urban development. The experiences by the City of Austin represent the extraordinary resources such as land use and labor and costs to effectively apply such strategies. Importantly, most of the cities do not have access to such resources.

In addition, keeping the balance between three major issues of flood control, erosion control, and water quality was not achievable due to the following factors:

The prioritization of the goals: In the inner-city, Austin, flood and erosion control missions were more important than the water quality goals, because the municipality members assumed that the inner-city is unworthy to protect.

The implementation method of contradictory missions: Channelization and stabilization of the creek beds has destroyed natural processes that enhance the quality of water.

So, I suggest that in the policy making stage, it is important to investigate policies be aligned together. In addition, the program should be designed in a manner that its implementation is in correlation with all major issues. In the reality, prioritization in the designing program phase and the implementation phases is unavoidable due to finite financial resources of cities. But, prioritization in policy making stage threatens the balance of overall policies and their expected outcomes. This is evident in Austin's Watershed Master Plan where even the writers assume that the water quality missions cannot be achieved. In the program design phase, the responsibility of implementation can be delegated to organizations outside the Municipality body. The municipality may keep its inspection rights to ensure proper implementation of the programs.

To justify the deficiencies of water quality program, the Watershed Master Plan mentioned that the municipality has no control in the areas outside the city's jurisdictions. Municipalities are responsible for areas within their jurisdictions, but they have to share their knowledge with their neighbors in an effective and meaningful manner. Hence, I argue municipalities should form a committee to share common regional interests.

Although Austin has been a pioneer city in dealing with water issues, there were deficiencies in its approach. First, the introduction of sand filters in building code has resulted in limited innovation. Second, there was a lack of innovation in BMPs. Although alternatives to sand filters were introduced later, alternative BMPs were not implemented widely after utilizing sand filters by developers. So, different measures should be entered the building codes. Finally, early methods of bank stabilizations cost the city a considerable amount of funding, and they were redefined in order to reduce the adverse effects. Hence, I argue that pot-implementation's refinements of novel methods should be considered.

In conclusion, the City and its residents "nature protection" point of view in dealing with the complex network of urban development resulted in a frustrating process of correcting previous activities. Moreover, the municipality's efforts for educating residents were not efficient, because it was not successful in changing the perspective of residents. Hence, the role of public education and involvement can be highlighted here as an important measure of any water management policy and program.

2.7. Seattle

2.7.1. Background and Major Issues

The city of Seattle is famous for its rainy characteristic. The mental preoccupation with rain not only involves precipitation but the unavoidable cloudy and dark conditions. Seattle is in the Puget Sound Convergence Zone between the Cascade and Olympic Mountains, where clouds and rain are trapped for three-quarters of the year. The bright side of Seattle's climate is that the moderate conditions also result in a lack of severe metrological events such as droughts and flooding, although long term risks of earthquakes and volcanoes are a continual threat [1].

Seattle is located within the state of Washington in the North West of the United States. It lies approximately 160 miles north of Portland. The climatic conditions are similar to the Yorkshire region, experiencing over 960mm of rainfall per year and an average of 30cm of snow2. Seattle Public Utility (SPU) manages and provides the foul and surface water drainage to 170,000 customers. Outside of these areas, King County provides drainage facilities. Within the greater metropolitan area of Seattle, there is a population of over 1.3 million. Seattle first started to implement green stormwater infrastructure in the late 1990s [2].

Seattle has a long tradition of environment preservation activities. Importantly, the fact that the city's creeks are severely affected by the urbanization and removed or reduced number of salmon species in these creeks has highlighted the importance of sustainable watershed preservation. The condition of the Seattle's creeks is closely related to the city's drainage network development. There are three types of drainage network in Seattle [3]:

- Combined sewer network
- Ditches and culverts
- Separated and partially separated networks

The combined sewer network which is originally designed by Benezette Williams in the nineteenth century, serves about one-third of the geographic area of the city and caries a combination of sanitary and stormwater volumes to Metro's regional wastewater treatment plants. The ditches and culverts network covers another third of the city. These networks are spread in the northern areas of the city which were annexed primarily in the 1950s. These networks were agreed to be upgraded by municipality, but due to funding constrains, significant infrastructure upgrades have been completed only on major arterials. Additionally, separated and partially separated networks handle some stormwater volumes separately from sanitary wastewater volumes in the remaining third of the municipality's jurisdiction.

The ditch-and-culvert networks and the separated or partially separated networks discharge directly into the city's creeks. The creeks serve as the trunk lines for these networks because they are low-elevation features that provide an existing and inexpensive conveyance channel for urban runoff. These drainage networks are an eco-technic hybrid that binds land development to waterflows and their biota, including salmon. Seattle once had some forty creeks that sustained healthy salmon population; the conversion of these creeks to drainage conduits, along with loss of habitat due to urban development, has resulted in only four creeks that can sustain salmonid population today (see figure 1).

The city has four major creeks in different parts. However a certain issue has highlighted the importance of sustainable watershed preservation of the city's creeks. In 1999 the U.S. National Marine Fisheries Services listed wild salmon population as threatened under the Endangered Species Act (ESA). The restoration of salmon had to be done through the restoration of the degraded waterways in Seattle which were significantly modified in the twentieth century to allow for urban development. In the most extreme cases, they were completely filled in or directed into pipes. Today, the creeks of Seattle are a particular form of water that provides multiple insights into the relations between the city and nature. They receive a great deal of attention and energy from the municipality and residents.

The people power is an important factor of the Seattle's municipality structure. After the 50s and 60s fights over governance control, ultimate control of urban politics were be directed nor by the regional government or by municipality elected officials but by an active citizenry. Hence, many Seattleites participated in environmental movements such as back-to-the-land, bioregionalism, and appropriate technology.

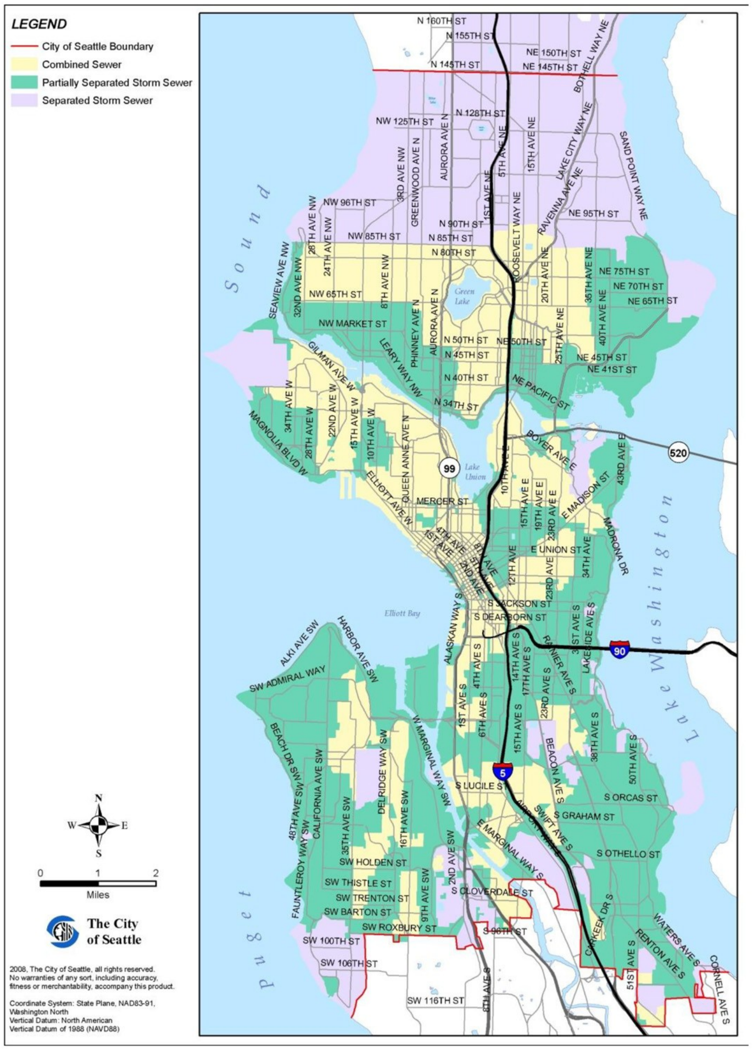


Figure 36 Map of City Drainage Systems [3]

2.7.2. Policy

In 1994 the city released its twenty-year vision, Toward a Sustainable Seattle. The comprehensive plan was based on values of environmental stewardship, social equity, economic opportunity, and community, with an emphasis on channeling development into urban villages and centers. Then, local plans by neighborhood organizations were invited by the municipality to comply with the goals of the comprehensive plan. Although, the neighborhood plans were not legally binding, they required new development proposals that conflict with plan goals to go through a review and revision process.

Importantly, urban environmental restoration was a significant focus of neighborhood planning efforts. Residents singled out creeks, parks, and open spaces as places where nonhuman elements of the city resided and as important places to restore and protect. In 1992, Mayor Rice acknowledged the significance of nature in the city in his introduction to the two-year Environmental Priorities Program.

Former Mayor Rice embraced a relational perspective that recognized humans and the built environment as part of nature rather than separate from it. He understood the growing importance of urban creeks to those residents who lived adjacent to them, signaling out urban runoff as “perhaps the most pervasive and difficult factor to control water quality problem” in Seattle. The creeks have become a perfect place to direct the energies of self-governance and reverence of nature.

The Seattle Public Utilities (SPU) was formed in 1997 for the sake of combining the municipal government’s operations of water supply, wastewater conveyance, stormwater management, and solid waste management into one organization. The drainage activities of this organization are divided into four major programs: stormwater and flood control, landslide mitigation, aquatic resource protection- water quality, and aquatic resource protection- habitat. The SPU has issued three comprehensive Drainage Plans in1998, 1995, and 2004. Each of the plans places an increasing emphasis on water quality and habitat protection due to a variety of state and federal environmental protection laws notably the *Clean Water Act* (CWA) and the *Endangered Species Act* (ESA).

The municipal government has officially recognized urban creeks as an element of the city's drainage networks since the late 1990s, and has made a concerted effort to improve water quality conditions and restore habitat. However, there have been many nongovernmental efforts since the 1960s to change the conveyance logic of urban drainage in the city initiated by community activists who want to improve the conditions of their neighborhoods. The activities by Community activists to reorient drainage patterns in Seattle suggest that the municipality is not the only urban environmental manager, and the grassroots work of residents reorients urban nature in ways that are strikingly different from the municipality techno-managerial approach.

The City of Seattle *Stormwater Management Plan* was developed in compliance with the 2007 NPDES Phase I Municipal Stormwater Permit to [4]:

- Protect water quality
- Reduce the discharge of pollutants to the “maximum extent practicable”

- Satisfy appropriate requirements of the Clean Water Act
- Meet state requirements to use all known, available, and reasonable methods to prevent and control pollution to waters of the state

The burgeoning support of urban creek restoration among urban residents is served as a springboard for institutional reform within the municipal government. When Mayor Schell came into office in early 1998, he recognized the upcoming millennium and the imminent ESA listing as an opportunity to establish historic municipal government programs. His unique background for a mayor made him an ambitious visionary with big ideas. He recognized the connection between neighborhood activities and the environmental character of the city. Schell's conflation of salmon health and human health was a reflection of his belief in the standard prescription for sustainable development. He looked at environmental protection and economic development as complementary rather than competing goals.

He inaugurated the Urban Creeks Legacy Program in 1999, which focused on the four creeks restoration. The approach represented a unique form of environmental protection with the goal of public education and infrastructure improvement rather than biological restoration and protection. The creeks restoration was not only for returning salmon, but also for creatures that range from deer and eagles to algae and aquatic insects. They were places of meditation and treat, outdoor classrooms, filters for runoff, corridors for both hikers and wildlife, and a place to teach children how to pick a future.

2.7.3. Design Standards

In Seattle, initial efforts to save salmon species is now turned into a city-wide will to implement a sustainable stormwater management program. The city has two programs: the NDS approach by the SPU, which is a step-by-step evolution from prototype projects to large scale redevelopments, and the Green Factor as a subsequent program of the Berlin’s BAF.

2.7.3.1. The Municipality's Natural Drainage Systems Approach

To initiate the Urban Creeks Legacy Program, Schell asked SPU staff members to develop a pilot project to reduce the impact of urban runoff on receiving creeks. Due to the fact that the Seattle’s urban area is almost completely built up, they focused on the leveraging the public rights-of-way instead of Greenfield protection. The pubic rights-of-way comprised 25 percent of the city’s land use. In return, a new logic of urban drainage that traced problems and solutions of urban drainage back to the source was presented. The result was the Natural Drainage Systems (NDS) approach. The NDS mimics the pre-urban forested condition as closely as possible without adopting the aesthetic look of the forest. The NDS approach, similar to LID, involves strategies of infiltration, flow attenuation, filtration, bioremediation with soil and plants, reduction of impervious surface coverage, and provision of pedestrian amenities.

2.7.3.2. Green Factor as a Land Use Planning Tool

The "Green Factor" landscape requirement of Seattle is designed to increase the quantity and quality of planted areas and to build the city's green infrastructure through development regulation. It allows flexibility for developers and designers to meet development standards. The Green Factor is currently applied to new developments in some urban areas. Vegetation layers and increased stormwater infiltration are highly encouraged to favor the ecological functionality of the urban landscape.

Although, the Green Factor is based on the experiences gained in Berlin and Malmo, it is designed on the unique environment conditions of Seattle. In general, it works similar to BAF with different description of weighting factors and minimum Green Factor Scores for different land uses.

2.7.4. Programs

2.7.4.1. Natural Drainage System (NDS)

2.7.4.1.1. Street Edge Alternative Street

Street Edge Alternative (SEA) Street was the first project to follow the NDS approach, a small, single block retrofit project in the Piper's Creek watershed. One of the reasons why this particular place was chosen was the fact that the Piper's creek watershed has a ditch and culvert stormwater drainage network. Hence, the project was not only a retrofit project but also an upgrade to a street with an antiquated infrastructure. The SPU staff received strong support from local residents. They had a collaborative design process with residents and the design team negotiated the various issues such as street and sidewalk width, curb height, and number of parking spaces, as well as runoff pathways and locations of swales. The existing street width was reduced from twenty-five feet to fourteen feet, a significant number of parking spaces were removed, and a series of bio-swales along with a four-foot-wide sidewalk were constructed on the west side of the street. In some cases, the swales were lined with an impermeable barrier to avoid basement flooding issues. Finally, a landscape architect worked with homeowners to integrate the street edges with their properties and to select from a palette of native and nonnative plants.

The project was completed in 2001 and it cost $850000. Although it is a small cost compared to other SPU projects, it reflects the high costs of such projects. The project was a prototype, and change in the street character was dramatic, transforming a nondescript two-lane residential street with a ditch-and-culvert drainage network into a meandering, narrow road with lush vegetation and a series of swales. The design slowed vehicle traffic, provided a sidewalk for pedestrians. The new street design reduced the impervious cover by 11 percent. Except for heavy and infrequent rainfalls, the project has the ability to attenuate all or almost all runoff. In contrast to some resident's concerns about the curb-and-gutter design and reduced number of parking spaces, the residents from the SEA street and adjacent streets began to use the right-of-way in new ways (see figure 2). It changed into a walking space where people could walk and kids could play. It completely reinvents the aesthetic and functional qualities of public right of way. However, it is not merely an upgrade to the city's drainage network. The dual purpose was restoring the natural hydrologic function of the urbanized watershed while increasing residents' understanding of the natural processes of what landscape architects call "eco-revelatory design". The goal of eco-revelatory design is highlighting the connections between human and nonhuman through a process of revealing and marking.

Figure 37 SEA Street Before and After redevelopment [5].

The battles that erupted between municipal departments over the modification of right of way areas were the most difficult problems of this project. The transportation and emergency services department had concerns about safety of children with respect to open drainage swales and access of emergency vehicles and adequate provision of parking. Due to the fact that the project was initiated by the municipality, the SPU had more negotiating power with other municipal departments and could successfully push for more radical reinterpretations of street function.

The project received numerous regional and national awards. Based on its success, the SPU went on to replicate, expand, and revise the SEA street process with four more projects.

2.7.4.1.2. The Grid and the Swale: The High Point Redevelopment

The High Point Redevelopment project (figure 3) is a complete redevelopment of a 129-acre site in the Longfellow Creek watershed of West Seattle. In the early 2000s, Seattle Housing Authority (SHA) decided to redevelop the community and initiated a master planning process to create a walk-able, multiuse, New Urbanist neighborhood with modest green building strategies. Fortunately, the SPU staff members were just coining off their initial success with SEA Street and were looking for an opportunity to scale up their approach to a larger project. They saw the High Point Redevelopment, encompassing almost 10 percent of the Longfellow Creek watershed, as an ideal opportunity and approaches SHA about a possible collaboration.

SHA agreed to incorporate the NDS approach at High Point under three conditions. First, the SPU would pay the difference between the conventional SHA agreed to incorporate the NDS approach at High Point network cost and the upgraded NDS network. SPU was willing to pay for this performance upgrade because it would partially fulfill the goals of the Urban Creek Legacy Program for Longfellow Creek and would serve as another example of the efficacy of the NDS approach. Second, SHA required that SPU be responsible for obtaining municipal approval for the various building permits for the project. The SPU staff agreed this point, because of some reasons. First, the SPU was an inside municipal government agency and a public corporation affiliated, but simultaneously, it is separated from the other municipal departments. Second and Most importantly, SHA wanted to assure that the appearance of the project would not be affected by the NDS approach, following on the aesthetic philosophy of "normalcy" as promoted by New Urbanist designers.

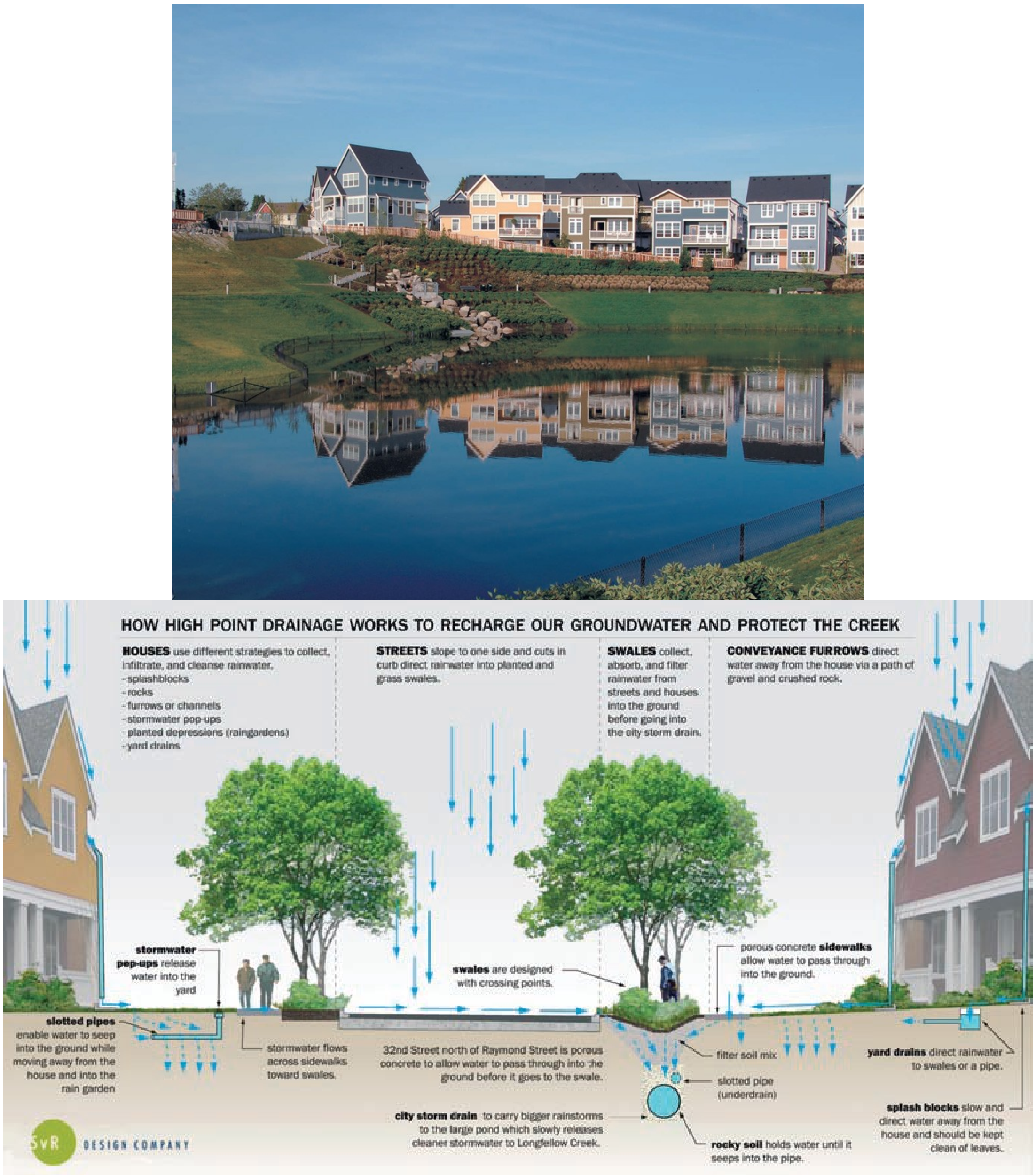


Figure 38 High Point Redevelopment project [5].

So, under these circumstances, the design team with considering the various goals of the project created a high density, walk-able, environmentally friendly, and affordable community over the next three years. The level of collaboration between the various city agencies, particularly in designing the thirty-four blocks of right-of-way, was unprecedented.

The extended negotiations over changing the drainage regime at High Point revealed the dominance of conventional stormwater logic not only in the practices of design professionals and municipal experts but also in the municipal development codes. The design team was fortunate to have dedicated municipal staff members who were willing to challenge the existing standards and also the leading sustainable architecture and engineering firms in the city.

In some cases, the project goals of creating a dense urban environment of New Urbanist development were in direct contradiction with the NDS goals, reflecting the struggle between ecological and neo-traditional designers over the last three decades. At times, there was an undercurrent of resentment by the design team that the project was being compromised by the NDS approach, but eventually the team members found amenable design solutions to satisfy the numerous and conflicting project goals. Today, the project is internationally known as one of the most successful attempts to meet both social and environmental sustainability goals in an urban context.

In terms of drainage, the design reflects a hybrid of the NDS approach and a conventional curb-and-gutter network. Narrow streets slant to one side rather than from the center to each shoulder, and curb and gutter is used to direct stormwater to twenty-two-thousand linear feet of bio-swales, where it is absorbed and filtered. Some of the swales were designed to be shallower than the standard NDS swale to provide more play area for children. The SPU developed a Technical Requirements Manual that spelled out the philosophy and design implications for the site developers. Although there were some compromises, the team felt that it achieved all of its goals. Despite the documented Performance o the previous NDS projects, the state Department of Ecology questioned the efficacy of the NDS approach for larger storms and ultimately required the design team to include a traditional catch basin and conveyance network as well as a large detention pond as a backup stormwater network. Project team members predicted that the conventional network would become unnecessary, and the large detention pond area would eventually be redeveloped as a park or additional housing. The overall increase in cost for the drainage upgrades was $3 million, and the new network was expected to reduce runoff from a one-inch storm by 80 percent when compared with a conventional network. In other words, the majority of rainfall from a typical storm would be infiltrated rather than discharged to Longfellow Creek.

The master planning process included design of not only the rights-of-way but also the private properties in the development. It gave the design team the opportunity to extend the NDS approach beyond publicly owned land. Some of the single-family houses have rain chains that provide a visible flow of water as it goes from the roof to the lawn where it is infiltrated, a form of technological transparency or eco-revelatory design. Other residences have downspouts that are connected to underground perforated pipes to gradually infiltrate rainwater into the subsurface. The SPU team developed an informational packet for homeowners outlining the drainage features to serve as an educator of new residents in the future. Furthermore, the project team included drainage restrictions in the subdivision recorded documents and future homeowner association covenants to address impervious cover and landscaping requirements.

2.7.4.2. Green Factor

The scoring system of the Green Factor is developed to encourage larger plants, permeable paving, green roofs, vegetated walls, existing trees preservation, and layering of vegetation along streets and other visibly public areas. Furthermore, some beneficial bonuses are provided for such projects. Importantly, the automated score sheet calculator enables the designers to easily experiment with different combinations. The goals of the Green Factor are:

- Growing livable neighborhoods
- Improving air quality
- Creating habitat for birds and beneficial insects and
- Mitigating Urban Heat Island effects
- Reducing stormwater runoffs
- Protecting receiving waters
- Reducing public infrastructure costs

The green factor utilizes a user friendly automated score sheet. Each kind of development in different regions of the city should score at least the minimum green factor score associated to that region. The green factor was initially applied to commercial zones in 2006 and by aid of revision and changing point values and adding some new categories to the system; it is now spread throughout the city of Seattle.

Table 19 Green Factor weighting factor table.

Surface type description	Weighting factor
Sealed - Surface is impermeable to air and water and has no plant growth (concrete, asphalt, slabs with a solid sub-base)	0.0

Partially Sealed – Surface is permeable to water and air and has no plant growth (clinker brick, mosaic paving, slabs with a sand or gravel sub-base)	0.3
Semi-open – Surface permeable to water and air; infiltration; plant growth (gravel with grass coverage, wood-block paving, honeycomb brick with grass)	0.5
Surfaces with vegetation, unconnected to soil below, such as underground garages with less than 80 cm of soil covering	0.5
Surfaces with vegetation that have no connection to soil below but with more than 80 cm of soil covering	0.7
Surfaces with vegetation, connected to soil below available for development of flora and fauna	1
Rainwater infiltration per m² of roof area over surfaces with existing vegetation	0.2
Greenery covering walls and outer walls with no windows; actual height up to 10 m	0.5
Green roof 0.7	0.7

The Green factor experiences in the city of Seattle may emerge recommendations such as:

- For achieving better scores it is better to have open spaces situated on-grade when possible.
- Using drought tolerant and native plants can boost the function and gain point on green factor.
- As rain gardens are relatively low cost and highly functional, they are a good candidate to score higher in Green Factor.
- Green walls are flexible to design, and low cost. They have aesthetic and functional benefits and a high green factor score.
- On-grade permeable paving can provide an additional 0.5/SF factor.

2.7.5. Efficiency of the Design

Seattle is successful in shifting the perspective of its citizens from protection assumption toward integration assumption, and it has successfully used the active citizenry governance power and will to achieve the goals of a newly born sustainable stormwater management plan.

2.7.5.1. NDS

The success of the NDS approach is illustrated in the achievement of SEA Street project. The monitoring results of this project for two years indicated that 99% reduction of the total urban runoff volume was achieved. The outcomes of the SEA Street are presented in table 2.

Table 20 Cost-benefit analyses of the SEA Street [4].

Street Type	*Local street* SEA Street	*Local street* Traditional
Community Benefits	▪ one sidewalk per block ▪ new street paving ▪ traffic calming ▪ high neighborhood aesthetic	▪ two sidewalks per block ▪ new street paving ▪ no traffic calming ▪ no neighborhood aesthetic
Ecological Benefits	▪ high protection for aquatic biota ▪ mimics natural process ▪ bio-remediate pollutants	▪ high protection from flooding ▪ some water quality
% impervious area	35%	35%
Cost per block (330 linear feet)	$325,000	$425,000

A significant advantage of the High Point project is that there were no community members; existing low-income residents were moved to other SHA facilities. SHA held a number of meetings with residents from adjacent neighborhoods to address traffic, density, and aesthetic qualities of the redevelopment, but these residents were not central stakeholders in the project. However, the novelty of the design required additional meetings and training for the housing developers.

An important aim of the intensive design process at High Point was addressing and correcting the restriction in the existing municipal code and make changes, so the NDS approach would be allowed (but not required) for future projects. What once was a pilot project approach on SEA Street gained momentum as the standard approach to manage urban runoff in Seattle. The large size of High Point created an opportunity to rewrite the codes that govern urban drainage in the city and permanently changed the relations between water and the city's residents. The extended negotiations over urban runoff at High Point revealed the pervasiveness of conventional environmental management, not only in the practice of design professionals and municipal experts but also in municipal regulations. The Promethean logic of controlling nature through big engineering was ingrained in the DNA of the city through its land use development codes. The emphasis on changing the development codes demonstrated how the NDS approach relied on the existing formal mode of techno-managerial governance. However, this emphasis on code revision rather than experimentation at High Point sacrificed many of the social learning aspects of the NDS approach. Specifically, High Point has the look and feel of a traditional residential development; the eco-revelatory character of the other NDS projects is less apparent here. Hence, the NDS approach missed some of its educational benefits in favor of a "have your cake and eat it too" approach of simultaneously achieving social and environmental performance. The SHA required a neighborhood that had a "normal" feel. The high performance infrastructure is subservient to the social aspirations of the project; the aesthetics of the traditional neighborhood supersede that of water flows.

2.7.5.2. Green Factor

The Seattle's Green Factor program is a successful program in terms of entering the building code and also gaining citizens' support, because it has been built on the public background of protecting Salmon. Reasons for its success can be categorized as:

- Appling in the whole city
- Justifying people, designers, developers and policy makers that there is a direct relationship between Salmons' health and the environment's health
- Understanding the rules of the program clearly by policy makers, designers, developers and residents
- Reducing the uncertainty about the program

2.7.6. Conclusion

The City of Seattle has followed the idea of directly linking the health of residents and the health environment similar to the current approach of the City of Melbourne. The following factors are the main reasons of this prosperity:

- It was a realistic and step-by-step approach instead of an ambitious approach.
- It was built on people's concern about Salmon's health and not just on federal requirements such as Clean Water Act or Endangered Species Act.
- It addressed health, ecology, hydrology, and climate change issues simultaneously.
- It considered the key role of public education in redefining the human-nature relationship through community engagement and public involvement in local projects.

2.8. Portland

2.8.1. Background and Major Issues

Portland is known as one of the greenest cities in the US. The most important driver for the City to rethink its water policies was the extreme pressure on its combined sanitary and stormwater sewers and the frequent overflows. It is worth mentioning the important role of the people in determining the success of Portland's approach.

Portland is located within the state of Oregon in the North West of the United States. The city has a population of 575,000, increasing to 2 million across the metropolitan area. Its average rainfall is approximately 940mm per year and 13 cm of snow1. The Bureau of Environmental Services (BES) has municipal responsibility for managing surface water, as well as the foul sewerage [1]. Portland's stormwater program began in the early 1990s in response to the National Pollutant Discharge Elimination System (NPDES). The Municipal Separate Storm Sewer System (MS4) Discharge Permit was issued by the Oregon Department of Environmental Quality (ODEQ) to address water quality regulations [2].

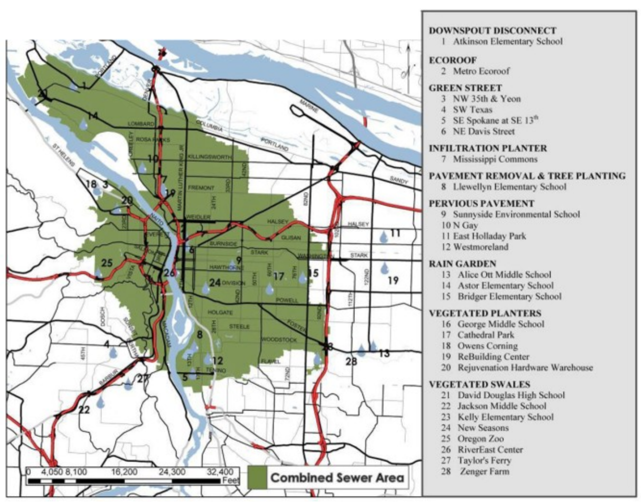


Figure 39 Half of Portland's area is served by Combined Sewer Network [3]

One-half of Portland is served by a combined sewer system (see figure 1), and the other half is served by a separated system. When it rains, stormwater runoff mixes with sewage in the combined system, overloading drains. Some of the sewage stormwater mixture then overflows into to the Willamette River and Columbia Slough. Heavy rainfall can also cause combined sewers to back up into cellars. These combined sewer overflows (CSOs) occurred an average of

100 days each year before 2011. Portland is constructing large tunnels to catch and redirect combined sewage overflows for treatment, but also using decentralized solutions such as green streets, Ecoroof (commonly known as green roofs), rain gardens, swales, planters, and disconnected downspouts to keep as much stormwater as possible out of the sewer system [3].

2.8.2. Policy

The City of Portland has attempted to apply decentralized stormwater management on city-scale through coordinated initiatives, rather than direct planning. In this case, because of existing pressure on the combined system, the initiative came about more or less by necessity. But a potential crisis turned into an opportunity. In 2008, Portland's Mayor Sam Adams announced the *Grey to Green Initiative*, which provides a budget of 50 million dollars over five years to increase the rate of green space in the city, not limited to, but particularly for stormwater management concerns [3]. Based on the *Grey to Green Initiative*, 43 acres of eco roofs, 50,000 street trees and 920 green streets were planned to be implemented until 2013 [4].

The proper solution that the BES have implemented to overcome the problem of pressure on the combined sewer system and its frequent overflows, included vast implementation of BMP's in different parts of the city to reactivate the local hydrological cycle [3].

Their focus was to develop an approach to advance green infrastructure and sustainable stormwater management which is connected with public education activities.

Because there were a number of possible approaches that could be adopted to require BMPs, in 1996 the City created a Stormwater Policy Advisory Committee (SPAC), which included a diverse group of stakeholders from landscape architectures, architectures, engineers, institutional organizations, and the stormwater treatment industry, to provide input to the City on stormwater matters [5].

Portland began developing a stormwater management plan. As part of the process of developing the plan, the team at BES examined the City's procedures and practices to identify activities the City already performed that met the new regulations. They also began implementing and monitoring new techniques to determine BMP feasibility and effectiveness. Armed with this information, they created a matrix of regulatory requirements and current practices to highlight where the practices met, exceeded, or failed to address the regulations. They then collaborated with other departments to identify new BMPs that were needed to meet the regulations, and in doing so established a "to-do" list and timeline [5].

2.8.3. Design Standards

Portland is using two approaches to tackle the problems associated with excessive pressure on its local sewage system during heavy rain: 1. Expand and enlarge its combined sewage system (conventional solution), 2. Implement decentralized solutions.

The city of Portland has initiated several programs in regards to sustainable stormwater development, including [3]:

- An Ecoroof Program,
- A Green Streets Program,
- A Downspout Disconnection Program,
- An Innovative Wet Weather Program,

The general goals of these programs are to reduce the stormwater volumes as much as possible in addition to enhancing the quality of life of residents. These programs include implementation of numerous Best Management Practices (BMPs) (see figure2-4) and the City is responsible for implantation of these BMPs. It has presented a few templates and the developers should choose between them.

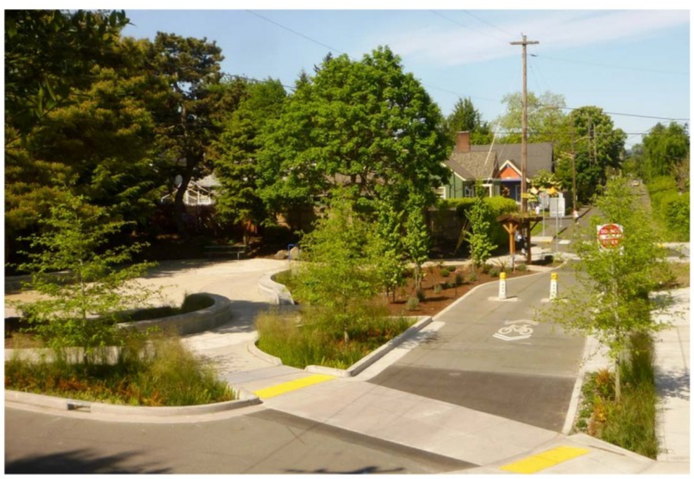


Figure 40 Holmes Park Green Street

Figure 41 An Ecoroof Example in Portland, [3]

Figure 42 Rain garden and infiltration planter at Mt. Tabor Middle School, [3].

One of the most important reasons why the city opted for decentralized solutions was their reduced cost compared to conventional solutions. The decentralized measures in public spaces are funded by capital funds and the money from the *Grey to Green* initiative. Portland also has received grants to fund sustainable stormwater management solutions. For example, the Innovative Wet Weather Program is funded with a grant from the federal Environmental Protection Agency. In addition, there are also private initiatives which can be co-financed with municipal funding after negotiations [3].

2.8.4. Efficiency of the Design

The outcomes of the BES approach are:

- Pressure reduction on sewer system
- Minimization of flood damage
- And reactivated local hydrological cycle

By the ending point of the *Grey to Green Initiative* in 2013, 191 eco-roofs covering 11 acres of rooftop were completed, over 32,200 new street and yard trees were planted, and 867 new green street facilities were completed [6]. As a result, the pressure on the combined sewer system has reduced dramatically (see figure 5). The City of Portland completed its 20-year CSO Control Program in December 2011. The program reduced CSOs to the Columbia Slough by more than 99% and to the Willamette River by 94%. Instead of an average of 50 Willamette River CSO events each year, there are now an average of four CSO events each winter and one event every third summer during only very heavy rain storms [7].

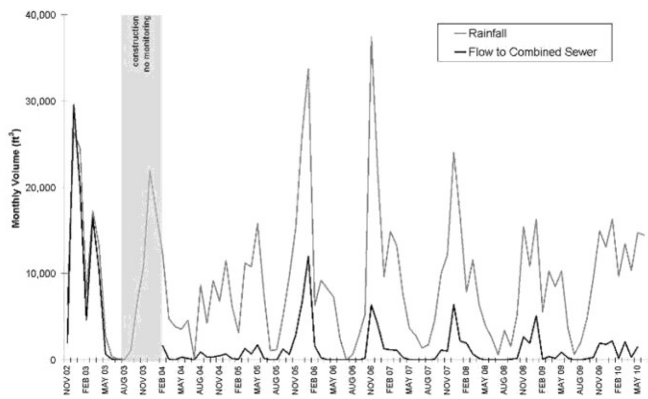


Figure 43 Monitoring at Glencoe Elementary School showing reduced inflow volumes to the combined sewer system [3].

There is an argument regarding whether Portland's approach is coherent enough to be considered as a program. However, it is very important to note that their approach has resulted in solving the initial problem and reputed the city as "the most sustainable city in the US" by exposing the BMPs to the public and improved amenity. The reason for this success is that they have identified the problem profoundly and came up with the most effective, yet simple, solution for it. Other problems and issues regarding this approach are:

- Different levels of success for individual projects
- Template based solution rather than case specific designs
- Long-term maintenance duties are not properly clarified

Although such approach limits the innovation, as people liked them and they gained popularity, long waiting lists of requested cases are reported in Portland. The City of Portland is a good example of how decentralized stormwater management can be applied on city level through coordinated initiatives, rather than direct planning.

Decentralised installations are sometimes even viewed by the public as community gardens, strengthening local identity. Hence, Intensive and creative public outreach largely contributed to this success [3].

Ultimately, the resolve of the City of Portland and participation of Portland residents plays a major role in helping to make the city famous as the "Most Sustainable City in the USA" [8].

The Grey to Green Initiative demonstrates that individual site specific decentralized measures can function on their own and be linked together to manage stormwater on district or even potentially at an urban scale. Green roofs, infiltration areas, pervious surface materials, and other such measures all make a small contribution to a more sustainable handling of water resources and when integrated with urban planning or landscape design, the potential exists to make a city more attractive [3]. Furthermore the case of Portland shows that when decentralized stormwater planning becomes publicly known, it has a positive impact on the inhabitants' identification with the city and with the issue of stormwater, prompting private citizens to take part in this development [3].

2.8.5. Conclusion

The case study of Portland reveals the effectiveness of decentralized BMPs to reduce the adverse impacts of urban development. However, there are a few fundamental problems with the initiative based approach of the City of Portland. First, there is no overall city-wide plan for decentralized stormwater management. Portland’s approach does not follow any milestones, and it only defined an end point of implementing a predefined number of facilities. This has resulted in uneven distribution of facilities throughout the city. Secondly, their approach is highly dependent on the amount of funds the initiatives can provide and it is hard, if not impossible, to determine the effectiveness of this approach in creating long-term behavior change among residents. Also, And lastly, we cannot be sure whether the success of this approach was due to enhanced understanding of residents about environmental issues, or was it just because the residents interpreted that these facilities beautify the urban environment. Hence, I believe that it is challenging to conclude whether this initiative based approach can be suggested to other cities or not.

3. Identified Connections and Disconnections in Case Studies and the Proposed Framework

3.1. Identifying Connections and Disconnects

In the previous chapters, experiences by different cities in dealing with water issues were presented in the form of case studies. In this chapter, I attempt to analyze key topics from case studies to discuss urban water issues, policies that address water issues, programs that enforce policies, and the implementation of programs, as well as links between these phases. In the next chapter, I will use the conclusions from my analysis of the connections and disconnects between issue, policy, program and implementation in urban water management to form a comprehensive framework to aid municipalities in dealing with urban water issues.

3.1.1. Water Issues

In following section, I will describe the urban water issues, discuss the role of humans in their creation, and their interrelation. Urban water issues are caused by changes in natural hydrological systems through the following factors: urban development, climate change, and increased human consumption.

3.1.1.1. Urban development related issues

Poor Water quality: Poor urban water quality is caused by the discharge of polluted urban runoff into urban water bodies and the degradation of the ability of these water bodies to perform the natural purification processes in the riparian zones. For example, the water quality of many of Austin's creeks has been degraded for two reasons: Firstly, uncontrolled and untreated urban stormwater is directly discharged into urban water bodies; Secondly, the channelization and creek edge stabilization efforts have created disconnections with natural vegetation and soils of the surrounding riparian zone [1]. In Portland, the excessive urban runoff from its impervious surfaces overwhelmed the combined sewer system and the overflow of polluted water into Willamette River use to happen for an average of 100 days each year [2].

Groundwater recharge: In order to be a sustainable source of drinking water, groundwater must be recharged by being infiltrated through soil. However, urban development restricts this natural process, and as a result groundwater levels decline. For example, the City of Berlin used to withdraw more from its aquifer than was being recharged through precipitation caused declining aquifer levels and reduced water availability in the area [3].

Habitat loss: Urban development also reduces habitat for animals and plants by changing land use and degrading waterways. For example, most of Seattle's waterways were modified in order to create space for urban development. These modifications, including conducting parts of creeks through pipes, seriously affected the condition of Lake Washington, as the receiving water, and therefore the health of salmon species [4].

Erosion: Changes in land use by urban development also reduce riparian vegetation and soil stability because the increase volume of runoff results is the removal of plants, and plant roots that act as bank stabilizer against erosion. In Austin, urban policies permitted the construction of concrete embankments near creek edges to remediate the effects of the Memorial Day flood (major 1981 flood) which caused soil erosion near creek edges. This development resulted in loss of the riparian zone around creeks, and therefore soil in these regions became more vulnerable to scouring of the river's bottom and increase erosion risk [1].

3.1.1.2. Climate change related issues

Drought and decreasing water availability: As a consequence of climate change in lower latitudes, conventional water resources are no longer reliable for supplying potable water for urban demand. For instance, in Australia precipitation has reduced which resulted in more than a decade of drought. This condition has reduced the ability of Australian cities to provide convention water resources for its citizens [5], [6].

Flooding: The challenges of excess water and resultant flooding in cities with high latitudes are a consequence of more concentrated rain events. As a lowest lying delta metropolis and one of the largest ports in the world, Rotterdam faces flood risk by rising sea levels and rainwater that cannot be infiltrated. Importantly, the City of Rotterdam's conventional solutions such as levee heightening and strengthening do not address the flooding issue comprehensively [7].

3.1.1.3. Human behaviors' related issues

The shortage of water resources for human demand: Because of the rapid population growth over recent years, conventional water resources have been unable to meet the demands by residents. The lack of water resources is the main reason for demand reduction policies in Berlin, Sydney, and Melbourne. Also, water resource shortages in Melbourne and Sydney are related to climate change as well [5], [6].

3.1.1.4. Water issues are interrelated

Hydrological regimes are composed of numerous multifunctional natural processes. These natural processes include soil functions of water infiltration and groundwater recharge, water purification and fortification of soil against erosion by plants on creek or river edges, and evapotranspiration from vegetation and evaporation from soil. Current urban water issues are consequences of disturbances in natural hydrological regimes and their natural processes. Therefore, efforts to address individual water issues could adversely affect other aspects of the natural hydrological process and create new water issues. As an example, creek edge stabilization efforts in Austin's inner-city to address erosion issue, have disconnected creeks from the natural surroundings and resulted in a loss of the purification functionality of riparian vegetation, which also resulted in poor water quality issue [1].

3.1.2. How cities have been addressing water issues

In this section, I will analyze how case studies linked their water issues to policies and highlight their experiences.

The City of Austin's policy to protect Barton Springs was ineffective because the City allowance of conventional development in the recharge area of Barton Springs was permitted without realizing the impacts to water quality of downstream. As a result, implementation of BMPs to protect Barton Springs could not remediate the adverse effects of pollution and degraded Barton Springs [8]. In this case, it is important to note that the incorrect perception of the City of Austin about the water issue did not correlate with the real cause of pollution.

As mentioned before, the construction near the creek edges in Austin's inner-city was permitted by the City of Austin after The Memorial Day flood. This resulted in the loss of the purifying functionality of the riparian zone because this zone was replaced by hard surfaces and buildings. Moreover, the inner-city flood and erosion control policies resulted in further separation of the creeks from their soil and riparian zones, and worsened the water quality of the creeks as well as increase in the flooding potential. In a remedial and incremental approach, the City created additional water quality policies which included attempts to reduce the polluted urban runoff volumes, stabilizing creek edges with geosynthetic fabrics and in rare occasions, property buyouts [1]. Instead of changing their viewpoint, they continue to incrementally create new policies to remediate the adverse effects of their prior policies. Thus, the City of Austin has failed to develop a comprehensive understanding of the causes of water issues.

Similarly, the City of Portland's policy to reduce the runoff volume on the combined sewer system by urban runoff volume reduction [2] was inefficient because the policy was not translated into a comprehensive city-wide plan for stormwater reduction on a decentralized management. The City of Portland has attempted to address an individual water issue of Combined Sewer Overflow (CSO) by a handful of novel but untested source control measures. Their approach has resulted in implementation of numerous BMPs unevenly spread throughout different city districts. Also, the residents misinterpreted this approach as a way to improve the quality of urban spaces, but not as a comprehensive stormwater water runoff control.

On the other hand, the City of Berlin attempted to address the water issue of limited regional water resources by achieving water self-sufficiency through demand reduction and domestic provision of potable water policies [9]. By safeguarding and protecting recharge functions and groundwater balance, urban runoff is treated and used to recharge groundwater [10]. In addition to their success in demand reduction, this policy has resulted in reduced demand on existing water system supplies because the amount of treated water discharged into the groundwater is far more than the amount of extracted groundwater. In conclusion, the residents of Berlin know the true value of natural water resources because of the experiences they gained from the physical isolation of West Berlin during the Cold War. This cultural feature has complemented the City of Berlin's comprehensive knowledge of about local water systems and guaranteed the success of its self-sufficiency ideas.

In Seattle, salmon species were becoming scarce in Lake Washington due to unhealthy condition of supplying creeks. The City of Seattle has used this fact as a driver to make ambitious changes in water policies [4]. They created a new way of holistic thinking about the connection between this keystone specie and the urban water quality. Moreover, the City recognized the tight link between the health of residents and the health of salmon. Thus, in order to bring back salmon to the lakes, the City restored the creek to their natural function and hence the local water cycle, which is also better for the health of the salmon and the urban population. Importantly, the urban environmental restoration was also a significant demand by Seattle's environmental activist community groups.

Rotterdam's levees had to be constantly strengthened through an incremental approach to cope with the increased frequency of rainfall and sea level rise due to climate change. In addition, the city had to design programs to reduce flood risks and address all water issues comprehensively

[7]. For example, the Waterplan 2 reduces flood risk by creating innovative solutions for water management such as water squares and innovative diverse large water detention areas. Similarly, the city of Melbourne addressed the sources of pollution by analyzing the effects of land use and development on stormwater discharges. Based on this novel way of holistic thinking, the *Total Watermark City as a Catchment* [11] policy comprehensively considers local water issues and the impact of human decisions on water flows. Moreover, the city of Melbourne's demand reduction and recycled water use policies are expected to achieve respective federal targets sooner than its 2030 deadline [5] because water resource shortages are well represented for residents. In contrast, the City of Sydney focused only on cost-benefit analyses of its policies and in some instances, critical aspects of the water issues were neglected. For example, water shortage crises were not highlighted resulting in failed recycled water use policies. I will present more details about these policies in the next section.

The policies from these case studies were briefly studied and analyzed in this section. In the next section, I will summarize the main factors necessary to translate these policies into programs.

3.1.3. Converting Policies to Programs

In the previous section, I described how certain municipalities have addressed their water issues through different policies. In this part, I will highlight the important factors necessary for translating water policies into programs.

3.1.3.1. Creation of political will by emphasizing on severity of water issues

Municipalities often attempt to create political will to support their programs. They do this by presenting information, evidence, and highlighting the severity of the water issues to local residents. For example, the City of Melbourne has published an informative WSUD Guidelines [5] with the target audience of developers, residents, and Council staff. As figure 2 of this Guidelines [5] shows, roughly 40% of Melbourne average inflow was reduced between 1997 and 2008. This visual representation helped residents rethink the issue of local resource shortage, become aware of the local problem, and be better prepared to accept the programs of demand reduction and water reuse. As the example of Melbourne shows, in order to make a strong connection between the creation of policy and designing, implanting, and successfully accomplishing programs, it is important to align the perception of residents with the reality of local water issues.

New Australian federal policies require major cities to meet 30% of their water demand with recycled water by 2030 [6]. In contrast to the City of Melbourne which has made its residents aware of its local water scarcity through visual presentations, no attempts are evident in the City of Sydney's Decentralized Water Master Plan to highlight the local water resource shortage issue. The only reason that was presented in this Master Plan to support the demand reduction and recycled water use programs was that they were required by the federal government and a cost-benefit analysis by Sydney Water that concludes the implementation of recycled water schemes does not provide financial benefits [6]. Hence, the City of Sydney does not support its policies with representation of its local water issue and this fact plays an important role in the fact that it is currently only using 7% recycled water.

3.1.3.2. Integration of the programs into social context of the cities

Municipalities often attempt to include residents in programs via public involvement and education. Through my research, I have identified the following two main approaches for building the relationship between municipalities and residents:

- Conventional solely top-down environmental governance by municipalities
- Utilizing potentials of residents in environmental governance as a complementary to the top-down approach

In conventional top-down environmental governance method, the municipality regulates human-nature relationship that affects residents directly. The other method of environmental governance, considers collaboration between municipalities and residents as complementary to top-down decision making to ensure the decisions' acceptance among residents. By conventional method, there is a possibility that the municipalities' priorities over ride residents' local interests which could and result in general disappointment and disenfranchisement among residents. For example, Austin's prioritization of conventional development practices in the Barton Springs Zone resulted in neglecting the point of view of residents who valued the health of Barton Spring [8].

Importantly, when local interests of communities are not addressed by municipal programs, resident groups can oppose them through grassroots activities. For example, the Natural Drainage System (NDS) program by Seattle Public Utility (SPU) is designed to present cost-effective and ecologically beneficial alternative sustainable street designs that reduce the urban runoff volumes. It has been successful in projects such as the Street Edge Alternative (SEA) Street because of public acceptance and participation, but on rare occasions it has also resulted in conflicts between

the municipality and local residents like the controversy over the North-Gate Mall Redevelopment. During this project, neighborhood activist groups in favor of daylighting the Thornton Creek and opposed plans both by the developer and the SPU [4]. Unfortunately, the SPU's NDS solution did not convince the developer that the daylighting was within reasonable costs, or the activist groups that it is the most beneficial solution for the creek's health.
Utilizing potentials of residents in environmental governance emphasizes mutual problem solving. This method redirects residents from potential protest to active participation in programs. For example, during the approval procedure of the Waterplan 2 in Rotterdam, the ideas of residents were requested by public announcements in newspapers and the confirmation meetings were open to public and residents who could contribute to its development. More importantly, citizens were also involved in breaking down the cities Waterplan 2 into district level water plans. As a result, it was revealed that residents have some concerns about the safety of using water plazas as playgrounds. As a result of this feedback an alternative solutions for this problem was developed by the City [7].

3.1.3.3. Adapting Programs from Other Cities

Some cities have adapted successful water programs from pioneering cities. For example, the Biotope Area Factor (BAF) was originally introduced to reduce the impact of dense urban development in Berlin's city center [10]. The success of BAF program in increasing the green coverage and reducing stormwater runoff was well accepted by residents and developers. This acceptance has eased its implementation which has encouraged the Seattle and Malmo to adapt similar programs. Malmo has the idea of BAF to developed two programs [12]: the Green Space Factor (GSF) for increasing green coverage in new developments in a densely built area of the city and the Green Points System (GPS) mostly for biodiversity enhancement purposes. Moreover, the City of Seattle reviewed BAF and GSF and developed Green Factor [13] on the basis of unique environmental conditions of Seattle and Seattle Public Utility (SPU)'s clear understanding of the local water issues.

In contrast, the adaptation of Water Sensitive Urban Design program by the City of Sydney presents insightful understanding about the potential insignificances due to incomprehensive adaptation of programs. The WSUD program was designed in Australia [14] based on national water issues of waterways' pollution due to discharges of polluted urban runoff, resource shortage due to climate change, and demand growth due to population growth. This program simultaneously addresses multiple water issues, in addition to increasing biodiversity and amenity. However, Sydney adapted the WSUD to merely reduce water pollution [6]. Hence, the City has concluded that retrofitting the WSUD in private spaces will be less beneficial [6]. I argue that by this method, primary opportunities that this program provides as a resource for recycled water use, and biodiversity and social amenity benefits are neglected and undervalued.

3.1.4. Linking Programs and Implementations

In this section, I will explain why some cities have been successful in implementing their programs and why other cities have failed to do so.

3.1.4.1. Retrofit, Redevelopment, or New Development

There is a vast variety of opportunities for cities to incorporate programs, including retrofit, redevelopment and new development projects. Here, I will summarize how cities have implemented different processes' development.

Austin's *Watershed Master Plan* expects that out of its three major goals, water quality goals are less likely to be achieved because there are not enough retrofit opportunities in the inner-city to implement the water quality measures and facilities [1]. This approach neglected potential contribution from projects in public spaces, and therefore, Austin's efforts to improve the water quality of its creeks in the inner-city are limited to a scattered network of sand filters and the implementation of a few wet ponds in parks.

In contrast, Sydney's Council presented a cost-benefit analysis between different project types in *Decentralized Water Master Plan* [6] and concluded that incorporating the WSUD in redevelopment projects was the most cost effective way to reduce the pollution of waterways. Moreover, the analysis found that renewing public spaces such as roads, parks, and footpaths are possible to incorporate the WSUD in highly urbanized areas.

3.1.4.2. Promoting innovative multifunctional measures

In order to implement programs more efficiently, cities often seek compact and multifunctional technical measures. Here, I will explain some insightful trends in designing such programs.

An essential aim of the Waterplan 2 program in Rotterdam was promoting innovation. To do this, water square which is invented by De Urbanisten (an urban research and design office) and Studio Marco Vermeulen (a design office for architecture, urban design, landscape and research) was able to temporarily store stormwater, and create an attractive quality of public space at the same time. This multifunctional solution was designed based on the climate resiliency, flood protection, and attractive city policies [7].

On the contrary, Austin simply included sand filters in the building code without considering any other alternatives such as vegetated filter strips, rain gardens, rain water harvesting, etc. that were included later in the building code [1]. Although Sand filters are great for reducing suspended pollutants, they have limited effects on nutrients. Moreover, Portland's green street program resulted in limited innovative design and a loss of local characteristics by limiting the design to only four pre-designed templates [2].

3.1.4.3. Similarities of new regulations with development schedules

When regulations are implemented by developers, potential conflicts during this process will definitely result in improper implementation of programs. In this part, I will analyze the relationship between developers and regulations.

The success of the BAF in enhancing the soil functionality, water balance, and provision of vegetation in densely developed areas is a result of its flexibility and resemblance to common ordinary planning regulations, e.g. Floor Space Ratio (FSR). Its flexibility allows developers to choose between a number of different options for greening or creating permeable surfaces [10], and its resemblance to other planning ratios reduces the confusions of developers about this programs.

In contrast, the Green Pointing System Version 2 in Malmo was not successfully implemented [12] because developers were required to build biotopes, habitats, and animal housing in their new developments. Such professional requirements are beyond the usual capabilities of developers. As a result, developers failed to implement the demands set by the program and no single developer could achieve an acceptable biodiversity results.

3.1.5. Implementation

3.1.5.1. Prototype Projects and Milestones

In order to implement programs in cities, municipalities often develop implementation schedules. In this section, I will present and analyze the milestones the City of Seattle have defined for scaling up the implementation of NDS program [4] as a successful example, and an additional step from the City of Malmo's experience in implementing the GSF.

The City of Seattle began implementing the NDS program through the SEA Street prototype project, which was a small street renewal project that aimed to highlight water sensitive measures and facilities. During implementation, the SPU staff received insightful feedback from local residents about how implementation could be improved. The staff also worked closely with other municipal departments such as the department of planning and transportation to make temporary changes in regulations and building codes. The project was completed in 2001 and the outcomes emphasized on reduced urban runoff volumes, improved residents' well-being, and added properties' value.

After the SEA Street project, implementations were scaled up to limited implementations in different parts of the city to analyze deficiencies over time. The sequence of projects, 4 blocks, 21 acres, 110 Cascade Project in 2003, 15 blocks, 32 acres, Broadview Green Grid in 2005, and 12 blocks, 49 acres, Pinehurst Green Grid in 2007 are all projects that have scaled up the ideas of the SEA Street project. Currently, the City of Seattle is implementing the NDS approach on a City-wide scale. As an example, I can refer to 34 blocks, 129 acres, High Point project which was completed in 2010.

The City of Malmo has followed a similar trend in implementing the GSF. However, reforms of GSF included an additional post-implementation evaluation phase one year after implementation of each phase. These evaluations included analyses of feedbacks from residents, landowners, and developers, and success of programs in achieving their target goals such as enhancement of green coverage. Through this, the City of Malmo has managed to achieve a balance between the goals of GSF, residents' interests, and developers' abilities.

3.1.5.2. Maintenance

Proper maintenance of existing facilities is an important part of implementations that ensures the long-term functionality of programs. In this part, I will present examples from case studies to illustrate the maintenance related issues including long-term maintenance issues and proper delegation of maintenance responsibilities among stakeholders.

In Portland [2], long-term maintenance responsibilities of green streets have not been clarified adequately. Moreover, the maintenance budget is only enough for removal of sediments and replacement of dead plants to ensure the functionality of facilities, but not enough to keep up the aesthetics qualities of the development. Due to these problems, the City is currently refining the planting plans for green streets to attractive and low-maintenance plants. In addition, the City has initiated the complementary program of green street stewardship [15] through which volunteered citizens are organized to lend assistance with simple maintenance activities.

The City of Austin's efforts to maintain BMPs only in single family residents are problematic because the number of such facilities is growing very fast due to population growth and proper maintenance requires large budgets and number of staff [1].

The City of Rotterdam has filled this gap by dividing the clarified maintenance responsibilities for different large scale facilities among its departments. Underground water storage is maintained by the Water Management Department, Water Squares are partly maintained by the Water Management Department and Public Clean Service. For small scale facilities in residential buildings such as green roofs, the owner is held responsible for maintenance [7] activities and the municipality only provides owners with instructions.

3.1.6. Conclusions

In general, today's urban water issues are caused by adverse effects of urban development on local hydrology and natural water processes. In addition, climate change and population growth act as stressors to worsen these issues. Moreover, due to the decentralized and interrelated nature of these natural processes, the urban water issues cannot be solved by fragmented policies and individual programs by municipalities. Our conventional methods of environmental governance either have been ineffective in solving these issues, or have worsened the problems. Hence, municipalities, residents, and any other stakeholder whose actions affect water in urban environment should collaborate with each other to solve the urban water issues.

3.2. Proposing a Universal Water Framework

To deal with the complex and interrelated urban water issues that our cities face today, I have developed a framework that deals with these issues in a holistic and comprehensive manner rather than individually and incrementally. Current proposals to modify existing policies do not move us toward water abundance but perhaps toward water scarcity (citation). Framing water issues in terms of water abundance helps create solutions in a comprehensive manner. While our current policies continue to frame water issues in terms of water scarcity which does not prepare us for a sustainable future and does not provide a clear plan of action, because they react to specific isolated issues rather than addressing the entire system of water.

In this chapter, I will present conclusions from the previous chapter to draw guidelines for municipalities to enhance the relationship between issues, policies, programs and implementations in urban water managements.

3.2.1. Water issues

Water issues are symptoms of disturbances in hydrological regimes and manifest as environmental extremes such as excessive flooding, polluted water bodies and aquifers, as well as gradually degrading of the earth's biodiversity. On a global scale, climate change related water issues are caused by the human activity, but regionally, water issues are directly caused by interferences in regional hydrological regimes due to urban development (citation). Since water issues are interrelated, fragmented and non-synergetic policies will create unintended consequences and not solve the water issues that we continually deal with.

3.2.2. Filling the gap between issues and policies

In the following section, I will describe how a holistic understanding of the causes of water issues can successfully address them by policies without causing unintended consequences on other water issues.

Through the incremental problem-solving approach of most conventional policies, policies are created for each the symptom of individual water issue without considering their possible impact on other related water issue. Therefore, the interrelations between water issues are often neglected and they are considered as isolated problems without impacts on each other. Addressing present water issues requires a whole new way of thinking about the interrelation between water issues in a comprehensive manner as “a One Water concept”, rather than dealing with individual water issues separately and incrementally. One Water is an intelligential conceptual framework that looks at all water, storm, waste, natural, surface and sub-surface water as interconnected and interdependent.

In this regard, it is important to consider each individual water issues as indicators of disturbances in entire hydrology system, and integrated solutions should attempt to bring back the hydrological balance. In other words, municipalities should attempt to comprehensively solve the causes of water issues, instead of simply dealing with the consequences of separate water problems. This should be done by restoring the natural functions of water systems as much as possible. To start, the underlying structure of local water systems should be understood to correct false perceptions about water issues. If perceptions about water issues are not in line with the reality of the hydrology, it will result in inefficient and ineffective policies.

Importantly, the act of policy making is highly local and depends on the cultural background of each city including natural history, general interests of residents, and geological and geographical location of cities. Hence, suggesting policies that can be successful in all parts of the world is not feasible. However, I have identified that the following resolutions are shared among cities that have been successful in making effective urban water policies:

- Restoring natural hydrological regimes within the urban areas
- Empowering community groups through public education and public participation
- Providing livable amenities
- Increasing biodiversity
- Promoting demand management and water reuse

In this section, I have discussed why municipalities should address water issues through holistic and comprehensive policies. In the next section, I will discuss how these policies should be translated into practical and feasible programs.

3.2.3. Program Design Guidelines

While the previous section presents guidelines for making holistic policies, this section explains how municipalities can translate policies into pragmatic programs. This section starts with guidelines to fill the gaps between policies and programs and is followed by guidelines for designing programs.

3.2.3.1. Filling the Gaps between Policies and Programs

In this section, I will explain how municipalities can create strong relationship between their water policies and implementable programs.

3.2.3.1.1. Highlight compelling policy that necessitates change in water governance

The success of policies in creating political will highly depend on the following factors: how well the water issues are understood in relation to the hydrology of the area, how well the policies are articulated understood and accepted by different stakeholders. Federal or state policies are not reliable drivers of change and need to be modified to fit the local condition because they generally do not have a sense of local water issues. These issues and their severity can only be sensed by residents and local authorities i.e. municipalities and local water providers. Therefore, municipalities should inform other stakeholders about water issues and prepare them to participate and understand the reasons for the necessary changes in water governance. In this regard, visual representation of water issues through informative diagrams, illustrations, or pictures is a very effective way to increase public awareness and correct false perceptions. In order to create programs that residents accept well, it is important to highlight the local drivers for change. For example, Los Vegas' Lake Mead level gradually declined due to the fact that the watershed was unable to compensate for the extreme demand by users downstream. The plummeted level of the Lake had created a 100 feet "bathtub ring" from minerals deposition around the lake by 2002. Doug Bennett has revealed that having the citizens of Los Vegas area be able to see the first hand shocking impact of the drought was key to prime the community to accept more sustainable landscapes [1].

3.2.3.1.2. Public involvement by promises of addressing local water issues

Since the program takes a holistic approach to water issues, it should assure the residents that their local water concerns will be addressed, because failure to address local water concerns could result in grassroots activities opposing top-down comprehensive environmental governance. This gap of public involvement should be filled by promoting public education through participation in the act of program design. This has two benefits: firstly, the residents will become familiar with the potentials of programs to address their local concerns; secondly, participation of the residents in program design phase means that they invest their social capital and thirdly their knowledge of the local water issues could be invaluable information in the design of the policy and program. Therefore, the program can be expected to have long term success.

3.2.3.2. Considerations on Program Design

In the previous parts, guidelines to connect water issues with policies and programs were presented. In this part, I will present guidelines about designing realistic, implementable, and functional programs.

3.2.3.2.1. Adapting successful programs by other cities

Adapting successful programs is a legitimate way to avoid designing new ones on a trial basis. After developing comprehensive understanding about local water issues, municipalities should study programs by other cities with similar ones. However, the adaptation should be done with consideration for local environmental conditions. When doing so, municipalities should consider the full potential of the adapted program. These potentials include the adapted program's ability to address multiple policies, and sub-benefits that are not considered by policies. Moreover, the potential for adapted programs to be integrated to other local programs should not be overlooked.

3.2.3.2.2. Program should require reasonable budgets

When translating policies into programs, program designers should consider the financial capacities of municipalities. Ambitious programs may need substantial amount of funds, and if municipalities cannot allocate the necessary funds, then the programs will be ineffective. Hence, it is important to consider the costs of technical measures that programs prescribe. For example, designing systems that control the natural flow of water requires large scale and extremely costly measures such as fortified tunnels and levees. In contrast, restoration of natural processes requires a large number of small scales but cost-effective source control measures. Hence, in financial terms, programs that follow source control approach to execute policies could be less costly than programs that prescribe only civil engineering solution rather than using nature to assist.

3.2.4. Guidelines for Translation of Programs into Implementation

In this section, I will present guidelines for municipalities to avoid inefficiencies during conversion of programs into regulations.

3.2.4.1. Getting the Best from the Programs by an Opportunistic Approach

Failure to distinguish between different projects types such as retrofit projects, redevelopment projects, and new development projects can result in a loss of potential opportunities for achieving target goals, especially in dense urban areas. Conventionally, municipalities assume that these spaces are previously built and programs cannot be implemented in them. As municipalities spend a substantial amount of funds on projects renewing public spaces including roads, parks, and pavements, such projects are great opportunities to incorporate urban water management programs. Hence, municipalities should undergo cost-benefit analyses to evaluate how different project types in buildings and public spaces can potentially contribute the implementation of programs.

3.2.4.2. Promoting Innovative Multifunctional Technical Measures

The implementation of innovative technical measures is a reliable way to improve the functionality of programs. In this section, I will present guidelines for development and successful implementation of such measures.

Implementing programs in previously built environment of cities means that there will be restraints on available space to implement technical measures and facilities. Therefore, multi-functional technical solutions that address multiple goals are more beneficial than single purpose measures. As an example, water plazas in Rotterdam can simultaneously address climate change resiliency and flood protection policies by temporary store stormwater and attractive city policy by providing amenity for residents. Hence, municipalities should create permanent links with universities and research institutes to best understand local water issues, make holistic policies, and to find innovative technical measures that simultaneously address different water issues. Such collaborations in designing innovative measures can be seen in creation of water plazas were the City of Rotterdam worked closely with the Delft University, and other research institutes.

In order to ensure the implementation of innovative solutions, municipalities should promote alternative measures in regulations and building codes. When a particular measure is exclusively entered into regulations, the developers would develop established implementation routines over time which creates a technological momentum that limits the implementation of innovative solutions. In addition, template based designs should also be avoided because such designs often can result in a loss of local characteristics of different districts.

3.2.4.3. Simplicity and Flexibility of Regulations

Rethinking our approach toward water in cities does not necessarily mean that we have to create series regulations that are totally different in form and requirements. In fact, new regulations that do not mimic prior regulations can result in confusion among developers. Regulations that require them to implement highly professional requirements in their buildings have proven to result in improper implementation. For example, the developers were unable to meet the unusual requirements of building biotopes and habitats by Green Pointing System: Ver. 2. Hence, new regulations should at least modestly resemble existing regulations to avoid causing confusion, be flexible in order to provide a range of different options for developers, and not make requirements that exceed the usual capabilities of developers to ensure proper implementation of the program. However, in places where new requirements like biodiversity are defined, the developers should be trained to understand how they must implement these requirements.

In this section, guidelines to successfully bridging the gaps during the translation of programs into implementable regulations were discussed. In the last section, I will present guidelines for the implementation phase.

3.2.5. Implementation Guidelines

3.2.5.1. Milestones and Gradual Implementation

The implementation of major water management programs that cover the entire area of a city cannot be done instantly, but needs a series of implementation phases that involves acts of continuous learning of inefficiencies and gradual modification of existing regulations. In order to have implementation routine, municipalities should define three milestones: First creating a prototype, continuing on with a limited implementation program and then a full implementation throughout the entire city. The Prototyping phase includes implementation of small scale projects that showcase the new water approach, analyzing feedbacks from local residents to figure out the shortcomings of new regulations, and resolving potential legal barriers. This phase should be followed by limited implementation where the prototype is scaled up in projects in different parts of the city. During this phase, regulations should still be modified to achieve a final version that can be implemented on city-wide scale. In the last phase, regulations should be integrated in site design and building codes and then the program should be implemented in the whole city along with staff trained on the regulations should be started.

1.1.1.1. Proper Maintenance

Although maintenance activities usually take place after implementation, they have the most important role in ensuring proper functionality of facilities and therefore the final success of the programs. Hence, municipalities should value these activities as much as others. In this regard, municipalities should clarify the maintenance responsibilities for the different stakeholders. An effective way to do so is by dividing the maintenance responsibilities for facilities in public spaces among different departments of the municipality that have their assets in these spaces, and holding property owners responsible for the maintenance of small scale facilities on their property. This method is prescribed because maintenance of a large number of small scale facilities requires large budgets and numerous staff. In this regard, the municipality should provide owners with maintenance manuals, professional consultation, and replacement materials.

4. Application of the Proposed Framework to Minneapolis

4.1. Minneapolis' Current Condition

In this section, I describe current water issues in the city of Minneapolis and the method the city is addressing them. As will be discussed in this section, all water issues seem to be focused on stormwater management in Minneapolis. Hence, I have focuses exclusively on the development of the Municipal Separate Storm Sewer System (MS4), the related policies, current programs, and means of implementation.

4.1.1. Background and Local Water Issues

Minneapolis is the largest city in the state of Minnesota. As of 2013, the estimated population of the city of Minneapolis was 400,070 [1]. Minneapolis and its adjacent city of Saint Paul form the Twin Cities metropolitan area, with the area containing approximately 3.8 million residents [2]. Minneapolis has a total area of 58.4 square miles and of this 6% is water [3]. Twelve lakes, three large ponds, and five unnamed wetlands are within Minneapolis [4]. The city experiences a full range of precipitation and related weather events, including snow, sleet, ice, rain, thunderstorms, tornadoes, heat waves, and fog [5].

Minnesota is the land of a thousand lakes and Minneapolis is called the *city of lakes* which depicts the fundamental value of the water in the local culture. The defining physical characteristic of the city was brought to the region during the last ice age ten thousand years ago. Ice blocks deposited in valleys by retreating glaciers created the lakes of Minneapolis [6]. Fed by a receding glacier, torrents of water from a glacial river cut the Mississippi riverbed [7]. The geology of Minneapolis is consisted of thin layers of unconsolidated quaternary glacial sediments stacked upon multiple thick layers of regionally confining limestone bedrock. Between these layers, lie 5 layers of aquifers, namely Decorah-Platteville-Glenwood, St. Peter, Prairie du Chien-Jordan, Franconia-Ironton-Galesville, and Mt. Simon-Hinckley [8]. The geologic sections and description of these layers are illustrated in figures 1 through 5 [8-11].

Cherished by the residents, the Chain of Lakes is a significant local focal point which frames the characteristics of the city with water abundance. It consists of 353 acres Lake Harriet, 421 acres Lake Calhoun, 103 acres Lake of the Isles, 170 acres Cedar Lake, and other smaller lakes within Minneapolis boundaries [6]. Moreover, the Mississippi River runs within the city boundaries. Also, Minnesota River and St. Croix River are present in the Twin Cities. Bassett

Creek, Minnehaha Creek, Shingle Creek and five unnamed wetlands are other water features of the city [6].

In general, the City of Minneapolis is facing major water issues of flooding risk, pollution of groundwater and water bodies, increase in total suspended solids, and maintaining water level of lakes and aquifers.

The City of Minneapolis started putting sewers underground around 1870. The combined sanitary and stormwater sewers directly discharged into Mississippi River until 1938 when first sewage treatment plant was added to the network. As the city grew and more impervious surfaces were constructed there was more runoff than the capacity of the combined network's which resulted in Combined Sewer Overflows (CSOs). In 1922, the City began to construct separate storm drain network in new parts of the city. The separation of combined sewer network was further extended to all parts of the city in 1986 by Minneapolis Public Works (MPW) and today more than 95% of Minneapolis is served by separated networks of storm and sanitary sewer [12]. The separation of storm sewer has resulted in reductions of the frequency of CSOs, urban flooding, and improvements in water quality of Mississippi River and urban creeks.

The urban environment of Minneapolis has always been at risk of flooding. In 1998, the locally known *Super Storm* resulted in the 9.15 inches record of rainfall which is the largest official single-day rainfall for the Twin Cities [13]. As a result, extraordinary amount of wastewater discharges from the Lake Minnetonka into the Minnehaha Creek and caused damage to 9,000 homes, killed two people, and caused $27 million in damage [14]. After that, the City built dams to control the water level in the lake Minnetonka [15]. Moreover, in 1997 the amount of water that fell by torrential rainstorms was greatly beyond the capacity of City storm and sanitary sewer systems and water backed up onto streets, into basements, creeks, and rivers [17]. The flooding risk is directly linked with the function of MS4. Before the separation of sewers, the combined sewer network was incapable of conveying the sewers in storm events. However, the separated storm sewer does not still have the capacity for the excessive amount of urban runoff of impervious surfaces.

Regarding the pollution, before the separation of sewers, CSOs was a major cause of pollution to both urban environment and water bodies. Moreover, industrial sewers used to be directly discharged into water bodies. Today, the municipality has managed to eliminate almost the entire point sources of industrial sewer discharges over recent years [16]. In superfund sites are point sources of pollution ground is polluted due to past chemical practices such as dry cleaners. There used to be 25 federal or state designated superfund sites in Minneapolis out of which 6 have been cleaned and others have undergone significant cleanup and redevelopment over recent years [4]. Figure 10, illustrates the location of a few of these sites [18].

Today, the majority of concerns about pollution are about the non-point source pollution and discharge of stormwater into water bodies. In order to determine the quality of water bodies, Environmental Protection Agency (EPA) uses Carlson's Trophic State Index (TSI) [19] to measure nitrogen, phosphorus, and other biological nutrients. As measured TSI indicate [4], the water quality of lakes has to be improved to be "Fishable" or "Swimmable" (see figure 6).

Additionally, Minneapolis is located at the north most limits of the Great Lakes karst landscape and the local geological properties of Minneapolis are dominated by existence of limestone bedrocks. These bedrocks are approximately in the depth of about 50 feet or more below the quaternary sediment cover [20] (see Figure 1 [24], for a more detailed map about the depth of the bedrocks, please refer to [20]). When infiltrated water reaches to these limestones, it creates chemical reactions with the calcium-carbonate which results in cracks or sinks in bedrock structure. These gaps are widened over time and the filtering barrier between surface water and groundwater is washed out and a direct link between surface water and aquifers are created. Hence, as the soil barrier between surface water and groundwater is being eliminated, the water quality of aquifers is threatened by pollution of surface waters. Due to this phenomenon, water table system in Minneapolis have been assessed as highly or very highly sensitive to pollution and Prairie du Chien-Jordan aquifer as moderately or higher than moderately sensitive to pollution [21].

Importantly, Minneapolis is benefited by one of the most educated residents in the US [22]. They are also actively engaged in many aspects of the City's governance. As a result, there are a handful of examples of collaboration between public agencies and the City in dealing with water issues. For example, the initial report by Water Quality Management Citizen Advisory Committee was supported by MPRB, City Council, and neighborhood groups. As a result of this collaboration, The Green Report was developed which outlined measures to improve and preserve major water resources [23]. A list of these activities is presented in [24].

Water supply is managed by four watershed districts: Bassett Creek Water Management Commission (BCWMC), Minnehaha Creek Watershed District (MCWD), Mississippi Watershed Management Organization (MWMO), and Shingle Creek Watershed Management Commission (SCWMC). Watershed Management Organizations (WMOs) are given the role of managing individual water bodies in the Twin Cities [24]. Stormwater is managed by Minneapolis Park &

Recreation Board (MPRB) in public parks and Minneapolis Public Works (MPW) in the rest of the city. The potable water for Minneapolis and its suburbs is sourced exclusively from Mississippi River, whereas St. Paul and its suburban clients supplement Mississippi River water with tributary inflow to its Vadnais Lake reservoir system and with high-capacity groundwater wells [6].

4.1.2. Policies

The creation of Clean Water Act (CWA) by Environmental Protection Agency (EPA) in 1970s plays an important role in shaping the current water management approach of the City of Minneapolis. The CWA is driving all municipalities throughout the country to improve the water quality of surface waters to be fishable or swimmable by reducing the amount of discharged pollutants. Most of the current activities by the City are the result of addressing the requirements of the CWA administered by Minnesota Pollution Control Agency (MPCA) for the City of Minneapolis. To implement the federal requirements of the CWA, cities must obtain a NPDES permit and develop a stormwater management program. As Minneapolis' population exceeds 100,000 it has to obtain and renew a National Pollutant Discharge Elimination System (NPDES) MS4 phase I permit [25] every ten years. The MPCA has issues the initial permit in 2011 and current permit in 2013.

As a requirement of the NPDES program, EPA requires states to submit a list of impaired water bodies and the EPA puts those water bodies in 303(d) list for protection. For each impaired waterbody, one or multiple Total Maximum Daily Load (TMDL) is defined and point source polluters must not exceed that limit. In relation with water quality issues, the City of Minneapolis has only responded to the requirements of 303(d) list presented by MPCA. In addition to meeting the federal or state requirements of the MS4 permit the City's stormwater management activities must also conform to various other policies. These policies are listed in the Table 1 in the appendix [26]. However, meeting the federal requirements was more important than these local policies in the creation of the Stormwater Management Program (SWMP), which is the City's most essential program that deals with the urban stormwater [16].

4.1.3. Current Programs

This section will analyze the key programs by the City of Minneapolis that deal with urban stormwater. Most of the programs in Minneapolis rely on the function of the MS4 requirements; they either present guidelines for its implementation or complementary guidelines to ensure its proper functionality. The problem with this singular approach is that although it has been successful in reducing the flooding risk and CSOs, the storm sewer system has become a point-source of pollution which collects polluters from non-point sources of pollution such as streets and buildings and it is hard to remove these pollutants from the stormwater. Moreover, the storm sewer system limits the natural infiltration processes which are needed to maintain local aquifer levels. The City has executed the Local Surface Water Management Plan (LSWMP), which is a general program and covers a wide range of topics including provision of potable water, stormwater management, and lake management. For stormwater management, LSWMP covers Stormwater Management Program (SWMP), Flood Mitigation Program, and Stormwater Utility Fee. Moreover, the City's CSO program have successfully attempted to remove any rain-leader connected to sanitary sewer and any cross-connections between the sanitary and storm sewers, and in general eliminating all downspouts to the sanitary sewer, which has dramatically reduced the risks of CSOs.

4.1.3.1. Stormwater Management Program (SWMP)

Minneapolis Public Works Surface Water & Sewers Division in conjunction with Minneapolis Park & Recreation Board (MPRB) proposed the Minneapolis Stormwater Management Program in 2011, which was approved by MPCA In 2013. This program is a prerequisite of the federal NPDES program by the EPA and its objective is to provide clear and comprehensive guidance for operation of separated storm and sanitary conveyance and treatment systems [26].

The aim of Public Education and Outreach portion of the SWMP is to reduce the pollutant load and proper management of stormwater discharge into storm sewer system and improve water quality through citizen behavior change. The program attempts to detect illicit discharges to the stormwater system and eliminate them. In order to do so, the SWMP emphasizes the education of residents to understand that storm sewer system is discharged without treatment into local water bodies and discourage the discharge of pollutants through it.

The storm sewer does not provide capacity for conveyance in extreme rain events. Hence, SWMP has defined some research topics to find alternative solutions to the MS4 system. This research includes Runoff Volume Reduction Plan (SMP No. 5.6) and evaluation of alternative green infrastructure techniques for Flood Mitigation (SMP No. 5.5). These alternative solutions mostly include incorporation of source control measures similar to the LID, for example, bio-infiltration and rain gardens. As Lois Eberhart, water resources administrator at MPW and the leader of SMP No. 5.6 mentions [16], there are some barriers in this regard including:

- Structural reasons: Minneapolis' topography is composed of Karst limestone and infiltration may cause Calcium-Carbonate to break down and result in soil structure collapse. In addition, due to compaction of soil in urban area, the water may not soak well and cause damage to infrastructures. In contrast to the opinion of the MPW staff, such BMPs can be implemented in karst landscapes; although with some levels of precautions regarding the infiltration. For instance, the MPCA has published a table that lists these considerations. This table is presented in the Table 2 in the appendix [27].
- On-ground pollutants: There are legacy pollutants in the urban soils from practices over the last century; for example chemicals from dry cleaners' activities. The City is not sure whether they should leave the pollution and pave over it so it does not move into the groundwater or is it better to get it dispersed into groundwater. However, no matter what decision they make, the groundwater will continue to flow through these soils and moves and cleans these pollutants, and it cannot be stopped. It is impossible to keep the pollutants in one place. Moreover, if the infiltration is allowed, the pollution might spread faster, but it also dilutes faster as well. Hence, perhaps a combination of soil remediation at the site and infiltration of clean groundwater for dilution might be considered as a potential solution.

4.1.3.2. Flood Mitigation Program

Flooding Mitigation Program was initiated after the flooding that occurred in summer of 1997. The aim of the program is to detain and reduce the rate of the stormwater so that the storm sewer can accommodate the rate and volumes of the stormwater. The initial program included replacement of houses in floodplains with flood ponds [23] and later, implementation of underground detention tanks so that in severe storm events, these tanks could detain the stormwater as long as the storm sewer network could catch up It was not efficient in the beginning because it was very expensive and was only trying to reduce flooding risk by rate reduction, but today as they are considering the Three R's it is more convincing [23]. This civil engineering method of dealing with flooding required substantial amount of funds. For example, a single 5 block project in North Minneapolis cost about $7 million [2]. The estimated budget of the entire program was $86 million in 2002 [28]. Moreover, the program was not efficient at all because these measures did not provide any water quality benefits and only detained the stormwater.

Today, this program is not only reducing the flood risks but includes water quality and TMDL objectives as well. This is done through implementation of new type of projects that try to achieve volume reduction, TMDL load reduction, and rate reduction, known as three “R”s. By this approach, the Flood Mitigation Program has turned into Flood Mitigation with Alternative Stormwater Management program since 2012 [29].

4.1.3.3. Stormwater Utility Fee Program

The MS4 system requires that stormwater is treated with grit chambers which are only effective to reduce Total Suspended Solids (TSSs). Hence, the City needed complementary programs similar to the stormwater management program (SWMP) to improve the water quality of the stormwater. The City has introduced the Stormwater Utility Bill to improve the quality and reduce the quantity of urban runoff since March 2005. This program includes a set of straight forward landscape regulations. The utility fee is calculated based on the area of impervious surfaces on each site. The implementations of effective BMPs that either reduce the quantity of discharges or improve the water quality are rewarded with incentives up to 100 percent of the monthly charges.

The suggested BMPs by this program are divided into two groups of: stormwater quality BMPs includes Rain Gardens, Pervious Pavers, Wet Ponds, Dry Wells, Sand Filters, Filter Strips, Infiltration trenches, and Green Roofs; and stormwater quantity BMPs includes BMPs that can demonstrate the on-site capacity to retain 10-year or 100-year rain events [30-32].

The interesting feature of this program is this program puts a monetary value on water issues of pollution and flooding and translates them into financial aspects which are easily understood by residents [15].

4.1.4. Implementation

Although the above programs of the City of Minneapolis are executed only very recently, there are a few points to analyze about their implementation. Regarding public involvement and education, the City has completed a diverse range of activities. For example, the department of Public Works has attempted to reach out to the immigrant communities of Minneapolis and to understand how their behaviors could be modified. The department has determined that some communities are not exposed to scientific literature; instead they prefer to receive their information by listening to their elders. Hence, the staff put together a film called the "Nature of Water" whose stars are immigrant with positions of authority and they are talking about how these communities should change their behavior about water consumption and pollution. In addition there is an ongoing program to educate children in schools to ensure a knowledgeable future generation [16]. The aim of these activities is to effectively promote source control strategies, alongside the organized street sweeping (by the municipality), to discourage the discharge of pollutants, including organics from lawns and oil from engines by residents. Moreover, the municipality presents consultations for residents about how they can meet the requirements for Stormwater Utility Fee incentives. These consultations includes describing the different BMP alternatives that owners can implement on their properties and financial consultation on how they can garner funds for these projects.

4.2. Applying the Proposed Framework on the Case of Minneapolis

The City of Minneapolis has recently started to rethink their approach toward urban stormwater. This is evident in their newly executed programs of SWMP (since 2013), Flood Mitigation Program (since 2012), and Stormwater Utility Fee (Since 2005). However, there are still major gaps between urban water issues, policies, programs, and implementation in this city. These gaps include:

1. A comprehensive understanding about the local urban water issues is not developed yet. This comprehensive understanding should be accepted by all stakeholders, and recognize the inter-relation between local water issues.
2. There is a compelling need for local policies that recognize the interrelations between local water issues and progress in a trajectory to address the causes of local water issues and improve the quality of life of residents.
3. Overall policies follow an incremental approach to maintain existing infrastructure, reduce pollution and flooding risk. It is not clear where these efforts are heading, because an end point is not considered for the policies and programs.
4. The programs are detached from each other, and there is a need to develop a program with an integrative Low Impact Development (LID) approach to address all of the local water issues throughout the whole city areas.
5. The potential of residents is not fully taken advantage of and the municipality is guiding its residents only in implementation of the SWMP.

6. The City should evaluate whether programs in other cities can be adapted for Minneapolis or not.
7. The Stormwater Utility Bill incentives only promote the implementation of water quality BMPs in 18% of city's area and there is a need for opportunistic approach to cover all the area of the city.
8. At is questionable that why the City has some concerns about designing a city-wide program for implementation of source control BMP measures while such measures are promoted by the Stormwater Utility Fee incentives and Flood Mitigation programs.

In the following, I present guidelines from the proposed framework to fill these gaps by developing new policies to comprehensively address all the water issues and designing programs with the LID approach. These programs should aim for retaining small storms and considering the existing stormwater sewer as a back-up system that conveys excessive stormwater in big storm event. By this approach, the pollutants are dealt with on each site and the clean stormwater enters the sewer.

4.2.1. Comprehensive Understanding of Local Water Issue

As a recent study by United States Geological Survey (USGS) suggests [33], the lakes near Minneapolis are directly connected to the groundwater. Moreover, the local karst landscape suggests that the local hydrological regime is composed of a complex network of interconnected and interdependent groundwater (four layers of aquifer stacked above each other as depicted in the figure 2 [22]), base flow, surface waters, lakes and rivers. Hence, I interpret that surface water and the groundwater are the same type of water because they are not separated completely and discharge of polluted water not only pollutes the surface water but the groundwater as well.

In addition, there is a two-folded issue about infiltration: if the stormwater is infiltrated directly into soil, it may cause solution of bedrock and result in creation of sinkholes; but limiting the infiltration of surface water into base flow and groundwater has potentially resulted in improper replenishment of groundwater. Hence, because of the complexity of the water issues in Minneapolis, the City has to develop a comprehensive understand of what causes these water issues, how they are related, and what residents can do about them.

The problem here is that most of the people do not know anything about local water issue of pollution and karst landscapes at all. In addition there are reports that indicate local residents have incorrect perceptions about the cause of local water issues [33]. Therefore, the City has to use its experience in public education in a trajectory to correct the misperception of residents, to improve the knowledge of residents about water issues and to depict the enhanced quality of life in abundance of clear water. In order to do so, the City has to create a common ground to enhance the comprehensive understanding of residents about current water issues, how they are created, and how they viscerally affect the quality of their daily lives. I suggest that after development of the comprehensive understanding, it should be publicly published as a manual or report through popular media including local newspapers, Internet, and TV and public meetings and discussion sessions should be held to explain it.

4.2.2. The Need for Local Policies

As mentioned earlier, the City has only responded to federal and state policies in dealing with water quality issues. There are multiple problems about this approach including:

- Although surface waters and ground waters are connected, the 303(d) list only includes impaired lakes, creeks, and rivers, and but groundwater and wetlands are not considered [17]. The assessments of the MPCA indicate that the local aquifers are seriously contaminated in Twin Cities Metropolitan Area (TCMA) [Groundwater Contamination].
- The act of identifying impaired water bodies by EPA, defining TMDLs by MPCA and practicing them has a slow process. For example, since 1994, 86 sections of the Mississippi River assessed as impaired [34] and respective TMDLs have been defined since 2008. But they are not referred to in the SWMP 2013 [26].
- The TMDL approach is an example of incremental approach toward environmental governance. The consequences of urban development in terms of pollution are only identified after the development of urban spaces. Hence, it is only a trajectory of improving the quality of water bodies and does not promote preventive solutions. In other words, the TDML approach only attempts to reduce the amount of pollutants in water bodies by setting standards, but does not attempt to prevent the pollution before and during construction of cities.
- The EPA requirements (federal) and the MPCA requirements (state level) policies cannot illuminate the interrelation between local water issues of Minneapolis because they are only addressing the impaired water bodies. The local water issues in Minneapolis are not limited to pollution of water bodies and include flooding and erosion risk and improper recharge of groundwater as well. In a karst landscape, the declination of aquifer levels

can result in creation of sinkholes [35] as well and the City has not yet developed any program to address this issue.

I argue that there is an essential need for the creation of local water policies that recognize the interrelation between these water issues. These new policies should recognize that creation of urban runoff due to impervious surfaces is the cause of pollution in water bodies and groundwater, flooding risk, and improper replenishment of aquifers and encourage specific solutions in the local context of the karst landscape. Hence, the ending point and the long term trajectory of these policies should be aquifers with drinkable water quality. Moreover, instead of the current incremental approach, these policies should portrait an end point where elimination of non-point sources pollution and a healthy urban-nature environment enhance the quality of life of residents and other species.

4.2.3. Public Education and Involvement

Currently, the public education and involvement programs in the SWMP are focused on reducing the pollutant discharges into the storm sewer. I rarely found public outcries about the water pollution issue in Minneapolis. This means residents do not care much about the urban water bodies and I relate this to the following factors:

- The pollution crises are an abstract issue and residents cannot see their urban water bodies are polluted.
- They are not aware of the existence and importance of the contaminated aquifers.
- They are not aware of the fact that these impaired waters have detrimental effects to the ecosystem services we depend on. In other words, the dependence of our survivability to what goes on in the nature is not properly clarified for them.

Moreover, the Watersheds need to be more involved in public education to continue to get the MS4 Permit. Because the districts have the capacity to levy taxes they can raise a lot of money to improve the water quality. They also should be cooperative rather than competitive.
Because of the social context of the city, there is a potential for collaboration between municipality and resident groups to develop alternative LID programs to the SWMP. This will result to not only behavioral changes among residents, but also creating an environmentally concerned society. In addition, by actively involving in the development of the water programs, residents understand about the causes of water issues and the methods by which the City is

addressing these issues. Doing so will develop a loving and caring residents who value the natural water processes and attempt to restore the hydrological balance.

4.2.4. Adapting programs from other cities

Minneapolis and Berlin both share water issues about groundwater recharge and are surrounded with chain of lakes. Therefore, adaptation of the Biotope Area Factor (BAF) program from Berlin is implementable in south Minneapolis and adjacent areas to Mississippi River (figure 7) [23] where sandy soil geology resembles Berlin's conditions [36].

In Seattle, only one third of the city was served by separated stormwater and sanitary sewer networks. The City of Seattle has developed a Natural Drainage System (NDS) that utilizes LID principles to purify and reduce the stormwater volumes. In comparison, 31% of Minneapolis area is covered by streets and highways (see figure 8) [23]. These streets are either served by gutters or are directly connected to the storm sewer. There is a great opportunity to develop an alternative sustainable street design program to reduce the stormwater pollution and volumes, similar to NDS approach in Seattle. By this method, streets of Minneapolis can be transformed from non-point sources of pollution into district level BMPs, which means to retain the stormwater on-site, infiltrate it, allow plants and trees to absorb it for evapotranspiration, and detain it to slow the discharge rate. A few examples of the NDS street projects in Seattle are illustrated in Figure 9 In the appendix.

4.2.5. Opportunistic Approach

The Stormwater Management Program (SWMP) program properly distinguishes the opportunities of private and public new developments and redevelopment projects and provides guidelines for construction and maintenance of these projects to control sediments and erosion risk. Through this process, programs are implemented throughout the city by considering opportunities of all urban spaces.

However, not all programs in Minneapolis follow this approach. The Stormwater Utility Fee program might incentivize the reduction of the quantity and improve the quality of urban runoff in multi-family residential, industrial, and commercial land uses (collectively covering 18% of the jurisdiction area), but the amount of incentives it provides for single family residential are too low to encourage the implementation of BMPs in this type of land use; Considering the fact that 28% of total land use area of Minneapolis is covered with single-family residential areas(see figure 8) [23]. However, purely financial incentives are not a reliable approach toward creating long-term and comprehensive behavior changes. Hence, public education beside incentives is the best solution.

4.2.6. Promoting Innovative Multifunctional Technical Measures

The City has some critical concerns about developing alternative city-scale LID and green infrastructure programs beside the SWMP. This is mainly because the infiltration of stormwater in karst landscapes contributes to the solution of limestone bedrocks, creation of sinkholes, and groundwater pollution due to direct discharge of surface water into the groundwater [23]. However, as mentioned, the depth of the quaternary sediment cover over the local bedrock is enough to support infiltration from BMPs such as ordinary rain gardens without causing structural damages to the properties [15]. Moreover, the implementation of structural BMPs is recommended by Flood Mitigation Program and also the Stormwater Utility Fee incentives. Importantly, LID BMPs are not solely about infiltration: they emphasize on dealing with stormwater at its source through a handful of alternative measures that includes detention, reuse, and evapotranspiration as well as infiltration. A table of recommendation for implementation of BMPS in sensitive karst landscapes by MPCA is represented in Table 2 in the appendix. Moreover, a local map should be developed in a collaborative research with the University of Minnesota and other research institutes to identify the districts in which direct infiltration contributes to bedrock solution.

Appendix

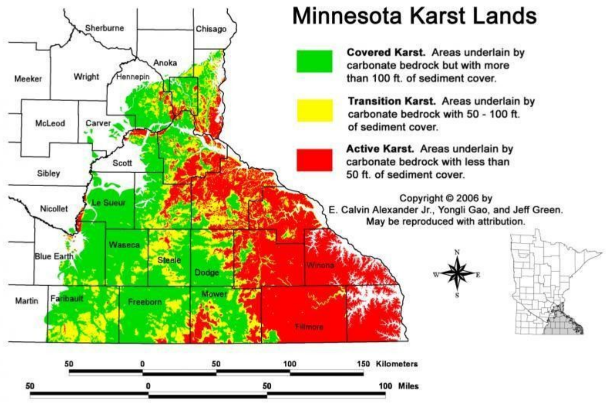


Figure 44 Distribution of Karst Lands in South East Minnesota [37].

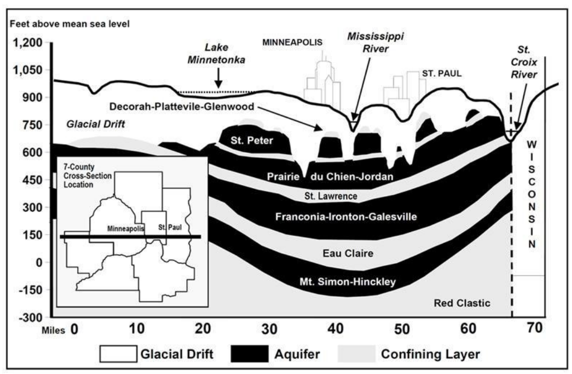


Figure 45 Twin Cities Metropolitan Area Aquifer Basin [6]

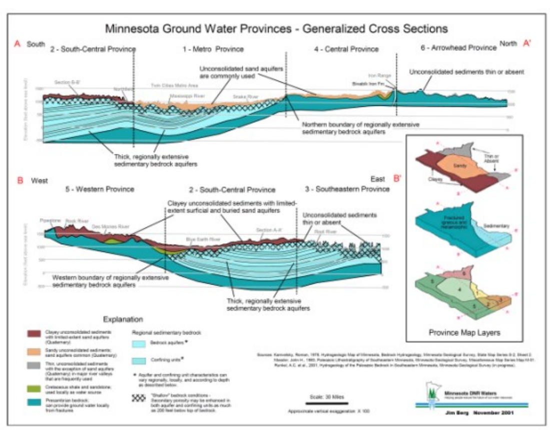


Figure 46 Geological Cross Section of TCMA, [9].

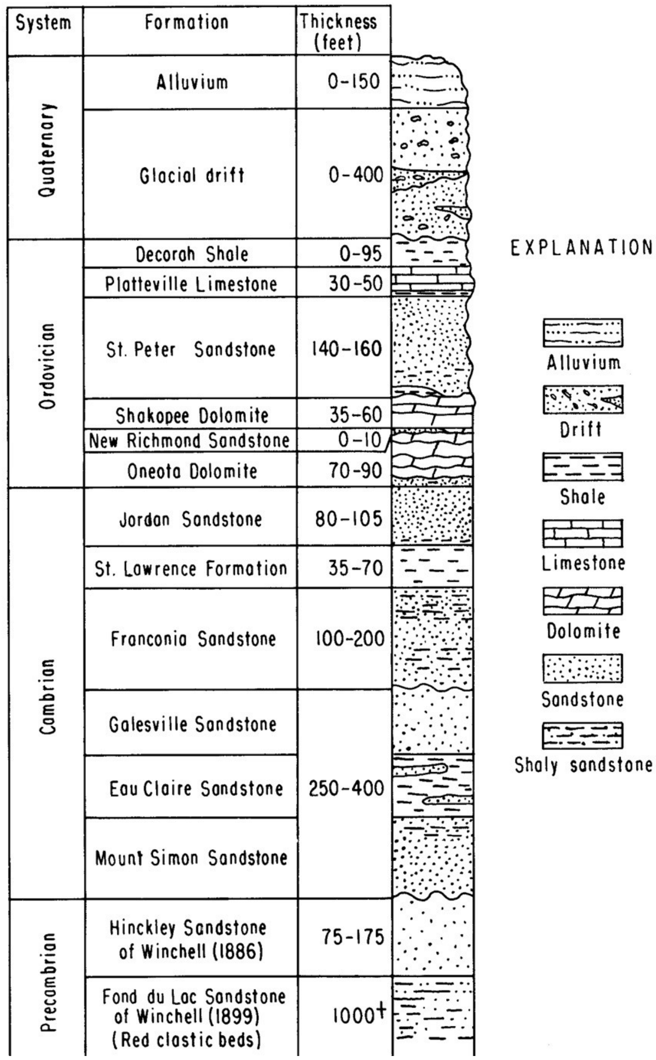


Figure 47 Generalized Geologic Section of the Minneapolis- St. Paul Area, [10].

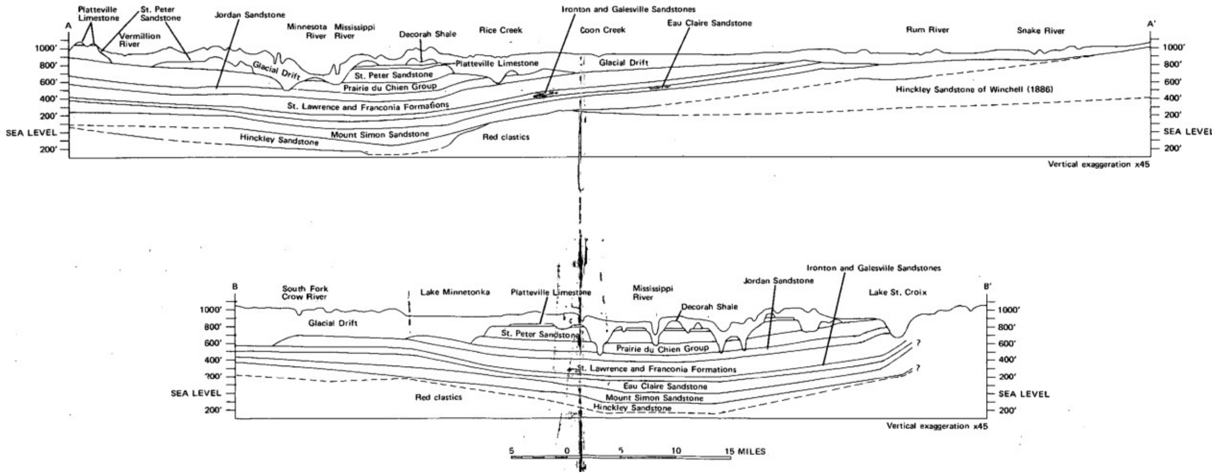


Figure 48 Generalized cross sections of the Metropolitan Area artesian basin, [11]

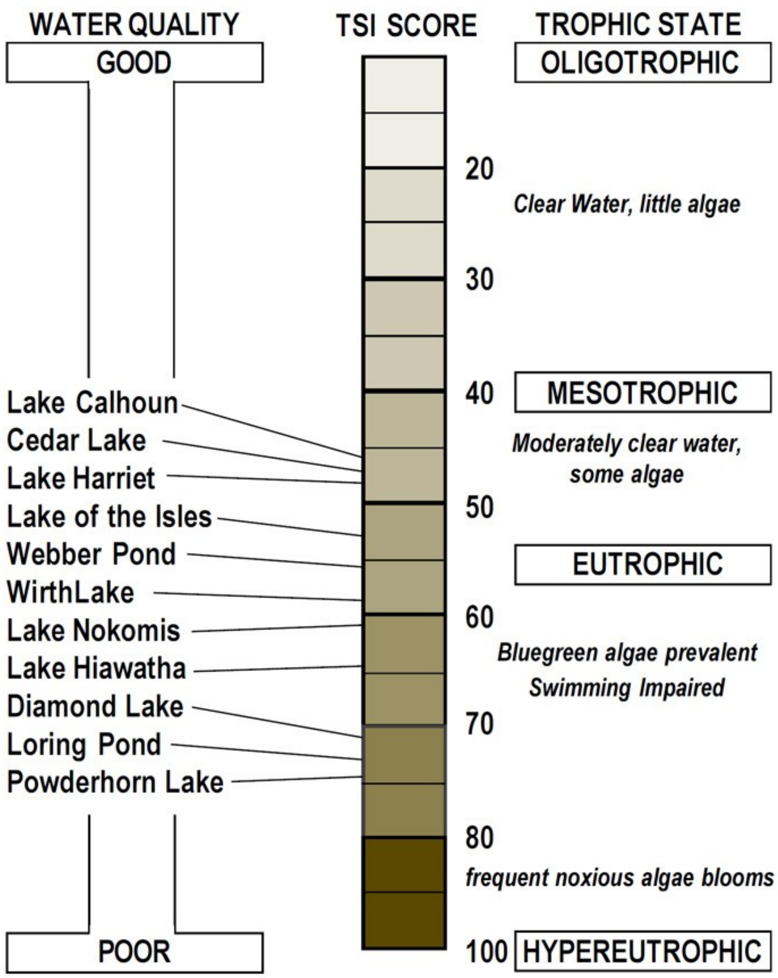


Figure 49 Carlson's Trophic State Index of Minneapolis' lakes, [4].

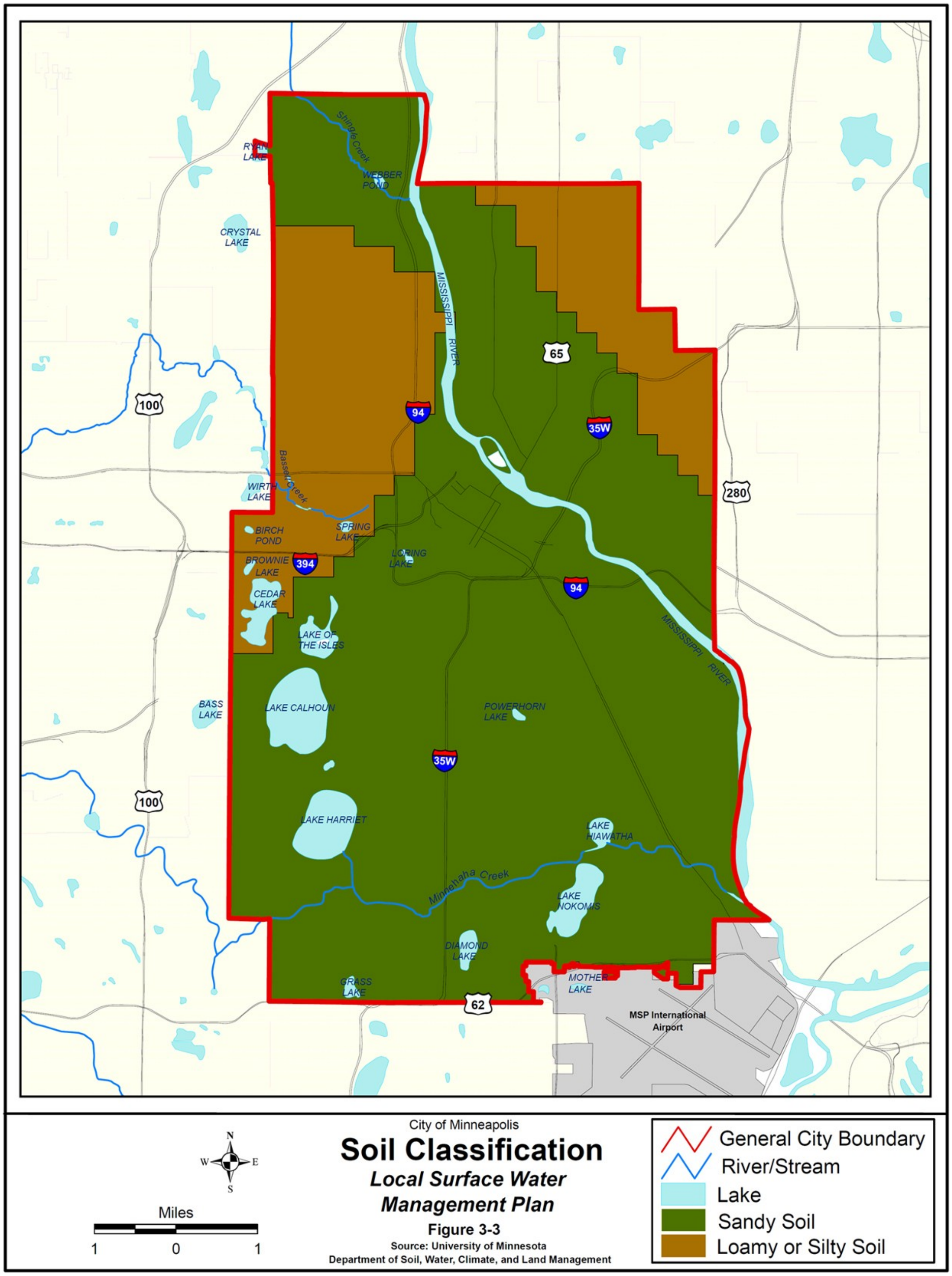


Figure 50 Soil Classifications of the Minneapolis, LSWMP, the City of Minneapolis [23].

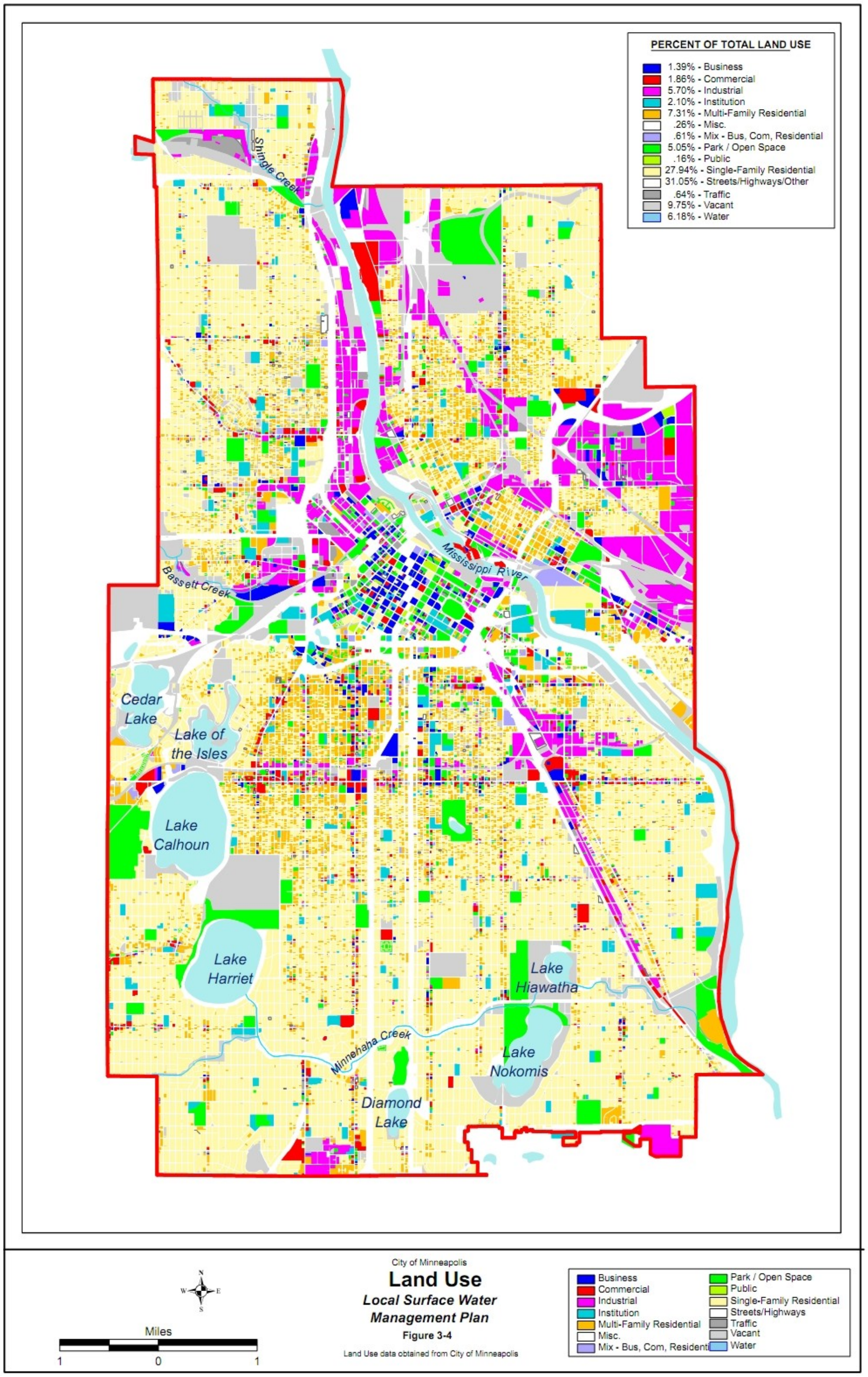
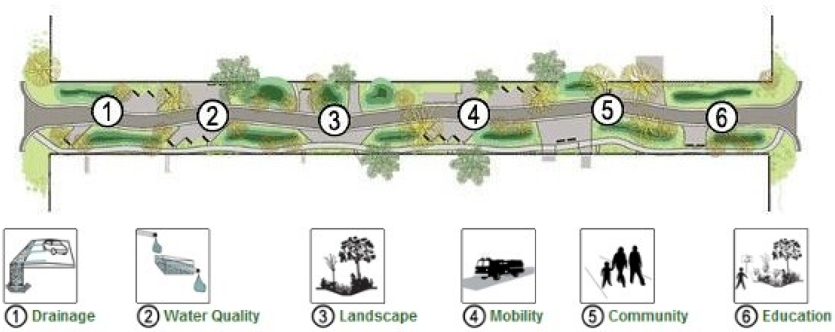


Figure 51 Minneapolis Land Use Percentages, LSWMP, The City of Minneapolis [23].

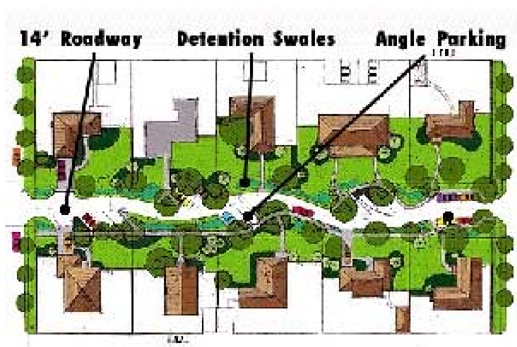
Broadview Green Grid NDS Area [38]

Schematic Drawing for the Cistern Steps on Vine Street [39]

110th Cascade Project [40]



Seattle SEA Streets [41]



SEA Street [43]

SEA Street [42]

Figure 9 Examples of NDS Street Design in Seattle

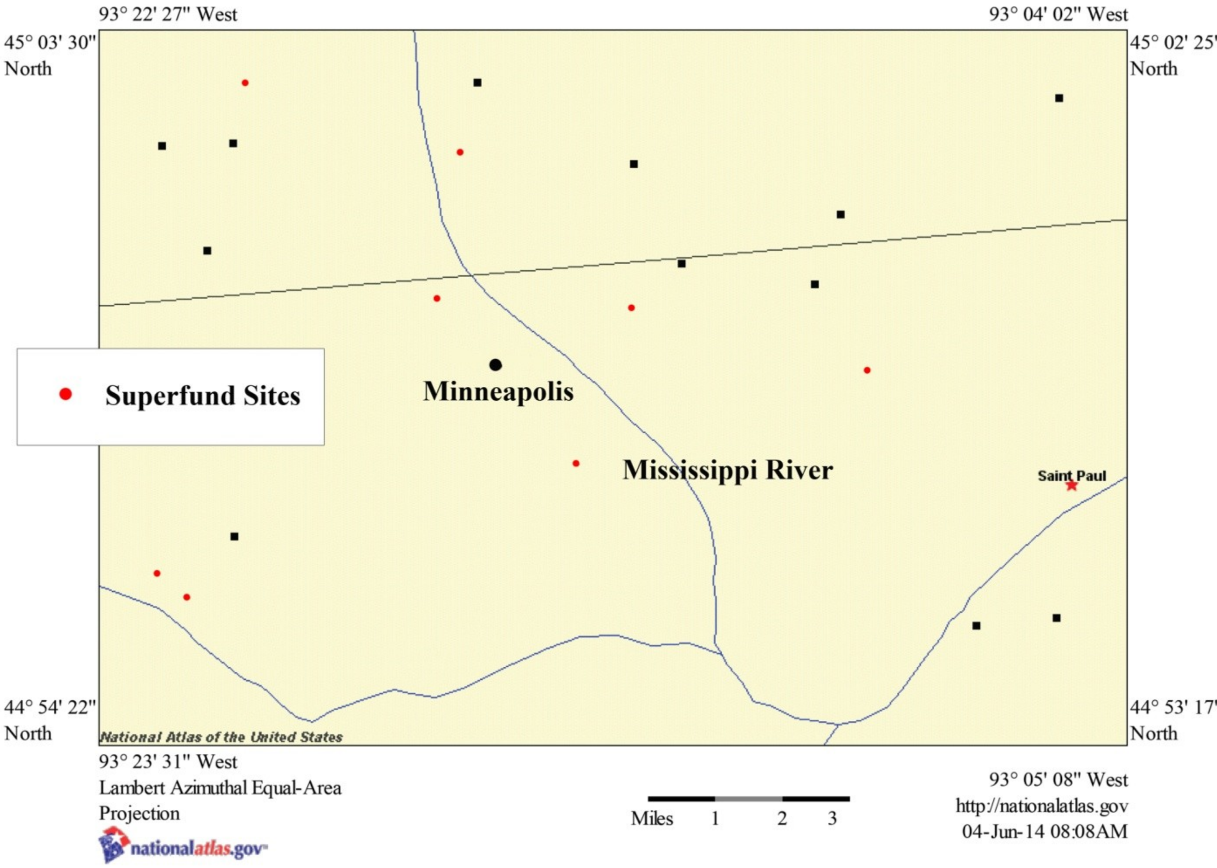


Figure 10 Superfund Sites Near Minneapolis, National Atlas [33].

Table 11- List of Water Policies Affecting Stormwater Management.

2010 Goals Established by Mayor and City Council	• A Safe Place to Call Home • Jobs & Economic Vitality • Livable Communities, Healthy Lives • Many People, One Minneapolis • Eco-Focused • A City That Works
Minneapolis Plan for Sustainable Growth Policies	• Enhance the safety, appearance, and effectiveness of the city's infrastructure. • Make city government more responsive to the needs of people who use its services. • Integrate environmental, social and economic goals into decision making processes at all levels. • Protect and enhance air quality and reduce greenhouse gas emissions.

	• Encourage sustainable design practices in the planning, construction and operations of new developments, large additions and building renovations. • Support the efficient use of land and development that reduces the reliance on fossil fuels. • Advocate for federal, state, metropolitan and county policies and programs that support sustainable development. • Preserve and protect land from pollution and encourage the remediation of contaminated sites. • Encourage a healthy thriving urban tree canopy and other desirable forms of vegetation. • Be a steward of clean water by protecting and enhancing its surface and groundwater systems. • Preserve and enhance the quality of the urban environment to promote sustainable lifestyles for its citizens. • Provide residents and visitors information about recreational locations, events, programs and education opportunities. • Work to restore and preserve ecosystem functions in green open spaces. • Design streets and sidewalks to ensure safety, pedestrian comfort and aesthetic appeal. • Landscaping … to complement the scale of the site and its surroundings; enhance the built environment… and environmental benefits.
Minneapolis Greenprint Sustainability Initiatives	• Reduce Carbon Dioxide Emissions • Increase the Use of Renewable Energy • Improve Air Quality Levels • Prevent, Reduce, Reuse and Recycle • Reduce Airport Noise and the Environmental Impacts of the Airport • Expand the City's Tree Canopy • Reduce Stormwater Pollution Entering Lakes, Creeks and Mississippi R. • Improve the Water Quality of Minneapolis Lakes • Grow a Green Economy
Water Resource Guiding Principles	• Maintain and Enhance Infrastructure • Provide Cost-effective Services • Meet or Surpass Regulatory Requirements • Protect People, Property and the Environment • Educate and Engage the Public and Stakeholders • Enhance Livability and Safety
MPRB Comprehensive Plan Goals	• Sound management techniques provide healthy, diverse, and sustainable natural resources • Healthy boulevard trees connect all city residents to their park system. • Knowledgeable stewards and partners generously support the system's natural resources.

	• Park facility renewal and development respects history and focuses on sustainability, accessibility, flexibility, and beauty. • Focused land management supports current and future generations. • Easily accessible information supports enjoyment and use of the park and recreation system.
MPRB Strategic Direction	• Address issues of aging infrastructure • Focus on partnerships • Become a national leader in issues of sustainability • Focus on new strategies of community engagement

Table 12 MPCA Considerations for structural BMP use in karst settings

BMP	Karst considerations
Considerations for structural BMP use in karst settings	If containment levels remain high after treatment or if water inflow presents a threat, an under drain and-or use of a synthetic or other impermeable membrane liner should be considered to seal the bottom of the system.
Media filter	If containment levels remain high after treatment or if water inflow presents a threat, an under drain and-or use of a synthetic or other impermeable membrane liner should be considered to seal the bottom of the system.
Vegetative filter	Avoid water ponding Should be engineered to avoid channel erosion and optimize pollutant removal
Infiltration trench or basin	Not typically recommended in active karst areas due to sinkhole formation and inadequate treatment by a scarcity of underlying soils If used, should have supporting geotechnical investigations and calculations Pre-treatment should be extensive to limit risk of groundwater contamination Local review authority should be consulted for approval
Stormwater ponds	Should be constructed with a synthetic or clay liner in active karst areas Should have supporting geotechnical investigations and calculations Should be limited to a maximum ponding depth (e.g. < 10 feet)
Constructed wetlands	Should be constructed with a synthetic or clay liner in active karst areas Should have supporting geotechnical investigations and calculations Should be limited to a maximum ponding depth (e.g. < 10 feet)

5. Conclusion

Today, it is increasingly recognized that the cities that humankind has built simply cannot be separated from its natural habitat to ensure our survival on this magnificent planet. We have to redefine our perceptions about the urban environment, water management, wildlife, and the integration of our urban habitat into the nature world practically; without degrading both.

Water is one of the most powerful, yet delicate forces of nature. The current trends of increased urbanization, effects of climate change and population growth demonstrates that cities will face more severe urban water issues in the near future. Our current approach of incrementally solving individual water issues is proven to be inefficient and ineffective. We have to follow a whole new approach toward urban water management. This new approach encompasses the tracking the systemic causes of water issues and conceptualizing these water issues as interconnected and not separate symptoms of the degraded local, regional, and global water cycles. This novel approach cannot be accomplished by only municipalities but also needs active participation by all urban water stakeholders including residents.

My case studies revealed that water issues are local in their nature and each city has its own unique hydrological, geological, cultural, and political context. Hence, instead of applying universal solutions for local water issues, I have proposed more specific alternatives that municipalities and residents can employ based on their local contexts. My thesis proposes an alternative to the application of universal solutions that I presented in the introduction chapter. I argued the importance of the relationship of urban water management between policy, program and implementation in comprehensively solving urban water issues. Through analyzing the connections and disconnects between policies, programs and implementation strategies in various case studies.

In the interrelation of issues, between policy, program and implementation, municipalities should understand local water issues comprehensively by considering all the resources of water such as surface water, groundwater, lakes and rivers as integrated components of local water cycles and remove regulatory barriers that treat them separately and uncommented. Then, cities should develop a simplified and comprehensive understanding about local hydrological regime and respective water issues for residents. As most of these components are very abstract, people usually cannot understand the interconnectedness of water in the urban environment. Urban residents often are not familiar with topics such as level drop of aquifers, flows of groundwater, existence of water tables, and base-flow because they cannot see them. Hence, municipalities should depict local water issues through visual representation to create a visceral and emotional relationship with urban water issues and their impact on their quality of life.

Consequently, to address current local water issues municipalities should make local comprehensive water policies based on the comprehensive understanding of local water issues. Federal and state policies are not specific enough to address local water issues. These policies that presently deal with individual water issues separately and incrementally, should be re-conceptualized to consider all water components in cities as an integrated concept. Furthermore, by actively involving residents in policy making and program designing, municipalities can ensure the investment of social capital of residents in the programs and expect corresponding and perhaps permanent behavior changes.

In program designing we have to bring back the balance to the local water cycle by limiting the physical barriers that urban development has created against natural water cycles and flows in cities and limit the water bodies' pollution. For this purpose, we have to use and mimic natural processes like infiltration of stormwater through soil and its purifying functions. The programs should treat the urban environment and every potential space as mini catchments for infiltration. The perception that the previously built urban spaces does not allow to incorporate sustainable urban water strategies should be rethought and different opportunities for renewal and redevelopment projects, and retrofit projects in private or public urban spaces should be implemented and monitored. In addition to source control strategies and the promotion of demand reduction and water reuse should be implemented to further reduce the human adverse impacts on local hydrological

Finally, sustainable urban water programs should be translated into understandable and flexible regulations for implementation that is compatible with development schedules. Moreover, logical milestones for gradual implementation of the programs should be considered. Finally, maintenance responsibilities for different stakeholders should be properly clarified to ensure long-term functionality of implemented measures and facilities.

The proposed framework can be considered as the outcome of this paper. Although it is not the ultimate solution to urban water issues, it can assist municipalities in taking initial steps in rethinking their approach toward water in cities. It presents guidelines for municipalities to bridge the gaps between their local water policies, program design and implementation strategies.

The current trend of rapid urban population growth suggests more urban development, more impervious surfaces, excessive urban runoff, more water pollution, and more rapid exploitation of water resources seems to be the current design strategies. If municipalities and residents neglect the indispensible and urgent efforts to remediate our past adverse practices, the degradation of nature and threats on our urban environment reach a disastrous point where both urban residents and the natural habitants will have a continuous degradation of quality of life with possibly no return. We are living in the beginning of the sustainability era and now it is the time for municipalities to take action in the act of creating mutual dialogue and problem solving to ensure the resiliency of our communities in facing current urban water issues. In the end, dealing with current urban water issues is not only an important effort to enhance the quality of life in cities, but a prerequisite to assure the healthiness of us and the future generations on this planet.

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