Green Infrastructure Application in the Chelsea River Subwatershed

GREEN INFRASTRUCTURE APPLICATION IN THE CHELASEA RIVER SUBWATERSHED

A Master Project Presented

by

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Submitted to the Department of
Landscape Architecture and Regional Planning of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF LANDSCAPE ARCHITECTURE

February 2010

Master of Landscape Architecture

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ABSTRACT

GREEN INFRASTRUCTURE APPLICATION IN THE CHELSEA RIVER SUBWATERSHED

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This master project uses green infrastructure as a tool to protect urban environment and wildlife habitat under degradation due to urbanization in the Chelsea River Subwatershed in eastern Massachusetts. The goal of the project is to improve the Chelsea River Subwatershed, and therefore to improve the impaired Chelsea River by identifying the best locations for urban landscape interventions and creating blue-green network with green infrastructure in the subwatershed. Site visits, literature review, background data search, interview with government staff and watershed associations helped with site analysis to identify the problems and potentials for green infrastructure implementation. Landscape Urbanism theory as basis of Green Infrastructure provides guidance on the selection of strategies for green infrastructure implementation in urban watershed. Specific watershed management approaches including stormwater management BMPs, river and saltmarsh restoration and urban forest are adopted.

The comprehensive concept plan proposes a green infrastructure network in the Chelsea River Subwatershed composed of open spaces and green hubs linked by linear connections such as green streets, waterfront buffer and trails with stormwater BMPs and public access at specific sites. A design proposal for the waterfront park provides example of the implementation of green infrastructure approaches at a community scale. The benefits provided by the project to Chelsea River and Chelsea River Subwatershed include improving water quality of river, increasing biodiversity in the subwatershed, promoting environmental justice, supporting the sustainability of people's life, etc.

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A. Background – Urbanization

At the beginning of the 20th century, only 16 cities in the world had populations larger than a million people, yet at the close of the century more than 5 hundred cities had more than a million inhabitants, many boasting more than 10 million residents and still expanding (Corner, 2006). This phenomenon is called “urbanization”, the physical growth of rural or natural land into urban areas as a result of population immigration to an existing, or emerging, urban area. Urbanization happens when people move into cities to seek economic opportunities. This is heightened during times of change from a pre-industrial society to an industrial one. Urbanization creates a number of negative environment and public health outcomes, such as the urban heat island, air pollution, threaten to watershed ecosystem and biodiversity reduction.

1. Watershed Urbanization

Urbanization has a number of documented physical, chemical and ecological effects on stream and watershed:

Urbanization changes the watershed surface conditions, which leads to the change of hydrology (Fig. 1). A dominant feature of urbanization is a decrease in pervious surface and increase in impervious surface of the catchment to precipitation, leading to a decrease in infiltration and an increase in surface runoff (Paul and Meyer, 2001). In addition, removal of the forest reduces evapotranspiration and increases the amount

of stormwater overland and subsurface flow. Paving and sewer construction directly increase stormflow volume and peak discharge and shorten the time of concentration in relatively small precipitation events (Cretaz and Barten, 2007). The increase in overland flow and stormflow with urban development cause a reduction in groundwater recharge and a reduction in base flow following a storm event. Baseflow may be augmented by wastewater treatment plant effluent; however, this can cause important changes to water quality.

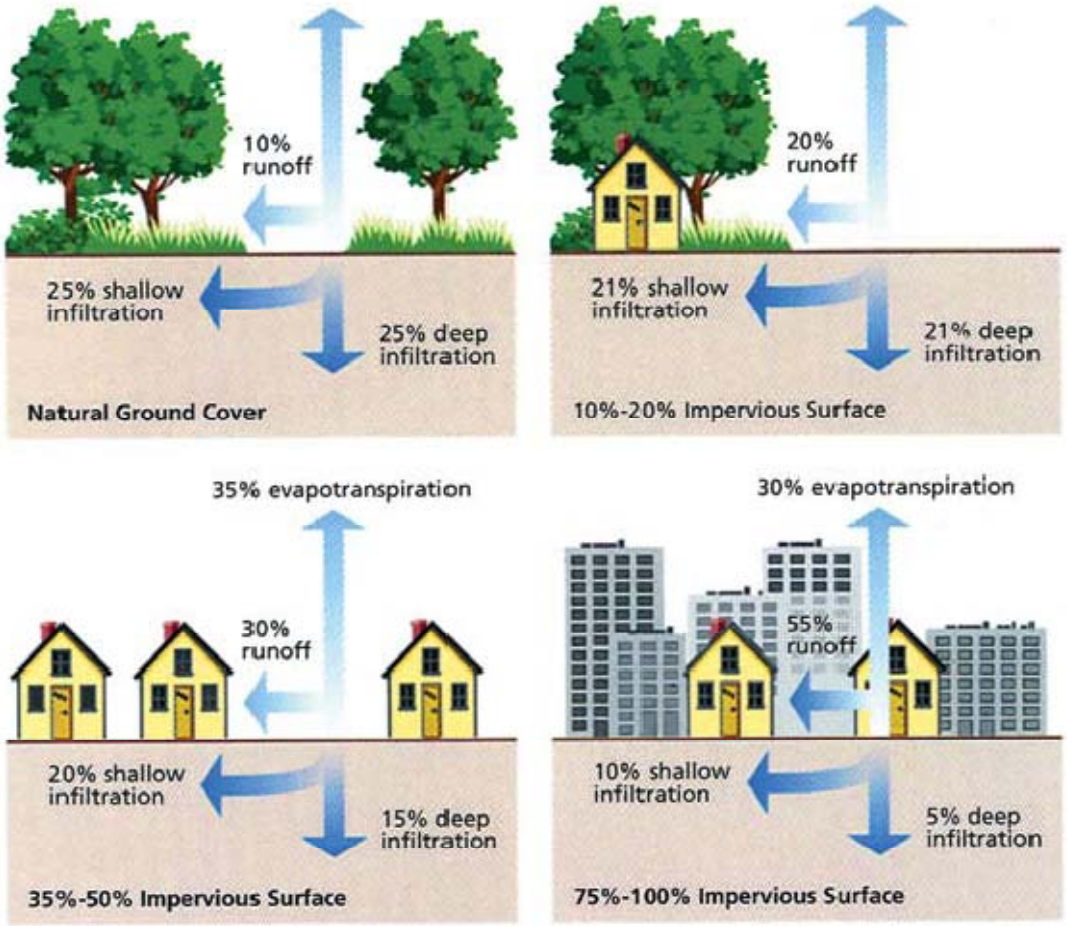


Fig. 1: the Impacts of Impervious Cover on the Hydrologic Cycle (Source: FISRWG, 1998)

The major impact of urbanization on basin geomorphology is an alteration of channel form. Stream channel widening happens in response to persistent changes in sediment supply and bankfull discharge. During the construction phase of

urbanization, hillslope erosion increases sediment supply leading to bed aggradation and overbank deposition; after construction ceases, sediment supply decrease and bankfull flows increase leads to increased channel erosion resulting in channel widening and incision (Paul and Meyer, 2001; Riley, 1998).

Urban development introduces a rich assortment of chemical pollutants into surface water bodies. Nutrients and pesticides are common pollutants in urban watershed. Other pollutants originating in urban areas include transportation-related pollutants (such as road salt and polycyclic aromatic hydrocarbons), heavy metals, fecal contaminants, volatile organic compounds, polychlorinated biphenyls, etc (Paul and Meyer, 2001). The problem of combined sewer overflows (CSOs) which carry sewage and stormwater draining from city streets in the same pipe has received great attention and concern. Under dry weather conditions, sewage and stormwater is delivered to wastewater treatment plants (WWTP) via a single, combined system. Following rainstorms, however, the combined volume of wastewater and storm water often exceeds the capacity of treatment facilities and CSOs are designated to overflow, releasing storm water and untreated wastewater (sewage, industrial waste, toxic material and floating debris) directly into streams, rivers, lakes and coastal estuaries. This raises the levels of bacteria, pathogens and toxic substances and can cause health problems for humans and wildlife (Paul and Meyer, 2001). Figure 2 illustrates how CSOs work in heavy rainstorms in Boston Harbor.

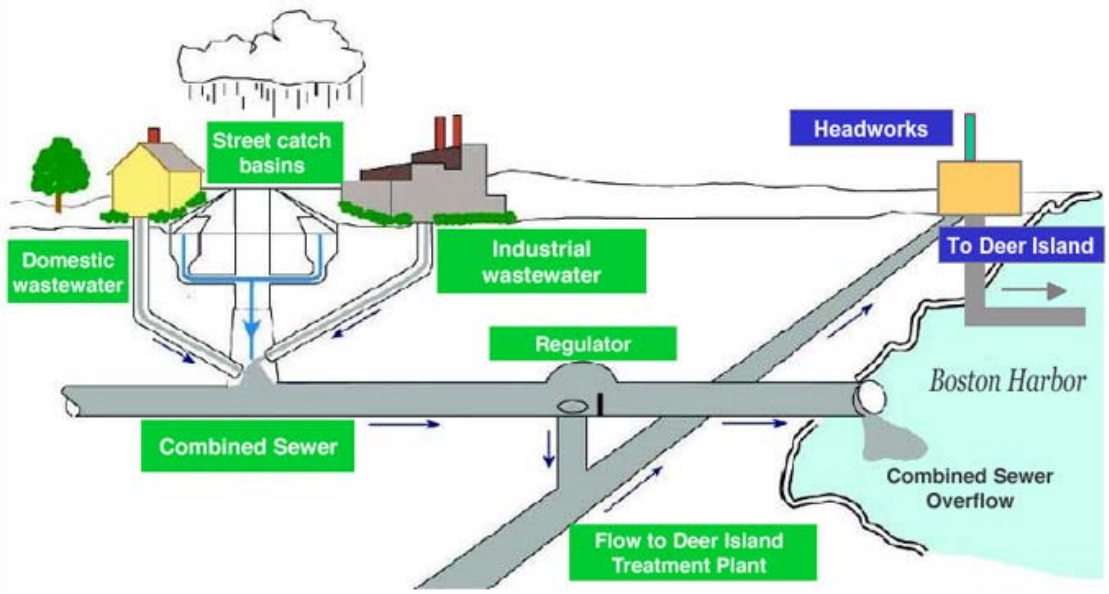


Fig. 2: CSOs in heavy rainstorms in Boston Harbor (source: Massachusetts Water Resources Authority, http://www.mwra.com/cso/html/whatiscso.html)

In urban watershed, with the change of water cycle, ecosystem processes change, such as primary productivity, leaf decomposition and nutrient cycling. Wastewater treatment plants and CSOs discharges can increase dissolved and particulate organic carbon concentrations. The Carbon inputs affect dissolved oxygen in streams. Oxygen deficit has been shown elevated in urban streams. In addition, urbanization affects the nature of transported organic matter by altering the quantity and quality of organic matter and organic retention. Furthermore, ecosystem metabolism also changes due to urbanization. For example, studies show the urban river has higher gross primary production and community respiration than the forested river (Paul and Meyer, 2001).

Another ecological effect of urbanization is the biological degradation in urban streams. There are many causes such as physical habitat, water quality and food web disturbances. The types of species affected by urbanization cover a wide range including microbes, algae, macrophytes, invertebrates and fish. The reduction of biodiversity has been given increasingly global attention. Biodiversity in urbanized

watershed will be addressed in the following section.

Therefore, the urbanization has resulted in a lot of problems to the environment and ecosystem in watersheds which in turn threatens human's health and the future of our life.

2. Biodiversity in Urbanized Watersheds

Biodiversity—the variability among living organisms on the earth and the habits that support them (Ahern, Leduc and York, 2006) —sustains human life. Biodiversity includes the diversity within and between species and within and between ecosystems. Biodiversity among ecosystems not only provides for a wide range of animal species, it also provides people with food, medicine, and shelter (Benedict and McMahon 2006).

Habitat loss and fragmentation are important factors contributing to a reduction in the planet's biodiversity (Rolstad 1991). Besides resource extraction in mining, fishing, and forestry, most habitat loss and fragmentation is due to urban development (Rudd, Vala and Schaefer 2002). In highly modified landscapes, and especially in urban environment habitat, habitat connectivity is greatly reduced, often resulting in habitat fragmentation. Disruption of hydrologic connectivity is a major concern when planning for sustainability (Ahern 2007).

Fragmentation, a common landscape pattern, is often associated with the loss and isolation of habitat. The spatial scale at which fragmentation occurs is important when identifying strategies to cope with continued habitat loss and isolation (Dramstad, Olson and Forman, 1996). Franklin, Noon and George, 2002 defined "habitat

fragmentation" as both state and process: Habitat fragmentation is the discontinuity, resulting from a given set of mechanisms, in the spatial distribution of resources and conditions present in an area at a given scale that affects occupancy, reproduction or survival in a particular species. Habitat fragmentation can be static, such as land transformation, or results from disturbance. Disturbance can be "natural" (fire, wind, etc.) or anthropogenic (logging, agriculture, urbanization, etc.).

In aquatic systems, fragmentation greatly impacts the aquatic organisms. The most obvious effects of fragmentation are seen in highly migratory species. However, even non-migratory fish species need to move over large areas to use different kinds of landscape features for various reasons. Similarly, other aquatic organisms also require connectivity across larger scales and experience population declines when isolated. Human-induced fragmentation of aquatic systems includes dams, culverts that create velocity, jump, or exhaustion barriers for aquatic organisms, thermal pollution discharge, channelization and hardening of rivers and streams, and stream enclosures (Eagle et al. 2005). There is growing concern about the role of river and stream crossings, especially culverts, in disrupting river and stream continuity. Three stream crossing problems—undersized crossings, shallow crossings, and crossings that are perched—can be barriers to fish and wildlife and lead to several common consequences (Amy Singler and Brian Graber 2005).

Aquatic ecosystems have important ecological function because they provide resources such as food and water for many animals and breeding habitat for amphibians (Lindenmayer and Franklin 2002). Also, they provide pathways for

wildlife to get from one habitat location to another through urban area.

Temporal variability, human manipulation of annual flow and the pattern of human settlement together make clean freshwater a rare entity and maintaining water quality an often contentious issue. Landscape manipulation is considered one of the greatest threats to riverine ecosystems (Freeman and Ray 2001). Urbanization poses vexing challenges to the ecological sustainability and restoration of stream ecosystems (Walton, Salling and Wyles 2007). Stream habitat and biota in urban settings are often profoundly degraded in comparison to natural or less-impacted rural conditions. Urbanization and conversion of floodplain to cropland, e.g. can often lead to increased agricultural sediment loading, degradation of wildlife habitat, altered river geomorphology and reduced water quality (Freeman and Ray 2001).

Studies have addressed the relationship between watershed urbanization and biotic integrity in streams. For instance, the study in historically urbanized areas of Ohio, USA examines the relationship between urban land use and the biological health of streams and tracked the health of three streams over a decade in the rapidly suburbanizing Columbus, Ohio metropolitan area. The study shows that the health of streams, as measured by the Index of Biotic Integrity, declined significantly when the amount of urban land use measured as impervious cover exceeded 13.8%, and fell below expectations consistent with Clean Water Act goals when impervious cover exceeded 27.1% (Miltner 2004). The Index of Biotic Integrity (IBI) used in this study is a multi-metric index first developed by Pr. James Karr to assess biotic integrity of stream using fish communities. The index is provided by summing over 12 fish

community parameters related to species composition and ecological structure (Karr 1981). The IBI presented the advantage of a refined biotic assessment system and is widely used (Simon and Lyons 1995).

There are more studies of urban effects on aquatic invertebrates than on any other group. All aspects of aquatic invertebrate habitat are altered by urbanization. General effects of urbanization on stream invertebrates can be summarized: decreased diversity in response to toxins, temperature change, siltation and organic nutrients; decreased abundances in response to toxins and siltation; and increased abundances in response to inorganic and organic nutrients (Resh and Grodhous 1983, Wiederholm 1984). Specifically, the causes such as sediment toxicity, riparian deforestation, road construction, aquatic insect colonization have been studied (Paul and Meyer 2001). For example, riparian deforestation associated with urbanization reduces food availability, affects stream temperature and disrupts sediment, nutrient and toxin uptake from surface runoff. Streams that had higher benthic index of biotic integrity scores for a given level of ISC were always related to greater riparian forest cover in watershed suggesting riparian zones in some urban catchments may buffer streams from urban impacts. The value of riparian forests is reduced if the stormwater system is designed to bypass them and discharge directly into the stream (Paul and Meyer, 2001).

In summary, urbanization has great impacts on watershed and water bodies, which leads to the change of urban hydrology and watershed geomorphology and an increase of pollution in urban watershed. Additionally, studies have shown that urbanization

poses challenges to the ecological sustainability and restoration of stream ecosystems. Most habitat loss and fragmentation, important factors contributing to a reduction in biodiversity, are due to the urban development. The ecological effects of urbanization on watershed, including ecosystem processes change and biodiversity degradation, have received a lot attention and concerns.

B. Green Infrastructure

It is increasingly clear that green infrastructure serves as a tool to protect urban wildlife habitat by enhancing the connectivity of open space. Green Infrastructure is a concept originating in the United States in the mid-1990s that highlights the importance of the natural environment in decisions about land use planning. Green infrastructure has its origin in two important concepts: (1) linking parks and other green spaces for the benefit of people, and (2) preserving and linking natural areas to benefit biodiversity and counter habitat fragmentation (Benedict and McMahon 2006). The benefit of green infrastructure can be shown in the definition for green infrastructure given by a Green Infrastructure Work Group under the leadership of the Conservation Fund and the USDA Forest Service:

"Green infrastructure is our nation's natural life support system — an interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life for America's communities and people."

This also gives us a picture of what green infrastructure looks like and what are the elements of green infrastructure. Green infrastructure encompasses a wide variety of natural and restored native ecosystems and landscape features that make up a system of “hubs” and “links” (Benedict and McMahon 2006). The specific implication of green infrastructure varies, including urban agriculture, green walls, urban woodlands, street trees, green roofs, sensitive urban design, parks, and gardens, etc.

The main benefits of Green Infrastructure to hydrology include rainfall interception, increased soil infiltration, water uptake, water storage, decreasing peak flows and volume of stromwater that require management. There are some successful practical examples of implemented Green Infrastructure. For instance, Street Edge Alternatives (SEA Streets) Project located in northwest Seattle at a neighborhood scale (Fig. 3), and the Staten Island Bluebelt in New York City (Fig. 4), at a watershed scale, both use green infrastructure instead of sewers to manage stormwater in a more natural way. They have been recognized for effective hydrological performance and providing multiple functions such as wildlife habitat, recreation, water quality improvement, neighborhood beautification and so on.

Fig. 3: SEA Street Project, Seattle, MA (Source: Seattle Public Utilities. http://www.seattle.gov/UTIL/About_SPU/Drainage_&_Sewer_System/Natural_Drainage_Systems/Street_Edge_Alternatives/COS_004467.asp)

Fig. 4: Illustration of the Staten Island Bluebelt Project (Source: New York City Department of Environmental Protection, http://home2.nyc.gov/html/dep/html/dep_projects/bluebelt.shtml)

The watershed urbanization changes urban hydrology which therefore contributes to many other ecological issues such as biodiversity reduction. Green Infrastructure provides multiple benefits and has been shown a great opportunity to deal with these problems. This project will make research on how to restore the urban watershed and the impaired water body with green infrastructure and give concept plan and recommendations for green infrastructure implementation in the urban watershed.

II. Literature Review

This chapter will review the previous literature on 1) the definitions, principles and implementation scales of green infrastructure, 2) Landscape Urbanism theories as basis of green infrastructure implementation, 3) urban watershed management with green infrastructure.

A. Green Infrastructure

Webster's *New World Dictionary* defines "infrastructure" as "substructure or underlying foundation, especially the basic installations and facilities on which the continuance and growth of a community depends". Usually, when people hear the term infrastructure, most of them think of gray infrastructure such as roads and sewers; or social infrastructure such as hospitals and schools. These types of facilities are often referred to as built infrastructure. The key concept of green infrastructure is based on a paradigm shift that elements of the natural environment - waterways and vegetation, etc. - are equally essential forms of infrastructure to those other "built" forms (Beatley 2000).

The definitions of green infrastructure vary significantly depending on the focus of the document and the work of the researchers who compiled it. This is readily apparent if the work of Williamson, 2003 and TEP, 2005 are compared (Mell 2008). TEP is a multi-disciplinary practice providing environmental consultancy in UK.

"Green Infrastructure: the physical environment within and between cities, towns and villages. The network of open spaces, waterways, gardens, woodlands, green corridors, street trees and open countryside that brings many social, economic and

environmental benefits to local people and communities."

-TEP, 2005

"Our nation's natural life support system - an interconnected network of protected land and water that supports native species, maintains natural ecological processes, sustains air and water resources and contributes to the health and quality of life for America's communities and people."

-Williamson, 2003

TEP highlights the spatial elements of green infrastructure development before outlining the green infrastructure's benefit. In contrast to the TEP definition, Williamson places the greatest importance on ecological ideas (Mell 2008). However, some common ideas do exist in their definitions. For example, they both affirm that green infrastructure is a network which can bring benefit to people and community.

Looking at the definitions of green infrastructure recently made by Davies et al., 2006 and Ahern 2007, multi-functionality, multi-scale and connectivity are emphasized.

Green infrastructure is the physical environment within and between our cities, towns and villages. It is a network of ***multi-functional*** *open spaces, including formal parks, gardens, woodlands, green corridors, waterways, street trees and open countryside. It comprises all environmental resources, and thus a green infrastructure approach also contributes towards* ***sustainable*** *resource management.*

-Davies et al., 2006

Green infrastructure is an emerging planning and design concept that is

principally structured by a ***hybrid*** *hydrological/drainage network,* ***complementing*** *and* ***linking*** *relict green areas with built infrastructure that provides ecological functions.*

-Ahern, 2007

The Abiotic, Biotic and Cultural (ABC) resource model is applied to articulate the key ecological functions of a green urban infrastructure. This comprehensive multi-functional model is consistent with landscape ecology perspective that recognizes the needs and reciprocal impacts humans on biotic and abiotic systems and processes, supporting the broad principles of sustainability and also builds on the fundamental pattern: process dynamic interrelationship (Ahern 2007).

The principles of green infrastructure have been studied. As Benedict and McMahon 2006 addresses, planners and designers should follow these principles to implement green infrastructure:

1) Green infrastructure should be the framework for conservation and development.
2) Design and plan green infrastructure *before* development
3) Linkage is key
4) Green infrastructure functions across multiple jurisdictions and at different scales.
5) Green infrastructure is grounded in sound science and land use planning theories and practices.
6) Green infrastructure is a critical public investment.
7) Green infrastructure involves diverse stakeholders.

In the urban environment, the green infrastructure approach can be implemented at

multi-scale: the individual parcel, the community or neighborhoods and the city or metropolitan region (Ahern 2007; Benedict and McMahon 2006). Green infrastructure should be applied as a gradient process. An example taken in Ahern 2007 presents that ABC functions respond differently across a continuum of urban water courses, which suggests employment of a mixed range of hydrological types to provide a complete suite of ABC functions. Connectivity plays an important role in creating an ecological network in urban environment with aim to maintain biodiversity, which requires an implementation at wide-range scale. However, Most land conservation programs in the U.S. have focused on protecting individual sites with important natural or cultural resources (Benedict and McMahon 2006). So, green infrastructure at community scale which connects individual site and city should be recognized as a key component of a broader regional green infrastructure plan.

In sum, when taking the urban watershed condition into consideration, these principles and features of green infrastructure should be highlighted:

1) Adaptation to urban environment

Although it is difficult to implement green infrastructure in urban environment where the “green” and “grey” infrastructure used to stand oppositely, using natural elements to function as infrastructure, as a basic feature of green infrastructure, should be given priority when employing green infrastructure tools. However, goals and objectives for green infrastructure implementation need to be set up reasonably with adaptation to the existing urban environment. For example, the effects of green infrastructure on biodiversity may be less obvious in urban area than in suburban or

rural areas within the same period. It should be implemented gradually according to different phases.

2) Connectivity and multi-scale

As addressed above, connectivity is important for green infrastructure to provide ecological services. However, it is very hard to maintain connectivity in urban watershed where habitat is heavily fragmented. Connectivity can be enhanced by creating green infrastructure network with combination of “blue” (hydrological network) and “green” (open space and green space such as park system and green corridors). Based on ecological principles, urban hydrology will be restored and habitat will be provided and connected with this network. Just like river hierarchy in a watershed, implementing green infrastructure at multi-scale require a hierarchy of the network. There should be green infrastructure facility installed in every subwatershed. The watershed as a whole should be covered by green infrastructure network system with arteries connecting different subwatershed.

3) Multi-function

Because of space limitation and close relationship with people’s life, multi-functional is especially important for green infrastructure in urban watershed. In addition to ecological function, green infrastructure can also be potential to benefit these areas: recreation, education, economy, social communication, water and air quality, traffic calming, public health as well as people’s life style.

B. Landscape Urbanism as Basis of Green Infrastructure Implementation

Recently many green infrastructure implementations have been grounded in

Landscape Urbanism theory. Over the past decade, landscape has emerged as a model for contemporary urbanism as described through the formulation “Landscape Urbanism”.

The origins of Landscape Urbanism can be traced to postmodern critiques of modernist architecture and planning (Waldheim 2006). Landscape Urbanism emerges along with the tide of postmodern urbanism within design professions. Contemporary theories of landscape urbanism reject the ecological systems with pastoral images of “nature”, reject the opposition of nature and city, and recommend the use of infrastructural systems and the public landscapes as the ordering mechanisms of the urban field.

James Corner and Charles Waldheim are among the instructors, practitioners, and theorists who have been most responsible for articulating the terms of landscape urbanism.

James Corner defines Landscape Urbanism as a theory of urbanism which is capable of organizing the city and enhancing the urban experience with landscape as a model of urbanism in his essay titled *Terra Fluxus*. He argues that the concept of landscape urbanism suggests a more promising, more radical and more creative form of practice than that defined by rigid disciplinary categorizations today when cityscape and landscape are not clearly separated any more. The significant potentials of landscape urbanism lie in the ability to shift scales, to locate urban fabrics in their regional and biotic contexts, and to design relationships between dynamic environmental processes and urban form (Corner 2006).

Four provisional themes of Landscape Urbanism are sketched by James Corner in this essay: processes over time, the staging of surfaces, the operational or working method, and imaginary.

The first theme addresses processes over time. The principle is that the processes of urbanization are much more significant for the shaping of urban relationships than are the spatial forms of urbanism in and of themselves, which suggests shifting attention away from the object qualities of space to the systems that condition the distribution and density of urban form (Corner 2006). Landscape Urbanism advocates that future urbanisms must derive more from an understanding of process – how things work with space and time.

Pattern and process are highlighted in ecological thinking. Ecology itself becomes a useful lens through which to project alternative urban futures. Cities can become more sustainable by modeling urban processes on ecological principles of form and function by which natural ecosystems operate (Newman and Jennings 2008). Corner draws on a Landscape Ecology tradition that defines the landscape very broadly as a mosaic of "the total spatial and visual entity of human living space" (Shane 2004). Different from the ecology outlined earlier which has been used only in the context of "nature" and exclusive of the city, Landscape Urbanism relates to the space-time ecology that treats all forces and agents working in the urban field and considers them as continuous networks of inter-relationships (Corner 2006).

The second theme projects landscape urbanism with the phenomenon of horizontal surface. An understanding of "surface" as urban infrastructure is emphasized. Because

urban infrastructure stages the ground for more future possibility than architecture, this approach is more strategic means over ends and operational logic over compositional design. Landscape Urbanism is considered as a kind of urbanism that anticipates change, open-endedness and negotiation, working across vast surfaces of potential over time.

These two themes of Landscape Urbanism suggest Landscape Urbanist critic former theories and re-considerate traditional concept as well as operative techniques, which lead to the last two themes - operation or working methods and imaginary. The union of landscape with urbanism promises new relational and systemic workings across territories of vast scale and scope. The lack of the techniques to address the sheer scope of issues is deserving of more attention and research (Corner 2006).

Charles Waldheim defined Landscape Urbanism as a branch of landscape ecology, concentrating on the organization of human activities in the natural landscape (Shane, 2004). His essay “Landscape as Urbanism” focuses on the discourses surrounding landscape and urbanism over the past quarter-century, constructing a lineage for the emergent practice.

Landscape Urbanism theory provides guidance on the selection of strategies for green infrastructure implementation in urban watershed which will be highlighted as follows:

1) Landscape framework

Establish green infrastructure network as a form of landscape framework in urban watershed.

2) Ecological principle

Green Infrastructure approaches root in ecological principles. For example, changing the channel form to restore river hydrology and connecting green hubs with green corridors to enhance habitats.

3) Surface

Vast surface transformation include turning impervious surface to pervious surface as much as possible, changing landform when needed, for example, to make transition in riparian area, and adding green roof and green walls to compensate green loss in urban area.

4) Potential for future

Some environmental sensitive areas will be protected by buffer and left for evolution so that they can be at least kept from degradation due to urban development and still potential for future use. Accordingly, human activity will be restricted in conservation areas.

5) Brownfield redevelopment

Clean up brownfield and reclaim them for redevelopment with green infrastructure. For instance, a riparian brownfield can be redeveloped to a new type of neighborhood interacting and benefiting river and people.

C. Urban Watershed Management with Green Infrastructure

Urban watersheds are complex geographic mosaics and integrated physical systems whose proper functioning depends upon the interplay of hydrologic, chemical, and

ecological elements (Platt 2006). Environmental Protection Agency (EPA) defines "urban watershed management" as the technological approach of managing the stormwater runoff generated from rainfall in an urban environment. It indicates the importance of stormwater management. However, in a broader sense, this phrase can refer to the technological approach of managing the water system in an urban watershed. The recent trend of urban watershed management is to manage water in limited urban land using natural principles of hydrological processes.

Urban watershed management is considered to be made at multiple scales, from the whole watershed to an individual parcel. An emerging concept of "neighborshed" which refers to a base unit within the larger city system that has a distinct ecological and social identity and function (Rottle and Maryman 2006), divides the whole watershed into several parts, working as a transitional unit within the broad range of scale.

1. Stormwater Best Management Practices

Urban BMPs address 3 major issues: stormwater management, reduction of nonpoint source pollutants and sediment control at construction sites (Paul and Meyer 2001). EPA's definition of urban water management indicates the critical importance of stormwater management. Stormwater management can regulate flow, help to maintain the stability of stream channels and reduce the transport of pollutants from urban and suburban buildings and streets (Paul and Meyer 2001). Recent innovations in urban BMPs focus on improving water quality, minimizing the need for expensive pipe-and-pond stormwater systems by increasing infiltration and soil storage at new

development sites. These strategies are often referred to as “Low Impact Design” (LID).

The stormwater BMPs are listed in Table 1, classified into 4 categories.

Table 1: Stormwater Management Measurements

Type	BMPs
Policy/Regulations	Conservation Easement
	Stream/Wetland Management and Restoration
	Watershed Development Ordinance
Planning Process	Conservation Development
	Floodplain Zoning
	Impervious Area Reduction
	Open Space/Natural Greenway
	Riparian Buffer
Site Stormwater BMPs	Bioswales
	Filter Strip/Level Spreaders
	Green Roofs
	Naturalized Detention and Infiltration Trench
	Porous Pavement
	Structural Soils
	Rain Barrels/Cisterns
	Rain Gardens
Landscaping	Native Landscaping

Reference: Conservation Design Forum, 2004 and Day & Dickinson, 2008

Examples of some prevailing stormwater BMPs are presented as follows:

1) Bioswale

Bioswale is defined as vegetated swale system with an infiltration trench designed to retain and temporarily store runoff, typically from impervious surfaces. Bioswales can replace curb and gutter systems as well as storm sewers that convey runoff. Bioswales are planted with native grasses and forbs that enhance filtration, cooling, and cleansing of water in order to improve water quality and prevent sealing of subsoils as illustrated by Fig. 5 and Fig. 6 (Conservation Design Forum 2004).

Fig. 5: Bioswale (Source: USDA http://www.ia.nrcs.usda.gov/features/images/Gallery/bioswale6.jpg)

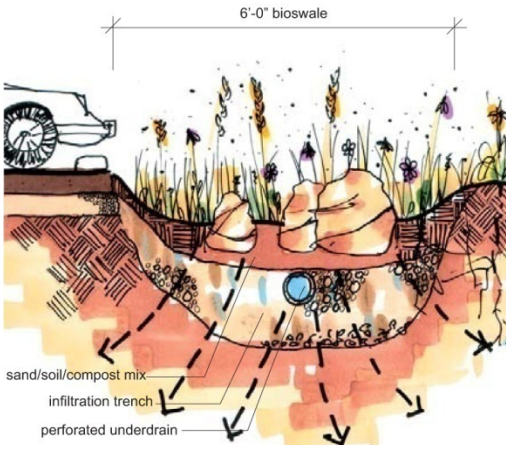


Fig. 6: Cross-section of a Bioswale (Source: Conservation Design Forum, 2004)

2) Bioretention Basin / Rain Garden

Bioretention basins are shallow depressions filled with sandy soil, topped with a thick layer of mulch, and planted with dense vegetation (Metropolitan Area Planning Council). Bioretention basins temporarily hold water to allow for infiltration. Stormwater is directed to the basin and then percolates through the system where it is treated by a number of physical, chemical and biological processes (Fig. 7). The slowed, cleaned water is allowed to infiltrate native soils or directed to nearby stormwater drains or receiving waters. The multiple benefit of bioretention practices include reducing peak discharge rates and total runoff volume, increasing infiltration

and underground recharge, improving water quality, providing habitat and landscape attractiveness (Fig. 8).

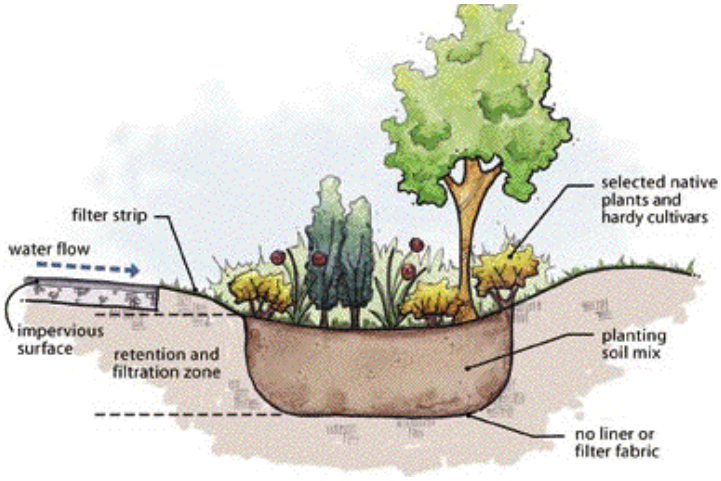


Fig. 7: Rain Garden (Illustration courtesy of the Low Impact Development Technical Guidance Manual for Puget Sound)

Fig. 8: People Building a Rain Garden at Elkhart Environmental Center, IN

3) Filter Strip/ Level Spreaders

A filter strip is an area with dense, preferably native vegetative cover that is used to filter and absorb sheet flow runoff, typically from impervious areas (Fig. 9, Fig. 10). A level spreader is a trench laid on the contour to distribute runoff over filter strip areas (Conservation Design Forum 2004). The benefits of filter strip system include:

removing suspended solids, heavy metals, trash, oil and grease, reducing peak discharge rate and total runoff volume, providing modest infiltration and recharge, providing snow storage areas and improving site landscaping. Filter strips work best when they are at least 20 feet long (downhill axis), though shorter strips will still provide some treatment (Metropolitan Area Planning Council).

Fig. 9: Filter Strip and Level Spreader (Source: Conservation Design Forum, 2004)

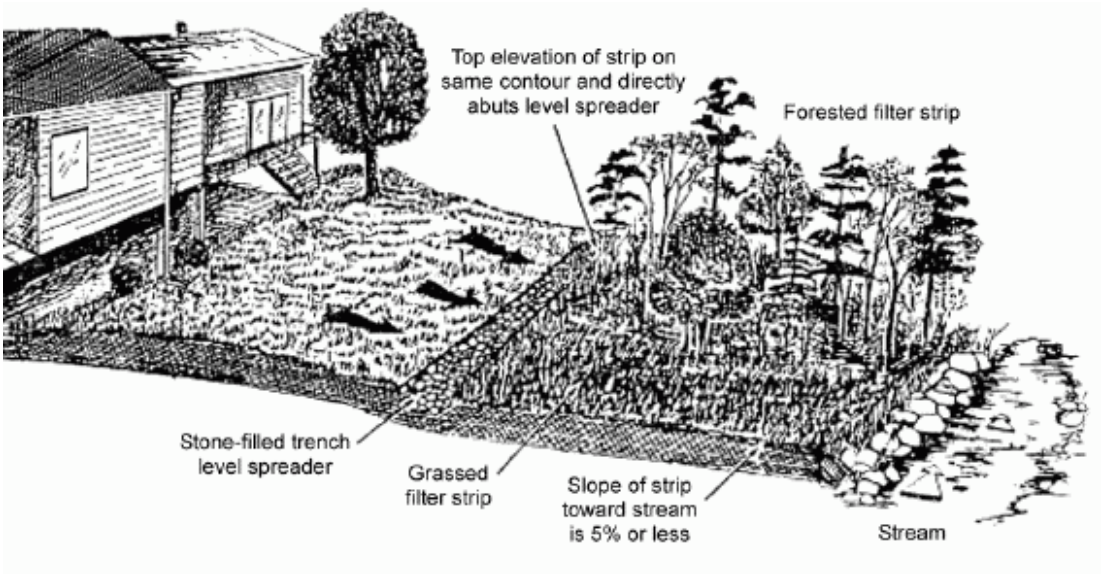


Fig. 10: Filter Strip Combining Grass and Wood Areas (Source: Metropolitan Council http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STFiltFilterStrips.pdf)

4) Green Roofs

A green roof is a vegetated roof system that stores rainwater in a lightweight engineered soil medium, where the water is taken up by plants and transpired into the air (Fig. 11). As a result, much less water runs off the roof, as compared to conventional rooftops (Metropolitan Area Planning Council). Green roofs effectively reduce stormwater runoff, reduce peak discharge rates, lower heating and cooling costs and provide aesthetic values (Fig. 12).

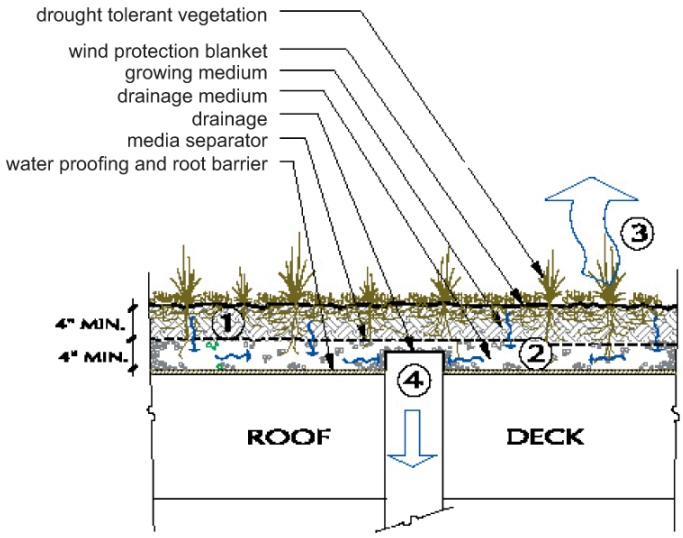


Fig. 11: Cross Section of an Extensive Green Roof (Source: Conservation Design Forum, 2004)

Fig. 12: Green Roof (City Hall, Chicago, IL) (Source: Conservation Design Forum)

5) Permeable Pavement

All permeable paving systems consist of a durable, load bearing, pervious surface overlying a crushed stone base that stores rainwater before it infiltrates into the

underlying soil (Metropolitan Area Planning Council). Permeable paving techniques include porous asphalt, pervious concrete, paving stones, and manufactured “grass pavers” made of concrete or plastic (Fig. 13). Permeable paving may be used for walkways, patios, plazas, driveways, parking stalls, and overflow parking areas (Fig. 14). Permeable paving allows rainwater to percolate through the paving and into the ground before it runs off. This approach reduces stormwater runoff volumes and minimizes the pollutants introduced into stormwater runoff.

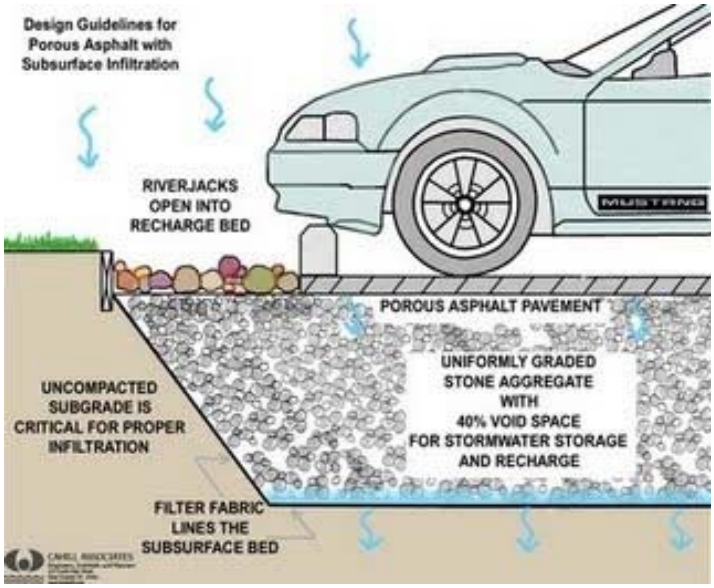


Fig. 13: A Schematic Cross Section of Permeable Paving (Source: Cahill Associates, Inc. 2004)

Fig. 14: Porous Pavement in Parking Lot (Source: Conservation Design Forum, 2004)

6) Structural Soils

Structural soils can be used as a new space-saving BMP to mitigate runoff from pavement areas. In urban area, traditional tree pits usually limit canopy cover. Larger tree canopies require greater soil volume. Structural soils support the weight of pavement, cars and other structures and provide space for tree roots to flourish under paved sites with porosity of 30 - 35%, and infiltration rates of 514 cm/hour (Day and Dickinson 2008). Fig. 15 illustrates how the structural soils work. Structural soils may be used in many places, such as street tree pits and parking lots. Besides increasing tree canopy, structural soils also provide multiple benefits such as storing water under pavement and out of the way, enhancing infiltration and improving water quality and so on.

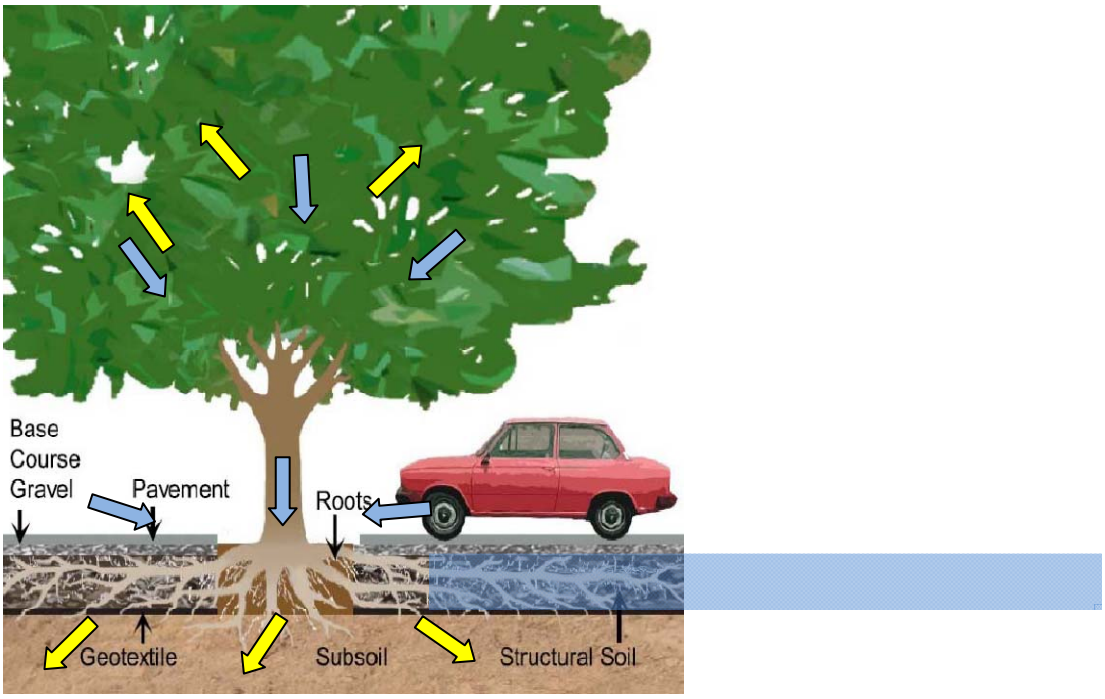


Fig. 15: Structural Soils BMPs System (Adapted from Day and Dickinson, 2008)

1) Water enters the structural soil reservoir through pavement swales and tree pits or through porous pavement (shown by blue arrows)
2) Water filters through the structural soil and recharges the groundwater below or is transpired by the tree (shown by yellow arrows)

2. River and Salt Marsh Restoration

The accumulated body of research on urban watersheds and urban streams suggests that a combination of restoration strategies addressing both fine-scale (e.g., protecting and revegetating riparian buffers and enhancing stream habitat, reshaping or replacement of unstable stream reaches into appropriately designed functional streams and associated floodplains) and broad scale (e.g., increasing watershed infiltration, removal of the watershed disturbances that are causing stream instability) issues will be necessary to improve the abundance, diversity and health of biotic communities restoration strategies as measured biological response.

Salt marshes, as one of coastal wetlands, are those halophytic and salt tolerant grasslands found in the middle and high latitudes along protected coastlines (Zhu et al. 2004). They are subjected to tidal action as well as high salinities. Major benefit and functions of coastal wetland's include shoreline protection, support of coastal fisheries, wildlife habitat and water quality management. Salt marshes are one of the most biologically productive habitats on the planet. However, salt marshes have disappeared rapidly during the last century accompanying an increase in population and coastal development (Copeland 1998). Salt marsh restoration methods include restoration of tidal flow, removal of fill, removal of creek obstructions, diversion of stormwater flow, restoration of sediment supply, removal of invasive species, as well as reestablishment of native salt marsh vegetation (Copeland 1998).

Oil pollution has been known to cause the impairment of salt marshes. It impacts not only water quality but also wetland vegetation, wildlife that rely on the salt

marshes and ecosystem (Zhu et al. 2004). Salt marshes are among the most sensitive ecosystems and therefore the most difficult to clean. Bioremediation has been recognized as one of the least intrusive methods and has been shown effective in oil contamination cleanup and treatment in salt marshes (Zhu et al. 2004).

Bioremediation and phytoremediation are emerging technologies to restore contaminated salt marshes. Biostimulation based bioremediation attempts to accelerate the natural degradation process of contaminants, such as petroleum hydrocarbons, by adding non-bacterial agents to overcome factors that limit bacterial hydrocarbon degradation(Zhu et al. 2004, Lin et al. 2003). Phytoremediation, the use of vegetation for the in-situ treatment of contaminated soil and water, promises effective and inexpensive cleanup of pollutants (Lin et al. 2003). Plants can be used to clean up metals, pesticides, solvents, explosives, crude oil, polycyclic aromatic hydrocarbons, and landfill leachates from contaminated soils (U.S. EPA 1998). Phytoremediation reduces contamination in soil by enhancing oil degradation, absorption of the organic contaminant onto the surface of the roots and subsequent uptake and/or degradation. Current studies have proved the great potential of phytoremediation by small cordgrass (some species of the genus Spartina) for the cleanup of hydrocarbon contaminated soil in salt marshes (Lin et al. 2003, Castillo and Figueroa 2009) and that bioremediation by N and P fertilization enhances the efficacy of oil phytoremediation (Lin et al. 2003).

3. Urban Watershed Forest

Forests provide numerous benefits that can be divided by scales and further categorized into economic, environmental and community benefits. Table 2 summarizes these benefits.

Table 2: Economic, Environmental and Community Benefits of Trees

Scale	Category	Benefit
Watershed	Environmental	• Reduce storm water runoff • Improve regional air quality • Reduce stream channel erosion • Improve soil and water quality • Provide habitat for terrestrial and aquatic wildlife • Reduce summer air and water temperatures
Parcel	Economic	• Decrease heating and cooling costs • Reduce construction and maintenance costs (by decreasing costs related to clearing, grading, paving, mowing, and storm water management) • Increase property values • Positively influence consumer behavior
	Environmental	• Reduce urban heat island effect • Enhance function of storm water treatment practices
	Community	• Increase livability • Improve health and well-being • Block UV radiation • Provide shade • Buffer wind and noise • Increase recreational opportunities • Provide esthetic value

Source: Cappiella, Schueler, and Wright. 2005

Urbanization has great impact on forest such as forest fragmentation and tree canopy cover decline. Remaining urban forest fragments are exposed to high stresses from nearby development. The typical Characteristics of urban forest fragments are summarized as follows (Cappiella, Schueler, and Wright 2005):

- Lack of vergical structure
- Populations of invasive plants may dominate
- Fewer native species may present
- Trash and other illegally dumped material is present
- Lack of species diveristy (often a monoculture)

- High propotion of edge habitat to interior habitat
- Lack of understorey or herbaceous layer
- Poor, compacted soils
- Subject to clearing and encroachment
- Subject to erosion and excessive stormwater runoff
- Subject to overbrowsing by deer due to uncontrolled populations
- Large populations of exotic earthworms
- Soil nitrogen present primarily as nitrate

Based on the preceding principles, urban watershed forestry has three goals:

1) ***Protect*** undeveloped forests from human encroachment and impacts of land development by creating and applying various planning techniques, regulatory tools and incentives.
2) ***Enhance*** the health, condition, and function of urban forest fragments.
3) ***Reforest*** open land through active replanting or natural regeneration.

To meet these goals and objectives, more specific techniques for maintaining and increasing forest cover in a watershed can be implemented. Table 3 lists the techniques according to the corresponding goals and objectives.

Table 3: Summary of Protection, Enhancement and Reforestation Techniques

Goals	Objectives	Techniques
Protect	A. Protect Priority Forests	1. Conservation easements 2. Land acquisition 3. Transfer of development rights
	B. Prevent Forest Loss During Development and Redevelopment	4. Bonus and incentive zoning 5. Clearing and grading requirements 6. Forest conservation regulations 7. Open space design 8. Overlay zoning 9. Performance-based zoning 10. Storm water credits 11. Stream buffer ordinances
	C. Maintain Existing Forest Canopy	12. Protection of significant trees 13. Tree removal restrictions for developed areas
Enhance	D. Enhance Forest Fragments	14. Increase forest area where possible 15. Increase habitat diversity 16. Manage deer 17. Protect soils from erosion and compaction 18. Provide food, cover, and nesting sites for wildlife 19. Reduce or eliminate invasive species 20. Remove trash and prevent dumping
Reforest	E. Plant Trees During Development and Redevelopment	21. Landscaping requirements 22. Planting trees in storm water treatment practices 23. Planting trees in other open areas 24. Shading and canopy requirements
	F. Reforest Public Land	25. Allow natural regeneration 26. Actively reforest public lands
	G. Reforest Private Land	27. Education 28. Incentives for tree planting 29. Stewardship and neighborhood action

Source: Cappiella, Schueler, and Wright, 2005

Setting numerical targets for forest cover helps to provide guidance for implementation of increasing forest cover. Across the United States, tree canopy cover currently averages 27% in urban areas and 33% in metropolitan areas (Dwyer and Nowak 2000). American Forests recommends 40% cover for most metropolitan areas east of Mississippi and the Pacific Northwest (American Forests 2003). “Grow Boston Greener”, a campaign with collaboration between the City of Boston, the Commonwealth of Massachusetts, the US Forest Service and Boston’s Urban Forest Coalition, set up a goal to increase the City’s canopy coverage from 29% to 35% by

planting 100,000 new trees by 2020.

The quality of urban forest fragments in the watershed can be enhanced by increasing habitat diversity. Specific measures are described as follows:

1) Vertical Structure

Vertical structure evaluates the variety of vertical vegetative layers in a forest. Fig. 16 illustrates a forest with high habitat and species diversity. Urban forest fragments often lack an understory. Planting understory species using native trees in these areas is a way to increase the diversity of habitat in an urban forest.

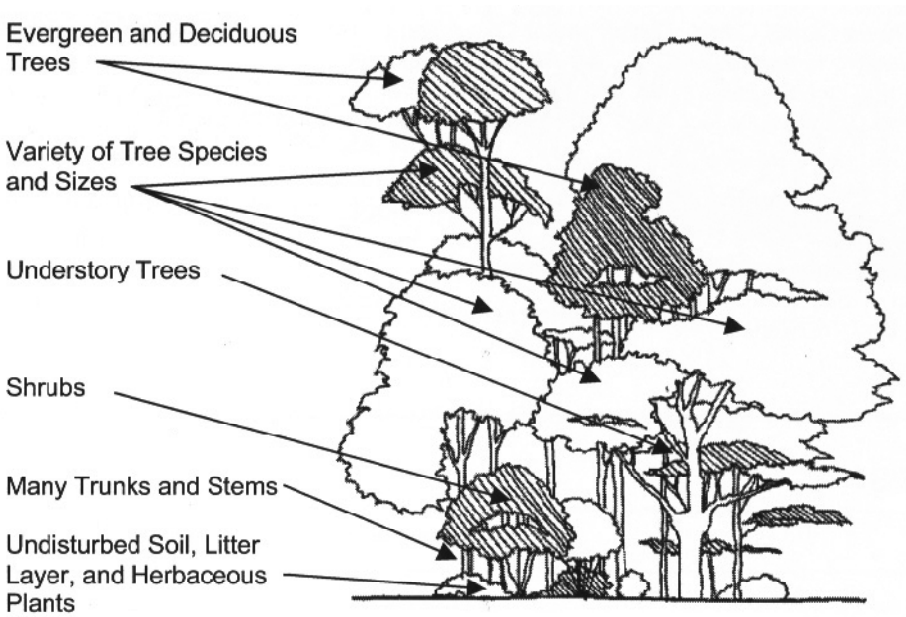


Fig. 16: Example of Forest with Good Habitat Diversity and Vertical Structure (Source: Cappiella, Schueler, and Wright, 2005)

2) A gradual transition at the forest edge

Forest edge habitat can be improved by creating a soft edge or transition rather than a hard edge or abrupt change from forest to field. A gradual transition (Fig. 17) from herbaceous cover to shrubs and small trees to tall trees provides a greater diversity of habitat types and also reduces predation and nest parasitism along the forest edge (Hanssen 2003). It mitigates the edge effects and makes the interior habitat more

valuable for interior species.

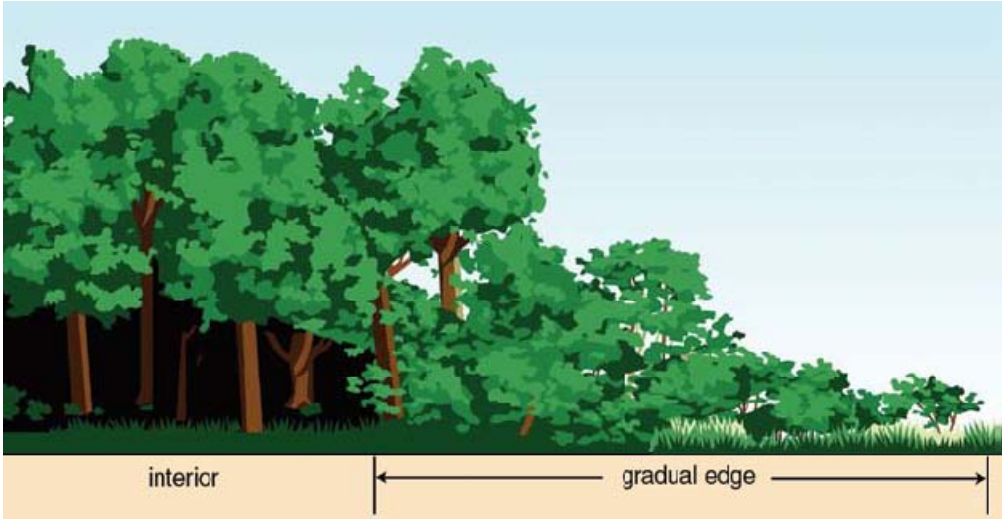


Fig. 17: Soft or Gradual Forest Edge Provides a Gradual Transition from Forest to Field and Benefits Wildlife (Source: FISRWG, 1998)

3) Woody debris and leaf litter

Another simple method to restore habitat diversity is to leave the woody debris and leaf litter which provide unique habitat features within a natural forest but often eliminated in urban forest. Woody debris from downed trees or fallen branches should be left in place as they are a source of food for insects and fungi and provide habitat for amphibians, reptiles, and small mammals. Woody debris and leaf litter also contribute organic matter to the soil, which improves water retention and infiltration and recharges (Cappiella, Schueler, and Wright 2005)

4) Vernal pools and spring seeps

Vernal pools and spring seeps are 2 important types of aquatic habitats within a forest because they provide a fresh source of water year round. Enhancing the buffer around these natural features is another restoration method that improves habitat. Alternatively, vernal pools can be created if none exists. (Cappiella, Schueler, and

Wright 2005).

In brief, the literature review above is composed of 3 parts, synthesizing the overview, a theory basis and some specific approaches of green infrastructure. The first section is an overview research on green infrastructure, including discussions on the definitions, functions, principles as well as implementation scales. The second section introduces the definition, origin, themes of Landscape Urbanism. Strategies of green infrastructure implementation in urban watershed based on Landscape Urbanism are summarized. The third section introduces specific approaches of green infrastructure application in urban watershed management including stormwater management BMPs, river and salt marsh restoration and urban forest. All the tools selected can be applied in urban environment although the specific places and conditions may vary according to the characters of each tool. Green infrastructure network is an integration of these approaches.

III. Methodology

A. Goals and Objectives

The goal of the project is to improve Chelsea River Subwatershed, and therefore to improve the impaired Chelsea River by identifying the best locations for urban landscape interventions and creating blue-green network with green infrastructure in the subwatershed.

The project will meet these objectives:

1) Improve water quality of Chelsea River by cleaning up the contaminated subwatershed and water body
2) Increase biodiversity by salt marsh restoration and habitat enhancement in the subwatershed
3) Create and connect open space to provide more access to water for scenery, recreation, education and economical boost.
4) Promote environmental justice and increase walkability to support the public health of people's life.

B. Research Methods

The research methods include site visits, literature review, background data search, interviews with government officers and watershed associations, site analysis with MassGIS and other mapping tools, and case studies.

1. Literature Review

Literature review (see Chapter Ⅱ) helps to understand what green infrastructure is,

how green infrastructure work, what Landscape Urbanism is, what guidance Landscape Urbanism provides on the selection of strategies of green infrastructure in urban watershed, what watershed management approaches of green infrastructure can be used in urban watershed. Understanding the definition, principles and theory basis of green infrastructure is essential to make a green infrastructure plan. When applied in practice, the approaches will be adjusted according to the condition of specific sites.

2. Data Search

Background data of Chelsea River Subwatershed was collected by searching library data base; visiting regional environmental relevant websites such as US EPA (Environmental Protection Agency), Mass DEP (Department of Environmental Protection), Mass DCR (Department of Conservation and Recreation), MassWildlife (The Massachusetts Division of Fisheries and Wildlife), Massachusetts Water Resources Authority (MWRA), the Urban Ecology Institute; and consulting local government agency, association Mystic River Watershed Association (MyRWA) stuff, Charles River Watershed Association who were doing a project in Chelsea River subwatershed too, government officers of Chelsea, Revere, Everett and Boston and The Chelsea Creek Action Group (CCAG). The data include the history and existing conditions of Chelsea River Subwatershed. The data of existing conditions cover the information about physical environments, demographics, community life and previous plans for Chelsea River Subwatershed made by government and non-profit organizations.

3. Site Analysis

Series of maps of Chelsea River Subwatershed was made using ArcGIS 9.3 and other online mapping tools such as MetroBoston DataCommon based on the data from MassGIS, etc. The historical transformation and existing condition of Chelsea River Subwatershed was presented. The maps cover the investigation on geography, topography, soil, hydrology, land use, traffic, combined storm/sewer system, impervious surface, coastal natural community, brownfield sites and tree canopy distribution of Chelsea River Subwatershed. Further, the maps were classified to synthesize the problems and potentials in the 3 aspects- hydrology, biodiversity and recreation- specifically. Based on the site analysis, the location and approach of green infrastructure implementation were selected for each concentration above. The final concept plan is made by combination of the concept for these 3 concentrations.

4. Case Study

Project Name: “Port Lands Estuary: Reinventing the Don River as an Agent of Urbanism”

Location: Toronto's post-industrial Port Lands, Ontario, Canada

Size: 280 acres

Team: Landscape architects, architects, planners, hydrologists, and a litany of other experts as well

Team leader and landscape architects: Michael Van Valkenburgh Associates (MVVA), Inc., Landscape Architects, New York, NY

Project Timeline: Master Plan completed in 2007, implementation unknown

Client: Waterfront Toronto

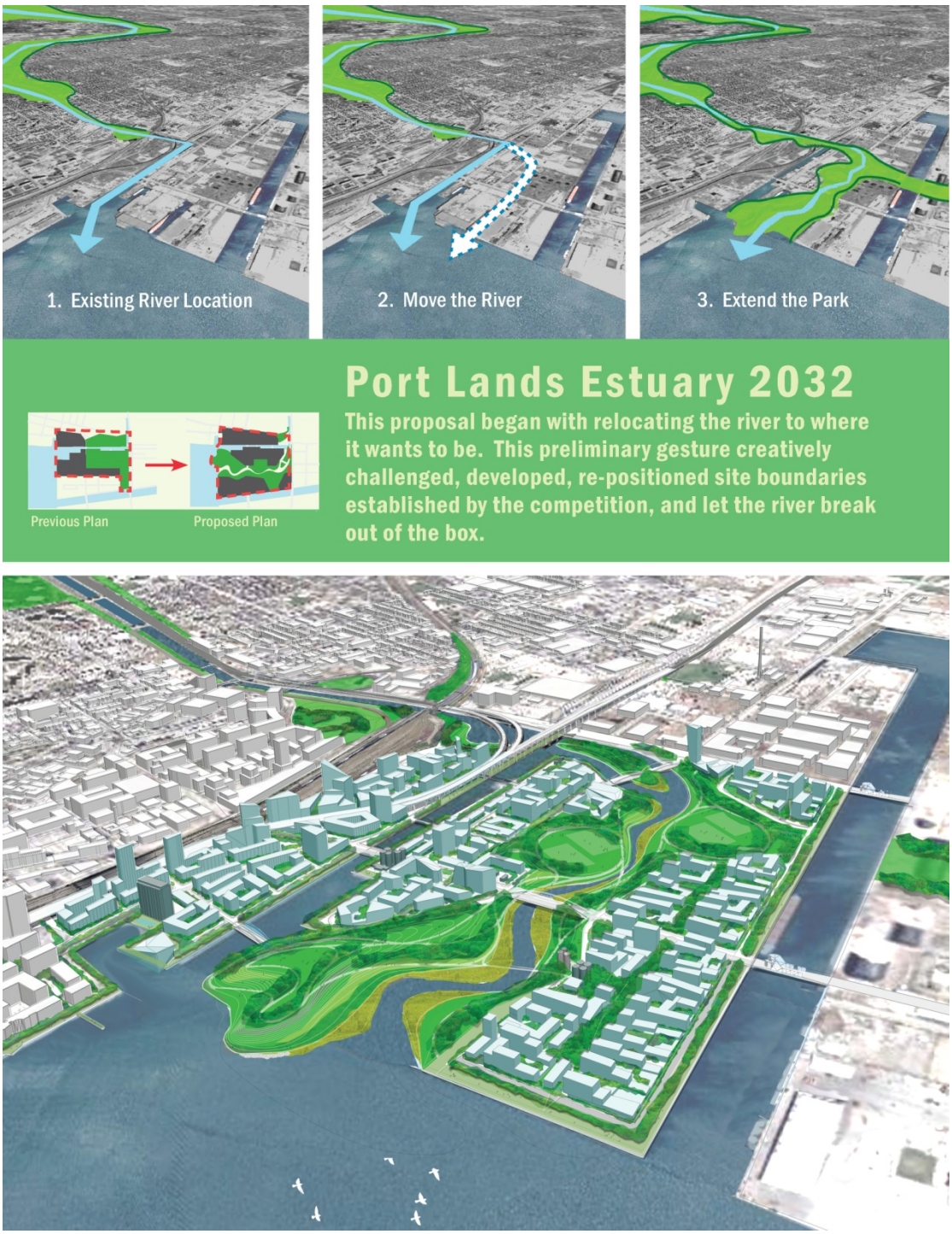


Fig. 18: Port Lands Estuary 2032 (MVVA Team 2007)

Fig. 19: Port Lands Estuary Plan (MVVA Team 2007)

Port Lands Estuary project was chosen as a case study because of the context proximity to my master project and a match of topics. The project is the result of a winning entry in a 2007 international design competition for Toronto's Port Lands. The project won ASLA Honor Award for Analysis and Planning 2008. Comments were given by 2008 Professional Awards Jury: "*Ecological and sustainable strategies*

drive the program, which is a fresh approach to urban design. The landscape architect has created images that convey a compelling story to convince the public and the authorities to make something happen. Sweeping and powerful".

Toronto is in transition, recycling its industrial parts. Currently, the Don River cuts through Toronto just east of downtown and hits the Keating Channel, a rectilinear ship slip as the end to the river's course. The site is located on a former wetland created by the Lower Don River as it emptied into Lake Ontario but filled in the early 20th century (American Society of Landscape Architects). Devoid of natural features, public infrastructure, and neighborhood amenities, the site is incapable of supporting new urban growth.

The Port Lands Estuary proposal describes a new type of neighborhood for Toronto, one that is designed to interact with the river and the lake in a dynamic and balanced relationship – an urban estuary. The planning framework for a vibrant new mixed-use riverfront and lakefront neighborhood is developed through a landscape-based approach that unifies the goals of ecological restoration and urban design with potentially transformative effects. The specific goals of the project are set as follows (MVVA Team 2007):

- Providing restored mouth for Toronto's Don River
- Recapturing the waterfront in a substantive way
- Making sustainable neighborhood for the 21st century
- Inviting diverse lifestyle opportunities
- Ensuring an active and vibrant public realm

- Providing high-quality materials in buildings and public spaces
- Providing a good balance of motorists, cyclists, and pedestrians

MVVA's concept seeks to release the Don River "where it wants to be, at the shore of Lake Ontario." Instead of creating naturalized banks along the straight course of the existing channel connecting the Don River with the lake, the Port Lands Estuary proposal keeps the Keating Channel as an urban artifact and neighborhood amenity and creates a new mouth for the river that flows logically from the upstream source, bypassing the abrupt right turn created by the channel (ASLA). A new naturalized river channel will be cut through the center of what is now a flat, mostly vacant, industrial wasteland (Fig. 18). A large new meandering riverfront park becomes the centerpiece of a new mixed-use neighborhood. "The remaining land would then be populated with mixed uses, including housing, retail uses, employment opportunities, and light industry. The Keating Channel would retain a harder urban edge, while the new "estuary" of the Don River would form a linear park complete with trails, recreational fields, and restored natural areas. The new estuary would also help manage stormwater from the proposed development" (Arvidsom 2008).

In essence, Port Lands Estuary project illustrates an example of how to transform a post-industrial waste land to an agent of urbanism with a new balanced relationship between city and water (Fig. 19). Driven by ecological strategies, the project involves re-configuring of the existing river's edge, removal of huge areas of land in the Portland area, and the creation of a naturalized river's mouth and floodplain (Roche 2008). This transformation will act as a catalyst, supporting the development of the

Lower Don Lands as a series of distinct neighborhoods formed by the river and the harbor, each of which will have the complete DNA of a vibrant city (MVVA Team 2007).

In addition to landscape framework, the ecological strategies applied to the design of the Port Lands Estuary can be referential. The naturalization project is the establishment of fully functioning river-mouth ecology (Fig. 20). Processes to “grow” the estuary through natural means are engaged. For instance, using scientific approaches to predicting fluvial processes in order to “harvest” the material produced by the river as material for the project will provide the opportunity for the mouth of the river to evolve over time (MVVA Team 2007). Other strategies include sheltered winter microclimates, cool summer microclimates, stromwater collection and treatment, and a diversity of habitats linking the Great Lakes aquatic ecosystem and the Atlantic migratory flyway, etc.

Fig. 20: View Looking East from the Hilltop towards Cherry Street Bridge (MVVA Team 2007)

IV. Project Background

This chapter will introduce the background of the project including the context and geographic character, natural character, history and existing condition of the Chelsea River Subwatershed.

A. Context and Geographic Character of the Chelsea River Subwatershed

1. Location

The Chelsea River subwatershed locates in eastern Massachusetts, one of the subwatersheds of lower Mystic River Watershed (Fig. 21). Chelsea River ((locally known as “Chelsea Creek”) is a short waterway that runs along the shore of Chelsea, MA to Boston’s Inner Harbor and connects the communities of the cities of Boston, Revere and Everett. The Chelsea River Subwatershd covers an area of about 10.29 Mi^2.

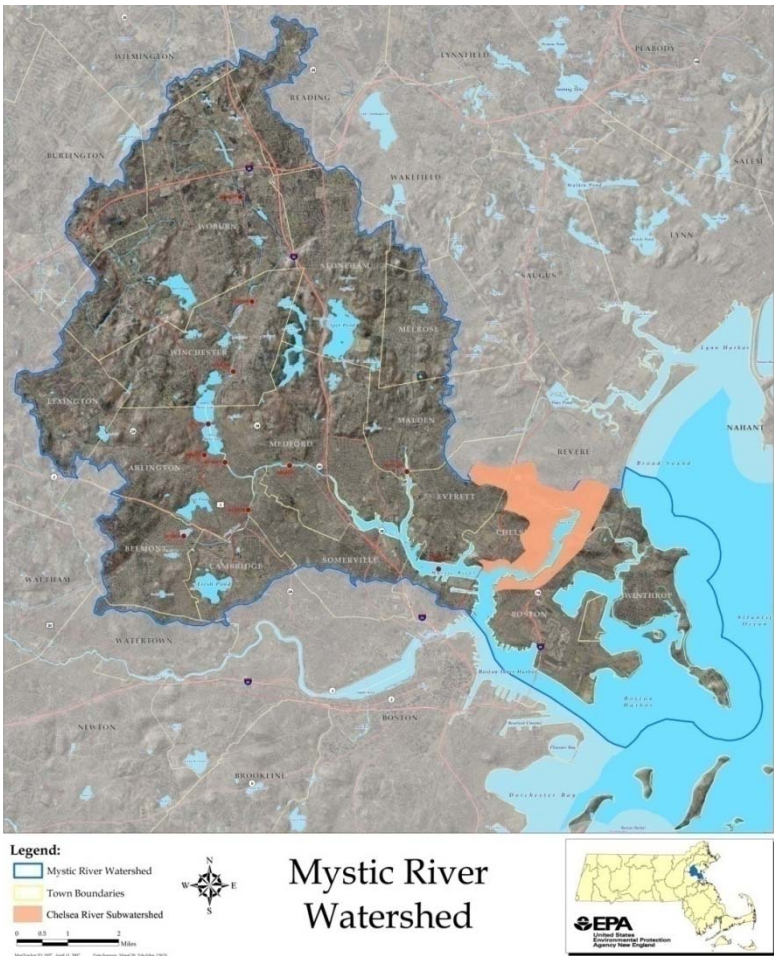


Fig. 21: Location Map of Chelsea River Subwatershed (adapted from the map of Mystic River Watershed. Source: EPA)

2. Demographics

According to the investigation by EPA (Fig. 22), most areas of the Chelsea River Subwatershed fall into the categories of minority, low income or both. As of the census of 2000 (American Fact Finder), in the city of Chelsea which covers the most part of the Chelsea River Subwatershed, there were 35,080 people, 11,888 households, and 7,608 families residing. The population density was 16,036 people per square mile. The racial makeup of the city was 57.95% White, 7.25 Black or African American, 0.48% Native American, 4.69% Asian, 0.09% Pacific Islander, 22.94% from other races. Hispanic or Latino of any race was 48.42% of the population. The median income for a household in the city was $30,161. About 20.6% of families and

23.3% of the population were below the poverty line, including 28.8% of those under age 18 and 20.9% of those at age of 65 or over.

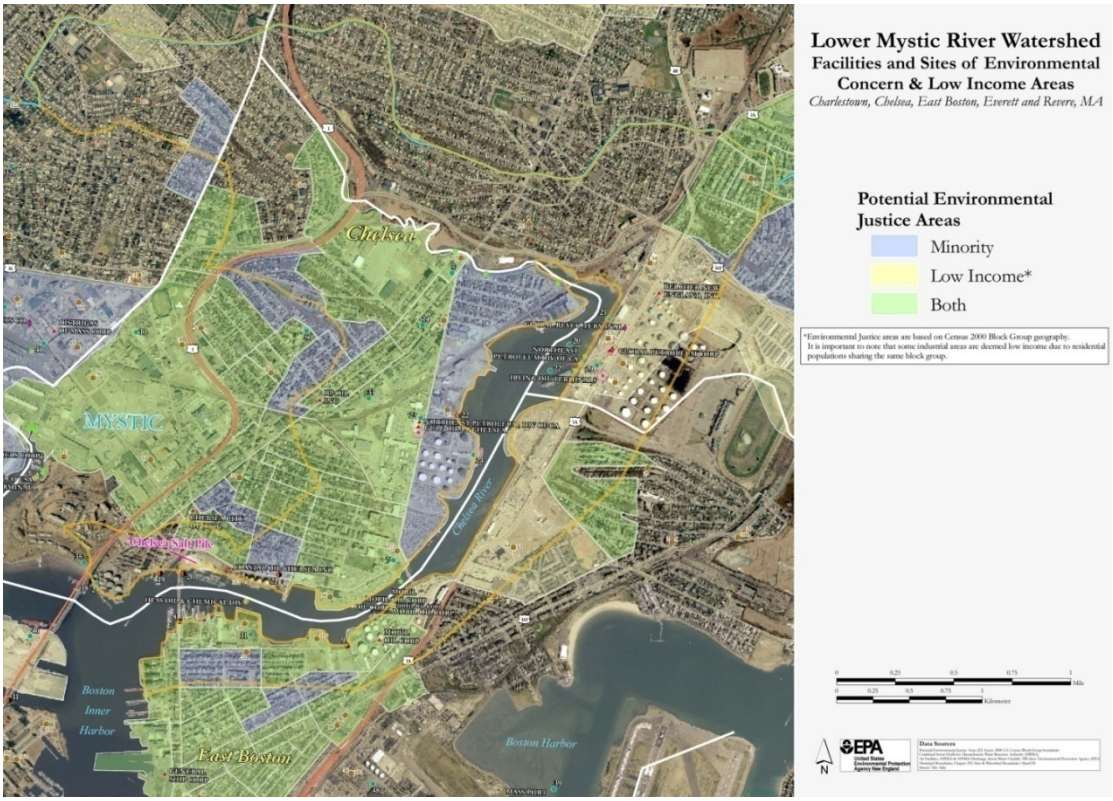


Fig. 22: Potential Environmental Justice Areas (adapted from the map "Lower Mystic River Watershed: Facilities and Sites of Environmental Concern & Low Income Area" Source: US EPA)

3. History

Three hundred years ago, the Creek was bordered by extensive salt marshes. In May of 1775, the first naval battle of the American Revolution was fought on Chelsea Creek, ending with the sinking of the British ship Diana. By the late 1800s, the Meridian Street drawbridge had been built, and many industries, such as New England Pottery Company and Condor Street Iron Foundry, were operating along Chelsea Creek. Historically, Chelsea's development was the result of water related transportation facilities, including bridges, ferries, and Naval installations.

Today, Chelsea Creek's salt marshes are nearly gone because tidal hydrodynamics

changed because of salt marsh filling, dam, and contamination, etc. They were replaced by heavy industrial uses servicing much of New England, illustrated by comparison of Fig. 23 and Fig. 24. All of the jet fuel for Logan International Airport is stored along Chelsea Creek, as well as 70-80% of the region's heating oil and road salt for 250 Massachusetts communities. There are also freight forwarding companies, abandoned boat/salvage yards, a tannery, and unused contaminated land.

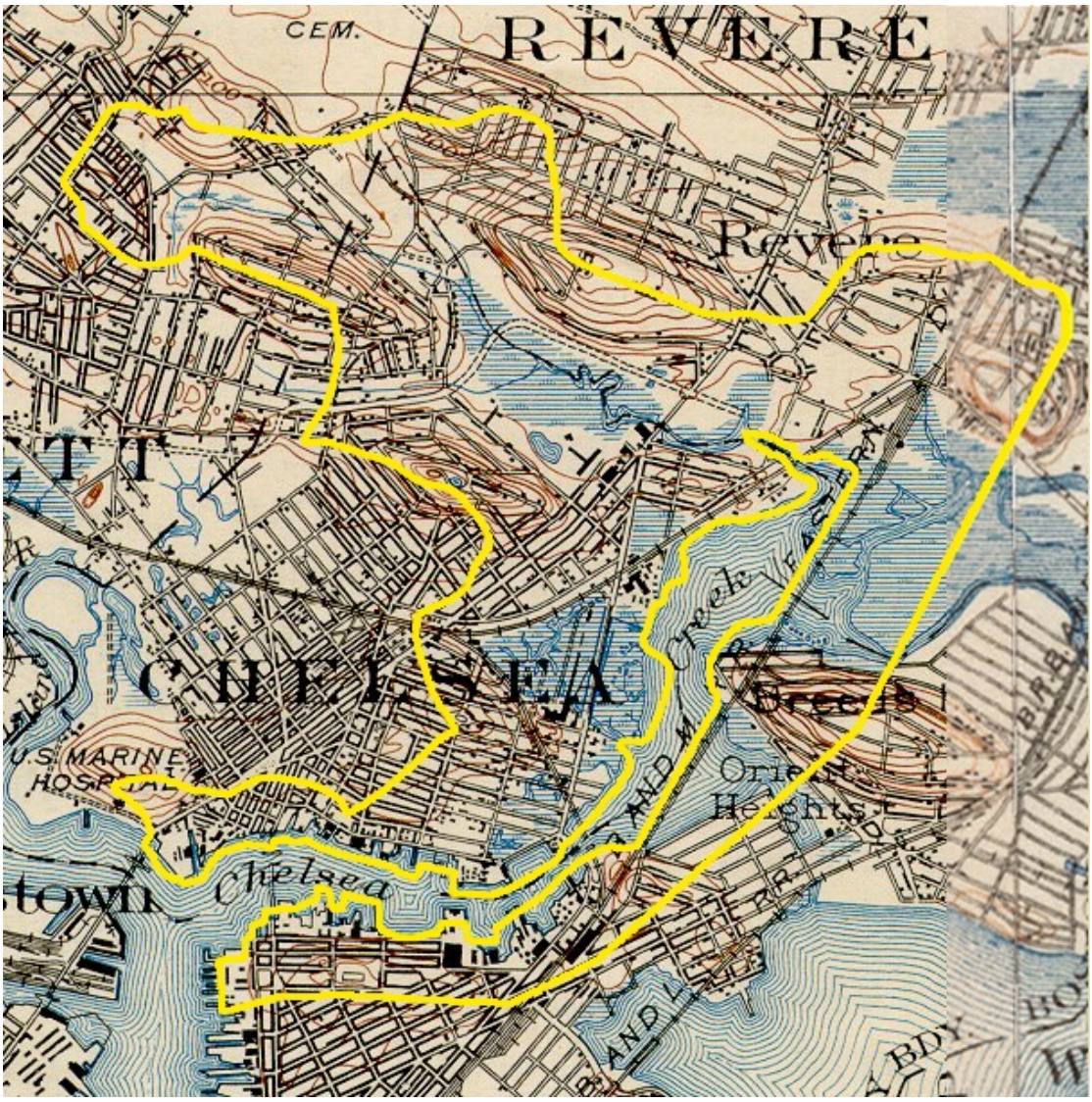


Fig. 23: USGS Historical Coastal Topographic Map Image of the Chelsea River Subwatershed (1890-1900) (Source: MassGIS)

B. Natural Characters of the Chelsea River Subwatershed

1. Topography

The topography of Chelsea consists primarily of coastal lowlands, punctuated by drumlins formed during the last Ice Age with the highest point of 187 Ft above sea level on top of the drumlin on the north of the subwatershed (Fig. 4.4). The lowest points are along the river with the height of about 9 Ft above sea level. The topography of the area provides a number of amenities for recreational development, both on the hills that provide nice views over the city to the Harbor and Boston, and along the waterfront. However, these opportunities have not been fully development currently.

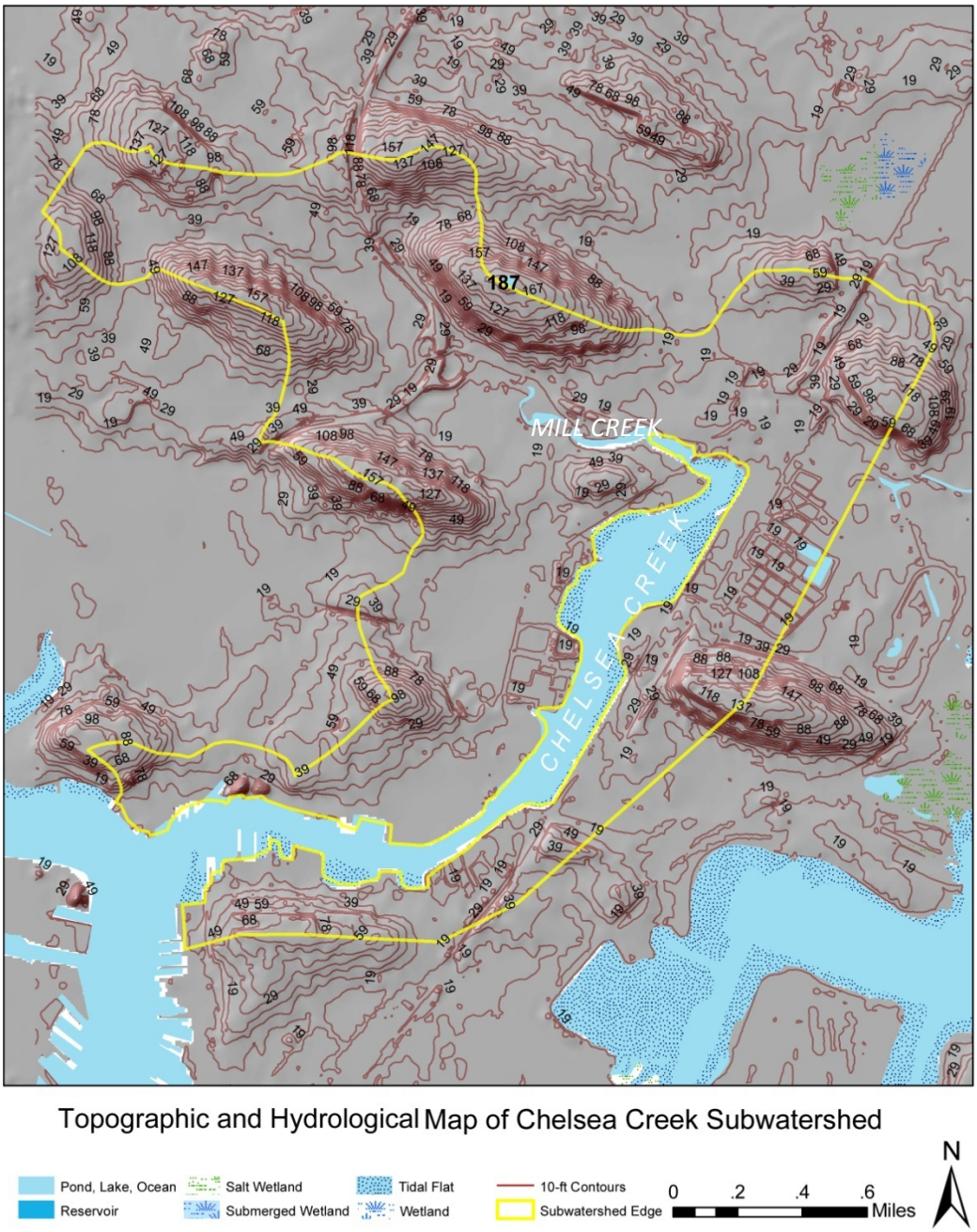


Fig. 24: Topographic and Hydrological Map of Chelsea River Subwatershed

2. Hydrology

The Chelsea River starts at a former pond at the intersection of Revere Beach Parkway and US Route 1. Mill Creek, the upstream of Chelsea River, meanders east for 0.5 miles then takes a sharp south and widens significantly as it runs between Chelsea and the Boston neighborhood of East Boston (Fig. 24).

Under the Massachusetts Water Quality Standards, the Chelsea River is classified as an SB Class body of water, meaning that it has the potential to be a habitat for fish and other aquatic life and used for swimming, boating, and restricted shell fishing. Currently, the Creek does not meet standards for ammonia, excess organic material, dissolved oxygen, pathogens, oil and grease, taste/odor/color, and turbidity (cloudiness) (Chelsea Creek Action Group and US EPA 2003). Most of the land next to the Creek is drained by CSOs and used by industrial and transportation related businesses which create many potential sources of pollution for the Creek (Fig. 25). In addition, because the area surrounding the Creek is highly developed with mostly paved surfaces and heavy traffic, “non-point source pollution” is also a source of water pollution.

Fig. 25: the Pollution and Erosion in Mill River

3. Habitat

The Chelsea River Subwatershed is a highly industrialized urban watershed. There is little information available about the habitat in the subwatershed. We cannot find any habitat within the Chelsea River Subwatershed which falls into any of the

Fig. 26: Saltmarsh along Chelsea River as an Important Habitat

following important habitat categories of the Natural Heritage & Endangered Species Program (NHESP) – Priority/Estimated Habitats of Rare Species, Certified/Potential Vernal Pools, BioMap Core Habitat/Supporting Natural Landscape, and Living Waters Core Habitats/Critical Supporting Watersheds. The only Priority Natural Vegetation Communities in Chelsea River Subwatershed are the coastal natural communities which are mainly composed of tidal flat and salt marsh (Fig. 26, Fig. 27). However, with improving water quality in Boston Harbor, the diversity of wildlife in these areas has increased.

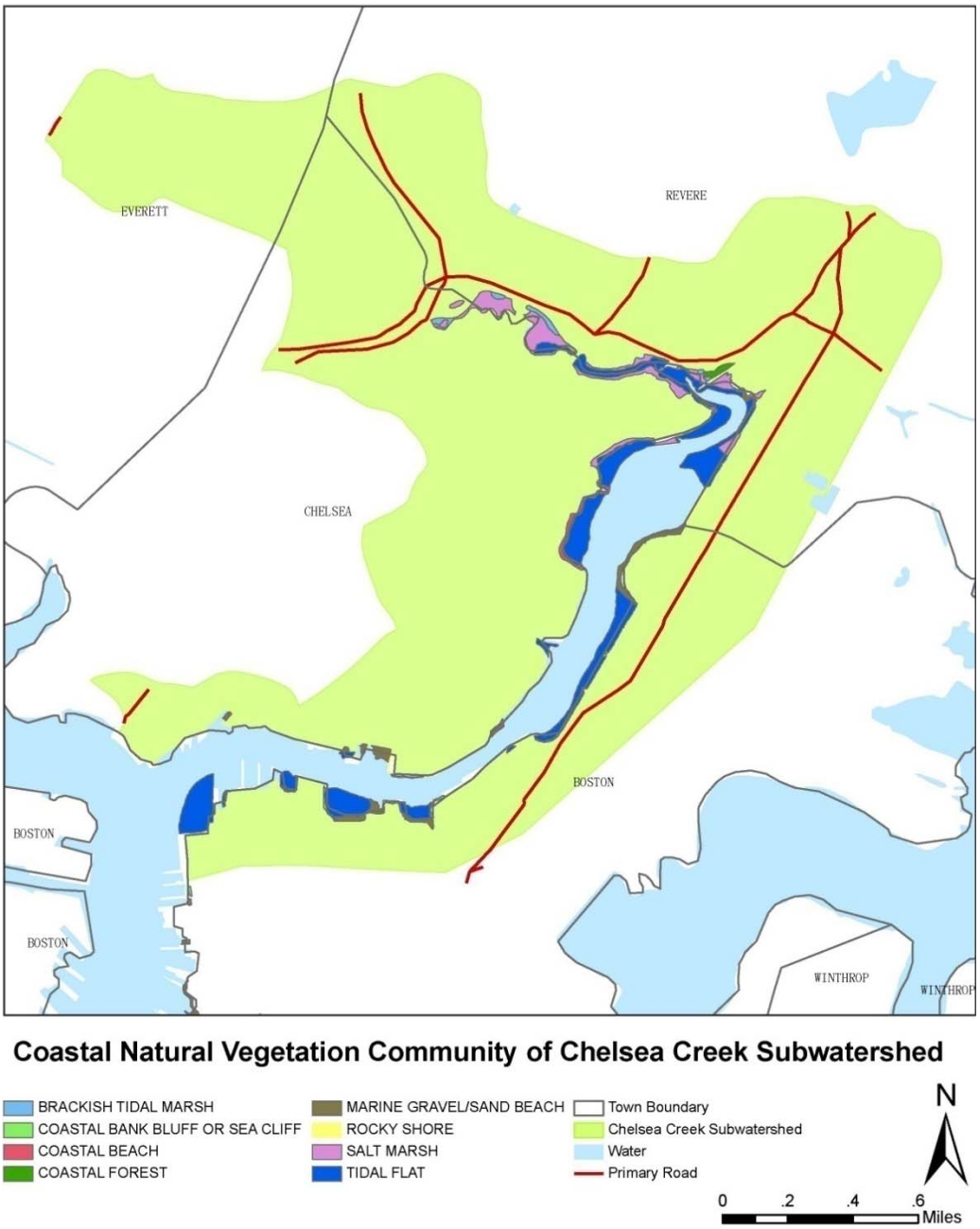


Fig. 27: Coastal Natural Vegetation Community of Chelsea Creek Subwatershed
(Source: Mass GIS)

4. Tree Canopy

Tree canopy map (Fig. 28) was made by tracing the outline of trees on the USGS Color Ortho Imagery (2008) updated on 2/20/2009. Tree canopy in Chelsea Rivers Subwatershed is distributed unevenly. Most of the tree canopies are concentrated on the neighborhood, along the highways and railways. In the areas along the river, there

is almost no tree canopy cover where the land is used for industry and transportation business. Overall, the percentage of tree canopy cover in Chelsea River Subwatershed is very low, only about 4.3% (= area of the total tree canopy/area of Chelsea River Subwatershed). The area of the total tree canopy and the area of Chelsea River Subwatershed were calculated using ArcGIS. A healthy canopy cover in the urban environment provides vital environmental, social, and economic benefits for the urban community such as increase in quality and water quality, minimizing the urban heat island, saving energy, increase in people's sense of community, decrease in violent behavior, improving local business activity and increase in property values (Urban Ecology Institute 2008). Lack of tree canopy can result in environmental burdens for the communities.

Fig. 28: Tree Canopy Map of Chelsea River Subwatershed

5. Open Space

Environmental, historic and scenic resources exist in the Chelsea Subwatershed which could be used to enrich the experiences of residents but have not been fully developed (Fig. 29).

Fig. 29: View towards Boston at the Parking Lot along the Edge of Chelsea River

Fig. 30 identifies the National Register Districts in the subwatershed. Fig. 31 identifies the scenic areas with great views on hill tops and along waters. Fig. 32 illustrates the open spaces in the Chelsea River Subwatershed including recreation, scenic, historical/cultural and others. Residents in the subwatershed are still in great need of open spaces and recreation facilities. The low income level of a significant proportion of the population greatly limits their access to commercial entertainment or recreation facilities. Chelsea River is a unique water resource for the communities and one that could provide recreational and educational benefit to the community, but there are currently few accesses or little recreational space available to residents along the Creek. The area along the Creek is a Designated Port Area (DPA) and recreational uses have not traditionally been allowed. Development and preservation of open space and parks is often limited by the availability of land. Vacant lots are an opportunity to add open space and take advantage of an underutilized resource.

Open spaces need to be connected to each other and regionally. Trails can provide places for recreation and opportunity to connect open spaces. There are several programs working on creating and connecting the trails in the Chelsea River Subwatershed. There is a walking trail along Mill Creek constructed recently for recreation and education purposes. It is not heavily used now based on the author's observation. Fig. 32 illustrates the existing, considered and potential trails identified by Mass DCR, Fig. 33 by Boston Harborwalk and Fig. 34 by Metropolitan Area Planning Council. All these programs have just covered part of the Chelsea River Subwatershed. A more comprehensive trail plan is needed to combine the advantages of these programs and cover all the important and potential places.

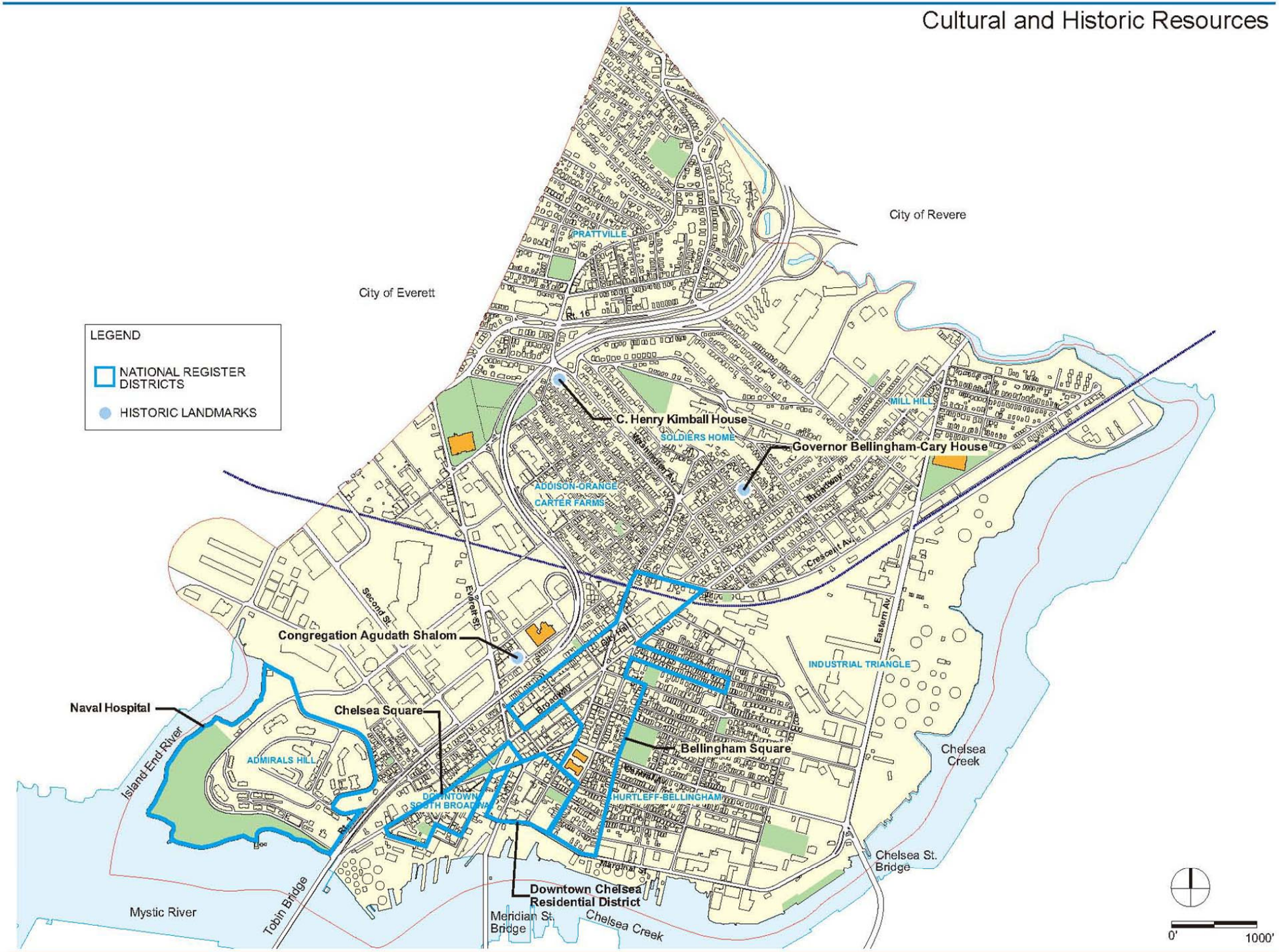
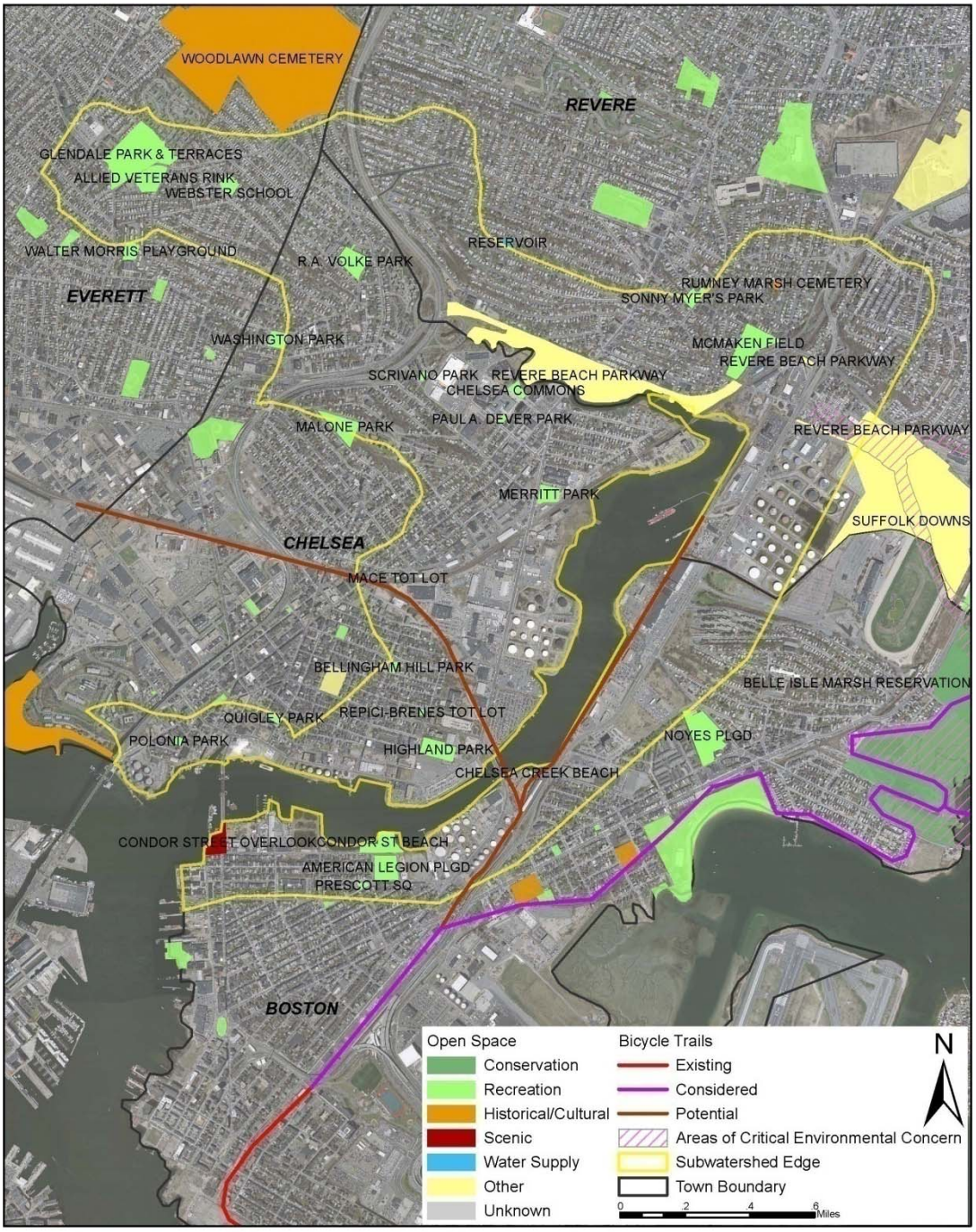


Fig. 30: Cultural and Historical Resources in Chelsea, MA (Chelsea Open Space Plan, 2003)

Fig. 31: Map of Scenic Resources in Chelsea, MA (Chelsea Open Space Plan, 2003)



Open Space Map of Chelsea Creek Subwatershed

Fig. 32: Open Space Map of Chelsea River Subwatershed

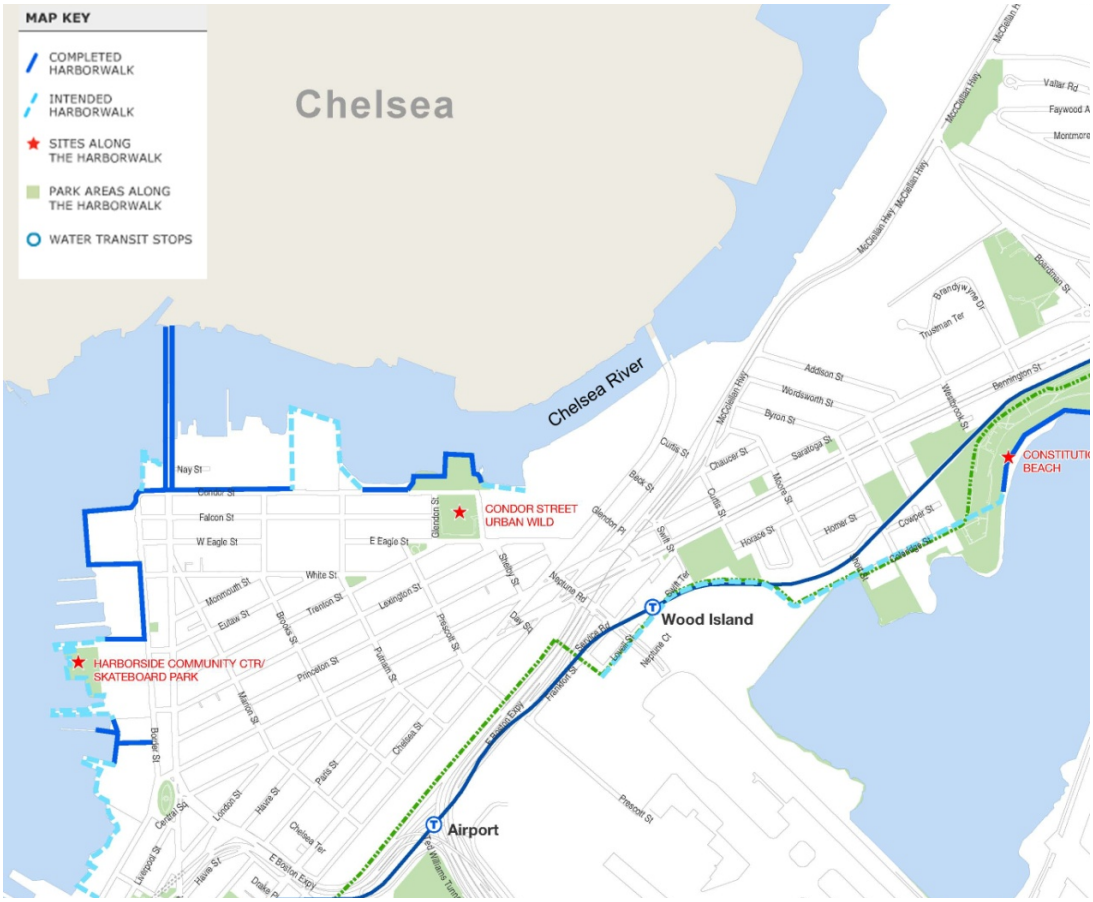


Fig. 33: East Boston Harborwalk (part) (Source: Boston Harborwalk http://www.bostonharborwalk.com/placestogo/location.php?nid=4)

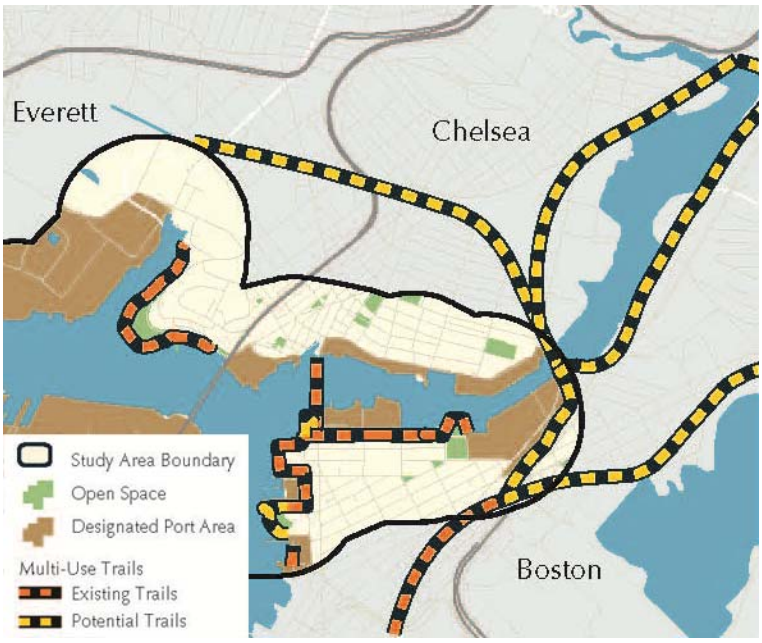


Fig. 34: The Lower Mystic River Corridor Project (Chelsea Part) (Source: MAPC)

C. Existing Conditions of the Chelsea River Subwatershed

1. Land Use

The Chelsea River Subwatershed is highly developed urban land (Fig. 35). Chelsea River is almost surrounded by large areas of industrial and transportation land. Along it's shorelines you will find major oil farms, factories, airport related businesses like parking and freight forwarding companies, an enormous rock salt pile, and other industry. The commercial areas are located mainly at the intersection of highways near Mill Creek, along Broadway, a major road cutting the subwatershed north-south, and on the south part of the subwatershed within City of Chelsea. In residential area, the land is densely settled. Within the large areas of industrial and transportation lands, some urban open spaces still exist which include urban parks, forests, and some waste lands. These lands are important and vulnerable because of the proximity of industrial and transportation land. They are potential to be maintained or redeveloped for ecological service, recreation and other purposes to support the community and balance the relationship between river and communities.

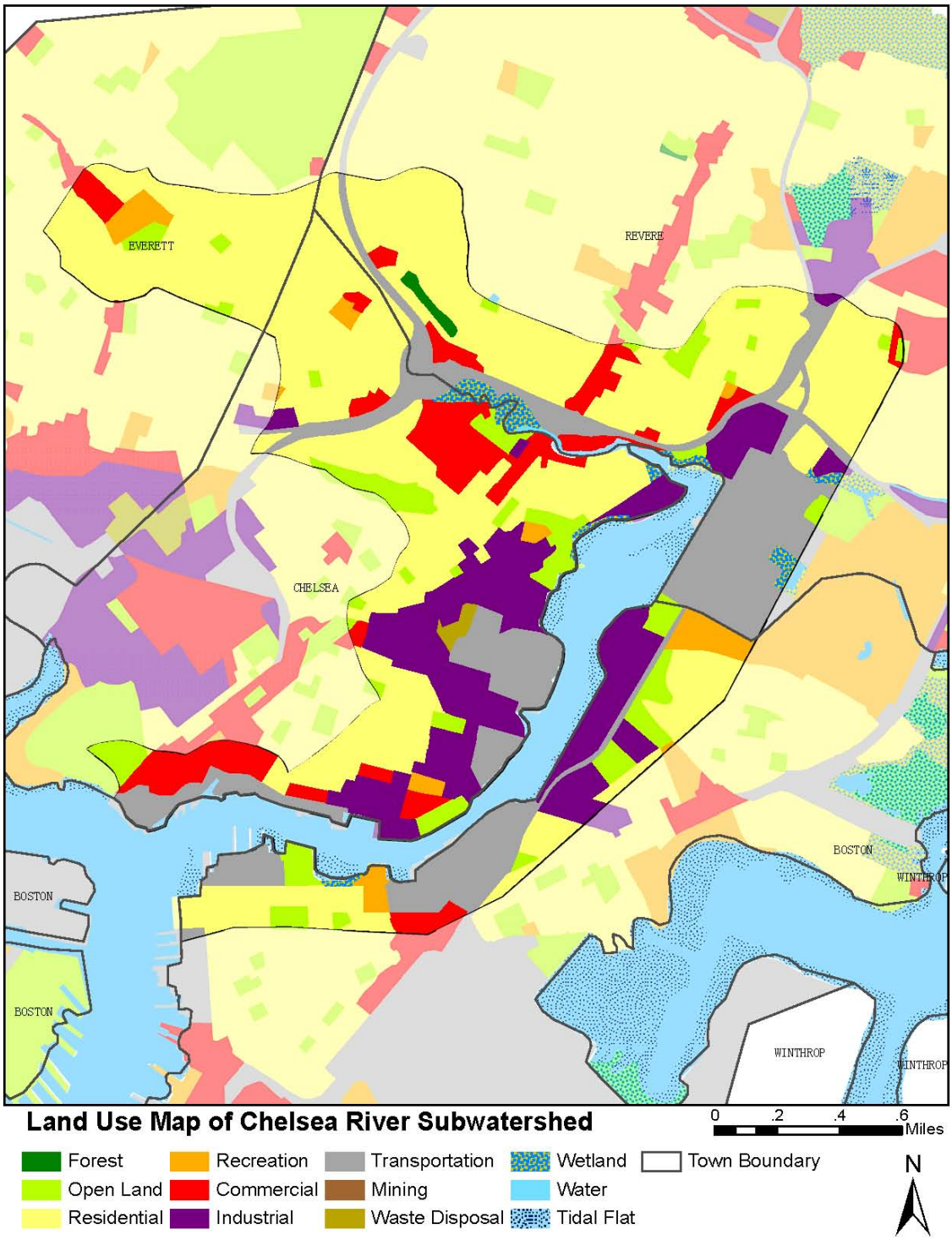


Fig. 35: Land Use Map of Chelsea River Subwatershed

2. Transportation

The communities in the Chelsea River Subwatershed are all densely populated communities located adjacent to several major roadways serving the City of Boston, including Routes 1, 1A and 16. Chelsea and East Boston are also home and adjacent

to many industries that use trucks to transport their goods. As a result, there are a large number of trucks that pass through these communities on a daily basis. There are many public and environmental health concerns related to traffic, such as air pollution and water pollution. Besides, heavy traffic has been found to lower property values, undermine the cohesiveness of a community, increase crime, and cause noise pollution. Fig. 36 shows that the rail station and the blue line station are the major traffic hubs of Chelsea River Subwatershed. It is within walking distance (1/2 mile) from the river to the blue line station, while not to the rail station. Multiple modes of transportation are potential and needs to be encouraged. The abandoned railway plays an important role in linking the rail station, subway station and high ways.

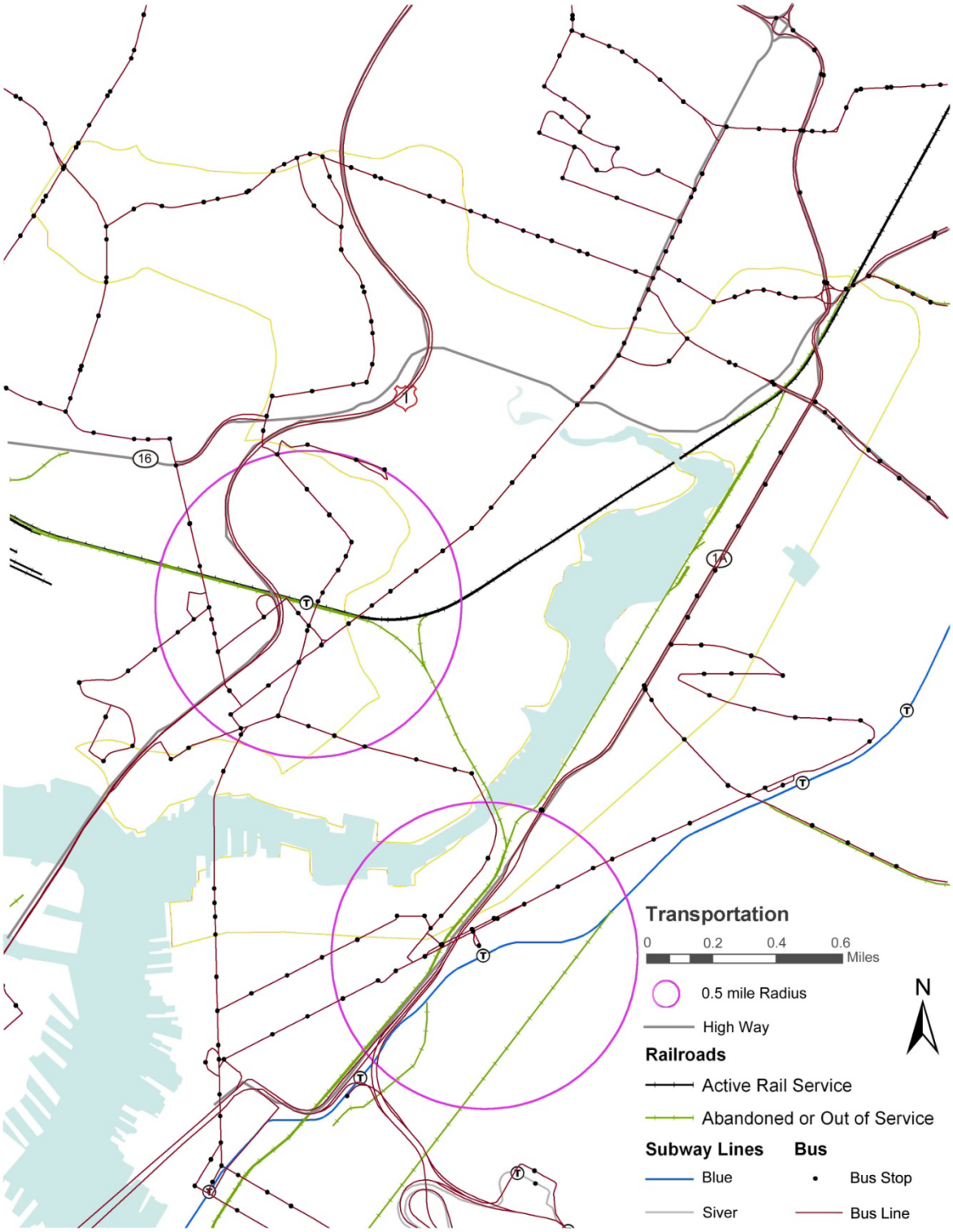


Fig. 36: Transportation Map of Chelsea River Subwatershed

3. Combined Stormwater / Sewage System map

There are 7 sewage outfalls and many drainage outfalls in Chelsea River Subwatershed, all of which are located along the river. Fig. 37, from City of Chelsea,

MA presents the pipes of CSOs system in most areas of the Chelsea River Subwatershed within the City of Chelsea. Fig. 38 identifies the location of the pipes in detail. Recently, the Boston and Chelsea have combined sewer systems that connect to MWRA's system. MWRA developed a CSO Control Plan in 1994 and completed some projects to control CSOs. All point sources must obtain a NPDES (National Pollutant Discharge Elimination System) permit. The nine oil companies that discharge into the Creek are required by NPDES permits to monitor their discharge for volume, total suspended solids, oil and grease, and other organic pollutants. Although limited by NPDES permit, CSOs can still contribute different kinds of pollutants including heavy metals and pathogens to the Creek during heavy storms.

Fig. 37: Map of Existing Sewage System in City of Chelsea, MA (Source: City of Chelsea, MA)

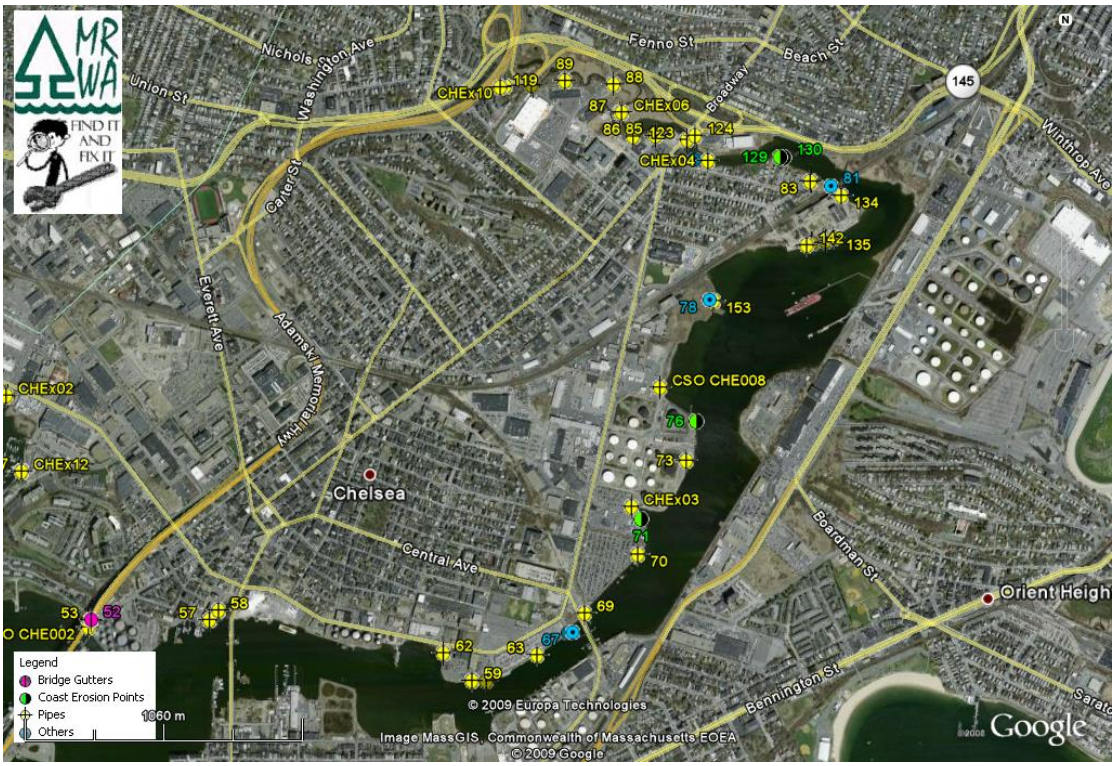


Fig. 38: Pipes Survey by MyRWA (Source: Mystic River Watershed Association)

4. Impervious Surface

There are large areas of high percentage of impervious surface on highways, streets, along the Chelsea River which are industrial land and transportation business land and near the highway intersection which is now a commercial center, while in residential areas on the north of the subwatershed, the percentage of impervious surface is much lower (Fig. 39). There are some lands of high percentage of pervious surface scattered in the impervious surface land. They are railways, parks and waste lands. The large amount of impervious surface makes stormwater runoff a problem to the Chelsea River Subwatershd because pollutants that are deposited on paved surfaces such as oil drips, tire wear, animal waste, and chemicals within the watershed area are washed into storm drains and then into the Creek during rainstorms or just directly washed into the water body without uptake and treatment by buffers between

the river and paved surfaces.

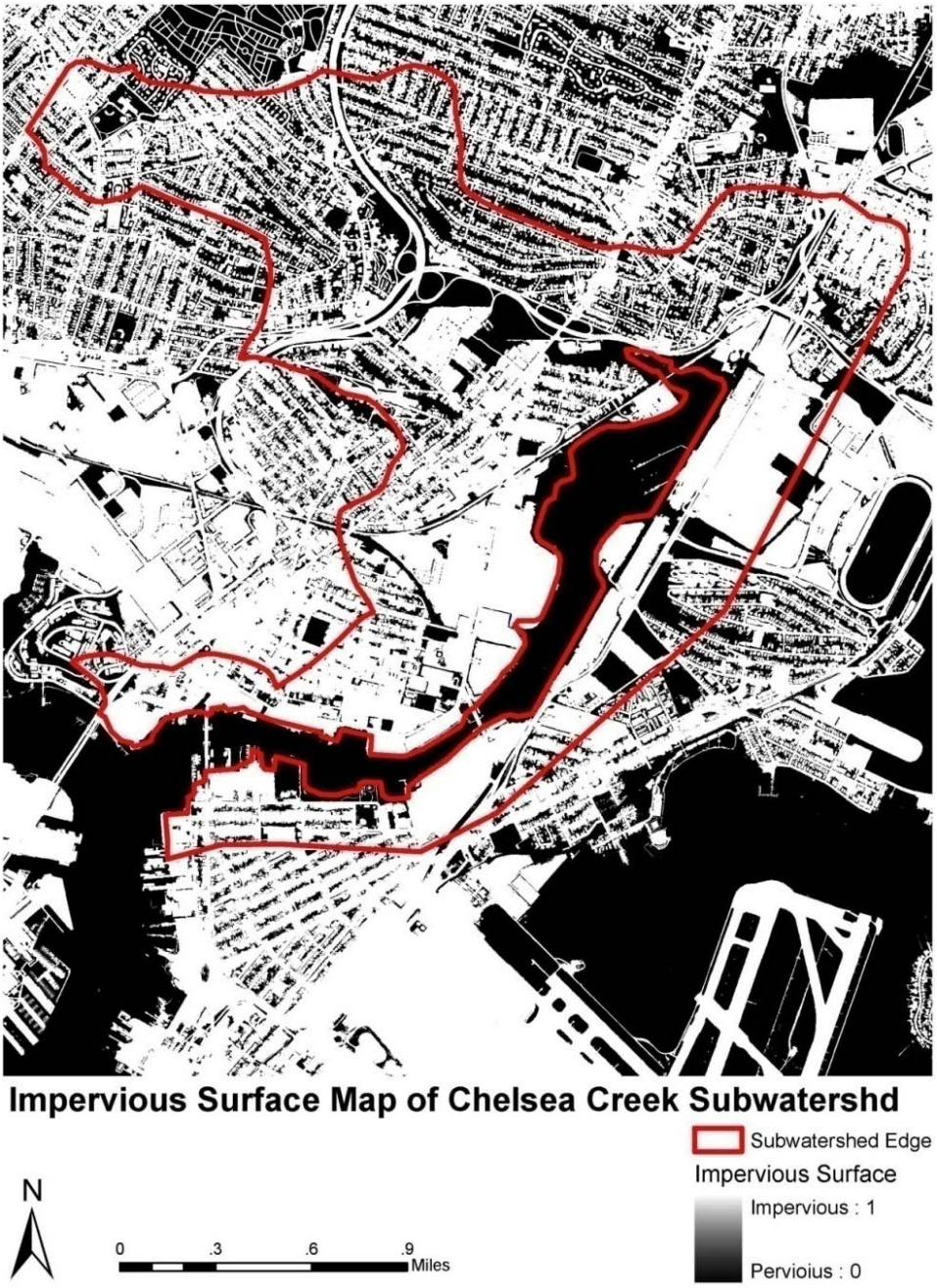


Fig. 39: Impervious Surface Map of Chelsea River Subwatershd

5. Waste Land & Contamination

Vacant lots have been identified in Chelsea. An inventory of vacant lots found many to be overgrown and littered with trash or contaminated with industrial waste and may require some treatment before the land can be safely used.

Chapter 21E is Massachusetts Oil and Hazardous Material Release Prevention

and Response Act. Sites contaminated with hazardous waste or oil spills are called Chapter 21E sites, after the MA DEP Act which regulates these sites. Spills from Chapter 21E hazardous waste sites and the petroleum storage terminals harm the Creek's water quality. Since 1997, there have been at least 40 petroleum spills documented in Chelsea Creek (Chelsea Creek Action Group and US EPA 2003). Some of the Chapter 21E sites have been cleaned up, but unidentified or unmitigated sites may continue to affect water quality by leaching from contaminated groundwater and sediment around the Creek. The locations of the MassDEP Tier Classified Oil and/or Hazardous Material Sites have been mapped and data available from MassGIS (Fig. 40). However the area of each contaminated site is not available which obstructs further clearing up the waste sites in detail.

Fig. 40: Chapter 21E Sites in Chelsea River Subwatershed

V. Site Analysis

The Chelsea River is one of the most industrialized rivers in Massachusetts. Overall, there are great environmental issues and concerns in the Chelsea River Subwatershed.

The major problems are summarized as follows:

1) Chelsea River Pollution

Long-term industrial use of the waterfront, with large tank farms, indicates that much of the waterfront may be contaminated with hazardous materials. Studies have proven that the river is contaminated by CSOs effluent and non point source pollutant such as oil and road salt, which leads to the low water quality.

2) Biodiversity Degradation

The level of Biodiversity is low in the Chelsea River Subwatershed. Only a few habitats are scattered in the densely developed urban areas. The salt marshes are nearly gone. There are no resource protection areas, and no rare, threatened and/or endangered species.

3) Low Percentage of Tree Canopy Cover

The average percentage of Tree Canopy Cover in the Chelsea River Subwatershed is very low, despite the high percentage of Tree Canopy Cover in residential areas. Most of areas with low percentage of Tree Canopy Cover are industrial and commercial areas. Lack of tree canopy cover relates to a lot of environmental, social and economical problems.

4) Lack of Open Space

The communities in the Chelsea River Subwatershed have a strong need for all

types open space and recreational facilities and a system of linkages between the facilities. There is little public access to water. There are some existing trails in and near the subwatershed but need to be connected to others and regionally.

5) Environmental Injustice

Studies indicates that even after five years of regional, grassroots, environmental justice work and the creation of the Massachusetts Environmental Justice Policy, ecological hazards in low-income communities and communities of color have increased (Faber and Krieg 2005). Most of the communities in the Chelsea River Subwatershed are low income and/or minority and remain most environmentally overburdened communities in Massachusetts with unequal exposure to environmental hazards.

However, assets and potentials for improvement do exist in the Chelsea River Subwatershed. The natural, historical and scenic resources can be made advantage of to enrich resident's experience as open space. For example, Chelsea River gives the city a unique character and a potentially high degree of access to waterfront areas; the topography of the area provides a number of amenities for recreational development. Biodiversity opportunities exist for reclamation of degraded salt marsh areas in the Mill Creek. The existing dense tree canopy cover in residential areas shows potential to become a green hub to enhance habitat. In addition, people in the subwatershed are very active in improving the environments, including the government, non-profit organization and grass root groups. A lot of environmental inventories, investigations and plans have been done by them.

Three aspects are studied in detail to identify the potential for green infrastructure implementation in the Chelsea River Subwatershed – stormwater management, biodiversity and recreation.

1) Stormwater Management

The analysis of stormwater management is mainly based on the inventories on hydrology, impervious surface and combined storm/sewer system (Fig. 41). Major elements are abstracted and presented in Fig. 42. The urban hydrology in the Chelsea River Subwatershed is impacted by both of topology and combined stormwater/sewer systems. The large area of impervious land adjacent to the river with industrial and transportation land use causes non-point pollutions to the water and pollution to the groundwater while the combined stormwater/sewer system are another concern because it release contamination to water during storm events.

The areas with high percentage of pervious surface are potential to filter and treat the stormwater/sewer effluent before it is washed to the river. These are the potential areas where green infrastructure will be applied such as bioretention basins.

To make hierarchical concept plan to improve the urban hydrology and stormwater management, the Chelsea River Subwatershed is divided into several “neighborsheds” (definition addressed in the literature chapter) (Fig. 43) based on the analysis of the topography and CSOs. The neighborshed map helps to make sure that in every neighborshed, there will be urban BMPs for stormwater management.

Fig. 41: Environmental Inventory of Stormwater Management

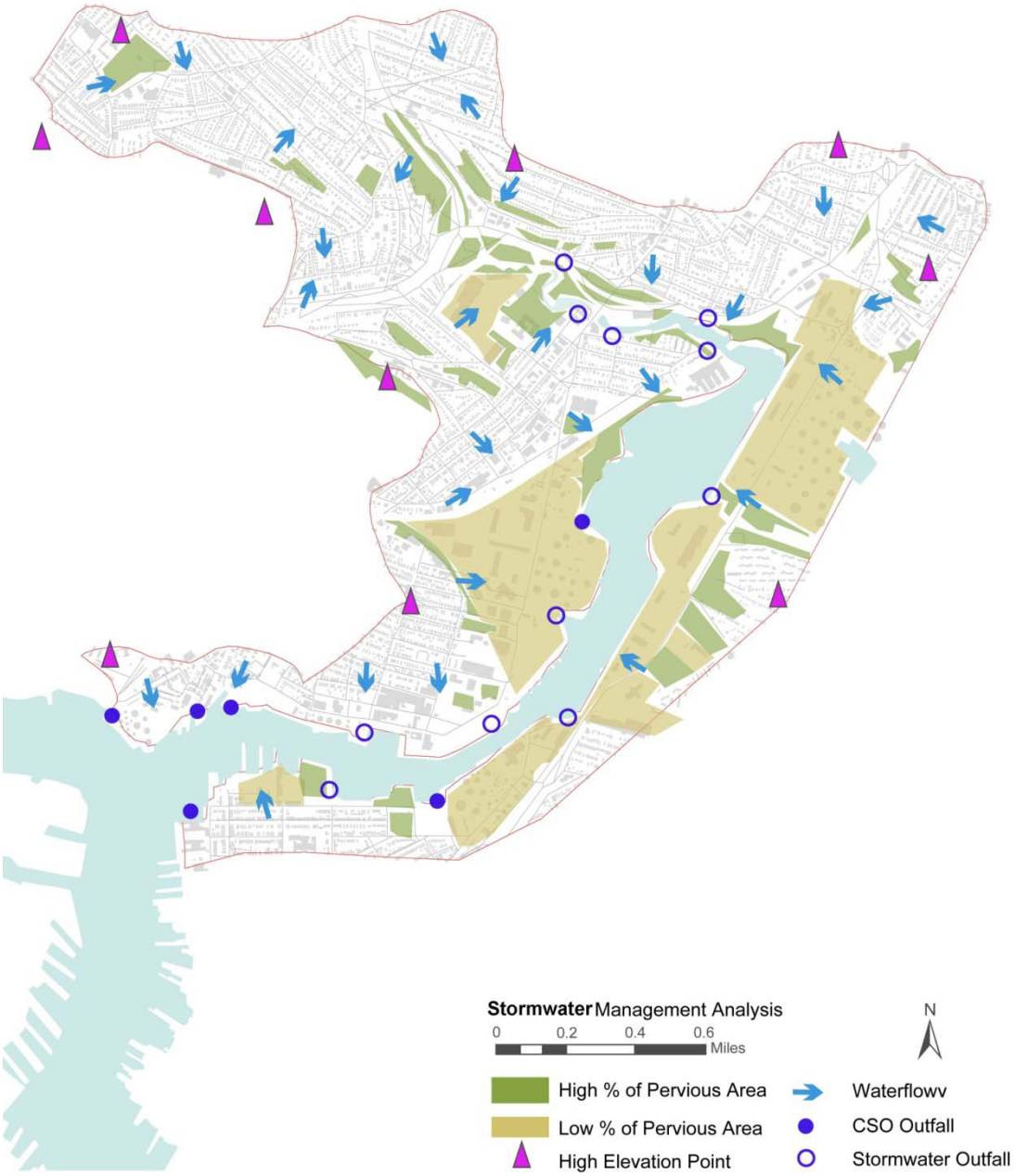


Fig. 42: Stormwater Management Analysis

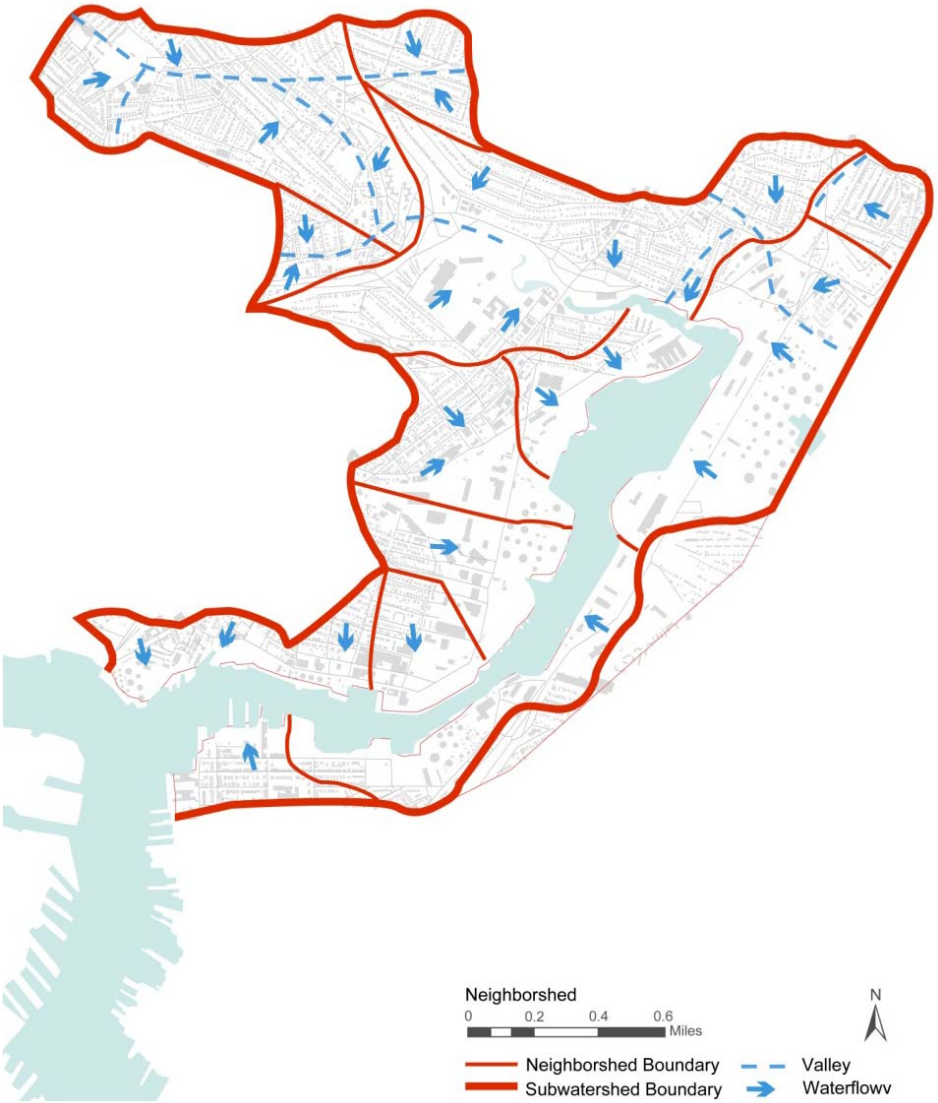


Fig. 43: Neighborsheds in the Chelsea River Subwatershed

2) Biodiversity

The biodiversity analysis is made based on the inventory of tree canopy, costal natural vegetation community and hydrology (Fig. 44). The major problems of biodiversity are low tree canopy cover, habitat fragmentation, salt marsh loss and degradation. There is little tree canopy in the areas of industrial, commercial and transportation business with impervious surface, for example, the parking lots.

Fig. 45 sketches the areas with high percentage of tree canopy cover based on the author's observation which are potential to be enhanced to a green hub. The green

strips along major highways and the railroads, active or abandoned can be developed as green corridor to connect the green hubs.

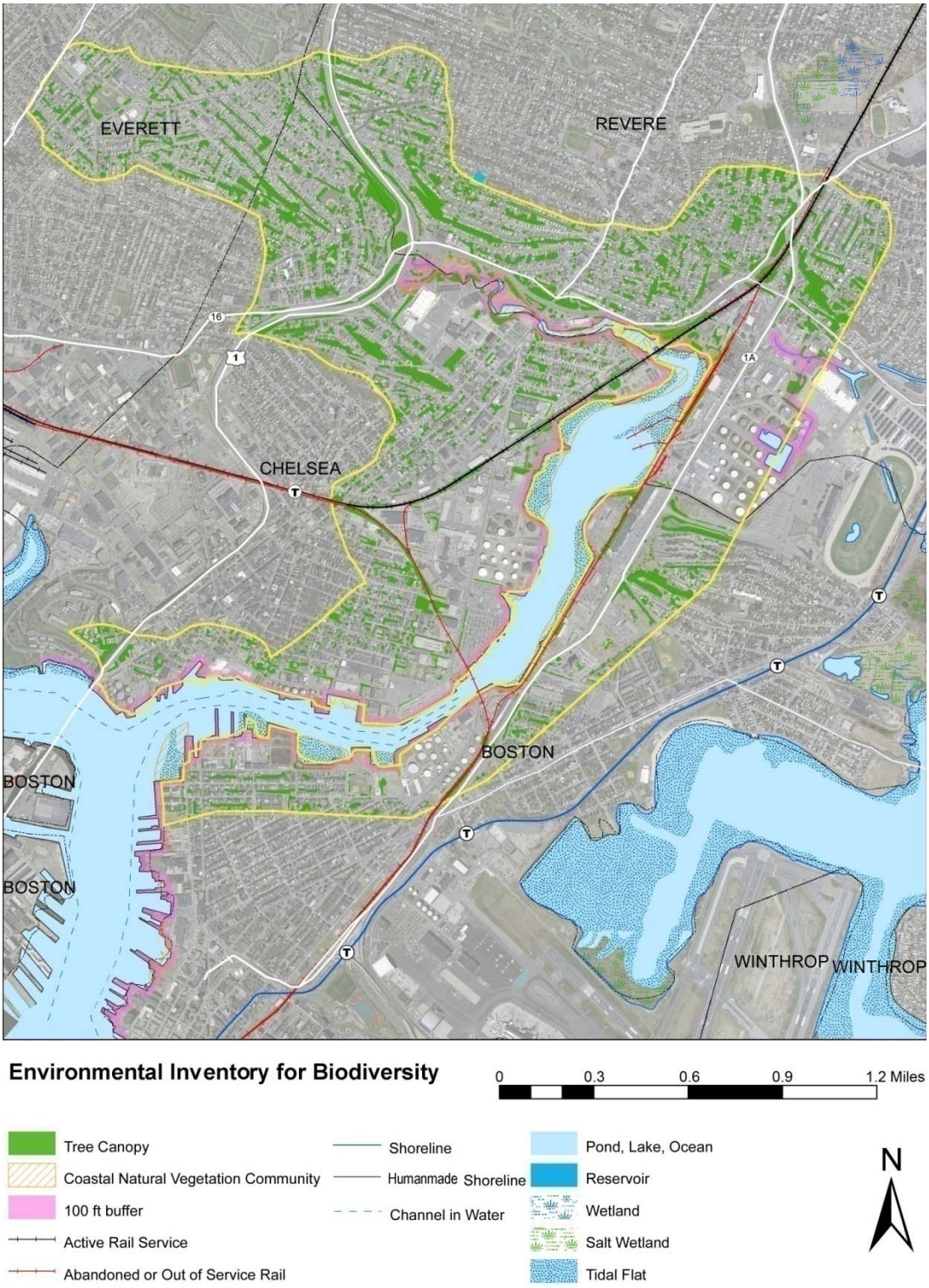


Fig. 44: Environmental Inventory for Biodiversity

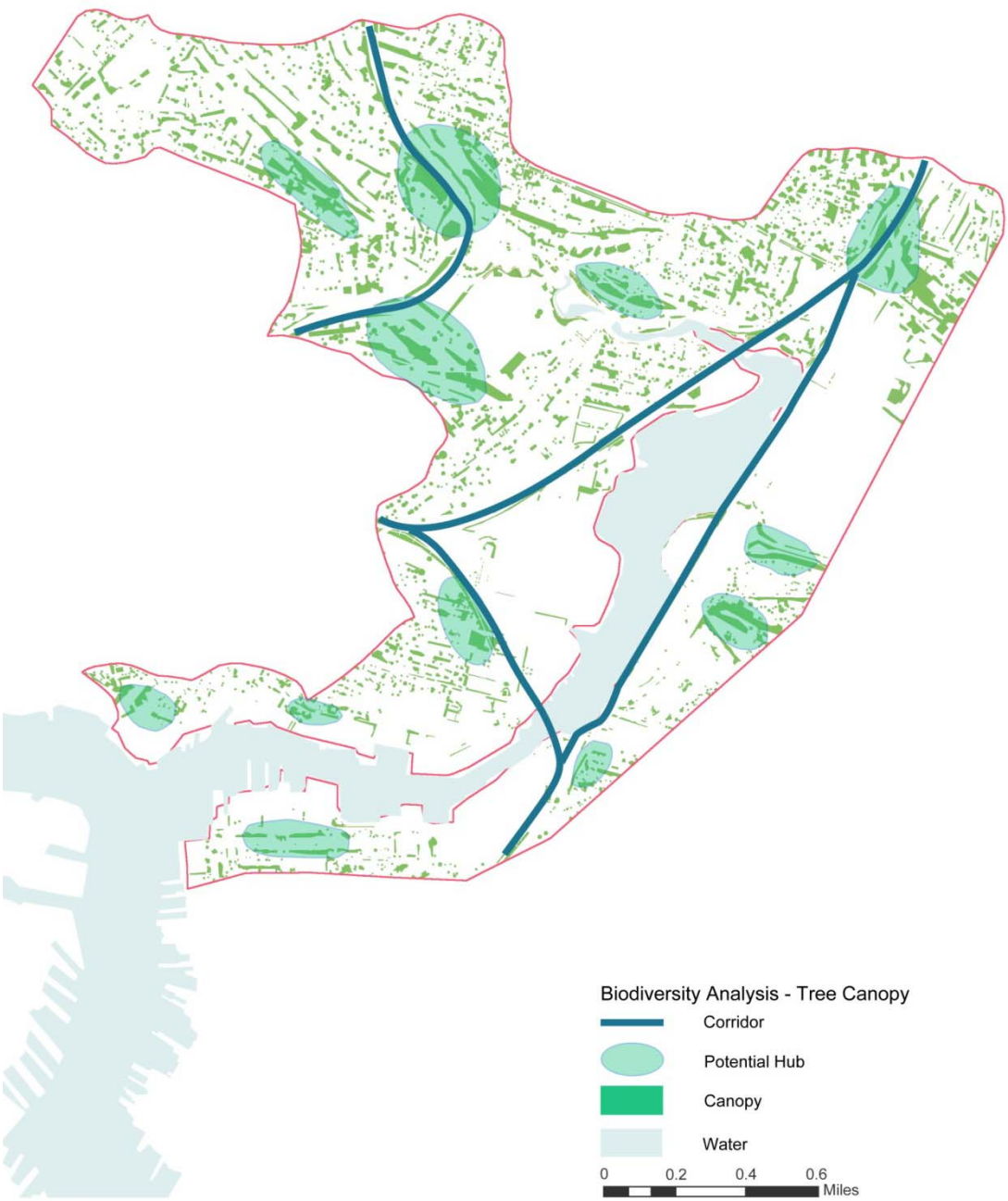


Fig. 45: Biodiversity Analysis

3) Recreation

The analysis of recreation aspect is mainly based on the inventory of open space, trails, transportation, etc. (Fig. 46). Layers of each type have been extracted for analysis (Fig. 47 a,b,c, Fig. 48).

The problems of recreation aspect include lack of open space and recreation facilities, lack of connection between them. In addition, there is need of more trails to

link the open spaces, transportation hubs and lead to the proximity to water.

The potentials for recreation include:

The existing boat landings are public accesses to water which can provide recreation service. Multi-purpose trails can be created using the abandoned railroad or on the site along the active railroad as needed.

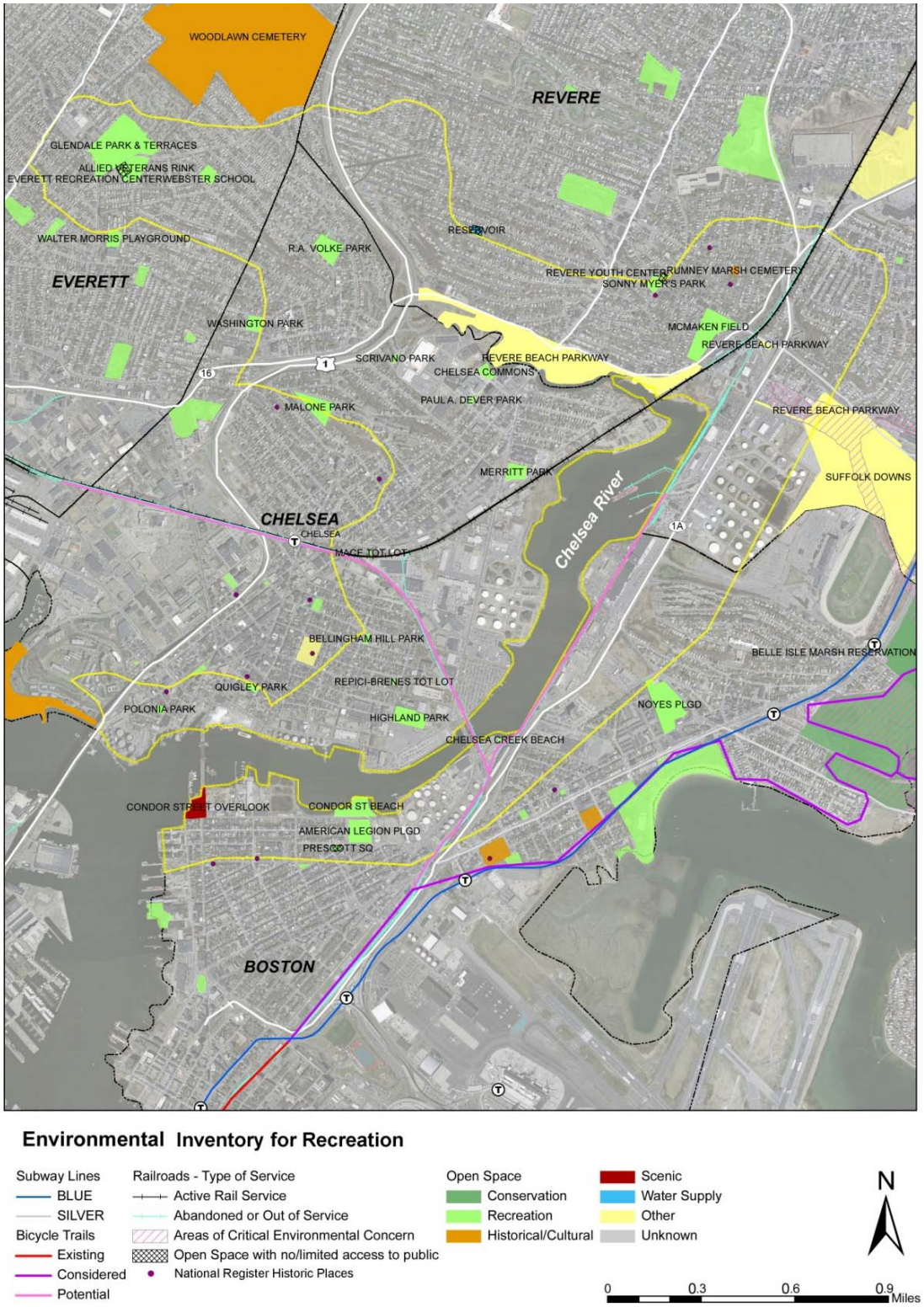


Fig. 46: Environmental Inventory for Recreation

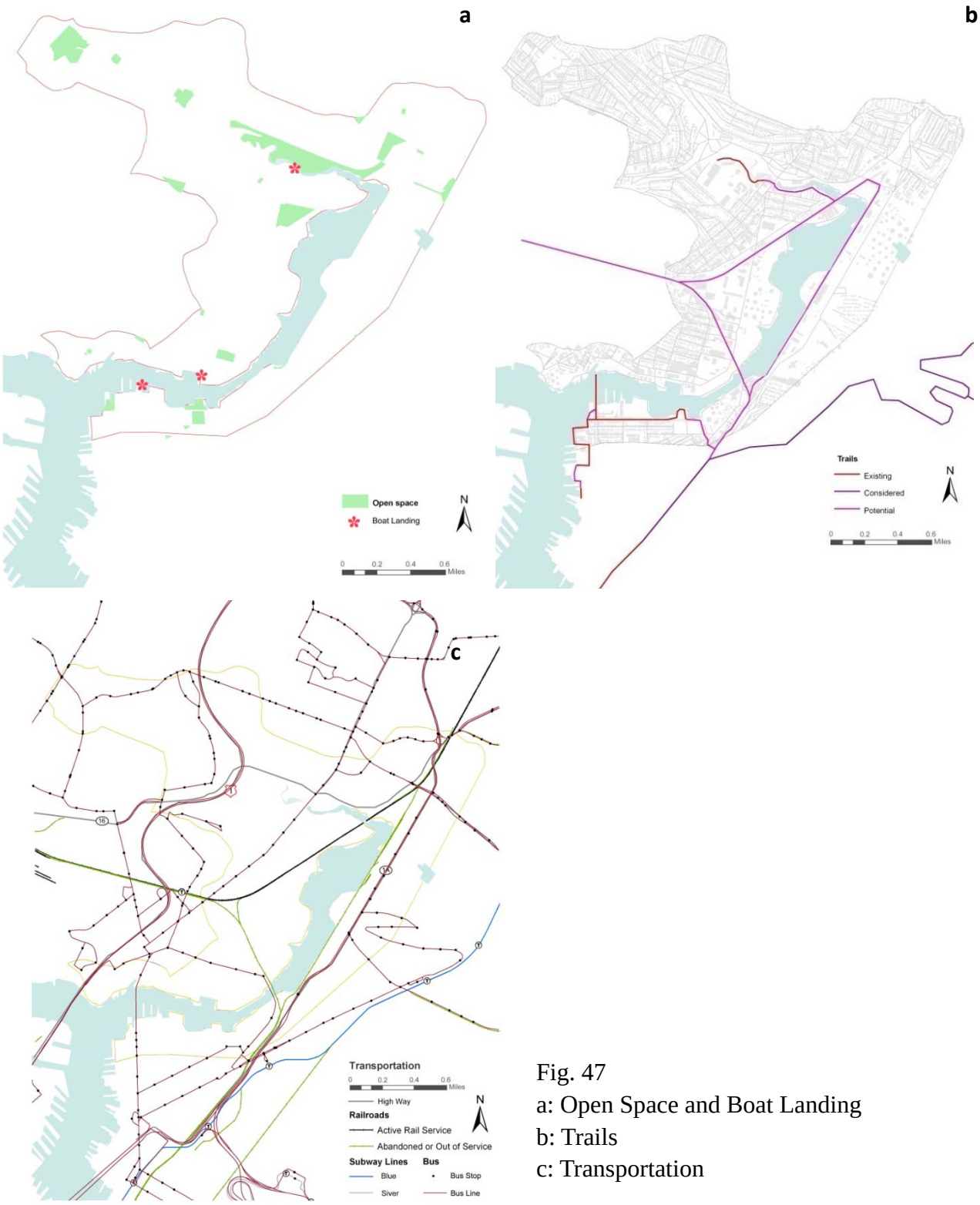


Fig. 47
a: Open Space and Boat Landing
b: Trails
c: Transportation

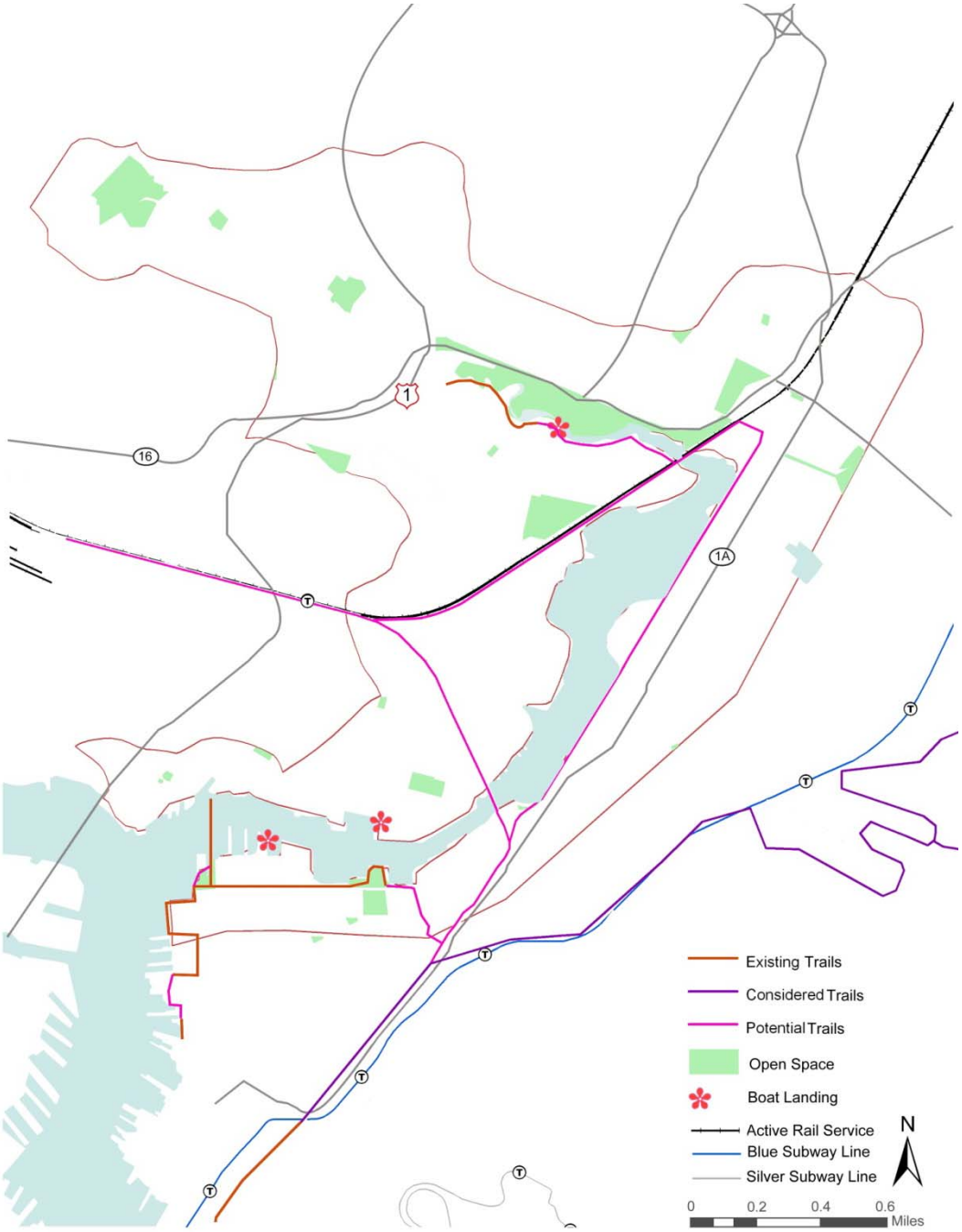


Fig. 48: Recreation Analysis

VI. Design Proposal

To meet the goal of the project, 4 themes of my design have been identified. The concept plan for Green Infrastructure in the Chelsea River Subwatershed is made by integration of concept plans for stormwater management, biodiversity and recreation. Finally, a waterfront park design is developed as an example of green infrastructure implementation in a finer scale.

A. Themes

The 4 themes for the design are RESTORATION, CONNECTIVITY, MULTI-FUNCTION, and FLEXIBILITY.

1) Restoration

Restore the impaired Chelsea River, restore the habitat and restore the relationship between people and Chelsea River in the typical industrialized urban subwatershed.

2) Connectivity

Connectivity is the key feature of the Green Infrastructure network. It does not only mean connectivity of habitat, but also the connectivity between open spaces and hydrological connectivity between neighborsheds.

3) Multi-function

In addition to ecological function, green infrastructure network will also service for these areas: recreation, education, economy, social communication, water and air quality, traffic calming, public health, etc.

4) Flexibility

To keep the environmental sensitive areas from degradation and potential for future

use, these areas such as salt marshes will be protected by buffer and left for evolution with passive activities allowed.

B. Concept

The concept of the master project is to establish a blue-green network with green infrastructure to improve the environment of Chelsea River Subwatershed and restore Chelsea River. Green infrastructure network in the Chelsea River Subwatershed is composed of open spaces and green hubs linked by linear connections such as green streets, waterfront buffer and trails with stormwater BMPs and public access at specific sites (Fig. 49).

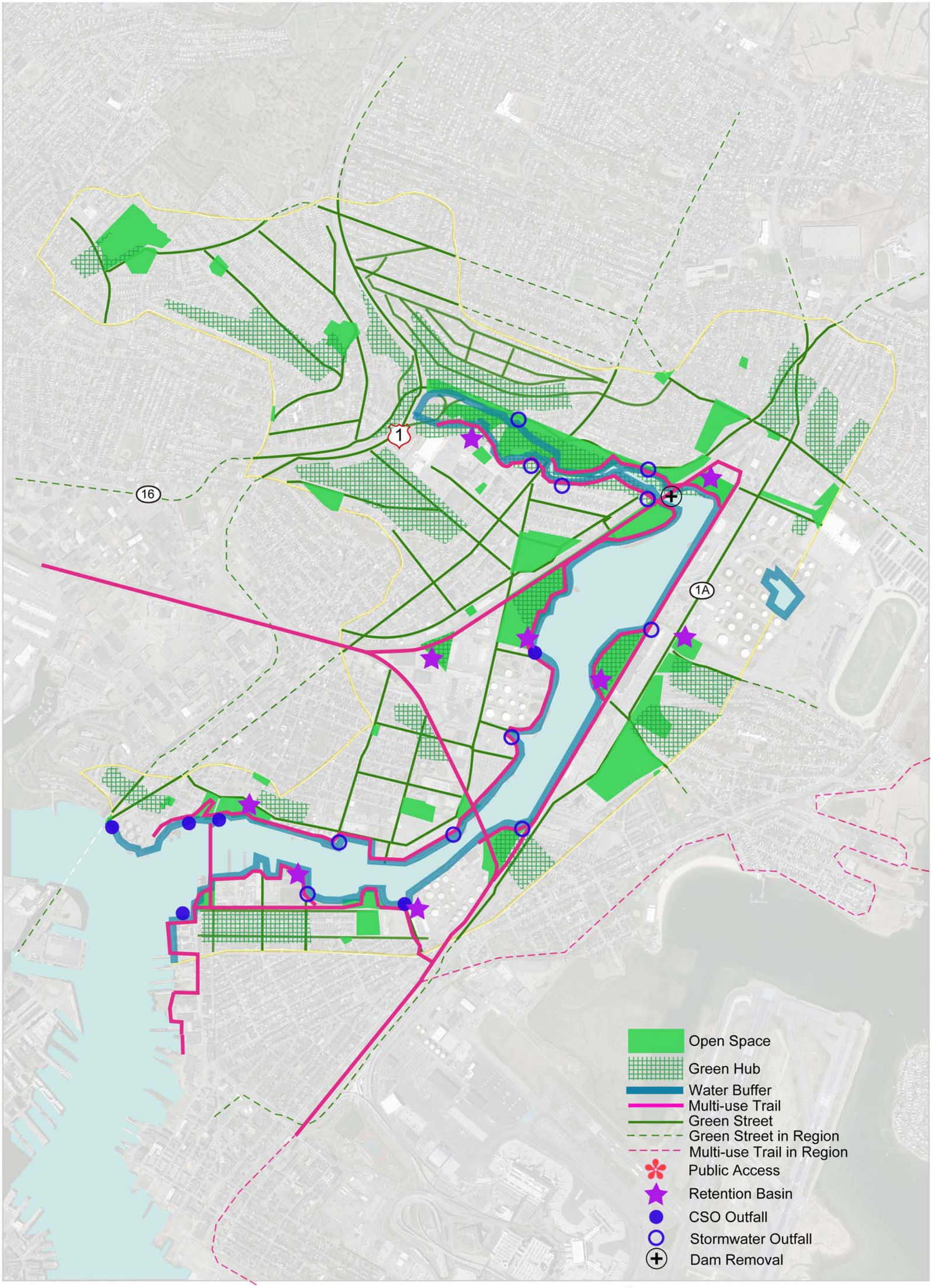


Fig. 49: Green Infrastructure Concept Plan for Chelsea River Subwatershed

1) Stormwater Management

Waterfront buffer will be set up of at least 30 ft wide along the shoreline of Chelsea River. It is a riparian vegetated zone acting as a filter for water flowing into the river. Buffers with a wide variety of vegetation types (trees, grasses, bushes, etc.) will absorb more nutrients than buffers with just one type of vegetation.

The goal for stormwater management is to substitute the proposed “blue” network, a natural drainage system, for CSOs finally (Fig. 50). Stromwater management BMPs such as retention basin or wetland will be applied in the places with pervious surface which are existing parks, salt marshes, landfills or overgrown waste lands to filter and treat the stormwater / CSOs. These Stormwater management BMPs are distributed evenly along river so that stromwater or CSOs from every neighborshed can be treated before flowing to the water. High-tech stormwater management treatment facility may be used to help treat the CSOs.

Major roads, railways, abandoned railways and some local streets in neighborhoods near river will be developed for natural drainage linkage using swales, retention basins, etc.

In neighborhoods, stormwater collection and onsite treatment are proposed. Green roof will be installed in new buildings. In the large areas of impervious land such as parking lots, permeable pavement will be applied. Filter strip can also be established adjacent to the parking lot to reduce pollution washed by the stromwater from parking lots.

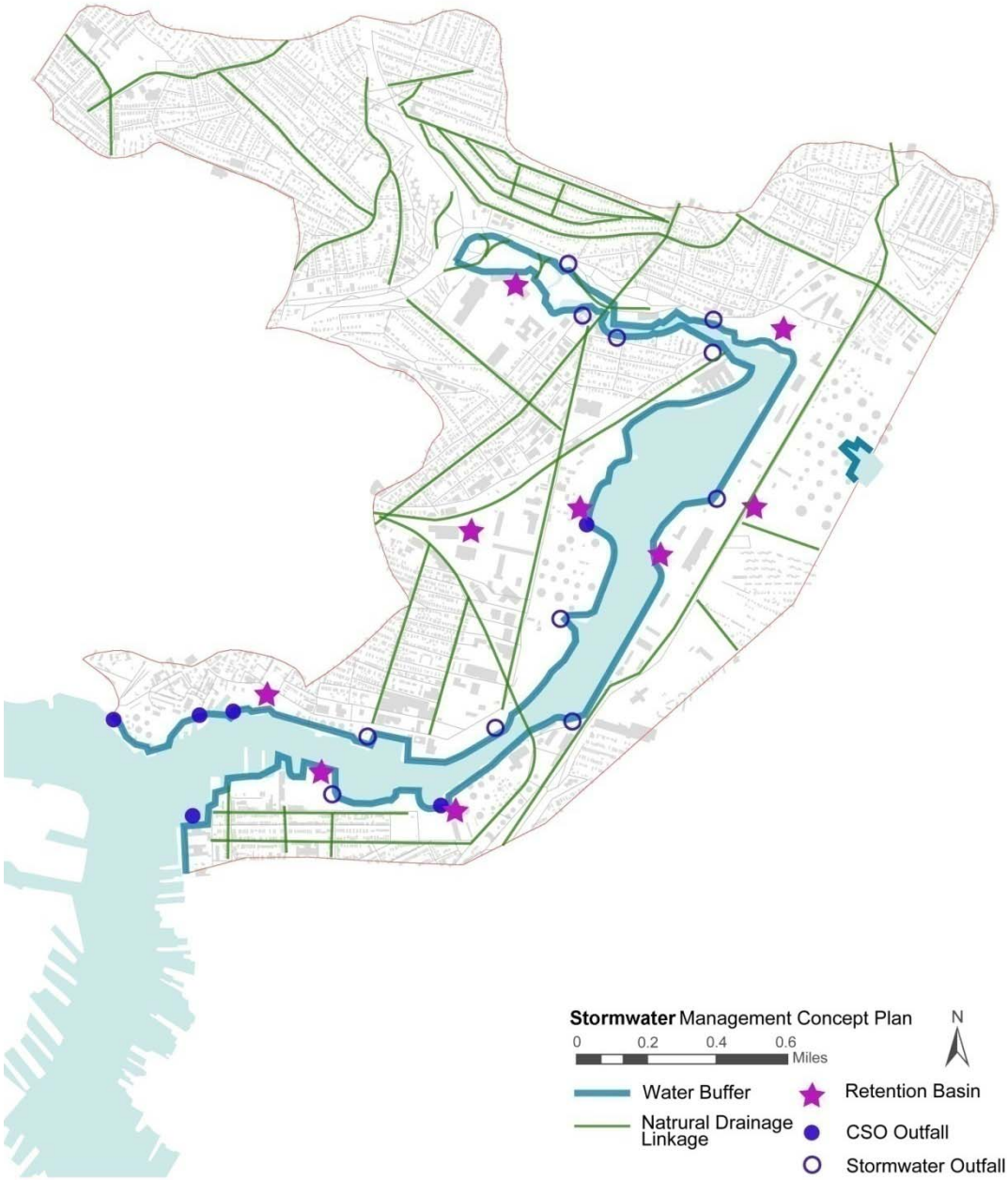


Fig. 50: Stormwater Management Concept Plan

2) Biodiversity

Biodiversity will be increased by establishing the habitat network composed of green hubs and green corridors (Fig. 51).

Enhance the areas with high percentage of existing tree canopy as green hubs by preserving the existing trees and planting more trees. These green hubs are

mainly the areas along Mill Creek, parks, forests as well as green spaces in neighborhoods.

Street trees and waterways can be used to create green corridors. The abandoned railroad, the strips along the active railroad and major roads connecting the large green hubs and water will become primary corridor since they are relatively wider which indicates there is more space for trees canopy. Other streets which connect the green hubs will become secondary corridor by adding vegetations. Structural soils can be used for street trees for bigger tree canopy cover. Grow Boston Greener, a collaborative effort of the City of Boston and its partners in Boston's Urban Forest Coalition, set the goals to increase the urban tree canopy cover from 29% to 35% by the year 2030, by planting 100,000 trees though out the city by 2020. Because of proximity to Boston, conditions in Chelsea River Subwatershed are similar to that in Boston. The goals for tree canopy cover could be set similar to Boston. However, because the percentage of existing tree canopy coverage in the Chelsea River Subwatershed is very low, the goal for the tree canopy cover should be lower than Boston's in a near future. Average 15% tree canopy coverage by the year 2030 has been a great progress for the Chelsea River Subwatershed.

To restore the aquatic habitat, riparian buffer is established to protect the impacts by the surrounding areas. Saltmarsh restoration can be made by the following methods: 1) Clean up the brownfield sites near saltmarsh. The saltmarsh is mainly contaminated by oil which can be reduced and removed by

phytoremediation of trees; 2) Remove the invasive species such as *Phragmites australis* and plant native species instead such as *Spartina alterniflora*; 3) Reestablish tidal hydrodynamics by widening the water way of saltmarshes and removing the dam currently not in use.

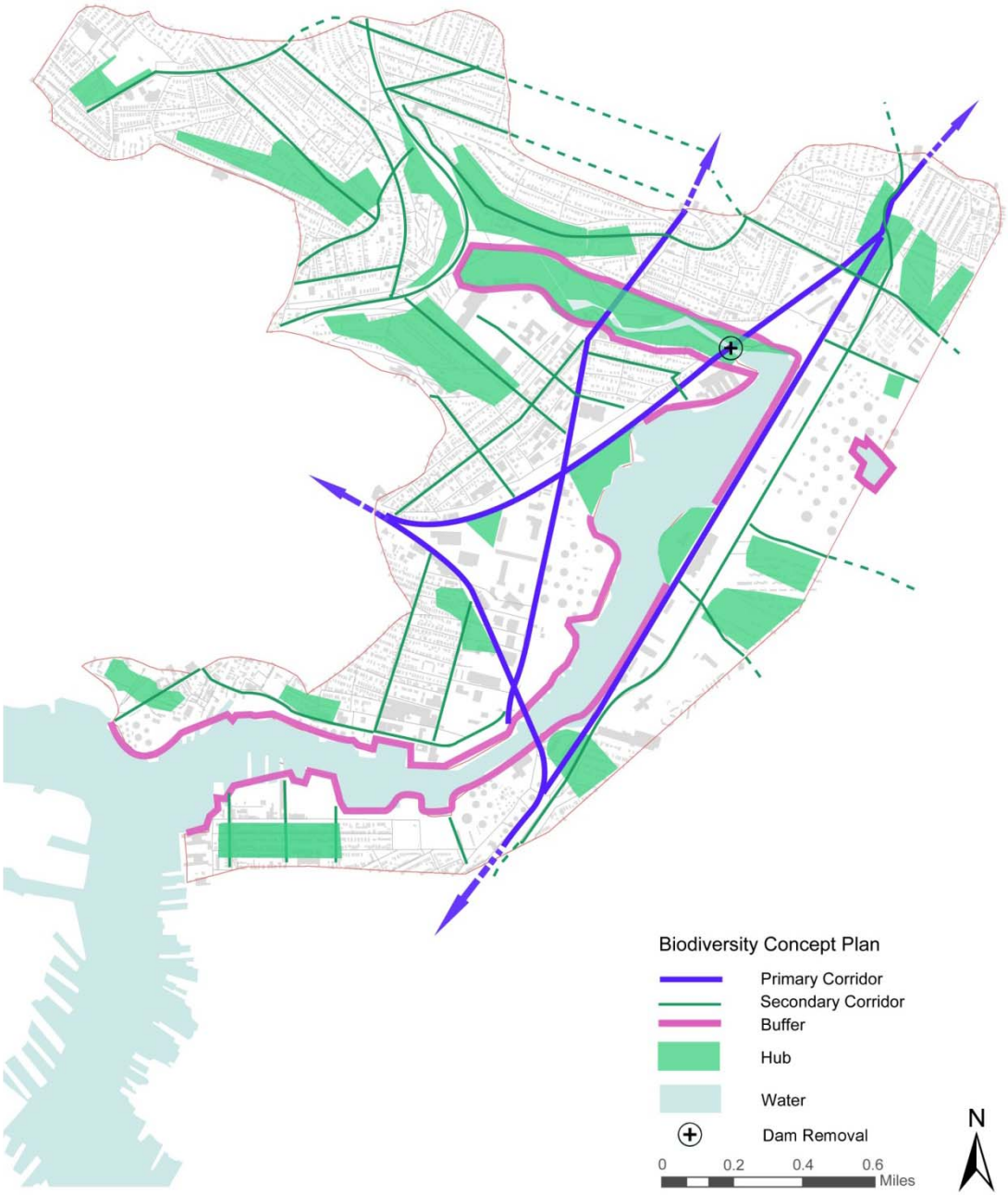


Fig. 51: Biodiversity Concept Plan

3) Recreation

New urban open spaces are proposed near river to meet people's need in open space and recreation (Fig. 52). These areas include waste lands, existing salt pile, vacant lots, etc. To link the open spaces, waterfront multi-use trail is created connecting existing trail along Mill Creek and Boston Harborwalk. Abandoned railroad is redeveloped as multi-use trail connecting the waterfront to surrounding community, transportation hubs and regionally. Totally 0.14 Mi^2 new open spaces and 10.45 Miles new trail will be added. Another way to connect the open spaces is via roads which can be developed to be scenic roads or more pedestrian/bicycle friendly green street.

In addition, public access to water will be increased by adding boat landing and road extension. The additional boat landings are located either in proposed open space or on the multi-use trail. The boat landing provides support for water related recreation such as kayaking and canoeing. Extending road to water will increase the interaction between water and the communities.

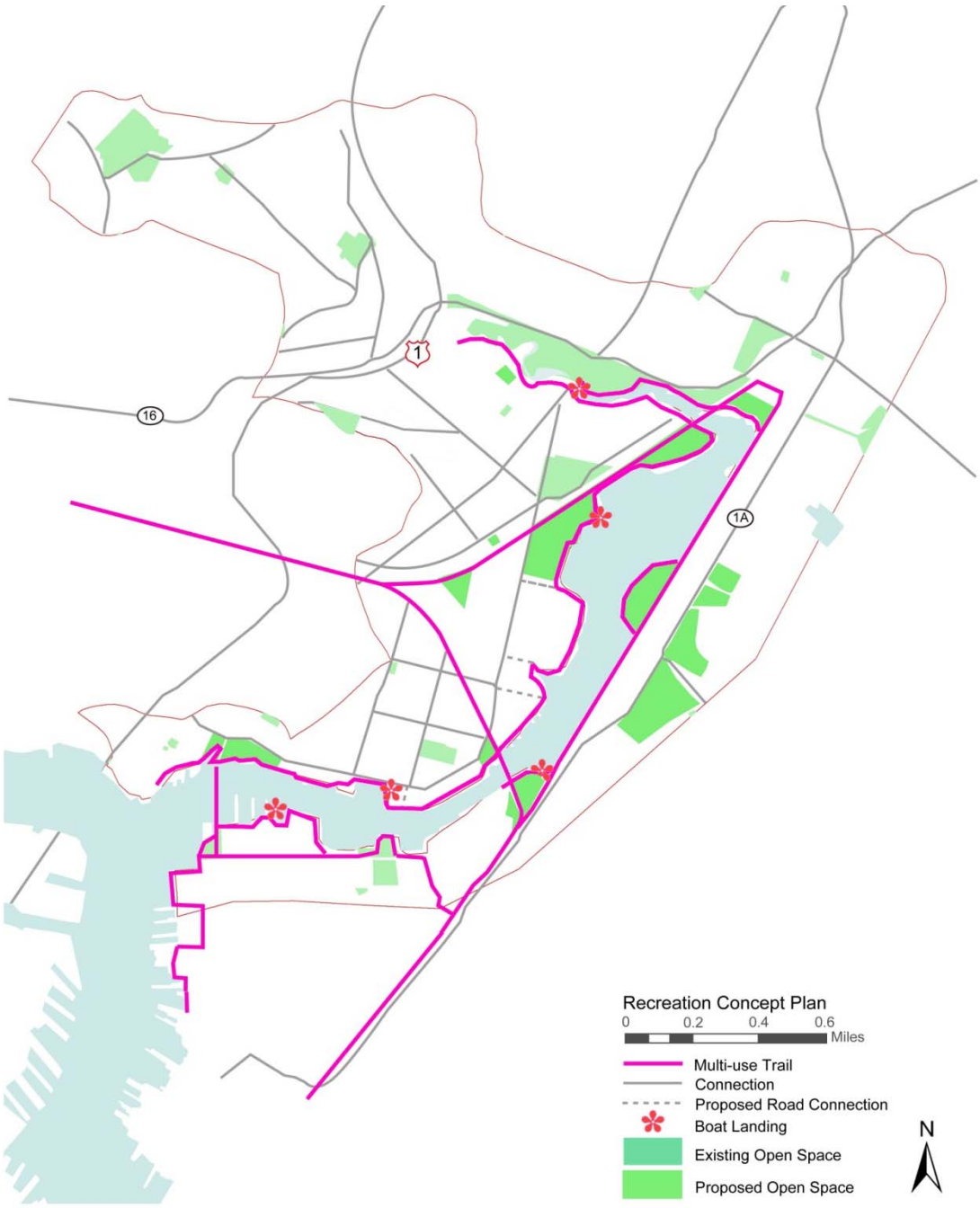


Fig. 52: Recreation Concept Plan

C. Waterfront Park Design

1. Overview of the Site

The focus area is a petroleum/oil related industrial land located at the intersection of the railroad and the major road Broadway. It was coastal wetland in history and

filled later for industry. Some of the buildings in the site are not in use. The only access to the site is on the Broadway, not for public. Across the railroad is the Mary C. Burke Elementary School. The future Forbes Park, to the northeast of the site, now under construction, will be a new mixed-use, waterfront loft community, setting a higher standard for sustainable and environmentally responsible urban lifestyles. There is a CSO outfall still in use in the site which will be removed in future according to the *Combined Sewer Overflow Control Plan* by Massachusetts Water Resources Authority. Nice views towards Boston exist from the overgrown waste land. The major habitat along shoreline here is tidal flat. Fig. 53, Fig. 54 and Fig. 55 illustrates the location and existing condition of the site.

Fig. 53
a: Location of Focus Area
b: Existing Condition of the Site

Fig. 54: Abandoned Building in the Focus Area

Fig. 55: Overgrown Waste Land in the Focus Area

2. Design Proposal

The site is proposed to be redeveloped as a waterfront park with saltmarsh and habitat restoration as major purposes and providing public access to Chelsea River as well.

The park is protected by buffer from the impact by the surrounding industrial lands. A diverse of habitat will be created in the site, from saltmarsh to wood land, gradually transforming along with the riparian landform change (Fig. 56, Fig. 57). The shore line will be pushed back. Soil excavated from the site will be used to form the subtle landform on site. Local plants will be chosen and planted with a variety of vertical

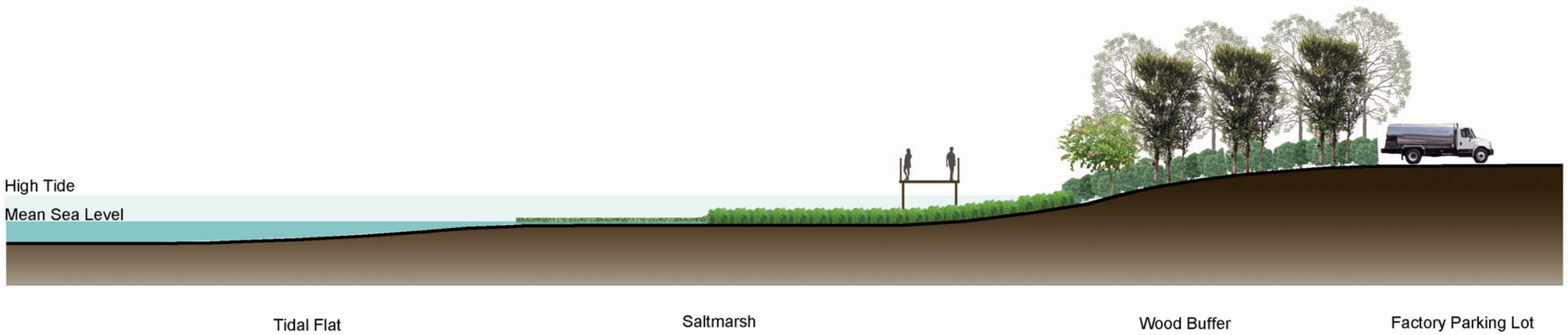
vegetative layers, for example, Northern Catalpa (Catalpa speciosa), Eastern Red Cedar (Juniperus virginiana), Winterberry (Ilex verticillata) and Marsh Marigold (Caltha palustris).

The park provides both active and passive recreation opportunity with passive recreation as major type. The “Active” land-use category includes the multi-use trail, plaza and boat landing; The “Passive” land-use category includes lawn, picnic area, wildlife watching spot, beach and pedestrian trail (Fig. 58), etc. 3 public accesses to the waterfront will be added through trails.

Stromwater and CSO overflows will be treated by saltmarsh before washed into the river. Supplementary sewage treatment facility such as ultraviolet (UV) irradiation is needed to reduce the concentrations of pathogens is needed before the saltmarsh treatment. The CSO outfall will be substituted at last. Stromwater from nearby parking lot will be filtered via filter strip and retention basin, conveyed to the stormwater storage tank under boardwalk and then discharged to the river after sedimentation and treatment in the tank (Fig. 59).

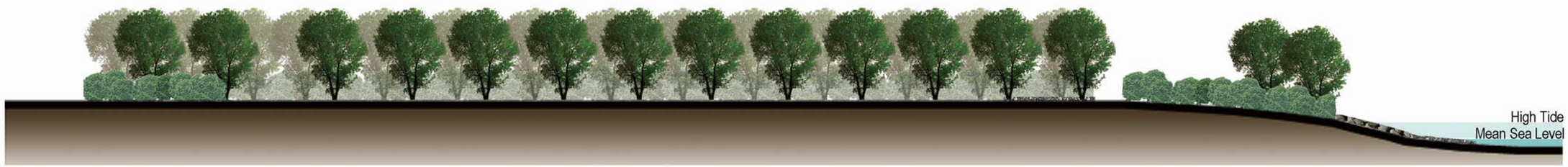
Fig. 56 Waterfront Park Plan

Section A-A Existing

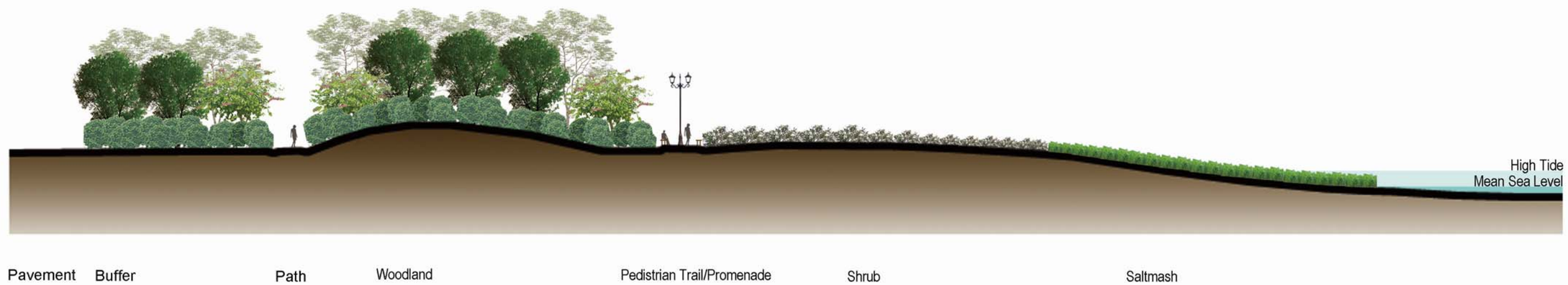


Section A-A Proposed

Fig. 57 Section A-A

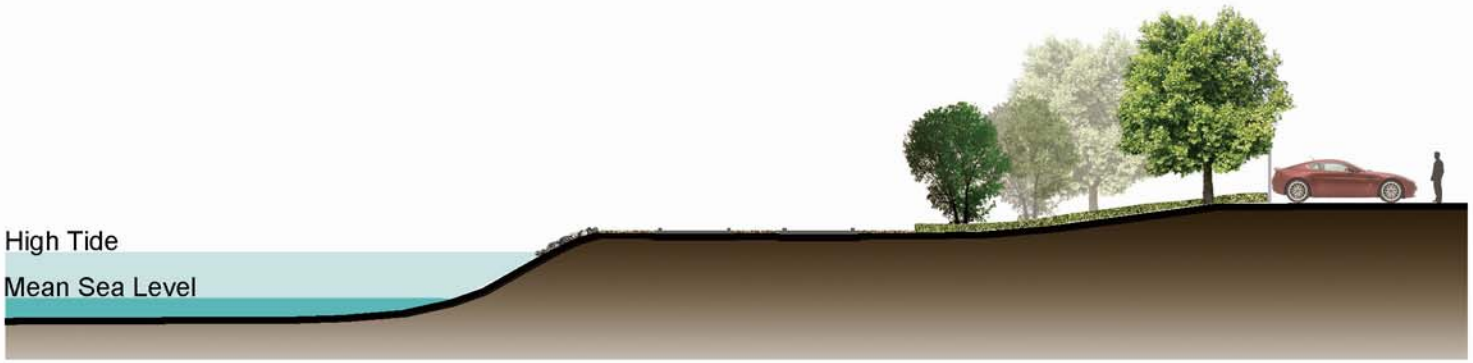


Section B-B Existing

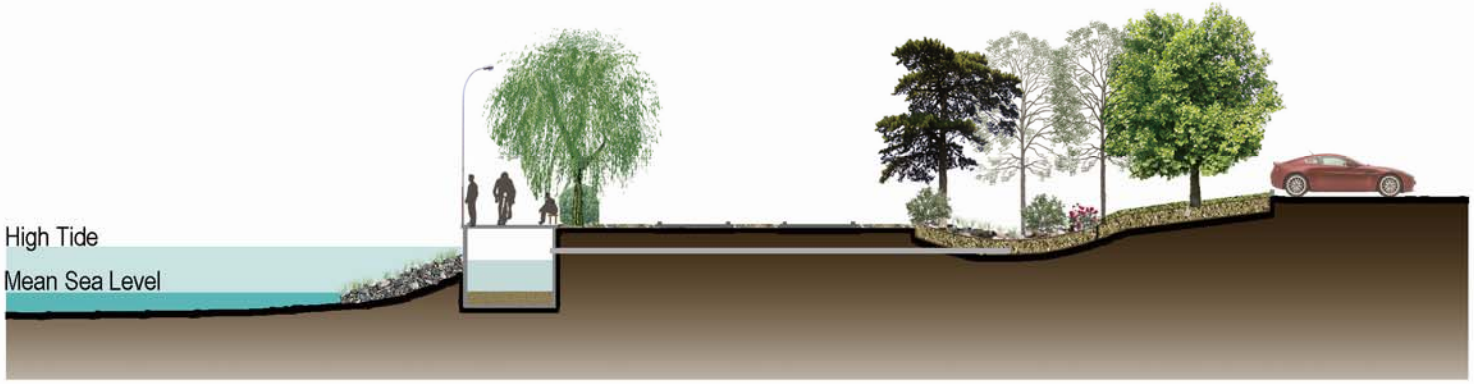


Section B-B Proposed

Fig. 58 Section B-B



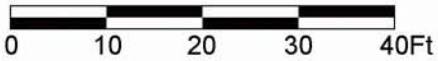
Section C-C Existing



Riprap Stormwater Storage Tank Railroad Retention Basin Filter Strip Parking Lot

Section C-C Proposed

Fig. 59 Section C-C



D. Potential New Development with Green Infrastructure

In addition to great increase in the amount of open space in Chelsea River Subwatershed, Green Infrastructure can serve as a catalyst, supporting new development of the communities near water. The “Blue-green Network” will affect people’s activities by strengthening connections between people and water. There will be a lot of opportunities for the land use reconfiguration along the river’s edge. Future development is open-ended. Here, one of the land use change recommendations is put forward. Based on the map made by combining the green infrastructure network concept with the existing land use map (Fig. 60), the potential areas for new development near water (shown in black in Fig. 61) are figured out These potential new development areas were mostly identified in the existing areas of transportation or industrial land use and adjacent to the blue-green network to make advantage of green infrastructure.

The recommendation proposes neighborhoods with diversity and richness. Part of the transportation or industrial land will be transformed to mixed use, residential, commercial and recreation land use along with the creation of open spaces (Fig. 62). Following the green infrastructure network establishment, the new development will continue balancing the relationship between people and water by supporting vibrant urban life as well as reducing the environmental impact of transportation and industry on Chelsea River.

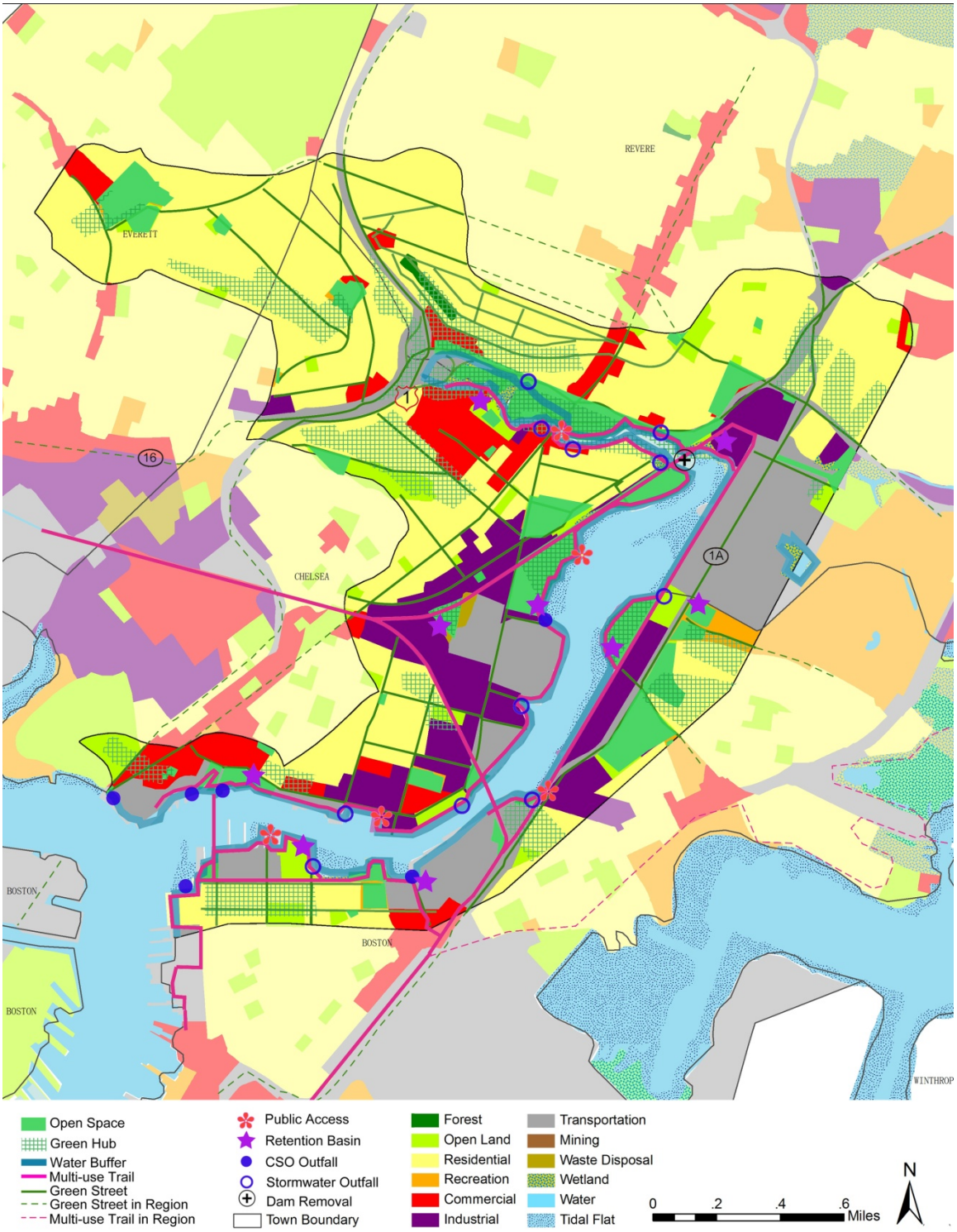


Fig. 60: Combined Map of Existing Land Use and Green Infrastructure Concept

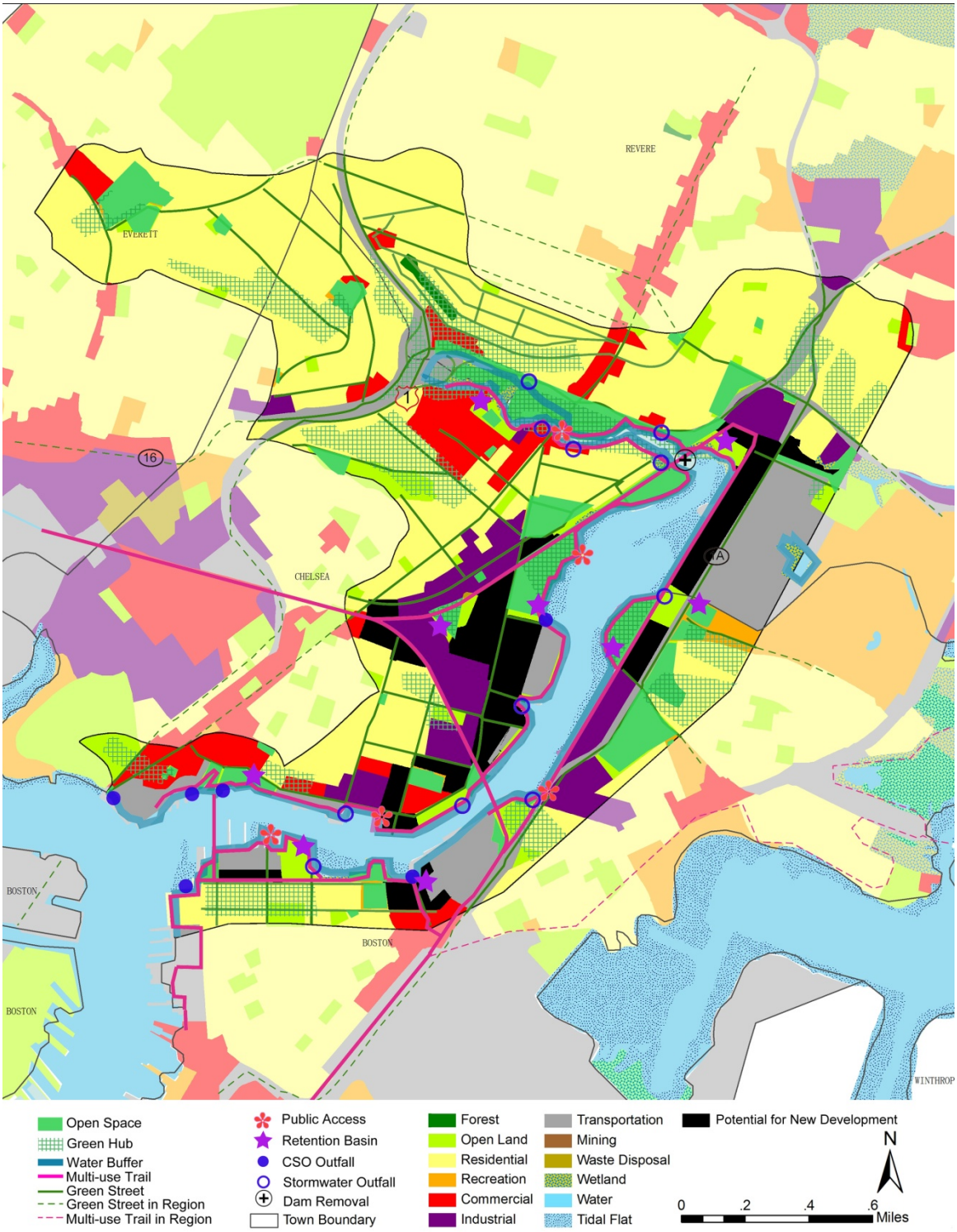


Fig. 61: Potential Areas for New Development near Water

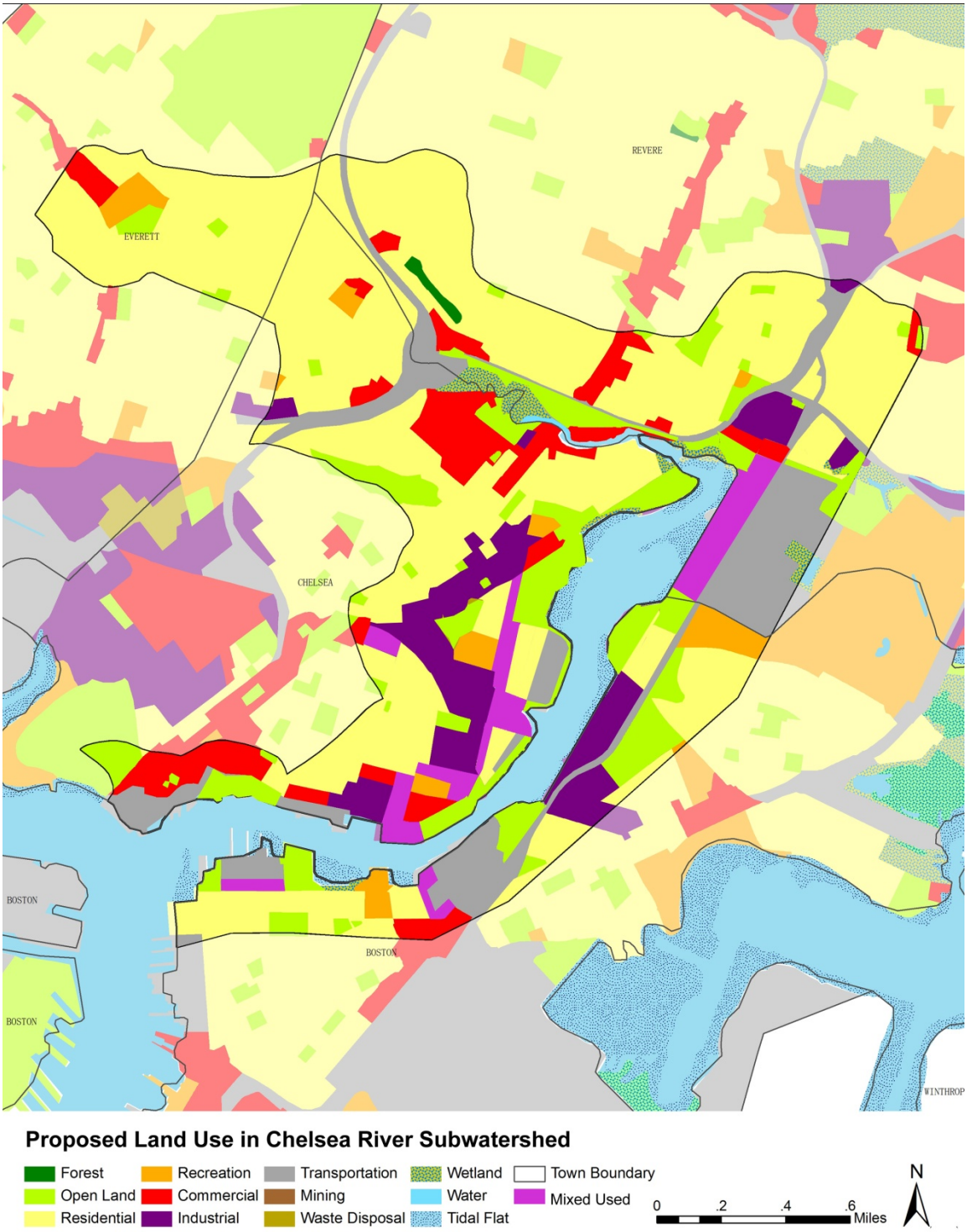


Fig. 62: Proposed Land Use in Chelsea River Subwatershed

VII. Conclusions

Urbanization has a number of documented negative effects on water body and watershed. Hydrology and ecosystem processes change in urban watershed due to urban development. In addition, biodiversity has been reduced because of habitat loss and fragmentation in urban watershed.

Green Infrastructure has been proven effective as a tool to protect urban environment and wildlife habitat by enhancing the connectivity of open space. Green infrastructure has a wide range of benefits and can be applied at multiple scales. Landscape Urbanism theory as basis of Green Infrastructure provides guidance on the selection of strategies for green infrastructure implementation in urban watershed. There are a lot of watershed management approaches including stormwater management BMPs, river and saltmarsh restoration and urban forest can be used in green infrastructure implementation in urban watershed.

The goal of the project is to improve Chelsea River Subwatershed, and therefore to improve the impaired Chelsea River by identifying the best locations for urban landscape interventions and creating blue-green network with green infrastructure in the subwatershed. Site visits, literature review, background data search, interview with government staff and watershed associations helped with site analysis to identify the problems and potentials for green infrastructure implementation.

The comprehensive concept plan proposes a green infrastructure network in Chelsea River Subwatershed composed of open spaces and green hubs linked by linear connections such as green streets, waterfront buffer and trails with stormwater

BMPs and public access at specific sites. The project conveys 4 themes: restoration, connectivity, multi-function and flexibility. Recommendations on green infrastructure implementation for stromwater management, biodiversity and recreation address the concept plan. A design proposal for the waterfront park provides example of the implementation of green infrastructure approaches at a community scale.

This project will have many benefits to Chelsea River and Chelsea River Subwatershed. The project will help improve water quality of Chelsea River by cleaning up the contaminated subwatershed and water body and increase biodiversity by salt marsh restoration and habitat enhancement in the subwatershed. Besides, the project will help improve the sustainability of people's life in the subwatershed because it can provide more access to water by creating and connecting open spaces, promote environmental justice, increase walkability, and support neighborhoods of diversity and richness with contribution to the reconfiguration of land use along the river's edge.

Further work is suggested to work on the phases and scenarios for the green infrastructure plan in Chelsea River Subwatershed. The plan will be adjusted according to the situation and implementation process to make sure that it is not only ideal but also practical.

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