PLANNING FOR INTELLIGENT TRANSPORTATION INFRASTRUCTURE ON THE ATLANTA DOWNTOWN CONNECTOR EXPRESSWAY

by

FRED THOMAS DAVIS

(Under the Direction of Jon Calabria)

ABSTRACT

Urban expressway corridors can be enhanced to accommodate a wider range of transportation including new public transit types and pedestrian and cycling pathways, and urban and ecological services such as parks and bioretention for stormwater runoff treatment. This research-design thesis identifies green infrastructure as a flexible design tool to improve urban expressways in regards to stormwater runoff, traffic, safety, transit, public health, economy, and community. After discussing new automobile technology that could organize traffic and reduce congestion on urban expressways, this thesis examines the current state of highway stormwater treatment and explores potential improvements. It then identifies green infrastructure as a flexible design tool to convert urban expressways into multi-modal transportation landscapes with improved stormwater control and other environmental, social, and economic urban benefits. A design application on the Atlanta downtown connector tests the strengths and weaknesses of using green infrastructure as such a strategy.

INDEX WORDS: Green infrastructure, Planning, Ecological infrastructure, Bioretention, Adaptive re-use, Stormwater

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LIST OF ACRONYMS

AASHTO – American Association of State Highway and Transportation Officials

ACC – Adaptive Cruise Control

BMP – Best Management Practice

CSO – Combined Sewer Overflow

CVN – Cooperative Vehicle Network

CWA – Clean Water Act

DOT – Department of Transportation

EPA – Environmental Protection Agency

GDOT – Georgia Department of Transportation

GI – Green Infrastructure

GSMM – Georgia Stormwater Management Manual

GSU – Georgia State University

HOV – High Occupancy Vehicle

I – Interstate

IVHS – Intelligent Vehicle Highway System

IVN – Intelligent Vehicle Network

LAF – Landscape Architecture Foundation

LID – Low Impact Development

MARTA – Metropolitan Atlanta Rapid Transit Authority

MDL – Maximum Daily Load

MEP – Maximum Extend Practicable

MID – Midtown Improvement District

MS4 – Municipal Separate Storm Sewer System

NHTSA – National Highway Transportation Safety Administration

NPDES – National Pollution Discharge Elimination System

POI – Point of Interest

PVC – Polyvinyl Chloride

SEA – Street Edge Alternatives

SWMP – Stormwater Management Plan

SWQMP – Stormwater Quality Management Plan

TMDL – Total Maximum Daily Load

TN – Total Nitrogen

TP – Total Phosphorus

TSS – Total Suspended Solids

US – United States

V2I – Vehicle to Infrastructure

V2V – Vehicle to Vehicle

V2X – V2I and V2X

VANET – Vehicular Ad Hoc Network

WQA – Water Quality Act

WQMP – Water Quality Management Plan

# CHAPTER 1

# INTRODUCTION

As cities continue to develop and expand, city planners are exploring the social, economic, and environmental benefits of using green infrastructure as an urban planning and design theory. Green infrastructure is a method of establishing overlapping infrastructure systems in the same physical space that mimic natural processes and mitigate the environmental effects of development. Part of the challenge of designing landscape and infrastructure is predicting how our needs might evolve in the future, and planning built works that can be easily adapted to suit a range of needs over time. In already-developed, highly constrained, dense urban areas, some of the tenets of green infrastructure are more difficult to apply. Green infrastructure works most holistically when it is used as a planning tool to expand development into natural areas, consolidating the development footprint into dense clusters that minimize disturbance of the surrounding ecology. This theory of development is often also referred to as low impact development (LID), because the goal is to reduce the impact of development on the environment.

The high concentration of impervious surfaces in urban areas from buildings' roofs, parking lots, and roads has already caused disruptions to the environment at multiple scales and through multiple processes. In many cases, development has already taken place in configurations that makes it nearly impossible to implement green infrastructure strategies at all scales. Retrofitting existing development with sustainable architectural and landscape design interventions such as rainwater cisterns or permeable pavement can accomplish a positive environmental change, but in many cases, the site is too constrained to implement such strategies.

The United States Interstate System, especially its urban corridors, is a prime example of a system that could benefit from a retrofit using green infrastructure principles if space could be made available within or adjacent to the physical footprint. Most expressways are limited in program, acting only as a transportation corridor for cars, trucks, and other types of automobiles. Moreover, the Interstate System contributes to several environmental problems including water and air pollution. The stormwater runoff from most of these expressways flows directly into municipal separate storm sewers (MS4s) or combined sewers that outlet into the surrounding watershed. The impetus of this thesis was the development of a design for systems that will use natural materials and processes to filter and reduce the pollutant load of the stormwater runoff, infiltrate as much as possible into the ground, and reduce the velocity of the remaining volume before it is discharged into the municipal sewer systems. However, the thesis also looks for opportunities to expand the expressway's infrastructure capacity to other realms.

Utilizing green infrastructure as a design strategy, this thesis proposes the idea that thoughtful adaptation and re-use of existing transportation infrastructure can accomplish environmental goals in a highly constrained urban context. Through careful planning and adaptive re-use, the design can also achieve economic and social goals as well. The infrastructure can be enhanced, programmed with an additional set of possible functions ranging from natural stormwater control measures such as bioretention and infiltration trenches, to linear farms, walking trails, public transportation, bicycle trails, green space and parks, habitat connectivity, pedestrian bridges, traffic noise reduction, solar power generators, wind power generators, landfill and DOT storage, underground utility, open-ended program for future use, educational opportunities, Wi-Fi, electric car-charging, and specialized lanes for different modes of transit.

The thesis will introduce and briefly touch on automotive technology currently in development, known as Adaptive Cruise Control (ACC) and Intelligent Vehicle Highway Systems (IVHS) that have the potential to radically alleviate congestion on urban expressways by allowing vehicles to form automated networks and communicate wirelessly with each other and with the road. Such technological advancements are currently being made that will have a profound impact on expressway landscapes of the future. Current models predict that within the next century, cars will operate autonomously by utilizing a combination of cameras, sonar, radar, software, and sensors embedded in the roads that allow cars to communicate wirelessly with each other and with the road (Bishop 2005). Studies have proven that this technology can significantly improve traffic safety, drastically reducing the chance of car accidents by eliminating the potential for human error behind the wheel. Another implication of the research is the forecasting of reduced congestion and lighter, more organized traffic flow, particularly on busy urban expressways. Algorithms will be written to coordinate traffic movement during rush hour so that heavy traffic is less likely to plague inner-city freeways.

Interstates have been widened repeatedly in the twentieth and twenty-first centuries to accommodate the high volume of automobile traffic converging on American downtowns from the bulging suburbs. In Atlanta as in many cities around the country, the Downtown Connector is now as wide as sixteen lanes across in certain areas, with plans to expand even more. If Adaptive Cruise Control (ACC) and Intelligent Vehicle Highway Systems (IVHS) improve traffic to the extent that the current capacity becomes unneeded or excess, then space can be reclaimed from redundant lanes to serve other pressing infrastructure needs. In the age of adaptive re-use of abandoned transportation infrastructure such as The Atlanta Beltline, the opportunities presented by the reduced congestion on urban expressways that will be made possible by ACC and IVHS are particularly relevant.

At its core, the design of this thesis seeks to transform the Atlanta Downtown Connector into a new type of urban system that is a symbol for regional watershed health, public education, and advanced transportation technology. Other ideas for improvements to the Atlanta Downtown Connector have been conceived. Most recently, SWA has designed a beautification project intended to bring art and plants to the highway in an effort to strengthen Atlanta's identity and appearance, and to attract development and capital (Atlanta Downtown Improvement District 2012). See Figure 1. However, this thesis proposes a more thorough and fundamental set of changes and improvements to the corridor whose impacts will extend far beyond beautification and temporary financial draws. The SWA design accomplishes little more than proposing new landscaping and public art, and while it claims to strengthen the identity of Atlanta, it does not adequately improve the Downtown Connector on any other level.

Figure 1: Concept Rendering, Atlanta Downtown Connector Transformation (http://www.swagroup.com/project/atlanta-i-75-i-85-connector.html)

## Research Objectives

This thesis asks the following research question: How can the environmental functionality of the Atlanta Downtown Connector be improved by redesigning the current expressway corridor to accommodate stormwater control measures using green infrastructure as a planning and design strategy? In order to investigate this question, the thesis will review the literature associated with green infrastructure theory and analyze its applicability to highly constrained urban sites. The research will focus on several definitions of green infrastructure, finally settling focus on the EPA definition that green infrastructure is "an approach to wet weather management that uses natural systems – or engineered systems that mimic natural processes – to enhance overall environmental quality and provide utility services" (Odefey et al., 2012). However, through the discussion of the various definitions of green infrastructure and precedent studies, in combination with an analysis of the needs of the Atlanta Downtown Connector corridor and the surrounding urban area, this thesis will also explore potential economic and social improvements that will hopefully be achieved concurrent with the environmental benefits of the design.

The research objectives of the thesis are to identify the needs for stormwater runoff treatment along the corridor, explore the benefits and limitations of using green infrastructure for stormwater runoff treatment in such a highly constrained urban environment, determine the present and future potential program of the potential reclaimed space from the expressway, design a system that addresses these needs and programs, to determine key incentives and stakeholders that will be involved with its development, and to generate planning guidelines for the implementation of this system.

Methodology and Thesis Structure

The methodology of this thesis is based on a critique of green infrastructure and its applicability to urban stormwater management within a piece of transportation infrastructure. It incorporates literature reviews, precedent studies, and a design application. The literature review encompasses current findings related to stormwater best management practices (BMPs), the current technical and administrative processes of stormwater runoff treatment on the United States Interstate System, adaptive cruise control and intelligent vehicle highway systems (and anticipated future traffic on urban expressways), and green infrastructure. Design precedents that address stormwater treatment in size-constrained urban areas or that utilize green infrastructure and/or adaptive re-use for urban or transportation-related projects are studied and analyzed in order to inform the design application. The design application uses the tenets of green infrastructure to create a piece of enhanced, intelligent transportation infrastructure in the physical space now occupied by the Downtown Connector. The principles of green infrastructure are utilized to recommend a planning process for the smooth implementation of this vision. A concluding analysis of the design application will determine the effectiveness of the strategies being utilized.

The thesis is organized into seven chapters beginning with Chapter 1, this introductory chapter. Chapter 2 gives a brief summary of the review of the literature related to the history of the United States Interstate System, an introduction to problems with stormwater runoff from urban expressways, and an overview of the Atlanta Downtown Connector, its history, and its current problems. The end of chapter 2 sets the table for the planning and design problem that this thesis will address. Chapter 3 is a review of the literature related to the Clean Water Act (CWA), the National Pollutant Discharge Elimination System (NPDES), the Municipal Separate

Storm Sewer System (MS4), Adaptive Cruise Control (ACC), and Intelligent Vehicle Highway Systems (IVHS). The governmental structure of stormwater management will be evaluated. Then, the contemporary and future technology associated with ACC and IVHS will further reinforce the potential for this thesis to propose a reprogramming of the Atlanta Downtown Connector using existing travel lanes as soon as traffic becomes automated. Chapter 4 is a review of the literature related to green infrastructure, its uses, scales, definitions, interpretations, benefits, and limitations. Chapter 4 will also introduce current stormwater BMPs recommended by the EPA and implemented by various state and local governments, and examine them through the lens of green infrastructure theory. Chapter 5 is a review of 9 pertinent precedents for this design. This chapter will discuss why each precedent was chosen and what lessons were gleaned from its design and level of success of implementation. Chapter 6 introduces the design problem. It begins with the Atlanta Downtown Connector site analysis and inventory, then focuses on the opportunities for a green infrastructure-based design to improve its environmental functionality, the various scales and stages of planning of such a design, site design for stormwater management, and, according to the tenets of green infrastructure, a Vision Statement, Mission Statement, and Implementation Plan. Chapter 7, the conclusion, discusses how successful green infrastructure will have been as a design and planning strategy for stormwater management, identifies areas for additional research, and posits the related futures of the Atlanta Downtown Connector.

## Limitations and Delimitations

This thesis is not an immediate prescription for stormwater management for the Atlanta Downtown Connector. It does not condone the subtraction of current rights-of-way or a forced reduction in traffic through means of reducing travel lanes. Rather, it envisages a more intelligent and sustainable model for urban expressways at a time in the future when the concepts of transportation, roads, automobiles, and driving have changed to such an extent that the 2014 transportation landscape will seem unrecognizable, flat, static, and obsolete. Given those physical urban changes, this thesis prescribes ways to plan, design, and implement built reconstructions to existing transportation infrastructure with specific guidelines and suggestions for the design of their physical characteristics.

While the idea that we will someday be able to significantly reduce the number of lanes in urban expressways might seem preposterous, nothing is outside the realm of possibility. Most major technological advancements in history have, just before or at the time of their arrival, seemed to the public impossible, uncanny, or "magical" (Edidin 2005). Motion pictures, television, radio, cellular phones, and the Internet were unfathomable by the layperson even just prior to their conception, and although each invention has drastically changed the course of humanity, may have seemed inconsequential at the time. In several hundred years, historians may reflect back on the time before ACC and IVHS became commonplace, saving lives and reducing congestion, and wonder, the same way we wonder about cell phones, "How did we survive before IVHS?" Accepting and planning ahead for the inevitable promotes morally defensible action, and is also a smart strategy for controlling infrastructure and development in an intelligent and sustainable way.

Negative reactions to this idea will include not only doubts that the technology will ever materialize, but also a resistance to the idea that the automobile-centric American lifestyle can or should be changed. However, instead of forcing people to commute by train, public transit, or carpool, this idea promotes the car culture and celebrates its potential for versatility – cars can act as a single car or a chain of cars. Semi-autonomous car chains and bus chains can become the new trains, operating within an existing (and sizable) infrastructure investment – the United States Interstate system. If new functionality is designed for it, the Interstate system and the significant investment in it will be accommodated and will not go to waste. Furthermore, constructing new infrastructure and new infrastructure types can be avoided, sparing valuable space, habitat, and resources.

The next chapter will review the history of the United States Interstate System to put the current problems into context. It will also discuss the Atlanta Downtown Connector to begin to establish site-specific problems and design opportunities.

# CHAPTER 2

# THE HIGHWAY PROBLEM

## History of United States Interstate System

The Eisenhower Interstate System was planned in the 1950s as a network of roads throughout the United States primarily for military defense purposes. Eisenhower envisioned the system as infrastructure for conveying military supplies and troops in case of invasion by a foreign country. In the almost 70 years of domestic peacetime since its implementation, the Interstate system has aided the tremendous growth of the U.S. economy by serving as a piece of infrastructure to convey people, goods and services between the industrialized cities and rural areas across the country. More recently, it has encouraged the suburban sprawl phenomenon and the United States car-centric society. These two problems have led to extreme congestion on the Interstate and a grave environmental crisis. With a price tag exceeding $400 billion, the Interstate system is one of the biggest investments ever made in the United States (Weingroff 1996).

Given the size of the investment the U.S. has made in the Interstate System, continued efforts to ensure that it performs efficiently, is utilized wisely and to the maximum extent possible, and causes no detriment to the environment are of substantial importance. In urban areas, the Interstate System contributes too large of an amount of pollution and harm to the surrounding watershed. By contrast, in rural areas, the amount of pollutants on the roadway is much less concentrated to begin with, and when it is washed away by stormwater, it can infiltrate into the soil and is filtered by vegetation in most cases. Figure 2 demonstrates the differences in stormwater runoff pollutants from urban and rural areas. In urban areas, the sheer number of different pollutants and their levels are quite staggering. Urban stormwater runoff contains, Arsenic, Asbestos, Chromium, Copper, Lead, Mercury, Nitrogen, Nitrates, Nitrites, Ammonia, Phosphorus, Polycyclic aromatic hydrocarbons, Ethylene Glycol, oil and grease, Fecal Coliform, E. Coli, and many other harmful substances. At their current levels, the pollutants far exceed the EPA's recommended levels for drinking water when they enter our waterways. Downstream, hundreds of millions of dollars are spent performing chemical treatments on the water to remove these toxins and make the water safe to use as a drinking source (Burns, 2012). Figure 3 shows every contaminant found in urban expressway stormwater runoff, its source, and a green infrastructure control measure that can be used to reduce or eliminate it. Figure 4 categorizes the various pollutants by their environmental or human hazard.

| Pollutant | Urban Highways | Rural Highways |
|---|---|---|
| | ADT>30,000 | ADT<30,000 |
| Total Suspended Solids | 142 | 41 |
| Volatile Suspended Solids | 39 | 12 |
| Total Organic Carbon | 25 | 8 |
| Chemical Oxygen Demand | 114 | 49 |
| Nitrate+Nitrite | 0.76 | 0.46 |
| Total Kjeldahl Nitrogen | 1.83 | 0.87 |
| PO4^3- | 0.4 | 0.16 |
| Copper | 0.054 | 0.022 |
| Lead | 0.4 | 0.08 |
| Zinc | 0.329 | 0.08 |

Figure 2: Table, Urban vs rural stormwater runoff pollutants comparison (Adapted from Burns, 2012)

| Pollutant | Source | Mean Loading | Range | EPA Drinking Water Limit | Treatment Methods |
|---|---|---|---|---|---|
| **Physical Contaminants** | | | | | |
| a) Total Solids | All particulates and dissolved contaminants | 481-1440 | 76-36,200 | | Bioretention systems, stormwater wetlands |
| b) Total Suspended Solids | Pavement wear, atmospheric deposition, maintenance, vehicles | 4-1223, 100(14) | 1.0-36,200 | | Permeable friction course, stormwater ponds, sand filters |
| c) Total Dissolved Solids | Pavement wear, atmospheric deposition | 178 | 75.9-2,792 | 500 | Vegetated roadsides appear to effectively remove TSS |
| **Inorganic Chemical Contaminants** | | | | | |
| a) Arsenic | Some pesticides, weed killers | 0.024-0.21 | 0.001-0.21 | 0.01 | Processes involved are precipitation, dissolution, adsorption, deposition, dissociation, transformation, complexation, and biochemical reactions |
| b) Asbestos | Wear of clutch and brake linings in vehicles, water mains | | | 7x10^6 fibres/l | Biofiltration, infiltration trenches |
| c) Cadmium | Wear of tires and brake pads, combustion of lubricating oils, insecticide application, corrosion | 0.0003-0.011 | 0.00005-13.73 | 0.005 | Constructed wetlands are the efficient BMPs to remove heavy metals |
| d) Calcium | Road deicing | 4.8-26.5 | 0.04-2113.8 | | |
| e) Chloride | Deicing salts, road ballast, pesticides | 33 | 0.3-25000 | 250 | |
| f) Chromium | Metal plating, moving parts, brake lining | 0.01-0.23, 0.022(3) | 0.001-2.3 | 0.1 | |
| g) Copper | Metal plating, bearing and brushing wear, moving engine parts, brake lining wear, fungicides and insecticides | 0.0065-0.15, 0.034(14) | 0.00006-1.41 | 1.3 | |
| h) Iron | Auto rust, steel highway structures (guard rails), moving engine parts | 0.98-12.0, 7.63(3) | 0.08-440.0 | 0.3 | |
| i) Lead | Auto exhaust, tire wear, lubricating oil and grease, bearing wear | 0.0209-1.558, 0.144(14) | 0.00057-26.0 | 0.015 | |
| j) Manganese | Wear of tires and brake pads | 0.11-0.67 | 0.007-3.80 | 0.05 | |
| k) Mercury | Batteries, paints | 15.42 ug/l | 0.00005-0.067 | 0.002 | |
| l) Nickel | Diesel fuel and petrol exhaust, lubricating oil, metal plating, brushing wear, brake lining wear, asphalt paving | 0.006-0.015 | 0.001-49.0 | 0.05-1.0 | |
| m) Nitrogen | | | | | |
| i) Total Nitrogen | | | 0.32-16.0 | | Constructed wetlands, biological uptake in wet ponds are efficient in removal of nitrogen and phosphorus from the stormwater |
| ii) Inorganic Nitrogen | | | 0.09-5.44 | | |
| iii) Organic Nitrogen | Fertilizers, animal excrement, vegetation matter, litter | | 0.32-16.0 | | |
| iv) Nitrate | | 0.84(3), 0.68(14) | 0.01-12.0 | 10 | |
| v) Nitrite | | | 0.02-1.49 | 1 | |
| vi) Ammonia | | | 0.01-4.3 | | |
| vii) Total Kjeldahl Nitrogen | | 1.7, 2.3 (12) | 0.32-16.0 | | |
| n) Sodium | Deicing salts | | 0.18-660 | 200 | |
| o) Sulphate | Atmospheric deposition by precipitation (acid rain), fertilizers | | 0.06-1252 | 250 | |
| p) Total Phosphorus | Tree leaves, fertilizers, lubricants | 0.015-0.82, 0.435(3) | 0.01-7.30 | | |
| q) Zinc | Tire wear, motor oil, grease | 0.0166-0.58, 0.160(14) | 0.0007-22.0 | 5 | |
| **Other Chemical Parameters** | | | | | |
| a) Biochemical Oxygen Demand | Biological organisms | 23 | 1.0-7700.0 | | BOD can be removed using treatment wetlands |
| b) Chemical Oxygen Demand | Organics | 103, 65(14) | 7.0-2200.0 | | |
| c) pH | | 6.5(3) | 4.5-8.7 | 6.5-8.5 | |
| **Organic Contaminants** | | | | | |
| a) Total Polycyclic aromatic hydrocarbons | Incomplete combustion of organic material, gasoline | | 0.00024-0.013 | | Most of the organic matter can be removed using dry detention basins and wet retention ponds |
| b) Benzo (a) pyrene | Leaching | 1.1 ug/l (15) | 2.5E6-1E2 | 0.0002 | |
| c) Polychlorinated biphenyl | Leaching of lubricants, hydraulic fluids, landfills | | 2.7E5-1.1E3 | 0.0005 | Organics are removed in wet retention ponds by biological breakdown using bacteria |
| d) Benzene | Spills and combustion of fuels | | 0.0035-0.013 | 0.005 | Infiltration techniques are also helpful in removing dissolved organic substances |
| e) Pentachlorophenol | Decomposition of wood preservative products | | 0.001-0.115 | 0.001 | |
| f) Ethylene Glycol | Deicing agent | | 3.4mg/m^3 (in air) | | |
| g) Oil and Grease | Leaks, spills, asphalt surface leachate, anti-freeze and hydraulic fluids, blow-by of motor lubricants | 15 | 0.001-110.0 | | Oil and grease can be removed by using manufactured separators or oil and grease traps |
| Microbial Contaminants | | | | | |
| a) Fecal Coliforms | Fecal material deposited from dogs, cats, rodents and birds onto soil, pavement, and cross sections | 1.6x10^2-2.5x10^5 CFU/100ml | 0.2-1.9E6 CFU/100ml | | Stormwater ponds, stormwater wetlands, infiltration trenches, dry detention basins |
| b) E Coli | Fecal matter | | 1.2x10^1-4.7x10^3 CFU/100ml | | |

Figure 3: Road Pollutants Index (Adapted from Burns, 2012)

| Constituents | Effects |
|---|---|
| Sediments - Suspended Solids, Dissolved Solids, Turbidity | Stream turbidity, habitat changes, recreation/aesthetic loss, contaminant transport, filling of lakes and reservoirs |
| Nutrients - Nitrate, Nitrite, Ammonia, Organic Nitrogen, Phosphate, Total Phosphorus | Algae blooms, eutrophication, ammonia and nitrate toxicity, recreation/aesthetic loss |
| Microbes - Total and Fecal Coliforms, Fecal Streptococci Viruses, E. Coli, Enterocci | Ear/intestinal infections, shellfish bed closure, recreation/aesthetic loss |
| Organic Matter - Vegetation, Sewage, Other oxygen demanding materials | Dissolved oxygen depletion, odors, fish kills |
| Toxic Pollutants - Heavy Metals (Cadmium, copper, lead, zinc), Organics, Hydrocarbons, Pesticides/Herbicides | Human and aquatic toxicity, bioaccumulation in the food chain |
| Thermal Pollution | Dissolved oxygen depletion, habitat changes |
| Trash and Debris | Recreation/aesthetic loss |

Figure 4: Table, Stormwater runoff Constituents and effects (Adapted from Center for Watershed Protection, 2001a)

Atlanta Downtown Connector

The Atlanta Downtown Connector is one of the widest, most heavily travelled sections of Interstate expressway in the United States. At its widest, it is 16 lanes across at a width of 215 feet. It winds through midtown and downtown Atlanta for approximately 8 miles, cutting a large swath through the heart of the city. The expressway is a physical, social, and economic barrier dividing neighborhoods from each other. It lies directly adjacent to thousands of workplaces, residential neighborhoods, cultural attractions, government centers, parks, shopping centers, and educational institutions. It is also one of the most congested expressways in the country. The majority of stormwater runoff from the connector is directed into MS4s which outlet into the surrounding creeks, eventually draining into the Chattahoochee and Ocmulgee Rivers (Allard 2010) (Stevens 2001). Figure 6 shows the Downtown Connector in relation to these 2 watersheds with the project area highlighted.

Federal legislation such as the Clean Water Act (CWA) regulates water discharging into natural waterways under the National Pollution Discharge Elimination System (NPDES) by requiring the operator or source of the discharge to apply for permits which control the amount of water and its pollution contents. With respect to the Atlanta Downtown Connector, the polluted stormwater runoff from the roadway is carried through MS4s that discharge into local streams and rivers. Because these MS4s are in the jurisdiction of the GDOT, the GDOT is, in theory and according to legislation, the NPDES permitee, and is thus accountable for the volume and quality of the stormwater runoff emanating from the Atlanta Downtown Connector. At the present time, there are not enough federal incentives or oversight to encourage the GDOT to adopt more rigorous or sustainable stormwater control measures, but legislation is currently changing. NPDES permitting language will soon include requirements for stormwater control measures to include green infrastructure strategies (U.S. EPA Action Strategy 2008).

Figure 5: Photo, Atlanta Downtown Connector

(https://c1.staticflickr.com/1/159/429664345_9c7010c321.jpg)

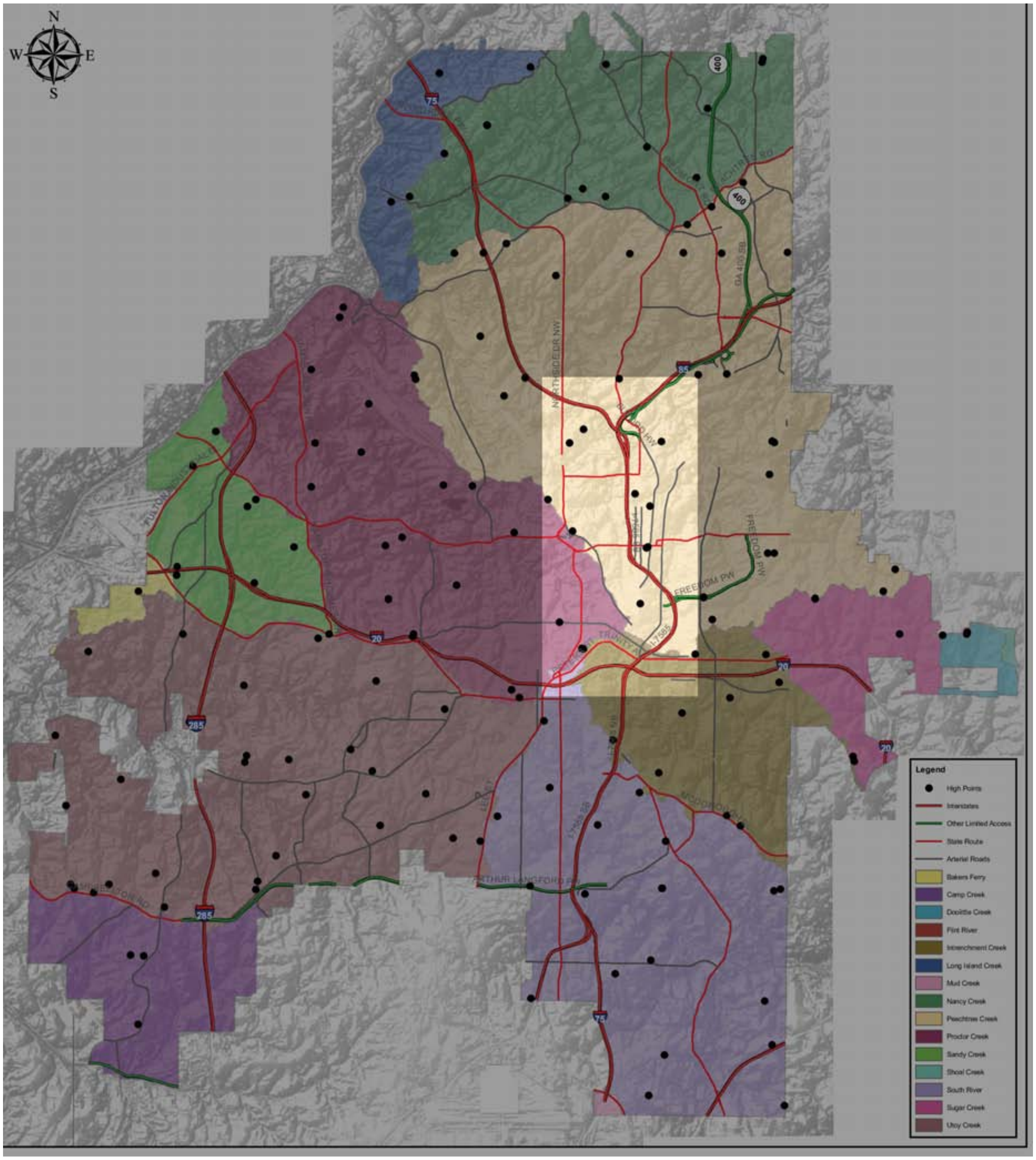



Figure 6: Map, Atlanta’s major highways with topographical high points and watersheds.

Project area is highlighted (Adapted from City of Atlanta 2011)

Design Opportunity

If there were a way to limit vehicular traffic on the expressway to just 3 or 4 lanes in each direction (such as reduced congestion through the implementation of IHVS or similar automated systems), the remainder of the space on the expressway once used as travel lanes that are now obsolete could be used for stormwater runoff treatment. Chapter 3 will discuss the problems with stormwater management on urban expressways ranging from bureaucratic hurdles to technological limitations, and also introduce the IVHS technology that will potentially reduce the demand for travel lanes. Chapter 4 will evaluate the current stormwater control measures recommended by the EPA for roadways and determine their applicability as green infrastructure design components to urban expressway corridors.

# CHAPTER 3

# HIGHWAY STORMWATER RUNOFF AND HIGHWAY TECHNOLOGY

## Highway Stormwater Runoff – Environmental Implications

As urban areas in the United States continue to expand, so does the amount of impervious surface comprising their roads, buildings, and parking lots. Increased impervious surfaces in urban areas contribute to many ecological problems, including impacting surface waters. Impervious surfaces gather large volumes of stormwater and convey them directly into streams and rivers via armored culverts and sewer systems instead of allowing natural infiltration. The result is a stress on the watershed and its ecosystem including erosion, pollution, and flooding. The unnatural velocity and volume of stormwater runoff from this urban cover destroys watershed quality by eroding stream and river banks. Stormwater runoff picks up a myriad of toxic pollutants from buildings and automobiles and deposits them directly into the streams and rivers without any sort of treatment or detoxification. Stormwater runoff from non-point sources is now the leading source of water pollution in the United States (Lee et al. 2007). Roads have the highest pollutant loads of most land use categories (Byrne 2007). Stormwater runoff and its associated problems are therefore largely a highway problem. In order to correct the damage being done to the watershed, a starting point must be the introduction of systems to roads that reduce the velocity and volume of stormwater runoff *and* filter or remove its pollutant load.

The interstate system was not designed with any form of sustainable stormwater management in mind. In Atlanta and most other urban areas, the roads are graded so that stormwater runoff flows to low points into culverts that direct it into storm sewers discharging into nearby riparian bodies. These streams and rivers are being inundated with an unnatural volume and force of water, leading to stress on the ecosystem and significant erosion. The runoff also carries dangerous toxins and heavy metals from the expressway surface which are harmful to water quality and wildlife in the ecosystem. There are many possible methods to solve the problem of stormwater runoff from urban roads, ranging from heavily engineered industrial facilities to simple, natural processes that slow down and filter stormwater runoff (Byrne 2007). Chapter 5 will introduce several successful projects that use ecological infrastructure to treat stormwater runoff from roads.

Vehicles contribute pollution to urban runoff in many ways: Engine coolants, antifreeze, oil, grease, and other hydrocarbons leak from the vehicles; Heavy metals such as cadmium, copper, and zinc are deposited onto the roads by brake pad and tire wear; vehicle exhaust contains high levels of nitrogen which is deposited onto roads (Byrne 2007).

Figure 7: Photo, Flooding of Atlanta Interstate, 2008 (http://blog.buckheadchurch.org/wp-content/uploads/2009/09/31267263.jpg)

Pilot projects have already demonstrated that incorporating natural stormwater management systems such as bioswales into the design and construction of streets has an enormous positive impact on runoff volume, velocity, and contamination, in addition to significant financial savings over traditional stormwater management strategies. For example, Seattle's SEA streets initiative has been shown to reduce runoff volume by 98 percent at a cost 25 percent below that of conventional street designs (Wise 2008). To illuminate how badly impervious surfaces exacerbate the stormwater problem, Figure 8 compares the pollutant rate of stormwater runoff from Asphalt, permeable pavers, and crushed stone.

| Pollutant | Asphalt | Paver | Crushed Stone |
|---|---|---|---|
| | (kg/ha/yr) | (kg/ha/yr) | (kg/ha/yr) |
| TSS | 230.1 | 23.1 | 9.6 |
| Nitrate | 1.78 | 1.25 | 0.15 |
| Ammonia | 0.65 | 0.12 | 0.03 |
| Total Phosphorus | 0.81 | 0.25 | 0.04 |
| Total Kjeldahl Nitrogen | 13.06 | 1.08 | 0.47 |

Figure 8: Table, runoff pollutant concentrations from various Paving materials (Adapted from Burns, 2012)

However, as bad as the environmental consequences of the current stormwater problem are, there are available cost-effective solutions ready to be implemented. Ferguson discusses a necessary transition in stormwater control in the Southeastern Piedmont region from detention to infiltration (Ferguson and Suckling 1990). Such a shift would restore groundwater aquifers, restore base flows of local water bodies during dry periods, reduce inundation of local water bodies during normal storm events, and reduce pollutant loads.

Highway Stormwater Runoff – Understanding Current Policy

To understand the current regulatory measures (and the associated problems) in place to control the problem of urban stormwater runoff from non-point sources in the United States, one must understand the complex bureaucratic arrangement in place between federal, state, and local governments. The United States Environmental Protection Agency (EPA) conducts the research to determine and recommend the appropriate standards for the federal legal regulations. The federal government uses legislation known as the Clean Water Act (CWA) and Water Quality Act (WQA) to set regulations on pollution of United States waterways. The National Pollution Discharge Elimination System (NPDES), originally a provision of the CWA, is a permitting program aimed at controlling pollution into United States waters. Initially, the NPDES focused on regulating pollution from point-sources, such as industrial and agricultural discharges. Later, the WQA acknowledged the magnitude of pollution from non-point sources, a major contributor of which is toxins carried by stormwater runoff from urban areas. The WQA expanded the reach of regulations of the NPDES into the realm of stormwater runoff by adding Municipal Separate Storm Sewer Systems (MS4s) into its jurisdiction (U.S. FR 1990).

However, aside from implementing written standards and regulations, none of the federal agencies or pieces of legislation actively prevents water pollution. State and local governments are responsible for the execution and implementation of the federally set water quality standards. In the case of MS4s, the responsibility of controlling the discharge pollution falls on a state, county, or city agency, and depends on the location of the actual system. The CWA requires each state to set individual water quality standards, acknowledging that each state's waters may be different and recognizing the state's right to govern itself (U.S. EPA 2002).

Most NPDES regulations rely on technology to control the amount of pollution entering waterways by setting numerical restrictions on volumes of toxins. However, MS4s, while classified as point-sources, are permitted differently. MS4s are only required to implement best management practices (BMPs) in order to reduce pollution "to the maximum extent practicable" (MEP). This is due to the legislation recognizing that many MS4s discharge stormwater that has been polluted by many diffuse sources, often out of the permitee's control. The following guidelines are the six minimum control measures outlined by the EPA in the NPDES:

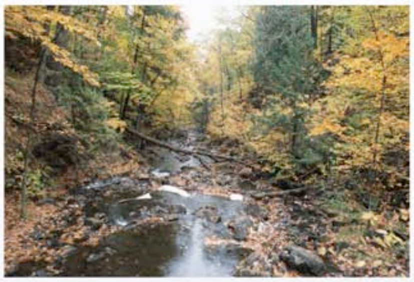
1. Public education and outreach on stormwater impacts
2. Public involvement/participation
3. Illicit discharge detection and elimination
4. Construction site stormwater runoff control
5. Post-construction stormwater management in development and redevelopment sites
6. Pollution prevention and good housekeeping for municipal operations (Georgia Department of Transportation 2011).

These control measures fall short of the necessary incentives and requirements for state and local governments to control water pollution, and do not take advantage of affordable and effective landscape solutions to the water pollution crisis. State and local governments take cues from the EPA when publishing literature related to stormwater control, failing to adopt rigorous enough standards and control measures or promote available stormwater management techniques. For example, see figures 9 and 10 below, pages of a leaflet of literature published by the GDOT with suggestions for stormwater performance improvement techniques such as checking your vehicle for leaks and throwing cigarette butts away in the proper place (Georgia Department of Transportation 2011).

Georgia Department of Transportation

## After the Storm: Stormwater Pollution Solutions

GDOT's efforts to keep our streams, rivers and lakes healthy and clean



### Did you know?

**The quality of Georgia's streams, rivers, and lakes are threatened by the daily activities of residents and businesses.** Thousands of stream miles throughout Georgia are impacted by stormwater runoff, which can carry harmful pollutants into our waterways. In fact, the leading threat to our water quality is from stormwater pollution, and the only way to combat its adverse effects is by educating people like you, to take actions to prevent it!

### What is stormwater runoff?

**Stormwater runoff is rain that flows off streets, rooftops and lawns.** Our many impervious surfaces like driveways, sidewalks, and streets prevent stormwater from naturally soaking into the ground, so it is often collected in storm-drains and drainage swales, where it flows untreated into streams, rivers and lakes.

### Why should you care about clean water?

**Can you imagine not being able to swim or fish in your favorite stream, river or lake?** Each time it rains, stormwater runoff from our roofs, streets, parking lots and lawns carries with it contaminants as it flows across these surfaces.

Unlike wastewater, the water that flows through our storm-drains is untreated before it enters our waterways. If polluted stormwater contaminates our water sources, the health of the aquatic ecosystem may be directly compromised. This can mean keeping the public from entering and using our rivers, lakes and streams. Stormwater pollution also makes monitoring and treating our drinking water more difficult and costly.

### How can we solve the problem?

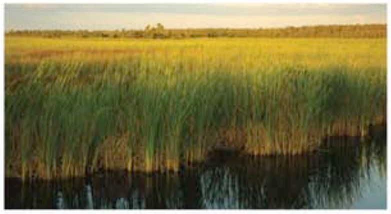
**As people learn more about the effects of stormwater runoff and how it impacts the quality of our streams, rivers and lakes, they can take positive actions to help minimize these negative effects.** People can make simple changes that can have far-reaching positive impacts. As more people learn that what goes into the storm-drains on their street flows directly into nearby streams and lakes—they will be more likely to take actions to prevent these pollutants from reaching our water supply. They will also be more likely to support efforts to address the problems of stormwater runoff quality in their community. See the list on the back of this page for specifics on what you can do to help.

### When it rains, it pollutes!

**Many people are unaware that the quality of our streams, rivers and lakes is threatened each time it rains. Stormwater runoff carries pollutants like oil and grease, lawn fertilizers, chemicals, pet waste, litter and other contaminants into our waterways. These pollutants are harmful to both people and aquatic life. The U.S. Environmental Protection Agency estimates that 80% of water pollution is caused by stormwater runoff.**

Figure 9: Leaflet, GDOT recommended stormwater BMPs (Georgia Department of Transportation 2011)

Georgia Department of Transportation



## An Untreated Mess!

**A common misconception is that water running from the street into a storm drain goes straight to a wastewater treatment plant, but it doesn't! Stormwater is seldom treated. Therefore pollutants that flow into a storm sewer system can go directly into a lake, stream, river, wetland, or coastal water. These materials are discharged into the water we use for swimming, fishing, and providing drinking water.**

## The effects of pollution

**Polluted stormwater runoff can have many adverse effects on plants, fish, animals, and people.** Sediment can cloud the water and make it difficult or impossible for aquatic plants to grow and can destroy aquatic habitats. Excess nutrients can cause rapid algae growth in a water body; when the algae dies it breaks down in a process that removes oxygen from the water. Less oxygen in the water makes it difficult for fish and other aquatic organisms to survive. Trash such as plastic bags, six-pack rings and cigarette butts that end up in the storm-drains can choke, suffocate, or disable aquatic life like fish, turtles, and birds. Household hazardous wastes like paint, used motor oil, pesticides, insecticides, solvents, and other similar fluids can poison aquatic life. Land animals and people can become sick or die from eating diseased fish and shellfish or from ingesting polluted water.

## What is the source of all these pollutants?

**We all are!** The fact is that we are all part of the stormwater pollution problem, and we can all choose to be part of the solution, as well. Many of the things we do on a daily basis, like taking care of our lawns, driving or washing our cars, and even walking our pets can contribute to stormwater pollution. Nobody wants polluted water—become part of the solution!

## What can I do to help?

- **First, never dump anything on the street, down a storm drain, or into a drainage ditch.** Report stormwater pollution on state routes by logging onto: www.dot.ga.gov/informationcenter/programs/environment/Pages/StormWater.aspx
- **Next, clean up after your pet in your yard, on walks, in public parks, and in rest-areas while traveling.** Clean up and bag pet waste, and throw it in the trash. GDOT provides pet waste stations at all highway rest stops.
- **Also, remember to check your vehicles for leaks and repair them.** Recycle motor oil and other vehicle fluids; clean up gasoline and oil leaks and spills immediately.
- **Learn more!** Education is the key to change. Signs and markers near storm drains warn residents that pollutants entering the drains will be carried untreated into a local waterbody.
- **Support a highway beautification program, and throw litter (even cigarette butts) in its proper place.** Encourage your employer to participate in the Sponsor-A-Highway program. Tell a friend or neighbor about how they can prevent stormwater pollution by helping to clean up litter and let them know how you get involved. You can also visit a Keep Georgia Beautiful affiliate. **Together we can help reduce stormwater pollution!**

BACKGROUND: On January 3, 2012, the National Pollutant Discharge Elimination System (NPDES) Permit #GAR041000 to the Georgia Department of Transportation (GDOT) for stormwater discharges from its municipal separate storm sewer system (MS4) to waters of the State became effective. The permit requires GDOT to reduce pollutants in stormwater through six minimum control measures: public education and outreach on stormwater impacts, public involvement/participation, illicit discharge detection and elimination, construction site stormwater runoff control, post-construction stormwater management, and pollution prevention/good housekeeping for municipal-type operations. The permit covers GDOT's roadways, drainage, detention ponds, etc.

FOR MORE INFORMATION VISIT:
**The Georgia Department of Transportation (GDOT)**
www.dot.ga.gov/informationcenter/programs/environment/Pages/default.aspx
**The U.S. Environmental Protection Agency** | www.epa.gov/npdes/stormwater or www.epa.gov/nps
**Clean Water Campaign** (in metro Atlanta) | 404.463.3259 | www.cleanwatercampaign.com

Figure 10: Leaflet, GDOT recommended stormwater BMPs (Georgia Department of Transportation 2011)

Section 303(d) of the Clean Water Act uses federal authority to require individual states to develop their own water quality standards. Each state sets water quality standards for their own waters. Section 303(d) requires states to identify waters that will remain polluted even after the application of technology-based pollution control measures and BMPs for water pollution control (including discharges from MS4s), prioritize these waters based on their use and the severity of the pollution, and establish “total maximum daily loads” (TMDLs) for the waters. Then, the states are required to generate a Water Quality Management Plan (WQMP) that specifies the best management practices to be used by state and local governments in order to control the sources of pollution to meet their individually defined water quality standards. The Clean Water Act authorizes the distribution of federal grants to help states develop these plans, which must then be approved by the EPA (U.S. FR 2002).

States’ waters are not permitted to exceed the set TMDLs. Thus, in theory all permittees in a given state are required to work together to reduce the pollution of runoff entering state waters. Since the CWA does not create any new authority to regulate these sources, state and local governments and/or other public or private initiatives must implement the control measures necessary for meeting the total maximum daily loads. Without a concrete method of enforcement, some argue that the CWA approach for regulating stormwater pollution is largely ineffective. However, federal incentives do actually encourage state and local government planning and programs to control stormwater pollution (Houck 2002).

The nature of stormwater management makes it a matter for local regulation (Pippin 2013). According to the Georgia Stormwater Management Manual, “local governments have a large responsibility for stormwater management in Georgia since it is at the city and county level where land use, development, and infrastructure decisions are typically made” (Center for

Watershed Protection, 2001c). The CWA stormwater regulation programs encourage a local emphasis on stormwater management by offering incentives and assistance to state and local governments to develop programs that address stormwater pollution. Local governments can take advantage of federal incentives by generating the required water quality plans using a comprehensive planning process to identify the most efficient opportunities to comply with federal regulations, using public/private partnerships and involving community input. Local governments are increasingly turning to green infrastructure to achieve the federal permitting requirements for stormwater because they simultaneously accomplish other community and public benefits through the use of infrastructure (U.S. EPA Action Strategy 2008).

Because the bureaucratic nature of stormwater management and the structure of oversight and accountability is so convoluted, figure 11 visually shows the theoretical structure of entities and organizations involved in stormwater management, as well as policies and programs that aim to control it. There is an opportunity for planners to coordinate involvement between state and local governments and agencies with community groups and other public and private stakeholders to streamline the stormwater management process so that it truly accomplishes its environmental goals. One benefit of a comprehensive and proactive planning process is that it increases the effectiveness of the stormwater management protocols mandated by legislature and policy, and ensures accountability of each entity in executing their responsibilities (Benedict and McMahon, 2006). Green infrastructure planning theory can be used in the case of the Atlanta Downtown Connector to execute more successful and effective coordination between stakeholders to ensure that the infrastructure upholds its environmental responsibility.

The GDOT does not currently adhere to the NPDES MS4 permitting process to reduce TMDLs because it is legally exempt from many of the requirements due to technical issues such as lack of documentation of metrics and proximity to certain historic sites (Georgia Association of Flood Management 2013). Moreover, the EPA does not penalize permittees who fail to meet its goals (Georgia Association of Flood Management 2013). This thesis cannot directly address these gaps in enforcement, but rather proposes a new protocol and set of guidelines for the GDOT and other stakeholders/permittees to follow in order to improve stormwater performance and more nearly meet the EPA goals for watershed health. This thesis identifies the NPDES process as an opportunity for further research to determine how compliance can be better streamlined and achieved.

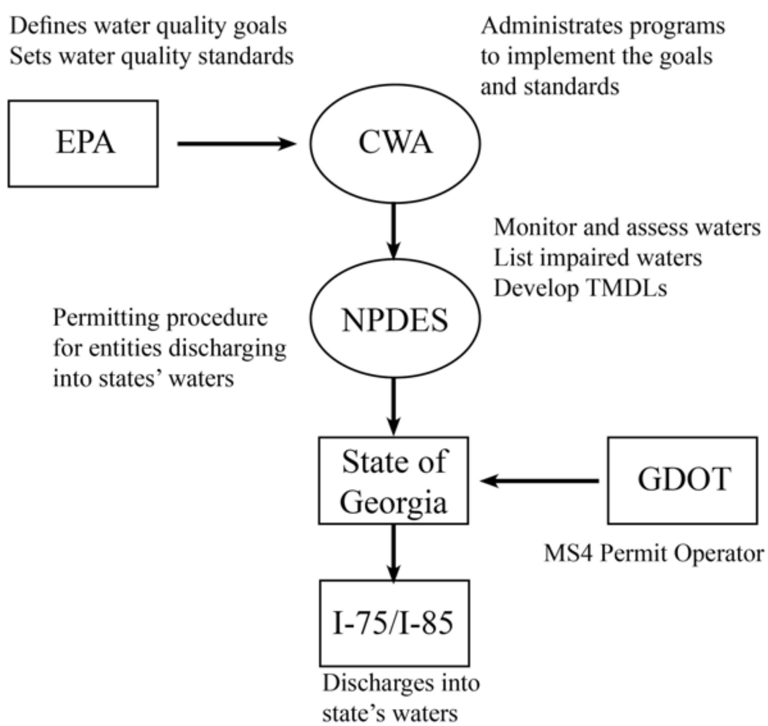



Figure 11: Diagram, chain of process for administrative stormwater control

Intelligent Vehicle Highway Systems (IVHS)

A nearly unimaginable scenario, if congestion were greatly alleviated on urban expressways, the width of the dedicated right-of-way for vehicular travel could be reduced. Space could be reclaimed from lanes no longer needed, and the program of the infrastructure could be augmented to include other critical functions such as open space and stormwater runoff treatment. The following paragraphs discuss research and technological innovation currently being conducted to improve vehicular transportation. The potential results of these improvements are improved traffic safety and reduced congestion, which could facilitate the reduction in width of dedicated right-of-way for vehicular travel in urban expressways and the emancipation of physical space for other infrastructure functions.

As a means to improve traffic congestion and reduce automobile accidents, companies including Volvo and Google are researching and designing new technology for cars and roads. Building upon existing technology known as Adaptive Cruise Control, or ACC, which uses a combination of cameras, sonar, and radar to maintain one vehicle's set distance from the one in front of it, Volvo is designing a system in which cars communicate wirelessly with each other and with the road to form groups or chains of cars that can move together as one unit through a highway, increasing speed and safety of travel while reducing fuel consumption. These systems are coming to be known as Intelligent Vehicle Highway Systems or IVHS. The engineers that developed Google Street View are working on advances in automated vehicle technology, and last year successfully drove two cars in tandem across Asia from Istanbul to Shanghai with no drivers (Le Lann 2012). This technology is already legal in Nevada, with the Department of Motor Vehicles there issuing a driver's license to a Google-outfitted Toyota Prius in 2012.

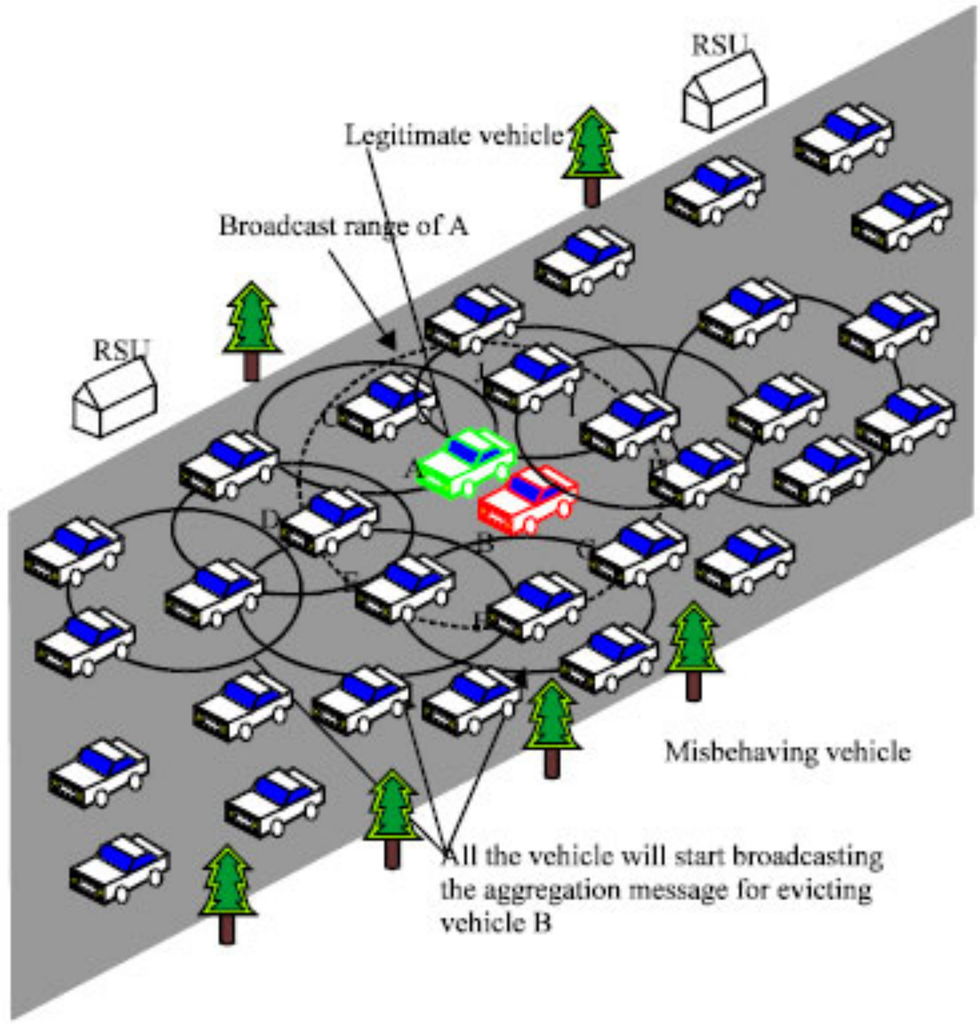



Figure 12: Diagram, Ad-hoc vehicular network

(http://docsdrive.com/images/ansinet/itj/2012/fig3-2k12-980-988.jpg)

Volvo is researching technology that would enable long chains of individual cars to operate on the highway as one unit resembling a train of cars. That way, groups of drivers all heading to the same part of town could link up for the majority of the distance they travel, and branch off from the train as needed when arriving at their individual destinations. Buses could operate in the same way. Linking groups of buses up together in chains would function in much the same way as trains do now, only they would not be dependent on the fixed positions of rails –

they could go anywhere where a road is built. The potential impact on public transportation functionality is significant (Bishop 2005).

Over the course of the next century, these advancements in technology could have an enormous positive impact on traffic congestion on our nation's interstates (CNN 2014). When the movement and traffic flow of all automobiles on an expressway is coordinated by software using algorithms and responding to sensors in the roads, it is conceivable that the traffic on once-crowded and dangerous fourteen- or sixteen-lane wide highways in city centers may become organized and light.

"There is a growing consensus that the highway capacity problem will not be solved by the traditional means of simply expanding the right-of-way and laying more pavement" (Chen and Ervin 1990, 364). Intelligent Vehicle Highway Systems will play a major role in solving the highway capacity problem. Expanding the right-of-way and laying more pavement would be a foolish, naïve, and short-sighted attempt at a solution. Instead, with advanced technology and software, we can create systems to facilitate the more efficient movement of vehicles on the expressway. Human error and differences in driving habits are largely responsible for the amount of congestion on urban freeways because they cause accidents and the stop-and-go phenomenon. If automobiles responded to each other more smoothly and operated at the same speed, much of the congestion would be eliminated.

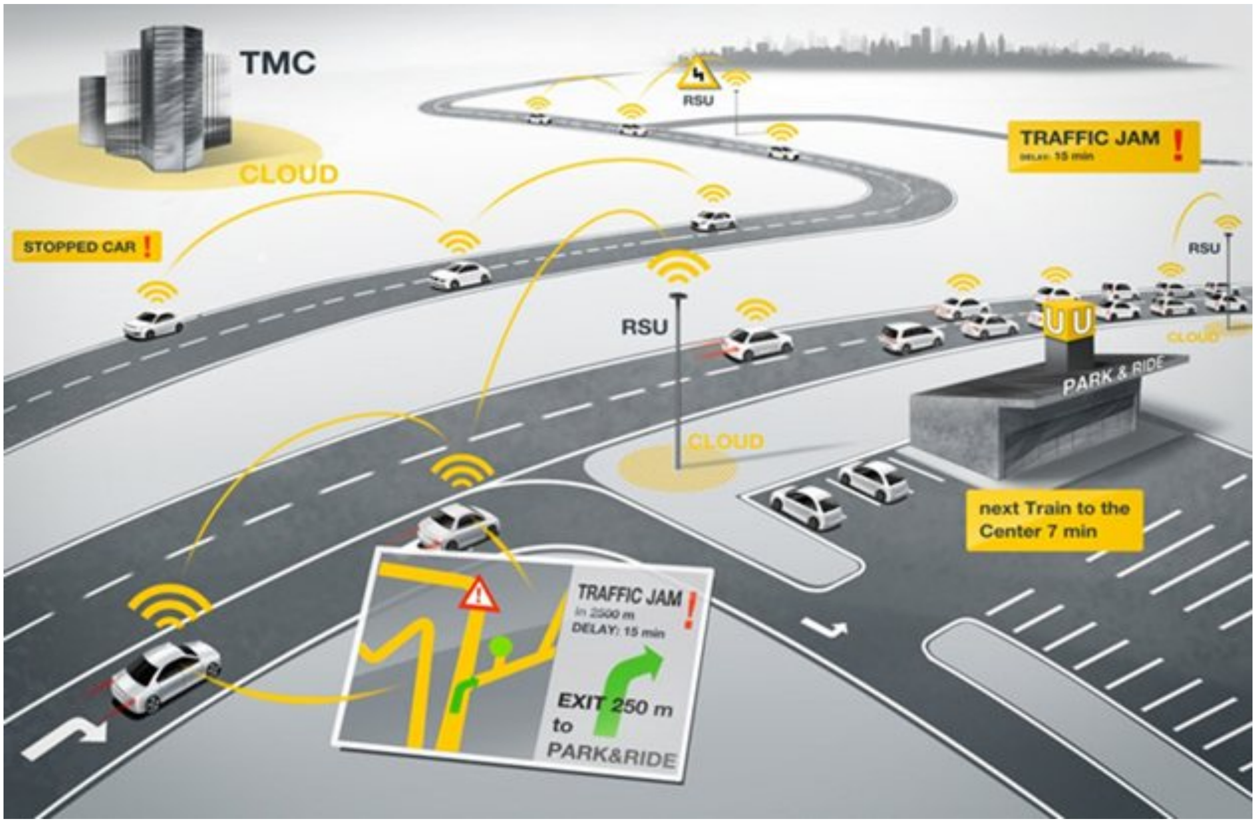



Figure 13: Diagram, Cooperative vehicle network (https://www.kapsch.net/getmedia/721a3d1a-49c8-4a03-a3f0-0d8542cb75fb/v2x_scheme?width=628&height=410)

With the reduced amount of congestion on urban expressways, travel corridors that were once sixteen or twenty lanes wide will now have a surplus of obsolete travel lanes. These lanes have the potential to be reclaimed and programmed with another set of uses ranging from bioretention for stormwater runoff treatment, to linear farms, walking trails, light-rail transit, canals, bicycle trails, green space and parks, wildlife bridges, pedestrian bridges, noise reduction, solar power generators, wind power generators, landfill and DOT storage, underground utility, open-ended program for future use, educational opportunities, Wi-Fi, electric car-charging, and specialized lanes for different types of transportation.

Those that support or may play a crucial role in the adaptation of IVNs are: The motoring public, the highway community (local, state, federal agencies), the technology community, our international competitors (particularly in Europe and Japan), early adopters of IVHS, the traffic safety community, and the academic research community (Chen and Ervin 1990). Skeptics include: Automotive and electronics industries who are skeptical the public infrastructure for IVHS will materialize, highway agencies who are skeptical IVHS technologies will deliver cost-effective solutions to real highway problems, and the diversity of responses from the private and public sectors regarding the adaptation of IVHS in general (Chen 1990). Many are concerned about the government's role in regulating something so fundamentally American as driving one's car. However, government agencies such as the National Highway Traffic Safety Administration (NHTSA) may soon begin to regulate and restrict drivers and cars without ACC, given the potential improvements in congestion and lives that could be saved with increased traffic safety. It may soon be illegal for a person to manually operate their car on an urban expressway. Part of the planning challenge of the design of this thesis will be obtaining public support and acceptance of this idea. The planning challenges will be further elucidated in chapters 4 and 6.

# CHAPTER 4

# GREEN INFRASTRUCTURE AS A STORMWATER MANAGEMENT STRATEGY FOR HIGHLY CONSTRAINED URBAN SITES

Natural approaches to stormwater management in urban areas are on the rise because of their low cost, the promotion of LID practices by the EPA and other government agencies, the effectiveness of natural materials and processes to combat stormwater runoff, and the high community acceptance of sustainable development. Green infrastructure, a strategy that encourages proactive planning and natural approaches to stormwater management, is increasingly discussed today by urban planners, landscape architects, and government organizations such as the EPA.

Traditional gray infrastructure for urban stormwater control includes combined sewers and MS4s that utilize heavily engineered concrete channels and pipes to convey water away from roads and neighborhoods and to the nearest natural water body. Aimed at controlling the flooding that rain events cause in urban areas with high concentrations of impervious surfaces, this type of infrastructure costs hundreds of millions of dollars to construct and maintain. Many urban dwellers are not aware of the complexity of gray infrastructure systems for stormwater control, because the systems hide the hydrologic processes of water conveyance in underground networks. As soon as the stormwater reaches the nearest culvert on the street which it flows, it disappears from the sight and consciousness of the urban dweller.

However, problems with the functionality of gray infrastructure are becoming increasingly common as urban areas continue to develop and expand and increased pressure is applied to the capacity of these engineered systems. Historic rainfalls occurred across Atlanta in the 2007 and 2008, with catastrophic flooding of expressways being some of the most significant consequences. The MS4s under these roadways were not able to handle the high volume of stormwater inundating the system, and overflows on roads across Atlanta made many highways impassable. The Peoplestown neighborhood experiences chronic flooding from Combined Sewer Overflows (CSO) because they do not have MS4s. Instead, stormwater comingles with wastewater in combined sewers. When these systems are overpowered by storm events, the overflows deliver raw untreated sewage into the neighborhoods where it creates unpleasant and unsanitary conditions for residents.

This chapter introduces efforts to alleviate the problems and limitations of gray stormwater infrastructure by introducing proven, natural "soft" control measures for urban stormwater management that can supplement or replace the traditional gray infrastructure techniques. These natural stormwater control measures include ways to mimic the natural hydrologic processes of undeveloped land by infiltrating as much stormwater into the ground as possible, preventing it from inundating the local waterways with an unnatural volume, velocity, and pollutant load. Some of these measures include bioretention, infiltration trenches, wet swales, dry swales, constructed wetlands, and other landscaped elements.

## Green Infrastructure

Green infrastructure is mentioned often today in the disciplines of Landscape Architecture, and Urban Planning and Design. Green infrastructure has many different purposes, scales, and applications, and it can be difficult to determine its exact definition. Benedict and McMahon define it as "an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to the people and wildlife" (Benedict and McMahon, 2006). Through this lens, green infrastructure acts at a large scale such as the region or watershed. Often synonymous with Low Impact Development (LID), it can be conceived of as an alternative to traditional urban or suburban development, where large tracts of land are cleared indiscriminately in order to develop residential, commercial, or industrial centers. With a green infrastructure approach, land clearing would be planned and coordinated with environment and habitat in mind, so as to minimize disruption to the local ecology. Development would then be built in dense areas, with any impervious areas surrounded by an engineered buffer of natural systems to mitigate their negative effects.

The Environmental Protection Agency (EPA) defines green infrastructure as "an approach to wet weather management that uses natural systems – or engineered systems that mimic natural processes – to enhance overall environmental quality and provide utility services" (Odefey et al., 2012). By this definition, green infrastructure can be interpreted as a smaller scale strategy, for instance, mitigating stormwater runoff from the impervious surfaces in one new road or building. For example, the SEA Streets program in Seattle, where bioswales adjacent to roads infiltrate stormwater runoff naturally into the ground, filter its pollutant load, and reduce its velocity before any overflow is discharged into the municipal storm sewer.

A practical interpretation of green infrastructure could be that it is a design strategy that involves looking at the landscape in relation to the many uses it could serve - for nature and people – and determining which of those uses makes the most sense (Benedict and McMahon, 2006). Green infrastructure often acts as many different pieces of infrastructure in one physical space, i.e. a stormwater treatment facility with engineered wetlands and other natural systems that also serves as a city park and, over time, remediates the brownfield on which it was developed, as is the case with Fresh Kills Park in Staten Island, New York. By meeting multiple infrastructure needs in the same space, green infrastructure reduces development footprint and saves money.

Green infrastructure emphasizes the quality and quantity of urban green spaces, their multi-functional role, and the importance of interconnections between habitats. If green infrastructure is proactively planned, developed and maintained, it has the potential to guide urban development by providing a framework for economic growth and nature conservation. Such an approach offers many opportunities for integration between urban development, nature conservation, and public health promotion (Tzoulas 2007). Because ecological networks alleviate the ecological impacts of habitat fragmentation, biodiversity conservation is an integral part of sustainable landscape design (Tzoulas 2007).

Figure 14: Concept Rendering, green infrastructure stormwater control with bicycle lane (http://4.bp.blogspot.com/-yI_B80bVFuM/Te8rWZ7ccQI/AAAAAAAAJtM/PSfW5UPT1IM/s1600/caisson1.jpg)

Highway Stormwater Runoff – Recommended BMPs

The Georgia Stormwater Management Manual has identified many best management practices for treating stormwater pollution and reducing its volume and velocity. Many of the strategies are based on green infrastructure, using natural materials and processes to mimic nature's natural capability to infiltrate and filter stormwater runoff. Figure 15 categorizes the control measures and shows the degree to which they are effective at removing certain pollutants.

| Structural Control | Total Suspended Solids | Total Phosphorus | Total Nitrogen | Fecal Coliform | Metals |
|---|---|---|---|---|---|
| **General Application Structural Controls** | | | | | |
| Stormwater ponds | 80 | 50 | 30 | 70* | 50 |
| Stormwater wetlands | 80 | 40 | 30 | 70* | 50 |
| Bioretention areas | 80 | 60 | 50 | | 80 |
| Sand Filters | 80 | 50 | 25 | 40 | 50 |
| Infiltration Trench | 80 | 60 | 60 | 90 | 90 |
| Enhanced Dry Swale | 80 | 50 | 50 | | 40 |
| Enhanced Wet Swale | 80 | 25 | 40 | | 20 |
| **Limited Application Structural Controls** | | | | | |
| Filter Strip | 50 | 20 | 20 | | 40 |
| Grass Channel | 50 | 25 | 20 | | 30 |
| Organic Filter | 80 | 60 | 40 | 50 | 75 |
| Underground Sand Filter | 80 | 50 | 25 | 40 | 50 |
| Submerged Gravel Wetland | 80 | 50 | 20 | 70 | 50 |
| Gravity (oil-grit) separator | 40 | 5 | 5 | | |
| Porous Concrete | ** | 50 | 65 | | 60 |
| Modular Porous Paver Systems | ** | 80 | 80 | | 90 |
| Alum Treatment | 90 | 80 | 60 | 90 | 75 |
| Proprietary Systems | *** | *** | *** | *** | *** |

Figure 15: Table, stormwater structural controls and associated pollutant removal effectiveness (Adapted from Center for Watershed Protection, 2001b)

## Bioretention

Bioretention refers to shallow, landscaped depressions located in parking lot islands, alongside impervious pavement, or within small pockets in residential areas. Stormwater flows into the depression where it can pond if necessary, but then gradually infiltrates into the soil bed. Pollutants are removed by adsorption, filtration, volatilization, ion exchange, and decomposition. Filtered runoff can be infiltrated or collected by an underdrain and discharged into the storm sewer system or directly into receiving waters.

Limitations of bioretention include its high construction cost as well as its low ability to remove nitrates. Along highways, bioretention requires additional right-of-way beyond standard clear-zone limits. It does not always achieve complete removal of Total Suspended Solids (TSS) when used alone, but it can be used in conjunction with other stormwater control measures. The system can become clogged if it receives runoff with high fine particle loads. Maximum pond depths may limit the amount of runoff that can be directed to the area (Corson 2006).

Figure 16: Photo, Bioretention area alongside roadway (http://staging.strand.com/wp-content/uploads/2011/03/BioretentionFacility_Cin.jpg)

**Grass Channel/Dry Swale**

Grass channels are gently sloping, open channels that convey stormwater. They offer a modest amount of runoff reduction and filtration by slowing water flows and increasing infiltration and filtration. They do not include a soil media or specific storage volume. They are relatively inexpensive stormwater control measures. They can be expected to remove 25% of TP and 35% of TN. When used with soil amendments, they can achieve a high level of hydrologic function.

At higher velocities, grass channels do not remove pollutants, but only convey the water. Grass channels require moderate maintenance including mowing, inspections to remove organic matter and debris, and sediment remediation. The extent of pollution reduction depends on the underlying soil characteristics, slope, and the velocity of the flow (Pippin 2013).

Figure 17: Photo, Grass Channel/Dry Swale

(http://www.thomasengineeringpa.com/images/Swale%202.JPG)

**Permeable Pavement**

Permeable pavement is a type of concrete or asphalt with voids in its uppermost layer allowing water to filter through it. It is made by using an aggregate without different particle sizes. Permeable paving can be used in place of impervious cover to allow greater infiltration of rainfall into the ground. Permeable paving reduces nutrient loads by 60-80% depending on the stormwater residence time designed into the system. It can significantly reduce the runoff volume and delay peak discharge from a rain event.

Permeable pavement is a relatively expensive treatment option, including construction costs and maintenance costs. It must be regularly vacuumed to remove accumulated sediment, and it must be regularly inspected to ensure water is infiltrating properly. Permeable pavements are not strong enough to tolerate extreme vehicle traffic and are not a good choice for travel lanes for cars, buses, and trucks, but they are ideally suited for walking paths and highway shoulders (Pippin 2013).

Figure 18: Photo, Permeable pavement
(http://greenvalues.cnt.org/national/images/permeable_pavement.jpg)

**Wet Swale**

Wet swales are engineered grass channels that not only convey stormwater from a roadway but also provide water quality benefits. They are distinguished from the simple drainage/grass channel by design features that maintain a saturated condition in soils at the bottom of the swale. They create an elongated wetland treatment system that treats stormwater through physical and biological action. They can also be sized to detain stormwater and address water quantity management needs.

Wet swales must be used in conjunction with other management practices to achieve an 80% TSS removal rate. They are not ideal for handling pollutants from off-site hotspots. They can also act as potential mosquito breeding areas.

Figure 19: Photo, Wet swale (http://www.leam.illinois.edu/1streetcorridor/group-tuesday/picture_281.jpg/image_preview)

**Stormwater Wetland**

Stormwater wetlands are constructed wetland systems designed to maximize the removal of pollutants from stormwater runoff via several mechanisms: microbial breakdown of pollutants, plant uptake, retention, settling, and adsorption. They temporarily store runoff in shallow pools that support conditions suitable for the growth of wetland plants. They also promote the growth of microbial populations which can extract soluble carbon and nutrients and potentially reduce BOD and fecal coliform concentrations. While they do not have the full range of ecological functions of natural wetlands, they are designed specifically for flood control and water quality purposes, making them ideally suited for stormwater control. When used properly, they have a relatively low maintenance cost, high community acceptance, high water quality benefit, high wildlife habitat benefit, and long effective lifespans.

They do require a significant treatment area beyond the standard clear-zone right-of-way. Stormwater wetlands also may not achieve 80% TSS removal rates by themselves but can be used in conjunction with other stormwater best management practices. They can also accumulate salts and scum which may be flushed out by large storm flows. Plant maintenance must be performed on a regular basis to provide nutrient removal (Corson 2006).

Figure 20: Photo, Large-scale stormwater wetland (http://eng.plantcitygov.com/mainpictures/5.jpg)

**Wet Pond**

Wet ponds are facilities which remove sediment, organic nutrients, and trace metals from stormwater runoff. This is accomplished by slowing down stormwater using an in-line permanent pool or pond effecting settling of pollutants. A permanent volume of water is incorporated into the design, with a water level between 6-8 feet. Biological processes occurring in the permanent pond pool aid in reducing the amount of soluble nutrients present in the water such as nitrate and ortho-phosphorus.

Wet ponds do require a significant treatment area beyond the standard clear-zone right-of-way. Heavy storms may re-suspend sediments normally present in the wet pond, and they are also a potential source for mosquito breeding (Corson 2006).

Figure 21: Photo, Wet pond (http://www.bae.ncsu.edu/stormwater/images/edenton.jpg)

**Extended Detention Pond**

Extended detention ponds work by combining shallow wetlands or small ponding areas with dry areas, and always incorporate a micropool at the outlet. They can achieve 80% TSS removal rates as a stand-alone best management practice. With a low construction cost, and a low to moderate maintenance cost, they are one of the most cost-effective treatment methods. They have a long effective lifespan, high community acceptance, and provide a medium wildlife habitat benefit.

Extended detention ponds are not ideally suited for ultra-urban settings, and they do require a significant treatment area beyond the standard clear-zone right-of-way. An adequate source of water is needed to maintain permanent water pool areas all year. The water can become stagnant and act as a potential for mosquito breeding areas. Heavy storms may re-suspend sediments (Corson 2006).

Figure 22: Photo, Extended detention pond (http://buemorris.com/images/Venezia5_jpg.jpg)

**Infiltration Trench**

Infiltration trenches are excavated trenches that have been lined and backfilled with stone to form a subsurface basin. Stormwater runoff is diverted into the trench and stored until it can infiltrate into the soil, usually over a period of several days. They are very adaptable BMPs and can be designed in many different practical configurations. They are ideal for ultra-urban sites, including small urban drainage areas. Infiltration trenches are most effective and have a longer life cycle when some type of pretreatment, such as vegetated filter strips or grass swales, is used in the design to remove sediment from the runoff. Infiltration trenches achieve 80% TSS removal rates as stand-alone BMP. They are highly effective at removing pollutants commonly found in highway stormwater runoff. They have a low maintenance cost.

Infiltration trenches have a high initial construction cost and cannot accept pollutants from off-site hotspots. They have a high clogging potential if not properly maintained. They do not provide any wildlife habitat benefit, although they have a high level of community acceptance. They require pretreatment to minimize sediment loading and clogging, and to achieve TSS removal (Corson 2006).

Figure 23: Photo, Roadside infiltration trench (Corson 2006)

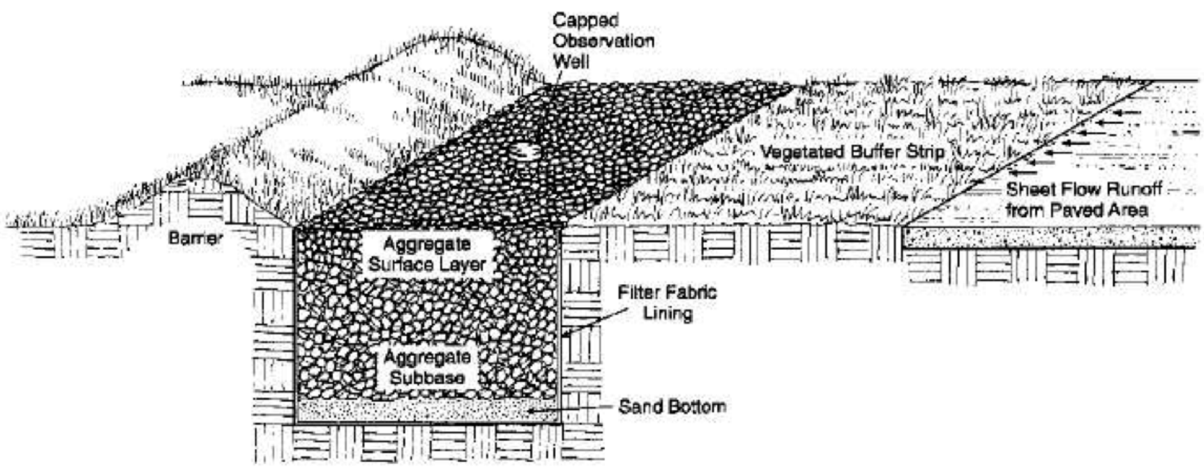



Figure 24: Section Drawing, Infiltration trench (Corson 2006)

Clearly, there are effective strategies for controlling stormwater runoff that involve natural materials and processes, and have a direct application to transportation systems in urban settings. Chapter 6 will use a design application on the Atlanta Downtown Connector expressway to determine which of the above elements has an application in stormwater control for highly-constrained urban expressways under the purview of green infrastructure theory.

Benefits of green infrastructure

Development according to the principles of green infrastructure always provides environmental, social and economic benefits, a "triple bottom line" that many believe to be a core qualifier for sustainability (Benedict and McMahon, 2006). A complete green infrastructure may have a considerable potential for improving the health of urban residents, based on the speculation that environmentally induced changes in psychological, emotional, and cognitive processes may induce or mediate changes in well-being and health (Tzoulas 2007).

The Landscape Architecture Foundation has prescribed a set of evaluative criteria for determining a landscape's overall performance based on seven categories or values (Calkins, 2012). This matrix can serve as a guide for designing infrastructure to ensure that it accomplishes as many goals as possible within the given space and application. See figure 25 below for the breakdown of the goals and values.

| Category | Value | Triple Bottom Line |
|---|---|---|
| Transportation | Land | Environmental |
| Land efficiency/preservation | | |
| Soil creation/restoration | | |
| Stormwater management | Water | |
| Water conservation | | |
| Water quality | | |
| Flood protection | | |
| Other water | | |
| Habitat preservation | Habitat | |
| Habitat creation/restoration | | |
| Energy use/emissions | Carbon, Energy, Air Quality | |
| Air quality | | |
| Temperature/urban heat island | | |
| Carbon storage/sequestration | | |
| Reused/recycled materials | Materials and Waste | |
| Local materials | | |
| Waste reduction | | |
| Green waste | | |
| Property values | Economic | Economic |
| Operation and management savings | | |
| Economic development | | |
| Job creation | | |
| Other economic | | |
| Recreation and social value | Social | Social |
| Public health and safety | | |
| Educational value | | |
| Noise mitigation | | |
| Scenic quality/views | | |
| Food production | | |
| Other social | | |

Figure 25: Table, Landscape Architecture Foundation Landscape Performance Evaluation Criteria Matrix (Adapted from Landscape Architecture Foundation, 2013).

Access to green space has been shown to improve the overall health of a population by improving air quality, reducing the urban heat island effect, leading people to spend a greater amount of time outdoors, and allowing them to be more physically active (Tzoulas 2007). The biophilia hypothesis suggests a biologically based, inherent human need to affiliate with life and lifelike processes and that contact with nature is fundamental to psychological well-being and personal fulfillment (Kellert and Wilson 1993).

Views of natural landscapes have also been shown to restore attention fatigue, quickening the recovery of attention-demanding cognitive performances (Kaplan and Kaplan 1989). Given the attention-demanding nature of driving, any features along a highway that improve focus or cognitive functioning have to be viewed as necessary safety features. Natural features and open spaces also enhance and improve the sense of community (Kim and Kaplan 2004).

The metro Atlanta area is an incredibly fragmented ecological and wildlife area. Linear features such as urban expressways have been proven to impede the movement of many kinds of wildlife (Tremblay 2009). Simple, inexpensive solutions can enhance habitat connectivity for wildlife in urban areas and promote the integrity of natural systems in urban areas, such as limiting gaps in vegetation, planting as many different heights of plant material as possible including tall tree canopy, and establishing good habitat on either side of the linear breach (Tremblay 2009).

Ecological corridors not only function as connectors of habitat nodes but they also act as habitats themselves (Ignatieva 2011). They serve as stepping stones which actually can be utilized by wildlife in urban areas, helping to connect and restore habitat (Ignatieva 2011). Swales and treatment wetlands provide riparian services, serve as biodiversity corridors, and provide benefits to people by greening urban areas and providing open outdoor areas for recreation (Ignatieva 2011).

Another benefit of a green infrastructure approach to planning is that green infrastructure is adaptable to new conditions. Because the future road and traffic conditions are uncertain, green infrastructure is an especially valuable approach to planning for future transportation infrastructure, such as the Atlanta Downtown Connector.

Limitations of Green Infrastructure

One limitation of green infrastructure as it pertains to this thesis is the fact that it is based on principles derived from twentieth and twenty-first century values, thinking, and ideals. This design, if it is ever realized, will most likely not be constructed until the end of the twenty-first or the beginning of the twenty-second century. In the amount of time it will take to realize the design, unforeseen changes could take place in our city at a physical level, in our policies at an environmental, social, or political level, or in our thinking and values at a philosophical level. Some of the principles of green infrastructure may be out of date or irrelevant by then.

Figure 26 demonstrates some of the impediments to implementing Green Infrastructure.

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

Figure 26: Table, green infrastructure Impediments and solutions (Adapted from Roy et al., 2008)

Another impediment to the implementation of green infrastructure is that current NPDES permitting requirements for many MS4 permits do not include language targeted to encourage the use of natural control measures. However, legislation is currently being rewritten to promote the incorporation of GI practices by state and local governments and require that more stringent attention be paid to their benefits (Pippin, 2013).

Planning

One key component of green infrastructure is a working partnership between many entities, in this case – city government, DOT, developers, environmental groups, and community organizations. This can be simplified and imagined as 3 categories of cooperating parties: government, public sector, and private sector. A successful model for this working partnership can be found in New Zealand, where cities have had success streamlining the planning process by joining participation from government institutions, designers, engineers, and planners to integrate stormwater management and other ecological services with roads and other infrastructure in various types of transit and recreation spaces (Ignatieva 2011). However, in the United States, the process is not as streamlined and there are still gaps in cooperation between the key players involved with stormwater planning.

Benedict and McMahon identify eight strategies crucial to the success of green infrastructure, with a heavy emphasis on planning and interdisciplinary cooperation:

- Create a leadership group to guide the green infrastructure initiative
- Design a green infrastructure network to link green space components across scales and political boundaries
- Develop an implementation plan to make the network design a reality

- Prepare a management and stewardship plan that meets the restoration and maintenance needs of all green infrastructure network components
- Inform and seek input from the public on the green infrastructure network design and plan
- Integrate green infrastructure into the planning processes of local, state, and federal agencies and other community and regional planning efforts
- Sell the public on the benefits of green infrastructure and the need for a green infrastructure network design
- Build partnerships with the people and organizations that can help support and sustain the green infrastructure initiative (Benedict and McMahon 2006)

These strategies may sound easier said than done, but the time is coming when federal oversight and legislation will force state and local governments to comply with green infrastructure methods. The EPA is now writing requirements for MS4 permits to document and inventory the green infrastructure elements used to accomplish their SWMPs. A small number of large-scale, high-profile projects have been tested which do involve green infrastructure. For example, The City of Atlanta spent $25 million on the stormwater detention facility in the Historic Fourth Ward Park, knowing that traditional infrastructure remediation for the problems facing the neighborhood would cost upwards of $40 million (Pippin, 2013). Recent updates to the Atlanta municipal code mandate stormwater control measures in accordance with environmental sustainability (Atlanta, Georgia 2014). The mayor of Atlanta, Kasim Reed has proclaimed an initiative to make Atlanta into one of the top ten most environmentally sustainable cities in the country.

## Conclusion

Green infrastructure theory involves a comprehensive, proactive planning process between a large network of stakeholders to achieve goals of environmental sustainability. Economy is often achieved by overlapping systems and organizations in such a way that social and economic benefits are also achieved. The Atlanta Downtown Connector is not being designed from scratch, but the tenets of green infrastructure can still be applied to a retrofit design for adaptive re-use so that it is more environmentally sustainable and effective from a stormwater management standpoint. The GDOT may be most interested in the prospect of meeting NPDES permitting requirements for stormwater runoff quantity and quality, especially in light of the impending, more stringent regulations and the inevitable increase in GDOT projects around the state. Other stakeholders such as community groups, city hall, and private developers may be most interested in the potential for the system to transform the city into a more livable, more prosperous urban center. The opportunity for green infrastructure theory to be utilized will help each of the stakeholders achieve the maximum desired effects with the most ease of implementation. Each of the stakeholders, including the GDOT, has an opportunity to set a good example of cooperative civic partnership and take credit for innovative solutions to urban problems of the 21st century and beyond.

Figure 27: Photo, Community input meeting, Dunwoody, Georgia

(http://www.reporternewspapers.net/wp-content/uploads/2011/01/012010-DU-master-plans.jpg)

# CHAPTER 5

## DESIGN PRECEDENTS

The following 9 precedents were chosen because of their applicability to the design of the Atlanta Downtown Connector improvements. Each project relates to at least one component of this thesis, and lessons can be extracted by studying their design and implementation. Each section will explain, if applicable, how the design of the precedent project:

1. Increases community interactions
2. Increases adjacent property values
3. Attracts new business to the vicinity
4. Improves the environment
5. Negative effects, BMPs, and/or lessons learned from the precedent
6. Created jobs through its design, construction, or implementation
7. Has strategies that can be studied and improved upon in order to inform the design of the Atlanta Downtown Connector

The precedent studies also help to focus the application of the tenets of green infrastructure to its application in this thesis for stormwater control on the Atlanta Downtown Connector. While the emphasis of this thesis is improving environmental performance of this piece of transportation infrastructure, green infrastructure also supports the improvement of economic and social functioning.

The SEA Streets and Skinny Streets precedents were chosen due to their design of green infrastructure stormwater control measures for roadways in the Pacific Northwest. Pioneers of sustainable stormwater development at site-level project scale, these programs have paved the way for research and implementation of sustainable roadway stormwater runoff control techniques.

The Embarcadero, Rose F. Kennedy Greenway, Cheonggyecheon Stream, and Madrid Rio projects were chosen due to their success at utilizing space left over by removing, reducing, or re-locating urban expressways. The urban physical, environmental, economic, and social needs of each project site were vastly different and each project addressed those needs through different design strategies and to varying degrees of success. The Embarcadero project demonstrates success in re-routing traffic from an existing expressway into the surface street grid in 2 locations in San Francisco, California, with smooth implementation and high community acceptance. The remaining footprint of the former freeway is converted into a multi-modal boulevard with light-rail transit, cycling and pedestrian promenades, and drastically improved connections between the urban fabric of several neighborhoods with the waterfront. The Rose F. Kennedy Greenway project highlights the enormous engineering and planning difficulties in performing changes to an existing expressway, and engineers and planners across the globe have learned from the challenges of Boston's associated Big Dig project to bury I-93, the "central artery." By comparison, the Madrid Rio project performed a similar, albeit less complex feat of civil engineering by burying the M-30 freeway in Madrid with a less problematic construction process and a more extensive landscape design scheme, with more new green space acreage that serves as a new urban amenity and improves ecological function.

The Atlanta Beltline and the High Line perhaps seem unrelated, but this thesis gleans similar lessons from their success toward an application of revitalizing and re-using abandoned transportation infrastructure. Both projects transform defunct rail corridors in highly constrained urban areas into successful projects that have had a profound impact on the economy of their surrounding neighborhoods and their cities as a whole. Each project also provides numerous community benefits including increasing access to green space, providing new parks, creating meeting places for neighborhoods, and stitching together disparate neighborhoods. This thesis understands the Atlanta Downtown Connector project in a similar context, for while it is not an abandoned rail corridor, it does have the potential for a portion of once-busy infrastructure to become obsolete, and therefore feasible for adaptive re-use.

Lastly, cycling infrastructure in Germany, the Netherlands, and Denmark are examined with regard to their success in creating and shaping public policy to promote cycling as a viable means of transportation infrastructure. The precedent is also valuable because of the innovative design of a variety of archetypes for integrating physically separate cycling infrastructure into combined transportation infrastructure such as expressways, roads, and rail corridors.

**SEA Streets – Seattle, Washington**

SEA (Street Edge Alternatives) Streets is an urban planning project in Seattle, Washington where quality of life, flooding and watershed quality are directly addressed by improving the environmental functioning of streets. Beginning in 2001, Seattle Public Utilities began testing prototypes for retrofitting streets with stormwater control devices. The first site was on Second Avenue NW, between N 117$^{th}$ and 120$^{th}$ Streets, chosen due to its lack of an existing drainage system and its need for general street improvements (Bennett 2000). The new design results in a narrower street right-of-way and a reduced asphalt width with wider landscaped areas on each side of the new roadway. The street also meanders slightly as a traffic calming strategy. In the landscaped buffers on either side of the street, six vegetated swales were installed that tie into the existing ditch and culvert system operated by Seattle Public Utilities.

Each swale varies in width, length, and soil depth, and contains an 8-inch PVC overflow pipe that connects it to the next swale in the sequence. In 2002, the first SEA Street was designed for a steeply sloping street, with cascading swales, intensive vegetation, and sediment traps to slow stormwater runoff velocity and improve water quality (Butler 2008). Each SEA Street prototype was found to reduce stormwater runoff volume by 98% (Taus 2002).

SEA Streets is an example of green infrastructure because it not only improves ecological function of the existing stormwater infrastructure, it simultaneously (and in the same space) makes other beneficial changes such as beautification, traffic calming, road and utility upkeep, etc. It utilizes the existing infrastructure where possible, by keeping the existing municipal separate storm sewer systems intact, but installing new infrastructure to pretreat the water before it is handled by the MS4s.

SEA Streets informs the design of this thesis because it shows how roadways were retrofitted successfully and with community acceptance to control stormwater runoff.

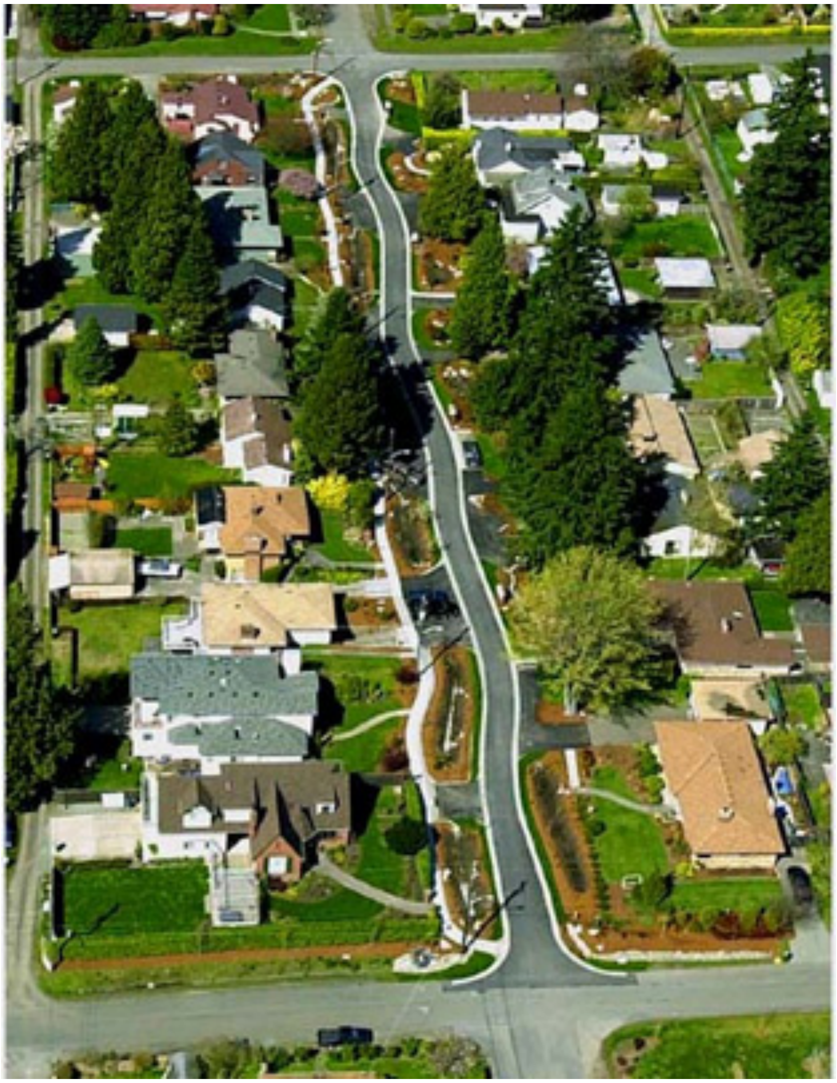


Figure 28: Photo, Aerial view of SEA Street prototype

(http://www.seattle.gov/dpd/Planning/Design_Commission/images/dpds_009619.jpg)

Figure 29: Photo, SEA Streets edge/corner condition

(http://www.psparchives.com/publications/our_work/stormwater/lid/LID_studies/images_large/04%20seastreet%20corner%202.jpg)

**Skinny Streets – Portland, Oregon**

The Skinny Streets project in Portland, Oregon, was initially started in 1991 as a method to combat several problems with Portland's roads infrastructure. Skinny Streets reduces the width of roads in residential areas to such an extent that there is only one available driving lane, with pullout areas for parallel parking and passing. The narrowing of the roads encourages slower and safer driving, imposes a smaller development footprint in the landscape, uses less asphalt, and requires less maintenance, saving tax dollars (Bray and Rhodes). Later in the project, Skinny Streets began developing guidelines for landscaped areas on either side of the road for the treatment of stormwater runoff. Several different configurations of swales are permitted, most of which contain slight slopes, curb cuts, trench drains, clay check dams, river rock, and native plants to filter out pollutants in the runoff (Butler 2008).

Skinny Streets informs the design of this thesis because it shows that overall right-of-way can be reduced, with community acceptance, because the street provides new services for the community, the environment, and the local economy.

Figure 30: Photo, Portland Skinny Streets roadside swale

(http://theintertwine.org/sites/theintertwine.org/files/adventure_imgs/SW12thandMontgomeryGreenStreet.jpg)

**The Embarcadero – San Francisco, California**

When San Francisco's Embarcadero freeway was damaged by the 1989 Loma Prieta earthquake, city officials opted to demolish the entire freeway, replacing it with an on-grade, unlimited-access boulevard, with substantial sidewalks along the waterfront, new landscaping and light-rail transit (Cervero et. al 2009). Even though the former Embarcadero freeway was a major transportation corridor connecting Interstate 80 from the Bay Bridge into downtown San Francisco, traffic in the city did not worsen, rather it was re-routed to other Bay Bridge ramps and the freely flowing grid of surface streets in the SoMa and financial districts. Improved signal timing, lane restriping, creation of one-way couplets, and expanded transit services further mitigated traffic impacts (Cervero et. al 2009).

Like the Embarcadero Freeway, San Francisco's Central Freeway, elevated State Highway 101, was also demolished and replaced with Octavia Boulevard. The Central Freeway was once the seamless connector of Highway 101 to the Golden Gate Bridge, routing traffic over Market Street and to the Oak/Fell couplet, back onto Highway 101 just south of the bridge. In its place, Octavia Boulevard was constructed, a Parisian-style road with different rights-of-way for various traffic speeds, separated by landscaped medians and ample sidewalks allowing right-of-way for bicyclists and pedestrians (Cervero et. al 2009).

The Embarcadero informs the design of this thesis because it represents a case where a limited access highway was removed from a city and its traffic successfully diverted to the surface street grid. It also sets the precedent for linear parks/greenway systems to exist in corridors left over or adapted from abandoned or adapted expressway corridors.


Ferry Building, San Francisco. Before Loma Prieta Earthquake and after.

Figure 31: Photo comparison, San Francisco Embarcadero before and after

(http://blog.publicbikes.com/wp-content/uploads/FerryBuildingBeforeAfter-white-590.jpg)

Figure 32: Photo, San Francisco Embarcadero (http://guias-viajar.com/estados-unidos/wp-content/uploads/2009/02/fotos-san-francisco-001.jpg)

**Rose F. Kennedy Greenway – Boston, Massachusetts**

The Rose F. Kennedy Greenway is a linear series of pocket parks in downtown Boston, in the space formerly taken up by Interstate 93, or what was referred to as Boston's "Central Artery," an elevated freeway cutting through downtown Boston and separating much of the city from the harbor and waterfront. Boston's Big Dig project, largely completed by 2006, was undertaken to relieve congestion in downtown Boston and to increase accessibility to Logan International Airport (Dettman et al. 2010). With the elevated freeway demolished, the surface area was carefully designed to maximize open space and increase connectivity between the financial district and the Boston harbor, Fort Point Channel, the Seaport district, and the North End.

The Rose F. Kennedy Greenway is another example of re-claiming abandoned (or in this case, re-located) transportation infrastructure and utilizing it for other pressing urban needs.


Figure 33: Photo comparison, Rose F. Kennedy Greenway, before and after (http://lauraanneburke.files.wordpress.com/2012/08/big-dig.jpg)

**Cheonggyecheon Stream – Seoul, South Korea**

The Cheonggyecheon Stream Restoration project in Seoul came about with the demolition of the above-ground Cheonggyecheon freeway in 2005, the construction of which decades earlier had resulted in the burying of the stream. In 2005, the expressway was demolished and the stream re-naturalized. In the former expressway's footprint is now a linear park and pedestrian walkway (Cervero et. al 2009).

Of primary concern in the Cheonggyecheon project was re-naturalization of the stream and its associated floodplain, because watershed deterioration had been increasing due to increased seasonal flooding. The demolition of the expressway allowed for adjacent green space to act as floodplain as well as parks. Another concern was protecting existing cultural amenities and providing new amenities for the people of Seoul (Hwang 2004). Seoul's then-mayor, Myung-Bak Lee, called the project "a new paradigm for urban management in the new century," saying "we want to make a city where people come first, not cars." Lee was subsequently named one of *Time* magazine's 45 "heroes of the environment" (Cervero et. al 2009).

The Cheonggyecheon Stream project informs the design of this thesis because it provides urban and cultural amenities in the place where an expressway corridor once existed. Although the stream was not completely re-naturalized, the introduction of flowing water and landscaped elements does contribute to the health of the local ecology and the enjoyment of the people.

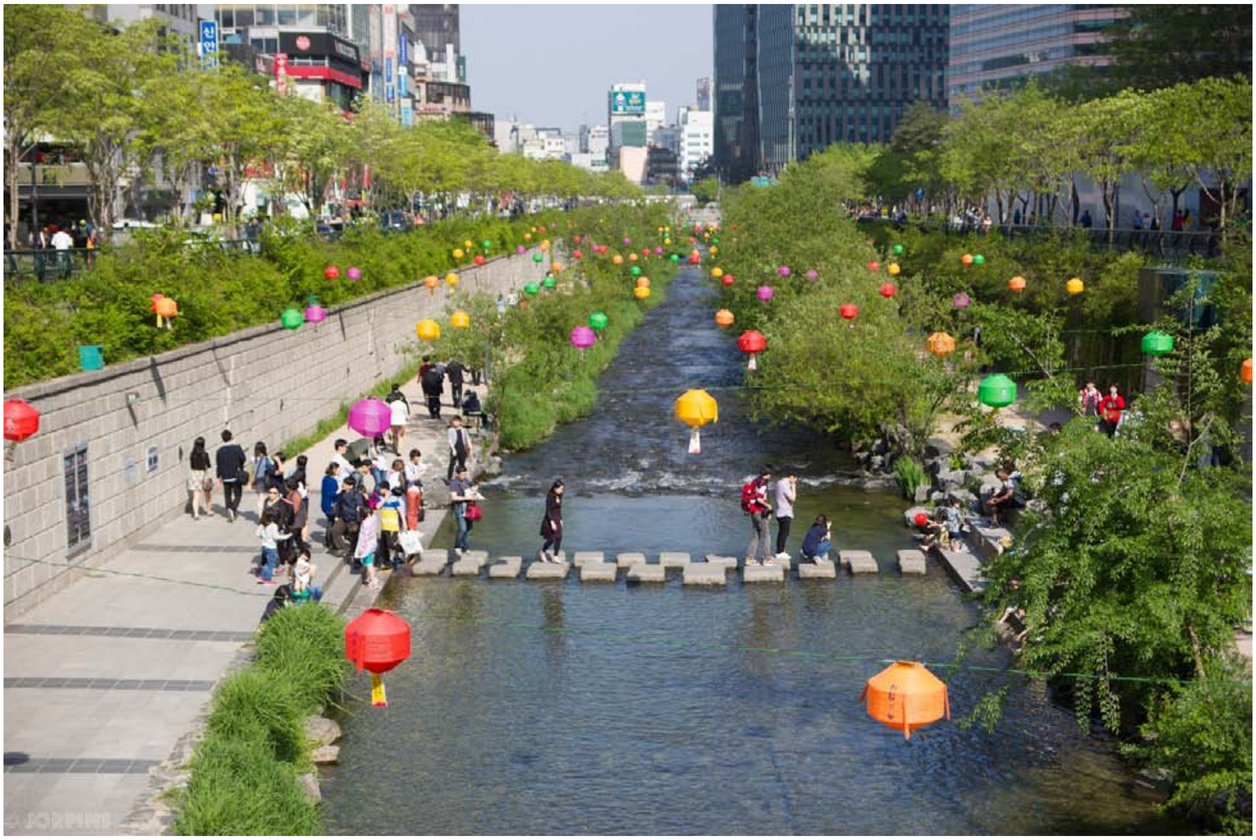


Figure 34: Photo, Cheonggyecheon Stream (http://4.bp.blogspot.com/-3cEJW0p4Xn0/UZb6W2xR4AI/AAAAAAAAE6Y/mi05VU17qxA/s1600/Buddhas_Birthday_Stream_20130511_8.jpg)


Figure 35: Photo comparison, Cheonggyecheon Stream, Before and after

(http://media.treehugger.com/assets/images/2011/10/seoul-mashup.jpg)

**Madrid Rio – Madrid, Spain**

The Madrid Rio project is a design to re-claim space along the banks of the Manzanares River in the city of Madrid, Spain that was left over when a 10-kilometer section of the M-30 expressway that once ran alongside the river was buried in an underground tunnel in 2008. In its place, city planners constructed miles of linear parks with different themes, planting over 27,000 trees native to the region, as well as other landscaping (Maric 2013). Very similar to Boston's Big Dig project and San Francisco's Embarcadero project, the removal of the above-ground expressway opened back up connections from the city to the waterfront, restoring the continuity of the urban fabric (Dobrick 2011).

The Madrid Rio project informs the design of this thesis because it is a successful integration of an urban expressway improvement with landscaped areas for ecological health and urban enjoyment.

Figure 36: Photo, Madrid Rio, Aerial view (http://www.across-spain.es/documentacion/images/2013/architecture%20IV/madrid_rio.jpg)

**Atlanta Beltline – Atlanta, Georgia**

The Atlanta Beltline is an infrastructure project in Atlanta, Georgia that utilizes space from abandoned railroad corridors all over the city to provide walking and cycling trails, new landscaping and green space, and the potential for light-rail transit that will augment the existing MARTA train and bus routes. Conceived as a design thesis for a Master of Architecture degree from Georgia Institute of Technology, the Atlanta Beltline is as much about improving and connecting Atlanta's urban fabric and re-vitalizing neighborhoods as it is about re-claiming and improving physical space.

The Atlanta Beltline informs the design of this thesis because it is an example of adapting abandoned transportation infrastructure into a system that includes transit, parks, running/cycling trails, and ecological services in the Atlanta area. Although the Downtown Connector will not be "abandoned" per se, space will be reclaimed from lanes that are no longer needed.

Figure 37: Photo comparison, Atlanta Beltline, Before and after (http://www.regatlanta.com/wp-content/uploads/2014/03/AtlantaBeltline.jpg)

Figure 38: Concept Rendering, Atlanta Beltline

(http://worldlandscapearchitect.com/image/PW/atlanta-beltline/HIGHLAND_two-tone.jpg)

**The High Line – New York, New York**

The New York City High Line is an elevated park in Manhattan built on an abandoned elevated rail road in Chelsea and the Meat Packing district. Instead of demolishing the abandoned infrastructure, city planners re-purposed it to act as a linear urban park, installing raised bed for landscape plants, hardscape paths, and seating (High Line Opens 2009).

Like the Atlanta Beltline, The High Line is applicable to the Atlanta Downtown Connector as a design precedent because it is a successful example of re-claiming abandoned transportation infrastructure and not letting it go to waste. If travel lanes can be eliminated from the Atlanta Downtown Connector, the space they once occupied could be re-purposed for other uses, such as stormwater control, other transportation and recreation types, and green space.

Figure 39: Photo, High Line NYC

(http://www.nycgovparks.org/photo_gallery/full_size/14433.jpg)

**Cycling Infrastructure – Germany, The Netherlands, and Denmark**

Cycling ridership in Germany, The Netherlands, and Denmark is more than 10 times higher than it is in the United States. The benefits of living in places where cycling is possible, easy, and even encouraged, are numerous. Residents get more exercise, spend more time outdoors, and have a transportation alternative to automobiles. Traffic is reduced in communities where more people ride their bicycle to work instead of driving their car.

Germany, The Netherlands, and Denmark have been at the forefront of policies to make cycling safe, convenient, and attractive (Pucher 2008). Cycling fatalities and serious injuries due to cycling accidents are significantly lower in these countries than they are in the US. This is due in large part to significant improvements and investment in cycling infrastructure and restricted car use. And according to the principle of "safety by numbers," more cycling facilitates safer cycling (Pucher 2008).

Studies have shown that perceived danger of cycling in any particular area is a significant detterent to ridership. In the United States, much of the effort to improve cycling safety has focused on increasing helmet use, in many cases, by law. However, the attitude in the European countries is that helmets discourage cycling by making it less convenient, less comfortable, and less fashionable (Pucher 2008). Instead, these countries invest in dedicated cycling infrastructure on popular transportation routes, providing safe, separate spaces for bicycle riders alongside major highways and city streets. The following table shows key policies and innovative measures used in Dutch, Danish, and German cities to promote safe and convenient cycling.

**Extensive systems of separate cycling facilities**

- Well-maintained, fully integrated paths, lanes and special bicycle streets in cities and surrounding regions
- Fully coordinated system of colour-coded directional signs for bicyclists
- Off-street short-cuts, such as mid-block connections and passages through dead-ends for cars

**Intersection modifications and priority traffic signals**

- Advance green lights for cyclists at most intersections
- Advanced cyclist waiting positions (ahead of cars) fed by special bike lanes facilitate safer and quicker crossings and turns
- Cyclist short-cuts to make right-hand turns before intersections and exemption from red traffic signals at T-intersections, thus increasing cyclist speed and safety
- Bike paths turn into brightly coloured bike lanes when crossing intersections
- Traffic signals are synchronized at cyclist speeds assuring consecutive green lights for cyclists (green wave)
- Bollards with flashing lights along bike routes signal cyclists the right speed to reach the next intersection at a green light

**Traffic calming**

- Traffic calming of all residential neighbourhoods via speed limit (30 km/hr) and physical infrastructure deterrents for cars
- Bicycle streets, narrow roads where bikes have absolute priority over cars
- 'Home Zones' with 7 km/hr speed limit, where cars must yield to pedestrians and cyclists using the road

**Bike parking**

- Large supply of good bike parking throughout the city
- Improved lighting and security of bike parking facilities often featuring guards, video-surveillance and priority parking for women

**Coordination with public transport**

- Extensive bike parking at all metro, suburban and regional train stations
- 'Call a Bike' programmes: bikes can be rented by cell phone at transit stops, paid for by the minute and left at any busy intersection in the city
- Bike rentals at most train stations
- Deluxe bike parking garages at some train stations, with video-surveillance, special lighting, music, repair services and bike rentals

**Traffic education and training**

- Comprehensive cycling training courses for virtually all school children with test by traffic police
- Special cycling training test tracks for children
- Stringent training of motorists to respect pedestrians and cyclists and avoid hitting them

**Traffic laws**

- Special legal protection for children and elderly cyclists
- Motorists assumed by law to be responsible for almost all crashes with cyclists
- Strict enforcement of cyclist rights by police and courts

Figure 40: Table, German, Dutch, and Danish cycling promotion measures and policies (Pucher and Buehler 2008)

Cycling infrastructure from Germany, The Netherlands, and Denmark informs the design of this thesis because it reinforces the positive aspects of encouraging ridership in the United States and demonstrates that it is possible to increase ridership.  Further, it aligns with goals of the Kasim Reed administration to make Atlanta one of the top ten most sustainable cities in the United States and to specifically implement innovative bike share programs such as those in San Francisco, Boston, New York, Chicago, London, and Amsterdam.


Figure 41: Photo, Separate cycling infrastructure, Denmark (Pucher and Buehler 2008)

Figure 42: Photo, Cycling infrastructure, The Netherlands

(http://thisoldcity.com/sites/default/files/images/netherlands_bike_lane_rbt.jpg)


Figure 43: Photo, Cycling Infrastructure, The Netherlands

(http://bicycledutch.files.wordpress.com/2013/02/enschede-cycle-bridge4.jpg)

Figure 44: Photo, Cycling Infrastructure, Germany (Pucher and Buehler 2008)

Figure 45: Photo, Public bicycle storage facility at metro station, Denmark (Pucher and Buehler 2008)

# CHAPTER 6

# DESIGN APPLICATION

Drawing from lessons gleaned from the precedent studies and the preceding review of the literature related to the United States Interstate System, the stormwater runoff regulatory system, recommended stormwater management BMPs, IVHS, and green infrastructure, the following chapter prescribes a design for the Atlanta Downtown Connector that utilizes green infrastructure to improve the stormwater control of the Atlanta Downtown Connector. The City of Atlanta has already identified the Downtown Connector as an element of the city that needs improvement, hiring SWA to re-design the corridor to better incorporate art and landscaping elements in order to attract capital to the city and improve its appearance. The holistic design application in this thesis, however, seeks to make fundamental improvements beyond these superficial categories.

## Site Analysis

For the purposes of this thesis, the portion of Interstate 75/Interstate 85, also known as the Atlanta Downtown Connector, between the Brookwood Interchange and Interstate 20 will be examined. The length of this portion of expressway is 4.18 miles. Starting from the southern end of the segment to study, I-20, the Downtown Connector winds north, veering to the east of the downtown business district and the state capitol, then back to the west of Peachtree center, where it makes a turn due north and runs north to the Brookwood Interchange along the western side of Midtown Atlanta. Figure 46 outlines the project boundary by identifying the boundaries of the chosen segment in measurements of a 6-minute walk and a 12-minute walk.

In the studied segment, there are five right-side entrances to the northbound lanes from city streets, (from Ralph David Abernathy Boulevard, I-20, Martin Luther King Jr. Drive SE, Freedom Parkway, Williams Street/Spring Street) and six right-side exits from the northbound lanes to city streets (Edgewood Avenue, Freedom Parkway, Pine Street/Peachtree Street, Spring Street, 10$^{th}$ Street, and 14$^{th}$ Street/17$^{th}$ Street). There are five right-side entrances to the southbound lanes from city streets, (from Edgewood Avenue, Freedom Parkway, Eliot Street, Spring Street/Williams Street, 10$^{th}$ Street) and six right-side exits from the southbound lanes to city streets (North Avenue, Williams Street, Courtland Street, Freedom Parkway, Jesse Hill Jr Drive NE, Capitol Ave, and I-20). There is also one left-side HOV entrance to the northbound lanes from a city street, (Williams Street) and two left-side HOV exits from the northbound lanes to city streets (Piedmont Avenue and I-75 Northbound after the Brookwood split). There are four left-side HOV entrances to the southbound lanes from city streets, (I-75 southbound from before the Brookwood split, John Portman Boulevard) and one left-side HOV exit from the southbound lanes to a city street (Williams Street). Figure 47 shows where these entrances and exits are located.

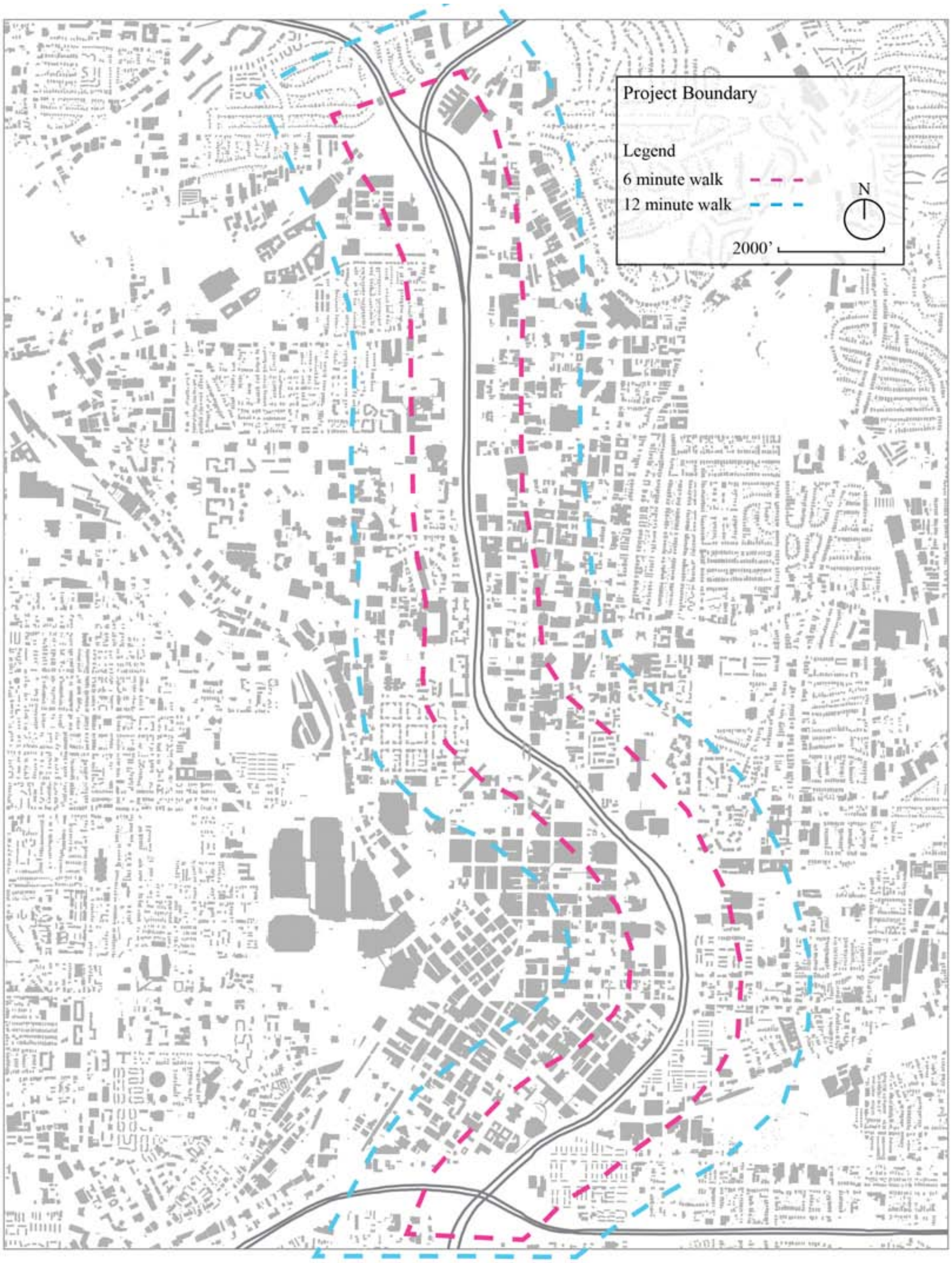



Figure 46: Inventory map, project boundary

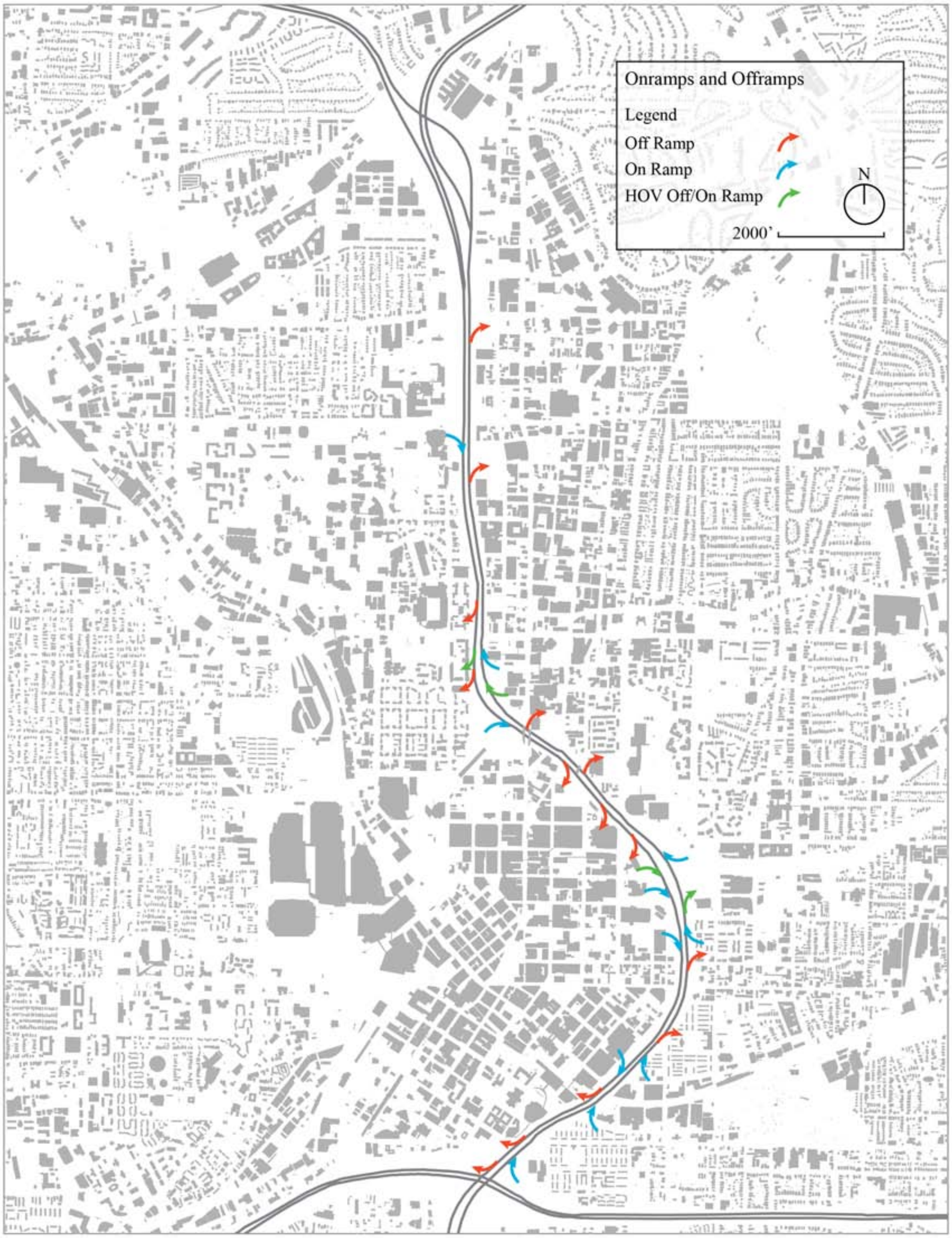



Figure 47: Inventory map, expressway entrances and exits

Numerous cultural institutions, hospitals, universities, landmarks, historical sites, parks, and other points of interest are within close proximity to the Downtown Connector and are therefore significant to the project, because they may be potential stakeholders in the development of an enhanced infrastructure on the expressway or in some other way interact with the proposed system. Figure 48 shows where these points of interest (POIs) are located.

- Savannah College of Art and Design
- Crestlawn Cemetery
- Atlanta Water Works and reservoir
- King Plow Arts Center
- Goat Farm
- Fulton County Jail
- Atlanta Community Food Bank
- Atlantic Station
- Turner Broadcasting Industries
- Turner Studios
- Midtown neighborhood
- High Museum
- Atlanta Symphony Hall
- Margaret Mitchell House
- Piedmont Park
- Grady High School
- Atlanta Beltline
- Georgia Institute of Technology

- Fox Theater
- Georgian Terrace Hotel
- Emory University Hospital Midtown
- Atlanta Civic Center
- Ponce City Market
- Historic Fourth Ward Park
- Atlanta Medical Center
- Martin Luther King District
- Ebenezer Baptist Church
- Atlanta Megabus Terminal
- Georgia Aquarium
- Centennial Olympic Park
- World of Coca Cola
- Georgia World Congress Center
- Georgia Dome
- Philips Arena
- CNN World Headquarters
- Five Points District
- Underground Atlanta
- Georgia State University
- Grady Hospital
- Children’s Hospital of Atlanta
- Georgia State Capitol

- Atlanta City Hall
- Morris Brown University
- Clark Atlanta University
- Spelman College
- Morehouse College
- West End Park
- Oakland Cemetery
- Grant Park
- Edgewood District
- Turner Field

Some of these organizations may be interested in partnering with the GDOT, the State of Georgia, Fulton County, and the City of Atlanta to develop an enhanced Downtown Connector. Other organizations that are not directly adjacent to the project, but that may have a stake in its implementation include the GDOT, MARTA, the City of Atlanta, the State of Georgia, Fulton County, the Midtown Alliance, the Midtown Improvement District, Bank of America, Delta Airlines, the Atlanta Streetcar, Volvo, and Google. The local cultural sites and urban amenities are especially important because they will play a role in the green infrastructure "hubs" of the design and relate to the "implementation quilt" within the urban fabric.

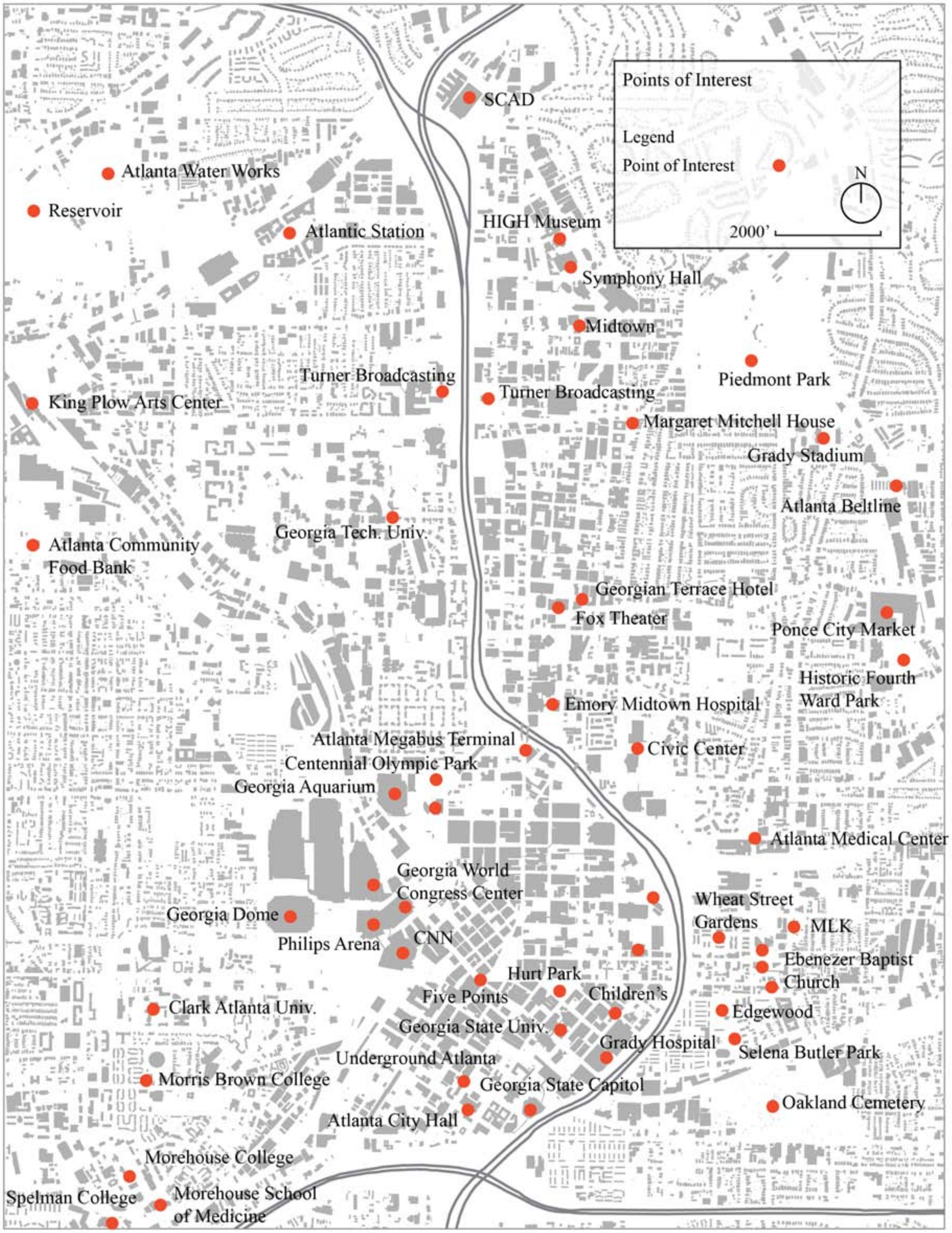



Figure 48: Inventory map, points of interest

Alongside the Downtown Connector, some of the border parcels are developed, and some are still undeveloped. Many parcels are currently being used as parking lots. If enough capital could be generated, many of these adjacent parcels could be purchased to serve the Downtown Connector infrastructure, being used as open space, parks, habitat, GDOT storage, or other uses. Each parcel would represent a patch in the "implementation quilt" of the Downtown Connector vision. Figure 49 shows the undeveloped parcels adjacent to the Downtown Connector.

If the expressway is the "corridor," according to the tenets of green infrastructure theory, the adjacent parcels purchased and incorporated into the project can serve as the "hubs." The Downtown Connector is the main spine of the project, with natural stormwater control features embedded into its design along the entire length of the corridor. It will include landscape features that address stormwater, as well as a multi-use paved trail for pedestrians and cyclists. By itself, the corridor would be a complete system effective at mitigating the consequences of stormwater. At a macro level, hubs are needed to reinforce the strength of the project and its goals for the city. The border parcels of the corridor can act as those open spaces and complete the network.

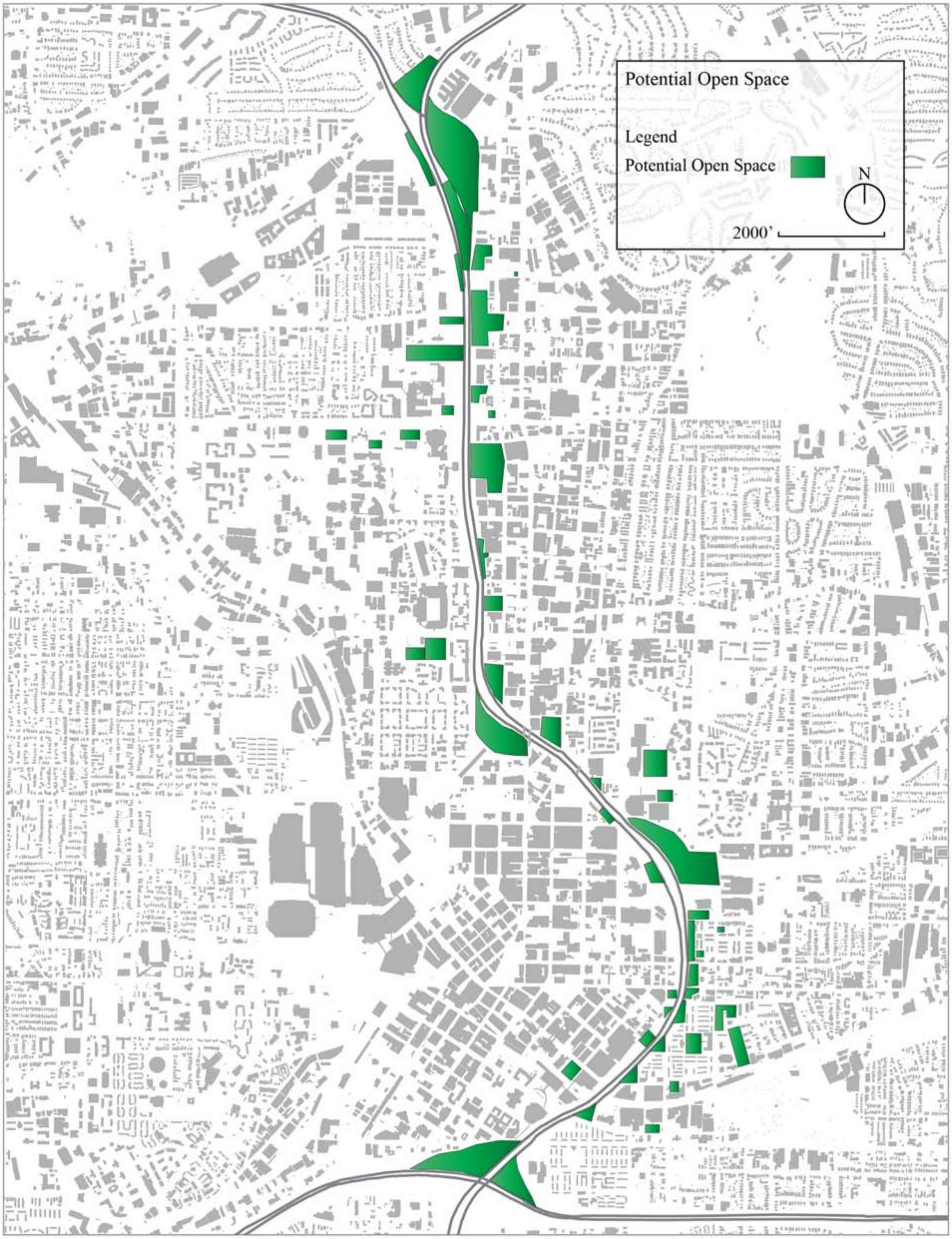



Figure 49: Inventory map, potential open space

Figure 50 illustrates the elevations of the Downtown Connector at a regular interval, as well as elevations of the surrounding urban fabric. This information can be used to determine low points or potential low points in the expressway where infiltration trenches and bioswales can terminate in riprap and drains to eventually connect into the MS4 system. In this way, the stormwater control measures designed into the Downtown Connector will supplement the existing capacity of MS4s to handle stormwater runoff volume and pollution.

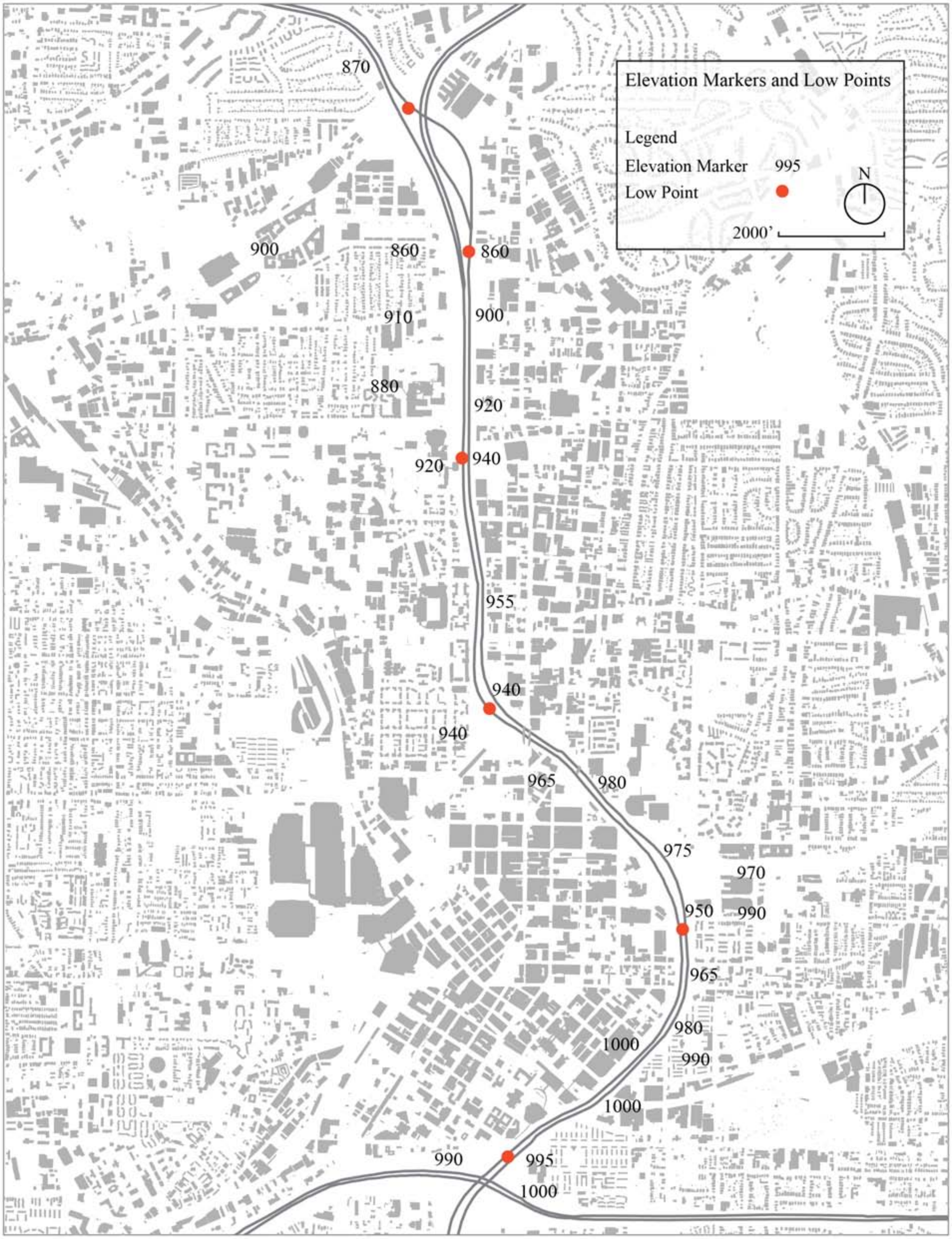



Figure 50: Inventory map, elevations

The studied segment is the most complex and heavily engineered stretch of expressway in the Atlanta area. It is also the most-travelled on a daily basis. These two facts alone make it feasible for enhancement and technological improvement. Moreover, federal and state stormwater regulations require the Georgia Department of Transportation (GDOT) to reduce contaminant loading of stormwater draining from their property or right-of-way in areas designated as Municipal Separate Storm Sewer Systems (MS4s) (Corson 2006). GDOT must continue to apply for National Pollutant Discharge Elimination System (NPDES) permits and implement a Storm Water Quality Management Plan (SWQMP) designed to improve the water quality of stormwater runoff (Corson 2006). Permitting requirements are updated every year, and soon they will mandate the use of green infrastructure elements to achieve the necessary goals.

The design problem is to create an expressway infrastructure that conveys vehicular traffic (yet is not anti-pedestrian), captures and treats all stormwater runoff by filtering, infiltrating, and/or detaining it, adapts to future public transit scenarios, provides a privileged right-of-way for pedestrians and bicyclists, provides open space for relaxation, provides better physical connectivity between opposite sides of the expressway, provides amenities for adjacent businesses, institutions, and neighborhoods, and creates new parks. The design application will test the effectiveness of green infrastructure theory at solving the design problem.

Other goals of the project include increasing adjacent property values, creating jobs, stimulating commercial and economic growth in the area, educating the public about the environmental consequences of transportation, enhancing the image of Atlanta, and creating a meaningful experience of the Downtown Connector for passengers and pedestrians. While the design portion of this thesis stops short of addressing any of these needs beyond stormwater control, pedestrian and cycling paths, open space, and improved community connectivity, these additional goals are integral to the application of green infrastructure to the Atlanta Downtown Connector project and are highlighted as opportunities for discussion and further research.

<u>Opportunities and Constraints</u>

The site analysis leads to an exploration of opportunities and constraints for any design addressing the improvement of the Downtown Connector. The Downtown Connector is a physical barrier to East-West movement, dividing large parts of the city from each other. Although there are several bridges spanning across it at major road crossings, the expressway still impedes free movement of pedestrians, street traffic, and wildlife. A successful design for the Downtown Connector will provide more routes for East-West connections over the corridor. With the advent of IVHS, the nature of regional and local mass public transportation will improve. Long trains of cars and buses can flow freely through the city, taking the place of traditional rail and light-rail transit. Rail transit is limited in its functionality because it is physically confined to the routes on which the rails are built. Because the highway network is so extensive, if regional and local transit operated using cars and buses, its area of service would be much larger and more versatile. A series of dedicated public transit routes, able to operate on the Downtown Connector, will be a great improvement to the region's transportation offerings. Increased open space on the Downtown Connector will also provide an opportunity for stormwater management using natural materials and processes, such as bioswales, infiltration trenches, detention ponds, and much more. It will also enable the corridor to provide parks, green space, and pathways for cycling and walking/running. Lastly, the site presents an opportunity to improve the image and perception of Atlanta from the perspective of residents and visitors alike. Using carefully selected landscape designs, artwork, and other graphics, the

Downtown Connector can communicate a message about Atlanta's vision for the future, while educating users about the environmental implications of transportation infrastructure.

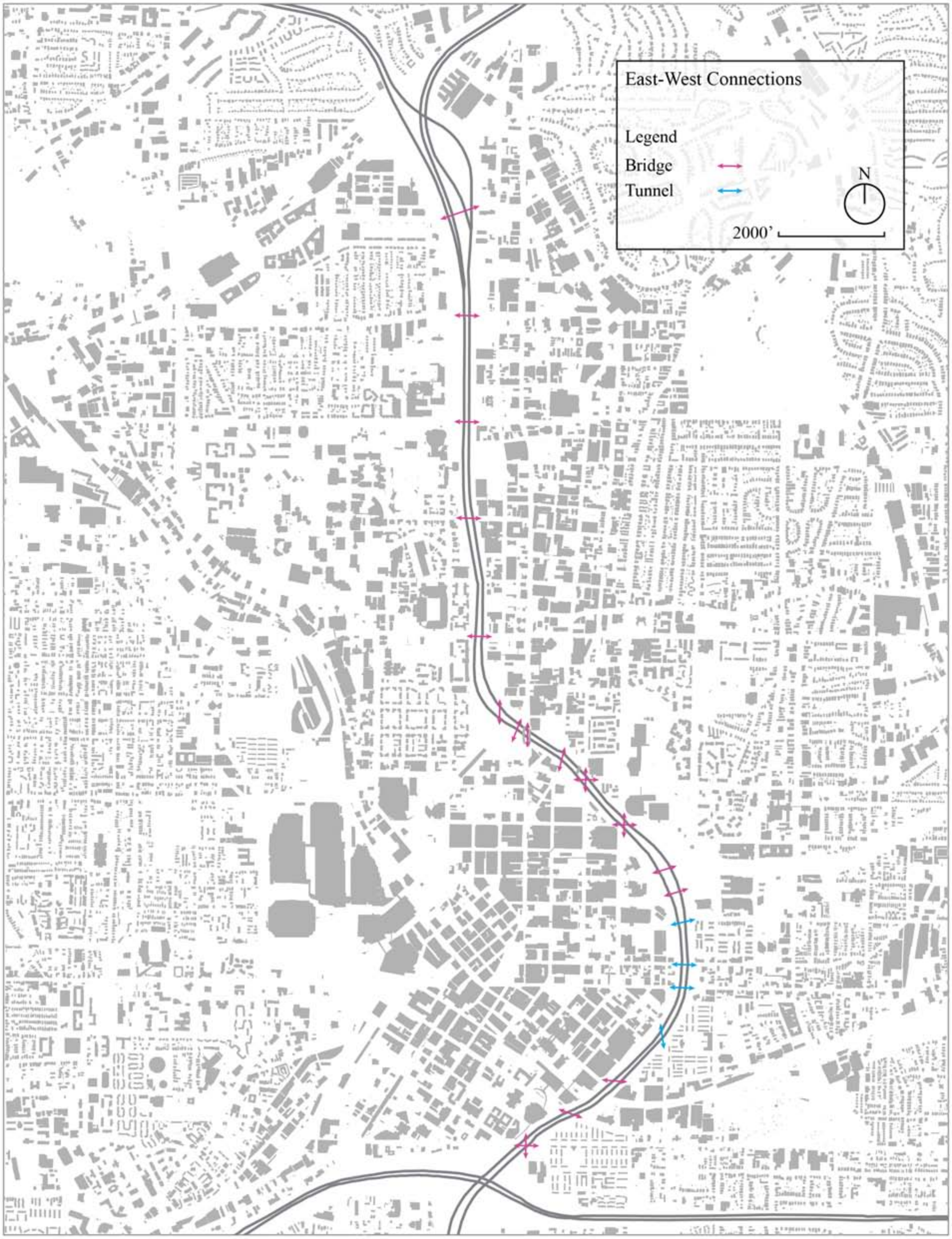



Figure 51: Inventory map, existing bridges and tunnels

Constraints for the design include a limited physical footprint in which to operate. The corridor operates in a tight urban envelope, bordered almost constantly by myriad properties and land uses. Expansions to its program must occur within the existing physical confines of the corridor. Another potential conflict is the ambition to leave all systems flexible so they can be easily and affordably adapted for future use. However, much of the infrastructure requires a significant monetary investment and considerable physical construction, such as storm sewer systems, surfaces to drive on, landscape plants, any conduits built for electrical, plumbing, mechanical, communication wiring, and other features. Also, the GDOT and other stakeholders lack sufficient incentive to fund the project, given that they are not being penalized by the EPA under the CWA for the current shortcomings of the stormwater management plan. However, once incentives and funding sources are identified, another challenge will be to discourage the stakeholders to meet only the minimum possible criteria, but rather, according to the theory of green infrastructure, synthesize efforts from all disciplines and maximize the potential of the system to do economic, environmental, and social good. Finally, the consequences and effects of using green infrastructure for improvements of this nature to an urban expressway have not been sufficiently studied or quantified. Since green infrastructure is arguably in its infancy, it will be some time before it is widely accepted as a valid strategy for growth and development. The conversion (loss) of existing right-of-way into other functions can be justified by the potential for flexibility, projected growth, MS4 permitting opportunities, and other ends.

Vision Statement

The Atlanta Downtown Connector project is a system of intelligent infrastructure that winds through the heart of downtown and midtown Atlanta. The system consists of a network of protected open spaces alongside cycling trails, bustling pedestrian walkways, and a boulevard-style road for the movement of automated groups of vehicles. All stormwater runoff is diverted into landscaped areas engineered to filter its pollutant load and reduce its volume and velocity before it is discharged into the MS4. The system prioritizes pedestrians, providing many East-West connections across the system, trails for walking and running, and pocket parks located close to urban POIs. This green ribbon should be composed primarily of “soft” elements, meaning bioswales, recreational trails, and vegetated areas, *rather than* light rail, third rail transit, new roads, and other hardscape. The project is a synthesis of improvements to many scales of infrastructure. The system is a catalyst for infill development along the edges of the adjacent neighborhoods. The experience of using the system communicates a message that Atlanta is a world leader in sustainability, transportation innovation, and urban planning.

The plans for IVHS should not be a substitute for continuing to improve regional transportation infrastructure, expand public transportation, and encourage people to carpool, telecommute, walk, and cycle to work.

Mission Statement

The Atlanta Downtown Connector project enhances the existing transportation infrastructure by allowing it to accomplish social, environmental, and economic goals within its current physical footprint. It will improve traffic safety, reduce congestion, and protect pedestrians. Physical connections are made to and between the adjacent neighborhoods. People living and working in Atlanta will use it as a landmark and a meeting place. The project will provide recreation space for the adjacent institutions and neighborhoods. It will protect the regional watershed by addressing stormwater runoff from the roadway, and provide habitat for local wildlife. Landscaped areas will help to reduce greenhouse gas emissions from vehicles. Atlanta will experience increased capital growth, economic stimulation, and new development as a result of the Downtown Connector project.

The mission of the project is to promote public health and protect water quality by educating the public about sustainable practices and eliminating pollutants from stormwater runoff.

Implementation Plan

Coordinating the implementation of the Downtown Connector corridor improvements will be a complicated process involving many different entities including GDOT, Federal Highway Administration, National Highway Traffic Safety Administration, Environmental Protection Agency, Department of Energy, City of Atlanta, State of Georgia, MARTA, Atlanta Beltline, and private developers, with heavy involvement from the general public. From the outset of the project, all entities must understand their role in the process. Responsibilities of each entity must be clear so that each party is accountable for their actions and the expectations placed upon them. Public forums and community meetings must be held to better understand the present needs of those who the project will serve, and also determine how those needs will change in the future.

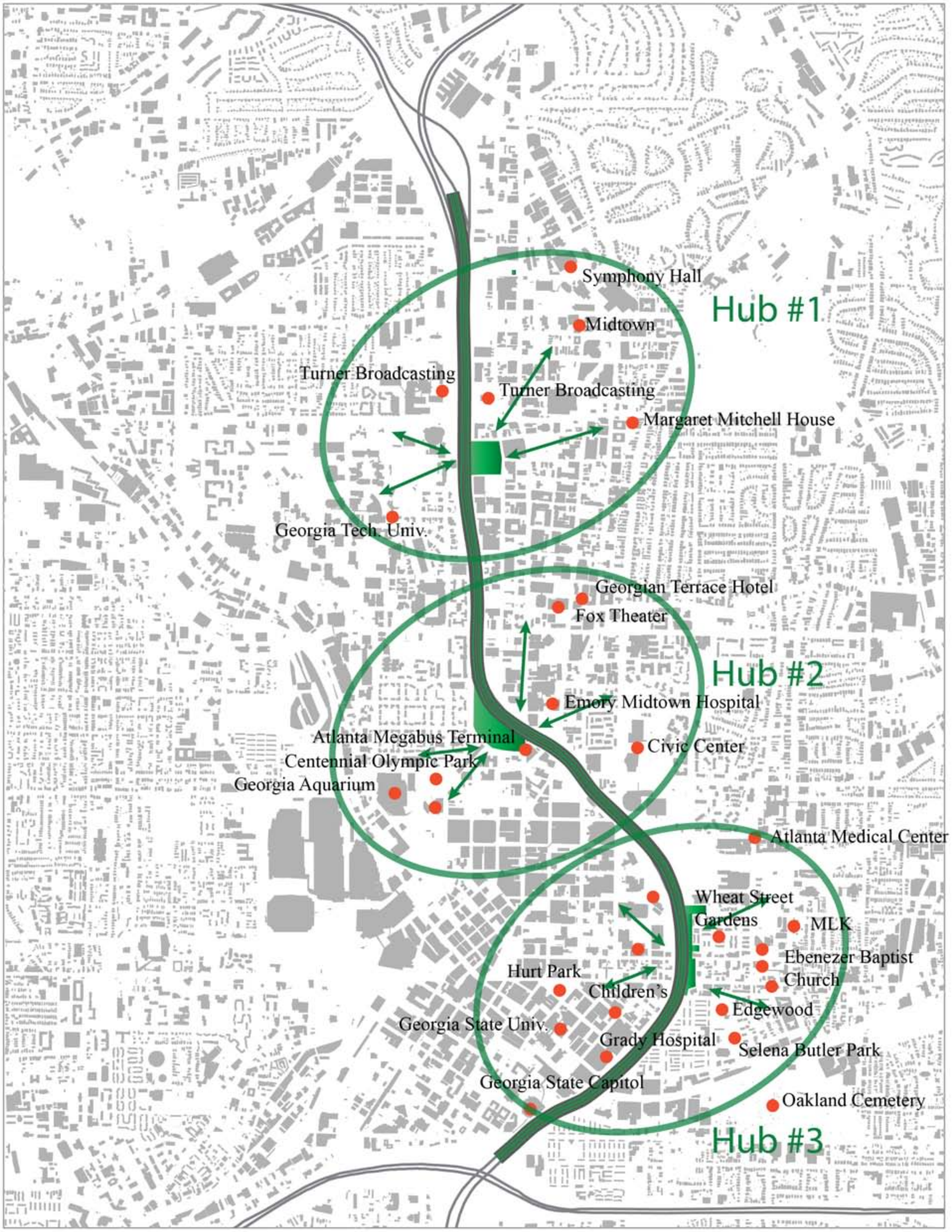



Figure 52: Conceptual site plan, phase 1

Figure 53: Photo, existing conditions (Google street view)

Figure 54: Section-Perspective Rendering, Downtown Connector looking South

Downtown Connector Site Design

The Downtown Connector will now be made up of 2 separated northbound rights-of-way and 2 separated southbound rights-of-way. There will be limited access between the rights-of-way in each direction. The innermost rights-of-way can be used as express lanes for all traffic, or they can be reserved for public transportation. It will be a continuous route between I-20 to the South and the Brookwood Interchange to the North. The outermost rights-of-way will designate one lane for entering/exiting and autonomous cars (cars not participating in a cooperative vehicle network), one lane for cooperative vehicle networks, one passing lane for cooperative vehicle networks, and a breakdown lane made of permeable paving. See Figure 55.

Long, narrow landscaped areas will be installed between each right-of-way. These medians will serve as physical buffers or separators between the roadways, areas to plant trees, shrubs, and grasses, and stormwater control facilities. Each stretch of roadway will be graded so that sheet flow is directed into the landscaped zone. Bioretention and infiltration trenches were chosen as the primary method of stormwater management because in combination, they are suitable for ultra-urban settings, accept all the pertinent pollutants, have a moderate maintenance cost, general community acceptance, a medium wildlife benefit, good heavy metal removal rate, low engineering design, and double as a landscaping feature (Corson 2006). Detention zones can be added as needed to supplement the capacity of the bioretention swales and infiltration trenches. Permeable pavements will be used wherever possible, such as on the breakdown lanes and walking/running trails, but admittedly, to date there is not an acceptable permeable pavement for high-speed vehicular traffic or bicycles. Chicago, for example, uses permeable pavements in its alleys, while keeping busier streets in the traditional asphalt (Wise 2008).

Figure 56 illustrates the sequence that stormwater follows from the moment it hits the pavement, through its journey downhill into a catchment basin, into a bioretention zone with grasses and other plants in an engineered soil medium designed to filter and infiltrate the water, then into a gravel infiltration trench designed to maximize potential infiltration, and finally, any remaining volume from larger storm events that terminates in riprap before exiting through a grate at a localized low point into the MS4 outlet. This sequence is the standard design that this thesis proposes to implement to control stormwater runoff from the expressway, but it is diagrammatic and can be adapted to the site-level conditions of the expressway as needed. Bioretention areas are the first measure of control and are sized at X percentage of the overall road surface area to capture the first inch of runoff from storm events. The second and third inches will not contain as many pollutants and can be infiltrated in the infiltration trenches which are sized at X percentage of the bioretention areas.

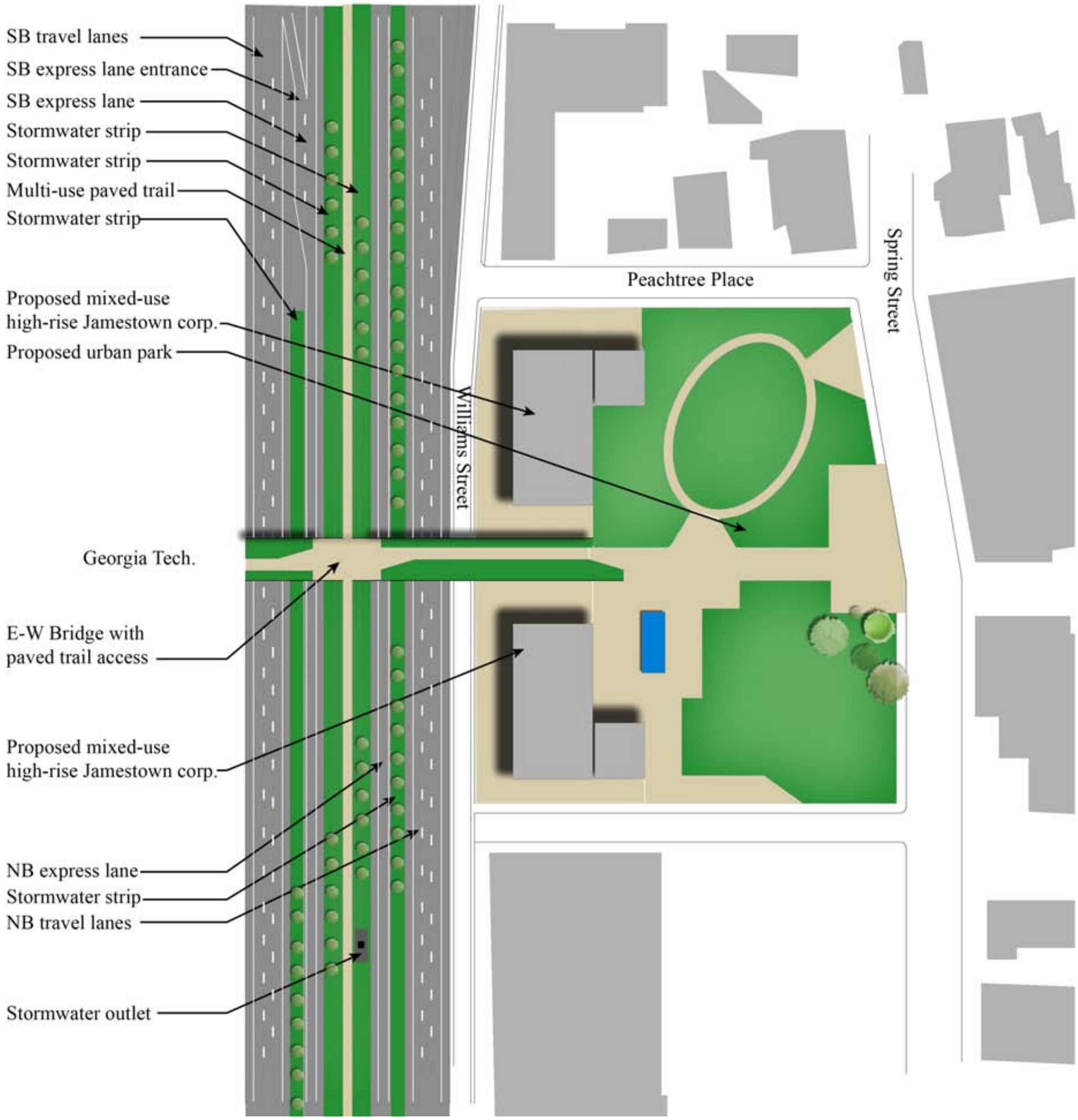



Figure 55: Plan, expressway design and adjacent proposed park

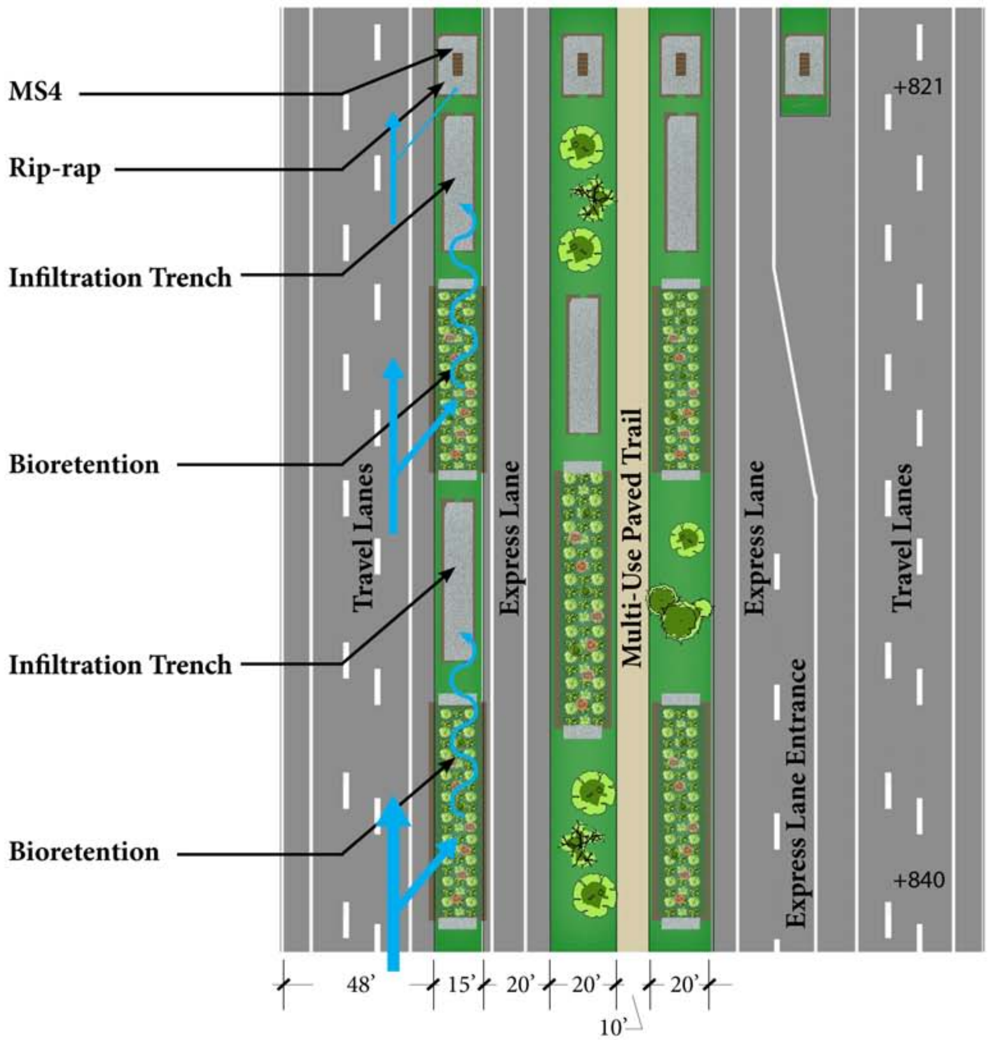



Figure 56: Typical plan, Expressway showing stormwater water flow direction and designed control measures

A central zone separating the northbound rights-of-way from the southbound rights-of-way will contain additional landscaping, stormwater control facilities, and a multi-use paved trail or trails for cycling and pedestrian activity. This part of the program will be an undulating ribbon that rises up to provide access to bridges that cross the expressway at street level, while the expressway rights-of-way will continue to bypass under these bridges. In this way, the multi-use paved trail and its zone will be extremely well integrated into the city fabric, increasing the number of connections the system makes with the surrounding community. See Figure 57.

Undeveloped parcels adjacent to the Downtown Connector will be purchased as funds become available and can be used for parking, transit hubs, DOT storage, parks and open space, new development, and flexible spaces. Economic and environmental solutions can also continue to evolve within the framework of the built system. As time progresses, the system will grow and expand according to the urban and social needs of the community.

Figure 52 illustrates a possible scheme for the initial phase of completion of the overall system, with landscaped stormwater controls in place along the entire length of the connector, as well as 3 of the adjacent "hubs" developed out of vacant parcels. The Midtown parcel, hub 1, between the expressway and Spring Street at 8$^{th}$ street was chosen as one of the "hubs" for several reasons. The Midtown area is the most dense in terms of development and population during the workday, at night, and on the weekends. Developers such as Jamestown Corporation are actively investing in real estate in the midtown area at a rapid pace and are completing similar projects on parcels in the area. Jamestown Corporation has been identified as a potential stakeholder for the Atlanta Downtown Connector transformation project. An East-West connection can be added at this hub across the expressway to connect Midtown with Georgia

Tech in the form of a pedestrian bridge. The bridge will also provide access to the multi-use paved trail that runs the length of the connector.

The Peachtree Center parcel, hub 2, where Spring Street crosses the expressway, was chosen as one of the “hubs” for phase 1 because of its proximity to the Atlanta megabus terminal, Centennial Olympic Park, World of Coca Cola, the Georgia Aquarium, Georgia Tech, the financial district, and many other adjacent points of interest. At a crucial bend in the roadway, this parcel is also one of the most highly visible potential “hubs” of the entire system. It can be used as an opportunity for visual communication to drivers and pedestrians about the project, and thought of as a gateway to Atlanta.

The MLK parcels, hub 3, was chosen as the last potential “hub” of phase 1 development. These parcels is important to the project because of its proximity to the Wheat Street Gardens public housing complex as well as other section 8 housing communities and lower-income neighborhoods. A hub for investment and development could potentially benefit this area most of all. These parcels were also selected because of their proximity to the Martin Luther King, Jr. cultural and historic districts, Freedom Parkway, Grady Hospital, and Georgia State University. See figure 48.

The highly visible nature of the project can also serve as an educational opportunity to teach users of the Downtown Connector about the ecological impact of automobile traffic, particularly in relation to water quality. The public is more likely to support a system of bioretention swales if they know it is improving the water quality. For this reason, multiple scales of systems of art, landscaping, and graphics will be installed to communicate the activities and purposes of the expressway. Some systems of art, landscaping, and graphics will be legible by drivers and passengers at high speeds, and others will provide more detail to visitors including cyclists and pedestrians in the central zone. The peripheral parks and open spaces will also be designed with areas that communicate the mission statement of the project. Literature will be made available to the public through public outreach, press, social media, and other avenues. The highly visible nature of the project can also serve as a message to the world about the identity of Atlanta – as an innovator of transportation technology and a pioneer of sustainability. The material aspects and experience of the urban expressway has the ability to define how we see ourselves in the city, as it offers a unique perspective from which to view the city (Robertson 2007).

Figure 57: Early concept rendering, Aerial view

# CHAPTER 7

# CONCLUSION

The purpose of this design is not simply to combat stormwater runoff, with the added bonus that it provides green space, public transportation, urban connectivity, and other urban benefits. Holistic thinking about every existing and proposed system in the built environment is necessary to ensure that they are designed to accomplish as many goals as they possibly can, while brainstorming about other ways they can be useful. Anything that only serves one, two, or three purposes is an unsustainable waste of space. In order to feel proud of our contributions to the world, our civilization, our generation of designers, builders, and planners must expand the boundaries of what our infrastructure is capable of.

Moreover, a paradigm shift in infrastructure design rationale is needed to begin imagining ways to eliminate the root causes of these and other environmental problems caused by urban development. Designers, planners, and academics have already envisaged such a paradigm shift; yet it has not been unilaterally embraced at a policy level by government organizations and their implementation structure. The situation can be likened to the realization that oil resources are finite and depleting rapidly, yet authorities have not communicated that urgency of the need to force the immediate implementation of alternative energy sources.

## Analysis of Design

The proposed planning process and design of the Downtown Connector emanates directly from the principles of green infrastructure. The planning process outlined in this thesis is successful in that it identifies some, if not most of the major stakeholders who will play a role in the implementation of a system for better stormwater management on the Downtown Connector through green infrastructure. The design is successful in that it integrates sustainable stormwater management strategies, adapted for the highly constrained urban area, with other infrastructure systems such as the pedestrian and cycling path and connects to adjacent "hubs" or nodes of space to act as catalysts for reinforced ecological improvements and economic development.

The thesis acknowledges that it cannot address every stakeholder or necessary design element through the scope of its research, but rather provides suggestions and a framework for conceptualizing the steps needed for a successful retrofit.

Encouraging the GDOT to improve its cooperation with the MS4 NPDES program and its environmental functionality with regard to the Downtown Connector stormwater runoff may be a good starting place to achieve the desired effect of the design. However, a successful implementation of the visionary design will require effort and action from other stakeholders. Many innovative designs or shifts in policy have often involved a "championing" effort from one or more prominent stakeholders. The City of Atlanta, in cooperation with non-profit groups and private developers, may ultimately be the driver for changes of this magnitude (as was the case with the Atlanta Beltline). (In fact, the thesis identifies another opportunity for further research the role that the Atlanta Beltline can play as a partner or stakeholder in the planning and design process.) The City of Atlanta launches green infrastructure initiatives in its planning and development policies to achieve real solutions to local goals and problems, and therefore may be more nurturing to a design of this nature than the GDOT, which is impeded by bureaucratic hurdles and financial constraints.

Additionally, the momentum to make such a change may come from new expectations from the millennial generation to rely less on private automobiles for transportation and a renewed commitment to and pride in sustainability. This thesis identifies as an opportunity for further research the sociological and cultural factors that can act as a catalyst for the planning and implementation of the design. With changing attitudes and behaviors of the coming generations, opportunities may exist to spearhead a movement of this kind.

From the perspective of the GDOT, concerns about the design will include adherence to the AASHTO guidelines regarding setbacks from rights-of-way, clear zones, maintenance zones, and other design standards. They will also include the legitimate concern of avoiding attracting wildlife to the site that could be in dangerous conflict with automobile traffic, such as deer and other animals. The speed limit on the Downtown Connector may need to be substantially reduced to allow trees and other landscaping to encroach more closely on the right-of-way.

One criticism of the achieved design that needs to be addressed is the location and position of various elements of the connector, including the different medians and placement of the multi-use paved trail for cyclists and pedestrians. One concern about having the multi-use paved trail in the middle of the connector, between the 2 rights-of-way, is that cyclists and pedestrians will not perceive the trail as a comfortable or safe place to operate. Although the design calls for the speed limit of the connector to be reduced to 35 miles per hour, placing a multi-use paved trail in the middle of a limited-access roadway may create the feeling of danger, isolation, or limited flexibility. By contrast, situating the multi-use paved trail to either side of the roadways, as an outside edge to the connector, would increase access from the surrounding neighborhoods to the trail and establish more opportunities for interaction and connectivity. Sufficient landscape area could be obtained in any position within the footprint of the expressway to mitigate stormwater runoff. Figure 58 illustrates the associated revision to the design.

Figure 58: Rendering, revision to proposed design

The concept of the thesis is a shift in infrastructure planning and design toward a new type of transportation infrastructure, rather than a renovation of the existing Downtown Connector to include landscape elements for stormwater control such as bioretention. The impetus of this shift will be a combination of all of the aforementioned elements coming together over time. This coming-together will depend on many factors, some of which may not have occurred to anyone yet, as they will happen over many years as thinking and attitudes evolve.

The program aligns with numerous ecological goals set forth by acts and agencies such as the CWA, the EPA, the NPDES permitting process, and the City of Atlanta. The goal for the design component of this thesis is to provide a framework for the organization and planning of urban expressways of the future. Another major goal of the thesis is to avoid projecting a need for additional transportation infrastructure to be built, such as laying new tracks for transit or light rail. Given the significant cost of the investment in the existing interstate and its current physical urban footprint, the thesis will rather try to design systems that fit into and take advantage of that framework, such as a transit system made of chains of buses that operate on the expressway, as opposed to a new rail system to be built in the green ribbon. This thesis proposes the idea that thoughtful adaptation and re-use of existing transportation infrastructure can accomplish social, economic, and ecological goals. Green infrastructure theory is successfully applied as a design strategy because it encourages the function of the existing roadway to be expanded to address economic, social, and environmental performance, even though the system is so tightly constrained in its urban context.

This thesis offers the opportunity to conduct infrastructure planning decades in advance of its construction, given that IVHS is not likely to be implemented for quite some time into the future. Rather than waiting for piecemeal solutions to the traffic and stormwater problems to develop haphazardly, planning can begin now, while there is a surplus of time, for the development of that future system. If executed correctly, the design could establish the urban and cultural identity of Atlanta as a world-leading transportation and technology innovation hub through the implementation of enhanced, multi-platform transportation and recreation infrastructure where community, ecology, and economy at multiple scales are all improved. A synthesis of infrastructure types, this project would have a profound economic, social, and environmental impact on the city of Atlanta and the broader region.

"The significant problems we face today cannot be solved by the same level of thinking that created them." – Albert Einstein

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