LIFE-CYCLE COST-BENEFIT ANALYSIS OF GREEN ROOFING SYSTEMS: THE ECONOMIC AND ENVIRONMENTAL IMPACT OF INSTALLING GREEN ROOFS ON ALL ATLANTA PUBLIC SCHOOLS

A Thesis
Presented to
The Academic Faculty

By

Melvin B Whatley

In Partial Fulfillment
Of the Requirements for the Degree
Masters of Science in Building Construction and
Integrated Facility Management in the
College of Architecture

Georgia Institute of Technology
May, 2011

LIFE-CYCLE COST-BENEFIT ANALYSIS OF GREEN ROOFING SYSTEMS: THE ECONOMIC AND ENVIRONMENTAL IMPACT OF INSTALLING GREEN ROOFS ON ALL ATLANTA PUBLIC SCHOOLS

Approved by:

Advisor, Dr. Baabak Ashuri
College of Architecture
Georgia Institute of Technology

Professor Kathy Roper
College of Architecture
Georgia Institute of Technology

Date Approved: April 4, 2011

ACKNOWLEDGEMENTS

First and foremost I give thanks and honor to our father God all mighty for giving us everything we need to make all things a possibility. My wonderful fiancée, Mateja Podgorsek, has never stopped believing in me or persistently encouraging me. She has been and invariable motivator although spending many evenings alone while I was either in class or off raising my 8 year daughter, Trinity, who lost her mother last year. I would also like to thank my mother, Dr. Clemmie Whatley, for being a constant source of inspiration and for her tireless support and leadership in helping me to raise Trinity. Another thank you goes to my father, Melvin Whatley, for his words of wisdom that serve to keep me grounded. And I thank Dr. Babaak Ashuri, Professor Kathy Roper, and Jacquelyn Strickland for their support in helping to structure this thesis.

Additionally, I would like to give a special thank you to Al Scenna, Project Manager with the Brookwood Group and Atlanta Public Schools (APS) Representative Construction Manager. Al not only played a very integral roll in helping me to obtain pertinent information about APS including the total square footage of flats roofs in APS, but also shared valuable opinions concerning APS's goal to become a leader in LEED for Schools developments. A special thank you also goes to Susanne Blam, Architect with Perkins & Will, for sharing her experiences with Springdale Park Elementary, "the first Atlanta Public Schools to attempt LEED Silver certification, Springdale Park Elementary School blends environmental and cultural elements in one cohesive design (Breedlove Land Planning News 2011)." Learning about Susanne's experiences encouraged me about the possibility of seeing APS implement a plan to install vegetative roofs on all of its schools. Finally, I would like to thank the following members of my project team on

the LEED for Schools 2009 major renovation currently taking place at Benjamin E Mays High School; Jimmy Haralson (Winter Superintendent), Heather Hardie (Winter Project Manager), and Bria Weiss (Winter Assistant Project Manager). Each of these individuals helps me everyday to understand what it takes to manage a LEED project for APS. Our project is scheduled to be substantially complete on 1 Dec 2001 and is on track to earn a LEED for Schools 2009 Silver Certification (approximately 54 Points; See Appendix E).

TABLE OF CONTENTS

LI ST OF TABLES

LI ST OF F IGURES

LIST OF ABBREVIATIONS

APS	Atlanta Public Schools
ARRA	American Recovery and Reinvestment Act of 2009
BABs	Build America Bonds
BCA	Benefits Cost Analysis
BIM	Building Information Modeling
BMP	Best Management Practices
BREEAM	Building Research Establishment Environmental Assessment Method
CDE	Community Development Entity
CE	Civil Engineer
CS	Core and Shell
CSOs	Combined Sewer Overflows
D–B	Design Build
EA	Energy and Atmosphere
EPA	Environmental Protection Agency
ET	Evapotranspiration
EQ	Indoor Environmental Quality
FSC	Forestry Stewardship Council
GBCI	Green Building Certification Institute
GBI	Green Building Initiative
GC	General Contractor
ID	Innovation and Design Process
LCC	Life Cycle Cost(s)

LEED	Leadership in Energy and Environmental Design
LID	Low-Impact Development
MEP	Mechanical, Electrical, and Plumbing
MR	Materials & Resources
MS4	Municipal Separate Storm Sewer System
NC	New Construction
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
QECBs	Qualified Energy Conservation Bonds
QZABs	Qualified Zone Academy Bonds
ROI	Return on Investment
SRI	Solar Reflectance Index
SS	Sustainable Sites
USGBC	United States Green Building Council
WE	Water Efficiency

SUMMARY

This study examines the relationship between environmental sustainability and green schools, seeking to highlight the benefits and determine the Net Present Value (NPV) installing vegetative roofs on all schools in the Atlanta Public Schools District. This study quantifies the costs and benefits of thin-layer, or extensive, green roof systems as they compare to typical flat roofs on Atlanta Public Schools. Quantifiable benefits are detailed and suggestions are made to create the means by which other social benefits may be quantified. The purpose of this thesis is to establish proof to the Atlanta Public Schools District that over a 40 year period there are more benefits associated with installing vegetative roofs on all of their flat roofs than there are costs. While some may argue that greens roof are more costly than traditional roof systems, this study provides evidence that the cumulative benefits over a 40 year life cycle associated with large scale green roof installations, such as on all Atlanta Public Schools, are greater than the initial costs incurred. Factors included in the analysis of benefits were reductions to energy/utility costs, reduced emissions, and avoided best management practices (BMPs). Other considerations include social benefits resulting from the mitigation of storm water runoff, reductions to the urban heat island, productivity level increases (students and teachers), and avoided regulatory fees.

Following an extensive literature review, the study determined green roofs are an extremely viable topic of discussion for school systems as a beneficial technology to pursue in regards to future sustainability. The findings of the literature review, as summarized, were further explored by a case study that analyzed the potential benefits of installing an extensive green roof on all Atlanta public schools. With the findings concluding that APS represents an important control group within Atlanta's Watershed community to study Best Management

Practices (BMPs) for storm water management as well as studying general sustainability practices for Atlanta, recommendations are made for further research seeking to quantify the many social benefits presented. Overall, the study contributes to APS's goal to establish itself as a national leader in sustainable development and to seek funding to accomplish this goal.

CHAPTER 1

INTRODUCTION

APS began greening its schools in 2009 with Springdale Park Elementary. “The district’s first “green” school serves about 400 kindergarten through fourth-grade students from the Druid Hills, Midtown, Poncey Highlands and Virginia-Highland neighborhoods who were redistricted from Morningside and Mary Lin elementary schools (Atlanta Public Schools, 2011).” The Atlanta Public Schools district represents a unique control group for metro Atlanta in fact that the benefits associated with green development are far reaching. Not only will tangible benefits result from greening school facilities, but also the potential social benefits related to child development are great. By installing green roofs on a significant portion of its flat roofs APS will be able to take advantage of the many benefits gained from storm water management, building envelope efficiency, reductions to the urban heat island, as well as participate in farm to school program such as Schoolyard Sprouts which are aimed promoting health for children through statewide health initiatives.

Schoolyard Sprouts originated in the fall of 2007 as the Little Sprouts Garden at the Morningside Kindergarten campus. Through community support from Murphy's Restaurant, Whole Foods Market Briarcliff, Farmer D Organics and Georgia State University, Schoolyard Sprouts helps to create farm to school programming at Morningside and Springdale Park Elementary. At Morningside Elementary gardening and farm to school became a school health and wellness initiative resulting in a Bronze Award from the Alliance for a Healthier Generation in 2009 (Blam 2011). Morningside was recently featured by Lt. Governor Casey Cagle in the announcement of a statewide school health initiative. Children at both schools participate by planting, caring for and harvesting the garden. Local chefs demonstrate how to prepare the food we grow and the children taste what the chef has prepared.

The garden provides an experiential learning opportunity to further explore Georgia Performance Standards. It is a perfect setting to learn about making healthy eating choices, locally grown produce, and environmental stewardship. This year Schoolyard Sprouts is entering into exciting new areas. They include:

- Student exposure across all grade levels to the garden with integrated curriculum and tastings
- Parent teacher education
- Improving the food server in the cafeteria
- Educational and fundraising events throughout the year

(Blam 2011)

Opportunities such as Schoolyard Sprouts bring further benefits into the green roof costs vs benefits equation by capitalizing on the opportunity to positively impact a unique demographic and humanities most precious resource, our children. Although difficult to quantify, metrics should be created that allow for legitimate quantification of production level increases resulting children's exposure to gardening integrated with curriculum, and well as sustainable technologies such as green roofs. In the essence of simplicity, this study analyzes the direct costs and benefits associated with installing extensive vegetative roof systems on APS, however, it is assumed that a portion of APS flat roofs would be allotted for intensive vegetative roof systems where gardening would take place.

As APS continues to strive toward a community of schools with high performance standards and high performance facilities, the first topics for discussion relates to obtaining funding for projects with presumably high return value. This study aims to prove that the installation of green roofs on APS buildings represents a major project with a high return on investment (ROI), however, the venture has considerable costs. Inevitably, sourcing for these types of major projects must be evaluated. The third chapter of this thesis is dedicated to laying the ground work for the reader regarding school facilities development and exploring funding opportunities available to APS. Prior to this, however, the research methodology is discussed in chapter 2. Chapter 4 consists of detailing the findings from literature review, while chapter 5 specifically focuses on the costs and benefits of installing extensive green roofs on APS. Chapter 6 is reserved for the overall results from the study along with recommendations for future studies. While some may argue that the costs associated with green roofs are much greater than that of conventional roof systems, the life-cycle costs analysis performed on installing green roofs on all of APS school facilities (chapter 5), provides proof that the benefits received from large scale green roof installations in urbanized locations are greater than the costs.

CHAPTER 2

RESEARCH METHODOLGY

2.1 Research Overview

This thesis began with the idea that the best way to increase sustainability in the built environment is to bridge the gap between our natural surroundings and man made structures. The natural environment has sustained itself for billions of years and "naturally" holds the key to successfully sustaining the built environment. Initially the thought was to bring the natural environment inside the walls of built environment through creative low maintenance technologies. One consideration to this end involves using hydroponic technology to create a semi-self sustaining plant environment inside the walls of a building. Just as a transformer feeds a building and electrical circuits are run from this transformer to feed power to the building, imagine this transformer was a large cistern with an automated controls unit which held a water and nutrient solution that fed circuits of plants throughout the building. This way multiple plants could be feed throughout the building, even those in areas not easily accessible, and the natural environment could more easily and with little maintenance be recreated with in the walls of buildings. Research on this topic is advisable and some literature exists, however, after a brief literature search and after consulting with Dr. Linda Thomas-Mobley the focus was redirected toward green schools and technologies that schools can realistically pursue today.

The need for high-performance school buildings or green schools is quite interesting considering how special of place school buildings are. They are the locus of education, the places where children come together to learn about civics and develop basic skills to be productive members of society. Schools are also used for adult education classes, voting, community events, and other activities and may symbolize the community itself. The results of this study should be of interest to a wide range of stakeholders, including school administrators, school district business managers, federal and state education officials, parents, and teachers, as well as architects, engineers and construction professionals specializing in school design, both green and conventional. In addition, research has shown that the quality of indoor environments can affect the health and development of children and adults. Furthermore, buildings, including schools, affect the natural environment, accounting for 40 percent of US energy use and 40 percent of atmospheric emissions, including greenhouse gases (National Research Council 2007). This study aims to draw correlations between green roof systems benefits and the goals of greens schools which are defined by the Committee to Review and Assess the Health and Productivity Benefits of Green Schools as "(1) to support the health and development (physical, social, intellectual) of students teachers and staff by providing a healthy, safe, comfortable, and functional physical environment; and (2) to have positive environmental and community attributes (National Research Council 2007)."

Green roof systems represent a technology that schools can realistically pursue today considering the amount of peer reviewed literature available and the potential benefits associated with them. Also known as "living roofs", green roofs serve several purposes for a building, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, and helping to lower urban air temperatures and combat the heat island effect (McDonough et al. 2003). The benefits of green roof systems will be discussed in further detail in chapter 4. There are two types of green roofs: intensive roofs, which are thicker and can support a wider variety of plants but are heavier and require more maintenance, and extensive roofs, which are covered in a light layer of vegetation and are lighter than an intensive green roof. Quantitative data for this thesis is provided in chapter 5 by a costs vs benefits analysis of installing an extensive roof on roughly all of APS flat roofs. The costs and benefits of intensive green roofing are not specifically discussed, however it is suggested that APS review using a portion of school roofs for intensive growing that would allow students, teachers and parents the ability to grow vegetables and produce on the rooftop.

2.2 Research Modeling

In order to properly report on the topic of green roof technology use on green schools, this research consists of both a qualitative synthesizing of data and quantitative data in the form of a case study. A mixed-methods approach was sought, particularly, triangulation consisting of the use of both qualitative and quantitative research techniques. Triangulation is selected as "the model when a researcher use two different methods in an attempt to confirm, cross-validate, or corroborate findings with in a single study. This method generally uses separate quantitative and qualitative methods as a means to off set the weaknesses inherent within one method with the strengths of the other method (Creswell 2003).

After deciding on the method of research, peer-reviewed sources of data were compiled. These data sources presented a wonderful anthology of tested results on the benefits associated with green roofs a correlation between these benefits and the goals of green schools. The case study of the Tanyard Branch watershed proved to be a viable source of quantitative data and was used as the basis to perform the BCA of extensive green roofs on APS.

Early on a literature map (Figure 2.1) was created to help layout data sources and topics of interest. From this literature map a simplified organizational chart (Figure 2.3) was created and serves as the foundation for the study and building the proof that over a 40 year period, the benefits outweigh the costs of install green roofs on all of APS flat roofs.

Figure 2.1 Literature Map

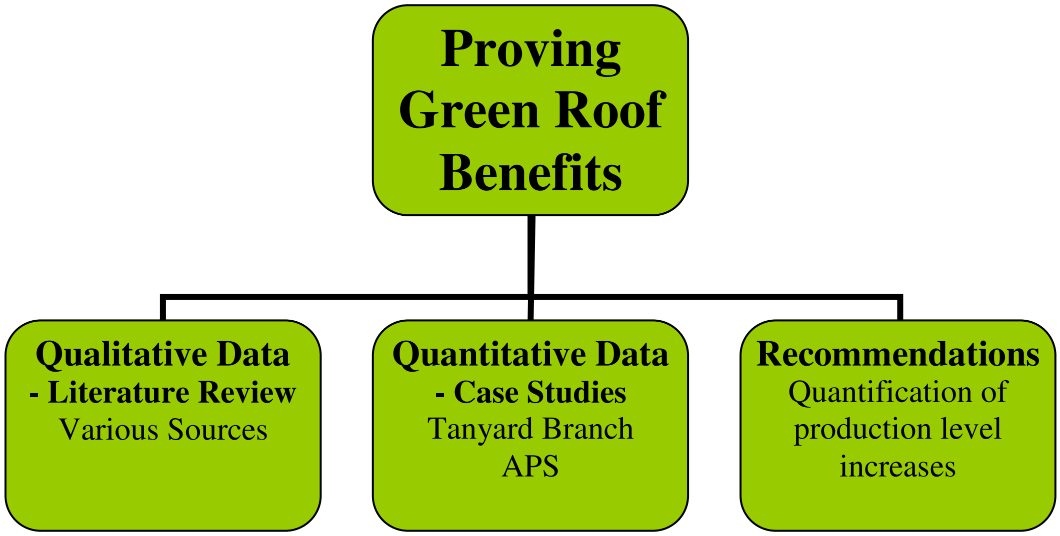


Figure 2.2 Organizational chart for proving green roof benefits

After establishing a working thesis topic, data was sourced and organized according to purpose. Green roof technology is a relatively new and emerging field in the United States so it was important that current material be used. However, testing of technology included in this study must be conducted over time so it was also important to find data reflecting time tested results. Multiple sources of peer-reviewed literature were complied and the results within compared in order to establish a basis of proof. The literature provided solid qualitative information regarding green schools and green roofs, and suggests strong potential benefits for the initiation of a program aimed at installing green roofs on all of Atlanta Public Schools. Since limited quantitative data currently exists that would help promote such programs, it is advisable that future studies be conducted with the purpose of quantifying the benefits associated with installing green roofs on K-12 schools including impacts on urbanization, energy savings, and productivity level increases for students and teachers.

CHAPTER 3

K-12 FUNDING SOURCES

3.1 Overview of the public schools' need for facilities improvements

For many reasons, some quantifiable and some non quantifiable, K-12 schools represent a group of buildings within our built environment for which a focused sustainability effort may prove exponentially beneficial. In most cities K-12 schools account for a significant portion of the impervious structures within the city. Schools are also the place where our most precious resources; our future leaders, educators, and workforce spend the majority of their time. Many school facilities in the United States are old, out-of-date, poorly maintained, and lack specific design elements that are likely to enhance teaching, learning, behavior, and other desirable outcomes. One reason why previous research regarding the effects of the physical school environment on educational outcomes has had little impact on the quality of schools is because there is a lack of knowledge about these relationships. The average age of school facilities in the U.S. is forty-two years (Rowand 1999), many needing major renovations. At the turn of the millennium it was reported that approximately $127 billion was needed to bring schools up to good overall condition (Lewis et al. 2000). According to Lewis, when surveyed about satisfaction with environmental conditions, including lighting, heating, ventilation, indoor air quality, acoustics or noise control, and physical security of buildings, forty-three percent of the schools responding reported at least one environmental factor as being unsatisfactory. Increasing enrollment and a push for smaller class sizes are creating a greater need for school construction and renovation. In 2001, school districts spent a record $28.6 billion on school construction (Agron 2002), with approximately fifty-eight percent going toward additions and modernizations. The following chart shows the most recent 4 years of capital outlay for school construction, land and building acquisition of public school districts. The types of projects included in school construction capital outlay are: new construction; building modernization; renewal of building systems; and major maintenance projects.

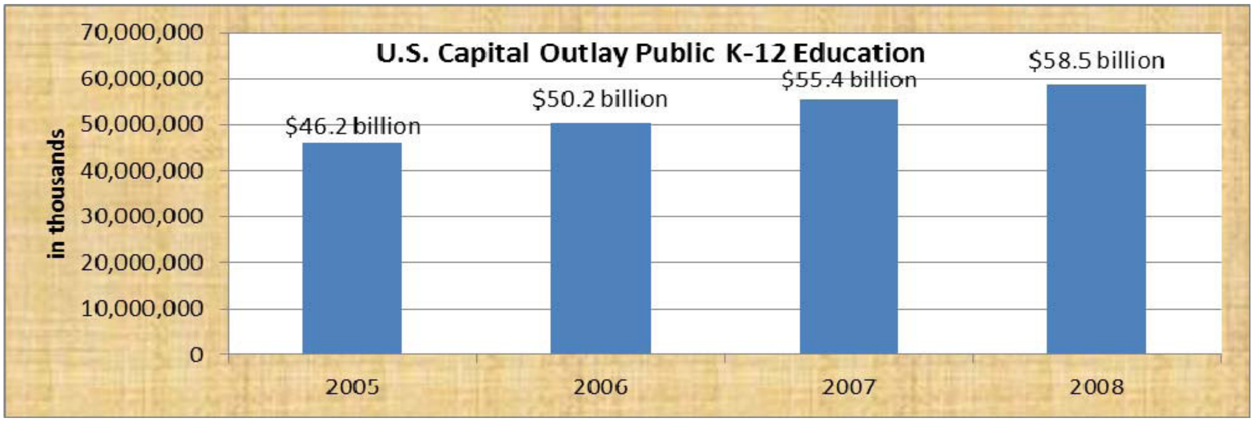


Figure 3.1 Public School Capital Outlay for School Construction, Land and Building Acquisition 2005-2008 (U.S. Census Bureau)

The federal programs that offer some support for local districts and charter schools for school facility construction projects fall into four types.

1) **Dedicated federal grants** for improving public school facilities;

2) **Allowable federal grants** where school districts or public charter schools are eligible to apply, but where funds are not specifically targeted to public school facilities;

3) **Dedicated federal tax credits or loans** for improving public school facilities; and

4) **Allowable federal tax credits or loans** where school districts are eligible to apply, but where the tax credits or loans are not specifically targeted for public school facilities.

3.2 Dedicated Federal Grant Programs for Public School Facilities

The U.S. Department of Education contributes an average of about 8.2% annually toward PK-12 public education operating costs (National Center for Education Statistics 2011). These annual recurring costs are for salaries and other program costs related to the U.S. Department of Education's mission to promote student achievement and the preparation for global competitiveness by fostering educational excellence and ensuring equal access. In contrast, as is shown in the charts below, U.S. Department of Education has extremely limited programs related to school facilities. Less than one tenth of a one percent of the total capital outlay for facilities is paid for with federal grant funds. For every one thousand dollars that states and local school districts spend on public school building improvements paid for through capital outlay, the federal government contributes about 86 cents (Filardo 2010).

The charts below contrast the U.S. Department of Education contribution toward local school district operating budgets and local school district capital budgets.

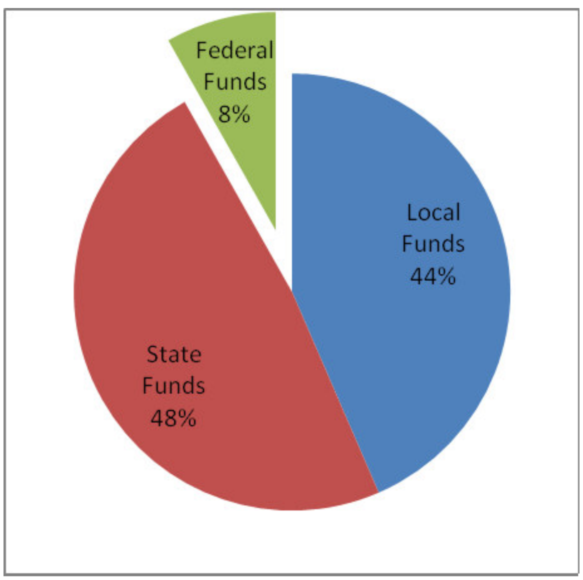


Figure 3.2a - Sources for PK-12 Operating Funds, 2008 (Filardo 2010)

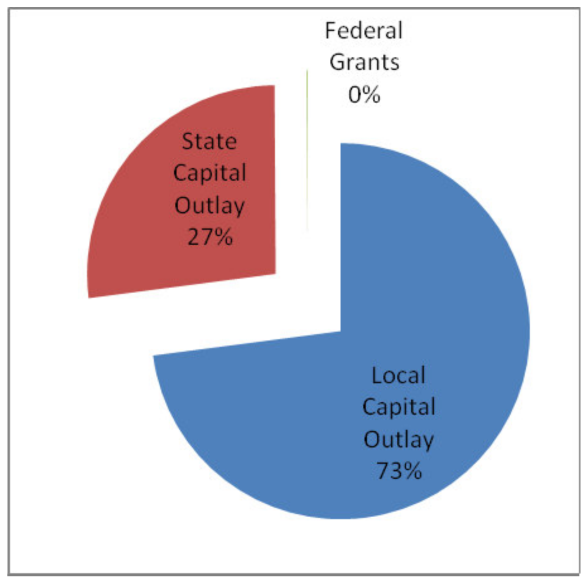


Figure 3.2b - Sources for PK-12 Capital Outlay Expenditures, 2008-2009 (Filardo 2010)

<u>3.3 Allowable Federal Grant Programs for Public School Facility Use</u>

There are a number of ongoing federal programs that allow funding for school facilities, but the programs are not dedicated specifically to the improvement of public school facilities. There are two types of federal grant programs where spending for facility improvements are permissible. One type is where program related funds are allowed to be used to improve facilities in order to support the program. The Head Start Program is one example of this. The Head Start Program includes grants that can be used for the purchase of a facility, renovation, and construction. The American Recovery and Reinvestment Act of 2009 (ARRA) appropriated an additional $2.1 billion and was expected to expand enrollment by 64,000 children and families. Head Start and Early Head Start grants are awarded to local governments, Indian tribes, school districts, nonprofit organizations and for-profit organizations (Filardo 2010). Because of the necessity for specially designed spaces for very young children, the Head Start Program permits their recipients to use funds for facilities. While nearly all of the funding is used to pay teachers and other operating costs related to providing early childhood education, it is legal to use some funds for facility improvements. The other type of eligible program is established to improve public facility infrastructure, but not specifically public school buildings or grounds. These programs permit school districts to apply for facility infrastructure funds along with other public sector entities. For example, school districts are eligible to apply for energy conservation grants as part of the State Energy Programs.

3.4 Tax and Finance Benefit Programs

Nearly all school districts finance the cost of new construction or major capital improvements to their school facilities and grounds, rather than paying for these costs with current year revenues. Federal tax credit or loan programs help school districts and public charter schools improve the facility conditions for teaching and learning. The American Reinvestment and Recovery Act of 2009 (ARRA) increased the tax credit programs and introduced new programs that could be utilized for school facilities. The U.S. Department of Treasury has various tax-credit bond programs available to public school districts, public charter schools and Bureau of Indian Affairs funded schools to reduce the cost of borrowing. These tax credit programs are:

Qualified Zone Academy Bonds

Established in 1997 and administered by the Internal Revenue Service, the Qualified Zone Academy Bonds (QZABs) allow school districts serving low-income students (35% or more free and reduced lunch) to issue tax-credit bonds that save on interest costs for financing school renovations and repairs (Filardo 2010). These bonds cannot be used for new construction. A public school is eligible as long as it fits under the definition of a qualified zone academy. A state's allocation is based on the state's population under the poverty line. The state education agencies have their own application processes for local entities.

Qualified School Construction Bonds

Administered by the Internal Revenue Service, the Qualified School Construction Bonds can be used to finance the construction, rehabilitation or repair of a public school facility or for the acquisition of land where a school will be built. This tax-credit program was created by the American Recovery and Reinvestment Act of 2009 (ARRA). After receiving their federal allocation, states in turn allocated to Local Education Agencies based on applications. All states were eligible and received an allocated amount in 2009 and 2010. Also eligible were the 100 largest low-income local educational agencies. As of September 2010, only 30% of the allocation was utilized (Filardo 2010).

Tax Credit Bonds for Bureau of Indian Affairs-Funded Schools, U.S. Department of Interior

This tax credit bond program is for the construction, modernization, and repair of Bureau of Indian Affairs funded school facilities. These bonds are intended to reduce the cost of Tribal Governments completing much needed construction or repairs of school facilities. To be eligible for this tax-credit bond program the applicant must be an Indian Tribal government.

3.5 Tax and Finance Benefit Programs with School Construction Eligibility

Finally, there are tax and finance benefit programs that school districts or public charter schools are eligible to apply for, but which are not designed specifically for school districts or public charter schools.

Build America Bonds

Created in 2009 by the American Recovery and Reinvestment Act, the Build America Bond Program (BABs) is intended to expand the market for municipal bonds by attracting buyers that normally would not buy tax-exempt bonds. There are no volume caps for the tax credit and direct payment BABs; however there is a $10 billion volume cap limitation for the Recovery Zone Economic Development BABs (Filardo 2010). State and local governments are eligible to use BABs on capital projects such as schools, hospitals, transportation infrastructure, and water and sewer upgrades. Build America Bonds have been used throughout the nation by school districts for funding school facilities construction. As of September of 2010, school districts and state school facility authorities had used around $14 billion in Build America Bonds, approximately 11% of total BABs issued (Filardo 2010).

Clean Renewable Energy Bonds

The Clean Renewable Energy Bonds can be used to obtain lower cost financing for clean energy projects and were available for school districts to use on school facilities. Allocation of bonds starts with the smallest dollar amount qualified application and continues until the volume cap for the category has been exhausted. Government agencies (including school districts), public power providers, and cooperative electric companies are eligible for these bonds.

Qualified Energy Conservation Bonds

QECBs can be used to finance a broad range of qualified conservation projects, including energy efficiency capital projects, research grants, green energy technology demonstration projects, and public energy efficiency education campaigns. Bond volumes are allocated to the states based on the state’s percentage of the U.S. population. The state must allocate bond volumes to large local governments (municipalities and counties with populations of 100,000 or more). Large local governments should contact their State Energy Office regarding this program. State, local and Tribal governments can utilize the Qualified Energy Conservation Bonds.

New Market Tax Credit Program

The program was created to help revitalize low-income communities within the United States. The program allows a bank or equity firm that lends to a Community Development Entity (CDE) to receive a 39% federal tax credit over seven years. A CDE is an organization that’s primary mission is serving or providing investment capital for low-income communities or persons. This program has been used by nonprofits building charter school facilities. CDEs can provide loans (or an equity investment) to charter schools for facilities in low-income neighborhoods.

Rural Community Facilities Program

This program is designed to develop essential community facilities for public use in rural areas, including school facilities. The Rural Community Facilities Program uses three flexible financial tools: the Community Facilities Guaranteed Loan Program, the Community Facilities Direct Loan Program, and the Community Facilities Grant Program. The rural community facilities grants, direct and guaranteed loans are available to municipalities, counties, special-purpose districts, non-profit corporations, and tribal governments to be used in rural areas and towns of up to 20,000 in population.

Conclusions for School District Financing

Except for tax law that provides very favorable financing for school districts and public charter schools who generally borrow funds to pay for the upfront hard and soft costs of school facility improvement or new construction projects, the federal government has assumed no responsibility for the quality of public school facilities for teaching and learning. There is no staff dedicated to this issue at the U.S. Department of Education. There is more staff time focused on this at the Department of Energy and the Environmental Protection Agency than at the U.S. Department of Education. It is considered a local school district responsibility. Considering this, it is important that local school districts do everything in their power to take advantage at all tax incentives and funding opportunities available to them. The growing trend for more sustainable development provides opportunities for schools districts to earn tax incentives and find funding for energy and resources saving green technologies implemented into development. The most popular platform by which to base green development strategies for school districts is LEED for Schools which will be discussed in the following segment. A case study on green roofs in Atlanta Public Schools will be explored in chapter 5 of this paper and presents one specific area by which school districts can focus green development in hopes of earning tax incentives and government funding.

3.6 Leadership in Energy and Environmental Design (LEED)

The LEED rating system offers a platform for which school districts and other building owners alike can not only pursue tax incentives and funding opportunities, but also reduce operating costs while reducing the negative impact their facilities have on out environment. As the green building sector grows exponentially, more and more building professionals, owners, and operators are seeing the benefits of green building and LEED certification. As stated by the Unites States Green Building Council (USGBC) "green design not only makes a positive impact on public health and the environment, it also reduces operating costs, enhances building and organizational marketability, potentially increases occupant productivity, and helps create a sustainable community." LEED fits into this market by providing rating systems that are voluntary, consensus-based, market-driven, based on accepted energy and environmental principles, and they strike a balance between established practices and emerging concepts.

Specifically for the school districts the LEED for Schools Rating System recognizes the unique nature of the design and construction of K-12 schools. Based on LEED for New Construction, it addresses issues such as classroom acoustics, master planning, mold prevention, and environmental site assessment. By addressing the uniqueness of school spaces and children's health issues, LEED for Schools provides a unique, comprehensive tool for schools that wish to build green, with measurable results. LEED for Schools is the recognized third-party standard for high performance schools that provide healthy environments for students, are comfortable for teachers, and are cost effective.

In 2007, LEED for Schools was released with 79 available points, a 10 point increase from the standard LEED NC rating system. This was due to added requirements and the availability of incremental points. In 2009, the total points available in the two systems was standardized at 100, with LEED NC being more heavily focused on Sustainable Sites, Energy, and Materials and Resources, while LEED for Schools featured additional points for Water Efficiency and Indoor Environmental Quality.

Many LEED for Schools strategies are based on the underlying realization that children are not little adults. Their bodies behave and respond differently to their surroundings, requiring extra attention to several key areas. For example, children have a higher respiration rate than adults, meaning that they are more susceptible to airborne contaminants. Accordingly, LEED for Schools places a stronger emphasis on Indoor Environmental Quality, including the addition of Low Emitting Materials categories for Furniture/Furnishings and Ceilings and Wall Systems, and the elimination of smoking in the building. A new credit, IEQc10, is meant to promote greater levels of mold prevention. With their reduced summer hours and traditional challenges with preventative maintenance, schools are especially susceptible to mold issues.

Many school districts are taking bold steps in the effort to improve Indoor Environmental Quality. Cincinnati Public Schools is in the process of implementing a district-wide Indoor Air Quality Program that will allow individuals to report IAQ issues to a district committee, as well as encourage schools to develop individual school-based IAQ teams.

"Many IAQ programs are created to address existing concerns; however, we're doing this as a proactive step. We feel implementation of an IAQ Program is a ‘best practice’ and helps to maintain, and improve on, our existing healthy environment," said Cynthia Eghbalnia, Environmental Health and Safety Coordinator for the district. "We are a strong supporter of the idea that a healthy environment improves learning and academic performance. At the school level, the proactive support of an Indoor Air Quality program fits nicely with the existing directive of most school wellness committees."

For districts looking to learn more about Indoor Air Quality, the U.S. Environmental Protection Agency provides "Tools for Schools," a program that offers a wealth of resources including case studies, the latest research, and an Action Kit that provides everything needed to begin improving IAQ in their buildings.

Another key component of the LEED for Schools rating system is IEQp3, the Minimum Acoustic Performance prerequisite. Because teaching is primarily delivered in an oral setting, eliminating extraneous sounds in the classroom is crucial to helping students learn. In addition, developing effective verbal communication skills and language proficiency is the foundation of advanced cognitive skills. Providing an acoustically-sound environment can literally help students unlock their abilities in all areas of learning.

Another credit, IEQc9, addresses Enhanced Acoustical Performance; however, architects and engineers must weigh the educational impact when pursuing this credit. IEQc9 typically drives classroom design into a configuration that is not conducive to many current methods of instruction. Many districts have chosen to forgo the enhanced acoustical performance in favor of a more flexible classroom design that better supports their curriculum and methods.

At any rate this focus on acoustical performance and indoor air quality in LEED for Schools strengthens the argument for green roof installations on schools. Vegetative roofs are shown to increase acoustical performance in buildings. In addition, vegetative roofs act as natural air filtration devices by eliminating many airborne contaminants with benefits including air quality improvements from the mitigation of nitrous oxides, volatile organic compounds by plants. The extent to which vegetative roof systems influence acoustical performance and air quality will be discussed in the literature review in chapter 4. Figure 3.3 shows the possible points available in LEED for Schools 2009.

LEED 2009 FOR SCHOOLS NEW CONSTRUCTION AND MAJOR RENOVATIONS PROJECT CHECKLIST

Sustainable Sites		24 Possible Points
☑ Prerequisite 1	Construction Activity Pollution Prevention	Required
☑ Prerequisite 2	Environmental Site Assessment	Required
☐ Credit 1	Site Selection	1
☐ Credit 2	Development Density and Community Connectivity	4
☐ Credit 3	Brownfield Redevelopment	1
☐ Credit 4.1	Alternative Transportation—Public Transportation Access	4
☐ Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
☐ Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	2
☐ Credit 4.4	Alternative Transportation—Parking Capacity	2
☐ Credit 5.1	Site Development—Protect or Restore Habitat	1
☐ Credit 5.2	Site Development—Maximize Open Space	1
☐ Credit 6.1	Stormwater Design—Quantity Control	1
☐ Credit 6.2	Stormwater Design—Quality Control	1
☐ Credit 7.1	Heat Island Effect—Nonroof	1
☐ Credit 7.2	Heat Island Effect—Roof	1
☐ Credit 8	Light Pollution Reduction	1
☐ Credit 9	Site Master Plan	1
☐ Credit 10	Joint Use of Facilities	1

Water Efficiency		11 Possible Points
☑ Prerequisite 1	Water Use Reduction	Required
☐ Credit 1	Water Efficient Landscaping	2-4
☐ Credit 2	Innovative Wastewater Technologies	2
☐ Credit 3	Water Use Reduction	2-4
☐ Credit 4	Process Water Use Reduction	1

Energy and Atmosphere		33 Possible Points
☑ Prerequisite 1	Fundamental Commissioning of Building Energy Systems	Required
☑ Prerequisite 2	Minimum Energy Performance	Required
☑ Prerequisite 3	Fundamental Refrigerant Management	Required
☐ Credit 1	Optimize Energy Performance	1–19
☐ Credit 2	On-site Renewable Energy	1–7
☐ Credit 3	Enhanced Commissioning	2
☐ Credit 4	Enhanced Refrigerant Management	1
☐ Credit 5	Measurement and Verification	2
☐ Credit 6	Green Power	2

Materials and Resources		13 Possible Points
☑ Prerequisite 1	Storage and Collection of Recyclables	Required
☐ Credit 1.1	Building Reuse—Maintain Existing Walls, Floors and Roof	1-2

LEED 2009 FOR SCHOOLS NEW CONSTRUCTION AND MAJOR RENOVATIONS PROJECT CHECKLIST (Figure 3.3 cont.)

☐ Credit 1.2	Building Reuse—Maintain Existing Interior Nonstructural Elements	1
☐ Credit 2	Construction Waste Management	1-2
☐ Credit 3	Materials Reuse	1-2
☐ Credit 4	Recycled Content	1-2
☐ Credit 5	Regional Materials	1-2
☐ Credit 6	Rapidly Renewable Materials	1
☐ Credit 7	Certified Wood	1
Indoor Environmental Quality		**19 Possible Points**
☑ Prerequisite 1	Minimum Indoor Air Quality Performance	Required
☑ Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Required
☑ Prerequisite 3	Minimum Acoustical Performance	Required
☐ Credit 1	Outdoor Air Delivery Monitoring	1
☐ Credit 2	Increased Ventilation	1
☐ Credit 3.1	Construction Indoor Air Quality Management Plan—During Construction	1
☐ Credit 3.2	Construction Indoor Air Quality Management Plan—Before Occupancy	1
☐ Credit 4	Low-Emitting Materials	1-4
☐ Credit 5	Indoor Chemical and Pollutant Source Control	1
☐ Credit 6.1	Controllability of Systems—Lighting	1
☐ Credit 6.2	Controllability of Systems—Thermal Comfort	1
☐ Credit 7.1	Thermal Comfort—Design	1
☐ Credit 7.2	Thermal Comfort—Verification	1
☐ Credit 8.1	Daylight and Views—Daylight	1-3
☐ Credit 8.2	Daylight and Views—Views	1
☐ Credit 9	Enhanced Acoustical Performance	1
☐ Credit 10	Mold Prevention	1
Innovation in Design		**6 Possible Points**
☐ Credit 1	Innovation in Design	1-4
☐ Credit 2	LEED Accredited Professional	1
☐ Credit 3	The School as a Teaching Tool	1
Regional Priority		**4 Possible Points**
☐ Credit 1	Regional Priority	1-4

LEED 2009 for Schools New Construction and Major Renovations

100 base points; 6 possible Innovation in Design and 4 Regional Priority points

Certified	40–49 points
Silver	50–59 points
Gold	60–79 points
Platinum	80 points and above

Figure 3.3 LEED 2009 for Schools New Construction and Major Renovation Project Checklist (USGBC)

One portion of the LEED for Schools Rating system is so unique that is deserves special mention. IDc3 provides credit for the use of the School as a Teaching Tool. This credit encourages the use of the building's sustainable design features as an experiential example of traditional lessons. The goal is to educate a generation of students who view sustainability as part of their everyday lives and understand how they and their surroundings impact the overall environment.

This research primarily focuses on green roof technology and the many benefits associated with green roofs. There are few to no single projects that the owner of a school facility can pursue that are as far reaching as the installation of a green roof. Referencing the project checklist above (Figure 3.3), the installation of a green roof can be used to obtain LEED points in Sustainable Sites (Site Development, Storm Water Design, Heat Island), Water Efficiency (Water Efficient Landscaping), Energy and Atmosphere (Optimize Energy Performance), Indoor Environmental Quality (Thermal Comfort, Acoustical Performance), as well as Innovation in Design (The school as a teaching tool). Not only could a school district earn valuable LEED points for all of its schools by implementing a large scale project such as installing green roofs on all of its schools, but it could also make a major contribution to its adjacent watershed community by helping to make significant reductions to wet water flows (WWF) including combined sewer overflow (CSO), sanitary sewer overflow (SSO), and storm water discharges. In addition, such a project would make considerable reductions to the urban heat island effect caused by a growing number of impervious structures throughout the community. This reduction to the ambient temperatures surrounding the school district will have measureable benefits to the maintenance/replacement of adjacent infrastructure. A detailed analysis of these benefits is performed in chapter 5 of this thesis in an effort to highlight the break even point and net present value (NPV) of green roof installations.

CHAPTER 4

LITERATURE REVIEW

4.1 Energy consumption, GHG emissions and Heat Island Effect

In exchange for flourishing cities built upwards, urban communities have sacrificed permeable and moist surface areas for impervious surfaces (buildings, pavements) and as a result, cities experience warmer climates than surrounding rural areas. This phenomenon is referred to as the Urban Heat Island Effect. Both domestically and internationally, cities have utilized cool pavements, increased tree cover and vegetation, green and heat-deflecting roofs to counteract the heat island effect. According to Hashem Akbari, author of many peer-reviewed journal articles on the subject of energy impacts of heat island reduction, planting vegetated cover on the roofs of city buildings is the ideal method because it simultaneously mitigates the heat island effect, reduces energy bills, mitigates storm water runoff, and improves building aesthetics.

The vegetation of rural areas has a direct role in reducing air temperatures through the process of evapotranspiration. The plants will absorb water through their roots and release it through their leaves into the air, through the act of transpiration and evaporation. This in turn helps disperse the ambient heat (Burba 2008). The impervious surfaces of urban areas, such as conventional roofs, parking lots, sidewalks and roads, replace vegetation, reduce the amount of water evaporated and the benefits of evapotranspiration are lost. During warm sunny summer days in rural areas, the moist or shaded surfaces will remain close to air temperature while the exposed dry surfaces in urban areas can be heated to temperatures as high as 90°F hotter than the air (Carter 2006). The difference in daytime surface temperatures between rural and urban areas ranges between 18 and 20°F (EPA 2008). Surface urban heat islands are strongest when the sun is shining during the day; but can also be observed at night.

Why should individuals be concerned about the urban heat island effect? The heat island effect negatively affects urban communities in various ways. Higher temperatures in the summertime lead to an increase in energy demand for cities, when compared with surrounding rural communities. Urban areas experience the burden of higher air conditioning costs in the summer and higher heating costs in the winter. One study found that the heat island effect was responsible for 5-10% of the peak electricity demand for the cooling of buildings in cities (Akbari 2005). Localized urban areas produce an augmented amount of greenhouse gas emissions and air pollution. The increase in energy demand produces greater greenhouse gas emissions from the power plants supplying the electricity (EPA 2008).

Impervious surfaces in cities result in a higher percentage of runoff and lower percentage of evapotranspiration than areas with natural ground cover. The hot impervious surfaces can transfer their stored heat to storm water, which will eventually make its way through storm drains and eventually to rivers, streams and lakes where the water temperatures of these bodies are also raised. The fluctuation in water temperature can adversely affect the ecosystem (EPA 2009). Higher heat can also lead to the quicker degradation and rutting of pavements (Mallickm 2009). There are also increased risks of heat-related illnesses (cramps, exhaustion, heat-stroke and respiratory difficulties) and even heat-related mortality (Changnon 1996).

Different studies using thermal remote sensing have measured the daytime surface temperatures in urban areas. The following maps were created by Robert Simmon using data from the NASA Landsat Program, in order to assess New York City's heat in the summer during daytime hours. The data was captured on August 14, 2002 at 10:30 AM (Scott 2006). The map labeled Figure 4.1a illustrates temperatures, with cooler temperatures in blue and hotter temperatures in yellow. The map labeled Figure 4.1b illustrates the location of vegetation throughout the city, with light green indicating a sparse amount of vegetation and dark green representing dense vegetation.

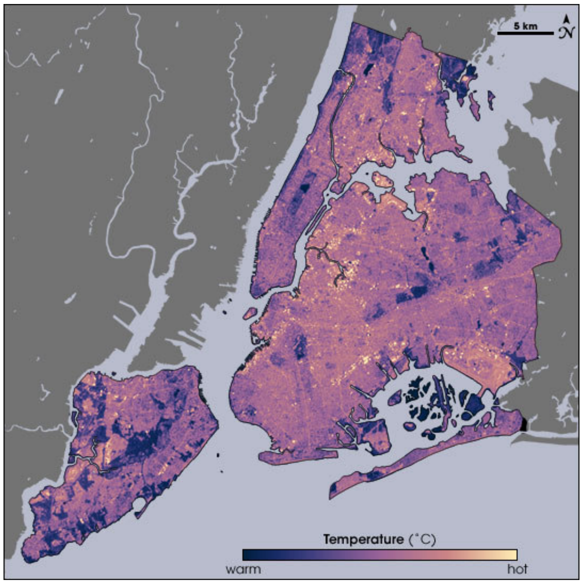


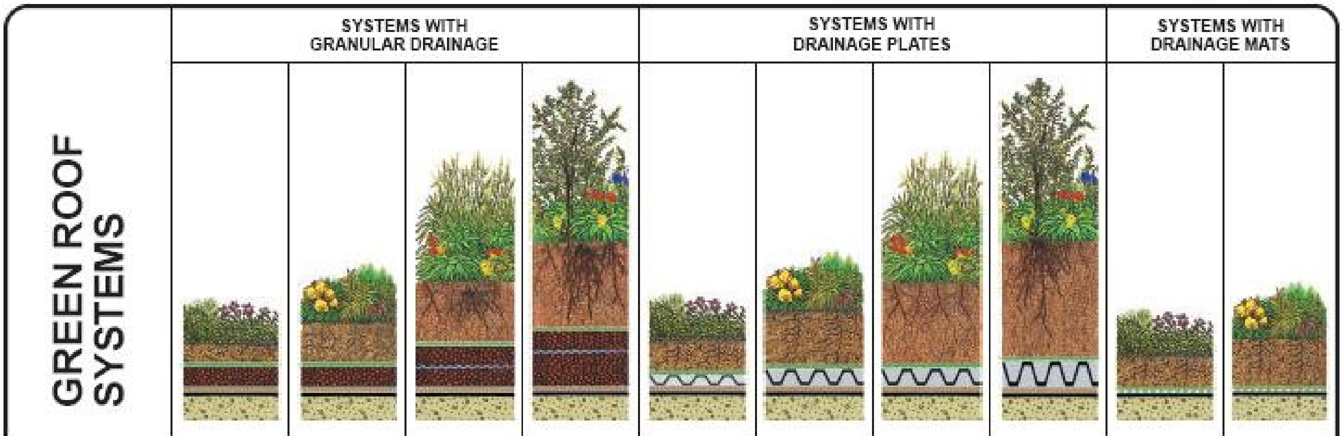
Figure 4.1a: Temperature Map (Scott 2006)

Figure 4.1b: Vegetation Map (Scott 2006)

These maps illustrate a correlation between areas with dense vegetation and cooler temperatures, suggesting the existence of the urban heat island effect.

4.2 Green Roof Basics

Flat roofs represent a significant percentage of the impervious structures in urban areas. In addition, roof tops are remain relative undisturbed places. That is that they are not used like other impervious surfaces such as roads and parking lots, thus they symbolize an ideal area that can be used to replace vital vegetation that has been destroyed by development. Modern-day green roofs mainly evolved in Europe, where government incentives have led to a burgeoning green roof market. Until 1970, green roofs were regarded as luxurious home amenities when Professor Hans Luz, a German Landscape Architect, proposed the use of green roofs as a means of improving the quality of the urban environment (McDonough et al. 2003). Figure 4.2 is an excellent visual representation of the cross-section of typical green roof systems.



	G1	G2	G3	G4	P1	P2	P3	P4	M1	M2
system designation	G1	G2	G3	G4	P1	P2	P3	P4	M1	M2
typical plants	sedum herbs	sedum herbs perennials	perennials grasses shrubs	grasses shrubs trees	sedum herbs	sedum herbs perennials	perrenials grasses shrubs	grasses shrubs trees	sedum herbs	sedum herbs perennials
extensive soil mix	2"	4"	-	-	3"	5"	-	-	3"	5"
intensive soil mix	-	-	6"	9"	-	-	8"	12"	-	-
separation fabric	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	1/8"	-	-
granular drainage	2"	2"	4"	6"	-	-	-	-	-	-
drainage plate	-	-	-	-	1"	1-1/2"	1-1/2"	2-1/2"	-	-
drainage mat	-	-	-	-	-	-	-	-	3/8"	3/8"
protection mat	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	1/4"	-	-
nominal thickness	4"	6"	10"	15"	4"	7"	10"	15"	3"	5"
dry weight	19 lbs/ft²	28 lbs/ft²	45 lbs/ft²	69 lbs/ft²	14 lbs/ft²	23 lbs/ft²	34 lbs/ft²	52 lbs/ft²	14 lbs/ft²	22 lbs/ft²
saturated weight	26 lbs/ft²	41 lbs/ft²	70 lbs/ft²	105 lbs/ft²	23 lbs/ft²	37 lbs/ft²	57 lbs/ft²	85 lbs/ft²	23 lbs/ft²	37 lbs/ft²
minimum slope	0:12	0:12	0:12	0:12	1/4:12	1/4:12	1/4:12	1/4:12	1:12	1:12
maximum slope	1:12	1:12	1:12	1:12	1:12	1:12	1:12	1:12	3:12	3:12
water retention	50%	60%	70%	80%	50%	60%	70%	80%	50%	60%
irrigation system	-	-	subsurface	subsurface	-	-	surface	surface	-	-

Figure 4.2 Cross Section of Common Green Roof Systems (Coffman 2004)

4.3 Green Roof Costs

Because of the greater amount of layers and intricacy, intensive roofs require a higher capital investment ($25-40+/sq ft) and have higher long-term maintenance costs. Extensive green roofs are the lighter weight and simpler designed roofs that typically cost $5-$25/sq ft or $54-$269/sqm (EPA 2008). There are various factors driving costs which lead to the wide range of cost estimates. The design and specifications of a project, the type of existing roof, roof accessibility and the type of new roof system required in re-roofing with a roof-root-repelling membrane, green roof system (the type and depth of growing medium, square footage of the green roof), the types of plants and season of installation, installation and labor and maintenance costs (typically only for the first two years) are all factored in to the extensive green roof cost range. These factors are cost drivers for intensive roofs, with the addition of an irrigation cost component and higher and long-term maintenance costs (Peck 2010).

A green roof recently installed atop a Duke University Hospital building with a roof area equal to ~6000 square feet, cost $17 to $20/sq ft in roofing assembly installation, which includes the price for the greening component, $8 to $10/sq ft (Pennigar 2011). Xero Flor America's pre-vegetated mats were used in the green roof because they have a synthetic fiber in them, which makes it easy and inexpensive if a portion of the green roof needs to be replaced. The design of intensive roofs do not allow for such simplified and cheap installations and replacement options. The goal of an extensive green roof is to design a roof that requires little to no maintenance and added structural support. Extensive green roofs are less expensive and the preferred type when retrofitting an older building.

4.4 Green Roof Benefits

There are many documented benefits of green roofs. They supply an otherwise dry region with thermal mass and evaporative cooling. Soil and plants also provide a natural insulation for the building structure, which aids in reducing energy use and minimizing utilities costs for businesses. Soil and plants used on the edifice absorb water, thus reducing storm water runoff. Green roofs also help reduce costs and the production of landfill-bound garbage by eliminating the use of petroleum-based shingles. Green roofs have numerous incentives for business owners as well. For example, many hotels have utilized green roofs to help with storm-water management, growing fresh produce for in-house use in restaurants, and for cutting costs because self-sustaining roofs require little to no maintenance (Cannarsa 2008). Aside from the environmental and economic benefits, green roofs are aesthetically pleasing, can help in promoting sustainable community gardens and in some instances can serve as additional city green spaces, as demonstrated by New York's High Line, a park built on an out of use railway in Manhattan (Friends of the High Line 2009).

Green Roofs and Energy

Buildings in the United States represent 38.9% of primary energy use and 72% of national electricity consumption, according to the Environmental Information Administration (2008). Buildings also account for 38% of all CO_2 emissions in the US (USGBC 2008). According to the American School and University's Annual Maintenance and Operation Study, the average total energy/utilities cost per student in the US rose from $232.55 in 2007 to $400 in 2009. This represents a 72% increase in energy costs in only two years. As energy consumption and subsequent costs increase, so do the CO_2 emissions from power plants. If Universities are to reduce their carbon footprint, changes need to be made to older buildings in order to reduce their impact on the environment.

Researchers have determined that vegetated roofs are able to reduce the heat-island effect (Akbari 2009) as well as significantly reduce energy consumption and costs (Hui 2002). A Canadian study determined that installing a 32,000 square foot green roof on a commercial building in Toronto would reduce the building's total cooling by 6% and the heating energy usage by 10% for a complete energy usage reduction of 21,000 kWh (Bass 2001). A similar study published in Building and Environment found that green roofs reduced building temperatures and increased the thermal comfort outdoors (Alexandri 2008).

Green Roofs for Storm Water Management

Urban development has led to large areas of impervious surfaces such as parking lots and building roofs. Runoff from these areas is causing problems for many urban and suburban communities. Not only is total volume of wet weather flow (WWF) increased, but peak flow rates are also increased. Implementation of traditional storm water best management practices (BMPs) in urban areas may not be practical in all circumstances due to limited available surface area and other concerns. Green roofs have been suggested as a means to reduce the storm water of development because they have been shown to both detain and retain storm water. Extensive green roof systems are proven to be major contributors to runoff reductions. According to a 2008 study by Timothy Carter, a 3.5 - 4 in. (8 -10 cm) deep green roof can retain 50% or more of the annual precipitation. Even when rainfall leads to saturated conditions, green roofs significantly increased the time to peak prior to producing runoff and are a prime storm water mitigation tool.

Significant water quality and quantity issues are caused by storm water runoff from developed areas in North America. For the five years from 1997 to 2001, the rate of urban development averaged 890,000 ha/year (2,400 ha/day) (NRCS 2003). Development results in water quality impairment and quantity management issues throughout the affected watersheds.

For example, nutrient loading (a widespread result of agricultural runoff) may be replaced as the critical impairment issue for a watershed by increased peak flows, flooding, and urban pollutant loads as runoff is collected from impervious pavement and roof surfaces (Hanley 2007). Wet weather flow (WWF) including combined sewer overflow (CSO), sanitary sewer overflow (SSO), and storm water discharges is one of the leading causes of water quality impairment in the United States and improvement of controls is one of two priority water focus areas cited by the EPA's Office of Water in its National Agenda for the Future (Perciasepe 2004). Pollution problems stemming from these WWFs are extensive throughout the country. Problem constituents in WWF include visible matter, pathogens, biochemical oxygen demand (BOD), suspended solids (SS), nutrients, and toxicants (e.g., heavy metals, pesticides, and petroleum hydrocarbons). National estimates have projected costs for WWF pollution abatement in the tens of billions of dollars (APWA 2002). Therefore, municipalities need alternatives to control the high costs of WWF treatment prior to release. This report presents data showing that green roofs are effective BMPs for mitigation of the environmental impacts to receiving waters associated with urban runoff. Greening of rooftops, by incorporating plants into the design of roofing systems, has been suggested as a method to reduce the impacts of storm water runoff by reducing the impervious surface within a developed zone (Scholz-Barth 2001). The benefits of green roofs for storm water control include direct retention of a portion of the rainfall, and delaying and decreasing the peak rate of runoff from the site (PACD 1998). Media depth and porosity play an important role in storm water retention and plant growth. Plant size and selection depend on the depth of the roof overburden (growing media) and local climate, but almost always consists of winter-hardy, drought tolerant, perennial plants, e.g., sedums which are a type of succulent, cactus-like plant.

4.5 Major Green Roof Findings

The use of green roofs in Germany is widespread and has been promoted in many cities through financial incentives (Pederson 2001). Economies of scale, contractor experience, and specialized equipment have reduced the cost of installing a green roof in Germany and throughout Europe. In contrast, installing a green roof in the United States can be very expensive, adding from at least $6/sqft ($65/sqm), to more than $30-$40/sqft ($320-$430/sqm), to the cost of the roof (Bick 2011). Other barriers also limit widespread use of green roofs in the US. Engineers, architects, developers, and policy makers are unsure of the actual quantifiable benefits of a green roof. In the U.S., Peck (2007) observed as recently as 2006, only 70 acres of green roofs had been planted, as compared to Germany where in 1996 alone, 2,500 acres of green roofs were installed (Peck et al., 1999); however, the 2006 totals represent a 24% increase over the previous year, and only account for reported projects. Annual reductions of runoff of 38 -54% and 38 -45% have been reported for 3 in. (8 cm) deep media (Miller 1998). A media depth of 2.5 in. (6.5 cm) can retain 40% of the rain for an individual 2-in. storm (Scholz-Barth 2001). The City of Portland, Oregon, has developed guidelines for green roofs that state that some jurisdictions may reduce water and sewer charges or may provide financial incentives to developers who retain storm water on site, and that green roofs can help reduce the size of storm water management ponds. Much of the existing published information on green roof performance in North America has been collected from pilot-scale or sometimes commercial-scale green roofs without replication. For example, recently Van Woert et al. (2005) performed studies of three simulated roof platforms with dimensions of 2.44 x 2.44 m (8 x 8 ft), divided into three sections, to quantify the effects of various treatments on storm water retention. The mean precipitation retention ranged from 48.7% for gravel test beds to 82.8% for vegetated test beds. Roof slope and green roof media depth also impacted storm water retention with the combination of reduced slope and deeper media reducing the runoff the most. They also observed moderation of peak flows. Little scientifically based replicated data have been collected in North America at the building scale. The EPA is emphasizing the use of BMPs to capture and treat runoff from small storms, especially the use of onsite BMPs, often termed low-impact development (LID), such as bio-retention, swales, or rain gardens. Green roofs offer a practical alternative for new construction and for retrofitting existing structures. Implementation of green roofs in European countries like Germany is a regulatory driven technology in the municipalities that have adopted mandates for green roofs on new buildings. With more municipalities in the United States looking for flexible ways to control storm water, including the use of storm water credits or watershed-based trading, developing new storm water controls such as green roofs is a vital initiative for the EPA. Green roofs appear to be a suitable technology for urban areas, as there is limited space to implement traditional storm water controls. Land values are too high to devote much surface area to storm water control devices. In addition, surface-based storm water control devices can be vandalized and may pose public access and safety issues. Green roofs can slow the runoff from roofs during larger storms and during smaller storms are capable of absorbing a majority if not all of the rainfall. In essence, the impervious area is decreased when planted roofs are installed on, or retrofitted to, buildings. The plants also act as a bio-filter in reducing the pollutant content of the rainfall. This technology reduces the heat island effect of standard roofs by replacing the low albedo surface, as well as by increasing evapo-transpiration, which helps cool the air by several degrees. Furthermore, because of reduced air temperature, less energy is needed for air conditioning (Osmundson 1999).

Van Woert et al. performed a study of water retention capabilities of green roofs installed on three facilities in Chicago. Storm water runoff was monitored and analyzed from January, 2005 through November, 2005. Replicated data were collected for 72 precipitation events from three green roofs and two flat asphalt roofs. Un-replicated data were collected from an unplanted, media-only roof section and rooftop detention section. Events included high-intensity, short duration (1 in. (25 mm) in 30 min) events and high total precipitation steady rate (2.65 in. (67.3 mm) over 8 hr) events. Unique data were also collected from winter precipitation events, including snow and ice. Green roofs retained over 50% of total precipitation during the study period. During the summer months, nearly 95% of the precipitation was retained. During winter, retention was smaller (<20%) and not significant. Peak flows were delayed by green roofs and in many cases peak flow rates were also reduced. Green roofs were most effective at delaying and reducing peak flows when they were not fully saturated. Rapid peak flows, i.e. high-intensity, short duration rainfalls were attenuated more than lower intensity, high-total volume longer period flows.

These data and data from other studies at this site confirm that under ambient conditions, a 3.5 -4 in. (8 -10 cm) deep green roof can retain 50% or more of the annual precipitation. The replicated data from this study provide the only available estimate of expected differences in performance from identical green roofs. Green roof runoff was quite consistent during the warm summer months (almost no runoff), but was more variable during winter months when runoff from buildings varied during some storm events from 80% for one building to 100% for others. Flow rates were reduced in runoff from green roofs until systems were saturated, at which point runoff flow roughly equaled the rate of precipitation input; however, peak flows were reduced and time-to-peak increased.

Monitoring Runoff Water Quality from Green Roofs

Storm water runoff samples were collected from green and flat asphalt roofs and analyzed for water quality parameters. Twenty-one precipitation events were evaluated for pH, EC, color, turbidity, and nitrate. Additionally, discrete samples were collected using manual techniques and brought back to Penn State's analytical laboratory for further analysis. A limited data set of five sampling events was analyzed for nutrients, hardness, and other ions. Analysis of the 21 precipitation events revealed that green roof runoff was colored yellow and had higher pH and EC (Van Woert et al. 2005). The increased pH was a benefit in an area of such acid precipitation. The smaller data set of five samples indicated that green roof runoff generally had equal or greater concentrations of nutrients (phosphorous and potassium) and hardness (calcium and magnesium) measured in solution than flat asphalt roof runoff. The concentration of green roof phosphorous release was comparable to that of known residential landscape values. Loadings of nutrients (to sustain plants) and hardness (a property of the clay based media) were significantly greater for the green roofs, approximately 300% for phosphorous and potassium, and as much as 1000% for magnesium (Van Woert et al. 2005). Analysis for other ions did not statistically discern whether the loadings were greater or lesser from green roofs. Partly, this is due to the small sampling size, but also indicates that beyond proper management of the planting media to reduce excess nutrient release, loadings from green roofs are not significant. Results based on this smaller, limited water quality monitoring data set (five samples) should be used cautiously.

Green roofs appeared to be beneficial for the removal of atmospheric nitrate. In the summer when green roofs retained nearly 100% of the precipitation almost no nitrate ran off the green roofs. Water quality impacts of a green roof are thus seasonal plant-related mechanisms and depend on both the input concentration and the precipitation and runoff rates. The data collected suggest that the best use of a green roof is probably in conjunction with other storm water BMPs such as bio-infiltration and rain gardens, where possible. Runoff discharged to storm water collection systems that have water quality BMPs, is preferred; however, the time delay and volume reduction provided by green roofs still offer receiving water quality benefits for storm water systems that discharge without treatment. For this reason, discharge of green roof runoff to a combined sewer system is appropriate and desirable, due to the significant reduction of volume discharge and extension of time to peak, regardless of discharge concentration. Green roofs are an important storm water technology for urban areas with limited space for retrofitting BMPs into the existing conveyance system.

Evaluating Evaporation and Evapotranspiration Rates of Green Roofs

Other findings from this study performed by Van Woert et al highlight the evapotranspiration (ET) capabilities of green roofs. Eight 0.5 m2 (6.1 ft2) weighing lysimeters planted with a mixture of delosperma nubigenum and sedum album were compared to unplanted media. These lysimeters were monitored during 21-day dry-down cycles during warm actively growing periods and cool dormant periods. Drying cycles lasted 21 days. Green roof plants rapidly lose water following irrigation after which water loss rates decline. This was a new finding. Initial ET from green roofs was similar to other measured systems and could be described using normal ET prediction equations such as Pennman-Monteith. Unplanted media lost water at a similar rate initially, but after several days, water loss rates declined below that of the green roofs. Thus plants are essential to the system, while the unplanted media are limited to evaporating water from the surface, the plants continue to remove water from down in the media, resulting in quick recharge of the storm water runoff reduction potential. These data demonstrate the superiority of a planted roof over an equivalent ballast roof for retention of storm water during the summer months. Rapid initial loss of water from these plants followed by drought adaptation is a new finding that provides an important component of any model or design tool to predict the effectiveness of a green roof as a storm water tool.

Factors Affecting Green Roof Establishment and Maintenance

Media type, depth, and early drought were evaluated as factors affecting establishment and early management of a green roof. A test procedure for evaluating long-term pH buffering of the roof was developed and evaluated. Early drought is very detrimental to the survival and establishment of green roof plants particularly with shallow media depths. Sedum species may survive but other green roof plants may not survive. The results suggest that 3 -4 in. (80 -100 mm) of irrigation with the potential for supplemental irrigation during establishment will result in better plant survival rates. Tests of the pH buffering capacity of the planting media suggest that the green roof media can buffer acid precipitation for approximately 10 years, after which it may be necessary to amend the media with lime to maintain the pH buffering capacity (Kumar 2005).

Green roofs can attain an annual 50% reduction in roof runoff. From a practical standpoint, this potentially translates into a reduction in area and volume control needed for the typical suite of water quality BMPs. In terms of practice, the storm water volume and increased time to peak control offered by green roofs could result in more building space, additional parking spaces or additional and usable open space. However, this concept would need to be field tested at a larger scale and the actual percent reduction in storm water BMPs would need to be evaluated, e.g., potential BMP reduction may be between 5 and 20%, not a full 50% annual capture, particularly in areas with dormant (winter) seasons. Clay-based media may be better in areas affected by drought due to water retaining capacity of the media. Shale-based media may be better for areas subject to more frequent precipitation, particularly acid precipitation.

In this project, several constituents of concern from the green roof were studied. Results demonstrated that green roofs may reduce certain pollutants, e.g., acid precipitation and nitrate, but that it may increase loadings directly related to these planted systems, e.g., phosphorous, potassium, calcium, and magnesium (Van Woert et al. 2005). Due to the variability in results, continued sample collection and analysis to minimize the variability may be warranted. Further testing of materials used for green roof construction and planting should be conducted to determine loadings coming from roofs. Also, other constituents from atmospheric deposition and building materials for standard roofing should be tested under controlled systems. According to Todd C. Rasmussen, Ph.D. Professor of Hydrology & Water Resources, Warnell School of Forestry and Natural Resources at The University of Georgia, the nitrate results should not be viewed as a surrogate for all nitrogen and future studies should look at total nitrogen, and potentially ammonia and total Kjeldahl Sampling for some of the water quality parameters was only represented by five storms; additional sampling is warranted due to the small size of this data set. In addition, only analyzing five paired events for green and flat asphalt roof runoff may have biased results toward lower loadings from the flat asphalt roofs as not as much rain was required to produce runoff, i.e., diluted flat asphalt runoff was compared to higher concentration, lower volume green roof runoff. If further comparison tests are performed to standard roofing materials and systems, paired analysis of loadings should include storm results from other roofing systems and should include a full range of precipitation events, from when green roofs are not producing runoff to events with large amounts of runoff. The greatest benefit green roofs can provide is the reduction in runoff, which is also a water quality benefit not adequately represented by the five paired data points. The field site provided statistically valid results for runoff volumes and much of the concentration data; however, the calculated loadings are based on relatively small experimental rooftops, when compared to an urban watershed. Due to the variability observed in this study, modeling loadings for green roofs for watershed management may require additional monitoring with full-scale roofs or multiple roofs in an urban setting. The size and time interval limited analysis of peak flows from the green roofs. Van Woert suggests that additional hydrology monitoring may be warranted on larger roofs to better determine potential peak flow values from green roofs. The half-media and half-detention roofs, while providing insight to the experiment, were of limited value for individual storms because of the absence of replicates. Splitting the roof into two media sections or two detention sections would have provided additional replicates. Another rain gauge or triangulation of rain gauges around the buildings would have provided more insight to rainfall totals. The laboratory studies indicate that ET can be modeled using standard equations; however, further testing should be conducted. Data suggest there may be a need to develop unique water loss model factors to account for water loss patterns in sedum carpet roofs to accurately predict rate of recharge for water detention capacity. The drought studies indicated some potential limitations without the use of irrigation. Van Woert et al. also determined that green roofs need to be tested in other climates so that further design specifications on plant mixtures, media depth and amendments, and potential irrigation requirements can be determined. Other climatic conditions should also include year-to-year or long-term studies, as it seems very likely that in dry years the green roof runoff would be far less than in wet years.

The effects of green roof runoff discharge on receiving waters or the potential for additional treatment of green roof discharge were not addressed. For suburban or agricultural areas, green roof runoff treatment may be as simple as directing the downspouts to grassed areas (vegetated filter strips or swales) or collecting green roof runoff in rain barrels to be used for irrigation, but this may not be practical for urban areas where there is limited room for storm water controls. For urban areas that have combined sewers, green roofs should be viewed as a benefit due to the volume reduction to the combined system and the delay in time to peak. The same can be said for storm water conveyance systems that drain to storm water BMPs. The effects of mixing and the delay in time to peak may be sufficient to allow discharge to storm water conveyance systems that discharge to a receiving water even without treatment; however, further studies or modeling exercises may be warranted. Directly discharging green roof runoff to a receiving water is not recommended. Additional lysimeter studies should be conducted to identify more plant species suitable for green roofs, especially varieties that are drought resistant and require minimal nutrient supplements.

CHAPTER 5

CASE STUDY

5.1 BCA of Green Roof Systems – Atlanta Public Schools

The results of Van Woert et al studies provide great insights into the beneficial nature of green roofs. Their findings were based off of relatively small scale modeling, but give foresight to large scale applications at the urban water shed level. The built environment has been a significant cause of environmental degradation in the previously undeveloped landscape. As public and private interest in restoring the environmental integrity of urban areas continues to increase, new construction practices are being developed that explicitly value beneficial environmental characteristics. The use of vegetation on a rooftop, as an alternative to traditional roofing materials is an increasingly utilized example of such practices. The vegetation and growing media perform a number of functions that improve environmental performance, including: absorption of rainfall, reduction of roof temperatures, improvement in ambient air quality, and provision of urban habitat. A better accounting of the green roof's total costs and benefits to society and to the private sector will aid in the design of policy instruments and educational materials that affect individual decisions about green roof construction. This study uses Atlanta Public Schools as an experimental green roof plot to develop a benefit cost analysis (BCA) for the life cycle of extensive (thin layer) green roof systems. The results from this analysis are compared with a traditional roofing scenario. The net present value (NPV) of this type of green roof currently ranges from 10% to 14% more expensive than its conventional counterpart (Carter 2006). A reduction of 20% in green roof construction cost would make the social NPV of the practice less than traditional roof NPV. Considering the positive social benefits and relatively novel nature of the practice, incentives encouraging the use of this practice in highly urbanized watersheds are strongly recommended.

The relationship between the built and natural environment has traditionally been one of complete opposition. Both terrestrial and aquatic ecosystems are drastically, and often times irrevocably, altered during the process of urbanization (Pickett 2001; Paul and Meyer 2001). Water regulation and supply, erosion control and sediment retention, nutrient cycling, climate regulation, and waste treatment changes are all ecosystem services either eliminated or significantly degraded in highly developed landscapes (Costanza 1997). The construction of man-made structures and impervious surfaces that are a defining feature of highly developed areas are an important causal element behind environmental decline in urban areas (Arnold and Gibbons 1996).

One reason why construction practices lead to environmental problems is that the costs of environmental degradation are not fully realized by the party who caused the damage. Thus, when evaluating construction costs, developers have historically viewed environmental damage as exogenous to the development process. Federal and state environmental laws have altered this situation to some extent in the last several decades. Developers have been limited by laws and regulations concerning erosion and sedimentation control, post-construction storm water control and urban tree preservation. Nonetheless, developers still make land use decisions without considering the full cost of the environmental damage that their activities create.

Positive incentives have been developed for more ecologically sensitive development, particularly for buildings. A rating system called leadership in energy and environmental design (LEED) has been created by the United States Green Building Council for certification of commercial buildings that have a reduced environmental impact. Many municipalities require buildings built with public funds to receive LEED certification. An adaption of this policy appears to be transforming construction practices for schools as LEED for Schools 2009 (discussed in chapter 3) is being utilized by school systems such as APS.

Specific building construction practices are being refined to create structures which have a much smaller impact on the surrounding landscape than previously thought possible. At the broadest scale, sites are selected for their proximity to public transportation, their ability to maximize open space and protect habitat, effectively manage storm water runoff, address the heat island effect found in urban areas, and reduce light pollution (www.usgbc.org). Sustainable water use for a building may involve xeriscaping, graywater reuse for irrigation, and the use of low-flow or composting toilets and non-water urinals, which are becoming increasingly cost effective (Gleick 2003). A building's energy use is also an extremely important component of sustainable design. From simply designing smaller structures to installing active solar panels or other on-site sources of self-supplied energy, there are a wide range of practices available to reduce a building's reliance upon fossil fuel energy sources.

Increasingly, building materials contain recycled material content in new construction and attempt to reuse as much of the existing structure in renovations as possible (Appendix E - Mays HS Renovation). Indoor environmental quality is also an important feature of green buildings. Paints and adhesives designated ''Low-VOC'' or ''No VOC'' (volatile organic compounds) reduces the low level toxic emissions found in older materials and improves indoor air quality for building occupants. Day-lighting larger portions of the structure improve the working environment in school buildings as well as reducing energy costs when high performance windows are used.

5.2 Designing Rooftops for Sustainability

Of these many ways that buildings can be designed and constructed in a more sustainable manner, the roof surface can easily be overlooked as space that can be designed into an environmental amenity for the building, not simply contributing to environmental problems. The rooftop is typically the same size as the building's footprint and is the structure's prime barrier against precipitation and solar radiation. To the extent that the roof surface can be transformed into useful space, the building becomes economically and functionally more efficient and can have a more benign effect on the surrounding landscape.

Published research has focused largely on the energy savings associated with different types of roofing systems. Akbari (2001) found that changing a roof from one with low albedo to high albedo in Sacramento, CA would decrease cooling energy use by 80%. Other studies have documented the affect of insulation on the heat flux at the roof surface, how to incorporate active and passive solar designs into rooftop systems, and the energy benefits associated with ventilated roof systems. These alternatives to traditional roofing systems are beginning to gain more of a market share and EPA has established an Energy Star rating system for roofing products, primarily identifying roofing membranes which have high albedos and the potential to significantly reduce building energy costs (www.energystar.gov).

While energy savings are an important function of alternative roof systems, other benefits may also be realized. In a traditional roofing system, rainfall hits the rooftop and is quickly channeled into the nearest gutter or storm sewer system with the goal being to have the roof shed water as quickly as possible. As discussed in chapter 4, regulations have mandated storm water management plans for municipalities and rooftop runoff control has become an important management practice for minimizing degradation of aquatic ecosystems. One solution is to create rainwater storage tanks which can capture rainfall from the roof surface and store it for a time before it is reused or slowly discharged. A more effective means, however, and one that also provides additional benefits relates to replacing the vegetation destroyed during development with rooftop vegetation.

Green roofs: multifunctional roof surfaces

The application of vegetation and growing media to the roof surface is an increasingly popular practice which produces improvements in both energy conservation and storm water management. These green roofs are multifunctional in that they provide numerous environmental benefits simultaneously. These benefits include: decreasing the surface temperature of the roof membrane and energy use in the building, retaining storm water for small storm events, increasing biodiversity and habitat in urban areas largely devoid of such space, and improving ambient air quality (Clark 2005). While these benefits are inherent in all green roof systems to some degree, depending on the design of the roof there is potential for other amenities as well. Accessibility and esthetic appeal for the building occupants, sound insulation and the potential for urban agriculture are all realistic benefits provided by green roof applications (Peck 1999).

As described in chapter 4, there are two general types of modern green roof systems: intensive and extensive. Intensive systems are characterized by deep (>6 in) growing media, opportunities for a diverse plant palate on the rooftop and high cost and maintenance requirements. Extensive systems are designed to be lightweight and easily retrofitted on existing roof surfaces. They contain thin growing media depths (2–6 in) and can support a limited number of drought tolerant plants that thrive in the limited water and nutrient conditions. Over 80% of green roofs in Germany are extensive systems and these types of green roofs are expected to offer the most cost-effective approach for roof greening (Harzmann 2002).

5.3 Economic Analysis of Green Roofs

While green roof projects have recently generated significant interest in design fields such as landscape architecture, little research has been done to evaluate the costs and benefits of green roof systems for urban applications. Much of the peer-reviewed literature on the economics of green roofing systems is found in conference proceedings and evaluate the private benefits at a single roof scale. Lee (2004) compared green roof and traditional roof life-cycle costs over 60 years for a single roof in Oregon. They found the green roof to be 7% more expensive than the conventional roof over this time. This analysis included extended roof life, energy savings, and storm water fee reduction in the economic benefits that the green roof provided. Clark (2006) demonstrated a return on investment of 11 years on a single green roof in Michigan when low green roof installation costs and high environmental benefits were considered. Alternative metrics to monetary values such as Eco-indicator values and energy analysis have been used to compare green roofs to conventional roofs in a sustainability context. These studies find green roofs provide significant environmental benefit over a traditional roof relative to the life cycle and embodied energy of its materials (Alcazar and Bass 2006; Coffman and Martin 2004; Kosareo and Ries 2006). Other published reports typically focus on a single green roof benefit or qualitatively describe a series of benefits derived from different types of green roofs.

Benefit cost analysis has been widely recognized as a useful framework for assessing the positive and negative aspects of prospective actions and policies, and for making the economic implications alternatives an explicit part of the decision-making process (Arrow 1996). Benefit-cost analysis compares alternatives over time as well as space, and uses discounting to summarize its findings into a measure of net present value (NPV). The test of NPV is a standard method for assessing present value of competing projects over time. In the case of this study, the roofing scenario with the lowest NPV is the preferred option as the low value indicates the least costly alternative.

This study quantifies the costs and benefits of thin-layer, or extensive, green roof systems as they compare to typical flat roofs on Atlanta Public Schools. The results from a similar study performed for the Tanyard Branch urban watershed in Athens Georgia were used as a basis for calculation and theory. The authors of the study Tanyard Branch, combined the local construction costs for an established green roof test site with experimentally collected storm water retention data and building energy analysis data into a single metric using conventional cost-benefit analytical techniques applied over the life cycle of a typical green roof. In order to carry out this analysis, the participants, led by Timothy Carter, Ph. D. in Ecology at the University of Georgia, relied on published data from other green roof research and practice for estimating these effects. This may introduce some bias, and indicates that this work is subject to revision as increasing experience with green roofs produces more and better data. This information was used to evaluate all Atlanta Public Schools as a case study for application of widespread green roofs. As green roof popularity continues to grow, it is important for accurate life-cycle benefit–cost analyses (BCA) of green roof systems to be performed to inform both policy makers who may allocate public funds for projects with public benefits, and private building owners who may see a future financial incentive to invest in new and relatively unproven technology. The project examines the feasibility of replacing all the flat roofs of

Atlanta Public Schools with green roof systems. This network of schools is located within the highly urbanized heart of Atlanta, Ga. which is home to the 430 mile Chattahoochee River that makes up the largest part of the Apalachiacola-Chattahoochee-Flint River Basin draining into the Gulf of Mexico.

The Tanyard Branch study used 2003 aerial photography, the impervious surfaces including rooftops were digitized into a geographic information system (GIS). About 53.8% of the land cover is impervious surface with rooftops accounting for 15.9% of the total land cover in the watershed (Figure 5.1). Flat roofs are the most viable candidates for greening as they often require no additional structural support and minimal design expertise for green roof installation (Banting 2005). Flat roofs constitute 176,234sqm or 7.4% of impervious surface for the Tanyard Branch watershed (Carter 2008). Comparatively, APS rooftops comprise roughly 551,985sqm (Appendix B) within Atlanta's watershed that has 26,088,720sqm of impervious surfaces which represents 2.1% of impervious surfaces for Atlanta's watershed (Scenna and Morris 2011).

For the Tanyard Branch project, a 42.64sqm green roof test plot was established in October 2002 on the campus of the University of Georgia (Fig. 5.2). The test plot was designed to be simple to build and easy to replicate using American Hydrotech's extensive garden roof. American Hydrotech, Inc. is a single source supplier for the specialized green roofing materials. These materials included a WSF40 root protection sheet, an SSM 45 moisture retention mat, a Floradrain FD40 synthetic drainage panel, and a Systemfilter SF geotextile filter sheet (American Hydrotech, 2002). The growing media was a Lightweight Roof Garden mix provided by ItSaul Natural, LLC. This soil mix is a blend of 55% Stalite expanded slate, 30% USGA sand, and 15% organic matter composed primarily of worm castings. This mix was spread to a depth of 7.62 cm. Six drought-tolerant plant species were selected for their ability to survive low nutrient conditions and extreme temperature fluctuations found at the roof surface. No irrigation or fertilization was applied except for the initial three days of planting (Carter 2006).

Fig.5.1 Tanyard Branch watershed impervious cover and stream network (Carter 2006)

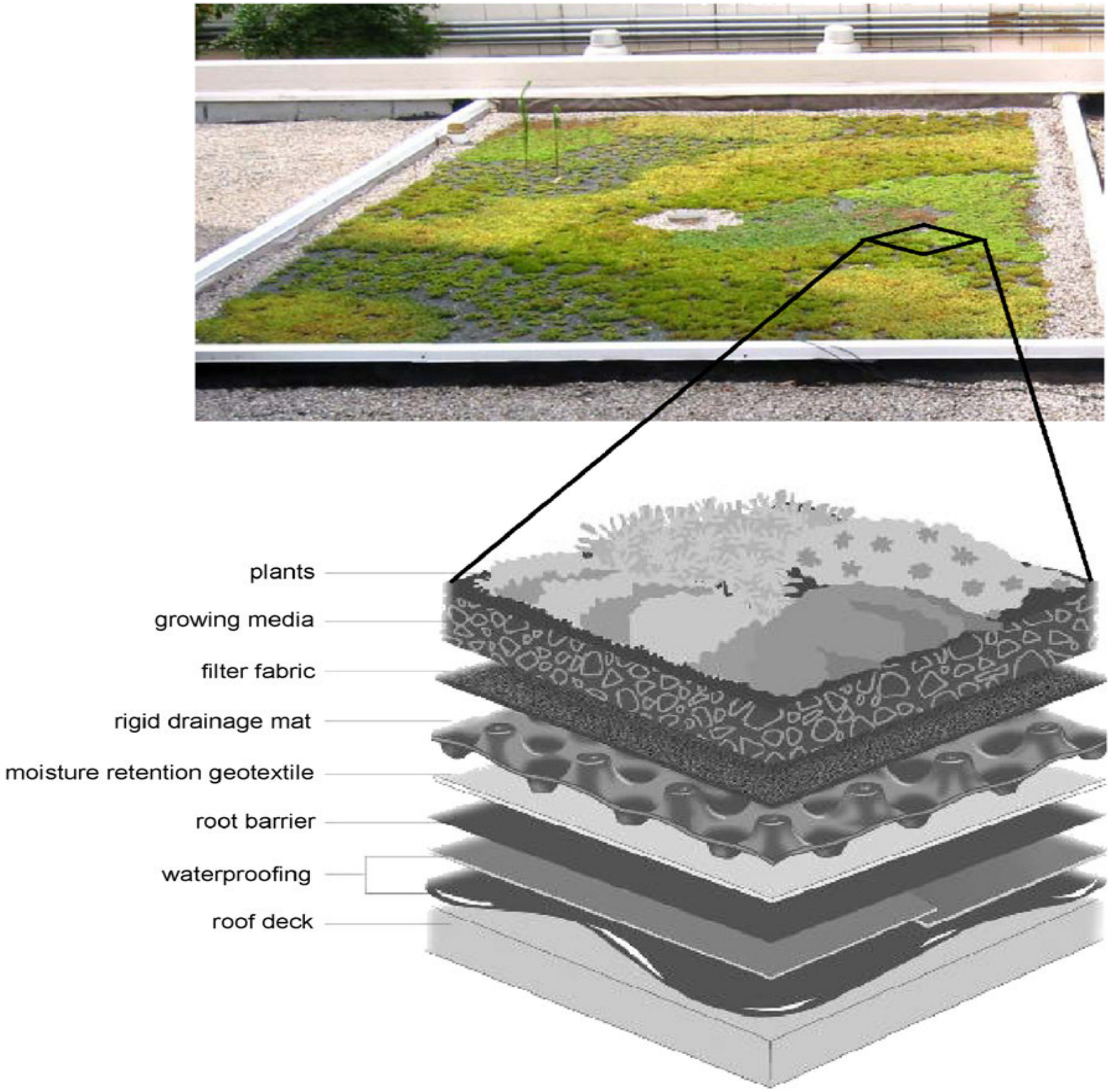


Fig.5.2 Green roof test plot and layer cross-section (Carter 2006)

5.4 BCA Framework – Discounting of Benefit Cost Flows and Sensitivity

Green roof BCA was performed according to an 8-stage framework found in Hanley and Spash (1993). The stages are: definition of project, identification of project impacts, identification of which impacts are economically relevant, physical quantification of relevant impacts, discounting of cost and benefit flows, application of the NPV test, and sensitivity analysis. The period of analysis was one green roofing cycle, which was estimated to be 40 years based on the doubling of the roof life due to the vegetated cover. Private BCA for greening a single flat roof of 929sqm as well as a social BCA of greening all the flat roofs in the watershed was performed. All roof greening occurred at year zero. Traditional roofs were greened at year zero and also underwent one reroofing cycle at year 20. Avoided storm water costs were applied at year zero. Energy and air quality benefits were applied every year of the analysis. A discount rate of 4% was applied to the reroofing scenario as well as all the green roof benefits.

The economically relevant impacts of widespread roof greening were established and physical quantification of these impacts were performed using the green roof test plot as a template for all new green roofs in APS. The benefits were divided into categories found in Table 5.1 with the conceptual framework outlined in Fig. 5.3. Analysis for the social BCA was performed at the APS school district scale while a private BCA was performed using a typical one-story 929sqm roof. Details of each category follow below and the results are summarized in Table 5.2.

The first category deals with construction and maintenance expenses. The construction costs of a typical built-up bituminous roof system on a concrete roof deck were taken from personal interviews with three local roofing contractors and additional verification from the Means Construction Cost Data. The traditional roof was assumed to have a 20-year guarantee on the waterproofing membrane and thus an effective 20-year life before replacement. The construction costs of a conventional roof were estimated to be $83.78/sqm. The cost estimate on the green roof was obtained from the test site as well as personal interviews with three single source green roofing manufacturers (Saul Nurseries, LiveRoof, and GreenGrid).

Table 5.1

Benefits from extensive green roof systems

Category		Quantified?
Construction and maintenance	Double the roof life	Yes
Storm water management	Sewer pipe size reduction	Yes
	Reduces need for alternative storm water BMPs	Yes
	Storm water utility fee reduction	Yes
Energy and insulation	Additional insulation Energy savings	Yes
Air quality	Nitrogen oxide uptake	Yes
Habitat/greenspace	Increase bird and insect habitat	No
Urban heat island	Reduction in ambient air temperatures	No

(Carter 2006)

Baseline scenario assumptions

Building

- all flat roofs are built-up roofs with gravel ballast
- reroofing cycle of twenty years
- reroofing occurs for all roofs at year zero and year twenty

Society

- need additional storm water retention
- NOx market for emission reduction

Private

- existing storm water utility fee
- insulation as required by local building codes

Green roof scenario assumptions

Building

- all flat roofs are extensively greened with 7.62cmof growing media
- reroofing cycle forty years
- green roofing occurs for all roofs at year zero

Society

- green roof storm water storage of 4.27 cm
- less electricity used from increased green roof insulation
- air quality improvement from green roof installation

Private

- water quality storage credit for stormwater utility fee
- energy savings frominsulation provided by green roofs
- NOx tradable credits

Figure 5.3 Modeling assumptions for private and social BCA (Carter 2006)

Table 5.2
Costs and benefits per square meter of roof

	Year	Unit values ($/sqm)
Costs		
TR construction and maintenance	0.2	83.78
GR construction and maintenance	0	155.41
Social benefits		
Avoided storm water BMP cost	0	9.06
Energy	1-40	0.37
Air quality	1-40	0.11
Private benefits		
Storm water utility fee credit	1-40	0.04
Energy	1-40	0.37
Air quality	1-40	0.11

(Carter 2006)

The average cost from these sources was compiled into a unit cost estimate of for initial construction of an extensive (7.62 cm of growing media) roof system. No additional waterproofing cost was added. While each installation would not have identical costs depending on accessibility, structural integrity, and design considerations, an estimate of $158.82/sqm was used based on average costs from the manufacturers and the local test plot. Maintenance on a thin-layer green roof is considered equivalent to the maintenance schedule of a traditional roof with visual inspections twice per year. Many industry groups claim green roofs can extend the life of the waterproofing membrane over 200% (Coffman 2004). This is due to the vegetation and growing media protecting the membrane from harmful ultra-violet radiation and physical damage. Since green roofs have only been used extensively in the United States in the past decade, there are few examples to verify this claim. However, engineered green roofs in Europe have been shown to function for over twice the life span of conventional roofing systems (Kohler

2001). For this study, green roofs are assumed to last for 40 years—twice the life span of conventional roofs.

While the unit construction cost of $158.82/sqm is used for the base case analysis, this most likely is at the high end of what would be experienced for widespread green roof construction in APS. It is partially based on estimates of what would be required to build an initial demonstration roof, and thus ignores economies of scale in materials purchasing as well as innovations in construction techniques developed as local contractors gain experience. Second, in Germany where the industry has been established for over 30 years, construction costs may be as much as 50% lower for larger installations (www.greenroofs.com). It is therefore assumed that true construction costs will vary between 50% and 100% of this initial estimate when the sensitivity analysis is performed.

Economic relevance of storm water management

Storm water management is a second economically relevant category. Under the US Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) Phases I and II storm water rules, jurisdictions with municipal separate storm sewer systems (MS4s) are required to develop a storm water management program relying upon storm water best management practices (BMPs) to control storm water discharges (EPA 2011). According to the EPA, the best way to mitigate storm water impacts from new developments is to use practices to treat, store, and infiltrate runoff onsite before it can affect water bodies downstream. Innovative site designs that reduce imperviousness and smaller-scale low impact development practices dispersed throughout a site are excellent ways to achieve the goals of reducing flows and improving water quality. Green roofs may potentially be one of the BMPs used to accomplish the goals of this program. Green roofs have been shown to retain a significantly higher percentage of storm water when compared to a traditional roofing system. A study in Michigan documented how, during medium volume rain events, a thin-layer green roof system retained 48% more rainfall than a gravel ballast roof (VanWoert 2005). The local test roof for the Tanyard Branch study was monitored for its ability to retain storm water from November 2003–November 2004. The green roof retained, on average, more than 77% of the rainfall throughout the year with retention performance determined primarily by total storm rainfall volume.

Using the storm water retention performance data and APS spatial information, total additional storm water storage from greening all flat roofs could be estimated for APS. The spatial analysis was formulated using data gathered from APS representatives and interpolated from data revealed from the Tanyard Branch study. Based on this data extensive greening will provide an additional 13.37 cm of storm water storage depth which results in total storage for APS of approximately 23,622 cubic meters. This retention data was then compared with published retention and cost data from other storm water BMPs for determining the cost for an equal amount of storage using other practices given the land cover in the watershed (EPA 1999). Since the experimental area is already highly urbanized, only BMPs which are typically used in an ultra-urban application were considered. These BMPs include sand filters, bio-retention areas, and porous pavement. Depending on the type of BMP used in the comparison, different cost savings may be realized (Table 5.3). The avoided cost of using alternative storm water BMPs is considered part of compliance with Phase II storm water rules in Atlanta and the benefits are included in the social BCA. Analysis was run by dividing the total storm water storage volume provided by green roofs equally among the three alternative BMPs and calculating the total cost of this alternative scenario (Table 5.3).

Table 5.3

Avoided cost of urban BMPs (source: EPA, 1999)

BMP	Cost ($/m^3 treatment)	Total cost ($) using flat green roof storage in APS
Bio-retention area	232.37	5,607,154 (232.37 x 23, 622)
Porous pavement	141	3,330,702 (141 x 23,622)
Sand filter	263.09	6,214,712 (263.09 x 23,622)
Equal distribution of the three BMPs	212.15	5,011,407 (212.15 x 23,622)

(Carter 2006)

An additional private storm water benefit for green roofs may be realized in the regulatory arena. Increasingly, jurisdictions are creating storm water utilities, which charge fees to parcel owners based on their parcel's storm water contribution to the system. These utilities generate income used exclusively for storm water management operations. Parcel owners are commonly given exemptions or credits if they can demonstrate that they are keeping their site from contributing runoff to the storm water system (Morris 2011). Atlanta has enacted a storm water utility and incorporated a system of credits for demonstrated on-site management. With the proper documentation, green roofs are assumed to accomplish the water quantity standards required for the storm water credit. In the case the roofs in Tanyard Branch, this results in a savings of approximately $0.04/sqm to $0.08/sqm based on building type (Table 5.4). This translates to savings of $0.04/sqm per year for APS school buildings or $22,079/year. Calculations were performed based on the spatial information of the schools in the APS. The total value was applied to the private BCA. This is a transfer payment which does not increase social welfare and therefore is not included in the social BCA.

Table 5.4

Storm water utility benefits by building type

Building type	Benefit ($/m^/year)	Total annual benefits in Tanyard Branch ($)
Commercial	0.04	3,306.65
Government	0.04	3,908.66
Multi-family residential	0.04	1,003.02
Single family residential	0.08	28.47
Total		7,485.95

(Carter 2006)

Another aspect of storm water management is the drainage collection of pipes, inlets and junction boxes collectively termed the storm sewer system. Retention of storm water before it reaches the system may result in resizing of the pipes during maintenance and repair of the infrastructure. The City of Atlanta has and MS4 storm sewer drainage system with an area of approximately 133.2 square miles, which may include more than 60,000 structures covering 10 storm water drainage basins, based on estimates provided in the City's 2006 Storm water Management Program (SWMP) Annual Report. Spatial data for the storm sewer system was acquired for the watershed from the city of Atlanta.

Cost savings to storm water infrastructure were developed in the Tanyard Branch study. Storm water pipes in Athens-Clarke County are a minimum of 38.1 cm (15 in) and most are designed for the 25-year storm event, which in Athens is 15.85 cm. Pipe costs were estimated according to Means (2005) with unlisted pipe dimensions priced using the power function derived from Means (2005):

C ¼ 0:6318$D^{1:4086}$,

where C is the cost of pipe ($/lf) and D the diameter of the pipe (in). Reductions in the storm flow volumes from the watershed outfall were calculated for a variety of storm events using StormNet Builder, a comprehensive storm water modeling package (Boss International 2005). This study is detailed in Carter (2006). The cost savings from a reduction in pipe size was then calculated and converted to a cost per linear meter of pipe. This cost saving showed a 4.6% reduction in size for the 25-year event and a 4.4% reduction for the 100-year event. These reductions are not significant enough to result in changes in pipe sizing due to green roof implementation; therefore no economic benefit from pipe resizing was used in the analysis. However, with a watershed community the size of Atlanta it is suggested that further studies account for these benefits. Other relevant features of storm water management affected by widespread green roof implementation were not a part of this study including the effect of green roof storm water retention on the reduction of combined sewer overflows (CSOs), a phenomenon having large environmental impacts resulting from the storm water systems found in many larger cities. It was estimated in the city of Toronto, for example, that avoiding CSOs using green roofs would save the city $46.6 million in infrastructure savings (Banting 2005).

Economic relevance of energy and insulation

The third economically relevant category is energy and insulation. Green roofs act to reduce the rooftop surface temperatures through leaf shading direct solar radiation, evaporation of moisture at the surface and transpiration of the plants which cool the ambient air above the roof. Thin layer green roof systems have consistently been shown to reduce the temperature fluctuations at the roof surface (Onmura 2001). Whether this translates into significant energy savings is not clear from the literature as in one study, energy use was evaluated for small experimental sheds containing green roofs and the vegetated treatments had little effect on total energy use in each structure (DeNard 2003). Other research, however, suggests that considerable energy cost savings can be realized when green roofs are used; enough for the lifecycle cost of a green roof to be less than a traditional roof when energy savings were included in the analysis (Wong 2003). Assuming that more energy costs savings can be realized on buildings where the ratio of the foot print of the building to the volume of the building is greater, schools are excellent candidates for realizing great energy savings. Many schools average no more than two stories and have expansive flat roofs. Benjamin E Mays High School, found in Appendix E, represents typical APS school construction. The benefits from energy savings are much greater with this type of structure in comparison to a high rise building where the majority of energy savings from a green roof would be realized only on the upper floors.

For the energy-related benefits in the Tanyard Branch study, local data were used. Adjacent to the storm water green roof test plot, a second experimental roof was constructed and an analysis of the thermal conductivity of growing media as well as energy load modeling was performed. Automated measurement of in situ micrometeorological parameters such as humidity, air temperature, wind speed, radiation, and soil temperature were combined with laboratory analysis of the engineered growing medium providing local data for simulation modeling. The simulation programs used were eQuest and HYDRUS-1D, a building energy model and a combined heat and moisture simulation, respectively. The modeled buildings used were 929sqm with both square and rectangular orientations. Modeling was performed at three different heights: 1, 3, and 8 stories. Additional details from this study can be found in Hilten (2005). Cost savings from the additional insulation provided by the green roof as well as the reductions in the heating and cooling loads were found for the building and converted into unit savings to be applied across APS. The green roof's insulating value was equivalent to R-2.8, which is similar to 2.54 cm of fiberboard, fiberglass, or perlite. These types of insulation average to $3.98/sqm and this value may be considered an avoided cost in the green roofing analysis. If this avoided cost is used, however, the building owner will not realize any energy savings as there is no net increase in insulation.

A more likely scenario is that the green roof will be added and provide additional insulation, not used as replacement for traditional insulation. This additional insulation value creates energy savings for the building owner. The authors of the Tanyard Branch study used the building energy savings modeled from a single-story 929sqm building (Hilten 2005). This type of building was selected because it represents the majority of flat-roofed buildings in the watershed they studied. The energy load reduction from the green roof system was modeled at 4222.56kWh/year. This is an energy savings of 3.3% which is less than half of the 8% used in the Wong et al. (2003) study. Residential rate surveys for the 2005 year were acquired from the Georgia Public Service Commission and the 2005 average rate of $0.082/kWh was applied to the energy savings modeled in the building. This current price is used for the conservative base case BCA, but assuming electricity prices will remain constant in real terms over the next 40 years is extremely optimistic. Policies to limit air pollution and climate change are likely to bring about significant increases in this price. For the sensitivity analysis, it is assumed that the actual rate of increase in energy prices will vary on a uniform distribution between 0% (the base case assumption) and 8% (a pessimistic but plausible assumption under significant future environmental regulation). All buildings in APS were estimated to have the same energy savings, although savings may vary based on the number of stories and orientation of each structure. The unit energy savings for current energy rates was $0.37/sqm/year (Table 5.5).

Table 5.5

Energy benefits associated with green roofs

Benefit	
Building energy savings (kWh/year)	4,222.56
Energy cost ($/kWh)	0.08
Building energy savings ($/m^2/year)	0.37
Total annual savings for APS ($)	204,234

(Carter 2006)
Building energy savings ($/m^2/year) = (4222.56 x .08) / 929
Total annual savings for APS ($) = 551985 x .37

Economic relevance of air quality

A fourth economically relevant category is air quality. While the potential may be great for green roofs to improve air quality in densely developed areas, the type of vegetation found on the rooftop largely determines the amount of air-quality improvement. Trees, grasses, and shrubs both filter pollutants and transpire moisture much differently than the Sedum plant species commonly found on modern green roof applications. Cross-applying air quality improvements from one type of green roof application to another can be very misleading. For example, air-quality benefits have been modeled for grass roofs in Toronto with the authors-finding significant economic benefits to air quality under grass roofing scenarios (Currie and Bass 2005). The Georgia test plot, however, was designed to be simple and easily replicable using Sedum plants. These plants do not have the same leaf area index, photosynthetic activity, or growth pattern as grasses thus making this particular air-quality benefit unsuitable for this study.

Other researchers evaluated nitrogen oxide uptake made by the Crassulaceae plant family of which Sedum is a member (Sayed 2001). While this CO2 uptake is well documented, the air-quality improvements provided by the function are less certain, but basic estimates for economic quantification of these improvements are possible by including Sedum green roofs as part of a cap-and trade emissions credit system. Using 2005 market value for NOx emission credits of $3375/ton, Clark (2005) estimated the credit for a Sedum green roof to be $0.11/sqm.
This value was applied to the current analysis as the air quality benefit since it was deemed more appropriate for the roof system used in this study. Both the private and public sectors benefit from this technology as green roofs reduce the pollutant loads in the ambient air of the city, and improve social welfare while allowing the private building owner to receive economic compensation from providing a service for industries looking to offset their polluting activities.

Unquantifiable categories

Other categories may be economically relevant in particular green roof applications, but were not included in this analysis either because of a lack of reliable data or incompatibility of the benefit with the type of green roof used in this study. Urban green space and habitat is clearly a benefit provided by green roofs and rooftop greening has been incorporated into plans to maintain urban habitat networks (Kim 2004). Valuation of urban green space is typically done through hedonic analysis relating house prices to green space type and location (Morancho 2003). While accessible rooftops provide the building owner or tenant with additional space for recreation or growing vegetables, the roof designed in this study does not perform these functions. However, it is suggested that portions of APS roofs receive intensive green roofs that allow for the growing of vegetables. In addition, these roofs should be used as physical learning environments for students and the community alike. Further studies should attempt to quantify the social benefits of these efforts. Without these suggested studies, the green space value must be derived strictly by the habitat value for biotic communities on the roofs themselves which is difficult to quantify and outside the scope of this project.

As discussed in chapter 4, urban centers have air temperatures higher than surrounding rural areas, a phenomenon commonly known as the urban heat island. In theory, since green roofs reduce the surface temperature of the rooftop, the ambient air temperature is lowered thus reducing the heat flow into the building and concomitant energy use needed to maintain comfortable interior building temperatures. Energy models demonstrate that widespread roof greening could lower temperatures city-wide by 0.1 – 0.8 degrees Celsius, a negligible amount considering the uncertainty in the models (Bass et al. 2003). Until more robust studies demonstrate otherwise, the energy cost savings from reducing the urban heat island due to widespread roof greening will be considered speculative and not included in this analysis.

5.5 Results – Application of NPV Test and Sensitivity Analysis

Green roof benefits were estimated for both private and social institutions. Results from these runs are shown in Tables 5.6 and 5.7. The benefits are considered conservative estimates where current pricing conditions are assumed and values based on the campus test plot are used.

Table 5.6

Conservative green roof social benefits ($) at the APS scale

Green roof benefit	Unit benefit ($/m^2)	($)
Avoided BMP costs (one time costs)	9.08	5,011,407 (212.15 x 23,622)
Energy	0.37	204,234 / year
Air quality	0.11	60,718 / year
Total social benefits over 40 years		15,609,487

(Carter 2006) (benefits used in NPV calculation in Appendix A)

Table 5.7

Conservative green roof private benefits for a 929 m^2 roof

Green roof benefit	Unit benefit ($/m^2)	($)
Storm water utility credit	0.04	780.80
Energy	0.37	6,870.53
Air quality	0.11	1,983.06
Total private benefits	0.52	9,634.38

(Carter 2006)

Compiling all the discounted costs and benefits associated with these two roofing systems allows for an NPV test to be performed. The total costs of installing thin-layer green roof systems on APS flat roofs are $87,213,630. The total costs of installing traditional built-up roofing systems on APS flat roofs are $45,814,755. If an equal distribution of all three storm water BMPs across APS is assumed, social benefits equal $15,609,487 and a social NPV of $76,958,088 which is 15% more than traditional roofing (Table 5.8).

The private analysis performed on an individual roof shows NPV of green roofs to be relatively more costly for the building owner when compared with the social BCA. Private costs differ in that they include a storm water utility fee credit rather than avoided storm water BMP costs. This results in a total construction cost of $144,478 for green roofs and 113,353 for conventional roofs at a 4% discount rate on a 929sqm building. Total private benefits from green roofing for the private building totaled $9634. This is 18.87% more than typical roofing.

The NPV test was recalculated with changes to various key parameters for sensitivity analysis. Sensitivity analysis helps determine on which parameters the NPV outcomes depend the most (Hanley and Spash 1993). The parameters were allowed to vary randomly between ranges of expected values over 10,000 trials. An average value from these trials was then calculated and compared with values found for the green roof NPV base case (Table 5.8). Sensitivity analysis was run for both the private and public green roofing scenarios.

The first parameter was the discount rate. Discount rates were modeled around the initial 4%, between the rates of 2% and 6%. Another key parameter was roof construction costs. As the industry continues to mature in North America it is likely that initial construction costs will decrease. Analysis was run with the cost of the green roofing system ranging from the existing cost to a 50% reduction in green roof construction costs. Finally, volatility in energy prices was considered with energy prices ranging from existing prices to a yearly increase of 8%.

Table 5.8

Comparison of green and conventional roof NPV

	Private roof ($)		APS Flat Roofs ($) – 4% dis.	
	Conservative	Average	Conservative	Average (35%)
Green roof costs	144,378.20	108,474.13	87,213,630	77,417,900
Green roof benefits	9634.38	19,040.24	15,609,487	20,551,650
Green roof NPV	134,743.80	89,433.89	76,958,088	50,176,806
Conventional roof NPV	113,352.95	113,352.95	66,724,011	66,724,011
Green/black roof cost ratio	1.19	0.79	1.15	0.75

(Carter 2006) (NPVs listed are derived from NPV calculations in Appendix A)

This sensitivity analysis is asymmetric, that is while discount rates vary around the central estimate, both green roof construction costs and energy costs vary only in the direction that is more sympathetic to the economics of using green roofs relative to conventional roofs. This is done because the current point estimates are in fact at the extremes. Green roofs are not going to be more expensive than our demonstration roof under conditions of dramatically increased construction, and electricity prices are not going to be lower than current prices given the expected course of environmental regulation and energy supply and demand. The assumptions used in this sensitivity analysis give a better picture of what the real economics of green roof construction are likely to be, while the base case estimate is a conservative or almost-worst case scenario.

The results from the sensitivity analysis demonstrated that given realistic assumptions about the changes in the costs and benefits of implementing green roof systems, the average NPV of green roofs is less than the current NPV of black roofs meaning that over the roof's life cycle it is cheaper to install green roofs than their traditional counterpart. The most important parameter was the construction cost estimate, which averaged $115/sqm, down from $158/sqm. Change in green roof benefits due to increased energy prices translated into significantly more energy benefits over the life cycle of the roof, up to $37.23/sqm from $28.28/sqm. Comparing the cost ratio between green and traditional roofing for the conservative NPV estimate and the average estimate generated by the sensitivity analysis show green roofs drop $0.40 on every dollar down to $0.79 from $1.19 for the private scenario and down to $0.75 from $1.15 when social accounting is performed (Table 5.8).

NOTE: SEE APPENDIX A FOR DETAILED SUMMARY OF ATLANTA PUBLIC SCHOOLS GREEN ROOF AND CONVENTIONAL ROOF NPV CALCULATIONS

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

BCA of widespread extensive roof greening of Atlanta Public Schools reveals a number of important considerations for both the private and public sectors when considering green roof installation. The most significant economic benefits are the increase in roof life, storm water BMP cost avoidance, and energy savings. The main construction benefit and best overall benefit in economic terms, of the extensive green roof is that it extends the life of the waterproofing membrane and eliminates the need for frequent reroofing. Without this benefit, green roofs would cost over 85% more than their traditional counterpart. One problem in realizing this benefit is that many waterproofing companies will still only guarantee their premium membranes for 25 years, which may reduce the incentive for a building owner to invest in a green roof during initial construction (Bick 2011). As long-term green roof projects are built and monitored, more experience and ultimately green roof life warrantees may help institutionalize this benefit.

Avoiding the cost of other more expensive storm water BMPs is an important green roof benefit. Since green roofs do not consume valuable urban land, there is no opportunity cost associated with them as there may be with other storm water BMPs such as bio-retention areas. Additionally, green roofs are independent of watershed soil type. They can be implemented anywhere there is a building as opposed to porous pavements, for example, which must have adequate soil permeability before installation is possible (Ferguson 2005). This analysis demonstrates that green roofs are most practically implemented in densely developed urban centers where other practices are impossible or cost-prohibitive. This storm water benefit is also public, accomplishing water quality and quantity goals for the jurisdiction, and therefore justifies the use of public funds to encourage building owners to use green roofs for storm water mitigation.

Annual energy savings for APS total over $200,000. While not as significant as extended roof life, this benefit will be continuously realized each year and help offset some of the initial upfront cost for the building owner. If the building is rented, as many commercial structures are, the tenant will receive this savings. This benefit may function as a marketing tool for the building owner to attract new tenants when leases are renewed. Given uncertainties about energy prices due to the possibility of increased regulation due to air quality and climate change concerns, it is possible that the conservative case has significantly underestimated these benefits. Sensitivity analysis shows that increasing energy prices would result in over $3,000,000 savings over the life cycle of the roof.

The benefit to the existing storm sewer system in Atlanta's watershed is relatively small in economic terms. This is primarily due to the nature of the stream system and the type of sewerage found in the watershed. The highly impacted urban stream shows little potential for economically quantifiable improvement strictly with green roof implementation. Much of the stream is piped and culverted with no change in the sizing of these facilities when green roofs are implemented. This is because extensive green roofs are highly effective at retaining storm water for small storm events with recurrence intervals of 1–2 years, but are less effective at retaining significant portions of runoff from the larger 25–100-year storms. Storm water systems are typically designed for these larger storm flows.

Additionally, the flood mitigation benefit is minimal. There may potentially be marginal improvement in the stream ecosystem with reduction of sediment transport capacity and reduced volume and frequency of runoff from small storm events. Site-specific conditions are important qualifiers that may not be true when evaluating green roof benefits in other watersheds. In addition, caution should be used in making inferences based on these results because construction and maintenance techniques, as well as estimates of their energy saving, storm water-retention, and air-quality improvement benefits, may change as greater experience brings both innovation and better information.

Sensitivity analysis demonstrates that application of green roofs under varying market conditions can significantly influence whether or not green roofs pass the NPV test when compared to traditional roofs. The base green roofing case used in this analysis is more of a ‘‘worst case scenario’’ than a realistic picture of future green roof installations. The average costs represented in the sensitivity analysis may be a more realistic picture of the pricing that future green roof installers will face. Since construction costs are the most likely of the parameters to decrease as well as the most influential in the NPV performed in this analysis, the conditions appear favorable for thin layer green roof systems to become more profitable than built-up asphalt roofs with further cost reductions among firms in the industry. Direct production and specialization in Germany has led to low unit costs of green roofing materials relative to the United States. A reason for this is that many of the single-source green roof suppliers in the United States simply are dealers of green roof products imported from German green roof companies, which increases the total cost of these materials. Further maturation of the industry in the United States should expand opportunities for more efficiency and price reductions across the spectrum of green roof products and services.

Expansion of urban areas and the built environment, combined with greater public interest in maintaining the integrity of ecological systems in these areas, has caused the construction industry to begin developing practices that have less environmental impact.

Innovative new materials and techniques will be largely governed by economic returns on this investment. Since many of the environmental goods affected by development are public in nature and rarely internalized by private firms, it is important to comprehensively evaluate each new practice so that there is a clear accounting of the costs and benefits to society as well as to private building owners.

This study evaluated one such innovative practice: the extensive green roof system. Applying a life-cycle BCA to this practice demonstrates that under current conditions, the NPV of traditional roofs is quite comparable to that of green roofs for APS. This valuation does not consider the many unquantifiable benefits associated with green roofs for APS. Changing reasonable assumptions about this analysis shows that green roofs may be more cost effective than traditional roofs given changes in green roof construction costs, higher energy prices, or possibly inclusion of other watershed-specific benefits. If energy costs rise or storm water protection becomes more of a public priority, both highly plausible possibilities, then green roofs become more economically attractive. While some may argue that green roofs are more costly than traditional roof systems, this study provides evidence that the cumulative benefits over a 40 year life cycle associated with large scale green roof installations, such as on all Atlanta Public Schools, are greater than the initial costs incurred.

Green roofs can provide both private and public benefits and should be included as a potential tool in watershed management manuals for use in highly developed areas. K-12 school buildings represent a unique group of buildings to target for further research given the far reaching potential benefits associated with them. Collaboration between multiple parties is extremely important in conducting successful research. School officials, architects, storm water professionals and watershed planners can only benefit from having more options to alleviate the environmental impacts of urbanization. An assortment of techniques allows for interested parties to use the practices most effective given their particular location, goals, and resource constraints. As areas continue to become more highly urbanized, reconciling development interests and environmental concerns is essential. The greater the number of practices available to accomplish this goal, the easier it will be to reconcile this future conflict between the built and natural environment.

6.2 Recommendations for Further Research

Implementation of a program to install green roofs on all of APS facilities presents a considerable costs hurdle. This thesis did not intend to detail the sources of funding for such a project, but was simply to address the beneficial opportunities available. The study aimed to draw correlations between green roof systems benefits and the goals of greens schools which are defined by the Committee to Review and Assess the Health and Productivity Benefits of Green Schools as "(1) to support the health and development (physical, social, intellectual) of students teachers and staff by providing a healthy, safe, comfortable, and functional physical environment; and (2) to have positive environmental and community attributes (National Research Council 2007)." This was accomplished by reporting on a plethora of peer-reviewed data that outlines green roof benefits as well as through the cost analysis which revealed compelling data supporting this thesis.

In designing research studies to evaluate the unbiased effects of green schools on student learning or student and teacher health, several issues must be addressed. These includes defining green schools for the purpose of scientific inquiry, defining performance and productivity outcomes plausibly related to green schools, and fully developing a theory explaining the links between green school design and health and learning effects. The hypotheses from these theories should be tested in ways that reduce systematic biases and provide compelling evidence about these linkages.

Implementation of green roofs in European countries like Germany is a regulatory driven technology in the municipalities that have adopted mandates for green roofs on new buildings. With more municipalities in the United States looking for flexible ways to control storm water, including the use of storm water credits or watershed-based trading, developing new storm water controls such as green roofs is a vital initiative for the EPA. Green roofs appear to be a suitable technology for urban areas, as there is limited space to implement traditional storm water controls. Land values are too high to devote much surface area to storm water control devices. In addition, surface-based storm water control devices can be vandalized and may pose public access and safety issues. Green roofs can slow the runoff from roofs during larger storms and during smaller storms are capable of absorbing a majority if not all of the rainfall. In essence, the impervious area is decreased when planted roofs are installed on, or retrofitted to, buildings. The plants also act as a bio-filter in reducing the pollutant content of the rainfall. This technology reduces the heat island effect of standard roofs by replacing the low albedo surface, as well as by increasing evapo-transpiration, which helps cool the air by several degrees. Furthermore, because of reduced air temperature, less energy is needed for air conditioning (Osmundson 1999).

The current state of national and state budgets may not warrant funding the installment of green roofs on an entire school district such as APS, at one time, but if studies of the cumulative benefits provide proof of a significantly lower NPV for greens roofs over a 40 year period, national and state funding institutions may be compelled to provide funding for such projects over time.

Further research into the emerging funding opportunities due to new energy policies is recommended for APS and other school districts. A study of the evolution of green roof technology and policy in Germany is recommended in order to gain insight on how to realize the same lower costs results (economies of scale / energy incentives) in the United States. Pilot studies should be created that monitor the impact of introducing of students green roofs and growing vegetables and metrics to quantify productivity level increases in students and teachers created. Test scores and productivity monitoring is recommended at current green schools and where green roofs are on green schools. In addition, more studies on widespread green roof usage (urbanized areas) instead of single roof applications are recommended with focus on combining green roof technology and other storm water management systems. Experiments with different types of substrates, plant materials, and green roof techniques based on the unique climatic conditions of the region being studied are also recommended. Additionally, consideration into the benefits provided through risk aversion such as avoided regulatory fees or the cost of not greening facilities is advisable. The costs burden to building owners who do not implement green practices such as green roofs could be higher than the costs of installing them.

APPENDIX A: Atlanta Public Schools NPV Calculations

Basis of APS NPV Calculations

	Costs	APS Roof Area	Total Costs ($)
Green roof costs range: $85/sqm to $215/sqm			
Cost used in Calculations:	$158/sqm	551985 sqm	(87,213,630)
Conventional roof costs range: $54/sqm to $109/sqm			
Cost used in Calculations:	$83/sqm	551985 sqm	(45,814,755)
Quantifiable benefits (verified):	**Savings**	**APS Roof Area / Volume**	**Total Savings ($)**
Avoided BMPs (Water treatment)	$212.15/cubic meter	23,622 cubic meters	5,011,407
Energy/Utility Reduction	$0.37/sqm/year	551985 sqm	204,234/year
Emissions (Air quality credit)	$0.11/sqm/year	551985 sqm	60,718/year
Soft Social Benefits:			
Mitigation of storm water runoff	see sum below		
Reductions to the urban heat island	see sum below		
Productivity level increases	see sum below		
Avoided regulatory fees	see sum below		
Conservative sum of soft social benefits (unverified):	$0.40/sqm/year	551985 sqm	220,794/year
Interest rate: 4%			
40yr			
Results:			
	NPV		
Conventional Roof	$66,724,011		
Green Roof - Conservative	$76,958,088		
Green Roof - Conservative with sum of soft social benefits	$72,413,466		
Green Roof - Averaged	$50,176,806		
*Averaged NPV calculation for green roofs based off sensitivity analysis and estimated increases in global energy costs			

These results suggests that green roof NPV values are comparable to that of conventional roofs even from a conservative perspective. The biggest contributor to lowered green roof NPV was found to be installation costs. The costs of green roofs are subject to decrease considering the novelty of the technology in the US and the potential economies of scale.

Net Present Value - Conventional Roofs

Operational Costs	Value
Cost	$45,814,755
Cost in year 20	$45,814,755
Interest rate	4%

	Expenses	Income		
Term in years	costs	Money saved by project	Cash flow	Cumulative cash flow
0	$45,814,755		$45,814,755	$45,814,755
1	0	$0	0	45,814,755
2	0	$0	0	45,814,755
3	0	$0	0	45,814,755
4	0	$0	0	45,814,755
5	0	$0	0	45,814,755
6	0	$0	0	45,814,755
7	0	$0	0	45,814,755
8	0	$0	0	45,814,755
9	0	$0	0	45,814,755
10	0	$0	0	45,814,755
11	0	$0	0	45,814,755
12	0	$0	0	45,814,755
13	0	$0	0	45,814,755
14	0	$0	0	45,814,755
15	0	$0	0	45,814,755
16	0	$0	0	45,814,755
17	0	$0	0	45,814,755
18	0	$0	0	45,814,755
19	0	$0	0	45,814,755
20	45,814,755	$0	45,814,755	91,629,510
21	0	$0	0	91,629,510
22	0	$0	0	91,629,510
23	0	$0	0	91,629,510
24	0	$0	0	91,629,510
25	0	$0	0	91,629,510
26	0	$0	0	91,629,510
27	0	$0	0	91,629,510
28	0	$0	0	91,629,510
29	0	$0	0	91,629,510
30	0	$0	0	91,629,510
31	0	$0	0	91,629,510
32	0	$0	0	91,629,510
33	0	$0	0	91,629,510
34	0	$0	0	91,629,510
35	0	$0	0	91,629,510
36	0	$0	0	91,629,510
37	0	$0	0	91,629,510
38	0	$0	0	91,629,510
39	0	$0	0	91,629,510
40	0	$0	0	91,629,510
			91,629,510	
		NPV=	**$66,724,011**	

Net Present Value - Conservative Green Roofs

Operational Costs	Value
Cost	$87,213,630
Avoided BMPs	$5,011,407
Benefit - Enegry	$204,234
Benefit - Air	60,718
Interest rate	4%

	Expenses	Income		
Term in years	Costs	Money saved	Cash flow	Cumulative cash flow
0	$82,202,223		$82,202,223	$82,202,223
1	0	$264,952	264,952	81,937,271
2	0	$264,952	264,952	81,672,319
3	0	$264,952	264,952	81,407,367
4	0	$264,952	264,952	81,142,415
5	0	$264,952	264,952	80,877,463
6	0	$264,952	264,952	80,612,511
7	0	$264,952	264,952	80,347,559
8	0	$264,952	264,952	80,082,607
9	0	$264,952	264,952	79,817,655
10	0	$264,952	264,952	79,552,703
11	0	$264,952	264,952	79,287,751
12	0	$264,952	264,952	79,022,799
13	0	$264,952	264,952	78,757,847
14	0	$264,952	264,952	78,492,895
15	0	$264,952	264,952	78,227,943
16	0	$264,952	264,952	77,962,991
17	0	$264,952	264,952	77,698,039
18	0	$264,952	264,952	77,433,087
19	0	$264,952	264,952	77,168,135
20	0	$264,952	264,952	76,903,183
21	0	$264,952	264,952	76,638,231
22	0	$264,952	264,952	76,373,279
23	0	$264,952	264,952	76,108,327
24	0	$264,952	264,952	75,843,375
25	0	$264,952	264,952	75,578,423
26	0	$264,952	264,952	75,313,471
27	0	$264,952	264,952	75,048,519
28	0	$264,952	264,952	74,783,567
29	0	$264,952	264,952	74,518,615
30	0	$264,952	264,952	74,253,663
31	0	$264,952	264,952	73,988,711
32	0	$264,952	264,952	73,723,759
33	0	$264,952	264,952	73,458,807
34	0	$264,952	264,952	73,193,855
35	0	$264,952	264,952	72,928,903
36	0	$264,952	264,952	72,663,951
37	0	$264,952	264,952	72,398,999
38	0	$264,952	264,952	72,134,047
39	0	$264,952	264,952	71,869,095
40	0	$264,952	264,952	71,604,143
			71,604,143	
		NPV =	**$76,958,088**	

Net Present Value - Green Roofs (Sum of Social Soft Benefits included)

Operational Costs	Value
Cost	$87,213,630
Avoided BMPs	$5,011,407
Benefit - Enegry	$204,234
Benefit - Air	60,718
Social Soft Benefits	$220,794
Interest rate	4%

	Expenses	Income		
Term in years	Costs	Money saved	Cash flow	Cumulative cash flow
0	$82,202,223		$82,202,223	$82,202,223
1	0	$485,746	485,746	81,716,477
2	0	$485,746	485,746	81,230,731
3	0	$485,746	485,746	80,744,985
4	0	$485,746	485,746	80,259,239
5	0	$485,746	485,746	79,773,493
6	0	$485,746	706,540	79,066,953
7	0	$485,746	485,746	78,581,207
8	0	$485,746	485,746	78,095,461
9	0	$485,746	485,746	77,609,715
10	0	$485,746	485,746	77,123,969
11	0	$485,746	485,746	76,638,223
12	0	$485,746	485,746	76,152,477
13	0	$485,746	485,746	75,666,731
14	0	$485,746	485,746	75,180,985
15	0	$485,746	485,746	74,695,239
16	0	$485,746	485,746	74,209,493
17	0	$485,746	485,746	73,723,747
18	0	$485,746	485,746	73,238,001
19	0	$485,746	485,746	72,752,255
20	0	$485,746	485,746	72,266,509
21	0	$485,746	485,746	71,780,763
22	0	$485,746	485,746	71,295,017
23	0	$485,746	485,746	70,809,271
24	0	$485,746	485,746	70,323,525
25	0	$485,746	485,746	69,837,779
26	0	$485,746	485,746	69,352,033
27	0	$485,746	485,746	68,866,287
28	0	$485,746	485,746	68,380,541
29	0	$485,746	485,746	67,894,795
30	0	$485,746	485,746	67,409,049
31	0	$485,746	485,746	66,923,303
32	0	$485,746	485,746	66,437,557
33	0	$485,746	485,746	65,951,811
34	0	$485,746	485,746	65,466,065
35	0	$485,746	485,746	64,980,319
36	0	$485,746	485,746	64,494,573
37	0	$485,746	485,746	64,008,827
38	0	$485,746	485,746	63,523,081
39	0	$485,746	485,746	63,037,335
40	0	$485,746	485,746	62,551,589
			62,551,589	
		NPV =	**$72,413,466**	

Net Present Value - Averaged Green Roofs

Operational Costs	Value
Cost	$63,478,275
Avoided BMPs	$6,200,000
Benefit - Enegry	$275,993
Benefit - Air	82,798
Interest rate	4%

	Expenses	Income		
Term in years	costs	Money saved by project	Cash flow	Cumulative cash flow
0	$57,278,275		$57,278,275	$57,278,275
1	0	$358,791	358,791	56,919,484
2	0	$358,791	358,791	56,560,693
3	0	$358,791	358,791	56,201,902
4	0	$358,791	358,791	55,843,111
5	0	$358,791	358,791	55,484,320
6	0	$358,791	358,791	55,125,529
7	0	$358,791	358,791	54,766,738
8	0	$358,791	358,791	54,407,947
9	0	$358,791	358,791	54,049,156
10	0	$358,791	358,791	53,690,365
11	0	$358,791	358,791	53,331,574
12	0	$358,791	358,791	52,972,783
13	0	$358,791	358,791	52,613,992
14	0	$358,791	358,791	52,255,201
15	0	$358,791	358,791	51,896,410
16	0	$358,791	358,791	51,537,619
17	0	$358,791	358,791	51,178,828
18	0	$358,791	358,791	50,820,037
19	0	$358,791	358,791	50,461,246
20	0	$358,791	358,791	50,102,455
21	0	$358,791	358,791	49,743,664
22	0	$358,791	358,791	49,384,873
23	0	$358,791	358,791	49,026,082
24	0	$358,791	358,791	48,667,291
25	0	$358,791	358,791	48,308,500
26	0	$358,791	358,791	47,949,709
27	0	$358,791	358,791	47,590,918
28	0	$358,791	358,791	47,232,127
29	0	$358,791	358,791	46,873,336
30	0	$358,791	358,791	46,514,545
31	0	$358,791	358,791	46,155,754
32	0	$358,791	358,791	45,796,963
33	0	$358,791	358,791	45,438,172
34	0	$358,791	358,791	45,079,381
35	0	$358,791	358,791	44,720,590
36	0	$358,791	358,791	44,361,799
37	0	$358,791	358,791	44,003,008
38	0	$358,791	358,791	43,644,217
39	0	$358,791	358,791	43,285,426
40	0	$358,791	358,791	42,926,635
			42,926,635	
		NPV=	**$50,176,806**	

APPENDIX B: Area of Atlanta Public School Roofs and Atlanta Watershed Impervious Surfaces

Atlanta Public School Roof Square Footage

Site Name	Roof Square Footage
ADAMSVILLE ELEMENTARY SCHOOL	69,387
ARCHER HIGH SCHOOL	127,537
B.E MAYS HIGH SCHOOL	150,738
BEECHER HILLS ELEMENTARY SCHOOL	48,908
BENTEEN ELEMENTARY SCHOOL	79,182
BETHUNE ELEMENTARYSCHOOL	115,196
BLALOCK ELEMENTARY SCHOOL	44,961
BOLTON ACADEMY	54,027
BRANDON ELEMENTARY SCHOOL	42,287
BROWN MIDDLE SCHOOL	66,446
BUNCHE ELEMENTARY SCHOOL	60,861
BURGESS ELEMENTARY SCHOOL	59,892
C.W. HILL ELEMENTARY SCHOOL	40,525
CAPITOL VIEW ELEMENTARY SCHOOL	28,628
CARSON MIDDLE SCHOOL	77,902
CASCADE ELEMENTARY SCHOOL	65,861
CENTENNIAL PLACE ELEMENTARY	58,333
CLEVELAND ELEMENTARY SCHOOL	85,454
CLEVELAND ELEMENTARY SCHOOL (OLD ANNEX)	32,560
COAN MIDDLE SCHOOL	101,255
COMMUNITY EDUCATION PARTNERS	65,146
CONNALLY ELEMENTARY SCHOOL	55,392
CONTINENTAL COLONY ELEMENTARY SCHOOL	73,778
CRIM HIGH SCHOOL	113,458
D.H STANTON ELEMENTARY SCHOOL	42,235
DEERWOOD ACADEMY	94,524
DOBBS ELEMENTARY SCHOOL	86,195
DOUGLASS HIGH SCHOOL	128,962
EASTLAKE HIGH SCHOOL	39,341
F.L. STANTON ELEMENTARY SCHOOL	37,402
FAIN ELEMENTARY SCHOOL	40,807
FICKETT ELEMENTARY SCHOOL	47,263
FINCH ELEMENTARY SCHOOL	55,111
GARDEN HILLS ELEMENTARY SCHOOL	52,873
GIDEONS ELEMENTARY SCHOOL	57,951
GRADY HIGH SCHOOL	122,242
GROVE PARK ELEMENTARY SCHOOL	54,310
HARPER-ARCHER MIDDLE SCHOOL	127,916
HERDON ELEMENTARY SCHOOL	72,075
HOPE ELEMENTARY SCHOOL	49,780
HUMPHRIES ELEMENTARY SCHOOL	38,899
INMAN MIDDLE SCHOOL	61,871
JACKSON ELEMENTARY SCHOOL	70,592
JOHN F KENNEDY MIDDLE SCHOOL	88,092
KIMBERLY ELEMENTARY SCHOOL	60,744
KING MIDDLE SCHOOL	101,825
KIPP ACHIEVE ACADEMY	56,439
KIPP WAYS ACADEMY	21,359

LONG MIDDLE SCHOOL	83,375
LONG MIDDLE SCHOOL / MARSHALL MIDDLE	42,262
M.A. JONES ELEMENTARY SCHOOL	61,117
MARY LIN ELEMENTARY SCHOOL	43,706
MILES ELEMENTARY SCHOOL	85,414
NORTH ATLANTA HIGH SCHOOL	145,194
OGLETHORPE ELEMENTARY SCHOOL	55,820
PARKS MIDDLE SCHOOL	48,628
PARKSIDE ELEMENTARY SCHOOL	83,510
PERKERSON ELEMENTARY SCHOOL	75,878
PEYTON FORREST ELEMENTARY SCHOOL	72,134
PRICE MIDDLE SCHOOL	74,441
RIVERS ELEMENTARY SCHOOL	60,121
SCOTT ELEMENTARY SCHOOL	55,963
SLATER ELEMENTARY SCHOOL	48,291
SMITH ELEMENTARY SCHOOL	63,627
SOUTH ATLANTA HIGH SCHOOL	127,674
SUTTON MIDDLE SCHOOL	60,929
SUTTON MIDDLE SCHOOL (TEMO LOCATION)	22,383
SYLVAN ELEMENTARY SCHOOL	53,547
TECH HIGH SCHOOL	25,973
THE NEW SCHOOLS AT CARVER	165,475
THERRELL HIGH SCHOOL	113,497
THOMASVILLE HEIGHTS ELEMENTARY SCHOOL	56,866
TOOMER ELEMENTARY SCHOOL	53,179
TOWNS ELEMENTARY SCHOOL	73,312
TURNER MIDDLE SCHOOL	64,183
USHER ELEMENTARY SCHOOL	69,331
VENETIAN HILLS ELEMENTARY SCHOOL	45,623
WALDEN MIDDLE SCHOOL	40,910
WASHINGTON HIGH SCHOOL	110,151
WATERS ELEMENTARY SCHOOL	84,259
WEST MANOR ELEMENTARY SCHOOL	38,216
WHITE ELEMENTARY SCHOOL	50,372
WHITEFOORD ELEMENTARY SCHOOL	40,306
WILLIAM M BOYD ELEMENTARY SCHOOL	49,196
WILLIAM ELEMENTARY SCHOOL	52,691
WOODSON ELEMENTARY SCHOOL	47,291
YOUNG MIDDLE SCHOOL	70,150
Grand Total	5,941,517sf or 551,985 m^2

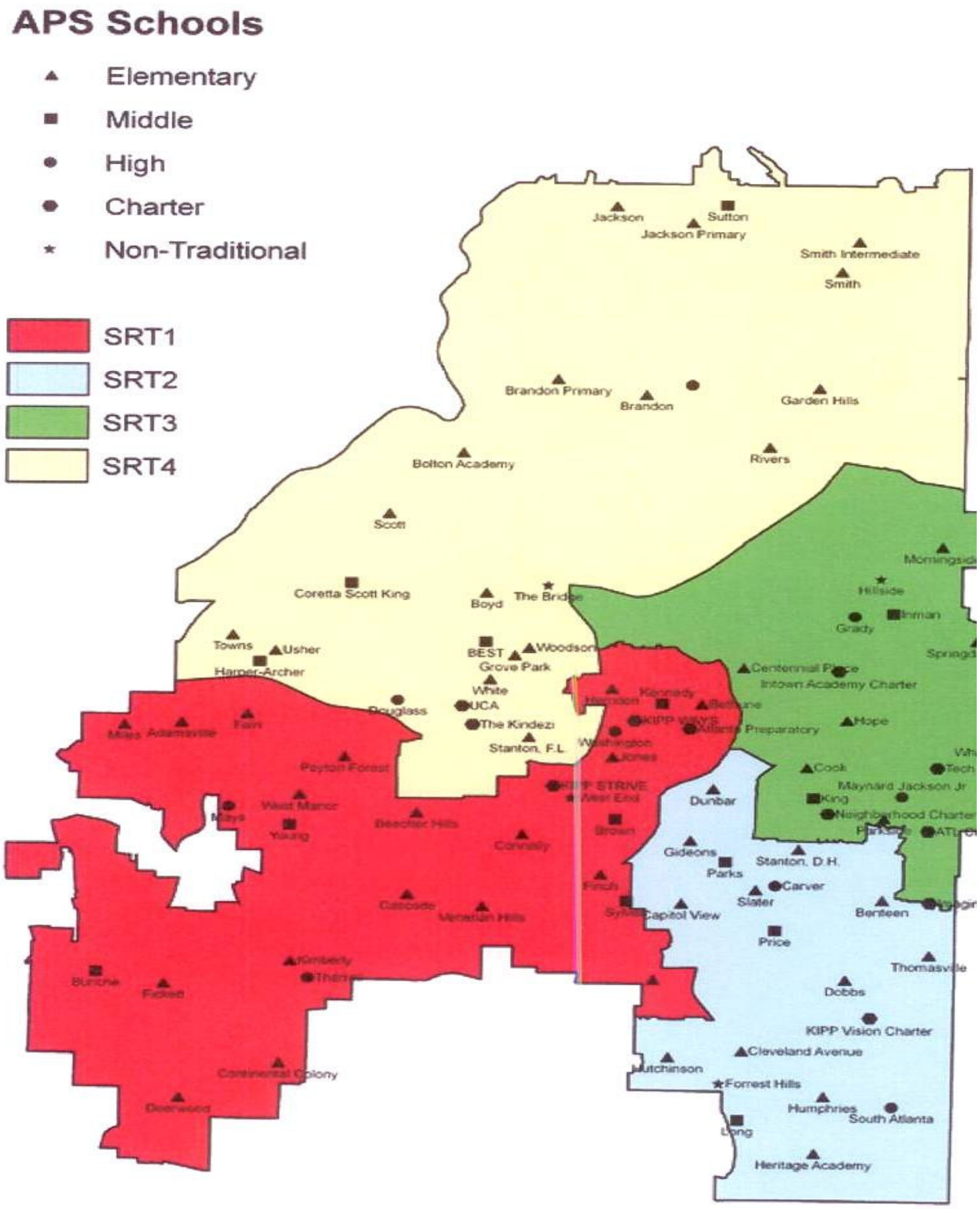
(Scenna 2011)

The square footage of impervious surfaces in Atlanta's Watershed is roughly 280,816,643 Square Feet or 26,088,720 m^2 (Morris 2011)

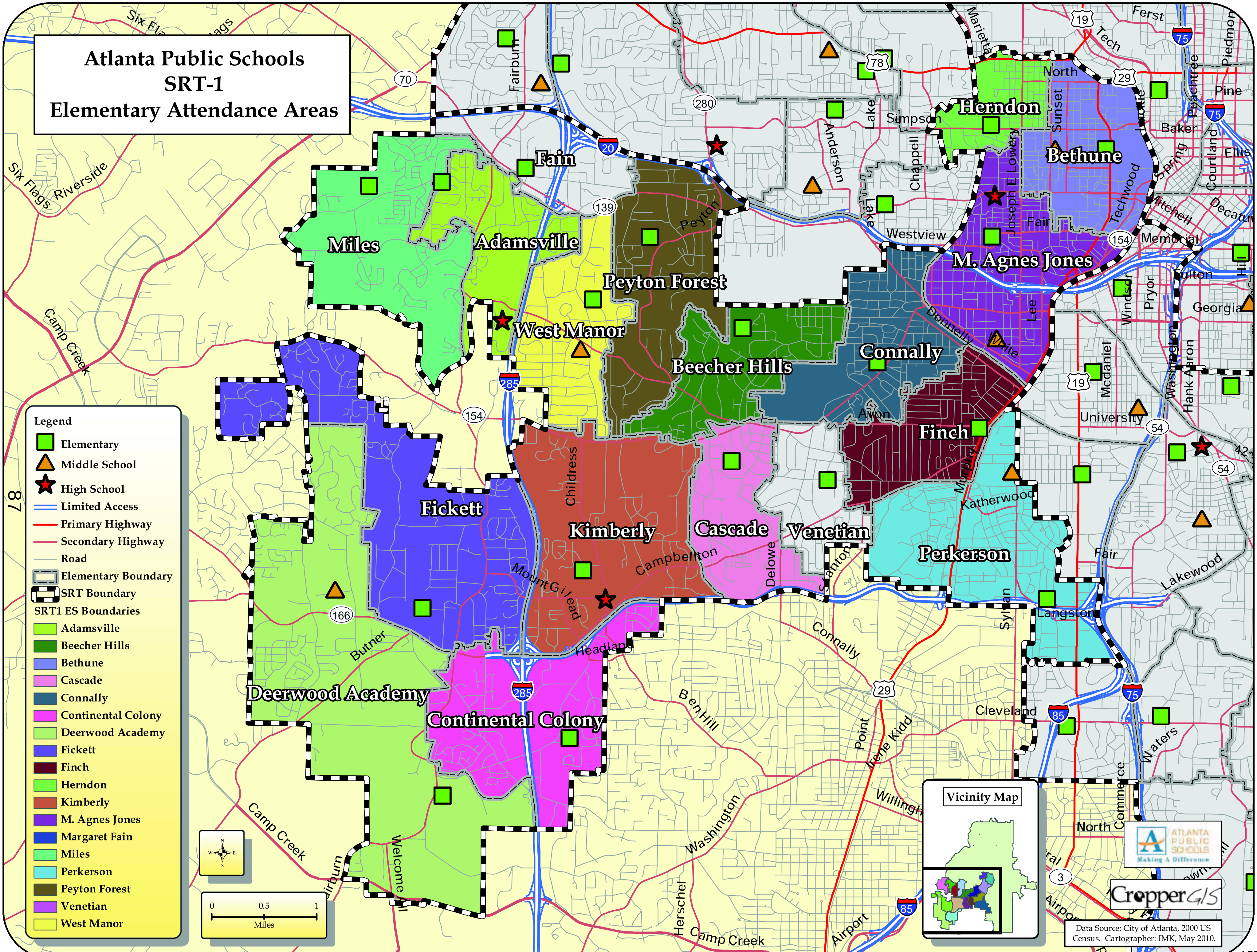
551,985 / 26,088,720 = 2.1%

APPENDIX C: Map of Atlanta Public Schools

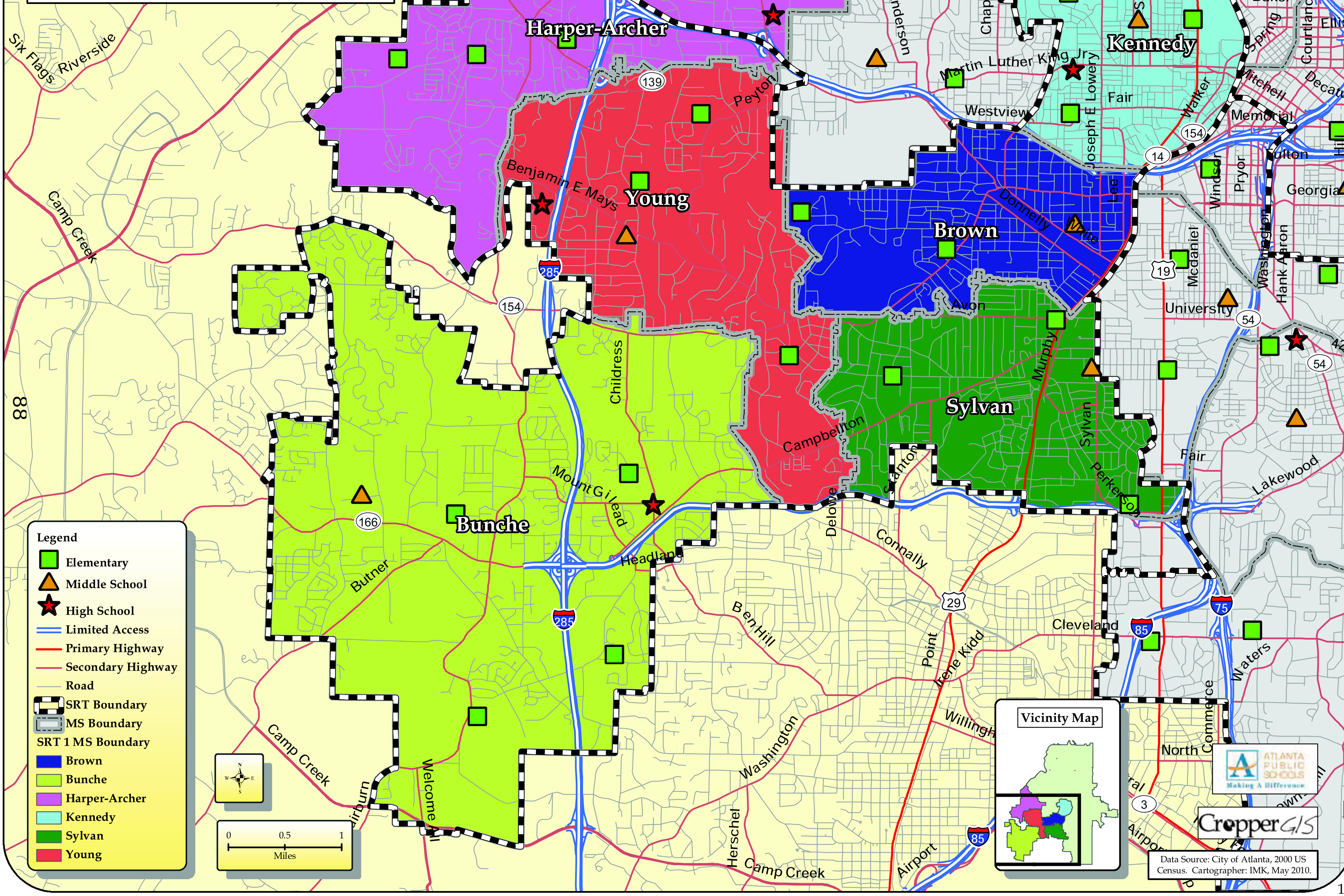
Map of Schools



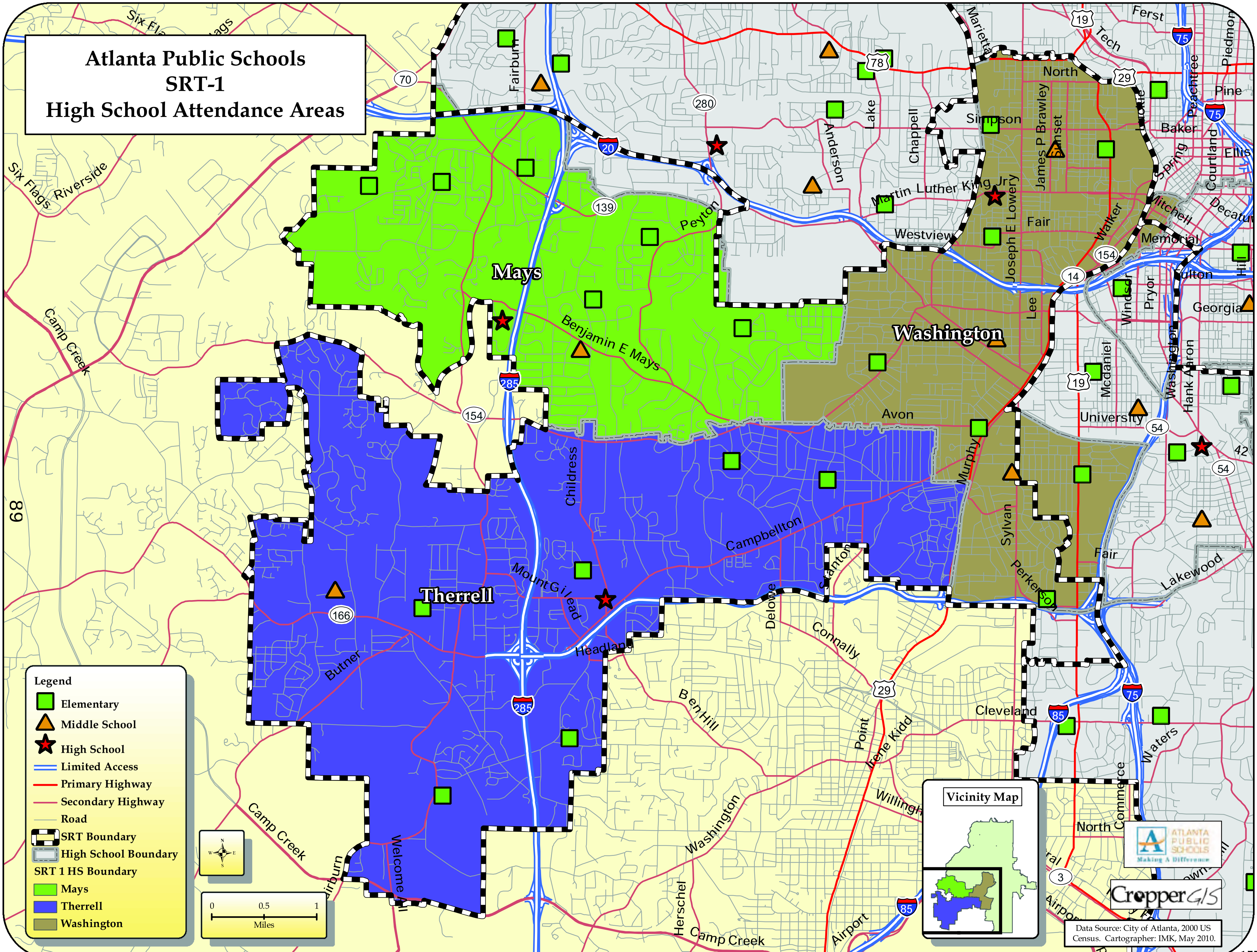
Atlanta Public Schools
2010 - 2011

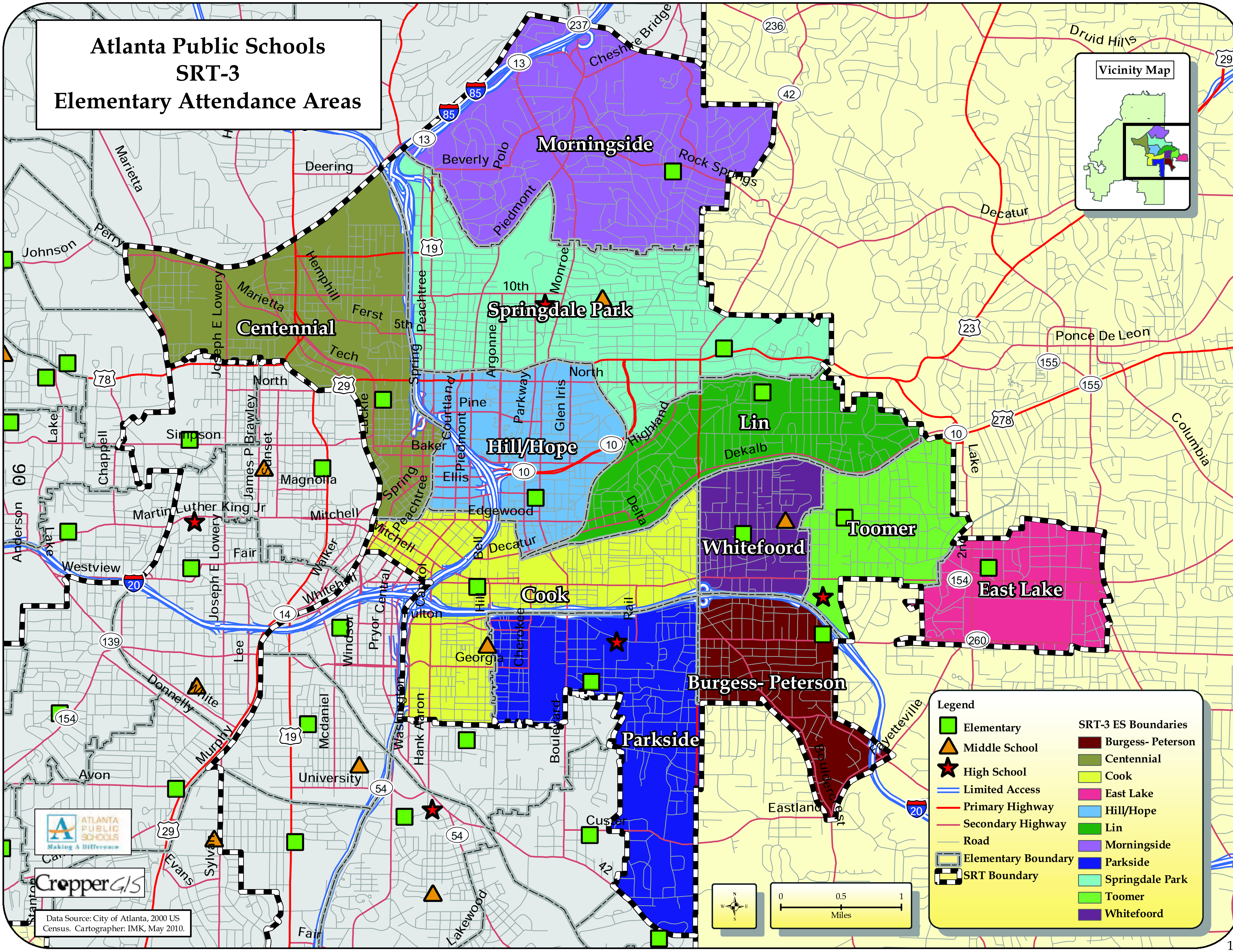

Atlanta Public Schools
SRT-1
Elementary Attendance Areas
Legend
Elementary
Middle School
High School
Limited Access
Primary Highway
Secondary Highway
Road
Elementary Boundary
SRT Boundary
SRT1 ES Boundaries
Adamsville
Beecher Hills
Bethune
Cascade
Connally
Continental Colony
Deerwood Academy
Fickett
Finch
Herndon
Kimberly
M. Agnes Jones
Margaret Fain
Miles
Perkerson
Peyton Forest
Venetian
West Manor
0
0.5
1
Miles
Miles
Adamsville
Fain
Peyton Forest
West Manor
Beecher Hills
Connally
M. Agnes Jones
Herndon
Bethune
Finch
Fickett
Kimberly
Cascade
Venetian
Perkerson
Deerwood Academy
Continental Colony
Vicinity Map
ATLANTA PUBLIC SCHOOLS
Making A Difference
CropperGIS
Data Source: City of Atlanta, 2000 US Census. Cartographer: IMK, May 2010.

Atlanta Public Schools
SRT-1
Middle School Attendance Areas

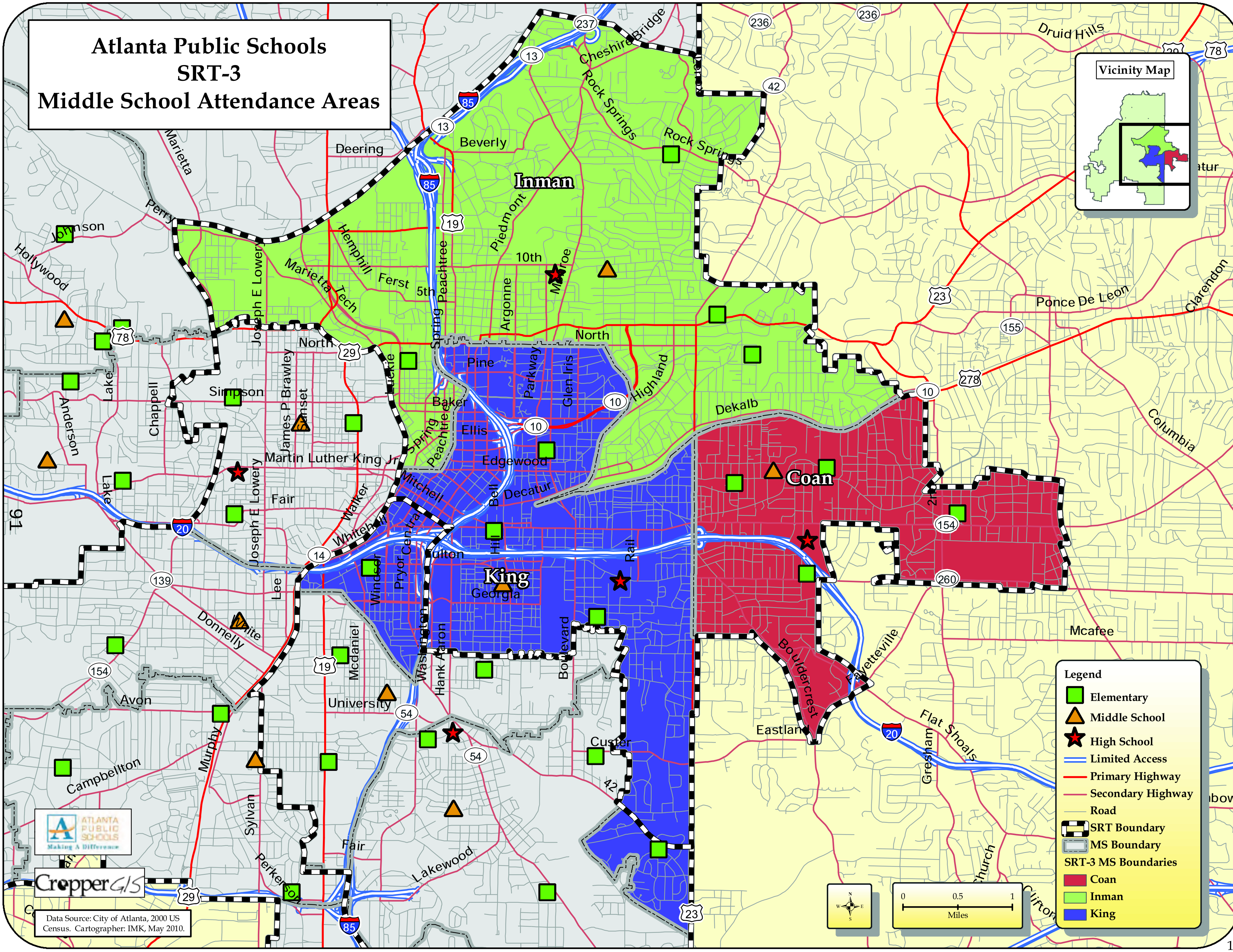


Atlanta Public Schools
SRT-1
High School Attendance Areas

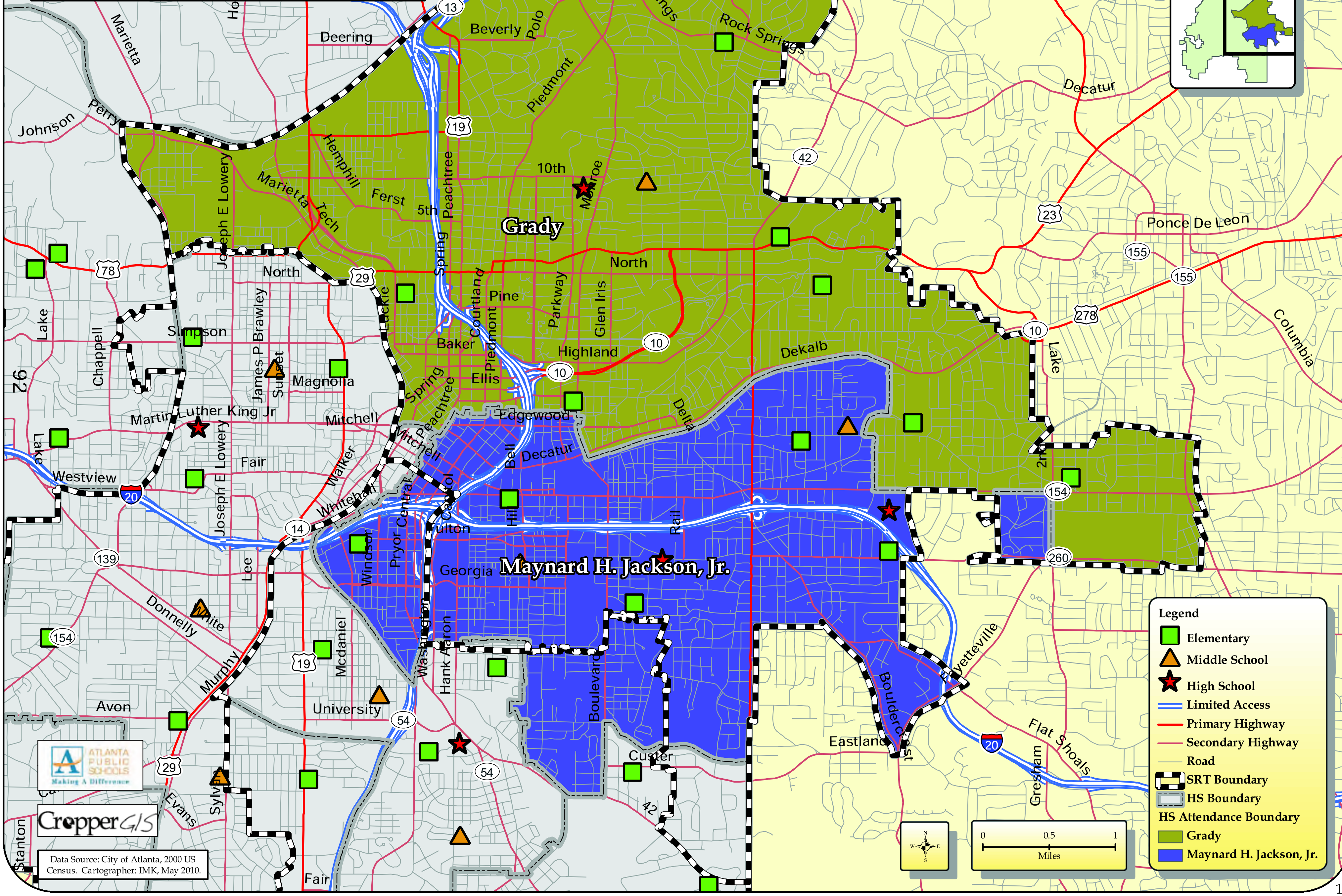


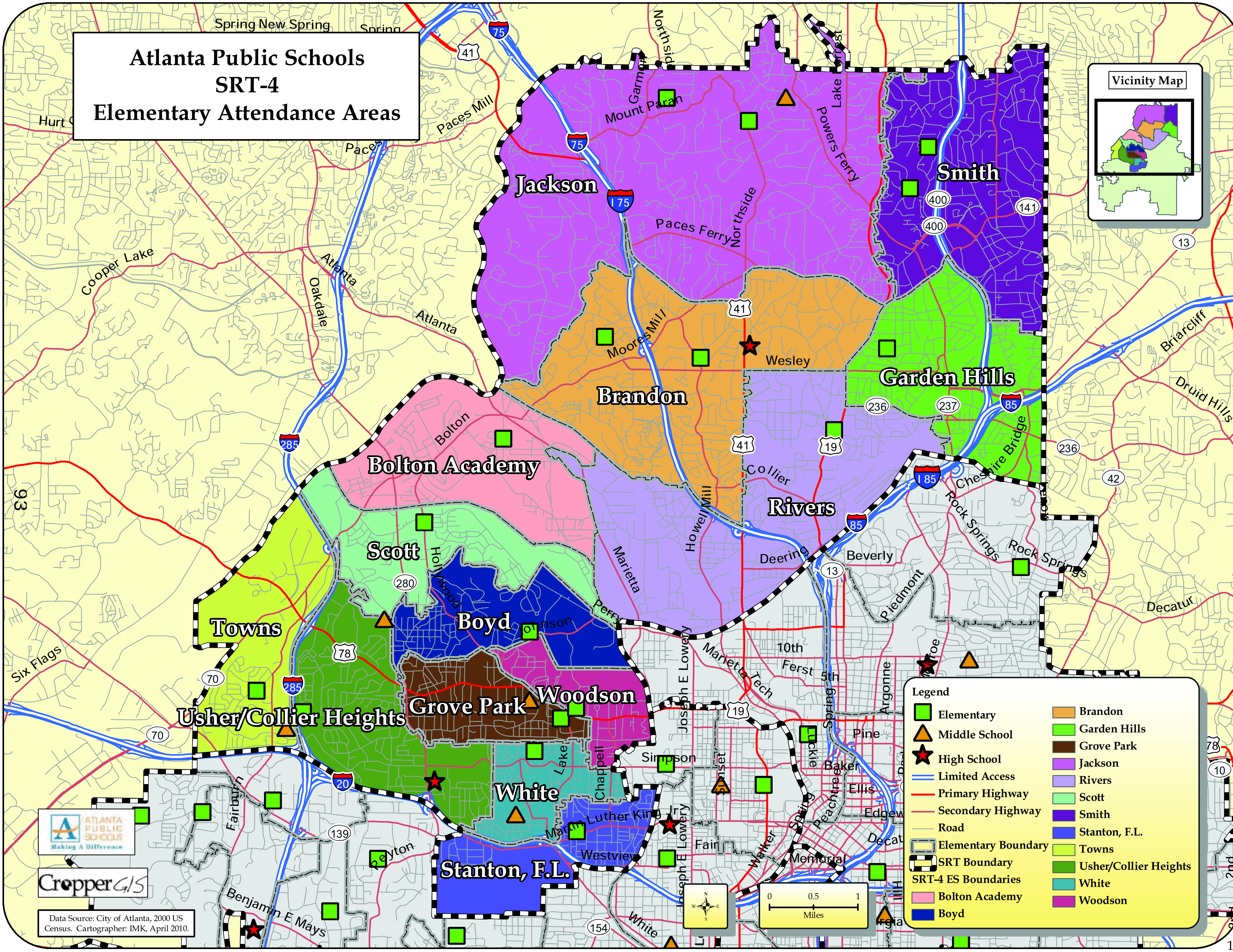

Atlanta Public Schools
SRT-3
Elementary Attendance Areas
Vicinity Map
Morningside
Springdale Park
Centennial
Hill/Hope
Lin
Whitefoord
Toomer
East Lake
Cook
Burgess- Peterson
Parkside
Legend
Elementary
Middle School
High School
Limited Access
Primary Highway
Secondary Highway
Road
Elementary Boundary
SRT Boundary
SRT-3 ES Boundaries
Burgess- Peterson
Centennial
Cook
East Lake
Hill/Hope
Lin
Morningside
Parkside
Springdale Park
Toomer
Whitefoord
0
0.5
1
Miles
Data Source: City of Atlanta, 2000 US Census. Cartographer: IMK, May 2010.
ATLANTA PUBLIC SCHOOLS
Making A Difference
CropperGIS

Atlanta Public Schools
SRT-3
Middle School Attendance Areas

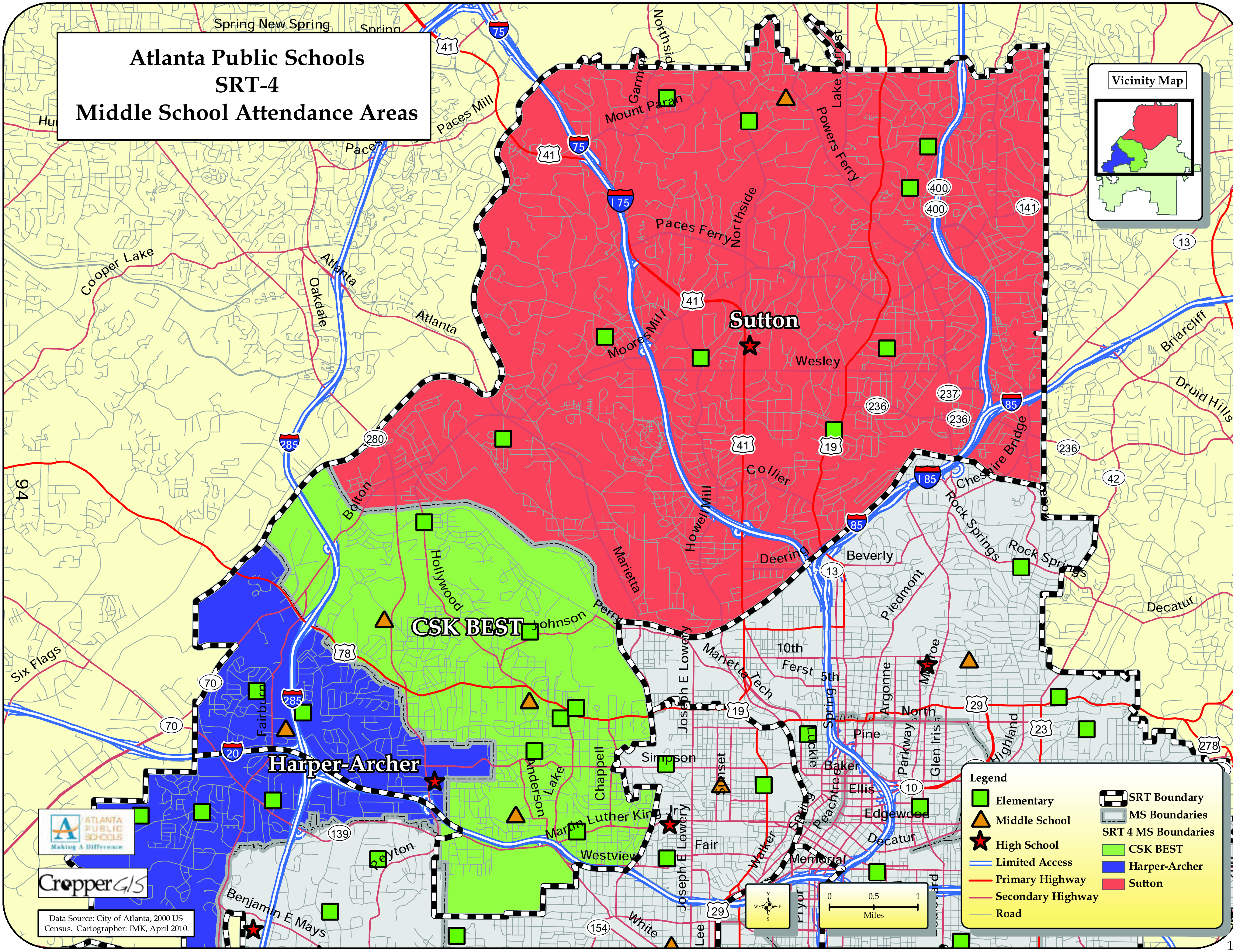


Atlanta Public Schools
SRT-3
High School Attendance Areas

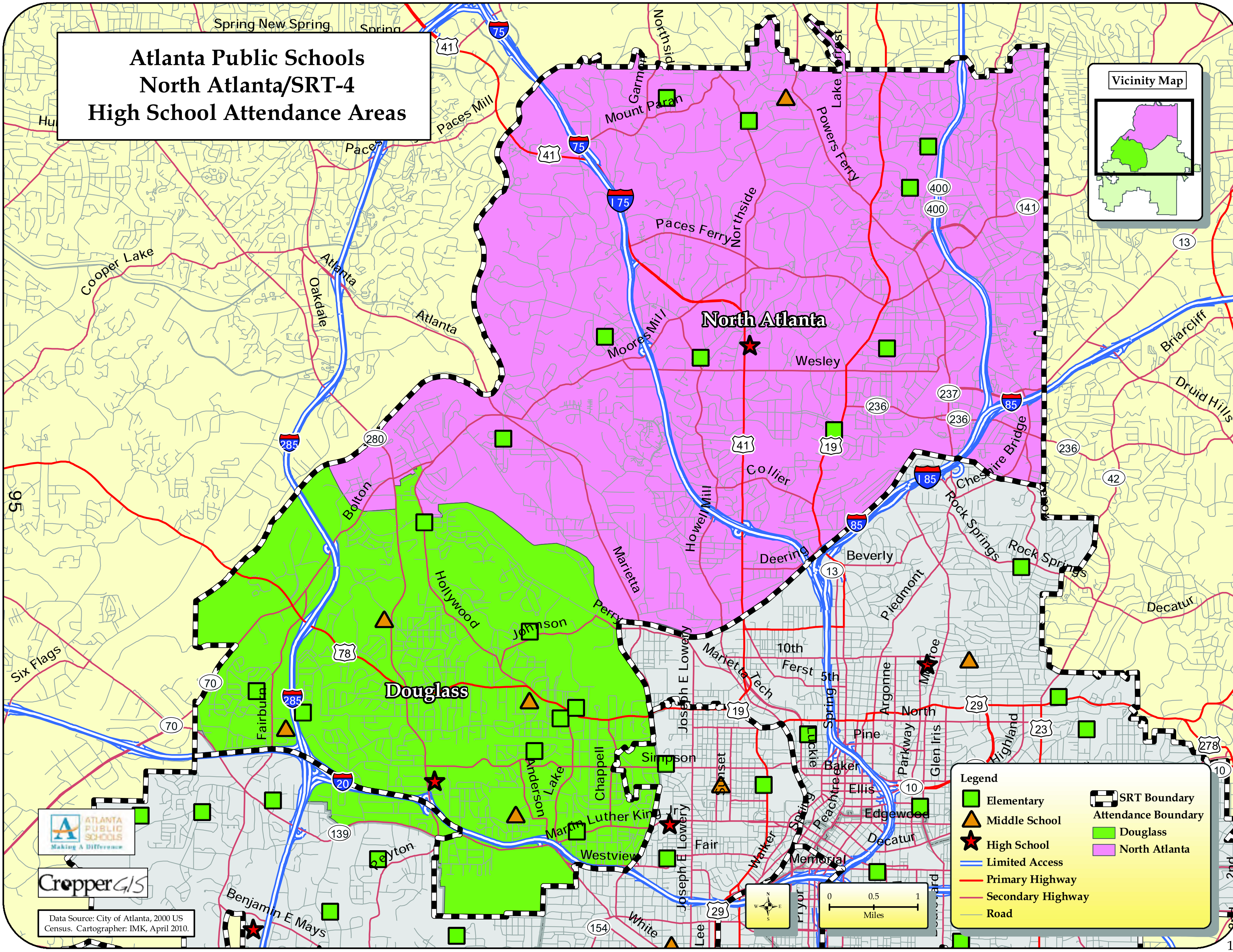



Atlanta Public Schools
SRT-4
Elementary Attendance Areas
Jackson
Smith
Brandon
Garden Hills
Rivers
Bolton Academy
Scott
Boyd
Towns
Woodson
Grove Park
Usher/Collier Heights
White
Stanton, F.L.
Vicinity Map
Legend
Elementary
Middle School
High School
Limited Access
Primary Highway
Secondary Highway
Road
Elementary Boundary
SRT Boundary
SRT-4 ES Boundaries
Bolton Academy
Boyd
Brandon
Garden Hills
Grove Park
Jackson
Rivers
Scott
Smith
Stanton, F.L.
Towns
Usher/Collier Heights
White
Woodson
0 0.5 1
Miles
Atlanta Public Schools
Making A Difference
CropperGIS
Data Source: City of Atlanta, 2000 US Census. Cartographer: IMK, April 2010.

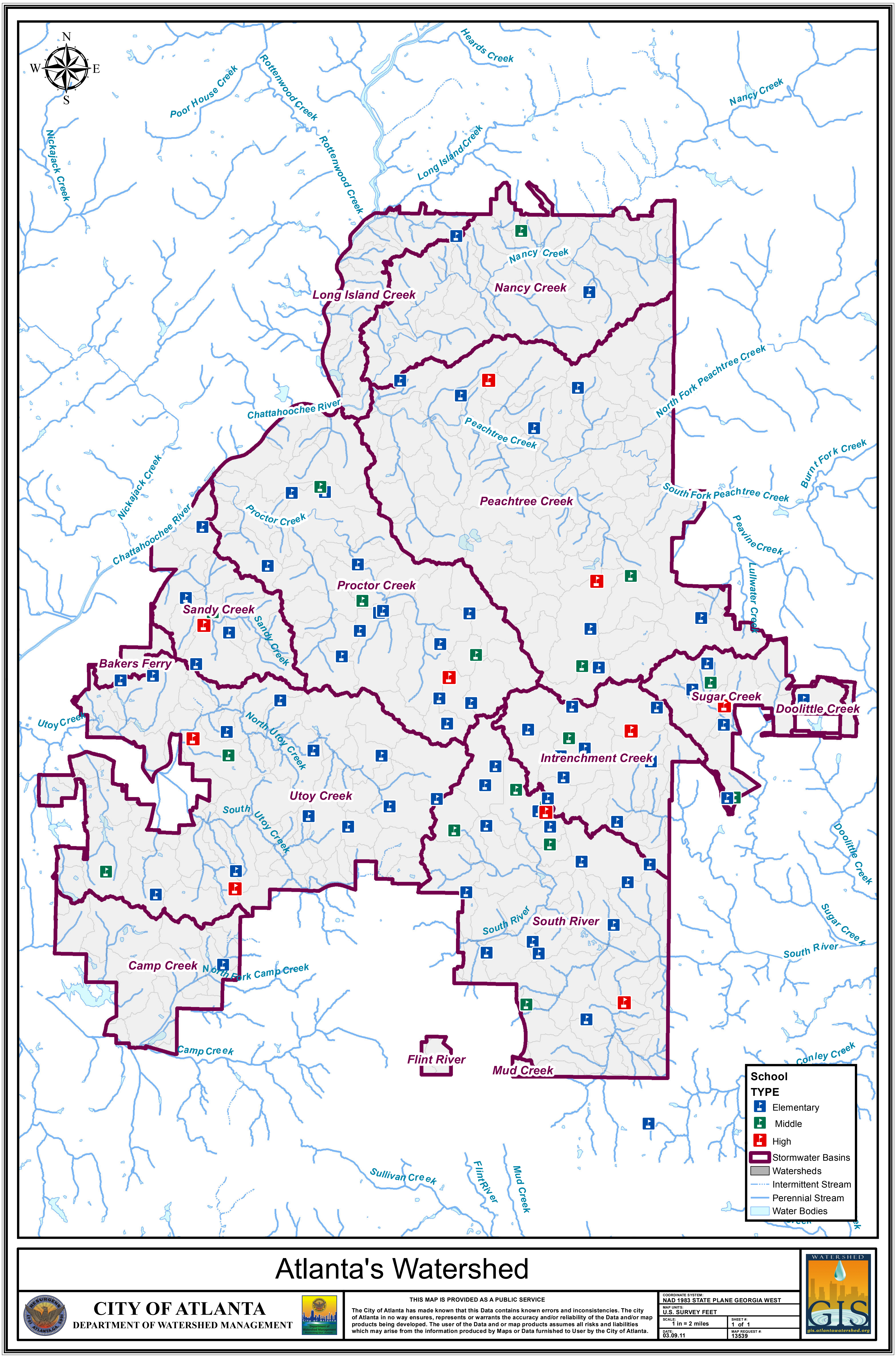
Atlanta Public Schools
SRT-4
Middle School Attendance Areas



Atlanta Public Schools
North Atlanta/SRT-4
High School Attendance Areas



APPENDIX D: Map of Atlanta's Watershed


Atlanta's Watershed
CITY OF ATLANTA
DEPARTMENT OF WATERSHED MANAGEMENT
THIS MAP IS PROVIDED AS A PUBLIC SERVICE
The City of Atlanta has made known that this Data contains known errors and inconsistencies. The city of Atlanta in no way ensures, represents or warrants the accuracy and/or reliability of the Data and/or map products being developed. The user of the Data and or map products assumes all risks and liabilities which may arise from the information produced by Maps or Data furnished to User by the City of Atlanta.
COORDINATE SYSTEM: NAD 1983 STATE PLANE GEORGIA WEST
MAP UNITS: U.S. SURVEY FEET
SCALE: 1 in = 2 miles
SHEET #: 1 of 1
DATE: 03.09.11
MAP REQUEST #: 13539
School
TYPE
Elementary
Middle
High
Stormwater Basins
Watersheds
Intermittent Stream
Perennial Stream
Water Bodies
N
S
E
W
Long Island Creek
Nancy Creek
Peachtree Creek
Proctor Creek
Sandy Creek
Bakers Ferry
Utoy Creek
Intrenchment Creek
Sugar Creek
Doolittle Creek
South River
Camp Creek
Flint River
Mud Creek
Poor House Creek
Rottenwood Creek
Heards Creek
Nickajack Creek
Long Island Creek
Chattahoochee River
North Fork Peachtree Creek
South Fork Peachtree Creek
Burnt Fork Creek
Peavine Creek
Lullwater Creek
North Utoy Creek
South Utoy Creek
North Fork Camp Creek
Sullivan Creek
Conley Creek

APPENDIX E: Benjamin E Mays High School – LEED for Schools 2009 (Silver) Major Renovation

LEED 2009 for Schools New Construction and Major Renovation

Project Checklist

Benjamin E.Mays High School

08.31.10

Y	N	?	Sustainable Sites		Possible Points: 24
12	2	10			
Y			Prereq 1	Construction Activity Pollution Prevention	
Y			Prereq 1	Environmental Site Assessment	
	1		Credit 1	Site Selection	1
		4	Credit 2	Development Density and Community Connectivity	4
	1		Credit 3	Brownfield Redevelopment	1
2		2	Credit 4.1	Alternative Transportation—Public Transportation Access	4
1			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
2			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	2
2			Credit 4.4	Alternative Transportation—Parking Capacity	2
		1	Credit 5.1	Site Development—Protect or Restore Habitat	1
		1	Credit 5.2	Site Development—Maximize Open Space	1
1			Credit 6.1	Stormwater Design—Quantity Control	1
1			Credit 6.2	Stormwater Design—Quality Control	1
		1	Credit 7.1	Heat Island Effect—Non-roof	1
1			Credit 7.2	Heat Island Effect—Roof	1
1			Credit 8	Light Pollution Reduction	1
1			Credit 9	Site Master Plan	1
		1	Credit 10	Joint Use of Facilities	1

5	4	2	Water Efficiency		Possible Points: 11
Y			Prereq 1	Water Use Reduction—20% Reduction	
	4		Credit 1	Water Efficient Landscaping	2 to 4
2			Credit 2	Innovative Wastewater Technologies	2
2		2	Credit 3	Water Use Reduction	2 to 4
1			Credit 3	Process Water Use Reduction	1

11	7	15	Energy and Atmosphere		Possible Points: 33
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
6		13	Credit 1	Optimize Energy Performance	1 to 19
	7		Credit 2	On-Site Renewable Energy	1 to 7
2			Credit 3	Enhanced Commissioning	2
1			Credit 4	Enhanced Refrigerant Management	1
2			Credit 5	Measurement and Verification	2
		2	Credit 6	Green Power	2

9	4	1	Materials and Resources		Possible Points: 13
Y			Prereq 1	Storage and Collection of Recyclables	
2			Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 2
	2		Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
2			Credit 2	Construction Waste Management	1 to 2

Y	N	?	Materials and Resources, Continued		
	2		Credit 3	Materials Reuse	1 to 2
2			Credit 4	Recycled Content	1 to 2
2			Credit 5	Regional Materials	1 to 2
		1	Credit 6	Rapidly Renewable Materials	1
1			Credit 7	Certified Wood	1

11	1	7	Indoor Environmental Quality		Possible Points: 19
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
Y			Prereq 3	Minimum Acoustical Performance	
1			Credit 1	Outdoor Air Delivery Monitoring	1
	1		Credit 2	Increased Ventilation	1
1			Credit 3.1	Construction IAQ Management Plan—During Construction	1
		1	Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
4			Credit 4	Low-Emitting Materials	1 to 4
		1	Credit 5	Indoor Chemical and Pollutant Source Control	1
1			Credit 6.1	Controllability of Systems—Lighting	1
1			Credit 6.2	Controllability of Systems—Thermal Comfort	1
1			Credit 7.1	Thermal Comfort—Design	1
1			Credit 7.2	Thermal Comfort—Verification	1
		3	Credit 8.1	Daylight and Views—Daylight	1 to 3
		1	Credit 8.2	Daylight and Views—Views	1
		1	Credit 9	Enhanced Acoustical Performance	1
1			Credit 10	Mold Prevention	1

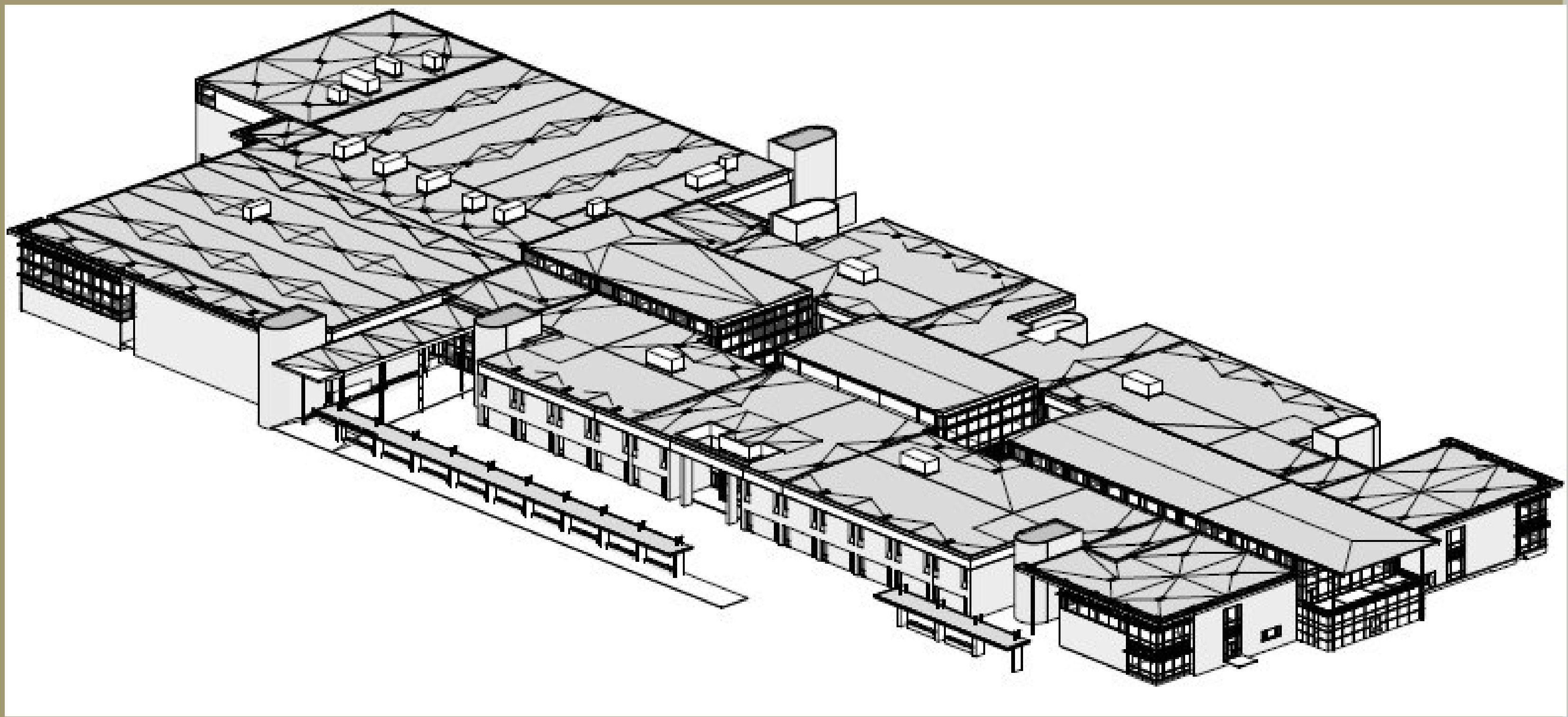
4		2	Innovation and Design Process		Possible Points: 6
1			Credit 1.1	Innovation in Design: Specific Title	1
1			Credit 1.2	Innovation in Design: Specific Title	1
		1	Credit 1.3	Innovation in Design: Specific Title	1
		1	Credit 1.4	Innovation in Design: Specific Title	1
1			Credit 2	LEED Accredited Professional	1
1			Credit 3	The School as a Teaching Tool	1

2		2	Regional Priority Credits		Possible Points: 4
1			Credit 1.1	Regional Priority: Specific Credit	1
1			Credit 1.2	Regional Priority: Specific Credit	1
		1	Credit 1.3	Regional Priority: Specific Credit	1
		1	Credit 1.4	Regional Priority: Specific Credit	1

54	18	39	Total		Possible Points: 110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

Benjamin E. Mays High School



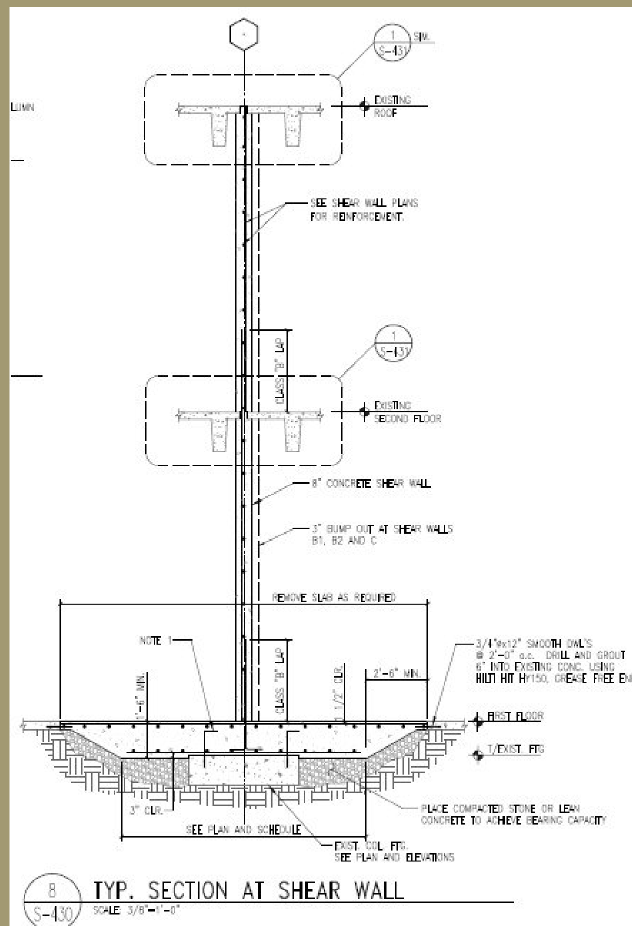
Structural Demolition

Structural Demolition

Structural Demolition

Structural Methods

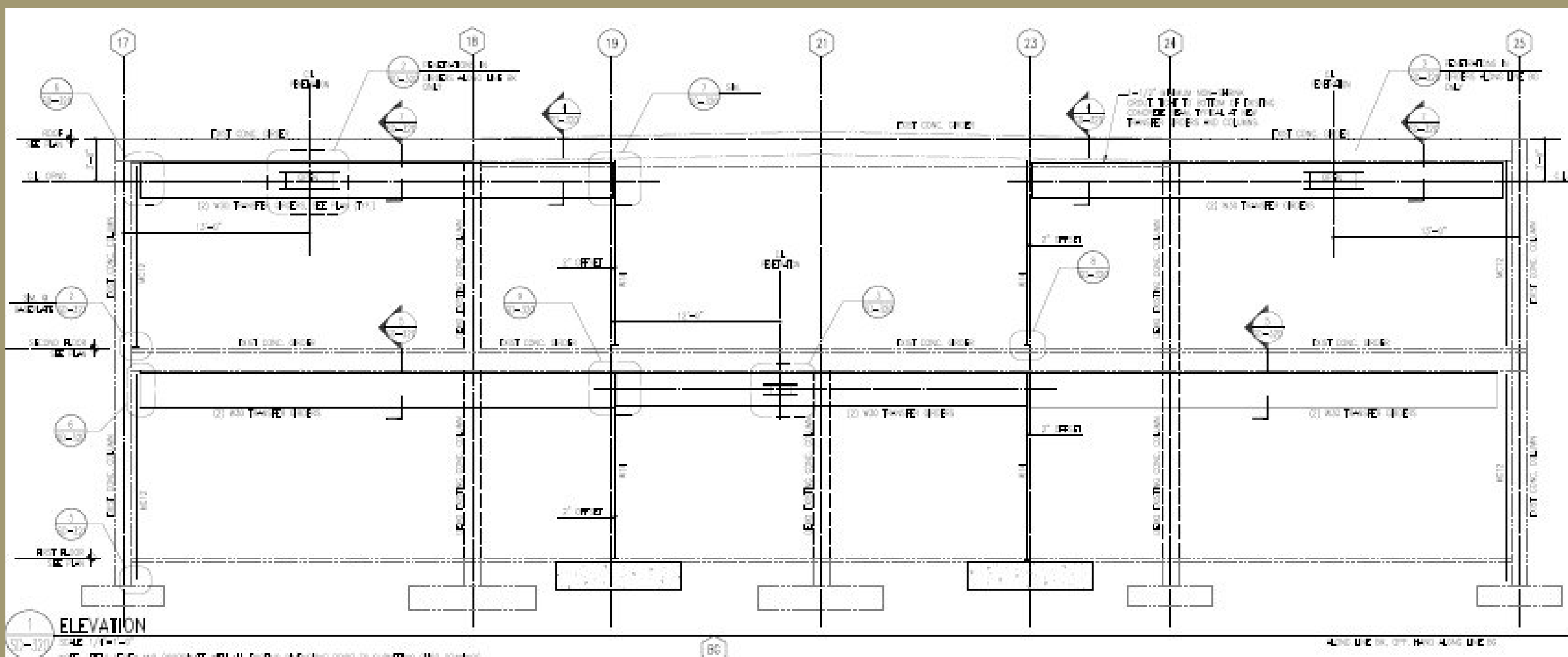
Shear walls



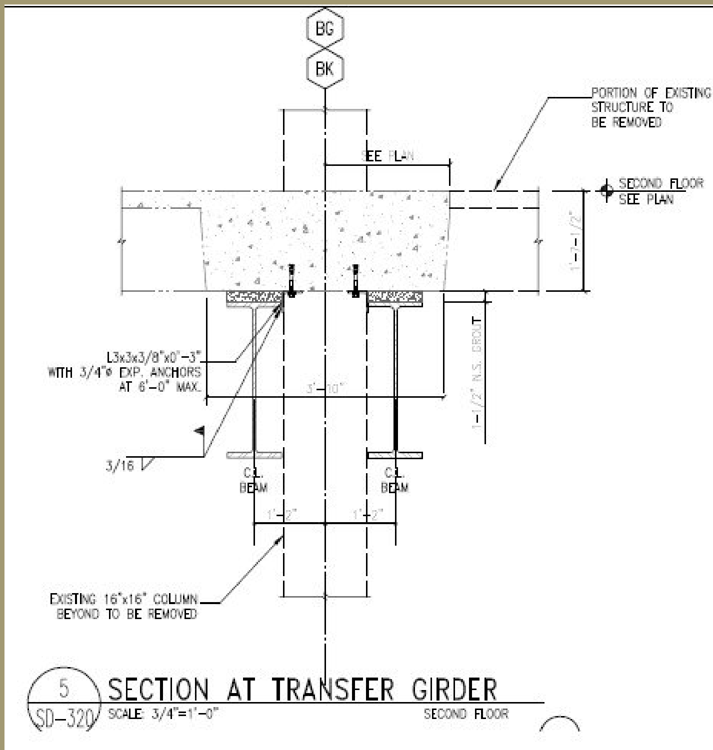
WINTER CONSTRUCTION

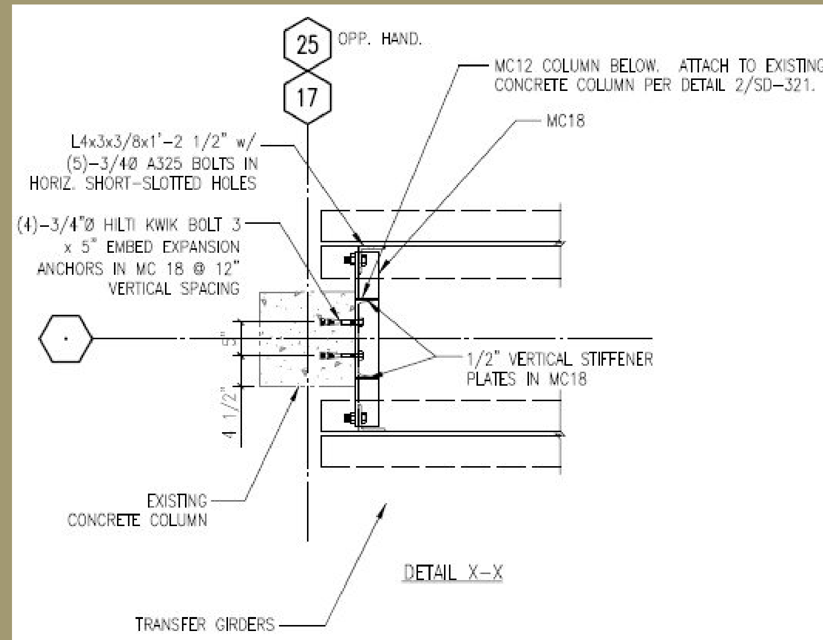
Structural Methods

Demo Steel



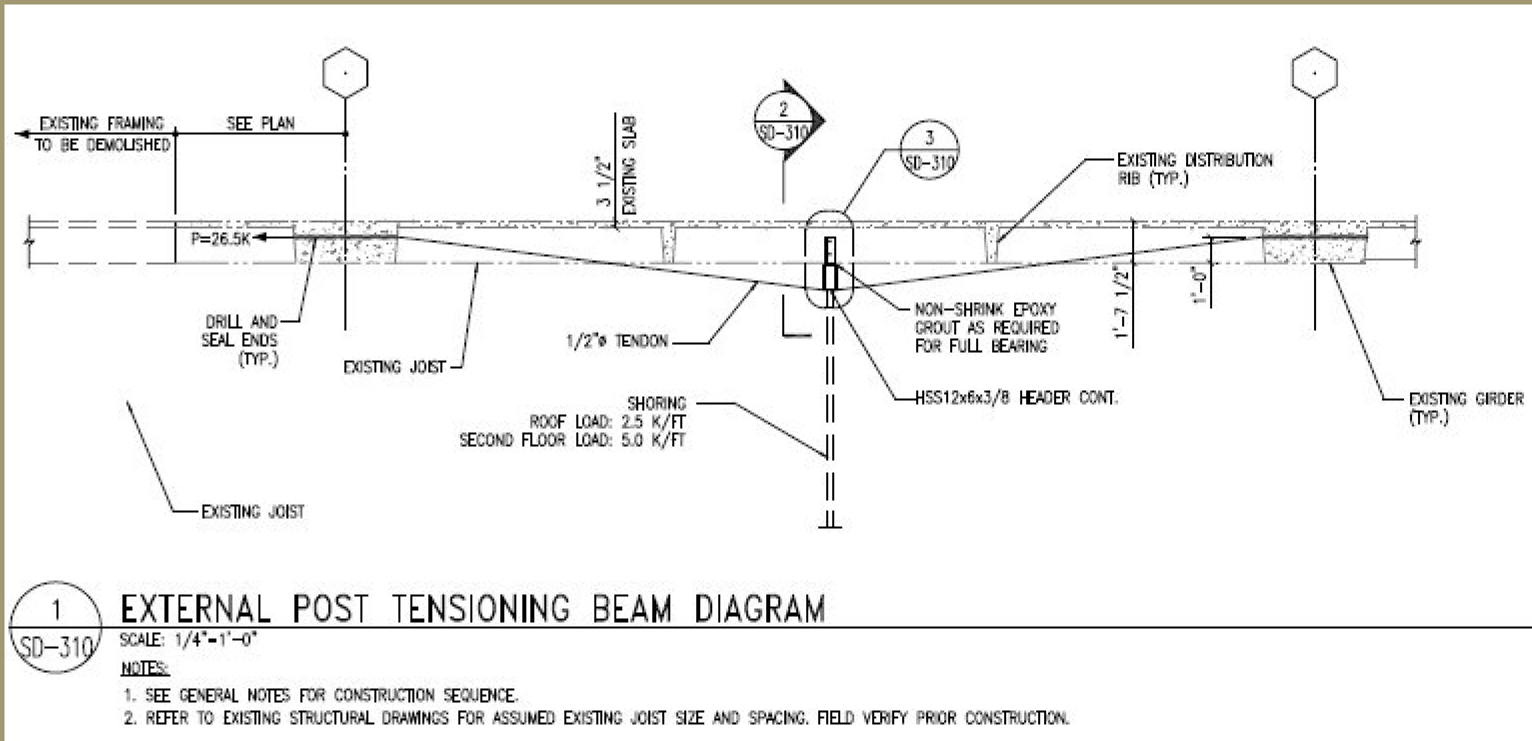
Structural Methods





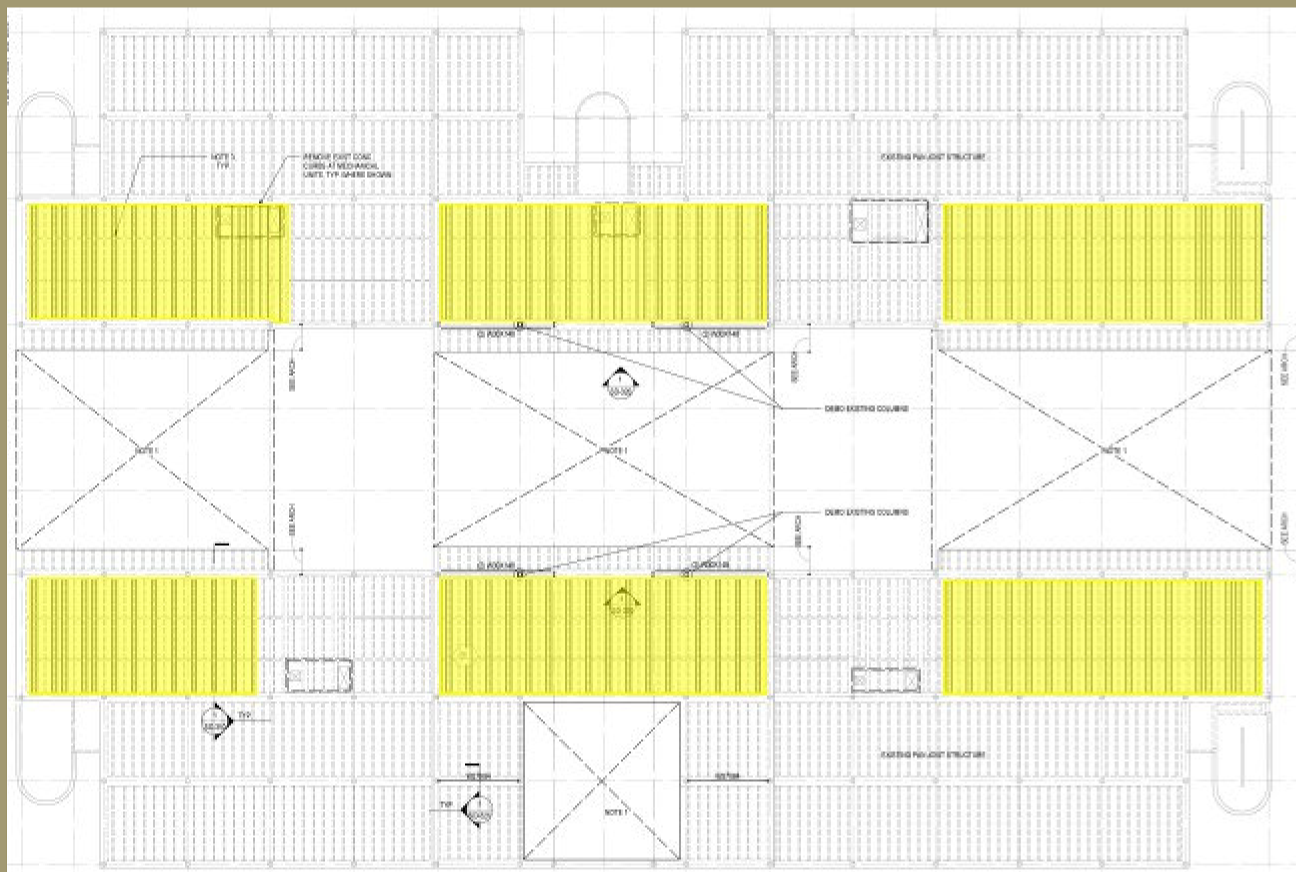
Demo Steel Details

Structural Methods



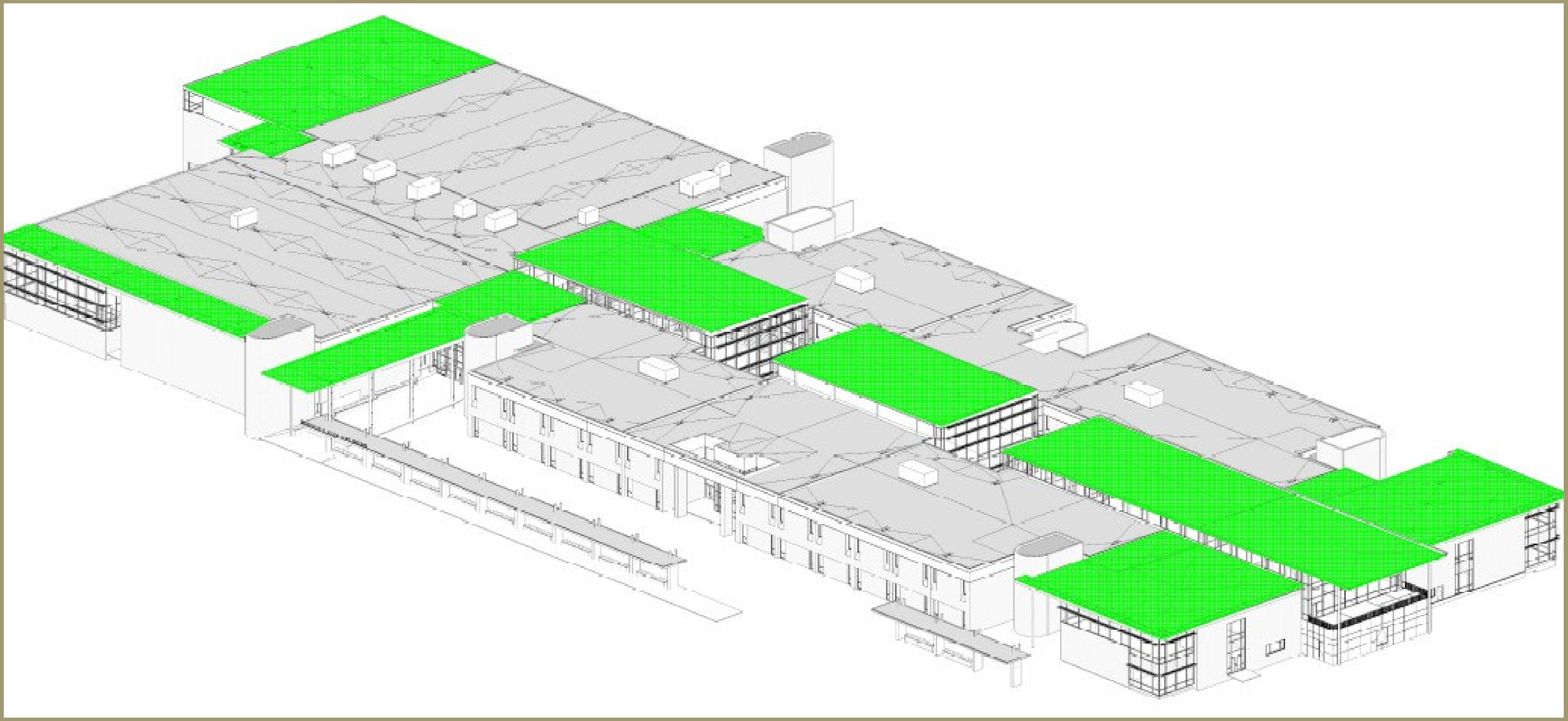
External Post Tensioning

Structural Methods



External PT layout, above 1st and second floors

Finished Product



Finished Product

Finished Product

Finished Product

REFERENCES

Akbari, H., Pomerantz, M., Taho, H., 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy 70, 295–310.

Akbari, H. (2005). "Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigatio*n*." LBNL-58285. Berkeley, CA: Lawrence Berkeley National Laboratory

Alcazar, S., Bass, B., 2006. Life cycle assessment of green roofs—case study of an eight-story residential building in Madrid and implications for green roof benefits. In: Proceedings of the Fourth North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Boston, MA. The Cardinal Group, Toronto, 11–12 May.

Alexandri, E. and Jones, P. (2008). "Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates." *Building and Environment* 43, pp 480-493.

Al-Sanea, S., 2002. Thermal performance of building roof elements. Building and Environmental 37, 665-675.

Agron, J. (2002). Bucking the trend: The 28th annual official education construction report [Electronic version]. *American School & University, May, 2002*. Retrieved February 4, 2003, from http://asumag.com/ac/may_2002/index.htm

American Hydrotech, Inc., 2002. The Garden Roof Planning Guide. American Hydrotech, Inc. Chicago, IL.

Arnold, C., Gibbons, J., 1996. Impervious surface coverage. Journal of the American Planning Association 62, 243–259.

Arrow, K., Cropper, M., Eads, G., Hahn, R., Lave, L., Noll, R., Portney, P., Russell, M., Schmalensee, R., Smith, V., Stavins, R., 1996. Is there a role for benefit–cost analysis in environmental, health, and safetyregulation? Science 272, 221–222.

Atlanta Public Schools, www.atlanta.K12.ga.us

Banting, D., Doshi, H., Li, J., Missios, P., Au, A., Currie, B., Verrati, M., 2005. Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto. Available at /http://www.toronto.ca/greenroofs/findings.htmS. Accessed in February 2006.

Bass, B., Krayenhoff, E., Martilli, A., Stull, R., Auls, H., 2003. The impact of green roofs on Toronto's Urban Heat Island. In: Proceedings of the First North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Chicago. The Cardinal Group, Toronto, pp. 292–304, 29–30 May.

Bass, Brad and Bas Baskaran. (2001). "Evaluating rooftop and vertical gardens as an adaptation strategy for urban areas." CCAF Impacts and Adaptation Progress Report April 1, 1999-March 31, 2001. Institute for Research in Construction. http://www.roofmeadow.com/technical/publications/BBass_GreenRoofs_2001.pdf

Bick, Ian 2011. Summers Roofing Company. Personal Interview.

Blam, Susanne 2011. Perkins & Will Architects. Personal Interview.

Boss International, 2005. StormNet Builder. Wisconsin, Boss International. Brenneisen, S., 2005. Green roofs - recapturing urban space for wildlife - a challenge for urban planning and environmental education. In: Proceedings of the Third North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Washington, DC, 4–6 May. The Cardinal Group, Toronto, pp. 449–456.

Breedlove Land Planning News, www.breedlovelandplanning.wordpress.com

Burba, George. (2010). "The Encyclopedia of Earth: Evapotranspiration." http://www.eo earth.org/article/Evapotranspiration.

Carter, Timothy and Andrew Keeler. (2008). "Life cycle cost benefit analysis of extensive vegetated roof systems." *Journal of Environmental Management* 87, pp 350-363.

Carter, T., 2006. Vegetated roofs for urban ecosystem remediation: performance and policy in the Tanyard Branch Watershed. Ph.D. Dissertation, Institute of Ecology, University of Georgia, Athens, GA.

Carter, T., Rasmussen, T., 2006. Evaluation of the hydrologic behavior of green roofs. Journal of the American Water Resources Association 42, 1261–1294.

Cannarsa, Andrew (2008). "Hilton hotel to sport area's largest green roof". The Examiner. http://www.examiner.com/a-1341059~Hilton_ hotel_to_ sport_area_s_ largest_green_roof.html

Cassidy, R., 2003. Building Design and Construction White Paper on Sustainability. A supplement to Building Design and Construction magazine. Available at http://www.bdcmag.com/ newstrends/BDCWhitePaperR2.pdfS www.bdcmag.com/newstrends/ BDCWhitePaperR2.pdf. Accessed in November 2005.

Changnon, S.A., K. E. Kunkel, and B. C. Reinke. (1996). "Impacts and responses to the 1995 heat wave: A call to action." *Bulletin of the American Meteorological Society* .77: 1497–1506. doi:10.1175/1520-0477(1996)077<1497:IARTTH>2.0.CO;2.

Che-Ani, A.I. (2009). "Mitigating the Urban Heat Island Effect: Some Points without Altering Existing City Planning." *European Journal of Scientific Research*. Vol.35 No.2: 204-216. http://www.eurojournals.com/ejsr_35_2_06.pdf

Ciampi, M., Leccese, F., Tuoni, G., 2005. Energy analysis of ventilated and micro-ventilated roofs. Solar Energy 79, 183–192.

Clark, C., Talbot, B., Bulkley, J., Adriaens, P., 2005. Optimization of green roofs for air pollution mitigation. In: Proceedings of the Third North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Washington, DC. The Cardinal Group, Toronto, pp. 482–497, 4–6 May.

Clark, C., Adrians, P., Talbot, B., 2006. Probabilistic economic analysis of green roof benefits for policy design. In: Proceedings of the Fourth North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Boston, MA, The Cardinal Group, Toronto, 11–12 May.

Coffman, R., Martin, J., 2004. The Sustainability of an agricultural roof garden. In: Proceedings of the Second North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, OR, The Cardinal Group, Toronto, 2–4 June.

Costanza, R., D'Arge, R., De Groot, R., Faber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., Van der Belt, M., 1997. The value of the world's ecosystems and natural capital. Nature 387, 253–260.

Creswell, John W., 2nd Edition, Sage Publications 2003. Research Design – Qualitative, Quantitative, and Mixed Methods Approaches.

Currie, B.A., Bass, B., 2005. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. In: Proceedings of the Third North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Washington, DC. The Cardinal Group, Toronto. pp. 495–511, 4–6 May.

Denardo, J., Jarrett, A., Manbeck, H., Beattie, D., Berghage, R., 2003. Green roof mitigation of stormwater and energy usage. ASAE Meeting Paper No. 032305, ASAE, St. Joseph, Michigan.

Environmental Protection Agency (EPA), 1999. Preliminary data summary of urban storm water best management practices. EPA 821-R-99- 012, EPA Office of Water, Washington, DC.

Environmental Systems Research Institute, Inc. (ESRI), 1999. ArcView GIS 3.2 for Windows. Environmental Systems Research Institute, Inc., Redlands, CA.

Ferguson, B., 2005. Porous Pavements. Taylor & Francis, Florida.

Filardo, M., O'Donnell, S. November 2010. 21st Century School Funding; Improving Urban Public School Facilities, Washington, DC.

Friends of the High Line. (2010). "High Line." http://www.thehighline.org/

Gleick, P., 2003. Water use. Annual Review of Environmental Resources 28, 275–314.
Gusa, Adem. “Re: MEM student inquiry: green roofs.” Email message. 16 September 2010.

Hanley, N., Spash, C., 2007. Cost–benefit Analysis and the Environment. Edward Elger, England.

Harzmann, U., 2002. German green roofs. In: Proceedings of the Annual Green Roof Construction Conference, Chicago, IL, Roofscapes, Inc.

Heras, M., Jimenez, M., San Isidro, M., Zarzalejo, L., Perez, M., 2005. Energetic analysis of a passive solar design, incorporated in a courtyard after refurbishment, using and innovative cover component based in a sawtooth roof concept. Solar Energy 78, 85–96.

Herbert, S., England, L., Buesching, J., Crowley, J., Meyer, J., Summer 2002 Design Studio, 2003. Tanyard Branch: demonstrating an interdisciplinary approach to the design phase of an urban stream restoration. In: Hatcher, K.J. (Ed.), Proceedings of the 2003 Georgia Water Resources Conference, University of Georgia, Athens, GA.

Hilten, R., 2005. An analysis of the energetic and storm water mediation potential of green roofs. M.S. Thesis, Department of Biological and Agricultural Engineering, University of Georgia, Athens, GA.

Horvath, A., 2004. Construction materials and the environment. Annual Review of Environmental Resources 29, 181–204.

Hui, S. C. M. and Law, A. Y. M. (2002). “Green Design and Construction of Site Offices.” Research Report for Gamon-Skanska Limited, Department of Mechanical Engineering, The University of Hong Kong, Hong Kong..

Kim, K., 2004. The application of the biosphere reserve concept to urban areas: the case of green rooftops for habitat network in Seoul. Annals of the New York Academy of Sciences 1023, 187–214.

Kohler, M., Schmidt, M., Grimme, F., Laar, M., Gusmao, F., 2001. Urban water retention by greened roofs in temperate and tropical climate. In: Proceedings of the 38th IFLA World Congress, Singapore.

Kosareo, L., Ries, R., 2006. Life Cycle Assessment of a green roof in Pittsburgh. In: Proceedings of the Fourth North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Boston, MA, The Cardinal Group, Toronto, 11–12 May.

Kumar, R., Kaushik, S., 2005. Performance evaluation of green roof and shading for thermal protection of buildings. Building and Environment 40, 1505–1511.
Lee, A., 2004. Life cycle cost analysis—green roofs form an investment. In: Proceedings of the Second North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, OR, The Cardinal Group, Toronto, 2–4 June.

Lewis, Laurie; Snow, Kyle; Farris, Elizabeth; Condition of America's Public School Facilities: 1999, p. 37 Functional Age of Schools, National Center for Education Statistics, June 2000; http://nces.ed.gov/pubs2000/2000032.pdf

Madsen Roofing and Waterproofing. (2010) "Estimating Roof Maintenance Costs." http://www.madsenroof.com/roofing_services/roof_mainenance_program.htm

Mallickm, Rajib B, B. Chen, and S. Bhowmick. "Reduction of Urban Heat Island Effect through Harvest of Heat Energy from Asphalt Pavements." http://heatisland2009.lbl. gov/docs/211420-mallick-doc.pdf

Maneewan, S., Hirunlabh, J., Khedari, J., Zeghmati, B., Teekasap, S., 2005. Heat gain reduction by means of thermoelectric roof solar collector. Solar Energy 78, 495–503.

McDonough, M., Braungart, M., Anastas, P., Zimmerman, J. Applying the Principles of Green Engineering to Cradle-to-Cradle Design. Environmental Science Technology, 2003, 37 (23), pp 434A–441A.

Means, R., 2005. Building Construction Cost Data. R.S. Means, Kingston, MA.

Morancho, A., 2003. A hedonic evaluation of urban green areas. Landscape and Urban Planning 66, 35–41.

Morris, Tonia 2011. GIS Technician Principal, City of Atlanta Dept. Watershed Management

National Association of Home Builders, 2004. NAHB Model Green Home Building Guidelines. Available at /www.nahb.org/gbgS. Accessed in February 2006.

National Center for Education Statistics; http://nces.ed.gov/fastfacts

National Research Council, 2007. Green Schools: Attributes for Health and Learning, The National Academies Press, Washington, D.C.

Onmura, S., Matsumoto, M., Hokoi, S., 2001. Study on evaporative cooling effect of roof lawn gardens. Energy and Buildings 33, 653–666.

Palumbo, Steve. "Re: Physics and Teer." Email messages. October 2010.
Paul, M., Meyer, J., 2001. Streams in the urban landscape. Annual Review of Ecological Systems 32, 333–365.

Peck, Steven and Monica Kuhn. (2010). "Design Guidelines for Green Roofs." http://egov.cityofchicago.org/webportal/COCWebPortal/COC_ATTACH/design_guidelines_for_green_roofs.pdf

Peck, S.W., Callaghan, C., Kuhn, M., Bass, B., 1999. Greenbacks from Green Roofs: Forging a New Industry in Canada. Canada Mortgage and Housing Corporation. Available at /http://www.greenroofs.org/pdf/Greenbacks.pdfS. Accessed in June 2005.

Pennigar, Tim. "Re: Green roofs: inquiry from graduate student." Email message. February 2011.

Pickett, S., Cadenasso, M., Grove, J., Nilon, C., Pouyat, R., Zipperer, W., Costanza, R., 2001. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annual Review of Ecological Systems 32, 127–157.

Rowand, Cassandra; How Old are America's Public Schools?, National Center for Education Statistics, 1999; http://nces.ed.gov/pubs99/1999048.pdf

Sayed, O., 2001. Crassulacean acid metabolism 1975–2000, a checklist. Phytosynthetica 39, 339–352.

Scenna, Al 2011. Project Manager, Brookwood Group – APS Construction Manger. Personal Interview

Scott, Michon. (2006) "Beating the Heat in the World's Big Cities." http://earthobservatory.nasa.gov/Features/GreenRoof/printall.php.

The United States Environmental Protection Agency (EPA). (2008). "Reducing Urban Heat Islands: Compendium of Strategies." http://www.epa.gov/heatisld/about/ index.htm

The United States Environmental Protection Agency (EPA). (2009). "Heat Island Effect." http://www.epa.gov/heatisld/about/index.htm.

U.S. Census Bureau, June 2010, Public Education Finances, www2.census.gov

United States Green Building Council. (2009). LEED for Schools Reference Guide, Version 3. Washington, D .C .

Vaes, G., Berlamont, J., 2001. The effect of rainwater storage tanks on design storms. Urban Water 3, 303–307.

VanWoert, N.D., Rowe, D., Andresen, J., Rugh, C., Fernandez, R., Xiao, L., 2005. Green roof stormwater retention: effects of roof surface, slope, and media depth. Journal of Environmental Quality 34, 1036–1044.

Voogt, James A. (2004). “Urban Heat Islands: Hotter Cities.” http://www.action bioscience.org/environment

Warseck, Karen. (2010). “Roofing Maintenance Cost Calculations.” Facilities Net. http://www.facilitiesnet.com/roofing/article/Roofing-Maintenance-Cost-Calculations--11896

Wong, N.H., Tay, S., Wong, R., Ong, C.L., Sia, A., 2003. Life cycle cost analysis of rooftop gardens in Singapore. Building and Environment 38, 499–509.