A GEOGRAPHIC APPROACH TO MODELING THE IMPACT OF GREEN ROOFS ON COMBINED SEWER OVERFLOWS IN THE BRONX

by

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ABSTRACT OF THE THESIS

A Geographic Approach to Modeling the Impact of Green Roofs

on Combined Sewer Overflows in the Bronx

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The Bronx, New York, like many older urban areas in the United States, suffers from the negative environmental impacts from combined sewer overflows (CSOs). Green roofs have been proposed as a best management practice to reduce stormwater runoff and CSOs. These vegetated roof tops can detain rainfall along with providing other benefits to the building owner and community. This paper describes a green roof stormwater model designed for the Bronx, New York. Building-level geographic data was used to estimate the potential area for green roof implementation in each sewer system subcatchment. A software program was designed as a decision support system with a green roof micro-model, a simple sewer system model, and an interactive map. The model results show that if extensive green roofs were implemented on all available flat roof space, then annual CSOs could be reduced by over 30%. This paper discusses the geographic variation of the model results, and the effectiveness of green roofs as a CSO best management practice is used to rank subcatchment performance.

Acknowledgement

I was inspired by many great faculty members at Rutgers, and each of their courses has informed my work in their own way. I would like to thank my advisor and committee for keeping me focused over the past year as I attempted to weave these threads together into my own story. The interdisciplinary modeling project described in this paper was a team effort, where I had the pleasure of working with several talented people. I thank Jim for his advice and Anand for his enthusiasm. Most of all, I thank Matthew for his patience.

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Chapter 1. Introduction

Introduction

Ecologically designed urban infrastructure, such as green roofs, are gaining popularity as cities strive to become more sustainable. Concerns over global warming, public health, and fiscal efficiency are bringing support to urban environmental issues in new and innovative ways. Green roofs provide multiple benefits, including stormwater management and energy efficiency. They are an especially suitable type of green infrastructure for dense urban areas.

An environmental problem common in northeastern American cities is combined sewer overflows (CSOs). Rainstorms can cause untreated sewage to be discharged directly into local waterways along with contaminated runoff, impacting water quality and public health. Traditional wastewater engineering solutions to increase system capacity are costly to build and must compete for limited municipal funds. One alternative solution for stormwater management are green roofs, which use plantings in lightweight soil material on top of buildings. Green roofs can capture a significant amount of rainfall, lessening the burden on the sewer system, as well as filtering the water that is discharged after being detained. In addition to these benefits which reduce combined sewer overflows, green roofs also reduce energy needs by providing building insulation, reduce costs for the building owner by doubling the roof lifespan, and provide valuable green space in dense urban environments. The mix of public and private benefits afforded by green roofs makes them suitable for incentives such as tax rebates and reduced stormwater fees.

Figure 1. Green roof on the Bronx Courthouse. Photo May 16, 2007, Kate Shackford, BOEDC.

This project takes advantage of the detailed geographic information available for the Bronx, New York, to model the potential for green roofs to reduce combined sewer overflows. Each sewer subcatchment area contains flat-roofed buildings that could be sites for green roofs. If enough green roofs were built, the CSOs would be reduced, improving water quality and public health. A software model called the Bronx Green Roof Stormwater Simulation Tool was developed to simulate the impact of these potential green roofs on the sewer system. This model combines engineering models with a geographic information system (GIS), displaying potential CSO reduction through a map interface. As a decision support system, it is intended to be used as a planning tool for stormwater control. This paper focuses on the data development and mapping aspects of the project. It contextualizes the use of green roofs as a best management practice for stormwater runoff related issues, and as related to sustainable city initiatives.

Research questions

This paper addresses three research questions. First, we look at how GIS and urban planning data can be applied to urban sustainability issues. What data are available for the Bronx, and how can they be used? Secondly, we ask if green roofs can be used to reduce stormwater runoff. How much flat roof area is available, and is it enough to allow green roofs to have an impact on combined sewer overflows? Finally, we examine the model results to find where placing green roofs in the Bronx would have the most impact on combined sewer overflows.

This paper is situated in the field of geography to emphasize the importance of place. Geographic techniques are used to evaluate information at the building and neighborhood scale. Geography can also provide a framework for interdisciplinary studies, examining relationships between the human and natural environments. This makes geography especially suitable for sustainability research, integrating social, economic, and environmental systems. In this paper we focus on the geographic data and techniques used in the project, and the geographic variation of the model results.

Project design

This project developed a software model to link potential green roof areas to sewer system impacts in the Bronx. GIS tools were used to analyze existing building data, to quantify the areas where green roofs could be constructed in each sewer system subcatchment. We combined several municipal datasets to determine building characteristics. This data-rich geographic approach allows research at the neighborhood scale, rather than a broader regional analysis.

This geographic information was linked to a green roof model and a sewer model to simulate the impact of green roofs on stormwater runoff and CSOs. A software program was designed to link all data and model components together, to create an easy to use decision support system for the Bronx Overall Economic Development Corporation. Model results are presented through an interactive map interface for geographic visualization and exploration.

Many combinations of green roof designs can be simulated, with three different rainfall conditions, for a one-year period. The user-specified green roof scenarios are applied across the entire borough of the Bronx to find the relative impact in different subcatchments.

Results

For this paper, the model was run fifteen times with a representative range of the available parameters. The results are reported in terms of borough-wide CSO reduction as well as the outfall overflow reduction for each subcatchment. The high performance design scenarios showed over 30 percent reduction in CSOs borough-wide.

The model results varied by subcatchment, with a larger response in combined sewer subcatchments as compared to separate sewer subcatchments. Little impact was seen in park areas, where there are few buildings. In some design scenarios, CSOs were completely eliminated at outfalls with small amounts of discharges. Several subcatchments were identified as being the most sensitive to green roof construction. Outfalls HP-009 and HP-011 stood out for having the highest reductions of CSOs by volume. For outfalls WI-0060 and HP-0021 the cost-benefit ratio of green roof area to CSO reduction was particularly high.

Thesis overview

In the next chapter we cover a literature review for three separate topics that are integrated in this project. These are urban sustainability, green roofs, and environmental mapping and models. Urban sustainability is defined using a variety of ecological, social, and economic contexts. Green roofs are reviewed in terms of their construction and the multiple benefits they provide. The benefit of stormwater reduction, the focus of this project, is examined in more detail. The literature review concludes with an overview of environmental mapping and models, the tools used in our methodology. This includes GIS as an information technology and visualization tool.

In the methodology chapter we review the overall project design and its components. The data sources for our Bronx case study are described. The geoprocessing steps and graphical user interface design, performed by the author, are described in detail.

The next chapter describes the project results. First, the new data created by the geoprocessing are presented. The rest of the chapter focuses on the model simulations. Several variations of running the model are compared for a range of results. A simple scoring system was created to find the subcatchments most sensitive to green roof construction.

In the conclusions chapter we consider the meaning of the model results and suggest several avenues for further research. These include ways to implement more detailed sewer models, and application to other counties. Our model shows that green roofs can have a meaningful impact of combined sewer overflows, and that the sensitivity of the sewer system response varies geographically. We recommend that our model be used with additional cost-benefit analysis to evaluate green roofs as a best management practice for stormwater control.

The last section of the paper are the appendices. These include the decision support system's user manual and supporting information, input and output data tables, and additional model results in map and table formats.

Chapter 2. Literature Review

Introduction

This literature review includes three topics, each relating to different aspects of the green roof modeling study. We move from problem, to solution, to methodology. The first topic is *sustainable cities*, which looks at the broad picture of urban sustainability in the academic literature. This establishes the general theoretical context in which this research project is situated.

The next topic is *green roofs*, which describes this type of green infrastructure. Green roofs can contribute to urban sustainability in multiple ways. One of the measurable benefits of green roofs is the reduction of stormwater runoff and combined sewer overflows, which can cause water quality problems in urban areas.

The final section is about *environmental mapping and models*. This includes some of the techniques used to evaluate the potential of green technologies in reaching specific sustainability goals. Decision support systems can integrate engineering models, maps, and visualization tools into user-friendly software applications. An integral part of our project used geographic information systems (GIS) to create model inputs from detailed building-level data, and to present the model results as an interactive map.

Sustainable cities

Sustainability introduction

The literature on sustainability spans many fields. Work is being done in the disciplines of geography, urban planning, environmental science, engineering, and economics. Sustainability by widest definition includes environmental, social, and economic factors.

While many calls have been made detailing the need for sustainability, there is little agreement on what specific measures should be taken. Proposed solutions range from making existing processes more efficient to completely new ways of living, building, and trading. Much of current research focuses on easily measured physical characteristics, rather than social and political factors. Interdisciplinary approaches have been proposed for a more integrated study of sustainability.

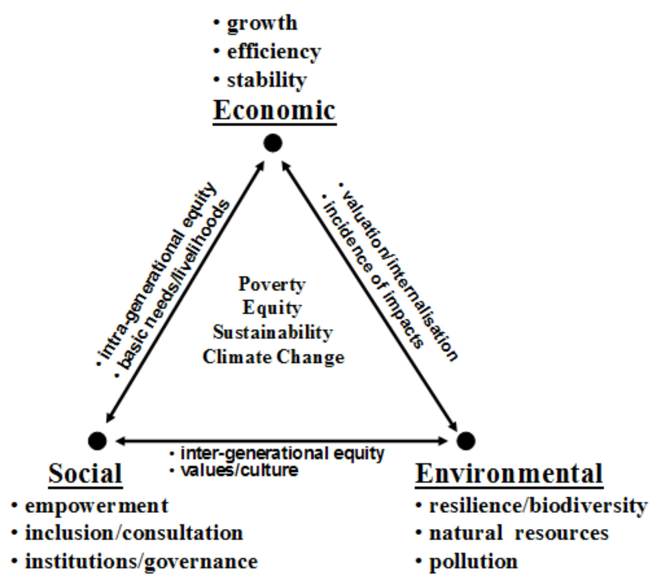


Figure 2. Sustainable development triangle (Munasinghe 2007).

A useful way of describing sustainability that has emerged is the sustainability triangle. The three aspects of environmental, economic, and social sustainability must be present for true sustainability to be possible. For environmental sustainability, this includes the wise use of natural resources, preserving biodiversity, and minimizing pollution. Economic sustainability encourages efficient use of resources, thoughtful development, and stable markets. Social sustainability requires that all people's basic needs are met, empowering communities, and having responsible government. Munasinghe (2007) has defined these three aspects as the points of a sustainable development triangle, shown in Figure 2. Each aspect is connected to the others, and must be balanced.

History

Writers and scholars have long lamented the destructive nature of human impact upon the landscape. Ideas about sustainable development have been around for a long time, but without always using the term "sustainable". For centuries, environmental problems were blamed on high population levels. The idea of carrying capacity goes back to Thomas Malthus' writings in 1798. Drawing from Adam Smith's ideas of populations at equilibrium, Malthus theorized that there are absolute limits to population growth. When a population becomes too large, its numbers are limited through the mechanisms of misery and starvation. Technology may temporarily be able to extend the limits of growth, but does not eliminate them. Marx's writings on population limits emphasized the importance of societal pressures rather than biological limits (Meek 1971). With the industrial revolution came a more pragmatic and utilitarian approach. George Marsh wrote of humans disrupting the harmonies of nature. He believed in the need for conservation as an integral part of responsible science and practical development (Robbins 2004).

The industrial revolution also accelerated the pace of urban development. Carl Sauer (1938) wrote "there is a dominant geographic theme which deals with the growing mastery of man over his environment." Much of humanity's long history had been in symbiotic balance with nature, until industrialization allowed greater control over the landscape. He recognized the unsustainability of high commercial production that depended on exploiting colonial resources, even describing the commercial economy of the times as having "suicidal qualities." He wrote, "We have not yet learned the difference between yield and loot. We do not like to be economic realists." He also called for integration of physical and social sciences, as later scholars would repeat.

In the late 20th century, the discourse on limits to growth continued with Ehrlich's "population bomb." It was believed that environmental degradation caused by overpopulation was what threatened quality of life (Meek 1971). But the dramatic predictions of mass starvation and other catastrophes failed to materialize. The green revolution and family planning allowed people on average to live longer healthier lives.

It has been acknowledged that the economy is not independent of environmental restraints. At the global level, limits unarguably exist in terms of finite material resources and space. The production of pollution has been recognized as economically inefficient (Daly 1973). In the 1990's, "ecological services" became of interest. Monetary values were estimated for natural services such as flood control and pollution abatement, and compared with their costly technological alternatives. The intense technological substitutes required in urban environments are not considered to be sustainable in the long term.

The current literature on sustainability often focuses on consumption (Rees and Wackernagel 1996). It is not large populations that are thought to be the problem; rather it is the high levels of consumption of material goods. Affluence creates high-consumption lifestyles, which demand more land for suburban homes, more fuel for transportation, and more raw materials for manufactured products. This generates the need for more capacity for waste disposal and pollutes the environment.

Common futures

The concept of sustainability became more widespread with the United Nations conference of the World Commission on Environment and Development. This produced *Our Common Future*, also referred to as the Brundtland Report, in 1987. The report called for "a new era of economic growth, one that must be based on policies that sustain and expand the environmental resource base" (Brundtland 1987). Sustainability was seen as a necessity for combating the related problems of poverty and environmental degradation. The report defined sustainable development in the following way:

> *"Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. The concept of sustainable development does imply limits—not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities." (Brundtland 1987)*

One of the key recommendations given to governments was to provide clean and healthy cities. This issue was the focus of the United Nations' Habitat II, the second Conference on Human Settlements, held in Istanbul in 1996. One of the significant contributions of this conference was *Habitat Agenda-Agenda 21*, a document calling cities to lead the way in sustainable development and outlining the role of governments. Many cities have developed "Local Agenda 21" processes—in 1996 there were already over 1500 processes in 49 countries (Brugmann 1996). They are based on the definition of sustainable development as "development that delivers basic environmental, social, and economic services to all without threatening the viability of the natural, built, and social systems upon which these services depend." The processes are decision-making criteria that seek to balance economic, community, and ecological systems at the local level. They also aim to factor in local and global impacts of development, and attempt to balance long-term sustainability with present local needs. The typical steps of a Local Agenda 21 process are similar to traditional environmental planning methods with some modifications, placing more emphasis on participatory approaches, measuring global impacts, and locally maintaining strategic control.

Sustainable cities

The growth of cities makes the sustainable development of urban areas especially important. Currently, around half of the world's population lives in cities, and urban inhabitants may reach 70 percent of the population by 2050 (UN 2007).

In the United States, cities have changed over time through economic development and with environmental and social services. City living was dramatically improved in the late 19th century with the sanitary revolution, including advances in plumbing and sewers (Satterthwaite 1997). Separating land uses through planning and zoning became important in the 1920's, and suburbanization shaped the landscape after World War II (Platt 2004). In the 1960's, writers such as Jacobs (1961) and Whyte (1968) began to challenge many of the assumptions of urban planning and sprawl, emphasizing efficiency and aesthetics for both physical and cultural environments. Growth management of the 1970's became smart growth in the 1990's, with a focus on environmentally friendly urban development (Platt 2004).

Even with these improvements, cities remain highly modified environments. Cities, being human built and controlled, have until recently been thought of as separate from ecology. Enlightenment had left a legacy of dividing humans from nature, and sustainability is one way of bringing them back together. Today, nature is being rediscovered in cities, inspired in part from geography and landscape architecture work by White, McHarg, and Whyte in the 1960s (Platt 2006).

Can cities be sustainable environments? By the narrowest definition of sustainability, a city cannot exist in a self-contained manner. Cities need to import food, raw materials, and consumer goods. They also need to export goods for trade, and export waste materials. However, the high density of city living offers many advantages that contribute towards sustainability. These include lower infrastructure costs, low per capita demand for land, more efficient heating of buildings, and less dependence on cars and fossil fuels. Cities are cultural centers and important for social sustainability. As centers of commerce, they are essential for economic sustainability. Many authors have discussed the sustainable aspects of cities in terms of urban impact, energy use, transportation, and health (Hough 1984; Alberti and Susskind 1996; Rees and Wackernagel 1996; Blassingame 1998).

Like the discourse on global sustainability, there is no commonly held definition of sustainability at the city level. Research approaches differ in scale, disciplinary approach, subjective perceptions, causality, and variability (van Kamp et al. 2003). Satterthwaite (1997) writes that with such varying definitions of sustainability, many places are already taking actions that could be construed to be sustainable. Agencies may claim to be promoting sustainable development that in fact is contributing to unsustainable patterns according to other definitions. Satterthwaite found much of the literature focused solely on either ecological sustainability or sustainable development. This divide misses the point of the Brundtland Report that both concerns need to be integrated.

Acselrad (2001) has grouped sustainable city representations from the literature in terms of *quality of life*, the *legitimization of urban policies*, and *technical-material representation*s. Each realm can be thought of in terms of being sustainable unto itself (a city's policies are successful in sustaining the city's services at appropriate levels), as well as in relation to global sustainability issues. They illustrate some of the interconnectedness of the social, economic, and environmental aspects of the sustainability triangle. Quality of life emphasizes the social issues of sanitation, citizenship, and equity. This is important for public health and competing for global capital. The political realm views the city as a space for the legitimization of urban policies, requiring adequate urban services, investments in infrastructure, and the ability of a city to manage risk. The technical-material representation of cities focuses on the physical transfer of materials and energy. A city can become more sustainable through the better use of space, materials, and energy.

Since physical characteristics are easier to quantify than social or political ones, technical-material sustainability is studied more often. Urban metabolism studies consider both man-made and natural systems, and include the idea of resilience, allowing the urban ecosystem to recover from disturbance (Acselrad 2001).

Achieving sustainability

Satterthwaite (1997) has outlined the following sustainability goals for cities, following from the Brundtland Report. To meet the needs of the present requires: the economic needs of livelihood and security; social, cultural, and health needs including healthy living and working environments, sanitation, education, and housing choices; and political needs including political participation, civil rights, and environmental legislation. Goals for meeting needs of future generations require: minimizing use of non-renewable resources including fuels, as well as preserving cultural and historical assets; sustainable use of finite renewable resources; and wastes not overtaxing capacities of sinks to absorb or dilute them without adverse effects.

The actions required to meet these goals have been summarized by Acselrad (2001). Efficiency is achieved by reducing material waste. The scale of economic growth is limited. Justice and ecology are combined for equality. Withdrawing from world markets ensures self-sufficiency. Ethics emphasize the link between material development and future conditions.

To implement sustainability goals, the fields of physical and social sciences, policy, and planning will need to be better integrated in a multi-disciplinary approach. Sustainability advocates point out that “green” engineering not enough by itself, since even the most efficient production methods can overwhelm natural systems. Historically, engineering has focused on a single media at a time, but what is needed is more collaboration between engineering and other disciplines. Proposed “metadisciplines” include industrial ecology and sustainability science.

Industrial ecology is a specialized field that aims to integrate multiple aspects of sustainability. Its approach is to re-embed industrial activity into both social and natural contexts. While related to the ideas of urban metabolism and city ecology, it also looks at the interrelationships between producers and consumers. It “aims at an industrial metabolism that is consistent with nature’s metabolism,” considering both the sources and sinks of materials (Huber 2000). Socolow (1994) outlines the concerns of industrial ecology to be: having a long term perspective; being global in scope; avoiding the overwhelming of natural systems; addressing vulnerability; mass flow analysis; and the centrality of producers as agents of change. By considering all these realms simultaneously through industrial ecology, a better approach towards sustainability can be made. The outlook of industrial ecologists is generally more positive than in other disciplines. Businesses can be motivated to implement environmental management practices for legal, economic, and social reasons. Industrial ecology studies have found pollution prevention to be more cost-effective than remediation and clean-up costs (Huber 2000).

Sustainability science and engineering has also been suggested as a new metadiscipline (Mihelcic et al. 2003). Sustainability science is more ambitions than industrial ecology in trying to incorporate even more perspectives. Sustainability science would integrate many disciplines, including: physical science, social science, and engineering; economics; industrial ecology and design; information technology, remote sensing, and GIS; human and environmental impact modeling and risk assessment; social and behavioral research tools; global context sustainability; and education.

Sustainable cities summary

Sustainability is a goal of environmentalists, geographers, planners, engineers, economists, and may others. People in all disciplines recognize that efforts in their field alone are insufficient to make the kinds of changes needed to achieve sustainability. One of the major obstacles to such integration is bridging the gap between the environmental and policy communities (Brown 2003). Environmental quality specialists need to understand the functioning and language of planning processes to be able to provide information more suitable for development planning. The physical science research needed for sustainable development is more mature than in the social sciences. Difficult questions need to be resolved about the distribution of benefits and burdens, requiring the involvement of politicians to address accountability issues. However, making sacrifices and accepting local burdens are not popular political platforms. Creative methods of addressing these issues in a positive way are needed.

Cities are a promising place for the implementation of sustainability goals. A recent survey reported the number of cities with green programs as increasing from only two in 1997, to ninety-two cities in 2008, with an additional thirty-six cities with programs in development (Herman 2008). Local non-governmental organizations have embraced sustainability along with other environmental and social issues, and many international development projects attempt to incorporate ideas of sustainable development. While their implementation may not be perfect, they have been successful in raising awareness about sustainability issues on a wide scale. On an individual scale, many businesses have realized the competitive advantage of a “green” image.

Green roofs

Green roof introduction

Green roofs, or vegetated rooftops, are one type of green infrastructure that can contribute to sustainable cities. They address the goals of industrial ecology and sustainability science by providing an integrated ecological-industrial system that reduces waste and maximizes energy capture (Oberndorfer et al. 2007). As cities are highly modified environments, green roofs are especially suitable to restore lost ecological services such as filtering rainfall and providing habitat. Unlike more traditional environmental engineering management technologies, they simultaneously provide multiple benefits including building insulation and reducing the urban heat island effect. Green roofs are also effective at capturing stormwater runoff, which is of particular interest in cities with combined sewer overflow problems.

Stormwater runoff

The United States Environmental Protection Agency (USEPA) reports that urban stormwater runoff is the largest source of water quality impairments for rivers and streams, and the third largest source for lakes (VanWoert et al. 2005). More than ten trillion gallons of untreated stormwater enter US waterways every year (Dorfman and Rosselot 2008), causing a variety of environmental problems including floods, erosion, and poor water quality. Stormwater discharged from sewer pipes can also cause erosion and scouring in streams. The runoff travels over contaminated surfaces and transports pollutants such as metals, pesticides, and nutrients from the land into natural waterways. The USEPA has estimated that the amount of stormwater runoff from a typical city block is more than five times as much as from a woodlot (VanWoert et al. 2005).

Impervious surfaces disrupt the natural cycle of water infiltrating permeable ground, and is one of the contributing factors to stormwater management problems. The amount of imperious surfaces in a watershed can be generally related to the water quality in stormwater runoff and local waterways (Kloss and Calarusse 2006). Impervious surfaces include buildings, roads, sidewalks, parking lots, and other paved surfaces. In an undeveloped landscape, rainfall is intercepted and slowed down by vegetation. Water evaporates from leaves, or is absorbed into the soil and slowly released to streams and groundwater. In a highly developed landscape, rainfall quickly runs off impervious surfaces and is channeled into engineered systems (Rosenzweig, Gaffin, and Parshall 2006).

Across the continental United States, there is an estimated twenty-five million acres of impervious surfaces, nearly one quarter of the developed land area. Urban areas often have 45 percent of their area covered by impervious surfaces (Kloss and Calarusse 2006), with buildings alone taking up as much as 32 percent of their area (Oberndorfer et al. 2007).

In older cities, combined sewer systems carry both stormwater and sanitary waste flow to water treatment plants. Approximately 742 municipalities across the United States have combined sewer systems, and serve forty-six million people (Dorfman and Rosselot 2008). When there is heavy rainfall, the combined sewers often discharge untreated sewage directly into the waterways.

Figure 3 illustrates the flow of rainfall through a combined sewer system. When the capacity of the waste water treatment plant is reached, the regulator diverts the flow to the combined sewer overflow outfall. This trigger point varies depending on the residual capacity of the regulator, which is the difference between the maximum capacity and dry weather flow.

These combined sewer overflows (CSOs) cause both environmental and public health problems, triggering beach closings and swimming and fishing advisories (Kloss and Calarusse 2006; USEPA 2007a). There are an estimated 43,000 CSO events in the US every year, discharging 850 gallons (Dorfman and Rosselot 2008).

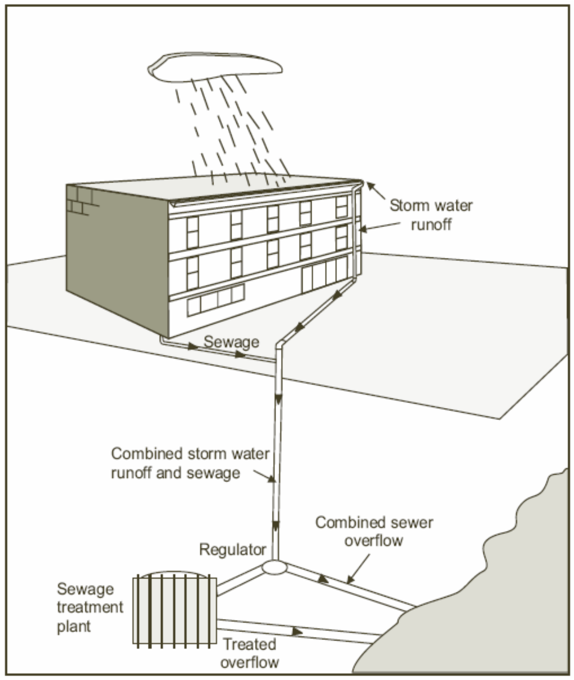


Figure 3. Combined sewer system diagram (Rosenzweig, Gaffin, and Parshall 2006).

The Clean Water Act of 1972 was intended to control both point and non-point source pollution, including CSOs and contaminated stormwater. It established guidelines to protect the nation's water resources, with the goal of making surface waters fishable and swimmable (NRC 2001). Newer USEPA regulations in 1992 required states to list all water bodies which fail to meet water quality standards for their designated uses (usually fishing and swimming) (NRC 2001). A 2000 amendment required cities to develop long term control plans to specifically address combined sewer overflows.

These programs made significant improvements in water quality, mainly from reducing industrial point sources of pollution through the National Pollutant Discharge Elimination System (NPDES) permitting program. However, many water bodies are still impaired, and in1996 an estimated 40 percent of water bodies were still in violation of fishing and swimming standards (NYC Mayor's Office 2007). In 2001, the National Research Council estimated that approximately 21,000 water bodies in the United States failed to meet water quality standards (NRC 2001). Nearly all municipalities with CSO outfalls continue to experience discharges, and as of 2004, only 59 percent had submitted long term control plans. Water quality problems caused over 26,000 beach closing and advisory days nationally in 2007. Over 10,000 days were due to polluted runoff and stormwater, and 4,000 were sewage-related (Dorfman and Rosselot 2008). The largest cause of water quality impairments in the United States is pathogens, followed by mercury, other metals, sediment, and nutrients. The most common pathogen is fecal coliform, present in nearly half of pathogen-impaired waters (USEPA 2008b).

Green infrastructure

Green infrastructure offers several alternative methods for managing stormwater runoff. These methods treat water as an important resource rather than a waste product. Green infrastructure includes green roofs, rain gardens, vegetated swales, permeable pavement, rainwater collection, wetlands, riparian protection, and other natural methods (Kloss and Calarusse 2006). They can be retrofitted into existing sites, or incorporated into new developments. Green infrastructure techniques recreate some of the ecological processes lost in the built up urban environment. Rather than attempting to control the water with pipes and tanks, soil and vegetation are used to slow the movement of water through the landscape. Stormwater is filtered, contained, and detained, improving the water quality along the way, and improving the hydrologic balance in highly-impervious urban areas (Rosenzweig, Gaffin, and Parshall 2006).

These decentralized stormwater management techniques are not yet common practice in the United States. They challenge conventional development practices, which are large scale and centralized (Keeley 2007; Montalto et al. 2007). Traditional stormwater engineering solutions, such as waste water treatment plant upgrades and constructing underground storage tanks, are very expensive. However, green infrastructure methods can actually cost less to implement than more traditional engineering techniques. Perceptions of high cost, limited space, and uncertain effectiveness remain as common barriers to green infrastructure implementation.

Green infrastructure alternatives have been getting increasing support in the United States in recent years. A “Green Infrastructure Action Strategy” (USEPA 2008c) has been developed by a coalition of the USEPA, American Rivers, the Natural Resources Defense Council, and other organizations to promote green infrastructure and facilitate networking and collaboration. New incentives for stormwater management are being developed, including guidelines for granting credits for using green infrastructure in meeting Clean Water Act requirement (USEPA 2007a). At the local level, municipalities around the United States have begun implementing a variety of incentive programs. These include tax credits, expedited permit processing, and stormwater fees based on the amount of impervious surfaces on a property (Kloss and Calarusse 2006; Keeley 2007).

Green roofs

Green roofs, or vegetated building rooftops, are one way to reintroduce ecological functions lost to impervious surfaces (Oberndorfer et al. 2007). While not common in the United States, a tradition of vegetated roofs goes back centuries in places such as the Swiss Alps and Britain (Rosenzweig, Gaffin, and Parshall 2006). Today, green roofs are more prevalent in European countries, especially Germany. An estimated 14 percent annually of new flat roofed buildings in Germany are vegetated (VanWoert et al. 2005;

Hoffman 2006; Oberndorfer et al. 2007). They are becoming more popular in the United States, particularly in Chicago, Portland, Seattle, and Washington D.C. (Doshi et al. 2005; Taylor 2007; Wachtel 2007).

Green roofs are constructed using several layers to protect the building roof from plant roots and water leaks. The diagram in Figure 4 illustrates these layers. The top layer is a lightweight substrate growth of engineered soil. This material tends to have high mineral content and only 10 percent organic matter (Oberndorfer et al. 2007). Green roofs can be built in place layer by layer onsite, or be installed as interlocking modular systems or as precultivated vegetation blankets.

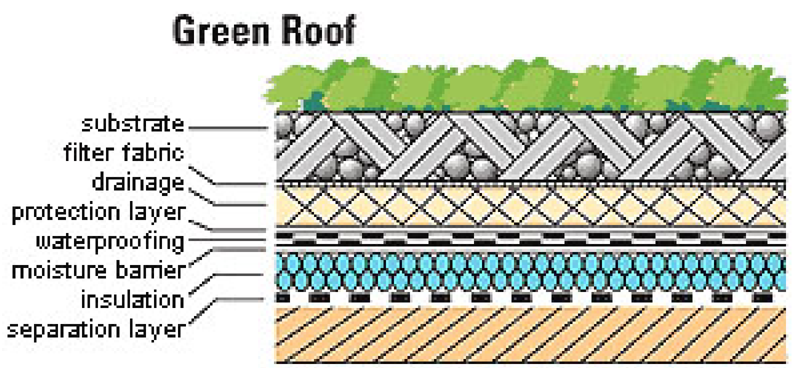


Figure 4. Typical components of a green roof (USEPA 2007b).

Green roofs can be *extensive* or *intensive*. Extensive green roofs generally have six inches of growth substrate or less, and require little maintenance. Intensive green roofs have a growth substrate depth greater than six inches and can be used as park or garden type areas (USEPA 2007a). Most existing flat roofed buildings can accommodate extensive (thinner) green roofs without structural reinforcements.

Other design considerations include the type of layered waterproofing system and plant selection. *Sedum* is a popular plant choice for its stress-tolerant characteristics and minimal growth substrate depth requirements (Oberndorfer et al. 2007). Careful maintenance during the first year is important to establish healthy vegetation.

Green roofs can be integrated into new building designs, or retrofitted onto existing buildings. They can be constructed on roofs with up to 20 percent slope, and up to 40 percent slope with modified construction (USEPA 2007a).

Benefits

Green roofs provide multiple benefits to both the building owner and the public at large. Benefits come from providing the building with insulation, and restoring ecological services. Public health is improved by reducing pollution, both by directly removing chemicals from water and air, and by avoiding the need to construct new power and sewer facilities. Some of these benefits are listed in Table 1.

Private Benefits	Public Benefits
Increase building energy efficiency	Reduce stormwater runoff and CSOs
Reduce heating & cooling costs	Reduce urban heat island effect
Increase acoustic insulation	Remove pollutants from water (heavy metals, nutrients)
Double the roof lifespan	Remove pollutants from air
Provide open space for recreation	Reduce ground level ozone
Food production	Reduce peak time energy demands
Increase fire resistance	Provide habitat for birds and insects
Increase property value	Provide green space for aesthetics and stress relief
	Increase neighborhood marketing value

Table 1. Public and private benefits of green roofs (VanWoert et al. 2005; Rosenzweig, Gaffin, and Parshall 2006; Oberndorfer et al. 2007; USEPA 2007a).

Green roofs can be effectively used to reduce stormwater runoff from buildings through the absorption, storage, and evapotranspiration of rainfall. According to the USEPA (2007a), "the amount of stormwater that a green roof mitigates is directly proportional to the area it covers, the depth and type of growing medium, slope, and the type of plants selected." Precipitation from small storms can be completely captured by a green roof. For larger storms, runoff is detained until the storage capacity of the growth substrate is saturated. The water is either used by the plants in evapotranspiration, collected for reuse, or is slowly released to a drainage system. By acting as a stormwater management system in this way, the overall peak flow discharged to the sewer system is reduced and combined sewer overflows can be avoided.

Green roofs are especially suitable as a stormwater best management practice for cities where undeveloped land is scarce. The USEPA (2007a) describes "ultra-urban" areas as "densely developed areas in which little pervious surface exists," and recommends that "green roofs are ideal for ultra-urban areas because they provide stormwater benefits and other valuable ecological services without consuming additional land." Green roofs can be installed at a variety of scales, allowing for widespread implementation. More common low impact stormwater management methods, such as storage ponds and constructed wetlands, have high space requirements and are often not feasible in urban areas (Oberndorfer et al. 2007).

Site-suitability is also an important consideration for selecting a stormwater control technology. Green roofs are a recommended best management practice for brownfield sites, where past industrial use has left contamination (USEPA 2008a). Low impact re-development techniques that utilize stormwater infiltration into the ground are not appropriate because pollutants would travel with the stormwater runoff. Using green roofs would allow much of the stormwater to be captured and evaporated without ever touching the ground.

Green roof research

Studies are being performed in a range of climates to quantify the benefits of green roofs. According to the USEPA (2007a), a general assumption is that extensive green roofs will absorb 50 percent of rainfall. Other estimates include that an extensive green roof will absorb a two inch rainfall event, and an intensive green roof a four inch rainfall event. Figure 5 shows a comparison stormwater runoff from a conventional and green roof for a hypothetical area. A green roof has a lower volume of runoff as well as delaying the time of peak flow.

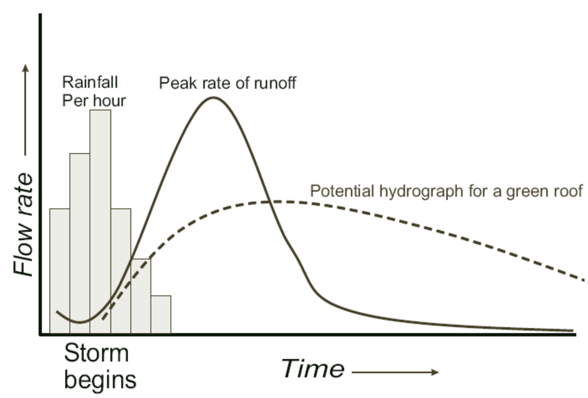


Figure 5. Hydrograph comparing runoff from a conventional roof and a green roof (Rosenzweig, Gaffin, and Parshall 2006).

Studies on the performance of existing green roofs have found annual stormwater runoff reduction in the range of 50 to 83 percent, depending on the depth of the growth substrate and plant selection (VanWoert et al. 2005; Villarreal and Bengtsson 2005). The measured green roof capture from a single rainfall event can be as much as 100 percent.

Penn State research has found that a green roof captured 80 percent of a rainfall event as compared to 24 percent captured by a conventional roof, while retention at peak runoff was still high at 74 percent (Rosenzweig, Gaffin, and Parshall 2006). For comparison, the runoff capture in a natural system is more than 90 percent (Kloss and Calarusse 2006).

Several of the green roof design parameters are being studied for their relative effectiveness. VanWoert *et al*. (2005) found the depth of the growth substrate to have the largest effect on stormwater retention. Research by Villarreal and Bengtsson (2005) looked at the impact of roof slope on green roof stormwater detention and retention. A study by Lazzarin, Castellotti, and Busato (2005) modeled the thermal effects of a green roof in summer and winter conditions, finding evapotranspiration to have a significant impact.

Cost-benefits

The cost of installing a green roof is sometimes seen as prohibitive, as extensive green roofs can cost between $5 and $20 per square foot, and intensive green roofs can cost between $20 and $80 per square foot (USEPA 2007a). While this is more than traditional roofing, the multiple benefits can make a green roof cost effective over the long-term. An extensive green roof is generally twice as expensive to install as a conventional roof, but lasts twice as long. Economic studies have found green roofs to be cost effective when environmental services were included as additional benefits (Rosenzweig, Gaffin, and Parshall 2006; Clark, Adriaens, and Talbot 2008). The benefits measured include extended roof lifespan, stormwater mitigation, energy savings, and improved air quality.

Other studies have focused on comparing the use of green roofs as a stormwater best management practice with more traditional engineering techniques. For example, installing green roofs can eliminate or reduce the need for detention tanks at an individual site (Post 2007). The Ford Motor Plant in Dearborn, Michigan, has the largest green roof in the world at 10.4 acres. Ford saved around $10 million by installing the green roof rather than constructing more conventional stormwater controls (Earth Pledge 2005).

The net present value of a green roof has been estimated at 10 to 14 percent higher than traditional roofs, with construction costs needing to be reduced by 20 percent to achieve a favorable cost-benefit (Carter and Keeler 2008). This price reduction is thought to be feasible as green roofs become more common and more suppliers enter the market. At the Ford Plant, the large area allowed a lower price per square foot than smaller green roof installations.

Green roofs have higher installation costs than some other stormwater best management practices such as bioretention or porous pavement, but have been found to be more cost-effective where space is limited (Carter and Keeler 2008; Montalto 2008). Because constructing a green roof on a building does not require additional space, there is no opportunity cost associated as with most other stormwater controls.

Stormwater models

The impact of green roofs on stormwater on a larger scale can be estimated using computer models. Models have been created as simple newer networks and as detailed hydrologic models. The scale may consider an individual subcatchment or the drainage system for an entire city. For example, a Washington D.C. modeling study found that installing green roofs on 20 percent of buildings over 100,000 square feet would reduce annual stormwater runoff by 300 million gallons and CSO events by 15 percent (USEPA 2007a).

Toronto's green roof modeling study (Doshi et al. 2005) is the most comprehensive report of its kind for North America to date. Multiple green roof benefits were quantified on a city-wide basis. These included stormwater runoff reduction, CSO reduction, improved air quality, reduced urban heat island effect, and reduced building energy consumption. The model assumed that green roofs would be built on all flat roofs greater than 350 square meters, with 75 percent coverage using an extensive green roof design. Toronto has 21 percent of its land area covered by buildings, and the total roof area that the green roofs were applied to in the model was 8 percent of the land area, for 5,000 hectares of green roofs. Once the physical impacts were modeled, a cost-benefit analysis was applied. The monetary savings was calculated as $312 million initially, with $37 million annual savings, in Canadian dollars. The largest source of savings, $117 million, came from the reduction in stormwater which eliminated the need for significant sewer system upgrades.

Green roof conclusions

While the benefits of installing individual green roofs are notable, an even greater effect may be seen from the combined effect of more green acreage in a neighborhood. The cumulative effects of individual green roofs on neighborhood and city-scale problems such as CSOs and the heat island effect may not be measurable until a critical mass is reached. As was done in Toronto, computer models can be used to estimate these impacts at larger scales, such as the city and county levels.

Beyond their measurable benefits, green roofs have the potential for improving urban life on even a greater scale. Rosenzweig and colleagues (2006) have envisioned an array of social impacts from green roofs, including the integration of nature with urban life in the post-industrial city:

> *"Given sufficient acreage, green roofs of varying sizes, functions, and designs would constitute a mosaic of inter-related vegetative spaces; individual ecological patches whose benefits could be greatly multiplied to the point of producing larger-scale transformations of urban ecologies. Operating in this complex infrastructural fashion, green roofs would attain a social relevance that would produce a feedback loop reinforcing their deployment across the urban landscape, and greatly impacting their perceived value. From this perspective we can begin to ask how green roofs can be creatively considered in an urban context. Are they a sign of changing perceptions about the city? Do they indicate an extension of nature within the city or do they point to a commingling of the natural and built environments in a manner that might lead toward increased resilience and a more integrated socio-natural relationship? How do they impact the dynamics of the urban organism? What can they tell us about other ecological questions at the scale of urban infrastructure? The scale and position from which these questions are explored will affect how green roofs are seen and understood. Urban green roofs as individual entities may be viewed as extensions of private space. They may also be seen as providing specific, localized benefits to the operation of buildings. Collectively, however, they have the capacity to impact urban ecology and, therefore, may also be understood in infrastructural terms." (Towers and Rothstein, in Rosenzweig, Gaffin, and Parshall 2006).*

Thriving cities are in a constant state of renewal and reconstruction, which provides many opportunities for green building. By the year 2030 it is estimated that half of the total building square footage in the United States (around 200 billion square feet) will have been built after 2000 (Kloss and Calarusse 2006). These new developments provide many opportunities for green buildings. A green roof can easily be incorporated during the design stage to ensure proper structural support for the additional weight. To encourage green roof implementation, several cities have enacted tax credits, density credits, and best management practice requirements (Taylor 2007; USEPA 2007a).

As cities continue to grow and redevelop, the impacts of impervious surfaces must be taken into consideration. Kloss and Calarusse (2006) write that "conventional methods of stormwater control will not be able to adequately manage the higher amount of stormwater pollution implied by this increased imperviousness." While green roofs are not yet thought of as standard stormwater controls in the United States, standard engineering modeling tools can be used to evaluate them as a best management practice. The geographic distribution of green infrastructure will determine the response of stormwater runoff in the sewer system. The type of detailed map data now available for many urban areas allows for the coupling of site-specific stormwater controls with engineering models.

Environmental mapping and models

Mapping introduction

Maps and models are important to our understanding of the world. This includes cartographic visualizations of geography, and more generally, a structured and symbolic way of thinking. Peuquet (2002) describes a map as a uniquely complex combination of image, language, and mathematics. MacEachren (1995) defines a map as a spatial representation, which can in turn stimulate other spatial representations. This representation is an act of knowledge construction.

The fields of geography, cartography, environmental science, and engineering are all closely involved with geographic mapping and modeling. Maps and models are useful for studying phenomenon that occur at large and small scales which are not directly observable. They also enable better understanding of complex systems by including both detail and context.

The term cartography has been redefined from "making maps" to "organizing and communicating geographic information" (MacEachren 1995). The field of cartography now encompasses geographic information systems (GIS), remote sensing, visual art, cognitive science, sociology, cognitive psychology, environmental psychology, semiotics, history of science, and philosophy of science. Cartographic techniques have changed considerably with technology, with the components of data creation, software programming, and visual design becoming more closely entwined with GIS. We will use the expanded definition of cartography as an organizing principle for the following section of the literature review, then take a look at the use of maps and models for studying environmental systems.

Cartography

> *ge·og·ra·phy*
>
> *Etymology: Latin geographia, from Greek geOgraphia, from geOgraphein to describe the earth's surface, from geO-+ graphein to write*
>
> *(Merriam-Webster Online Dictionary)*

The terms "maps" and "mapping" have a variety of meanings even within the field of geography. According to MacEachren (1995), "cartography is a field with a long practical history and a short academic one." Perkins (2004) has found that "there has indeed been no serious historiography of the role mapping plays in the creation of geographical knowledge in the academy."

The academics that indeed are studying maps have a variety of different perspectives. The main division in these approaches can be described as *art* vs. *science*. Social theorists and cultural geographers such as Harley, Cosgrove, and Wood have deconstructed maps as texts and examined their social meanings and influences. On the other hand, scientists, GIS developers, and urban planners have been concerned with the practical application of maps. Perkins (2003) has categorized map research into five themes which we will discuss below: *visualization and representation*, *socially* *acceptable technology*, *maps as designs or texts*, *maps as performance*, and *knowledge spaces*.

Visualization and representation includes scientific research on “how maps work.” Maps are a highly-efficient way to communicate information. Graphic images are particularly effective for portraying and retrieving information, and for gathering new insights. There are many good references for designing effective maps and graphics (Mark et al. 1999; Tufte 2001; Brewer 2005). A cognitive research approach can aid in designing maps that better reflect our mental processes. According to Peuquet (2002), the “detection of spatial patterns and groupings is hardwired into the human visual system.” Cartographic maps are understood through a process of detecting a visual array, prompting a visual description, which interacts with knowledge schemata, which forms a cognitive representation (MacEachren 1995). In map terms, this process is feature identification, feature comparison, and space-time feature analysis. The map reader goes through “seeing that—reasoning why” cycles. Studies have found that extracting information from a map is best performed when the visual representation matches the schemata, which are the rules and patterns we use to interpret information. Once the mind has sorted out a map’s symbolization, it can move on to higher-level cognitive processing.

Geographic information science is beginning to integrate these cognitive approaches to data exploration into software and data design. Research is being done to use GIS for highly-interactive data visualizations. Experimenting with visual images can lead to new discoveries and insights through “emergence,” the detection of unanticipated features. Cognitively, this happens by making high-level associations by instantly detecting patterns and coherence (Peuquet 2002). Altering scale and time can reveal different patterns.

A different research focus has been on maps as socially acceptable technology. Critiques of GIS emerged in the 1990's, raising both ethical considerations and the possibility of its democratizing potential. Pickles (2004) and others have challenged the idea of GIS as a neutral technology. Much research in this area has come from a political-ecology-technology perspective, concerned with the way technological mapping methods conflict with local knowledge systems and values. There is also concern over privacy issues with the growth of surveillance technology and data availability.

Evaluating maps either as designs or texts has been another approach to research. These included discussions of "cartographic anxiety" over the modernist and universalist tendencies of maps. An academic critique of cartography, most notably from Harley and Wood (2003), explores the meaning *in* maps versus the meaning *of* maps (MacEachren 1995). Their work has challenged the assumption of maps as neutral documents.

Further studies have examined maps as documents of power in terms of nationhood, military applications, colonialism, in commercial sectors, and in the media. Cartography has always required both technical and creative choices to be made. However, the modern computerized methods of cartography are still often seen as representing an objective and neutral reality. These maps are often used to justify urban planning and policy decisions (Peuquet 2002) and the underlying assumptions are not discussed.

Maps as performance is a newer research focus on the process of map making, derived in part from an older tradition of examining non-western cartography. Many visual artists use mapping concepts in their work (Wood 2006). Artists interested in psychogeography are questioning power relationships by experiments which interact with place and mapmaking. Literary and historical studies have also become interested in mapping.

Perkins' last research category is knowledge spaces. Turnbull (2000) writes on how scientific knowledge is constructed by different groups, including cartography. GIScience has emerged as a theoretical framework which includes "effective representations systematically derived for specific application contexts," which allows for new and better solutions to be discovered, which includes formalized concepts of space, and integrates new insights into cognition (Peuquet 2002). GIS is, to an extent, a manifestation of GIScience as a knowledge space.

Geographic information systems

GIS is a technology that touches on many of the previous research areas. It includes the tools commonly used to present, manage, and analyze spatial data. GIS is used to create visualizations, and has been the focus of socially acceptable technology debates, along with remote sensing.

GIS has been evolving in the academic sector since the 1960's (Chrisman 2006) and the commercial sector since the 1970's (PlanGraphics 2005). There are many books describing the technical aspects of GIS, which are updated as new software is released. By the 1990's, the field had matured into GIScience and was looking for unifying theories (Peuquet 2002).

The popularization of GIS software has changed the way people think about maps, and even more so with the proliferation of internet mapping. The internet has had a tremendous stimulating impact on map making and map use (Kraak 2004). Wood (2003) writes, “the numbers of both cartographers and maps are increasing by orders of magnitude.” He describes this as a return to the original impetus for making maps in the first place: “This new visual-thinking environment takes maximum advantage of our instinctive cognitive mapping powers which can be used, even more effectively, in a kind of geovisual dialogue with the cartographic/geographic visualization system.” Furthermore, the distinction between map users and map makers has been blurred with interactive mapping technologies.

Peuquet (2002) writes of using GIS, “Maps have become an intermediary representation as part of a highly interactive user interface. The computer display becomes a user-generated representation that intermediates between the human mental representation and the computer database representation, and is at the same time a representation of information that in its own right directly aids the thinking process.”

Urban data

While the general public strongly associates maps with geography, Perkins (2004) has found a decline in their academic use. However, map use has remained an important part of urban planning. Common planning map subjects include demographics, land use patterns, property boundaries, and transportation networks. The vast increase in digital data now allows a much more nuanced examination of urban geography (Harris and Longley 2000).

Much urban data is collected and maintained by government agencies to facilitate management and planning. For example, parcel boundaries are used in conjunction with property tax assessments, and road right-of-ways are used for infrastructure maintenance.

A 2005 survey found that nearly all states had automated the collection of parcel attributes into databases, and approximately 67 percent of parcel maps had been digitized (Stage and von Meyer 2006). This simplifies data updates, and facilitates sharing by multiple agencies for operational efficiency. Planners and consultants also use this data for land use mapping and other purposes.

Urban planning data can be integrated with environmental data in software models, creating powerful tools for planning and decision-making. These models allow the comparison of various "what if" scenarios. Models may simulate complex phenomenon over time, or be used to trace cause-and-effect relationships. Mapping is an important component of these models. GIS is used to create, manage, analyze, and present spatial data. The GIS may either be fully integrated or used as a separate component. For some computationally complex models, it can be more efficient to use GIS to pre- and post-process data separately from running the model itself (Batty 2005).

Some engineering models that integrate GIS include water quality and sewer system models. The geographic distribution of land uses, soil types, and slopes are common model components. Stormwater runoff models may use data including land use maps based on parcels, or land cover maps derived from aerial photography or satellite data. Land cover data may be combined with soil data, especially in less developed regions with more pervious surfaces.

Environmental models

Environmental modeling allows the study of systems at scales too large for direct observation, including the city level. Much of scientific research relies on these models, especially as scale increases from the city to the global level. Rosenzweig writes, "Recent research has provided a much greater understanding of the complexities and interactions of the physical, biophysical, and social realms of the urban environment. Areas of particular focus are the urban heat island, the urban biosphere, urban hydrology, and climate change" (Rosenzweig, Gaffin, and Parshall 2006).

Environmental models can use empirical or deterministic methods. Empirical models are statistically based, and developed from field and laboratory observations. They are derived using regression techniques, and therefore are best suited when used with a similar range of data as the model was developed with. Deterministic models use mathematical formulations that approximate environmental processes directly. These models need to be calibrated using field measurements. Deterministic models are considered more reliable for making predictions (WERF 2001). A model specializes in a particular environmental component, such as land surface, water bodies, atmosphere, or built systems. Separate models can be linked together to create complex systems.

Models can be made more accurate through calibration. This entails adjusting model coefficients to make the predicted behavior better match observed results. Calibration must be done with care, by only changing coefficients within acceptable ranges. To improve the fit of model results to existing data on a point-to-point basis (curve fitting) would undermine the use of the model as a predictive tool (DePinto 2004).

Once calibrated, a model's reliability can be estimated through the process of model confirmation. One of the last steps in the model development process, this is rarely performed due to time and budget constraints (DePinto 2004). Model confirmation requires running a calibrated model with a new data set using different conditions. If the error resulting from using the new data set is no larger than the error from the original calibration model runs, then the model is considered to be confirmed. This confirmation process is important to determining the uncertainty, and thus the margin of safety. With a well-calibrated and confirmed model, uncertainty can be quantified as the difference between predicted conditions (from model output) and observed conditions (from collected data).

Environmental models are probabilistic in nature and always include some degree of uncertainty. The National Resource Council recognized that "more complex modeling will not necessarily assure that uncertainty is reduced, and in fact it can compound problems of uncertain predictions" (2001). As models become more complex, they do not necessarily become more accurate. Conversely, the greater number of variables in a complex model can introduce more uncertainty. This is because of the limitations of mathematical models to approximate complex ecological and biological systems. Figure 6 graphically illustrates the relationship between complexity and reliability.

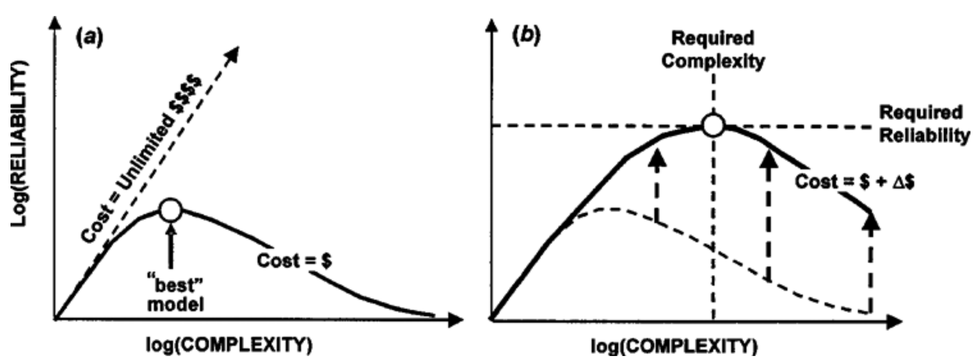


Figure 6. Model reliability versus complexity: (a) Modeling isolated from decisions; (b) modeling as influenced by decision context (from Chapra 2003).

These figures illustrate the tradeoffs between model complexity, reliability, cost, and time. Here complexity refers to the mathematical equations used in the model. Costs result from data collection and parameter estimation efforts. The dashed line in Figure 6a represents increasing model complexity creating increasingly accurate models. This assumes we have the ability to perfectly characterize ecological processes, and that personnel and budget resources are unlimited.

In reality, at some point increasing the complexity of the model will outpace available knowledge and resources. Funding to support data collection for additional variables may not be available. Further, our understanding of the ecological processes in a particular place may not be fully developed. Because of time and budget constraints, addressing these limitations may not be feasible. Data collection programs can take months to a year, which may overrun the available time. Additional variables also mean more time needs to be spent on model calibration.

Decision support systems

Decision support systems can employ a series of linked models. Designed for managers rather than engineers, these systems provide an interface to present model results and evaluate alternative management strategies. Information may be presented as a combination of tables, graphs, and maps. For example, a sewer model may be linked to a water quality model to simulate the effect of stormwater discharges on natural waterways.

Improvements in computing power have made these kinds of tools more available to regulatory agencies and community stakeholders. This has helped change the dynamics of the modeling process to be more inclusive. Rather than the engineer performing all of the analysis and presenting the best solution to decision makers, more people can be involved in the decision-making process, as illustrated in Figure 7. Some decision support systems have even been made available online to increase the number of stakeholders that can be involved (Chen, Herr, and Weintraub 2004; Dymond 2004). This change in model use is helpful because involving more stakeholders increases the likelihood of a plan's success. The best technical solution may not be the most appropriate given political or economic conditions, and managers can take specific local issues into consideration.

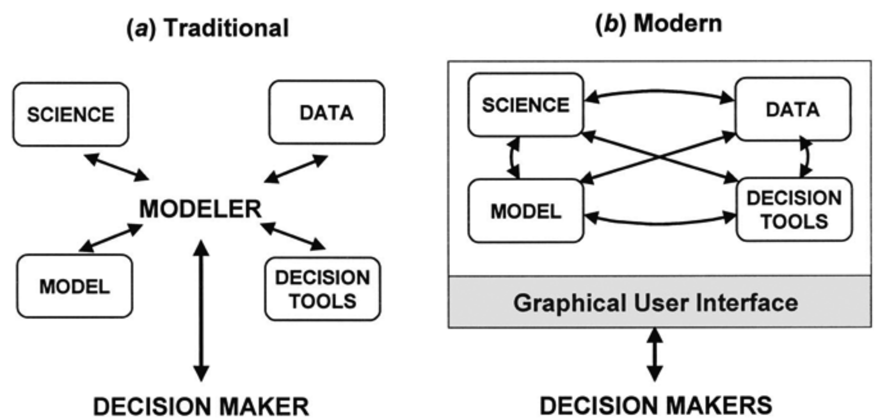


Figure 7. Information flow between components in decision-making process: (a) Historical and (b) present. The "decision makers" in (b) refer to both regulatory agencies and stakeholders (from Chapra 2003).

With a simple decision support system, the model may be re-run with different input parameters determined by the managers. In these cases, model run time and file storage requirements are not prohibitive. More complex models, which may take hours or days of computing time to run, will typically only present their results within a decision support system.

Mapping summary

In both urban planning and environmental management, the map is where various professionals and decision-makers come together with the public. The map provides a common language for community, government, planners, scientists, and engineers. While not always drawing attention to itself as a "knowledge space" or "document of power", the map is essential to environmental management and planning. The maps and data we use shape the debates over public policy and urban planning issues.

The increase in geographic data available for cities in recent years can be used to enable more informed decision-making. Detailed maps and models allow new kinds of urban planning questions to be asked. Rather than being limited to information aggregated at the county or zip code level, specific questions can be modeled at the block and neighborhood scale, using parcel and building level data. These geographic data and models are being applied to urban sustainability research.

"The challenge of integration across scales permeates urban research, as questions and hypotheses, methods and analyses shift from individual buildings, to neighborhoods, boroughs, cities proper, and metropolitan regions. Global climate and hydrological models need to be downscaled, while building-level energy analyses need to be upscaled to analyze questions related to individual and social functions of ecological infrastructure" (Rosenzweig, Gaffin, and Parshall 2006).

Literature Review Summary

As cities adopt sustainability goals, they are increasingly turning to green infrastructure solutions. Green roofs are an attractive green technology because of the multiplicity of public and private benefits. These benefits have been summarized in the format of the sustainability triangle in Figure 8. Private benefits, such as reduced building cooling costs, are related to public benefits by reducing air pollution. With widespread implementation, these benefits can be further compounded by reducing energy demands, which can offset the need for constructing additional power plants.

Green roofs are starting to be used as best management practices for stormwater runoff. Field studies have shown their effectiveness at retaining and detaining precipitation in a variety of climates and weather conditions. Eliminating CSOs at the source reduces pollution by prevention, and contributes to sustainability in several ways. Not only is the environment protected from point source pollutants such as bacteria, metals, and sediments, but resources are saved by avoiding the need for additional water treatment. Large amounts of capital are required to construct additional water collection and treatment capacity, and to run and maintain the facilities.

The impact of green roofs on reducing stormwater on a larger scale can be estimated using engineering models. Geographically-specific models can help in planning the allocation of scarce resources to maximize public benefits. These models include maps in the form of GIS data, decision support systems, and cartographic products. These maps are an important tool for communicating technical information between engineers, decision makers, and the public.

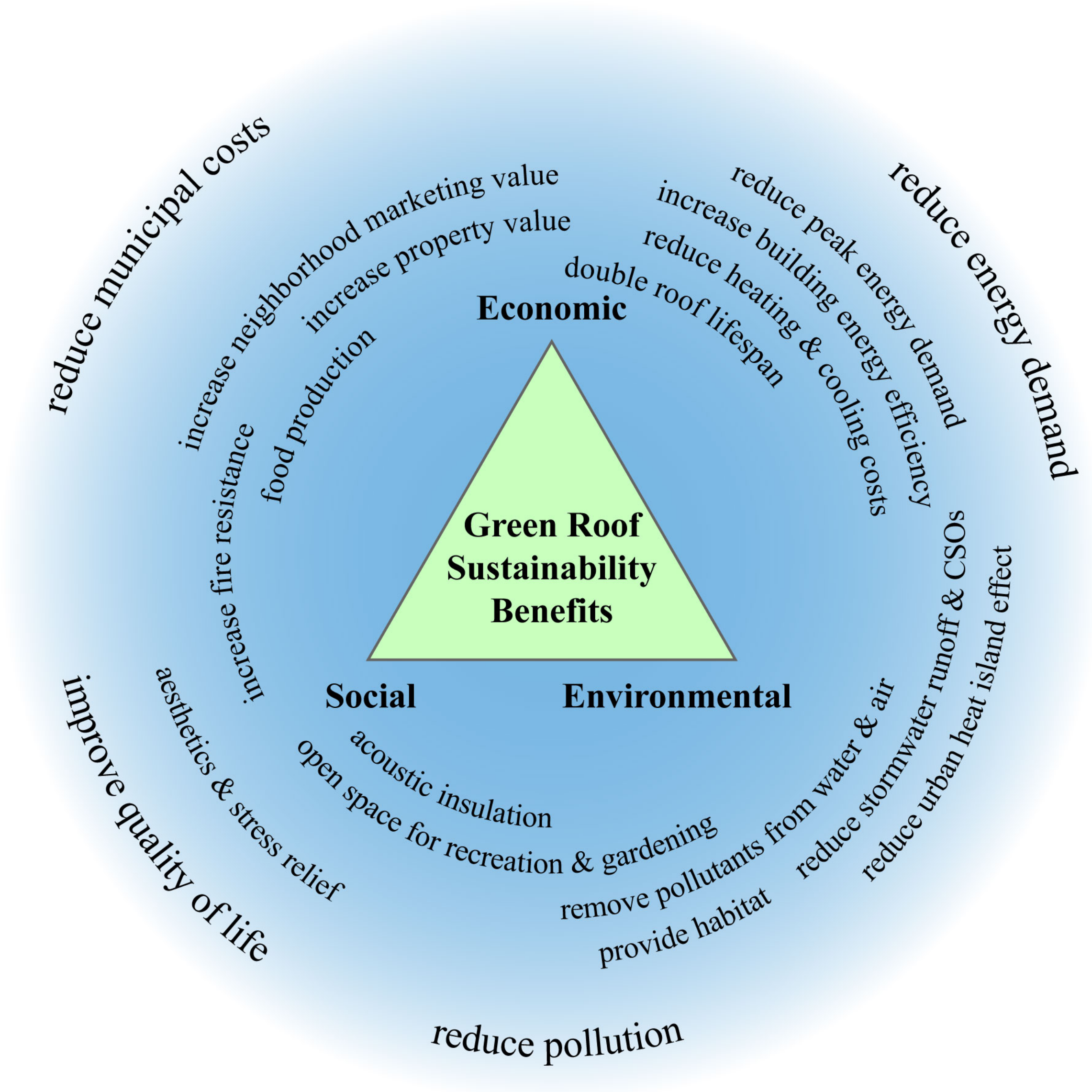


Figure 8. Green roof benefits contribute to sustainability (adapted from Figure 2 and Table 1). Specific private benefits are indicated in the inner circles, with public benefits in the outer circles.

Chapter 3. Methodology

Introduction

The Bronx, New York, like many older urban areas in America, is impacted by combined sewer overflows (CSOs). The Bronx is an “ultra-urban area” with high population density and a highly development landscape. These characteristics together often cause stormwater runoff problems. Municipal governments are studying ways to reduce these problems in response to USEPA regulations and community concerns. A recent Columbia University report states that “widespread adoption of green roofs as a roofing technology can potentially address multiple environmental and human health problems in New York City, including the urban heat island effect, global climate change, and stormwater runoff” (Rosenzweig, Gaffin, and Parshall 2006).

This paper describes a single case study where we have developed a computer model called the Bronx Green Roof Stormwater Simulation Tool. Designed as a decision support system, it is intended to be used as a general planning tool to assess the relative impact of green roof designs on reducing CSOs across the borough. The Bronx is geographically data-rich, with a high-resolution GIS base map, detailed building data including building classes and rooflines, and calibrated sewer models. This allowed the calculation of available space for green roofs on flat-roofed buildings.

Case Study Background

Bronx, New York

New York City is comprised of five boroughs, which are also separate counties. The Bronx, the only borough connected to the mainland United States, is the gateway to the rest of New York City and Long Island. The Bronx is unique in many ways. Its forty-two square miles contain some of New York City's poorest neighborhoods alongside national landmarks such as the Bronx Zoo and Yankee Stadium. The map in Figure 9 shows an overview of the borough. The Bronx is crisscrossed by many highways and contains several large park areas.

The Bronx can be considered a major metropolitan area in its own right. If each New York City borough were to be considered separate cities, the Bronx would be ranked as the country's ninth largest city, with a population of 1,332,650 as reported in the 2000 Census. The Bronx is home to 17 percent of New York City's population, 7 percent of New York State's population, and nearly half a percent of the country's population (NYCDCP 2001). The population density in the Bronx is 49.5 people per acre. After dramatic population losses in the 1970's due to "white flight," the Bronx has rebounded and saw a population increase of 10.7 percent between 1990 and 2000.

There are approximately 90,000 buildings in the Bronx, covering 18 percent of the land area. Based on building class data, approximately 78 percent of these buildings are estimated to have flat roofs, for a total of nearly 3,750 acres of flat roofs, or 14 percent of the total land area. According to 2005 NYC Department of Finance data, the average year of building construction is 1940 (standard deviation 28.9 years).

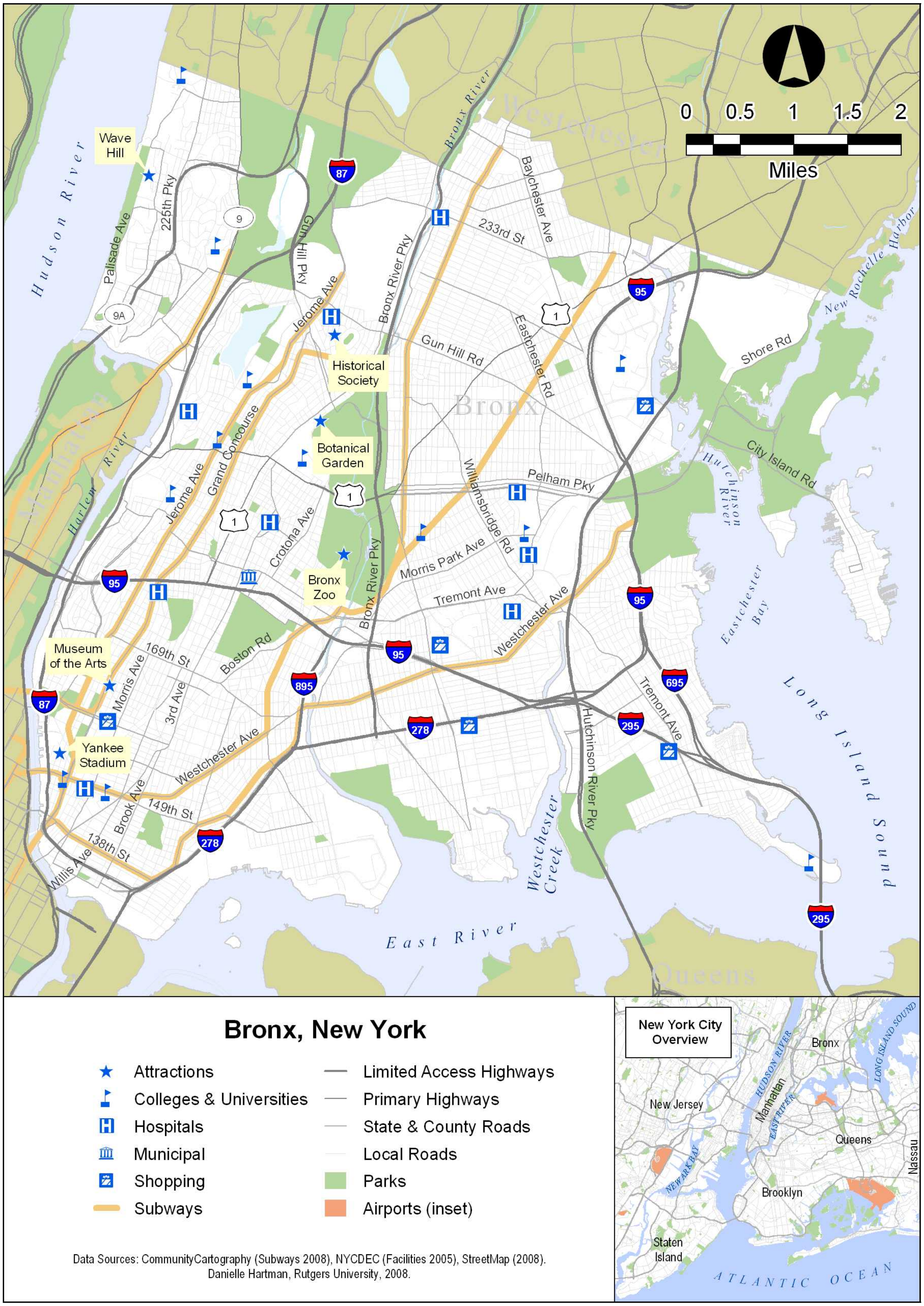


Figure 9. Bronx overview map.

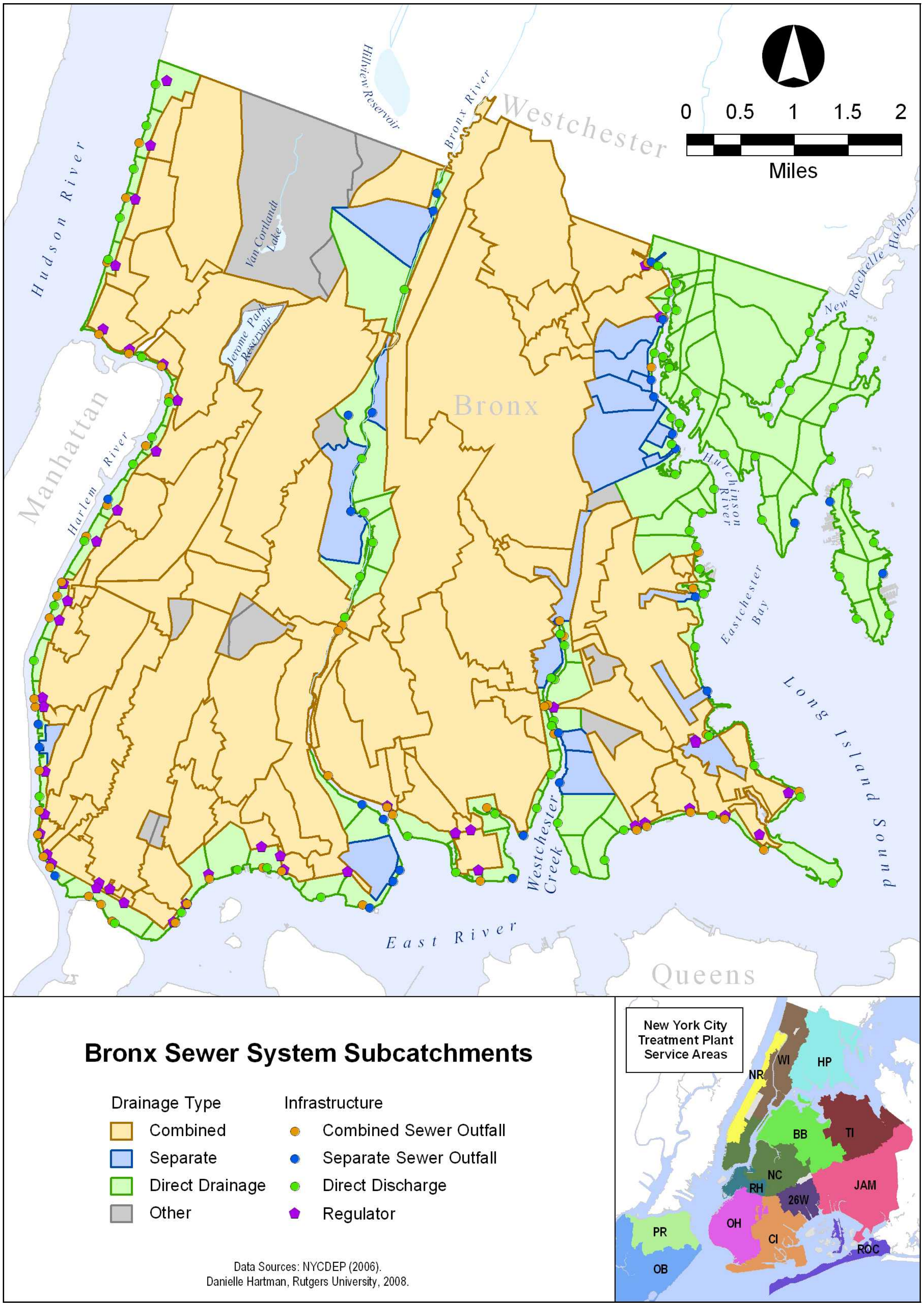


Figure 10. Bronx Sewer System Drainage Subcatchments.

The Bronx contains over 200 individual sewer system subcatchments, or sewersheds, of various sizes. The map in Figure 10 shows the type of sewer system for each subcatchment area. The borough is primarily served by a combined sewer system, which covers 69 percent of its area. Only 6 percent of the borough's area is serviced by a separate sewer system, having separate pipes for sanitary and storm flow. The remaining 25 percent area has direct and other drainage, which includes parks, cemeteries, and shoreline areas (NYCDEP 2007a, NYCDEP 2007b).

As seen in Figure 11, land uses in the Bronx are mostly residential, followed in total area by open space, then public facilities, and small amounts of transportation, commercial, industrial and vacant land. Note that this map is based on tax lots, and does not include the area for roads or sidewalks. The Bronx has 36 percent of its tax lot area as residential, with a mix of houses and apartment buildings. Industrial uses are concentrated along the shorefront. Several large parks dominate portions of the borough, contributing to the 30 percent area for open space and outdoor recreation.

While 30 percent of tax lot area for open space and recreation may seem high, this is not evenly distributed across the borough. It also includes paved surfaces such as playgrounds, recreation courts, and sitting areas. Using a different data set, open space is calculated as 23 percent of the borough's land area, or approximately 6,100 acres. This value comes from the NYCMap data set, which delineated open spaces larger than 2 acres from aerial photographs. Table 2 shows a summary of the NYCMap base map data layers. The map in Figure 12 shows these large parks by sewer system subcatchment, and their uneven distribution across the borough.

Figure 11. Bronx land use map, based on tax lots.

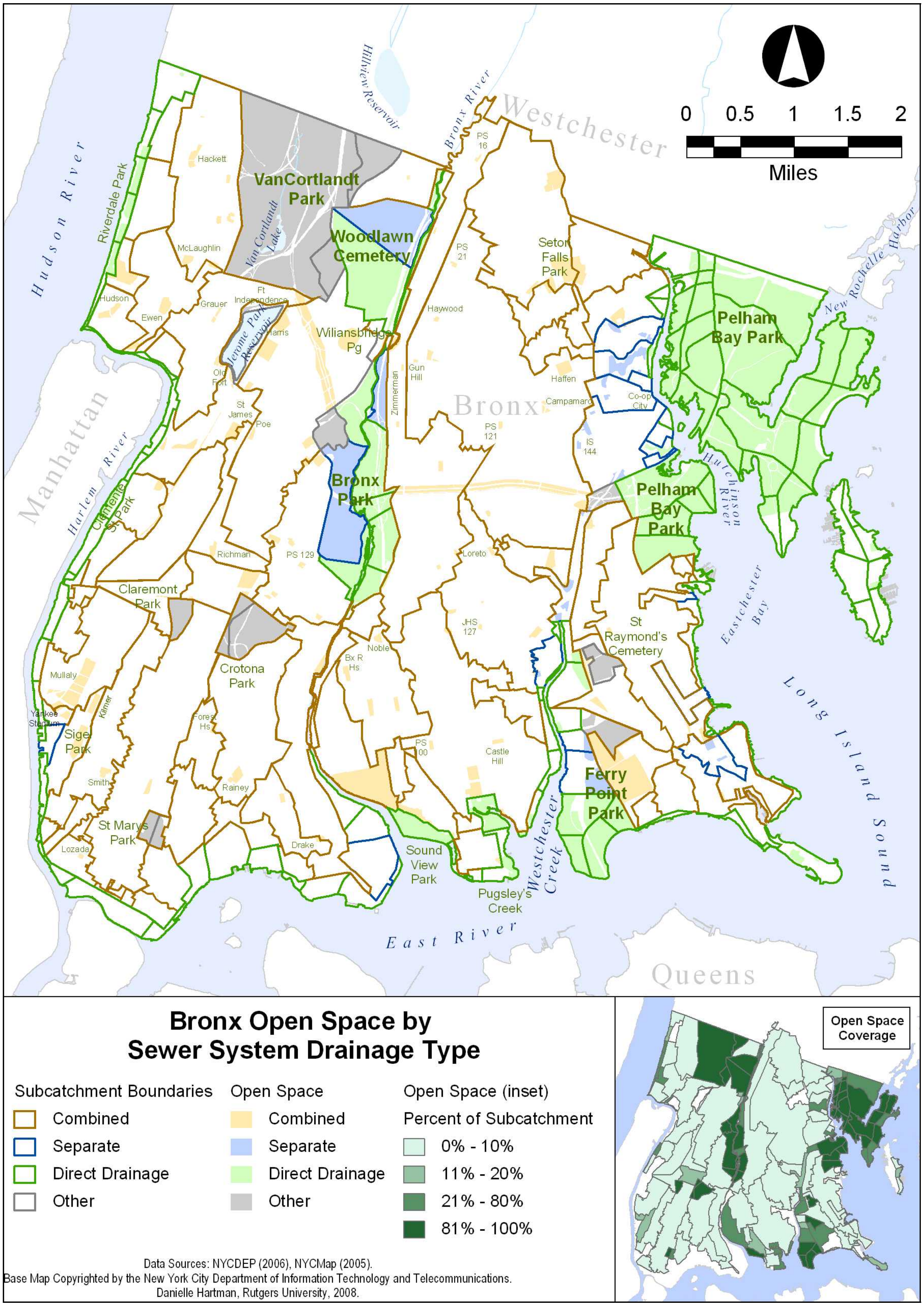


Figure 12. Bronx open space, by drainage type. Labeled with percent of subcatchment covered by open space.

	Acres	Land Area
Buildings	4,800	18%
Open Space	6,104	23%
Roads, Sidewalks, Other	15,608	59%
Total	26,512	100%

Table 2. Bronx land area by type. From the 2005 NYCMap GIS data.

There are many Bronx neighborhoods dominated by impervious surfaces, including roads, parking lots, and buildings. According to the National Land Cover Data from the USGS, the average imperviousness for the borough is 22 percent. Figure 13 shows this data overlaid with the sewer subcatchments. The average imperviousness by sewer system subcatchment ranges from 0 to nearly 98 percent.

This highly developed landscape is subject to many environmental problems including air and water pollution. The Bronx contains heavy industrial sites, transportation terminals, and high levels of truck traffic. Residents have some of the highest asthma rates in the country (Maantay 2007). The demographics of the Bronx, which include over 80 percent minority population, make these environmental concerns also issues of environmental justice. The Bronx is the most disadvantaged NYC borough in terms of poverty levels, education, and female-headed households with children (NYCDCP 2001). The map in Figure 14 shows these demographics by Census tract.

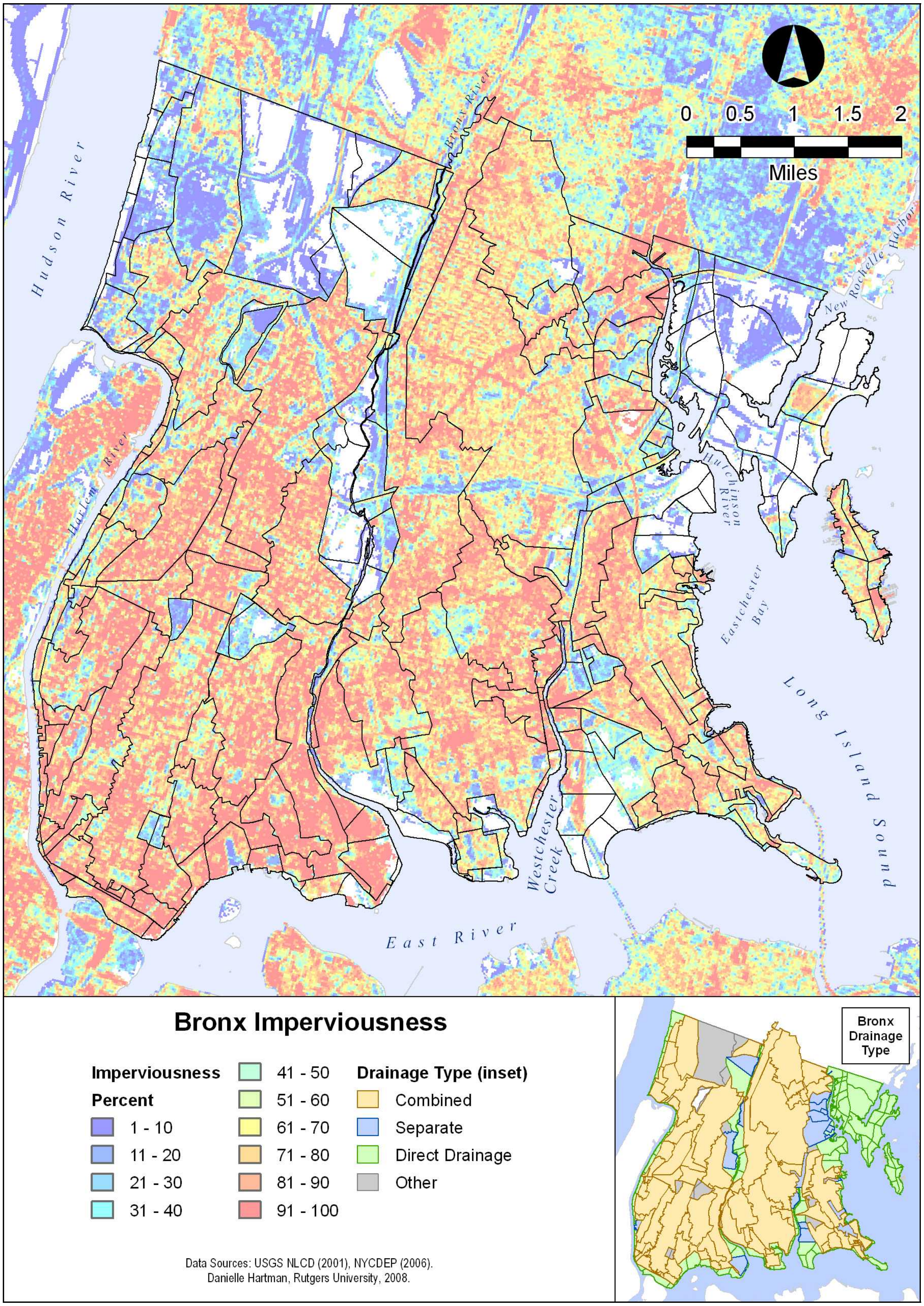


Figure 13. Bronx imperviousness.

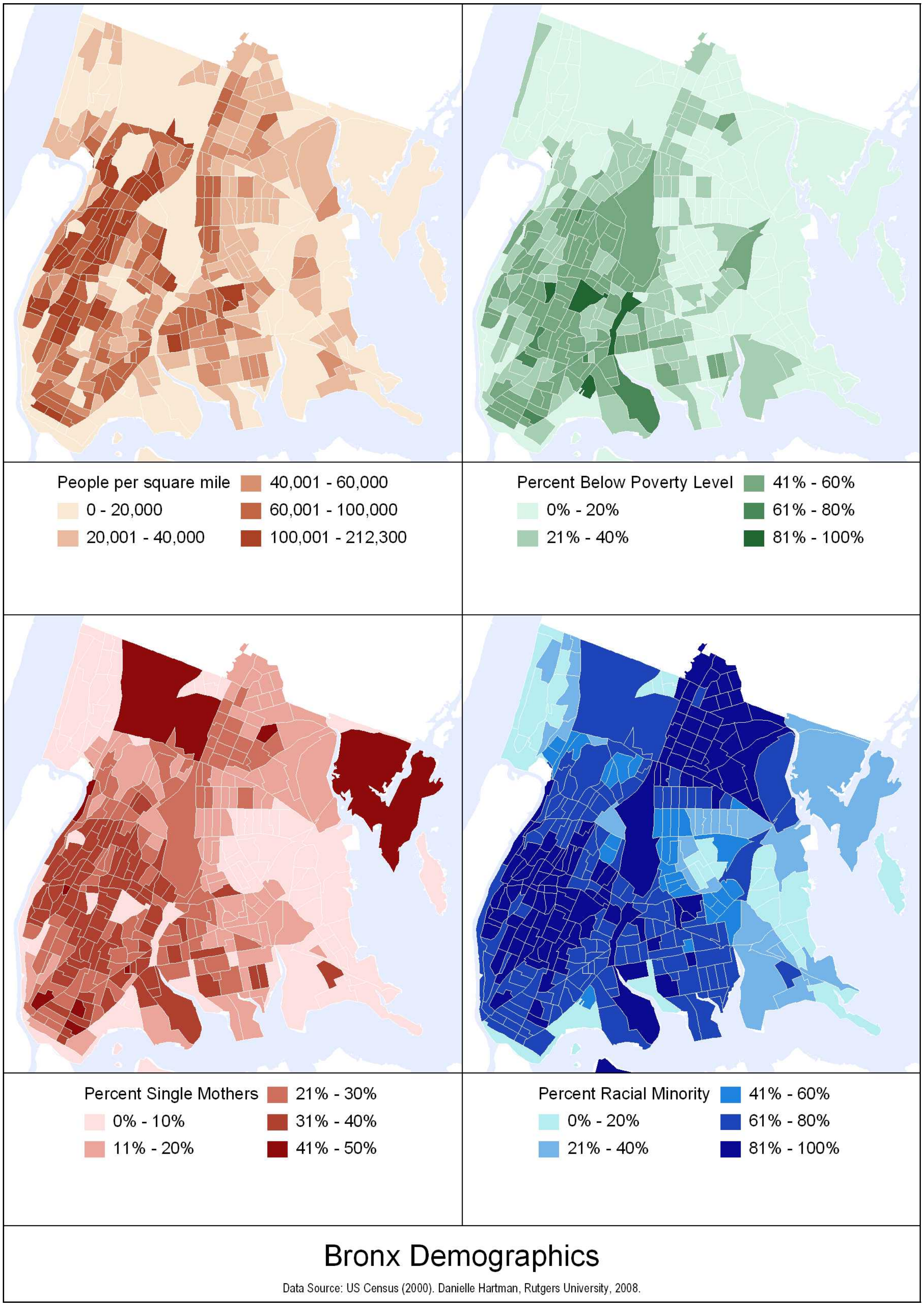


Figure 14. Bronx demographics. Population density, poverty, racial minorities, and single mothers by Census tract.

Combined Sewer Overflows

One of the environmental problems facing the Bronx is CSOs, which contribute to local water quality problems. Figure 15 shows outfall HP-007 along the Bronx River. CSOs in New York City cause beach closings, limit recreation, impair navigation and necessitate dredging, contaminate fish and shellfish, increase floatable debris, and cause algal blooms (Basil and Plumb 2006). Some of the factors contributing to CSOs include increased population, and landscape changes such as the loss of wetlands and vegetation through increased development (NYC Mayor's Office 2007). The USEPA has estimated that 20 percent of stormwater runoff in NYC originates from rooftops, with another 20 percent from private driveways, and 60 percent from roads and sidewalks (Heaney et al. 1999).

Figure 15. Combined sewer outfall HP-007. Photo courtesy of Bronx River Alliance.

As shown in Figure 16, major waterways around the Bronx include the Hudson and Harlem Rivers to the west, Long Island Sound to the east, and the East River to the south. The Bronx River bisects the borough north to south. The Hutchinson River, Westchester Creek, and Eastchester Bay also are in the Bronx. All of these water bodies have water quality problems, and are considered to be “impaired” according to USEPA standards.

There are more than six billion gallons of combined sewer overflows discharged from the Bronx every year (HydroQual 2007). In New York City, CSOs can occur weekly and be triggered by as little as one-tenth of an inch of rain. Water pollution control plants are designed to have enough capacity to treat twice the average daily flow, which is insufficient during many storms. The Bronx is served by two waste water treatment plants, Hunts Point and Wards Island, as seen on the inset map of Figure 10. Hunts Point, serving central and eastern parts of the Bronx, has a total capacity of 400 million gallons per day (NYCDEP 2007a). Wards Island, serving the western parts of the Bronx and part of northern Manhattan, has a total capacity of 550 million gallons per day (NYCDEP 2007b). Only 61 percent of annual rainwater is captured and treated in New York City. CSO discharge typically contains 90 percent stormwater and 10 percent sewage (NYC Mayor’s Office 2007).

The Bronx has eight public beaches that monitor water quality, and seven of these beaches experienced closings and advisories in 2007 (Dorfman and Rosselot 2008). There were a total of eighty four separate events that closed these beaches for a collective 300 days last year. Advisories were given due to predicted CSO and stormwater pollution, based on computer model simulations.

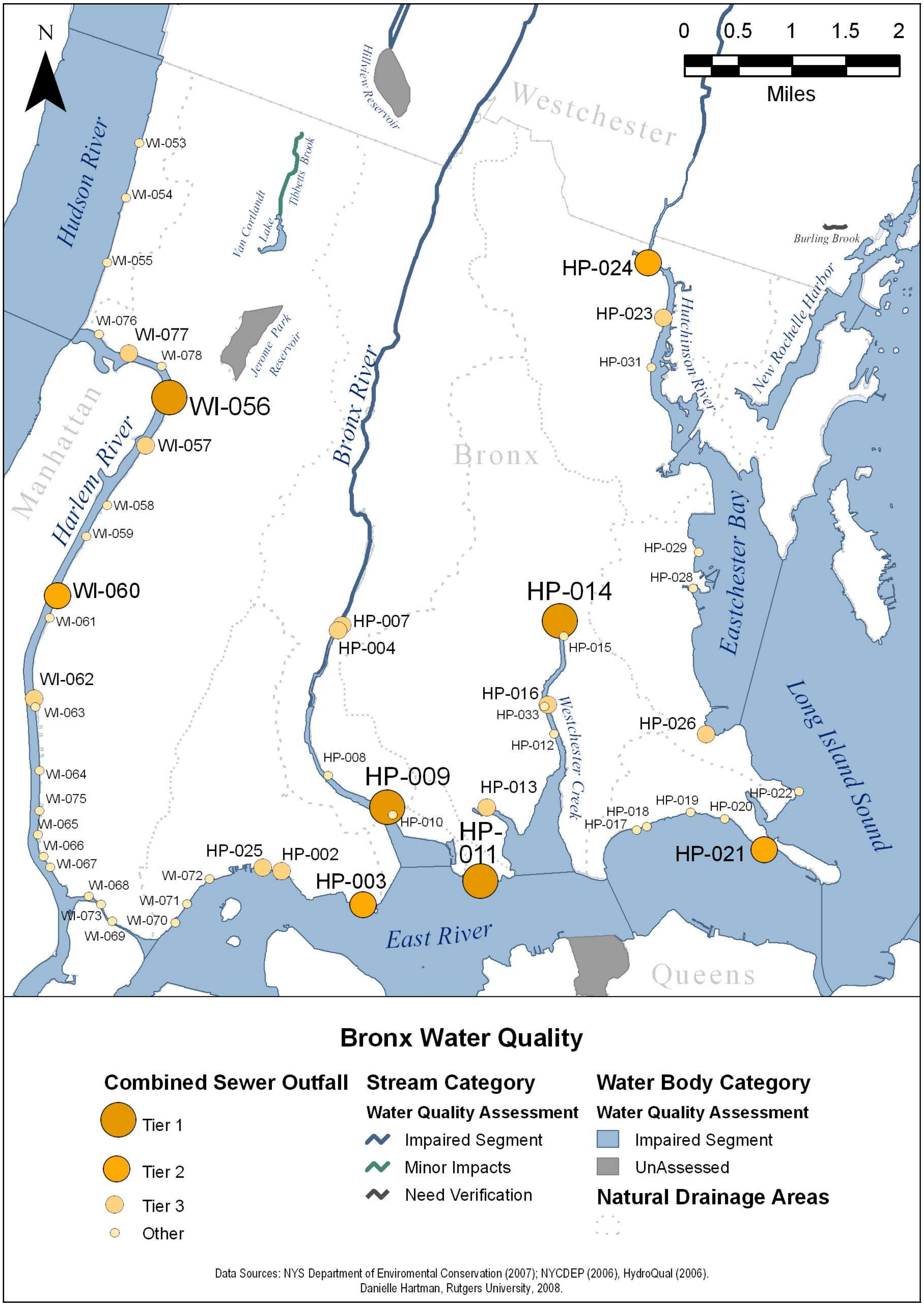


Figure 16. Bronx water quality and combined sewer overflow locations.

Outfall	Million Gallons/Year	Tier	Bronx CSO
WI-056	1,343.6	1	21.9%
HP-009	771.2	1	12.6%
HP-014	745.4	1	12.1%
HP-011	613.3	1	10.0%
HP-003	259.9	2	4.2%
HP-021	259.5	2	4.2%
HP-024	255.7	2	4.2%
WI-060	194.3	2	3.2%
HP-023	158.5	3	2.6%
WI-057	148.2	3	2.4%
HP-004	128.7	3	2.1%
HP-025	126.7	3	2.1%
HP-002	115.0	3	1.9%
HP-026	113.9	3	1.9%
HP-013	102.8	3	1.7%
HP-007	98.3	3	1.6%
WI-062	93.8	3	1.5%
WI-077	77.2	3	1.3%
HP-016	71.9	3	1.2%

Table 3. Bronx outfalls with the most CSO discharges. Based on InfoWorks modeling with average rainfall conditions (adapted from HydroQual 2007).

It is important to note that many CSO statistics come from computer models, not actual field measurements. Outfall sampling programs in New York City are limited (Basil and Plumb 2006). Field data is used to calibrate these models, which for the sewer New York City system include RAINMAN, SWMM, and InfoWorks.

The outfalls with the most overflows are shown in Figure 16 and Table 3**.** According to a ranking of NYC outfalls by total CSO volume, the Tier 1 outfalls have the most CSOs, and together create half of NYC's overflows. In the Bronx, the Tier 1 outfalls are WI-056, HP-009, HP-014, and HP-011. Tier 2 outfalls include HP-003, HP-021, HP-024, and WI-060, and contribute the next 20 percent of CSOs citywide. There are 11 Tier 3 outfalls in the Bronx, which contribute the next 20 percent of CSOs. The remaining outfalls together contribute the last 10 percent of overflows (HydroQual 2007).

Since the Clean Water Act, New York City has spent approximately $35 billion on improving water quality. The combined sewer overflow capture has increased from only 30 percent in 1980, to 70 percent today. The NYC Department of Environmental Protection is planning further improvements to the sewer system through the Long Term Control Plan. Several traditional engineering mitigation strategies are being evaluated, which are expected to increase the city-wide CSO capture rate to 75 percent (NYC Mayor's Office 2007).

The New York City Mayor's Office has undertaken an ambitious step towards sustainability with PlaNYC (2007), outlining specific sustainability goals for the City to achieve by 2030. There are many agencies responsible for managing the New York City landscape, as shown in Figure 17, which this initiative will help to coordinate. One of the PlaNYC goals is to improve water quality, allowing the City to open 90 percent of the City's waterways to recreation. Even if these ambitious goals are met, the freshwater portion of the Bronx River will still be impaired, with no contact allowed (NYC Mayor's Office 2007).

Specific PlaNYC initiatives include green infrastructure as best management practices. A tax incentive was recently approved to encourage green roofs in New York City, allowing building owners a tax abatement of $4.50 per square foot to offset the costs of a green roof (New York State Assembly 2008). Several pilot sites (two commercial, and four residential) are being developed by the City to study the effectiveness of green roofs on reducing CSOs (NYC Mayor's Office 2007).

Figure 17. Agencies responsible for various land uses in New York City. “One of the reasons that CSOs are such a tough problem is that the issue crosses so many different jurisdictions” (Zidar 2007).

Non-governmental organizations promoting green infrastructure in NYC include Earth Pledge, Riverkeeper and S.W.I.M. Bronx-based organizations include Sustainable South Bronx, the Bronx River Alliance, and Youth Ministries for Peace and Justice. Some of these groups have constructed their own green roofs, and are conducting their own studies.

Riverkeeper (Seggos 2006) has estimated the cost-benefits for reducing CSOs in NYC. For the same investment in traditional end-of-pipe stormwater management, there could be greater CSO reduction by using a variety of green infrastructure alternatives, as shown in Table 4. For the same $1,000 investment, the City could get a five-times greater CSO reduction by using incentives for private green roof installation. For an investment of $2.1 billion, the conventional approach used in the Long Term Control Plan would capture 5.1 billion gallons of CSOs per year, where source control could capture 7.2 billion gallons per year. The source control option has additional savings from not needing to treat the captured stormwater, plus the multiple environmental benefits from green infrastructure (Basil and Plumb 2006).

CSO Control	Gallons Decreased
Traditional end-of-pipe	2,400
Green streets	14,800
Street trees	13,270
Rain barrels	9,000
Green roofs on new buildings	810
Green roofs on existing buildings	865
Green roof incentives	12,000

Table 4. CSO reductions possible for $1,000 investment in NYC (Seggos 2006).

Project background

The Bronx Overall Economic Development Corporation (BOEDC) has sponsored several green building projects, including grants and loans for green roofs. To date, ten green roofs have been constructed, and funding secured for four more. Kate Shackford, director of the Bronx Initiative for Energy and the Environment at BOEDC, commissioned a borough-wide interactive software model to evaluate the potential impact of green roof installations on reducing CSOs. The resulting model was called the "Bronx Green Roof Stormwater Simulation Tool" and was used for the analysis presented in this paper.

The model was developed by the joint project team of Earth Pledge, HydroQual, Inc. and CommunityCartography, Inc. Earth Pledge is a non-profit environmental organization that promotes green roofs and other sustainable technologies. They have developed computer programs that model a green roof's physical characteristics including precipitation capture and retention. HydroQual is an engineering firm specializing in environmental models, including NYC stormwater and sewer models. CommunityCartography (now a part of Halcrow, Inc.) performs GIS analysis and maintains a spatial data warehouse for NYC, including detailed building information.

This project builds on several earlier studies conducted by the project team of Earth Pledge, HydroQual, and CommunityCartography. An initial study in 2001 included data mining of municipal databases for existing building information to find potential green roof locations. Using parcel maps and property databases, flat roof areas were calculated and “big box” buildings were identified within each borough of New York City. This found 12 percent flat roof coverage in the Bronx, or 3,303 acres. Nearly half of this area was comprised of buildings larger than 10,000 square feet.

A modeling study was performed for the Newtown Creek and North River service area, both combined sewer areas in New York City. The model looked at the impact of installing green roofs on stormwater runoff, again utilizing GIS data of flat roofed buildings (Rosenzweig, Gaffin, and Parshall 2006). The areas each had 29 percent of their land covered by flat roofed buildings (1,135 acres and 2,451 acres). The model found that when green roofs were built on 10 percent of the existing flat roof area, there was up to a 2 percent reduction in stormwater runoff. Building on 50 percent of the area resulted in up to a 10 percent reduction in stormwater runoff.

A subsequent study for the drainage subcatchment for Pace University, within the Newtown Creek service area, expanded the scope to include CSOs in addition to stormwater runoff. A model was developed as an interactive computer program that allowed several green roofs design variations to be selected for growth substrate type, growth substrate depth, and vegetation type. A GIS-based interface allowed specific buildings to be selected, and the impact of installing green roofs on CSOs was estimated based on the type of green roof specified (Hoffman 2006).

Model Development

Overview

The Bronx Green Roof Stormwater Simulation Tool project included software design, data development, and model integration. This project builds on the team's previous efforts in New York City, combining GIS and engineering models. It takes advantage of the data richness for the Bronx, utilizing building outlines and detailed building classes.

Part of this project was to create a graphical user interface (GUI) for a decision support system. It was designed to be easy to use and quickly deliver results. The GUI streamlined the creation of model inputs, integrated a green roof model and a sewer model, and post-processed the results. A map interface was used to display the results, to take advantage of spatial cognition for information processing. In addition to aiding pattern recognition, using a geographic map provides context lacking in a network diagram or a list of numbers in a table.

GIS was used to enhance the existing engineering model. Simple sewer models such as the one used here do not include maps. Rather, maps are used separately in the creation of model inputs, such as drainage area and imperviousness lookup tables. The engineering model functions independently of the map once the model data has been developed. These types of engineering models often lack a GUI, and output their results as text tables which require post-processing. Maps and charts are then created separately to communicate results. While not user-friendly, these models have the advantage of experience—they have been debugged and calibrated over several years of use.

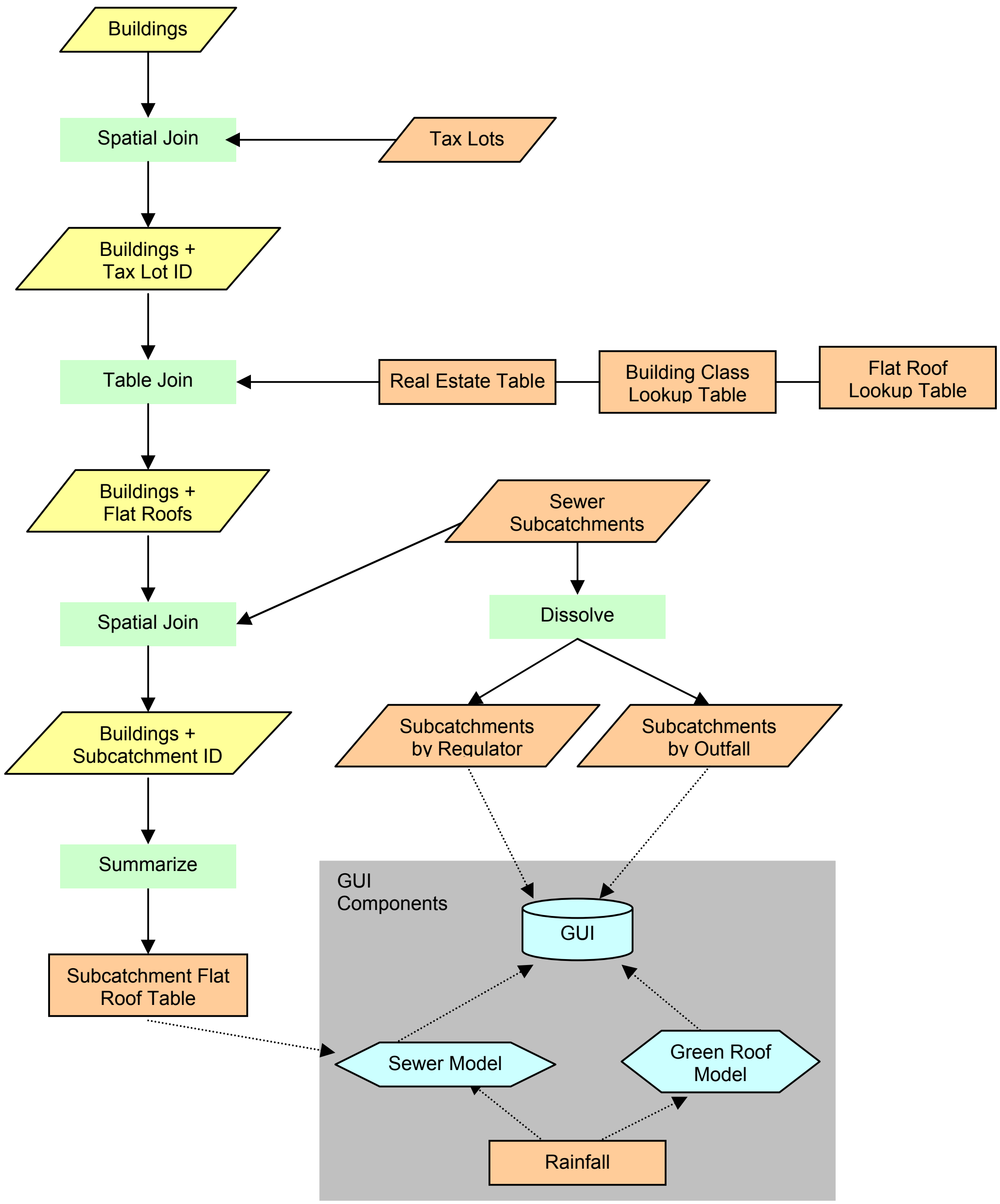


Figure 18. Overview of geoprocessing steps as part of model development for the Bronx Green Roof Stormwater Simulation Tool.

The Bronx model discussed here differs from other NYC sewer models in that it uses an administrative area to define the spatial extent (Bronx borough), rather than the sewer system boundaries as defined by treatment plant service areas. As shown in the inset map of Figure10, the Bronx includes all of the Hunts Point service area and more than half of the Wards Island service area. Existing sewer system models were customized to run just the Bronx portions of the sewer system.

Team members collaborated to develop the overall project design. The author, as an employee of HydroQual and CommunityCartography, was responsible for all GIS processing and GUI development. A HydroQual engineer developed the sewer model based on previous work performed for the NYC Department of Environmental Protection. Earth Pledge staff developed a green roof micro-model which provides runoff characteristics. These two model components are described in more detail in Appendix I, the software manual. The GIS data development and GUI design, performed by the author, are described in the rest of this chapter. The flow chart in Figure 18 provides an overview of the data development process used in this project.

Data Sources

The data for calculating roof areas was obtained from CommunityCartography's spatial data warehouse, which includes New York City data from public sources. This type of data is used for a variety of planning purposes, including cartography and data mining. Information on buildings, tax lots, and building classes were combined using ArcGIS geoprocessing tools to find the aggregate flat roof area for each sewer system subcatchment.

Sewer system data were available from HydroQual's previous work for the NYC Department of Environmental Protection (NYCDEP), including the Long Term Control Plan. Data from the Hunts Point and Wards Island (Bronx portion only) subcatchments were used.

Building map

Building roof polygon data is available from the New York City Department of Information Technology and Telecommunications (NYCDOITT). This data is part of the NYCMap data set, derived from aerial photographs. NYCMap data also includes street centerlines, curb lines, open space, transportation structures, rail lines, shoreline, and spot elevations. There are 97,370 building polygons in the Bronx study area. Building records do not contain any database attributes for address or property ID information. Horizontal accuracy is very good at one to two feet. Data is licensed by NYCDOITT and can be obtained for approved purposes. The 2005 version of the data was used.

Tax lot map

Tax lot data comes from the New York City Department of City Planning (NYCDCP), part of the Bytes of the Big Apple data set. There are 88,785 tax lots in the Bronx study area. Tax lot polygons have block and lot ID as attributes. This data was originally created on an older base map and is not as spatially accurate as the NYCMap data files. Data is licensed and can be purchased from NYCDCP. The 2004 version of the data was used.

Real estate table

The Real Property Assessment Database (RPAD) is maintained by the New York City Department of Finance (NYCDOF). This file lists property tax assessments, plus detailed property information useful for a variety of data mining projects and tax lot-based maps. There are 89,990 physical property records for the Bronx, with additional records for condos and easements. The fixed portion version of the database is available in Microsoft Access database format with nearly one hundred data fields. The attributes used in this project include block, lot, building class, number of buildings, and apportionment. Other attributes include address, owner, zoning, tax class, lot and building dimensions, year built and altered, and market and assessed values for land and total property values. It can be used with lookup tables for building class, zoning, and tax class codes. The data is available for purchase from NYCDOF and from private companies. The 2007 version of the data was used.

Building class lookup table

This lookup table includes the 240 building class codes in the RPAD table, with expanded descriptor fields for building use and land use based on NYCDOF references. This table is often joined to the RPAD table and tax lot polygons to create land use maps. This information is included in Tables 17A and 17B of Appendix III, as the basis for the flat roof lookup table.

Flat roof lookup table

The flat roof lookup table was developed by CommunityCartography for a 2001 Earth Pledge green roof study. It includes the building class lookup table plus a field indicating if each building class is likely to have a flat roof or not. Generally, multi-unit residential and commercial, industrial, and public facilities buildings are designated as having flat roofs. 176 classes are designated as having flat roofs. This information is included in Tables 17A and 17B of Appendix III.

Subcatchment map

These are polygons showing the sewer system drainage subcatchments, with attributes for the sewer system type: combined, separate, direct drainage, or other. Additional attributes include the water body, regulator, and outfall each area drains to. They were developed based on paper “Infiltration and Inflow” maps showing the sewer network on each street. There are 210 individual subcatchments in the Bronx study area. This includes all 147 of the Hunts Point subcatchments, and sixty-three of the 136 Wards Island subcatchments. Data was created by HydroQual for NYCDEP for various modeling projects over the years.

Outfall map

This is a point data layer showing the location of outfalls, where water is discharged along the shoreline. Types include combined sewer outfalls, separate sewer outfalls, and stormwater outfalls. The sewer model also uses “imaginary” outfalls to represent discharge from certain direct drainage areas that do not have physical outfalls associated with them. These don’t exist as pipes but are necessary for the model to account for non-point source runoff. There are 163 outfalls represented in the model. Data was created by HydroQual for NYCDEP, based in part from discharge permit information.

Regulator map

This is a point data layer with attributes for regulators, the weirs which regulate flow in the sewer system. Each regulator has a particular capacity, obtained by monitoring the inflow and the overflow at the associated outfall. Regulators control the volume of flow to the waste water treatment plant, and when necessary divert flow to an overflow outfall. Bypassing the treatment plant prevents system backups and flooding. Data was created by HydroQual for NYCDEP from "Regulator Improvement Program" maps.

Sewer system network

This model component includes information on the sewer system network connections. Network diagrams are included as Figures 29 and 30 in Appendix II. This information is from NYCDEP's "Infiltration and Inflow" maps, and used in the RAINMAN model.

Imperviousness

Another model component is imperviousness values, which were calculated from GIS data sources and calibrated to field observation data. Values can range from zero (for water) to one (for fully developed). This information is from the RAINMAN model and is embedded in the software code.

Rainfall data

Hourly precipitation data was obtained from the LaGuarida Airport rain gage, maintained by the National Oceanographic and Atmospheric Administration. For this study, three years of rainfall data were used from the long-term hourly rainfall record (ranging from calendar year 1948 to 2007). Year 1988 rainfall, with an annual rainfall of 40.69 inches, represents average conditions. Year 2001, with an annual rainfall of about 32.07 inches, represents dry conditions. Year 2003, with total annual rainfall of 51.82 inches, represents wet conditions.

Data development

For this project, several data sets were combined to find the roof area of existing buildings. These included the building map, the tax lot map, the RPAD table, and lookup tables. This resulted in a building polygon layer with a roof type attribute, indicating suitability for green roofs. The area of existing flat roofs was summarized by sewer system subcatchment, and used as a model input. Geoprocessing was performed using ESRI's ArcGIS 9.2 software.

First, tax lots were spatially joined to the NYCMap building layer to obtain tax lot IDs for each building polygon. The public release of the building data does not include any location attributes. Polygon-based spatial joins in ArcGIS can result in null values when the polygons from different layers only partially intersect. Because the building and tax lot map layers are not always well aligned, building polygons were converted to centroids, or center points, before joining. The building centroids were spatially joined to the tax lot polygons with the ArcGIS "join to nearest" option. Where there was a many-to-one relationship between a tax lot and several building structures, each building was assigned the same attributes. The resulting centroid attribute table was joined back to the building polygons by feature ID. This resulted in a building polygon layer with tax lot ID attributes.

Next, selected fields from the RPAD table were joined to the building polygon layer using the tax lot ID field. The primary piece of information used was building class. Additional building-related fields in RPAD were used to help check the building-tax lot spatial join. The newly-attributed building polygons were checked for misalignments.

Transportation structures such as bridge supports were removed. This resulted in a building polygon layer with building class attributes.

RPAD attributes also include building information in the form of frontage and depth measurements, total gross square footage, number of stories, and number of buildings. The table does not directly include building footprint or roof area. Multiplying RPAD building frontage times depth is one way to estimate the building roof area. However, this cannot account for irregularly shaped buildings. The table does include an attribute that flags if a building is irregularly shaped, which in the Bronx is 21 percent of properties. Another limitation of the RPAD data is that records are kept by tax lots, not by buildings. This makes storing building information for tax lots with multiple buildings problematic. In this project, all area calculations were performed on the NYCMap building polygon layer because of its greater precision.

Next, the flat roof lookup table was joined to the building layer. This table is based on the RPAD building class lookup table, and indicates if a building is likely to have a flat roof or not. This resulted in a building polygon layer with roof type attributes.

The next data processing step was to spatially join the sewer system subcatchment polygons to the buildings. Again, the building centroids were used with “join to nearest” so that buildings split by subcatchment boundaries would obtain attributes. This resulted in a final building polygon layer with attributes for tax lot ID, building class, roof type, sewer system subcatchment ID, regulator, and outfall.

The resulting attribute table was summarized in ArcGIS, grouped by roof type and regulator, with a sum of the shape area. The resulting table, which indicates the total flat roof area for each regulator, was used as an input in the sewer model.

Additional sewer system subcatchment layers were created to work with the sewer model. Each subcatchment has both a regulator and outfall designation. Because of the cross connections in the sewer network, these are not always one-to-one relationships between subcatchment, regulator and outfall. This can be seen in Figures 29 and 30 in Appendix II, the schematic diagrams of the sewer network. The subcatchment polygons were dissolved two separate times, based on regulator and outfall attributes to create separate map layers for model inputs and outputs. The original layer has 210 unique subcatchments. For model inputs, there are 191 regulator areas. This represents the land area that drains to the portion of the sewer network that is controlled by a specific regulator.

For model outputs, there are 163 outfall areas. This represents the contributing land area for a specific outfall, responsible for its discharge. There were fifteen outfall areas where flow directed to the same outfall came from subcatchments of different types (combined, separate, or direct). For these the type with the largest contributing area was used, which were all over 50 percent. The three versions of the subcatchment data (original subcatchments, regulator areas, and outfall areas) were used at different times in the modeling process.

Decision Support System

A number of assumptions needed to be made in designing the green roof model. The ideal building for a green roof would have a large flat roof with few obstructions, and be structurally able to support the weight of a green roof fully saturated with precipitation. This software model applies the green roof designs uniformly across all flat roofed buildings in a subcatchment, rather than selecting individual buildings. Because of this model constraint, the green roof design options needed to be conservative to realistically allow a wide application.

Because we were modeling existing buildings, the weight of the green roofs was an important consideration. According to the USEPA (2007a), most existing flat roofed buildings can accommodate extensive green roofs without structural reinforcements. In this project the design options were limited to extensive green roofs with a growth substrate depth of up to six inches. This would allow the model to be applied across all flat roofed buildings in a subcatchment, without the need to filter the data by structural capacity, estimated from building age and construction codes.

According to the USEPA (2007a), "the amount of stormwater that a green roof mitigates is directly proportional to the area it covers, the depth and type of growing medium, slope, and the type of plants selected." The green roof micro-model was designed with these options, while assuming the roof is flat.

This software program models different scenarios for constructing green roofs in the Bronx and displays the effect on the sewer system on a map. The sewer model and green roof model are linked to a graphical user interface (GUI). The GUI was written in Borland's Delphi program (Pascal-based) with Tatuk GIS libraries. The User Manual in Appendix I describes the program in detail, with additional information in Appendix II.

A simple sewer model based on the NYCDEP's RAINMAN was used so the program could be run in minutes. Some of the more complicated NYC models, such as InfoWorks, can take hours to run a year-long simulation. The program simulates one year, using hourly precipitation data. The run-time for the model calculations is approximately thirty seconds.

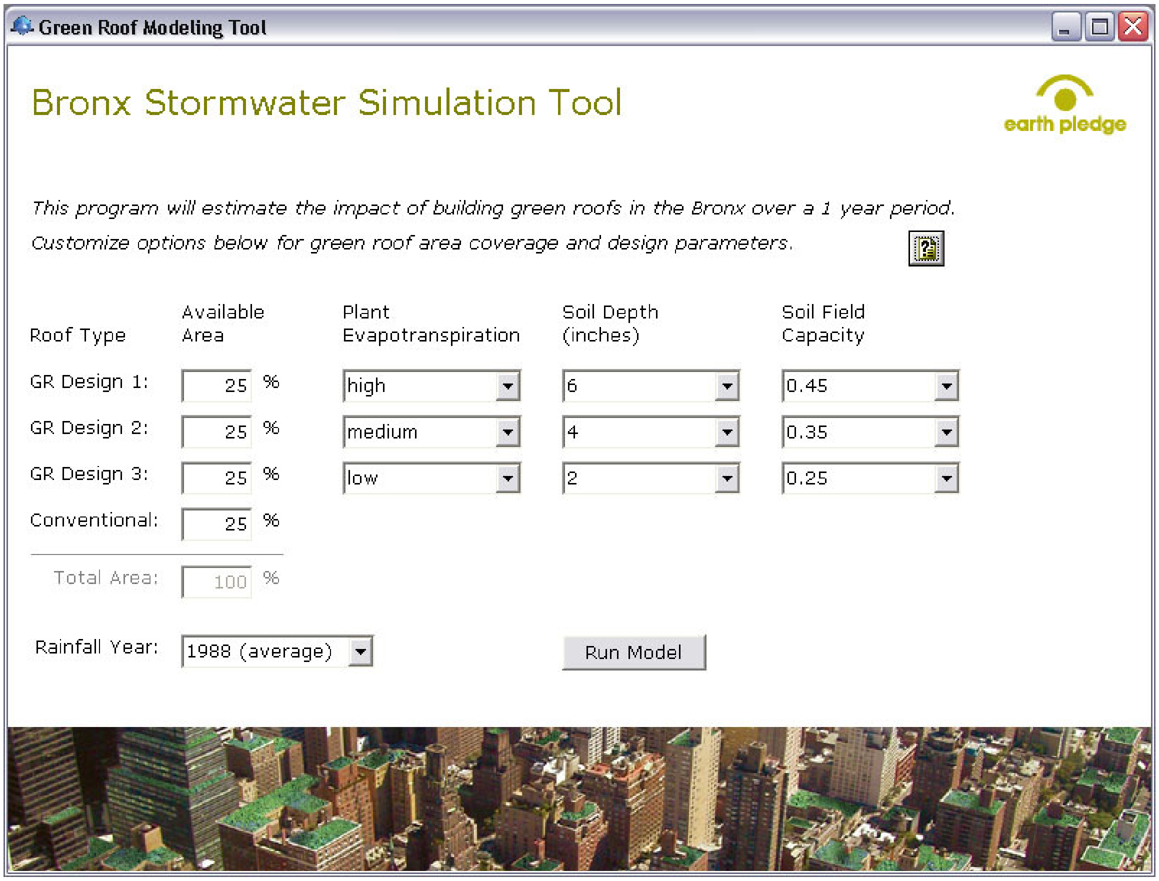


Figure 19. Decision support system input screen.

The GUI allows the user to specify up to three different green roof designs to uniformly apply across the Bronx. Each design has a plant evapotranspiration type, soil substrate depth, and soil field capacity. The user also specifies the percent of available flat roof area to apply each design to. Three different rainfall datasets are available for average, wet, and dry years. The input GUI is shown in Figure 19. The user-specified options for green roof designs and rainfall year are used as inputs to the sewer and green roof models, as described in the User Manual.

After the green roof micro-model and sewer models are run, the output files are processed. The resulting data table is joined to the outfall area subcatchment polygons and displayed on an interactive map. This functions as a self-contained GIS to facilitate data exploration. The user can customize the map with full access to each layer's display options. Model results are stored in a Microsoft Access database, making the data available to users who want to perform more advanced analysis.

The GUI for the results screen is shown in Figure 20. The model inputs are included with regulator area subcatchment polygons symbolized as a green equal-interval choropleth map (0 to 50 percent), showing the percent of land area covered by flat roofs. Model outputs are included in two formats. Outfall area subcatchments are symbolized as a blue equal-interval choropleth map (0 to 100 percent), showing the percent of overflow reduction by volume. Pie charts are also included for each outfall area subcatchment as graduated symbols, sized by the overflow volume under baseline conditions (no green roofs). The green slices represent the reduction in overflow volume that is possible with the green roofs applied in the model run. These symbols are the same for all subcatchment types. All results are yearly totals and are displayed the same way for all drainage types.

Additional information is provided around the map. Summary statistics for only the combined sewer subcatchments are provided, as the reduction in CSO volume and hours. An "identify" tool allows clicking on a subcatchment to view its model results for overflow volume, overflow events, and peak flow compared to baseline conditions. Other reference layers include the original subcatchment areas by sewer system type, outfall points, and administrative districts. The building outlines are not provided with the model because of data license considerations.

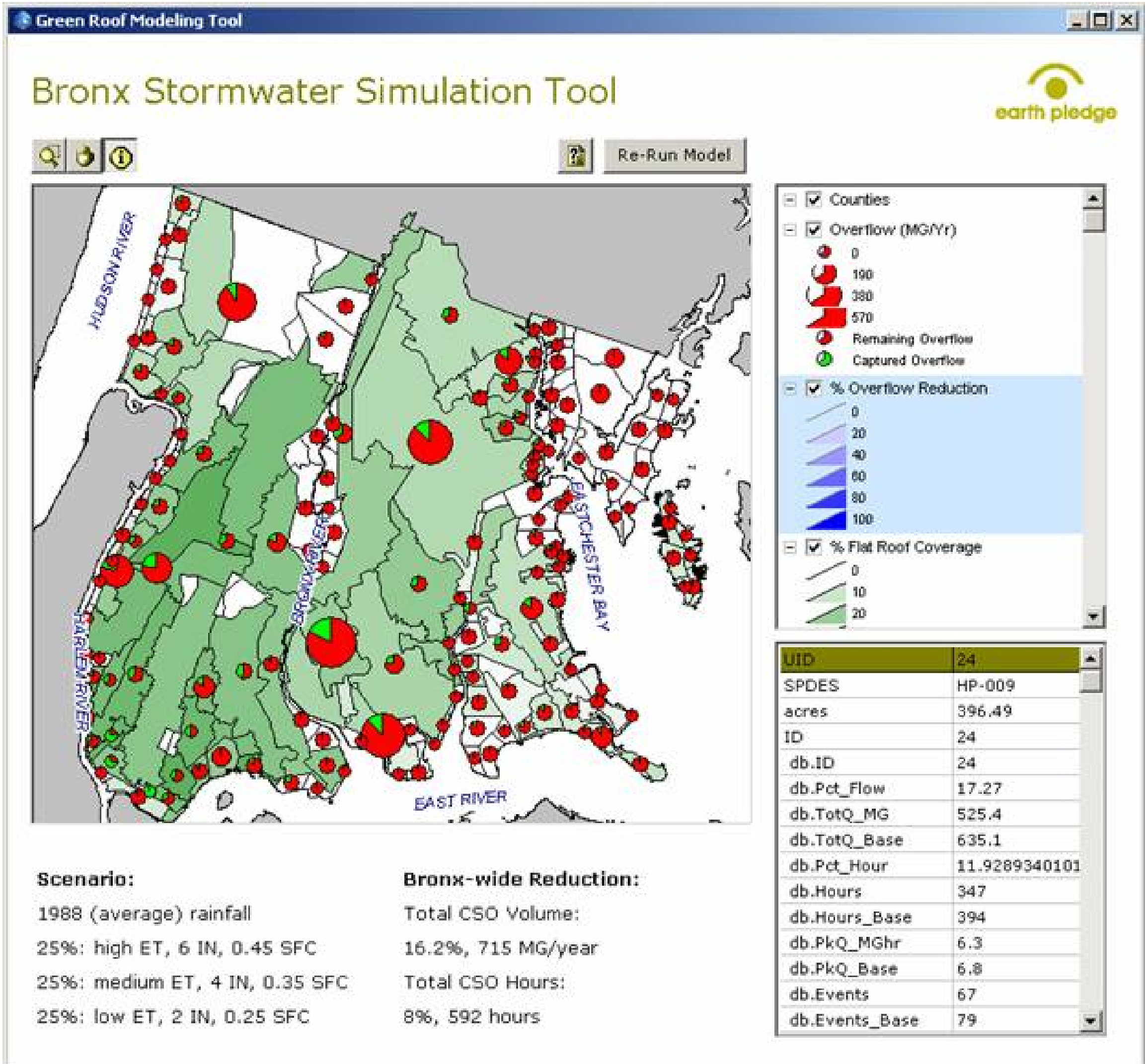


Figure 20. Decision support system results screen. Model inputs shown as green polygons, and model outputs are shown as pie charts.

Summary

The Bronx Green Roof Stormwater Simulation Tool can easily be run multiple times to compare different design scenarios. For this paper, the model was run fifteen times varying the settings. Subcatchments were ranked by their performance, in terms of green roof area divided by stormwater runoff reduction. The results were compared based on the outfall subcatchment areas, for combined sewer outfall areas only.

Chapter 4. Results

Introduction

The Bronx Green Roof Stormwater Simulation Tool was run to model fifteen different design scenarios. Three sets of parameters were varied independently: green roof design, green roof area coverage, and rainfall year. Model results showed that constructing extensive green roofs on existing buildings in the Bronx can reduce combined sewer overflows (CSOs). Reductions were seen in all performance measures: overflow volume, number of overflow events, and overflow hours.

In this chapter we begin by reviewing the new files created during data development. Then a summary of the results is presented, focusing on combined sewer areas. Additional figures and tables for all subcatchment types are included in the appendices. A scoring system was used to normalize CSO response by green roof area, allowing subcatchments to be compared for sensitivity to green roofs as a stormwater best management practice.

Data development

The data geoprocessing steps performed during the model development process resulted in several new maps and tables. These include flat roofed buildings and subcatchment area summaries.

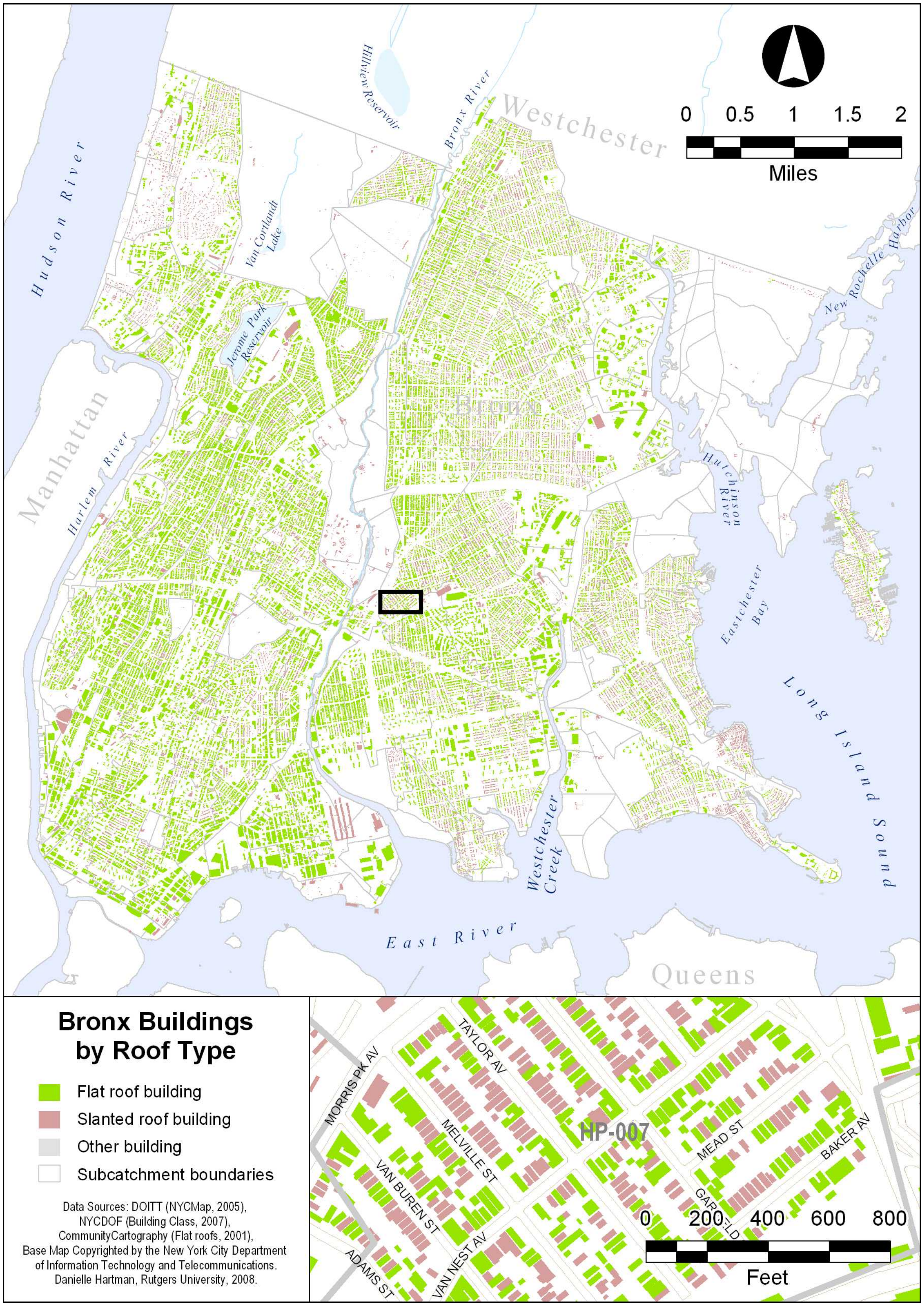


Figure 21. Borough overview and close-up of building data, colored by roof type.

Building data

The building layer with flat roof information is shown in Figure 21. The large park areas are apparent by the lack of buildings. West of the Bronx River are large areas of primarily flat roofed buildings, corresponding to the areas of highest population density along the Grand Concourse and parallel subway lines. The largest buildings are concentrated along the South Bronx waterfront industrial areas. As you move east of the Bronx River into more primarily residential neighborhoods, the buildings become smaller and have fewer flat roofs on one- and two-family homes.

Each of the 89,990 RPAD records for the Bronx contains a building class designation, allowing flat roof status to be assigned. Of the 97,370 building polygons, only thirty (0.03 percent) failed to join to the tax lot data. The difference in record numbers between the RPAD records and the building polygons comes from two factors. A single property in the RPAD data can have multiple buildings, or none. Also, a single building might be represented by multiple polygons due to the way the files were created from aerial photographs.

The 2001 flat roof analysis by CommunityCartography had indicated that 12 percent of the Bronx land area was covered by flat roofs. This is slightly less than the value of 14 percent used in the current project. Some of this difference may be explained as change over time, with increased development between 2000 and 2007. Another contributing factor to the difference is the data processing methodology. In the current project, the NYCMap building polygons were used for more accurate measurements of irregular buildings, and inclusion of small structures such as garages. The 2001 value was based only on the building areas calculated as building frontage times depth, as listed in the RPAD database. The same building frontage times depth calculation on the 2007 RPAD database found 3,585 acres of flat roofs, or 13.52 percent of the land area. This is only 4 percent different from the 3,748 flat roof acres (14.14 percent) as calculated using the NYCMap building polygons. The remaining difference in the 2001 and 2007 values can be attributed to development.

Subcatchment data

The map in Figure 22 shows some of the files used as model inputs. This includes the regulators, regulator area subcatchments, and aggregate flat roof coverage. These values represent the space available for green roofs within each regulator's drainage area. The subcatchments with low building coverage are parks, cemeteries, and shorefront areas. Subcatchments west of the Bronx River tend to have higher flat roof density, with three subcatchments over 30 percent.

Borough-wide, flat roofed buildings cover 14 percent of the land area of the Bronx. The building statistics summarized by drainage type are shown in Table 5. For just the areas with combined sewer systems, the aggregate flat roof building coverage is 19 percent. Areas with separate sewer systems have an aggregate 10 percent coverage by flat roofs.

	Land Acres	Building Acres	Flat Roof Acres	Buildings % of Land Area	Flat Roof % of Land Area
Combined Sewer Drainage	18,293	4,352	3,448	24%	19%
Separate Sewer Drainage	1,452	191	144	13%	10%
Direct Drainage	5,059	243	152	5%	3%
Other Drainage	1,708	14	4	< 1%	< 1%
Total	26,512	4,800	3,748	18%	14%

Table 5. Aggregate roof area by sewer system type. Based on original subcatchment polygons.

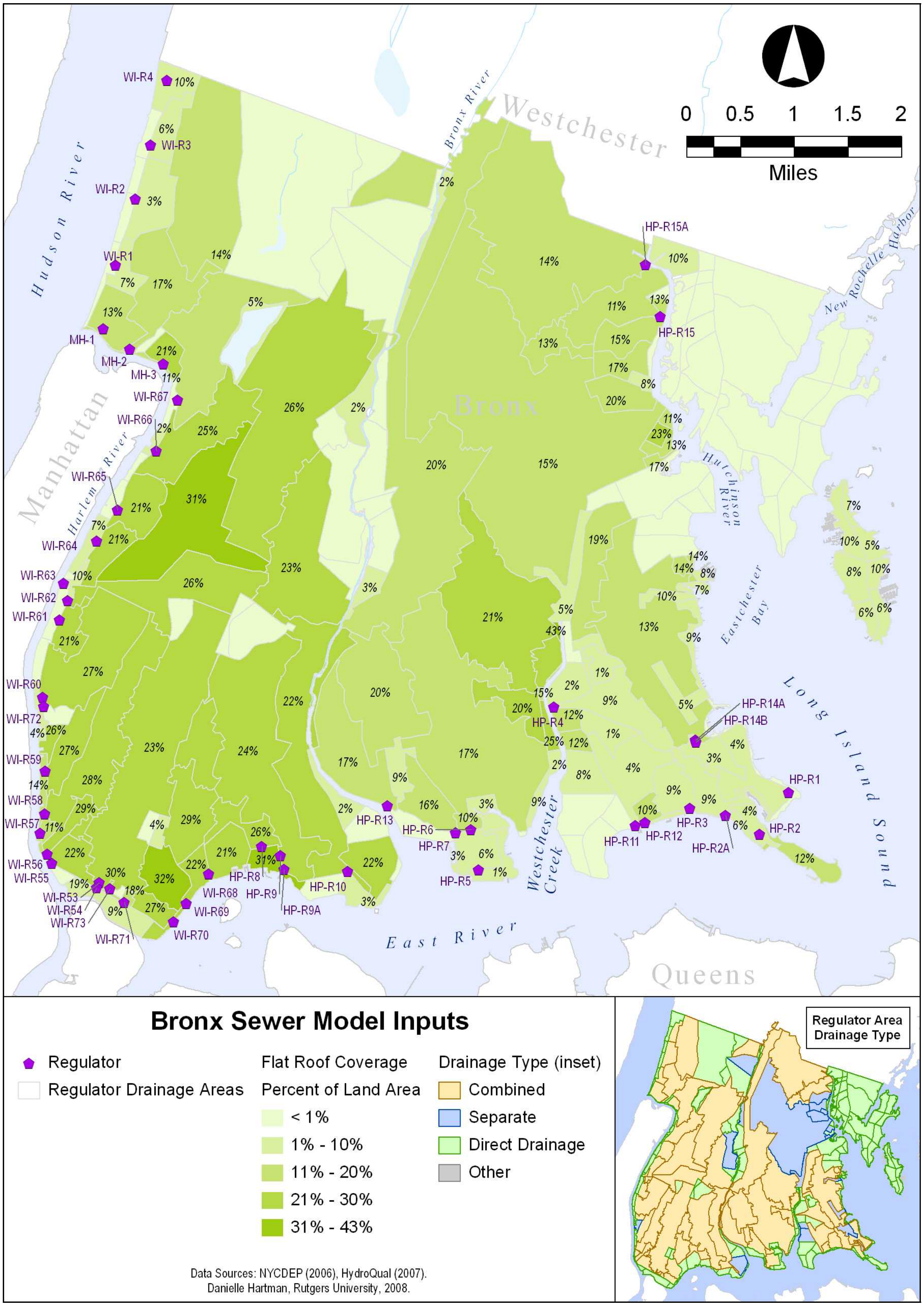


Figure 22. Model inputs, with flat roof coverage by regulator area subcatchments. Flat roof acreage was used as a sewer model input.

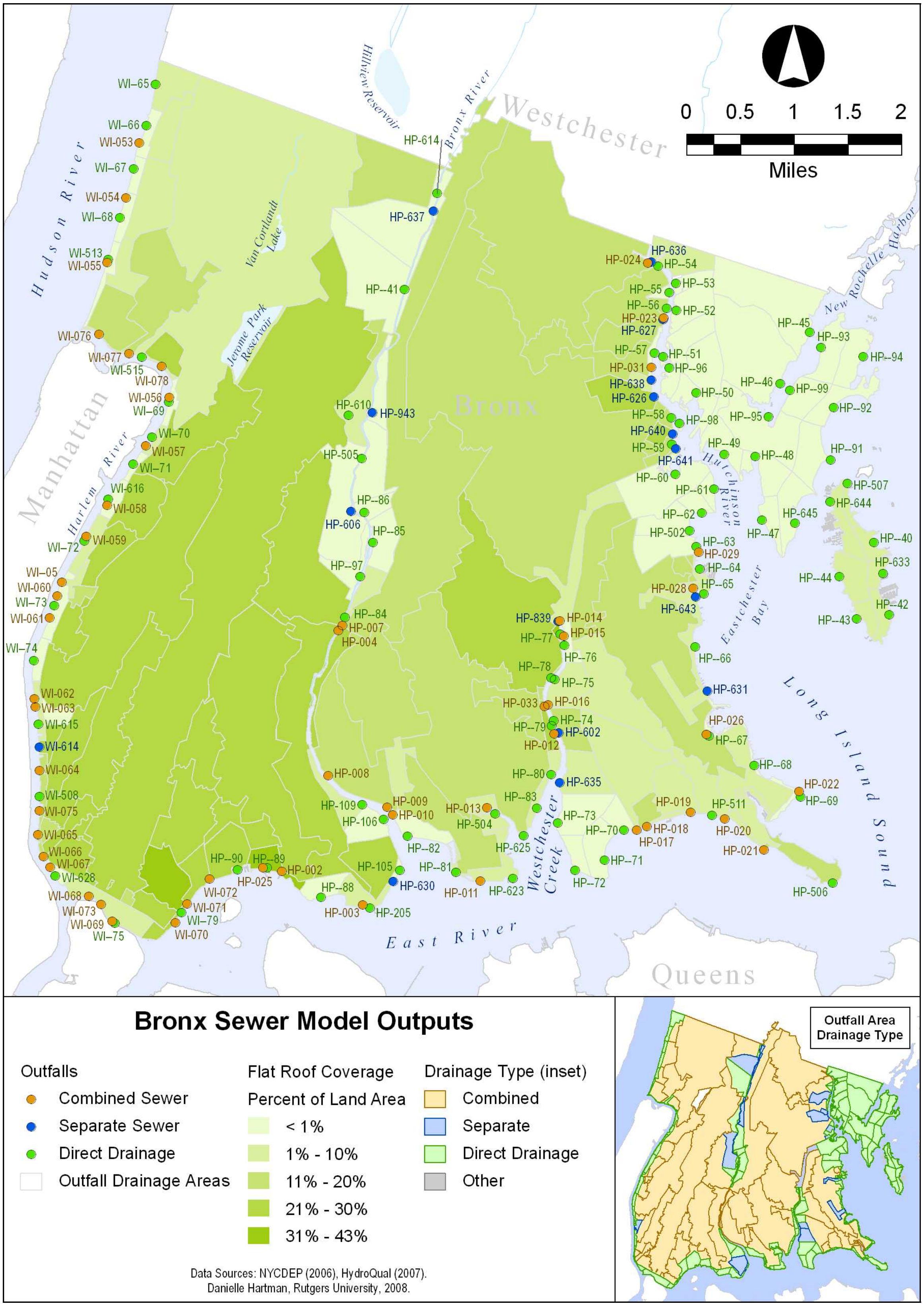


Figure 23. Model outputs, with flat roof coverage by outfall area subcatchments.

The data files related to the model outputs are shown in Figure 23. This includes the outfalls and outfall area subcatchments. The flat roof areas were aggregated by outfall area subcatchments as part of the sensitivity scoring for CSO reduction, since model results are reported by outfall and not regulator. The flat roof data is listed by subcatchment in Table 17 of Appendix III.

Model results

The model can simulate many scenarios, by selecting from ten different drop-down menus with three options each, and allocating area into four groups using various proportions. In this paper we will review fifteen scenarios using a representative range of settings. First, a mixed scenario was run, with a combination of three green roof designs and leaving some un-greened flat roof space. Next, several different scenarios were run to show the range of model responses to different parameters. These included varying the green roof design settings (high, medium, and low performance combinations), green roof area coverage, and rainfall year.

The results for combined sewer subcatchments are the focus of this paper. Model results for all subcatchment types are available in Appendix III. Screenshots of the GUI are included, along with tables and CSO summary maps. Results for “events” are reported in this chapter with the borough totals as the maximum reduction of events at any single outfall, while the events in the Appendices are listed for each subcatchment individually. The subcatchments were ranked according to the sensitivity of their CSO reduction per acre of green roof. These results are included as tables and summary maps in Appendix V.

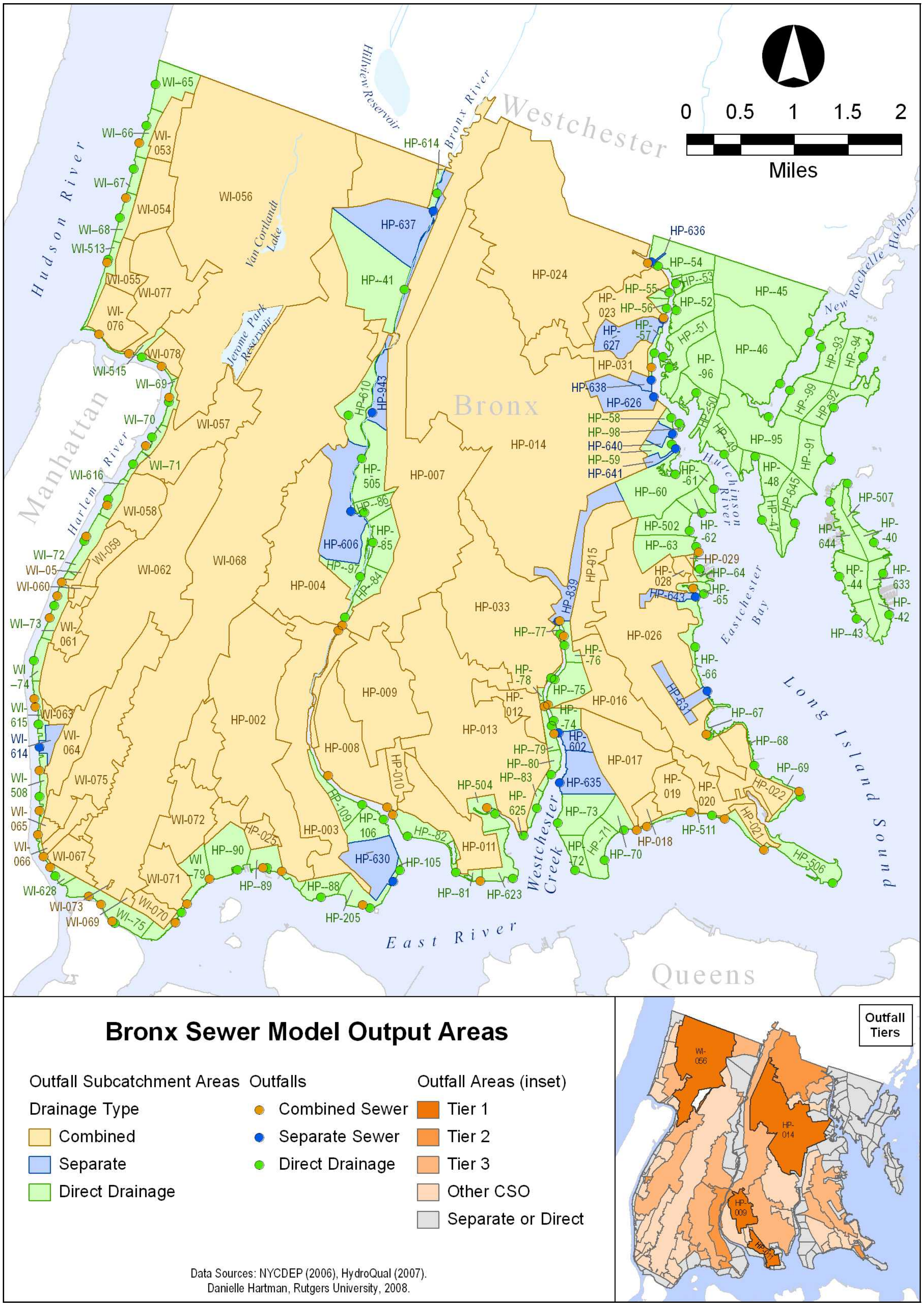


Figure 24. Model outfall areas reference map.

Model results are reported as the annual reduction of overflow by volume, events, and hours. Tables do not include records where the result values are all zero. Throughout the appendices, results maps and tables are lettered A through O for the fifteen model scenarios. The model outfall area map in Figure 24 can be used as a reference for the location of specific outfall areas discussed in the results.

Mixed green roof scenario

A “mixed” scenario was run, combining different green roof designs and leaving un-greened space. This is intended to represent a mix of designs that might occur when using multiple locations and designers. The green roof designs were 25 percent area each for low evapotranspiration/2 inches soil depth/0.25 soil field capacity (“low performance” scenario), medium evapotranspiration/4 inches soil depth/0.35 soil field capacity (“medium performance” scenario), and high evapotranspiration/6 inches soil depth/0.45 soil field capacity (“high performance” scenario). An area of 25 percent was left as conventional roofing to leave space for infrastructure such as storage sheds, ventilation units, and walkways. Figure 25 shows the model results screen, with the full results available in Appendix IV as Tables 19M and 20M.

With average rainfall conditions, over one year for the entire borough, the model showed a total CSO reduction of 731 million gallons by volume (16 percent), 12 events maximum (15 percent), and 637 hours (8 percent). The average subcatchment volume reduction was 15 million gallons per year (22 percent), with a standard deviation of 23 million gallons (20 percent). The average individual subcatchment events reduction was 4 per year (13 percent), with a standard deviation of 3 (13 percent). The average subcatchment hours reduction was 13 per year (15 percent), with a standard deviation of 11 (15 percent).

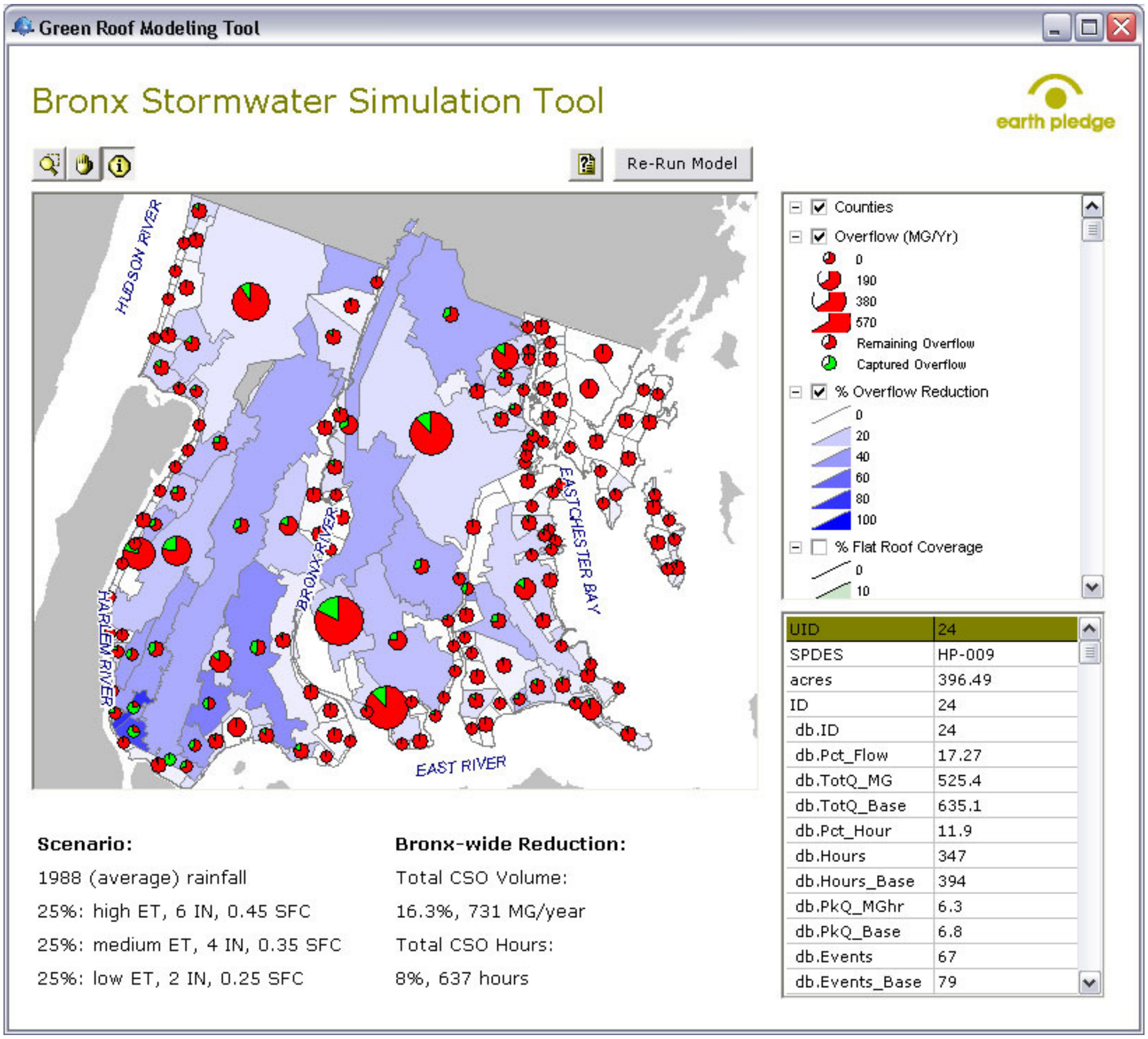


Figure 25. Model results for the mixed green roof scenario, for an average rainfall year.

Outfall HP-009, a Tier 1 outfall, showed the greatest response in terms of absolute reduction in CSOs. The CSO reductions were 110 million gallons (a 17 percent reduction), 12 events (a 15 percent reduction at this outfall), and 47 hours (a 12 percent reduction) per year. This is shown on the map in Figure 25 as the largest pie chart, where the overall size represents the CSO volume for the baseline conditions (no green roofs), and the green slice represents the volume of CSOs that are prevented by green roofs.

CSOs were completely eliminated at outfall WI-069, in the south west corner of the Bronx. As shown on the map, this is one of the smaller subcatchment areas with a small amount of annual CSOs (the subcatchment is obscured by the green pie chart symbol). Twenty percent of the nine acre subcatchment is covered by flat roofed buildings, enough to eliminate the five annual overflow events. No effect was seen in outfall WI-063, where there aren't enough buildings in the twenty-eight acre area to have an impact on the thirty-three annual CSO events. There are six outfalls with no CSOs in an average rainfall year (these are the smallest red pie charts).

Variations in green roof design

The model was run three times, each with 100 percent coverage by a single green roof design, and average rainfall. The green roof designs were low evapotranspiration/2 inches soil depth/0.25 soil field capacity for the low performance scenario, medium evapotranspiration/4 inches soil depth/0.35 soil field capacity for the medium performance scenario, and high evapotranspiration/6 inches soil depth/0.45 soil field capacity for the high performance scenario. Further variations were not analyzed for this paper. A more nuanced analysis is more suited to the standalone version of the green roof micro-model, which has more options than the 3x3x3 available in this GUI.

Results figures and tables for the three design scenarios are included in Appendix IV (series D, E, and F), and summarized in Table 6 below. The borough-wide CSO volume reduction increases from 9 to 22 to 31 percent as the green roof designs increase in capacity. The borough reduction of maximum events increases from 18 percent for the low and medium designs, to 73 percent for the high performance design. CSO reduction for hours increases 4 percent for each green roof type up to 16 percent. As much as 1,398 million gallons, 19 events, and 1,217 hours of CSOs could be avoided each year with full coverage of high performance green roofs.

Borough-wide Reduction		Low Performance	Medium Performance	High Performance
Volume	Million Gallons/Year	410	1,001	1,398
	Percent	9%	22%	31%
Events	Maximum Events/Year	14	14	19
	Maximum Percent	18%	18%	73%
Hours	Hours/Year	562	904	1,217
	Percent	7%	11%	15%

Table 6. Bronx-wide summary of model response to different green roofs performance scenarios, each with 100 percent coverage and average rainfall.

The high performance green roof scenario with 100 percent coverage illustrates the higher end of the range for extensive green roofs in an average rainfall year. In this scenario, the largest reduction in absolute volume and hours was seen in outfall HP-009, with 205 million gallons (a 32 percent reduction) and 67 hours (a 17 percent reduction) per year. The outfall with the greatest reduction in individual events was WI-072, with 19 events per year (a 73 percent reduction at this outfall).

For the medium performance green roof scenario, HP-009 showed the greatest reduction for all measures, with 152 million gallons per year (a 24 percent reduction), 14 events per year (an 18 percent reduction at this outfall), and 55 hours per year (a 14 percent reduction).

For the low performance green roof scenario, HP-009 again showed the greatest reductions, with 89 million gallons per year (a 15 percent reduction), 14 events per year (an 18 percent reduction at this outfall), and 40 hours per year (a 10 percent reduction).

Variations in percent coverage

The model was run with 25 percent, 50 percent, and 75 percent coverage by the high performance green roof settings for the average rainfall year. The model results are included as maps and tables in Appendix IV (series A, B, and C), and summarized in Table 7. The cumulative borough-wide CSO reduction increases in a linear fashion with coverage, with each green roof area increase of 25 percent resulting in approximately an 8 percent reduction in volume, and 4 percent in hours. Reduction of maximum events increases more dramatically, as it is reported as a single maximum value rather than the sum of each outfall

Borough-wide Reduction		25% Coverage	50% Coverage	75% Coverage	100% Coverage
Volume	Million Gallons/Year	375	733	1,074	1,398
	Percent	8%	16%	24%	31%
Events	Maximum Events/Year	6	12	15	19
	Maximum Percent	23%	46%	58%	73%
Hours	Hours/Year	309	599	877	1,217
	Percent	4%	8%	11%	15%

Table 7. Bronx-wide summary of model response to varying coverage, with high performance green roofs and average rainfall.

In these scenarios, the largest absolute reductions were seen mainly in outfalls HP-009 and WI-072. For the 75 percent coverage scenario, HP-009 showed the greatest reduction at 152 million gallons per year (a 24 percent reduction) and 50 hours per year (a 13 percent reduction). Outfall WI-072 had the greatest reduction of events at 15 per year (a 58 percent reduction at this outfall).

For the 50 percent coverage scenario, HP-009 showed the greatest reduction at 101 million gallons per year (a 16 percent reduction) and hours again at 50 per year (a 13 percent reduction). Outfall WI-072 had the greatest reduction of events at 12 per year (a 46 percent reduction at this outfall).

For the 25 percent coverage scenario, HP-009 showed the greatest volume reduction at 50 million gallons per year (an 8 percent reduction). Outfall WI-072 had the greatest reduction of events at 6 per year (a 23 percent reduction at this outfall). Outfall HP-021, a Tier 2 outfall, had the greatest reduction in hours at 24 per year (a 10 percent reduction).

Variations in rainfall

High performance

The high performance scenario was run with 100 percent coverage for the dry (2001) and wet (2003) rainfall years. These results are reported as series G and J in Appendix IV, and summarized in Table 8.

Running the model with a dry rainfall year (2001) reduced CSOs by 1,185 million gallons (a 39 percent reduction), 18 events (45 percent reduction), and 1,269 hours (19 percent reduction) over a year. The dry rainfall year had rainfall events with lesser intensity in terms of inches per hour, allowing green roofs to capture a larger percentage of the precipitation before becoming saturated and discharging the runoff to the sewer system.

Running the model with a wet rainfall year (2003) reduced CSOs by 1,338 million gallons (a 23 percent reduction), 14 events (an 18 percent reduction at this outfall), and 1,262 hours (a 13 percent reduction) over a year. The wet rainfall year shows a smaller amount of CSO capture for volume and events. This suggests that the green roofs reach their storage capacity more quickly during larger storms, or have less time to dry out between rain events.

Borough-wide Reduction		Average Rainfall (1988)	Dry Rainfall (2001)	Wet Rainfall (2003)
Volume	Million Gallons/Year	1,398	1,185	1,338
	Percent	31%	39%	23%
Events	Maximum Events/Year	19	18	14
	Maximum Percent	73%	45%	18%
Hours	Hours/Year	1,217	1,269	1,262
	Percent	15%	19%	13%

Table 8. Bronx-wide summary of model response to varying rainfall year, using 100 percent coverage and high performance green roofs.

The outfalls with the greatest CSO reduction are somewhat different for the dry rainfall year. HP-009 showed the greatest volume reduction at 204 million gallons per year (a 42 percent reduction). Outfall WI-057, a Tier 3 outfall, had the greatest reduction of events at 18 per year (a 45 percent reduction at this outfall). Outfall WI-060, a Tier 2 outfall, had the greatest reduction in hours at 76 per year (a 15 percent reduction).

The outfalls with the greatest CSO reduction are again somewhat different for the wet rainfall year. HP-009 showed the greatest volume reduction at 202 million gallons per year (a 26 percent reduction). Outfall HP-023, a Tier 3 outfall, had the greatest reduction of events at 14 per year (an 18 percent reduction at this outfall). Outfall HP-

025, a Tier 3 outfall, had the greatest reduction in hours at 103 per year (a 14 percent reduction).

Medium performance

The medium performance scenario was run with 100 percent coverage for the dry (2001) and wet (2003) rainfall years. These results are reported as series H and K in Appendix IV, and summarized in Table 9. These designs showed a slightly stronger response in the dry year, and smaller response in the wet year.

Borough-wide reduction		Average Rainfall (1988)	Dry Rainfall (2001)	Wet Rainfall (2003)
Volume	Million Gallons/Year	1,001	834	796
	Percent	22%	28%	14%
Events	Maximum Events/Year	14	15	12
	Maximum Percent	18%	38%	18%
Hours	Hours/Year	904	954	947
	Percent	11%	15%	10%

Table 9. Bronx-wide summary of CSO model response to the medium performance green roof scenario, by rainfall year.

The outfalls with the greatest CSO reduction for the medium performance scenario and dry rainfall year were as follows. HP-009 showed the greatest volume reduction at 155 million gallons per year (a 32 percent reduction). Outfall WI-057, a Tier 3 outfall, had the greatest reduction of events at 15 per year (a 38 percent reduction at this outfall). Outfall WI-060 again had the greatest reduction in hours, at 59 per year (a 12 percent reduction).

For the medium performance scenario and wet rainfall year, HP-009 again showed the greatest volume reduction at 145 million gallons per year (a 19 percent reduction). Outfall WI-076 had the greatest reduction of events at 12 per year (an 18 percent reduction at this outfall). Outfall WI-060 again had the greatest reduction in hours, at 91 per year (an 18 percent reduction).

Low performance

The low performance scenario was run with 100 percent coverage for the dry (2001) and wet (2003) rainfall years. These results are reported as series I and L in Appendix IV, and summarized in Table 10. These designs showed a slightly stronger response in the dry year, and a slightly smaller response in the wet year.

Borough-wide reduction		Average Rainfall (1988)	Dry Rainfall (2001)	Wet Rainfall (2003)
Volume	Million Gallons/Year	410	425	243
	Percent	9%	14%	4%
Events	Maximum Events/Year	14	8	12
	Maximum Percent	18%	50%	15%
Hours	Hours/Year	562	593	600
	Percent	7%	9%	6%

Table 10. Bronx-wide summary of CSO model response to the low performance green roof scenario, by rainfall year.

The outfalls with the greatest CSO reduction for the low performance scenario and dry rainfall year were as follows. HP-009 showed the greatest volume reduction at 95 million gallons per year (a 19 percent reduction). Outfall WI-075 had the greatest reduction of events at 8 per year (a 50 percent reduction at this outfall). Outfall WI-060 again had the greatest reduction in hours, at 43 per year (an 8 percent reduction).

For the low performance scenario and wet rainfall year, HP-009 again showed the greatest volume reduction at 78 million gallons per year (a 10 percent reduction). Outfall HP-023 had the greatest reduction of events at 12 per year (a 15 percent reduction at this outfall). Outfall WI-060 again had the greatest reduction in hours, at 82 per year (an 11 percent reduction).

Mixed design

The mixed design scenario was run for the dry (2001) and wet (2003) rainfall years. These results are reported as series M and O in Appendix IV, and summarized in Table 11. These designs showed a stronger response in the dry year, and smaller response in the wet year.

Borough-wide reduction		Average Rainfall (1988)	Dry Rainfall (2001)	Wet Rainfall (2003)
Volume	Million Gallons/Year	731	637	619
	Percent	16%	21%	11%
Events	Maximum Events/Year	12	10	10
	Maximum Percent	15%	30%	15%
Hours	Hours/Year	637	685	618
	Percent	8%	11%	6%

Table 11. Bronx-wide summary of CSO model response to the mixed green roof scenario, by rainfall year.

The outfalls with the greatest CSO reduction are slightly different for the mixed scenario and dry rainfall year. HP-009 showed the greatest volume reduction at 113 million gallons per year (a 23 percent reduction). Outfall WI-062, a Tier 3 outfall, had the greatest reduction of events at 10 per year (a 30 percent reduction at this outfall). Outfall WI-060 again had the greatest reduction in hours, at 46 per year (a 9 percent reduction).

For the mixed scenario and wet rainfall year, HP-009 again showed the greatest volume reduction at 106 million gallons per year (a 14 percent reduction). Outfall WI-076 had the greatest reduction of events at 10 per year (a 15 percent reduction at this outfall). Outfall WI-060 again had the greatest reduction in hours, at 82 per year (an 11 percent reduction).

Geographic variation

Subcatchment variation

For all design scenarios, the model results varied geographically between subcatchments. Summary maps of modeled volume reduction are shown in Figure 26. Summary maps encompassing all fifteen model runs with reduction in volume, events, and hours are included as Figures 32 through 35 in Appendix IV. Overall, the results by subcatchment ranged from 0 to 100 percent reduction in CSOs.

Some of the smallest subcatchments show the strongest response to the model in terms of percent reduction of CSOs. Outfalls WI-061, WI-066, and WI-067 showed reductions over 80 percent in several scenarios. These subcatchments have some of the lowest volume of annual CSOs, and with between 20 and 30 percent flat roof coverage, are more sensitive to stormwater controls. Outfall WI-060, a Tier 2 outfall with a small subcatchment area, had the greatest reduction in CSO hours for seven of the model scenarios.

For larger subcatchments, HP-002 showed a strong response across the model scenarios. HP-002 is a Tier 3 outfall with 22.8 million gallons of CSOs in an average year. The greatest reduction in CSO by volume was nearly 91 percent, with the high performance scenario in a dry year.

Tier 1 outfalls

The Tier 1 outfalls are the largest CSO dischargers by volume. These include (in order of magnitude) WI-056, HP-009, HP-014, and HP-011. Maps of these subcatchments are shown in Appendix VI.

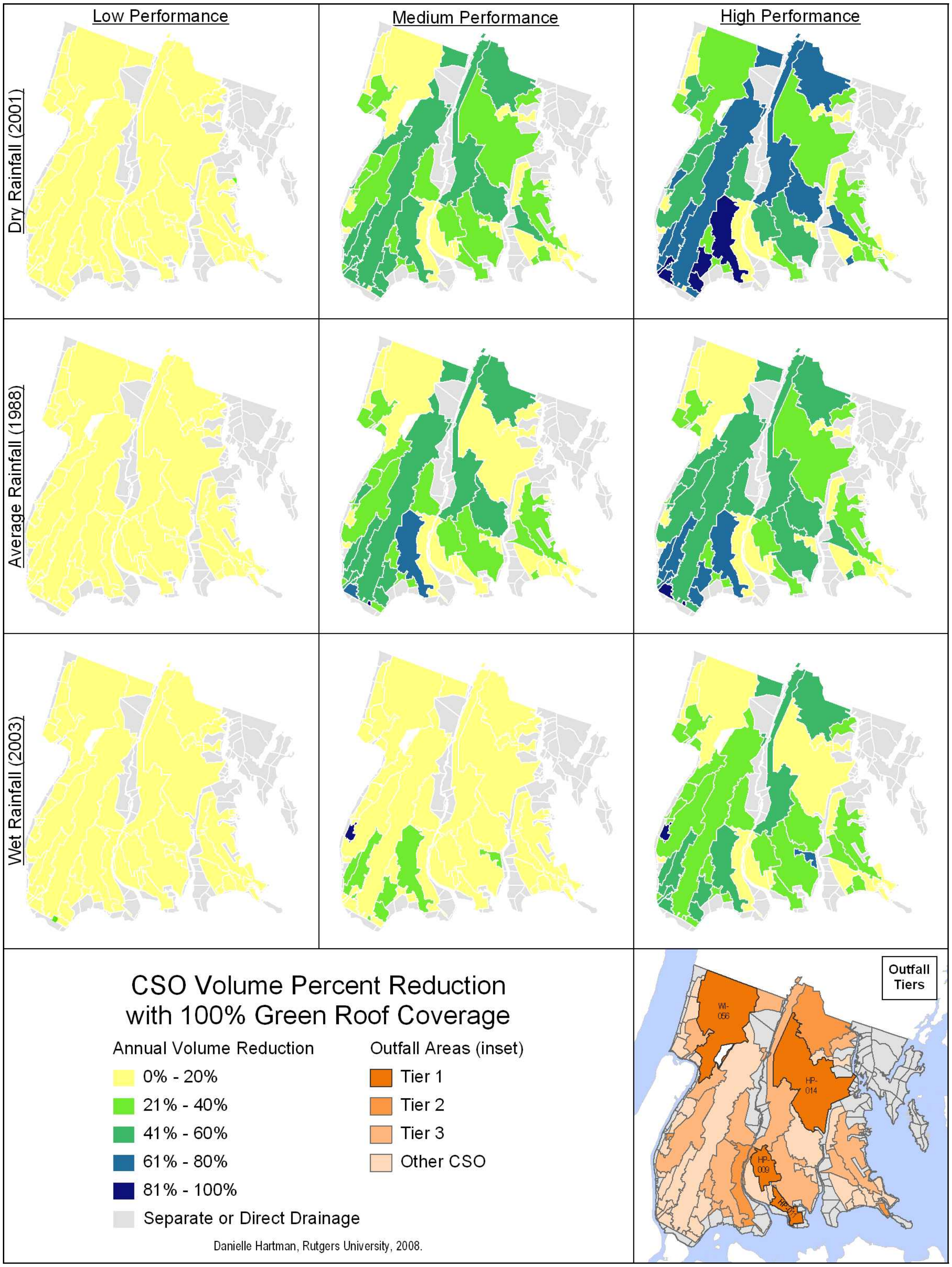


Figure 26. Summary of subcatchment volume reduction by performance scenario and rainfall.

Outfall WI-056 is the largest in terms of annual CSOs, and third largest in outfall subcatchment area. It occupies 2,114 acres in the northwest of the Bronx, and only contains 156 acres of flat roofs, or 7 percent of the land area. Approximately half of this outfall subcatchment area includes Van Cortlandt Park. Modeled CSO reductions ranged from 15 to 81 million gallons per year (3 to 23 percent).

Outfall HP-009, the second largest discharger, stands out in the model results for having the greatest quantity of CSO reduction as measured in million gallons per year. HP-009 discharges over 770 million gallons of CSOs into the mouth of the Bronx River in an average year, which is nearly 13 percent of Bronx CSOs by volume. This subcatchment is a medium-sized area of nearly 400 acres, which contains more than 1,500 flat roofed buildings covering over 79 acres (20 percent of land area).

Scenario	Reduced Volume		Reduced Events		Reduced Hours	
(design, coverage, rainfall)	Million Gallons/Year	Percent	Events	Percent	Hours/Year	Percent
high, 100%, average	204.6	32%	15	19%	67	17%
high, 100%, dry	203.9	42%	11	15%	60	18%
high, 100%, wet	201.5	26%	8	8%	49	10%
medium, 100%, dry	155	32%	8	11%	29	9%
medium, 100%, average	152.4	24%	14	18%	55	14%
high, 75%, average	151.8	24%	12	15%	50	13%
medium, 100%, wet	144.5	19%	6	6%	38	8%
mixed design, dry	112.6	23%	6	8%	27	8%
mixed design, average	109.7	17%	12	15%	47	12%
mixed design, wet	105.9	14%	5	5%	20	4%
high, 50%, average	100.6	16%	12	15%	50	13%
low, 100%, dry	94.8	19%	7	10%	17	5%
low, 100%, average	88.6	14%	14	18%	40	10%
low, 100%, wet	77.6	10%	5	5%	33	7%
high, 25%, average	49.7	8%	0	0%	0	0%

Table 12. Summary of model results for HP-009. Sorted by volume reduction.

For each model scenario, HP-009 had the largest reduction in CSOs by volume. It also had the largest reduction in events for three of the model scenarios, and the largest reduction in hours for six of the model scenarios. The results for HP-009 are summarized in Table 12. With green roof implementation, the volume of CSOs was reduced as much as 200 million gallons per year with full coverage of the high performance green roofs design. Percent CSO volume reduction ranged from 8 to 42 percent.

Outfall HP-014 is the second largest outfall area subcatchment with an area of 2,308 acres, containing 344 acres of green roofs (15 percent of land area). It is responsible for 745 million gallons of CSO discharges in an average year, or 12 percent of the borough's total volume. Model results ranged from reductions of 10 to 136 million gallons per year (up to 26 percent).

Outfall HP-011 discharges 613 million gallons of CSOs in an average year, which is 10 percent of the borough's total CSO volume. It has an outfall subcatchment area of 238 acres, containing 28 acres of flat roofs (12 percent of land area). Modeled scenarios showed CSO reductions from 33 to 136 million gallons per year (up to 35 percent). The high performance green roofs with 100 percent coverage all had reductions over 130 million gallons per year.

Sewer system type

A strong response was seen in the results for combined sewer subcatchments compared to separate sewer and direct drainage subcatchments. Several separate and direct drainage subcatchments showed little to no response to green roofs, as would be expected with less flat roof area available. Table 13 summarizes the model results by subcatchment type, for the scenario with 100 percent coverage with high performance green roofs and average rainfall.

The total volume reduction was 31 percent for combined sewer outfalls, compared to 11 percent volume reduction for separate sewer outfalls, and 6 percent volume reduction for direct drainage and other outfalls. The percent reduction in hours was also much lower for the separate sewer and direct drainage outfalls. Percent reduction in maximum events was similar for direct drainage outfalls, and much lower for separate outfalls.

Borough-wide reduction		Combined Sewers	Separate Sewers	Direct & Other Drainage
	Acres	20,184	5,030	1,211
Volume	Million Gallons/Year	1,398	58	123
	Percent	31%	11%	6%
Events	Maximum Events/Year	19	17	55
	Maximum Percent	73%	28%	71%
Hours	Hours/Year	1,217	515	1,231
	Percent	15%	6%	3%

Table 13. Bronx-wide summary of model response by outfall area subcatchment type, using 100 percent coverage with the high performance green roof scenario and average rainfall.

Subcatchment sensitivity

Performance scores

Because the overall area and available flat roof coverage varies by subcatchment across the borough, a scoring system was devised to normalize the model results by green roof area. The model measures the response of the sewer system in terms of reduced overflows, based on the available area covered by flat roofed buildings. For our scoring system, a simple calculation was performed to divide the overflow reduction by the area of flat roofs that was greened. This gives "millions of gallons per acre" for reduced overflow volume, "hours per acre" for reduced overflow time, and "events per acre" for overflow events. Since each measure has been recalculated per area unit, the results can better be compared across different subcatchments.

Scores for CSO subcatchments were calculated for the model scenarios with high, medium, and low performance designs. These scores are included in Appendix V as Tables 21A through 21L. The borough-wide scores for each model scenario are shown in Table 14.

Scenario	Rainfall	Volume	Events	Hours
high 25%	average	0.4283	0.0777	0.3529
high 50%	average	0.4188	0.0879	0.3421
high 75%	average	0.4089	0.0899	0.3339
high 100%	average	0.3991	0.0879	0.3475
medium 100%	average	0.2858	0.0657	0.2581
low 100%	average	0.1171	0.0431	0.1605
high 100%	dry	0.3383	0.0868	0.3624
medium 100%	dry	0.2382	0.0640	0.2724
low 100%	dry	0.1214	0.0437	0.1693
high 100%	wet	0.3820	0.0720	0.3604
medium 100%	wet	0.2273	0.0554	0.2704
low 100%	wet	0.0693	0.0383	0.1713
Maximum		0.4283	0.0899	0.3624
Average		0.2862	0.0677	0.2834
Standard Deviation		0.1301	0.0191	0.0790

Table 14. Summary of borough-wide performance scores. Score represents annual CSO reduction by acre of green roof.

The highest score for volume was 0.43, for the high performance scenario with 25 percent coverage and average rainfall. The volume score decreased slightly as percent coverage increased. As would be expected, the scores were lower for the medium performance green roof design, and lowest for the low performance design.

The maximum score for events was 0.09, for the high performance scenario with 75 percent coverage and average rainfall. The maximum score for hours was 0.36, for the high performance scenario with 100 percent coverage and dry rainfall.

Figure 27 shows just the scores for volume for model scenarios varied by green roof design and rainfall. Figures 36 through 38 in Appendix V show the scores for volume, events, and hours varied by green roof design, amount of coverage, and rainfall. Because of the large range of scores, a logarithmic scale was used for choropleth mapping class breaks.

For the scores by subcatchment, small and medium sized subcatchments tended to score better than large subcatchments. Scores for events tended to be lower than the volume and hours scores. In some cases, the hours scores were lower than the volume scores, and sometimes they were higher.

The highest volume score was 41 million gallons per acre, for WI-060 with 25 percent coverage of the high performance green roof design in an average year. Five subcatchments had volume scores greater than 1 million gallons per acre of green roof, for all twelve model scenarios. These were WI-060, HP-021, HP-011, HP-023, and HP-009. The smallest of these subcatchments is WI-060 at 20 acres, and largest is HP-009 at nearly 400 acres.

The highest events score was seen in HP-029 with 15 events per acre of green roof, with 100 percent coverage of the high performance design and dry rainfall. HP-029 had four other model scenarios with scores higher than 10 events per acre. The only subcatchment with scores higher than one event per acre for all twelve model scenarios was HP-021.

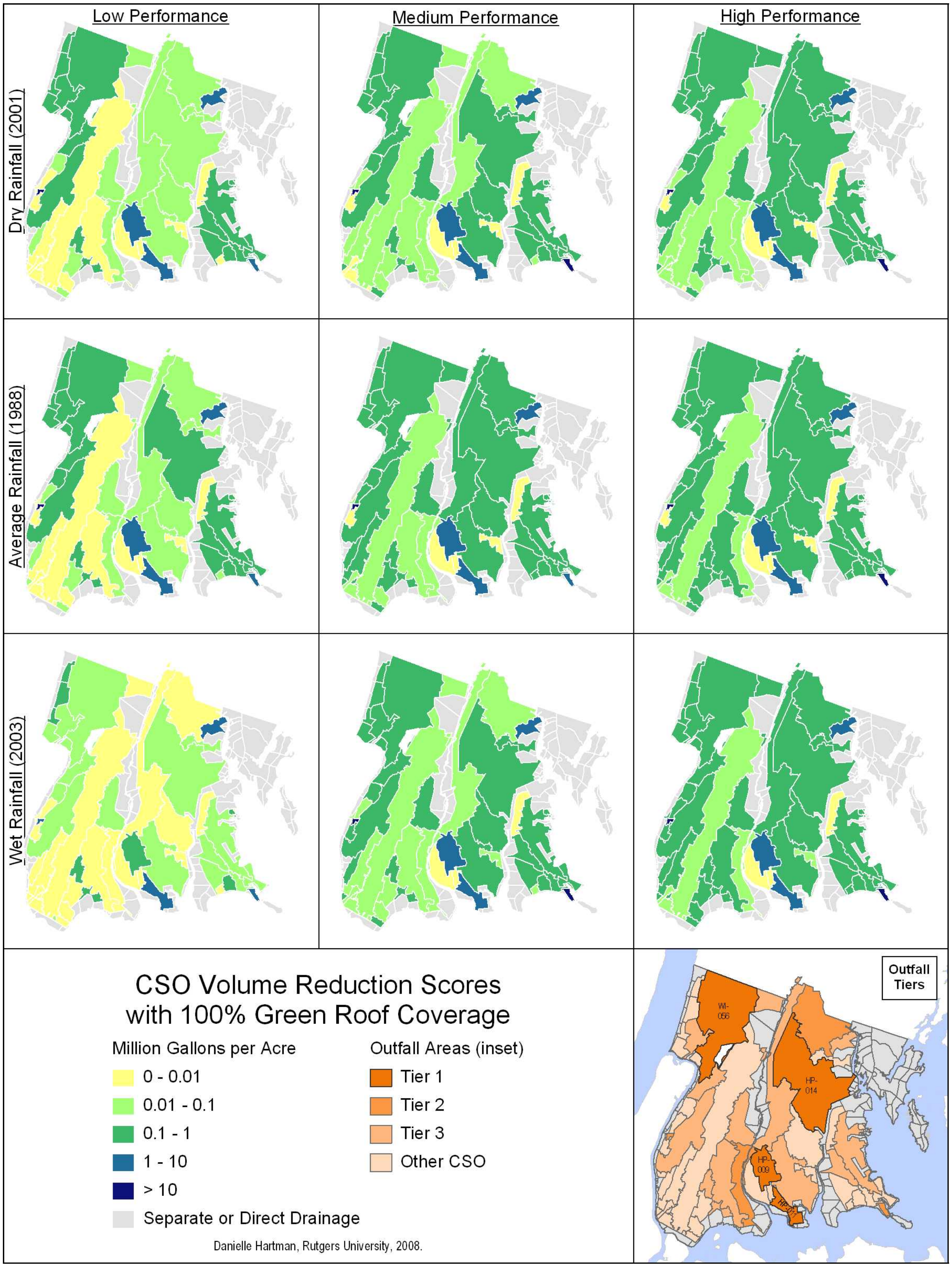


Figure 27. Summary of subcatchment volume reduction scores by performance scenario and rainfall. Reduction in combined sewer overflows is normalized by green roof area.

The highest events score was 60 events per acre, seen in HP-021 for the 25 percent coverage of high performance green roofs and average rainfall. HP-021 was the only subcatchment to score higher than 10 events per acre for all twelve model scenarios. There were ten subcatchments that scored greater than one hour per acre of green roof for all model scenarios.

Performance ranking

The performance scores were used to rank subcatchments for their overall sensitivity to green roofs as a stormwater best management practice. The overall rank was assigned by calculating three separate ranks for volume, hours, and events, and then taking the average.

A summary of the scores for the top five overall ranked subcatchments is shown in Table 15. The top five ranking subcatchments by volume are summarized in Table 16. Detail maps of these subcatchments are included in Appendix VI. The ranking of CSO volume scores was consistent across all model scenarios, whereas the events and hours ranking varied. The overall ranking varied across model scenarios beyond the first-ranked subcatchment.

The best ranking outfalls are HP-021 and WI-060, both Tier 2 outfalls. Outfall HP-021 was ranked first overall, and ranked second by volume. This outfall has a small subcatchment area of 43 acres, and less than 2 acres of flat roof area. Outfall WI-060 was the second-ranked subcatchment overall. It also was the highest ranked by volume, with scores ranging from 8 to 40 million gallons per acre. The subcatchment for WI-060 is also small at 20 acres, and contains 3.25 acres of flat roofs. Because these subcatchments have small areas and high CSOs, the borough-wide green roof implementation may be disproportionately reflected in these scores. Additional modeling scenarios are recommended to focus on the impact of installing green roofs in one subcatchment at a time.

The lowest-scoring subcatchments overall were HP-002, HP-003, HP-007, and WI-068. Several other subcatchments scored zero across all model scenarios because they do not experience many CSOs. These were HP-008, HP-010, HP-012, HP-015, WI-061, WI-063, and WI-073.

Of the top five scoring subcatchments for volume, two are Tier 1 (HP-011 and HP-009), two are Tier 2 (WI-060 and HP-021), and one is Tier 3 (HP-023). These are outfalls that experience high volumes of CSOs, and show large reductions in the model simulations. These Tier 2 and 3 outfalls have small subcatchment areas, under 50 acres each. The top ranking Tier 1 outfalls have large subcatchment areas, giving more opportunities to construct green roofs.

HP-011 has a subcatchment area of 238 acres, and contains 28 acres of flat roofs (12 percent of land area). Model results show volume reductions of over 130 million gallons per year, up to 35 percent. Outfall HP-009 was described previously, having the largest volume reduction for each model scenario.

Outfall	Million Gallons /Acre	Events /Acre	Hours /Acre	Flow	Events	Hours	Overall Rank	Green Roof	Rainfall
HP-021	13.15	6.20	26.06	2	1	2	1	high 100%	wet
	12.66	2.48	28.54	2	4	1	1	high 100%	dry
43 acres	10.92	9.93	59.56	2	1	1	1	high 25%	average
	10.55	4.96	29.78	2	2	2	1	high 50%	average
<2 acres	10.55	5.58	23.58	2	1	2	1	medium 100%	wet
flat roofs	10.42	4.96	25.44	2	2	2	1	high 100%	average
	10.42	1.86	24.20	2	5	1	1	medium 100%	dry
Tier 2	10.26	5.79	31.43	2	2	1	1	high 75%	average
	7.69	4.34	21.71	2	2	1	1	medium 100%	average
	6.27	5.58	17.37	2	1	2	1	low 100%	wet
	6.14	1.86	17.37	2	4	1	1	low 100%	dry
	5.21	4.34	16.13	2	1	1	1	low 100%	average
WI-060	40.75	2.05	20.09	1	6	3	2	high 75%	average
	40.07	1.54	15.07	1	6	3	2	high 100%	average
20 acres	33.86	0.62	23.37	1	11	3	2	high 100%	dry
	28.63	1.54	12.92	1	5	3	2	medium 100%	average
3 acres	23.80	1.23	18.14	1	6	3	2	medium 100%	dry
flat roofs	12.30	1.23	13.22	1	6	3	2	low 100%	dry
Tier 2	11.72	1.23	10.15	1	3	2	2	low 100%	average
HP-028	0.72	3.39	16.20	8	3	4	2	high 100%	wet
	0.45	2.64	13.94	9	3	3	2	medium 100%	wet
20 acres	0.19	2.26	11.30	10	2	3	2	low 100%	wet
	0.68	0.75	10.55	9	9	5	3	high 50%	average
<3 acres	0.64	2.26	15.07	8	5	4	3	high 100%	dry
flat roofs	0.49	2.26	12.81	8	4	4	3	medium 100%	dry
	0.60	1.51	21.09	13	6	4	4	high 25%	average
	0.49	0.75	8.66	9	10	5	4	medium 100%	average
	0.26	0.75	5.65	7	5	5	4	low 100%	average
	0.23	2.64	8.66	10	3	4	4	low 100%	dry
	0.64	1.13	9.42	10	10	6	5	high 100%	average
WI-055	1.00	3.01	18.07	6	2	6	2	high 25%	average
	0.70	1.51	9.04	8	6	6	2	high 50%	average
59 acres	0.75	1.00	6.02	6	7	9	3	high 100%	wet
	0.70	1.00	6.02	7	9	8	3	high 75%	average
4 acres	0.68	0.75	6.78	7	8	7	4	high 100%	dry
flat roofs	0.53	0.50	5.02	6	11	9	4	medium 100%	dry
	0.28	0.50	5.02	6	11	6	5	low 100%	wet
WI-053	0.80	1.52	10.41	6	7	5	3	high 100%	average
	0.61	1.30	8.89	6	6	4	3	medium 100%	average
80 acres	0.35	1.52	7.59	6	2	4	3	low 100%	average
	0.52	0.43	5.85	7	13	6	4	medium 100%	dry
5 acres	0.52	0.65	7.59	7	11	5	4	medium 100%	wet
flat roofs	0.30	0.43	4.99	6	10	5	5	low 100%	dry
	0.26	0.43	6.72	7	12	4	5	low 100%	wet

Table 15. Summary of top ranking subcatchments.

Outfall	Million Gallons/Acre	Events /Acre	Hours /Acre	Flow	Events	Hours	Overall	Green Roof	Rainfall
WI-060	41.45	0	0	1	32	36	18	high 25%	average
	40.96	0	0	1	40	41	27	high 50%	average
20 acres	40.75	2.05	20.09	1	6	3	2	high 75%	average
	40.07	1.54	15.07	1	6	3	2	high 100%	average
3 acres	37.02	0	31.67	1	45	1	14	high 100%	wet
flat roofs	33.86	0.62	23.37	1	11	3	2	high 100%	dry
	28.63	1.54	12.92	1	5	3	2	medium 100%	average
Tier 2	23.80	1.23	18.14	1	6	3	2	medium 100%	dry
	22.72	0	27.98	1	44	1	14	medium 100%	wet
	12.30	1.23	13.22	1	6	3	2	low 100%	dry
	11.72	1.23	10.15	1	3	2	2	low 100%	average
	8.76	0	25.22	1	33	1	10	low 100%	average
HP-021	13.15	6.20	26.06	2	1	2	1	high 100%	wet
	12.66	2.48	28.54	2	4	1	1	high 100%	dry
43 acres	10.92	9.93	59.56	2	1	1	1	high 25%	average
	10.55	5.58	23.58	2	1	2	1	medium 100%	wet
<2 acres	10.55	4.96	29.78	2	2	2	1	high 50%	average
flat roofs	10.42	4.96	25.44	2	2	2	1	high 100%	average
	10.42	1.86	24.20	2	5	1	1	medium 100%	dry
Tier 2	10.26	5.79	31.43	2	2	1	1	high 75%	average
	7.69	4.34	21.71	2	2	1	1	medium 100%	average
	6.27	5.58	17.37	2	1	2	1	low 100%	wet
	6.14	1.86	17.37	2	4	1	1	low 100%	dry
	5.21	4.34	0.13	2	1	1	1	low 100%	average
HP-011	4.93	0.43	0.72	3	14	22	9	high 25%	average
	4.91	0.29	1.34	3	19	21	11	high 100%	wet
238 acres	4.86	0.29	1.12	3	23	20	15	high 100%	dry
	4.82	0.29	1.30	3	21	18	10	high 50%	average
28 acres	4.78	0.18	1.05	3	26	21	17	high 100%	average
flat roofs	4.72	0.19	1.01	3	25	21	15	high 75%	average
	3.74	0.25	0.98	3	18	19	13	medium 100%	dry
Tier 1	3.42	0.18	0.76	3	23	21	14	medium 100%	average
	3.22	0.29	1.19	3	16	19	9	medium 100%	wet
	2.19	0.18	0.58	3	16	19	10	low 100%	dry
	1.91	0.11	0.58	3	19	18	11	low 100%	average
	1.18	0.25	0.83	3	15	16	9	low 100%	wet
HP-023	3.72	0.56	3.03	4	12	13	7	high 100%	average
	3.65	0.34	3.48	4	20	11	9	high 100%	dry
3 acres	3.64	0.67	3.74	4	10	11	4	high 75%	average
	3.55	0.67	4.04	4	10	9	3	high 50%	average
<1 acres	3.43	0.45	2.69	4	13	11	6	high 25%	average
flat roofs	3.41	0.78	3.81	4	8	10	3	high 100%	wet
	2.79	0.28	2.97	4	17	11	8	medium 100%	dry
Tier 3	2.68	0.45	2.47	4	12	11	6	medium 100%	average
	2.41	0.67	3.31	4	9	10	4	medium 100%	wet
	1.67	0.28	2.13	4	13	10	8	low 100%	dry
	1.60	0.45	1.79	4	8	9	5	low 100%	average
	1.14	0.67	2.52	4	6	9	4	low 100%	wet
HP-009	2.58	0.19	0.84	5	25	24	18	high 100%	average
	2.57	0.14	0.76	5	27	27	20	high 100%	dry
396 acres	2.55	0.20	0.84	5	24	24	17	high 75%	average
	2.54	0.10	0.62	5	30	27	19	high 100%	wet
79 acres	2.54	0.30	1.26	5	19	19	11	high 50%	average
flat roofs	2.51	0	0	5	32	36	21	high 25%	average
	1.95	0.10	0.37	5	26	28	21	medium 100%	dry
Tier 1	1.92	0.18	0.69	5	24	23	18	medium 100%	average
	1.82	0.08	0.48	5	25	25	17	medium 100%	wet
	1.20	0.09	0.21	5	24	26	16	low 100%	dry
	1.12	0.18	0.50	5	15	20	11	low 100%	average
	0.98	0.06	0.42	5	22	18	14	low 100%	wet

Table 16. Summary of top ranking subcatchments by volume.

Summary

This project used municipal data at the tax lot and building level to find suitable areas for green roof placement, in terms of location and acreage. This methodology offers greater precision than raster-based land cover calculations, where data may only be available at a scale of 10- or 30-meter pixels. However, both methods rely on interpretation to derive land classes, and ground-truthing is recommended.

Our model shows that green roofs can have a meaningful impact on reducing stormwater runoff in the Bronx. With some design scenarios, the borough-wide CSO reduction was over 30 percent. Proportionally, a greater reduction was seen in terms of volume, compared to events and hours.

The model also shows that the impact varies geographically, with some areas more responsive to green roofs in terms of CSO reduction. Tier 1 outfalls HP-009 and HP-011 showed particularly large reductions in CSO volumes. The Tier 2 outfalls HP-021 and WI-060 were the most sensitive across all performance measures. These high scoring subcatchments provide the best opportunities for using green roofs as a stormwater best management practice.

Chapter 5. Conclusions

Introduction

The Bronx Green Roof Stormwater Simulation Tool integrates municipal GIS data, a green roof micro-model, and a sewer system model. By using a simple sewer model, it can quickly identify areas in the Bronx most suitable for green roofs as a stormwater best management practice. As an interactive decision support system, different combinations of green roof designs can be evaluated for a more flexible evaluation of planning strategies.

The model results show that green roofs can reduce combined sewer overflows (CSOs) in the Bronx. This paper focused on the results for combined sewer areas, finding a different magnitude of response in each subcatchment. The scoring analysis identified the subcatchments with the strongest cost-benefit for stormwater management. A few areas stood out as being the most sensitive, including WI-060, HP-021, HP-009, and HP-011. These and other subcatchments with strong model responses should be considered as prime candidates for pilot studies and funding for using green roofs as a stormwater best management practice.

The model described in this paper cannot quantify the impact of site-specific green roof installations on stormwater runoff. It instead looks at the issue on a wider scale to see the range of what is possible with widespread implementation of green infrastructure. Given the large scope of water quality problems in the Bronx, these model results are encouraging and support the call for more serious consideration of green roofs as a best management practice.

To further develop a greening strategy for the Bronx, additional information will be needed to identify specific buildings for green roof implementation. Some of this information, such as building age, use, and ownership is publicly available in the RPAD database. Weight bearing capacity and other possible design limitations will need to be investigated through other means. To estimate the CSO reduction from greening specific buildings, a more detailed sewer model such as InfoWorks can be run for the area of interest.

Suitability of data for use

The sewer model used in this project was based on the relatively simple RAINMAN program because of its fast run time. This model does not include runoff travel time, snowmelt, or fine scale details such as individual catch basins. RAINMAN has been calibrated based on the more complex InfoWorks model, which is described in the New York City Long Term Control Plan reports (NYCDEP 2007a, NYCDEP 2007b).

The green roof micro-model component represents a best estimate of precipitation capture and retention based on available research. Earth Pledge, the City of New York, and other organizations are studying the performance of constructed green roofs in a variety of climates to better calibrate these models.

This project relied on municipal data to calculate available area for green roofs. This included GIS data for building shapes and tax assessment records. These files are the same data sources used for planning maps and queries by government, consultants, and academic researchers. For example, for a typical land use study, the same building class data are grouped into land use categories and joined to tax lot polygons to create thematic maps.

The accuracy of any spatial analysis is limited by the resolution of the data. In this project, the subcatchment boundaries have the least spatial accuracy. The data were developed at a broad scale from the "Infiltration and Inflow" maps. As can be seen in the map figures in Appendix VI, some of these boundaries were drawn to zigzag from curb to curb, rather than following a street centerline. While visual inspections were made for data misalignments, it is possible for a building to incorrectly be assigned to an adjacent subcatchment. This is a typical occurrence when working with data designed at differing scales. Improving the spatial resolution of the sewer model components would increase the precision of the results. A more detailed sewer model, such as InfoWorks, is better able to take advantage of the high spatial resolution of building-level data.

The building data is the most spatially accurate of the files used, with horizontal accuracy of two feet. The spatial accuracy of the tax lot polygon varies throughout the City. For this reason, the building centroids were used in the spatial join. Although the joined data was visually inspected for misalignments, there may be small buildings that are assigned incorrectly to an adjacent narrow lot. Typically, these misalignments occur along a series of narrow tax lots with similar building classes, such as row homes, so the flat roof designations are not thought to introduce significant errors for the purposes of this study.

While the geoprocessing of building data had a low number of unmatched features, it does not ensure the matches are temporally or spatially correct. The data sets contributing to this project are maintained by different public agencies with varying update cycles. The property assessment information from RPAD may not refer to the same building polygon captured from the aerial photograph. Additionally, tax lot boundaries may be redrawn during redevelopment. It is possible for a building to have been demolished and/or reconstructed without the updated information appearing in all data sets. We found that the difference in the RPAD and NYCMap building area calculations was small when aggregated at the county/borough level. Future projects at this large scale might use the RPAD data alone to save time on data processing. Instead, tax lots would be assigned to subcatchments rather than the building polygons, and flat roof area calculated from building frontage and depth.

Directions for further research

Subcatchment sensitivity

The sensitivity scores presented in this paper represent the results of reducing runoff on a borough-wide scale. Due to the nature of the connections in the sewer network, outfalls with flow originating from other subcatchments farther up the network may see some CSO reductions due to green roof installations in these “upstream” subcatchments. For example, the subcatchment for WI-053 had a higher sensitivity score than might be expected from the small amount of flat roof area available. The largest subcatchments do not always have the largest amounts of CSOs, as might be expected.

Further analysis of these results might look at the cumulative CSO reduction and green roof area on a network-basis, aggregating values at each step along the network path. Some of the “reach” numbering methods used for stream networks might be applied. An analysis of subcatchment size, imperviousness, and network position could be used to refine the scores presented here. We might find that the scores are similar for large subcatchments and those located higher up on the network.

Design assumptions

One of the assumptions used in this project was that building classes can be used to predict roof type. The building class-flat roof lookup table was developed in an earlier project, based on best professional judgment. These flat roof assignments have not yet been verified through fieldwork. This model would benefit from further research such as sampling buildings of different classes, and examining oblique photographs or 3D data for roof characteristics. Visual inspections of small areas could be performed with access to building rooftops for direct observation. While buildings with slanted roofs can still be candidates for green roofs, their capacity for stormwater retention is reduced (VanWoert et al. 2005, Villarreal and Bengtsson 2005).

Past modeling projects have assumed that 25 to 30 percent of roof area is not available for green roof design, due to infrastructure such as ventilation units, sheds, and water towers (Doshi et al. 2005). This area determination also appears to be based on best professional judgment and would benefit from further analysis. Roof features could be measured from high-resolution aerial photographs to better quantify these non-available areas. The increasing availability and affordability of LIDAR data also offers possibilities for evaluating roof characteristics. Roof slope and structures might be measured from LIDAR-derived 3D models.

A different way to calculate a portion of the non-available roof area would be to use the NYCMap building roof line data, a line map layer that represents walls and changes in building height. A single building may be represented by multiple adjacent polygons, where aerial photo processing software detected boundaries. The NYCMap building data has been released in several versions, some including these roof level distinctions, while others have merged the multiple parts into single building polygons. The roofline data is not often used, but could add value in a buffer analysis. The roof area calculations could be fine-tuned by accounting for non-planted borders along edge features.

Some green roof models created for other cities chose to exclude buildings under a minimum size. Future models for the Bronx and New York City might consider setting a threshold of this type, to filter out garages, sheds, and other small structures not likely to be greened.

Because our model was widely applied, potential green roof space was allocated without regard to weight bearing capacity. The model only considered extensive green roofs because they are lighter, with up to six inches of soil substrate. The RPAD database includes information on building age and alteration years, which could be correlated with construction codes, as was done in the Pace University site study. This would help to identify buildings as candidates for intensive green roofs, allowing for deeper soils and therefore greater rainfall retention capacity. Buildings with less weight bearing capacity could be limited to thinner extensive green roofs.

Sewer modeling

Our simple sewer model indicates that green roofs can have a meaningful impact on reducing CSOs. Several follow up projects are recommended to expand on these findings. The existing model applies green roof scenarios uniformly across all subcatchments in the Bronx. It would be useful to model the impact of constructing green roofs in individual subcatchments. A more sophisticated GUI could be developed to allow a single subcatchment to be chosen, using a map as part of the input interface. This would allow the model inputs to be specified in acres, rather than percent of available flat roofs.

An alternative to a new decision support system GUI would be to have an engineer run a series of monte carlo simulations, with green roofs applied to individual subcatchments. Variations in acreage and green roof design could also be evaluated as a part of these modeling series. With this approach, a summary of the results would be presented to decision makers, rather than having them configure inputs and run the model themselves. As the time and expense would increase with the number of simulations considered, this type of analysis might focus on only Tier 1 and Tier 2 outfalls.

Another variation would be to alter the time interval modeled. The current model evaluates the sewer system impact over an entire year. As was done in earlier NYC studies, the model could be run for specific storm intensities and durations.

A more detailed sewer model such as InfoWorks has the ability to measure the impact of greening individual buildings with more precision. With this increased geographic detail, specific buildings could be modeled along with travel time and neighborhood geography. For example, a building surrounded by a lawn would have a different relationship with the sewer system than a building surrounded by a parking lot, since the additional permeable lawn could capture some of the runoff as it travels towards the sewer catch basin.

Project expansion

These modeling approaches can be used along with site-specific cost-benefit studies. Green roofs can be compared with other stormwater best management practices, such as other green infrastructure, and more traditional engineering controls. A data-rich

GIS approach can be used to determine site-suitability for different types of stormwater controls, which would then be linked to a stormwater model. Site-suitability would include identifying brownfield sites based on past industrial use.

Green roof research is currently being performed in a variety of disciplines. Collaborative studies, such as presented by Columbia University (Rosenzweig, Gaffin, and Parshall 2006), are an important way to emphasize the multifaceted benefits of green roofs. The detailed cost-benefit analysis performed in Toronto (Doshi et al. 2005) is another strong example of a multidisciplinary study. The type of work done by the Columbia University team could be expanded to a cost-benefit analysis for the entire City of New York in a similar way.

Policy studies might evaluate the effectiveness of collaborative research to promote sustainability goals. Specifically, the effectiveness of decision support systems could be evaluated for their effectiveness at influencing and informing policy development. A policy study might also look at the impact of the new green roof tax incentives in New York City, or more generally the success of PlaNYC to reach its sustainability goals.

Geographic expansion

Of the existing green roof models for New York City, this model for the Bronx covers one of the largest geographic areas. Most previous studies have focused on one or two waste water treatment plant service areas. Since the same municipal data are available for all of New York City, the current model could be easily duplicated for the other four boroughs, or developed as a city-wide model.

Our modeling approach could also be applied to other cities, where the existence of sewer models and detailed building data would allow. These types of information are becoming more common as cities create digital base maps and infrastructure models. While detailed sewer models provide more nuanced analysis, they also require more effort to design and calibrate. A simple model, as used in this study, would still provide useful results at the city or county scale. As for building information, most cities maintain basic property databases for management purposes. Where digital building map data does not exist, these records can be used if they include building area measurements. Building class information of sufficient detail, for the identification of flat roofs, may be the most difficult model input to obtain. Future developments with LIDAR data processing may provide alternative approaches.

For places without well-developed sewer models, other methods can be used. For example, Montalto (2007) has developed a "low impact development rapid assessment" method for CSOs. This method calculates the amount of rainfall that triggers CSO discharges. From this, stormwater best management practices can be designed to modify the drainage area's imperviousness, according to the volume reduction that is required to eliminate the CSOs. Outfall monitoring data may need to be collected and drainage areas defined, but a full sewer model is not required.

Summary

Green roofs can contribute to sustainable cities in a variety of ways. They are notable in that they simultaneously contribute to aspects of environmental, economic, and social sustainability. The creation of green space out of unused or underutilized rooftops is a unique benefit to green roofs. They can also be funded and managed by private entities, with multiple benefits realized by the public and private sector.

In ultra-urban areas such as the Bronx, green roofs may be more suitable for stormwater management than other controls because of site-specific factors. Because land is limited, there may not be sufficient space to implement green infrastructure stormwater controls such as rain gardens or bio-swales, and constructing more traditional engineering controls are cost-prohibitive. Green roofs are especially suitable in areas with densely packed soil, where low permeability would inhibit runoff from percolating into the groundwater. Because green roofs prevent stormwater runoff from coming into contact with the ground, they are a preferred best management practice in areas with past industrial use.

The Bronx is in a unique position for the implementation of green roofs. Highly developed and with heavy environmental burdens, the need for green infrastructure is strong. Even if the goals of the NYC Long Term Control Plan and PlaNYC are met, the Bronx River will still remain impaired at the level of “no contact allowed” (NYC Mayor’s Office 2007). As the population of New York City is expected to grow by one million residents by the year 2030, the impacts that this increased population on the City’s infrastructure must be taken into account.

New York City is the largest municipal government in the United States, and is one of its own largest property owners (Hsu 2006). This provides many opportunities for implementing sustainable city initiatives, as with PlaNYC. Green roofs, being highly visible and with an array of public and private benefits, can be a great catalyst for these efforts. As Rosenzweig writes, “Green roofs have the potential to change how urban environments, and the role of nature within them, are perceived" (Rosenzweig, Gaffin, and Parshall 2006). The green roof installed on the Bronx County Courthouse in 2006 has been such a success that the managing agency (NYC Department of Citywide Administrative Services) has plans to construct three more (Kate Shackford, BIEE Director at BOEDC, personal communication, 15 September 2008).

Green roofs have the potential to make real improvements to the quality of life in the Bronx. Because of the multiplicity of benefits, they should be considered for any structurally-suitable existing buildings, and for any new construction. Their stormwater management potential varies by their location in the sewershed, depending on the area of land contributing stormwater runoff, the availability of suitable roof space, and the regulator's location in the sewer network. This makes green roofs more cost-effective in some subcatchments over others, and potentially more cost effective than traditional engineering CSO controls in some areas. In these cases New York City should consider funding options in additional to the new tax credits. Green roofs on both public and private buildings should be seriously considered as part of stormwater management planning.

References

Acselrad, H. 2001. The multiple discourses on urban sustainability. Paper presented at the 2001 Open Meeting of the Human Dimensions of Global Environmental Change Research Community, October 6-8, at the Columbia University Earth Institute, NY.

Alberti, M., and L. Susskind. 1996. Managing urban sustainability: An introduction to the special issue. *EIA Review* 16: 213-221.

Arnold, Ken. 2000. "Between explanation and inspiration: Images in science." In *Strange and Charmed: Science and the Contemporary Visual Arts*. ed. Sian Ede, 68-83. London: Calouste Gulbenkian Foundation.

Batty, Michael. 2005. "Approaches to Modeling in GIS: Spatial Representation and Temporal Dynamics." In *GIS, Spatial Analysis, and Modeling*. ed. David J. Maguire, Michael Batty, and Michael Goodchild, 41-61. Redlands, CA: ESRI Press.

Blassingame, L. 1998. Sustainable cities: Oxymoron, utopia, or inevitability? *Social Science Journal* 35(4): 1-13.

Blaut, James M., David Stea, Christopher Spencer, and Mark Blades. 2003. Mapping as a cultural and cognitive universal. *Annals of the Association of American Geographers* 93(1): 165-185.

Brewer, Cynthia. 2005. *Designing Better Maps-A Guide for GIS Users*. Redlands, CA: ESRI Press.

Brown, A. L. 2003. Increasing the utility of urban environmental quality information. *Landscape and Urban Planning* 65: 85-93.

Brugmann, J. 1996. Planning for sustainability at the local government level. *EIA Review* 16: 363-379.

Brundtland, G. H. 1987. *Our Common Future – World Commission on Environment and Development.* Oxford: Oxford University Press.

Carter, Timothy, and Anthony Keeler. 2008. Life-cycle cost-benefit analysis of extensive vegetated roof systems. *Journal of Environmental Management* 87: 350-363.

Chapra, S. C. 2003. Engineering water quality models and TMDLs. *Journal of Water Resources Planning and Management* July/August: 247-256.

Chen, C. W., J. Herr, and L. Weintraub. 2004. Decision support system for stakeholder involvement. *Journal of Environmental Engineering* June: 714-721.

Chrisman, Nick. 2006. *Charting the Unknown: How Computer Mapping at Harvard Became GIS*. Redlands, CA: ESRI Press.

Clark, Corrie, Peter Adriaens, and F. Brian Talbot. 2008. Green roof valuation: A probabilistic economic analysis of environmental benefits. *Environmental Science & Technology* 42(6): 2155-2161.

DePinto, J. V., P. L. Freedman, D. M. Dilks, and W. M. Larson. 2004. Models quantify the total maximum daily load process. *Journal of Environmental Engineering* June: 703-713.

Dorfman, Mark, and Kirsten Sinclair Rosselot. 2008. *Testing the Waters: A Guide to Water Quality at Vacation Beaches, 18th Edition*. New York: Natural Resources Defense Council.

Doshi, Hitesh, Doug Banting, James Li, Paul Missios, Angela Au, Beth Anna Currie, and Michael Verrati. 2005. *Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto*. Ontario: Ryerson University. http://www.toronto.ca/greenroofs/findings.htm. (Accessed October 11, 2007).

Dymond, R. L., B. Regmi, V. K. Lohani, and R. Dietz. 2004. Interdisciplinary web-enabled spatial decision support system for watershed management. *Journal of Water Resources Planning and Management* July/August: 290-300.

Earth Pledge. 2005. *Green Roofs: Ecological Design and Construction*. Atglen, PA: Schiffer Books.

Elshorbagy, A., R. S. V. Teegavarapu, and L. Ormsbee. 2005. Total maximum daily load (TMDL) approach to surface water quality management: concepts, issues, and applications. *Canadian Journal of Civil Engineering* 32: 442-448.

Harley, J. B. 2001. Deconstructing the map. In *The New Nature of Maps*, ed. Paul Laxton. Baltimore, MD: The Johns Hopkins University Press. (originally in *Cartographica* 26(2): 1-20, 1989.)

Harris, Richard J., and Paul A. Longley. 2000. New Data and Approaches for Urban Analysis: Modeling Residential Densities. *Transactions in GIS* 4(3): 217-234.

Haughton, G. 1999. Searching for the sustainable city: Competing philosophical rationales and processes of "ideological capture" in Adelaide, South Australia. *Urban Studies* 36(11): 1891-1906.

Herman, Kate. 2008. Numbers: Sustainable Cities. *Architect,* January: 40.

Hoffman, Leslie. 2006. Green roof storm water modeling. *BioCycle*, February: 38-40.

Hsu, David. 2006. *Sustainable New York City*. New York: Design Trust for Public Space and the New York City Office of Environmental Coordination.

Huber, J. 2000. Towards industrial ecology: Sustainable development as a concept of ecological modernization. *Journal of Environmental Policy & Planning* 2: 269-285.

HydroQual, Inc., 2007. Tier I Water Quality Impact Responses. http://www.hydroqual.com/projects/ltcp/open_water/wq_response/cso_harbor_table.pdf. (Accessed June 15, 2008.)

Jacobs, J. 1961. *The Death and Life of Great American Cities*. New York: Random House.

Keeley, Melissa. 2007. Using Individual Parcel Assessments to Improve Stormwater Management. *Journal of the American Planning Association* 73(2): 149-160.

Kumaraswamy, Anand, Danielle Hartman, and Jim Hallden. 2008. Study of the Impact of Greenroofs on CSOs in the Bronx. Paper presented at HydroQual, January 15, in Mahwah, NJ.

Kloss, Christopher, and Crystal Calarusse. 2006. *Rooftops to Rivers*. New York: Natural Resources Defense Council.

Kraak, Menno-Jan. 2004. The role of the map in a Web-GIS environment. *Journal of Geographic Systems* 6: 83-93.

Lazzarin, Renato, Francesco Castellotti, and Filippo Busato. 2005. Experimental measurements and numerical modeling of a green roof. *Energy and Buildings* 37: 1260-1267.

Maantay, Juliana. 2007. Asthma and air pollution in the Bronx: Methodological and data considerations in using GIS for environmental justice and health research. *Health & Place* 13: 32–56.

MacEachren, Alan. 1995. *How Maps Work: Representation, Visualization, and Design*. New York: Guilford Press.

Malthus, T. R. 1959 (orig. 1798). *Population: The First Essay*. Ann Arbor, MI: University of Michigan Press.

Mark, David M., Christian Freksa, Stephen C. Hirtle, Robert Lloyd, and Barbara Tversky. 1999. Cognitive models of geographical space. *International Journal of Geographical Information Science* 13(8): 747-774.

Meek, R.L. 1971. *Marx and Engels on the Population Bomb*. Berkeley: Ramparts Press.

Merriam-Webster Online Dictionary. http://www.m-w.com/dictionary/geography. (Accessed April 23, 2006).

Mihelcic, J. R., J. C. Crittenden, M. J. Small, D. R. Shonnard, D. R. Hokanson, Q. Zhang, H. Chen, S. A. Sorby, V. U. James, J. W. Sutherland, and J. L. Schnoor. 2003.

Sustainability science and engineering: The emergence of a new metadiscipline. *Environmental Science & Technology* 37(23): 5314-5324.

Montalto, Franco, Christopher Behr, Katherine Alfredo, Max Wolf, Matvey Arye, and Mary Walsh. 2007. Rapid assessment of the cost-effectiveness of low impact development for CSO control. *Landscape and Urban Planning* 82: 117-131.

Munasinghe, Mohan. 2007. Sustainable development triangle. In *Encyclopedia of Earth*. Eds. Cutler J. Cleveland. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment (February 10). http://eoearth.org/article/Sustainable_development_triangle. (Accessed July 21, 2008).

National Research Council. 2001. *Assessing the TMDL approach to water quality management*.Washington, D.C.: National Academy Press.

New York City Department of City Planning (NYCDCP). 2001. NYC2000: Results from the 2000 Census, Population Growth and Race/Hispanic Composition. City of New York. NYC DCP #01-11. http://www.nyc.gov/html/dcp/pdf/census/nyc20001.pdf

New York City Department of Environmental Protection (NYCDEP). 2007a. *Landside Modeling Report, Volume 4: Hunts Point WPCP*. City of New York, Bureau of Engineering Design & Construction.

———. 2007b. *Landside Modeling Report, Volume 14: Wards Island WPCP*. City of New York, Bureau of Engineering Design & Construction.

New York City Mayor's Office, Long Term Planning and Sustainability. 2007. PlaNYC. City of New York. http://nyc.gov/planyc. (Accessed June 15, 2008).

New York State Assembly. 2006. Bill 11226 in Assembly May 22, 2008. http://assembly.state.ny.us/leg/?bn=A11226&sh=t. (Accessed August 25, 2008).

Oberndorfer, Erica, Jeremy Lundholm, Brad Bass, Reid R. Coffman, Hitesh Doshi, Nigel Dunnett, Stuart Gaffin, Manfred Köhler, Karen K.Y. Liu, and Bradley Rowe. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience* 57(10): 823-833.

Perkins, C. 2003. Cartography: mapping theory. *Progress in Human Geography* 27(3): 341-351.

———. 2004. Cartography-cultures of mapping: power in practice. *Progress in Human Geography* 28(3): 381-391.

Peuquet, Donna. 2002. *Representations of Space and Time*. New York: Guilford Press.

Pickles, John. 2004. "The cartographic gaze, global visions and modalities of visual culture." In *A History of Spaces*, 75-91. London: Routledge.

Platt, Rutherford H. 2004. Toward ecological cities – Adapting to the 21st century metropolis. *Environment* 46:5: 11-27.

———. 2006. Urban watershed management: Sustainability, one stream at a time. *Environment* 48:4: 26-42.

Post, Nadine. 2007. Green-roof study results offer positive surprises. *Engineering News-Record* 258:14:20.

Robbins, P. 2004. *Political Ecology*. Oxford: Blackwell Publishing.

Rosenzweig, C., S. Gaffin, and L. Parshall. 2006. *Green Roofs in the New York Metropolitan Region: Research Report.* New York: Columbia University Center for Climate Systems Research and NASA Goddard Institute for Space Studies.

Satterthwaite, D. 1997. Sustainable cities or cities that contribute to sustainable development? *Urban Studies* 34:10: 1667-1691.

Sauer, C. 1969. Theme of plant and animal destruction in economic history. In *Land and Life – A Selection from the writings of Carl Ortwin Sauer*, edited by J. Leighly. Berkeley, CA: University of California Press. Originally published in *Journal of Farm Economics* 20: 765-775 (1938).

Seggos, Basil, and Chris Plumb. 2006. *Sustainable Raindrops: Cleaning New York Harbor by Greening the Urban Landscape*. New York: Riverkeeper. http://www.riverkepper.org. (Accessed June 15, 2008).

Socolow, R. 1994. Six Perspectives from industrial ecology. In *Industrial Ecology and Global Change*. New York: Columbia University Press.

Stage, David, and Nancy von Meyer. 2006. *An Assessment of Best Practices in Seven State Parcel Management Programs*. FGDC Cadastral Data Subcommittee.

Taylor, David. 2007. Spheres of Influence: Growing Green Roofs, City by City. *Environmental Health Perspectives* 115:6: A306-311.

Tufte, Edward. 2001. *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press.

Turnbull, D. 2000. *Masons, tricksters and cartographers: comparative studies in the sociology of science*. Amsterdam: Harwood Academic.

United Nations. 2007. World Urbanization Prospects: The 2007 Revision Population Database. http://esa.un.org/unup. (Accessed July 21, 2008.)

United States Environmental Protection Agency (USEPA). 2007a. National Pollutant Discharge Elimination System – Green Roofs. http://www.epa.gov/npdes/stormwater/menuofbmps. (Accessed June 15, 2008).

———. 2007b. Heat Island Effect – Green Roofs. http://www.epa.gov/hiri/strategies/greenroofs.html. (Accessed July 14, 2008.)

———. 2008a. Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas. EPA-560-F-07-231. http://www.epa.gov/brownfields. (Accessed April 11, 2008.)

———. 2008b. National Summary of Impaired Waters and TMDL Information. http://iaspub.epa.gov/waters10/attains_nation_cy.control?p_report_type=T. (Accessed July 21, 2008.)

———. 2008c. Managing Wet Weather with Green Infrastructure Action Strategy 2008. http://www.epa.gov/npdes/greeninfrastructure. (Accessed June 15, 2008.)

VanWoert, Nicholaus, D. Bradley Rowe, Jeffrey Andresen, Clayton Rugh, R. Thomas Fernandez, and Lan Xiao. 2005. Green roof stormwater retention: Effects of roof surface, slope, and media depth. *Journal of Environmental Quality* 34: 1036-1044.

Villarreal, Edgar, and Lars Bengtsson. 2005. Response of a Sedum green-roof to individual rain events. *Ecological Engineering* 25: 1-7.

Wachtel, Joshua. 2007. Storm water management, green roof style. *BioCycle* May: 42-46.

Whyte, W. 1968. *The Last Landscape*. Garden City, NY: Doubleday & Co.

Wood, Michael. 2003. Some personal reflections on change…The past and future of cartography. *The Cartographic Journal* 40(2): 111-115.

———. 2006. Map Art. *Cartographic Perspectives* 53: 5-14.

Zidar, Kate. 2007. *The Citizens Guide to the Sewershed: Newtown Creek Water Pollution Control Plant Drainage Area*. New York: Lower East Side Ecology Center and Pratt Institute Graduate Center for Planning and the Environment.

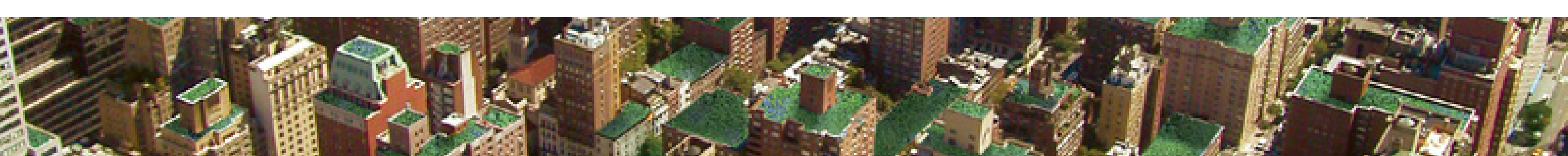
Appendix I. Bronx Green Roof Stormwater Simulation Tool Software Manual

Bronx Stormwater Simulation Tool

Introduction

Earth Pledge and HydroQual have developed a tailored version of the Green Roof Stormwater Model for the Bronx, in order to accelerate the adoption of green roofs in the area. Green roofs, as a best management practice, can simultaneously mitigate multiple environmental challenges such as stormwater runoff, combined sewer overflows (CSOs), the urban heat island effect, power plant emission pollution, and lack of green space. These issues all impact the quality of life in urban areas such as the Bronx.

We hope this Stormwater Simulation Tool, when paired with education programs, will increase awareness of CSO problems as they relate to development and impervious surfaces in the Bronx. Furthermore, the model can be used as a tool to quantify the impacts of development on city infrastructure, and assist in showing the monetary value of green roof adoption as a best management practice. As the ability of green roofs to mitigate stormwater has been proven in other municipalities, the Bronx Stormwater Simulation Tool can aid city officials and policy makers in developing rationale for policy and incentives for green roof development in particular areas based on ROI. Furthermore, we hope to inspire every borough to follow the Bronx’s lead in addressing CSO and stormwater issues.



Overview

This program calculates the estimated reduction in stormwater runoff and CSOs for various green roof scenarios in the Bronx. The efficacy of green roofs as a best management practice for reducing CSOs can be evaluated at the county and drainage subbasin scales. Green roofs may reduce CSOs by both retaining and detaining rainfall—stormwater volume is reduced, and discharge can be delayed to reduce peak flows. This modeling analysis treats green roofs as a fully developed element of a mechanistic model of the sewer system, so that a genuine assessment of their impact can be made on a broad scale.

The green roof opportunity area has been calculated for each drainage subbasin as the percent of land occupied by flat-roofed buildings. With this software program, the user can specify up to three green roof design scenarios with different planting and material types. These scenarios are then applied to the green roof opportunity area for each drainage subbasin on a percentage basis. In this version of the program, the same scenarios are used across the entire borough.

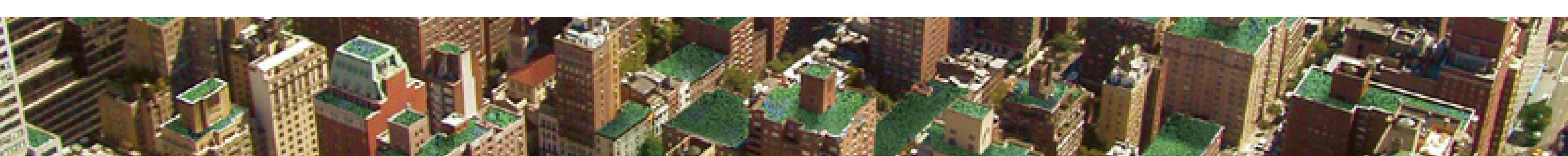
A green roof micro-model calculates the amount of precipitation captured by the design scenarios, and passes this information as reduced rainfall intensity to a sewer system model. Three years of rainfall data are available to estimate average, wet, and dry conditions. The results of the model are presented in an interactive map with attributes. Annual data is provided for total overflow volume, overflow hours, overflow events, and peak flow intensity. The annual reduction in overflow is calculated from a baseline (with no green roofs built). Results are available for each outfall drainage subbasin, and as a Bronx-wide combined sewer area summary.

Installation

Copy the entire contents of the CD (or extract the zip file) to any hard drive. Double-click on the *.exe file to start the application.

The program was developed for the Windows operating system, and requires write-permission to its folder to save the model output files.

Some computers will require the additional *DFORRT.DLL* file; you may remove this if it conflicts with another version already on your computer.



About the Models

The Stormwater Simulation Tool incorporates two models: the Earth Pledge green roof micro model, and the HydroQual sewer model. The micro model calculates the effect of the user-specified green roof scenarios in terms of reduced rainfall intensities, and passes this data along to the sewer model.

Micro model: The micro model determines the impacts of a green roof on an individual building, on a per-area basis. The model accounts for rainfall capture, retention, evaporation, and delayed release. This version of the micro model allows for inputs in standard mode, allowing the user to select from a matrix of pre-programmed green roof plant and growing medium options to evaluate the impact of a green roof installation. (A separate advanced mode model is available, which requires more detailed input from the user regarding the specific green roof and ambient condition variables.) The user can compare various design approaches to stormwater retention by changing the design inputs of the green roof. The user can also compare the performance of green roofs to conventional roofs based on the model's outputs.

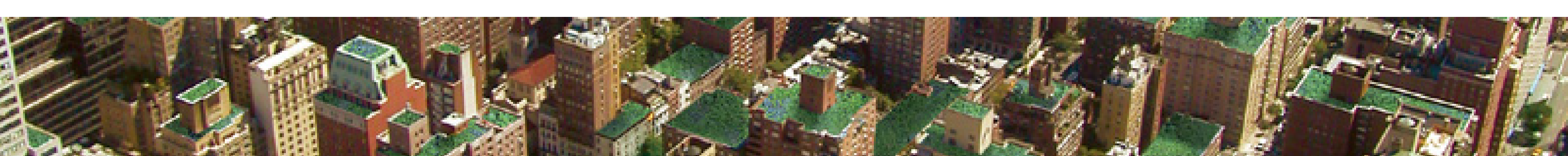
This version of the micro model focuses on extensive green roof designs. Extensive green roofs require only a few inches of soil (1-6 inches) and little additional irrigation or care. Typically, they include sedums, grasses, and wildflowers. It is important to note that extensive roofs are often unable to accommodate regular human traffic. (Intensive green roofs require from 6 inches to four feet of soil, and can accommodate vegetables, shrubs, flowers, and trees. Due to soil depth, weight should be considered in the building and planning stages, so as not to overburden the home or building below. For this reason, intensive green roofs are not modeled here.)

Sewer model: The sewer system model is comprised of a network of drainage subbasins in the Hunts Point and Wards Island Water Pollution Control Plant (WPCP) service areas. The primary basis of the model is the development of a flow balance around each modeled regulator device, with discharges to outfalls. The model employs a steady-state flow balance for each model time step of one hour.

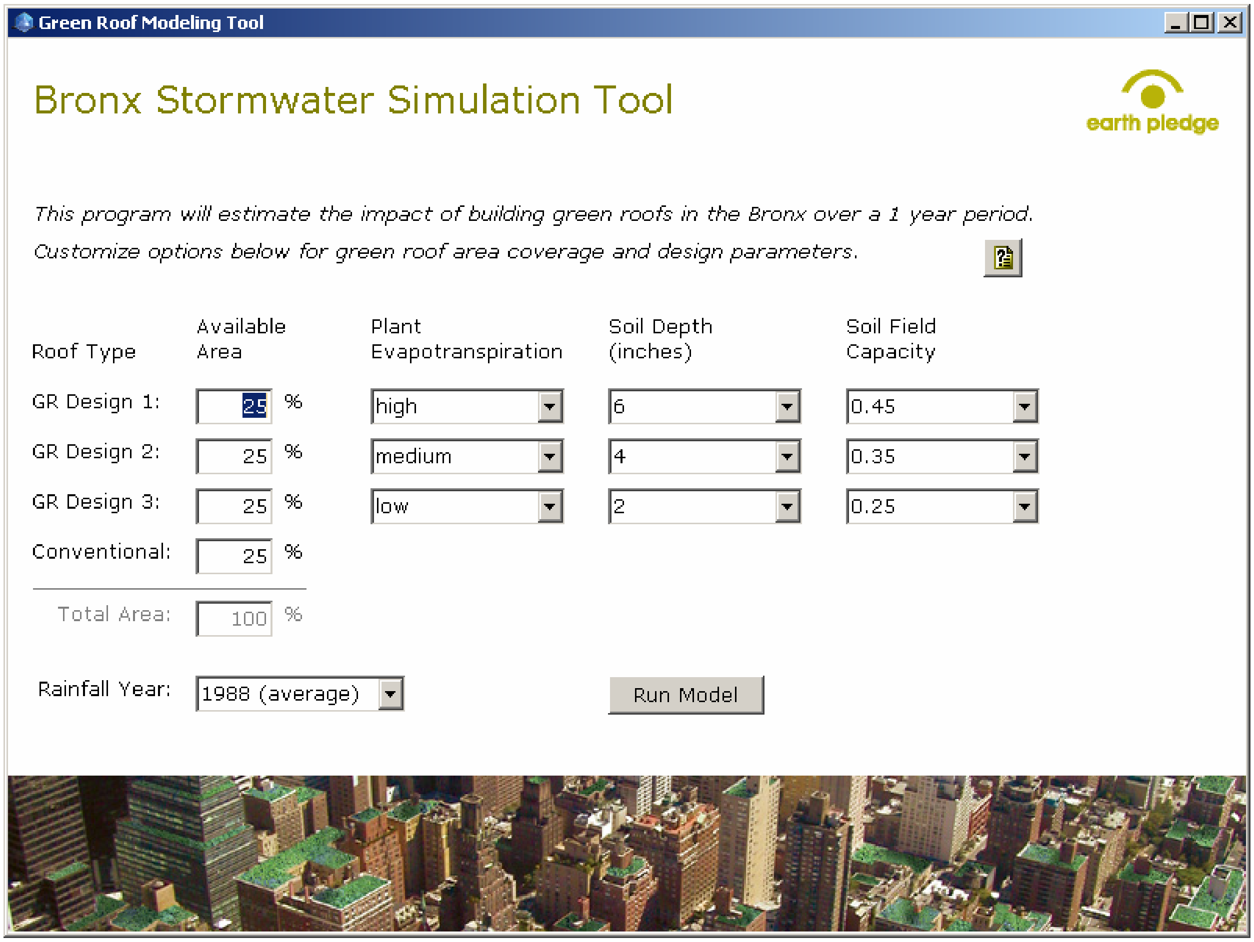
The sewer model checks for flow balance around each regulator, by comparing the total inflow against the regulator capacity. Inflows to a particular regulator consist of any flow contributions from upstream regulators, plus the dry-weather flow associated with the tributary subbasin, plus the rainfall runoff generated from the tributary subbasin during wet weather.

The rainfall runoff from the tributary subbasin is comprised of the runoff from ground and conventional-roofed areas (obtained by the Rational formula), and the runoff from each of the green roof design areas with their respective micro-model outputs (proportioned based on their respective allocation).

Inflows in excess of the regulator capacity flow to a specified downstream device or to an outfall, while inflows up to the regulator capacity flow to the treatment plant.



Input Screen

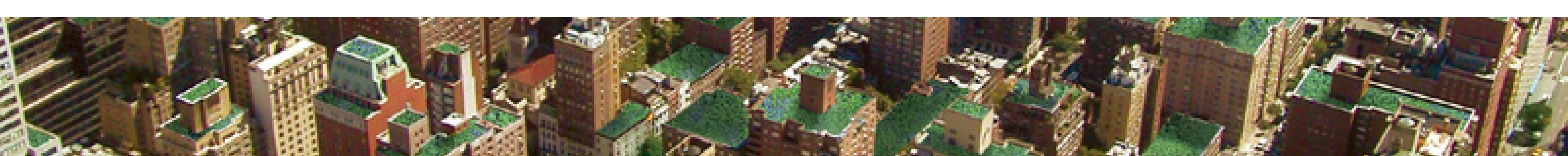


To use the model, select up to three different green roof designs, which will be applied proportionally to the available flat roofs in each drainage subbasin. A green roof design has three options each for plant evapotranspiration (vegetation types), soil depths, and soil field capacities.

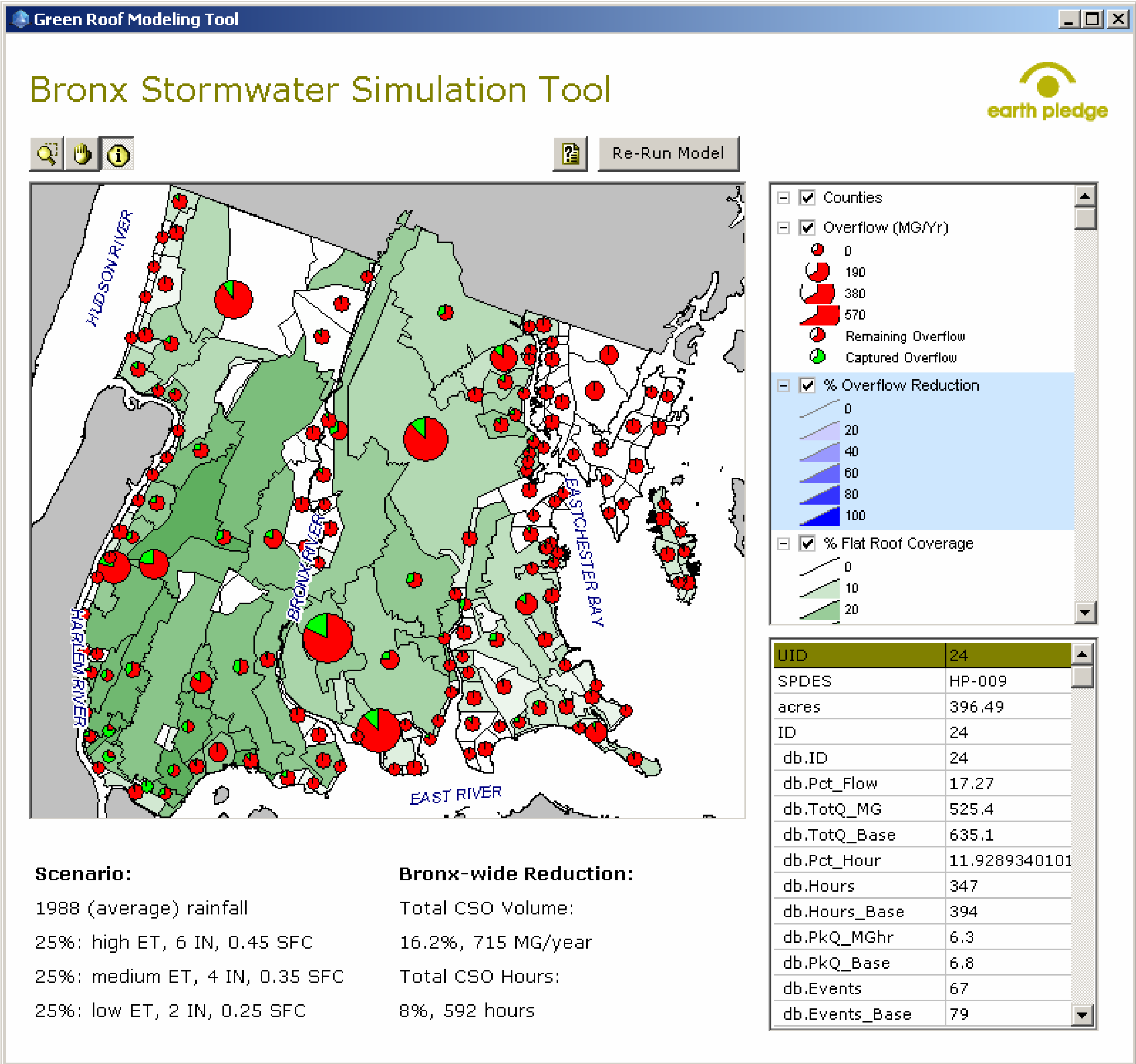
A 25% conventional roofing area is suggested to account for roof infrastructure such as fans, water towers, sheds, etc. This conventional roof option can also be used for sensitivity analysis.

Three rainfall years are available for use: 1988 for average conditions, 2001 for dry conditions, and 2003 for wet conditions. These years are often used for modeling, as they are representative of annual rainfall conditions between 1950 and 2006.

Year	Total Annual Rainfall	Percentile	Condition
1988	40.69 inches	42nd	Average
2001	32.07 inches	13th	Dry
2003	51.82 inches	89th	Wet



Output Screen

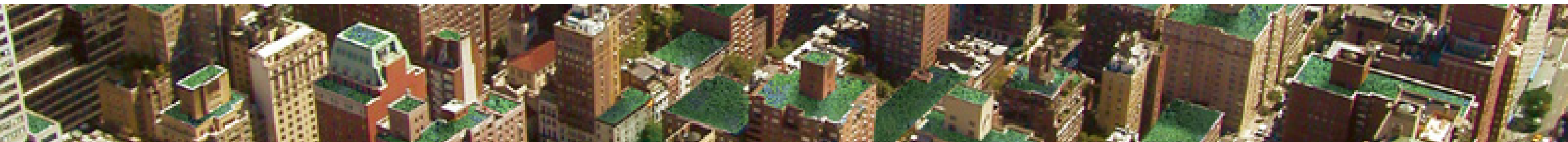


Zoom: Click button with magnifier icon to activate zoom-in, zoom-out. Drag a rectangle to reset zoom area. Drag top to bottom/left to right to zoom in. Drag bottom to top/right to left to zoom out.

Pan: Click hand icon to activate pan-drag. Drag the map to a new extent.

Identify: Click "i" button to view data for a map feature from the highlighted layer.

Legend layers are listed in drawing order, and may be rearranged. Map colors, symbols, and labels can be modified by double-clicking the layer in the map legend. See http://www.TatukGIS.com for additional help on formatting options.



Map Data

There are several different layers of the drainage subbasins in the map viewer, with slightly different boundaries. The drainage subbasin boundaries are approximate.

Drainage Area Types: The type of sewer system is indicated by the striped overlay later [Drainage Area Type], and is the smallest unit used by the sewer model.

The Bronx primarily has a combined sewer system, with 69% of its area. Only 6% of the borough by area is serviced by a separate sewer system, having separate pipes for sanitary and storm flow. The remaining 25% has direct and other drainage.

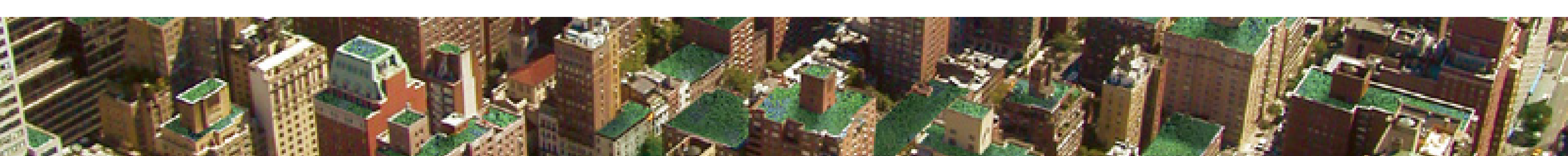
Attributes for Drainage Area Types:

WPCP	Water pollution control plant
Type	Combined, separate, direct drainage, or other sewer system
Regulator	Sewer system regulator ID
Outfall	Sewer system outfall ID
Stormdrain	Sewer system storm drain ID
Direct	Direct drainage area model ID
Acres	Area in acres
Rec	ID number
RAINMANIN	ID number for model input
RAINMANOUT	outfall ID for model output
GIS_AREA	Map area in square feet
GIS_LENGTH	Map perimeter in feet

Overflow Reduction: Model output subbasins are aggregated by outfall, shown in two separate layers as blue polygons [Overflow (MG/Year)] and as pie charts [% Overflow Reduction].

Attributes for Overflow (MG/Year) and % Overflow Reduction:

SPDES	Outfall ID
Acres	Area in acres
ID	ID number
Pct_Flow	% reduction in annual overflow
TotQ_MG	Total annual overflow in million gallons per year with green roof scenario
TotQ_Base	Total annual overflow in million gallons per year for base condition rainfall year, no green roofs
Pct_Hour	% reduction in overflow hours per year
Hours	Total overflow hours per year with green roof scenario
Hours_Base	Total overflow hours per year for base condition rainfall year
PkQ_MGhr	Peak flow in million gallons per hour for green roof scenario
PkQ_Base	Peak flow in million gallons per hour, base condition rainfall
Events	Number of overflow events per year for green roof scenario
Events_Base	Number of overflow events per year, base condition rainfall



Flat Roof Coverage: Model input subbasins are aggregated by regulator, and are displayed here with building information in green [% Flat Roof Coverage].

Building area estimates are based on the NYC Department of Information technology and Telecommunications building shapefile (2005). Buildings with flat roofs were estimated by using the building classes from the NYC Department of Finance Real Property Assessment Database (2007).

Overall, flat roofed buildings cover 14% of the land area of the Bronx. For just the areas with combined sewer systems, the flat roof building coverage is 19%. Areas with separate sewer systems have 10% coverage by flat roofs. The coverage for individual drainage subbasins can be obtained by using the "identify" tool.

Attributes for % Flat Roof Coverage:

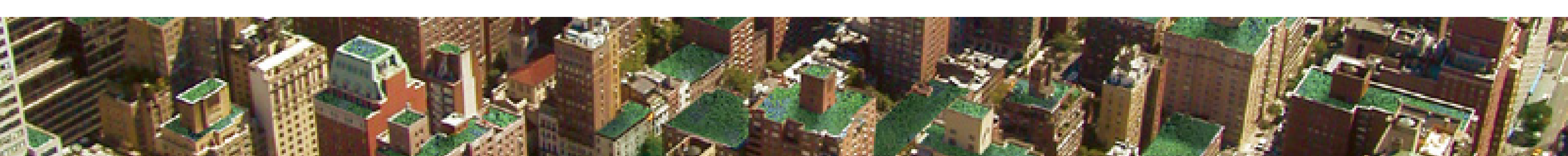
RAINMANIN	ID number
Bldgs	Number of buildings
BldgAcre	Acres of land covered by buildings
Bldg_Pct	% of land covered by buildings
FlatAcre	Acres of land covered by flat-roofed buildings
Flat_Pct	% of land covered by flat-roofed buildings

Outfalls: The locations of combined and storm sewer outfalls are shown as points.

Attributes for Outfall:

SPDES	Outfall ID
Feature	Type of outfall or drain
Type	Combined or separate sewer system
ID	ID number

Basemap Layers: Political districts are from the NYC Department of City Planning, with attributes added by CommunityCartography.



User Agreement and Disclaimer

This disclaimer is issued in regard to the computer software program referred to as *greenroof.exe* developed by HydroQual, Inc.

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Acknowledgements

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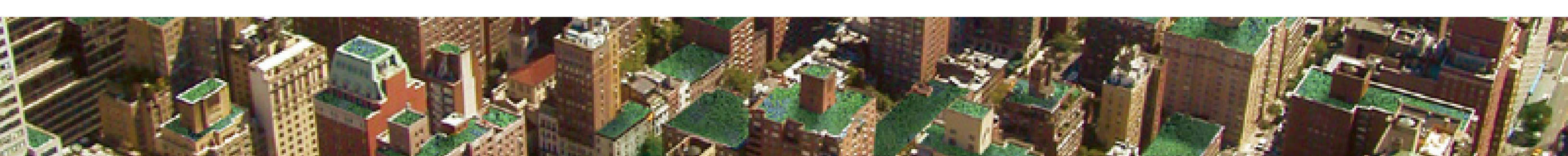

Appendix II. Sewer Model Supplemental Information

Sewer models typically calculate runoff as a function of area, corresponding runoff coefficient (85 to 90 percent of imperviousness cover), and rainfall intensity. Each subcatchment has its own runoff coefficient, which has been calculated in previous modeling studies based on GIS analysis of land use types. The calculations used in this program have been modified to account for the three potential green roof designs, with each subcatchment subdivided into three potential green roof areas and one remaining/non flat-roofed area, with a modified runoff coefficient to account for the building area removed for potential green roof use.

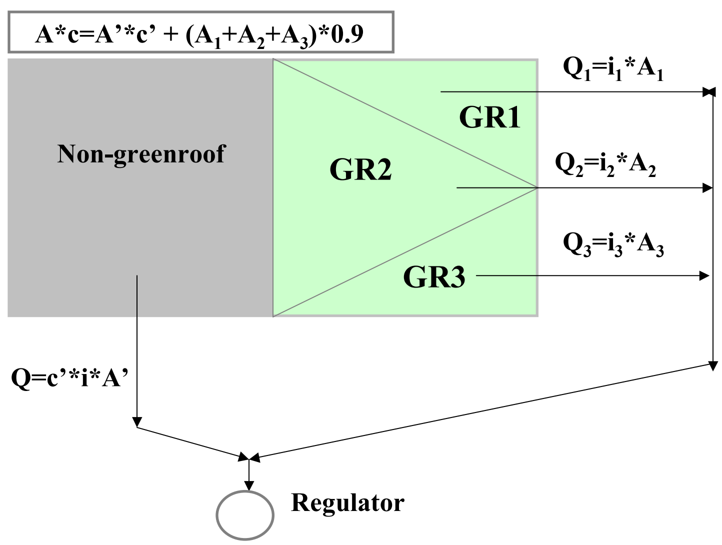

Figure 28. Runoff calculations used in the Bronx Green Roof Stormwater Simulation Tool (Kumaraswamy, Hartman, and Hallden 2008). The potential green roof area specified by the user as "conventional" is calculated as impervious with c=0.9. Variables are defined as:

A: drainage area
Q: runoff volume
c: runoff coefficient from land use data
i: rainfall intensity
i_n: reduced rainfall intensity from micro-model, runoff per unit area

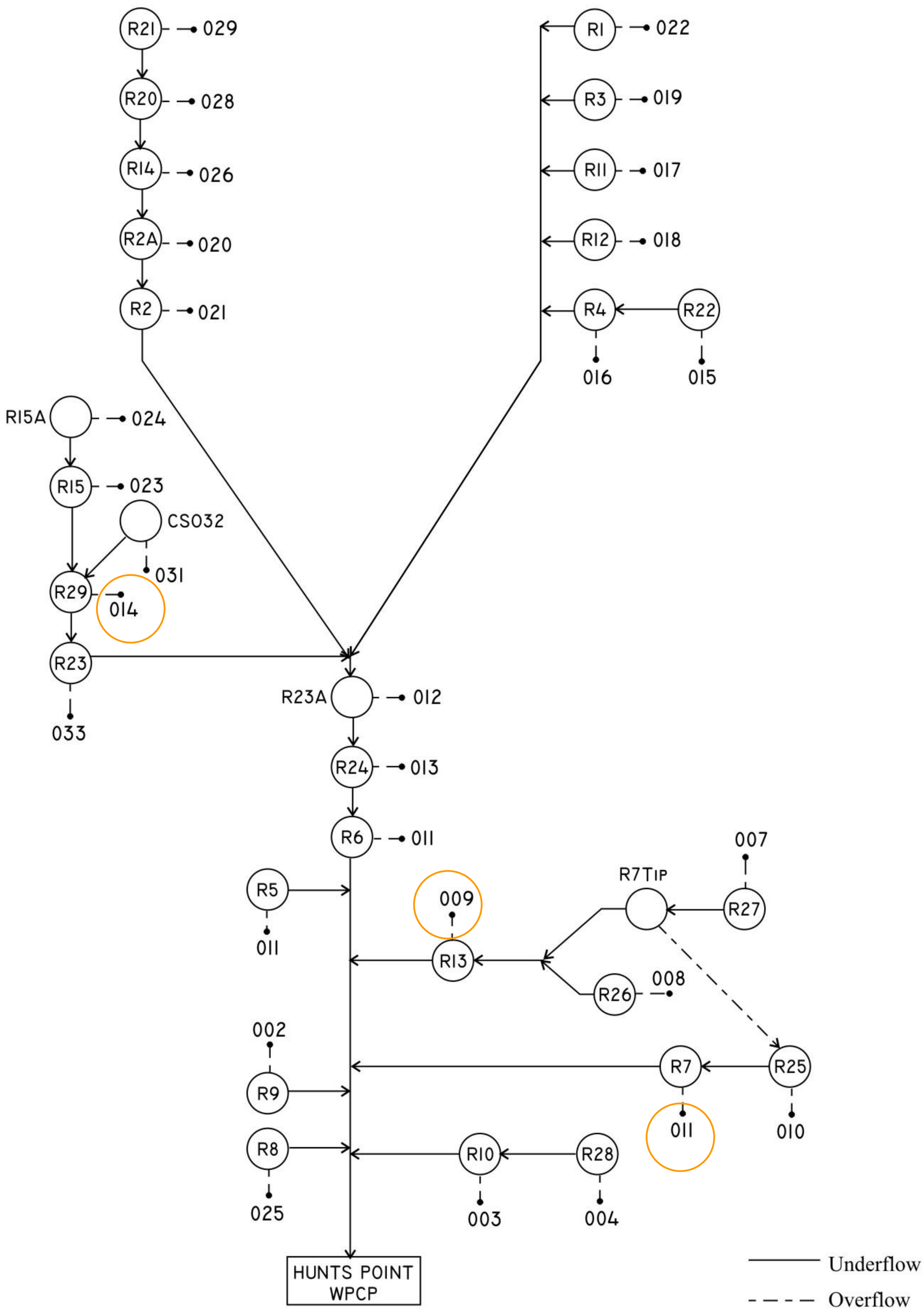

Figure 29. Hunts Point sewer system schematic (Kumaraswamy, Hartman, and Hallden 2008). Black dots are outfalls, open circles are regulators. Tier 1 outfalls have been circled.

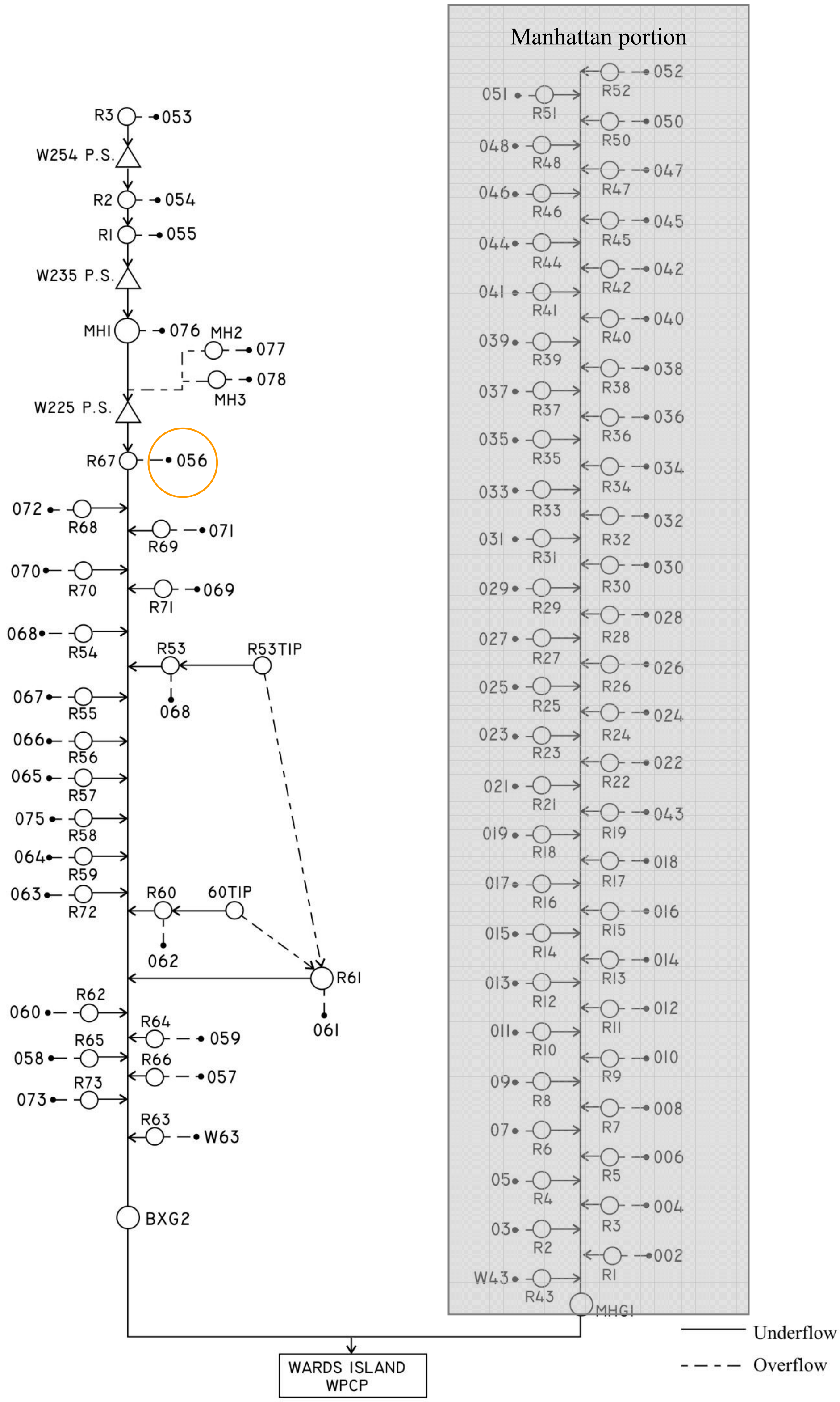

Figure 30. Wards Island sewer system schematic (Kumaraswamy, Hartman, and Hallden 2008). Tier 1 outfall has been circled.

Appendix III. Geoprocessing Summary Tables

Building Class	Total Acres	Polygon Count	Building Class Type	Building Class Type 2
B1	354	15,235	Two Family Dwellings	Brick
B3	113	5,481	Two Family Dwellings	Converted (from One Family)
B9	41	1,960	Two Family Dwellings	Miscellaneous (City types, Old, etc)
C0	281	11,190	Walk-Up Apartments	Three Families
C1	295	3,151	Walk-Up Apartments	Over Six Families
C2	31	994	Walk-Up Apartments	Five or Six Families
C3	69	2,201	Walk-Up Apartments	Four Families
C4	10	222	Walk-Up Apartments	Old Law Tenements
C5	3	72	Walk-Up Apartments	Converted Dwellings or Rooming Housing
C6	20	272	Walk-Up Apartments	Cooperatives (Others than Condominiums)
C7	126	1,261	Walk-Up Apartments	Over Six Families with Stores
D1	290	1,484	Elevator Apartments	Semi-Fireproof (Without Stores)
D3	95	496	Elevator Apartments	Fireproof (Standard Construction Without Stores)
D4	132	440	Elevator Apartments	Cooperatives (Others than Condominiums)
D5	12	85	Elevator Apartments	Converted
D6	15	72	Elevator Apartments	Fireproof - with Stores
D7	101	427	Elevator Apartments	Semi-Fireproof with Stores
D8	1	3	Elevator Apartments	Luxury Types
D9	14	73	Elevator Apartments	Miscellaneous
E1	102	288	Warehouses	Fireproof
E3	41	139	Warehouses	Other
E4	6	33	Warehouses	Frame-Metal
E7	15	44	Warehouses	Other
E9	99	445	Warehouses	Miscellaneous
F1	37	114	Factories & Industrial Buildings	Heavy Manufacturing (Fireproof)
F2	23	52	Factories & Industrial Buildings	Special Construction (Printing Plant, etc, Fireproof)
F4	65	230	Factories & Industrial Buildings	Semi-Fireproof
F5	10	56	Factories & Industrial Buildings	Light Manufacturing
F8	7	30	Factories & Industrial Buildings	Tank Forms
F9	65	363	Factories & Industrial Buildings	Miscellaneous
G0	6	563	Garages & Gasoline Stations	Other
G1	33	108	Garages & Gasoline Stations	Garages - Two or More Stories
G2	61	558	Garages & Gasoline Stations	Garages - One Story (Semi-Fireproof or Fireproof)
G3	<1	7	Garages & Gasoline Stations	Garage & Gas Station Combined
G4	5	113	Garages & Gasoline Stations	Gas Stations - With Enclosed Lubrication Plant or Workshop
G5	3	61	Garages & Gasoline Stations	Gas Stations - Without Enclosed Lubrication Plant or Workshop
G6	1	33	Garages & Gasoline Stations	Licensed Parking Lots
G7	3	122	Garages & Gasoline Stations	Residential Tax Class I Garage
G8	5	32	Garages & Gasoline Stations	Garages With Showrooms
G9	59	616	Garages & Gasoline Stations	Miscellaneous
H3	<1	1	Hotels	Transient Occupancy Types - Midtown Manhattan Area
H4	4	19	Hotels	Motels
H6	<1	3	Hotels	Apartment Hotels
H9	2	13	Hotels	Miscellaneous
I1	46	114	Hospitals & Health Facilities	Hospitals, Sanitariums, Mental Institutions
I2	<1	2	Hospitals & Health Facilities	Infirmaries
I3	1	4	Hospitals & Health Facilities	Dispensaries
I4	1	5	Hospitals & Health Facilities	Staff Facilities
I5	10	67	Hospitals & Health Facilities	Health Centers, Child Centers, Clinics
I6	18	60	Hospitals & Health Facilities	Nursing Homes
I7	5	27	Hospitals & Health Facilities	Adult Care Facilities
I9	9	62	Hospitals & Health Facilities	Miscellaneous
J3	1	1	Theatres	Motion Picture Theaters with Balcony
J5	<1	2	Theatres	Theaters in Mixed-Use Buildings
J8	2	1	Theatres	Multiplex-Motion Picture Theaters
K1	234	1,759	Store Buildings (Taxpayers Included)	One Story Store Buildings
K2	57	495	Store Buildings (Taxpayers Included)	Two Story Store, or Store & Office Buildings
K3	4	12	Store Buildings (Taxpayers Included)	Department Stores, Multi-Story

Table 17A. Bronx flat roofed buildings summary.

Building Class	Total Acres	Polygon Count	Building Class Type	Building Class Type 2
K4	13	285	Store Buildings (Taxpayers Included)	Stores, Apartments Above
K6	28	24	Store Buildings (Taxpayers Included)	Shopping Centers with Parking Facilities
K7	4	45	Store Buildings (Taxpayers Included)	Funeral homes
K9	55	383	Store Buildings (Taxpayers Included)	Miscellaneous
L2	<1	2	Loft Buildings	Fireproof - Loft & Storage types (Without Retail Stores)
L8	1	13	Loft Buildings	With Retail Stores (Other than Type I)
L9	1	5	Loft Buildings	Miscellaneous
N1	<1	9	Asylums & Homes	Asylums
N2	13	91	Asylums & Homes	Homes for Indigent Children, Aged, Homeless
N3	1	14	Asylums & Homes	Orphanages
N4	<1	1	Asylums & Homes	Juvenile Detention Houses
N9	6	75	Asylums & Homes	Miscellaneous
O1	11	45	Office Buildings	Fireproof - Up to Nine Stories
O2	1	1	Office Buildings	Ten Stories & Over (Side Streets Type)
O3	<1	2	Office Buildings	Ten Stories & Over (Main Avenue Type)
O5	3	27	Office Buildings	Semi-Fireproof
O6	7	55	Office Buildings	Bank Buildings (Designed Exclusively for Banking)
O7	17	147	Office Buildings	Professional Buildings
O8	2	41	Office Buildings	With Residential Apartments
O9	34	266	Office Buildings	Miscellaneous
P1	<1	1	Indoor Public Assembly & Cultural Facilities	Concert Halls
P2	2	24	Indoor Public Assembly & Cultural Facilities	Lodge Rooms
P3	2	10	Indoor Public Assembly & Cultural Facilities	YWCA, YMCA, YWHA, YMHA, PAL
P5	9	51	Indoor Public Assembly & Cultural Facilities	Community Centers
P7	<1	3	Indoor Public Assembly & Cultural Facilities	Museums
P8	5	34	Indoor Public Assembly & Cultural Facilities	Libraries
R0	56	636	Condominiums	Other
S0	1	33	Primarily Residential-Mixed Use	Primarily One Family Dwellings With Two Stores or Offices
S1	12	486	Primarily Residential-Mixed Use	Primarily One Family Dwellings With One Store or Office
S2	23	840	Primarily Residential-Mixed Use	Primarily Two Family Dwellings With One Store or Office
S3	8	283	Primarily Residential-Mixed Use	Primarily Three Family Dwellings With One Store or Office
S4	5	150	Primarily Residential-Mixed Use	Primarily Four Family Dwellings With One Store or Office
S5	4	133	Primarily Residential-Mixed Use	Primarily Five to Six Family Dwellings With One Store or Office
S9	14	366	Primarily Residential-Mixed Use	Primarily One to Six Family Dwellings With Stores or Offices
W1	186	322	Educational Facilities	Public, Elementary, Junior & Senior High Schools
W2	26	114	Educational Facilities	Parochial Schools, Yeshivas
W3	12	97	Educational Facilities	Schools or Academics
W4	5	24	Educational Facilities	Training Schools
W5	18	52	Educational Facilities	City University
W6	29	105	Educational Facilities	Other Colleges & Universities
W7	1	5	Educational Facilities	Theological Seminaries
W8	1	8	Educational Facilities	Other Private Schools
W9	12	67	Educational Facilities	Miscellaneous
Y1	3	42	Selected Governmental Facilities	Fire Department
Y2	5	22	Selected Governmental Facilities	Police Department
Y3	94	527	Selected Governmental Facilities	Prisons, Jails, Houses of Detention
Y4	13	41	Selected Governmental Facilities	Military & Naval Installations
Y6	32	83	Selected Governmental Facilities	Department of Sanitation
Y8	<1	1	Selected Governmental Facilities	Department of Public Works
Y9	2	20	Selected Governmental Facilities	Department of Environmental Protection
Z0	<1	40	Miscellaneous	Other
Z1	5	7	Miscellaneous	Court Houses
Z3	11	28	Miscellaneous	Post Offices
Z4	<1	1	Miscellaneous	Foreign Governments

Table 17A. Bronx flat roofed buildings summary (continued).

Building Class	Total Acres	Polygon Count	Building Class Type	Building Class Type 2
A0	1	24	One Family Dwellings	Cape Cods
A1	210	10,720	One Family Dwellings	Two Stories Detached (Small or Moderate size, with or without Attic)
A2	96	3,857	One Family Dwellings	One Story (Permanent Living Quarters)
A3	24	564	One Family Dwellings	Large Suburban Residences
A4	1	30	One Family Dwellings	City Residences
A5	149	9,323	One Family Dwellings	Attached or Semi-Detached
A6	1	63	One Family Dwellings	Summer Cottages/Mobile Home/Trailer
A7	2	26	One Family Dwellings	Mansion Types or Town Houses
A8	25	1,188	One Family Dwellings	Bungalow Colony-Land Cooperatively Owned
A9	18	886	One Family Dwellings	Miscellaneous (Old Building, Attached & Semi-Detached Frame Houses, etc)
B2	217	9,466	Two Family Dwellings	Frame
C9	17	211	Walk-Up Apartments	Garden Apartments/Mobile Home Parks/Trailer Parks
K5	6	78	Store Buildings	Diners, Franchised Type Stand
M1	70	688	Religious Facilities	Churches, Synagogues, Chapels
M2	1	11	Religious Facilities	Mission Houses (Non-Residential)
M3	3	74	Religious Facilities	Parsonages, Rectories
M4	5	51	Religious Facilities	Convents
M9	14	158	Religious Facilities	Miscellaneous
P4	1	14	Indoor Public Assembly & Cultural Facilities	Beach Clubs
P6	3	11	Indoor Public Assembly & Cultural Facilities	Amusement Places, Bathhouses, Boat Houses
P9	2	17	Indoor Public Assembly & Cultural Facilities	Miscellaneous (Including Riding Academics & Stables)
Q1	30	436	Outdoor Recreational Facilities	Parks
Q2	1	42	Outdoor Recreational Facilities	Playgrounds
Q3	2	5	Outdoor Recreational Facilities	Outdoor Pools
Q6	9	5	Outdoor Recreational Facilities	Stadiums, Race Tracks, Baseball Fields
Q7	<1	2	Outdoor Recreational Facilities	Tennis Courts
Q8	2	47	Outdoor Recreational Facilities	Marinas/Yacht Clubs
Q9	<1	3	Outdoor Recreational Facilities	Miscellaneous
T2	<1	3	Transportation Facilities	Piers, Docks, Bulkheads
T9	7	8	Transportation Facilities	Miscellaneous
U1	<1	1	Utility Bureau Properties	Bridges, Tunnels, Highways
U2	8	68	Utility Bureau Properties	Gas or Electric Utilities
U4	5	18	Utility Bureau Properties	Telephone Utilities
U6	6	69	Utility Bureau Properties	Railroads, Private Ownership
U7	20	140	Utility Bureau Properties	Transportation, Public Ownership
U8	5	58	Utility Bureau Properties	Revocable Consents
U9	5	27	Utility Bureau Properties	Miscellaneous (Including Private Improvements in City Land & in Public Places
V0	7	358	Vacant Land	Zoned Residential
V1	9	202	Vacant Land	Not Zoned Residential
V2	<1	12	Vacant Land	Not Zoned Residential, but Adjacent to Tax Class I Dwelling
V3	<1	3	Vacant Land	Hospitals
V4	<1	1	Vacant Land	Police or Fire Department
V5	<1	1	Vacant Land	School Sites or Yards
V9	2	42	Vacant Land	Miscellaneous (Dept of Real Estate & Other Public Places)
Z2	5	4	Miscellaneous	Public Parking Areas
Z6	<1	4	Miscellaneous	Land Under Water
Z8	4	111	Miscellaneous	Cemeteries
Z9	38	374	Miscellaneous	Other

Table 17B. Bronx non-flat roofed buildings summary.

Outfall	Land Acres	All Buildings			Flat Roofed Buildings		
		Count	Acres	% Land Area	Count	Acres	% Land Area
HP-002	849	3,139	208	24%	2,031	176	21%
HP-003	554	1,675	141	26%	1,210	120	22%
HP-004	505	2,449	138	27%	1,678	117	23%
HP-007	1,507	9,021	364	24%	5,621	281	19%
HP-008	306	1,041	54	18%	985	51	17%
HP-009	396	1,734	84	21%	1,587	79	20%
HP-010	56	84	9	16%	38	5	9%
HP-011	238	1,815	49	20%	863	28	12%
HP-012	104	599	20	19%	315	14	13%
HP-013	994	5,514	217	22%	3,345	170	17%
HP-014	2,308	15,572	486	21%	8,944	344	15%
HP-015	199	1,986	53	27%	1,185	37	19%
HP-016	259	1,375	33	13%	763	20	8%
HP-017	259	231	11	4%	125	8	3%
HP-018	33	291	7	20%	134	3	10%
HP-019	98	1,020	19	19%	405	9	9%
HP-020	113	764	18	16%	389	10	9%
HP-021	43	332	7	17%	51	2	4%
HP-022	138	1,175	26	19%	216	6	4%
HP-023	169	211	20	12%	142	18	11%
HP-024	1,139	8,534	237	21%	4,536	158	14%
HP-025	228	770	64	28%	528	58	26%
HP-026	774	6,374	163	21%	2,867	90	12%
HP-028	20	185	4	22%	98	3	14%
HP-029	3	33	1	23%	16	<1	14%
HP-031	169	757	31	18%	411	25	15%
HP-033	708	4,770	202	29%	2,946	157	22%
WI--05	16	6	2	9%	6	2	9%
WI-053	80	124	11	14%	21	5	6%
WI-054	149	217	14	9%	29	4	3%
WI-055	59	54	5	9%	26	4	7%
WI-056	2,113	3,431	208	10%	1,748	156	7%
WI-057	283	910	80	28%	636	71	25%
WI-058	129	415	30	24%	314	27	21%
WI-059	85	332	21	24%	188	18	21%
WI-060	20	31	4	19%	27	3	16%
WI-061	72	191	17	24%	141	15	21%
WI-062	946	2,920	284	30%	2,418	264	28%
WI-063	28	6	9	31%	0	0	<1%
WI-064	130	189	36	28%	157	35	27%
WI-065	17	19	2	15%	18	2	11%
WI-066	53	111	16	30%	104	16	29%
WI-067	78	197	18	24%	169	17	22%
WI-068	2,507	8,435	668	27%	6,080	580	23%
WI-069	9	25	2	20%	16	2	18%
WI-070	48	149	16	34%	106	13	27%
WI-071	119	281	40	34%	208	37	32%
WI-072	203	767	60	30%	457	53	26%
WI-073	1	4	<1	30%	4	<1	30%
WI-075	404	1,129	121	30%	951	113	28%
WI-076	125	149	20	16%	66	16	13%
WI-077	287	862	60	21%	450	49	17%
WI-078	54	229	14	25%	122	11	21%

Table 18A. Model output summary table, combined sewer subcatchments.

Outfall	Land Acres	All Buildings			Flat Roofed Buildings		
		Count	Acres	% Land Area	Count	Acres	% Land Area
HP-602	30	9	4	12%	4	4	12%
HP-606	206	86	7	4%	0	0	
HP-626	98	49	21	21%	46	20	20%
HP-627	97	28	14	15%	27	14	15%
HP-630	120	66	27	22%	66	27	22%
HP-631	54	209	6	11%	68	3	5%
HP-635	93	58	8	9%	18	7	8%
HP-636	1	0	0		0	0	
HP-637	233	47	2	1%	6	1	1%
HP-638	17	7	2	10%	5	1	8%
HP-640	22	6	5	23%	6	5	23%
HP-641	12	20	2	18%	13	2	17%
HP-643	26	203	5	18%	102	3	9%
HP-839	123	35	5	4%	19	4	4%
HP-943	55	1	<1	<1%	0	0	
WI-614	25	18	11	43%	17	7	26%

Table 18B. Model output summary table, separate sewer subcatchments.

Outfall	Land Acres	All Buildings			Flat Roofed Buildings		
		Count	Acres	% Land Area	Count	Acres	% Land Area
HP--40	32	222	6	18%	32	2	5%
HP--41	274	50	2	1%	13	1	<1%
HP--42	35	111	5	14%	26	2	6%
HP--43	30	230	6	19%	44	2	6%
HP--44	71	730	16	23%	237	6	8%
HP--45	273	55	3	1%	5	<1	<1%
HP--46	312	7	<1	<1%	0	0	
HP--47	40	6	<1	1%	0	0	
HP--48	67	0	0		0	0	
HP--49	75	4	<1	<1%	0	0	
HP--50	62	5	<1	1%	0	0	
HP--51	101	0	0		0	0	
HP--52	77	0	0		0	0	
HP--53	29	0	0		0	0	
HP--54	91	233	10	11%	115	7	8%
HP--55	10	0	0		0	0	
HP--56	12	6	2	13%	5	2	13%
HP--57	12	0	0		0	0	
HP--58	10	2	1	10%	2	1	10%
HP--59	21	7	3	13%	7	3	13%
HP--60	180	7	<1	<1%	0	0	
HP--61	21	0	0		0	0	
HP--62	29	0	0		0	0	
HP--63	87	7	<1	<1%	0	0	
HP--64	9	26	1	9%	24	1	8%
HP--65	15	53	2	12%	33	1	6%
HP--66	38	101	6	15%	39	3	9%
HP--67	13	7	<1	2%	2	<1	1%
HP--68	5	18	<1	7%	0	0	
HP--69	16	21	1	4%	2	<1	1%
HP--70	37	0	0		0	0	
HP--71	70	0	0		0	0	
HP--72	36	0	0		0	0	
HP--73	94	14	1	1%	0	0	
HP--74	35	17	4	12%	16	4	11%
HP--75	71	1	2	2%	1	2	2%
HP--76	24	0	0		0	0	
HP--77	5	15	2	43%	15	2	43%
HP--78	6	6	1	15%	6	1	15%
HP--79	23	19	6	25%	18	6	25%
HP--80	20	3	<1	2%	2	<1	2%
HP--81	16	20	1	5%	8	<1	3%
HP--82	56	8	<1	<1%	0	0	
HP--83	14	13	2	12%	8	1	9%
HP--84	44	20	2	5%	5	1	3%
HP--85	77	11	2	2%	0	0	
HP--86	34	2	<1	<1%	0	0	

Table 18C. Model output summary table, direct drainage and other subcatchments.

Outfall	Land Acres	All Buildings			Flat Roofed Buildings		
		Count	Acres	% Land Area	Count	Acres	% Land Area
HP--88	44	40	2	4%	0	0	
HP--89	48	25	16	33%	19	15	31%
HP--90	99	13	21	21%	13	21	21%
HP--91	81	8	<1	<1%	0	0	
HP--92	67	9	1	2%	0	0	
HP--93	79	0	0		0	0	
HP--94	72	1	<1	<1%	0	0	
HP--95	194	6	<1	<1%	0	0	
HP--96	96	0	0		0	0	
HP--97	56	38	3	5%	0	0	
HP--98	2	0	0		0	0	
HP--99	70	0	0		0	0	
HP-105	6	0	0		0	0	
HP-106	58	30	9	16%	0	0	
HP-109	52	45	8	16%	4	1	2%
HP-205	46	27	4	9%	5	1	3%
HP-502	71	1	<1	<1%	0	0	
HP-504	46	17	2	3%	11	1	3%
HP-505	112	27	2	2%	0	0	
HP-506	69	52	8	12%	43	8	12%
HP-507	17	123	3	19%	59	1	7%
HP-511	27	181	5	20%	11	2	6%
HP-610	88	4	1	2%	2	1	1%
HP-614	13	1	<1	1%	0	0	
HP-623	46	74	2	4%	22	<1	1%
HP-625	2	0	0		0	0	
HP-633	26	113	4	15%	48	3	10%
HP-644	57	351	10	18%	134	6	10%
HP-645	71	19	1	1%	0	0	
WI--65	80	32	8	10%	30	8	10%
WI--66	29	16	1	5%	1	<1	<1%
WI--67	20	0	0		0	0	
WI--68	27	7	<1	1%	0	0	
WI--69	19	2	<1	1%	0	0	
WI--70	16	7	<1	3%	3	<1	2%
WI--71	10	0	0		0	0	
WI--72	43	13	5	12%	11	3	7%
WI--73	37	7	<1	<1%	4	<1	<1%
WI--74	23	0	0		0	0	
WI--75	91	15	9	9%	5	8	9%
WI--79	74	39	18	24%	23	16	22%
WI-508	29	20	5	15%	16	4	14%
WI-513	27	6	<1	<1%	0	0	
WI-515	26	5	2	7%	1	1	6%
WI-615	22	3	1	4%	2	1	4%
WI-616	26	3	<1	1%	1	<1	1%
WI-628	16	10	<1	1%	2	<1	<1%

Table 18C. Model output summary table, direct drainage and other subcatchments (continued).

Appendix IV. Model Results

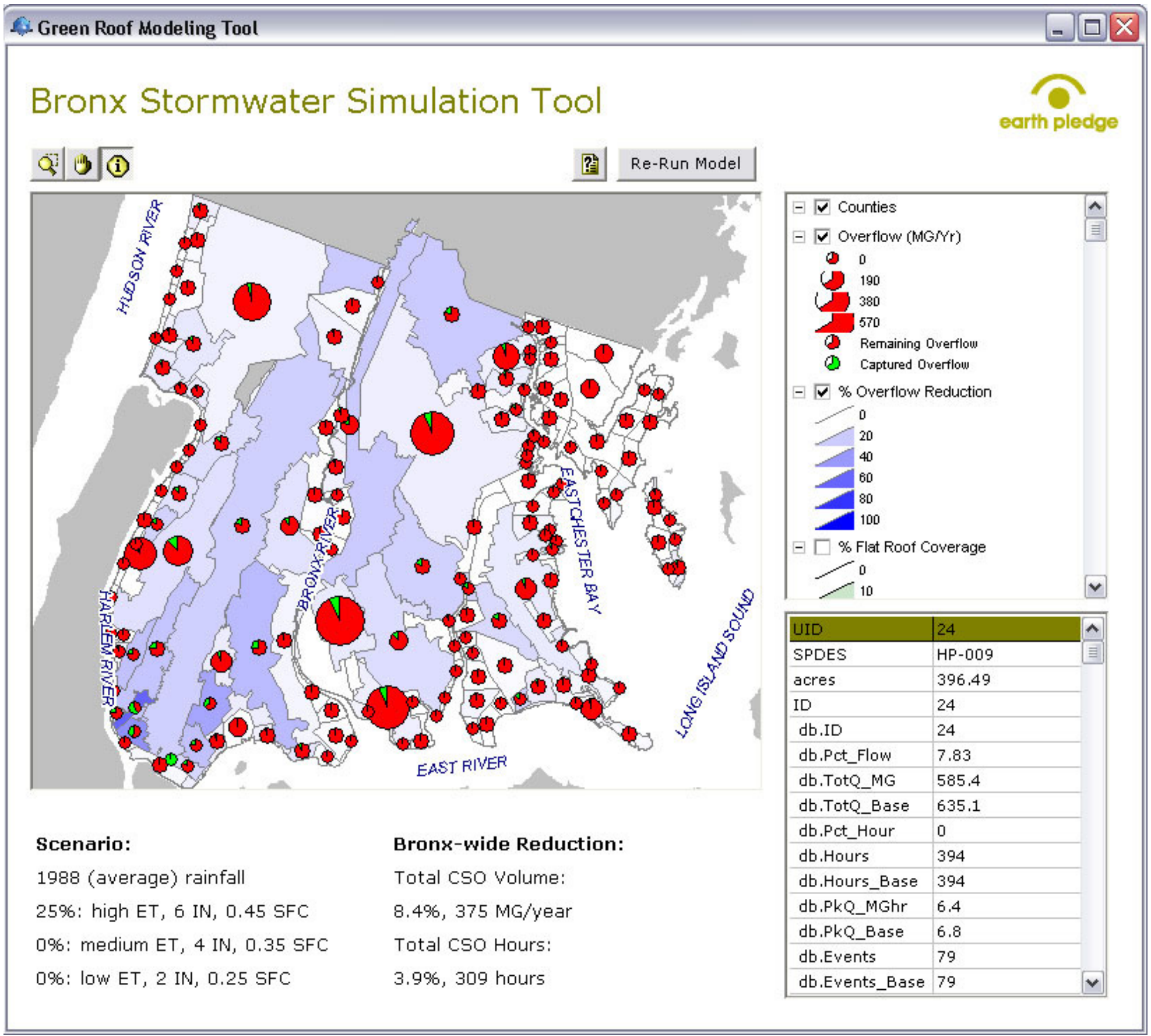

Figure 31A. Results for high performance scenario, 25% coverage, average rainfall.

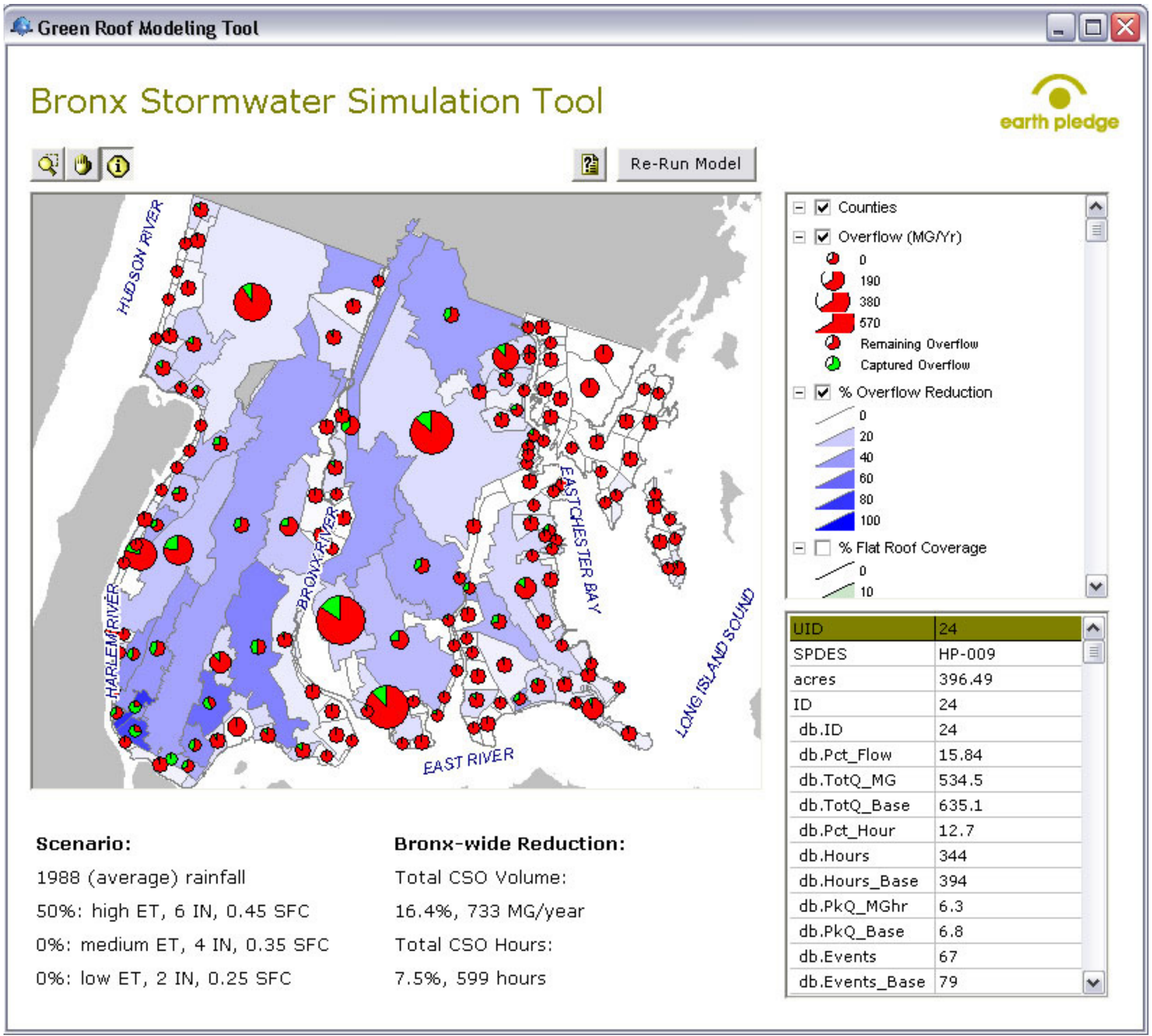

Figure 31B. Results for high performance scenario, 50% coverage, average rainfall.

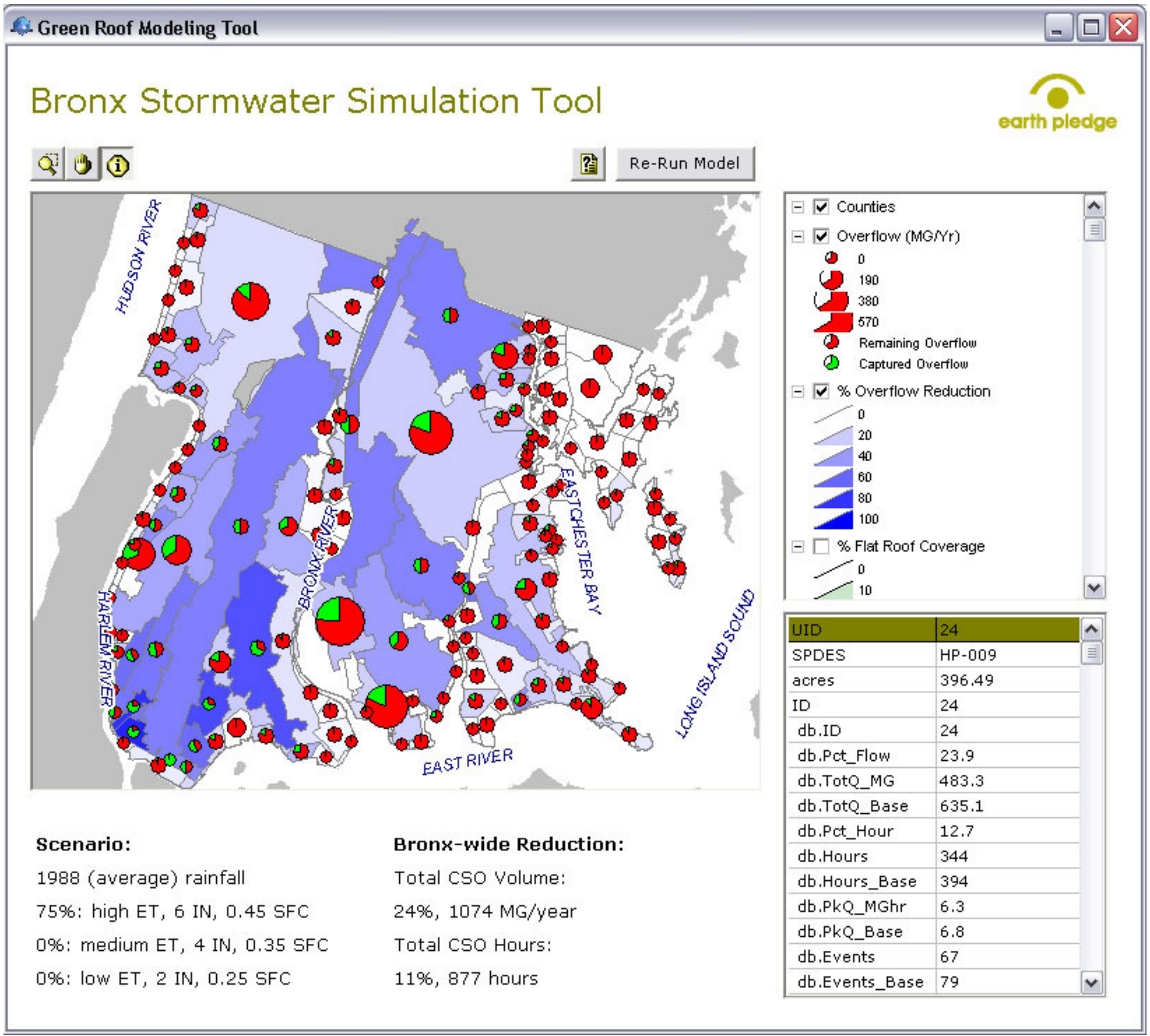

Figure 31C. Results for high performance scenario, 75% coverage, average rainfall.

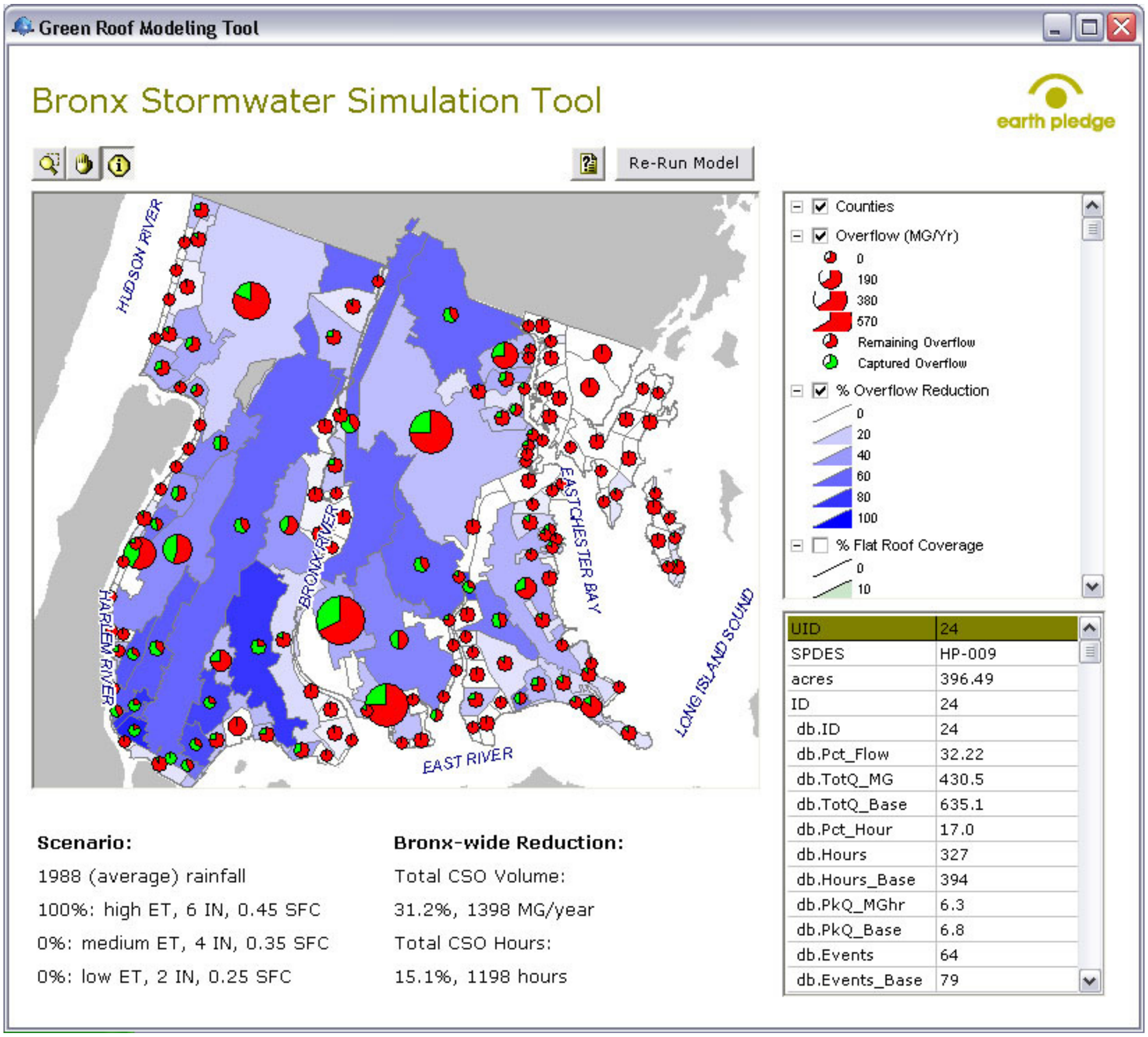

Figure 31D. Results for high performance scenario, 100% coverage, average rainfall.

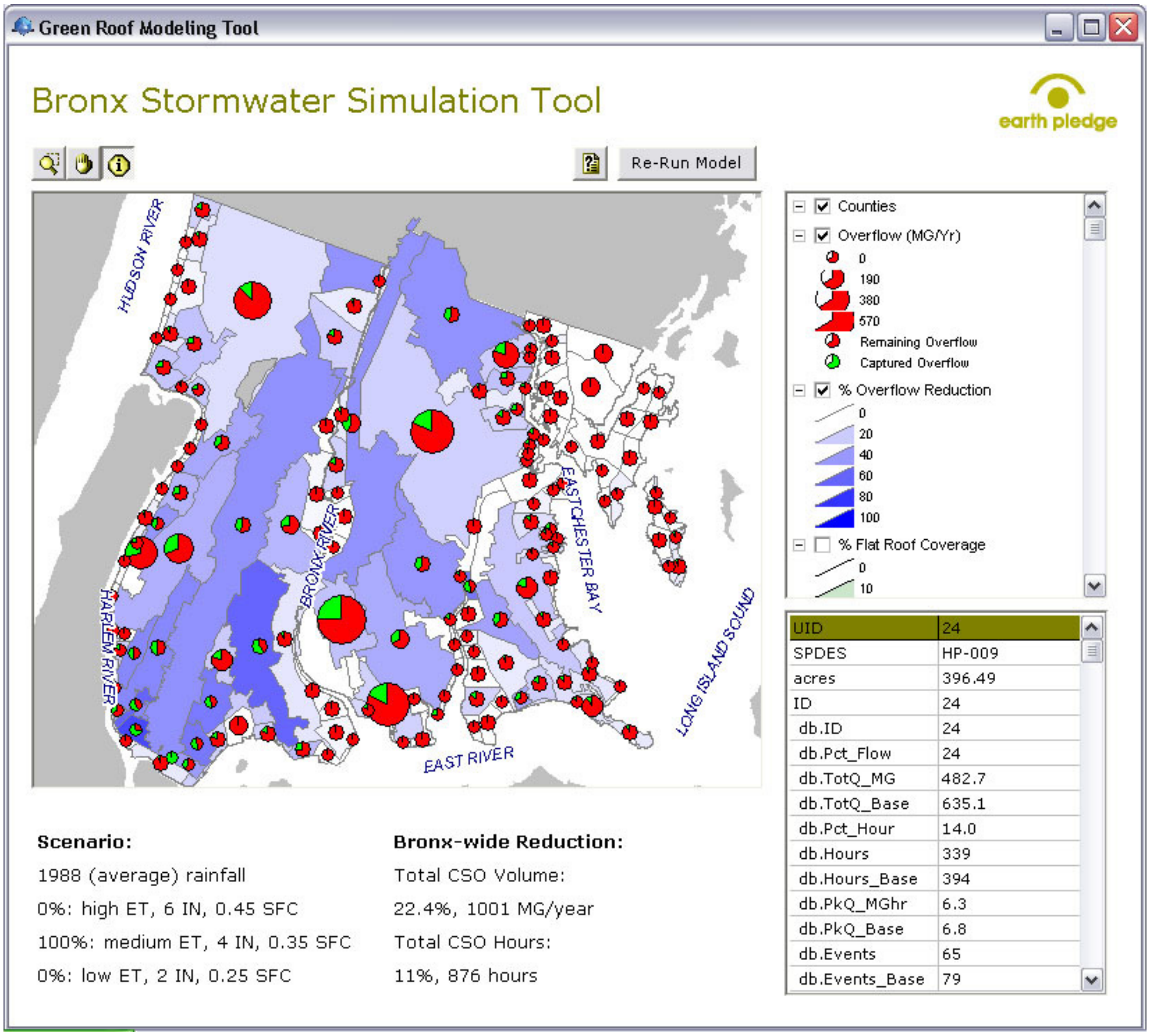

Figure 31E. Results for medium performance scenario, 100% coverage, average rainfall.

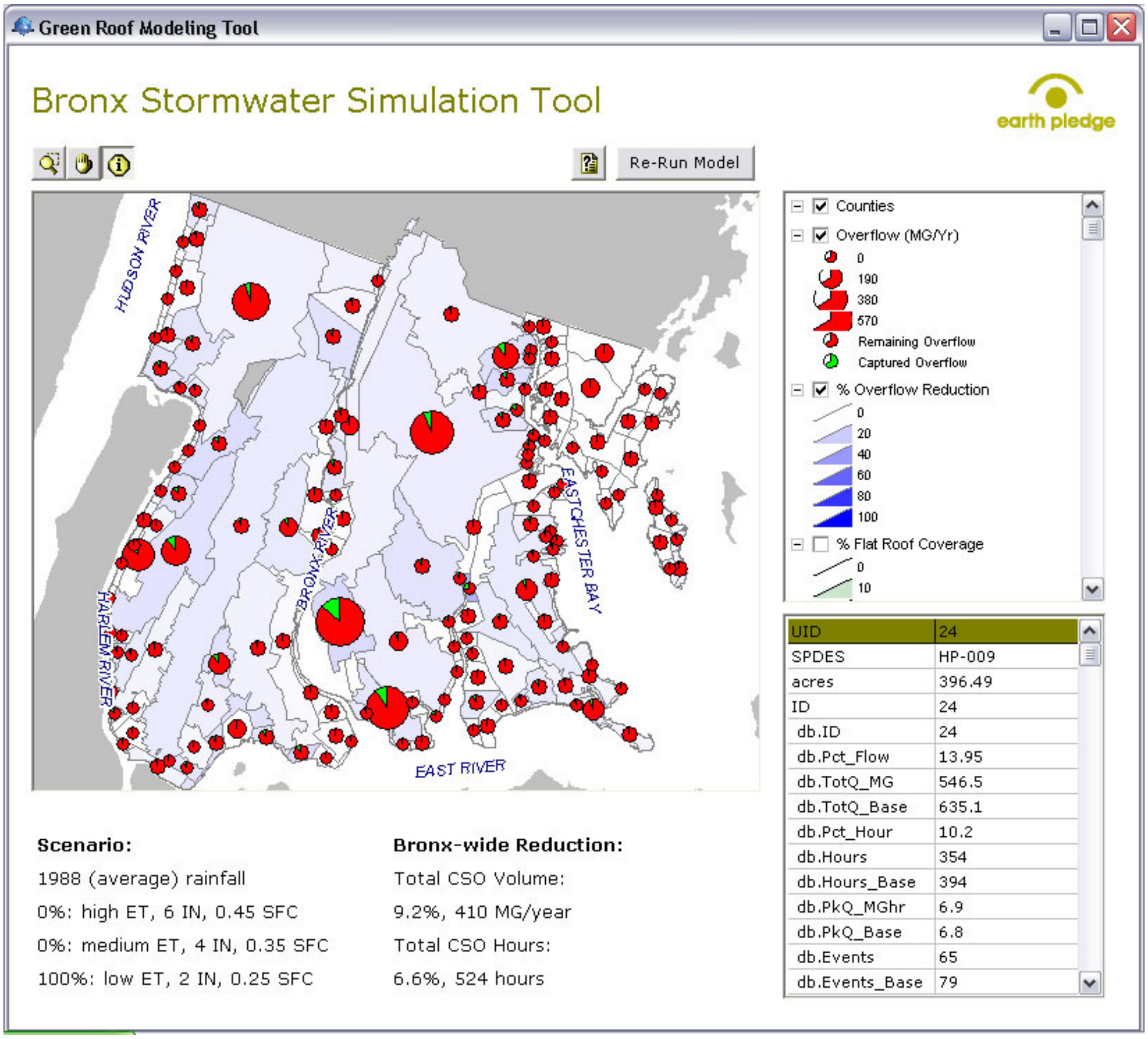

Figure 31F. Results for low performance scenario, 100% coverage, average rainfall.

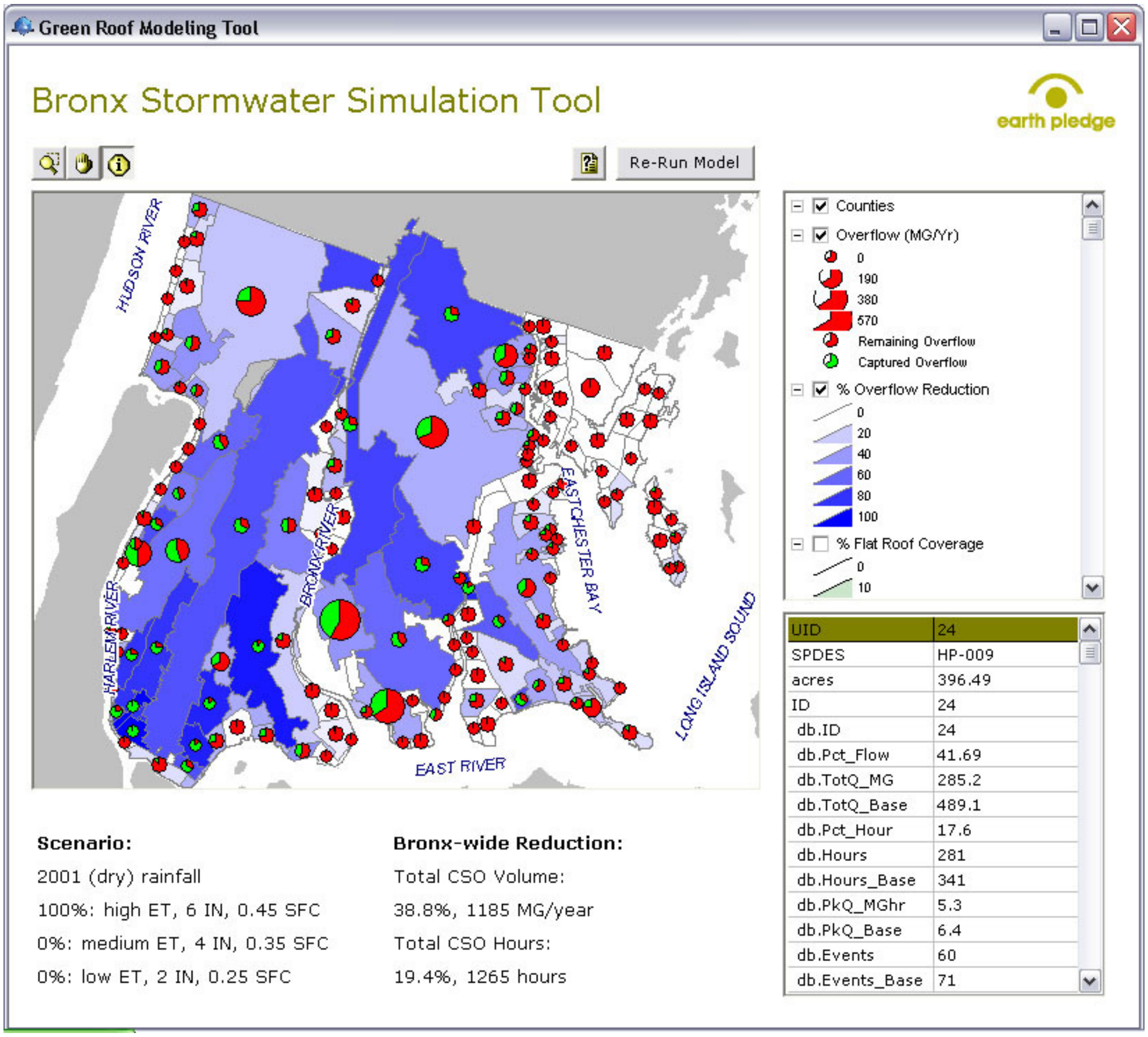

Figure 31G. Results for high performance scenario, 100% coverage, dry rainfall.

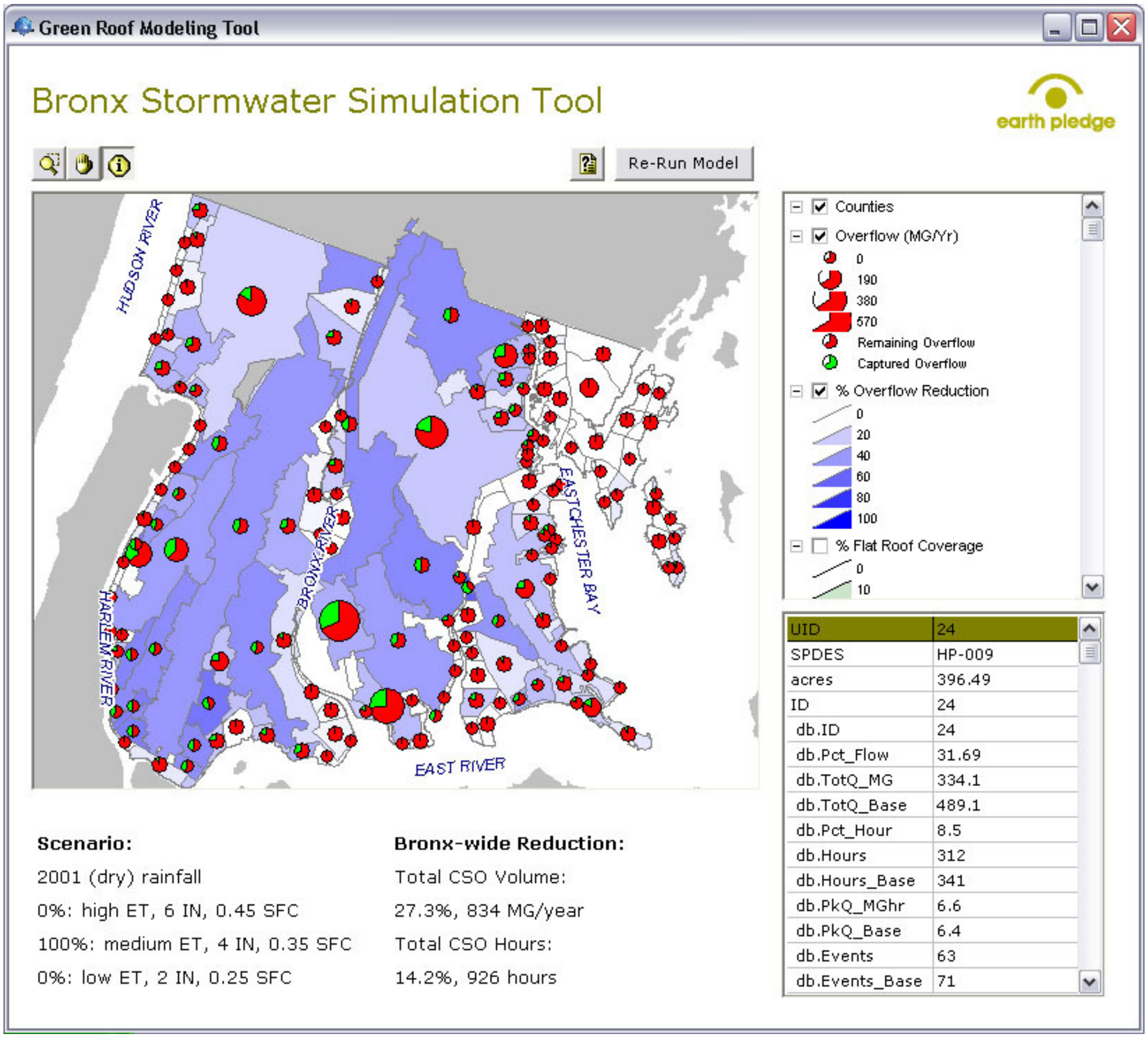

Figure 31H. Results for medium performance scenario, 100% coverage, dry rainfall.

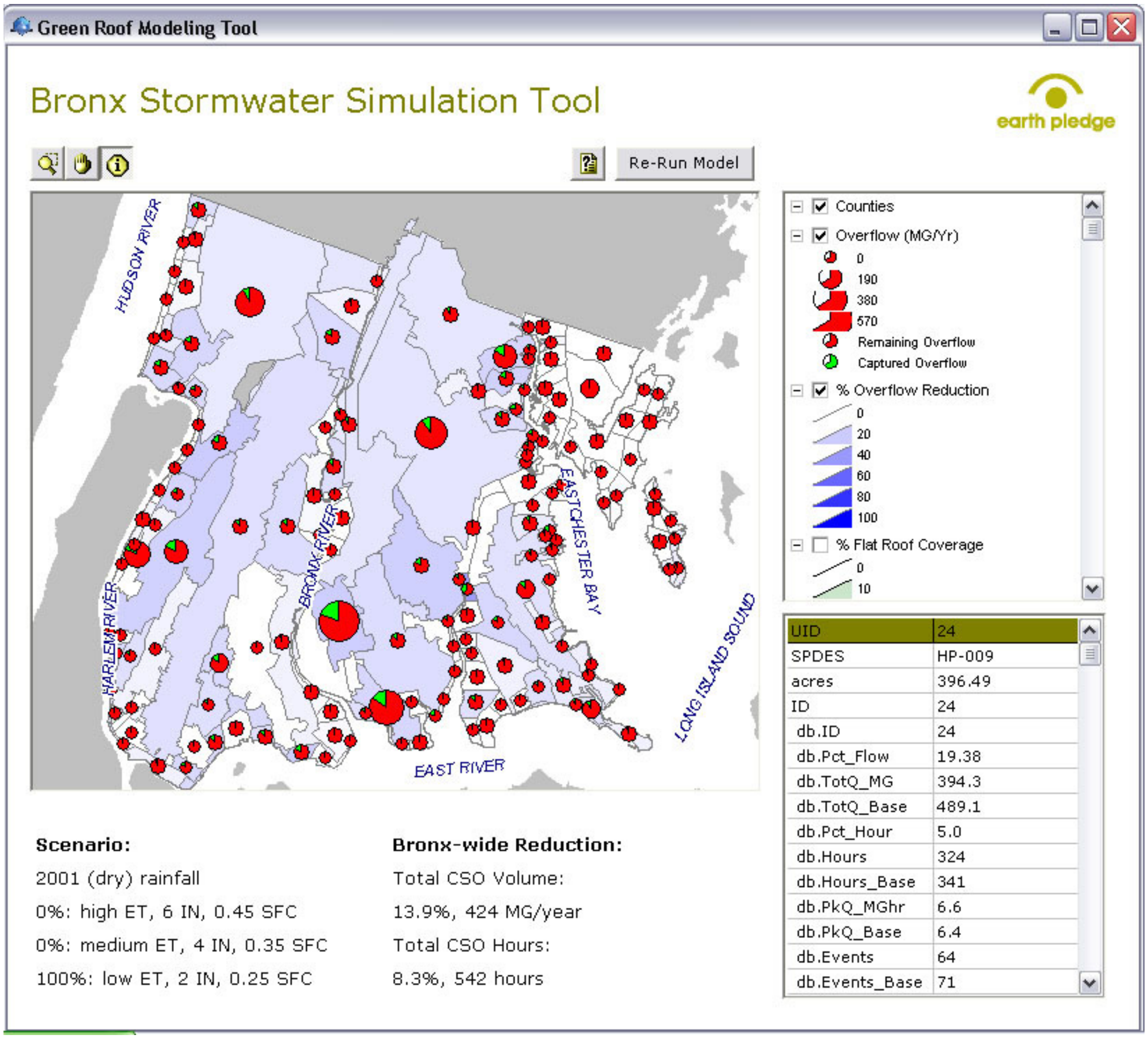

Figure 31I. Results for low performance scenario, 100% coverage, dry rainfall.

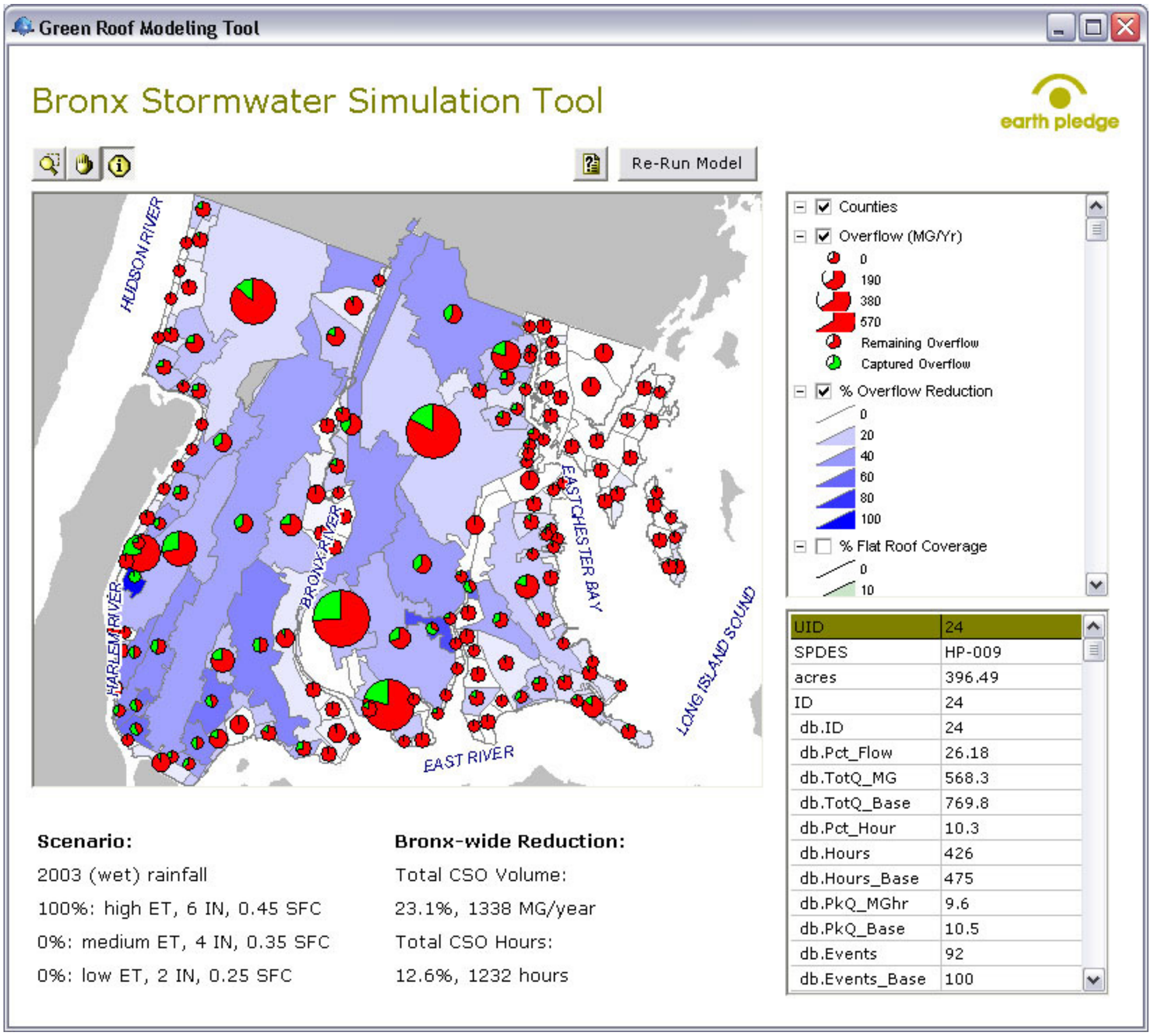

Figure 31J. Results for high performance scenario, 100% coverage, wet rainfall.

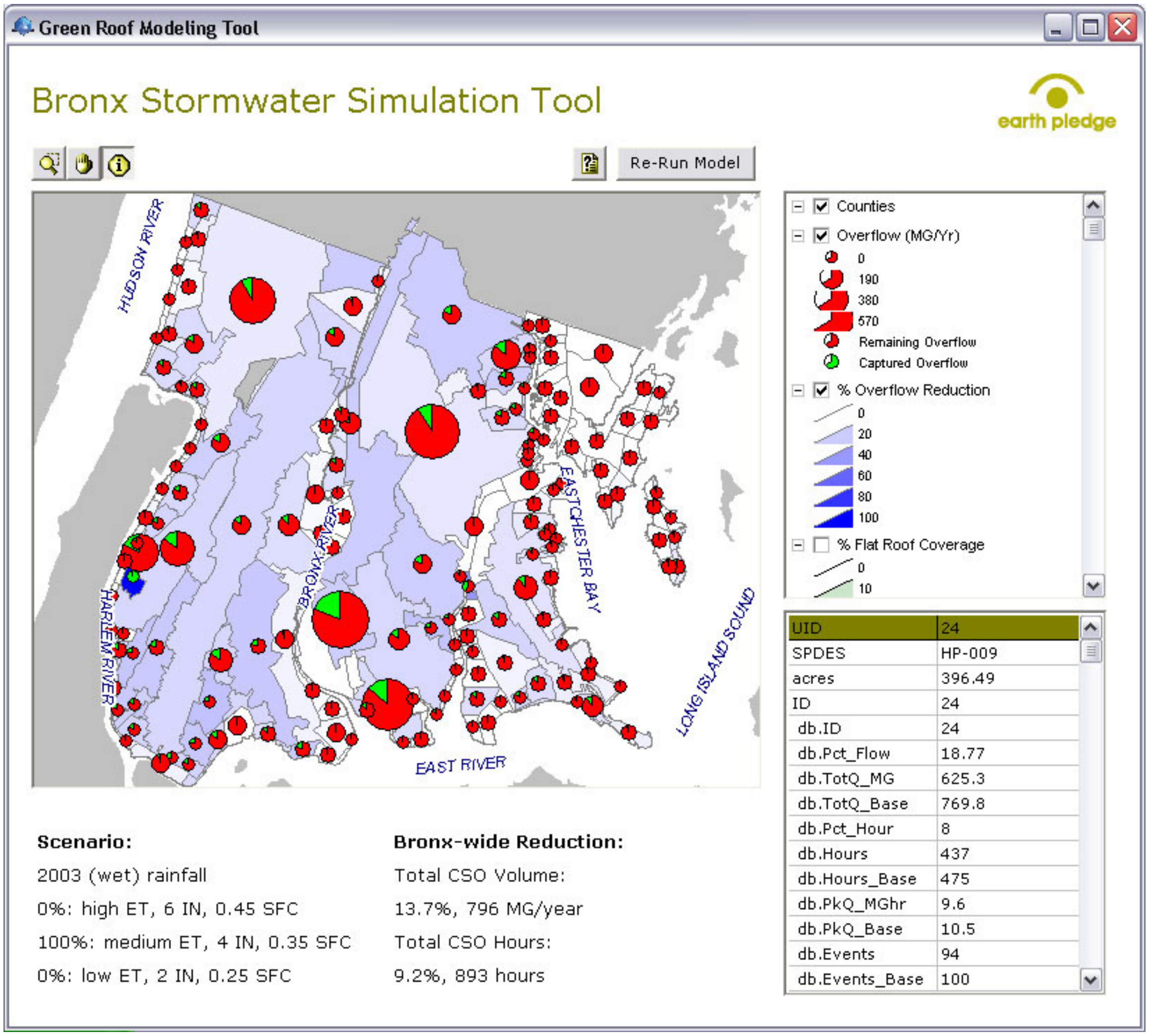

Figure 31K. Results for medium performance scenario, 100% coverage, wet rainfall.

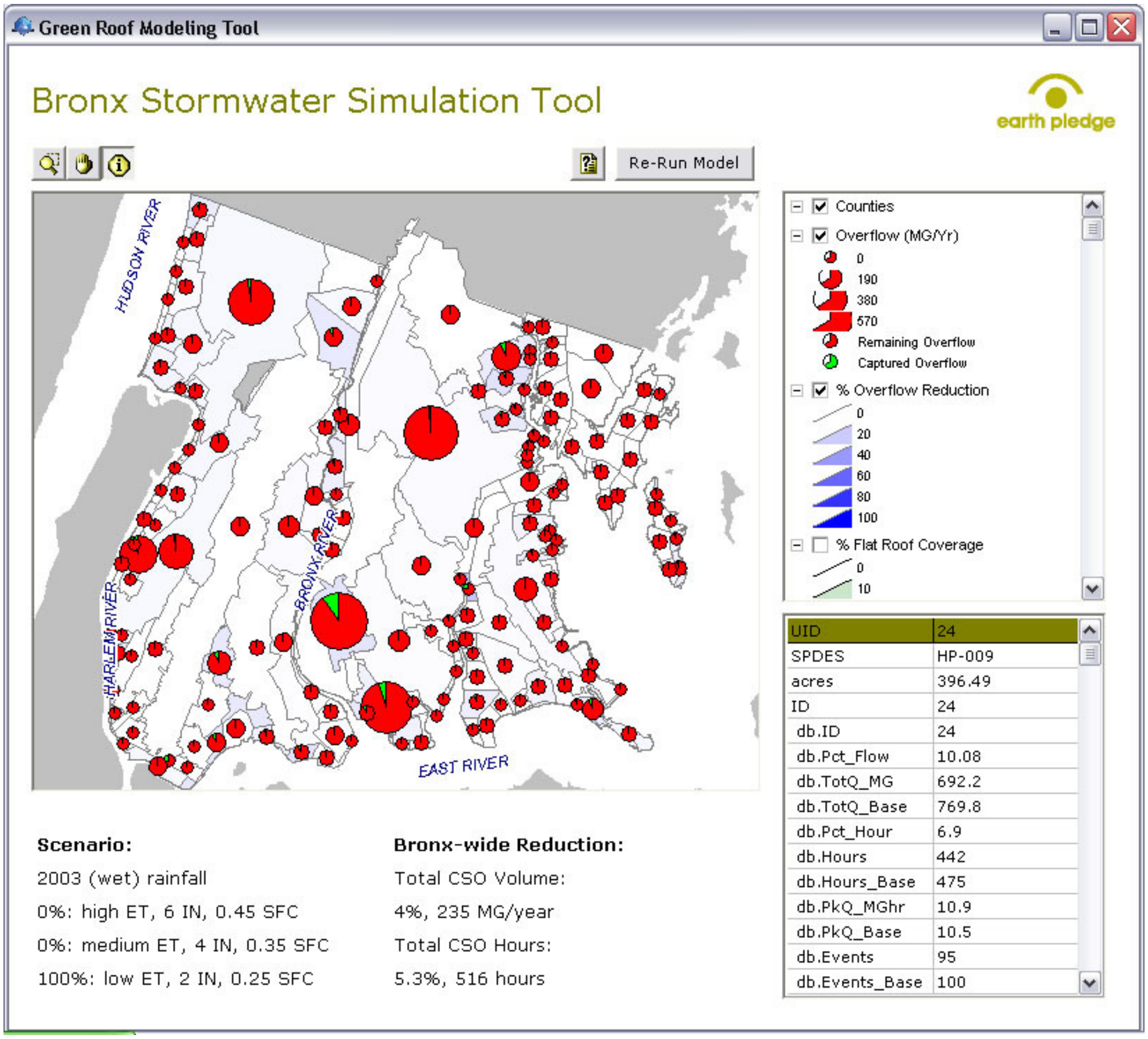

Figure 31L. Results for low performance scenario, 100% coverage, wet rainfall.

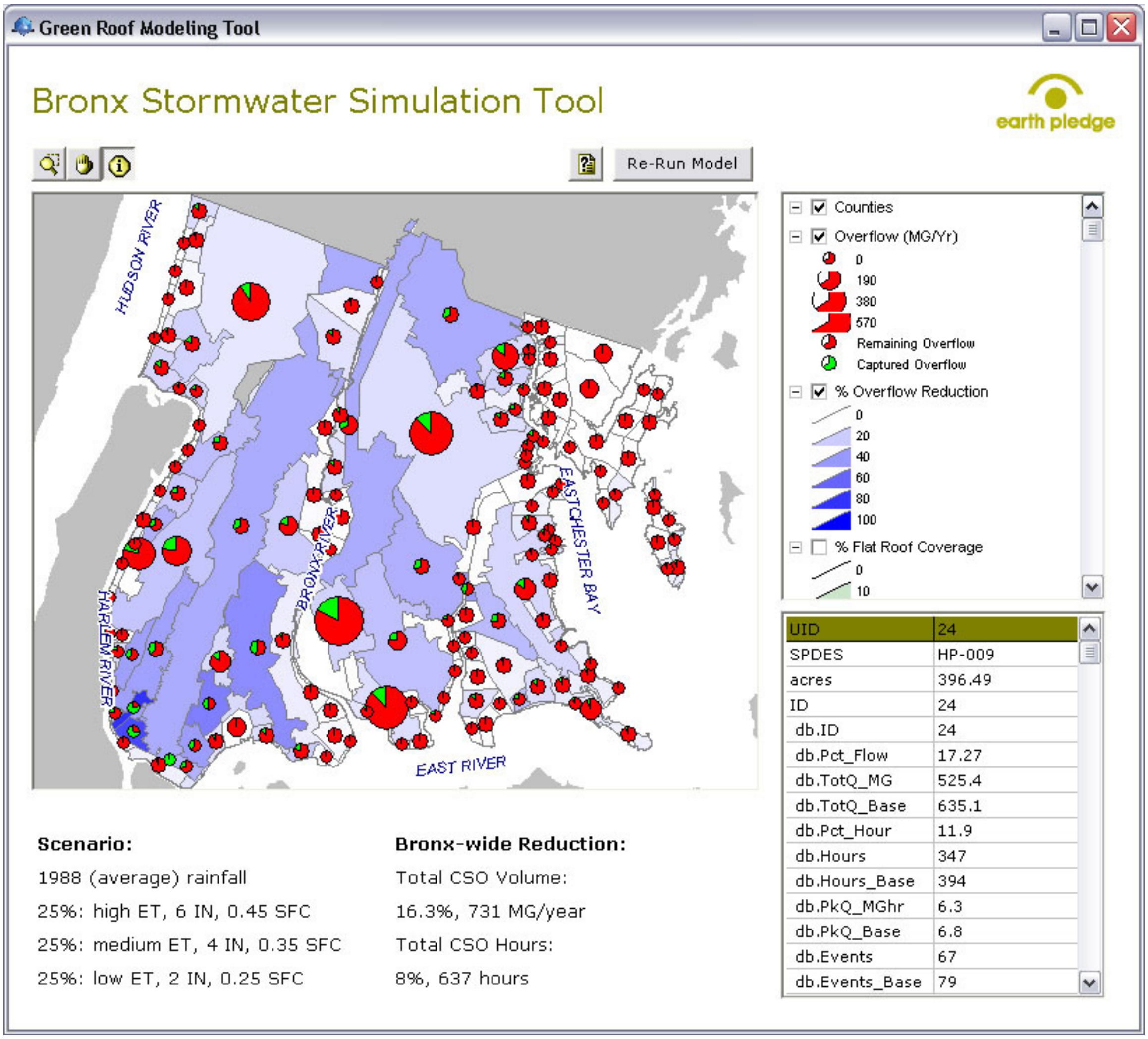

Figure 31M. Results for mixed scenario, 25% coverage each high/medium/low, average rainfall.

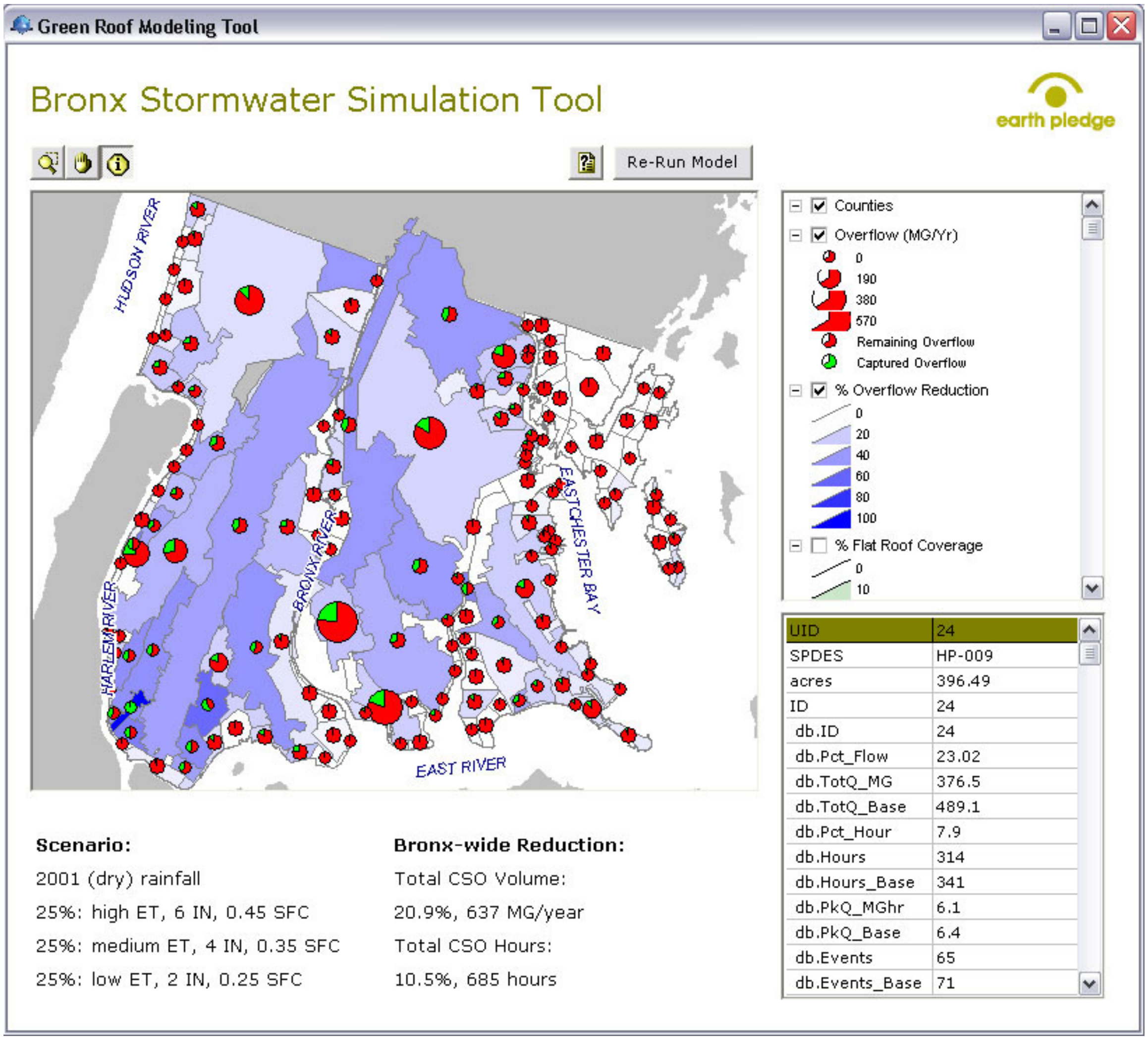

Figure 31N. Results for mixed scenario, 25% coverage each high/medium/low, dry rainfall.

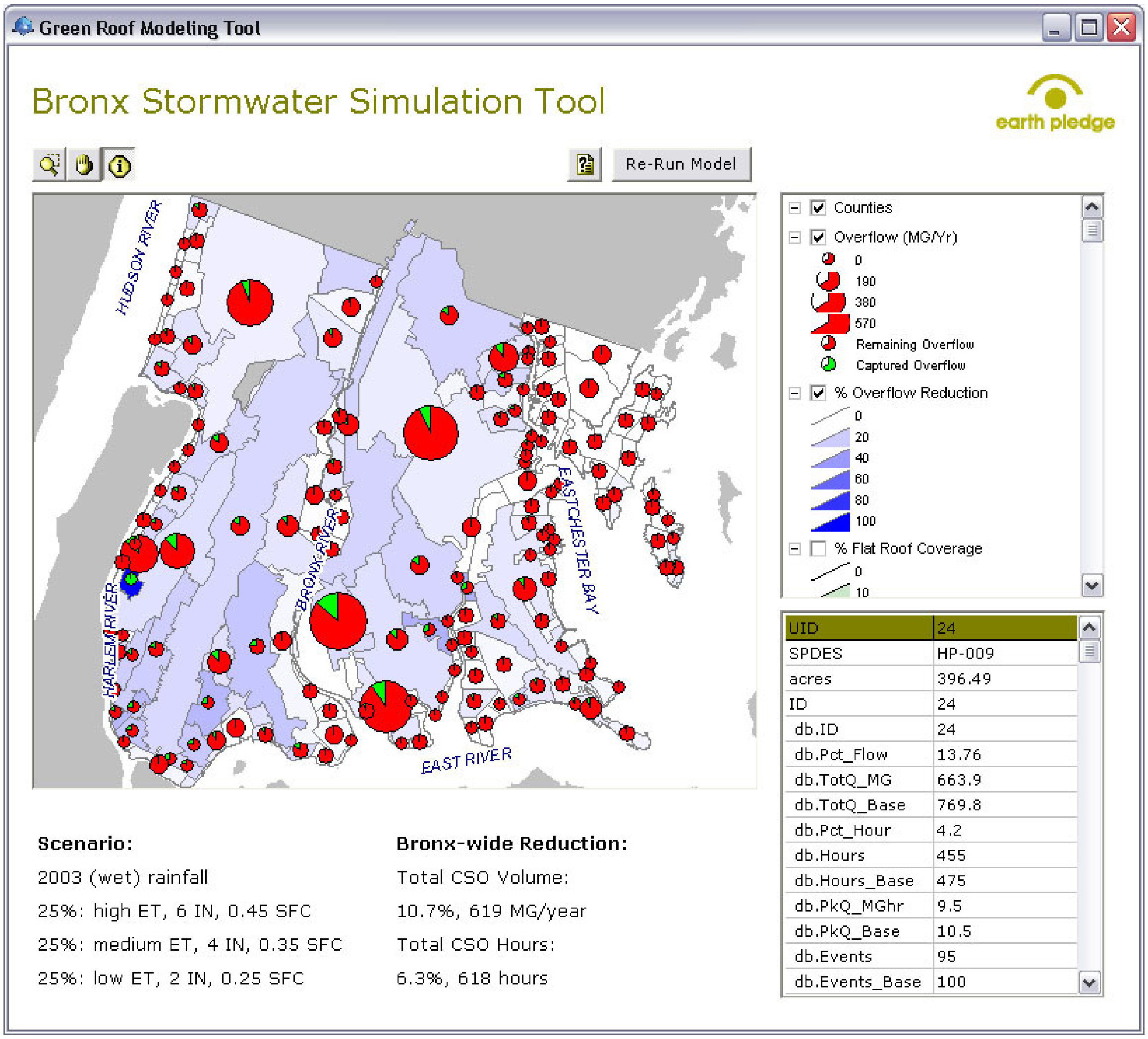

Figure 31O. Results for mixed scenario, 25% coverage each high/medium/low, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	16.7	8	14	2.2	6.1	2	4	27	20	22
HP-003	51.7	26	66	3	2.1	0	0	4	0	0
HP-004	77.2	35	88	3.6	9.6	0	3	11	0	3
HP-007	63.8	19	45	4.9	16.2	3	11	20	14	20
HP-009	585.4	79	394	6.4	49.7	0	0	8	0	0
HP-011	500.5	48	180	6.6	34.1	3	5	6	6	3
HP-013	87.5	25	65	5.2	13.5	1	1	13	4	2
HP-014	496.3	39	123	18	35.5	1	6	7	3	5
HP-016	24.5	27	68	1.4	4.2	3	5	15	10	7
HP-017	37	52	196	1	0.8	0	0	2	0	0
HP-018	1	18	37	0.1	0.2	0	3	17	0	8
HP-019	18.8	57	224	0.4	1.4	4	24	7	7	10
HP-020	34.3	39	123	1.1	1.4	1	6	4	3	5
HP-021	116	57	224	0.9	4.4	4	24	4	7	10
HP-022	23.9	41	138	0.8	0.9	0	0	4	0	0
HP-023	230.6	60	253	3.2	15.3	2	12	6	3	5
HP-024	36.6	19	45	2.8	9.3	3	11	20	14	20
HP-025	127.4	91	568	1.8	9.6	0	0	7	0	0
HP-026	141.1	91	568	4.4	12.2	0	0	8	0	0
HP-028	11	62	271	0.2	0.4	1	14	4	2	5
HP-029	0.5	18	39	0	0	0	3	0	0	7
HP-031	49.4	91	568	0.8	1.2	0	0	2	0	0
HP-033	53.7	36	96	2.3	11.4	1	8	18	3	8
WI--05	0.4	5	10	0.1	0	0	1	0	0	9
WI-053	30.6	86	447	0.5	0.9	0	0	3	0	0
WI-054	42.6	63	290	0.9	0.7	1	22	2	2	7
WI-055	19.7	64	319	0.3	1	3	18	5	4	5
WI-056	426	52	196	11.1	20.4	0	0	5	0	0
WI-057	52.2	46	149	1.6	7.8	1	12	13	2	7
WI-058	22	42	142	0.7	2.7	2	0	11	5	0
WI-059	3.8	11	23	0.4	0.8	2	6	17	15	21
WI-060	281	91	568	7.7	33.7	0	0	11	0	0
WI-062	246.9	39	121	8.7	33	1	8	12	3	6
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	8	21	55	0.5	2.5	3	8	24	13	13
WI-065	0.7	18	39	0.1	0.2	1	8	22	5	17
WI-066	0.2	4	5	0.1	0.3	1	5	60	20	50
WI-067	0.4	5	7	0.1	0.3	0	3	43	0	30
WI-068	41.5	28	72	3.2	9.3	5	7	18	15	9
WI-069	0	4	5	0	0.1	1	3	100	20	38
WI-070	5.9	32	81	0.3	1.1	3	8	16	9	9
WI-071	4.8	12	24	0.5	1.5	1	6	24	8	20
WI-072	7.3	20	51	0.5	3.9	6	15	35	23	23
WI-075	19.9	14	32	1.8	5.8	4	7	23	22	18
WI-076	27.1	52	200	0.7	2.3	2	6	8	4	3
WI-077	58.6	47	164	1.7	5.9	1	13	9	2	7
WI-078	14.3	47	164	0.4	1.3	1	13	8	2	7

Table 19A. CSO results for high performance scenario, 25% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	11.7	7	13	2.2	11.1	3	5	49	30	28
HP-003	49.7	26	66	2.9	4.1	0	0	8	0	0
HP-004	68	32	83	3.3	18.8	3	8	22	9	9
HP-007	50.4	16	38	4.6	29.6	6	18	37	27	32
HP-009	534.5	67	344	6.3	100.6	12	50	16	15	13
HP-011	467.9	47	167	6.4	66.7	4	18	12	8	10
HP-013	74.3	23	60	4.7	26.7	3	6	26	12	9
HP-014	461.9	39	121	16.9	69.9	1	8	13	3	6
HP-016	20.4	24	64	1.2	8.3	6	9	29	20	12
HP-017	35.6	51	186	0.9	2.2	1	10	6	2	5
HP-018	0.8	14	32	0.1	0.4	4	8	33	22	20
HP-019	17.5	54	210	0.4	2.7	7	38	13	11	15
HP-020	33.1	39	121	1.1	2.6	1	8	7	3	6
HP-021	111.9	57	224	0.9	8.5	4	24	7	7	10
HP-022	23.1	40	133	0.8	1.7	1	5	7	2	4
HP-023	214.2	56	229	3.1	31.7	6	36	13	10	14
HP-024	29	16	38	2.7	16.9	6	18	37	27	32
HP-025	118.7	91	568	1.7	18.3	0	0	13	0	0
HP-026	129.1	91	568	4	24.2	0	0	16	0	0
HP-028	10.5	62	271	0.2	0.9	1	14	8	2	5
HP-029	0.4	16	34	0	0.1	2	8	20	11	19
HP-031	48	91	568	0.7	2.6	0	0	5	0	0
HP-033	43.2	30	82	2.3	21.9	7	22	34	19	21
WI--05	0.4	5	10	0.1	0	0	1	0	0	9
WI-053	29.7	86	447	0.5	1.8	0	0	6	0	0
WI-054	42	63	290	0.8	1.3	1	22	3	2	7
WI-055	19.3	64	319	0.3	1.4	3	18	7	4	5
WI-056	405.8	51	186	10.6	40.6	1	10	9	2	5
WI-057	44.5	42	141	1.6	15.5	5	20	26	11	12
WI-058	19.3	40	131	0.7	5.4	4	11	22	9	8
WI-059	3.1	10	20	0.4	1.5	3	9	33	23	31
WI-060	248.1	91	568	7.3	66.6	0	0	21	0	0
WI-062	215.2	38	115	8.2	64.7	2	14	23	5	11
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	6.1	18	43	0.5	4.4	6	20	42	25	32
WI-065	0.6	15	36	0	0.3	4	11	33	21	23
WI-066	0.1	1	2	0.1	0.4	4	8	80	80	80
WI-067	0.2	4	5	0.1	0.5	1	5	71	20	50
WI-068	32.6	26	69	3	18.2	7	10	36	21	13
WI-069	0	4	5	0	0.1	1	3	100	20	38
WI-070	4.8	27	73	0.3	2.2	8	16	31	23	18
WI-071	3.6	10	20	0.5	2.7	3	10	43	23	33
WI-072	4.8	14	34	0.5	6.4	12	32	57	46	48
WI-075	15.4	12	24	1.8	10.3	6	15	40	33	38
WI-076	24.7	51	189	0.6	4.7	3	17	16	6	8
WI-077	53.1	47	160	1.6	11.4	1	17	18	2	10
WI-078	13.1	47	160	0.4	2.5	1	17	16	2	10

Table 19B. CSO results for high performance scenario, 50% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	7.2	7	12	2.2	15.6	3	6	68	30	33
HP-003	47.9	26	66	2.8	5.9	0	0	11	0	0
HP-004	59.7	28	76	3.3	27.1	7	15	31	20	16
HP-007	40	13	30	4.7	40	9	26	50	41	46
HP-009	483.3	67	344	6.3	151.8	12	50	24	15	13
HP-011	436.7	47	164	6.4	97.9	4	21	18	8	11
HP-013	62.7	20	49	4.8	38.3	6	17	38	23	26
HP-014	428.1	38	117	16	103.7	2	12	20	5	9
HP-016	16.8	21	54	1.3	11.9	9	19	41	30	26
HP-017	34.8	51	186	0.9	3	1	10	8	2	5
HP-018	0.7	12	25	0.1	0.5	6	15	42	33	38
HP-019	16.2	53	207	0.4	4	8	41	20	13	17
HP-020	31.4	38	111	1	4.3	2	18	12	5	14
HP-021	108	54	210	0.9	12.4	7	38	10	11	15
HP-022	22.3	40	133	0.8	2.5	1	5	10	2	4
HP-023	197.2	53	215	3	48.7	9	50	20	15	19
HP-024	23.1	13	30	2.7	22.8	9	26	50	41	46
HP-025	109	91	568	1.7	28	0	0	20	0	0
HP-026	117.5	91	568	4	35.8	0	0	23	0	0
HP-028	10.1	62	271	0.2	1.3	1	14	11	2	5
HP-029	0.4	14	32	0	0.1	4	10	20	22	24
HP-031	46.5	91	568	0.7	4.1	0	0	8	0	0
HP-033	34	27	75	2.3	31.1	10	29	48	27	28
WI--05	0.3	5	10	0.1	0.1	0	1	25	0	9
WI-053	29.1	86	447	0.4	2.4	0	0	8	0	0
WI-054	41.5	63	290	0.8	1.8	1	22	4	2	7
WI-055	18.6	64	319	0.3	2.1	3	18	10	4	5
WI-056	385.6	48	184	10	60.8	4	12	14	8	6
WI-057	37.4	40	123	1.6	22.6	7	38	38	15	24
WI-058	16.8	39	119	0.7	7.9	5	23	32	11	16
WI-059	2.6	9	18	0.4	2	4	11	43	31	38
WI-060	215.3	86	519	7.3	99.4	5	49	32	5	9
WI-062	183.5	37	104	8.3	96.4	3	25	34	8	19
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	4.6	14	34	0.5	5.9	10	29	56	42	46
WI-065	0.5	13	28	0	0.4	6	19	44	32	40
WI-066	0.1	1	2	0.1	0.4	4	8	80	80	80
WI-067	0.1	1	2	0.1	0.6	4	8	86	80	80
WI-068	25.5	23	63	3	25.3	10	16	50	30	20
WI-069	0	1	2	0	0.1	4	6	100	80	75
WI-070	3.8	22	62	0.3	3.2	13	27	46	37	30
WI-071	2.7	9	17	0.5	3.6	4	13	57	31	43
WI-072	3.3	11	26	0.6	7.9	15	40	71	58	61
WI-075	12	10	19	1.8	13.7	8	20	53	44	51
WI-076	22.6	48	184	0.6	6.8	6	22	23	11	11
WI-077	48.2	43	153	1.6	16.3	5	24	25	10	14
WI-078	12	43	153	0.4	3.6	5	24	23	10	14

Table 19C. CSO results for high performance scenario, 75% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	4.8	6	8	2.3	18	4	10	79	40	56
HP-003	46.1	25	64	2.8	7.7	1	2	14	4	3
HP-004	51.6	26	72	3.3	35.2	9	19	41	26	21
HP-007	32.2	11	25	4.8	47.8	11	31	60	50	55
HP-009	430.5	64	327	6.3	204.6	15	67	32	19	17
HP-011	402.4	46	156	6.4	132.2	5	29	25	10	16
HP-013	53	18	43	4.8	48	8	23	48	31	35
HP-014	395.9	38	115	16.1	135.9	2	14	26	5	11
HP-016	13.8	19	46	1.3	14.9	11	27	52	37	37
HP-017	33.6	51	186	0.9	4.2	1	10	11	2	5
HP-018	0.6	10	21	0.1	0.6	8	19	50	44	48
HP-019	14.8	51	194	0.4	5.4	10	54	27	16	22
HP-020	30	38	112	1	5.7	2	17	16	5	13
HP-021	103.6	53	207	0.9	16.8	8	41	14	13	17
HP-022	21.4	39	127	0.7	3.4	2	11	14	5	8
HP-023	179.5	52	211	3	66.4	10	54	27	16	20
HP-024	18.6	11	25	2.8	27.3	11	31	59	50	55
HP-025	99.7	86	519	1.8	37.3	5	49	27	5	9
HP-026	107.1	92	587	4.1	46.2	0	0	30	0	0
HP-028	9.7	60	260	0.2	1.7	3	25	15	5	9
HP-029	0.3	12	27	0	0.2	6	15	40	33	36
HP-031	45.1	91	568	0.7	5.5	0	0	11	0	0
HP-033	26.7	22	57	2.4	38.4	15	47	59	41	45
WI--05	0.3	5	10	0.1	0.1	0	1	25	0	9
WI-053	27.8	79	399	0.4	3.7	7	48	12	8	11
WI-054	41	63	290	0.8	2.3	1	22	5	2	7
WI-055	18.1	64	319	0.3	2.6	3	18	13	4	5
WI-056	365.8	48	184	9.9	80.6	4	12	18	8	6
WI-057	31.1	39	114	1.6	28.9	8	47	48	17	29
WI-058	14.4	38	109	0.7	10.3	6	33	42	14	23
WI-059	2.1	9	17	0.4	2.5	4	12	54	31	41
WI-060	184.4	86	519	7.4	130.3	5	49	41	5	9
WI-062	153.9	31	91	8.4	126	9	38	45	23	29
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	3.6	11	28	0.6	6.9	13	35	66	54	56
WI-065	0.4	11	24	0	0.5	8	23	56	42	49
WI-066	0.1	1	1	0.1	0.4	4	9	80	80	90
WI-067	0.1	1	2	0.1	0.6	4	8	86	80	80
WI-068	20.6	21	51	3.1	30.2	12	28	59	36	35
WI-069	0	1	1	0	0.1	4	7	100	80	88
WI-070	3.1	18	48	0.3	3.9	17	41	56	49	46
WI-071	1.9	9	15	0.5	4.4	4	15	70	31	50
WI-072	3	7	18	0.6	8.2	19	48	73	73	73
WI-075	9.2	9	17	1.8	16.5	9	22	64	50	56
WI-076	20.4	47	168	0.6	9	7	38	31	13	18
WI-077	43	41	140	1.6	21.5	7	37	33	15	21
WI-078	10.7	42	146	0.4	4.9	6	31	31	13	18

Table 19D. CSO results for high performance scenario, 100% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	9.1	7	11	2.3	13.7	3	7	60	30	39
HP-003	48.5	25	64	2.8	5.3	1	2	10	4	3
HP-004	62.2	28	76	3.4	24.6	7	15	28	20	16
HP-007	46.1	15	35	4.8	33.9	7	21	42	32	38
HP-009	482.7	65	339	6.3	152.4	14	55	24	18	14
HP-011	439.9	46	164	6.4	94.7	5	21	18	10	11
HP-013	68.1	20	51	4.8	32.9	6	15	33	23	23
HP-014	435.3	38	120	17	96.5	2	9	18	5	7
HP-016	18.4	22	56	1.3	10.3	8	17	36	27	23
HP-017	34.8	51	187	0.9	3	1	9	8	2	5
HP-018	0.8	14	30	0.1	0.4	4	10	33	22	25
HP-019	16.4	52	205	0.4	3.8	9	43	19	15	17
HP-020	31.5	38	118	1.1	4.2	2	11	12	5	9
HP-021	108	54	213	0.9	12.4	7	35	10	11	14
HP-022	22.4	39	128	0.8	2.4	2	10	10	5	7
HP-023	198.1	54	221	3.1	47.8	8	44	19	13	17
HP-024	26.5	15	35	2.8	19.4	7	21	42	32	38
HP-025	109.1	86	526	1.8	27.9	5	42	20	5	7
HP-026	120.8	92	596	4.2	32.5	0	0	21	0	0
HP-028	10.1	61	262	0.2	1.3	2	23	11	3	8
HP-029	0.4	15	33	0	0.1	3	9	20	17	21
HP-031	46.6	91	568	0.7	4	0	0	8	0	0
HP-033	38.5	27	72	2.4	26.6	10	32	41	27	31
WI--05	0.3	5	10	0.1	0.1	0	1	25	0	9
WI-053	28.7	80	406	0.5	2.8	6	41	9	7	9
WI-054	41.6	63	294	0.8	1.7	1	18	4	2	6
WI-055	18.7	64	322	0.3	2	3	15	10	4	4
WI-056	388.8	49	186	10.5	57.6	3	10	13	6	5
WI-057	39.6	40	130	1.6	20.4	7	31	34	15	19
WI-058	17.4	39	119	0.7	7.3	5	23	30	11	16
WI-059	2.7	11	21	0.4	1.9	2	8	41	15	28
WI-060	221.6	86	526	7.4	93.1	5	42	30	5	7
WI-062	192.7	32	101	8.4	87.2	8	28	31	20	22
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	5.6	15	39	0.6	4.9	9	24	47	38	38
WI-065	0.6	15	34	0	0.3	4	13	33	21	28
WI-066	0.2	2	4	0.1	0.3	3	6	60	60	60
WI-067	0.2	2	4	0.1	0.5	3	6	71	60	60
WI-068	29.1	23	58	3.1	21.7	10	21	43	30	27
WI-069	0	2	4	0	0.1	3	4	100	60	50
WI-070	4.3	24	61	0.3	2.7	11	28	39	31	31
WI-071	3	12	21	0.5	3.3	1	9	52	8	30
WI-072	5.4	15	33	0.6	5.8	11	33	52	42	50
WI-075	13.7	13	24	1.8	12	5	15	47	28	38
WI-076	22.9	48	175	0.6	6.5	6	31	22	11	15
WI-077	49.2	42	151	1.6	15.3	6	26	24	13	15
WI-078	12.2	43	157	0.4	3.4	5	20	22	10	11

Table 19E. CSO results for medium performance scenario, 100% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	21.6	8	16	3	1.2	2	2	5	20	11
HP-003	52.5	25	65	3	1.3	1	1	2	4	2
HP-004	79.8	30	83	4	7	5	8	8	14	9
HP-007	75.6	19	46	5.8	4.4	3	10	6	14	18
HP-009	546.5	65	354	6.9	88.6	14	40	14	18	10
HP-011	481.7	48	169	6.8	52.9	3	16	10	6	9
HP-013	93.9	23	59	5.8	7.1	3	7	7	12	11
HP-014	495.2	38	126	18.8	36.6	2	3	7	5	2
HP-016	26.4	25	64	1.5	2.3	5	9	8	17	12
HP-017	36.5	51	190	1	1.3	1	6	3	2	3
HP-018	1.1	18	39	0.1	0.1	0	1	8	0	3
HP-019	18.5	52	217	0.4	1.7	9	31	8	15	13
HP-020	33.7	38	122	1.1	2	2	7	6	5	5
HP-021	112	54	222	0.9	8.4	7	26	7	11	10
HP-022	23.8	39	130	0.8	1	2	8	4	5	6
HP-023	217.4	54	233	3.2	28.5	8	32	12	13	12
HP-024	43.4	19	46	3.3	2.5	3	10	5	14	18
HP-025	122.1	88	536	2	14.9	3	32	11	3	6
HP-026	141.5	92	606	4.7	11.8	0	0	8	0	0
HP-028	10.7	61	270	0.2	0.7	2	15	6	3	5
HP-029	0.5	18	38	0	0	0	4	0	0	10
HP-031	48.9	91	568	0.8	1.7	0	0	3	0	0
HP-033	58.2	28	84	2.8	6.9	9	20	11	24	19
WI--05	0.4	5	11	0.1	0	0	0	0	0	0
WI-053	29.9	79	412	0.5	1.6	7	35	5	8	8
WI-054	42.5	63	298	0.9	0.8	1	14	2	2	4
WI-055	19.7	64	324	0.3	1	3	13	5	4	4
WI-056	420.2	52	192	11.4	26.2	0	4	6	0	2
WI-057	52.3	41	140	1.9	7.7	6	21	13	13	13
WI-058	21.9	40	125	0.8	2.8	4	17	11	9	12
WI-059	4.4	13	28	0.5	0.2	0	1	4	0	3
WI-060	276.6	87	535	8.4	38.1	4	33	12	4	6
WI-062	249.1	33	109	9.5	30.8	7	20	11	18	16
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	9.7	20	51	0.7	0.8	4	12	8	17	19
WI-065	0.8	19	45	0.1	0.1	0	2	11	0	4
WI-066	0.5	5	9	0.1	0	0	1	0	0	10
WI-067	0.7	5	9	0.1	0	0	1	0	0	10
WI-068	46.9	25	67	4.1	3.9	8	12	8	24	15
WI-069	0.1	5	8	0	0	0	0	0	0	0
WI-070	6.3	27	71	0.3	0.7	8	18	10	23	20
WI-071	6.1	14	29	0.6	0	0	1	3	0	3
WI-072	10.5	23	53	0.7	0.7	3	13	6	12	20
WI-075	24.6	16	34	2.2	1.1	2	5	4	11	13
WI-076	26.5	51	185	0.7	2.9	3	21	10	6	10
WI-077	58.1	44	160	1.8	6.4	4	17	10	8	10
WI-078	14.3	45	164	0.4	1.3	3	13	8	6	7

Table 19F. CSO results for low performance scenario, 100% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	0.9	1	1	0.9	9	4	9	91	80	90
HP-003	25	18	40	2.4	6.1	2	7	20	10	15
HP-004	25.8	18	42	2.2	25.9	7	21	50	28	33
HP-007	11.2	6	12	2.8	32.4	10	23	74	63	66
HP-009	285.2	60	281	5.3	203.9	11	60	42	15	18
HP-011	255	37	116	5.6	134.3	8	31	35	18	21
HP-013	24.1	14	25	3	34.2	6	22	59	30	47
HP-014	225.2	28	80	12.9	105.6	5	17	32	15	18
HP-016	6.1	14	25	0.8	10.7	6	22	64	30	47
HP-017	21.8	45	147	0.8	3.6	0	8	14	0	5
HP-018	0.2	5	10	0	0.4	11	17	67	69	63
HP-019	9.3	45	151	0.3	4.8	4	54	34	8	26
HP-020	18	26	74	0.9	4.8	7	23	21	21	24
HP-021	74.1	45	159	0.9	20.4	4	46	22	8	22
HP-022	12.9	30	93	0.6	2.8	3	10	18	9	10
HP-023	114.7	45	159	2.8	65.1	6	62	36	12	28
HP-024	6.5	6	12	1.6	18.4	10	23	74	63	66
HP-025	70.4	82	432	1.3	35.2	2	76	33	2	15
HP-026	63.9	84	512	2.9	37.1	0	0	37	0	0
HP-028	6.7	49	207	0.2	1.7	6	40	20	11	16
HP-029	0.2	9	16	0	0.1	7	12	33	44	43
HP-031	33.6	84	508	0.6	5	0	0	13	0	0
HP-033	11.3	16	31	1.6	28.2	12	41	71	43	57
WI--05	0.1	3	5	0	0.1	0	1	50	0	17
WI-053	20.4	71	345	0.4	3.4	2	43	14	3	11
WI-054	29	56	249	0.7	2.3	3	26	7	5	9
WI-055	12.9	59	276	0.3	2.7	3	27	17	5	9
WI-056	231.4	43	138	8.5	70.3	2	17	23	4	11
WI-057	15.8	22	67	1.1	23.4	18	60	60	45	47
WI-058	7.7	24	71	0.5	8.1	13	44	51	35	38
WI-059	0.7	4	7	0.2	1.6	7	10	70	64	59
WI-060	109.3	82	432	5.4	110.1	2	76	50	2	15
WI-062	77.3	21	60	6	97.7	12	37	56	36	38
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	1.2	5	12	0.3	4.7	13	30	80	72	71
WI-065	0.1	5	11	0	0.4	12	19	80	71	63
WI-066	0	1	1	0	0.2	1	3	100	50	75
WI-067	0	0	0	0	0.2	2	3	100	100	100
WI-068	8.6	15	27	1.2	18.2	5	21	68	25	44
WI-069	0	0	0	0	0	1	2	0	100	100
WI-070	1.3	15	27	0.2	2.8	9	31	68	38	53
WI-071	0.4	3	4	0.3	2.7	9	14	87	75	78
WI-072	0.9	3	6	0.4	5.6	17	41	86	85	87
WI-075	2.7	4	8	1	10.5	12	18	80	75	69
WI-076	12.3	39	124	0.4	7.8	7	49	39	15	28
WI-077	24.6	30	95	1.1	18.1	13	40	42	30	30
WI-078	6.3	33	102	0.3	4.1	10	33	39	23	24

Table 19G. CSO results for high performance scenario, 100% coverage, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	5.6	3	4	2.6	4.3	2	6	43	40	60
HP-003	27.2	19	41	2.7	3.9	1	6	13	5	13
HP-004	35.2	21	51	3.6	16.5	4	12	32	16	19
HP-007	24.2	10	18	5.2	19.4	6	17	45	38	49
HP-009	334.1	63	312	6.6	155	8	29	32	11	9
HP-011	285.9	38	120	6.6	103.4	7	27	27	16	18
HP-013	36.4	17	31	5.2	21.9	3	16	38	15	34
HP-014	259.9	28	85	17.2	70.9	5	12	21	15	12
HP-016	9.9	17	31	1.4	6.9	3	16	41	15	34
HP-017	22.8	45	149	0.9	2.6	0	6	10	0	4
HP-018	0.4	8	15	0.1	0.2	8	12	33	50	44
HP-019	10.6	46	160	0.4	3.5	3	45	25	6	22
HP-020	19.4	26	79	1	3.4	7	18	15	21	19
HP-021	77.7	46	166	0.9	16.8	3	39	18	6	19
HP-022	13.8	30	95	0.8	1.9	3	8	12	9	8
HP-023	130	46	168	3	49.8	5	53	28	10	24
HP-024	13.9	10	18	3	11	6	17	44	38	49
HP-025	79.8	80	450	1.9	25.8	4	58	24	5	11
HP-026	76.5	83	536	4.3	24.5	1	0	24	1	0
HP-028	7.1	49	213	0.2	1.3	6	34	15	11	14
HP-029	0.2	10	19	0	0.1	6	9	33	38	32
HP-031	35	84	508	0.7	3.6	0	0	9	0	0
HP-033	21.4	20	41	2.5	18.1	8	31	46	29	43
WI--05	0.1	3	6	0.1	0.1	0	0	50	0	0
WI-053	21.4	71	361	0.4	2.4	2	27	10	3	7
WI-054	29.7	56	255	0.8	1.6	3	20	5	5	7
WI-055	13.5	60	283	0.3	2.1	2	20	13	3	7
WI-056	251	43	146	10.5	50.7	2	9	17	4	6
WI-057	23.2	25	77	1.7	16	15	50	41	38	39
WI-058	10.4	25	76	0.7	5.4	12	39	34	32	34
WI-059	1.4	6	9	0.4	0.9	5	8	39	45	47
WI-060	142	80	449	7.8	77.4	4	59	35	5	12
WI-062	110	23	69	8.8	65	10	28	37	30	29
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	3.1	12	20	0.6	2.8	6	22	47	33	52
WI-065	0.3	9	17	0.1	0.2	8	13	40	47	43
WI-066	0.1	3	3	0.1	0.1	0	1	50	0	25
WI-067	0.1	2	2	0.1	0.1	0	1	50	0	33
WI-068	16	19	35	3.5	10.8	1	13	40	5	27
WI-069	0	1	1	0	0	0	1	0	0	50
WI-070	2.3	19	38	0.3	1.8	5	20	44	21	34
WI-071	1.7	6	10	0.6	1.4	6	8	45	50	44
WI-072	3	11	18	0.6	3.5	9	29	54	45	62
WI-075	7.3	6	12	2	5.9	10	14	45	63	54
WI-076	14.5	42	134	0.7	5.6	4	39	28	9	23
WI-077	29.9	31	101	1.7	12.8	12	34	30	28	25
WI-078	7.5	34	107	0.4	2.9	9	28	28	21	21

Table 19H. CSO results for medium performance scenario, 100% coverage, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	11	6	11	2.6	0	0	0	0	0	0
HP-003	29.5	19	43	2.7	1.6	1	4	5	5	9
HP-004	44.9	21	54	3.6	6.8	4	9	13	16	14
HP-007	39.4	12	26	5.2	4.2	4	9	10	25	26
HP-009	394.3	64	324	6.6	94.8	7	17	19	10	5
HP-011	328.7	40	131	6.6	60.6	5	16	16	11	11
HP-013	50.5	18	36	5.2	7.8	2	11	13	10	23
HP-014	296.7	30	89	17.2	34.1	3	8	10	9	8
HP-016	14.2	18	37	1.4	2.6	2	10	15	10	21
HP-017	24	46	152	0.9	1.4	0	3	6	0	2
HP-018	0.6	11	22	0.1	0	5	5	0	31	19
HP-019	12.4	47	174	0.4	1.7	2	31	12	4	15
HP-020	20.9	29	86	1	1.9	4	11	8	12	11
HP-021	84.6	46	177	0.9	9.9	3	28	10	6	14
HP-022	14.7	33	99	0.8	1	0	4	6	0	4
HP-023	150	46	183	3	29.8	5	38	17	10	17
HP-024	22.6	12	26	3	2.3	4	9	9	25	26
HP-025	90.3	80	467	1.9	15.3	4	41	14	5	8
HP-026	89.6	82	553	4.3	11.4	2	0	11	2	0
HP-028	7.8	48	224	0.2	0.6	7	23	7	13	9
HP-029	0.2	11	21	0	0.1	5	7	33	31	25
HP-031	36.8	84	508	0.7	1.8	0	0	5	0	0
HP-033	32.2	21	51	2.5	7.3	7	21	18	25	29
WI--05	0.2	3	6	0.1	0	0	0	0	0	0
WI-053	22.4	71	365	0.4	1.4	2	23	6	3	6
WI-054	30.4	56	258	0.8	0.9	3	17	3	5	6
WI-055	14.4	60	288	0.3	1.2	2	15	8	3	5
WI-056	275.2	45	157	10.5	26.5	0	0	9	0	0
WI-057	31.4	33	96	1.7	7.8	7	31	20	18	24
WI-058	13.2	30	89	0.7	2.6	7	26	16	19	23
WI-059	2.2	8	14	0.4	0.1	3	3	4	27	18
WI-060	179.4	80	465	7.8	40	4	43	18	5	8
WI-062	144.2	26	81	8.8	30.8	7	16	18	21	16
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	5.2	15	30	0.6	0.7	3	12	12	17	29
WI-065	0.5	11	25	0.1	0	6	5	0	35	17
WI-066	0.2	3	6	0.1	0	0	0	0	0	0
WI-067	0.2	2	4	0.1	0	0	0	0	0	0
WI-068	23.7	20	42	3.5	3.1	0	6	12	0	13
WI-069	0	1	2	0	0	0	0	0	0	0
WI-070	3.5	20	45	0.3	0.6	4	13	15	17	22
WI-071	3.2	8	15	0.6	0	4	3	0	33	17
WI-072	5.7	15	30	0.6	0.8	5	17	12	25	36
WI-075	12.6	8	18	2	0.6	8	8	5	50	31
WI-076	17.2	44	152	0.7	2.9	2	21	14	4	12
WI-077	36.1	38	119	1.7	6.6	5	16	15	12	12
WI-078	8.9	38	122	0.4	1.5	5	13	14	12	10

Table 19I. CSO results for low performance scenario, 100% coverage, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	24.6	9	18	6.6	22.9	7	17	48	44	49
HP-003	72.5	26	62	6	7.1	1	3	9	4	5
HP-004	89.3	32	88	7.1	29.7	4	17	25	11	16
HP-007	78.5	20	41	11.1	53.5	4	16	41	17	28
HP-009	568.3	92	426	9.6	201.5	8	49	26	8	10
HP-011	511.6	51	187	8.9	135.8	8	37	21	14	17
HP-012	0.4	1	1	0.4	0.9	1	2	69	50	67
HP-013	104.7	22	55	10.3	43.8	5	10	29	19	15
HP-014	577	42	136	32.8	119.6	3	17	17	7	11
HP-016	27.7	23	62	2.8	13.6	7	14	33	23	18
HP-017	44.4	60	228	1.8	3.8	2	11	8	3	5
HP-018	1.3	19	38	0.2	0.7	2	12	35	10	24
HP-019	20.4	61	241	0.8	5.2	12	53	20	16	18
HP-020	40.8	39	129	2	5.4	6	24	12	13	16
HP-021	125.9	63	252	1.2	21.2	10	42	14	14	14
HP-022	29.2	45	152	1.5	3.1	2	14	10	4	8
HP-023	233	65	264	4.4	60.8	14	68	21	18	20
HP-024	45.3	20	41	6.5	30.7	4	16	40	17	28
HP-025	134	117	642	3.2	39	0	103	23	0	14
HP-026	158.9	116	775	8.2	40.7	0	0	20	0	0
HP-028	12.5	75	315	0.3	1.9	9	43	13	11	12
HP-029	0.6	20	43	0	0.1	2	9	14	9	17
HP-031	58.6	116	745	1.3	5.4	0	0	8	0	0
HP-033	54.3	29	86	5	33.3	10	32	38	26	27
WI--05	0.7	10	16	0.2	0.2	1	4	22	9	20
WI-053	35.9	101	493	0.8	3.4	3	39	9	3	7
WI-054	52.3	83	360	1.5	2.5	7	31	5	8	8
WI-055	23.3	91	398	0.6	3	4	24	11	4	6
WI-056	492.2	57	218	19.2	77.5	5	21	14	8	9
WI-057	51.6	43	132	3.2	26	11	67	34	20	34
WI-058	22.9	41	129	1.4	9.1	7	43	28	15	25
WI-059	5.7	14	29	1	3.2	2	10	36	13	26
WI-060	285.7	117	642	13.5	120.4	0	103	30	0	14
WI-061	0	0	0	0	1.8	1	1	100	100	100
WI-062	257.1	35	113	15.3	101.3	10	40	28	22	26
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	8.7	19	39	1.2	7.3	7	22	46	27	36
WI-065	0.8	18	37	0.1	0.5	5	16	38	22	30
WI-066	0.5	4	6	0.3	0.6	4	8	55	50	57
WI-067	0.8	5	7	0.4	1	3	6	56	38	46
WI-068	51.1	24	70	9	29.1	6	9	36	20	11
WI-069	0.2	3	5	0.1	0.1	1	2	33	25	29
WI-070	6.2	27	76	0.6	3.3	6	19	35	18	20
WI-071	6.6	12	25	1.3	5.6	5	17	46	29	40
WI-072	7.7	15	38	1.3	8.9	12	27	54	44	42
WI-075	26.1	16	30	4.5	20	5	20	43	24	40
WI-076	28.9	54	206	1.2	8.6	12	50	23	18	20
WI-077	62.8	49	168	3.1	20	7	39	24	13	19
WI-078	15.4	49	172	0.7	4.7	7	35	23	13	17

Table 19J. CSO results for high performance scenario, 100% coverage, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	37.5	12	24	6.6	10	4	11	21	25	31
HP-003	75.9	26	62	6.2	3.7	1	3	5	4	5
HP-004	103.8	32	93	7.1	15.2	4	12	13	11	11
HP-007	106.2	22	49	11.1	25.8	2	8	20	8	14
HP-009	625.3	94	437	9.6	144.5	6	38	19	6	8
HP-011	558.3	51	191	9	89.1	8	33	14	14	15
HP-012	1	2	3	0.4	0.3	0	0	23	0	0
HP-013	126.4	26	61	10.3	22.1	1	4	15	4	6
HP-014	632.1	42	146	34.7	64.5	3	7	9	7	5
HP-016	34.5	26	67	2.8	6.8	4	9	16	13	12
HP-017	45.9	60	229	1.9	2.3	2	10	5	3	4
HP-018	1.7	20	45	0.2	0.3	1	5	15	5	10
HP-019	22.3	62	246	0.8	3.3	11	48	13	15	16
HP-020	43.1	38	139	2.2	3.1	7	14	7	16	9
HP-021	130.1	64	256	1.2	17	9	38	12	12	13
HP-022	30.6	45	155	1.6	1.7	2	11	5	4	7
HP-023	250.9	67	273	4.7	42.9	12	59	15	15	18
HP-024	61.2	22	49	6.5	14.8	2	8	19	8	14
HP-025	145.8	116	654	3.2	27.2	0	91	16	0	12
HP-026	177.6	115	799	8.3	22	1	0	11	1	0
HP-028	13.2	77	321	0.3	1.2	7	37	8	8	10
HP-029	0.7	20	47	0	0	2	5	0	9	10
HP-031	60.7	116	745	1.4	3.3	0	0	5	0	0
HP-033	70.8	32	98	5	16.8	7	20	19	18	17
WI--05	0.8	10	17	0.2	0.1	1	3	11	9	15
WI-053	36.9	101	497	0.9	2.4	3	35	6	3	7
WI-054	53.1	84	364	1.6	1.7	6	27	3	7	7
WI-055	24.2	93	402	0.6	2.1	2	20	8	2	5
WI-056	522.3	57	222	20.7	47.4	5	17	8	8	7
WI-057	63.4	43	153	3.2	14.2	11	46	18	20	23
WI-058	27.1	41	146	1.4	4.9	7	26	15	15	15
WI-059	7.4	15	34	1	1.5	1	5	17	6	13
WI-060	332.2	116	654	13.5	73.9	0	91	18	0	12
WI-061	0	0	0	0	1.8	1	1	100	100	100
WI-062	304.2	36	128	15.3	54.2	9	25	15	20	16
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	12.5	21	48	1.2	3.5	5	13	22	19	21
WI-065	1.1	20	45	0.1	0.2	3	8	15	13	15
WI-066	0.9	7	10	0.3	0.2	1	4	18	13	29
WI-067	1.5	7	10	0.4	0.3	1	3	17	13	23
WI-068	67.6	27	73	9	12.6	3	6	16	10	8
WI-069	0.2	4	6	0.1	0.1	0	1	33	0	14
WI-070	7.9	30	84	0.6	1.6	3	11	17	9	12
WI-071	9.6	15	33	1.3	2.6	2	9	21	12	21
WI-072	12.6	22	51	1.3	4	5	14	24	19	22
WI-075	36.6	18	39	4.5	9.5	3	11	21	14	22
WI-076	32.3	54	211	1.2	5.2	12	45	14	18	18
WI-077	71.3	49	179	3.1	11.5	7	28	14	13	14
WI-078	17.4	49	180	0.7	2.7	7	27	13	13	13

Table 19K. CSO results for medium performance scenario, 100% coverage, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	50.1	14	30	8.4	0	2	5	0	13	14
HP-003	79	26	64	6.5	0.6	1	1	1	4	2
HP-004	117.3	33	96	8.7	1.7	3	9	1	8	9
HP-007	132	24	54	13.8	0	0	3	0	0	5
HP-009	692.2	95	442	10.9	77.6	5	33	10	5	7
HP-011	614.6	52	201	10	32.8	7	23	5	12	10
HP-012	1.5	2	3	0.7	0	0	0	0	0	0
HP-013	146.8	27	65	12.5	1.7	0	0	1	0	0
HP-014	686.5	43	158	39.7	10.1	2	0	1	4	0
HP-016	40.8	27	72	3.4	0.5	3	4	1	10	5
HP-017	47.6	60	229	2	0.6	2	10	1	3	4
HP-018	2	21	49	0.2	0	0	1	0	0	2
HP-019	24.5	62	255	0.9	1.1	11	39	4	15	13
HP-020	45.7	42	156	2.3	0.5	3	0	1	7	0
HP-021	137	64	266	1.3	10.1	9	28	7	12	10
HP-022	32	45	161	1.7	0.3	2	5	1	4	3
HP-023	273.5	67	287	5	20.3	12	45	7	15	14
HP-024	76	24	54	8	0	0	3	0	0	5
HP-025	158.6	116	665	3.8	14.4	0	80	8	0	11
HP-026	195.9	113	817	9.9	3.7	3	0	2	3	0
HP-028	13.9	78	328	0.4	0.5	6	30	3	7	8
HP-029	0.7	21	50	0.1	0	1	2	0	5	4
HP-031	63	116	745	1.5	1	0	0	2	0	0
HP-033	86.5	37	111	6	1.1	2	7	1	5	6
WI--05	0.9	10	19	0.2	0	1	1	0	9	5
WI-053	38.1	102	501	0.9	1.2	2	31	3	2	6
WI-054	54	85	369	1.6	0.8	5	22	1	6	6
WI-055	25.2	93	402	0.7	1.1	2	20	4	2	5
WI-056	554.9	57	231	23	14.8	5	8	3	8	3
WI-057	75.3	47	178	3.8	2.3	7	21	3	13	11
WI-058	31.3	45	168	1.6	0.7	3	4	2	6	2
WI-059	9	17	41	1.2	0	0	0	0	0	0
WI-060	377.6	116	663	15	28.5	0	82	7	0	11
WI-061	3	1	1	3	0	0	0	0	0	0
WI-062	348.6	41	149	17.1	9.8	4	4	3	9	3
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	16	25	57	1.5	0	1	4	0	4	7
WI-065	1.3	22	50	0.1	0	1	3	0	4	6
WI-066	1.3	9	15	0.3	0	0	0	0	0	0
WI-067	2	8	14	0.6	0	0	0	0	0	0
WI-068	82.3	27	77	11.1	0	3	2	0	10	3
WI-069	0.2	5	7	0.1	0.1	0	0	33	0	0
WI-070	9.5	32	92	0.7	0	1	3	0	3	3
WI-071	12.4	17	40	1.7	0	0	2	0	0	5
WI-072	17.2	27	65	1.5	0	0	0	0	0	0
WI-075	46.7	21	48	5.6	0	0	2	0	0	4
WI-076	35.9	55	222	1.5	1.6	11	34	4	17	13
WI-077	80.2	49	193	3.8	2.6	7	14	3	13	7
WI-078	19.5	49	192	0.9	0.6	7	15	3	13	7

Table 19L. CSO results for low performance scenario, 100% coverage, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	12.6	7	13	2.2	10.2	3	5	45	30	28
HP-003	50	26	66	2.9	3.8	0	0	7	0	0
HP-004	69.3	31	81	3.4	17.5	4	10	20	11	11
HP-007	53.9	17	41	4.7	26.1	5	15	33	23	27
HP-009	525.4	67	347	6.3	109.7	12	47	17	15	12
HP-011	465.2	47	170	6.4	69.4	4	15	13	8	8
HP-013	76.6	20	55	4.8	24.4	6	11	24	23	17
HP-014	462.9	38	120	17	68.9	2	9	13	5	7
HP-016	21.1	22	61	1.3	7.6	8	12	26	27	16
HP-017	35.8	51	187	0.9	2	1	9	5	2	5
HP-018	0.9	15	35	0.1	0.3	3	5	25	17	13
HP-019	17.5	55	212	0.4	2.7	6	36	13	10	15
HP-020	32.8	38	118	1.1	2.9	2	11	8	5	9
HP-021	111.1	55	216	0.9	9.3	6	32	8	10	13
HP-022	23.1	40	134	0.8	1.7	1	4	7	2	3
HP-023	211.4	54	225	3.1	34.5	8	40	14	13	15
HP-024	31	17	41	2.7	14.9	5	15	32	23	27
HP-025	116.9	91	568	1.7	20.1	0	0	15	0	0
HP-026	129.3	91	568	4.2	24	0	0	16	0	0
HP-028	10.4	62	271	0.2	1	1	14	9	2	5
HP-029	0.5	18	38	0	0	0	4	0	0	10
HP-031	47.9	91	568	0.7	2.7	0	0	5	0	0
HP-033	44.9	31	83	2.3	20.2	6	21	31	16	20
WI--05	0.4	5	10	0.1	0	0	1	0	0	9
WI-053	29.7	86	447	0.5	1.8	0	0	6	0	0
WI-054	42.1	63	290	0.8	1.2	1	22	3	2	7
WI-055	19.2	64	319	0.3	1.5	3	18	7	4	5
WI-056	404.9	49	186	10.5	41.5	3	10	9	6	5
WI-057	44.8	41	135	1.6	15.2	6	26	25	13	16
WI-058	19.4	39	128	0.7	5.3	5	14	21	11	10
WI-059	3.2	10	20	0.4	1.4	3	9	30	23	31
WI-060	248.2	87	535	7.3	66.5	4	33	21	4	6
WI-062	217	37	112	8.3	62.9	3	17	22	8	13
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	6.6	19	48	0.5	3.9	5	15	37	21	24
WI-065	0.7	16	39	0	0.2	3	8	22	16	17
WI-066	0.1	2	3	0.1	0.4	3	7	80	60	70
WI-067	0.2	3	4	0.1	0.5	2	6	71	40	60
WI-068	34.2	25	69	3	16.6	8	10	33	24	13
WI-069	0	4	5	0	0.1	1	3	100	20	38
WI-070	4.9	26	71	0.3	2.1	9	18	30	26	20
WI-071	3.9	10	20	0.5	2.4	3	10	38	23	33
WI-072	5.6	15	39	0.6	5.6	11	27	50	42	41
WI-075	16.2	12	25	1.8	9.5	6	14	37	33	36
WI-076	24.7	49	186	0.6	4.7	5	20	16	9	10
WI-077	53.4	45	160	1.6	11.1	3	17	17	6	10
WI-078	13.1	45	160	0.4	2.5	3	17	16	6	10

Table 19M. CSO results for mixed scenario, 25% coverage each high/medium/low, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	5.8	3	6	1.8	4.1	2	4	41	40	40
HP-003	28	19	46	2.6	3.1	1	1	10	5	2
HP-004	38.6	21	54	3.2	13.1	4	9	25	16	14
HP-007	26.2	11	22	4.2	17.4	5	13	40	31	37
HP-009	376.5	65	314	6.1	112.6	6	27	23	8	8
HP-011	314.1	41	127	6.3	75.2	4	20	19	9	14
HP-013	40.3	18	36	4.6	18	2	11	31	10	23
HP-014	276.1	28	81	16	54.7	5	16	17	15	16
HP-016	11.2	19	39	1.2	5.6	1	8	33	5	17
HP-017	23.6	45	149	0.9	1.8	0	6	7	0	4
HP-018	0.4	10	19	0.1	0.2	6	8	33	38	30
HP-019	11.6	46	170	0.4	2.5	3	35	18	6	17
HP-020	20.2	28	80	1	2.6	5	17	11	15	18
HP-021	83	45	178	0.9	11.5	4	27	12	8	13
HP-022	14.3	33	101	0.7	1.4	0	2	9	0	2
HP-023	144.1	45	180	3	35.7	6	41	20	12	19
HP-024	15.1	11	22	2.5	9.8	5	13	39	31	37
HP-025	86.5	84	508	1.6	19.1	0	0	18	0	0
HP-026	81.7	84	508	3.9	19.3	0	0	19	0	0
HP-028	7.5	51	223	0.2	0.9	4	24	11	7	10
HP-029	0.3	13	22	0	0	3	6	0	19	21
HP-031	36	84	508	0.7	2.6	0	0	7	0	0
HP-033	24.2	22	53	2.1	15.3	6	19	39	21	26
WI--05	0.1	3	6	0.1	0.1	0	0	50	0	0
WI-053	22.2	73	388	0.4	1.6	0	0	7	0	0
WI-054	30.1	56	249	0.8	1.2	3	26	4	5	9
WI-055	14	60	277	0.3	1.6	2	26	10	3	9
WI-056	264.4	43	146	9.9	37.3	2	9	12	4	6
WI-057	26.3	30	89	1.5	12.9	10	38	33	25	30
WI-058	11.5	28	87	0.6	4.3	9	28	27	24	24
WI-059	1.5	5	10	0.3	0.8	6	7	35	55	41
WI-060	161.2	80	462	7	58.2	4	46	27	5	9
WI-062	124.4	23	75	7.9	50.6	10	22	29	30	23
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	3.3	13	25	0.5	2.6	5	17	44	28	40
WI-065	0.3	10	21	0	0.2	7	9	40	41	30
WI-066	0	1	1	0	0.2	1	3	100	50	75
WI-067	0.1	1	1	0.1	0.1	1	2	50	50	67
WI-068	17.1	19	41	2.6	9.7	1	7	36	5	15
WI-069	0	1	1	0	0	0	1	0	0	50
WI-070	2.6	20	42	0.2	1.5	4	16	37	17	28
WI-071	1.7	5	8	0.4	1.4	7	10	45	58	56
WI-072	2.7	11	22	0.4	3.8	9	25	58	45	53
WI-075	7.5	8	15	1.6	5.7	8	11	43	50	42
WI-076	15.9	43	146	0.6	4.2	3	27	21	7	16
WI-077	32.9	36	111	1.5	9.8	7	24	23	16	18
WI-078	8.1	36	111	0.4	2.3	7	24	22	16	18

Table 19N. CSO results for mixed scenario, 25% coverage each high/medium/low, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	37	12	24	6.5	10.5	4	11	22	25	31
HP-003	76.8	27	64	6.3	2.8	0	1	4	0	2
HP-004	106.7	33	93	7.4	12.3	3	12	10	8	11
HP-007	109.8	21	52	11	22.2	3	5	17	13	9
HP-009	663.9	95	455	9.5	105.9	5	20	14	5	4
HP-011	582.7	53	202	9.2	64.7	6	22	10	10	10
HP-012	0.9	2	3	0.4	0.4	0	0	31	0	0
HP-013	130.6	25	61	10.8	17.9	2	4	12	7	6
HP-014	646	43	142	35.9	50.6	2	11	7	4	7
HP-016	35.8	27	71	2.8	5.5	3	5	13	10	7
HP-017	46.6	60	229	1.9	1.6	2	10	3	3	4
HP-018	1.7	20	47	0.2	0.3	1	3	15	5	6
HP-019	23.1	64	260	0.8	2.5	9	34	10	12	12
HP-020	44	43	141	2.2	2.2	2	12	5	4	8
HP-021	135.2	67	269	1.2	11.9	6	25	8	8	9
HP-022	31.1	45	158	1.6	1.2	2	8	4	4	5
HP-023	262.7	69	283	4.8	31.1	10	49	11	13	15
HP-024	63.3	21	52	6.4	12.7	3	5	17	13	9
HP-025	152.9	116	745	3.2	20.1	0	0	12	0	0
HP-026	181.2	116	745	8.7	18.4	0	0	9	0	0
HP-028	13.5	79	340	0.4	0.9	5	18	6	6	5
HP-029	0.7	21	49	0.1	0	1	3	0	5	6
HP-031	61.6	116	745	1.4	2.4	0	0	4	0	0
HP-033	73.2	33	101	4.9	14.4	6	17	16	15	14
WI--05	0.9	10	18	0.2	0	1	2	0	9	10
WI-053	37.7	104	532	0.9	1.6	0	0	4	0	0
WI-054	53.7	84	361	1.6	1.1	6	30	2	7	8
WI-055	24.6	91	398	0.6	1.7	4	24	6	4	6
WI-056	534.3	56	223	21.2	35.4	6	16	6	10	7
WI-057	65.9	47	169	3.1	11.7	7	30	15	13	15
WI-058	28	45	157	1.4	4	3	15	13	6	9
WI-059	7.5	16	36	1	1.4	0	3	16	0	8
WI-060	350.6	116	663	13.4	55.5	0	82	14	0	11
WI-061	0	0	0	0	1.8	1	1	100	100	100
WI-062	314.8	39	136	15.4	43.6	6	17	12	13	11
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	12.9	24	56	1.2	3.1	2	5	19	8	8
WI-065	1.1	20	50	0.1	0.2	3	3	15	13	6
WI-066	0.8	6	9	0.2	0.3	2	5	27	25	36
WI-067	1.4	6	9	0.4	0.4	2	4	22	25	31
WI-068	68.4	28	77	8.9	11.8	2	2	15	7	3
WI-069	0.2	4	6	0.1	0.1	0	1	33	0	14
WI-070	8.1	31	86	0.6	1.4	2	9	15	6	9
WI-071	9.6	15	34	1.3	2.6	2	8	21	12	19
WI-072	12	22	55	1.2	4.6	5	10	28	19	15
WI-075	37.3	20	43	4.4	8.8	1	7	19	5	14
WI-076	33.4	56	223	1.3	4.1	10	33	11	15	13
WI-077	74.1	52	189	3.2	8.7	4	18	11	7	9
WI-078	18	52	189	0.8	2.1	4	18	10	7	9

Table 19O. CSO results for mixed scenario, 25% coverage each high/medium/low, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	16.7	8	14	2.2	6.1	2	4	27	20	22
HP-003	51.7	26	66	3	2.1	0	0	4	0	0
HP-004	77.2	35	88	3.6	9.6	0	3	11	0	3
HP-007	63.8	19	45	4.9	16.2	3	11	20	14	20
HP-009	585.4	79	394	6.4	49.7	0	0	8	0	0
HP-011	500.5	48	180	6.6	34.1	3	5	6	6	3
HP-013	87.5	25	65	5.2	13.5	1	1	13	4	2
HP-014	496.3	39	123	18	35.5	1	6	7	3	5
HP-016	24.5	27	68	1.4	4.2	3	5	15	10	7
HP-017	37	52	196	1	0.8	0	0	2	0	0
HP-018	1	18	37	0.1	0.2	0	3	17	0	8
HP-019	18.8	57	224	0.4	1.4	4	24	7	7	10
HP-020	34.3	39	123	1.1	1.4	1	6	4	3	5
HP-021	116	57	224	0.9	4.4	4	24	4	7	10
HP-022	23.9	41	138	0.8	0.9	0	0	4	0	0
HP-023	230.6	60	253	3.2	15.3	2	12	6	3	5
HP-024	36.6	19	45	2.8	9.3	3	11	20	14	20
HP-025	127.4	91	568	1.8	9.6	0	0	7	0	0
HP-026	141.1	91	568	4.4	12.2	0	0	8	0	0
HP-028	11	62	271	0.2	0.4	1	14	4	2	5
HP-029	0.5	18	39	0	0	0	3	0	0	7
HP-031	49.4	91	568	0.8	1.2	0	0	2	0	0
HP-033	53.7	36	96	2.3	11.4	1	8	18	3	8
WI--05	0.4	5	10	0.1	0	0	1	0	0	9
WI-053	30.6	86	447	0.5	0.9	0	0	3	0	0
WI-054	42.6	63	290	0.9	0.7	1	22	2	2	7
WI-055	19.7	64	319	0.3	1	3	18	5	4	5
WI-056	426	52	196	11.1	20.4	0	0	5	0	0
WI-057	52.2	46	149	1.6	7.8	1	12	13	2	7
WI-058	22	42	142	0.7	2.7	2	0	11	5	0
WI-059	3.8	11	23	0.4	0.8	2	6	17	15	21
WI-060	281	91	568	7.7	33.7	0	0	11	0	0
WI-062	246.9	39	121	8.7	33	1	8	12	3	6
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	8	21	55	0.5	2.5	3	8	24	13	13
WI-065	0.7	18	39	0.1	0.2	1	8	22	5	17
WI-066	0.2	4	5	0.1	0.3	1	5	60	20	50
WI-067	0.4	5	7	0.1	0.3	0	3	43	0	30
WI-068	41.5	28	72	3.2	9.3	5	7	18	15	9
WI-069	0	4	5	0	0.1	1	3	100	20	38
WI-070	5.9	32	81	0.3	1.1	3	8	16	9	9
WI-071	4.8	12	24	0.5	1.5	1	6	24	8	20
WI-072	7.3	20	51	0.5	3.9	6	15	35	23	23
WI-075	19.9	14	32	1.8	5.8	4	7	23	22	18
WI-076	27.1	52	200	0.7	2.3	2	6	8	4	3
WI-077	58.6	47	164	1.7	5.9	1	13	9	2	7
WI-078	14.3	47	164	0.4	1.3	1	13	8	2	7

Table 20A. CSO results for high performance scenario, 25% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	11.7	7	13	2.2	11.1	3	5	49	30	28
HP-003	49.7	26	66	2.9	4.1	0	0	8	0	0
HP-004	68	32	83	3.3	18.8	3	8	22	9	9
HP-007	50.4	16	38	4.6	29.6	6	18	37	27	32
HP-009	534.5	67	344	6.3	100.6	12	50	16	15	13
HP-011	467.9	47	167	6.4	66.7	4	18	12	8	10
HP-013	74.3	23	60	4.7	26.7	3	6	26	12	9
HP-014	461.9	39	121	16.9	69.9	1	8	13	3	6
HP-016	20.4	24	64	1.2	8.3	6	9	29	20	12
HP-017	35.6	51	186	0.9	2.2	1	10	6	2	5
HP-018	0.8	14	32	0.1	0.4	4	8	33	22	20
HP-019	17.5	54	210	0.4	2.7	7	38	13	11	15
HP-020	33.1	39	121	1.1	2.6	1	8	7	3	6
HP-021	111.9	57	224	0.9	8.5	4	24	7	7	10
HP-022	23.1	40	133	0.8	1.7	1	5	7	2	4
HP-023	214.2	56	229	3.1	31.7	6	36	13	10	14
HP-024	29	16	38	2.7	16.9	6	18	37	27	32
HP-025	118.7	91	568	1.7	18.3	0	0	13	0	0
HP-026	129.1	91	568	4	24.2	0	0	16	0	0
HP-028	10.5	62	271	0.2	0.9	1	14	8	2	5
HP-029	0.4	16	34	0	0.1	2	8	20	11	19
HP-031	48	91	568	0.7	2.6	0	0	5	0	0
HP-033	43.2	30	82	2.3	21.9	7	22	34	19	21
WI--05	0.4	5	10	0.1	0	0	1	0	0	9
WI-053	29.7	86	447	0.5	1.8	0	0	6	0	0
WI-054	42	63	290	0.8	1.3	1	22	3	2	7
WI-055	19.3	64	319	0.3	1.4	3	18	7	4	5
WI-056	405.8	51	186	10.6	40.6	1	10	9	2	5
WI-057	44.5	42	141	1.6	15.5	5	20	26	11	12
WI-058	19.3	40	131	0.7	5.4	4	11	22	9	8
WI-059	3.1	10	20	0.4	1.5	3	9	33	23	31
WI-060	248.1	91	568	7.3	66.6	0	0	21	0	0
WI-062	215.2	38	115	8.2	64.7	2	14	23	5	11
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	6.1	18	43	0.5	4.4	6	20	42	25	32
WI-065	0.6	15	36	0	0.3	4	11	33	21	23
WI-066	0.1	1	2	0.1	0.4	4	8	80	80	80
WI-067	0.2	4	5	0.1	0.5	1	5	71	20	50
WI-068	32.6	26	69	3	18.2	7	10	36	21	13
WI-069	0	4	5	0	0.1	1	3	100	20	38
WI-070	4.8	27	73	0.3	2.2	8	16	31	23	18
WI-071	3.6	10	20	0.5	2.7	3	10	43	23	33
WI-072	4.8	14	34	0.5	6.4	12	32	57	46	48
WI-075	15.4	12	24	1.8	10.3	6	15	40	33	38
WI-076	24.7	51	189	0.6	4.7	3	17	16	6	8
WI-077	53.1	47	160	1.6	11.4	1	17	18	2	10
WI-078	13.1	47	160	0.4	2.5	1	17	16	2	10

Table 20B. CSO results for high performance scenario, 50% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	7.2	7	12	2.2	15.6	3	6	68	30	33
HP-003	47.9	26	66	2.8	5.9	0	0	11	0	0
HP-004	59.7	28	76	3.3	27.1	7	15	31	20	16
HP-007	40	13	30	4.7	40	9	26	50	41	46
HP-009	483.3	67	344	6.3	151.8	12	50	24	15	13
HP-011	436.7	47	164	6.4	97.9	4	21	18	8	11
HP-013	62.7	20	49	4.8	38.3	6	17	38	23	26
HP-014	428.1	38	117	16	103.7	2	12	20	5	9
HP-016	16.8	21	54	1.3	11.9	9	19	41	30	26
HP-017	34.8	51	186	0.9	3	1	10	8	2	5
HP-018	0.7	12	25	0.1	0.5	6	15	42	33	38
HP-019	16.2	53	207	0.4	4	8	41	20	13	17
HP-020	31.4	38	111	1	4.3	2	18	12	5	14
HP-021	108	54	210	0.9	12.4	7	38	10	11	15
HP-022	22.3	40	133	0.8	2.5	1	5	10	2	4
HP-023	197.2	53	215	3	48.7	9	50	20	15	19
HP-024	23.1	13	30	2.7	22.8	9	26	50	41	46
HP-025	109	91	568	1.7	28	0	0	20	0	0
HP-026	117.5	91	568	4	35.8	0	0	23	0	0
HP-028	10.1	62	271	0.2	1.3	1	14	11	2	5
HP-029	0.4	14	32	0	0.1	4	10	20	22	24
HP-031	46.5	91	568	0.7	4.1	0	0	8	0	0
HP-033	34	27	75	2.3	31.1	10	29	48	27	28
WI--05	0.3	5	10	0.1	0.1	0	1	25	0	9
WI-053	29.1	86	447	0.4	2.4	0	0	8	0	0
WI-054	41.5	63	290	0.8	1.8	1	22	4	2	7
WI-055	18.6	64	319	0.3	2.1	3	18	10	4	5
WI-056	385.6	48	184	10	60.8	4	12	14	8	6
WI-057	37.4	40	123	1.6	22.6	7	38	38	15	24
WI-058	16.8	39	119	0.7	7.9	5	23	32	11	16
WI-059	2.6	9	18	0.4	2	4	11	43	31	38
WI-060	215.3	86	519	7.3	99.4	5	49	32	5	9
WI-062	183.5	37	104	8.3	96.4	3	25	34	8	19
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	4.6	14	34	0.5	5.9	10	29	56	42	46
WI-065	0.5	13	28	0	0.4	6	19	44	32	40
WI-066	0.1	1	2	0.1	0.4	4	8	80	80	80
WI-067	0.1	1	2	0.1	0.6	4	8	86	80	80
WI-068	25.5	23	63	3	25.3	10	16	50	30	20
WI-069	0	1	2	0	0.1	4	6	100	80	75
WI-070	3.8	22	62	0.3	3.2	13	27	46	37	30
WI-071	2.7	9	17	0.5	3.6	4	13	57	31	43
WI-072	3.3	11	26	0.6	7.9	15	40	71	58	61
WI-075	12	10	19	1.8	13.7	8	20	53	44	51
WI-076	22.6	48	184	0.6	6.8	6	22	23	11	11
WI-077	48.2	43	153	1.6	16.3	5	24	25	10	14
WI-078	12	43	153	0.4	3.6	5	24	23	10	14

Table 20C. CSO results for high performance scenario, 75% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	4.8	6	8	2.3	18	4	10	79	40	56
HP-003	46.1	25	64	2.8	7.7	1	2	14	4	3
HP-004	51.6	26	72	3.3	35.2	9	19	41	26	21
HP-007	32.2	11	25	4.8	47.8	11	31	60	50	55
HP-009	430.5	64	327	6.3	204.6	15	67	32	19	17
HP-011	402.4	46	156	6.4	132.2	5	29	25	10	16
HP-013	53	18	43	4.8	48	8	23	48	31	35
HP-014	395.9	38	115	16.1	135.9	2	14	26	5	11
HP-016	13.8	19	46	1.3	14.9	11	27	52	37	37
HP-017	33.6	51	186	0.9	4.2	1	10	11	2	5
HP-018	0.6	10	21	0.1	0.6	8	19	50	44	48
HP-019	14.8	51	194	0.4	5.4	10	54	27	16	22
HP-020	30	38	112	1	5.7	2	17	16	5	13
HP-021	103.6	53	207	0.9	16.8	8	41	14	13	17
HP-022	21.4	39	127	0.7	3.4	2	11	14	5	8
HP-023	179.5	52	211	3	66.4	10	54	27	16	20
HP-024	18.6	11	25	2.8	27.3	11	31	59	50	55
HP-025	99.7	86	519	1.8	37.3	5	49	27	5	9
HP-026	107.1	92	587	4.1	46.2	0	0	30	0	0
HP-028	9.7	60	260	0.2	1.7	3	25	15	5	9
HP-029	0.3	12	27	0	0.2	6	15	40	33	36
HP-031	45.1	91	568	0.7	5.5	0	0	11	0	0
HP-033	26.7	22	57	2.4	38.4	15	47	59	41	45
WI--05	0.3	5	10	0.1	0.1	0	1	25	0	9
WI-053	27.8	79	399	0.4	3.7	7	48	12	8	11
WI-054	41	63	290	0.8	2.3	1	22	5	2	7
WI-055	18.1	64	319	0.3	2.6	3	18	13	4	5
WI-056	365.8	48	184	9.9	80.6	4	12	18	8	6
WI-057	31.1	39	114	1.6	28.9	8	47	48	17	29
WI-058	14.4	38	109	0.7	10.3	6	33	42	14	23
WI-059	2.1	9	17	0.4	2.5	4	12	54	31	41
WI-060	184.4	86	519	7.4	130.3	5	49	41	5	9
WI-062	153.9	31	91	8.4	126	9	38	45	23	29
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	3.6	11	28	0.6	6.9	13	35	66	54	56
WI-065	0.4	11	24	0	0.5	8	23	56	42	49
WI-066	0.1	1	1	0.1	0.4	4	9	80	80	90
WI-067	0.1	1	2	0.1	0.6	4	8	86	80	80
WI-068	20.6	21	51	3.1	30.2	12	28	59	36	35
WI-069	0	1	1	0	0.1	4	7	100	80	88
WI-070	3.1	18	48	0.3	3.9	17	41	56	49	46
WI-071	1.9	9	15	0.5	4.4	4	15	70	31	50
WI-072	3	7	18	0.6	8.2	19	48	73	73	73
WI-075	9.2	9	17	1.8	16.5	9	22	64	50	56
WI-076	20.4	47	168	0.6	9	7	38	31	13	18
WI-077	43	41	140	1.6	21.5	7	37	33	15	21
WI-078	10.7	42	146	0.4	4.9	6	31	31	13	18

Table 20D. CSO results for high performance scenario, 100% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	9.1	7	11	2.3	13.7	3	7	60	30	39
HP-003	48.5	25	64	2.8	5.3	1	2	10	4	3
HP-004	62.2	28	76	3.4	24.6	7	15	28	20	16
HP-007	46.1	15	35	4.8	33.9	7	21	42	32	38
HP-009	482.7	65	339	6.3	152.4	14	55	24	18	14
HP-011	439.9	46	164	6.4	94.7	5	21	18	10	11
HP-013	68.1	20	51	4.8	32.9	6	15	33	23	23
HP-014	435.3	38	120	17	96.5	2	9	18	5	7
HP-016	18.4	22	56	1.3	10.3	8	17	36	27	23
HP-017	34.8	51	187	0.9	3	1	9	8	2	5
HP-018	0.8	14	30	0.1	0.4	4	10	33	22	25
HP-019	16.4	52	205	0.4	3.8	9	43	19	15	17
HP-020	31.5	38	118	1.1	4.2	2	11	12	5	9
HP-021	108	54	213	0.9	12.4	7	35	10	11	14
HP-022	22.4	39	128	0.8	2.4	2	10	10	5	7
HP-023	198.1	54	221	3.1	47.8	8	44	19	13	17
HP-024	26.5	15	35	2.8	19.4	7	21	42	32	38
HP-025	109.1	86	526	1.8	27.9	5	42	20	5	7
HP-026	120.8	92	596	4.2	32.5	0	0	21	0	0
HP-028	10.1	61	262	0.2	1.3	2	23	11	3	8
HP-029	0.4	15	33	0	0.1	3	9	20	17	21
HP-031	46.6	91	568	0.7	4	0	0	8	0	0
HP-033	38.5	27	72	2.4	26.6	10	32	41	27	31
WI--05	0.3	5	10	0.1	0.1	0	1	25	0	9
WI-053	28.7	80	406	0.5	2.8	6	41	9	7	9
WI-054	41.6	63	294	0.8	1.7	1	18	4	2	6
WI-055	18.7	64	322	0.3	2	3	15	10	4	4
WI-056	388.8	49	186	10.5	57.6	3	10	13	6	5
WI-057	39.6	40	130	1.6	20.4	7	31	34	15	19
WI-058	17.4	39	119	0.7	7.3	5	23	30	11	16
WI-059	2.7	11	21	0.4	1.9	2	8	41	15	28
WI-060	221.6	86	526	7.4	93.1	5	42	30	5	7
WI-062	192.7	32	101	8.4	87.2	8	28	31	20	22
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	5.6	15	39	0.6	4.9	9	24	47	38	38
WI-065	0.6	15	34	0	0.3	4	13	33	21	28
WI-066	0.2	2	4	0.1	0.3	3	6	60	60	60
WI-067	0.2	2	4	0.1	0.5	3	6	71	60	60
WI-068	29.1	23	58	3.1	21.7	10	21	43	30	27
WI-069	0	2	4	0	0.1	3	4	100	60	50
WI-070	4.3	24	61	0.3	2.7	11	28	39	31	31
WI-071	3	12	21	0.5	3.3	1	9	52	8	30
WI-072	5.4	15	33	0.6	5.8	11	33	52	42	50
WI-075	13.7	13	24	1.8	12	5	15	47	28	38
WI-076	22.9	48	175	0.6	6.5	6	31	22	11	15
WI-077	49.2	42	151	1.6	15.3	6	26	24	13	15
WI-078	12.2	43	157	0.4	3.4	5	20	22	10	11

Table 20E. CSO results for medium performance scenario, 100% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	21.6	8	16	3	1.2	2	2	5	20	11
HP-003	52.5	25	65	3	1.3	1	1	2	4	2
HP-004	79.8	30	83	4	7	5	8	8	14	9
HP-007	75.6	19	46	5.8	4.4	3	10	6	14	18
HP-009	546.5	65	354	6.9	88.6	14	40	14	18	10
HP-011	481.7	48	169	6.8	52.9	3	16	10	6	9
HP-013	93.9	23	59	5.8	7.1	3	7	7	12	11
HP-014	495.2	38	126	18.8	36.6	2	3	7	5	2
HP-016	26.4	25	64	1.5	2.3	5	9	8	17	12
HP-017	36.5	51	190	1	1.3	1	6	3	2	3
HP-018	1.1	18	39	0.1	0.1	0	1	8	0	3
HP-019	18.5	52	217	0.4	1.7	9	31	8	15	13
HP-020	33.7	38	122	1.1	2	2	7	6	5	5
HP-021	112	54	222	0.9	8.4	7	26	7	11	10
HP-022	23.8	39	130	0.8	1	2	8	4	5	6
HP-023	217.4	54	233	3.2	28.5	8	32	12	13	12
HP-024	43.4	19	46	3.3	2.5	3	10	5	14	18
HP-025	122.1	88	536	2	14.9	3	32	11	3	6
HP-026	141.5	92	606	4.7	11.8	0	0	8	0	0
HP-028	10.7	61	270	0.2	0.7	2	15	6	3	5
HP-029	0.5	18	38	0	0	0	4	0	0	10
HP-031	48.9	91	568	0.8	1.7	0	0	3	0	0
HP-033	58.2	28	84	2.8	6.9	9	20	11	24	19
WI--05	0.4	5	11	0.1	0	0	0	0	0	0
WI-053	29.9	79	412	0.5	1.6	7	35	5	8	8
WI-054	42.5	63	298	0.9	0.8	1	14	2	2	4
WI-055	19.7	64	324	0.3	1	3	13	5	4	4
WI-056	420.2	52	192	11.4	26.2	0	4	6	0	2
WI-057	52.3	41	140	1.9	7.7	6	21	13	13	13
WI-058	21.9	40	125	0.8	2.8	4	17	11	9	12
WI-059	4.4	13	28	0.5	0.2	0	1	4	0	3
WI-060	276.6	87	535	8.4	38.1	4	33	12	4	6
WI-062	249.1	33	109	9.5	30.8	7	20	11	18	16
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	9.7	20	51	0.7	0.8	4	12	8	17	19
WI-065	0.8	19	45	0.1	0.1	0	2	11	0	4
WI-066	0.5	5	9	0.1	0	0	1	0	0	10
WI-067	0.7	5	9	0.1	0	0	1	0	0	10
WI-068	46.9	25	67	4.1	3.9	8	12	8	24	15
WI-069	0.1	5	8	0	0	0	0	0	0	0
WI-070	6.3	27	71	0.3	0.7	8	18	10	23	20
WI-071	6.1	14	29	0.6	0	0	1	3	0	3
WI-072	10.5	23	53	0.7	0.7	3	13	6	12	20
WI-075	24.6	16	34	2.2	1.1	2	5	4	11	13
WI-076	26.5	51	185	0.7	2.9	3	21	10	6	10
WI-077	58.1	44	160	1.8	6.4	4	17	10	8	10
WI-078	14.3	45	164	0.4	1.3	3	13	8	6	7

Table 20F. CSO results for low performance scenario, 100% coverage, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	0.9	1	1	0.9	9	4	9	91	80	90
HP-003	25	18	40	2.4	6.1	2	7	20	10	15
HP-004	25.8	18	42	2.2	25.9	7	21	50	28	33
HP-007	11.2	6	12	2.8	32.4	10	23	74	63	66
HP-009	285.2	60	281	5.3	203.9	11	60	42	15	18
HP-011	255	37	116	5.6	134.3	8	31	35	18	21
HP-013	24.1	14	25	3	34.2	6	22	59	30	47
HP-014	225.2	28	80	12.9	105.6	5	17	32	15	18
HP-016	6.1	14	25	0.8	10.7	6	22	64	30	47
HP-017	21.8	45	147	0.8	3.6	0	8	14	0	5
HP-018	0.2	5	10	0	0.4	11	17	67	69	63
HP-019	9.3	45	151	0.3	4.8	4	54	34	8	26
HP-020	18	26	74	0.9	4.8	7	23	21	21	24
HP-021	74.1	45	159	0.9	20.4	4	46	22	8	22
HP-022	12.9	30	93	0.6	2.8	3	10	18	9	10
HP-023	114.7	45	159	2.8	65.1	6	62	36	12	28
HP-024	6.5	6	12	1.6	18.4	10	23	74	63	66
HP-025	70.4	82	432	1.3	35.2	2	76	33	2	15
HP-026	63.9	84	512	2.9	37.1	0	0	37	0	0
HP-028	6.7	49	207	0.2	1.7	6	40	20	11	16
HP-029	0.2	9	16	0	0.1	7	12	33	44	43
HP-031	33.6	84	508	0.6	5	0	0	13	0	0
HP-033	11.3	16	31	1.6	28.2	12	41	71	43	57
WI--05	0.1	3	5	0	0.1	0	1	50	0	17
WI-053	20.4	71	345	0.4	3.4	2	43	14	3	11
WI-054	29	56	249	0.7	2.3	3	26	7	5	9
WI-055	12.9	59	276	0.3	2.7	3	27	17	5	9
WI-056	231.4	43	138	8.5	70.3	2	17	23	4	11
WI-057	15.8	22	67	1.1	23.4	18	60	60	45	47
WI-058	7.7	24	71	0.5	8.1	13	44	51	35	38
WI-059	0.7	4	7	0.2	1.6	7	10	70	64	59
WI-060	109.3	82	432	5.4	110.1	2	76	50	2	15
WI-062	77.3	21	60	6	97.7	12	37	56	36	38
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	1.2	5	12	0.3	4.7	13	30	80	72	71
WI-065	0.1	5	11	0	0.4	12	19	80	71	63
WI-066	0	1	1	0	0.2	1	3	100	50	75
WI-067	0	0	0	0	0.2	2	3	100	100	100
WI-068	8.6	15	27	1.2	18.2	5	21	68	25	44
WI-069	0	0	0	0	0	1	2	0	100	100
WI-070	1.3	15	27	0.2	2.8	9	31	68	38	53
WI-071	0.4	3	4	0.3	2.7	9	14	87	75	78
WI-072	0.9	3	6	0.4	5.6	17	41	86	85	87
WI-075	2.7	4	8	1	10.5	12	18	80	75	69
WI-076	12.3	39	124	0.4	7.8	7	49	39	15	28
WI-077	24.6	30	95	1.1	18.1	13	40	42	30	30
WI-078	6.3	33	102	0.3	4.1	10	33	39	23	24

Table 20G. CSO results for high performance scenario, 100% coverage, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	5.6	3	4	2.6	4.3	2	6	43	40	60
HP-003	27.2	19	41	2.7	3.9	1	6	13	5	13
HP-004	35.2	21	51	3.6	16.5	4	12	32	16	19
HP-007	24.2	10	18	5.2	19.4	6	17	45	38	49
HP-009	334.1	63	312	6.6	155	8	29	32	11	9
HP-011	285.9	38	120	6.6	103.4	7	27	27	16	18
HP-013	36.4	17	31	5.2	21.9	3	16	38	15	34
HP-014	259.9	28	85	17.2	70.9	5	12	21	15	12
HP-016	9.9	17	31	1.4	6.9	3	16	41	15	34
HP-017	22.8	45	149	0.9	2.6	0	6	10	0	4
HP-018	0.4	8	15	0.1	0.2	8	12	33	50	44
HP-019	10.6	46	160	0.4	3.5	3	45	25	6	22
HP-020	19.4	26	79	1	3.4	7	18	15	21	19
HP-021	77.7	46	166	0.9	16.8	3	39	18	6	19
HP-022	13.8	30	95	0.8	1.9	3	8	12	9	8
HP-023	130	46	168	3	49.8	5	53	28	10	24
HP-024	13.9	10	18	3	11	6	17	44	38	49
HP-025	79.8	80	450	1.9	25.8	4	58	24	5	11
HP-026	76.5	83	536	4.3	24.5	1	0	24	1	0
HP-028	7.1	49	213	0.2	1.3	6	34	15	11	14
HP-029	0.2	10	19	0	0.1	6	9	33	38	32
HP-031	35	84	508	0.7	3.6	0	0	9	0	0
HP-033	21.4	20	41	2.5	18.1	8	31	46	29	43
WI--05	0.1	3	6	0.1	0.1	0	0	50	0	0
WI-053	21.4	71	361	0.4	2.4	2	27	10	3	7
WI-054	29.7	56	255	0.8	1.6	3	20	5	5	7
WI-055	13.5	60	283	0.3	2.1	2	20	13	3	7
WI-056	251	43	146	10.5	50.7	2	9	17	4	6
WI-057	23.2	25	77	1.7	16	15	50	41	38	39
WI-058	10.4	25	76	0.7	5.4	12	39	34	32	34
WI-059	1.4	6	9	0.4	0.9	5	8	39	45	47
WI-060	142	80	449	7.8	77.4	4	59	35	5	12
WI-062	110	23	69	8.8	65	10	28	37	30	29
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	3.1	12	20	0.6	2.8	6	22	47	33	52
WI-065	0.3	9	17	0.1	0.2	8	13	40	47	43
WI-066	0.1	3	3	0.1	0.1	0	1	50	0	25
WI-067	0.1	2	2	0.1	0.1	0	1	50	0	33
WI-068	16	19	35	3.5	10.8	1	13	40	5	27
WI-069	0	1	1	0	0	0	1	0	0	50
WI-070	2.3	19	38	0.3	1.8	5	20	44	21	34
WI-071	1.7	6	10	0.6	1.4	6	8	45	50	44
WI-072	3	11	18	0.6	3.5	9	29	54	45	62
WI-075	7.3	6	12	2	5.9	10	14	45	63	54
WI-076	14.5	42	134	0.7	5.6	4	39	28	9	23
WI-077	29.9	31	101	1.7	12.8	12	34	30	28	25
WI-078	7.5	34	107	0.4	2.9	9	28	28	21	21

Table 20H. CSO results for medium performance scenario, 100% coverage, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	11	6	11	2.6	0	0	0	0	0	0
HP-003	29.5	19	43	2.7	1.6	1	4	5	5	9
HP-004	44.9	21	54	3.6	6.8	4	9	13	16	14
HP-007	39.4	12	26	5.2	4.2	4	9	10	25	26
HP-009	394.3	64	324	6.6	94.8	7	17	19	10	5
HP-011	328.7	40	131	6.6	60.6	5	16	16	11	11
HP-013	50.5	18	36	5.2	7.8	2	11	13	10	23
HP-014	296.7	30	89	17.2	34.1	3	8	10	9	8
HP-016	14.2	18	37	1.4	2.6	2	10	15	10	21
HP-017	24	46	152	0.9	1.4	0	3	6	0	2
HP-018	0.6	11	22	0.1	0	5	5	0	31	19
HP-019	12.4	47	174	0.4	1.7	2	31	12	4	15
HP-020	20.9	29	86	1	1.9	4	11	8	12	11
HP-021	84.6	46	177	0.9	9.9	3	28	10	6	14
HP-022	14.7	33	99	0.8	1	0	4	6	0	4
HP-023	150	46	183	3	29.8	5	38	17	10	17
HP-024	22.6	12	26	3	2.3	4	9	9	25	26
HP-025	90.3	80	467	1.9	15.3	4	41	14	5	8
HP-026	89.6	82	553	4.3	11.4	2	0	11	2	0
HP-028	7.8	48	224	0.2	0.6	7	23	7	13	9
HP-029	0.2	11	21	0	0.1	5	7	33	31	25
HP-031	36.8	84	508	0.7	1.8	0	0	5	0	0
HP-033	32.2	21	51	2.5	7.3	7	21	18	25	29
WI--05	0.2	3	6	0.1	0	0	0	0	0	0
WI-053	22.4	71	365	0.4	1.4	2	23	6	3	6
WI-054	30.4	56	258	0.8	0.9	3	17	3	5	6
WI-055	14.4	60	288	0.3	1.2	2	15	8	3	5
WI-056	275.2	45	157	10.5	26.5	0	0	9	0	0
WI-057	31.4	33	96	1.7	7.8	7	31	20	18	24
WI-058	13.2	30	89	0.7	2.6	7	26	16	19	23
WI-059	2.2	8	14	0.4	0.1	3	3	4	27	18
WI-060	179.4	80	465	7.8	40	4	43	18	5	8
WI-062	144.2	26	81	8.8	30.8	7	16	18	21	16
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	5.2	15	30	0.6	0.7	3	12	12	17	29
WI-065	0.5	11	25	0.1	0	6	5	0	35	17
WI-066	0.2	3	6	0.1	0	0	0	0	0	0
WI-067	0.2	2	4	0.1	0	0	0	0	0	0
WI-068	23.7	20	42	3.5	3.1	0	6	12	0	13
WI-069	0	1	2	0	0	0	0	0	0	0
WI-070	3.5	20	45	0.3	0.6	4	13	15	17	22
WI-071	3.2	8	15	0.6	0	4	3	0	33	17
WI-072	5.7	15	30	0.6	0.8	5	17	12	25	36
WI-075	12.6	8	18	2	0.6	8	8	5	50	31
WI-076	17.2	44	152	0.7	2.9	2	21	14	4	12
WI-077	36.1	38	119	1.7	6.6	5	16	15	12	12
WI-078	8.9	38	122	0.4	1.5	5	13	14	12	10

Table 20I. CSO results for low performance scenario, 100% coverage, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	24.6	9	18	6.6	22.9	7	17	48	44	49
HP-003	72.5	26	62	6	7.1	1	3	9	4	5
HP-004	89.3	32	88	7.1	29.7	4	17	25	11	16
HP-007	78.5	20	41	11.1	53.5	4	16	41	17	28
HP-009	568.3	92	426	9.6	201.5	8	49	26	8	10
HP-011	511.6	51	187	8.9	135.8	8	37	21	14	17
HP-012	0.4	1	1	0.4	0.9	1	2	69	50	67
HP-013	104.7	22	55	10.3	43.8	5	10	29	19	15
HP-014	577	42	136	32.8	119.6	3	17	17	7	11
HP-016	27.7	23	62	2.8	13.6	7	14	33	23	18
HP-017	44.4	60	228	1.8	3.8	2	11	8	3	5
HP-018	1.3	19	38	0.2	0.7	2	12	35	10	24
HP-019	20.4	61	241	0.8	5.2	12	53	20	16	18
HP-020	40.8	39	129	2	5.4	6	24	12	13	16
HP-021	125.9	63	252	1.2	21.2	10	42	14	14	14
HP-022	29.2	45	152	1.5	3.1	2	14	10	4	8
HP-023	233	65	264	4.4	60.8	14	68	21	18	20
HP-024	45.3	20	41	6.5	30.7	4	16	40	17	28
HP-025	134	117	642	3.2	39	0	103	23	0	14
HP-026	158.9	116	775	8.2	40.7	0	0	20	0	0
HP-028	12.5	75	315	0.3	1.9	9	43	13	11	12
HP-029	0.6	20	43	0	0.1	2	9	14	9	17
HP-031	58.6	116	745	1.3	5.4	0	0	8	0	0
HP-033	54.3	29	86	5	33.3	10	32	38	26	27
WI--05	0.7	10	16	0.2	0.2	1	4	22	9	20
WI-053	35.9	101	493	0.8	3.4	3	39	9	3	7
WI-054	52.3	83	360	1.5	2.5	7	31	5	8	8
WI-055	23.3	91	398	0.6	3	4	24	11	4	6
WI-056	492.2	57	218	19.2	77.5	5	21	14	8	9
WI-057	51.6	43	132	3.2	26	11	67	34	20	34
WI-058	22.9	41	129	1.4	9.1	7	43	28	15	25
WI-059	5.7	14	29	1	3.2	2	10	36	13	26
WI-060	285.7	117	642	13.5	120.4	0	103	30	0	14
WI-061	0	0	0	0	1.8	1	1	100	100	100
WI-062	257.1	35	113	15.3	101.3	10	40	28	22	26
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	8.7	19	39	1.2	7.3	7	22	46	27	36
WI-065	0.8	18	37	0.1	0.5	5	16	38	22	30
WI-066	0.5	4	6	0.3	0.6	4	8	55	50	57
WI-067	0.8	5	7	0.4	1	3	6	56	38	46
WI-068	51.1	24	70	9	29.1	6	9	36	20	11
WI-069	0.2	3	5	0.1	0.1	1	2	33	25	29
WI-070	6.2	27	76	0.6	3.3	6	19	35	18	20
WI-071	6.6	12	25	1.3	5.6	5	17	46	29	40
WI-072	7.7	15	38	1.3	8.9	12	27	54	44	42
WI-075	26.1	16	30	4.5	20	5	20	43	24	40
WI-076	28.9	54	206	1.2	8.6	12	50	23	18	20
WI-077	62.8	49	168	3.1	20	7	39	24	13	19
WI-078	15.4	49	172	0.7	4.7	7	35	23	13	17

Table 20J. CSO results for high performance scenario, 100% coverage, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	37.5	12	24	6.6	10	4	11	21	25	31
HP-003	75.9	26	62	6.2	3.7	1	3	5	4	5
HP-004	103.8	32	93	7.1	15.2	4	12	13	11	11
HP-007	106.2	22	49	11.1	25.8	2	8	20	8	14
HP-009	625.3	94	437	9.6	144.5	6	38	19	6	8
HP-011	558.3	51	191	9	89.1	8	33	14	14	15
HP-012	1	2	3	0.4	0.3	0	0	23	0	0
HP-013	126.4	26	61	10.3	22.1	1	4	15	4	6
HP-014	632.1	42	146	34.7	64.5	3	7	9	7	5
HP-016	34.5	26	67	2.8	6.8	4	9	16	13	12
HP-017	45.9	60	229	1.9	2.3	2	10	5	3	4
HP-018	1.7	20	45	0.2	0.3	1	5	15	5	10
HP-019	22.3	62	246	0.8	3.3	11	48	13	15	16
HP-020	43.1	38	139	2.2	3.1	7	14	7	16	9
HP-021	130.1	64	256	1.2	17	9	38	12	12	13
HP-022	30.6	45	155	1.6	1.7	2	11	5	4	7
HP-023	250.9	67	273	4.7	42.9	12	59	15	15	18
HP-024	61.2	22	49	6.5	14.8	2	8	19	8	14
HP-025	145.8	116	654	3.2	27.2	0	91	16	0	12
HP-026	177.6	115	799	8.3	22	1	0	11	1	0
HP-028	13.2	77	321	0.3	1.2	7	37	8	8	10
HP-029	0.7	20	47	0	0	2	5	0	9	10
HP-031	60.7	116	745	1.4	3.3	0	0	5	0	0
HP-033	70.8	32	98	5	16.8	7	20	19	18	17
WI--05	0.8	10	17	0.2	0.1	1	3	11	9	15
WI-053	36.9	101	497	0.9	2.4	3	35	6	3	7
WI-054	53.1	84	364	1.6	1.7	6	27	3	7	7
WI-055	24.2	93	402	0.6	2.1	2	20	8	2	5
WI-056	522.3	57	222	20.7	47.4	5	17	8	8	7
WI-057	63.4	43	153	3.2	14.2	11	46	18	20	23
WI-058	27.1	41	146	1.4	4.9	7	26	15	15	15
WI-059	7.4	15	34	1	1.5	1	5	17	6	13
WI-060	332.2	116	654	13.5	73.9	0	91	18	0	12
WI-061	0	0	0	0	1.8	1	1	100	100	100
WI-062	304.2	36	128	15.3	54.2	9	25	15	20	16
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	12.5	21	48	1.2	3.5	5	13	22	19	21
WI-065	1.1	20	45	0.1	0.2	3	8	15	13	15
WI-066	0.9	7	10	0.3	0.2	1	4	18	13	29
WI-067	1.5	7	10	0.4	0.3	1	3	17	13	23
WI-068	67.6	27	73	9	12.6	3	6	16	10	8
WI-069	0.2	4	6	0.1	0.1	0	1	33	0	14
WI-070	7.9	30	84	0.6	1.6	3	11	17	9	12
WI-071	9.6	15	33	1.3	2.6	2	9	21	12	21
WI-072	12.6	22	51	1.3	4	5	14	24	19	22
WI-075	36.6	18	39	4.5	9.5	3	11	21	14	22
WI-076	32.3	54	211	1.2	5.2	12	45	14	18	18
WI-077	71.3	49	179	3.1	11.5	7	28	14	13	14
WI-078	17.4	49	180	0.7	2.7	7	27	13	13	13

Table 20K. CSO results for medium performance scenario, 100% coverage, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	50.1	14	30	8.4	0	2	5	0	13	14
HP-003	79	26	64	6.5	0.6	1	1	1	4	2
HP-004	117.3	33	96	8.7	1.7	3	9	1	8	9
HP-007	132	24	54	13.8	0	0	3	0	0	5
HP-009	692.2	95	442	10.9	77.6	5	33	10	5	7
HP-011	614.6	52	201	10	32.8	7	23	5	12	10
HP-012	1.5	2	3	0.7	0	0	0	0	0	0
HP-013	146.8	27	65	12.5	1.7	0	0	1	0	0
HP-014	686.5	43	158	39.7	10.1	2	0	1	4	0
HP-016	40.8	27	72	3.4	0.5	3	4	1	10	5
HP-017	47.6	60	229	2	0.6	2	10	1	3	4
HP-018	2	21	49	0.2	0	0	1	0	0	2
HP-019	24.5	62	255	0.9	1.1	11	39	4	15	13
HP-020	45.7	42	156	2.3	0.5	3	0	1	7	0
HP-021	137	64	266	1.3	10.1	9	28	7	12	10
HP-022	32	45	161	1.7	0.3	2	5	1	4	3
HP-023	273.5	67	287	5	20.3	12	45	7	15	14
HP-024	76	24	54	8	0	0	3	0	0	5
HP-025	158.6	116	665	3.8	14.4	0	80	8	0	11
HP-026	195.9	113	817	9.9	3.7	3	0	2	3	0
HP-028	13.9	78	328	0.4	0.5	6	30	3	7	8
HP-029	0.7	21	50	0.1	0	1	2	0	5	4
HP-031	63	116	745	1.5	1	0	0	2	0	0
HP-033	86.5	37	111	6	1.1	2	7	1	5	6
WI--05	0.9	10	19	0.2	0	1	1	0	9	5
WI-053	38.1	102	501	0.9	1.2	2	31	3	2	6
WI-054	54	85	369	1.6	0.8	5	22	1	6	6
WI-055	25.2	93	402	0.7	1.1	2	20	4	2	5
WI-056	554.9	57	231	23	14.8	5	8	3	8	3
WI-057	75.3	47	178	3.8	2.3	7	21	3	13	11
WI-058	31.3	45	168	1.6	0.7	3	4	2	6	2
WI-059	9	17	41	1.2	0	0	0	0	0	0
WI-060	377.6	116	663	15	28.5	0	82	7	0	11
WI-061	3	1	1	3	0	0	0	0	0	0
WI-062	348.6	41	149	17.1	9.8	4	4	3	9	3
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	16	25	57	1.5	0	1	4	0	4	7
WI-065	1.3	22	50	0.1	0	1	3	0	4	6
WI-066	1.3	9	15	0.3	0	0	0	0	0	0
WI-067	2	8	14	0.6	0	0	0	0	0	0
WI-068	82.3	27	77	11.1	0	3	2	0	10	3
WI-069	0.2	5	7	0.1	0.1	0	0	33	0	0
WI-070	9.5	32	92	0.7	0	1	3	0	3	3
WI-071	12.4	17	40	1.7	0	0	2	0	0	5
WI-072	17.2	27	65	1.5	0	0	0	0	0	0
WI-075	46.7	21	48	5.6	0	0	2	0	0	4
WI-076	35.9	55	222	1.5	1.6	11	34	4	17	13
WI-077	80.2	49	193	3.8	2.6	7	14	3	13	7
WI-078	19.5	49	192	0.9	0.6	7	15	3	13	7

Table 20L. CSO results for low performance scenario, 100% coverage, wet rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	12.6	7	13	2.2	10.2	3	5	45	30	28
HP-003	50	26	66	2.9	3.8	0	0	7	0	0
HP-004	69.3	31	81	3.4	17.5	4	10	20	11	11
HP-007	53.9	17	41	4.7	26.1	5	15	33	23	27
HP-009	525.4	67	347	6.3	109.7	12	47	17	15	12
HP-011	465.2	47	170	6.4	69.4	4	15	13	8	8
HP-013	76.6	20	55	4.8	24.4	6	11	24	23	17
HP-014	462.9	38	120	17	68.9	2	9	13	5	7
HP-016	21.1	22	61	1.3	7.6	8	12	26	27	16
HP-017	35.8	51	187	0.9	2	1	9	5	2	5
HP-018	0.9	15	35	0.1	0.3	3	5	25	17	13
HP-019	17.5	55	212	0.4	2.7	6	36	13	10	15
HP-020	32.8	38	118	1.1	2.9	2	11	8	5	9
HP-021	111.1	55	216	0.9	9.3	6	32	8	10	13
HP-022	23.1	40	134	0.8	1.7	1	4	7	2	3
HP-023	211.4	54	225	3.1	34.5	8	40	14	13	15
HP-024	31	17	41	2.7	14.9	5	15	32	23	27
HP-025	116.9	91	568	1.7	20.1	0	0	15	0	0
HP-026	129.3	91	568	4.2	24	0	0	16	0	0
HP-028	10.4	62	271	0.2	1	1	14	9	2	5
HP-029	0.5	18	38	0	0	0	4	0	0	10
HP-031	47.9	91	568	0.7	2.7	0	0	5	0	0
HP-033	44.9	31	83	2.3	20.2	6	21	31	16	20
WI--05	0.4	5	10	0.1	0	0	1	0	0	9
WI-053	29.7	86	447	0.5	1.8	0	0	6	0	0
WI-054	42.1	63	290	0.8	1.2	1	22	3	2	7
WI-055	19.2	64	319	0.3	1.5	3	18	7	4	5
WI-056	404.9	49	186	10.5	41.5	3	10	9	6	5
WI-057	44.8	41	135	1.6	15.2	6	26	25	13	16
WI-058	19.4	39	128	0.7	5.3	5	14	21	11	10
WI-059	3.2	10	20	0.4	1.4	3	9	30	23	31
WI-060	248.2	87	535	7.3	66.5	4	33	21	4	6
WI-062	217	37	112	8.3	62.9	3	17	22	8	13
WI-063	3.7	33	79	0.2	0	0	0	0	0	0
WI-064	6.6	19	48	0.5	3.9	5	15	37	21	24
WI-065	0.7	16	39	0	0.2	3	8	22	16	17
WI-066	0.1	2	3	0.1	0.4	3	7	80	60	70
WI-067	0.2	3	4	0.1	0.5	2	6	71	40	60
WI-068	34.2	25	69	3	16.6	8	10	33	24	13
WI-069	0	4	5	0	0.1	1	3	100	20	38
WI-070	4.9	26	71	0.3	2.1	9	18	30	26	20
WI-071	3.9	10	20	0.5	2.4	3	10	38	23	33
WI-072	5.6	15	39	0.6	5.6	11	27	50	42	41
WI-075	16.2	12	25	1.8	9.5	6	14	37	33	36
WI-076	24.7	49	186	0.6	4.7	5	20	16	9	10
WI-077	53.4	45	160	1.6	11.1	3	17	17	6	10
WI-078	13.1	45	160	0.4	2.5	3	17	16	6	10

Table 20M. CSO results for mixed scenario, 25% coverage each high/medium/low, average rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	5.8	3	6	1.8	4.1	2	4	41	40	40
HP-003	28	19	46	2.6	3.1	1	1	10	5	2
HP-004	38.6	21	54	3.2	13.1	4	9	25	16	14
HP-007	26.2	11	22	4.2	17.4	5	13	40	31	37
HP-009	376.5	65	314	6.1	112.6	6	27	23	8	8
HP-011	314.1	41	127	6.3	75.2	4	20	19	9	14
HP-013	40.3	18	36	4.6	18	2	11	31	10	23
HP-014	276.1	28	81	16	54.7	5	16	17	15	16
HP-016	11.2	19	39	1.2	5.6	1	8	33	5	17
HP-017	23.6	45	149	0.9	1.8	0	6	7	0	4
HP-018	0.4	10	19	0.1	0.2	6	8	33	38	30
HP-019	11.6	46	170	0.4	2.5	3	35	18	6	17
HP-020	20.2	28	80	1	2.6	5	17	11	15	18
HP-021	83	45	178	0.9	11.5	4	27	12	8	13
HP-022	14.3	33	101	0.7	1.4	0	2	9	0	2
HP-023	144.1	45	180	3	35.7	6	41	20	12	19
HP-024	15.1	11	22	2.5	9.8	5	13	39	31	37
HP-025	86.5	84	508	1.6	19.1	0	0	18	0	0
HP-026	81.7	84	508	3.9	19.3	0	0	19	0	0
HP-028	7.5	51	223	0.2	0.9	4	24	11	7	10
HP-029	0.3	13	22	0	0	3	6	0	19	21
HP-031	36	84	508	0.7	2.6	0	0	7	0	0
HP-033	24.2	22	53	2.1	15.3	6	19	39	21	26
WI--05	0.1	3	6	0.1	0.1	0	0	50	0	0
WI-053	22.2	73	388	0.4	1.6	0	0	7	0	0
WI-054	30.1	56	249	0.8	1.2	3	26	4	5	9
WI-055	14	60	277	0.3	1.6	2	26	10	3	9
WI-056	264.4	43	146	9.9	37.3	2	9	12	4	6
WI-057	26.3	30	89	1.5	12.9	10	38	33	25	30
WI-058	11.5	28	87	0.6	4.3	9	28	27	24	24
WI-059	1.5	5	10	0.3	0.8	6	7	35	55	41
WI-060	161.2	80	462	7	58.2	4	46	27	5	9
WI-062	124.4	23	75	7.9	50.6	10	22	29	30	23
WI-063	2.1	20	48	0.2	0	0	0	0	0	0
WI-064	3.3	13	25	0.5	2.6	5	17	44	28	40
WI-065	0.3	10	21	0	0.2	7	9	40	41	30
WI-066	0	1	1	0	0.2	1	3	100	50	75
WI-067	0.1	1	1	0.1	0.1	1	2	50	50	67
WI-068	17.1	19	41	2.6	9.7	1	7	36	5	15
WI-069	0	1	1	0	0	0	1	0	0	50
WI-070	2.6	20	42	0.2	1.5	4	16	37	17	28
WI-071	1.7	5	8	0.4	1.4	7	10	45	58	56
WI-072	2.7	11	22	0.4	3.8	9	25	58	45	53
WI-075	7.5	8	15	1.6	5.7	8	11	43	50	42
WI-076	15.9	43	146	0.6	4.2	3	27	21	7	16
WI-077	32.9	36	111	1.5	9.8	7	24	23	16	18
WI-078	8.1	36	111	0.4	2.3	7	24	22	16	18

Table 20N. CSO results for mixed scenario, 25% coverage each high/medium/low, dry rainfall.

Outfall	Model Results				Reduction			Percent Reduction		
	Million Gallons	Events	Hours	Peak Mil Gal/Hr	Million Gallons	Events	Hours	Flow	Events	Hours
HP-002	37	12	24	6.5	10.5	4	11	22	25	31
HP-003	76.8	27	64	6.3	2.8	0	1	4	0	2
HP-004	106.7	33	93	7.4	12.3	3	12	10	8	11
HP-007	109.8	21	52	11	22.2	3	5	17	13	9
HP-009	663.9	95	455	9.5	105.9	5	20	14	5	4
HP-011	582.7	53	202	9.2	64.7	6	22	10	10	10
HP-012	0.9	2	3	0.4	0.4	0	0	31	0	0
HP-013	130.6	25	61	10.8	17.9	2	4	12	7	6
HP-014	646	43	142	35.9	50.6	2	11	7	4	7
HP-016	35.8	27	71	2.8	5.5	3	5	13	10	7
HP-017	46.6	60	229	1.9	1.6	2	10	3	3	4
HP-018	1.7	20	47	0.2	0.3	1	3	15	5	6
HP-019	23.1	64	260	0.8	2.5	9	34	10	12	12
HP-020	44	43	141	2.2	2.2	2	12	5	4	8
HP-021	135.2	67	269	1.2	11.9	6	25	8	8	9
HP-022	31.1	45	158	1.6	1.2	2	8	4	4	5
HP-023	262.7	69	283	4.8	31.1	10	49	11	13	15
HP-024	63.3	21	52	6.4	12.7	3	5	17	13	9
HP-025	152.9	116	745	3.2	20.1	0	0	12	0	0
HP-026	181.2	116	745	8.7	18.4	0	0	9	0	0
HP-028	13.5	79	340	0.4	0.9	5	18	6	6	5
HP-029	0.7	21	49	0.1	0	1	3	0	5	6
HP-031	61.6	116	745	1.4	2.4	0	0	4	0	0
HP-033	73.2	33	101	4.9	14.4	6	17	16	15	14
WI--05	0.9	10	18	0.2	0	1	2	0	9	10
WI-053	37.7	104	532	0.9	1.6	0	0	4	0	0
WI-054	53.7	84	361	1.6	1.1	6	30	2	7	8
WI-055	24.6	91	398	0.6	1.7	4	24	6	4	6
WI-056	534.3	56	223	21.2	35.4	6	16	6	10	7
WI-057	65.9	47	169	3.1	11.7	7	30	15	13	15
WI-058	28	45	157	1.4	4	3	15	13	6	9
WI-059	7.5	16	36	1	1.4	0	3	16	0	8
WI-060	350.6	116	663	13.4	55.5	0	82	14	0	11
WI-061	0	0	0	0	1.8	1	1	100	100	100
WI-062	314.8	39	136	15.4	43.6	6	17	12	13	11
WI-063	5	30	79	0.4	0	0	0	0	0	0
WI-064	12.9	24	56	1.2	3.1	2	5	19	8	8
WI-065	1.1	20	50	0.1	0.2	3	3	15	13	6
WI-066	0.8	6	9	0.2	0.3	2	5	27	25	36
WI-067	1.4	6	9	0.4	0.4	2	4	22	25	31
WI-068	68.4	28	77	8.9	11.8	2	2	15	7	3
WI-069	0.2	4	6	0.1	0.1	0	1	33	0	14
WI-070	8.1	31	86	0.6	1.4	2	9	15	6	9
WI-071	9.6	15	34	1.3	2.6	2	8	21	12	19
WI-072	12	22	55	1.2	4.6	5	10	28	19	15
WI-075	37.3	20	43	4.4	8.8	1	7	19	5	14
WI-076	33.4	56	223	1.3	4.1	10	33	11	15	13
WI-077	74.1	52	189	3.2	8.7	4	18	11	7	9
WI-078	18	52	189	0.8	2.1	4	18	10	7	9

Table 20O. CSO results for mixed scenario, 25% coverage each high/medium/low, wet rainfall.

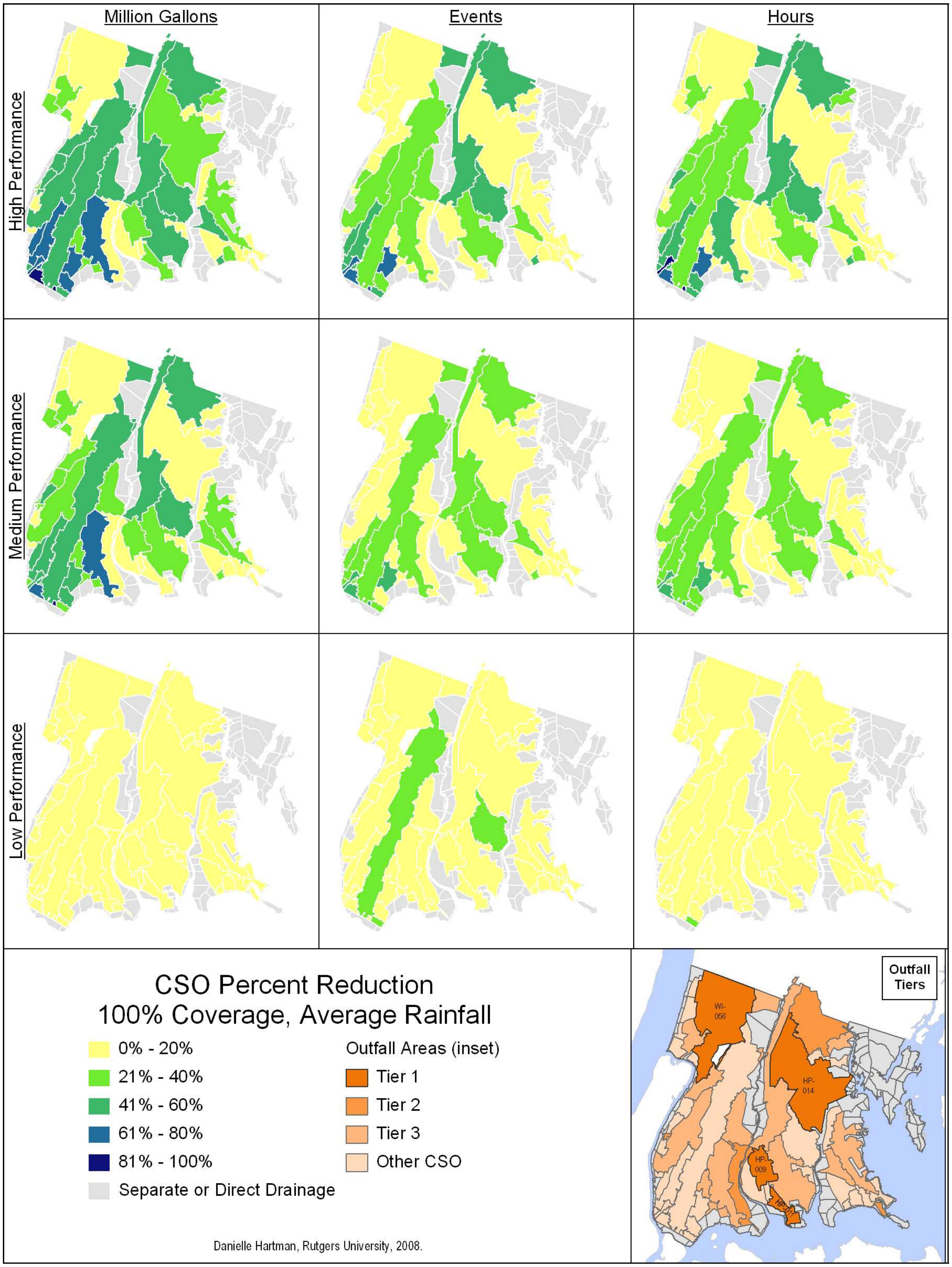

Figure 32. Summary of subcatchment results by performance scenario.

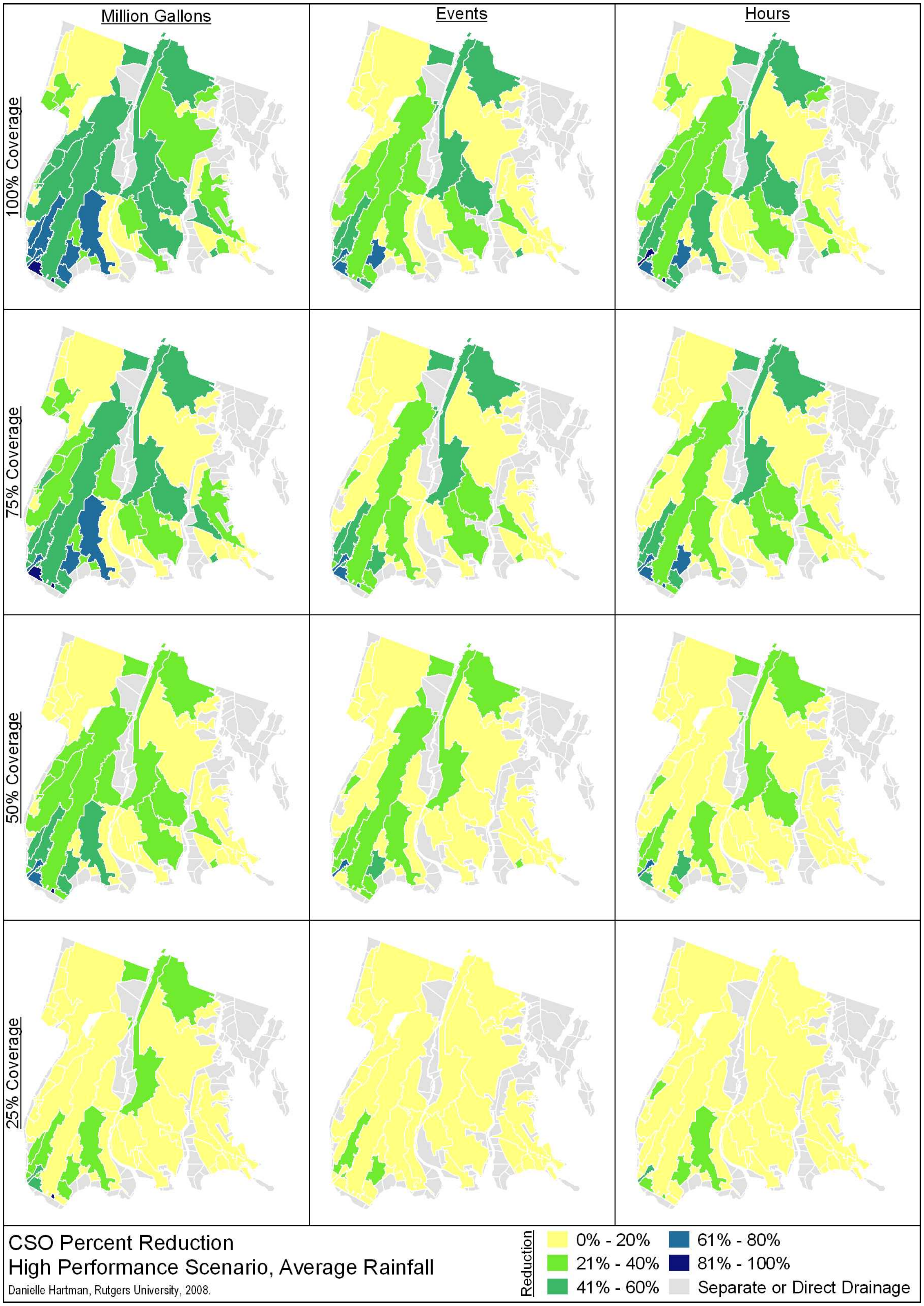

Figure 33. Summary of subcatchment results by coverage, high performance scenario.

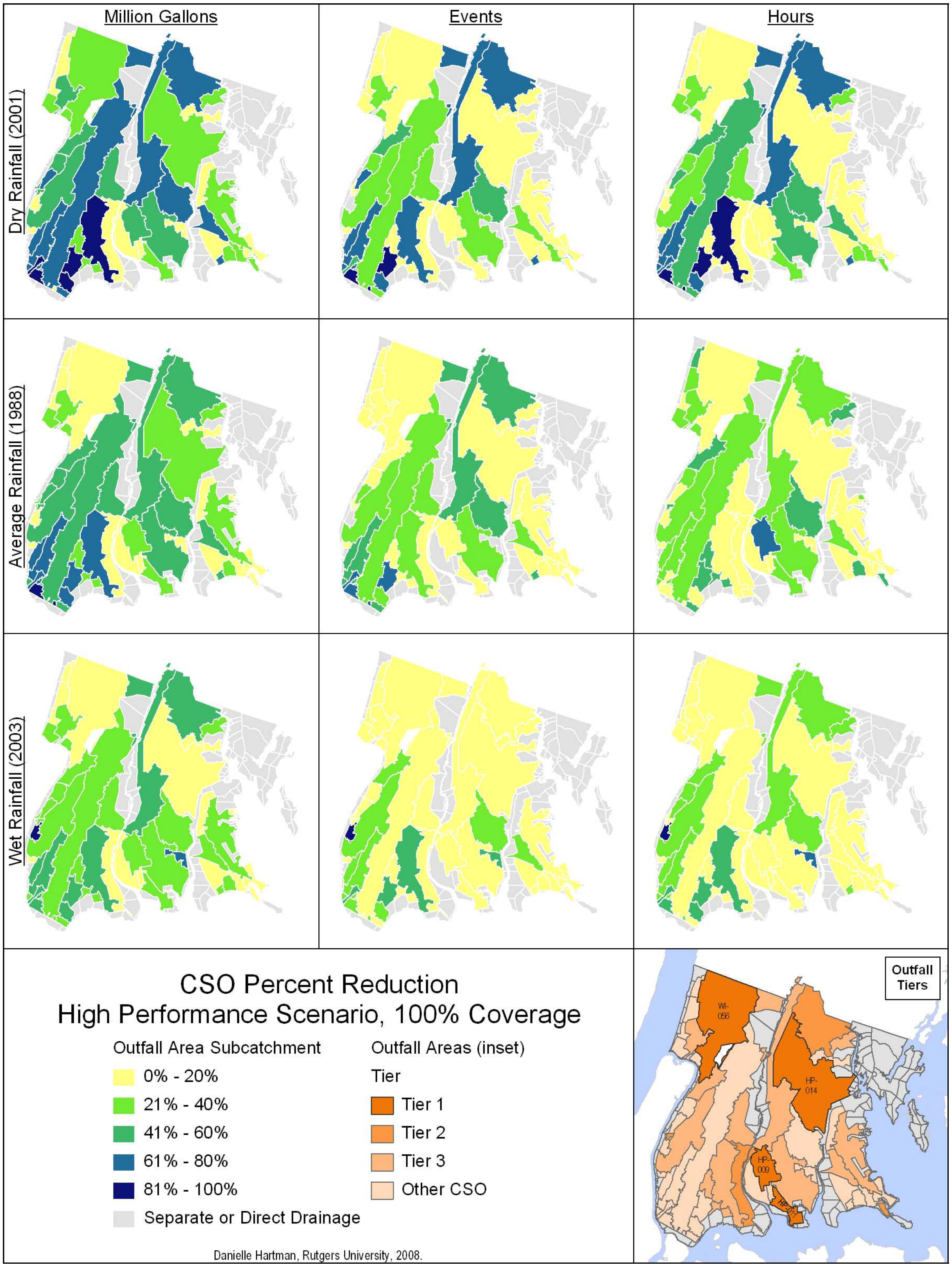

Figure 34. Summary of subcatchment results by rainfall, high performance scenario.

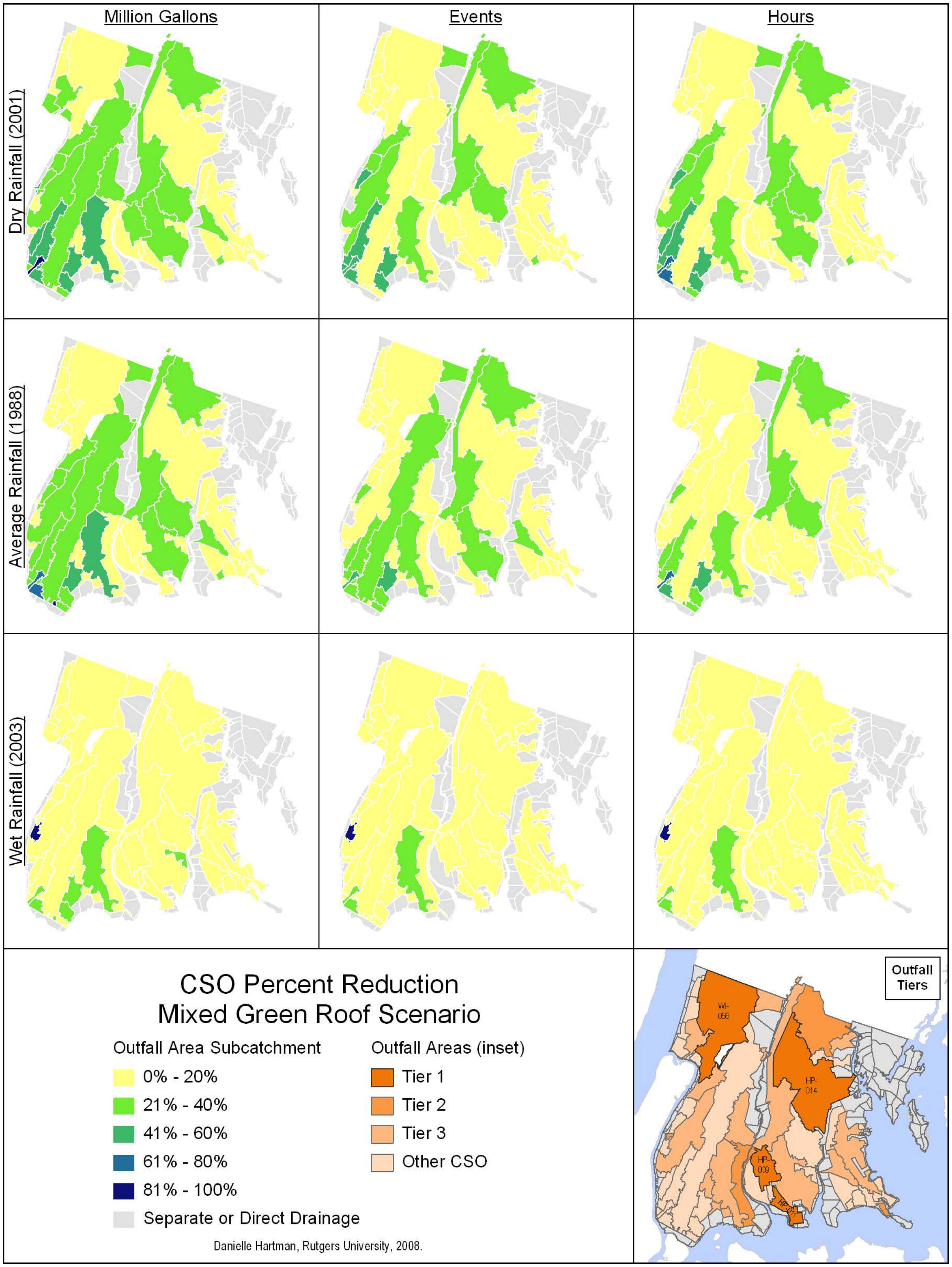

Figure 35. Summary of subcatchment results by rainfall, mixed scenario.

Appendix V. Model Ranking

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	10.9190	9.9263	59.5580	2	1	1	1
WI-055	1.0040	3.0119	18.0715	6	2	6	2
WI-054	0.7242	1.0345	22.7594	9	7	3	3
HP-028	0.6027	1.5067	21.0945	13	6	4	4
HP-019	0.6487	1.8535	11.1212	11	5	7	4
HP-023	3.4315	0.4486	2.6914	4	13	11	6
WI-065	0.4536	2.2679	18.1432	21	4	5	7
HP-016	0.8357	0.5970	0.9949	7	9	20	8
HP-011	4.9276	0.4335	0.7225	3	14	22	9
WI-076	0.5624	0.4891	1.4672	15	10	15	10
WI-069	0.2415	2.4151	7.2454	32	3	8	11
HP-020	0.5633	0.4024	2.4142	14	15	14	11
WI-078	0.4662	0.3586	4.6617	20	16	9	13
WI-070	0.3411	0.9303	2.4809	26	8	13	14
WI-072	0.2943	0.4528	1.1321	29	11	18	15
WI-077	0.4860	0.0824	1.0708	19	22	19	16
WI-059	0.1808	0.4520	1.3560	38	12	16	17
WI-064	0.2868	0.3441	0.9176	31	17	21	18
WI-060	41.4518	0	0	1	32	36	18
WI-057	0.4374	0.0561	0.6730	22	24	24	20
HP-009	2.5070	0	0	5	32	36	21
HP-018	0.2332	0	3.4985	34	32	10	22
WI-053	0.7805	0	0	8	32	36	22
WI-066	0.0769	0.2563	1.2816	41	19	17	24
WI-062	0.4994	0.0151	0.1211	18	30	30	25
WI-058	0.3935	0.2915	0	24	18	36	25
HP-025	0.6600	0	0	10	32	36	25
HP-022	0.6253	0	0	12	32	36	28
HP-024	0.2360	0.0761	0.2792	33	23	26	29
HP-029	0	0	25.1669	49	32	2	30
WI-075	0.2050	0.1414	0.2474	36	20	27	30
HP-026	0.5397	0	0	16	32	36	32
WI-071	0.1603	0.1069	0.6412	39	21	25	33
WI-056	0.5217	0	0	17	32	36	33
HP-033	0.2910	0.0255	0.2042	30	28	28	35
HP-014	0.4123	0.0116	0.0697	23	31	33	36
HP-007	0.2304	0.0427	0.1565	35	26	29	37
HP-004	0.3277	0	0.1024	27	32	31	37
HP-013	0.3185	0.0236	0.0236	28	29	35	39
WI--05	0	0	2.6475	49	32	12	40
HP-017	0.3906	0	0	25	32	36	40
HP-002	0.1388	0.0455	0.0910	40	25	32	42
WI-067	0.0690	0	0.6896	43	32	23	43
WI-068	0.0641	0.0345	0.0483	44	27	34	44
HP-031	0.1915	0	0	37	32	36	44
HP-003	0.0699	0	0	42	32	36	46

Table 21A. CSO ranking for high performance scenario, 25% coverage, average rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	10.5467	4.9632	29.7790	2	2	2	1
WI-055	0.7028	1.5060	9.0357	8	6	6	2
HP-028	0.6780	0.7534	10.5472	9	9	5	3
HP-023	3.5549	0.6728	4.0371	4	10	9	3
HP-019	0.6256	1.6218	8.8043	12	5	7	5
HP-029	0.4194	8.3890	33.5559	23	1	1	6
WI-054	0.6724	0.5173	11.3797	10	12	4	7
WI-065	0.3402	4.5358	12.4734	27	3	3	8
HP-016	0.8258	0.5970	0.8954	6	11	24	9
HP-011	4.8192	0.2890	1.3005	3	21	18	10
WI-076	0.5746	0.3668	2.0785	14	15	14	11
HP-009	2.5373	0.3027	1.2611	5	19	19	11
HP-022	0.5905	0.3474	1.7368	13	16	15	13
HP-018	0.2332	2.3323	4.6647	33	4	8	14
WI-070	0.3411	1.2404	2.4809	26	7	12	14
HP-017	0.5371	0.2441	2.4413	15	22	13	16
WI-078	0.4482	0.1793	3.0481	21	24	11	17
HP-020	0.5231	0.2012	1.6095	17	23	16	17
WI-069	0.1208	1.2076	3.6227	41	8	10	19
WI-072	0.2415	0.4528	1.2075	32	14	20	20
WI-064	0.2523	0.3441	1.1470	31	17	21	21
WI-058	0.3935	0.2915	0.8016	25	20	25	22
WI-057	0.4346	0.1402	0.5608	22	26	28	23
WI-059	0.1695	0.3390	1.0170	38	18	23	24
WI-077	0.4695	0.0412	0.7001	20	33	26	24
WI-066	0.0513	0.5127	1.0253	45	13	22	26
WI-060	40.9598	0	0	1	40	41	27
WI-053	0.7805	0	0	7	40	41	28
HP-033	0.2795	0.0893	0.2808	30	29	30	29
WI-056	0.5191	0.0128	0.1279	18	38	35	30
HP-004	0.3209	0.0512	0.1365	28	31	33	31
WI-062	0.4896	0.0151	0.1059	19	37	36	31
HP-025	0.6290	0	0	11	40	41	31
WI-071	0.1443	0.1603	0.5344	39	25	29	34
WI-075	0.1820	0.1060	0.2650	37	28	31	35
HP-024	0.2145	0.0761	0.2284	34	30	32	35
HP-026	0.5353	0	0	16	40	41	37
WI-067	0.0575	0.1149	0.5747	44	27	27	38
HP-013	0.3150	0.0354	0.0708	29	34	37	39
HP-007	0.2105	0.0427	0.1280	35	32	34	40
HP-014	0.4059	0.0058	0.0465	24	39	39	41
WI--05	0	0	1.3237	46	40	17	42
HP-002	0.1263	0.0341	0.0569	40	35	38	43
HP-031	0.2074	0	0	36	40	41	44
WI-068	0.0627	0.0241	0.0345	43	36	40	45
HP-003	0.0682	0	0	42	40	41	46

Table 21B. CSO ranking for high performance scenario, 50% coverage, average rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	10.2572	5.7904	31.4334	2	2	1	1
WI-060	40.7548	2.0500	20.0904	1	6	3	2
WI-055	0.7028	1.0040	6.0238	7	9	8	3
HP-023	3.6409	0.6728	3.7381	4	10	11	4
HP-019	0.6178	1.2357	6.3329	12	8	7	5
HP-028	0.6529	0.5022	7.0315	9	13	6	6
HP-029	0.2796	11.1853	27.9633	29	1	2	7
WI-054	0.6207	0.3448	7.5865	11	17	5	8
WI-065	0.3024	4.5358	14.3634	27	3	4	9
HP-016	0.7893	0.5970	1.2602	6	12	17	10
WI-078	0.4303	0.5977	2.8688	21	11	12	11
WI-076	0.5543	0.4891	1.7932	15	14	15	11
WI-070	0.3308	1.3438	2.7910	25	7	13	13
HP-018	0.1944	2.3323	5.8308	34	5	9	14
HP-020	0.5767	0.2682	2.4142	14	21	14	15
HP-011	4.7156	0.1927	1.0115	3	25	21	15
HP-009	2.5524	0.2018	0.8407	5	24	24	17
HP-022	0.5789	0.2316	1.1579	13	23	18	18
WI-069	0.0805	3.2202	4.8302	42	4	10	19
HP-017	0.4883	0.1628	1.6275	18	26	16	20
WI-058	0.3838	0.2429	1.1173	24	22	19	21
WI-064	0.2256	0.3823	1.1088	31	15	20	22
WI-072	0.1987	0.3774	1.0063	33	16	22	23
WI-077	0.4475	0.1373	0.6590	20	28	28	24
WI-057	0.4225	0.1309	0.7104	22	29	26	25
WI-059	0.1507	0.3013	0.8287	38	20	25	26
WI-066	0.0342	0.3418	0.6835	46	18	27	27
WI-056	0.5183	0.0341	0.1023	17	36	38	27
WI-053	0.6938	0	0	8	41	42	27
HP-033	0.2646	0.0851	0.2467	30	31	31	30
HP-004	0.3084	0.0796	0.1707	26	32	34	30
WI-067	0.0460	0.3065	0.6130	45	19	29	32
HP-025	0.6416	0	0	10	41	42	32
WI-062	0.4863	0.0151	0.1261	19	39	36	34
WI-071	0.1282	0.1425	0.4631	39	27	30	35
HP-013	0.3012	0.0472	0.1337	28	34	35	36
WI-075	0.1614	0.0942	0.2356	37	30	32	37
HP-026	0.5279	0	0	16	41	42	37
HP-024	0.1929	0.0761	0.2200	35	33	33	39
HP-014	0.4014	0.0077	0.0465	23	40	39	40
WI--05	0.0882	0	0.8825	41	41	23	41
HP-007	0.1897	0.0427	0.1233	36	35	37	42
HP-031	0.2180	0	0	32	41	42	43
HP-002	0.1183	0.0228	0.0455	40	38	40	44
WI-068	0.0581	0.0230	0.0368	44	37	41	45
HP-003	0.0654	0	0	43	41	42	46

Table 21C. CSO ranking for high performance scenario, 75% coverage, average rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	10.4227	4.9632	25.4362	2	2	2	1
WI-060	40.0680	1.5375	15.0678	1	6	3	2
WI-053	0.8022	1.5177	10.4070	6	7	5	3
HP-029	0.4194	12.5835	31.4587	22	1	1	4
HP-028	0.6404	1.1301	9.4172	10	10	6	5
HP-019	0.6256	1.1585	6.2557	11	9	7	6
WI-055	0.6526	0.7530	4.5179	8	11	10	7
HP-023	3.7231	0.5607	3.0278	4	12	13	7
WI-065	0.2835	4.5358	13.0404	28	3	4	9
HP-016	0.7412	0.5472	1.3431	7	13	18	10
WI-054	0.5948	0.2586	5.6899	12	19	8	11
WI-076	0.5502	0.4279	2.3230	15	15	15	12
WI-070	0.3024	1.3180	3.1786	26	8	12	13
HP-018	0.1749	2.3323	5.5393	33	5	9	14
HP-022	0.5905	0.3474	1.9105	13	18	16	14
WI-078	0.4393	0.5379	2.7791	21	14	14	16
HP-011	4.7758	0.1806	1.0476	3	26	21	17
HP-009	2.5802	0.1892	0.8449	5	25	24	18
HP-020	0.5734	0.2012	1.7101	14	24	17	19
WI-069	0.0604	2.4151	4.2265	43	4	11	20
HP-017	0.5127	0.1221	1.2206	17	28	19	21
HP-025	0.6410	0.0859	0.8421	9	32	25	22
WI-058	0.3753	0.2186	1.2023	25	23	20	23
WI-064	0.1979	0.3728	1.0036	32	16	22	24
WI-077	0.4427	0.1441	0.7619	20	27	26	25
WI-072	0.1547	0.3585	0.9057	36	17	23	26
WI-057	0.4052	0.1122	0.6589	23	29	29	27
WI-059	0.1412	0.2260	0.6780	38	22	27	28
HP-033	0.2450	0.0957	0.2999	30	31	33	29
WI-062	0.4767	0.0341	0.1438	19	38	37	29
WI-056	0.5153	0.0256	0.0767	16	39	40	31
WI-066	0.0256	0.2563	0.5767	46	20	30	32
WI-067	0.0345	0.2299	0.4597	45	21	31	33
HP-004	0.3004	0.0768	0.1621	27	34	36	33
WI-071	0.1176	0.1069	0.4008	39	30	32	35
HP-024	0.1732	0.0698	0.1967	34	35	34	36
HP-013	0.2831	0.0472	0.1357	29	36	38	36
WI-075	0.1458	0.0795	0.1944	37	33	35	38
HP-026	0.5110	0	0	18	44	45	39
HP-014	0.3946	0.0058	0.0406	24	43	43	40
HP-007	0.1700	0.0391	0.1102	35	37	39	41
WI--05	0.0662	0	0.6619	41	44	28	42
HP-031	0.2194	0	0	31	44	45	43
HP-002	0.1024	0.0228	0.0569	40	40	41	44
WI-068	0.0520	0.0207	0.0483	44	41	42	45
HP-003	0.0640	0.0083	0.0166	42	42	44	46

Table 21D. CSO ranking for high performance scenario, 100% coverage, average rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	7.6929	4.3428	21.7139	2	2	1	1
WI-060	28.6288	1.5375	12.9152	1	5	3	2
WI-053	0.6071	1.3009	8.8893	6	6	4	3
HP-028	0.4897	0.7534	8.6638	9	10	5	4
HP-019	0.4402	1.0426	4.9814	11	8	7	5
HP-023	2.6802	0.4486	2.4671	4	12	11	6
WI-055	0.5020	0.7530	3.7649	8	11	9	7
HP-029	0.2097	6.2917	18.8752	26	1	2	8
WI-054	0.4397	0.2586	4.6553	12	17	8	9
WI-065	0.1701	2.2679	7.3707	29	3	6	10
HP-016	0.5124	0.3980	0.8457	7	14	19	11
WI-076	0.3974	0.3668	1.8951	15	15	14	12
HP-022	0.4168	0.3474	1.7368	14	16	16	13
HP-011	3.4211	0.1806	0.7586	3	23	21	14
WI-070	0.2093	0.8528	2.1707	27	9	13	15
WI-078	0.3048	0.4482	1.7930	21	13	15	15
HP-020	0.4225	0.2012	1.1065	13	20	17	17
HP-018	0.1166	1.1662	2.9154	35	7	10	18
HP-009	1.9219	0.1766	0.6936	5	24	23	18
WI-069	0.0604	1.8113	2.4151	42	4	12	20
HP-017	0.3662	0.1221	1.0986	17	27	18	21
HP-025	0.4795	0.0859	0.7218	10	30	22	21
WI-058	0.2660	0.1822	0.8380	24	22	20	23
WI-077	0.3151	0.1236	0.5354	20	26	27	24
WI-064	0.1405	0.2581	0.6882	32	18	24	25
WI-057	0.2860	0.0981	0.4346	22	29	29	26
WI-072	0.1094	0.2075	0.6226	36	19	26	27
WI-062	0.3299	0.0303	0.1059	19	36	37	28
WI-059	0.1073	0.1130	0.4520	37	28	28	29
HP-004	0.2099	0.0597	0.1280	25	32	36	29
HP-033	0.1697	0.0638	0.2042	30	31	33	31
WI-056	0.3683	0.0192	0.0639	16	39	40	32
WI-066	0.0192	0.1922	0.3845	46	21	30	33
HP-024	0.1231	0.0444	0.1333	33	33	34	34
WI-067	0.0287	0.1724	0.3448	45	25	31	35
HP-013	0.1941	0.0354	0.0885	28	35	38	35
WI-075	0.1060	0.0442	0.1325	38	34	35	37
HP-026	0.3594	0	0	18	44	45	37
WI-071	0.0882	0.0267	0.2405	39	37	32	39
HP-014	0.2802	0.0058	0.0261	23	43	43	40
WI--05	0.0662	0	0.6619	41	44	25	41
HP-007	0.1206	0.0249	0.0747	34	38	39	42
HP-031	0.1595	0	0	31	44	45	43
HP-002	0.0779	0.0171	0.0398	40	41	41	44
WI-068	0.0374	0.0172	0.0362	44	40	42	45
HP-003	0.0441	0.0083	0.0166	43	42	44	46

Table 21E. CSO ranking for medium performance scenario, 100% coverage, average rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	5.2113	4.3428	16.1303	2	1	1	1
WI-060	11.7160	1.2300	10.1477	1	3	2	2
WI-053	0.3469	1.5177	7.5884	6	2	4	3
HP-028	0.2637	0.7534	5.6503	7	5	5	4
HP-023	1.5980	0.4486	1.7943	4	8	9	5
HP-019	0.1969	1.0426	3.5912	12	4	7	6
WI-055	0.2510	0.7530	3.2629	9	6	8	6
WI-054	0.2069	0.2586	3.6208	10	11	6	8
HP-022	0.1737	0.3474	1.3894	14	9	11	9
WI-076	0.1773	0.1834	1.2838	13	14	12	10
HP-020	0.2012	0.2012	0.7042	11	13	16	11
HP-011	1.9111	0.1084	0.5780	3	19	18	11
HP-009	1.1173	0.1766	0.5044	5	15	20	11
WI-078	0.1165	0.2689	1.1654	19	10	13	14
WI-070	0.0543	0.6202	1.3955	28	7	10	15
HP-017	0.1587	0.1221	0.7324	16	17	15	16
HP-025	0.2561	0.0516	0.5500	8	24	19	17
HP-016	0.1144	0.2487	0.4477	21	12	21	18
WI-058	0.1020	0.1457	0.6194	24	16	17	19
WI-077	0.1318	0.0824	0.3501	17	21	22	20
WI-057	0.1080	0.0841	0.2944	22	20	24	21
WI-064	0.0229	0.1147	0.3441	32	18	23	22
WI-062	0.1165	0.0265	0.0757	20	26	28	23
WI-065	0.0567	0	1.1339	27	35	14	24
HP-033	0.0440	0.0574	0.1276	29	22	27	25
HP-029	0	0	8.3890	41	35	3	26
HP-004	0.0597	0.0427	0.0683	26	25	29	27
WI-072	0.0132	0.0566	0.2453	35	23	26	28
WI-056	0.1675	0	0.0256	15	35	38	29
HP-018	0.0292	0	0.2915	31	35	25	30
HP-024	0.0159	0.0190	0.0635	33	27	31	30
HP-013	0.0419	0.0177	0.0413	30	28	35	32
HP-026	0.1305	0	0	18	35	43	33
HP-014	0.1063	0.0058	0.0087	23	34	41	34
WI-075	0.0097	0.0177	0.0442	38	29	34	35
HP-007	0.0156	0.0107	0.0356	34	32	36	36
HP-031	0.0678	0	0	25	35	43	37
WI-059	0.0113	0	0.0565	36	35	33	38
WI-066	0	0	0.0641	41	35	30	39
WI-067	0	0	0.0575	41	35	32	40
WI-068	0.0067	0.0138	0.0207	40	30	39	41
HP-002	0.0068	0.0114	0.0114	39	31	40	42
HP-003	0.0108	0.0083	0.0083	37	33	42	43
WI-071	0	0	0.0267	41	35	37	44

Table 21F. CSO ranking for low performance scenario, 100% coverage, average rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	12.6561	2.4816	28.5382	2	4	1	1
WI-060	33.8564	0.6150	23.3704	1	11	3	2
HP-028	0.6404	2.2601	15.0675	8	5	4	3
WI-055	0.6777	0.7530	6.7768	7	8	7	4
WI-054	0.5948	0.7759	6.7244	10	7	8	5
WI-053	0.7372	0.4336	9.3229	6	16	6	6
HP-029	0.2097	14.6807	25.1669	28	1	2	7
WI-065	0.2268	6.8037	10.7725	25	2	5	8
HP-019	0.5561	0.4634	6.2557	11	15	9	9
HP-023	3.6502	0.3364	3.4764	4	20	11	9
HP-020	0.4828	0.7042	2.3136	14	9	15	11
WI-078	0.3676	0.8965	2.9584	21	6	13	12
HP-022	0.4863	0.5210	1.7368	13	13	16	13
WI-076	0.4768	0.4279	2.9955	15	17	12	14
HP-011	4.8517	0.2890	1.1199	3	23	20	15
HP-018	0.1166	3.2070	4.9562	34	3	10	16
WI-070	0.2171	0.6977	2.4033	27	10	14	17
WI-058	0.2951	0.4736	1.6031	24	14	17	18
HP-016	0.5323	0.2985	1.0944	12	22	21	18
HP-009	2.5713	0.1387	0.7566	5	27	27	20
HP-025	0.6050	0.0344	1.3062	9	37	18	21
WI-077	0.3727	0.2677	0.8237	19	24	25	22
WI-057	0.3281	0.2524	0.8412	22	25	24	23
WI-064	0.1348	0.3728	0.8603	32	19	23	24
WI-069	0	0.6038	1.2076	46	12	19	25
HP-017	0.4394	0	0.9765	17	43	22	26
WI-072	0.1057	0.3208	0.7736	36	21	26	27
WI-059	0.0904	0.3955	0.5650	38	18	29	28
WI-062	0.3697	0.0454	0.1400	20	34	37	29
HP-033	0.1800	0.0766	0.2616	31	30	31	30
HP-004	0.2210	0.0597	0.1792	26	33	33	30
WI-071	0.0721	0.2405	0.3741	39	26	30	32
WI-056	0.4495	0.0128	0.1087	16	41	39	33
WI-075	0.0928	0.1060	0.1590	37	29	35	34
HP-024	0.1168	0.0635	0.1459	33	32	36	34
HP-013	0.2017	0.0354	0.1298	29	36	38	36
HP-014	0.3066	0.0145	0.0494	23	40	43	37
HP-026	0.4103	0	0	18	43	45	37
WI-066	0.0128	0.0641	0.1922	44	31	32	39
WI-067	0.0115	0.1149	0.1724	45	28	34	39
HP-007	0.1152	0.0356	0.0818	35	35	40	41
WI--05	0.0662	0	0.6619	40	43	28	42
HP-031	0.1994	0	0	30	43	45	43
HP-002	0.0512	0.0228	0.0512	41	38	42	44
HP-003	0.0507	0.0166	0.0582	42	39	41	45
WI-068	0.0314	0.0086	0.0362	43	42	44	46

Table 21G. CSO ranking for high performance scenario, 100% coverage, dry rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	10.4227	1.8612	24.1955	2	5	1	1
WI-060	23.8010	1.2300	18.1428	1	6	3	2
HP-028	0.4897	2.2601	12.8074	8	4	4	3
HP-029	0.2097	12.5835	18.8752	23	1	2	4
WI-053	0.5203	0.4336	5.8539	7	13	6	4
WI-054	0.4138	0.7759	5.1726	10	8	8	4
WI-055	0.5271	0.5020	5.0199	6	11	9	4
HP-023	2.7923	0.2804	2.9718	4	17	11	8
HP-019	0.4055	0.3475	5.2131	11	15	7	9
HP-020	0.3420	0.7042	1.8107	14	9	14	10
WI-065	0.1134	4.5358	7.3707	31	2	5	11
WI-078	0.2600	0.8068	2.5102	20	7	12	12
HP-011	3.7354	0.2529	0.9754	3	18	19	13
HP-022	0.3300	0.5210	1.3894	15	10	17	14
WI-076	0.3423	0.2445	2.3841	13	20	13	15
HP-018	0.0583	2.3323	3.4985	37	3	10	16
WI-058	0.1967	0.4372	1.4209	25	12	16	17
HP-025	0.4434	0.0687	0.9968	9	28	18	18
WI-070	0.1395	0.3876	1.5505	28	14	15	19
HP-016	0.3432	0.1492	0.7959	12	25	20	19
HP-009	1.9547	0.1009	0.3657	5	26	28	21
WI-077	0.2636	0.2471	0.7001	19	19	23	22
WI-057	0.2243	0.2103	0.7010	22	21	22	23
WI-064	0.0803	0.1721	0.6309	32	22	24	24
HP-017	0.3174	0	0.7324	17	41	21	25
WI-059	0.0508	0.2825	0.4520	39	16	27	26
WI-072	0.0660	0.1698	0.5472	36	23	26	27
WI-062	0.2459	0.0378	0.1059	21	31	33	27
HP-033	0.1155	0.0511	0.1978	30	29	30	29
WI-056	0.3241	0.0128	0.0575	16	36	38	30
WI-071	0.0374	0.1603	0.2137	40	24	29	31
HP-004	0.1408	0.0341	0.1024	27	32	34	31
HP-024	0.0698	0.0381	0.1079	33	30	32	33
WI-075	0.0521	0.0883	0.1237	38	27	31	34
HP-013	0.1292	0.0177	0.0944	29	34	35	35
HP-014	0.2058	0.0145	0.0348	24	35	41	36
HP-026	0.2710	0.0111	0	18	38	44	36
HP-007	0.0690	0.0213	0.0605	34	33	37	38
HP-031	0.1436	0	0	26	41	44	39
WI-069	0	0	0.6038	46	41	25	40
HP-003	0.0324	0.0083	0.0499	41	39	40	41
WI--05	0.0662	0	0	35	41	44	41
WI-066	0.0064	0	0.0641	44	41	36	43
HP-002	0.0245	0.0114	0.0341	42	37	42	43
WI-067	0.0057	0	0.0575	45	41	39	45
WI-068	0.0186	0.0017	0.0224	43	40	43	46

Table 21H. CSO ranking for medium performance scenario, 100% coverage, dry rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	6.1419	1.8612	17.3711	2	4	1	1
WI-060	12.3002	1.2300	13.2228	1	6	3	2
HP-029	0.2097	10.4862	14.6807	11	1	2	3
HP-028	0.2260	2.6368	8.6638	10	3	4	4
WI-053	0.3035	0.4336	4.9867	6	10	5	5
WI-054	0.2328	0.7759	4.3967	9	7	6	6
WI-055	0.3012	0.5020	3.7649	7	8	7	6
HP-023	1.6709	0.2804	2.1307	4	13	10	8
HP-019	0.1969	0.2317	3.5912	12	15	8	9
HP-020	0.1911	0.4024	1.1065	13	11	14	10
HP-011	2.1892	0.1806	0.5780	3	16	19	10
WI-078	0.1345	0.4482	1.1654	19	9	13	12
WI-076	0.1773	0.1223	1.2838	14	18	12	13
WI-065	0	3.4018	2.8349	39	2	9	14
HP-025	0.2629	0.0687	0.7046	8	27	17	15
HP-018	0	1.4577	1.4577	39	5	11	16
WI-058	0.0947	0.2550	0.9473	25	14	16	16
HP-009	1.1955	0.0883	0.2144	5	24	26	16
WI-070	0.0465	0.3101	1.0078	29	12	15	19
HP-016	0.1293	0.0995	0.4975	20	21	20	20
WI-077	0.1359	0.1030	0.3295	18	20	24	21
WI-057	0.1094	0.0981	0.4346	23	22	21	22
HP-022	0.1737	0	0.6947	15	37	18	23
HP-017	0.1709	0	0.3662	16	37	22	24
WI-064	0.0201	0.0860	0.3441	31	25	23	25
WI-072	0.0151	0.0943	0.3208	32	23	25	26
WI-059	0.0056	0.1695	0.1695	36	17	27	26
HP-033	0.0466	0.0447	0.1340	28	28	28	28
WI-062	0.1165	0.0265	0.0605	22	30	33	29
HP-004	0.0580	0.0341	0.0768	27	29	30	30
WI-071	0	0.1069	0.0802	39	19	29	31
HP-026	0.1261	0.0221	0	21	32	39	32
WI-056	0.1694	0	0	17	37	39	33
WI-075	0.0053	0.0707	0.0707	38	26	31	34
HP-013	0.0460	0.0118	0.0649	30	34	32	35
HP-014	0.0990	0.0087	0.0232	24	35	37	35
HP-024	0.0146	0.0254	0.0571	34	31	34	37
HP-007	0.0149	0.0142	0.0320	33	33	36	38
HP-031	0.0718	0	0	26	37	39	38
HP-003	0.0133	0.0083	0.0333	35	36	35	40
WI-068	0.0053	0	0.0103	37	37	38	41

Table 21I. CSO ranking for low performance scenario, 100% coverage, dry rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	13.1524	6.2040	26.0566	2	1	2	1
HP-028	0.7157	3.3902	16.1975	8	3	4	2
WI-055	0.7530	1.0040	6.0238	6	7	9	3
HP-023	3.4091	0.7850	3.8128	4	8	10	3
WI-054	0.6466	1.8104	8.0175	11	5	7	5
WI-053	0.7372	0.6504	8.4557	7	11	6	6
HP-019	0.6024	1.3902	6.1398	12	6	8	7
WI-065	0.2835	2.8349	9.0716	25	4	5	8
HP-029	0.2097	4.1945	18.8752	31	2	3	9
WI-076	0.5257	0.7336	3.0566	15	9	13	10
WI-078	0.4213	0.6275	3.1377	19	12	12	11
HP-020	0.5432	0.6036	2.4142	13	14	16	11
HP-011	4.9059	0.2890	1.3367	3	19	21	11
WI-060	37.0237	0	31.6731	1	45	1	14
HP-022	0.5384	0.3474	2.4315	14	18	15	14
HP-016	0.6765	0.3482	0.6964	9	17	25	16
HP-018	0.2041	0.5831	3.4985	33	15	11	17
HP-017	0.4638	0.2441	1.3427	17	22	20	17
WI-070	0.2558	0.4652	1.4730	27	16	19	19
HP-009	2.5411	0.1009	0.6179	5	30	27	19
WI-058	0.3316	0.2550	1.5667	24	21	18	21
WI--05	0.1324	0.6619	2.6475	40	10	14	22
WI-057	0.3645	0.1542	0.9393	22	26	23	23
WI-077	0.4118	0.1441	0.8031	20	27	24	24
HP-025	0.6703	0	1.7702	10	45	17	25
WI-069	0.0604	0.6038	1.2076	44	13	22	26
WI-064	0.2093	0.2007	0.6309	32	24	26	27
WI-072	0.1679	0.2264	0.5094	38	23	30	28
WI-062	0.3833	0.0378	0.1513	21	36	35	29
WI-056	0.4955	0.0320	0.1343	16	38	38	29
WI-059	0.1808	0.1130	0.5650	36	29	28	31
HP-033	0.2125	0.0638	0.2042	30	33	33	32
WI-066	0.0384	0.2563	0.5127	48	20	29	33
WI-071	0.1496	0.1336	0.4542	39	28	31	34
HP-004	0.2535	0.0341	0.1451	28	37	37	35
WI-067	0.0575	0.1724	0.3448	46	25	32	36
WI-075	0.1767	0.0442	0.1767	37	34	34	37
HP-013	0.2584	0.0295	0.0590	26	39	42	38
HP-012	0.0664	0.0737	0.1475	43	31	36	39
HP-014	0.3472	0.0087	0.0494	23	43	44	39
HP-026	0.4501	0	0	18	45	47	39
HP-024	0.1948	0.0254	0.1015	34	40	39	42
WI-061	0.1208	0.0671	0.0671	42	32	41	43
HP-002	0.1303	0.0398	0.0967	41	35	40	44
HP-007	0.1903	0.0142	0.0569	35	41	43	45
HP-031	0.2154	0	0	29	45	47	46
HP-003	0.0591	0.0083	0.0250	45	44	45	47
WI-068	0.0502	0.0103	0.0155	47	42	46	48

Table 21J. CSO ranking for high performance scenario, 100% coverage, wet rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	10.5467	5.5836	23.5751	2	1	2	1
HP-028	0.4520	2.6368	13.9374	9	3	3	2
WI-054	0.4397	1.5518	6.9830	10	5	6	3
WI-053	0.5203	0.6504	7.5884	7	11	5	4
HP-023	2.4054	0.6728	3.3082	4	9	10	4
HP-019	0.3823	1.2743	5.5606	11	6	7	6
WI-055	0.5271	0.5020	5.0199	6	13	8	7
WI-076	0.3179	0.7336	2.7509	13	7	11	8
HP-011	3.2188	0.2890	1.1922	3	16	19	9
HP-020	0.3118	0.7042	1.4083	14	8	17	10
WI-065	0.1134	1.7009	4.5358	30	4	9	11
WI-078	0.2421	0.6275	2.4205	19	12	12	11
HP-022	0.2953	0.3474	1.9105	16	14	14	13
WI-060	22.7247	0	27.9830	1	44	1	14
HP-017	0.2807	0.2441	1.2206	17	18	18	15
HP-029	0	4.1945	10.4862	48	2	4	16
HP-009	1.8223	0.0757	0.4792	5	25	25	17
HP-016	0.3383	0.1990	0.4477	12	20	26	18
WI-058	0.1785	0.2550	0.9473	24	17	20	19
WI--05	0.0662	0.6619	1.9856	40	10	13	20
WI-057	0.1991	0.1542	0.6449	22	21	22	21
HP-018	0.0875	0.2915	1.4577	35	15	16	22
WI-077	0.2368	0.1441	0.5766	20	22	24	22
HP-025	0.4675	0	1.5639	8	44	15	24
WI-070	0.1240	0.2326	0.8528	28	19	21	25
WI-064	0.1004	0.1434	0.3728	32	23	27	26
WI-056	0.3030	0.0320	0.1087	15	34	34	27
WI-072	0.0755	0.0943	0.2642	38	24	29	28
WI-062	0.2051	0.0341	0.0946	21	33	37	28
WI-059	0.0847	0.0565	0.2825	36	29	28	30
WI-061	0.1208	0.0671	0.0671	29	26	38	30
HP-004	0.1297	0.0341	0.1024	27	32	35	32
HP-033	0.1072	0.0447	0.1276	31	31	33	33
WI-071	0.0695	0.0534	0.2405	39	30	31	34
HP-026	0.2433	0.0111	0	18	38	46	35
WI-066	0.0128	0.0641	0.2563	47	27	30	36
WI-067	0.0172	0.0575	0.1724	46	28	32	37
HP-014	0.1873	0.0087	0.0203	23	39	44	37
WI-069	0.0604	0	0.6038	41	44	23	39
WI-075	0.0839	0.0265	0.0972	37	35	36	39
HP-024	0.0939	0.0127	0.0508	33	37	40	41
HP-013	0.1304	0.0059	0.0236	26	42	43	42
HP-031	0.1316	0	0	25	44	46	43
HP-007	0.0917	0.0071	0.0284	34	41	41	44
HP-002	0.0569	0.0228	0.0626	42	36	39	45
HP-003	0.0308	0.0083	0.0250	43	40	42	46
WI-068	0.0217	0.0052	0.0103	45	43	45	47
HP-012	0.0221	0	0	44	44	46	48

Table 21K. CSO ranking for medium performance scenario, 100% coverage, wet rainfall.

Outfall	CSO Reduction			Rank			
	Million Gallons/Acre	Events/Acre	Hours/Acre	Flow	Events	Hours	Overall
HP-021	6.2660	5.5836	17.3711	2	1	2	1
HP-028	0.1883	2.2601	11.3006	10	2	3	2
WI-054	0.2069	1.2931	5.6899	9	4	5	3
HP-023	1.1382	0.6728	2.5232	4	6	9	4
WI-053	0.2602	0.4336	6.7212	7	12	4	5
WI-055	0.2761	0.5020	5.0199	6	11	6	5
HP-019	0.1274	1.2743	4.5180	11	5	7	5
WI-076	0.0978	0.6725	2.0785	12	7	10	8
HP-011	1.1849	0.2529	0.8309	3	15	16	9
WI-060	8.7639	0	25.2155	1	33	1	10
WI-078	0.0538	0.6275	1.3447	16	9	13	11
HP-029	0	2.0972	4.1945	31	3	8	12
HP-017	0.0732	0.2441	1.2206	14	16	14	13
HP-009	0.9786	0.0631	0.4162	5	22	18	14
HP-022	0.0521	0.3474	0.8684	18	13	15	15
WI-065	0	0.5670	1.7009	31	10	11	16
HP-025	0.2475	0	1.3749	8	33	12	17
WI--05	0	0.6619	0.6619	31	8	17	18
WI-077	0.0535	0.1441	0.2883	17	18	21	18
WI-057	0.0322	0.0981	0.2944	23	20	19	20
WI-056	0.0946	0.0320	0.0511	13	24	28	21
HP-016	0.0249	0.1492	0.1990	26	17	23	22
WI-058	0.0255	0.1093	0.1457	25	19	24	23
HP-020	0.0503	0.3018	0	19	14	37	24
WI-070	0	0.0775	0.2326	31	21	22	25
HP-004	0.0145	0.0256	0.0768	27	26	26	26
HP-026	0.0409	0.0332	0	20	23	37	27
WI-064	0	0.0287	0.1147	31	25	25	28
WI-062	0.0371	0.0151	0.0151	22	27	33	29
HP-018	0	0	0.2915	31	33	20	30
WI-069	0.0604	0	0	15	33	37	31
HP-033	0.0070	0.0128	0.0447	29	28	29	32
HP-002	0	0.0114	0.0284	31	29	30	33
WI-071	0	0	0.0534	31	33	27	34
HP-031	0.0399	0	0	21	33	37	34
HP-014	0.0293	0.0058	0	24	31	37	36
HP-024	0	0	0.0190	31	33	31	37
HP-003	0.0050	0.0083	0.0083	30	30	35	37
WI-075	0	0	0.0177	31	33	32	39
HP-007	0	0	0.0107	31	33	34	40
HP-013	0.0100	0	0	28	33	37	40
WI-068	0	0.0052	0.0034	31	32	36	42

Table 21L. CSO ranking for low performance scenario, 100% coverage, wet rainfall.

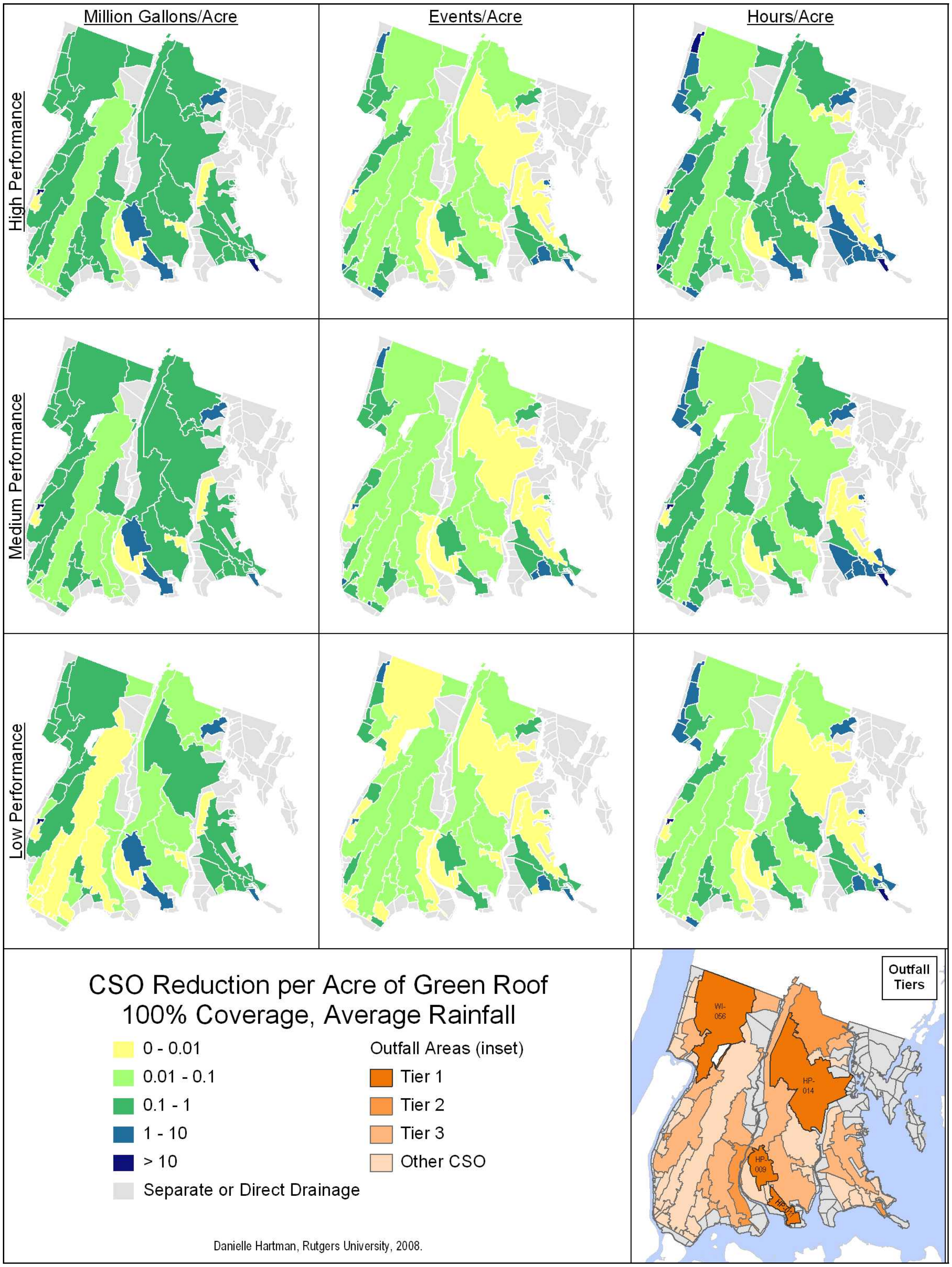

Figure 36. Summary of subcatchment scores by performance scenario. Reduction in combined sewer overflows normalized by green roof area.

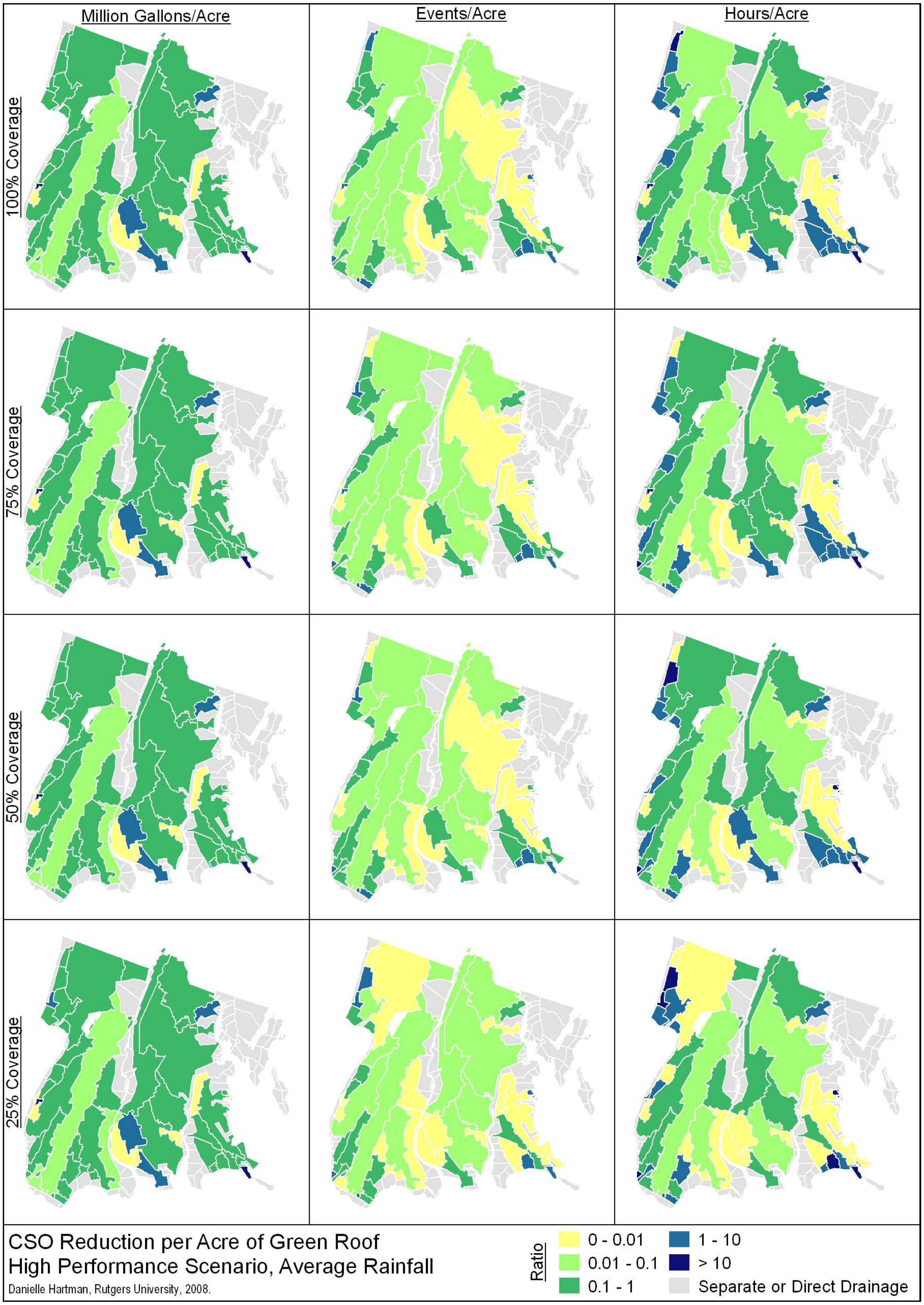

Figure 37. Summary of subcatchment scores by coverage, high performance scenario. Reduction in combined sewer overflows normalized by green roof area.

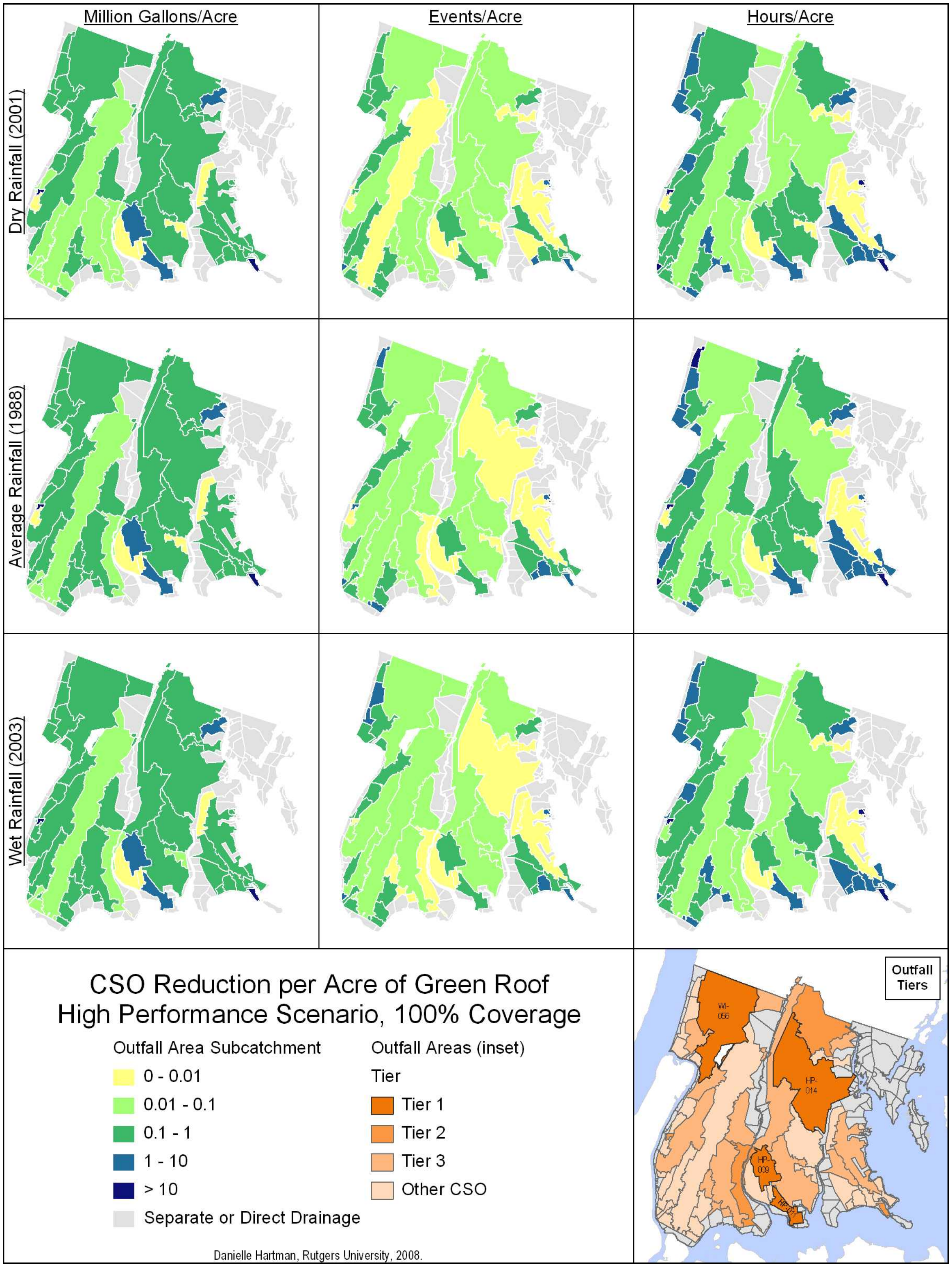

Figure 38. Summary of subcatchment scores by rainfall, high performance scenario. Reduction in combined sewer overflows normalized by green roof area.

Appendix VI. Reference Maps

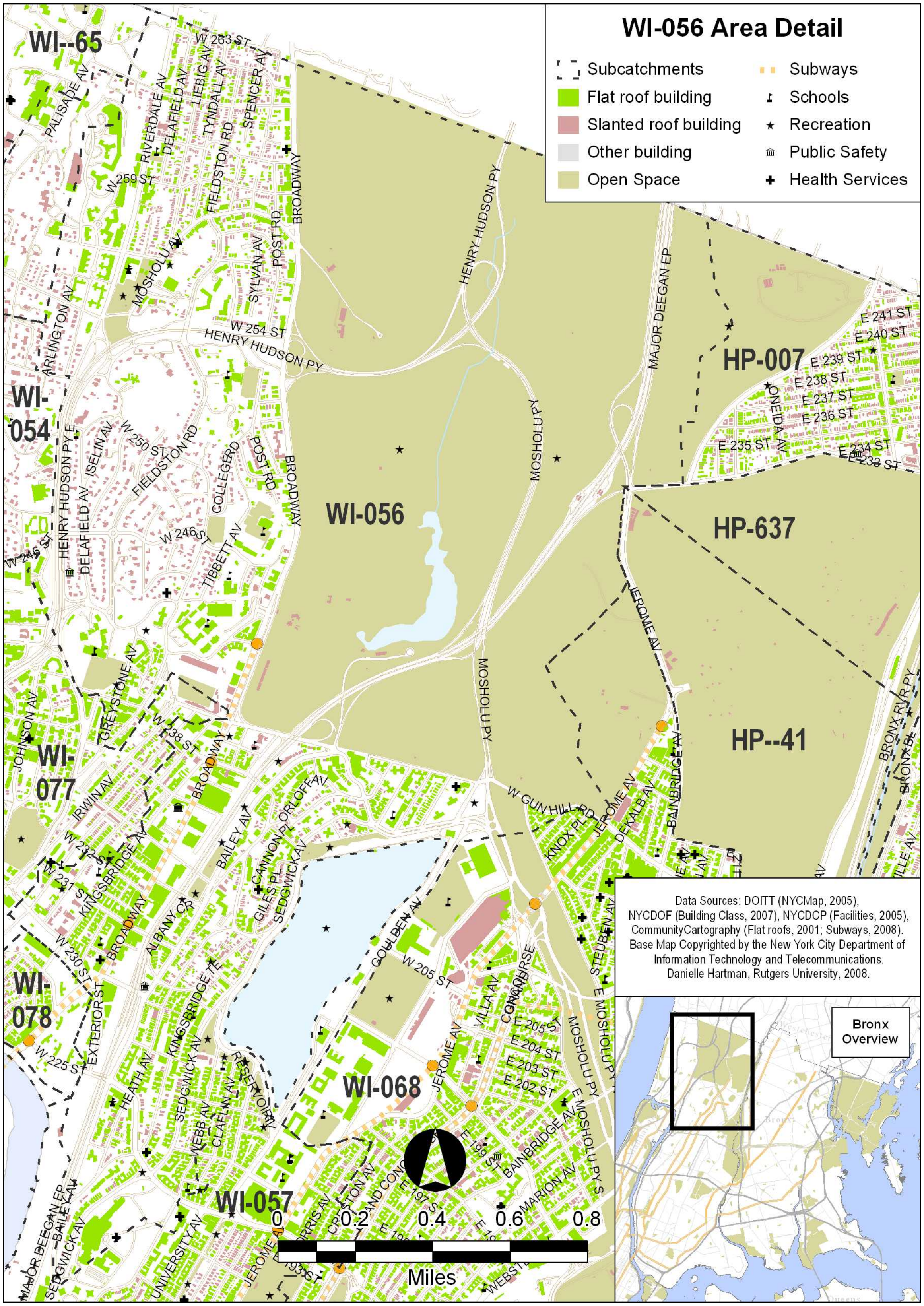

Figure 39. Map of WI-056 outfall area subcatchment. This outfall produces the most Bronx CSOs by volume.

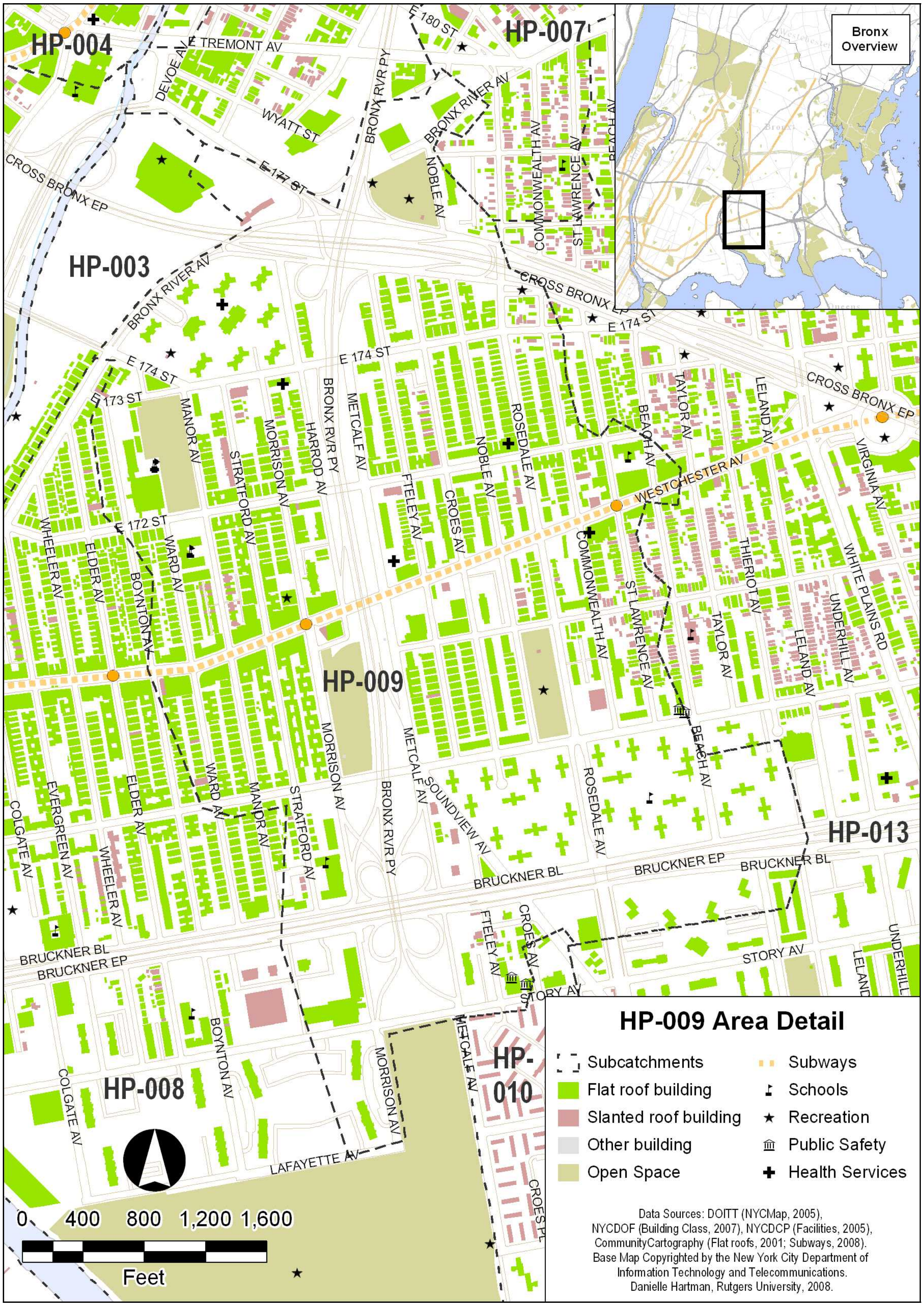

Figure 40. Map of HP-009 subcatchment. This Tier 1 outfall produces the second most Bronx CSOs by volume. It also showed the greatest volume reduction across all green roof model scenarios.

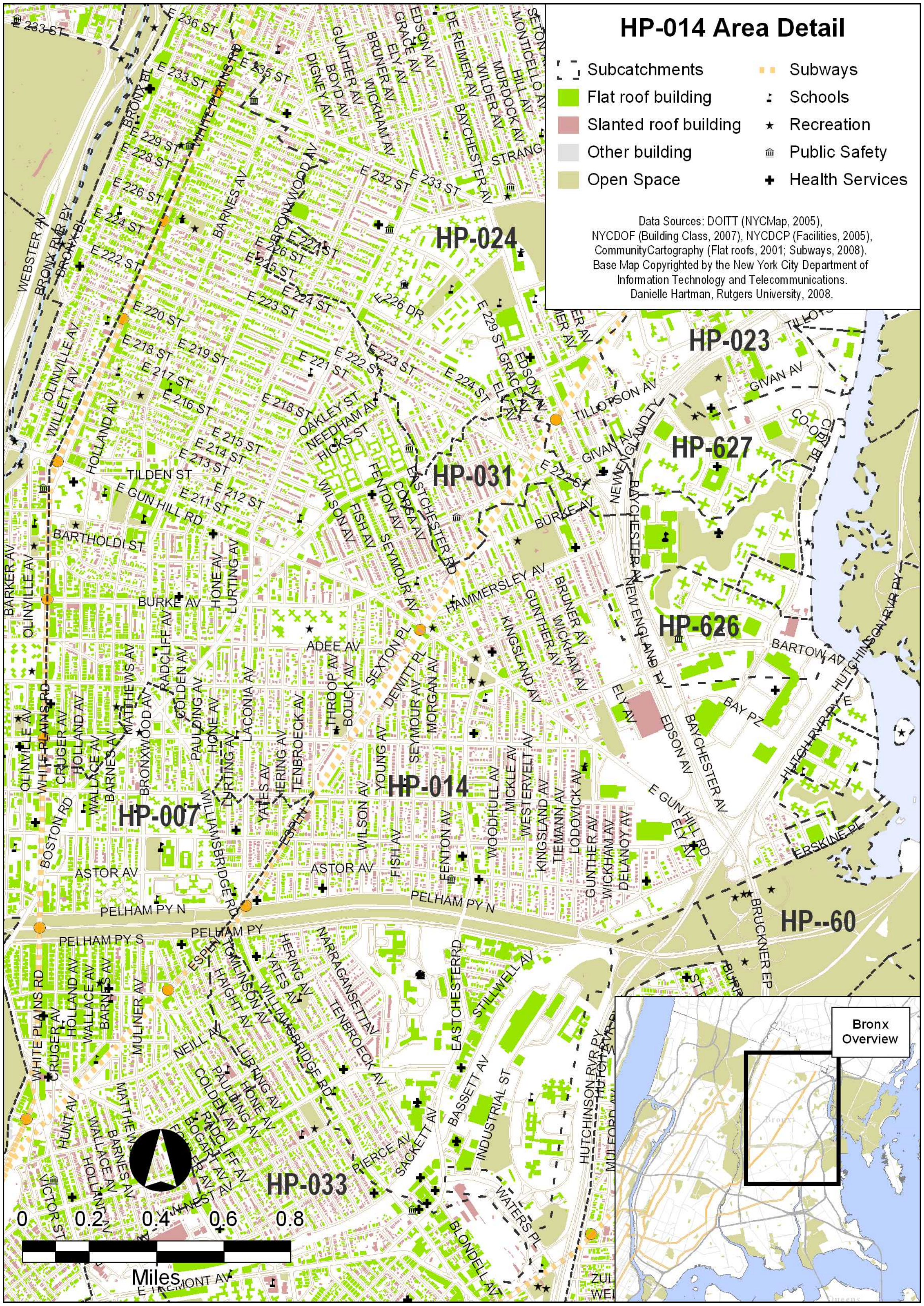

Figure 41. Map of HP-014 subcatchment. This Tier 1 outfall produces the third most Bronx CSOs by volume.

Figure 42. Map of HP-011 subcatchment. This Tier 1 outfall produced the fourth most Bronx CSOs by volume. It showed a strong response to modeled green roofs scenarios, highly sensitive to volume reduction.

Figure 43. Map of HP-003 subcatchment. This is a Tier 2 outfall.

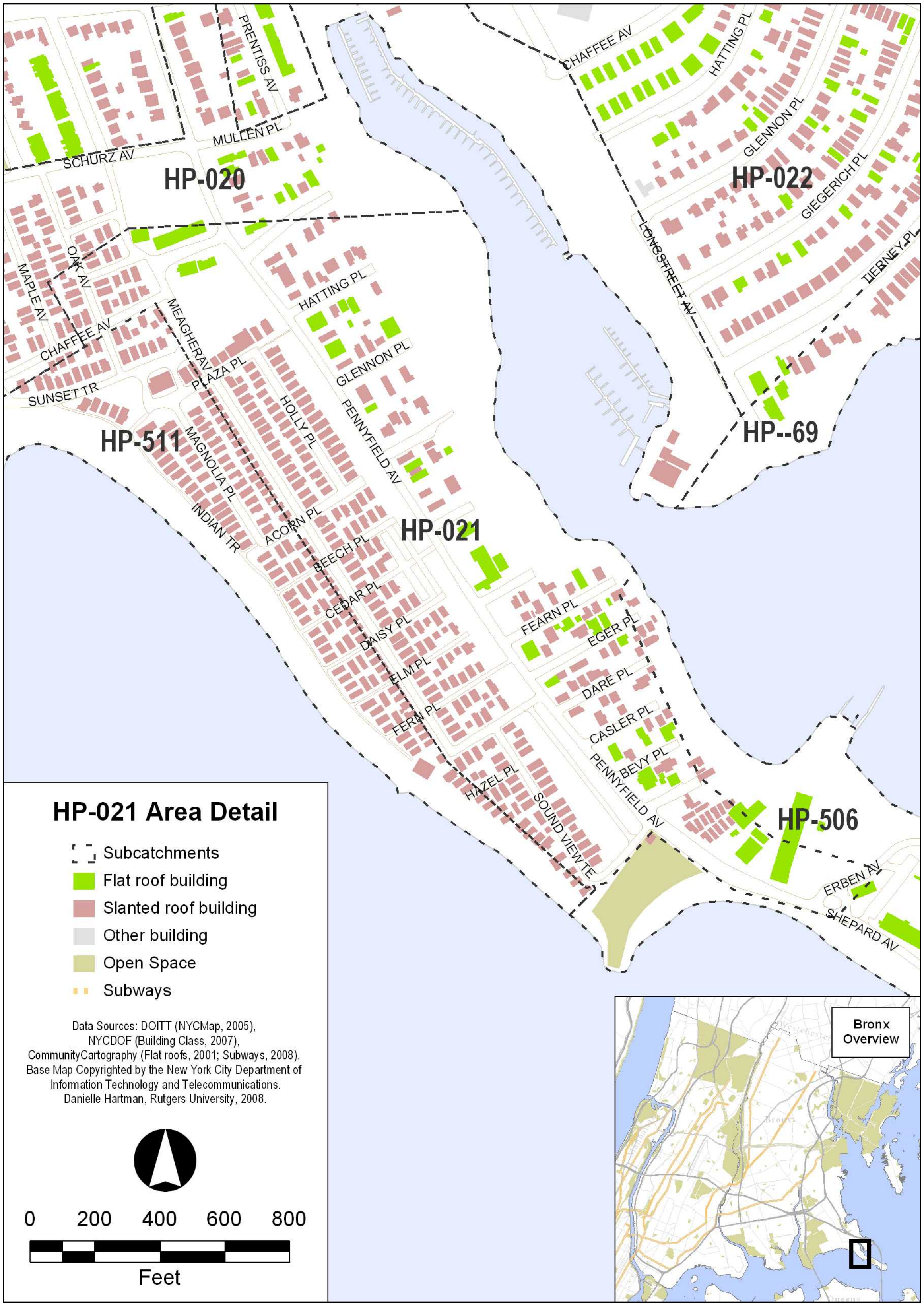

Figure 44. Map of HP-021 subcatchment. This is a Tier 2 outfall and was most sensitive to modeled green roof scenarios overall.

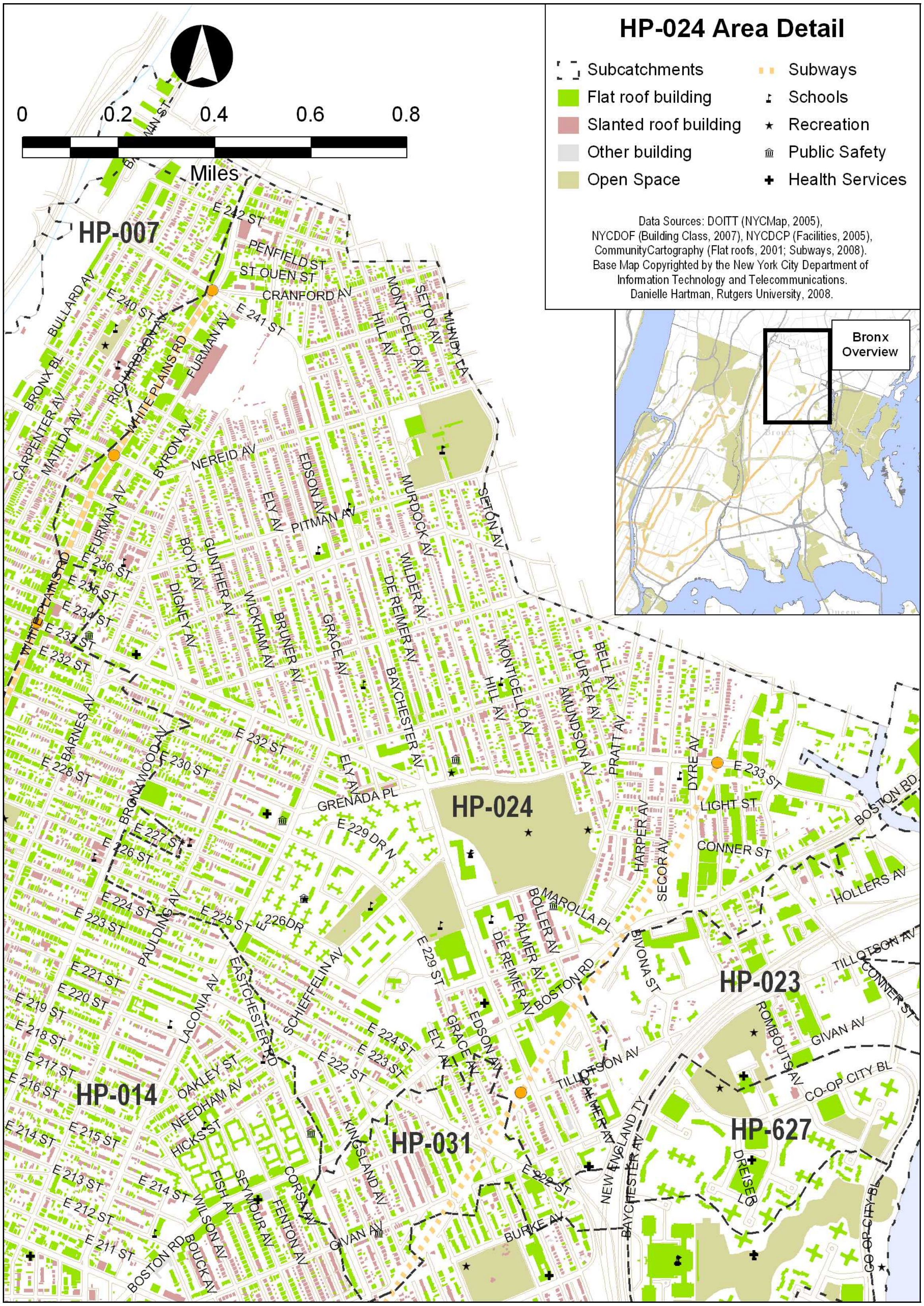

Figure 45. Map of HP-024 subcatchment. This is a Tier 2 outfall.

Figure 46. Map of WI-060 subcatchment. This Tier 2 outfall was the most sensitive to volume reduction, second most sensitive overall to modeled green roof scenarios.

Figure 47. Map of HP-028 subcatchment. This outfall ranked third most sensitive overall to modeled green roof scenarios.

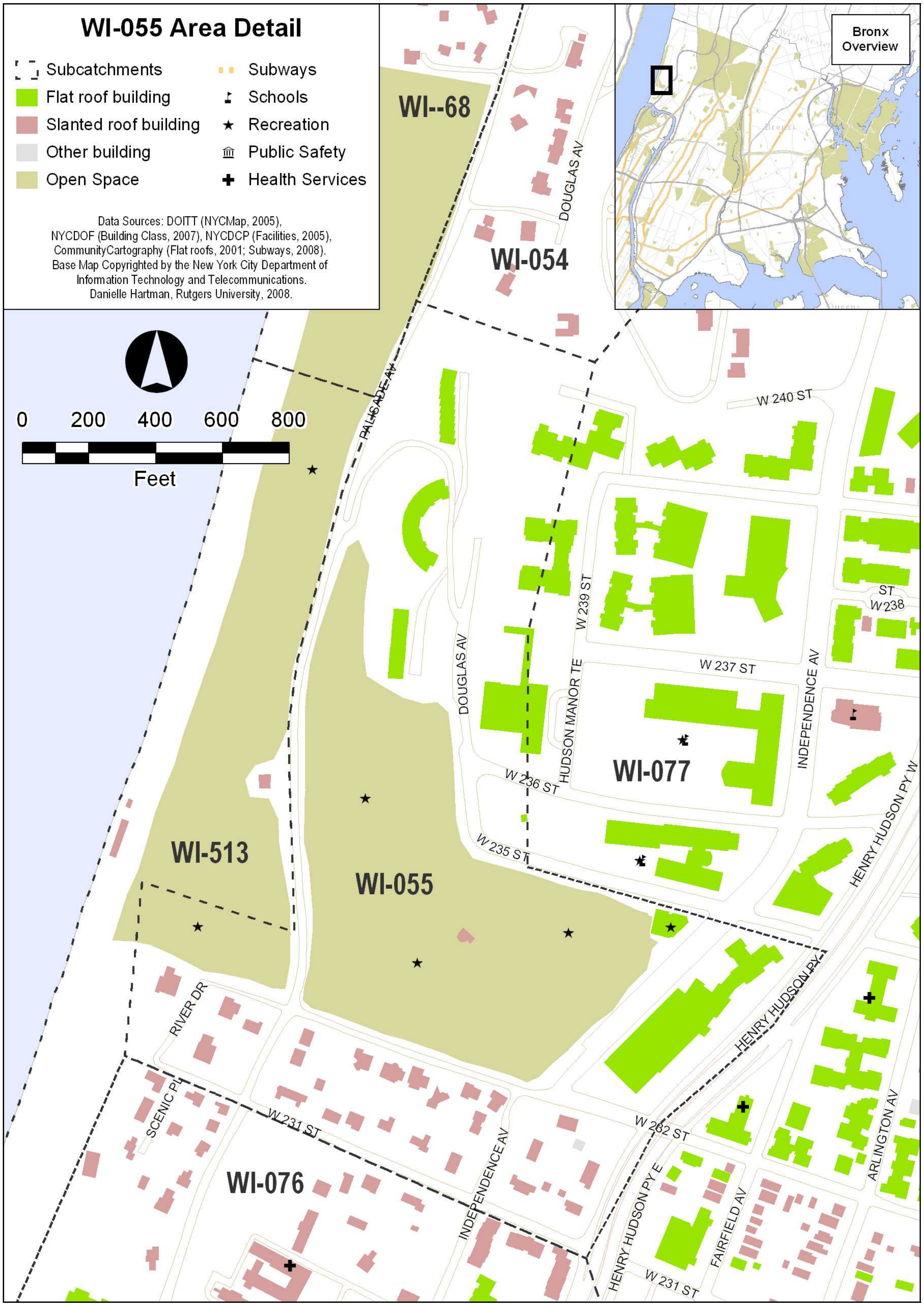

Figure 48. Map of WI-055 subcatchment. This outfall ranked fourth most sensitive overall to modeled green roof scenarios.

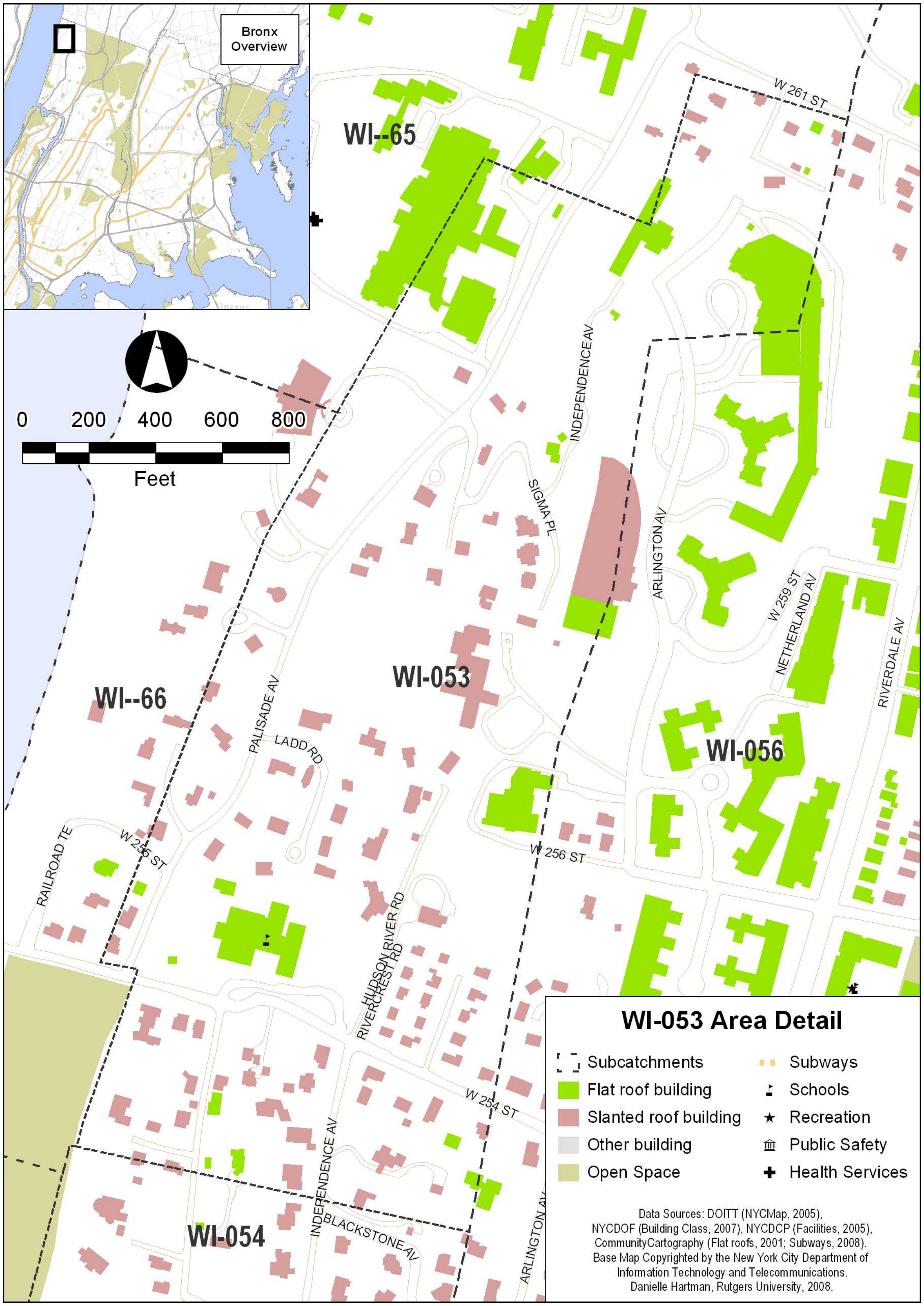

Figure 49. Map of WI-053 subcatchment. This outfall ranked fifth most sensitive overall to modeled green roof scenarios.

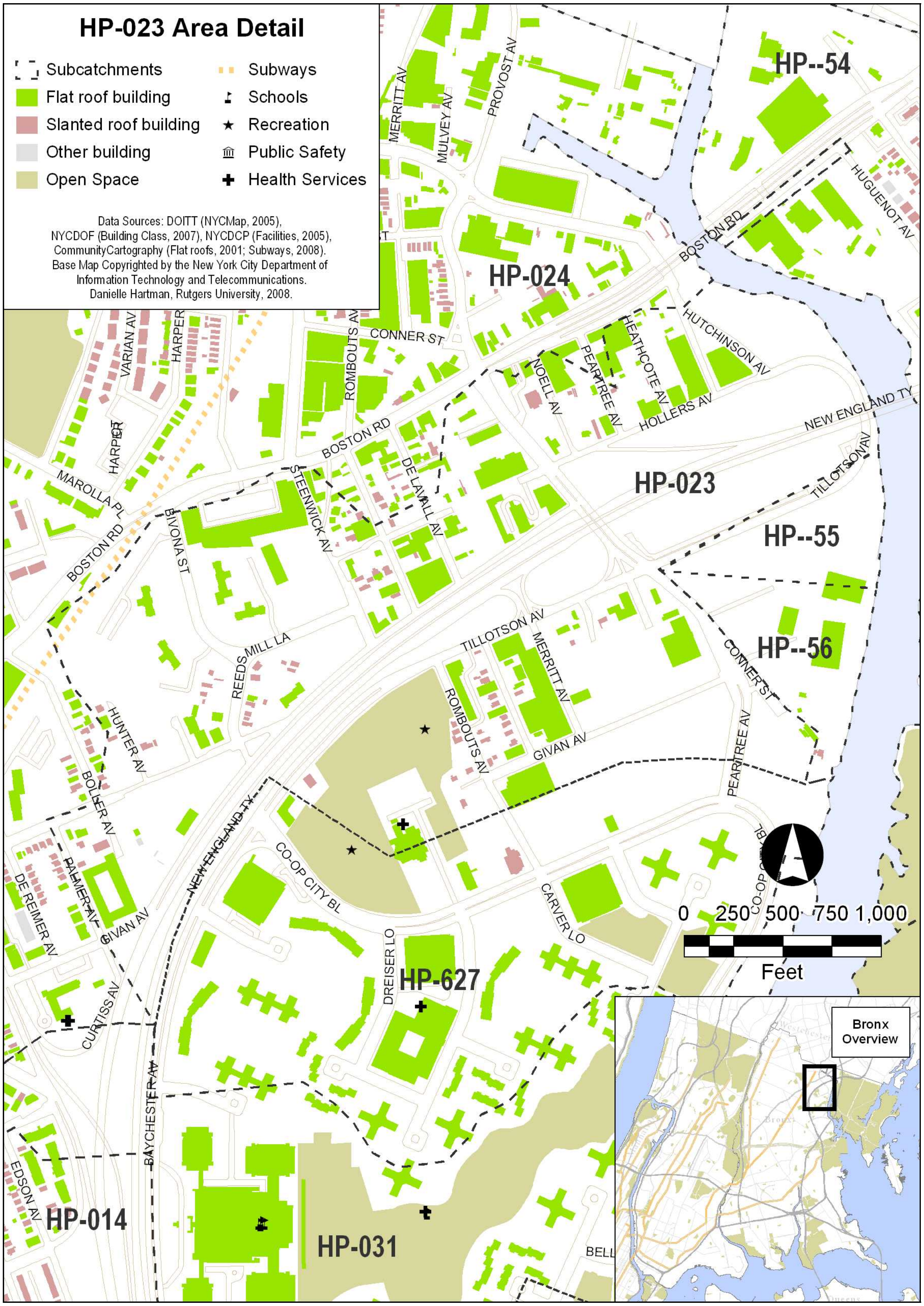

Figure 50. Map of HP-023 subcatchment. This Tier 3 outfall ranked fourth most sensitive to volume reduction.

Curriculum Vita

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Education

2004 – 2008	Rutgers University, M.S. in Geography
1994 – 1998	Swarthmore College, B.A. in Biology and Environmental Studies

Employment

2008 – present	Halcrow, New York NY, Senior GIS Specialist
1998 – 2008	CommunityCartography, Mahwah NJ, Spatial Data Manager
1998 – 2008	HydroQual, Inc., Mahwah NJ, Project Scientist

Publications

Hartman, D. 2008. GVA Williams Manhattan. Map in *Cartography Design Annual #1*, ed. Nick Springer.

Hartman, D. 2006. Fulton Ferry, Brooklyn. Map in *National Geographic Collegiate Atlas of the World*, page 17.

Hartman, D. 2006. New York, Global Island. Map in *Places & Spaces*, ed. Katy Börner and Elisha Hardy, Association of American Geographers. http://www.scimaps.org.

Hartman, D., B. George, and J. St. John. 2003. Time Series Analysis of New York Harbor Water Quality. Poster presented at ESRI International User Conference, July 7-11 in San Diego, CA.

Hartman, D. 2002. Posters and GIS display in *We Love New York Exhibit*, Eyebeam Gallery, New York.

Hartman, D. 2001. Serving Maps (and Dinner!) for 'Brooklyn Eats' at iBrooklyn.com. Presented at ESRI International User Conference, on July 11 in San Diego, CA.