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Models for Greening Urban Redevelopment Projects: A Case Study of the Blackstone Canal District in Worcester, Massachusetts

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Abstract

This project explored the feasibility of incorporating green infrastructure, as a supplement to gray infrastructure, into urban redevelopment projects in the Blackstone Canal District of Worcester, Massachusetts. Interviews, aerial photos and secondary research were used to assess urban runoff volumes, the projected costs of infrastructural upgrades and the savings associated with green infrastructure. Our final recommendation was that green infrastructure would provide a valuable complement to the current waste water system utilized by the city.

Executive Summary

Recently, there has been a significant amount of attention directed towards the redevelopment of the Blackstone Canal District in Worcester, Massachusetts. This project examines the advantages of incorporating green infrastructure into these redevelopment plans. In particular, this project looks at utilizing this form of infrastructure as a means of minimizing the urban runoff problem. Green infrastructure is an interconnected network of open spaces and natural areas such as greenways, wetlands, parks, forests and regions of natural vegetation, designed with the intention of maximizing ecological benefits. The economics behind green infrastructure are important to the city of Worcester because it would alleviate the financial burden of runoff management by distributing costs among private property owners.

Our research indicates that the use of green infrastructure in the Canal District could eliminate a significant amount of runoff produced during major storm events, precluding the need for expensive infrastructural upgrades to the Combined Sewer Overflow (CSO) system. Additionally, the financial obligation associated with runoff management will be reduced because of a redistribution of financial responsibility from the City to private developers, and because the costs associated with the treatment of runoff under 'normal' conditions would be significantly reduced.

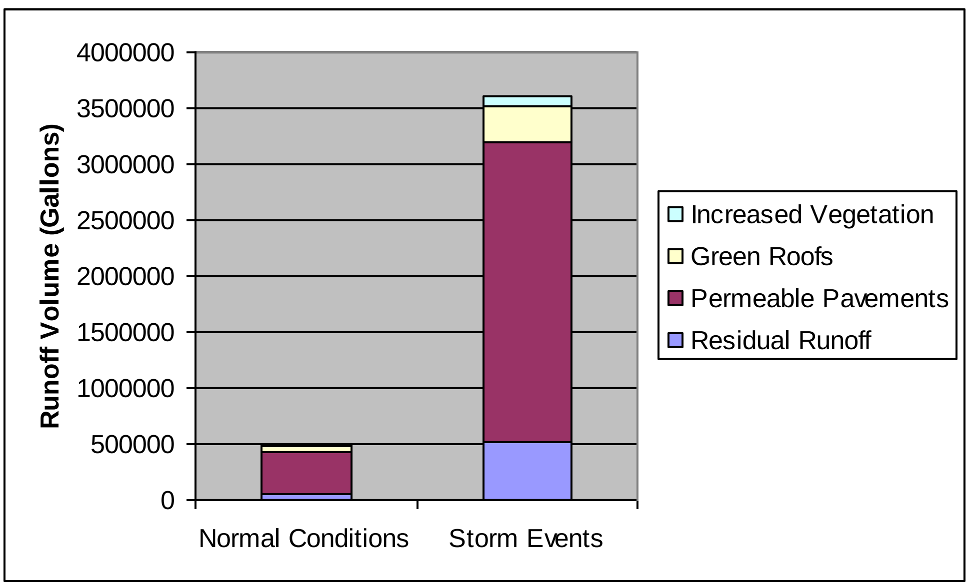
Three forms of green infrastructure (permeable pavements, green roofs and increased arboreal vegetation) are most appropriate for implementation in the Blackstone Canal District.

a) **Permeable Pavements**- Permeable pavements can be implemented by using different forms of permeable materials as substitutes for conventional paving materials with no loss of serviceability. These surfaces facilitate the continuous infiltration of storm water into the ground and also reduce the pollutant content in runoff. If installed appropriately, permeable pavements, whether porous asphalt, porous concrete, grass/gravel pavers or traditional bricks, are 100% efficient under both normal conditions and storm events. Based on our analysis, permeable pavements could replace 105 acres of conventional pavement in the Canal District, which would reduce runoff by 374,280 gallons per day under normal conditions, and 2,665,324 gallons during a major storm event.
b) **Green Roofs** - A green roof is an ecological roofing system that serves to compliment or replace a conventional roofing system. It is typically composed of appropriately planted vegetation, established over a water resistant membrane in order to protect the structure upon which it is placed (EPA, 2007b). The efficiency of green roofs ranges from 66.5% under normal conditions to 57.5% during major storm events. Based on our analysis, 22.8 acres of green roofs could be installed in the Canal District, which would reduce runoff by 54,347 gallons per day under normal conditions and 334,633 gallons during a storm event.
c) **Increase in Vegetation** - Assuming appropriate installation conditions, a typical medium sized tree intercepts and absorbs about 198.33 gallons of rainfall per month, which corresponds to a runoff reduction of 50 gallons per inch of rain. Following consultation with an urban forester, the project team determined that

the Canal District would be able to accommodate 15 trees per acre for a total of 1575 trees. These trees can be planted in areas such as sidewalks and parking lots. In order to do so, the pavement must be removed around the tree for the growth to occur. Collectively, these trees would reduce runoff by 10,395 gallons per day under normal conditions and 74,025 gallons during a storm event.

The project team determined that the combined effect of these solutions would reduce runoff by 87.8% during normal conditions and 85.4% during large storm events, shown in Figure 1. On average the Blackstone Canal District receives .132 inches of rain per day, which equates to 500,000 gallons of runoff per day. The proposed green infrastructure would reduce this to 60,978 gallons/day. For a typical large storm event, this produces an average of .94 inches of rain per day and 3.6 million gallons (MG) of runoff leaving only 0.5 MG of runoff to flow into the storm water system. As shown in Figure 1, the effect of arboreal vegetation small compared with the reduction in runoff from permeable pavements but the ancillary benefits of air filtration, temperature regulation and aesthetics make it worthy of consideration. Similarly, while green roofs have minimal impact during normal conditions, they have substantial impacts during storm events and also deliver ancillary benefits, such as reduced heating and cooling costs in the buildings in which they are installed

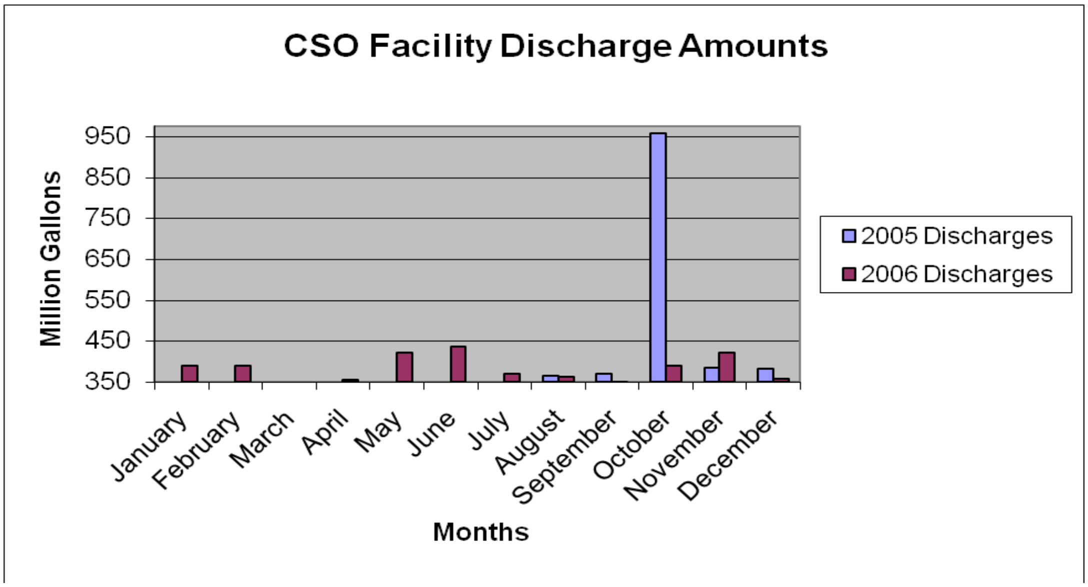
Figure 1: Runoff Reduction

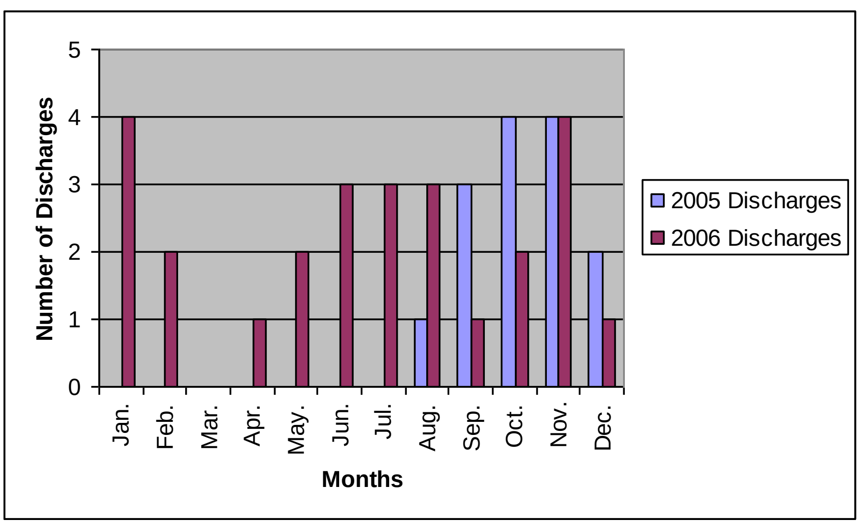


The current waste water system that serves the Blackstone Canal District and the rest of the City of Worcester is a combined sewer overflow (CSO) system, supplemented by a large water retention facility. This system carries both raw sewage and rainwater through a common conduit and then sends it to the Millbury waste water treatment plant to be cleansed. When the capacity of the system exceeds the amount that the treatment plant can handle a series of tanks with a 350MG maximum capacity retain the water until it can be effectively treated. During smaller storm events, this system can adequately handle the increased volume of storm water. However, a storm event that exceeds approximately 0.3 inches of rain per day produces enough runoff to exceed the capacity of the facility. In such instances, the excess waste water is discharged directly into the Blackstone River after only a flash treatment, which entails the filtration of solids followed by chlorination (Plant Superintendent of the Millbury Wastewater Treatment, personal communication, November 14, 2007).

Through our research, we found that the CSO facility discharged flash-treated waste water into the Blackstone River 14 times in 2005 and 26 times in 2006, see Figure 2. Reducing the number of these that occur per year is one of the primary concerns of the EPA. In order to accomplish this goal, they have mandated that the city of Worcester implement a program to reduce the number per annum to two by 2010. If the city does not comply with this mandate in a timely manner, they will most likely be fined.

Figure 2: Discharge Data





One plan that has been proposed to fix the problem is the construction of an alternate storm water management system designed to replace the current CSO system. The projected cost of this upgrade to the city is $180 million. (DPW contact, personal communication, November 14, 2007). These upgrades would serve to accommodate the increased volume during storms, but the costs would place a significant financial burden on the city, disrupt daily life during construction efforts and render the current infrastructure, which deals with the CSO system, obsolete.

The implementation of green infrastructure within the Canal District would serve as a much more advantageous and cost effective method of complying with the EPA's mandate. Assuming that the efficiency of the applicable forms of green infrastructure is 85.4%, as discussed previously, the number of discharges that would have occurred in 2005 would be two and only four would have occurred in 2006. A graphical illustration comparing the actual volume of discharged waste water, with the amount that would have been discharged if green infrastructure had been incorporated for 2005 is shown in Figure 3 and information for 2006 is shown in Figure 4.

Figure 3: 2005 Discharge Data

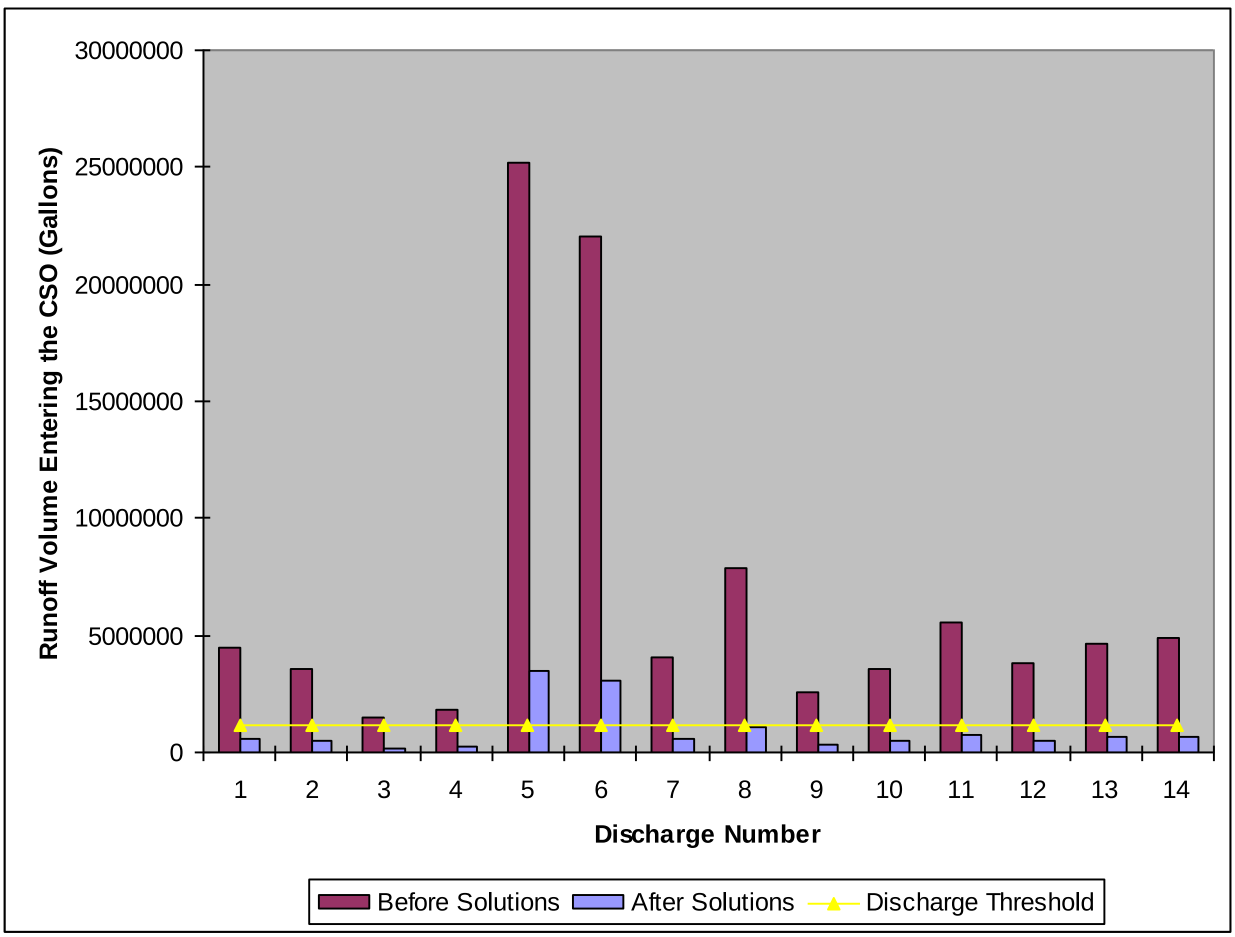
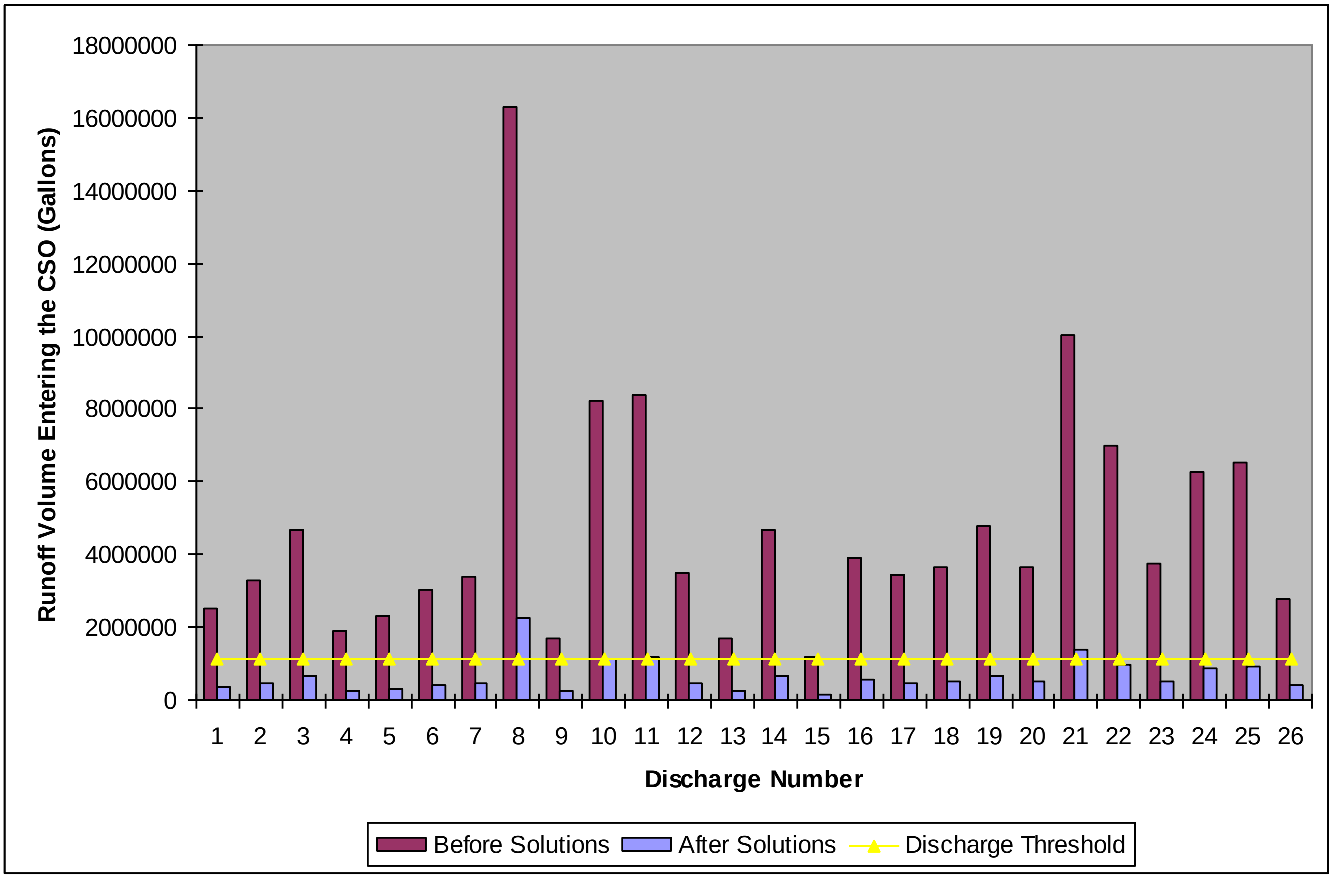


Figure 4: 2006 Discharge Data



Apart from avoiding expensive upgrades to the current CSO system, the green solutions also provide the city of Worcester with ongoing cost savings during normal conditions. By reducing the volume of runoff entering the system from the Canal District, the green solutions reduce monthly waste water treatment by $12,364 for a net savings of $148,368 per year.

In conclusion, green infrastructure eliminates the necessity to perform expensive infrastructural upgrades to the current CSO system by complying with the EPA standards in a cost-effective and alternative fashion. Implementing these solutions would switch some of the financial obligation of runoff management from the city to the private property owner, while at the same time producing regular monthly savings for the city. With large scale redevelopment anticipated for the Blackstone Canal District in the near future, this is an opportune moment for the City of Worcester to explore what incentives and mechanisms might be employed to encourage the implementation of green infrastructure.

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1: Introduction

The rise of the American 'inner city' was a dominant feature of the early 20th century (Koebel, 1996). Initially, this growth occurred at a steady rate (Chudacoff, 2006). However, during the post World War II era, significant technological advancements brought about a remarkable increase in growth rates, allowing cities to expand rapidly (Koebel, 1996). This expansion came about largely in the form of suburbanization, a process that involves large scale population movement from inner cities to their outskirts (Stergios, 2007).This movement was closely followed by the relocation of industry and commerce away from the inner cities, because of the availability of better opportunities elsewhere (Stergios, 2007). As a result, by the late 1960s the inner cores of several U.S. cities were subjected to economic neglect and physical deterioration (Koebel, 1996; Stergios, 2007).

Inner city degradation was further intensified by exploitation of natural resources and ecological systems in order to meet increasing population needs (Hassan & Scholes & Ash, 2005). The focus of growth and development away from inner cities meant a lack of investment and wealth in such areas. This brought about a variety of urban problems, such as pollution, lack of natural settings, undesirable climate changes, unhealthy living conditions, and limited aesthetic appeal. Furthermore, inefficient allocation of natural resources towards installing grey infrastructure instead of green infrastructure resulted in a reduction of ecological services, such as biodiversity, abundant vegetation and clean water bodies. Since these services are conditions through which natural ecosystems sustain human life, they have been deemed essential for fulfilling basic requirements of a healthy survival (Daily, 1997). The lack of ecological services has contributed to the worsening of living conditions within inner cities (Zipperer & Wu & Pouyat & Pickett, 2000).

Despite the increases in urban problems, efforts have been made to combat these drawbacks. One such effort is urban redevelopment, which focuses on extending and stabilizing living conditions within inner cities through restoration of existing infrastructure (Planetizen, 2007). Urban redevelopment includes intensive reconstruction of physically deteriorated structures, optimum allocation of social and organizational capital, encouragement of new investments, and promotion of residential spaces

(Planetizen, 2007). In particular, urban redevelopment can address the improvement of ecological conditions in inner cities, mostly through the incorporation of green infrastructure into new plans. Urban redevelopment presents an opportunity to re-introduce ecological services into urban settings, which could lead to an overall improvement in the quality of urban life.

This study explores the idea of ecological services and urban redevelopment through an investigation of the Blackstone Canal District in Worcester, Massachusetts. Worcester clearly exhibits the urban pattern of an American inner city. It was established as one of the first industrial cities of the nation, initiated by the construction of the Blackstone Canal between Worcester and Providence, Rhode Island. The canal provided Worcester access to a seaport and facilitated the transportation of goods in bulk (Worcester Historical, 2007). As a result, both industrial and business development escalated within the city (Worcester Historical, 2007). The area around the canal contained a significant portion of this development and came to be known as the Canal District. This district experienced further development after the advent of the Worcester-Providence railroad system, which made transportation of industrial goods much more efficient (Worcester Historical, 2007).

However, like many industrialized areas of the US, the district's success was short-lived. Because of its history, the canal district has also experienced a variety of environment related problems such as excessive urban runoff and pollution (C. Novick, personal communication, October 30, 2007). Most past efforts to alleviate these problems have proven inadequate due to a lack of originality, excessive reliance on expensive technology, and limited environmental perspective (C. Novick, personal communication, October 30, 2007). As a result, it is imperative to consider cost effectiveness and environmental benefits when approaching potential solutions to the problems of the Canal District.

This project explores the possibility of incorporating ecological services in the redevelopment of the Canal District, placing a primary focus on urban runoff, because it has become a high-priority concern to the district. Furthermore, the project makes recommendations for ecologically based solutions for the runoff problem. The solutions, by and large, pass the costs on to the private sector, an appealing notion in these times of local fiscal crisis. The study will show the potential savings to waste water treatment expenditure by presenting a comparison between current and future waste water treatment costs assuming both conventional and ecological treatment approaches. Moreover, a critical evaluation will be performed to determine expenses incurred by the projected conventional alternatives to the current combined sewer overflow system. This will provide a basis for a comparison between conventional alternatives and ecologically based solutions.

2: Background

Traditional urban development primarily focuses on enhancing human life and prosperity (Frey, 1999). It ignores, however, the impact that development has on the natural environment (University of Oregon, 1999). It was only after the manifestation of severe urban problems, like pollution, that urban planners began to look into alternative approaches to development (Frey, 1999). These alternative approaches adopt green infrastructure and similar ecologically sensitive development practices and emphasize the sustainability of natural resources and the preservation of environmental components. Incorporation of ecological services into the redevelopment of existing urban infrastructure can be achieved in nationwide redevelopment plans, if feasibility and profitability are made readily evident.

Ecological Services and their Importance

Ecological services are the conditions and processes through which the natural ecosystems, and the species that comprise them, sustain and fulfill human life (Daily, 1997). This concept can be explained in terms of the benefits provided by the components of nature to individuals, households, communities and economies to promote their overall well being (Boyd & Banzhaf, 2006). These services can be classified into three categories (Ecological Society, 2000; Daily, 1997):

1. Production and maintenance of natural resources;
2. Control and moderation of natural calamities; and,
3. Sustenance and development of life.

Table 1 illustrates specific benefits corresponding to each of the above categories. These benefits create a foundation for development, upon which human life is maintained and supported.

Table 1: Ecological Services and Corresponding Benefits (Ecological Society, 2000; Daily, 1997)

Categories of Ecological Service	Benefit
Production and Maintenance of Natural Resources	Increased Natural and Agricultural Vegetation; Biodiversity; Longevity of Soil Quality; Improved Air and Water Quality
Control and Moderation of Natural Calamities	Flood Mitigation; Soil Erosion Prevention; Landslide Preclusion; Climate Stability; Drought Avoidance
Sustenance and Development of Life	Availability and Enhancement of Natural Habitat; Aesthetically Pleasing Landscape; Detoxification and Decomposition of Wastes; Translocation of Nutrients

Table 1 lists only a few benefits for each category, but there are many. For instance, the maintenance of natural resources such as water bodies can improve their quality, leading to more diverse aquatic systems and a richer source of nutrients for surrounding land, animals and even for human purposes. Moreover, efforts to stabilize the climate can reduce the harmful effects of natural disasters and better prepare societies to cope with stress management, reducing the number of diseases or deaths that may otherwise occur. In fact, ecological services are so pervasive in nature that the majority of them remain imperceptible to most individuals going about their daily lives (Daily, 1997). The indiscernible nature of ecological services can be illustrated by depicting how they have been neglected by conventional urban ideals.

Conventional Urban Ideals

Urbanization resulted from either a conscious choice, or as a result of influential factors such as transportation ease, natural defense advantages, market structures, and administrative systems. Regardless of a city's origin, once established, the same factors that influenced its site contributed to its formidable growth and development as people searched to achieve urban ideals associated with civilization, prosperity and fulfillment of needs. Some of the notable characteristics of the ideals are as follows

- Urbanization is a concept is highly anthropocentric in nature, placing humans as central figures in the world, and their insatiable needs as matters of utmost urgency.
- Natural resources and components are valued only to the extent to which they are recognizable as useful to humans. All useful resources can be exploited with minimal consideration towards their preservation, and those deemed irrelevant are expendable. There is an assumption that the supply of resources is inexhaustible.
- Technological advancement is considered to be the solution to all supposed deficiencies of nature and has the capacity to effectively replicate natural systems and processes.

Despite the significant enhancement of urban lifestyle that technology has induced, the vision behind it has been myopic. The immediate benefits produced by urbanization are outweighed by the negative long-term effects, which can primarily be attributed to the extravagant use of natural resources, and a lack of sustainability within the system. Thus, the problems associated with this past trend show that there are limitations within conventional urban ideals.

Limitations of Conventional Urban Ideals

Human growth and development, which primarily relies on the utilization of natural resources, initially occurred at a scale which could be easily accommodated by nature and its system of resource replenishment (Hassan et al., 2005). However, this was thrown out of balance with the advent of rapid urban growth due to increases in population. As a result, increased human demands caused exploitation of the natural environment and its associated ecological services (Feeney, 2007). It was at this point that the limitations of conventional urban development came into play. Such limitations manifest themselves in innumerable forms, including pollution, climate alteration, soil erosion, increased natural calamities, and severe natural resource depletion.

It can be concluded that conventional urban development has a narrow vision, which disregards other factors that affect long term conditions, such as the health of the environment. This past trend caused urbanized centers to lose their ability to sustain significant amounts of ecological services, and be subjected to severe shortages of natural resources (Feeney, 2007). Furthermore, technological growth, which had initially been looked upon as a panacea to all the problems caused by urbanization, turned out to have limitations of its own, especially due to its inability to supplant lost ecological services within the urban settings (Grubler, 1998). Designing a system of growth that did not foster environmental protection sustainability was a flawed approach towards development. Recently, numerous efforts have been made towards the mitigation of such problems through the reintroduction of ecological services into the existing urban infrastructure.

Ecological Services in an Urban Context

In spite of the damage, the scope of the problem is not yet so overwhelming that it precludes all possibility of amendment. Incorporating the concept of ecological services within the urban context is highly feasible and has been attempted in various ways during the past several decades with favorable results. The most common of these are detailed below:

1. ***Green Infrastructure***: Green infrastructure is an interconnected network of open spaces and natural areas such as greenways, wetlands, parks, forests and regions of natural vegetation (Green Value, 2007). Such technology emphasizes planning to maximize the benefit of conservation efforts. Furthermore, it also protects natural ecosystems and provides the associated benefits to the environment.
2. ***Smart Growth:*** It is a process that concentrates growth within the central regions of an urban setting to avoid the occurrence of urban sprawl (United, 2005).
3. ***Sustainable Developments:*** Sustainable development is a concept that has a variety of different meanings, each designed to suit specific circumstances and settings (Portney, 2003). In essence, it is a socio-ecological process that attempts to meet current and future human needs without compromising the quality of the environment.

The primary advantage of these modes of redevelopment can be explained in terms of their ability to provide the benefits of ecological services within urban settings without having to alter significant urban characteristics that have become important aspects of the lives of the urban population.

The necessity to implement these services within an urban context is becoming more apparent as the number and magnitude of untreated problems continues to escalate. The traditional approach to dealing with urban problems usually entails the establishment of highly sophisticated and expensive infrastructure, such as waste water treatment plants, air purifiers, and embankments for flood and landslide prevention. Although this method has proven to be effective to a certain extent, it usually places a significant financial burden on the community. Therefore, administrative agencies are usually hesitant to implement these solutions unless the circumstances deteriorate to the worst possible conditions (C. Novick, personal communication, October 30, 2007). The alternative option is to implement solutions that embody the principles behind ecological services, so that the problems can be preemptively eliminated.

The Incorporation of Ecological Services into the Blackstone Canal District

The Blackstone Canal District in Worcester, Massachusetts is an example of an urban area established according to conventional development ideas and slated for future redevelopment. The most significant of these redevelopment attempts is outlined below:

> **Free the Blackstone** - A redevelopment project that has been proposed to the City of Worcester by the Blackstone Canal Task Force in order to revitalize the Canal District. The revitalization has been projected to occur primarily through the introduction of mixed development that comprises residential units, commercial and entertainment centers, office spaces, and medical facilities. The main strategy is to replicate the Blackstone Canal, utilize canal water for recreational and aesthetic purposes, and install natural vegetation at numerous sites (Free, 2007).

This redevelopment plan, along with other attempts, such as the Blackstone Heritage Corridor, presents an avenue through which ecological services can be incorporated into the Canal District. In order to fully understand the need for these services, it is necessary to understand the problems that plague this area and their direct consequences on the community.

The Urban Problems of the Blackstone Canal District

Urban problems are diverse in nature, ranging from overpopulation to poverty to air pollution, and have a large impact on the communities that they affect (Urban Problems, 1997). The issue at hand arises not from those which can be clearly detected and combated, but from those which are highly subtle in nature. The Blackstone Canal District suffers from many of these problems, the most prominent of which are excessive amounts of urban runoff, heat pollution and air pollution (C. Novick, personal communication, October 30, 2007).

Urban runoff poses as the most significant problem within the Blackstone Canal district for a variety of reasons. Runoff originates when precipitation travels across non-porous surfaces gathering sediment and pollutants. Then, through the use of various channels, the runoff deposits such materials into local water systems (EPA, 2006). It was rapid urban growth that caused existing systems to become inadequate to deal with urban runoff. Additionally, cities were distracted by bigger, more visible and detrimental problems like point source pollution, and failed to realize urban runoff would turn into an environmental concern (EPA, 1980). This neglect along with factors such as topographical positioning, overabundance of non-permeable surfaces, and an inadequate waste water disposal system are the primary reasons why urban runoff is a significant problem within the area (EPA, 1983). A detailed analysis of these contributing factors follows.

Topography

Topography plays a role in determining the negative impact of urban runoff in a given area. The downward speed and direction of water flow is guided and determined by the surface over which it flows (EPA, 1983). Consequently, areas at the base of hills act as catch basins during storms, and must be able to accommodate for excess amounts of water (C. Novick, personal communication, October 30, 2007). The Canal District suffers from this disadvantage because it is located at the base of the seven hills of Worcester and, therefore, collects a majority of the water from different areas during storm events.

Overabundance of Non-Permeable Surfaces

In most cases, the artificial surfaces of cities are composed of impermeable materials, like asphalt or concrete, which do not allow water to penetrate or freely flow through them. “In densely packed cities such as New York and San Francisco impervious surfaces may cover more than 90 percent of the ground” (Perkins, 2004). The Canal District is composed primarily of rooftops and parking lots, and consists of a similar percentage of impermeable pavements (C. Novick, personal communication, October 30, 2007). These serve to accentuate the propagation of runoff because during storm events, water has no way of percolating into the ground. Additionally, such surfaces serve as the conduit by which water is directed to topographically disadvantageous locations (EPA, 1983).

Inadequate Waste Water Systems

Limitations and deficiencies within urban waste water systems stem from overcapacity and poorly structured initial design. Moreover, increasing urban populations result in a perpetual and constantly growing demand for both fresh water and waste water management, but the systems responsible for providing these resources remain unchanged. Initial designs usually take into account these demographic changes but they fail to accommodate for the increased amounts of urban runoff produced during storm events (EPA, 1983).

Combined Sewer Overflow (CSO) System

The combined sewer overflow (CSO) system is an example in the Blackstone Canal District of an inadequate system that cannot handle overcapacity in an effective manner. It is defined as a piping system that carries both raw sewage and rainwater in the same conduit (EPA, 2007a). A CSO system is established in order to provide a means of escape for excess water that cannot be handled by the regular storm drainage system. The underlying idea behind the system is valuable, because it provides a mechanism that discharges overflow during large storm events to prevent line blowouts (EPA, 2007a). In most CSO systems in the case of an overflow, the excess waste water is directed towards a nearby body of water; however, in the city of Worcester, the overflow is directed into a set of pools to hold the excess for flash treatment (DPW contact, personal communication, November 14, 2007).

The Blackstone Canal District suffers from the negative effects of urban runoff such as pollution and flooding. Within the city of Worcester storm water management is conducted by utilizing the CSO system, followed by the transfer of combined sewage and storm water to the treatment facility for advanced treatment. This procedure is sufficient to handle the increased volume during regular precipitation events, but fails during major storms. In such cases the treatment facility cannot accommodate for the increased volume appropriately, so excess volume receives an abbreviated form of treatment. First, it is filtered to remove solids, then it is flash-treated through chlorination and de-chlorination, third, it is discarded into the Blackstone River (Plant Superintendent of the Millbury Wastewater Treatment, personal communication, November 14, 2007). This form of flash treatment produces water far inferior in terms of quality than full waste water treatment. Reducing the number of these discharges is one of the primary concerns of the EPA. Upgrading the current system, however, would cost a large amount of money (DPW contact, personal communication, November 14, 2007). The alternative to these costly infrastructural upgrades is to implement ecological solutions to urban runoff; these are discussed in the following sections.

Solutions to Urban Runoff

The techniques utilized to eliminate the problems associated with urban runoff can be classified into three broad categories:

i. Ecological solutions utilize natural resources to mitigate the effects of runoff, while simultaneously providing the ancillary benefits of heat reduction and air cleansing.

ii. Technologically based ecological solutions are ecological in nature but require the use and application of technologically governed instruments. This combination of the technological and ecological solutions provide developers with highly effective substitutes for conventional construction methods, while providing a solution to the urban problems of runoff, air pollution and excess heat.

iii. Ecologically beneficial technological solutions deal with the problems associated with urban runoff in a purely technical way. These devices do not contain physical forms of green infrastructure but seek to promote green development and foster its growth.

Table 2 differentiates some alternative solutions into their particular categories.

Table 2: Categorization of Alternative Solutions

Ecological Solutions	Technologically based ecological solutions	Ecologically beneficial technological solutions
• Increase in Vegetation Cover • Wetlands	• Green Roofs • Rainwater Harvesting • Gray water Harvesting	• Permeable Surfaces • Cool Roofs

A detailed analysis of the solutions contained within each of these three categories follows below, along with a list of the practical advantages associated with utilizing ecological services.

Ecological Solutions

Increase in Vegetation Cover

Straightforward solutions are often sought for reducing pollution and improving the overall water quality within natural water systems; an example of such a solution is the simple increase in vegetation cover around the city. The abundance of vegetation would either prevent a large portion of the rain from making contact with the ground, or cause it to be absorbed and retained by the soil. The water, instead of contributing to urban runoff, either gets trapped in top soil and percolates into the deeper layers, or gets absorbed through roots into plants and eventually evapo-transpires back into the air. However, this can be a complicated process since the vegetation has to be carefully chosen, located and planted to ensure that it can grow successfully. For instance, in certain urban areas such as those near main roads, shrubs and smaller plants are more appropriate than trees as lower vegetation minimizes viewing obstructions (MassHighway contact, personal communication, November 26, 2007). An ecological solution that would avoid these problems would be the construction of wetlands, marshes and natural retention ponds.

Wetlands

Wetlands are natural environments located at the interface between a terrestrial and an aquatic ecosystem. They consist of water either at the surface or within the root zone of their constituent plants, unique soil conditions that differ from surrounding soils and vegetation that is well adapted to wet soil and flooding conditions (Mitsch & Gosselink, 1993). The basic concept of wetlands is the same as that of marshes, retention ponds, swales, swamps, wet prairies and bogs (Mitsch & Gosselink, 1993). Wetlands are a highly effective means of reducing the amount of runoff resulting from rainwater. In fact, the rainwater content in urban runoff after passing through wetlands has been observed to fall from 60 percent to between 5 and 15 percent on average (Bolund & Hunhammar, 1999). This is achieved primarily because the loss of velocity experienced by runoff as water enters the wetland area generates forces that dislodge and filter out the sediments and associated chemicals (Mitsch & Gosselink, 1993). They also significantly prevent the water pollution caused by runoff sedimentation, and have been found to remove 80 to 90 percent of sediments, 20 to 60 percent of heavy metals, and 70 to 90 percent of nitrogen from runoff (Otto & McCormick & Leccese 2004). They achieve this by facilitating natural filtration, precipitation, decomposition and de-nitrification processes that cleanse the runoff water of the pollutants before it actually arrives at its final destination (Mitsch & Gosselink, 1993).

There have been several successful projects that support the construction of wetlands as economically and ecologically beneficial (EPA, 1993). One such study was performed in Lake Prairie, Grayslake, Illinois. In this case, the construction of wetlands allowed natural sedimentation, filtration and biological treatment of waste water to take place before it entered the lake itself. As a result, the wetlands helped retain an enhanced water quality of the lake and thus, the aesthetic and ecological value of the area, with minimal maintenance requirement (The Prairie Project, 2005). This scenario enables us to create an analogy to an urban setting in which the combination of vegetation, soft ground, wetlands and water detaining bodies can effectively cleanse and reduce the amount of haphazard runoff.

To fully evaluate the case for application of wetlands to an urban setting, both the drawbacks and benefits of wetlands must be noted and compared. These are outlined below in Table 3**Error! Reference source not found.**. However, when considering the negative impacts, further evaluation will show that the long-term benefits of these methods by far outweigh the shortcomings. For example, the presence of insects and small rodents is an avoidable issue if the wetland is well-maintained and houses are a reasonable distance from the natural setting. In contrast, wetlands can provide biodiversity, increase nutrients for surrounding plants, reduce runoff, and increase property values due to increased visual appeal. It is also essential to consider that wetlands are not an immediate solution, but rather a progressive process that takes years to yield optimum results (Mitsch & Gosselink, 1993).

Table 3: Advantages and Disadvantages of Wetlands

Advantages	Disadvantages
1. Increase in biodiversity	1. Presence of small animals and rodents may be a nuisance to residents (Bolund & Hunhammar, 1999).
2. Increase in aesthetic value (Bolund & Hunhammar, 1999).	2. May increase bad odors and mosquitoes (Bolund & Hunhammar, 1999).
3. Reduction in waste water treatment costs (Otto et al., 2004).	
4. Reduces flooding (Otto et al., 2004).	
5. Facilitation of high levels of mineral uptake (Mitsch & Gosselink, 1993).	
6. Avoiding the build-up of pollutants in patches of surrounding soil (Herricks, 1995).	

Technologically Based Ecological Solutions

Green Roofs

A green roof is an ecological roofing system that serves to compliment or replace a conventional roofing system. It is typically composed of properly planted vegetation, established over a water resistant membrane in order to protect the structure upon which it is placed (EPA, 2007b). Green roofs can be classified into two distinct categories: extensive or intensive. The primary differences between the two is that the former is built on a smaller scale, requires less irrigation and maintenance, and is not usually accessible to everyone; but the latter is more excessive and can accommodate far more vegetation. For most buildings going through redevelopment in the Blackstone Canal District, retro-fitting would have to be done to install green roofs, making extensive roofs the more appropriate choice. Table 4**Error! Reference source not found.**, from Katrin Schloz-Barth, summarizes the differences between intensive and extensive green roofs.

Table 4: Types of Green Roofs

Characteristic	Intensive Green Roof	Extensive Green Roof
Soil	Requires minimum of one foot of soil depth	Requires only 1 to 5 inches of soil depth
Vegetation	Accommodates large trees, shrubs, and well-maintained gardens	Capable of including many kinds of vegetative ground cover and grasses
Load	Adds 80-150 pounds per square foot of load to building structure	Adds only 12-50 pounds per square foot depending on soil characteristics and the type of substrate
Access	Regular access accomodated and encouraged	Usually not designed for public accessibility
Maintenance	Significant maintenance required	Annual maintenance walks should be performed until plants fill in
Drainage	Includes complex irrigation and drainage systems	Irrigation and drainage systems are simple

Both intensive and extensive green roofs have particular advantages and disadvantages, as shown in Table 5. From the table, once again, it is apparent that extensive green roof systems are more appropriate for retro-fitting into existing structures, and can provide benefits of increasing biodiversity, reducing runoff and increasing aesthetic values. If used appropriately, each type of green roof will be effective in both cost savings and providing ecological services.

Table 5: Advantages and Disadvantages

Extensive Green Roof	Intensive Green Roof
• thin soil, little or not irrigation, stressful conditions for plants	• deep soil, irrigation system, more favorable conditions for plants
Advantages: • lightweight - roof generally does not require strengthening • suitable for large areas • suitable for roofs with 0-30° (slope) • low maintenance • often no need for irrigation and drainage systems • relatively little technical expertise needed • often suitable for retrofit projects • can leave vegetation to develop spontaneously • relatively inexpensive • looks more natural • easier for planning authority to demand green roof as a condition of planning approvals	**Advantages:** • allows greater diversity of plants and habitats • good insulation properties • can simulate a wildlife garden on the ground; can be made very attractive; visually often accessible, with more diverse utilization of the roof i.e. for recreation, growing food, as open space.
Disadvantages: • more limited choice of plants • usually no access for recreation or use • unattractive to some, especially in winter	**Disadvantages:** • greater weight loading on roof • need for irrigation and drainage systems (greater need for energy, water, materials, etc) • higher cost • more complex systems and expertise required

Source : Johnston, 1996, p. 54

The green roof serves as a means to limit the quantity of water reaching the ground. On average, a green roof, with three to five inches of soil, will retain about 75% of the rain water landing on the surface (EPA, 2007b), which will substantially lower the amount of water that makes its way to the pavement. With this reduction, a smaller strain is placed on the CSO system during large storm events.

As expressed above, both intensive and extensive roofs provide multiple benefits for the area in which they are implemented. The greenery can purify the air and moderate the temperature of its surroundings, while the soil can provide an absorption layer for water. Overall, green roofs provide a variety of different ways to address various environmental problems in urban areas.

Rainwater Harvesting

Rainwater harvesting is a process that involves the collection and storage of rain water and surface runoff in a retention basin and the subsequent utilization of the collected water for productive purposes. Water collected in rooftops is filtered repeatedly, and passed through a silt trap mechanism before storage. It can be recharged in open wells (open at ground level), bore wells (dug into the ground) or percolation pits. The 'harvested' water can be primarily used for activities that do not require sophisticated treatment or purification, including toilet sanitation, garden watering, automotive cleansing, and many other domestic uses. This concept is not only an efficient method of reusing rainwater, but it can also play a major role towards the reduction of urban runoff.

As with most proposals, there are both costs and benefits that have to be considered for rainwater harvesting. Not only does this method of water harvesting reduce urban runoff, it also regulates underground water, prevents urban flooding and conserves water. The minimal requirement of regular maintenance of containers is often considered a minor drawback when implementing rainwater harvesting designs. The advantages and disadvantages are outlined below in Table 6:

Table 6: Advantages and disadvantages of rainwater harvesting

Advantages	Disadvantages
Less need for municipally treated water, thus leading to water conservation (McGill, 2002)	May require regular maintenance and cleaning to avoid contamination
Regulation of water volume in soil (McGill, 2002)	
Regulation of water availability (McGill, 2002)	
Minimization of urban flooding	
Can be kept free from contamination	

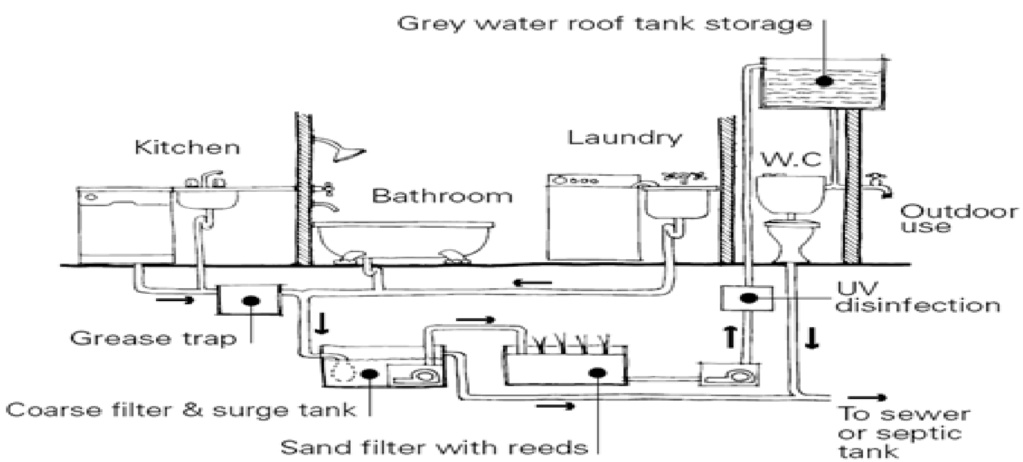
Thus, since rainfall eventually contributes to storm water runoff, employing rainwater harvesting systems can decrease the amount of runoff and related problems.

Gray water Harvesting

Water discharged from household activities, such as washing dishes, showering, and washing laundry can be classified as gray water. Gray water can be reused for productive purposes such as landscape irrigation, watering houseplants, and flushing toilets (Fane & Reardon, 2005). This can be achieved by implementing an effective filtration process that passes the water through top soil layers or sand (Gray water, 2006).

Figure 5 below shows a rough plan for collecting gray water so that it could be reused in toilets and for outdoor purposes (Fane & Reardon, 2005). Gray water from the laundry, kitchen and bathrooms flows through various traps and sand filters to remove grease and other solid contaminants. The water is disinfected using ultraviolet light and stored in a roof tank until further use.

Figure 5: Gray water treatment and re-use. (Source: Simon Fane and Chris Reardon, Wastewater Reuse, 2005)



Like with all environmental solutions, the advantages and disadvantages of implementation and operation should be taken into consideration. These are shown in

Table 7. Similar to rainwater harvesting, regular maintenance is needed, but gray water harvesting also reduces runoff, re-uses water and thus prevents wastage of water, and uses otherwise wasted nutrients to environmental benefits.

Table 7: Advantages and Disadvantages of Gray water Harvesting

Advantages (Ludwig, 2005)	**Disadvantages** (Fane and Reardon, 2005)
Conservation of water	Monitoring is required for treatment
Reduction in wastewater volume	Periodic maintenance required
A cheaper substitute for water-cleansing systems	
Wasted nutrients can fertilize plants	
Less energy wasted in pumping water	

Ecologically Beneficial Technological Solutions

Permeable Surfaces

The first potential technological solution to the runoff problem is to implement different forms of permeable (or pervious) pavement as substitutes for conventional materials. Traditional materials used for surface coating, like asphalt or concrete, provide hard surfaces for vehicle and pedestrian travel, but at the same time, they produce two adverse effects. The first of these is that they provide no infiltration points for storm water. The second is that they harbor and contain a variety of common everyday pollutants. Permeable surfaces, on the other hand, provide urban areas with the necessary trafficable areas, while enabling the continuous infiltration of storm water, reduction in pollutants, limitation of CSO events and prevention of natural destruction in the form of erosion and floods (Pennsylvania, 2005). Permeable surfaces have a wide variety of different applications, but they cannot be used as a replacement for conventional materials in every circumstance. Low trafficked city streets, parking lots, domestic driveways and sidewalks are all acceptable applications for permeable pavements, but their porous nature prevents them from being durable enough for high volume city streets, and in areas of high sedimentation, their functionality can potentially be hindered. The benefits that are produced as a result of these surfaces make them an essential component of runoff control in urban areas.

In a general sense, permeable pavement consists of a layer of porous material, either asphalt, concrete, composite materials or traditional bricks, placed over a structured aggregate surface. The aggregate surface is variable in its thickness depending upon the geographical dimensions of the location, and serves to provide a temporary storage for water, while it slowly infiltrates into the underlying soil (Pennsylvania, 2005). Aesthetically, these materials look extremely similar to conventional products and because installation techniques are extremely similar to those of conventional materials, the initial costs are kept to a minimum. Since the lifespan of permeable materials is similar to that of conventional materials under favorable conditions, the long term costs are also reasonable. A description of the major types of permeable pavements is listed in Table 8, as well as the advantages and disadvantages associated with each type (Pennsylvania, 2005; Toolbase, 2007; Brown, 2004; Invisible, 2007). From the table, it can be seen that the advantages of one kind of permeable material can be used to overcome the drawbacks of another. For instance, plastic grids and permeable asphalt can be used instead of permeable concrete to combat weather fluctuations. Similarly, pavers and traditional bricks can be installed in areas requiring minimum maintenance, instead of plastic grids.

Table 8: Types of Pavements

Type of Pavement	Advantages	Disadvantages
Permeable Asphalt	• Same installation as traditional asphalt • Does not crack because of cold weather	• Cannot withstand high volumes of traffic • Cannot withstand high volumes of water • Sedimentation hinders overall effects
Permeable Concrete	• 15-25% voids to allow water to absorb through • Same installation procedure	• Voids weaken structure • Aggregate subsurface needs to be installed • Cannot function in cold weather or with high traffic volume
Plastic Grids	• Strong and durable • Voids to allow water absorption • Material not affected by weather fluctuations	• Significant amount of maintenance • Breaks down under high volumes of traffic
Pavers and Traditional Bricks	• High absorption in the grout • Low maintenance	• Positioning shifts overtime • Reduction of storm water runoff is limited • High installation costs for large areas

Cool Roofs

Cool roofs are a technological solution that does not address the problems associated with urban runoff, but they can be considered an ancillary solution. A cool roof is simply a roof that is colored so that it reflects sunlight instead of absorbing it like a darker colored roofing system (EPA, 2007d). The roof serves to lower the overall temperature within an urbanized area, provide lower cooling costs for the building, and promote the growth of vegetation during exceptionally warm months (2007d). In an ideal situation, this roof could be used as a compliment to a green roof, covering the portions that are still composed of conventional roofing materials.

Advantages of Ecologically Driven Solutions

Ecologically sensitive developments and redevelopments are not necessarily more expensive than conventional methods. However, planners, builders, owners and government regulators often resist them due to lack of awareness about the newer techniques and their ecological and economical benefits (Otto et al., 2004). One way to build a stronger case for approval and acceptance of ecological solutions is to consider all the possible advantages, both economic and ecological. These advantages are highlighted below, with particular emphasis on which implemented solution may provide these benefits.

i. **Air filtration-** In urban areas, air pollution caused by transportation mediums and industrial buildings can prove to be quite hazardous to human health and be a deterrent to aesthetic value in the community. Increasing vegetation cover elevates the filtering of particulate matter (Bolund, 1999). In fact, studies have shown that parks full of trees can remove up to 85% of impurities in the air and trees along streets can remove up to 70% (Bolund, 1999). In Worcester itself, air pollution is a serious problem, since carbon monoxide, volatile organic emissions and sulfur dioxide emissions are all recorded at higher than 80% (Pollution, 2005). Thus, implementing solutions such as increase of vegetation cover, constructing wetlands and green roofs would not only perform the function of reducing runoff, but also provide the added benefit of air filtration.

ii. **Micro-climate regulation**- Natural ecosystems help to reduce heat pollution (Bolund, 1999). Water bodies help absorb heat, and vegetation cover helps in transpiration thus cooling temperatures (Bolund, 1999).

iii. **Noise reduction**-Vegetation and water bodies can contribute to the reduction of noise.

iv. **New Employment Opportunities**- Through the implementation of ecologically sensitive redevelopment, construction and cleanup jobs may be created. Moreover, new development attracts services such as restaurants, shops and outdoor recreational places, ultimately creating more jobs, new opportunities and services in the area (Otto et al., 2004). However, it is essential for these businesses to maintain an environmental concern that does not further contribute to environmental pollution, but rather tries to mitigate such situations.

v. **Creation of Recreational Facilities**- By creating wetlands and green roofs, there is a chance to increase the biodiversity of plants, marine life and small animals. Moreover, open spaces, water bodies, green areas and biologically diverse places attract people to spend more time walking, biking, boating, fishing and other such outdoor activities (Otto et al., 2004). Studies have also shown that the presence of green spaces are psychologically soothing, and thus can reduce stress levels in highly urbanized, busy areas (Bolund, 1999). Therefore, not only does the ecology and economy benefit, residents of the area also receive lifestyle and leisure advantages.

vi. **Increase in tax revenue for economy**- Redevelopment of downtown areas attracts new businesses and real estate investments, increasing property values and boosting total revenues for an economy. Tourism, recreation and investment also increase. Consequently, there is more tax revenue collected in the economy (Otto et al., 2004). If allocated correctly, these revenues could contribute greatly to Worcester’s economy, which still had 18.7% of its residents living in poverty in 2005 (City Data, 2005).

vii. **Financial support**- New plans for development may attract federal and state funding. Often, private enterprises can sponsor development and cleaning programs if profits are involved from tourism, recreation or investment. Volunteer programs to clean up areas are also becoming more frequent (Otto et al., 2004).

Summary

There are a variety of alternative solutions to urban problems that can be implemented in an urban setting. Addressing the issues of urban runoff and water pollution can also contribute to reducing air and heat pollution and fostering economic progress and smart growth. Table 9 summarizes these designs and points out which ecological service is provided by each. Most solutions, especially increasing vegetation, green roofs and permeable surfaces, address the main problem of urban runoff, whilst adding to environmental benefits, smart growth and recreational opportunities.

Table 9: Summary of potential solutions

	Urban runoff volume reduction	Water pollution control	Air filtration	Noise reduction	Temperature regulation	Smart growth	Economy boost	Recreation
Arboreal Vegetation	✓	✓	✓	✓	✓			
Wetlands	✓	✓	✓	✓	✓		✓	✓
Rain-water Harvest	✓	✓						
Gray water Harvest	✓	✓				✓		
Green roofs	✓	✓	✓	✓	✓	✓	✓	✓
Permeable Surfaces	✓	✓				✓		
Cool roofs					✓	✓		

The proposed solutions that can be applicable to the Canal District can be selected based upon an assessment of their benefits and drawbacks. The solutions that were discussed previously but are excluded in the next section are gray water and rainwater harvesting, cool roofs and wetlands. The reasons why these solutions have been omitted are explained below.

- Rainwater and gray water harvesting are disregarded due to their domestic nature, which may make them relatively inexpensive, but also gives them limited practical applicability (Waskom, 2003). Despite their easy installation methods and water conservation schemes, their costs and savings would concern residents and not the city directly. This is so because these are personal installments that require private purchase and plumbing. Thus, any further analysis on them would not be relevant to the case study at hand.
- Wetlands provide great ecological benefits that can also prove to be economically valuable in the long run by saving on power costs, pollution treatment costs and increasing property value. However, since the Blackstone Canal District consists mostly of paved areas, installing wetlands would mean the extraction of non-permeable surfaces such as empty parking lots. This would not be a cost-effective or practical solution in a highly urbanized area such as the Canal District.
- Cool roofs are not a direct solution to reduction of urban runoff, but they certainly reduce heat pollution significantly. They are ideal for use in combination with green roofs to diminish pollution problems in Worcester. However, for the purpose of studying the reduction of urban runoff during the redevelopment of the Blackstone Canal District Area, they have been excluded since they provide no direct benefits to the specific problem of urban runoff.

Now that the effects of each of these solutions at reducing urban runoffs has been discussed, the next few sections focus primarily on finding the current costs of waste water treatment, estimating the potential increase in those costs due to the redevelopment of the Canal District, and evaluating the savings achieved by implementing the various forms of ecological solutions.

3: Methodology

In order for ecological services to be considered as a viable solution to the urban runoff problem in Worcester, the cost effectiveness associated with their implementation must be demonstrated. The objectives that were followed to fully assess this cost effectiveness are given below.

Objective #1: Calculating the Cost of Managing Runoff from the District

The purpose of Objective 1 is to quantify the amount of urban runoff produced in the Blackstone Canal District and then through the use of these data, assign a dollar value to the cost of its collection, treatment, and disposal. The tasks involved defining the area of the Blackstone Canal District, determining monthly rainfall amounts, calculating total urban runoff volume, and determining operational costs of the wastewater treatment plant.

Defining the Area of the Blackstone Canal District

In order to calculate the area of the Canal District, a series of geographical constraints needed to be identified to act as boundaries to the region. These constraints were based on information provided by the Greater Worcester Land Trust and graphically depicted with the aide of a geographical information system (GIS) and zoning maps. The zoning maps were found in the Worcester Public Library and on the City of Worcester’s website. Having defined the boundaries of the Canal District, building layer maps and other data layers, generated by the GIS software, were used to compute an approximate area of the district and the proportions of permeable and impermeable surfaces.

In order to determine runoff, the permeable area was subtracted from the total area. Additionally, surfaces that were composed of contaminated soil were classified as impermeable, because the city would not want to utilize such areas for water infiltration. Miscellaneous permeable areas, scattered throughout the district, were examined, and a single acreage value was assigned to represent the cumulative effect. Differentiation between the different surfaces was performed through the examination of aerial photos, provided by Google earth, and when necessary, visual inspections were performed.

Determining Total Monthly Rainfall Amounts

Precipitation records from the Blue Hill Observatory in Canton, Massachusetts were examined in order to determine the average monthly precipitation in the Canal District. The observatory provides a computed value for the average monthly rainfall within the city of Worcester. This average was determined from monthly data for the years 1981-2007 (Blue Hill, 2007). Although the observatory is located approximately 40 miles away from the test location, the legitimacy of the organization and the time frame in which precipitation data has been recorded made it the best and most credible source for this information. The data obtained was verified through examination of the IDcide website recommended by the Conservation Advocacy Coordinator at Mass Audubon (IDcide, 2007; Mass Audubon Conservation Advocacy Coordinator, personal communication, November 14, 2007). The IDcide website is a source of information obtained from weather stations in many cities. The necessary data was taken from the Worcester Regional AP Weather Station, which is approximately four miles from Worcester.

Estimating Total Urban Runoff Volume

After estimating the surface area of impermeable surfaces within the Canal District and estimating the monthly rainfall amounts, an approximate value for the volume of water produced within the Canal District was obtained. This value was computed by taking the square footage of the Canal District and multiplying it by the monthly rainfall amounts. The value is expressed in dimensions of cubic feet, which can then be simply converted to gallons by multiplying it by a conversion factor (Hajas, 1978). It should be noted that this value assumes that all precipitation that falls on impermeable surfaces contributes to runoff volumes because it does not take into account such things as evaporation and small scale water retention. These effects are minimal in comparison to the total volume of runoff and are therefore not taken into consideration here.

Equation 1: (Square Footage of Area) X (Monthly Rainfall in Feet) = Volume in Cubic Feet

Equation 2: (Volume in Cubic Feet) X (7.48 Gallons/1 Cubic Foot) = Volume in Gallons

This is a representative value for the amount of storm water that enters into the waste water system to be treated and is therefore extremely important in determining the cost of runoff to the city (Hajas, 1978).

Determining Operational Costs of the Waste Water Treatment Plant

The amount of runoff that the Blackstone Canal District contributes to the waste water system needs to be treated and therefore poses a cost to the city. The design of the system requires treatment of all runoff because original piping construction combined both sewage and runoff into regulators (Assistant Director of Sewers, Department of Public Works and Parks, personal communication, Nov. 14, 2007). In order to estimate this cost, information regarding the cost per unit to treat the water and the maximum volume that can be treated in a given time period was obtained. This information was ascertained through an interview conducted with the Director of the Upper Blackstone Water Pollution Abatement District (Millbury, 2007; personal communication, November 15, 2007).

The tasks performed above explain the procedure employed to obtain the information necessary to complete Objective #1. With the completion of these tasks a value can be approximated by multiplying the amount of runoff in the Blackstone Canal District by the cost per unit to treat the runoff at the treatment facility.

Equation 3: (Volume in Gallons of Urban Runoff) X (Cost of Treatment per Gallon) = Cost of Runoff

Equation 4: (Volume in Gallons of Urban Runoff) X (City Imposed Cost to Residents) = Revenue for City

Objective # 2: Calculating Future Costs of Waste Water Treatment

Having determined the average amount of runoff being generated within the Canal District and the cost incurred by the City of Worcester to treat a unit volume of waste water, the total amount of waste water being produced in the area by human activities was then calculated. When collectively analyzed, the three sets of data provided an approximate value of financial resources being expended towards the treatment of the waste water produced within the Canal District. Furthermore, it also enabled a comparison between the quantity of waste water being produced and the threshold value of the existing sewer system. However, it seemed insufficient to base the calculations on present circumstances only, since the information would become outdated with growth in the area. As a result, possible future developments within the Canal District and their ramifications were also taken into consideration. Among all such potential developments, the prospect of residential growth presents itself as the most significant, especially because of the strong emphasis the city administrators place on the revitalization of housing opportunities throughout Downtown Worcester (Worcester Municipal, 1999). With the redevelopment on the district, the only potential increase in waste water volume is that of the residential sewage because redevelopment does not require more pavements.

The analysis of determining present and future waste water production and treatment cost within the Canal District can be divided into five categories.

1. Estimating the volume of waste water currently being produced within the area.
2. Obtaining a close to accurate value for the total number of new residential units that the area can support within its existing infrastructure.
3. Determining the average waste water produced by a single unit.
4. Using the data obtained from steps (2) and (3), approximate the total increase in waste water induced by the residential growth.
5. Determining the total cost to treat the increased waste water.

Determining Current Volume of Waste Water Produced

In order to show the necessity for implementing alternative solutions for urban runoff treatment, it is required to determine the current strain being placed by the canal district on the treatment facility. This strain can be calculated by determining the amount of waste water produced within the canal district. The procedure is as follows: First, an assumption was made that every resident is equivalent to the average American, in terms of water consumption (National Wildlife, 2004; DPW contact, personal communication, Nov. 14, 2007). Next, the total number of residents within the Blackstone Canal District was obtained through examination of Worcester's demographic information provided by the U.S. Census Bureau. Having calculated both numbers, the approximate daily amount of wastewater entering into the treatment facility was determined by multiplying gallons per day by the number of residents in the district. The final monthly amount was found by multiplying the previous figure by the number of days in the targeted month.

Equation 5: (Gallons/ Day Used) X (# of People) = Daily Volume of Waste Water Excluding Runoff

Approximating the Increase in Residential Units

The Canal District is composed of a large number of functionally obsolete buildings, which have been slated for redevelopment into residential units (Fontane & Hayman, 2004). The buildings with redevelopment plans were determined through the following means:

a) Consulting with the Advocates of Revitalizing the Canal District:

There have been numerous efforts made towards encouraging the revitalization of the Canal District (Worcester Municipal, 1999). Among such efforts, the *Free the Blackstone* project stands out as the most ardent one, and is currently being led by the Blackstone Canal Taskforce. Because of the extent of research the project has conducted on the Canal District, the Chairman of the *Free the Blackstone* Taskforce was consulted (Free, 2007). The meeting involved a discussion followed by a tour of the area in which all buildings with a potential for residential redevelopment were pinpointed.

b) City of Worcester Administration:

Because the City of Worcester intends to promote residential development within the Canal District and is responsible for formulating policies on which future developments are based, the Division of Planning and Housing (DPH) is a valuable source of information on potential residential redevelopment within the area (Worcester Municipal, 1999). Furthermore, consulting with the DPH allowed for the determination of and inclusion in this study of buildings which might not have been known by private redevelopment firms and investors (City, 2007). This information was acquired mainly through two different sources.

1. The *Community Development Plan – Housing Policy* issued by the Division of Housing (Fontane & Hayman, 2004).
2. An interview was conducted with an Economic Development Planner with the City of Worcester, and an authority in the Canal District

c) Determining Total Units:

Having specified the buildings slated for redevelopment, the number of units contained within each were then determined through the following means:

1. News articles pertinent to the redevelopment of the Canal District found in the World Wide Web.
2. Contact made with the developers of the buildings.

Determining Waste Water Produced Per Additional Residential Unit

After estimating the number of buildings that can potentially be redeveloped into residential sites and the number of units collectively obtainable from them, the next step involved quantifying the average amount of waste water produced by each additional residential unit. This process included the following assumptions:

1. Each newly developed residential unit in the Canal District takes the form of a condominium or a loft apartment, since the existing infrastructure of the area cannot be significantly altered.
2. The residential units have a standard size and capacity.
3. Each condominium produces a constant value of waste water equivalent to the average waste water produced by the already existing condominiums in the City of Worcester.
4. Every drop of water consumed eventually makes its way to the waste water system. Thus water consumed is equivalent to waste water produced.

Determining Average Waste Water Quantity

The City of Worcester's *Utility Billing Usage Report* for the fiscal years 2006 and 2007 was obtained from the Department of Public Works. This report provided the following pertinent information:

1. Total amount of water consumed by condominiums in the City of Worcester.
2. The total number of condominiums billed.

The average water consumption per condominium was determined by dividing the total amount of water consumed by the number of condominiums. This value was assumed to be equivalent to the waste water generated by each additional residential unit.

Equation 6: Average Waste Water Production per Added Residential Unit = (Total Water Consumed by Condominiums) / (Total Number of Condominiums)

Calculating Total Residential Waste Water Volume Increase

The average waste water produced by a residential unit was multiplied by the total number of possible residential units in the Canal District, to determine the potential rise in waste water production within the area. This calculation can be represented by the following equation:

Equation 7: Total Increase in Waste Water Production = (Total Residential Unit Increase) X (Waste Water Production per Added Residential Unit) X (Cost of Waste Water Treatment per Unit Volume)

Calculating Total Cost for the Increased Waste Water Treatment

The total cost was obtained as the product of the total possible increase in the waste water within the Canal District and the cost to treat a unit volume of waste water in the City of Worcester.

Equation 8: Total Cost = (Total Increased Waste Water Volume) X (Cost of Waste Water Treatment per Unit Volume)

Objective #3: Calculating the Future Savings of Waste Water Treatment: Green Infrastructure

The purpose of objective 3 is to determine the future costs that would be associated with urban runoff, while making the assumption that ecologically based alternative solutions have been incorporated into both existing and newly developed infrastructure. In order to accurately estimate these costs a variety of tasks including the estimation of future population, approximation of increases in waste water volumes, calculating the area of surfaces that can have green infrastructure implemented, determining the amount of runoff mitigated by these solutions, and calculating the savings associated with this mitigation, were completed. Information pertaining to the first two tasks was required to complete objective 2, and the steps taken are chronicled within that section. The means by which the other tasks were completed is detailed below.

Calculating the Surface Area of Acceptable Green Infrastructure Locations

An approximation for the surface area of locations that would be suitable for the implementation of green infrastructure was determined through simultaneous evaluation of GIS building layer maps and aerial photos, obtained from Google Earth. The existing infrastructure within the Blackstone Canal District was examined to determine the general feasibility for the implementation of such solutions as increased vegetation, green roofs and permeable pavements. This examination process included looking at different building types, residential or commercial, and roof types, flat or pitched. Buildings with flat roofs were counted as areas acceptable for green roof implementation, whereas those with pitched roofs were considered unsuitable. Paved surfaces such as parking lots, low volume city streets and residential driveways were assumed to be replaceable by permeable surfaces. Those ecological solutions that could not realistically be incorporated into the Canal District, such as wetlands, rain water and gray water harvesting, were disregarded. Information was verified through a tour of the Canal District, conducted by the president of the Greater Worcester Land Trust. After selecting the appropriate surfaces, GIS software was used to draw polygons around the area and a total surface area value was estimated.

Determining Efficiency of Alternative Solutions

Determining the amount of mitigated runoff was done by evaluating the efficacy of the applicable alternative solutions. The efficiency for each solution was calculated as follows:

Increasing vegetation: The efficiency associated with increasing vegetation and tree cover was determined through an interview conducted with the assistant director in the Worcester Department of Public Works and through an online guide called “How Urbanization Affects the Water Cycle” under the NEMO California Partnership.

Green Roofs: The efficiency associated with incorporating green roofs into new or pre-existing structures was found through examination of a variety of different primary and secondary sources of information. An architect specializing in green infrastructure in Worcester was interviewed to ascertain information pertaining to the applicability of green roofs within the Blackstone Canal District. Additionally, installation companies, such as Roofscapes Inc. and Living Roofs Inc. were consulted to obtain statistical information in regards to performance. The secondary sources examined include “Design Guidelines for Green Roofs” by Steven Peck and Monica Kuhn (Alberta Association of

Architects) and the Low Impact Development, Inc. website (http://www.lid-stormwater.net/greenroofs/greenroofs_benefits.htm).

Porous Surfaces: In order to find out the efficiency of porous pavements, the Georgia Storm Water Management Manual (http://www.georgiastormwater.com/vol2/ 3-3-7.pdf), the Low Impact Development Website (http://www.lowimpactdevelopment.org/), and The Field Evaluation of Permeable Pavements for Stormwater Management (http://www.epa.gov/owow/nps/pavements.pdf) were evaluated. Additionally, a variety of companies such as PermaPave Industries, Inc., and Aggregate Industries were consulted to determine statistical information in regards to long term efficacy.

After calculating the efficiency of each alternative solution, this information was used in conjunction with the total potential surface area on which green infrastructure could be installed and the monthly rainfall data to estimate a value for the amount of runoff mitigated.

Equation 9: (Efficiency of Solution) X (Monthly Rainfall) X (Surface Area) = Total Volume Reduced

Monetary Savings Associated with Mitigation

The monetary savings associated with runoff mitigation was estimated by taking the volume of urban runoff retained by the solutions and multiplying it by the cost per unit at the waste water treatment plant.

Equation 10: (Retained Volume of Runoff) X (Cost of Waste Water Treatment) = Total Savings

Objective #4: Calculating the potential savings of green infrastructure during major storm events.

The purpose of objective 4 is to determine whether green infrastructure would be a more cost effective method of managing urban runoff during major storm events compared to the currently proposed infrastructural upgrades of the existing waste water treatment system. In order to accomplish this objective a variety of different tasks including the determination of 1) precipitation amounts during major storm events, 2) efficiency of green infrastructure during such events, 3) fines associated with discharges of excess waste water, and 4) costs associated with new infrastructural upgrades of the current waste water system. The means by which these tasks were completed is detailed as follows.

Determining Precipitation Amounts during Major Storm Events

To define a major storm event, records pertaining to the CSO facility's discharges were obtained from the DPW (personal communication, December 5, 2007). These records show how long the facility was operational, the discharge amounts, and the rainfall accumulated over the time and can be viewed in Appendix 1. To calculate the average storm, the total rainfall that occurred during each of the storm events that caused the CSO facility to discharge waste water was added together and divided by the total number of days the facility was open.

Efficiency of Green Infrastructure during Major Storm Events

Although the efficiency of all of the different forms of green infrastructure would be of interest to urban areas, the previously defined scope of the project limits the discussion to those solutions deemed as potentially acceptable within the Blackstone Canal District. The means through which information pertaining to the efficiency of green roofs, permeable pavements and increased vegetation was obtained is chronicled below.

Green Roofs- The efficiency of green roofs during large precipitation events was determined through an interview conducted with a respected architect in Worcester who has incorporated green roofs into his designs. Additionally, installation companies, such as Roofscapes Inc. and Living Roofs Inc. were consulted to obtain statistical information regarding performance.

Permeable Pavements- The efficiency of permeable pavements during large precipitation events was determined through examination of the Georgia Storm Water Management Manual (http://www.georgiastormwater.com/vol2/ 3-3-7.pdf), the Low Impact Development Website (http://www.lowimpactdevelopment.org/), and The Field

Evaluation of Permeable Pavements for Stormwater Management (http://www.epa.gov/owow/nps/pavements.pdf). Additionally, a variety of companies such as PermaPave Industries, Inc., Miller Micro, Grassy Pavers, Pervious Concrete and Aggregate Industries were consulted to obtain statistical information regarding long term efficacy.

Increased Vegetation - The efficiency associated with increasing vegetation and tree cover was determined through an interview conducted with the assistant director in the Worcester Department of Public Works and through an online guide called "How Urbanization Affects the Water Cycle" under the NEMO California Partnership.

Calculating Fines Associated with Excess Waste Water Volume Discharges

Calculating the cost of EPA-imposed fines associated with the discharge of untreated waste water during major storm events was determined through an interview with the superintendent of the Millbury Wastewater Treatment Plant and the District Engineer of the Upper Blackstone Water Pollution Abatement District. The numbers obtained were verified with information provided by an employee of the EPA.

Costs Associated with Infrastructural Upgrade of the Waste Water Treatment System

Determining the costs associated with upgrading the CSO infrastructure determined through information obtained from the Conservation Advocacy Coordinator at Mass Audubon. This was verified through an interview conducted with the assistant director of the DPW.

4: Findings

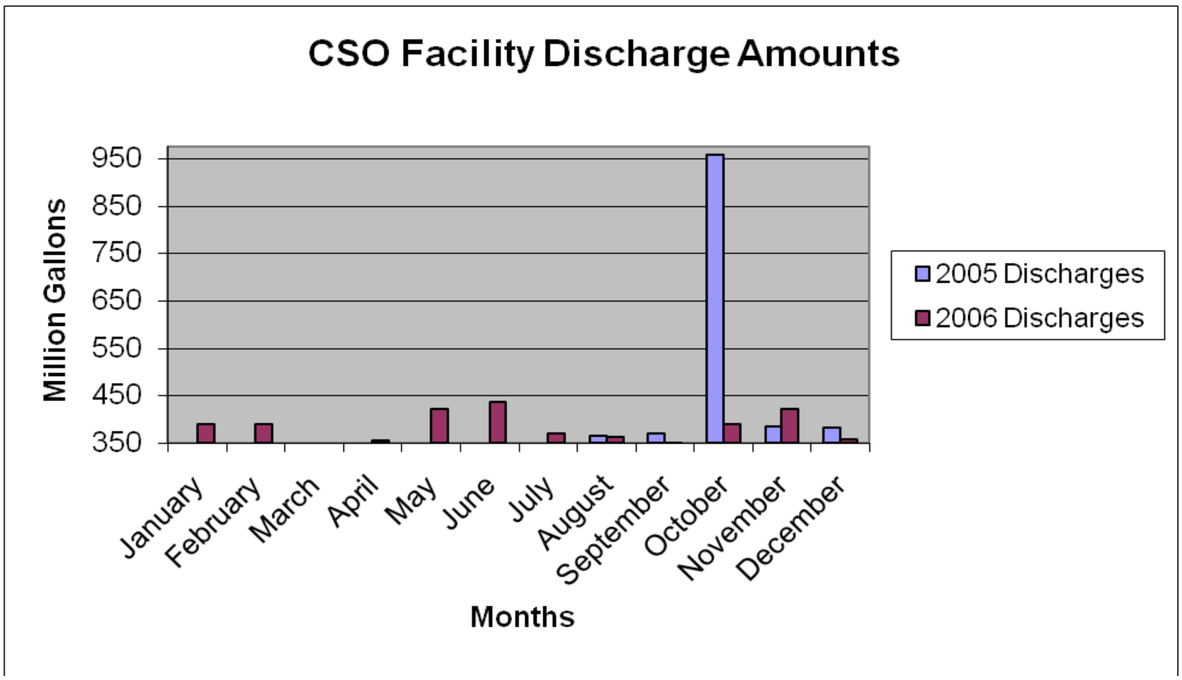
The methodology section of this paper specifies the means through which the advantages associated with implementing green infrastructure within the Canal District were gathered. This section of the paper details the information obtained, and provides an analysis of this data. This analysis is presented in the form of three findings. **Finding 1-** Excessive urban runoff will eventually force the City of Worcester to make significant infrastructural upgrades to the current CSO system. **Finding 2-** Green infrastructure, as a means of runoff mitigation, would preclude the need for expensive infrastructural upgrades to the CSO system. **Finding 3-** Green Infrastructure has a modest impact on the reduction in runoff treatment costs under normal conditions, but does offset the costs associated with increased waste water from the residential redevelopment of the Canal District.

Finding 1- Urban runoff will eventually force the City of Worcester to upgrade the current CSO system.

The current CSO system in Worcester is inadequate to handle the excess volume of runoff produced during significant storm events. This inadequacy manifests itself in the form of large discharges of partially treated waste water into the Blackstone River. Such discharges have been deemed both inordinate and hazardous by the EPA. Consequently, the City of Worcester is being forced to drastically reduce or eliminate the number of these discharges that occur per annum. One course of action that has been proposed is the revamping of the current system through the establishment of an alternative storm water management system.

We found that a storm event which exceeds approximately 0.3 inches of rain per day results in an amount of runoff that exceeds the capacity of the CSO treatment facility. In its current state, this facility can retain approximately 350 MG of waste water and hold it until it can be transferred to the waste water treatment plant. Under normal circumstances (i.e., precipitation of less than 0.3 in/day) the system can accommodate and effectively manage the amounts of waste water that it receives daily. However, during a major storm event the system's capacity is exceeded, and it is forced to discharge large volumes of partially treated or untreated waste water into clean water supplies. Partially treated waste water is water that receives a flash treatment, which entails the filtration of solids followed by chlorination. Figure 6 is a graph that shows the number and volumes of the discharges that occurred at the CSO treatment facility during 2005 and 2006. This data is significant to note because it indicates that the facility discharges fairly frequently and also shows that any large storm brings about the failure of the system. In the graph 350MG is used as the baseline because that is the total amount of waste water that can be retained by the facility, and the discharges would result from the volumes that exceed this quantity. The table at the bottom of Figure 2 illustrates the number of discharges that occurred during each of the months.

Figure 6: Discharge Data



Number of Discharges

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2005	0	0	0	0	0	0	0	1	3	4	4	2
2006	4	2	0	1	2	3	3	3	1	2	4	1

Since the annual number of such discharges is significantly higher than that stipulated by the EPA, it has been deemed imperative that changes be made as soon as possible in order to reduce the number of discharges. Through an EPA contact with expertise in the Worcester CSO system, it was learnt that the facility at this moment is allowed, by permit, to discharge into the Blackstone River without fear of penalty. However, the EPA has placed a time frame on the treatment facility to cut back the number of discharges to two per year by 2010. If this time frame is not adhered to, then the fines will come in to play. The cost for such projected infrastructural upgrades to the CSO system are estimated to be around 180 Million dollars, according to information obtained from a 2004 presentation given by the City of Worcester. Even though, these upgrades would serve to accommodate the increased volume of waste water during major storms, the costs would place a significant financial burden on the city, disrupt daily life during construction efforts and render the current CSO system obsolete.

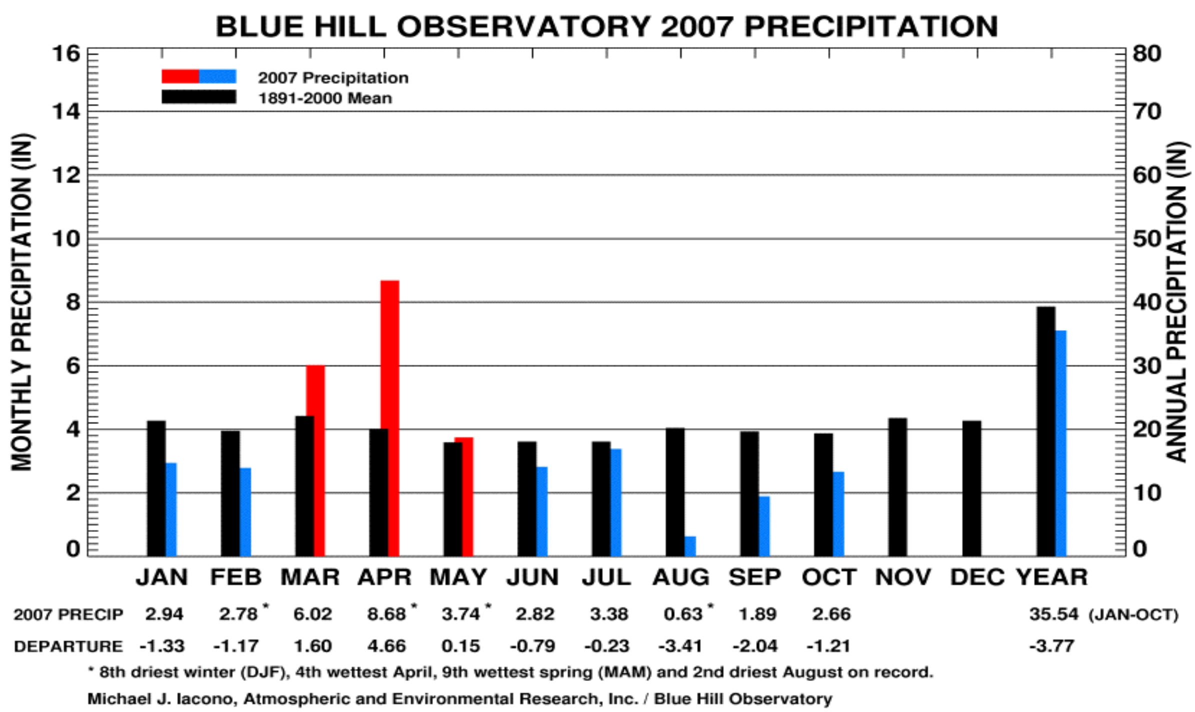
As a result, the importance for determining alternative solutions to the runoff problem has been observed. But, before going into potential solutions to the problem it is necessary to quantify the amount of runoff produced during typical storm events in order to facilitate a quantitative analysis of the efficacy of the solutions. The numbers pertaining to runoff volumes were evaluated through the rainfall data and the topographical features in the Canal District that contribute towards runoff production. The next sections detail the procedure and enumerate the specific numbers.

Rainfall Data

It was determined that the average daily rainfall produced in the Canal District is .132 in, and .94 during a typical large storm event. The average daily rainfall data was obtained through graphical analysis of the monthly rainfall data taken between 1891 and 2000, along with data from 2007. The graph in Through the correlation of the rainfall data with the impermeable surface area, it was determined that the average daily amount of urban runoff produced in the Canal District is 0.50 MG and during a typical storm event is 3.6 MG. The maximum amount of runoff generated within the Canal District that the CSO system can retain without discharge is 1.15 MG. This number was calculated based on the assumption that because the city discharges during a precipitation event that exceeds .3 in, the maximum amount of manageable runoff would correspond to this event. It was also assumed that during such an event the entire City of Worcester still contributes both runoff and waste water that needs to be treated.

graphically illustrates the information pertaining to the rainfall data. From this data, the rainfall during a typical large storm event was determined by averaging all of the storm events greater than .3 in, the rainfall that causes the failure of the CSO system, and then dividing this by the number of days over which they occurred. The data for the precipitation events that caused the failure of the CSO system was provided by the Assistant Director of the DPW, and is included in Appendix 1.

Figure 7: Rainfall Data

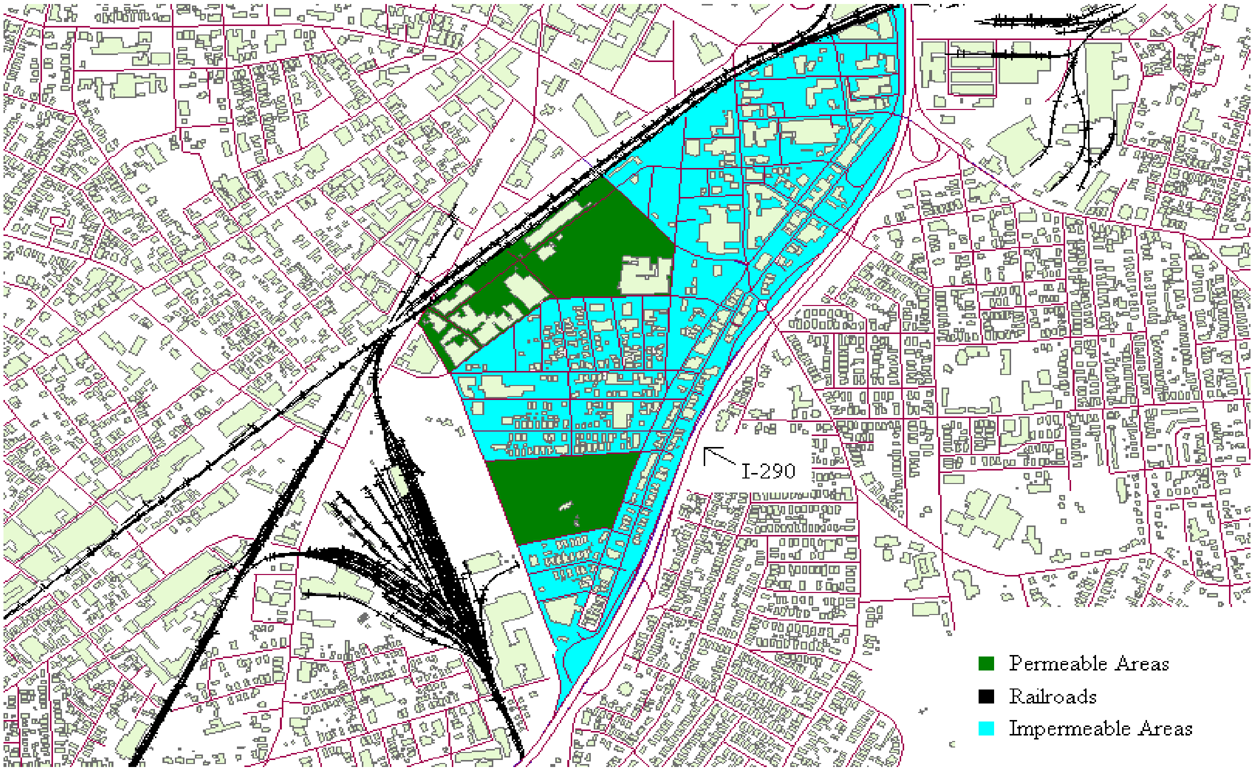


In order to obtain the volumes of runoff produced in the Canal District during precipitation events, it was necessary to correlate the rainfall data to the area of impermeable surfaces in the Canal District. The next section outlines the specific data pertaining to the impermeable area within the Canal District.

Impermeable Surface Area in the Canal District

We found that there are 141 acres of impermeable surface in the Blackstone Canal District. This number was obtained by taking the total area of the district (191 Acres) and subtracting the permeable surfaces (50 Acres). In addition, 5% of the total area was taken and subtracted to account for miscellaneous permeable surfaces, such as residential lawns.

Figure 8: Canal District



Through the correlation of the rainfall data with the impermeable surface area, it was determined that the average daily amount of urban runoff produced in the Canal District is 0.50 MG and during a typical storm event is 3.6 MG. The maximum amount of runoff generated within the Canal District that the CSO system can retain without discharge is 1.15 MG. This number was calculated based on the assumption that because the city discharges during a precipitation event that exceeds .3 in, the maximum amount of manageable runoff would correspond to this event. It was also assumed that during such an event the entire City of Worcester still contributes both runoff and waste water that needs to be treated.

The calculations performed to determine the volume of runoff produced on a daily basis under each of these circumstances is summarized in Table 10**.** This information allows for a comparison to be made between regular conditions and storm conditions to approximate how much runoff needs to be mitigated to avoid the expenditure of 180 million dollars for the restructuring of the CSO system, and the prevention of the inevitable fines that would have been levied by the EPA. From the information in the table, it can be seen that the CSO system can effectively manage 32% of the storm water that it receives from the Canal District during a major storm event. Consequently, a solution that mitigates around 68% of the runoff produced needs to be proposed.

Table 10: Runoff Produced

	Surface Area in Acres	Rainfall Data in Inches	Volume in Cubic Ft	Volume in MG
Average	141	.132	67,561.56	0.50
Typical Large Storm	141	.940	481,120.20	3.60
Max for CSO Failure	141	.300	153,549.00	1.15

Findings 2 - Green Infrastructure, as a means of runoff mitigation, would preclude the need for upgrades in the CSO system.

The applicability and efficiency of green infrastructure within the context of the Canal District were analyzed in order to determine if it served as a viable alternative to the costly upgrades in the CSO system. It was found that green infrastructure has the potential to reduce the number of discharges made by the CSO system through the reduction of runoff in the district.

Applicability of Solutions

While determining the applicability of the green infrastructure within the Canal District, it was assumed that the build out of each type of solution would occur to the maximum capacity. Even though they were unrealistic, the quantitative values associated with this 100% build out would act as the upper limit.

i. **Green Roofs:** Based on the area measurements carried out by the GIS software, it was determined that the total area of rooftops in the Canal District where green roofs are applicable is approximately equal to 22.8 acres.

ii. **Increased Arboreal Vegetation:** The placement and quantity of the trees in the Canal District are based on the following assumptions:

a) Trees can only be planted in land pockets within impermeable areas such as parking lots and sidewalks, since all the permeable areas are either unsuitable for tree plantation or are already efficient in terms of runoff absorption and elimination. The area of such impermeable surfaces that exclude rooftops is 105 acres.

b) Each tree takes up a 4ft. x 4ft. area, and there has to be at least 25-30 feet distance between adjacent trees on sidewalks (DPW Contact, personal communication, November 16, 2007).

c) On average, a sidewalk is about 5 feet wide.

The number of trees that can be placed in the Blackstone Canal District according to these assumptions, along with the recommendations provided by an urban forester, is 15 trees per acre. Given the 105 acres of impermeable surfaces within the district this equates to a maximum of 1575 trees.

iii. **Permeable Pavements:** The area measurements conducted through the GIS software indicated that the total amount of impermeable surfaces in the Canal District, where such pavements could be implemented, is approximately 105 Acres. This number was obtained as a difference between the total impermeable area (141 Acres) in the district and the total area of all its rooftops (36 Acres). Furthermore, the total area that would potentially be occupied by street trees was also taken into. Resultantly, the area in the Canal District where permeable pavements can be implemented is approximately equal to 104.42 acres

Efficiency of Solutions:

i. **Green Roofs:** Green roofs were found to be 66.5% efficient under normal conditions and 57.5% efficient during major storm events. The efficiency of green roofs at eliminating runoff was determined to be dependent on the following factors:

a. Structural limitations of the buildings
b. Vegetation used on the roofs
c. Depth of the soil

d. Type of soil used

Under normal conditions it was determined that green roofs are capable of absorbing between 58% (LID, 2007) to 75% (EPA, 2007c) of rain water. During major storm events, efficiency ranges from 40% to 75%. The average values of these numbers (66.5% and 57.5%) were taken as a representative value for the percentage of rain fall absorbed by green roofs. Utilizing the average value of rainfall experienced by Worcester per day under normal conditions (0.132 inches) and major storm events (0.94 inches), the total volume of runoff eliminated per day during each of those circumstances were as follows.

Normal Circumstances = 54,347 gal. /day

Major Storm Events = 334,633 gal. /storm

Under realistic conditions however, the extent of green roof build out will remain below 100 percent. Therefore the amount of runoff elimination gets reduced by a fraction with every subsequent decrease in build out percentage.

ii. **Increased Arboreal Vegetation:** It was determined that assuming average conditions, a typical medium sized tree intercepts and absorbs about 198.33 gallons of rainfall per month, which corresponds to a runoff reduction of 50 gallons per inch of rain. This number was derived by dividing the average monthly rainfall interception by the average monthly rainfall. During storm events the efficiency of arboreal vegetation is dependent upon the following factors:

a) Size and species of tree
b) Amount and variety of surrounding soil used for planting trees
c) Level of underground water table
d) Amount and duration of rainfall

It was determined that if tree plantation was carried out in the Canal District at its full potential (1575 trees), it would eliminate the following amounts of runoff in the two scenarios:

Normal Circumstances = 10,395 gal. /day

Major Storm Events = 74,025 gal. /day

iii. **Permeable Pavements:** Permeable pavements, whether porous asphalt, porous concrete, grass/gravel pavers or traditional bricks; were found to be 100% efficient during both normal conditions and storm events. In an idealized situation comprising of proper installation techniques and the use of suitable materials for the pavements, the physical limitations imposed upon these surfaces are non-existent. In such a case, the efficiency, in terms of water infiltration, is equivalent to approximately 100%, since the permeable pavements are installed with aggregate beds of appropriate thickness, and the type of material used is most suitable for the given topography and climate (Cambridge, 2007; Aggregate Industries, Inc, personal communication, November 2007; Cahill Associates, Inc., personal communication, November 2007). In addition to reducing runoff, these surfaces also have the capacity to compensate for the inefficiencies of the other forms of green infrastructure in terms of preventing runoff generation. As a result, for the purpose of this project the efficiency will be chosen as equal to 100%. However, these surfaces will not be considered capable of absorbing the excess runoff volumes resulting from the other forms of green infrastructure, in order to provide a more accurate reflection of the true savings generated by their implementation. The volume of runoff eliminated per day by the permeable pavements in the Canal District under the two circumstances are as follows:

Normal Circumstances = 374,280 gal. /day

Major Storm Events = 2,665,324 gal. /day

Summary and Analysis:

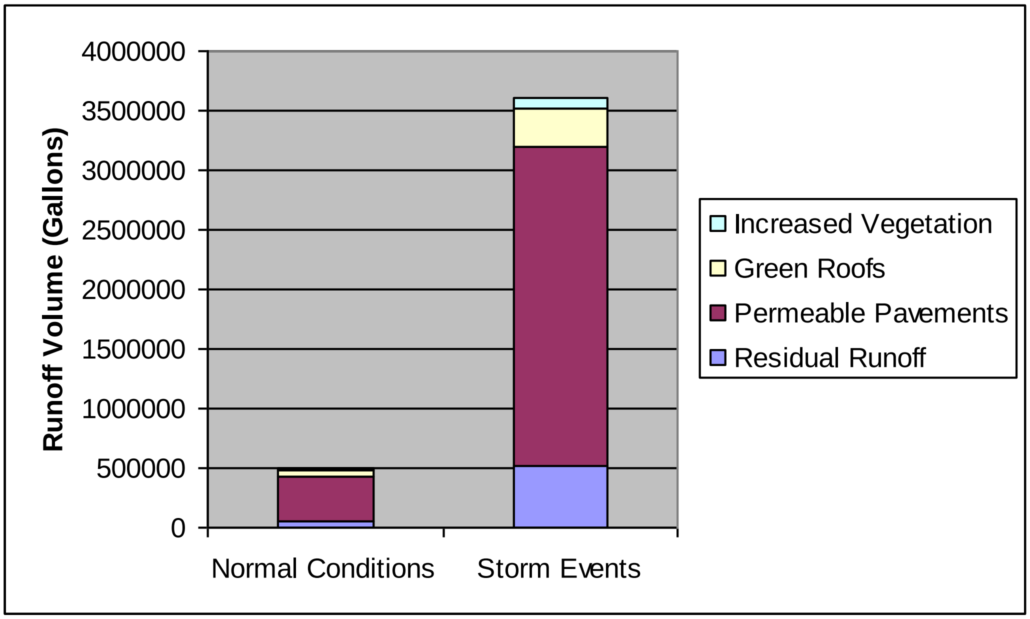
Table 11 illustrates the volume of runoff eliminated by each of the three solutions, assuming a maximum build out.

Table 11: Runoff Reduced

Solution	**Volume of Runoff Reduced (Gallons)**			**Excess Runoff (Gallons)**
	Green Roofs	**Increased Vegetation**	**Permeable Pavements**	
Normal Conditions	54347	10395	374280	60978
Storm Events	334633	74025	2665324	526018

This information can be graphically represented as shown in Figure 9. Each segment of a bar represents a certain volume of runoff associated either with a particular solution or that which is in excess. As it can be observed, permeable pavements, due to their high applicability and efficiency, can be attributed for eliminating the major portion of runoff volumes.

Figure 9: Runoff Reduced



The final column of the Table 11 represents the average amounts of runoff which are not eliminated during normal conditions and major storm events. Since, the CSO makes its discharges only when the amount of runoff exceeds 1.15 MG in the Canal District, and the values of the average excess runoffs during both circumstances is less than that number, it can be concluded that with the application of green infrastructure, the number of discharges made by the CSO can be drastically reduced.

When the discharge data from the CSO was examined, it was determined that there were altogether 14 discharges in 2005 and 26 discharges in 2006. Each discharge refers to the total amount of waste water passed into the Blackstone River throughout the duration of a particular storm event. The number of such discharges conducted by the CSO system exceeds the limits set by the EPA. However, through the utilization of green infrastructure as solutions to eliminating runoff, the number of discharges can be significantly reduced. Such improvement primarily stems from the fact that when collectively operated, the three solutions described above provide an outstanding efficiency 85.4% during major storm events and 87.8% under normal conditions, for eliminating runoff. The improvement is graphically illustrated by Figure 10 and Figure 11 below.

Figure 10 shows the graphical representation of the discharges that occurred in 2005. The blue curve indicates the amount of runoff entering the CSO before the implementation of green infrastructure and the red line represents that entering the CSO after the implementation of green infrastructure. The yellow line across the graph represents the threshold value of runoff entering the CSO, above which the CSO discharges the partially treated water into the Blackstone River. Green infrastructure for such a scenario has the capacity to reduce the number of discharges from 14 to 2.

Figure 10: 2005 Discharge Data

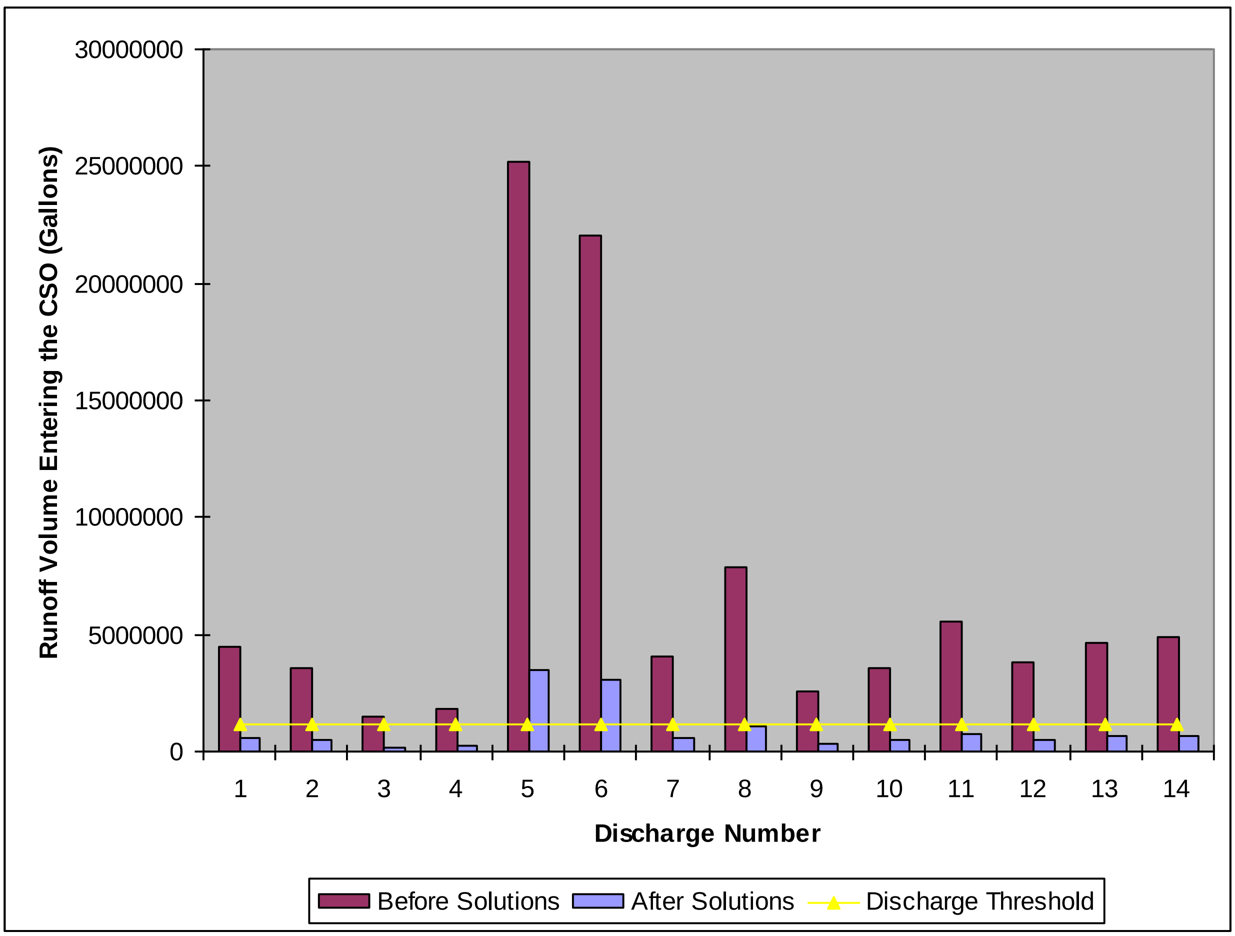
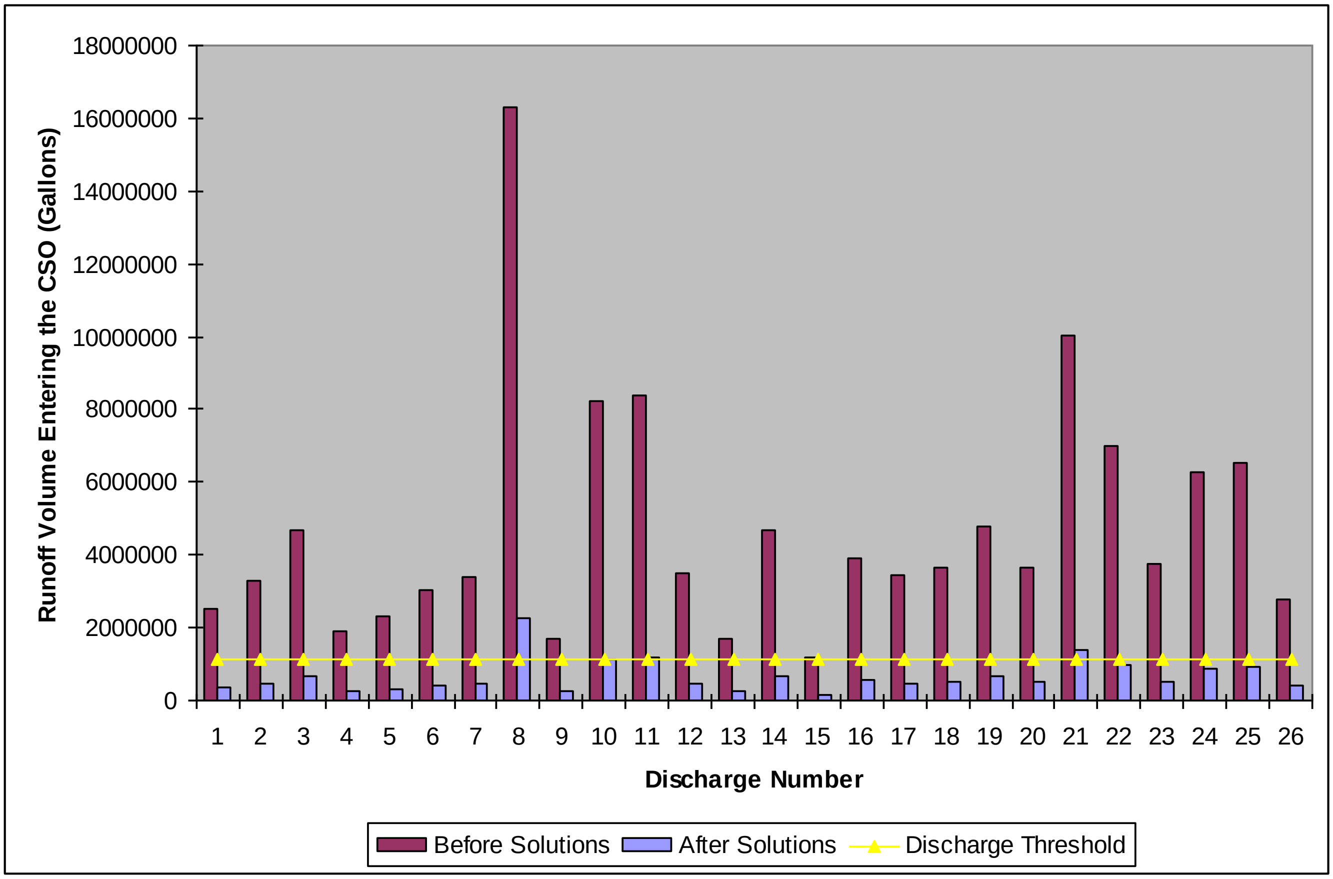


Figure 11 provides similar information for the year 2006. In this case, it can be observed that green infrastructure applied to a similar scenario has the potential to reduce the number of discharges from 26 to 4.

Figure 11: 2006 Discharge Data



The final results brought about by green infrastructure towards the elimination of urban runoff and reduction of the discharges performed by the CSO, show signs of significant improvement. As a result, it can be concluded that the application of green infrastructure into the Canal District, has the potential of preventing costly infrastructural upgrades into the current CSO system.

Findings 3: Green Infrastructure provides additional ancillary benefits

The primary benefit associated with implementing green infrastructure is to eliminate the necessity to separate the CSO system into separate components, but there are ancillary benefits which prove to be valuable to the city. These benefits are shown in the findings detailed below:

Current runoff management costs the city money and green infrastructure can serve to significantly lower the amount spent on its treatment.

Cost of Treatment

We found that at the present time the cost to treat 1000 gallons of waste water is $0.93. This information was obtained through an interview conducted with the Vice Chairman of the Upper Blackstone Water Pollution Abatement District (personal communication, November 15, 2007). This information was used to determine the total cost of runoff to the city and also to approximate the savings that would be produced if ecological solutions eliminated a portion of the storm water that needs to be treated.

The Monthly Cost of Runoff

We found that the cost per month to treat urban runoff produced in the Blackstone Canal District is $14,247.60. The cost for treatment was calculated by utilizing equation 3. This information forms the basis for a comparison between the costs of runoff before and after the implementation of ecological services.

Monthly Savings with Green Infrastructure

We found that the monthly savings that would be associated with the implementation of green infrastructure would be $12,364.00 assuming 100% build out and $6,196.65 assuming 50% build out. In the 100% build out scenario, green solutions have the potential to reduce urban runoff by 12.04 million gallons; and in scenario two, they can reduce urban runoff by 6.02 million gallons.

Table 12 illustrates the monthly monetary savings brought about by each of the three suggested solutions vegetation, green roofs and permeable pavements. The calculations were made based on equation 10. The savings come about because the treatment of the reduced volume of urban runoff does not need to be paid for.

Table 12: Savings Analysis

	Scenario 1: 100% Build Out ($ per month)	Scenario 2: 50% Build Out ($ per month)
Increase Vegetation	290.50	145.25
Green Roofs	1,536	768
Porous Pavements	10,537.50	5,283.40
Total Savings	**12,364.00**	**6,196.65**

Through this savings analysis, we can conclude that implementing green solutions have the potential to save the city between about $6,200 and $12,360 on a monthly basis, depending upon the percentage of solutions being installed. In one year, the city can save $74,400 even in a case where all solutions are implemented in 50% of applicable areas. Over years, these savings multiply to generate a large amount of reserves that can be used by the city for other useful and essential purposes instead of waste water treatment.

Future residential redevelopment of the Canal District will increase the volume of waste water and green infrastructure will reduce the strain that this places on the current system.

Currently, the City of Worcester spends about a quarter of a million dollars annually to treat waste water generated within the Canal District. With the ongoing trend of residential development in the area, the regions inside and immediately around the Canal District have been predicted to experience a significant growth in residential units. This growth will eventually add on to the waste water production in the area, causing the total sewage treatment cost to increase by approximately twenty five percent. Runoff treatment, since it is coupled with waste water for treatment, can act as a severe burden to both the treatment facilities and the city's budget. The following section describes the findings that led to this conclusion.

Determining Current Volume of Waste Water Produced

The current population living within the Canal District was approximated at 7500 residents (C. Novick, October 30, 2007), with each individual contributing an average value of 100 gallons of waste water per day, based on standard American resident values.

By using equation #5 mentioned in the Methodology, the daily volume of waste water produced in the Canal District was thus estimated to be 750,000 gallons. Through our calculations, we estimated that the annual cost for treating waste water incurred by the plant is $254,587.50. The table below shows the yearly volume of waste water produced in the Canal District and the cost associated with treating that water:

Annual waste water Volume	(750,000 gallons/day) * (365 days) **= 273,750,000 gallons**
Treatment Cost	(273,750,000 gallons) * ($.93/1000 gallons) **= $254,587.50**

This information is necessary because through further calculations, we can compare the total costs of waste water treatment once the redevelopment in the Canal District has been completed. This would lead the way for us to evaluate how much green solutions to urban runoff can save in such treatment costs. Thus, the next logical step would be to consider the potential growth of residential units in the Canal District.

Prospective Growth

The prospective redevelopment buildings within the Canal District were identified through sources mentioned in Objective # 2 of the Methodology. On adding up the total number of residential units that each developer intends to build up, it was estimated that in the near future the Canal District is expected to experience a growth of 323 additional residential units.

Table 13 illustrates the names of each of those developers, the buildings they own, and the number of residential units projected to be installed in each of those buildings.

Table 13: Redevelopment Buildings

No.	Buildings	Total Units
1	a) Kelly Square Lofts (2 Bldgs) b) Charlie's Surplus Bldg	8
2	a) Harrison St. Bldg b) Crompton Loom Works	40
3	a) Castellana's Bldg* b) Old St. John's School Bldg*	114
4	a) Heywood Bldg	8
5	a) Chevalier Furniture Bldg	89
6	a) Arrow Wholesale Bldg	30
7	a) Mendel Block	8
8	a) Atlantic Bag Bldg	8
9	a) Lucky Dog Bldg	18

* These buildings have been slated for redevelopment into student residence halls (Property owner, Phone Conversation). The total capacity of the buildings has been estimated to accommodate 342 standard college style dormitory rooms. The table above categorizes three of such rooms as being equivalent to a single residential unit, resulting in a total of 114 units.

This residential increase in the Canal District will be accompanied with an increase in the annual quantity of waste water produced within the area. It is important that this increase be quantified in order to understand and address concerns about the possibility of flooding during storm events due to the overloading of the sewer and waste water systems. The ensuing increase in treatment costs will also bring about economical concerns relating to additional financial burdens placed on the residents and the city administration alike. Therefore both the amount of waste water increase and the treatment costs must be determined. The next two sections concern with the determination of these quantities.

Determining Average Water Consumption per Residential Unit

On average, the amount of water consumed by each household unit was approximated to be 217,960 gallons per year. This quantity was obtained by dividing the total amount of water consumed by condominiums in the City of Worcester during 2006 and 2007 by the total number of condominiums in the city during those years. This information is illustrated in Table 14. When the total water consumption was divided by the total number of condominium units for a given year, the average value of water consumption for a single unit was estimated.

Table 14: Water Consumption in Condominiums (City of Worcester, Utility Billing Usage)

Year	Water Usage (Gal.)	No. of Units	Water Consumption per Unit (Gal.)
2007	167,402,804	792	211,367
2006	175,598,462	782	224,550
Average Consumption per Unit			217,960

As per the discussion in Objective #2 of the Methodology section, it was assumed that all the water consumed would eventually make its way to the waste water system. Therefore the condominium water consumption value served as a safe approximation for the average amount of waste water produced by a single residential unit added to the Canal District. This number enables the determination of the annual increase in waste water in the Canal District if it undergoes residential redevelopment up to its maximum projected capacity.

Annual Waste Water Increase in Canal District

The annual increase in waste water resulting from potential future residential growth in the Canal District was estimated to equal 70,401,080 gallons. This value was obtained as the product of the total possible increase in residential units and the average waste water produced per residential unit.

In comparison to the amount of waste water currently being produced within the Canal District, i.e. 273,750,000 gallons, the increase induced by residential growth is rather significant, and can be numerically represented as approximately 25.72% of the current amount of waste water already being produced. Green infrastructure would more than compensate for this increased amount of water and would alleviate the stress that this increased volume would put on the system.

5: Conclusion

This project sought to show that the implementation of green infrastructure would benefit Worcester, Massachusetts in a multitude of ways. We found that urban runoff poses as an environmental problem for the city, especially during storms when the city's combined sewer overflow system overloads and discharges excess water into the Blackstone River. Between the years 2005 and 2006, for instance, there were 40 discharges during storm events. Thus, the CSO system may not be obsolete, but it is certainly inadequate to handle storm water effectively. Currently, there are no fines implemented on the CSO plant for these discharges, but the EPA requires them to be reduced to two per annum by the year 2010. As a result, there are plans to separate the lines for sewage and runoff, but this will cost the city upwards of $180 million in infrastructural development.

In order to mitigate the effects of runoff, we examined three different forms of green infrastructure that would relieve the strain on the CSO system by absorbing a large portion of the runoff before it reaches the treatment plant. These solutions were green roofs, permeable pavements and increasing arboreal vegetation. We found that in the Blackstone Canal District, which consists of 141 acres of impermeable and 50 acres of permeable land, there is enough area for the implementation of the three alternative solutions. If installed to maximum capacity, there can be 22.8 acres of green roofs, 1575 tress in the 105 acres of impermeable surfaces, and 104.42 acres of permeable pavements installed. This results in a total runoff reduction of 87.9% in normal rain conditions, and 85.4% during large storms. Thus, these solutions can serve to complement the CSO system and reduce the need to perform rigorous infrastructural updates to the piping systems which would prove to be expensive and disruptive to the residents of the city.

Though our results showed a maximum value for reduced runoff during both normal and storm events, there are some limitations to these calculations. Firstly, it was assumed that the solutions were installed appropriately to optimize the amount of water retained. Moreover, the absorption of trees and green roofs would vary with soil depths, vegetation types, underground water table levels, and the soil types used for plantation. Thirdly, the scenario assumed in this project was one of complete 100% implementation, which means all solutions were expected to be installed in all possible areas. Thus, if the area that these solutions are implemented in is reduced, the amount of runoff reduced will also fall accordingly. And finally, during storm events, absorption rates can vary greatly depending upon the amount and duration of rainfall. However, with correct installation techniques, the alternative solutions can perform to their best and reduce runoff to their strain on the CSO system.

Although this project details the advantages of green infrastructure and shows the benefit that it can have on the Blackstone Canal District, more work still needs to be completed before implementation can occur. For that reason we recommend that future projects conduct research into the following areas.

Broadening the Area of Study**-** This project evaluated the benefits of green infrastructure in the Canal District alone without taking into consideration the surrounding communities. Conducting similar research to our work but broadening the area examined would prove further that green infrastructure is beneficial to the City of Worcester. In fact, this research project can serve as a model to assess implementation of green infrastructure in other urban centers.

Cost of solutions- Although we provided the benefits of the different forms of green infrastructure we were unable to evaluate the installation costs. For that reason it is difficult to make a true comparison of the cost difference between green and gray infrastructure. Further research may be done to perform cost-benefit and cost-effective analyzes of implementing these solutions in the long term.

Policy and Incentives- Convincing both the residents of the city and the developers to adopt this new philosophy and to pay for the implementation is a very important task. Although we were unable to conduct much research into this field it is important that a means of forcing or enticing private developers to adopt this idea be established.

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Appendix 1: Discharge Data

Quinsigamond Avenue Combined Sewer Overflow Treatment Facility Activation Frequency

1. August 14, 2005 through August 15, 2005, 6hr. 21min., 16.3MG, 1.17” rain
2. September 15, 2005, 2hr. 8min., 9.6 MG, .94” rain
3. September 17, 2005, 2hr.2min., 5.4 MG, .38” rain
4. September 29, 2005, 2hr. 10min., 4.9 MG, .48” rain
5. October 8, 2005 through October 11, 2005, 37hr.8min., 112.1 MG, 6.58” rain
6. October 14, 2005 through October 17, 2005, 85hr.41min.,196.2 MG, 5.75” rain
7. October 23, 2005, 9hr.25min., 19.4 MG, 1.07” rain
8. October 25, 2005 through October 26, 2005, 33hr. 41min., 78.8 MG, 2.06” rain
9. November 10, 2005, 66min., 1 MG, .68” rain
10. November 16, 2005 through November 17, 2005, 6hr. 18 min., 7.9 MG, .92” rain
11. November 22, 2005, 14hr. 27min., 18.7 MG, 1.44” rain
12. November 30, 2005, 10hr. 3min., 6.8 MG, 1” rain
13. December 16, 2005, 7hr. 19min., 11.5 MG, 1.22” rain
14. December 26, 2005 through December 27, 2005, 16hr. 42min., 21.7 MG, 1.27” rain

Quinsigamond Avenue Combined Sewer Overflow Treatment Facility
Activation Frequency

1. January 12, 2006, 4 hr.7 min., 3.4 MG, 0.66” rain
2. January 15, 2006, 5 hr.50 min., 2.9 MG, 0.86” rain
3. January 18, 2006, 11 hr.26 min., 31.5 MG, 1.22” rain
4. January 29, 2006, 1 hr 43 min, 1.9 MG, 0.50” rain
5. February 3, 2006, 6 hr 4 min., 6.6 MG, 0.61” rain
6. February 4, 2006, 21 hr 32 min., 34.2 MG, 0 .79” rain
7. April 4, 2006, 5 hr 47 min., 5.4 MG, 0.89” rain
8. May 12, 2006 through May 17, 2006, 56 hr 46 min., 68.1 MG, 4.26” rain
9. May 19, 2006, 4 hr 23 min., 3.3 MG, 0.45” rain
10. June 3, 2006 through June 4, 2006, 25 hr 38 min., 37.6 MG, 2.15” rain
11. June 7, 2006 through June 10, 2006, 57 hr 25 min., 45.2 MG, 2.19” rain
12. June 25, 2006, 2 hr 26 min., 3.6 MG, 0.92” rain
13. July 19, 2006, 2 hr 39 min., 3.3 MG, 0.44” rain
14. July 22, 2006 through July 23, 2006, 7 hr 21 min., 13.5 MG, 1.22” rain
15. July 28, 2006, 3 hr 32 min., 2.4 MG, 0.31” rain
16. August 15, 2006, 2 hr 11 min., 1.6 MG, 1.02” rain
17. August 20, 2006, 6 hr 57 min., 7.3 MG, 0.90” rain
18. August 27, 2006, 8 hr 47 min., 2.5 MG, 0.96” rain

Quinsigamond Avenue Combined Sewer Overflow Treatment Facility
Activation Frequency

19. September 3, 2006, 36 min., .1 MG 1.25” rain

20. October 12, 2006, 3 hr 10 min., 6.5 MG, 0.96” rain

21. October 28, 2006, 10 hr 45 min., 33.7 MG, 2.62” rain

22. November 8, 2006, 9 hr 29 min., 16.4 MG, 1.83” rain

23. November 11, 2006, 3 hr 51 min., 5.2 MG, 0.98” rain

24. November 17, 2006, 11 hr 49 min., 18.6 MG, 1.64”

25. November 23, 2006 through November 24, 2006, 13 hr 56 min., 31.4 MG, 1.7” rain

26. December 1, 2006 through December 2, 2006, 3 hr 58 min., 6.6 MG, 0.73” rain