Innovations for LEAP GI

Green Infrastructure Analysis, Design and Application in Detroit's Lower Eastside

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A report prepared for the Lower Eastside Action Plan
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Abstract

This project combined social science knowledge of landscape cues to care and perceived safety with hydrologic modeling through GIS to design, site, and analyze the stormwater performance of green infrastructure best management practices (BMPs) for urban stormwater in Detroit. The main impetus behind this project is that Detroit suffers from frequent combined sewer overflow (CSO) events. It also has a high proportion of abandoned property and vacant land, where structures have been demolished, and there are many ongoing housing demolitions. Working closely with leaders of the Lower East Side Action Plan for Detroit, we designed novel BMPs to use the extensive vacant land as well as ongoing demolitions as part of green infrastructure. These BMPs also incorporated non-stormwater benefits; enhancing perceptions of personal safety and amenity landscape character in the most vacant neighborhoods of Detroit. We designed green infrastructure innovations to optimize "within block" infiltration, evapotranspiration, detention, and retention, anticipate transport of urban contaminants, minimize costs, and plan for long-term maintenance of the installations. We then conducted a spatial analysis to identify the location and capacity for runoff retention and CSO volume reduction for stormwater treatment of these BMPs throughout the city. The hydrologic model developed in this project analyzed the stormwater holding capacity of the BMPs by segmenting the study area into catchments, comparing the runoff for the catchments under multiple storm and surface imperviousness scenarios, and compared the original untreated runoff and final treated runoff volume estimates. Finally, we developed specific applications of these BMP's for two actionable future redevelopment projects as proof-of-concept sites within the Lower Eastside of Detroit. The model demonstrated significant reductions in runoff for 2-year, 10-year, and 100-year storm events. However, BMPs were only sited in half of the catchments in the study area, resulting in both an unmet need for stormwater runoff reduction in some locations and excess runoff holding capacity in others. Therefore, the project provides an important stepping stone for future collaboration between LEAP and SNRE to consider the possibilities for improved networking and flow connections for stormwater within the district and the city.

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I. Introduction

Green Infrastructure in Legacy Cities

The City of Detroit has come to exemplify the problems of American post-industrial decline: like many other Midwestern rust-belt cities, this manufacturing town grew quickly with the rise of its commercial focus, the automobile, developing into an extensive city of low-density single-family housing. Declining industrialization, manufacturing job loss, and the departure of much of the middle class population to the suburbs beginning in the 1950s has led to widespread property abandonment and neighborhood divestiture. From its peak in 1950 of 1,850,000 people, the population of Detroit has dwindled to 713,800 in 2010, a 61% reduction in residents over the past 60 years (Dewar & Morrison, 2012). Within the city, some Lower East Side neighborhoods are highly vacant, with over 10,000 vacant lots and structures and 44% population decline on the Lower East Side since 2000 (LEAP, 2012a).

Compounding the problems caused by the shrinking population of Detroit are the realities faced by the people who remain in the city. As wealthier residents moved to the surrounding suburbs, the city population became proportionately poorer. Additionally, as a result of the decreased tax base and limited budget, the city can no longer afford to provide all infrastructural services to all residents of Detroit. A critical consideration in the future landscape and planning strategies of Detroit is acceptance that the jobs that supported economic and population growth will not be returned to the city in the foreseeable future, and that redevelopment of Detroit must proceed without rebuilding (Dewar & Morrison, 2012).

The concept of "right-sizing" has emerged as an alternative to popular Smart Growth urban design that encourages the sustainable management of urban growth through compact development, walkability, mixed land use, energy-efficient transportation, and urban green space (Jabareen, 2006). Pallagst (2007) criticizes the applicability of Smart Growth strategies to legacy cities that are experiencing population decline and widespread vacancy, and considers the importance of addressing shrinkage on a regional scale by comparing right-sizing strategies in Youngstown, Pittsburgh, and San Diego that incorporate the broader perspectives of multiple stakeholders, actors, and agencies. Schilling and Logan (2008) argue that right-sizing initiatives must also address the threat to public safety caused by abandoned buildings by stabilizing dysfunctional markets and distressed neighborhoods with extensive property abandonment to prevent the spread of vacancy and blight.

Problem Statement: Green Infrastructure Potential

Stormwater from impervious surfaces and compacted or clay soils places burdens on the aging combined sanitary and stormwater sewer infrastructure of Detroit. The concentrated volume of stormwater runoff contributes to combined sewer overflow (CSO) events, and the runoff itself is likely to contain oil and grease products, bacterial pathogens, heavy metals, salts, nutrients and sediment (Hill, 2009). Leaking sanitary sewer, drinking water distribution systems, and industrial wastewater contribute to dry weather discharge from an estimated 25 percent of stormwater outfalls, and up to 10 percent of all outfalls may be grossly contaminated with sewage in the US. Dry weather flow may contribute significant pollution to receiving streams on an annual basis despite low flow rates due to the long duration of these flows (NRC, 2009).

"Green infrastructure" is a relatively new and flexible term that refers to systems designed to manage stormwater that use or mimic a site's natural hydrologic processes as an alternative to piped stormwater sewer infrastructure (EPA, 2012b). Green infrastructure employs distributed source controls that incorporate vegetation, soils, and other natural processes to mitigate stormwater runoff before it reaches piped infrastructure systems and provide treatment to the associated pollutants (NRC, 2009). The green infrastructure innovations proposed and modeled in this project are intended to reduce local contribution to combined sewer overflows, to increase neighborhood landscape quality and contribute to quality of life, and to supplement existing aging infrastructure within the Lower Eastside neighborhoods of Detroit. Stormwater management strategies will complement the evolving Community Development Advocates of Detroit (CDAD) grassroots framework for the redevelopment of the city by aligning green infrastructure innovations with expectations for neighborhood density and character established through the CDAD participatory community planning process.

The functional goals of the green infrastructure innovations proposed by this project are to maximize "within block" infiltration, evapotranspiration, detention, and retention of stormwater, anticipate and plan for fate and transport of urban contaminants in the green infrastructure system, and minimize costs and anticipate means of long-term maintenance for stormwater management within green infrastructure installations. In addition, green infrastructure innovations will be designed to use planned capital investments to efficiently realize green infrastructure benefits and to choose green infrastructure approaches that are cost-efficient for the long term.
Integral to the development of the green infrastructure innovations modeled throughout the LEAP district are two proof-of-concept sites. The sites were selected to align with actionable projects. The first proof-of-concept site is the Mack Avenue Green Thoroughfare Project, located along Mack Avenue between Conner Avenue and Chalmers Street. The conversion of this inactive commercial

corridor to a green thoroughfare includes expediting demolition of abandoned buildings, planting low-maintenance vegetation on vacant lots, providing signage for wayfinding, and identifying a process to help the local businesses in operation on Mack Avenue to relocate to a more dense area of the corridor. As a prototype for Mack Avenue, this project considers a four-block section of the green thoroughfare from Conner Avenue to Dickerson. The second proof of concept site is part of the Hantz Woodlands Commercial Farm, located on parcels bounded by Burns St. to the west, Crane St. to the east, St. Paul St. to the north and East Jefferson Ave. to the south. This project proposes scenarios for the organization and aesthetic features of stormwater management woodlands under varying levels of occupancy within the site.

Non-stormwater benefits of green infrastructure are a crucial component to the strategies proposed in this project. Green infrastructure blocks will incorporate landscape "cues to care" to enhance perceptions of good care, personal safety, amenity landscape character, and neighborhood signature identity of green infrastructure blocks (Nassauer, 1995, 1997, 2011; Nassauer et al., 2009). Additionally, the project will build in the co-benefits of urban traffic calming, enhanced carbon storage for greenhouse gas mitigation, and stormwater storage for climate change adaptation.

Hoornbeek and Schwarz (2009) find that it is both difficult and expensive to reconfigure some types of the existing physical infrastructure. Infrastructure that operates on a fixed grid, including water lines, sewers, roads, and power lines, may need to extend through depopulated areas in order to reach viable neighborhoods. This is particularly true of the sewer and water infrastructure in Detroit, where combined sanitary sewer lines extend into other jurisdictions (DWSD, 2012). Infrastructure redundancy can be a back-up system in old infrastructural networks, allowing for the system to continue providing services to residents when failure occurs, for example, if water and sewer lines break or pumping stations come offline for maintenance. Local governments and utilities must also consider the high capital costs of removing physical infrastructure and the potential for existing infrastructure to provide flexibility and surplus capacity in the future as the legacy city is reconfigured (Hoornbeek and Schwarz 2009). Considering the importance of redundancy and reducing costs related to aging infrastructure, Hoornbeek and Schwarz argue for stormwater retention to supplement sewer infrastructure in order to reduce surface runoff, flooding, and erosion and potentially to offset both future stormwater management costs and regulatory requirements.

A number of recent studies have adopted green infrastructure as a key idea for the future form of legacy cities. Schilling (2009) argues for the potential of green infrastructure to not only improve water quality but also address the blight caused by vacant and abandoned properties when utilized in conjunction with land-banking and community driven planning. Schwarz (2012) explores green infrastructure as a holding strategy for future redevelopment of vacant land in Cleveland. A 2008 report by Nassauer et al. for Flint, Michigan proposed a long-term pattern for enhancing ecosystem services including water resources, amenity characteristics, and biodiversity potential as the number of vacant properties within Flint increases. The authors advance citizen engagement and perceptions of landscape care through maintenance as the first steps to develop a sense of ownership for neighborhood landscapes and green infrastructure in future land use patterns (Nassauer et al, 2008).

To develop green infrastructure typologies relevant to legacy cities, we conducted a literature review to explore the function and efficiency of current stormwater source control strategies, the role of landscape perception and safety in green infrastructure, and the potential for green infrastructure to contribute to climate change adaptations and other ecosystem services within the LEAP study area.

CDAD Typologies

Our team responded to the CDAD land use typologies by identifying relationships between our green infrastructure innovations and the future neighborhood occupancy conditions identified for the LEAP study area. The Community Development Advocates of Detroit is a trade association for nonprofit community-based development corporations in Detroit. CDAD proposes a new strategy for Detroit neighborhoods to address the social, economic, and environmental problems that have led to the city's decline through data-driven indicators of change, participatory neighborhood planning, and flexible, results-oriented plans (CDAD, 2012).

The Neighborhood Revitalization Strategic Framework was developed through the CDAD Futures Task Force to provide a communicative tool for community residents, businesses, and institutions to participate authentically in shaping the future of their neighborhoods. This framework describes distinct land use types to suggest how resources may be most effectively invested in different neighborhood conditions (CDAD 2012). These eleven types suggest conventional urban forms such as Traditional Residential and City Hub, as well as innovative forms that respond to the low-density conditions of many of Detroit's neighborhoods, including Green Venture, Urban Homestead, and Naturescape. The flexible, neighborhood-oriented nature of this framework encourages shared vision and grassroots revitalization of the city, and may be a model for neighborhoods in other legacy cities (Jones et al., 2012).

The green infrastructure innovations that we propose are located according to the area of vacant land available, the likelihood that building demolitions will occur in the near future, and also whether green infrastructure is located in the Naturescape type, as designated by the CDAD typology. Perceived safety and neighborhood landscape amenity character have been considered in the GI designs as well.

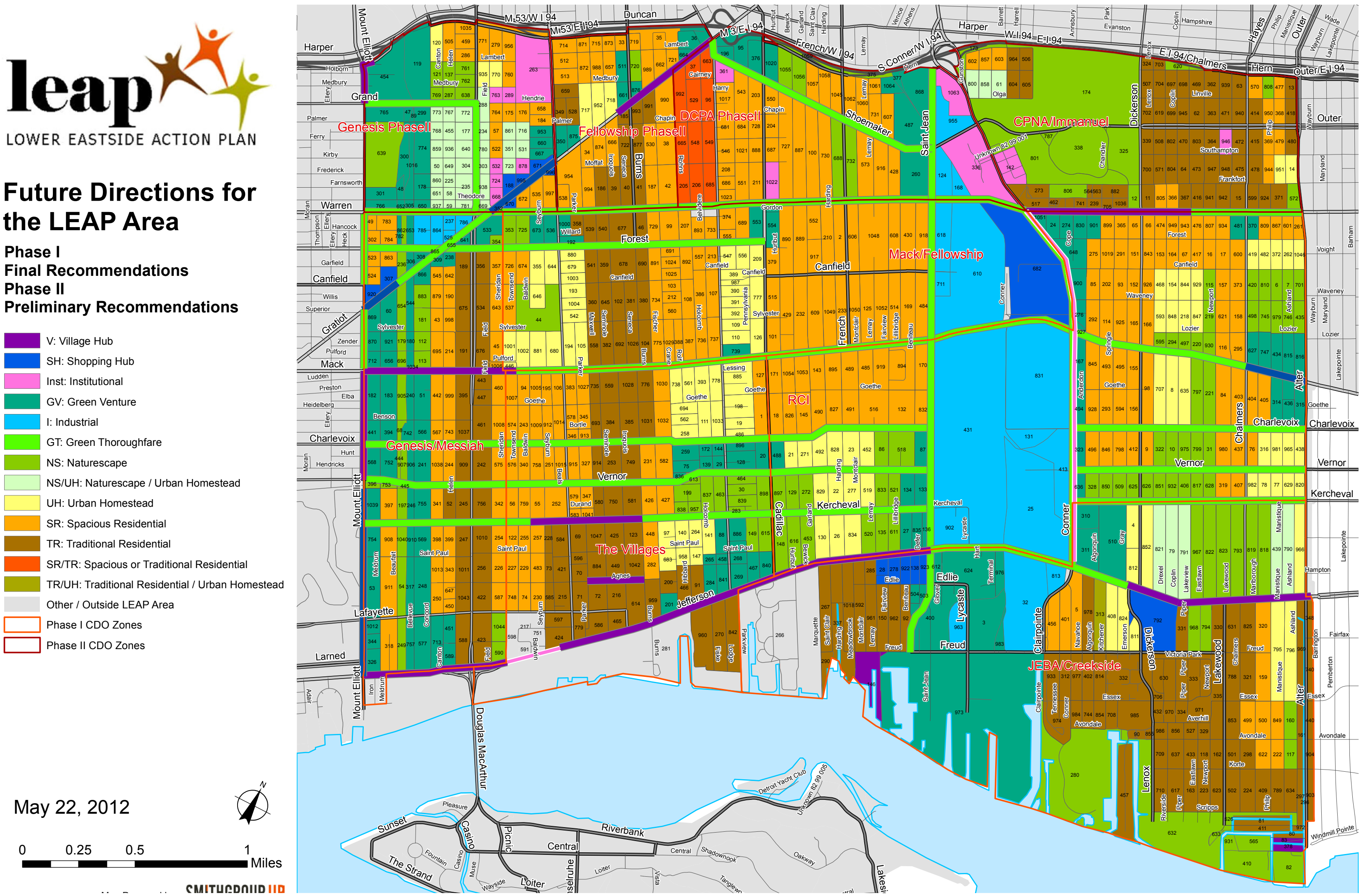

Figure I-1. LEAP Future Directions Plan. Graphic from the Summary Report of the Lower Eastside Action Plan.

Lower Eastside Action Plan (LEAP)

On the Lower East Side, grassroots community development corporations (CDCs) formed a successful community-driven project, the Lower East Side Action Plan (LEAP), with the aim to "engage people in a process to transform vacant land and property into uses that improve the quality of life in local neighborhoods and surrounding areas" (LEAP, 2013). LEAP works to improve community conditions in the Lower East Side by generating plans that address the vacant land problem, creating strategies that adapt vacant land for more efficient uses, recommending reasonable uses for vacant land based on neighborhood needs and surrounding conditions, and affecting policy changes to support vacant land adaptation (LEAP, 2012a).

This project provides analysis and recommendations that apply to both LEAP Phase I and Phase II study areas, encompassing an area of approximately 25 square miles, from Mount Elliot at its west boundary to Alter on the east, and from its south boundary at the Detroit River to I-94 at the north.

Through an iterative process incorporating both community insight and spatial analysis of mapped information, LEAP developed Future Directions Typologies that identify the location of CDAD typologies across Phase I and Phase II study areas. JJR, the landscape architecture Metropolitan Studio, and additional graduate students from the University of Michigan's School of Natural Resources and Environment focused on determining the suitability of Spacious Residential, Urban Homestead, Green Venture Zone, and Naturescape typologies within the district. Suitability maps were then integrated with Stakeholder Advisory Group (SAG) recommendations developed through extensive community outreach to develop Future Directions recommendations for the study areas (LEAP, 2012a, 2012b).

Development of green infrastructure innovations and integration of these innovations in proof-of-concept sites draws on the LEAP Future Directions recommendations and actionable projects developed for the study area. Specifically, green infrastructure innovations were designed to respond to areas of vacancy and the condition of building stock within the study area.

Soils and Geomorphology

The selection of appropriate stormwater source controls within Detroit is heavily dependent on soil characteristics and geomorphology. The City of Detroit is located within an extensive area of lacustrine geologic material consisting of intermixed clay and silt depositions and sand and gravel depositions, resulting from lake sediment laid during higher Lake Huron water levels. The majority of the LEAP study area is within an area of lacustrine clay and silt. The primary soil association within the LEAP district is Thetford-Granby-Tedrow association, described as a nearly level, very poorly drained to somewhat poorly drained soil with a coarse textured subsoil (Larson, 1977). On the northeast side of the study area lies an end moraine of fine-textured till resulting from the retreat of the Port Huron glacial lobe (Farrand & MDEQ, 1982). Groundwater is located within these layers of silts and clays in small, disconnected aquifers. Deep aquifer contamination vulnerability for this region is considered low. Non-soluble bedrock is located less than 50 feet from the surface, and soils are classified as moderately to slowly permeable over the least sensitive drift lithology (Lusch et al., 1992). Because of the shallow surface slopes and near surface bedrock within the area, groundwater is relatively close to the surface. The study area rises less than 30 feet in elevation above the level of Lake St. Clair (578 feet above sea level) which can be considered a minimum elevation for groundwater within the area. Groundwater mapping of the study area indicates that groundwater is shallow - generally located between 580 and 610 feet above sea level – approximately 10-40 feet below grade (MDEQ, 2005).

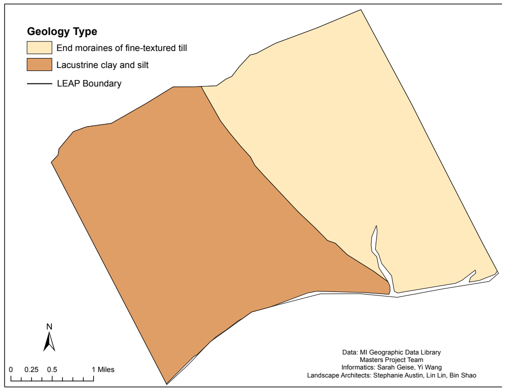

Figure I-2. Quaternary geology of Michigan.

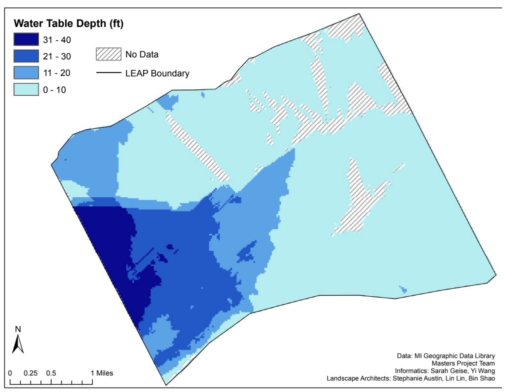

Figure I-3. Depth to water table.

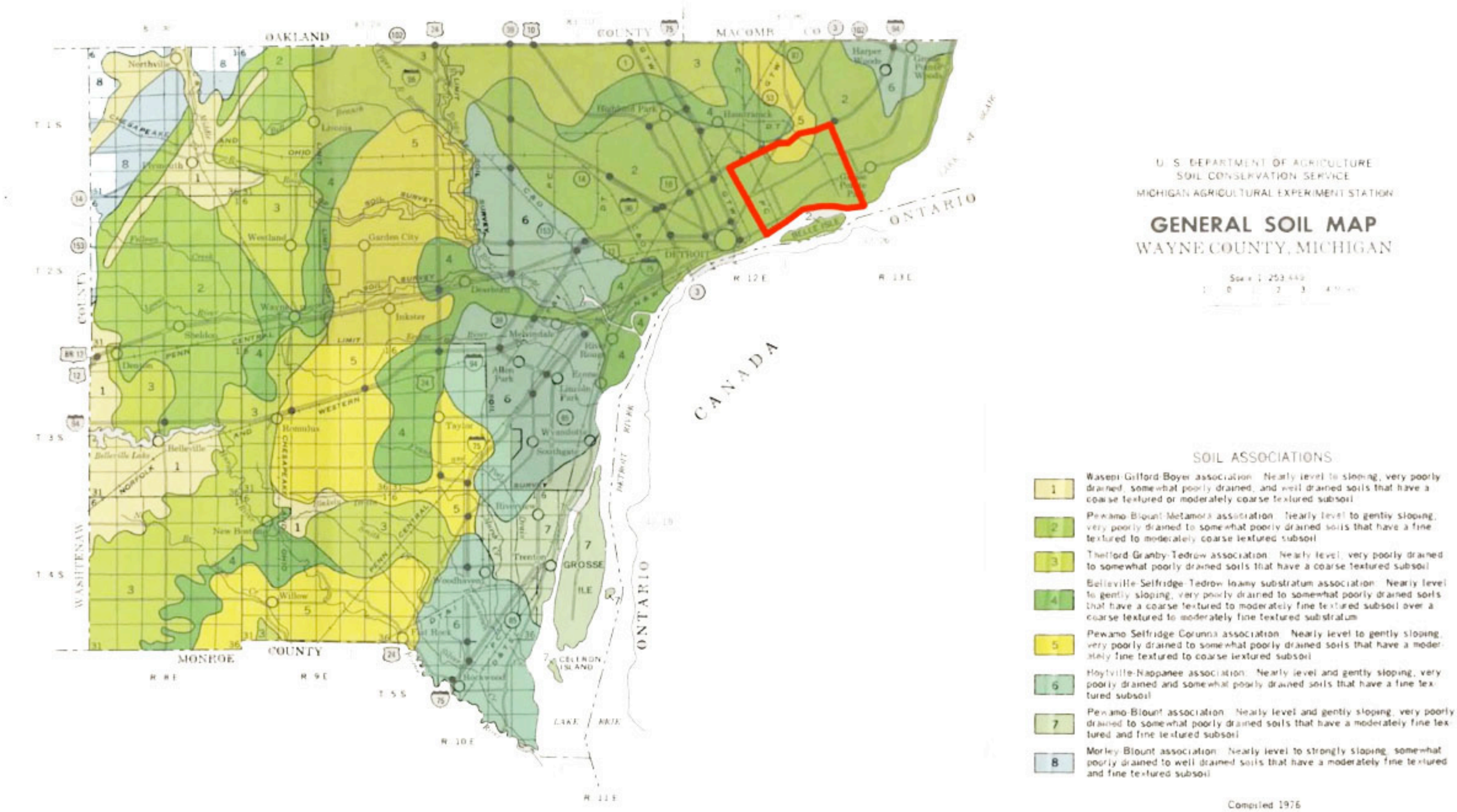

Figure I-4. Wayne County soils map indicating Thetford-Granby-Tedrow association as primary soil type for the LEAP district. Image from Larson, 1977.

Stormwater Conditions and Regulations

The City of Detroit's stormwater infrastructure is primarily a combined system, managing both stormwater and sanitary sewer through a shared infrastructure (DSWD 2012). As a municipal separate storm sewer system (MS4), the city is regulated by the National Pollution Discharge Elimination System (NPDES), a federal program designed to track point sources and minimize the discharge of pollutants ("Clean Water Act of 1972," 2002) to limit its discharge of combined sewage at permitted locations along the Detroit and Rouge Rivers when the transport and treatment capacity of the collection system and wastewater plant is exceeded (NPDES, 2011). The discharge of sewage at these locations is termed a combined sewer overflow (CSO) event. As of October 2012, there have been 25 CSO events in the year 2012. There were 42 CSO events in 2011, and 36 CSO events in 2010 (State of Michigan, 2012). In 2009 the total CSO quantity was 32 billion gallons, which included both untreated and partially treated sewage (Alliance for the Great Lakes, 2012).

Despite the occurrence of CSO events, Detroit's 2011 Stormwater Management Program Plan (SWMPP) states that "water quality of the Detroit River during dry weather periods is typically excellent, with dissolved oxygen levels consistently exceeding the state water quality standard of 7.0 mg/l." The SWMPP acknowledges that the Detroit River receives large volumes of treated and untreated combined sewage overflows during wet weather events. During and after these wet weather periods, CSO discharges exceed water quality standards for bacteria (E. coli). Concentrations of other pollutants including nutrients, oil and grease, chloride and ammonia are also detected in the Detroit River. In addition, more concentrated amounts of toxic organics and heavy metals are present in sediment deposits at various locations along the river. Bioaccumulative pollutants including mercury, PCBs, and dioxin are continued water quality concerns in the river due to their potential uptake by biota and eventual accumulation in fish and other aquatic wildlife (City of Detroit, 2011).

The Michigan Department of Environmental Quality (MDEQ) has designated the Detroit River as a water body that is not likely to attain water quality standards with available treatment technologies for several parameters. It is for this reason that Total Maximum Daily Load (TMDL) standards have been issued for pathogens, and studies have been required for PCB, DDT, dioxins, and mercury (City of Detroit, 2011). CSO events are considered to be the primary source of the elevated bacteria levels observed during and after rain events, and for which the TMDL standard has been issued (City of Detroit, 2011). In addition to CSO events, water quality in the Detroit River is potentially impacted by industrial and municipal wastewater discharges, pollutants from upstream sources, including discharges into Lake St. Clair, releases from contaminated sediments, and ballast water discharge from commercial vessels.

The Detroit River has been identified as a binational Area of Concern (AOC) through the U.S.-Canada Great Lakes Water Quality Agreement. As an AOC, the water quality of the river is monitored by the International Joint Commission. Due to current and historic pollution affecting water quality in the Detroit River, eleven Beneficial Use Impairments (BUIs) out of fourteen possible impairments have been identified in the River (EPA, 2012a). Each BUI represents a negative change in the "chemical, physical, or biological integrity of the river sufficient to cause any of the 14 use impairments" (International Joint Commission, 2011). The BUIs identified for the Detroit River include:

- Restrictions on fish and wildlife consumption
- Tainting of fish and wildlife consumption
- Restrictions on drinking water consumption, or taste and odor
- Degradation of fish and wildlife populations
- Beach closings
- Fish tumors or other deformities
- Degradation of aesthetics
- Bird or animal deformities or reproduction problems
- Degradation of benthos
- Restriction on dredging activities
- Loss of fish and wildlife habitat

The EPA identifies stormwater runoff and tributaries as major sources of the contamination impairing the Detroit River. Approximately 75 percent of the total land area of the watershed is located in Michigan, including the entire "sewershed" of the City of Detroit (EPA, 2012a). Improvements made to the stormwater system, including green infrastructure within the City of Detroit, could help to improve the water quality of the river. According to the USEPA, actions that would result in water quality improvements for the Detroit River AOC include "control of combined sewer overflows, control of sanitary sewer overflows, point and nonpoint source pollution controls, remediation of contaminated sediments, habitat restoration, and pollution prevention" (EPA, 2012a).

II. Literature Review

Green Infrastructure

"Green infrastructure" refers to systems designed to manage stormwater that use or mimic a site's natural hydrologic processes as an alternative to piped stormwater sewer infrastructure (EPA, 2012b). Efficient piped stormwater sewer infrastructure has been linked to the water quality and quantity problems associated with urban stream syndrome. Urban stream syndrome is characterized by high peak runoff from stormwater events (more frequent, larger storm flows), elevated concentrations of nutrients and contaminants, altered stream channels, and reduced biotic richness, with increased dominance of tolerant species. Combined sewer overflows, wastewater treatment plant outflows, and legacy pollutants also contribute to the degradation of urban streams (Walsh et al., 2005).

Green infrastructure employs distributed source controls that incorporate vegetation, soils, and other natural processes to mitigate stormwater runoff quantity and quality before it reaches piped infrastructure systems and provide treatment to the associated pollutants (NRC, 2009). The effectiveness of this decentralized system depends on the cumulative effects of source control measures across an entire watershed (City of New York, 2008).

Our project focuses primarily on land-based source controls that utilize detention, retention, and bioretention/bioinfiltration. The high availability of vacant land in Detroit allows for extensive use of land-based source controls. However, poorly drained soils throughout the study area limit the applicability of some infiltration source control techniques. Our project combines retention, detention, and small infiltration source controls to improve water quality and slow the introduction of water to the sewer system and reduce high flows during storm events. The following sections are an overview of the all the different types of source controls that can be combined in green infrastructure. Only some of these are broadly appropriate to the LEAP area.

Bioretention and Bioinfiltration

Vegetated source controls including bioinfiltration and bioretention use vegetation for infiltration and evapotranspiration to reduce the volume of runoff. The National Research Council indicates that source controls that infiltrate stormwater runoff promote groundwater recharge and stream base flows (NRC, 2009). These controls are designed to capture the "first flush" rainfall (generally the first ½") as close to where the rain falls as possible, and are therefore ideal for the upper end of treatment trains and upland zones of a watershed (NRC, 2009). Some bioinfiltration controls that can be adapted to clay soils can be applied in the LEAP study area. Bioinfiltration and bioretention provide a number of additional benefits beyond runoff reduction to both stormwater conditions and the surrounding area, including water quality improvement by reducing streambank erosion, capturing suspended solids, and removing some pollutants through filtration into the soil.

Stormwater retention techniques remove water from the stormwater infrastructure system for use or infiltration on-site. These strategies help to improve water quality by reducing the volume and frequency of flows that cause extensive physical disturbance to receiving waters. Retention strategies that allow for infiltration of stormwater into the soil also can provide some treatment benefits to polluted runoff (City of New York, 2008). Retention strategies may be vegetated or non-vegetated.

Variations

Vegetated controls include bioswales, bioretention, rain gardens, green roofs, Green Streets, and bioinfiltration. All of these source controls function by capturing water in a vegetated area and allowing the water to infiltrate over the first 24-72 hours following a storm event. Soils within these source controls may be amended to maximize the volume of water that can be held in the soil; vegetated controls may also be sited in sandy soils to promote infiltration (NRC, 2009).

Vegetated source controls vary in their designs and functions. Swales were originally designed to convey drainage from the sides of roads, and now may also incorporate increased contact time with runoff to remove pollutants and allow water to infiltrate. Both bioretention and bioinfiltration controls direct water into a sand filter or other storage area beneath the vegetated layer, or may be designed for the infiltration of water into the soil below (NRC, 2009).

Raingardens are typically incorporated into urban and suburban sites to slow down stormwater to infiltrate or be detained in soils rather than piped through sewer infrastructure to area lakes and streams. Nassauer et al. (1997) designed rainwater gardens to function as a network that retrofit residential streets in Maplewood, Minnesota that were experiencing periodic flooding. These garden amenities not only contributed to stormwater management and urban biodiversity through native plantings, but also provided a unified appearance for the neighborhood through gardens lining the streets and stone walls as a signature entrance to neighborhoods. In addition, rainwater gardens for the two-block demonstration area cost $138,000 compared to conventional street repaving and stormwater infrastructure replacement estimated at $151,000 (Nassauer et al., 1997).

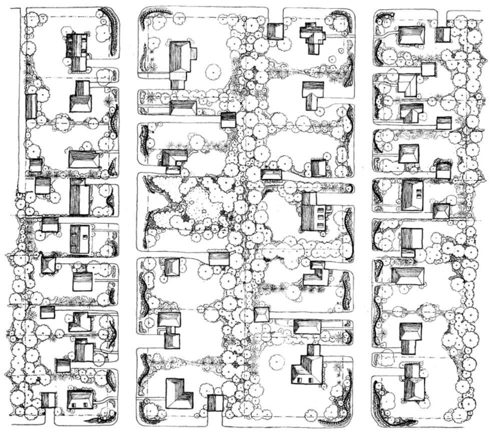

Figure II-1. Maplewood, MN neighborhood garden amenity plan. The plan highlights design unity, neighborhood signature entries, ecological nodes, connectivity, and neatness. Figure with permission from Nassauer et al., 1997.

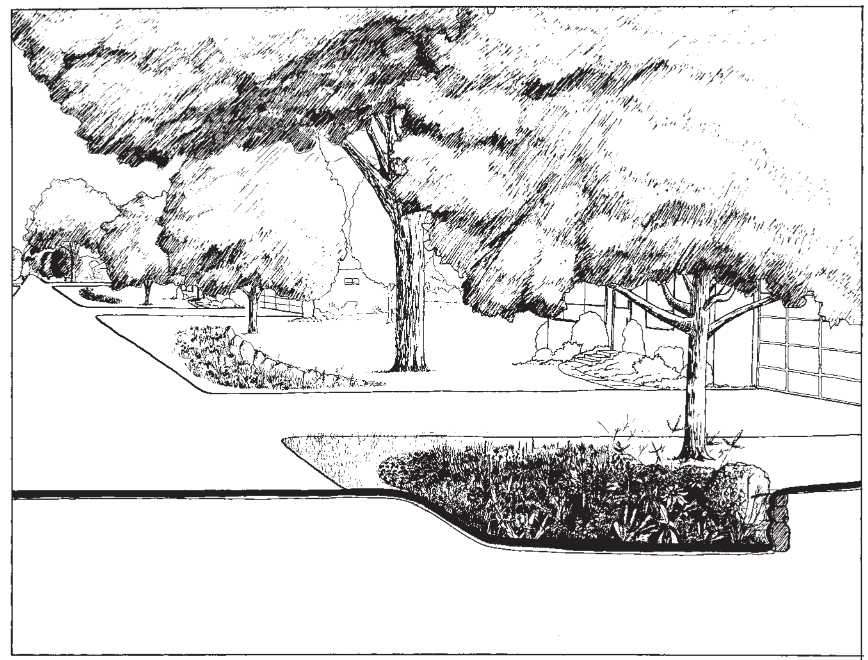

Figure II-2. Raingardens in a residential street right-of-way in Maplewood, MN. Figure with permission from Nassauer et al., 1997.

Stormwater Performance

Based on studies from both North America and Australia, the National Research Council (2009) reports that runoff volume reduction from vegetated source controls ranges from 20 to 99 percent A significant advantage of bioinfiltration is the flexibility of these systems to incorporate treatment. Though pollutant removal for vegetated storm controls varies by each source control, pollutant type, and soil type, vegetated controls generally capture sediment and suspended solids. The ability of these controls to trap sediment is significant in reducing pollutants that bind to sediment particles (NRC, 2009). Several recent studies indicate that metals, particulate nutrients, and carbon are also captured in the soil of vegetated source controls. Oil, grease, and ammonia are also captured by the organic layer. Other pollutants pass through the soil column, including nitrate and chlorides, though extended water retention within the soil may produce anaerobic conditions capable of inducing denitrification (NRC, 2009; Li and Davis, 2009).Overall, fate and transport of contaminants through vegetated source controls raises critical questions of long-term maintenance and monitoring of contaminant transport and accumulation.

Limitations

Bioinfiltration installation locations may be constrained by bedrock, high water table, soil contamination, and low soil percolation rates (City of New York, 2008). In general, the ability of vegetated controls to infiltrate stormwater and promote groundwater recharge is beneficial, particularly in areas of high impervious cover. However, these systems are vulnerable to toxic spills and other high pollutant concentrations that may pass through the soil column, and therefore additional consideration of contaminant fate and transport must be taken in locations where source controls may pollute the groundwater supply or downstream surface waters (NRC, 2009).

Maintenance

Maintenance of vegetated source controls is critical to both the long-term and short-term performance of these systems. According to the 2009 National Research Council report, failures of bioretention and bioinfiltration systems generally occur early in the life of the system and are commonly linked to sedimentation and reductions in infiltration capacity due to stripping of the topsoil or subsurface compaction. Vegetated cover within the contributing area reduces the likelihood of failure due to sedimentation. Further maintenance includes regular inspection for plant health and sediment buildup. Organic matter may need to be monitored and periodically removed to ensure infiltration and prevent pollutant and nutrient buildup (NRC, 2009).

Costs

Estimated costs for vegetated source controls vary according to type, design depth, and use of other constructed elements including grates, fences, and retaining walls. Construction costs generally include labor, demolition, soil preparation, grading, drains and overflows, and landscaping. Estimated costs over 20 to 40 years, including land costs, within the City of New York, where land costs are dramatically higher than in Detroit, range from relatively inexpensive installations such as sidewalk bioinfiltration and swales, at approximately $0.23 per gallon per year for sidewalk bioinfiltration and $0.31 per gallon per year for swales, to more expensive green streets and green roofs, which cost $0.53 per gallon per year and $3.33 per gallon per year, respectively (City of New York, 2008).

Non-Stormwater Benefits

In addition to stormwater management, bioinfiltration and bioretention source controls have the potential to provide numerous non-stormwater benefits to area residents and visitors, depending upon how they are designed. These benefits include improvements in air quality, increase in animal habitat, reduced energy demand, carbon sequestration and mitigation of greenhouse gas emissions, neighborhood beautification, and development of new local markets (City of New York, 2008).

Application to LEAP District

We anticipate that the lower cost of land in Detroit and the availability of vacant land and future demolitions will make land-based source controls a more cost effective solution for the LEAP study area. Cost estimations for source control installation have typically been calculated for high-density cities, such as New York, and include capital costs based on high land values. Additionally, the larger amount of available contiguous space will result in more stormwater control installations that will be effective in controlling larger quantities of stormwater runoff. Cost efficiency of source controls decreases with available space. Source controls that depend more on structural installations than land availability, such as Green Streets or green roofs, (City of New York, 2008), have more limited applicability, being relevant only to those CDAD typologies that promote higher density population or street redesign.

We anticipate that the low rate of infiltration for the predominantly clayey soils within the study area will deter groundwater contamination, despite the close proximity of the groundwater to the surface. The prevalence of clay/ silt soils in the study area also implies that retention strategies that do not rely on infiltration into the soil will be more effective in the LEAP District.

Rooftop Detention

Green roofs and blue roofs slow the time of concentration of the stormwater runoff to receiving streams by detaining the water on building rooftops. Blue roofs allow water to pond on the rooftop through the use of a flow restriction device around drains; overflow enters stormwater infrastructure by flowing over the collar of the roof drain. Green roofs store and treat this water through the use of plants adapted to both wet and dry conditions, such as sedum and other hardy succulents. In contrast to blue roofs, green roofs also provide some evapotranspiration and filtration through the growing medium (City of New York, 2008).

Stormwater Performance

Blue roofs have an estimated rooftop flow reduction of up to 85 percent compared to conventional roof drains. Though performance of green roofs depends on the growing medium, roof slope, and vegetation, runoff reduction ranges on average from 50 to 70 percent of total rainfall volume (City of New York, 2008). Water quality effects of green roofs are also variable with the age, maintenance, and growing medium, however, total pollutant loads from green roofs average less than pollutant loads from conventional roofs due to runoff retention (Rowe, 2011).

Limitations

Blue roof and green roof application is limited to buildings with flat, watertight roofs and sufficient load-bearing capacity to support the weight of water, growing medium, and plants. These roof alterations are most appropriate and cost-efficient on large commercial, multi-family residential, industrial, and institutional buildings, and are poorly suited to low-density land use (City of New York, 2008).

Costs

The primary costs associated with blue roofs are labor, flow restriction collars, and waterproof membrane; blue roofs cost $0.32 per gallon annually over 20 years. The costs for green roofs vary widely, but average $3.33 per gallon annually over 40 years. In addition to plants, growing medium, and waterproofing, green roofs take on additional costs due to potential structural and other repairs (City of New York, 2008).

Non-Stormwater Benefits

A 2011 survey by Rowe of green roof research considered the potential for green roofs to contribute to improvements in air quality, carbon sequestration, mitigation of urban heat island effect, reducing roof material input into landfills, and noise reduction. This survey indicates that green roofs play a supplemental role in reducing airborne pollutants and reducing building heating and cooling loads, with a potential reduction of 2% in electricity consumption and 9-11% reduction in natural gas per building with a green roof per year (Rowe, 2011).

Application to LEAP District

In high density areas with new development, green roofs and blue roofs are a relatively affordable source control (City of New York, 2008). However, the high incidence of vacancy in the LEAP area, as well as the high occurrence of pitched roofs on existing residential structures, which are inappropriate for green roof and blue roof construction, limits the applicability of these controls in the study area.

Filters

Small-scale stormwater controls such as sand filters, hydrodynamic devices, and small areas of bioinfiltration focus primarily on water quality treatment, and may be used in conjunction with other stormwater control measures to remove suspended sediments and pollutants from water entering other retention or infiltration systems and extend the longevity of these devices (NRC, 2009). The compact size of many filters makes these strategies advantageous for urban areas with space constraints (Hatt et al., 2007). Runoff treatment controls are excellent for retrofit situations, and may be included in the design of existing infrastructure or under parking lots (NRC, 2009).

Filters use sand, peat, or compost to remove sediment and pollutants from runoff. Sand filters are effective in removing suspended solids and ammonia nitrogen. Organic material such as peat or compost absorbs contaminants including metals and hydrocarbons. Hydrodynamic devices separate solids from runoff through rotational forces. In each of these devices, only small quantities of water are treated to improve water quality, while larger flows bypass the device and continue into other stormwater control measures or stormwater sewers (NRC, 2009).

Stormwater Performance

A comparison of six fine media filtration systems by Hatt et al. (2007) found that loads of total suspended solids, copper, lead, and zinc were all significantly reduced by all filter types. In general, sand filters performed better than soil-based media, where leaching or discharge of nitrogen is high. Capture of pollutants in the top 20% of the filter media suggests that the elevated discharge of nutrients from soil-based filters may be due to leaching of native material, not failure of the filter to capture incoming pollutants (Hatt et al., 2007).

Maintenance

The primary cause of hydraulic failure in filters tested by Hatt et al. (2007) was the formation of a clogging layer at the filter surface. The authors suggest that the top 2-5 cm of filter surface should be removed every 2 years. Removal of the top layer of the filter also helps to avoid excessive accumulation of heavy metals. However, this practice may limit the lifetime of the filter to approximately 10 years as lower pore spaces within the filter media become clogged (Hatt et al., 2007).

Non-Stormwater Benefits

Where filtration strategies incorporate vegetation, non-stormwater benefits of bioinfiltration, sometimes include improved air quality, potential habitat characteristics, reduced energy demand, increased carbon sequestration, and neighborhood beautification – depending upon their design (City of New York, 2008).

Application to LEAP District

Filtration source controls may be applied in the LEAP area to treat the first flush of rainwater from roadways and other polluted impervious surfaces.

Urban Forests

Urban forests contribute significantly to stormwater management by intercepting rainwater in the tree canopy and temporarily storing this water on the surface of leaves and branches (Xiao and MacPherson, 2003). Water within the tree canopy is either evaporated or retained temporarily, reducing the volume of peak runoff flows (Sanders, 1986).

Stormwater Performance

The capacity of an urban forest to intercept rainwater varies by tree size, tree architecture, and seasonal foliage variation (Xiao et al., 2000). A 2003 study of the Santa Monica, California urban forest by Xiao and MacPherson indicates that canopy interception of rainwater is greater for smaller rain events (1-year storms) than for rain flooding events (25-year storms).

Limitations

Urban forest canopy cover is limited by urban soil conditions, including compaction and elevated pH levels, which may cause urban reforestation efforts to be less effective at capturing rainfall (Xiao and MacPherson, 2003). However, water flow along tree trunks (stemflow) and preferential flow along roots may contribute to increased infiltration rates within compacted soils. In order to alter the drainage properties of urban soils, water penetration may require consistently moist soil and species tolerant to wet conditions (Bartens et al., 2008; Johnson and Lehmann, 2006).

Maintenance

Management of urban forests is dependent on clearly delineating the critical root zone, the area around a tree required for the tree's survival. Protecting this area from clearing and grading aids in preserving existing trees, and determining the zone for new plantings reduces the potential interference with sewer or septic lines. Trees selected for local conditions require less maintenance, and planting design should facilitate pick-up of litter (NPDES, 2012).

Costs

Numerous studies undertaken by the Center for Urban Forest Research have explored the costs and benefits of urban tree plantings, focusing on the potential for municipalities to gain a positive return on investment in urban forests through environmental, real estate, energy costs, and other benefits. MacPherson et al (2005) compare the costs and benefits of urban street trees in five western cities. Though variabilities in the costs and benefits of urban forests among these cities are high, the cities in the report returned benefits of $1.37 to $3.09 in energy savings, atmospheric carbon dioxide reductions, stormwater runoff reductions, air quality improvements, and aesthetics per dollar spent on trees annually.

Table 2. Annual benefits and costs for each city

Total benefits	Ft. Collins	Cheyenne	Bismarck	Berkeley	Glendale
Energy	112,025	186,967	84,348	553,061	116,735
CO_2	40,454	29,134	27,268	49,588	12,039
Air Quality	18,477	11,907	3,715	−20,635	32,571
Stormwater	403,597	55,297	496,227	215,648	37,298
Property increase	1,596,247	402,723	367,536	2,449,884	467,213
Total benefits	2,170,799	688,029	979,094	3,247,545	665,856
Total costs					
Planting	111,052	45,913	5,880	95,000	21,100
Pruning	405,344	84,677	94,850	770,000	88,412
Remove/dispose	130,487	23,337	50,061	70,000	12,710
Im/liter/gm waste	94,394	97,840	38,241	195,000	65,813
Infrastructure and liability	72,200	0	21,490	1,062,000	3,000
Amin/inspect/other	184,161	76,130	106,118	180,000	85,401
Total costs	997,638	327,897	316,640	2,372,000	276,436
Net benefits	1,173,161	358,133	662,454	875,545	389,421
BCRs	2.18	2.09	3.09	1.37	2.41

Table II-1. Comparison of costs from five cities, table from Macpherson et al., 2005.

Within the Midwest, MacPherson et al. (2011) estimate that a large tree will provide $3,790 in environmental, real estate, energy costs, and other benefits over its lifetime, a 250% return on investment. The Chicago Urban Forest Climate Project considered costs and benefits of 95,000 trees in Chicago over an estimated 30-year period. Planting costs were projected to be the greatest expenditure, and the largest benefits were associated with scenic, social, economic, and energy savings values, though air quality, temperature, and sequestration of carbon dioxide were also considered in the study. Cost-benefit ratios ranging from 1:2.1 for parks and 1: 3.5 for public housing and residential yards for an average of 1: 2.83, indicated that projected benefits are approximately 3 times the planting and maintenance costs (MacPherson et al., 1994). In addition to the non-stormwater benefits quantified through cost-benefit analysis of urban forests, climate change implications of urban forests are considered in the Ecosystem Services section of the literature review.

Non-Stormwater Benefits

In addition to the non-stormwater benefits quantified through cost-benefit analysis of urban forests, including energy savings, carbon dioxide sequestration, air quality improvement, and aesthetic benefits (MacPherson et al., 2005; MacPherson et al., 2011, MacPherson et al., 1994), climate change implications of urban forests are considered in the Ecosystem Services section of the literature review.

Application to LEAP District

As a highly effective land-based stormwater management technique, urban forests have excellent potential for application within the LEAP District. This project uses urban forests as part of a strategy to create green infrastructure wherever more than four vacant properties are adjacent to each other, and it demonstrates how this strategy can be used in a proof-of concept for an extensive commercial tree farm, stacking multiple ecosystem services into an urban forest.

Subsurface Controls for Retention and Infiltration

Similar to bioinfiltration, subsurface controls including infiltration trenches, permeable pavement and seepage pits rely on infiltration to reduce runoff volume, and provide additional benefits including groundwater recharge, water quality, and pollutant removal through filtration through the soil. In contrast to vegetated source controls, where water is held in the soil or ponds on the surface, water is held in a rock-filled bed, infiltration trench, or manufactured vault. The subsurface nature of these controls may also allow more water to be captured in a smaller amount of space, particularly where controls are build in conjunction with permeable pavement. Additionally, subsurface controls are not associated with safety concerns or worries about vector-borne diseases, like concerns about mosquitos (NRC, 2009), which may be associated with improperly designed surface controls. In addition, where soil, contamination, or groundwater conditions make infiltration impractical, subsurface source controls sometimes are designed to detain stormwater, allowing it to exit gradually through an outflow pipe or underdrain rather than infiltrating into the soil (City of New York, 2008).

Stormwater Performance

The National Research Council (2009) reports that runoff volume reduction for subsurface infiltration and retention source controls has been estimated between 50% and 95% by several recent studies, similar to the reduction rates estimated for vegetated runoff controls. A 2003 study by Brattebo and Booth investigated the performance after 6 years of permeable paving systems in Renton, Washington, that were underlain by subsurface retention, noting little surface wear and virtually no surface runoff with appropriate maintenance. In addition, water samples that had infiltrated through the permeable pavement system had significantly lower levels of copper, zinc, and motor oil than runoff from nearby conventional asphalt areas. Outflow concentrations of these pollutants had also decreased over the study period. Conductivity and hardness from water samples that had infiltrated through the permeable pavement remained constant over the study period, and zinc levels increased (Brattebo and Booth, 2003). However, while subsurface retention source controls aid help to prevent stream erosion and reduce the frequency of CSO events, these techniques do not effectively address stormwater runoff pollution (City of New York, 2008).

Limitations

Similar to bioinfiltration, the level of infiltration achieved through subsurface infiltration source controls depends on soil properties, the amount of contributing impervious surface, pollutant loading, and climate. Soils with poor drainage, including clay and silt, have been considered problematic for installation of subsurface infiltration source controls, and in these cases, subsurface retention controls with outflow devices are recommended (NRC, 2009). However, porous pavements can potentially reduce stormwater runoff and some pollutants from small storms or the first flush of large storms on clay soils, and may be capable of successfully infiltrating the bulk of infiltration from 2 cm storms or less (Dreelin et al., 2006).

Maintenance

Maintenance of subsurface stormwater controls is critical. Subsurface infiltration and retention source controls that utilize geotextile fabric to prevent sediment from entering the underground water storage may become clogged, and these controls may require pretreatment in the form of sediment forebays, grass strips, or manufactured devices to capture sediment as part of the system's design. Pretreatment devices require sediment removal as part of a maintenance plan, and porous surfaces should be vacuumed to remove sediment. Due to the underground nature of these controls, toxic spills must be dealt with proactively or the entire system may need to be replaced (NRC, 2009). Simulated maintenance of porous concrete and permeable interlocking concrete pavers underlain by subsurface retention demonstrated an increase in infiltration rates by at least an order of magnitude with adequate maintenance (Bean et al., 2007).

Costs

We assume that control of stormwater within the LEAP area must occur independently of new development, and therefore the cost of replacing streets, parking lots, and sidewalks with permeable paving including subsurface retention without the aid of redevelopment funding (estimated at $10 to $15 per square foot) is prohibitively high (City of New York, 2008). However, where demolitions are scheduled, we have designed subsurface controls that store stormwater for retention and infiltration within the space excavated for building basements. This could be constructed at a relatively low, marginal cost as part of demolition.

Applicability to LEAP District

Poorly drained soils within the study area make retention and detention more practical that infiltration in most cases. While conventional green infrastructure strategies, such as permeable paving, may be both impractical because of lack of development within the district and prohibitively expensive, innovative strategies that incorporate planned demolitions and capital improvements will be more cost efficient.

Rainwater Harvesting

Rainwater harvesting systems capture runoff from impervious surfaces in rain barrels, cisterns, or tanks. The captured water may be utilized for graywater applications, including lawn irrigation, toilet flushing, and car washing; therefore, these systems may provide economic benefit to users through the reduced water costs. For rainwater harvesting systems to be effective, the captured water must be consistently managed and regularly used so that full tanks are avoided and the system retains capacity for storm events (NRC, 2009).

Stormwater Performance

The stormwater performance of rainwater harvesting systems is dependent on a consistent, reliable demand for water that can be used to drawdown captured volumes and ensure adequate volume for retention of the next storm (EPA, 2013). A rain barrel simulation of a standard 208 I rain barrel by Jones and Hunt (2010) did not meet irrigation demand for six rooftops between 10 and 50 square meters, and the barrel was subject to frequent overflows. However, small rainwater harvesting systems may have an impact on both household irrigation usage and roof runoff volume compared to larger rainwater harvesting systems (Jones and Hunt, 2010).

Limitations

Since rainwater harvesting systems must be disconnected from rooftops in the winter to prevent freezing, these systems are only effective for stormwater management for half of the year (City of New York, 2008).

Maintenance

Rainwater harvesting systems must be disconnected in the winter to prevent freezing (City of New York, 2008). Other maintenance concerns include debris removal and cleaning filters and tanks. Collected water should be used as soon as possible following rain events to prevent bacteria growth (EPA, 2013).

Costs

Estimated costs for rain barrel and cistern installation and use are relatively low, with cisterns typically costing between $0.50 and $2 per gallon of capacity; rain barrels cost between $3 and $9 per gallon of capacity (City of New York, 2008).

Applicability to LEAP District

Rain barrels and cisterns are only appropriate for parcels with demand for harvested water, and require homeowner participation in maintenance and use. This may limit their applicability in the LEAP study area to those neighborhoods with sufficient density to support use of the collected water.

Green Infrastructure Costs

The costs of green infrastructure, including installation, maintenance, and the value of multiple benefits provided, vary considerably for each site due to differences in soil, topography, climatic conditions, land availability and costs, other social and economic factors, and regulatory requirements. Available cost information tends to focus on the construction costs of conventional stormwater management systems such as detention basins and wet ponds, rather than smaller scale infiltration strategies (NRC, 2009). Green infrastructure stormwater benefits are generally measured in terms of reduced public expenditures on the equivalent amount of "gray" stormwater infrastructure necessary to retain mitigated stormwater and treatment costs for water quality (ECONorthwest, 2007; CNT, 2010).

Capital and construction costs for source controls may be significantly lower than the overall lifetime costs of these devices, when long-term maintenance obligations are included. A large number of small-scale source controls may be installed at a watershed scale, but it is imperative for maintenance and financial obligations for these installations to be assigned if they are to safely function in the long-term (NRC, 2009).

Non-stormwater benefits can potentially significantly contribute to the value of green infrastructure. However, non-stormwater benefits are not easily monetized. Several conceptual frameworks have been developed to account for the contributions of these services to the overall function of the project. In general, these frameworks focus on the potential for non-stormwater ecosystem services to increase the sustainability, multifunctionality, and net cost reductions of the project (Brauman et al., 2007; Brown and Kellenberg, 2009; Sustainable Sites Initiative, 2008). A number of recent studies have explored the positive correlation between green infrastructure and property value increases based on proximity (ECONorthwest, 2007; CNT, 2010; Adelaja et al., 2008). Within Michigan, a report from the Michigan State University Land Policy Institute measured appreciation in properties within 1500 feet of high-quality green infrastructure between 2.3% and 6.3% in Oakland and Hillsdale counties compared to similar properties located more than 1500 feet from green infrastructure amenities (Adelaja et al., 2008).

In addition, a number of modeling tools have been developed to estimate costs and benefits of green infrastructure. As a part of this project, our team attended a meeting with LEAP and the Center for Neighborhood Technology (CNT) to discuss the application of CNT's Green Values Calculator to green infrastructure installations in Detroit. The Green Values Calculator estimates the range of benefits provided by five green infrastructure practices (green roofs, tree planting, bioretention and infiltration, permeable pavement, and water harvesting), including:

- Reduces water treatment needs
- Improves water quality
- Reduces gray infrastructure needs
- Reduces flooding
- Increase available water supply
- Increase groundwater recharge
- Reduces salt use
- Reduces energy use
- Improves air quality
- Reduces atmostpheric CO2
- Reduces urban heat island
- Improves aesthetics
- Increases recreational opportunity
- Reduces noise pollution
- Improves community cohesion
- Urban agriculture
- Improves habitat
- Cultivates public education opportunities (CNT, 2010)

This tool has the potential to estimate costs and benefits with relative accuracy within more highly developed cities. However, we found that the tool was less effective for estimating relative costs of green infrastructure alternative in Detroit, because it was not designed to consider areas with extensive vacant land and low land costs.

While installing stormwater control measures in existing urban areas tends to be more expensive than incorporating these measures into new construction, we anticipate that much of the cost of these projects in more densely populated urban areas- the cost of land acquisition- with be significantly reduced in a city where land costs are low because of vacancy. Vegetated land-based source controls are among the most effective at reducing runoff volumes and treating pollutants (NRC, 2009; City of New York, 2008). A number of these BMPs, including swales, have been demonstrated to be relatively low-cost in New York City (City of New York, 2008). Within Detroit, low land cost and availability of vacant properties and buildings that are likely to be demolished significantly increases the potential for widespread utilization of certain source controls. Additional cost-reducing measures include the incorporation of infiltration trench construction into building demolitions and incorporation of bioretention swales into road reconstruction. The incremental cost of installing stormwater controls in conjunction with these projects is expected to be relatively low compared to the overall project cost (City of New York, 2008).

Table 3: Costs of Source Control Technologies

SOURCE CONTROL	INCREMENTAL CAPITAL COST (PER SQ. FT. OR UNIT)	NET PRESENT VALUE (PER SQ. FT. OR UNIT)	LIFESPAN (YEARS)	COST PER YEAR	GALLONS* (PER SQ. FT. OR UNIT)	COST TO CAPTURE GALLON	ANNUAL COST PER GALLON
Blue Roof (2-inch detention)	$4.00	$4.00	20	$0.20	1.25	$3.21	$0.16
Rain Barrel (55-gallon tank)	$200	$200	20	$10.00	55	$3.64	$0.18
Sidewalk Biofiltration	$36.81	$39.68	20	$1.98	8.60	$4.61	$0.23
Porous Asphalt Parking Lane	$8.13	$10.33	20	$0.52	2.18	$4.74	$0.24
Porous Concrete Sidewalk	$6.83	$8.67	20	$0.43	1.82	$4.77	$0.24
Swale	$18.73	$22.50	40	$0.56	1.82	$12.39	$0.31
Blue Roof (1-inch detention)	$4.00	$4.00	20	$0.20	0.62	$6.42	$0.32
Cistern (500-gallon tank)	$3,700.00	$3,700.00	20	$185.00	500	$7.40	$0.37
Greenstreet	$42.67	$82.79	30	$2.07	5.24	$15.81	$0.53
Sidewalk Reservoir	$98.48	$110.41	20	$5.52	3.74	$29.52	$1.48
Green Roof	$24.45	$62.39	40	$1.56	0.47	$133.37	$3.33

REFERENCE CASES	INCREMENTAL CAPITAL COST (PER SQ. FT. OR UNIT)	NET PRESENT VALUE (PER SQ. FT. OR UNIT)	LIFESPAN	COST PER YEAR	CSO GALLONS (PER SQ. FT. OR UNIT)	COST TO CAPTURE GALLON	ANNUAL COST PER GALLON
Newtown Creek Tunnel	$1,299,000,000	$1,300,000,000	50	$26,000,000	40,000,000	$32.50	$0.65
Flushing Bay Tunnel	$1,038,000,000	$1,039,000,000	50	$20,800,000	25,000,000	$41.56	$0.83

* "Gallons" in the source control fields refers to gallons of stormwater runoff that can be retained or detained in those source controls. The exact relationship between those quantities and the corresponding reduction in CSOs is not yet established. See Appendix D.

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Table II-2. Costs of source control technologies, table from City of New York, 2008.

Ecosystem Services

In addition to its primary purpose as stormwater management, green infrastructure may provide other benefits to the local ecosystem and community. The EPA defines ecosystem services as "the many life-sustaining benefits we receive from nature—clean air and water, fertile soil for crop production, pollination, and flood control. These ecosystem services are important to environmental and human health and well-being, yet they are limited and often taken for granted" (2012). Ecosystem services provide a method to understand human relationships and values in the context of the environment, environmental design and environmental policy (Brauman et. al., 2007).

The Millennium Ecosystem Assessment defines four main categories of ecosystem services: provisioning, regulating, cultural, and supporting services (Alcamo and Bennett, 2003). Each of these services has potential to be incorporated into the green infrastructure innovations proposed in this project, and are discussed briefly in the following sections.

Provisioning services provide the natural resources for direct human use that are traded in the global economy, including food, freshwater, timber, energy, fuel, medicine, and fiber (Alcamo and Bennett, 2003).

Regulating services maintain the biophysical conditions that make human life possible, including benefits such as pollination of crops, water damage mitigation, and climate stabilization (Alcamo and Bennett, 2003).

Climate regulation services occur on both a global and local level, and including maintaining a balance of atmospheric gases that create breathable air, sequestering greenhouse gases, and regulating local climate and weather through temperature, precipitation, and humidity through shading, evapotranspiration, and windbreaks. Additional regulating services include the removal or reduction of pollutants from air and water, erosion and sediment control, and hazard mitigation services that reduce vulnerability to damage from flooding, storm surge, wildfire, and drought (Sustainable Sites Initiative, 2008).

As an example of regulating services within Detroit, included within the TGD 2011 report is a landcover-based analysis of green infrastructure benefits utilizing American Forests' CityGreen tool. This analysis estimated the decreased benefits and increased costs to the city resulting from a decrease in canopy between 2004 and 2008. Air pollutants increased by an estimated 24,694 lbs between 2004 and 2008, incurring increased costs to society (such as increased health care costs) of $56,789.81. Carbon storage decreased by 13,702 in this time period, though no pricing currently exists to estimate the financial implications of this loss. Stormwater detention capacity costs were estimated by calculating the stormwater storage volume needed for additional runoff generated due to the decrease in landcover, Stormwater storage was decreased by XX at an additional cost to the city of $55 million (The Greening of Detroit, 2011).

Cultural services include recreation, aesthetic appreciation, and intellectual and spiritual inspiration (Alcamo and Bennett, 2003). Though cultural services are challenging to identify and quantify, these services have important implications for providing links to underlying ecosystem processes, motivating public support for environmental protection, and providing positive contributions to human physical and psychological well-being in their own right (Daniel et. al., 2012). Of particular importance to this project are issues of perception of maintenance, attractiveness, safety, and control within neighborhoods with high levels of vacancy.

Supporting services include the underlying ecosystem processes that produce direct services; these services are fundamentally intermediate, not end products, and include the preservation of options (Alcamo and Bennett, 2003). Supporting services include waste decomposition and treatment, water supply regulation through the water cycle and maintenance of aquifers, and provision of refuge and reproduction habitat to plants and animals, which allows for the conservation of biological and genetic diversity and evolutionary processes (Sustainable Sites Initiative, 2008).

Landscape Perception: Care

Our report builds on past collaboration between LEAP and Joan Nassauer in the School of Natural Resources and Environment (SNRE), including the 2012 Master's project Creating Sustainable Neighborhood Design for Legacy Cities: A New Framework for Sustainability Assessment. The Sustainable Neighborhood Development for Legacy Cities (SND-LC) project provides recommendations for a new framework to measure neighborhood sustainability by integrating social capital, social equity, and ecological considerations through the strategic use of vacant land (Jones et al., 2012). It also draws on ongoing SNRE and Urban Planning research by Joan Nassauer and Margaret Dewar on social capital and cues to care in the most vacant neighborhoods of Detroit, the Graham Sustainability Institute supported Cues to Care project for the Lower Eastside of Detroit and Brightmoor. The following key ideas build on this past work and to ensure that landscape perception, cues to care, and perception of safety are designed into the green infrastructure innovations proposed by this project.

Landscape care is of particular importance in legacy cities, where extensive areas of vacant land and blighted properties have a negative effect on landscape aesthetics and environmental services. Nassauer (1995) defines care as "protecting or maintaining what we pay attention to." Care within the landscape communicates human intention and attention, connoting cultural values including stewardship, work ethic, and contributing to the community. Because care conveys "a response to what is visible," the concept of care may also be an effective tool for creating landscape change (Nassauer, 2011). "Cues to care" provide visual evidence of intentional maintenance within the landscape, and include:

- Neatness and order (no litter, things are put away, no weeds)
- Structures in good repair (e.g., well-painted, unbroken)
- Visible, crisp edges of different patch types (including gardens, cropped fields, ecological restorations, fragments of native ecosystems)
- Fences, especially between properties or between patches with different textures
- Trimmed trees and hedges or plants in straight rows
- Mown turf in at least a portion of the most publicly visible areas of a site
- Colorful flowers
- Bird boxes and lawn ornaments
- Signs that identify those who occupy the property or suggest the ecosystem functions that occur there, especially habitat functions (Nassauer, 2011)

The ecosystem services that are provided by ecologically designed landscapes must be maintained in order for these landscapes to continue to provide beneficial services. However, the cultural concept of "nature" and expectations for how "natural" landscapes should appear are often different from the scientific concepts of ecological function and the intrinsic appearance of the ecosystems that provide these services. For the benefits of these areas to be realized, such landscapes must be recognized and preserved as amenities (Nassauer, 1995).

The existence of ecologically beneficial landscapes in the future depends on the cultural sustainability of these spaces. Nassauer (1997) describes cultural sustainability as "landscapes that are ecologically sound, and that also evoke enjoyment and approval, are more likely to be sustained by appropriate human care over the long term." Within such landscapes, cues to care are utilized to align ecosystem services with cultural landscape preferences. The halo effect of landscape care is particularly relevant to raise the cultural value and aesthetic experience of ecosystem services associated with landscapes that appear innately "messy" or "unkempt" - for example, prairies and other native plantings in urban areas (Nassauer, 2011).

Small, culturally sustainable properties may be aggregated into larger-scale ecological landscape patterns by employing ecological designs at the neighborhood scale. In a 2005 study of exurban homeowners in southeastern Michigan, Nassauer et al (2009) found that neighborhood norms strongly affected individuals' own preferences for their residential landscape. The study suggest that the nature of these neighborhood-scale preferences as "clustered, localized, [and] more extensive than individual properties" makes the residential neighborhood a potentially successful scale for implementing environmentally beneficially landscapes over a larger geographic scale (Nassauer et al, 2009). Furthermore, within residential neighborhoods in Detroit, clusters of similar residential landscape preferences may aid in establishing "signature identities" for these blocks.

Landscape Perception: Safety

In response to an increase in urban crime, specific design and management techniques were developed beginning in the 1970s to reduce crime and fear of crime in urban space under the description Crime Prevention Through Environmental Design (CPTED). The concept of Crime Prevention Through Environmental Design stems from architect Oscar Newman's book Defensible Space (1972), which encouraged residents of an area to assume responsibility for the safety of their environment through the physical manipulation of urban space. Newman's strategies include delineating function for specific spaces, clearly defining paths of movement, "territorializing" outdoor space for adjacent residents, and providing continued visual surveillance (Newman, 1976).

Gerda Wekerle critiques Newman's Defensible Space Theory through the Safer Cities Approach, which emphasizes management and community involvement and recognizes the significance of fear of crime, particularly in vulnerable and minority populations. Wekerle categorizes urban safety strategies by their contributions to an individual's awareness of the environment, visibility by others, and ability to find help (Wekerle, 1995).

Awareness of the environment is primarily defined by the ability of site users to see and understand what is around and ahead in order to avoid dangerous situations. This is accomplished through adequate lighting, clear sightlines, and elimination of entrapment spots. Sufficient lighting contributes to a sense of personal security and encourages use of the site after dark, increasing the presence of activity and informal surveillance. Site users should be able to make eye contact with a person 15 yards away, a reasonable "fight or flight" distance. In conjunction with adequate lighting, the site should have sufficient "visual permeability" for users to both see the spaces around and ahead of them and be seen by other people in the area. Visual permeability is hindered by large columns, tall privacy fences, overgrown shrubbery, and grade separations, which can shield attackers from view. Long fences and landscape screens not only reduce site visibility, but also remove means of escape from potential victims and may create unchangeable routes that offer no other choice of movement to pedestrians. Entrapment spots, the small, confined spaces adjacent to well-traveled routes that may be created by these impermeable barriers, should also be eliminated to reduce both potential hidden locations for crime to occur and site users' fear of crime (Wekerle, 1995).

The strategy of "visibility by others" is closely related to site user's awareness of the environment. In addition to visual permeability, visibility by others is improved by reducing the sense of isolation within an urban space. Open spaces that appear to belong to no one may lead users to judge that signs of distress will not be seen, heard, or responded to. Existing land uses may contribute to the isolation of some spaces for all or part of the day, including inward-facing shopping plazas or low-density residential neighborhoods that are abandoned during the day. Therefore, Wekerle proposes mixed-use development to ensure that activity and "eyes on the street" are present within the neighborhood at all times of day. These proposed uses must be compatible with the needs of the community and with each other. The purpose of generating activity is to make an area more secure by populating it, and these uses cannot operate in isolation. Community involvement is necessary to encourage collective ownership and territoriality of these spaces through the use of open layouts with access and routes to public spaces (Wekerle, 1995).

Finding help in dangerous situations depends on clear signage and legible design within an urban space. The "legibility" of a space refers to the ability of users to navigate the area and receive assistance when in danger. Users must be able to escape, communicate, and access clearly marked avenues to emergency exits, alarms, and phones when in danger. Good site design ensures that signage is easily understood and activity nodes and paths are clearly designated and well-lit (Wekerle, 1995).

Wekerle notes the perception of parks and naturalized areas as potential "hot spots" for crime, particularly in cases where park spaces are buffered from the city to protect from noise, traffic, and views from surrounding buildings. These conditions may create areas of concealment and limit visibility and escape routes to users. Naturalized areas in particular have been linked to fear of crime and are viewed as high-risk areas by women and the general public. Wekerle proposes that parks be integrated into city life through community involvement in planning, design, management, and programming; high-risk zones including naturalized areas should be under the management of parks personnel. The New York City Parks Department has made significant improvements in the perception and safety of Union Square and Bryant Parks by focusing redevelopment efforts on removal of signs of physical and social incivility including graffiti and litter, citizen and private sector involvement, and moving activities to the edges of the parks (Wekerle, 1995).

Climate Change Impact

Green infrastructure has significant implications for climate change adaptation in the City of Detroit both through enhanced carbon storage for greenhouse gas mitigation and stormwater storage in future storm events. Climate change scenarios predict that the temperature in southeast Michigan may rise by 5.85°F (NASA 2001) and changes in precipitation are projected to occur between -30% and +40% seasonally, with precipitation declines in the summer and autumn and increases in the winter (IPCC 2007b). The predicted decrease in precipitation for the north-central United States is linked to a projected decline in water levels of the Great Lakes (IPCC, 2007b), though a recent study utilizing a Great Lakes Advanced Hydrologic Prediction System (AHPS) underscored the level of unpredictability of lake water level reactions to climate change (Gronewold, 2011).
Of particular importance to climate change adaptations in Detroit is the predicted volume decrease in Lake St. Clair. Lee et al. (1996) estimate that the lake level may decrease up to 1.6 meters. Lake level changes have the potential to impact wetlands, fish spawning, recreational activities, commercial navigation, municipal water supplies, and exposure of toxic sediments (Rhodes and Wiley, 1993). The Michigan Climate Action Council's 2009 Climate Action Plan recommends adaptive measures for the Detroit area including stormwater management in response to climate change predictions, ecological patch management for species movement, and practices to enhance ecological resilience (Jones et al., 2012).

Forest management has the ability to mitigate climate change through carbon storage and sequestration. Urban forests in Chicago are estimated by the Chicago Urban Forest Climate Project to capture approximately 6,142 tons of air pollutants and sequester approximately 155,000 tons of carbon per year (MacPherson et al., 1994). In urban areas, adaptive forest management can occur through increasing street tree density, enhancing the sequestration rate in new and existing forests, and decreasing forest degradation (IPCC, 2007a).

Reforestation, which reestablishes forest cover in areas that have been without tree canopy for more than 50 years (Kabat et al, 2005), could occur within the LEAP study area on vacant and abandoned properties. Reforestation within the city can both increase carbon sequestration and reduce external stresses on forest resource (Spittlehouse and Steward, 2003; Fischlin et al., 2007). Urban forests can be adapted to climate change through mixing of both fast and slow growing species, growing and harvesting patterns adapted to changing climate conditions, landscaping to minimize fire and disease, and salvaging dead timber (Spittlehouse and Stewart, 2003; Lesch, 2010). Over time, forest soils also act as a carbon sink, sequestering four times more carbon than terrestrial vegetation (Delgado and Follett, 2002).

Climate change impacts are predicted to result in increasingly variable levels of precipitation over the course of the 21st century (IPCC, 2007a). This variability in precipitation is anticipated to have distinct impacts on stormwater conditions. He et al. employed a regression-based statistical downscaling tool to predict stormwater changes in Calgary, Canada. The results of these studies indicate that increased rainfall intensity is linked to increased peak flows and runoff volumes in stormwater and increased turbidity in receiving waters. Additionally, intense storms in urban areas with aging infrastructure can lead to increased flooding (Tak et al., 2010). Land-based stormwater management controls that utilize retention, detention, and infiltration to replicate predevelopment conditions such as rain harvesting, rain gardens, brownfield redevelopment, greenstreets, urban forestry, and green infrastructure are recommended to both manage increased precipitation events and provide treatment of urban pollutants (Tsihrintzis and Hamid, 1997; Walsh et al., 2005; EPA, 2011).

III. Recommended Best Management Practices

We developed six green infrastructure best management practices (BMPs) specific to the conditions of vacancy and abandonment in the Lower East Side. These BMPs are designed to respond to the quantity of contiguous vacant parcels within a block and to consider any poor condition buildings as potential BMPs sites if they are demolished. Criteria for locating these BMP's throughout the LEAP area are determined by these same characteristics and discussed later in this report. Project designers and spatial analysts worked iteratively from initial BMP proposals to define the stormwater management and landscape characteristics of the six BMP's.

This process results in a range of BMP solutions that vary according to the number of aggregated vacant parcels and location within a Naturescape area (with implied maintenance requirements). Smaller aggregations of vacant parcels within relatively populated areas are characterized by mown lots with colorful flowers, while larger expanses of vacant property efficiently capture, infiltrate, and transpire stormwater through well-organized woodland installations. Larger contiguous expanses that are not within a Naturescape are also designed to ensure visibility for safety at the edges and between houses that have wooded areas nearby. To maximize stormwater capture, all BMPs incorporate shallow grading with a berm at the front facing the street to detain stormwater that would otherwise enter street drains. Potential demolition sites, including locations of poor condition buildings, are designed to incorporate stormwater retention and infiltration as part of the demolition process.

Bioretention Garden

Site Requirements

Bioretention gardens are designed for use on between one and three adjacent vacant parcels. Large trees on these lots are allowed to remain on the site to increase infiltration and evapotranspiration of stormwater, and grading is completed around the drip line of the trees. Where two to three vacant parcels are adjacent, these parcels are graded together to create a single retention garden.

Description

Bioretention gardens are designed to incorporate stormwater storage capacity and site maintenance into existing vacant parcels. Subtle site grading is utilized on site to capture stormwater through overland flow. The grading plan is designed to be implemented efficiently using a few passes by a grader, incorporating shallow slopes between 3% and 5% on the sides and back of the parcel and a low berm at the front of the parcel. The total depth of the bioretention garden is approximately one foot below street level and the berm rises to a height of one foot above street level. The linear berm at the front of the parcel provides a filter between stormwater and the street to increase the amount of stormwater held within the parcel and provides a consistent earthwork visual element along the edge of the street. In the case of a large storm event where the stormwater capacity of the site is exceeded, stormwater overflows out a piped connection through the berm, which acts as a weir.

Following grading, the bioretention garden is seeded with a standard grass mix and maintenance includes regular mowing of the site. In addition, berms are planted with low flowering perennials. Suggested plant mixes are listed in Appendix A.

Stormwater Capacity

Stormwater is captured in bioretention gardens through overland flow from nearby occupied parcels. Due to the poor drainage characteristics of soils within the study area, bioretention gardens are expected to act primarily to retain stormwater to reduce the volume of stormwater within piped infrastructure during and immediately following wet weather events. Limited infiltration and evapotranspiration may also manage some of the captured stormwater. The stormwater capacity of a bioretention garden is estimated as the total volume of water capable of being captured and held by the depression and berm; this volume varies by the number of adjacent vacant parcels included in the bioretention garden. One graded parcel is estimated to capture approximately 1,774.07 cubic feet of stormwater, two parcels are estimated to capture 4,807.41 cubic feet of stormwater, and three parcels are estimated to capture 7,840.74 cubic feet of stormwater.

Non-stormwater benefits

Bioretention gardens are designed to provide strong cues to care on previously vacant and overgrown parcels, including mowed areas and colorful flowers, to enhance perceptions of care and safety, discourage dumping, and improve aesthetics within the block. Repeated elements also contribute to neighborhood amenity and signature character. As a vegetated BMP, bioretention gardens provide some non-stormwater benefits related to the incorporation of plantings, including improvements in air quality and carbon sequestration. However, since bioretention gardens are planted with a standard grass mix and mowed, the BMP does not contribute significantly to reduced energy demand and increased provision of habitat.

Costs

Initial costs for the installation of bioretention gardens include site cleanup, grading, tilling (6"), topsoil (2"), reseeding, and associated machinery and labor costs. Continuing maintenance costs include regular mowing. TGD estimates costs for vegetated swales, a similar BMP designed as a depressional area vegetated with deep-rooted plant species, at $89,633.25 per acre (TGD, 2011).

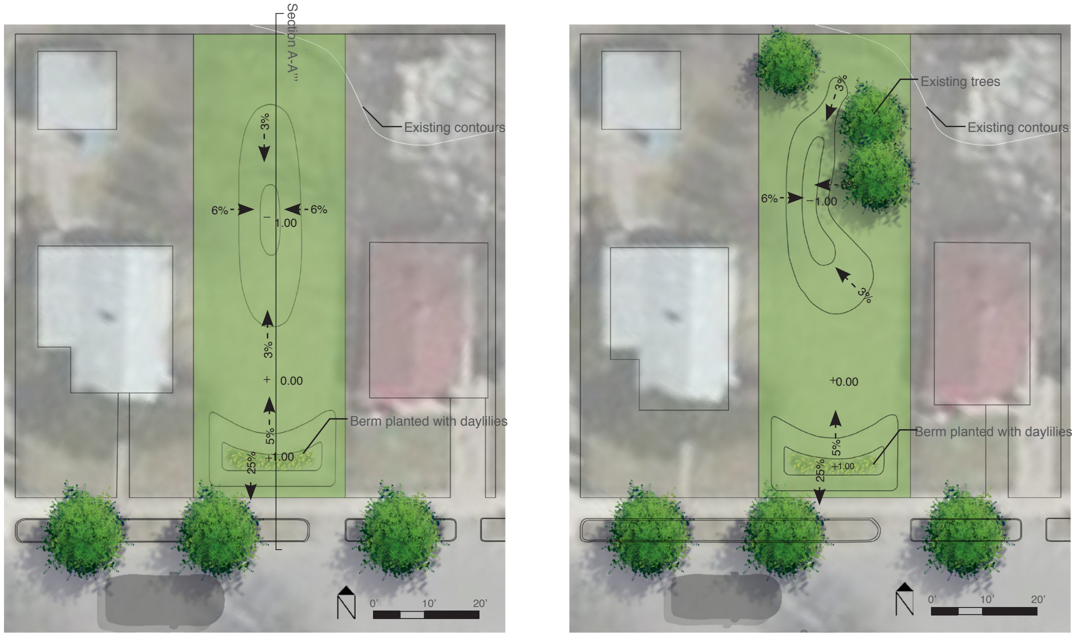


Figure III-1. Bioretention garden grading plan. Where trees are present on site, grading is completed outside of the dripline of existing trees. Perennials are planted on the low berm adjacent to the sidewalk.

Figure III-2: Base condition for bioretention garden: up to three adjacent vacant lots.

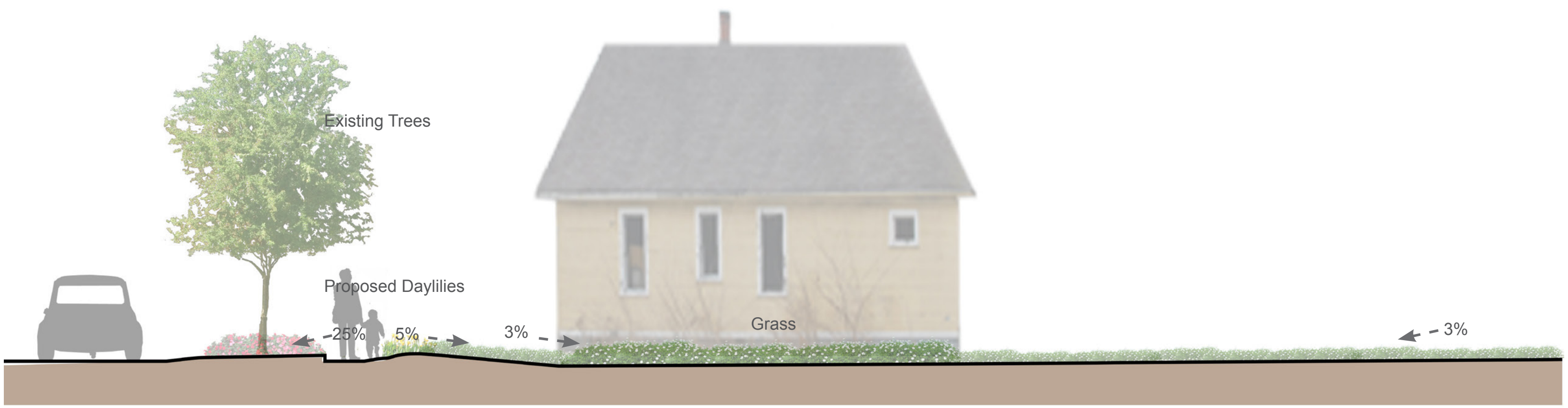


Figure III-3. Section A-A' through center of bioretention garden.

Figure III-4. Base condition for bioretention garden on multiple adjacent lots.

Figure III-5: Bioretention garden grading over three adjacent lots.

Infiltration Garden

Site Requirements

Infiltration gardens are installed on parcels with houses or other buildings slated for demolition. For the purpose of BMP siting and analysis, we assume that any currently vacant or poor condition building on the 2009 Residential Parcel Survey will be demolished in the near future.

Description

The infiltration garden utilizes the demolition process to incorporate retention capacity into newly vacant sites. The excavated basement of a demolition site is filled with coarse gravel and overlain with geotextile fabric and a thin layer of topsoil. Edges of the infiltration garden are defined by neat stone edges. The surface of the retention area is planted with shallow-rooted perennials including sedges and daylilies. A full selection of appropriate plantings is listed in Appendix A.

In addition to the stormwater retention space built during the demolition process, site grading similar to the techniques incorporated in bioretention gardens is utilized to facilitate overland flow of stormwater into the BMP and increase stormwater capacity on site. This includes both shallow slopes directing water into the retention area and the low, planted berm at the street edge of the site holding water within the parcel. Excess stormwater overflows out a piped connection through the berm. Graded areas of the site are reseeded with grasses, and maintenance of the infiltration garden includes regular mowing.

Stormwater Capacity

Due to the low infiltration rate of soils within the LEAP district, infiltration gardens are designed primarily to temporarily retain stormwater to reduce peak flow within the piped infrastructure during and immediately following wet weather events. A small amount of infiltration and evapotranspiration due to the plantings on site is anticipated.

Stormwater is captured in infiltration gardens either by overland flow into the retention space or by curb cut "bump-outs" that capture runoff from the street. Water is piped directly into the rain garden from a curb cut "bump-out." Stormwater capacity of the parcel includes both the gravel-filled retention space created out of the demolition basement and additional capacity from site grading. Total stormwater capacity for an infiltration garden is estimated at 2560 cubic feet in addition to the grading for stormwater capture on the parcel.

Non-stormwater benefits

As a vegetated BMP, infiltration gardens provide non-stormwater benefits related to the incorporation of plantings within the BMP, including improvements in air quality and carbon sequestration. Since plantings on top of the retention space are relatively shallow and the remainder of the site area is planted with grasses and mowed, we consider the contributions of this BMP to reduced energy demand and animal habitat to be limited. Careful design of infiltration gardens to provide cues to care including mowed areas, colorful flowers, and crisp edges also provide non-stormwater benefits including enhanced perceptions of care and safety and aesthetic improvements to the block. Repeated elements also contribute to neighborhood amenity and signature character.

Costs

Installation costs for infiltration gardens are incorporated into the capital costs associated with demolitions. Infiltration gardens require investment in gravel, geotextile fabric, site grading, topsoil, plantings, and associated machinery and labor costs. Infiltration gardens that incorporate piped connections to the retention space from curb cuts will incur greater materials and labor costs. Ongoing maintenance costs for the site include mowing and upkeep on retention structures. TGD estimates costs for vegetated swales, a similar small vegetated BMP with a stone subbase to increase stormwater storage capacity, at $89,633.25 per acre (TGD, 2011).

Figure III-6. Infiltration garden plan including grading around retention space.

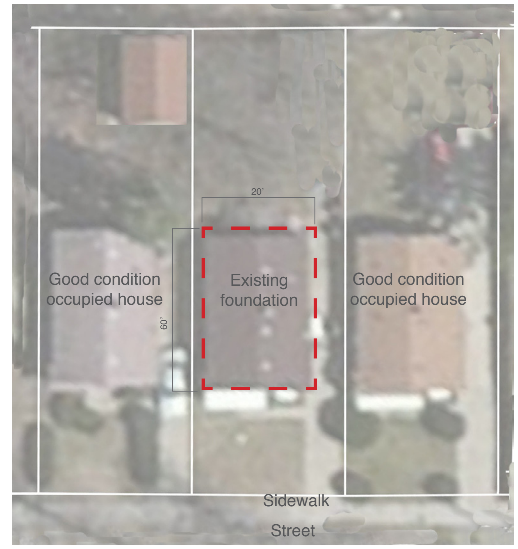


Figure III-7: Base condition for infiltration garden: poor condition building slated for demolition.

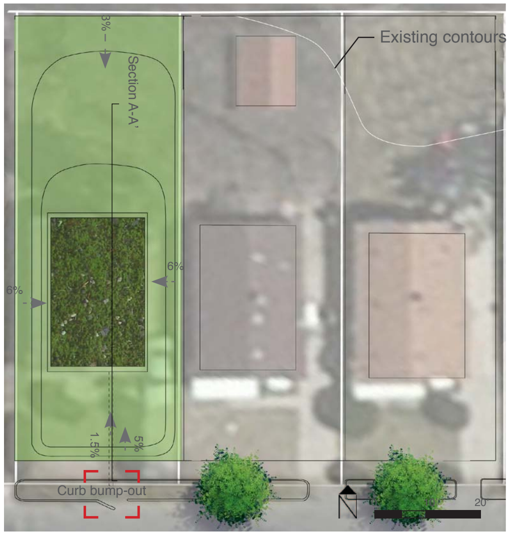


Figure III-8: Infiltration garden with curb "bump-out" to capture water from the street.

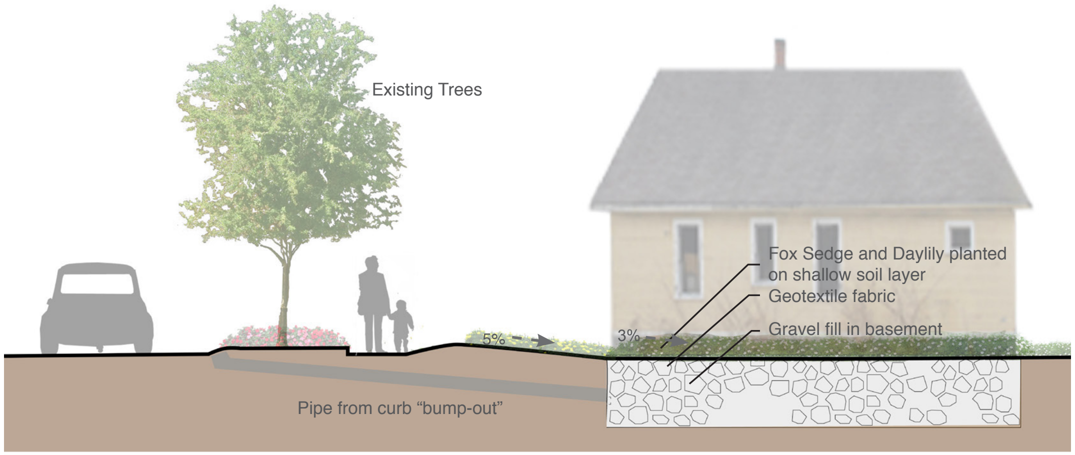


Figure III-9. Section A-A' through infiltration garden.

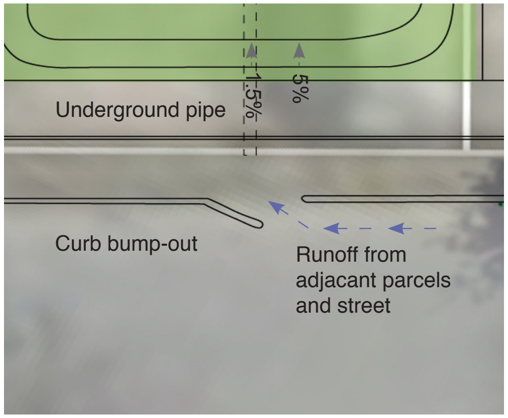


Figure III-10: Detail of curb "bump-out" option for stormwater capture from street.

Cistern

Site Requirements

In addition to the presence of a poor condition or vacant building slated for demolition, cistern installation within the study district requires a high level of neighborhood interest and commitment to cistern maintenance. Since the functionality of rainwater harvesting systems such as cisterns requires that captured stormwater be utilized between rain events, cisterns should be made available only to neighborhoods with a high enough residential density to support efficient use of the rainwater. Cisterns also require additional maintenance including downspout disconnect during the winter months and therefore require community commitment to their use and upkeep.

Description

As an alternative to infiltration gardens, cisterns may be installed in planned demolition sites. Cistern installation utilizes the excavated basement space for the placement of a standard 5000-gallon commercially available cistern. Captured rainwater is made available to adjacent homeowners for graywater uses including landscape irrigation and car washing.

Stormwater Capacity

The stormwater capacity of a cistern is based on the designed capacity of commercially available cisterns. For this project, a standard 5,000 gallon cistern was selected; this equates to 668.4 cubic feet of water storage. In order to maintain as much capacity as possible within the cistern, captured water must be used by neighborhood residents between wet weather events. Stormwater is captured in gravel-filled trenches aligned with house downspouts, allowing the water to be slowed and filtered before it reaches the cistern.

Non-Stormwater Benefits

The primary non-stormwater benefit of neighborhood cisterns is as a community-building tool that encourages neighborhood education and participation in stormwater reuse. Site maintenance may also contribute to enhanced perceptions of care and safety within the lot. Cistern usage may result in reduced energy costs and reduced water demand for irrigation and other gray water uses.

Costs

Due to their incorporation into demolition sites, excavation costs for cisterns are reduced compared to standard installation. Remaining costs include investment in the cistern itself, labor and machinery costs for installation, and site regrading, tilling, topsoil and reseeding. Maintenance costs include mowing, winter downspout disconnect, and cistern upkeep.

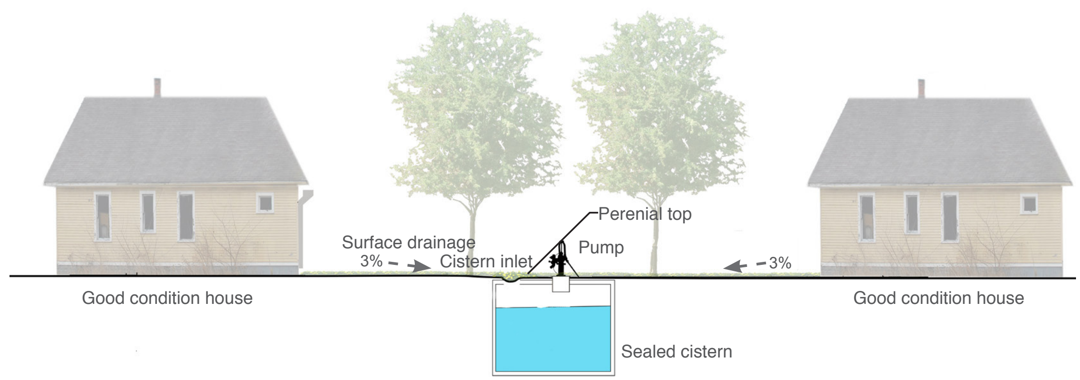


Figure III-11. Underground placement of cistern and connection to downspouts.

Small Urban Woodlot

Site Requirements

Small urban woodlots are installed on any group of 4-9 currently vacant parcels. The parcels may be located next to each other on one side of the block or on either side of an alley. Trees currently established within the alley and any existing street trees are allowed to remain to further contribute to stormwater capacity on the site.

Description

Urban woodlots are the primary BMP designed for four or more adjacent vacant parcels to maximize on the multiple contributions of urban forests to stormwater management. Forests are highly effective as a stormwater management technique because rainwater is intercepted and temporarily stored in the tree canopy, reducing peak flows, and water flow along trunks and tree roots may also contribute to increased infiltration rates in compacted soils (Xiao and MacPerson, 2003; Sanders, 1986; Bartens et al., 2008; Johnson and Lehmann, 2006).

Trees within the urban woodlot are planted in straight rows parallel to the street to contribute to a sense of order and care within the neighborhood. Rows are spaced 30 feet apart to impart a park-like atmosphere within the woodlot. The trees are spaced with 15 feet between trees within the rows, and may be thinned over the lifetime of the urban woodlot to respond to tree health and growing patterns as well as neighborhood density and visibility requirements to encourage a sense of safety. All small urban woodlots are planted with bare root stock seedlings painted white for visibility during the first years of growth.

In addition to tree plantings, urban woodlots incorporate site grading to increase the stormwater capacity of the BMP. Shallow 3% slopes on each side of the swale define a depression approximately one foot deep within the urban woodlot. Additional 10% swales are located on the sides and back of the lots to direct stormwater from adjacent lots and across the alley into the woodlot.

Species selection varies in order to increase the biodiversity within the woodlot and plan for climate change adaptation and disease. Tree selections are arranged on site to respond to hydrologic conditions within the swale by placing species with higher water requirements toward the bottom of the swale at the center of the lot and more drought tolerant species at the higher ends of the swale, at the back and the front of the lot. The first row of trees closest to pedestrians and the road is to be planted with street trees to establish neighborhood character along the street. Species in the small urban woodlot plan include Sycamore and Ginkgo as street trees along the street edge of the woodlot, Red Maple and Quaking Aspen in the center of the swale, and White Pine and Canadian Hemlock at the back edge of the woodlot. A full list of suggested species for urban woodlots is provided in Appendix A.

Perception of safety is critically important to the design and implementation of urban woodlots. A primary assumption in our design of BMPs for highly vacant neighborhoods is that the success of these BMPs depends on their acceptance within the community as neighborhood amenities; therefore, urban woodlots must contribute to a sense of safety and good care within the block. Perception of safety within urban woodlots is established through visibility through the woodlot. The closest row of trees to the street is aligned with the setback of houses on the block, approximately 25 feet from the street, allowing pedestrians on the sidewalk ample space from the woodlot itself and establishing lines of sight between the front doors of houses outside of the woodlot. Single-trunk tree species with high canopies are selected to allow for visibility under the canopy through the woodlot, and conifers, if used, are planted at the back of the site. Rows of tree plantings begin a minimum distance of 20 feet from the property line of adjacent occupied houses to increase open space around these homes and prevent tree root disruption of basements and foundations. Small urban woodlots are mowed on a regular basis to suppress weeds, establish visibility between trees, discourage dumping, and contribute to a sense of care and ownership within the neighborhood.

Where groups of 4-9 vacant parcels are located where the CDAD Naturescape typology applies, the character of the urban woodlot is altered to reflect larger woodlot installations described in the following sections. Naturescapes are described within the CDAD Strategic Framework (2012) as "low-maintenance managed natural landscapes intended to bolster air and water quality, and support indigenous wildlife" in areas of very low population density. Small urban woodlots within Naturescape areas incorporate more dense tree plantings with 15 foot by 15 foot spacing between trees and rows. In order to plan for safety and visibility within denser tree plantings, small urban woodlots within Naturescapes also incorporate a 45-foot space between the first row of trees and the second that allows for visibility between houses through the woodlot. Maintenance expectations including mowing between trees are lower for small urban woodlots within Naturescape areas than for small urban woodlots located in other CDAD typologies.

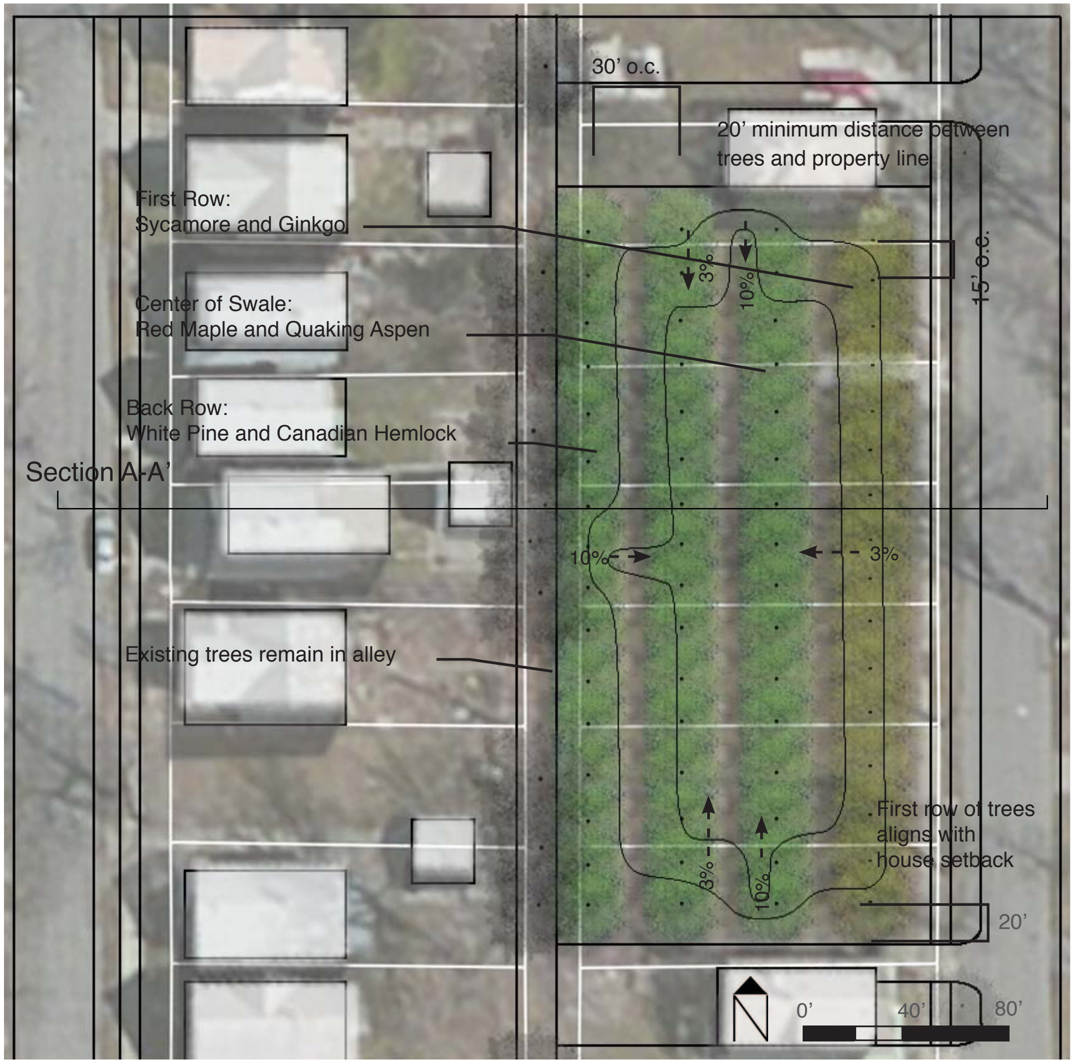


Figure III-12. Small urban garden for all CDAD typologies except Naturescape. The BMP incorporates greater spacing between trees and higher maintenance expectations for a "park-like" atmosphere within the woodlot.

Figure III-13: Base condition for small urban woodlot: between 4 and 9 adjacent vacant parcels.

Figure III-14. 20' minimum distance between trees and property line

Figure III-15. Small urban garden within CDAD Naturescape typology. Trees are planted more densely and a 45-foot space is provided between the first and second rows of trees for visibility between houses and into the woodlot.

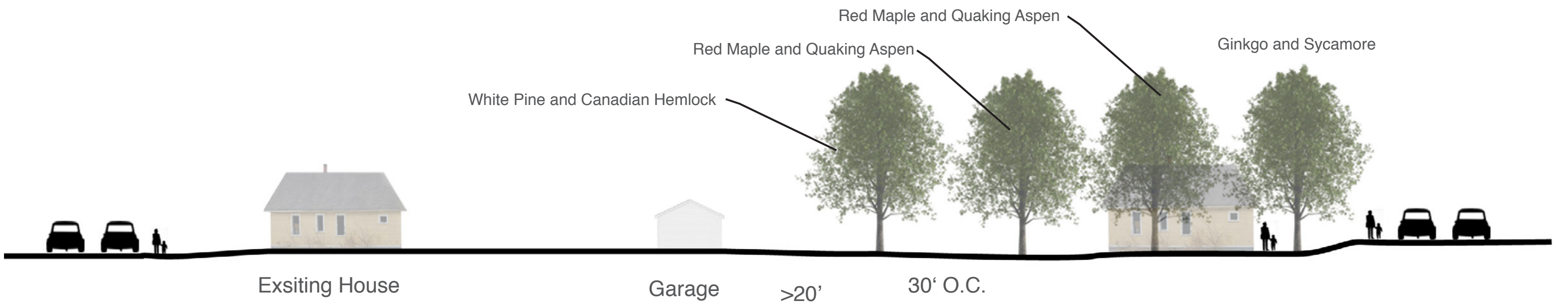


Figure III-16. Section A-A' through small urban woodlot located outside of CDAD Naturescape typology. The design features larger spacing between trees and higher maintenance expectations than those located in Naturescapes.

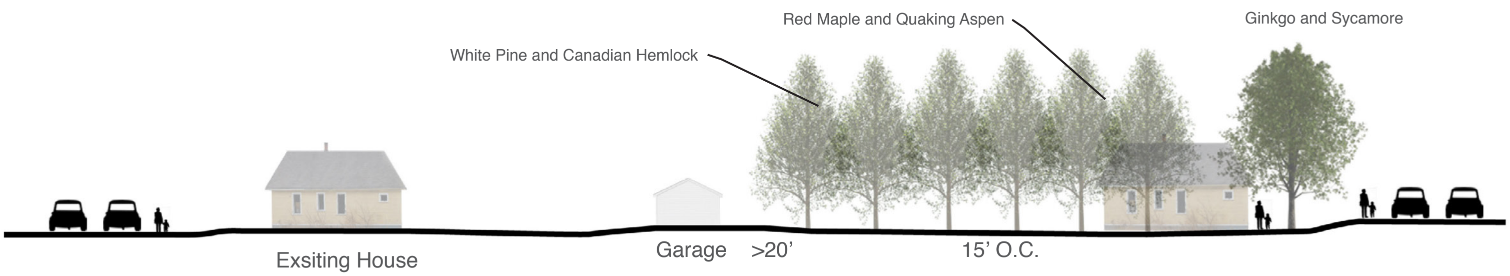


Figure III-17. Section B-B' through small urban woodlot within Naturescape typology.

Figure III-18. Section B-B' through small urban woodlot within Naturescape typology.

Stormwater Capacity

Stormwater is captured in urban woodlots through overland flow and interception of water within the tree canopy. Stormwater capacity is calculated to include the combined contributions of basin capacity and transpiration of water by trees.

Non-Stormwater Benefits

Numerous non-stormwater benefits have been documented for urban forests, including improvements to local climate and reductions in energy use, improvements to air quality, climate change adaptation, noise abatement, enhanced animal and plant habitats, improvements to soil quality, increases in real estate values, improvements to individual and public health, and improvements to community well-being (Nowak et. al., 2010). While not all of these non-stormwater benefits are equally important within depopulated areas of the city, the potential for urban forests to provide carbon storage and sequestration and mitigate climate change effects is particularly significant for this project (MacPherson et al., 1994; IPCC, 2007a; Kabat et al., 2005; Spittlehouse and Steward, 2003; Fischlin et al., 2007; Lesch, 2010; Delgado and Follett, 2002). The neighborhood amenity and aesthetic benefits of urban forests are also important, particularly in smaller, more visible urban woodlots that are installed in more populated areas of the LEAP district. These woodlots contribute to the perception of care and safety within the neighborhood through regular maintenance, establish a sense of neighborhood or block signature identity, and may eventually provide recreation space for neighborhood inhabitants.

Costs

The Greening of Detroit (TGD, 2011) provides a breakdown of costs associated with forested BMPs that lists estimated installation costs including trees, mulch, clearing and grubbing, tilling, topsoil, grading, and understory seeding. Table xx details these costs for contractor installation of the BMP. Since the urban woodlots proposed in this project will be planted with bare root stock rather than ball and burlap trees, the costs associated with tree planting proposed in this project will be significantly lower than the estimates provided by TGD. Bare root seedlings cost approximately \$1.00-\$2.00 each in contrast to the estimated \$385.00 each for 1.75"-2.5" cal. ball and burlap trees used in the TGD cost estimate (Cardno JFNew, 2013). Additional cost information from TGD is included in Appendix B. We anticipate that ongoing maintenance costs will include regular mowing, raking and disposing of leaves and debris, pest control, and tree pruning and thinning or removal of dead specimens as necessary.

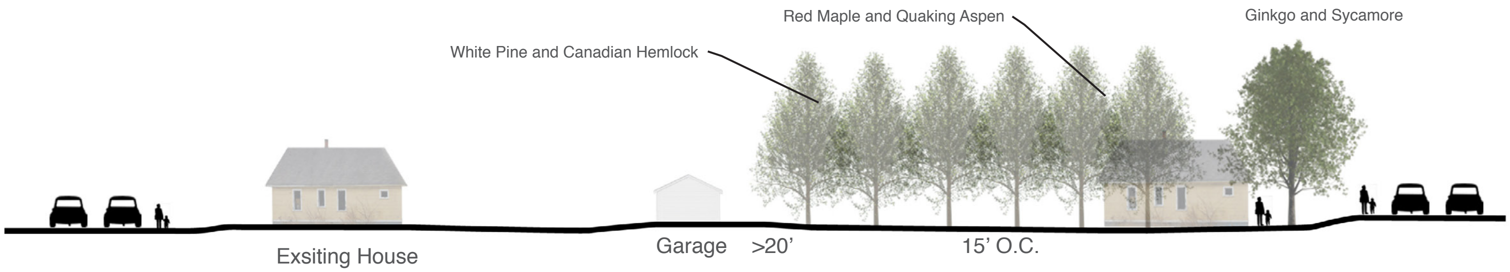


Figure III-19. Section A-A' through small urban woodlot within Naturescape typology.

Forested Areas	Unit Cost		1 Acre		1/2 Acre		1/4 Acre	
Line Item	Cost	Unit	Qty.	Cost	Qty.	Cost	Qty.	Cost
Trees (1.75" - 2.5" Cal.)	$ 385.00	EA	216	$ 83,160.00	108	$ 41,580.00	54	$20,790.00
Mulch (cyd)	$ 25.00	CYD	24	$ 600.00	12	$ 300.00	6	$ 150.00
Clearing and Grubbing	$ 5,000.00	LS	1	$ 5,000.00	0.5	$ 2,500.00	0.25	$ 1,250.00
Till (6" depth)	$ 2.75	1000 SF	43.6	$ 119.90	21.8	$ 59.95	10.9	$ 29.98
Topsoil (2" depth)	$ 20.00	CYD	270	$ 5,400.00	135	$ 2,700.00	68	$ 1,360.00
Fine Grading	$ 5.50	CYD	270	$ 1,485.00	135	$ 742.50	68	$ 4,083.75
Straw Mulch	$ 1.35	SY	4840	$ 6,534.00	2420	$ 3,267.00	1210	$ 1,633.50
Understory Seeding	Varies		1	$ 3,070.00	1	$ 1,685.00	1	$ 1,145.00
Cost Estimate				**$ 105,368.90**		**$ 52,834.45**		**$30,442.23**
Mobilization (5%)				$ 5,268.45		$ 2,641.72		$ 1,522.11
Total Cost				**$ 110,637.35**		**$ 55,476.17**		**$31,964.34**

Table III-1. Installation costs for contractor-installed forested BMP from The Greening of Detroit, 2011. Note the significant cost difference between ball and burlap trees (estimated at $385.00 each) and the bare root stock proposed for the woodlot BMPs (at $1.00-$2.00 each).

Medium Urban Woodlot

Site Requirements

Medium urban woodlots are located on continuous groups of 10-20 currently vacant parcels. Parcels may be adjacent to each other or located on either side of an alley. Currently existing street trees and trees within alleys remain to increase stormwater capacity within the BMP. The density and arrangement of trees within medium urban woodlots is the same within all CDAD typologies, including areas designated as Naturescapes.

Description

As the number of adjacent vacant lots increases, the density of urban woodlot plantings also increases to incorporate greater stormwater storage capacity. Trees within medium urban woodlots are planted on a dense 15-foot by 15-foot grid and trees may be thinned over time to facilitate tree health and visibility within the woodlot. Shallow grading to a depth of 1 foot below sidewalk grade, similar to the grading incorporated in small urban woodlots, is also utilized in medium urban woodlots. The swale is defined by 3% slopes on all sides with small 10% swales connecting to adjacent lots and across the alley to capture additional overland flow. Tree species selection and placement within the BMP are also similar to small urban woodlots, and include a variety of species arranged according to drought and flood tolerance within the swale. The row of trees closest to the street is selected to be a mix of street trees, and the back rows may be planted with conifers. Refer to Appendix X for a full list of suggested urban woodlot tree species. All trees are planted as 12-18" bare root stock.

Because of the increased planting density, medium urban woodlots incorporate additional safety and visibility considerations. In addition to single-stem canopy trees to provide visibility throughout the woodlot, a minimum 45-foot space between the first row of trees and all other rows allows for uninterrupted sight lines between occupied houses adjacent to the woodlot. This 45-foot space represents the "fight or flight" distance at which a pedestrian is able to recognize another individual and adjust their path according to perceived threat; however, the spacing between the first and second rows is also flexible and can increase to accommodate larger distances for longer houses based on the preferences of the adjacent homeowners. Twenty-foot spacing between trees and adjacent property lines is maintained to allow for visibility around occupied homes and prevent root damage to basements. Maintenance within medium urban woodlots includes some regular mowing and tree care, though these BMPs are not expected to be highly maintained to achieve the park-like quality of small urban woodlots.

Stormwater capacity for medium urban woodlots is calculated in a similar manner to the stormwater

Stormwater Capacity

capacity for small urban woodlots, including the contributions of both basin capacity and transpiration of water by trees.

Non-Stormwater Benefits

Medium urban woodlots incorporate similar non-stormwater benefits to other urban forests, including improvements to local climate and reductions in energy use, improvements to air quality, climate change adaptation, noise abatement, enhanced animal and plant habitats, improvements to soil quality, increases in real estate values, improvements to individual and public health, and improvements to community well-being (U.S. Forest Service, 2010). As forested areas become larger, we anticipate that they will have greater potential to provide benefits including provision of habitat, carbon sequestration, and air quality and soil quality improvements through increased biomass and greater patch size. Medium urban woodlots continue to provide neighborhood amenity and aesthetic benefits, though maintenance expectations are decreased in these areas compared to small urban woodlots.

Costs

Costs associated with planting medium urban woodlots are similar to the costs for small urban woodlots, consisting of installation costs including trees, mulch, clearing and grubbing, tilling, topsoil, grading, and understory seeding and maintenance costs including regular mowing, raking and disposing of leaves and debris, pest control, and tree pruning and thinning or removal of dead individuals. TGD has estimated the costs for installing and maintaining forested retention BMPs, a similar BMP to our urban woodlots that incorporates tree plantings and retention space; however, since the woodlots proposed in this project are planted with bare root stock rather than ball and burlap trees, we anticipate that installation costs per acre will be significantly reduced compared to these estimates. Detailed information on the costing tool developed by TGD can be found in Appendix X.

Figure III-20. Base condition for medium urban woodlot: 10-20 contiguous vacant parcels.

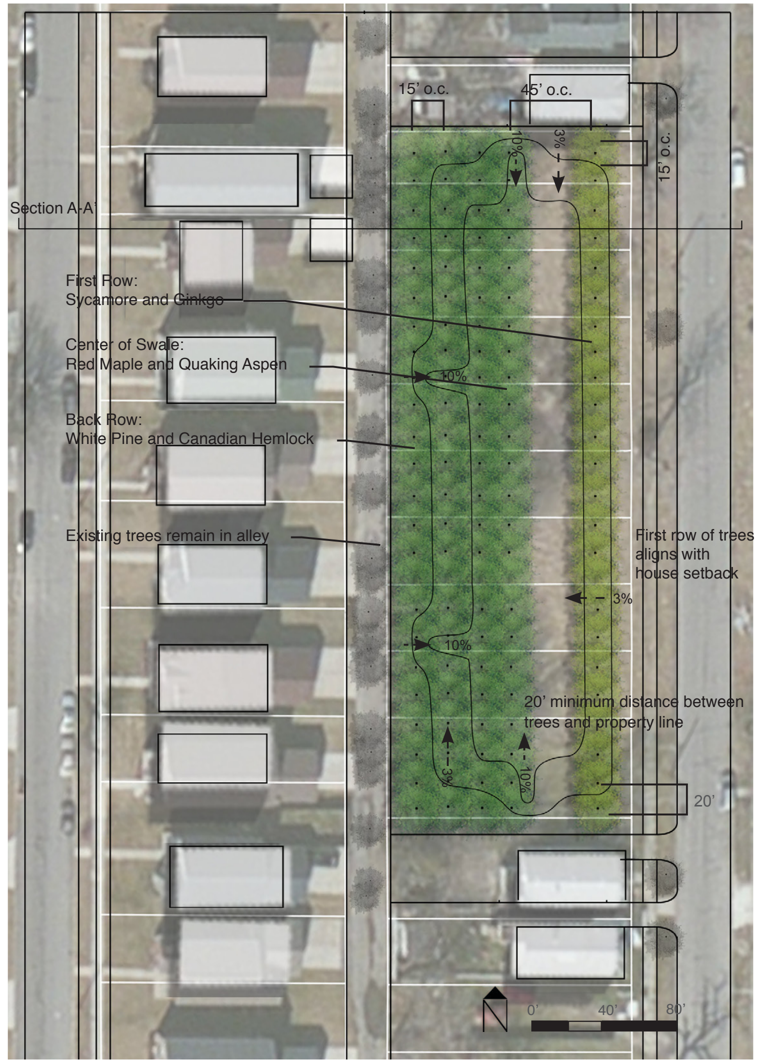


Figure III-21. Medium urban woodlot.

Figure III-23. Contiguous parcels within a medium urban woodlot may be located on either side of an alley. Existing trees remain in the alley.

Figure III-22. Base condition for medium urban woodlot: 10-20 contiguous vacant parcels.

Large Urban Woodlot

Site Requirements

Large urban woodlots are planned for 21 or more continuous vacant parcels. Vacant parcels may be adjacent to each other or located on either side of an alley. Due to the dense nature of the tree plantings and fewer provisions for safety and visibility, large urban woodlots are only located within the CDAD Naturescape typology planned for areas of very low population density where naturalized areas are expected.

Description

Extensive vacant areas within CDAD Naturescape areas maximize the benefits of urban forests as highly effective stormwater management BMPs through dense plantings that occupy a greater proportion of the vacant parcels than small or medium urban woodlots. Trees are planted on a 15-foot by 15-foot grid. No space is provided between the first and second rows in order to maximize canopy interception and rainwater infiltration into the soil.

Shallow grading maximizes stormwater capture within the site, and may extend across alleyways to a total depth of one foot. Side slopes at 3% and small swales at 10% slopes connecting to adjacent parcels similar to smaller woodlots are also utilized on large urban woodlots. Twenty-foot spacing between trees and adjacent property lines is also maintained to allow for visibility and prevent root damage to basements.

Once again, a diverse mix of species is established within the large urban woodlot to encourage climate change adaptation, increase habitat for native fauna, and protect woodlot stormwater management function against diseases affecting certain tree species. The rows of trees closest to the street remain street trees, and conifers are located toward the back of the woodlot to maintain as much visibility as possible through the lot. Large urban woodlots are expected to be low-maintenance and incorporate fewer cues to care than woodlots in more densely populated areas.

Stormwater Capacity

Stormwater capacity for large urban woodlots is calculated in a similar manner to the stormwater capacity for small urban woodlots, including the contributions of both basin capacity and transpiration of water by trees.

Non-Stormwater Benefits

Since large urban woodlots are located in areas of the LEAP district with extremely low population, their primary non-stormwater benefits are the additional contributions to local ecology and climate change adaptation provided by urban forests, including improvements to air quality, carbon storage and sequestration, enhanced animal and plant habitats, and improvements to soil quality. (U.S. Forest Service, 2010). Due to their low maintenance expectations and relatively low visibility, large urban woodlots have been designed to maximize provisional and regulating ecosystem services and contribute to neighborhood aesthetics and perceptions of care and safety in a more limited manner generally restricted to exterior views of the woodlot.

Costs

Similar to both types of smaller urban woodlots, costs for large urban woodlots include installation costs including trees, mulch, clearing and grubbing, tilling, topsoil, grading, and understory seeding and maintenance costs including regular mowing, raking and disposing of leaves and debris, pest control, and tree pruning and thinning or removal of dead individuals. TGD estimates the cost per acre of forested retention areas are detailed in Appendix x. Installation estimates for these BMPs is reduced due to the use of bare root stock rather than ball and burlap trees.

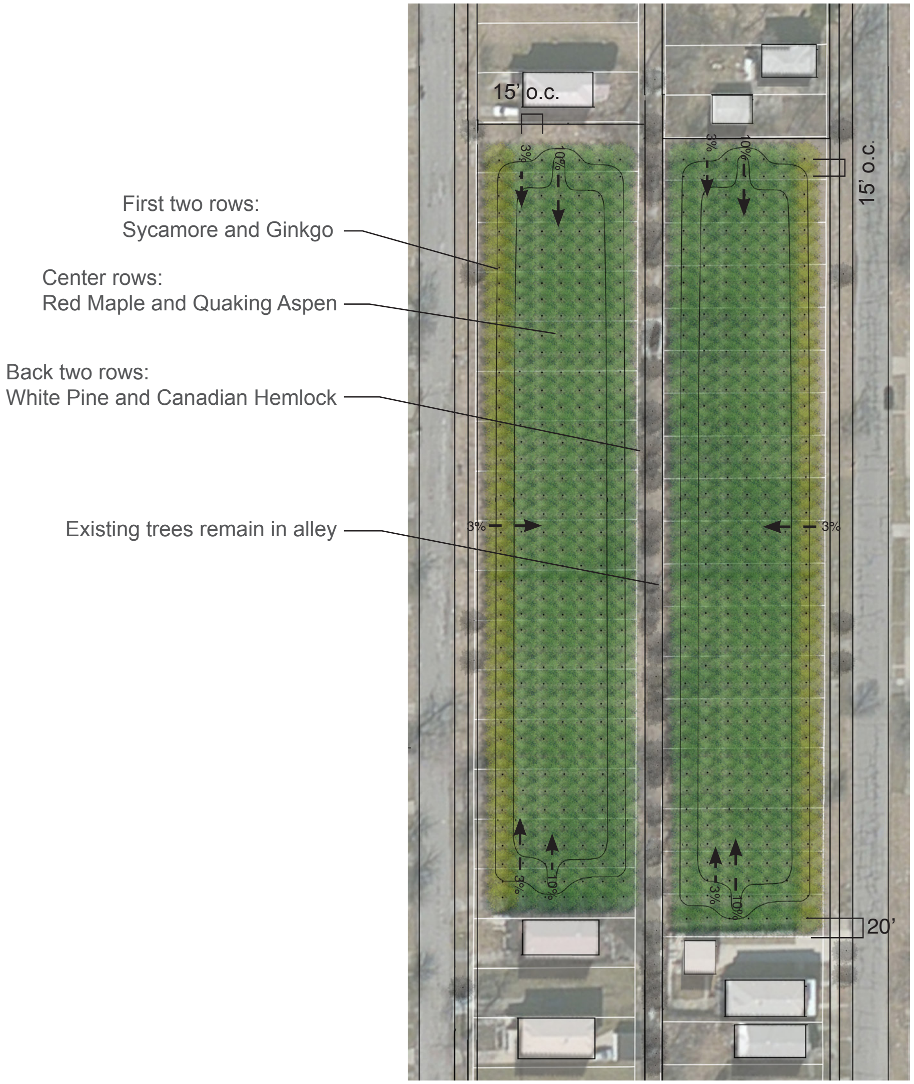


Figure III-24. Large urban woodlot in CDAD Naturescape typology.

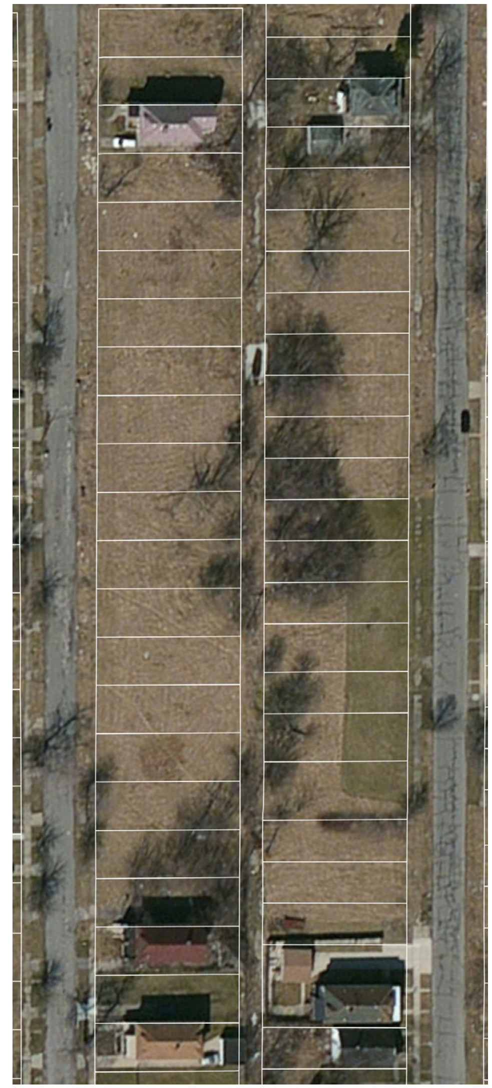


Figure III-25: Base condition for large urban woodlot: more than 21 contiguous vacant parcels.

Summary of BMP Non-Stormwater Benefits

Non-stormwater benefits of green infrastructure BMPs are a critical consideration in the development of BMPs for this project. Non-stormwater benefits contribute to the acceptance, maintenance, and longevity of BMPs within lower eastside communities by stacking benefits to the neighborhood into these installations, with particular emphasis on perceptions of care and safety. Non-stormwater benefits have been compiled from research on traditional BMPs and also draw heavily on green infrastructure proposals and assessments for the city of Detroit, including The Greening of Detroit’s 2011 “Planning and Beginning Reforesting of Detroit Using Strategic Ecological and Environmental Analysis” and the Center for Neighborhood Technology’s 2010 green infrastructure guide. Benefits are also derived from our research on safety and cues to care in legacy cities.

	Air Quality	Increased Habitat	Reduced Energy Demand	Carbon sequestration	Soil Quality	Perception of care	Perception of safety	Neighborhood Signature Character	Improves Community Cohesion	Improves aesthetics
Infiltration Garden	•					•	•	•		•
Cistern			•						•	
Bioretention Garden	•					•	•	•		•
Small Urban Woodlot	•	•	•	•	•	•	•	•		•
Medium Urban Woodlot	•	•	•	•	•	•	•			
Large Urban Woodlot	•	•	•	•	•					

Table III-2. Comparison of non-stormwater benefits of proposed BMPs.

IV. Urban Stormwater Spatial Analysis

We developed two models to analyze how the novel BMP's that we created could contribute to stormwater management in the LEAP area. First, we developed a hierarchical model to identify the most suitable locations for each of the six types of BMPs described in Chapter 3. The BMP Siting Model considers the number of contiguous vacant parcels, likely demolition sites, and location within a Naturescape CDAD type to find the most suitable locations for each of the 6 types of BMPs. The analysis unit in the Siting Model is to the parcel.

Second, we developed a suite of Hydrologic Performance Models to quantify stormwater run-off and to compare the amount of stormwater with the capacity of BMP's. The Hydrologic Model focuses on the effect of surface imperviousness, soil perviousness, and terrain features on stormwater flow. It operates in four steps. First, the model segments the urban study area into very small catchments (ranging in size from 4 square feet to 763,428 square feet – generally about .5 blocks to 1.5 blocks). Second, employing a sensitivity analysis, the model calculates the stormwater run-off generated by each catchment for three different storm events and six different estimates of surface imperviousness, demonstrated in table XX. (put a table THEM HERE). Third, it calculates the stormwater management capacity of BMP's located within each small catchment in the BMP Siting Model. Finally, it compares the run-off generated for each storm with BMP capacity within that small catchment. This allows the models to:

1. Demonstrate the spatial relationship between BMP capacity and stormwater runoff.
2. Calculate the overall quantitative relationship between BMP capacity and stormwater run-off within the LEAP area.

Hydrologic Model: Relationship to EPA SUSTAIN Model

SUSTAIN, or the System For Urban Stormwater Treatment and Analysis Integration Model (EPA, 2013b) was developed by the EPA as a decision support system to facilitate selection and placement of Best Management Practices (BMPs) and Low Impact Development (LID) techniques at strategic locations in urban watersheds. The model is also utilized by watershed and stormwater practitioners to develop, evaluate, and select optimal BMP combinations at various watershed scales on the basis of cost and effectiveness. SUSTAIN includes seven modules: Framework Manager, BMP Siting Tool, Land Module, BMP Module, Conveyance Module, Optimization Module, and Post-Processor.

These modules are developed to answer the following questions:
- Where, what type of, and how big should BMPs be?
- What are the most cost-effective solutions for meeting water quality and quantity objectives?
- How effective are BMPs in reducing runoff and pollutant loadings? (US Environmental Protection Agency, 2013)

Our goal in this project is to determine the most suitable placement for each green infrastructure BMP based on terrain factors, landuse/land cover, soil, and drainage area. In order to calculate the quantity of stormwater that can be managed through planned BMPs, we performed a trial of the BMP Siting Tool in the SUSTAIN model. The result of the Siting Tool for the LEAP study area proved unsatisfactory for the following reasons:
- Test results showed raster layers were locked in the BMP siting selection process. The reason for this complication is unclear to the GIS analysts. Initial analysis using the Siting Tool in SUSTAIN with the sample data provided by the EPA proved useful and effective. Through a trial with the sample data provided with the program, SUSTAIN demonstrated its feasibility for use on a small urban region with relatively coarse resolution data. However, the data available for our project was a higher resolution, which requires much more storage space and computational power. In order for the high resolution data to be useful in our project, the study area would need to be divided into smaller sections and each section independently run using the Siting Tool. Using this method, the analysis would require much more time and computing power.
- SUSTAIN does not satisfy the project's spatial needs. The spatial unit of analysis of this project was the parcel level, which is not a feasible input for the Siting Tool.
- The SUSTAIN Model has strict requirements for input data. Selection results rely heavily on specific data sets such as the percent of impervious cover and hydrologic soil groups which need to be in a specific format. However, detailed soil data is lacking in the study area and the impervious cover is at a different scale from SUSTAIN's criteria. Even though related data can

be found (e.g. print maps), many more steps, including digitalization and conversions, are needed to meet input data requirements. Too many functional assumptions would need to be made for meeting requirements of input data, as the GIS analysts are not familiar with the multitude of models that are combined within SUSTAIN.

- Not all of the BMPs developed by the project team, including all woodlot BMPs, did not directly match a BMP from the siting tool. The BMPs used in the project were designed for Detroit to specifically address large quantities of vacant land. As such, many were not typical of traditional BMPs, which commonly address issues in more densely developed areas.
- SUSTAIN requires a Windows XP operating system and ArcMap 9.3. Neither operating platforms is the most current version. The current operating systems are Windows 7 and ArcMap 10.1.This requirement proved to be a challenge for data analysis using SUSTAIN.

As a result of these many complications and challenges, SUSTAIN was not used further in this project.

The focus of our project is distinct from that of the SUSTAIN Model. The SUSTAIN siting tool can be used to combine 9 input datasets: a digital elevation model, land use, impervious percentage, streams, urban land use, hydrologic soil type, land ownership, roads, and ground water depth. This project focuses on siting analysis of surficial water flow of stormwater, which is a basis of our design and planning of stormwater green infrastructure. However, SUSTAIN's green infrastructure siting is related to ground water change, which plays a more important role in the consideration of siting factors. This is demonstrated by the successive steps such as pollutant simulation and chemical loading process simulation, the main purposes in the SUSTAIN Model. After careful consideration, we determined that adapting the SUSTAIN Model for our purposes was not efficient for this project.

Despite the decision to not use SUSTAIN, it offers some insight for resolving the BMP siting issue that we were able to use. We were able to adopt some aspects of SUSTAIN which were used in our hydrologic model for the LEAP area.

- Since BMP location suitability is based on analyzing surficial water flow, our spatial analysts implemented a hydrologic model similar to a step in the SUSTAIN process. Using the Arc Hydro tool, the LEAP district was segmented into the smallest possible catchments. To create the catchment areas, high-resolution DEM data and linear road data were used as inputs to the hydrology model.
- Elevation is an important factor in determining water flow direction and confluence in the SUSTAIN Model, and therefore a DEM is necessary in calculating a water network. A two-meter high-resolution DEM was selected because the LEAP study area is an urban area and the terrain is relatively flat. A course resolution DEM cannot show topographic relief of urban areas and a finer resolution was needed.
- The ArcHydro analysis tool typically uses stream data as the network input. Since there is no surficial stream in our urban study area to break up the flow of water, we used the assumption that roads could serve as the linear network that affects water flow.

BMP Siting Model

This portion of the project developed as a result of testing the EPA SUSTAIN siting module for BMPs and the land-based green infrastructure designs, a superior option compared to traditional green infrastructure approaches for Detroit. Parcels were chosen as the spatial unit of analysis for this project based on availability of the 2009 Detroit Residential Parcel Survey (DRPS). This survey classified 350,000 residential parcels in Detroit that met the following criteria of being either a single-family home, duplex, or multi-family structure up to four units. While this is not a comprehensive study of every parcel in Detroit, it addresses a large area of the city that is heavily subjected to vacancy, a focus of the survey. Classification of parcels included the housing type, the condition of existing houses, house vacancy status, and lot vacancy status (Detroit Collaborative, 2009).

In order to use this data for BMP siting, a number of assumptions were established. The first assumption is that houses with a condition listed as either "poor" or "demolish" could be considered for demolition, a common practice in the aging city with the increase in vacancies. Poor condition homes, referred to in the DRPS as condition 3, are characterized by major exterior damage with extensive repairs needed, and may not be structurally sound. Demolish condition homes, referred to as condition 4 homes, are not structurally sound (Detroit Collaborative, 2009). We consider all of parcels within either of these conditions available for potential green infrastructure utilization.

Methodology

BMP siting was accomplished using hierarchical classification in conjunction with green infrastructure design parameters set by the design team. Three categories were designated: infiltration trenches, bioretention areas, and varying sizes of urban woodlots.

The first step in the mapping process for BMP siting was to select all of the 3 and 4 condition houses and create an aggregated layer (referred to here as "blocks"). Within a block, all 3 or 4 condition parcels are combined into one shape to get the layer of potential demolitions. All of the parcels that had vacant lots were selected and aggregated using the same process. Blocks of 3 and 4 condition houses that shared a boundary with the vacant lots were then selected and added to the vacant lot blocks adjacent to them.

An intersect analysis was performed in ArcGIS to determine the count of parcels within each block. Based on the number of parcels in each block, the aggregated parcels were assigned a BMP. Starting from the highest number of adjacent parcels needed to constitute a BMP, the sites with more than 20 parcels were selected to be the largest urban woodlots. From the remaining blocks, 10-20 parcel sections were selected to be medium urban woodlots; then 4-9 parcel blocks were selected as small urban woodlots. Where there were only 1-3 vacant parcels in a block, the area was selected as a bioretention zone. Some locations had multiple 3 or 4 condition houses to be demolished in a row (2-4 parcels), which were designated for use for a multi-trench infiltration garden. Areas with just one parcel containing a 3 or 4 condition house were selected as a single site infiltration trench.

Cisterns are a subset of the single site infiltration trenches given local need and support. Single site infiltration trenches within 80 ft. of good condition, occupied houses were selected as potential cisterns. Figure IV-1 gives an overview of this process.

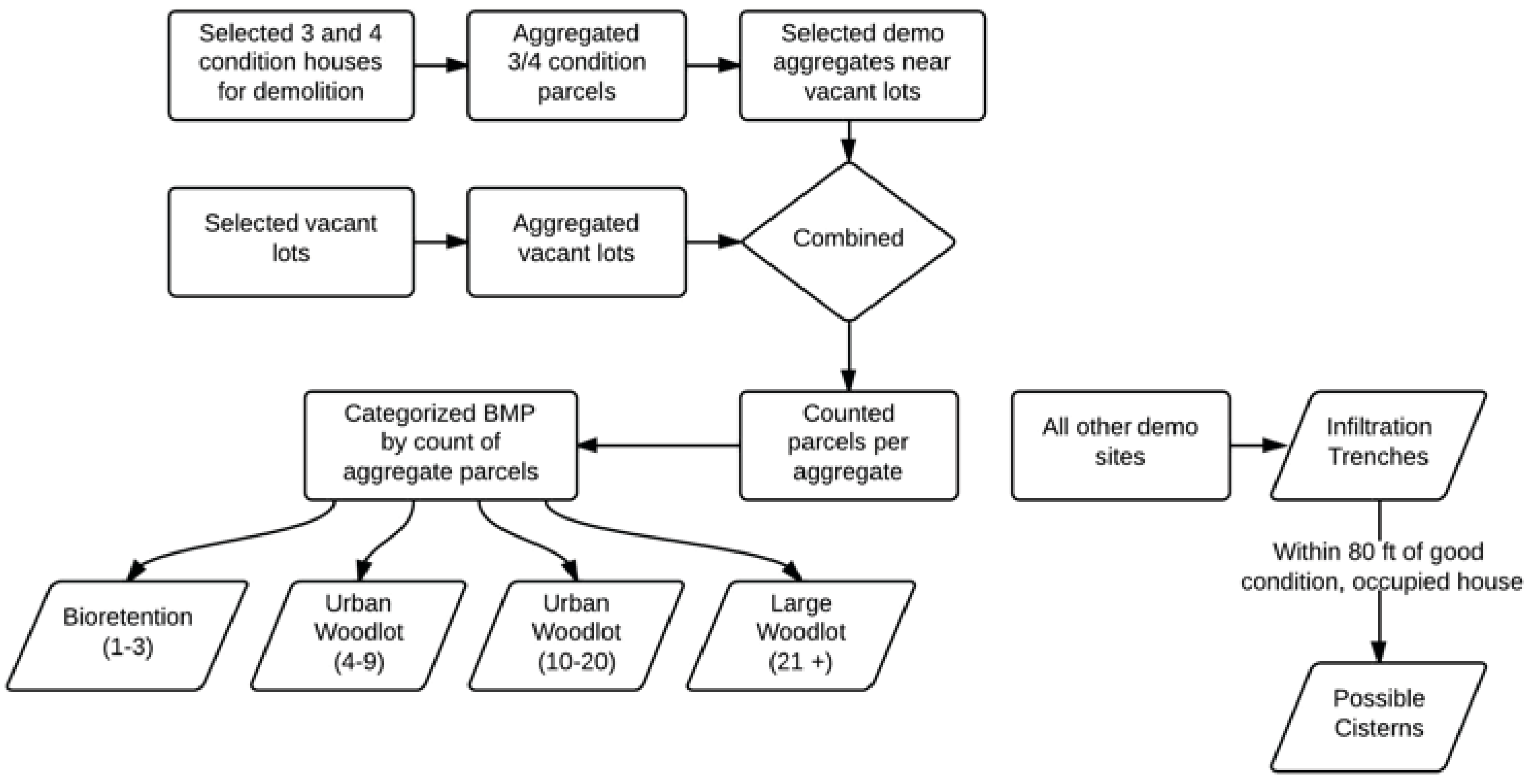


Figure IV-1. GIS analysis process for BMP siting.

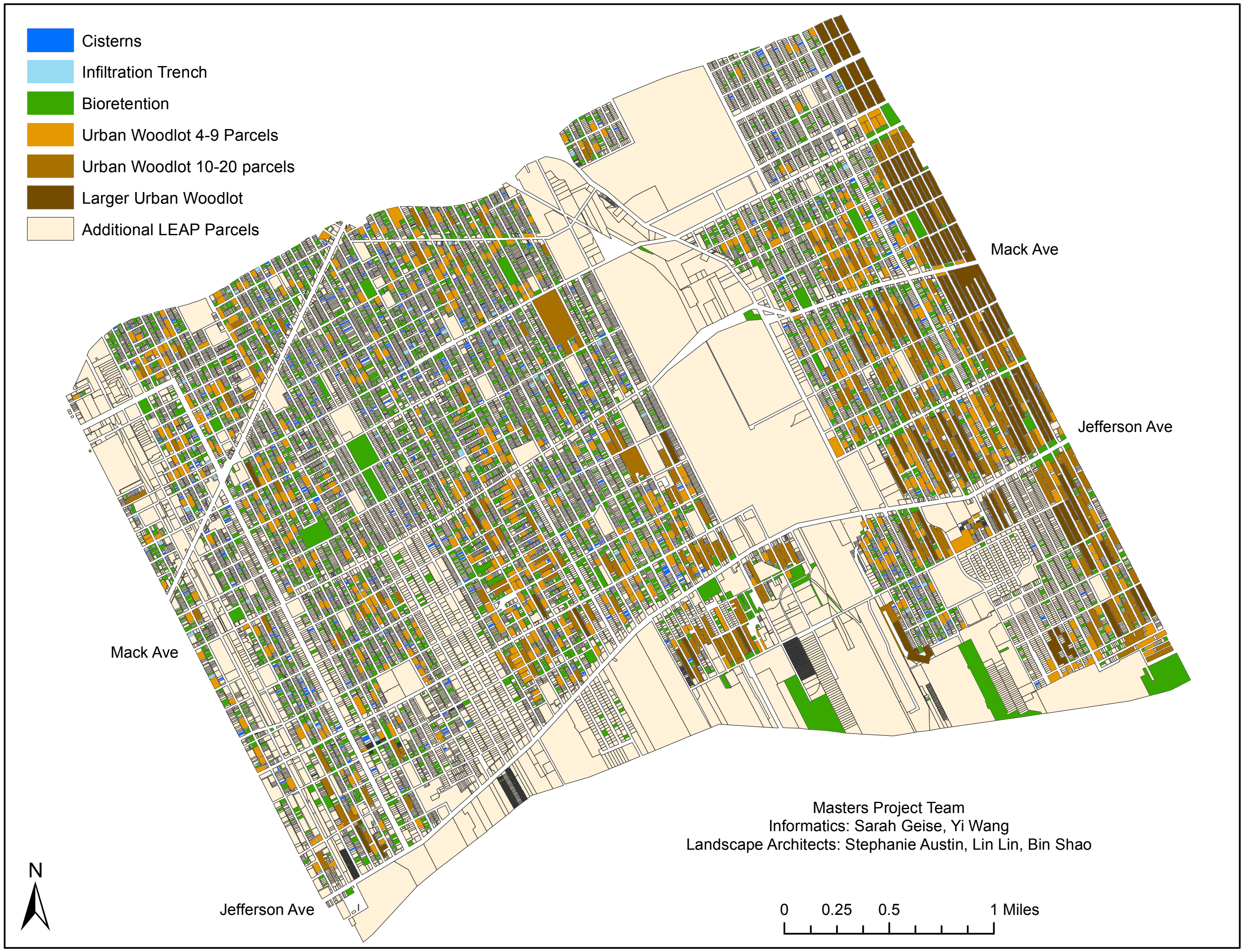


Figure IV-2. BMP siting within LEAP District

Results

The entire LEAP study area consists of 38,473 parcels. Of those, 1356 include poor or demolish condition (3 or 4 condition) houses and 15,877 are unimproved vacant lots. Overall, 102 sites are available for large urban woodlots, 237 sites aggregated between 10 and 20 parcels for medium urban woodlots, and 637 sites were suited for 4-9 parcel small urban woodlots. The BMP with the highest number of sites was the bioretention garden, with 3053 locations. Table x lists the full results of the total area of sited BMPs.

A large number of infiltration gardens were also sited. Only 54 sites could be used for multiple infiltration gardens but 352 sites are suitable for single parcel infiltration gardens. The majority of the single-parcel infiltration gardens would also be suitable for cisterns if local property owners wished to install and utilize a cistern.

The BMP results were overlain with the locations of CDAD Naturescapes to allow for comparisons between the areas that the community has indicated should be relatively depopulated and woodlots sited by this analysis. Urban woodlots are ost prominent on the eastern side of the study area, and a large number of urban woodlots of varying sizes were indeed sited within blocks designated as Naturescapes. The coincident location of woodlots and Naturescape areas indicates that the siting method for woodlot BMPs is relatively well aligned with the Future Directions Plan.

BMP Type	Total Area in LEAP District (square feet)	Total Area in LEAP District (acres)
Bioretention Garden	25910814	594.8
Infiltration Garden	1761312	40.4
Small Urban Woodlot	16157168	370.9
Medium Urban Woodlot	13168176	302.3
Large Urban Woodlot	10685960	245.3

Table IV-1. Calculated BMP areas for entire LEAP District.

Figure IV-3. BMP siting within CDAD Naturescape

Discussion

While the BMP siting method suggests that there are large areas of contiguous vacant land, there are some potential discrepancies between this data set and comparative analyses. Due to the fact that DRPS data is from 2009, we anticipate that there will be differences between the survey and aerial photographs found on public sites including Google Maps and Bing Maps. Because data collection for the survey was performed by volunteers, quality control was limited and larger errors were possible. Some blocks in the LEAP area with large numbers of lots designated as vacant by the 2009 Residential Parcel Survey appear to include numerous buildings when compared with aerial photos from both public mapping sources. These discrepancies primarily occur in the northeastern region of LEAP. While the DRPS may not be the most accurate and up-to-date data, it is the most comprehensive dataset available for the parcel level in Detroit. This project moves forward acknowledging that a level of error exists. Despite possible errors in data collection for the Residential Parcel Survey, ground knowledge suggests this is the most vacant area within the study, and therefore we assume that large urban woodlots may still be installed in this area.
.
This project has implications for the city as a whole in addition to the LEAP study area. Because the DRPS was performed city-wide, this GIS-based siting methodology could be scaled up and applied to the entire city. If these methods prove effective at test sites within the LEAP study area, the siting methodology presented here may also be a tool to help argue for changes to the policy on housing demolitions. Currently, the Detroit Buildings, Safety, Engineering and Environmental Department require that all demolished buildings be backfilled to grade level (City of Detroit, 20xx). In order for infiltration trenches to be an operational BMP this policy would need to be altered. Updates could potentially include a clause to leave basements/foundations intact and a clause negating the need for backfilling when green infrastructure BMPs are planned at the site in advance of demolition. The infiltration trench BMP currently calls for gravel infill, but other possible substrates such as sand and amended soil that could be used as fill. These alternative fill methods could provide additional micro-habitat types for growth of a greater variety of native species. Our second proof-of-concept site, Hantz Woodlands, explores this idea to provide a community learning resource.

Hydrologic Performance Models

Our Hydrological Performance Model considers only the surficial water flow, which can be effectively affected by elevation of terrain. A Digital Elevation Model (DEM) of study area is an important input data in this model. The actual and overall terrain of this region is relatively flat, so a typical coarse DEM cannot delineate the small terrain fluctuations. Consequently, we used a Lidar DEM with a spatial resolution of two feet, which can clearly delineate terrain features of urban area.

The second important input data is linear data. The first step in the model modifies a raw DEM by imposing linear feature onto it. Because the LEAP study area has no surficial streams, the influence of artificial infrastructure is more important than terrain fluctuations. In order to better simulate actual stormwater movement, we used road alignments as the linear features rather than a stream network to modify the high resolution raw DEM.

All the modeling steps are completed in Terrain Preprocessing in Arc hydro 10.1, which is an extension tool in ArcGIS and is used to delineate and characterize watersheds in raster and vector formats, define and analyze hydro geometric networks, manage time series data, and configure and export data to numerical models. The modeling process is described in a flow chart in Figure IV-4. A surficial water flow model in ArcGIS 10.1 is built based on this flow chart and can be used for future hydrologic modeling.

Catchment Delineation

Stream Definition computes a stream grid which contains a value for all the cells in the input flow accumulation grid that have a value greater than the given threshold. This is critical in determining the size of the catchment. A small threshold results in small polygons, a large number of catchments with small sizes. A sensitivity analysis is applied in this step to find the suitable threshold for sizes of catchments that are relevant to the design and management questions. After experimenting with a range of threshold values and checking the result of sizes and number of catchments, we chose 10000 cell number as the definition threshold.

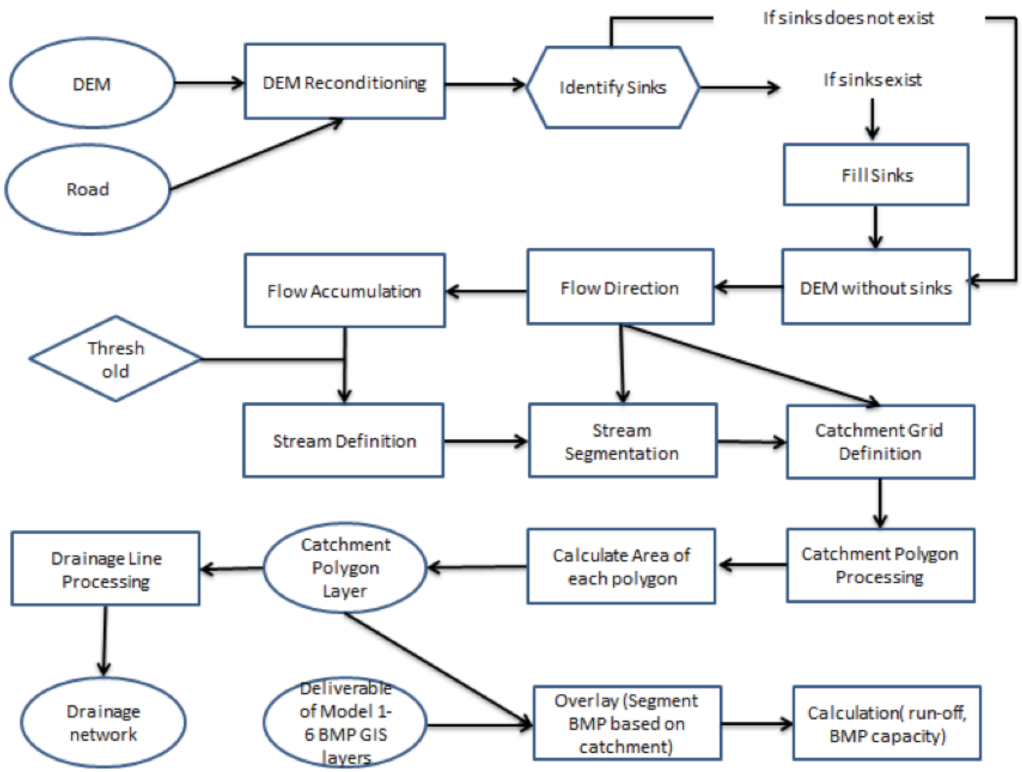


Figure IV-4. Flow chart of hydrologic modeling process.

Untreated Runoff Volume

Having delineated the catchments, we calculated the total original water runoff of each catchment based on Hershfield (1961) calculated two year, ten year and one hundred year storm events. The original runoff in each catchment is referred to as "untreated" by the BMPs for the purposes of this report. The spatial unit in all calculations is the catchment. The calculation is divided into three phases:

Calculation	Phase 1	Phase 2	Phase 3
Result	Original Runoff without BMP	Total BMP Capacity	Final Runoff with BMP

The unit of storm water runoff in each calculation is cubic feet per second. We use the ten-year storm water event as an example calculation.

Duration	**Intensity**	**Intensity per hour/iph**
30min	1.4	2.8
1hr	1.8	1.8

Table IV-2. The Michigan 10-year stormwater event for durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years, (Hershfield, 1961).

The rational method is used to calculate how much water will flow off a certain watershed in a given storm water event:

$$Q=(C)(i)(A)$$

Where:
Q= Peak rate of runoff in cubic feet per second (cfs);
C = Coefficient of Runoff (between 0 and 1);
i = Intensity of the storm, rainfall intensity, inches per hour (iph) for the design storm frequency and for the time of concentration of the drainage area;
A = Area of the Catchment (acres).

The coefficient of runoff is a dimensionless decimal that represents the ratio of runoff to rainfall. It is related to interception, infiltration, evaporation, depression storage and degree of imperviousness. A larger coefficient of runoff represents landcover and soil characteristics that cause a higher proportion of stormwater to run-off in any given storm event.

For the 10-year 30 min storm, i= 2.8 iph in 30 minutes event from table 1, so 10-year 30 minutes peak rate of runoff:

$$Q = CiA = C \times 2.8 \times A = 2.8AC \text{ cfs}$$

The storage volume required for 10-year 30min storm event is:

$$\text{Volume (10-year 30min)} = 2.8\ AC \times 30\text{min} \times 60\ \text{sec/min}$$
$$= 5040\ AC\ \text{ft3}$$

For the 10-year 60 min storm water situation, i= 1.8 iph in 60 minutes event from table 1, so the 10-year 60 minute peak rate of runoff is:

$$Q = CiA = C \times 1.8 \times A = 1.8AC \text{ cfs}$$

The storage volume required for 10 year 1 hour storm event is:

$$\text{Volume (10-year 30min)} = 1.8\ AC \times 60\text{min} \times 60\ \text{sec/min}$$
$$= 6408\ AC\ \text{ft}^3$$

For both 30 min and 1 hour storms, we conducted a sensitivity analysis with stormwater runoff coefficients. For the value of C (coefficient of runoff), a range of three values- 0.4, 0.5 and 0.6- are used as C in the calculation of Q. A is the area in acres of each catchment polygon, as delineated in the first step of the hydrologic model. For the 10-year storm, we calculated 6 groups of untreated runoff for each catchment:

Volume (10-year, C= 0.4, 30 min)= 5040* 0.4*A (acre) ft^3

Volume (10-year, C= 0.5, 30 min)= 5040* 0.5*A (acre) ft^3

Volume (10-year, C= 0.6, 30 min)= 5040* 0.6*A (acre) ft^3

Volume (10-year, C= 0.4, 60 min)= 6408* 0.4*A (acre) ft^3

Volume (10-year, C= 0.5, 60 min)= 6408* 0.5*A (acre) ft^3

Volume (10-year, C= 0.6, 60 min)= 6408* 0.6*A (acre) ft^3

With the same method and catchment polygon data, we calculated runoff without BMPs for every catchment for 2-year and 100-year storms. In total, 18 models of runoff without BMP's are compared in our sensitivity analysis. Intensity tables for the 2-year and 100-year events are in Appendix C.

Finally, we compared the capacity of all BMP's located in each catchment by the BMP siting model with runoff calculated for all 18 storm events in a sensitivity analysis. If a BMP intersected boundaries of two or more catchments, the BMP capacity is divided into several small parts that are assigned to the catchments contain them.

BMP Capacity

The capacity of each BMP in cubic feet was calculated using the following variables:

A: area of catchment (ft2);
P: percent of segment BMP polygon area to total BMP polygon area (%); BMP polygons are segmented by boundaries of catchment;
C: capacity of BMP (ft3).
K: number of parcels in a BMP that consist of a number of adjacent parcels (dimensionless unit).

1. Cistern:
   One Cistern is assumed to have a capacity of 5000 gallons of water. *K =1*, so,

$$C\ (cistern) = 5000gallon * (0.13368\ cubic\ feet/1\ gallon)\ K*P\ (\%)$$
$$= 668.4KP\ (ft3)$$

2. Infiltration Garden:
   Length, width and height are assumed to 40 feet, 20 feet and 8 feet. *K=1*, so,

$$C\ (IT) = 20*40*8*40\%*K*P\ (ft3)$$
$$= 2560KP\ (ft3)$$

3. Bioretention Garden: In the calculation of bioretention garden capacity, the basin is simplified

to a rectilinear shape, as in the topview shown in Fig. 6a. Assume *L, W* and *H* denote length, width and height of the basin, respectively. The slope rates along the long side and the wide side are denoted by r_L and r_W.To calculate the volume using calculus, the slopes are approximated into levels by staircase discretization, the cross sections along the center of the long side are illustrated in Fig. 6b. At level *n*, we have the following properties:

1. *Height:* $H_n = H/N$
2. *Width:* $W_n = W\text{-}2nH/r_W N$
3. *Length:* $L_n = L\text{-}2nH/rLN$
4. *Volume:* $V_n = W_n L_n H_n = (W\text{-}2nH/r_W N)(L\text{-}2nH/r_L N)H/N$

The total volume (capacity) of the basin is:

$$V = \lim_{N\to\infty}\sum_{n=0}^{N} V_n$$

$$= \lim_{N\to\infty}\sum_{n=0}^{N}\frac{H}{N}[WL - \frac{2nH}{N}(\frac{L}{r_W}+\frac{W}{r_L}) + \frac{4n^2H^2}{r_W r_L N^2}]$$

$$= WLH - H^2(\frac{L}{r_W}+\frac{W}{r_L}) + \frac{4H^3}{3r_W r_L}$$

Notice that from (2) to (3), we have used:

$$\sum_{n=0}^{N} n = N(N+1)/2 \quad \text{and}$$

$$\sum_{n=0}^{N} n^2 = N(N+1)(N+2)/6$$

When the number of parcels, *K=1*, we assume *L=120, W= 35, H=1,* r_L *=3%,* and r_W*= 6%.*

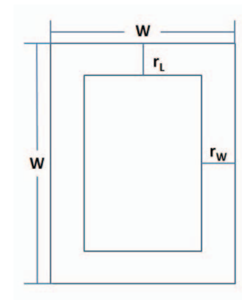


Fig. IV-6a. Bioretention garden top view.

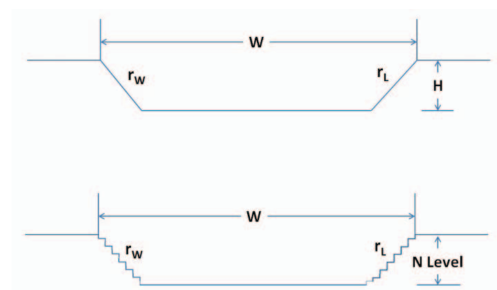


Fig. IV-6b. Bioretention garden section view.

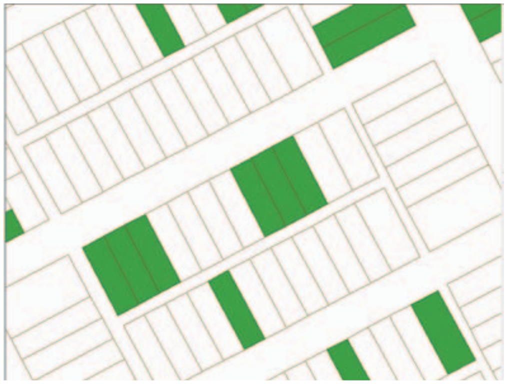


Fig. IV-7. Bioretention garden adjacent parcels.

When the long edge of two ore more parcels are adjacent to each other (when $K>1$), the width of the whole BMP is changed to $K*W$ and the length of the BMP remains as L. Because the maximum value of K is three, and the width of three parcels is 105', the width of K will never exceed L at 120'. Therefore, W and L will not need to be exchanged in the equation for calculating the capacity of bioretention gardens.

So when $K = 1, 2, 3,$

$$C(bioretention) = KWL - \left(\frac{L}{r_W} + \frac{KW}{r_L}\right) + \frac{4}{3r_W r_L}$$

$$= K*35*120-(120/0.06+K*35/0.03)+4/(3*0.03*0.06)$$

$$=[9100K/3-34000/27]P\ (ft3)$$

4. Urban Woodlots:
Urban Woodlot BMPs include three types, differentiated by size as indicated by the number of adjacent vacant parcels.

Classification	Woodlot 1	Woodlot 2	Woodlot 3
K(int)	(4, 9]	(9, 20]	(20, ∞)

The calculations for the stormwater capacity of urban woodlots includes both (1) water volume decreased through evapotranspiration by trees; (2) basin capacity.

(1). Evapotranspiration can be calculated using the Thornthwaite method (MDEQ, 2010) using 2012 precipitation and temperature data collected by the NOAA National Climatic Data Center. The results of potential evapotranspiration (PET) and estimated actual evapotranspiration (Actual PET) are summarized in table x. This project uses the potential evapotransipiration (PET) value for our calcultions of the woodlot's stormwater capacity.

Year	Month	Precipitation (m)	Temperature (C)	PET (mm)	Actual ET (mm)	PET (ft per ft^2)
2012	1	58.63	0	0	0	0
2012	2	25.63	0	0	0	0
2012	3	67.51	7	30.6	30.6	0.100393701
2012	4	48.48	6.44	30.24	30.24	0.099212598
2012	5	72.59	14.67	86.94	86.59	0.28523622
2012	6	76.9	18.83	115.2	111.9	0.377952756
2012	7	90.86	22.83	147.06	135.86	0.482480315
2012	8	74.87	19.56	115.2	103.87	0.377952756
2012	9	62.94	14.56	71.76	67.94	0.235433071
2012	10	121.57	8.61	37.05	37.05	0.121555118
2012	11	26.9	2.33	7.29	7.29	0.023917323
					Total	2.104133858

Table IV-3. Evapotranspiration estimates for urban woodlots.

Here A is the area (ft^2) of every urban woodlot.
So C *(Evapotranspiration)* = PET *(ft)*A'* *(ft^2)*P* =2.104A'P *(ft^3)*

(2). Basin capacity is calculated using same formula as for bio-retention capacity. K in all types of urban woodlots is larger than 4. When *K*=4, *K*W= 4*35=140>L*, so therefore the calculations for the basin capacity of urban woodlots must exchange *W* and *L* in the formula so that the value of *W* is less than *L*. The new formula is:

When $K>4$, $C(Basin)=\left[KWL-\left(\frac{KW}{r_W}+\frac{L}{r_L}\right)+\frac{4}{3r_W r_L}\right]*P$
$= K*35*120-(K*35/0.06+120/0.03)+4/(3*0.03*0.06)$
$=[10850K/3-88000/27]P(ft^3)$

So the capacity of an urban woodlot in each catchment is:
C *(woodlot)* = C *(Evapotranspiration)* + *C(Basin)*
$= 2.104AP\ (ft^3) + [10850K/3-88000/27]P\ (ft^3)$

Results

5. Total BMP Capacity
   Total BMP capacity in each catchment is sum of the capacity of all 6 types of BMP for all BMPs that are inside or intersect with boundary of a catchment.

In total, the number of small catchments delineated within the LEAP area was 4792. The spatial unit for all subsequent calculations is each catchment. This discussion focuses on results of three phases- untreated stormwater runoff without BMPs (Phase 1), BMP capacity (Phase 2) and treated stormwater runoff with BMPs (Phase 3) from both the perspectives of statistical quantitative comparisons and spatial distribution.

Phase 1

Untreated stormwater runoff without BMPs was calculated on all 4792 catchments. We analyzed the distribution of the 4792 results in every group (18 groups in total) by examining peak stormwater volumes distributed across 11 classes. Because 6 groups of results in one kind of storm water event (e.g. 10-year storm water event) must be compared to see how the runoff varies for all models in the sensitivity analysis, the same classification scheme is applied to all groups of untreated runoff. Results of untreated runoff in 10-year storm water event, 30 minute duration time and 0.4 runoff coefficient are chosen as baseline classification. This event is classified into 10 classes using the natural breaks method. For each of the other 5 groups of untreated runoff results, the classification scheme of the first 10 classes is the same but the 11th class is added and represents the runoff greater than maximum runoff in baseline group (10-year, 30min, C=0.4). The 11th class of baseline (10-year, 30 minute, 0.4 runoff coefficient) group is 0.

The number of catchments in 11 classes of untreated runoff in cubic feet in 18 groups of 10-year, 2-year and 100-year storm water event data is summarized in table IV-4. The line graph in figure IV-8 indicates the distribution of stormwater runoff among the catchments; peaks in the lines on the graph represent the most common quantities of runoff for each storm event scenario.

From the maps shown in Figure IV-9, the spatial mode of change among the 18 storm event scenarios is clear and matches the trend of changes shown in the line graphs. In order to better identify the overall changes in spatiality, 11 classes are merged to 7 classes. In these scenarios, catchments that are identified in blue experience higher volumes of runoff.

Untreated stormwater runoff results for the 2-year and 100-year storm events are listed in Appendices D and E.

10-year Storm Water Event		Number of Catchments					
Categories	Class	C=0.4 30 min	C=0.4, 60 min	C =0.5, 30 min	C =0.5, 60 min	C=0.6, 30 min	C=0.6, 60 min
1	0-709	846	760	770	681	692	627
2	709-1780	439	387	389	361	373	329
3	1780-2936	1299	760	805	259	390	242
4	2936-4187	821	941	927	978	1015	551
5	4187-5694	547	702	696	773	719	872
6	5694-7585	408	472	470	622	574	666
7	7585-10180	226	390	382	472	459	566
8	10180-13669	126	206	187	335	300	440
9	13669-19718	62	128	124	199	182	300
10	19718-35333	15	42	37	106	83	179
11	>35333	0	5	5	6	5	20

Table IV-4. Comparison of untreated runoff from all catchments in cubic feet for 10-year storm event. The table lists the number of catchments in 11 classes of capacity for three different runoff coefficients (0.4, 0.5, 0.6) and two different time periods (30 minutes and 60 minutes).

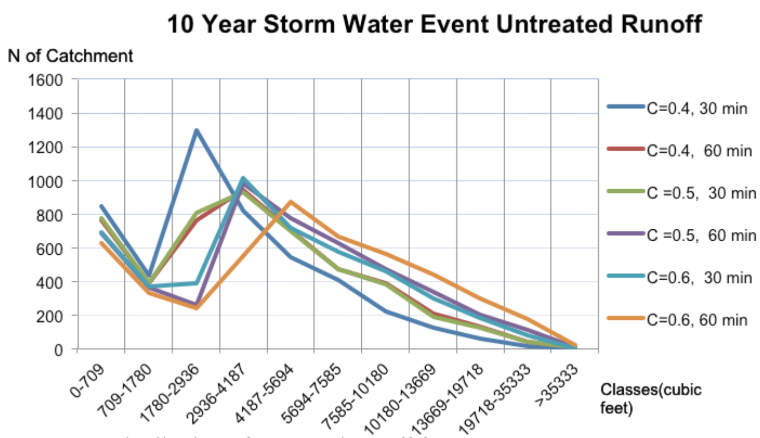


Figure IV-8. Distribution of untreated runoff for 10-year storm event. For many catchments, runoff volume clusters around approximately 1000-4000 cubic feet.

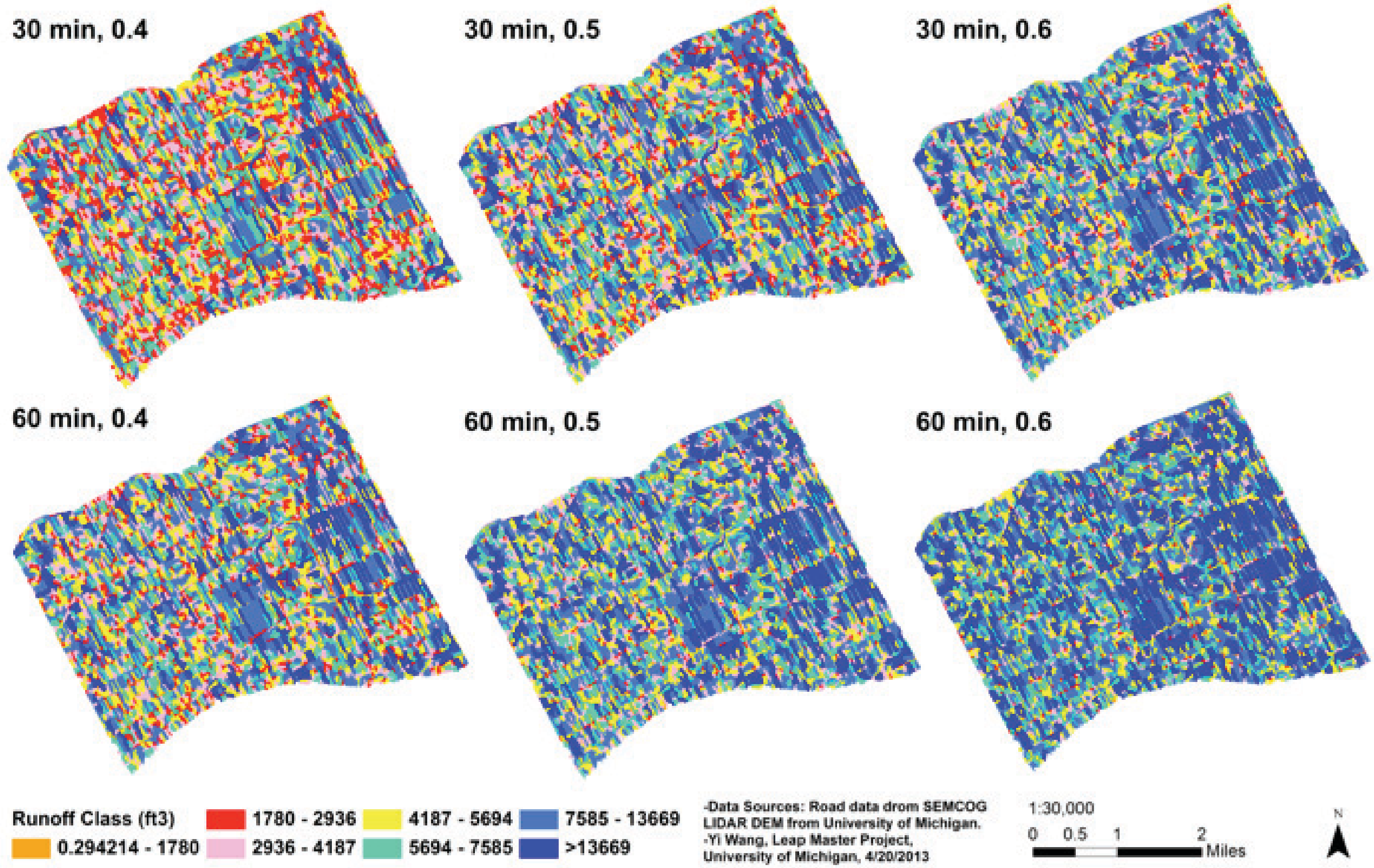


Figure IV-9. Comparison of sensitivity analysis for 10-year storm event for untreated runoff. Sensitivity analysis varies by duration of storm event and surface imperviousness.

Phase 2

Phase 2 considers the total capacity of all sited BMPs. The distribution of BMP capacity within the LEAP study area is mapped in figure IV-10. Since a BMP may not be located entirely in a catchment, the segmented BMP capacity in each catchment is calculated by the area proportion of parts of BMP inside a catchment to total area of same BMP inside and outside catchment. The calculated BMP total capacity results are classified into 8 classes. The classification scheme is shown below in table X.

Figure x maps the BMP stormwater storage capacity across the LEAP district. We see from this map that higher stormwater storage capacity is associated with the eastern side of the district, where a higher number of urban woodlots were sited using the BMP siting model. From table x we note that 2160 small catchments do not have appropriate locations for the six BMPs we developed for vacant parcels. This is almost half of total number of catchments in the LEAP area. Many of these catchments are characterized by commercial and industrial land uses.

Categories	BMP capacity Class	Number of Catchments
1	0	2124
2	0-500	338
3	500 -2000	564
4	2000-8000	489
5	8000-18000	197
6	18000-50000	546
7	50000-100000	321
8	>100000	213

Table IV-5. BMP total capacity classification in cubic feet.

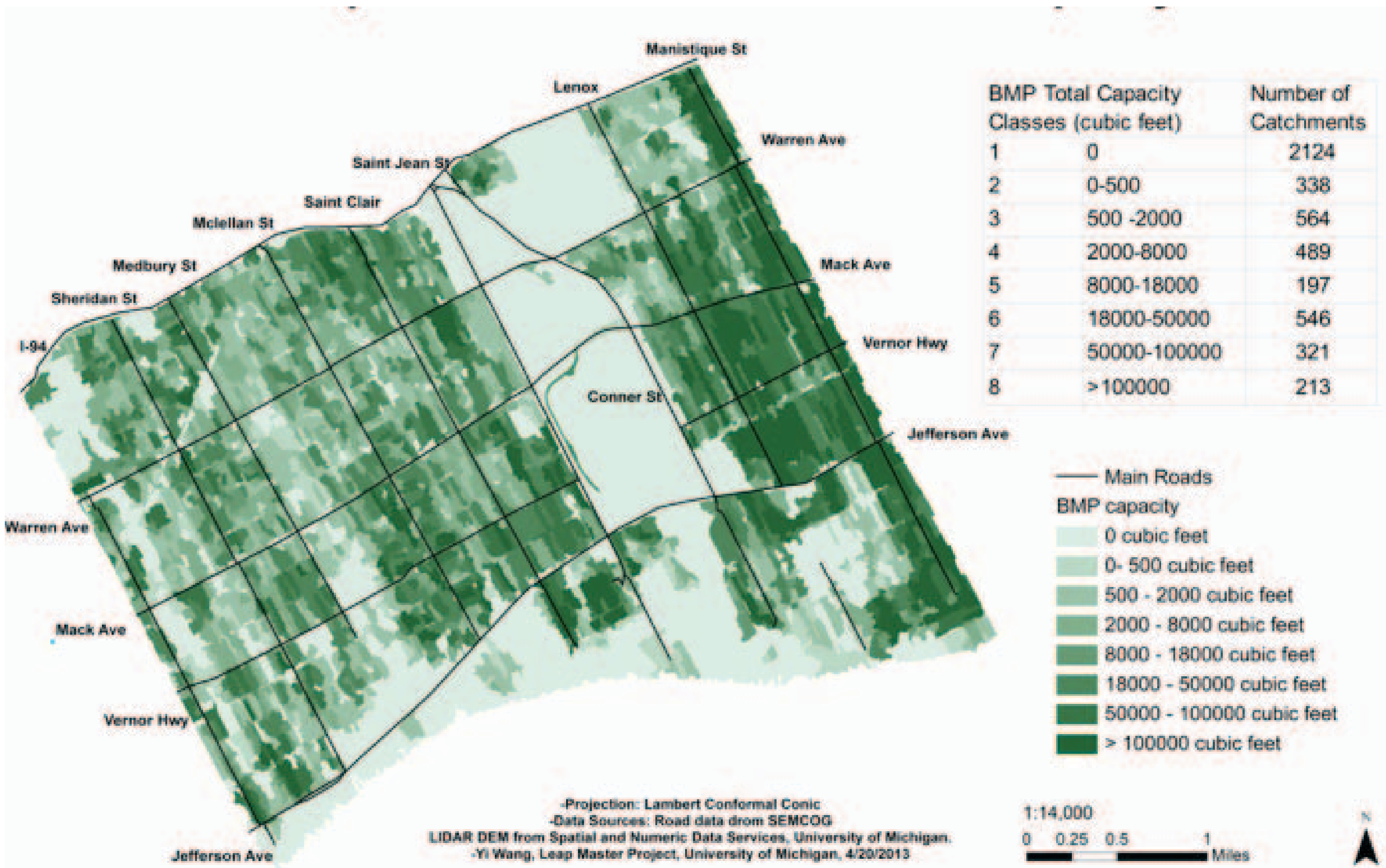


Figure IV-10. Spatial distribution of BMP total capacity for entire LEAP district.

Implementing the infiltration garden BMP is dependent on coordination with demolition activities. In order to determine the capacity of the proposed BMPs if demolitions are not included in the district as infiltration gardens, we compared the number of catchments with different overall management capacities in Figure IV-11. Based on these capacity calculations, we determined that infiltration gardens contribute a negligible amount to the total stormwater capacity of BMPs distributed within the LEAP area.

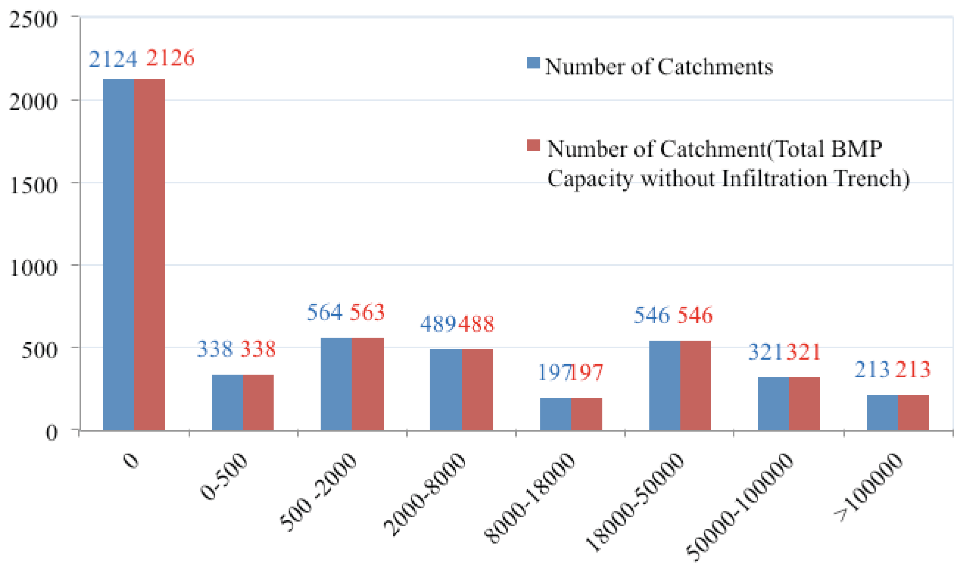


Figure IV-11. BMP total capacity with and without infiltration trenches.

Phase 3

Treated runoff is calculated by subtracting the total BMP capacity from the corresponding original untreated runoff in the same catchment. Results of the treated runoff in cubic feet of all 18 storm event groups are classified into 15 classes. The classification scheme and summary of number of catchments for the 10-year storm event are shown in table IV-6. Figure IV-12 describes the distribution of treated stormwater runoff based on the runoff from each catchment; the peaks of each line within the figure indicate the most common treated stormwater runoff volume for each storm event scenario.

Figure IV-13 maps the number of catchments that have excess stormwater handling capacity (below 0) and those that would need additional stormwater handling capacity (greater than 0) for the 10-year storm throughout the LEAP district. In order to demonstrate how effectively the BMPs manage stormwater, 15 classes of final runoff are merged into 7 classes, and original runoff is reclassified to 4 classes. Based on the trend lines from the final runoff line graph, three groups of results in each type of storm water event are selected to show the following spatiality of changes:

1. Runoff coefficient=0.4, duration time= 30min, minimum runoff situation;
2. Runoff coefficient=0.5, duration time= 60min, dramatic shift in runoff volumes;
3. Runoff coefficient=0.6, duration time= 60min, maximum runoff situation;

Maps in each scenario are shown in pairs of untreated and treated runoff, as seen in Figure IV-13. Treated runoff classes above zero on both maps are assigned the same color scheme to show where the BMPs effectively manage storm water runoff.

The results indicate that many catchments would continue to have unmet needs for stormwater handling, using only the six proposed BMPs for vacant land. It demonstrates a need to network catchments with unmet need with catchments that have excess capacity. It also suggests that conventional BMPs that do not rely on vacant land, for example rain gardens within the street right-of-way, should be utilized to augment the innovative BMPs for vacant property. The capacity available within the 2160 catchments without sites for any of the vacant property BMPs account for much but not all of the unmet stormwater capacity need.

10-year Storm Water Event		Number of Catchment					
Categories	Treated Runoff Class	C=0.4 30 min	C=0.4, 60 min	C =0.5, 30 min	C =0.5, 60 min	C=0.6, 30 min	C=0.6, 60 min
1	< -100000	191	187	187	181	184	176
2	-100000- -50000	295	294	294	289	291	284
3	-50000 - 25000	361	347	349	325	330	317
4	-25000 - -10000	317	315	316	328	326	325
5	-10000- -2000	238	206	209	186	188	176
6	-2000 - -1000	75	67	68	54	59	41
7	-1000 - 0	157	126	126	88	98	67
8	0 - 80	401	384	384	368	369	352
9	80 - 500	338	303	302	254	269	237
10	500 - 1300	396	338	346	324	334	190
11	1300 - 2300	581	342	345	291	298	254
12	2300 - 3300	512	594	610	368	430	241
13	3300 - 5000	458	559	551	697	646	675
14	5000 - 10000	391	569	550	728	707	883
15	>10000	81	161	155	311	263	474

Table IV-6. Summary of treated runoff distribution for 10-year storm event.

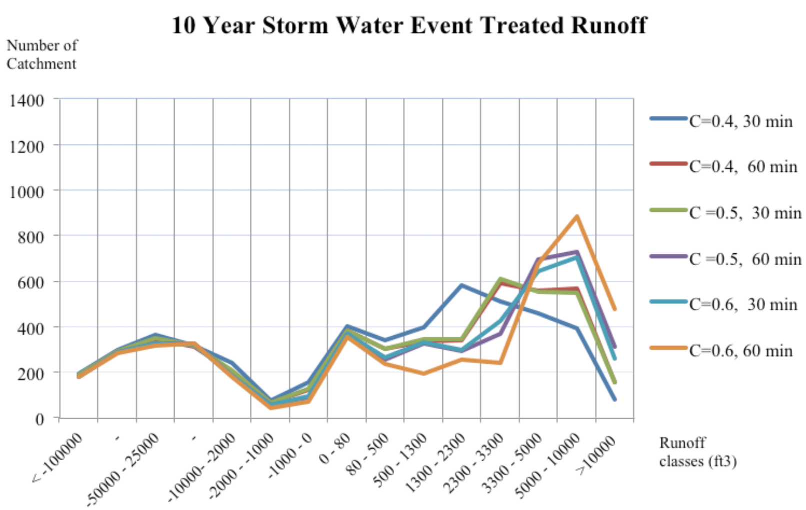
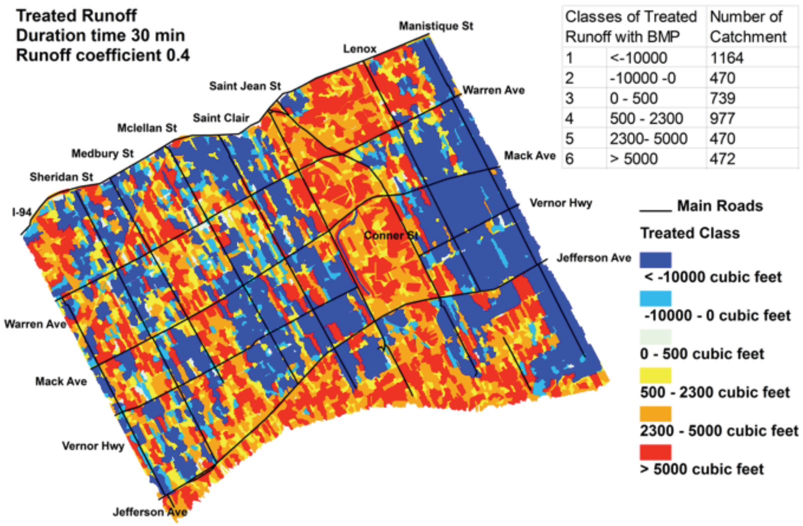
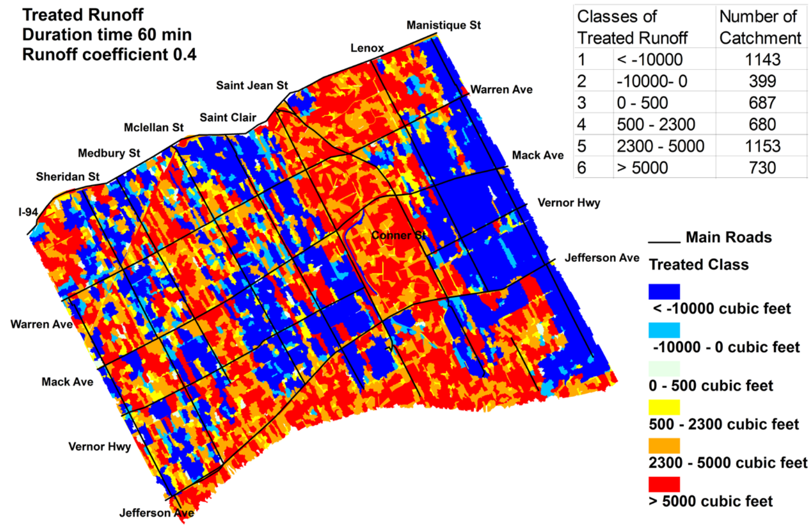


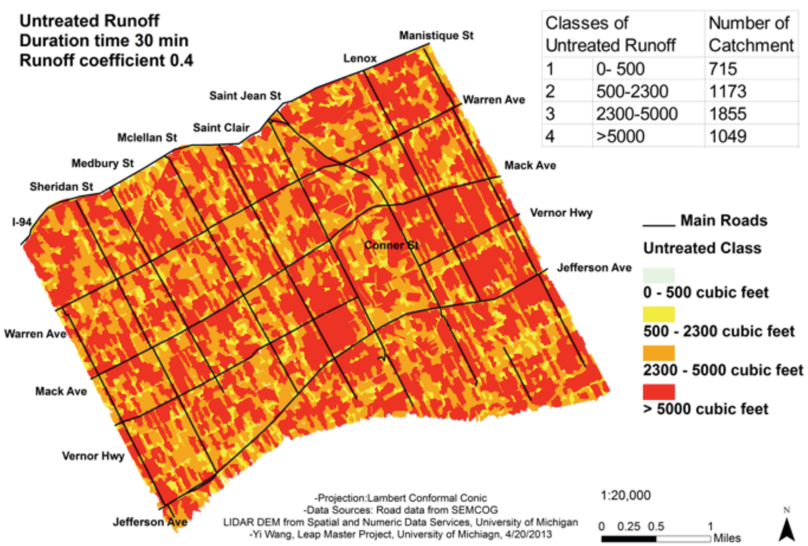
Figure IV-12. Distribution of treated runoff for all LEAP District catchments.



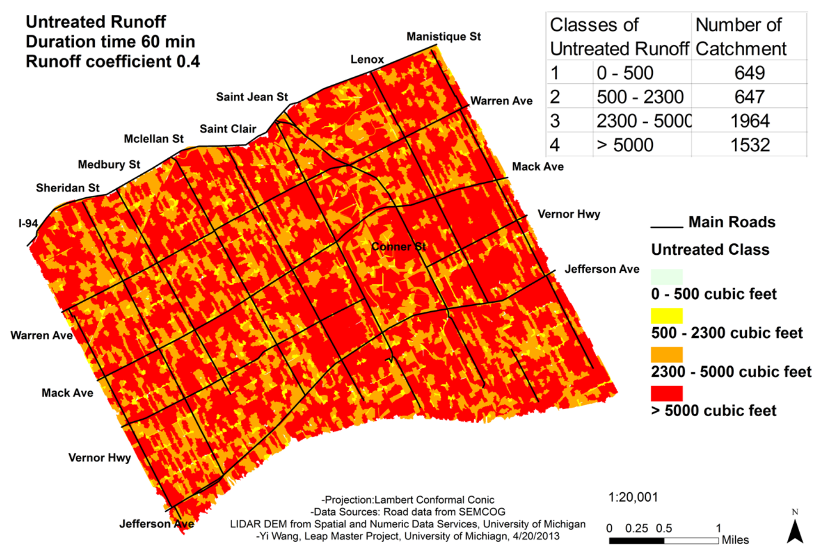
Classes of Treated Runoff with BMP		Number of Catchment
1	<-10000	1164
2	-10000 -0	470
3	0 - 500	739
4	500 - 2300	977
5	2300- 5000	470
6	> 5000	472



Classes of Treated Runoff		Number of Catchment
1	< -10000	1143
2	-10000- 0	399
3	0 - 500	687
4	500 - 2300	680
5	2300 - 5000	1153
6	> 5000	730



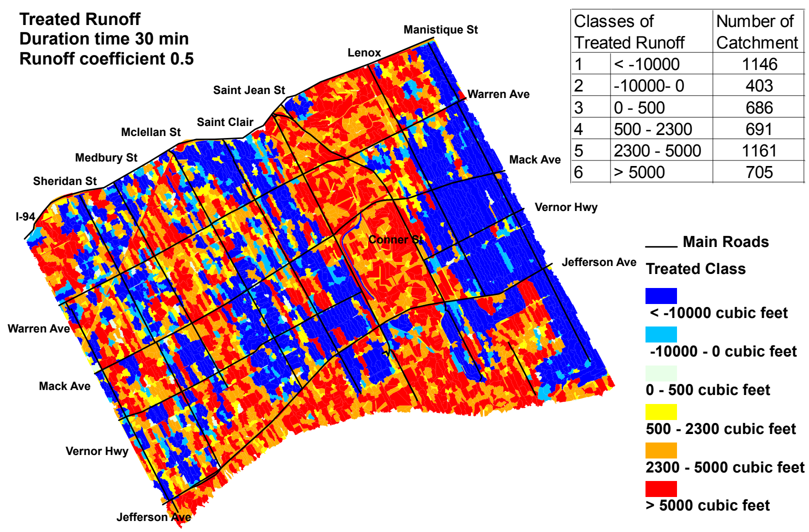
Classes of Untreated Runoff		Number of Catchment
1	0- 500	715
2	500-2300	1173
3	2300-5000	1855
4	>5000	1049



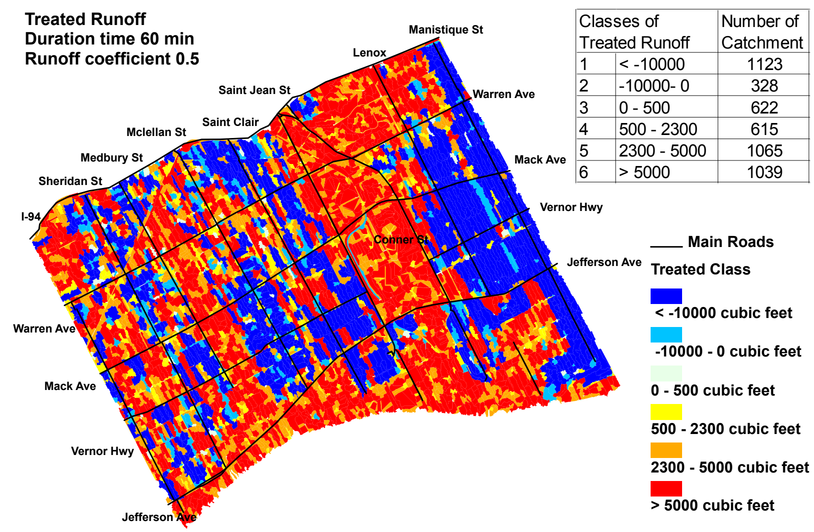
Classes of Untreated Runoff		Number of Catchment
1	0 - 500	649
2	500 - 2300	647
3	2300 - 5000	1964
4	> 5000	1532

Figure IV-13a. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 10-year storm event.

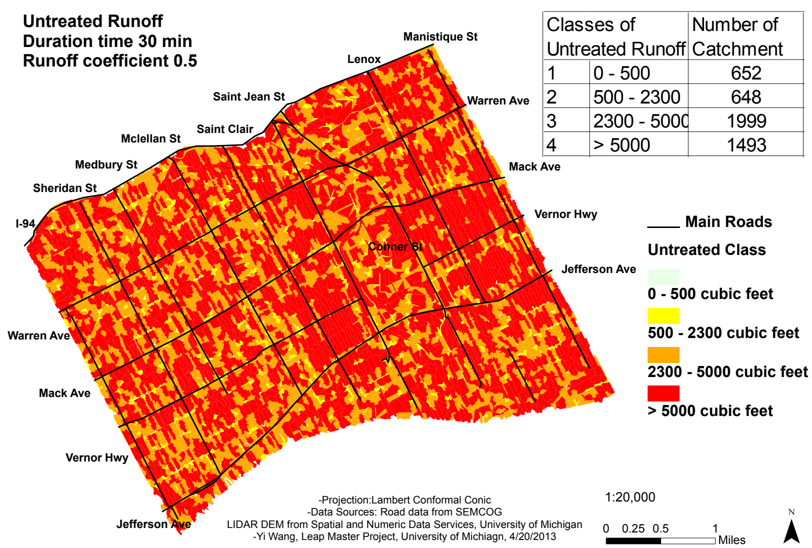
Classes of Treated Runoff		Number of Catchment
1	< -10000	1146
2	-10000- 0	403
3	0 - 500	686
4	500 - 2300	691
5	2300 - 5000	1161
6	> 5000	705



Classes of Treated Runoff		Number of Catchment
1	< -10000	1123
2	-10000- 0	328
3	0 - 500	622
4	500 - 2300	615
5	2300 - 5000	1065
6	> 5000	1039



Classes of Untreated Runoff		Number of Catchment
1	0 - 500	652
2	500 - 2300	648
3	2300 - 5000	1999
4	> 5000	1493



Classes of Untreated Runoff		Number of Catchment
1	0 - 500	572
2	500 - 2300	590
3	2300 - 5000	1590
4	> 5000	2040

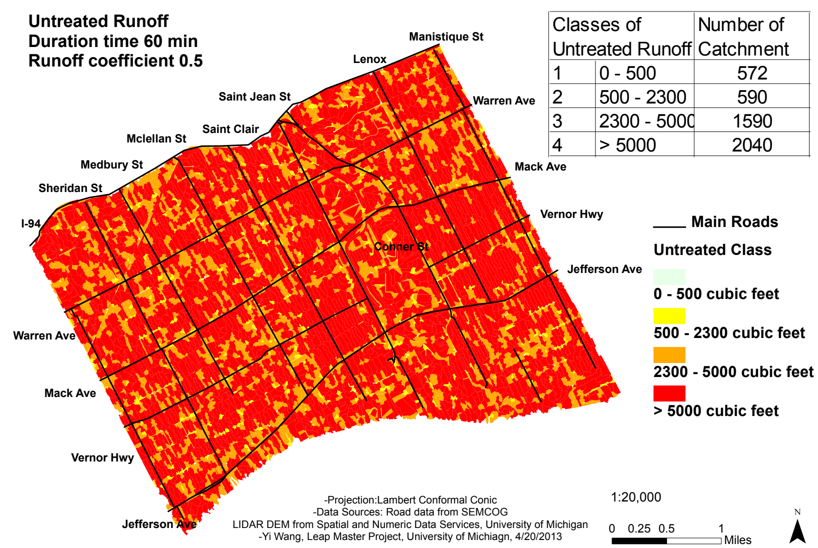
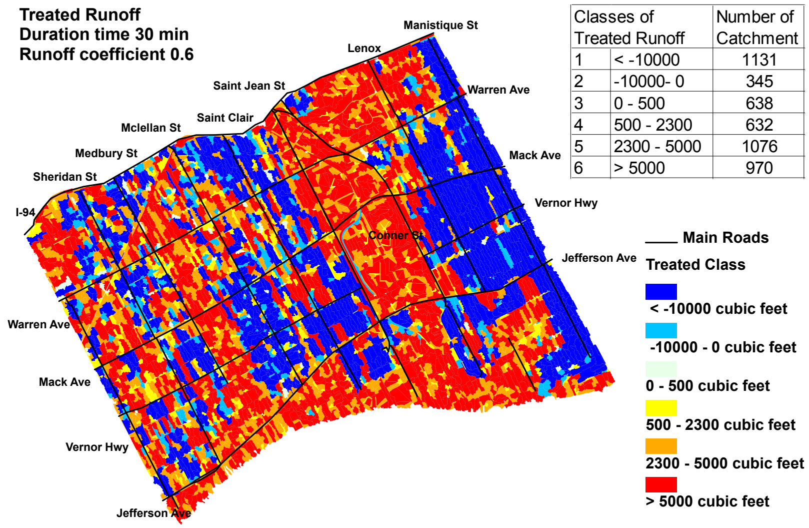
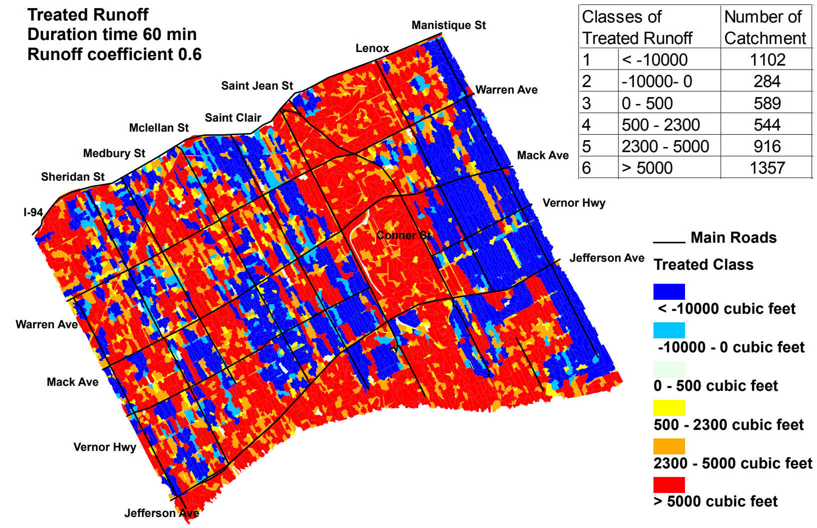


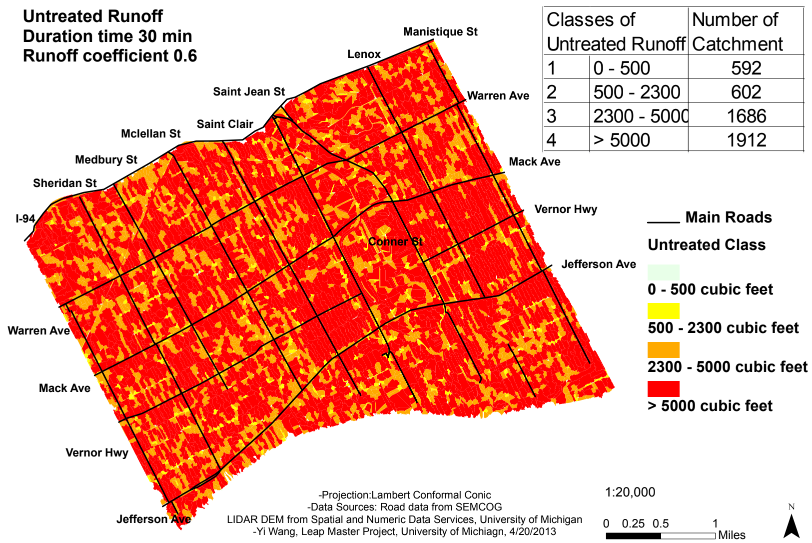
Figure IV-13b. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 10-year storm event.



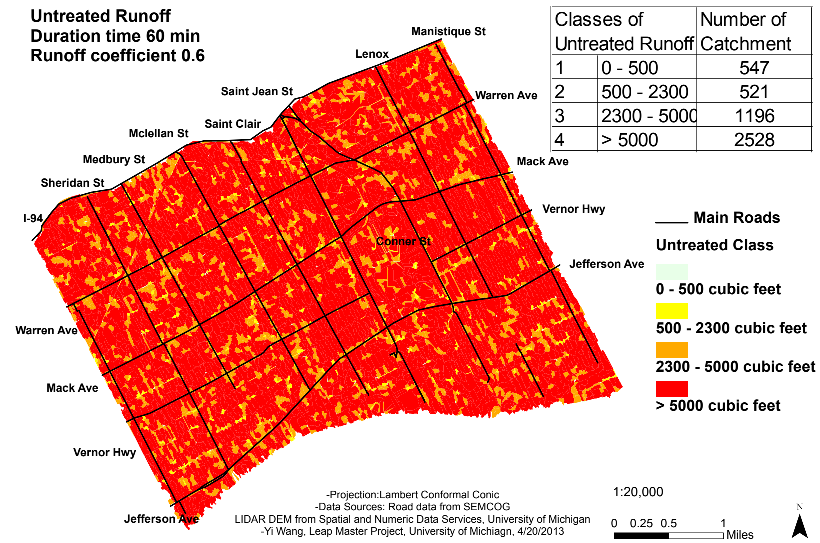
Classes of Treated Runoff		Number of Catchment
1	< -10000	1131
2	-10000- 0	345
3	0 - 500	638
4	500 - 2300	632
5	2300 - 5000	1076
6	> 5000	970



Classes of Treated Runoff		Number of Catchment
1	< -10000	1102
2	-10000- 0	284
3	0 - 500	589
4	500 - 2300	544
5	2300 - 5000	916
6	> 5000	1357



Classes of Untreated Runoff		Number of Catchment
1	0 - 500	592
2	500 - 2300	602
3	2300 - 5000	1686
4	> 5000	1912



Classes of Untreated Runoff		Number of Catchment
1	0 - 500	547
2	500 - 2300	521
3	2300 - 5000	1196
4	> 5000	2528

Figure IV-13c. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 10-year storm event.

V. Proof-of-Concept Sites

Proof-of-concept sites were selected from future projects within the LEAP district as pilot projects to demonstrate the potential application and function of green infrastructure installations. In addition to proposing concrete, actionable projects within the LEAP district, proof-of-concept sites acted as a tool in the iterative development of BMP types and their stormwater characteristics and siting within the LEAP district. The two projects selected for scenario development in this project- the Mack Avenue Green Thoroughfare and Hantz Woodlands- represent different conditions for vacancy and redevelopment represented by different CDAD typologies within the LEAP Future Directions Plan.

Mack Avenue Green Thoroughfare

Project Description

The Mack Avenue Green Thoroughfare landscape design project is located along a ¾ mile section of Mack Avenue between Conner St. and Chalmers St. The project will convert a blighted commercial corridor into a green byway that plans for the demolition of abandoned buildings, provides wayfinding signage for visitors to shopping areas to the east and west of the site, and provides space for public art. In addition, the corridor will be restructured as a complete street designed to provide safe access for all forms of transportation within the street (LAND, 2013).

The green thoroughfare plan for Mack Ave. proceeds under the assumption that there is no market for commercial business along the corridor and proposes strategies to maintain Mack Ave. as a clean, safe street without full occupation. Over the past fifty years, commercial activity along this once-vibrant corridor has severely declined. Less than 10 businesses currently occupy the 111 parcels along Mack Ave., and more than half of the property along the street is publicly owned due to tax foreclosure. There are currently 15 blighted buildings along the corridor, including 5 on city-owned land (LAND, 2013).

A Request for Proposals was prepared by on March 9, 2013 by the Land Assembly for Neighborhood Development (LAND), a not-for-profit organization committed to sustainable, community-driven development on Detroit's eastside. Design requirements for the green thoroughfare indicate the community's interest in "complete streets" treatment for Mack Avenue, stormwater management, environmentally and financially sustainable design elements, a low-maintenance plantings, and a plan for placement of public art (LAND, 2013).

The strategies proposed in this project address a four-block section of Mack Avenue from Conner St. to Dickerson St. The study area includes a gas station, church, and recently built senior center in addition to other small businesses. However, a large proportion of the land along this section of Mack Ave. is already vacant, and several blighted buildings also occupy the street front. The study area is characterized by relatively flat topography with slightly higher elevations to the north-west.

Two scenarios detail strategies for more or fewer structural changes to the street itself, with implications for the amount and character of green infrastructure incorporated into the corridor. The strategies proposed through the two Mack Avenue Green Thoroughfare scenarios are intended as typical strategies that could be employed on similar streets in Detroit.

Figure V-1. Mack Avenue Green Thoroughfare base condiiton.

Site Description

Figure V-2. Mack Avenue, existing conditions.

Figure V-3. Mack Avenue, existing conditions.

Complete Streets

Complete streets provide a safe, accessible and convenient corridor for users including bicyclists, transit riders, pedestrians, and motorists. In addition to providing space for all modes of transportation within the corridor, complete streets promote healthy communities by encouraging walking and biking as alternatives to driving and reducing traffic congestion. Design considerations for complete streets include narrowing the street to reduce traffic speeds, improving pedestrian safety through traffic calming and adequate sidewalks, and accommodating vulnerable populations such as the disabled and elderly through improved accessibility and visibility at crosswalks (APA, 20xx). Complete streets design features within both of the scenarios proposed for the Mack Avenue Green Thoroughfare include narrowing the street by reducing the number of traffic lanes on Mack Avenue, improving visibility at corners and providing additional crosswalks, separated bike and pedestrian lanes, and traffic calming and public health improvements through street trees and roadside plantings.

Scenario A

Scenario A proposes green infrastructure elements that are integrated into the existing structure of Mack Avenue, resulting in relatively modest alterations to the physical arrangement of the street.

In this scenario, Mack Avenue is designed as a complete street with designated spaces for all modes of transportation, including private vehicles, public transportation, bicycles, and pedestrians. The street width remains unchanged with added bike lanes, street trees, and roadside infiltration on both sides of Mack Avenue. Traffic lanes are reduced from seven lanes (including parking lanes) to five lanes with a center left turn lane. Ten-foot bike lanes are proposed for both sides of the street adjacent to traffic lanes.

Within the right-of-way, infiltration catch basins are proposed to replace areas of turf. Catch basins are graded with gentle 3% slopes on all sides to increase stormwater capacity. Sycamore and ginkgo are planted as street trees at 30 feet on center within catch basins. Appendix X lists suggested street tree plantings to accommodate stormwater management, biodiversity, and climate change adaptation. Infiltration catch basins are narrow roadside swales designed to capture the "first flush" (or first x inch) of stormwater from the street. The catch basins are a filtration BMP filled with amended soil or gravel and provide filtration and temporary retention of the most concentrated pollutants from the roadway. Stormwater is also evapotranspirated by plantings within the infiltration catch basin.

Turning visibility for vehicles was a key consideration at intersections within the study area, including the intersections of Mack Ave. and Anderdon St., Mack Ave. and Algonquin St., Mack

Ave. and Springle St., and Mack Ave. and Gray St. To ensure sightlines around these corners, street trees are not planned within 50 feet of the intersection. Low rain gardens of perennial flowers are planted within the infiltration catch basins at these corners to allow for visibility at the intersection and establish a sense of neighborhood block identity with ornamental plantings. Additional perennial selections are listed in Appendix X.
Poor condition buildings along the corridor have been demolished and rebuilt as infiltration gardens. Existing vacant lots have been graded for stormwater capture and replanted with grasses. Flowering perennials line berms at the front of these lots and contribute to the perception of maintenance and care along the corridor. Stormwater is captured in these gardens through overland flow from adjacent lots.

Vacant lots near the intersection of Mack Ave. and Conner St. are designed as an entry space to the green thoroughfare that captures street runoff and showcases green infrastructure BMPs, provides open space for public artwork, and establishes the character and landscape amenity value of the green thoroughfare. A wide infiltration catch basin along the road is planted with low, colorful perennial flowers. The vacant lots are graded as bioretention gardens, and colorful flowers are repeated on the berm at the front of the lots. Street trees are relocated to the back of the lot to define the outer edge of an expansive public space that quickly transitions into the green thoroughfare with similar repeated elements. The location of this open space at the key intersection of Mack Ave. and Conner St. provides a high-visibility opportunity for public artwork and community gatherings.

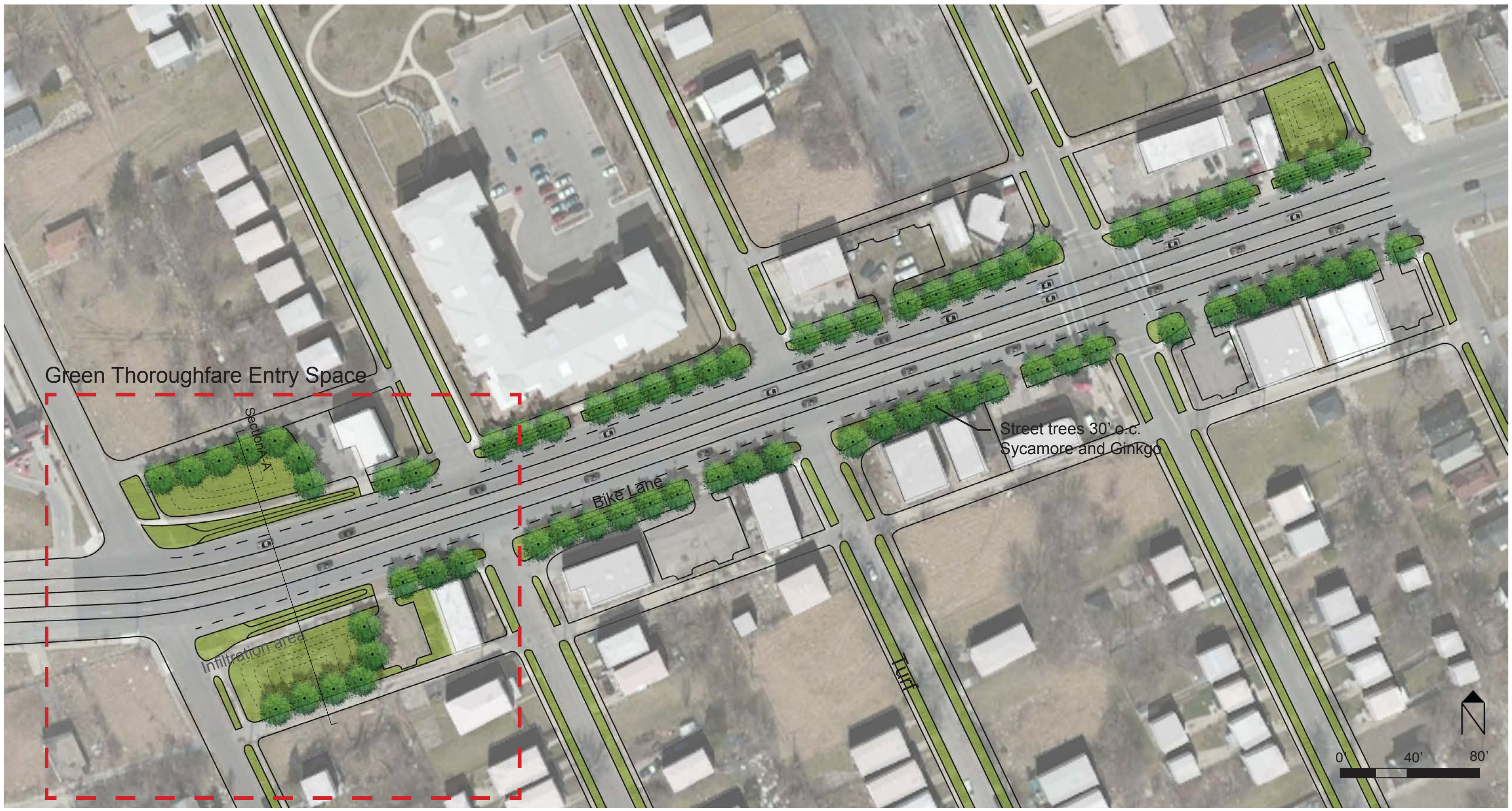


Figure V-4. Scenario A overall site plan.

Figure V-5. Detail plan of green thoroughfare entry space.

Figure V-6. First-year planting plan of entry space.

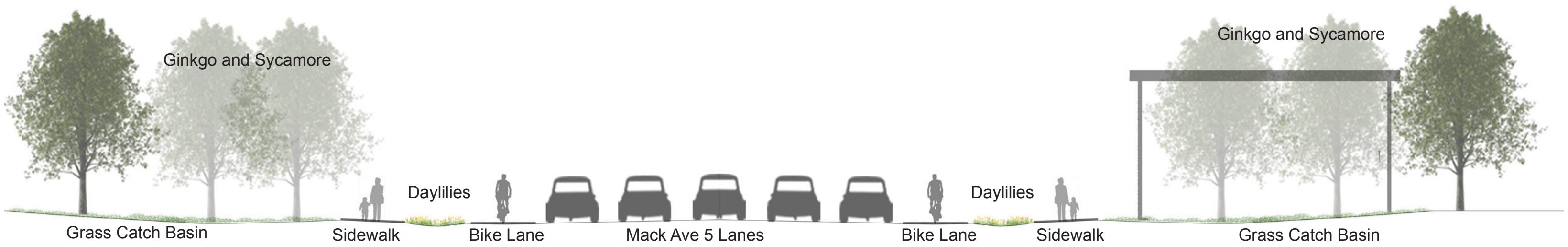


Figure V-7. Section through Mack Avenue delineating space for each mode of transportation including vehicles, public transportation, bikes, and pedestrians.

Scenario B

Scenario B proposes more extensive changes to the street design of Mack Avenue to fully incorporate alternate modes of transportation and stormwater management BMPs into the corridor. In Scenario B, Mack Avenue is redesigned as a complete street with three lanes reduced from seven lanes. Bike lanes and pedestrian sidewalks are separated from the street with planted buffers. The prominent public entry space into the green thoroughfare at the intersection of Mack Ave. and Conner St. also remains in this scenario as a key plan element.

Infiltration catch basins are installed in the right-of-way immediately adjacent to vehicle lanes to capture stormwater runoff from the street through curb cuts. The infiltration catch basins in scenario B have been increased in width relative to scenario A from x feet to x feet, increasing the stormwater storage capacity of the basins. As in scenario A, street trees are planted 30 feet on center within the infiltration catch basins, and rain gardens planted with low perennials occupy the ends of the infiltration catch basins as ornamental plantings that allow for visibility around street intersections and provide a neighborhood block identity and signs of care along the corridor.

Poor condition buildings have been demolished and the foundation spaces excavated and filled with gravel for use as infiltration gardens, and vacant lots have been graded as bioretention gardens. Both bioretention gardens and infiltration gardens capture stormwater through overland flow from adjacent lots. Infiltration gardens also receive overflow stormwater during large storm events from the street through a piped connection from infiltration catch basins located within the right-of-way.

Figure V-8. Scenario B overall site plan.

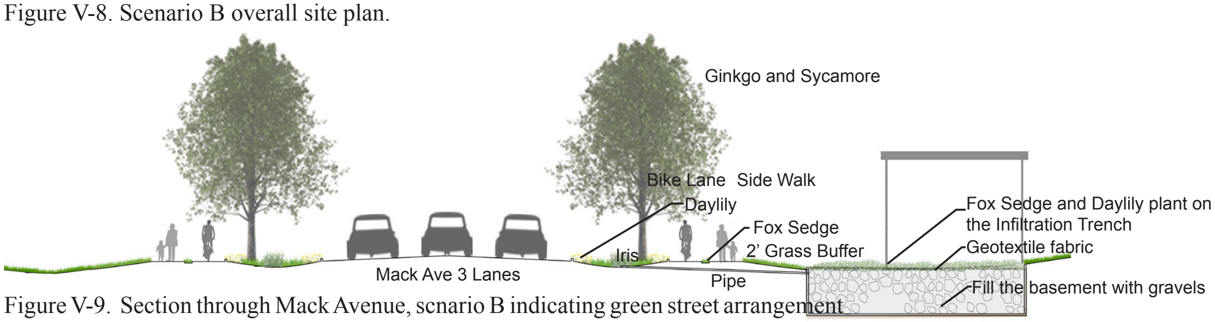


Figure V-9. Section through Mack Avenue, scnario B indicating green street arrangement and piped connection.

Figure V-10. First year planting plan of infiltration catch basins and infiltration gardens.

Figure V-11. Detail plan of connection between infiltration catch basins and infiltration garden from building demolition.

Hantz Woodlands Commercial Farm

Project Description

The Hantz Woodlands project proposes a commercial tree farm on Hantz Farms owned parcels with the additional goals to improve living conditions of blighted neighborhoods within the study area by demolishing dangerous structures, removing brush and dumped debris, and regular maintenance including mowing between trees. Hantz Farms received approval from the Detroit City Council to move forward with the project in December, 2012. As part of the agreement, the company is required to plant at least 15,000 trees on currently owned parcels. In addition to commercial tree production, Hantz Woodlands intends to encourage the use of the woodlots as an educational resource for the community, promoting biodiversity, species and variety experimentation, and plantings of native Michigan species.

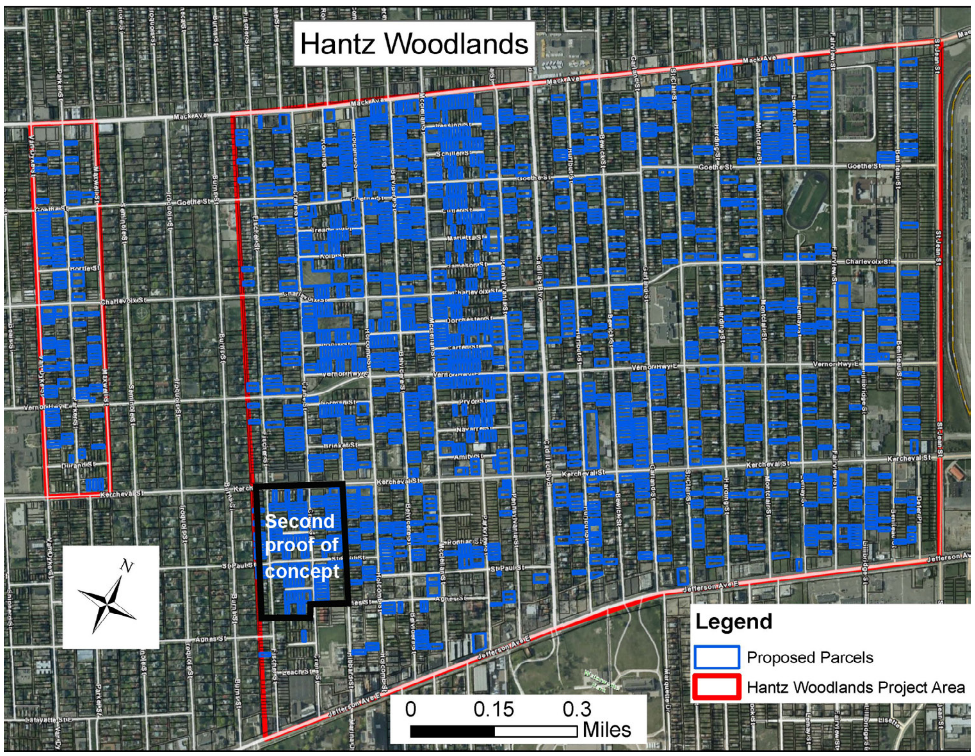


Figure V-12. Hantz Woodlands project area.

Site Description

Figure V-13. Hantz Woodlands site, existing conditions.

Figure V-14. Hantz Woodlands site, existing conditions.

The Hantz Woodlands project area is roughly 140 acres bound by Van Dyke to the west, St. Jean to the east, Mack Ave. to the north and Jefferson to the south (excluding Indian Village). Though the total number of parcels within the project is not yet precisely determined, approximately 1450 are likely to be purchased from the city, 126 from the state, and 66 from DPS. The parcels include both vacant parcels and potential demolitions.

The scenarios proposed in this project consider a four-block section of the Hantz Woodlands area bounded by St. Paul St. to the north, Jefferson Ave. to the south, Crane St. to the east, and Burns St. to the west. The study area was selected because it is a highly vacant area with a high proportion of parcels already owned by Hantz Woodlands. In addition, the site offers visual connections to more fully occupied neighborhoods located along Jefferson Avenue to the south, and there is current interest in building a retirement community within a block of the study area. Approximately half of the parcels within this proof-of-concept site have been purchased by Hantz Woodlands, and 23 households currently remain within the study area.

Figure V-15. Proof-of-concept site within the Hantz Woodlands project site, base condition.

Scenario A

Under Scenario A, we assume that Hantz Woodlands will not purchase any other properties within the study area. The number of households (23) will remain the same in 20 years. Trees are initially planted as spikes in dense groves on Hantz Woodlands properties on a 12-foot by 12-foot or 12-foot by 6-foot grid. The row of trees closest to the road is aligned to the setback of existing homes, generally between 20 and 25 feet away from the road. A 45-foot space (the "fight or flight" distance) is planned between the first row of trees and the second row to increase visibility between remaining homes and increase the perception of safety for pedestrians. Maintenance of the woodlot includes weekly mowing and thinning of trees within the rows as trees grow larger. Trees will not be irrigated as they are established.

Flowering trees are included in the design of Hantz Woodlands as an immediate aesthetic amenity for newly planted woodlots. Ball and burlap flowering trees are planted at the center of each grove of trees to provide spring color while other species are established. Due to the low height and low branching patterns of these species, placement of the flowering trees must ensure visibility for residents in adjacent houses through the woodlot, meet criteria for the 45-foot "fight or flight" distance, and ensure that no closed boundaries are created on the lot.

As with other woodlot BMPs designed for the LEAP district, woodlots on Hantz Woodlands properties incorporate grading to increase stormwater capacity. All adjacent Hantz Woodlands lots are graded with gentle 3% slopes and a maximum depth of approximately one foot. Poor condition houses that are demolished under this scenario utilize an alternate infiltration garden BMP that substitutes an amended soil or sand mix for the gravel fill in the excavated basement. This soil mix alters growing conditions and allows for greater species biodiversity and experimentation within the woodlot.
Tree species are selected both for economic value and resistance to pathogens. Species selections include Swamp White Oak, London Plane Tree, Hackberry, Red Oak, River Birch, Sweet Gum, Kentucky Coffee Tree, and Ginkgo. Flowering tree selections include Serviceberry, Red Bud, and Winter King Hawthorn. Additional information on plantings is located in Appendix X.

Twenty years after the initial planting, we anticipate that tree spacing will become greater and more scattered as some trees die out and rows of trees are thinned to ensure continued tree health and growth. Any incidental lots that are acquired by Hantz Woodlands under this scenario will be planted with trees, but no additional flowering trees will be installed.

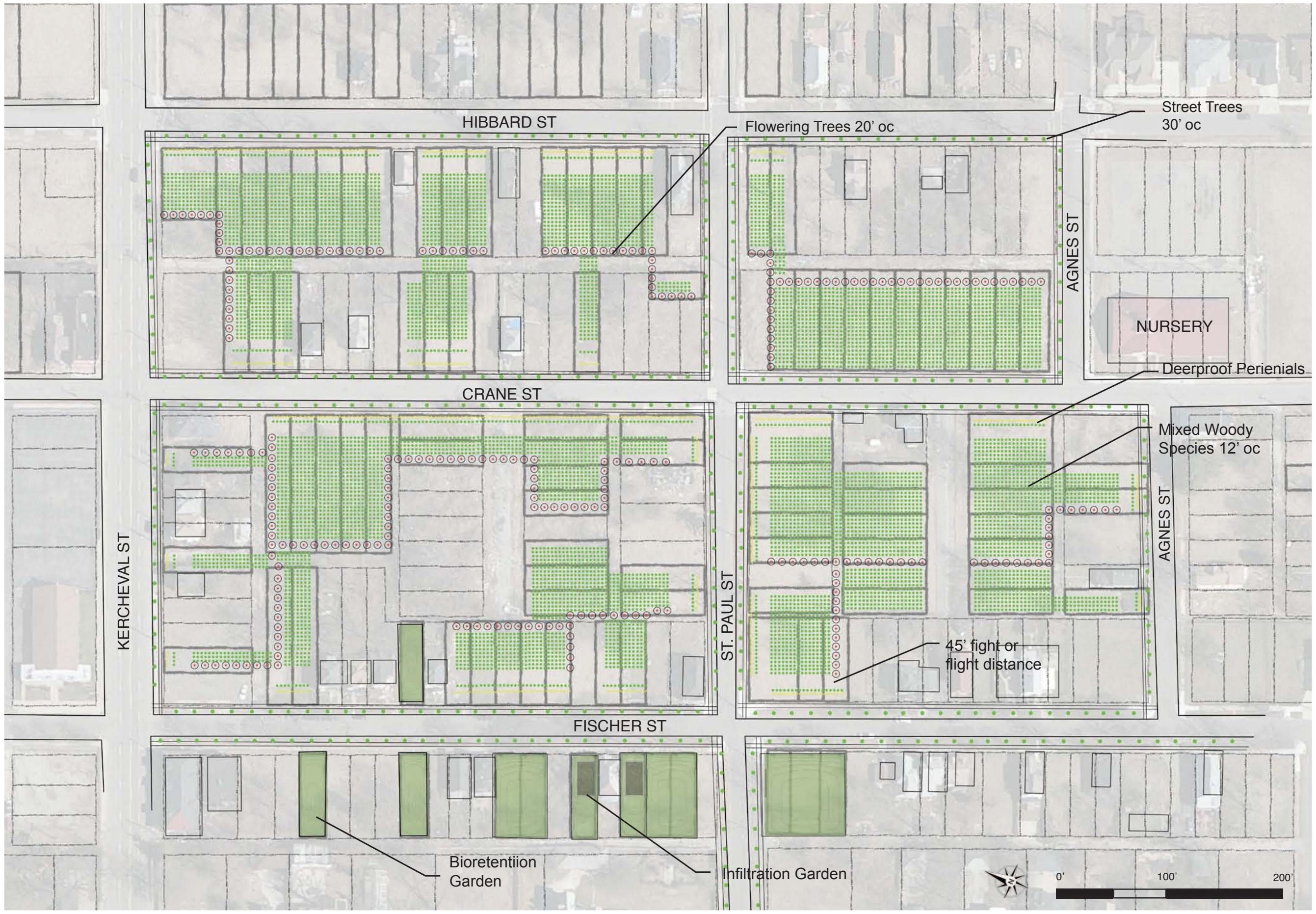


Figure V-16. Scenario A, 2-year planting plan.

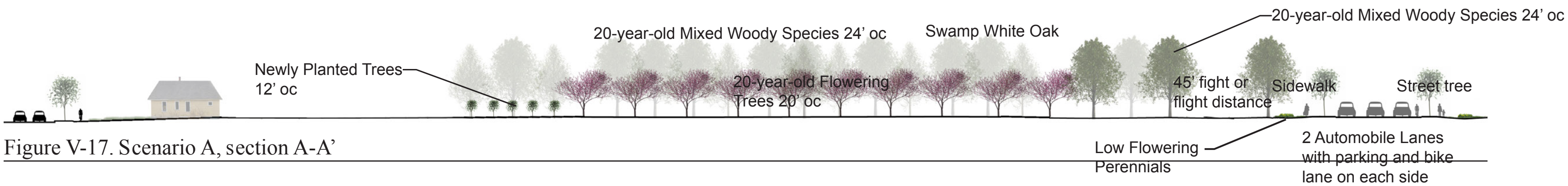


Figure V-17. Scenario A, section A-A'

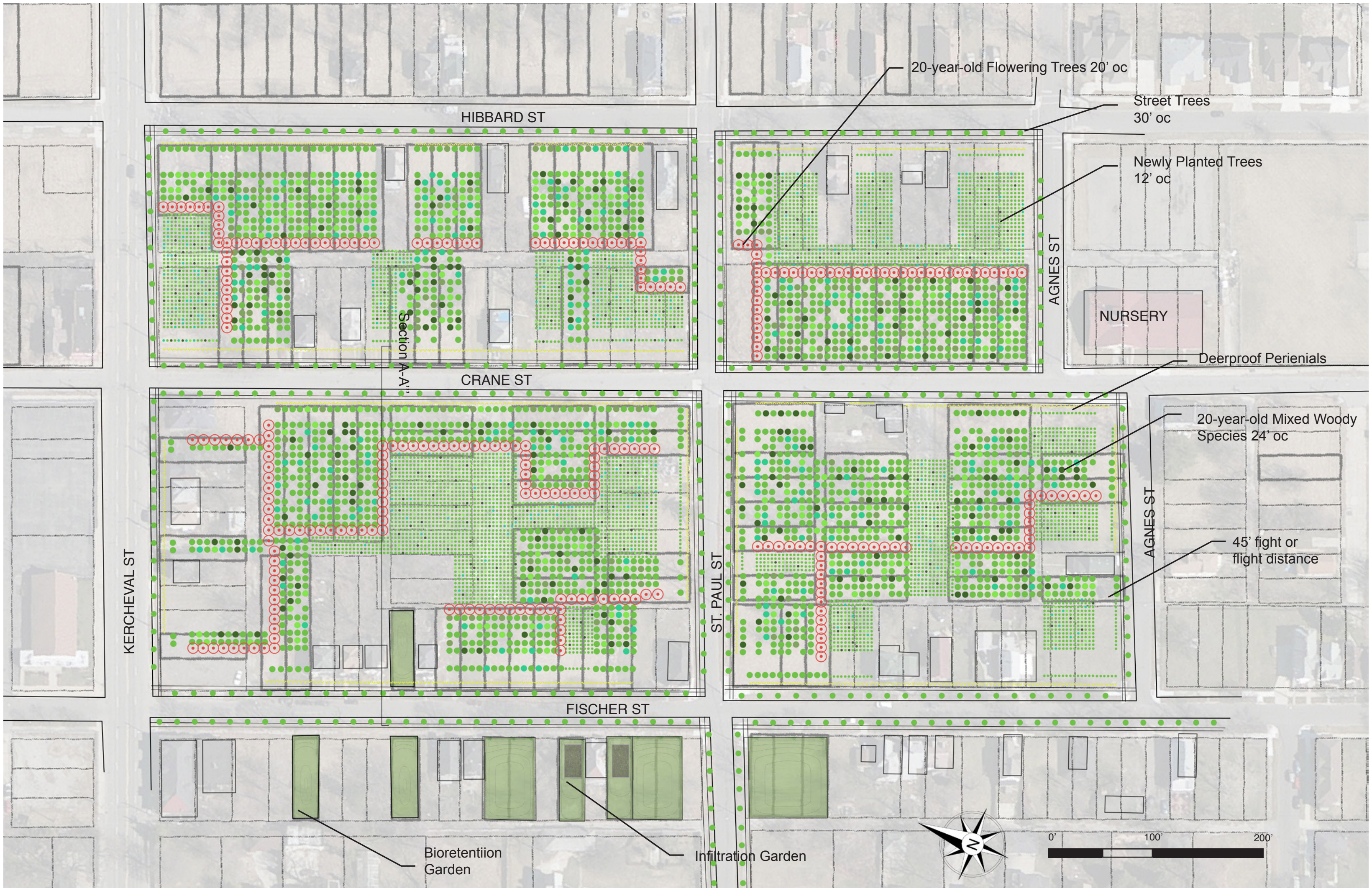


Figure V-18. Scenario A, 20-year plan.

Scenario B

Scenario B assumes that Hantz Woodlands will eventually acquire all properties within the proof-of-concept site, and the entire site will be planted as a woodlot. Since no residents remain in the study area, Crane St. and St. Paul St. will be closed and replaced with a gravel pedestrian path and a wide bioswale on either side of the street. The street right-of-way is gradually replanted with grasses, as the gravel pathway is narrower than the previously existing street.

Similar to Scenario A, a shallow swale is incorporated into the woodlot and demolished houses are filled with an amended soil or sand mix to alter growing conditions and increase potential species biodiversity. Trees are planted on an industry standard 12-foot by 6-foot or 12-foot by 12-foot grid. Ball and burlap flowering trees are initially planted within the center of each grove. In this scenario, no space is provided between the first and second row of trees adjacent to the street for visibility between adjacent houses, because no buildings remain within the study area.

After 20 years, trees have been thinned and some individuals have died out, resulting in a patchy planting pattern within the woodlot.

Figure V-19. Scenario B, 2-year plan.

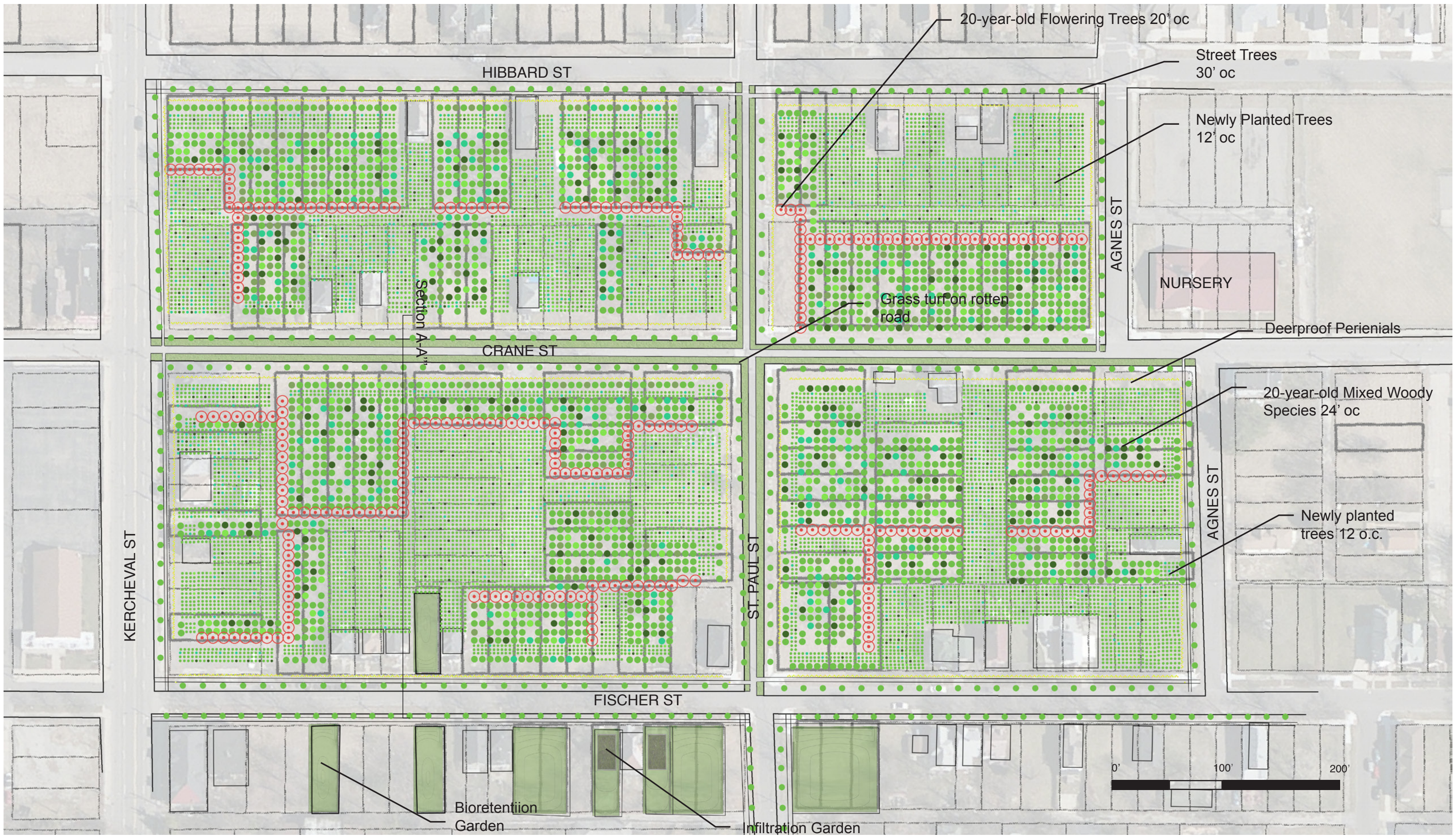


Figure V-20. Scenario B, 20-year plan.

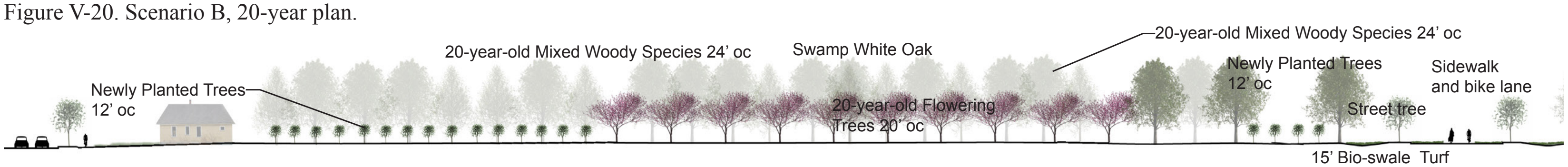


Figure V-21. Scenario B, section A-A'.

VI. Conclusion

This project proposes land-based green infrastructure best management practices (BMPs) that respond to the potential for vacant land and demolition sites to provide additional stormwater management capacity in Detroit. It demonstrates how these BMPs apply to two proof-of-concept sites within the Lower East Side of Detroit to. The project builds on past collaboration between LEAP and the University of Michigan School of Natural Resources and Environment including Creating Sustainable Neighborhood Design for Legacy Cities: A New Framework for Sustainability Assessment (Jones et al., 2012) and Documenting and Demonstrating Cues to Care and Neighborhood Care Dynamics in CDAD's "Urban Homesteads" and "Naturescapes" (Nassauer and Dewar, 2012). In addition, the project utilizes CDAD's Neighborhood Revitalization Strategic Framework typologies to inform the siting of best management practices within the study area. This report provides recommendations to LEAP and its partners for actionable projects.

Green infrastructure innovations were developed and mapped through an iterative, multi-scale process incorporating both the design of innovations within proof-of-concept sites and spatial analysis of the entire LEAP district. We designed green infrastructure innovations to optimize "within block" infiltration, evapotranspiration, detention, and retention, anticipate transport of urban contaminants, minimize costs, and plan for long-term maintenance of the installations. Specific applications of these green infrastructure innovations were developed for two sites within the Lower Eastside of Detroit in conjunction with proposed projects within the district. The two proof-of-concept sites also explored the application of green infrastructure innovations in two differing land use conditions and CDAD typologies.

We simultaneously conducted a spatial analysis to identify the location and capacity for runoff retention and CSO volume reduction for stormwater treatment of these BMP's throughout the city. A total of xxxx BMPs were sited throughout the LEAP district. Bioretention gardens, which provide shallow grading for stormwater retention, were the most prevalent BMP type.

Hydrologic modeling of the LEAP district utilized ArcHydro to subdivide the study area into 4857 catchments based on high-resolution topographic data and street locations, which we assumed to coincide with stormwater infrastructure. A total of 2160 catchments- almost half of all catchments within the study area did not contain a sited BMP. These catchments primarily correspond with commercial and industrial areas that do not meet BMP siting criteria. Stormwater capacity within these catchments may be increased by working with commercial and industrial land uses, by the installation of traditional stormwater BMPs, especially networked designs such as the raingardens installed in the street right-of-way in Maplewood, Minnesota (Nassauer et al., 1997). In addition, xxx catchments exhibited excess stormwater storage capacity during xx-year runoff events. Catchments with excess stormwater capacity generally contain urban woodlots, the most efficient BMP type. We propose that the next step in the green infrastructure plan for the LEAP district is to develop a network strategy that links areas of excess stormwater runoff with locations where excess stormwater storage capacity is available.

As a complementary effort to other green infrastructure initiatives within the City of Detroit, this project emphasizes the development of visibility, perceived safety, and cues to care as a significant application of multifunctional green infrastructure innovations. Evolving occupancy patterns and land use throughout the study area provide significant opportunities for green infrastructure innovations to provide stormwater management and reduce the occurrence of combined sewer overflow events. However, a major challenge addressed by green infrastructure in legacy cities is to utilize design to bring landscape amenity and safety to landscape ecological function.

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Appendix A: BMP Suggested Planting Lists

Botanical Name	Common Name	Height	MI Native	Tolerates Wet Sites	Drought Tolerant	Street Tree	Flowering Tree
Acer rubrum	Red Maple	50'-100'	•	•		•	
Acer saccarum	Sugar Maple	60'-100'	•	•		•	
Amelanchier x grandiflora 'Autumn Brilliance'	Autumn Brilliance Serviceberry	20'					•
Cercis canadensis	Redbud	12'-25'	•	•	•		•
Crataegus 'Winter King'	Winter King Hawthorn	25'			•		•
Ginkgo biloba	Ginkgo	50'-80'			•	•	
Gleditsia triacanthos	Honeylocust	60'-85'	•	•	•	•	
Gymnocladus dioica	Kentucky Coffeetree	60'-85'	•		•	•	
Pinus strobus	Eastern White Pine	70'-100'	•		•		
Platanus occidentalis	American Sycamore	65'-100'	•	•	•	•	
Platanus x acerifolia	London Planetree	65'-100'		•	•	•	
Populus tremuloides	Quaking Aspen	50'-110'	•	•			
Quercus alba	White Oak	70'-90'	•				
Quercus bicolor	Swamp White Oak	50'-80'	•	•			
Quercus imbricaria	Shingle Oak	40'-70'	•	•	•	•	
Quercus macrocarpa	Burr Oak	60'-85'	•	•	•	•	
Tilia cordata	Littleleaf Linden	30'-60'				•	
Tsuga canadensis	Eastern Hemlock	70'-100'	•	•			

Figure A-1. Tree planting options. Data compiled from Barnes (2004) and City of Ann Arbor (2010).

Botanical Name	**Common Name**	**Height**	**MI Native**	**Drought Tolerant**	**Tolerates Wet Sites**	**Deer Resistant**	**Bloom Color**	**Bloom Time**
Carex pensylvanica	Pennsylvania Sedge	8"-10"	•					
Carex vulpinoidea	Fox Sedge	1'-3'	•		•	•		
Coreopsis lanceolata	Tickseed	1'-2'	•	•		•	Yellow	May to July
Echinacea purpurea	Purple Coneflower	2'-4'	•	•		•	Purple	June to August
Geranium 'Gerwat'	Rozanne Cranesbill	1'-1.5'				•	Blue	May to September
Iris versicolor	Blue Flag Iris	2'-2.5'	•		•	•	Blue	May to June
Hemerocallis 'Stella D'Oro'	Stella D'Oro Daylily	8"-12"					Yellow	May to August
Liatris spicata	Blazing Star	2'-4'	•	•			Purple	July to August
Rudbeckia fulgida	Black-Eyed Susan	2'-3'	•	•		•	Yellow	June to October

Figure A-2. Low flowering perennial planting options. Data compiled from Missouri Botanical Garden (2013).

Appendix B: Summary of BMP Costs

This project utilizes cost estimations produced by The Greening of Detroit (2011) as the basis for costing similar BMPs within the city of Detroit. TGD developed cost estimates for their BMPs using past implantation projects, product catalogs and RS means data. Since all BMPs developed for this project incorporate grading, we do not anticipate that volunteer labor will be appropriate for installation of the BMPs described in this section.

	1 Acre Cost ($)	
BMP	**Volunteer**	**Contractor**
Tree Planting	$ 62,494.85	$ 110,637.35
Tree Planting with Retention		$ 111,998.26
Meadows Natural	$ 27,461.60	$ 29,110.10
Meadows Agricultural	$ 26,447.30	$ 28,096.85
Wet Meadows		$ 79,641.35
Rain Gardens	$ 301,220.00	$ 772,899.75
Bioswales		$ 89,633.25

Table III-3. Summary of per acre costs for implementation of BMPs using contractor and volunteers. Greyed out cells indicate that this BMP requires heavy machinery and is not considered appropriate for volunteers (TGD, 2011).

Appendix C: Two-year and 100-year Storm Intensity and Untreated Runoff Volume

Duration	Intensity	Intensity per hour/iph
30min	1	2
1hr	1.27	1.27

Table C-1. Michigan 2-year stormwater event.

Volume (2-year, C= 0.4, 30 min)= 3600* 0.4*A (acre) ft3
Volume (2-year, C= 0.5, 30 min)= 3600* 0.5*A (acre) ft3
Volume (2-year, C= 0.6, 30 min)= 3600* 0.6*A (acre) ft3
Volume (2-year, C= 0.4, 60 min)= 4572* 0.4*A (acre) ft3
Volume (2-year, C= 0.5, 60 min)= 4572* 0.5*A (acre) ft3
Volume (2-year, C= 0.6, 60 min)= 4572* 0.6*A (acre) ft3

Duration	Intensity	Intensity per hour/iph
30min	1.9	3.8
1hr	2.6	2.6

Table C-2. Michigan 100-year stormwater event.

Volume (100-year, C= 0.4, 30 min)= 6840* 0.4*A (acre) ft3
Volume (100-year, C= 0.5, 30 min)= 6840* 0.5*A (acre) ft3
Volume (100-year, C= 0.6, 30 min)= 6840* 0.6*A (acre) ft3
Volume (100-year, C= 0.4, 60 min)= 9360* 0.4*A (acre) ft3
Volume (100-year, C= 0.5, 60 min)= 9360* 0.5*A (acre) ft3
Volume (100-year, C= 0.6, 60 min)= 9360* 0.6*A (acre) ft3

Appendix D: Two-Year Storm Untreated Runoff Analysis

Categories	Class	C=0.4 30 min	C=0.4, 60 min	C =0.5, 30 min	C =0.5, 60 min	C=0.6, 30 min	C=0.6, 60 min
1	0-709	974	884	896	798	823	727
2	709-1780	1158	577	607	406	415	392
3	1780-2936	1234	1345	1342	1030	1169	584
4	2936-4187	629	806	797	698	837	992
5	4187-5694	409	500	490	615	600	713
6	5694-7585	204	354	364	458	429	514
7	7585-10180	118	171	153	306	282	429
8	10180-13669	49	100	92	155	136	231
9	13669-19718	12	49	45	99	81	148
10	19718-35333	5	6	6	26	19	57
11	>35333	0	0	0	1	1	5

Table D-1. Comparison of catchment capacity in cubic feet for 2-year storm event. The table lists the number of catchments at 11 classes of capacity for three different runoff coefficients (0.4, 0.5, 0.6) and two different time periods (30 minutes and 60 minutes).

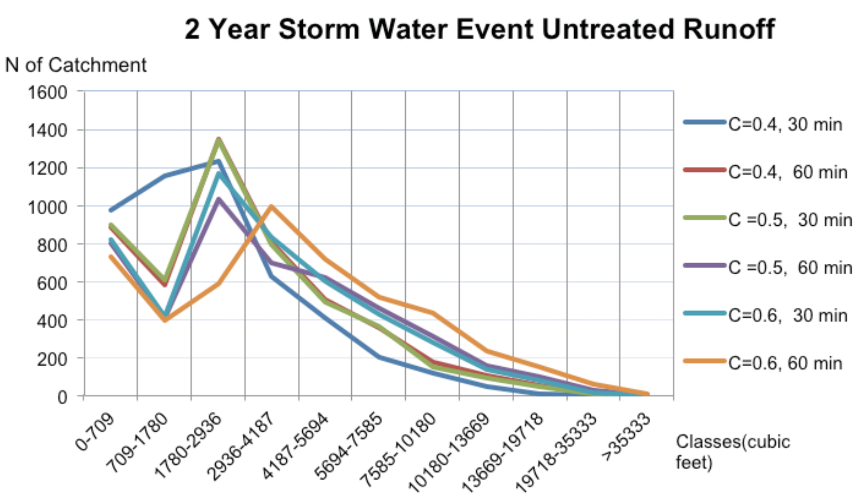


Figure D-1. Distribution of untreated runoff for all LEAP District catchments.

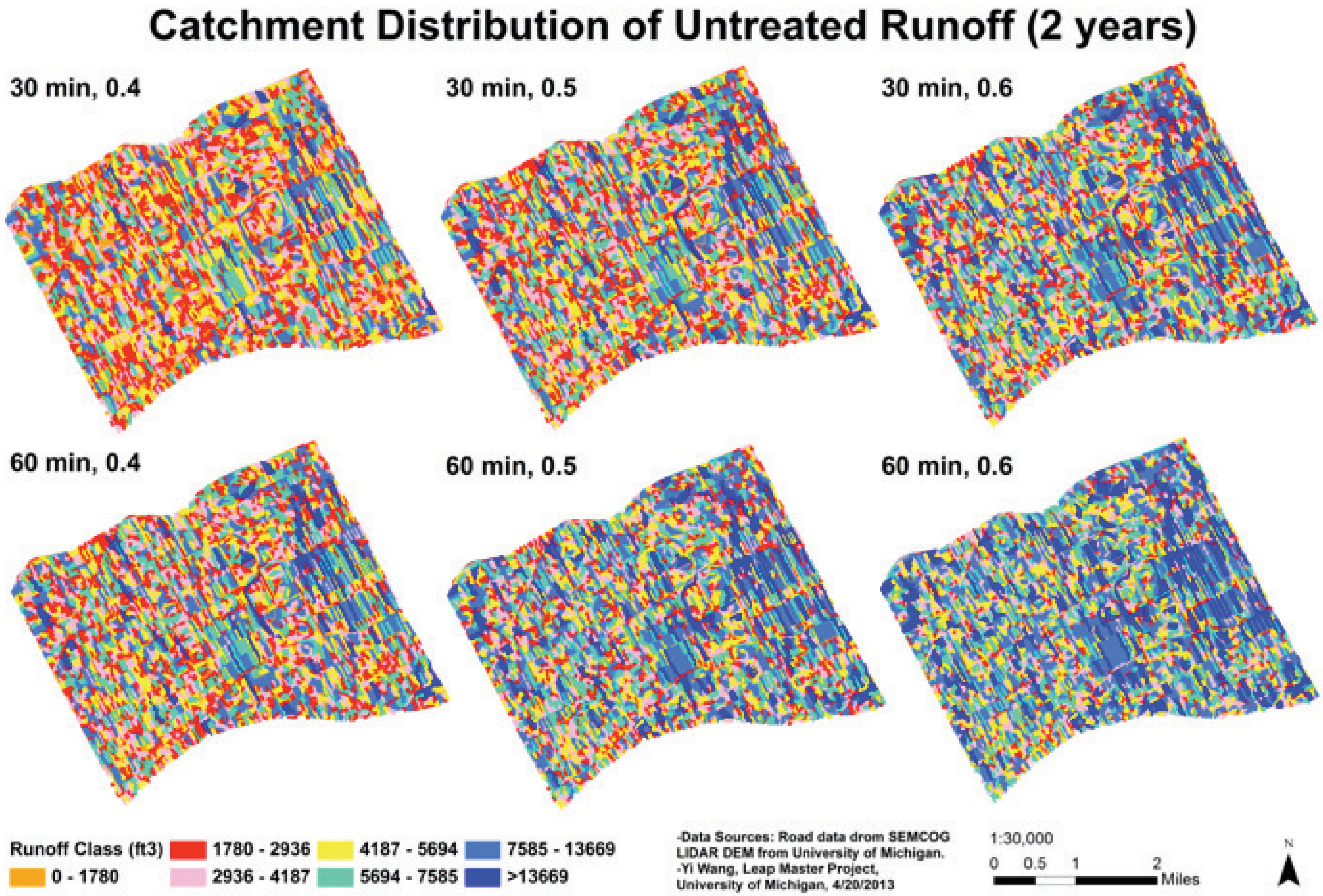


Figure D-2. Comparison of sensitivity analysis for 2-year storm event for untreated runoff. Sensitivity analysis varies by duration of storm event and surface imperviousness.

Appendix E: 100-Year Storm Untreated Runoff Analysis

Categories	Class	C=0.4 30 min	C=0.4, 60 min	C =0.5, 30 min	C =0.5, 60 min	C=0.6, 30 min	C=0.6, 60 min
1	0-709	728	639	667	568	608	541
2	709-1780	392	327	338	311	327	266
3	1780-2936	590	244	264	219	226	199
4	2936-4187	989	622	833	197	413	176
5	4187-5694	710	852	792	788	903	375
6	5694-7585	518	664	652	749	680	830
7	7585-10180	424	542	485	671	587	711
8	10180-13669	233	444	388	501	466	614
9	13669-19718	146	274	236	472	358	561
10	19718-35333	57	165	130	264	197	418
11	>35333	5	19	7	52	27	101

Table E-1. Comparison of catchment capacity in cubic feet for 100-year storm event. The table lists the number of catchments at 11 classes of capacity for three different runoff coefficients (0.4, 0.5, 0.6) and two different time periods (30 minutes and 60 minutes).

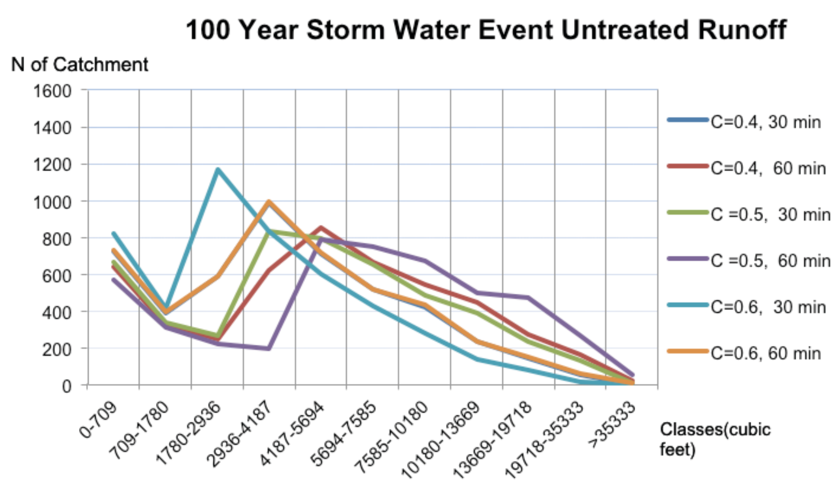


Figure E-1. Distribution of catchment capacity for 100-year storm event.

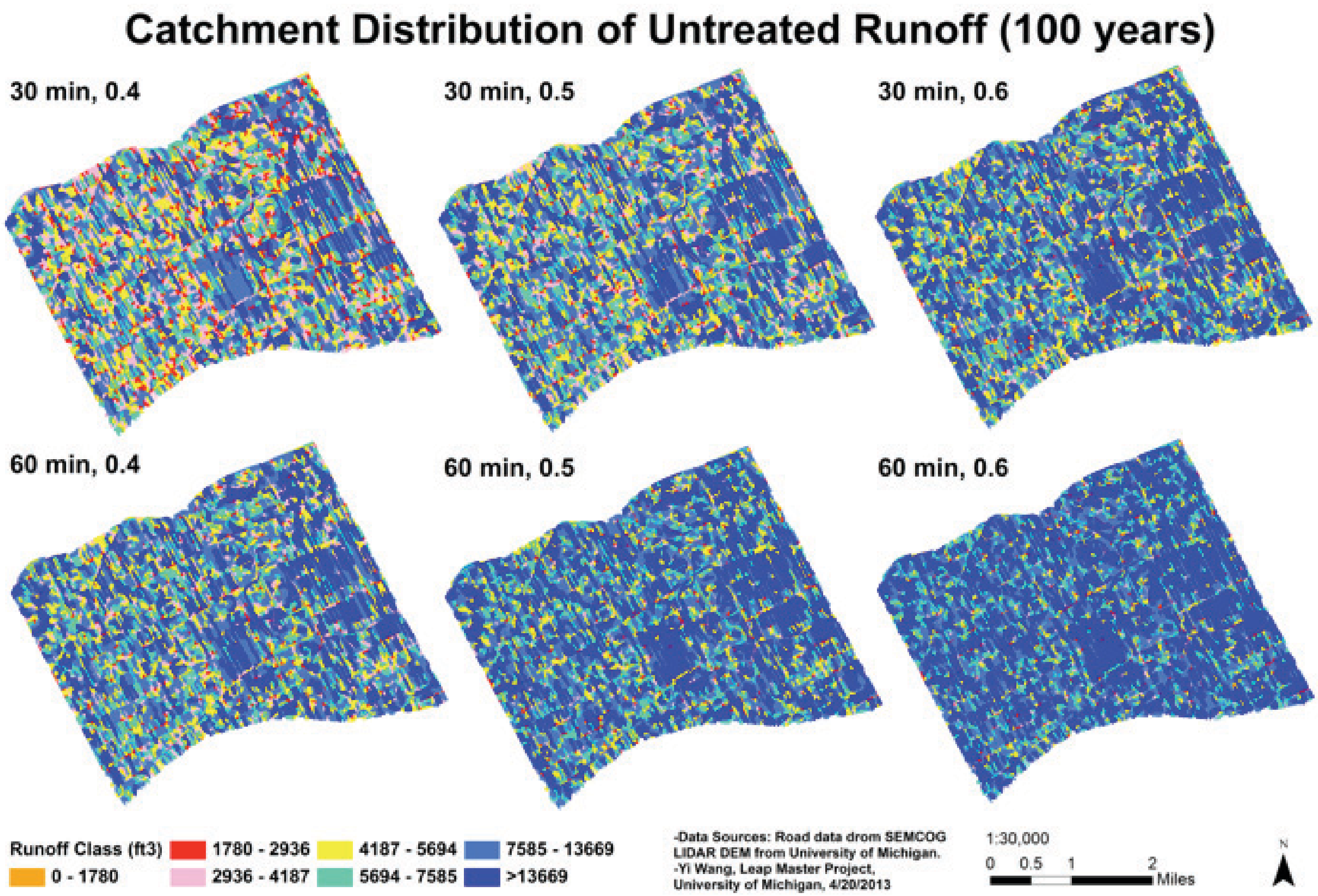


Figure E-2. Comparison of sensitivity analysis for 100-year storm event for untreated runoff. Sensitivity analysis varies by duration of storm event and surface imperviousness.

Appendix F: Two-Year Storm Treated Runoff Analysis

Categories	Treated Runoff Class	C=0.4 30 min	C=0.4, 60 min	C =0.5, 30 min	C =0.5, 60 min	C=0.6, 30 min	C=0.6, 60 min
1	< -100000	199	196	196	188	191	186
2	-100000- -50000	307	300	301	296	295	294
3	-50000 - 25000	367	360	361	353	356	341
4	-25000 - -10000	306	314	312	319	317	317
5	-10000- -2000	278	241	243	215	224	197
6	-2000 - -1000	115	96	98	77	77	60
7	-1000 - 0	188	162	160	139	149	120
8	0 - 80	432	410	416	386	387	375
9	80 - 500	438	360	367	323	329	289
10	500 - 1300	438	420	415	370	387	343
11	1300 - 2300	830	678	698	450	509	316
12	2300 - 3300	396	484	471	583	553	546
13	3300 - 5000	305	401	402	504	492	583
14	5000 - 10000	168	318	305	477	427	627
15	>10000	25	52	47	112	99	198

Table F-1. Summary of treated runoff distribution for 2-year storm event.

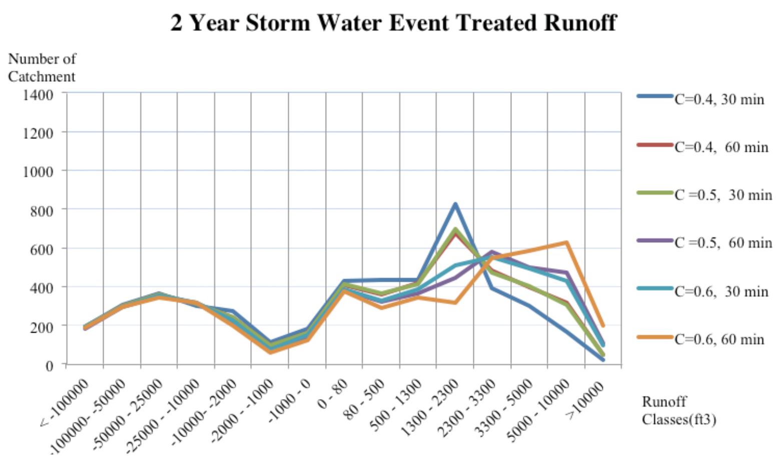
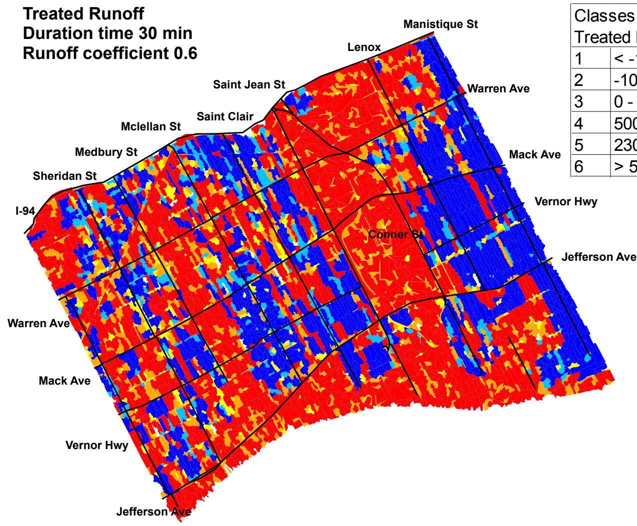


Figure F-1 Distribution of treated runoff for all LEAP District catchments.

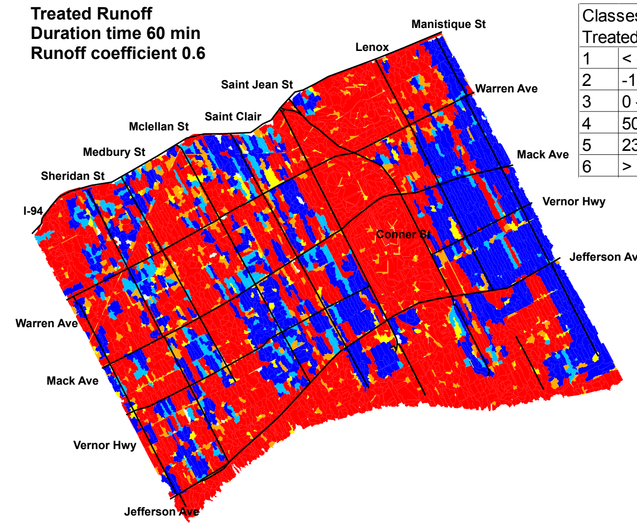
Treated Runoff
Duration time 30 min
Runoff coefficient 0.6



Classes of Treated Runoff		Number of Catchment
1	< -10000	1088
2	-10000- 0	273
3	0 - 500	574
4	500 - 2300	528
5	2300 - 5000	849
6	> 5000	1480

Main Roads
Treated Class
< -10000 cubic feet
-10000 - 0 cubic feet
0 - 500 cubic feet
500 - 2300 cubic feet
2300 - 5000 cubic feet
> 5000 cubic feet

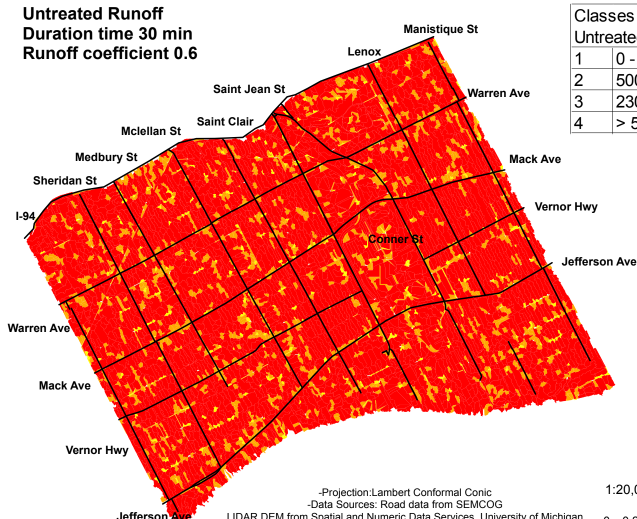
Treated Runoff
Duration time 60 min
Runoff coefficient 0.6



Classes of Treated Runoff		Number of Catchment
1	< -10000	1014
2	-10000- 0	263
3	0 - 500	508
4	500 - 2300	436
5	2300 - 5000	460
6	> 5000	2111

Main Roads
Treated Class
< -10000 cubic feet
-10000 - 0 cubic feet
0 - 500 cubic feet
500 - 2300 cubic feet
2300 - 5000 cubic feet
> 5000 cubic feet

Untreated Runoff
Duration time 30 min
Runoff coefficient 0.6



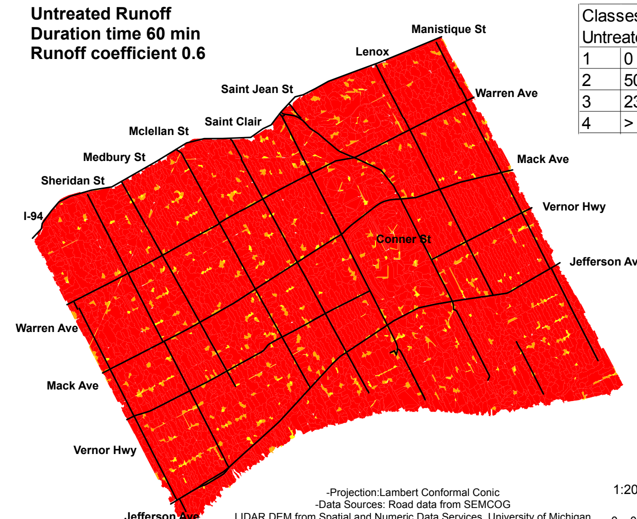
Classes of Untreated Runoff		Number of Catchment
1	0 - 500	534
2	500 - 2300	513
3	2300 - 5000	1042
4	> 5000	2703

Main Roads
Untreated Class
0 - 500 cubic feet
500 - 2300 cubic feet
2300 - 5000 cubic feet
> 5000 cubic feet

-Projection:Lambert Conformal Conic
-Data Sources: Road data from SEMCOG
LIDAR DEM from Spatial and Numeric Data Services, University of Michigan
-Yi Wang, Leap Master Project, University of Michigan, 4/20/2013

1:20,000
0 0.25 0.5 1 Miles
N

Untreated Runoff
Duration time 60 min
Runoff coefficient 0.6



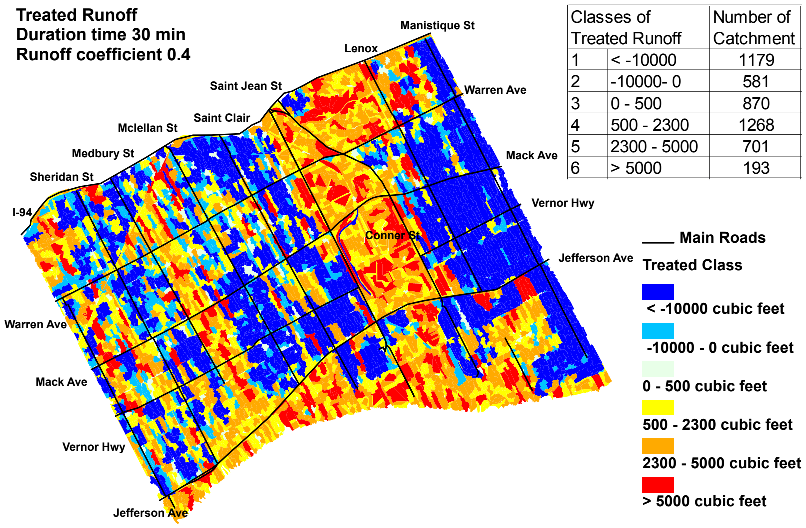
Classes of Untreated Runoff		Number of Catchment
1	0 - 500	480
2	500 - 2300	427
3	2300 - 5000	384
4	> 5000	3501

Main Roads
Untreated Class
0 - 500 cubic feet
500 - 2300 cubic feet
2300 - 5000 cubic feet
> 5000 cubic feet

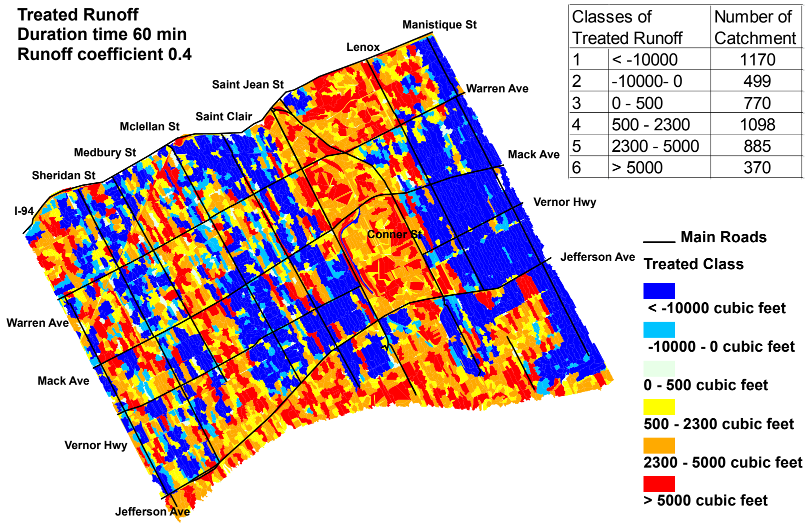
-Projection:Lambert Conformal Conic
-Data Sources: Road data from SEMCOG
LIDAR DEM from Spatial and Numeric Data Services, University of Michigan
-Yi Wang, Leap Master Project, University of Michigan, 4/20/2013

1:20,000
0 0.25 0.5 1 Miles
N

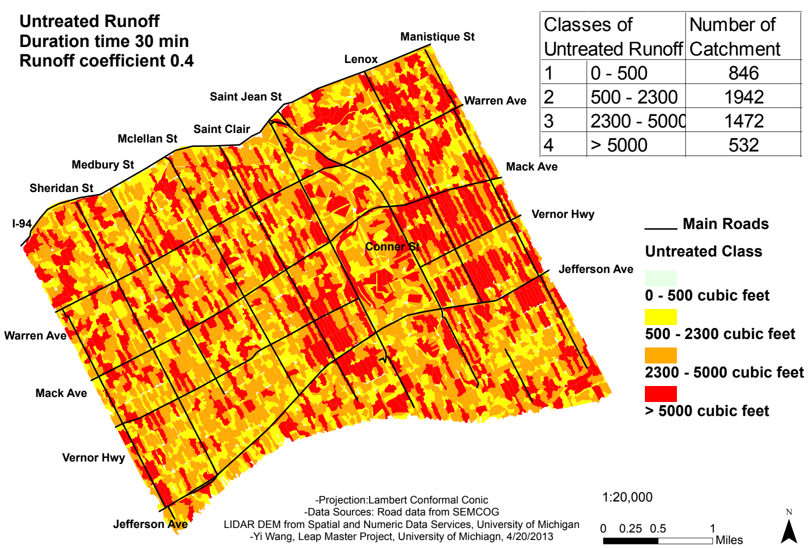
Figure F-2a. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 2-year storm event.



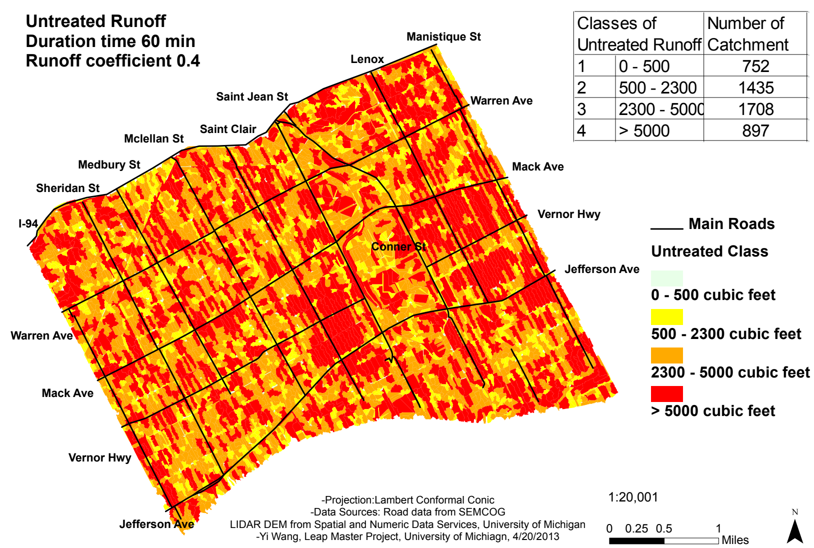
Classes of Treated Runoff		Number of Catchment
1	< -10000	1179
2	-10000- 0	581
3	0 - 500	870
4	500 - 2300	1268
5	2300 - 5000	701
6	> 5000	193



Classes of Treated Runoff		Number of Catchment
1	< -10000	1170
2	-10000- 0	499
3	0 - 500	770
4	500 - 2300	1098
5	2300 - 5000	885
6	> 5000	370

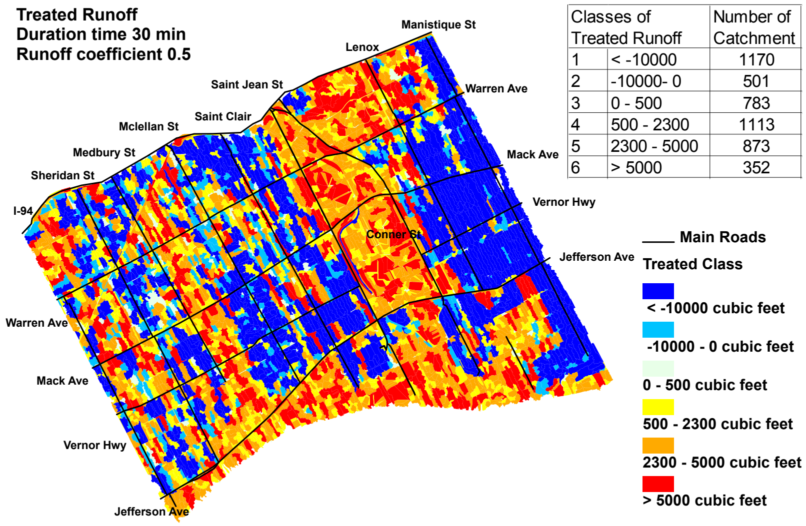


Classes of Untreated Runoff		Number of Catchment
1	0 - 500	846
2	500 - 2300	1942
3	2300 - 5000	1472
4	> 5000	532

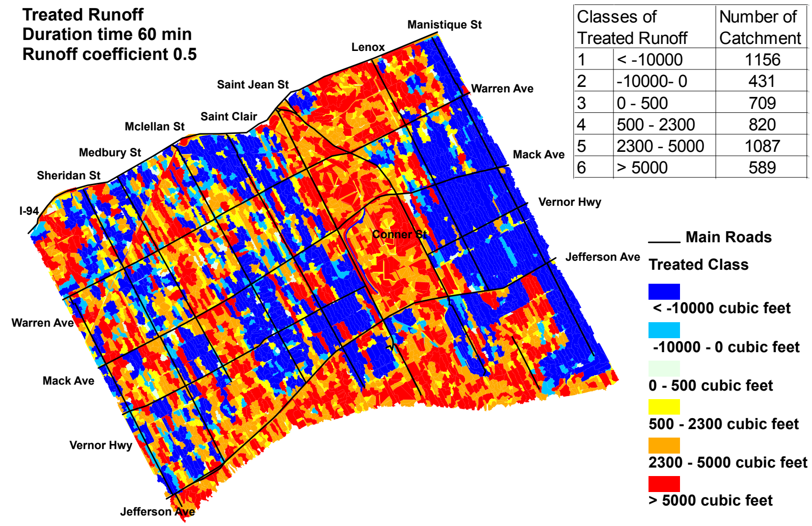


Classes of Untreated Runoff		Number of Catchment
1	0 - 500	752
2	500 - 2300	1435
3	2300 - 5000	1708
4	> 5000	897

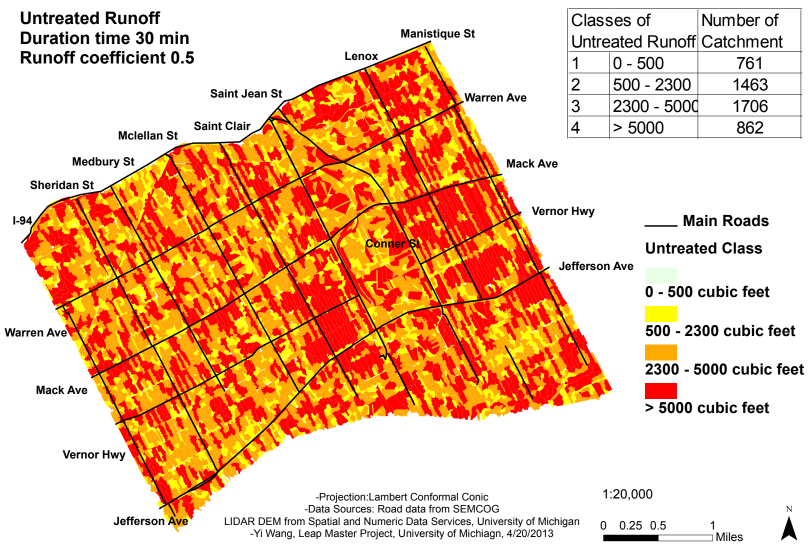
Figure F-2b. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 2-year storm event.



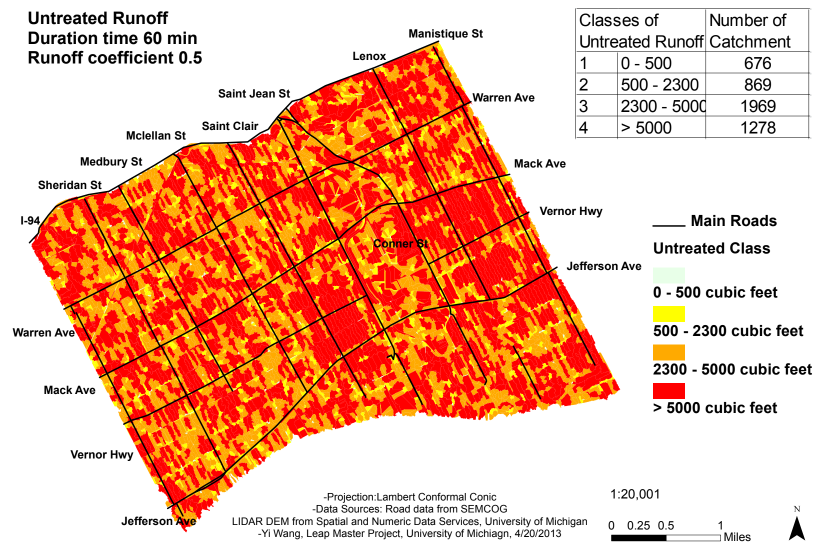
Classes of Treated Runoff		Number of Catchment
1	< -10000	1170
2	-10000- 0	501
3	0 - 500	783
4	500 - 2300	1113
5	2300 - 5000	873
6	> 5000	352



Classes of Treated Runoff		Number of Catchment
1	< -10000	1156
2	-10000- 0	431
3	0 - 500	709
4	500 - 2300	820
5	2300 - 5000	1087
6	> 5000	589



Classes of Untreated Runoff		Number of Catchment
1	0 - 500	761
2	500 - 2300	1463
3	2300 - 5000	1706
4	> 5000	862



Classes of Untreated Runoff		Number of Catchment
1	0 - 500	676
2	500 - 2300	869
3	2300 - 5000	1969
4	> 5000	1278

Figure F-2c. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 2-year storm event.

Appendix G: 100-Year Storm Treated Runoff Analysis

Categories	Treated Runoff Class	C=0.4 30 min	C=0.4, 60 min	C =0.5, 30 min	C =0.5, 60 min	C=0.6, 30 min	C=0.6, 60 min
1	< -100000	186	176	179	170	174	164
2	-100000- -50000	294	285	287	265	277	254
3	-50000 - 25000	342	319	321	305	317	299
4	-25000 - -10000	317	325	331	315	320	297
5	-10000- -2000	197	176	181	188	177	181
6	-2000 - -1000	60	41	48	31	40	36
7	-1000 - 0	122	77	84	55	56	46
8	0 - 80	373	349	366	324	347	312
9	80 - 500	289	237	241	212	227	196
10	500 - 1300	342	305	312	262	280	225
11	1300 - 2300	317	261	274	222	248	211
12	2300 - 3300	545	237	306	211	230	154
13	3300 - 5000	591	697	719	462	619	306
14	5000 - 10000	621	857	774	1078	948	1167
15	>10000	196	450	369	692	532	944

Table G-1. Summary of treated runoff distribution for 100-year storm event.

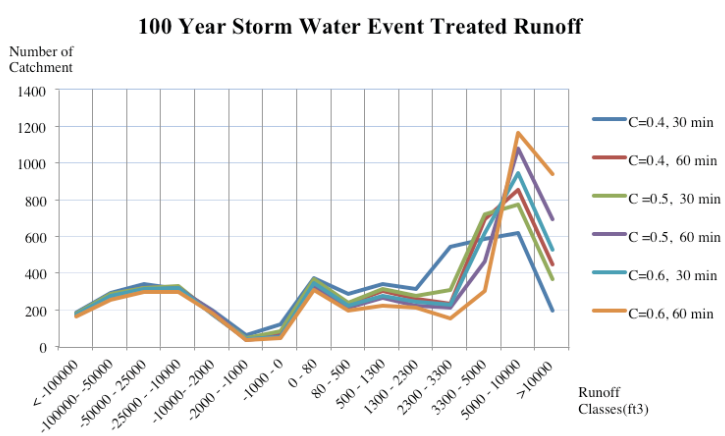
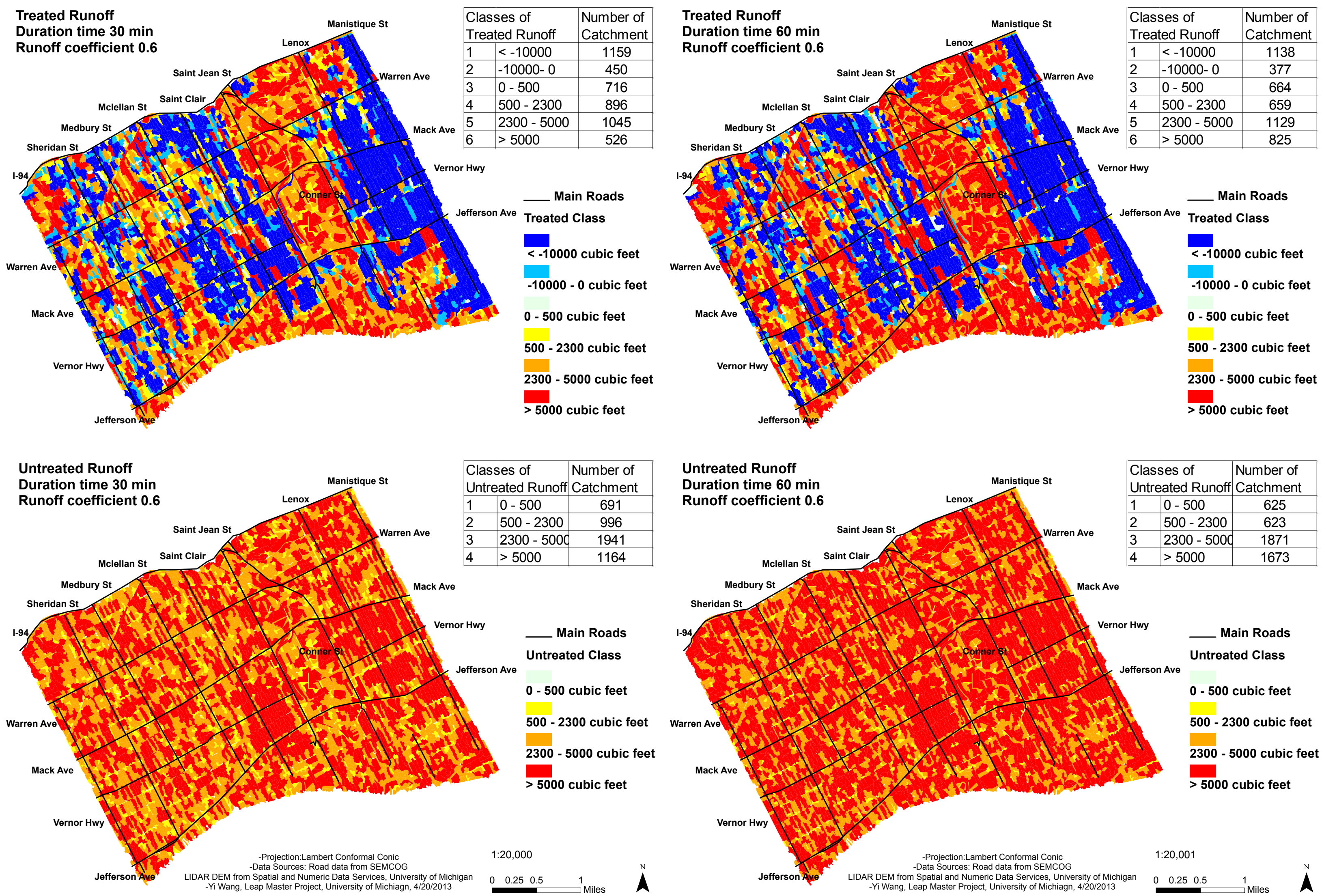


Figure G-1 Distribution of treated runoff for all LEAP District catchments.



Treated Runoff, Duration time 30 min:

Classes of Treated Runoff		Number of Catchment
1	< -10000	1159
2	-10000- 0	450
3	0 - 500	716
4	500 - 2300	896
5	2300 - 5000	1045
6	> 5000	526

Treated Runoff, Duration time 60 min:

Classes of Treated Runoff		Number of Catchment
1	< -10000	1138
2	-10000- 0	377
3	0 - 500	664
4	500 - 2300	659
5	2300 - 5000	1129
6	> 5000	825

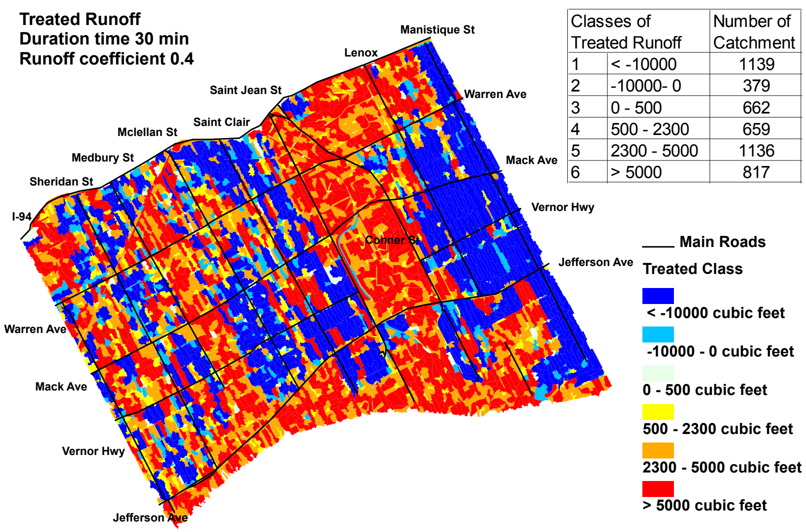
Untreated Runoff, Duration time 30 min:

Classes of Untreated Runoff		Number of Catchment
1	0 - 500	691
2	500 - 2300	996
3	2300 - 5000	1941
4	> 5000	1164

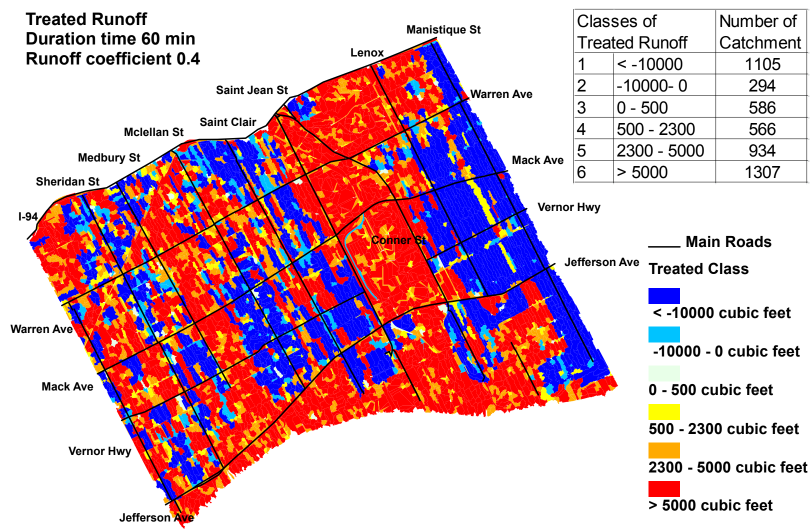
Untreated Runoff, Duration time 60 min:

Classes of Untreated Runoff		Number of Catchment
1	0 - 500	625
2	500 - 2300	623
3	2300 - 5000	1871
4	> 5000	1673

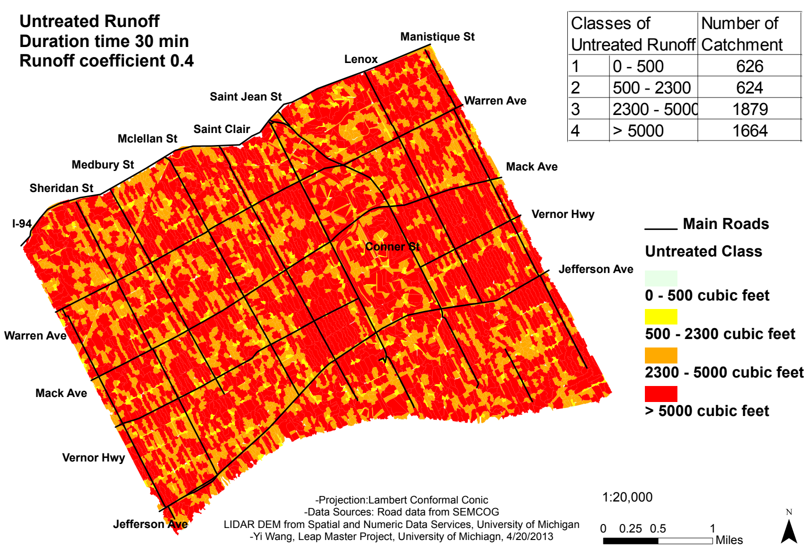
Figure G-2a. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 100-year storm event.



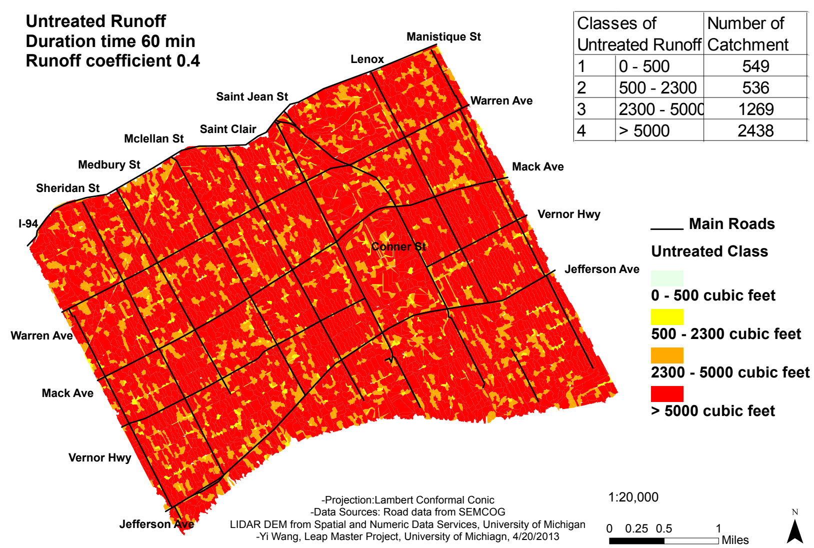
	Classes of Treated Runoff	Number of Catchment
1	< -10000	1139
2	-10000- 0	379
3	0 - 500	662
4	500 - 2300	659
5	2300 - 5000	1136
6	> 5000	817



	Classes of Treated Runoff	Number of Catchment
1	< -10000	1105
2	-10000- 0	294
3	0 - 500	586
4	500 - 2300	566
5	2300 - 5000	934
6	> 5000	1307

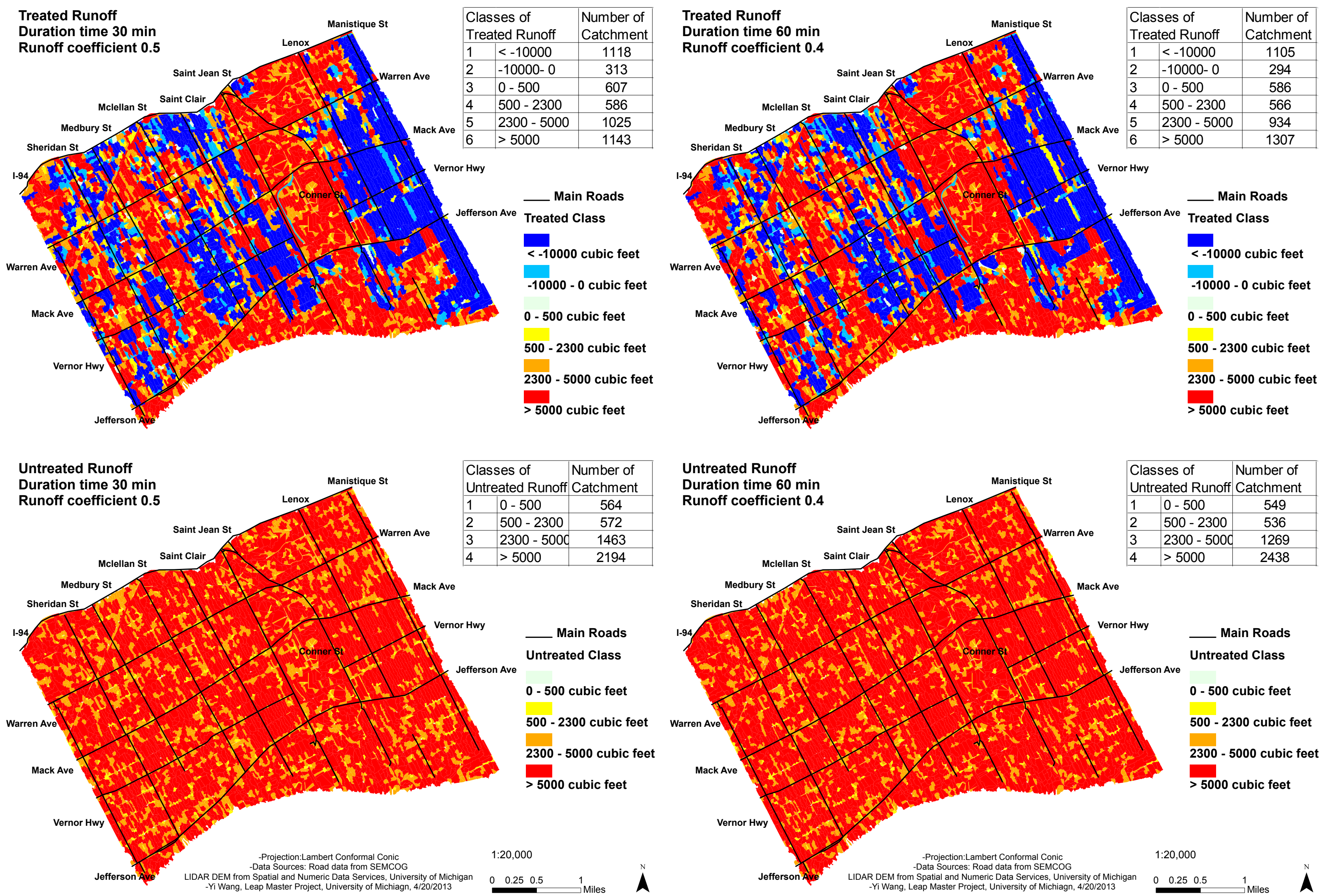


	Classes of Untreated Runoff	Number of Catchment
1	0 - 500	626
2	500 - 2300	624
3	2300 - 5000	1879
4	> 5000	1664



	Classes of Untreated Runoff	Number of Catchment
1	0 - 500	549
2	500 - 2300	536
3	2300 - 5000	1269
4	> 5000	2438

Figure G-2b. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 100-year storm event.



Treated Runoff, Duration time 30 min, Runoff coefficient 0.5:

	Classes of Treated Runoff	Number of Catchment
1	< -10000	1118
2	-10000- 0	313
3	0 - 500	607
4	500 - 2300	586
5	2300 - 5000	1025
6	> 5000	1143

Treated Runoff, Duration time 60 min, Runoff coefficient 0.4:

	Classes of Treated Runoff	Number of Catchment
1	< -10000	1105
2	-10000- 0	294
3	0 - 500	586
4	500 - 2300	566
5	2300 - 5000	934
6	> 5000	1307

Untreated Runoff, Duration time 30 min, Runoff coefficient 0.5:

	Classes of Untreated Runoff	Number of Catchment
1	0 - 500	564
2	500 - 2300	572
3	2300 - 5000	1463
4	> 5000	2194

Untreated Runoff, Duration time 60 min, Runoff coefficient 0.4:

	Classes of Untreated Runoff	Number of Catchment
1	0 - 500	549
2	500 - 2300	536
3	2300 - 5000	1269
4	> 5000	2438

Figure G-2c. Comparison of treated and untreated runoff after BMPs are sited for all imperviousness and duration scenarios for the 100-year storm event.