Stormwater Management in Southeast Detroit
Adaptive and Contextually Informed Green Infrastructure Strategies

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Abstract

This master's project focuses on the planning, analysis, and design of contextually informed green infrastructure strategies for adaptive stormwater management in Detroit. The city has observed significant population loss over the last half century, which puts a strain on the tax base required for the upkeep of stormwater and other key infrastructure services. Aging combined sewer systems in need of maintenance combined with increases in the frequency of extreme storm events related to climate change create a scenario in which finding an adaptive solution to stormwater management is becoming progressively more important.

The Jefferson-Chalmers neighborhood is located in Detroit's Lower Eastside and serves as the central study area for this project. The study aims to develop a suite of planning and design concepts for a network of site-based green infrastructure strategies for stormwater management that take advantage of Detroit's vacant land. Our approach is to create a networked system of a diverse array of green infrastructure stormwater controls. Stormwater management strategies are informed by the surrounding landscape context and respond to site-based opportunities and limitations. Primary research methods include GIS-based hydrologic modeling and studies of Detroit's combined sewer infrastructure, vacancy data, innovative green infrastructure strategies, and community stabilization plans. A small set of design concepts specific to the Jefferson-Chalmers neighborhood were also developed to illustrate actionable stormwater management strategies.

Key research findings include green infrastructure's potential to be a viable adaptive strategy for old cities with aging infrastructure. Additionally, context can inform limitations to green infrastructure strategies when addressing stormwater management issues. Recommendations for stormwater management interventions within the Jefferson-Chalmers neighborhood included the use of both source control retention and conveyance based solutions – two diametrically opposed strategies. Finally, the scale of green infrastructure interventions can be large when attempting to address stormwater management concerns. Addressing the full scope of stormwater management issues within the Jefferson-Chalmers boundaries will require additional interventions in significant areas outside the immediate context of the neighborhood.

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Section I. Introduction

From its peak of 1,850,000 residents in 1950, Detroit has experienced a significant 61% decline in total population and is now home to a mere 713,800 residents (U.S. Census, 2010). This substantial loss of population is not an uncommon occurrence in post-industrial U.S. cities. As was the case with many rust belt manufacturing centers, Detroit experienced rapid early growth as a major producer of automobiles, developing into an extensive city of predominantly low-density, single-family housing. However, 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 (Dewar & Morrison, 2012).

The loss of much of its middle class to the surrounding suburbs has put a strain on Detroit's tax base, while subsequently limiting budgets for municipal services and infrastructure improvements. Detroit's archaic stormwater infrastructure is one example of a municipal system in need of significant maintenance (Camp Dresser & McKee, 2003). This need for maintenance had become progressively more important with increases in the frequency of extreme storm events related to climate change (GLISA, 2013). As the city considers its future land use planning and infrastructure improvement strategies, it must acknowledge that the jobs once supporting its peak population and associated tax base will not be returning in the foreseeable future. Plans to revitalize Detroit must be adaptive and accept that efforts should not attempt a recovery to its historic metropolitan climax (Dewar & Morrison, 2012). This will include utilizing adaptive stormwater management strategies that are individually less costly than comprehensive repairs to Detroit's centralized system of pipe-based stormwater infrastructure – a system that was once supported by three times the city's current population.

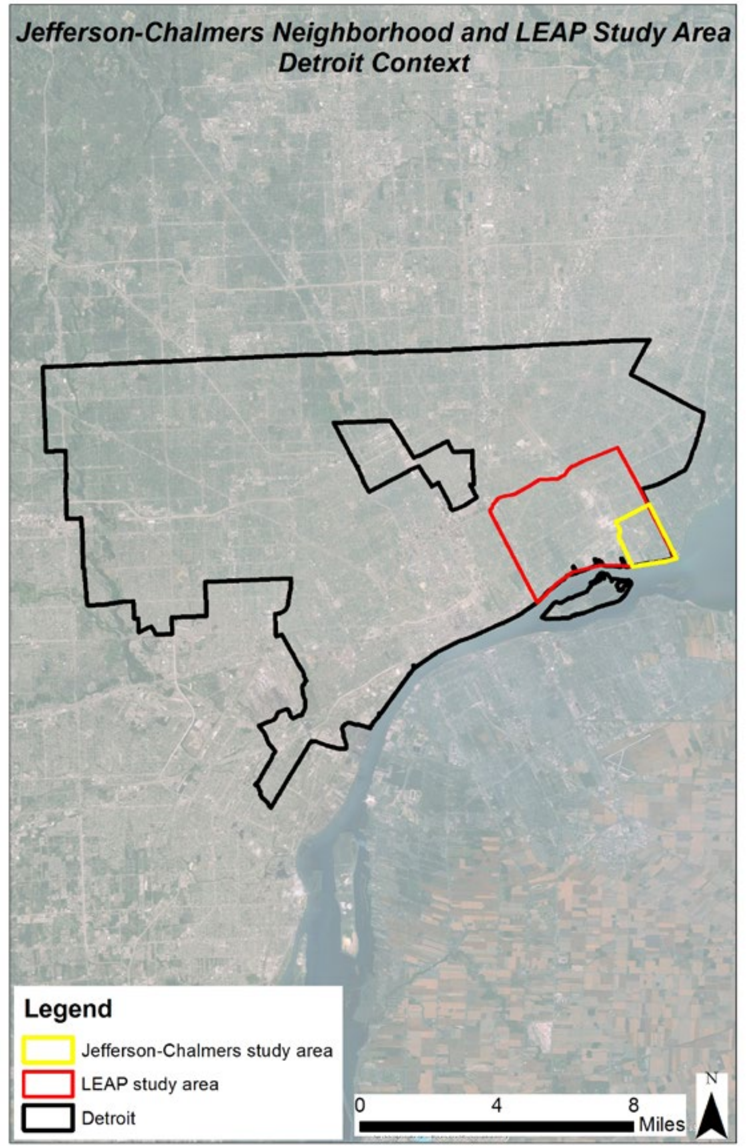

Figure 1:
Jefferson-Chalmers neighborhood within context of Detroit

(Data Sources: Detroit boundary from detroitmi.gov; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013)

Today, there are over 10,000 vacant lots and structures in the Lower Eastside neighborhoods of Detroit (Figures 1 &2) – an area that has experienced a 44% population decline since 2000 (LEAP, 2012). The Jefferson-Chalmers neighborhood occupies a portion of these lower eastside neighborhoods and will serve as the central study area for this master's project. The study aims to develop a suite of planning and design concepts for a network of site-based green infrastructure strategies for stormwater management that take advantage of Detroit's vacant land. Our approach is to create a networked system of a diverse array of green infrastructure stormwater controls. Stormwater management strategies are informed by the surrounding landscape context and respond to site-based opportunities and limitations. The Jefferson-Chalmers neighborhood provides a small-scale representation of the population decline crisis being faced by Detroit with vacancy rates over 90% on some blocks. The neighborhood occupies the extreme southeast corner of the city and covers an area roughly 1.5 square miles as measured in Google Earth.

Utilizing large tracts of vacant land versus more conventional green infrastructure retrofit projects is a more cost effective solution to stormwater management. Retrofit projects have relatively limited volume capacities and are of relatively high cost for their overall small contributions to distributed stormwater management (i.e. pervious pavers, right-of-way rain gardens, manufactured devices, etc.). This is compared to the less costly and potentially much larger - in stormwater capacity - stormwater management contributions of green infrastructure using vacant lots (Austin et al. 2013).

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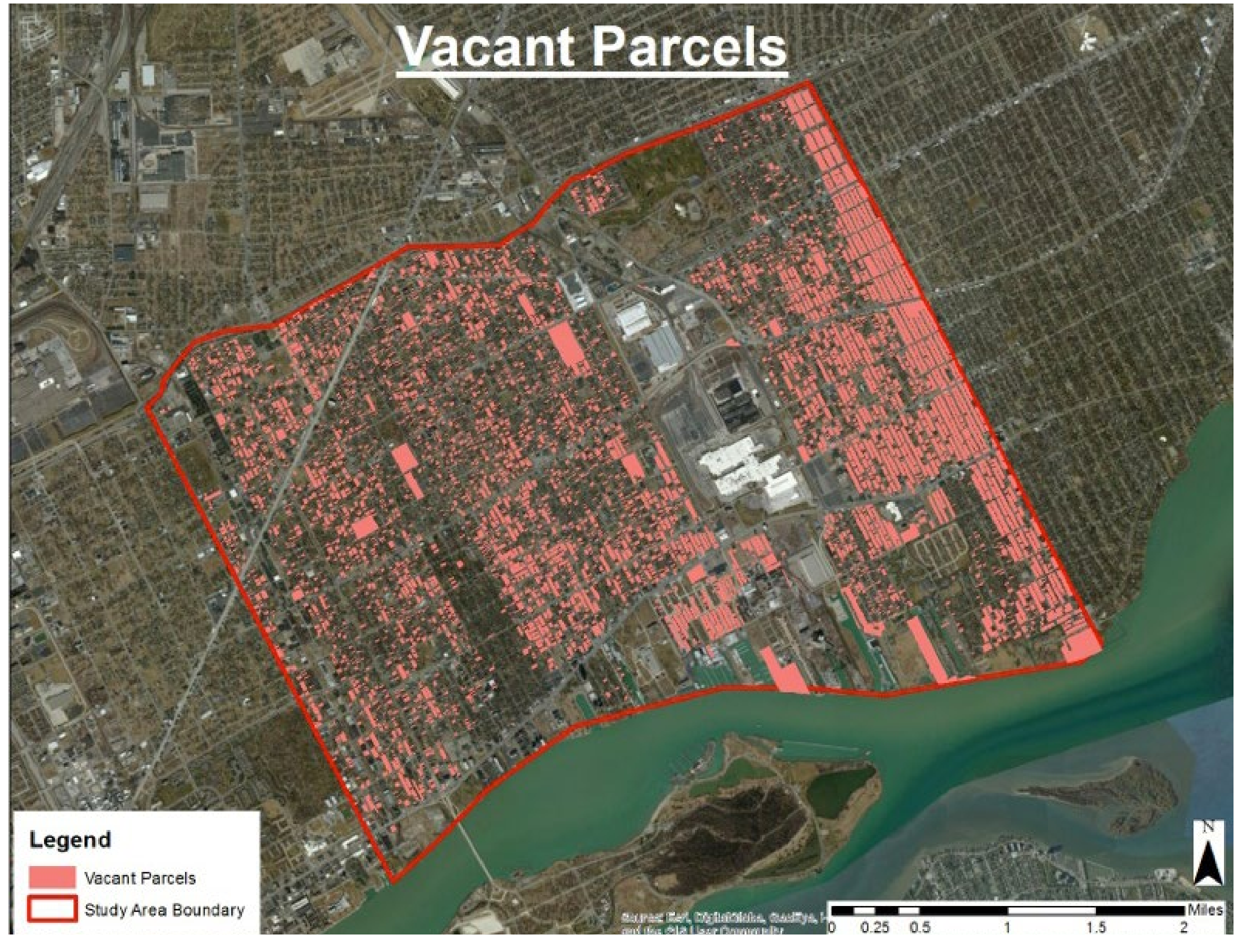


Figure 2:
Vacant parcels in Lower Eastside Detroit 2009

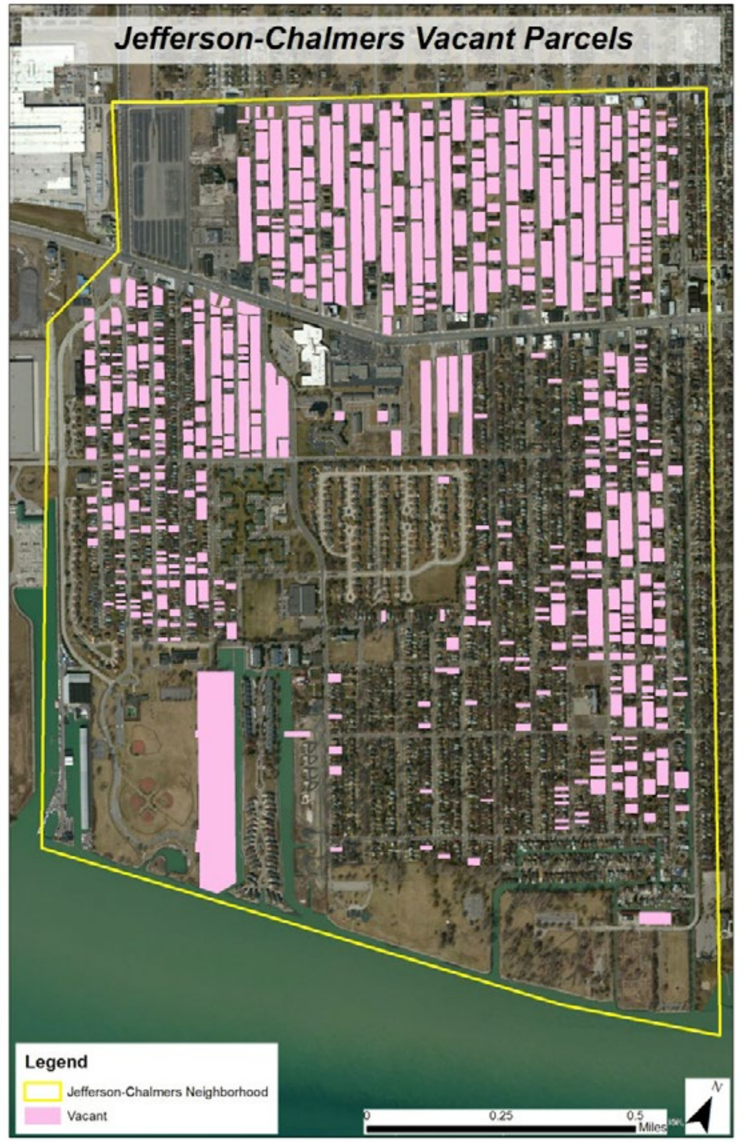
(Data Sources: Lower Eastside Detroit boundary digitized from Austin et al. 2013; Vacant parcels from Detroit Residential Parcel Survey, 2009)

Figure 3:
The Jefferson-Chalmers neighborhood is bounded by Alter Road on the east, Conner Street/Clairpointe Avenue on the west, Kercheval Street on the north, and the Detroit River to the south. Jefferson Avenue bisects the neighborhood

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013)

Figure 4:
Vacant parcels in Jefferson-Chalmers neighborhood 2009

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Vacant parcels from Detroit Residential Parcel Survey, 2009).



Stormwater Management

Detroit currently relies on an aging combined sewer system to manage its runoff. The age of the system makes it prone to compromises in its structural and functional integrity, while also creating the need for extensive and potentially costly maintenance repairs (Camp Dresser & McKee, 2003). Moreover, increasing frequency of extreme storms likely tied to climate change has created precipitation events that the city's sewer system is unable to handle. The above factors can combine to greatly increase the occurrence of sewer backups and neighborhood flooding (City of New York, 2008). Anecdotal evidence from representatives of the Jefferson East Business Association state that reports of neighborhood flooding, particularly of residential basements, are commonplace following storm events.

The presence of a topographical depression and the position of the Jefferson-Chalmers neighborhood within the context of Detroit's combined sewer system can inform why regular flooding is likely being reported. The Detroit River Interceptor (DRI), a major city stormwater collector, runs under the JEBA study area. The portion of the Detroit sewershed lying upstream and contributing water to the stretch of DRI routed under this neighborhood is extensive (see Figure 5). This results in all intercepted runoff from the east side of the city being conveyed under the Jefferson-Chalmers neighborhood. Once arriving under the neighborhood, Conner Creek pump station is required to convey all stormwater within the sewer lines into the portions of the DRI lying further downstream in the infrastructure network (see Figure 6) (Camp Dresser & McKee, 2003).

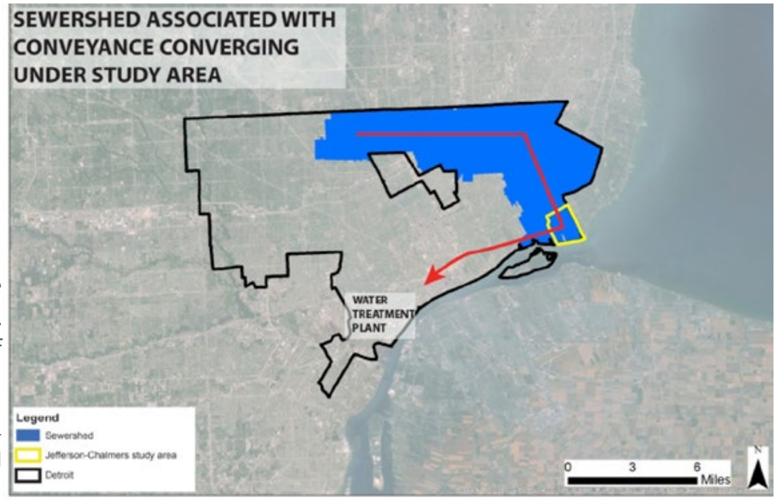


Figure 5:
Map displaying the extensive sewershed areas lying upstream of the stretch of DRI running under the Jefferson-Chalmers neighborhood. The red arrow represents the general path of intercepted runoff through the sewer system.

(Data Sources: Detroit boundary from detroitmi.gov; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Sewershed boundary digitized by MADE Studio from Camp Dresser & McKee DSWD survey data)

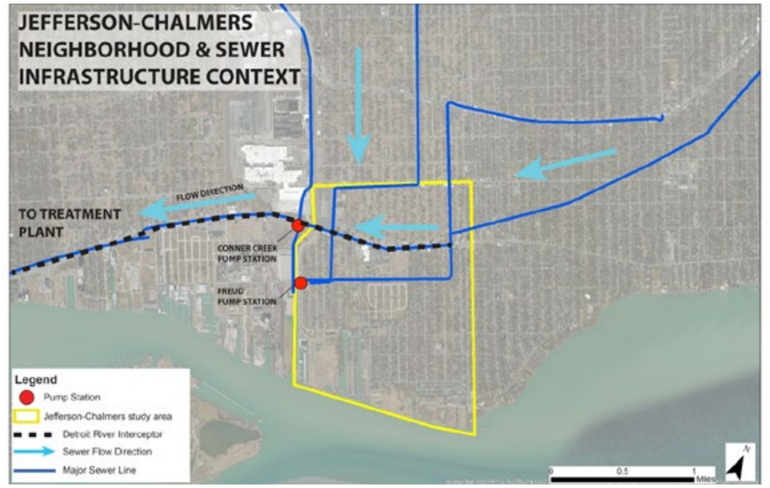


Figure 6:
Map displaying the Jefferson-Chalmers neighborhood within the context of major sewer infrastructure.

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Sewer infrastructure digitized by MADE Studio from Camp Dresser & McKee DSWD survey data)

An examination of the location of the interceptor's path through the neighborhood also coincides with a topographic anomaly – a large portion of the JEBA area exists at a lower elevation than the adjacent Detroit riverfront that borders the neighborhood's southern edge. This combination of aging sewer infrastructure, low topography, and the neighborhood's contextual relationship to the Conner Creek Pumping Station makes this area highly prone to significant flooding. Should a pump station or outfall within the JEBA neighborhood fail, or should a portion of the DRI running under the neighborhood be compromised, stormwater being conveyed through our site will be unable to exit the area. The flooding could be quite severe due to the extensive land area that makes up the effective storm sewer catchment contributing to the water being conveyed under the JEBA neighborhood via the DRI.

In addition to flooding issues, reliance on combined sewer systems also result in billions of gallons of combined sewer overflows (CSOs) being released into the Detroit and Rouge Rivers. These occurrences contribute to adverse impacts on water quality. There were 62 Detroit CSO events in 2013, 27 in 2012, 42 in 2011, and 36 in 2010 (State of Michigan, 2014). In 2009, a total of 32 billion gallons of CSOs including both untreated and partially treated sewage were released (Alliance for the Great Lakes, 2012). Detroit's 2011 Stormwater Management Program Plan (SWMPP) states that CSOs caused by wet weather events result in exceeded water quality standards for bacteria (E. coli). Concentrations of other pollutants including nutrients, oil, 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 water body. 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 above pollutants have all contributed to the Detroit River's poor water quality, which has led the water body to be identified as a binational Area of Concern (AOC) through the U.S.-Canada Great Lakes Water Quality Agreement with eleven out of a possible fourteen Beneficial Use Impairments being cited (EPA, 2012). The EPA has identified urban stormwater runoff as a major source of the contamination impairing the Detroit River. Improvements made to the stormwater management system, especially the use of green infrastructure within the city of Detroit, has been previously identified as a means to improve water quality of the River, particularly through the limitation of combined sewer overflows (EPA, 2012).

Green Infrastructure Potential Role of Vacant Land in Stormwater Management and Right Sizing

Green infrastructure is a relatively new and flexible term referring to systems designed to manage stormwater through the use or mimicry of a site's natural hydrologic processes as an alternative to piped stormwater infrastructure (EPA, 2014). Green infrastructure employs distributed source controls that incorporate vegetation, soils, and other natural processes. This mitigates stormwater runoff before it reaches piped infrastructure systems and provides treatment to the associated pollutants of the runoff (NRC, 2009). "Building and landscape designs that mimic natural systems, and infiltrate, retain, or detain rainfall on-site, can reduce excess flows into our sewers, streets, and waterways" (City of New York, 2008). It has also noted that green infrastructure systems provide ancillary benefits and is widely desired as a community amenity. These measures result in increased recreational and green space, higher quality of life, and boosted property values (City of New York, 2008).

The high amounts of vacant land in Detroit can play a pivotal role to address stormwater management through the use of green infrastructure. It has been argued that green infrastructure has the potential to not only improve water quality, but to also address the blight caused by vacant and abandoned properties (Schilling, 2009). 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 in neighborhood landscapes where conversion of vacant lots to these innovative uses has occurred (Nassauer et al, 2008).

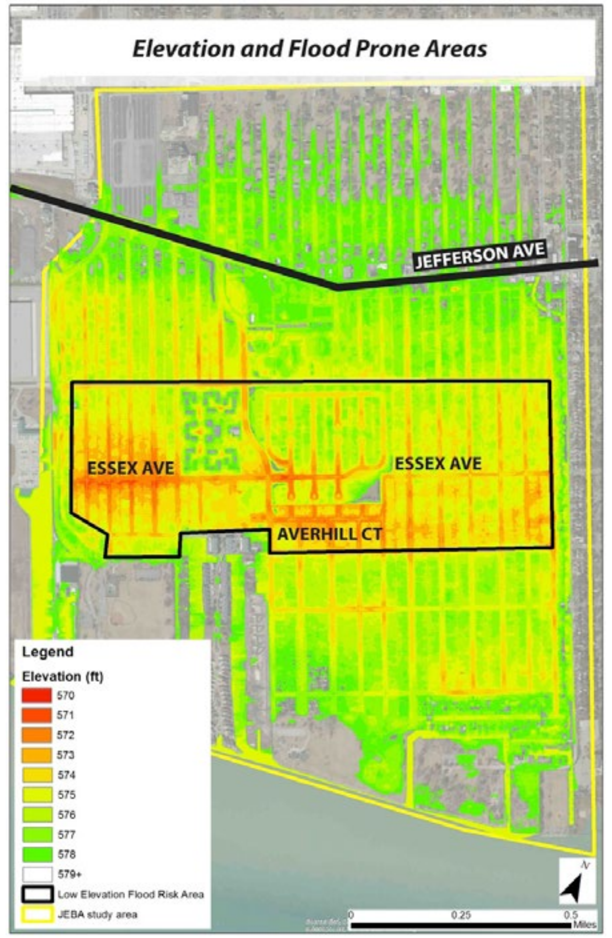


Figure 7:
Topography of the Jefferson-Chalmers neighborhood forms a "bowl" with areas in red representing lower elevation and green representing higher elevations. Sewer backup water within this "bowl area" would not be able to leave as runoff, making this area flood prone.

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; LiDAR DEM from University of Michigan).

Master's Project Goals

This master's project seeks to develop a suite of planning and design concepts for a network of site-based green infrastructure strategies that take advantage of Detroit's vacant land. Planning and design concepts focus on the aforementioned Jefferson-Chalmers neighborhood, but a multi-scalar approach will be utilized. This is to preserve applicability of the planning and design strategies throughout Detroit and other legacy cities seeking a future planning direction in the face of shrinking populations. Additionally, scale matters when planning a green infrastructure network to manage stormwater and provide other additional community benefits. "The majority of quantifiable benefits accrue to the community as a whole or are even more widespread… Community wide benefits require community-wide coordination… By themselves… onsite benefits likely are not sufficient in motivating home and business owners to provide green infrastructure to the level that makes economic sense" (NRC, 2009).

Our analysis combined grassroots neighborhood stabilization plans, Detroit vacant land analysis, sewer infrastructure studies, and GIS-based hydrologic modeling to inform the planning and design of site-based green infrastructure best management practices (BMPs). This also facilitated an assessment of some contextual limitations for site-based green infrastructure to mitigate flooding frequently reported in the Lower Eastside's Jefferson-Chalmers neighborhood. Where site-based green infrastructures techniques were limited in the mitigation of flood control, an alternative conveyance-based management solution was developed.

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Section II. The Jefferson East Business Association (JEBA) Study Area

Study Area Overview

Our study site consists of the Jefferson-Chalmers neighborhood situated along East Jefferson Avenue. Jefferson-Chalmers is a neighborhood associated with the Jefferson East Business Association (JEBA), an organization working to foster new development within the east Jefferson corridor (Jefferson East, Inc., 2013). Jefferson Avenue runs along the southern edge of the city, paralleling the Detroit Riverfront. This road links the Jefferson-Chalmers neighborhood with the downtown district (lying west) and the wealthy Grosse Pointe suburbs bordering the neighborhood to the east. The Jefferson-Chalmers neighborhood is bounded by Alter Road on the east, Conner Street/Clairpointe Avenue on the west, Kercheval Street on the north, and the Detroit River on the south. Jefferson Avenue runs approximately through the center of the Jefferson-Chalmers neighborhood, and is primarily commercial zoned (see Figure 3 above). The neighborhood is also flanked by Conner Creek to the west and Fox Creek to the east (see Figure 8 on the right).

Figure 8:
Creeks Flanking Jefferson-Chalmers neighborhood.

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; LiDAR DEM from University of Michigan).

Jefferson-Chalmers Neighborhood Stabilization Plan

JEBA supplied the master's project team with a 2013 stabilization plan for the Jefferson-Chalmers neighborhood authored by the Detroit Vacant Property Campaign (DVPC). The DVPC is a "cross-sector collaboration of community advocates and leaders" focused on "comprehensively responding to the city's vacant property crisis through education, outreach, technical assistance, vacant property planning, and policy work" (Detroit Vacant Property Campaign, 2013). The plan provides a good starting point for assessing the area's existing assets. These include a historic commercial district along Jefferson Avenue, the Riverbend Plaza shopping center, Victoria Park subdivision, a number of well-maintained apartment complexes, high-end canal and riverfront housing, 100+ acres of riverfront park, three schools (Casterns Elementary, GoLightly Vocational High School, and the K-8 Merit Academy), the National Register of Historic Places' Vanity Ballroom, historic Fischer mansion, the Bayview Yacht Club, and the recently completed Conner Greenway. The Jefferson-Chalmers Stabilization Plan also makes general note that "much" of the housing stock in the neighborhood is "comprised of attractive brick homes." The authors posit that "this quality housing stock provides a competitive advantage for the community" in attracting new residents (Detroit Vacant Property Campaign, 2013).

The Jefferson-Chalmers neighborhood stabilization plan also provides a number of broad planning goals to direct future development patterns of the neighborhood. The goals can

be divided into four general categories: 1) the preservation and enhancement of current neighborhood assets, 2) making the neighborhood safer, 3) making the neighborhood cleaner, and 4) encouraging investment from new and existing stakeholders (Detroit Vacant Property Campaign, 2013). In an attempt to advance these efforts, our master's project team selected specific components from the four goals above and integrated them into our design and planning work.

Components targeted from the "preservation and enhancement of current neighborhood assets" goal include the enhancement and preservation of the study site's riverfront parks, greenways, canals, and current homeowners. The stabilization plan emphasized the need for low maintenance and cost-effective strategies for the upkeep of these assets due to Detroit's current fiscal climate.

Components addressed from the "safer neighborhoods" goal include advocacy for the demolition of abandoned and blighted structures. It is believed that demolition can also help to reduce blight.

Components of focus from the "cleaner neighborhoods" goal include reducing blight, improving neighborhood streetscapes, and managing public and open land. The Stabilization Plan states that improving neighborhood streetscapes might involve creating a better pedestrian experience through landscaping (i.e. improving the curb tree-line) and public infrastructure improvements such as improved street lighting. The plan also suggested that managing public and open land might involve keeping vacant lots maintained and looking tidy. The document also states that public and open land should be considered in stormwater runoff management.

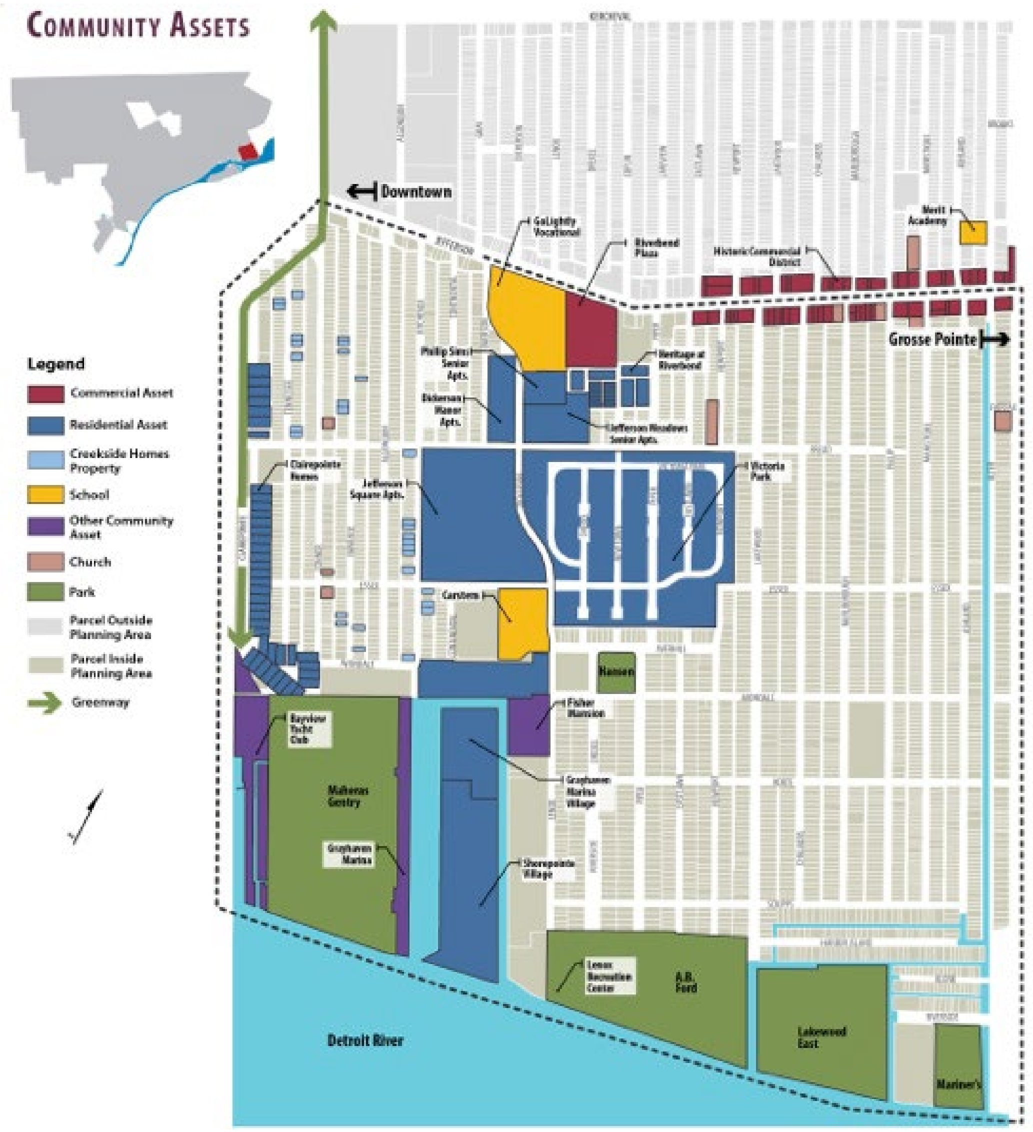

Figure 9:
Jefferson-Chalmers Neighborhood and Assets

(Source: Detroit Vacant Property Campaign, 2013 – page 7)

CDAD Neighborhood Revitalization Strategic Framework

Another document utilized to better inform planning and design decisions by the master's project team was the 2010 Neighborhood Revitalization Strategic Framework by The Community Development Advocates of Detroit (CDAD) Futures Task Force. The CDAD Futures Task Force was "formed out of a conviction that Detroit requires a bold new vision for its neighborhoods – one that acknowledges that [the City] will not reverse the loss of population for the foreseeable future, and that current conditions in Detroit's neighborhoods are socially, economically, and environmentally no longer sustainable" (Community Development Advocates of Detroit, 2010).

The CDAD framework champions the idea that development and the future direction of every area of the city must ultimately be addressed through the right type of intervention, even if that means the clearance of buildings and populations. It also promotes the active incorporation of Detroit's riverfront into neighborhood planning as a key distinguishing feature and asset of the city (Community Development Advocates of Detroit, 2010).

Indicators for appropriate future development direction were developed by the partnering organization Data Driven Detroit (D3). These indicators were used to generate eleven CDAD classifications for proposed future directions of Detroit's neighborhoods (see Appendix 3). These metrics were based on comprehensive residential analysis, corridor segment analysis (to determine strategic placement of commerce-based village/shopping hubs and green thoroughfares), and analysis of industrial parcels (Community Development Advocates of Detroit, 2010).

The Lower Eastside Action Plan (LEAP) has implemented the CDAD framework to propose future development directions for each of their neighborhoods (Community Development Advocates of Detroit, 2012). Because the Jefferson-Chalmers study area lies within the LEAP boundaries, we incorporated LEAP designation of CDAD classifications into the master's project team's planning and design work.

The map on the right displaying the CDAD neighborhood typologies of the Jefferson-Chalmers study area shows a strong residential core south of Jefferson. Conversely, the neighborhoods north of Jefferson are dominated by low-density and open/green space. The open/green space "naturescape" typology also characterizes the land areas adjacent to the Detroit River (currently city-owned parks). The eastern edge of our site is characterized by a band of spacious residential, urban homestead, and naturescape typologies. A single-block-wide band of traditional residential exists just beyond these lower density typologies along the extreme eastern boundary of our site. This likely reflects the presence of homes with higher real estate value. Finally, the commercial-oriented typologies of "village hub" and "shopping hub" exist along Jefferson Avenue with the western portion of Jefferson being designated a "green thoroughfare". These CDAD typologies strongly align with the distributions of vacant properties and the neighborhood assets described by the Jefferson-Chalmers Neighborhood Stabilization Plan. Low density and open space typologies such as "naturescape" and "urban homestead" strongly align with areas of high vacancy and few identified neighborhood assets. Higher density residential development such as "traditional" and "spacious residential" typologies are more aligned with areas displaying limited vacancy and higher concentrations of neighborhood assets.

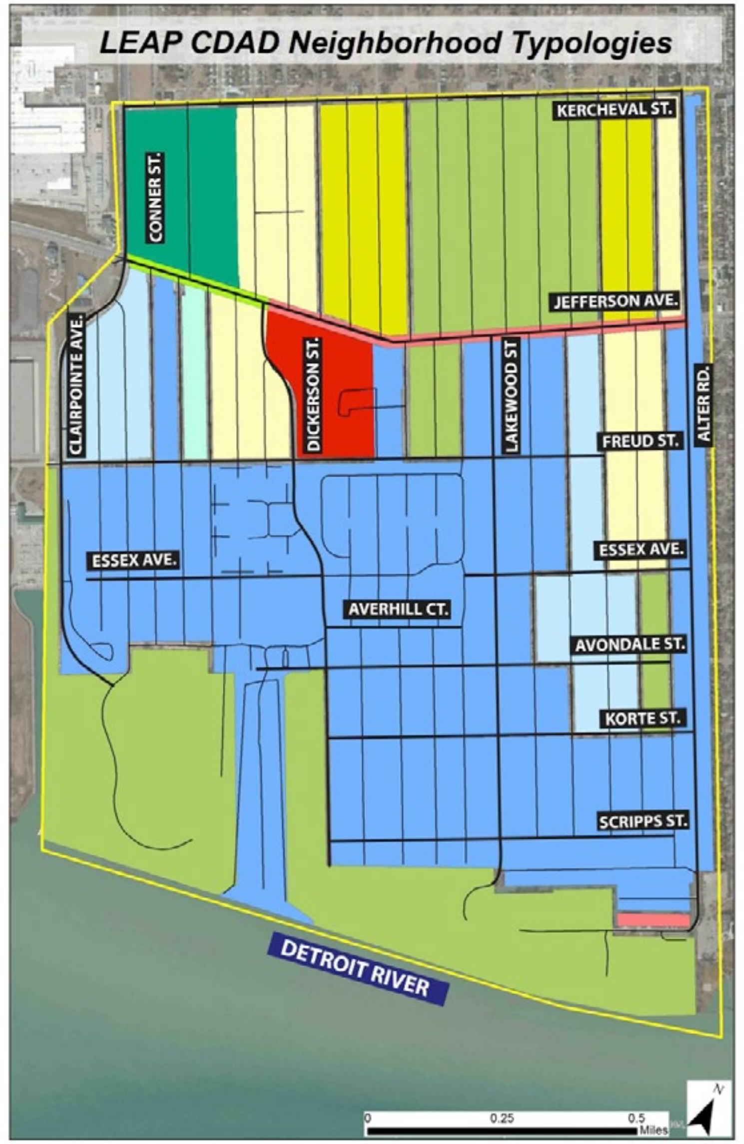

Figure 10:
Map Displaying 2010 LEAP CDAD Neighborhood Typologies in Jefferson-Chalmers Neighborhood and Roads.

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; CDAD typology boundaries digitized from Community Development Advocates of Detroit, 2010; Detroit roads from detroitmi.gov)

East Jefferson Stakeholder Outreach and Implementation Plan

A third document used by the master's project team to inform planning and design decisions includes the East Jefferson Stakeholder Outreach and Implementation Plan (East Jefferson Corridor Collaborative, 2010). This document was produced through a collaborative effort between JEBA and a number of other East Jefferson corridor community development organizations to generate dialogue about "corridor improvements in the East Jefferson area and to help determine [a plan of actionable development strategies] to increase the corridor's social and economic development". Overarching urban design goals outlined by the plan include connecting neighborhoods to the Detroit Riverfront, connecting the East Jefferson Corridor to Detroit's Downtown, strengthening commercial and retail corridors, enhanced neighborhood connections between community assets (i.e. parks, commercial districts, riverfront, etc.), restoring individual neighborhoods as "places", strengthening the edges of existing neighborhoods, the creation of clean and safe "complete streets", and the consideration of "green" development (East Jefferson Corridor Collaborative, 2010).

Although the plan was written in the scope of the entire East Jefferson Corridor (*need to show graphic of this somewhere), the portion of the corridor occupying the Jefferson-Chalmers study area was briefly addressed in greater detail by the document. Items of note within the plan are the presence of extremely sparsely populated neighborhoods north of Jefferson, a stronger residential presence south of Jefferson with some pockets of more limited density, relatively stable retail in Riverbend Plaza,

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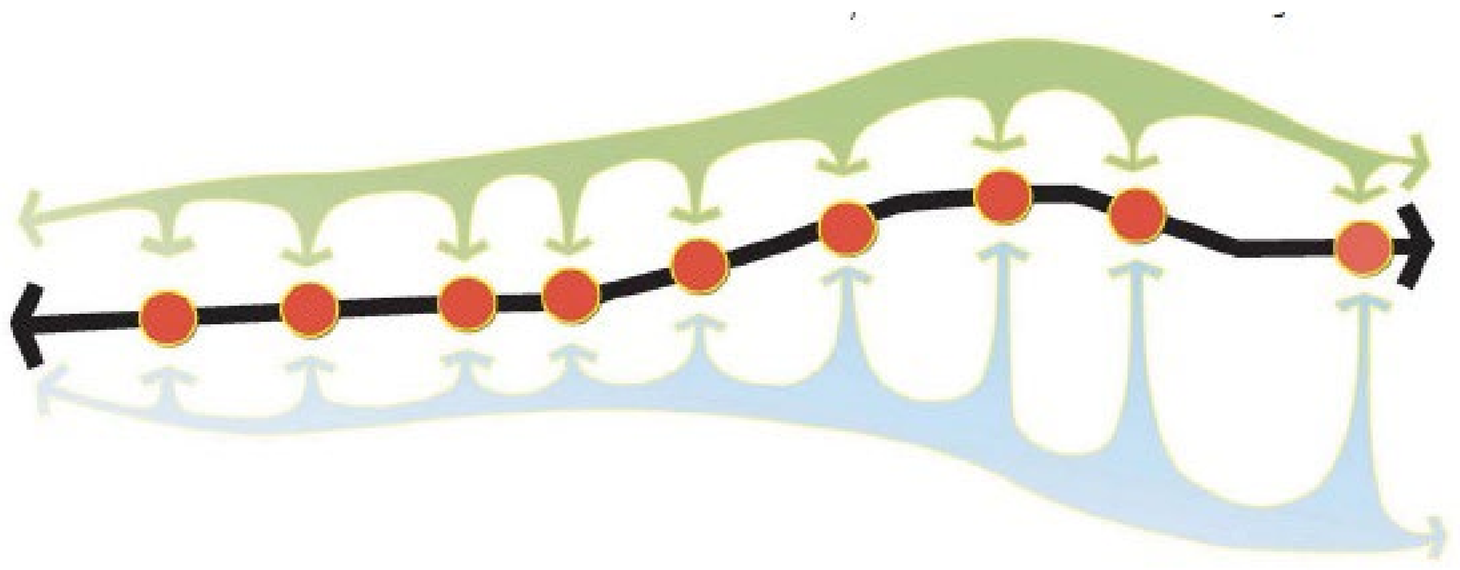

Figure 11:
"The graphic above illustrates the concept of connectedness throughout the corridor. Jefferson is the spine connecting the green of the neighborhoods and the blue of the River. They meet at key intersections along the corridor. Those intersections form the nexus for activity and future growth. This is where we begin…"

(Source: East Jefferson Corridor Collaborative, 2010) the eastern terminus of Jefferson Avenue with the potential to be a City gateway from the Grosse Pointes, a good stock of small historic brick commercial buildings along Jefferson, limited pedestrian-oriented development and activity, and riverfront parks that are "woefully underutilized" (East Jefferson Corridor Collaborative, 2010).

The authors of the plan state that it would be worthwhile to "explore hidden potential" of the neighborhoods and promote transit oriented uses (East Jefferson Corridor Collaborative, 2010). The hidden potential of the JEBA neighborhoods could be interpreted as the good stock of historic commercial buildings along East Jefferson, a quality housing stock within the area's still-strong neighborhoods, abundant vacant land for green development, the presence of an already completed stretch of greenway along Conner Avenue, abundant riverfront park area (including the recently renovated Maheras-Gentry Park), and many strong neighborhoods between Jefferson and the River with limited blight.

Also of note, the Plan suggests a series of greenways based on the presence of pre-existing greenways, river walks, and greenspaces. Further development of this greenway network could be harnessed to increase walkability and access to community amenities and the riverfront within the study neighborhood. It could also enhance the neighborhood's connection to Jefferson Avenue, which serves as the major arterial connection for the neighborhood to Detroit's downtown district.

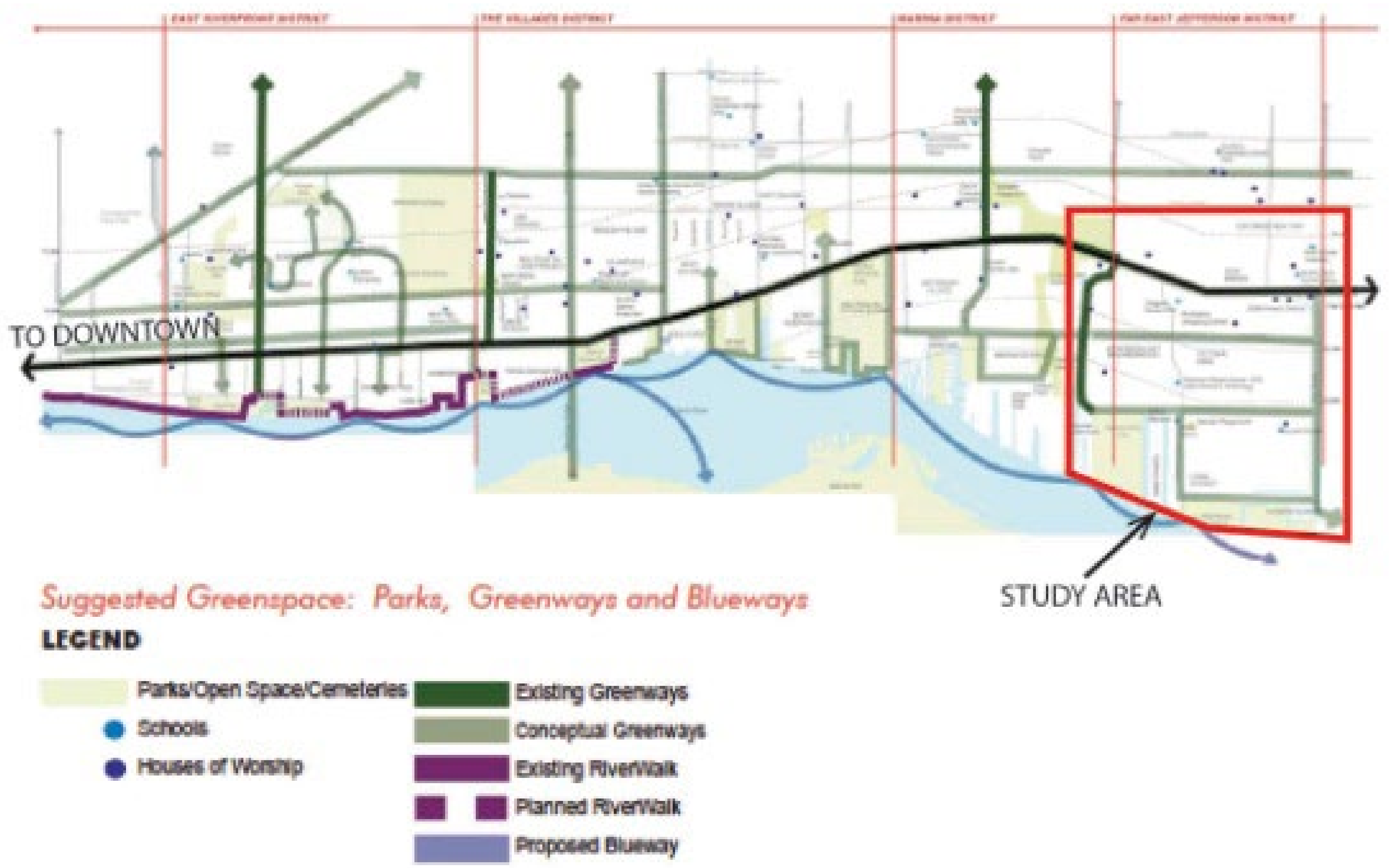

Figure 12:
Map showing pre-existing greenways, river walks, and greenspaces and suggested future greenway development in the East Jefferson Stakeholder Outreach and Implementation Plan 2010.

(East Jefferson Corridor Collaborative, 2010 – page 54)

Section III. Green Infrastructure - An Overview

Urbanization & Stormwater

Urbanization causes extensive alterations to an area's hydrology. It increases impervious areas of the landscape such that receiving waters in the affected watershed experience radically different flow regimes compared to its pre-urbanized state. The impact on a watershed's hydrology that is caused by these development decisions is compounded by historic urban design patterns that moved surface water away from structures and cities as fast as possible through the construction of pipe-based drainage networks. This rapid and efficient system to convey water away from urbanized areas results in stormwater flowing rapidly across and under the land surface where it will arrive at a stream channel or other nearby water body in short, concentrated bursts of high discharge. When combined with the introduction of pollutant sources that accompany urbanization (such as lawns, motor vehicles, domesticated animals, and industry), these changes in hydrology have led to water quality and habitat degradation in virtually all urban streams and associated receiving water bodies (NRC, 2009).

The scientific literature overwhelmingly agrees that nearly all the hydrologic and water quality problems associated with urbanization result from one underlying cause: loss of the water-retaining and evapotranspirating functions of the soil and vegetation in urban landscapes (NRC, 2009). Reliance on sewer-based stormwater management solutions, which facilitate the degradation of local streams and water bodies through rapid conveyance of high volumes of untreated discharge, are also more frequently being found to be less effective in preventing urban flooding due to a higher prevalence of sewer backups caused by increasing rates of extreme storm events. These effects are expected to become even more challenging to control as climate change increases the amount of annual rainfall and the severity of individual storms (City of New York, 2008).

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Decentralized Source Control Measures and Green Infrastructure

To supplement conventional and centralized stormwater management, a decentralized stormwater infrastructure network can be developed to temporarily store or permanently remove stormwater near where rain falls on impervious surfaces. The effectiveness of such decentralized systems depends upon the aggregate, cumulative effects of many small-scale source control measures. The incremental construction of source controls can also require more level cash flows and demands upon labor and material markets versus big lump sums for major infrastructure projects (City of New York, 2008).

"Green infrastructure" is a relatively new and flexible term referring to systems designed to manage stormwater through the use or mimicry of a site's natural hydrologic processes as an alternative to piped stormwater infrastructure (EPA, 2014). Green infrastructure employs distributed source controls that incorporate vegetation, soils, and other natural processes. This mitigates stormwater runoff before it reaches piped infrastructure systems and provides treatment to the associated pollutants of the runoff (NRC, 2009). Similarly, New York City's Mayor's Office of Long-Term Planning and Sustainability, a national leader in sustainable stormwater management, states that "stormwater runoff does not have to be an inevitable by-product of development. Building and landscape designs that mimic natural systems, and infiltrate, retain, or detain rainfall on-site, can reduce excess flows into our sewers, streets, and waterways" (City of New York, 2008). The office has also noted that green infrastructure systems provide ancillary benefits and is widely desired as a community amenity. It results in increased recreational and green space, higher quality of life, and boosted property values (City of New York, 2008). The master's project team feels that green infrastructure can be used to address many of the issues related to high flood risk and neighborhood stabilization goals described above in the JEBA neighborhood.

Structural versus Nonstructural Source Control Measures for Stormwater Management

The City of New York breaks source controls into the categories of technological and non-technological source control measures. Technological measures include blue roofs, rainwater harvesting, vegetated controls, permeable pavements, and green roofs. Non-technological control measures include design guidelines, performance measures, zoning requirements, and economic incentives (City of New York, 2008).

Similar to New York breaking source controls into non-technological and technological measures, SEMCOG categorizes source controls into two broad categories: nonstructural and structural best management practices (BMPs). Nonstructural BMPs take broader planning and design approaches, which are less "structural" in their form. They are not fixed or specific to one location. Structural BMPs, on the other hand, are decidedly more location specific and explicit in their physical form (SEMCOG, 2008). Primary characteristics of nonstructural BMPs are preventing stormwater runoff from a site and curbing initial pollutant loading. This differs from the goal of structural BMPs, which is to help mitigate stormwater related impacts after they have occurred (SEMCOG, 2008).

Many nonstructural BMPs apply to an entire site and often to an entire community, such as wetland protection through a community wetland ordinance. Non-structural BMPs might include cluster development, watershed and land-use planning, minimizing soil compaction, minimizing total disturbed area, protecting natural flow pathways, protecting riparian buffers, conservation of natural areas, reducing impervious surfaces, and downspout disconnection (SEMCOG, 2008; NRC, 2009). Some organizations have also discussed nonstructural BMPs as product substitution (NRC, 2009). For example, lead concentrations in stormwater have been reduced by at least a factor of four after the removal of lead from gasoline. Removing a contaminant from the runoff stream or limiting the creation of impervious surfaces simplifies and reduces the reliance on structural BMPs (NRC, 2009). Many prior investigators have observed that stormwater discharges would ideally be regulated through direct controls on land use and strict limits on both quantity and quality of stormwater runoff into surface waters (NRC, 2009).

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Overarching Green Infrastructure Typologies

The numbers of structural BMPs are extensive and no one source seems to provide an exhaustive list of techniques. Categorization of structural BMPs into discrete classes also varies widely. A 2013 SNRE master's project focusing on green infrastructure in Detroit's Lower Eastside grouped structural BMPs into six effective classes according to the opinion of the master's project team. These included bioretention and bioinfiltration, rooftop detention, filters, urban forests, subsurface controls for retention and infiltration, and rainwater harvesting (Austin et al. 2013).

Bioretention and bioinfiltration are source controls that use vegetation for soil infiltration and evapotranspiration to reduce the volume of runoff. These controls are designed to capture the "first flush" rainfall (generally the first ½") as close to where the rain falls as possible. These measures are thus ideal for the upper end of treatment trains and upland zones of a watershed (NRC, 2009). Vegetated controls include bioswales, bioretention, rain gardens, green roofs, green streets, and bioinfiltration (NRC, 2009).

Rooftop detention include green roofs and blue roofs that slow the time of centration of 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 flow restriction devices around drains. Overflow enters stormwater infrastructure by flowing over the collar of the roof drain. Green roofs store and treat water through the use of plants adapted to both wet and dry conditions, such as sedum and other hardy succulents (City of New York, 2008).

Filters are small-scale stormwater controls that use sand, peat, or compost to remove sediments and pollutants from runoff. These measures focus primarily on water quality treatment and may be used in conjunction with other stormwater control measures. Filters can remove suspended sediments and pollutants from water entering other retention or infiltration systems along treatment trains, which will extend the longevity of these other devices (NRC, 2009).

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). In natural woodland areas of Michigan, most of the annual rainfall reaching the ground plane infiltrate into the soil (SEMCOG, 2008).

Subsurface controls for retention and infiltration include techniques such as infiltration trenches, permeable pavement, and seepage pits. Similar to bioinfiltration, these methods rely on infiltration to reduce runoff volume, and provide additional benefits including groundwater recharge, water quality, and pollutant removal through filtration in the soil. In contrast to vegetated source controls where water is held in the soil or surface ponds, 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 built in conjunction with permeable pavement. Additionally, subsurface controls are not associated with safety concerns about vector-borne diseases like mosquitoes that are sometime associated with poorly designed surface controls (NRC, 2009). Subsurface source controls can also be designed to detain stormwater, allowing it to exit gradually through an outflow pipe or underdrain, when soil, groundwater, or contamination conditions prevent feasible soil infiltration (City of New York, 2008).

Rainwater harvesting systems capture runoff from impervious surfaces in rain barrels, cisterns, or tanks. This water may be used for graywater applications such as lawn irrigation, car washing, and toilet flushing if there is an ample nearby community presence for regular use and maintenance. In order for 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).

The City of New York has also assigned structural source control techniques into overarching categories. These include detention, retention, and bioretention/bioinfiltration. Detention is the temporary detainment of stormwater at the source while the peak runoff from a storm dissipates. Detention systems include techniques like rooftop detention systems (blue roofs) and underground storage tanks. By slowly releasing stormwater to the system, detention controls free up capacity in the sewer system, thus allowing water treatment plants more time to process and treat combined sewage and stormwater flows. Retention techniques, the second defined category, remove stormwater permanently from the system for use or infiltration on-site. Techniques include rain barrels, cisterns, and gravel beds that infiltrate runoff into the ground. The final category, bioretention or biofiltration vegetated source control techniques, work through the infiltration of water to the soil and the evapotranspiration of water by plants. The mechanisms behind these techniques mimic pre-development hydrology. Biofiltration strategies are subject to a number of site constraints, including soil characteristics, bedrock, high water table, and underground utilities (City of New York, 2008).

Table 2: Benefits and Limitations of Source Control Techniques

BENEFITS AND LIMITATIONS	BIOFILTRATION	RETENTION	DETENTION
Reduces CSOs	X	X	X
Reduces treatment costs	X	X	
Reduces potable water consumption		X	
Reduces flooding	X	X	X
Reduces sewer backups	X	X	X
Reduces separate/direct discharges	X	X	
Reduces strain on sewers	X	X	X
Provides a community asset	X		
Improves air quality	X		
Reduces urban heat island effect	X		
Limited by high groundwater and bedrock	X		
Higher capital expense than standard construction	X	X	X
Higher maintenance expense than standard construction	X	X	X

Figure 13:
Table showing benefits and limitation of source control techniques for stormwater management.

(Source: The City of New York, 2008 – page 36)

All technological sources controls have physical limitations depending on the stormwater technique used. This is particularly true of source controls in the biofiltration and bioretention category (i.e. bioinfiltration techniques and urban forests). The most significant limitation in dense urban areas is space (City of New York, 2008). Another major limitation to be considered is cost. Non-structural and policy-based source controls should be considered to manage stormwater before structural techniques are employed due to the cost-effective nature of not having to build and maintain a physical project (SEMCOG, 2008). However, the high amount of vacant land and associated low property costs within Detroit (compared to other urban settings) makes the city an ideal candidate for the use of structural green infrastructure to treat stormwater because space is no longer a limiting factor and costs are greatly reduced. Instead, focus should be on other potential physical constraints such as steep slopes, bedrock close to the surface, poorly infiltrating soils, and a high water table that could limit the effectiveness of source controls using infiltration (City of New York, 2008). For instance, SEMCOG provides the following recommended guidelines when designing rain gardens for bioretention: minimum separation of two-feet between base of rain garden and water table/bedrock; type A and B soils as preferential with C and D likely requiring an underdrain; and limited feasibility on steeper slopes with a grade greater than five percent (SEMCOG, 2008).

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Section IV. Current State of Stormwater Infrastructure Within the JEBA Neighborhood

In order to understand the current state of stormwater management within our site and determine where green infrastructure projects are needed most, we must first understand Detroit's sewer network. The collection system serving Detroit is predominantly a combined sewer system (Camp Dresser & McKee, 2003). A combined sewer carries both wastewater and storm water flows. Stormwater runoff is conveyed through a series of piped connections with progressively increasing diameters and conveyance capacities. The wastewater flow is picked up at the service connections, flows through the lateral, trunk, and interceptor sewers, and ultimately arrives at treatment stations (Camp Dresser & McKee, 2003). In the event of a heavy precipitation event, the system can become overloaded and will release excess capacity into the Detroit River as a combined sewer overflow (CSO) (Camp Dresser & McKee, 2003).

The Detroit River Interceptor (DRI), one of three major interceptor collectors in the city, runs under the Jefferson-Chalmers neighborhood (Figure 6) (Camp Dresser & McKee, 2003). The DRI was constructed in three major stages from 1927 to 1936 (Camp Dresser & McKee, 2003). At the same time, the East and West Jefferson Avenue Relief Sewers were installed to intercept and convey storm flow generated on the east side of the city to the Conner Creek Pumping Station. Conner Creek and Fox Creek, which flank the JEBA neighborhood, were also enclosed in 1929 and 1930 (respectively). Flows were diverted to the portion of DRI running under the neighborhood (Camp Dresser & McKee, 2003). Records could not be found for the construction history of lateral lines specific to the study area, but lateral sewer construction for the entirety of the city was completed by 1975 (Camp Dresser & McKee, 2003).

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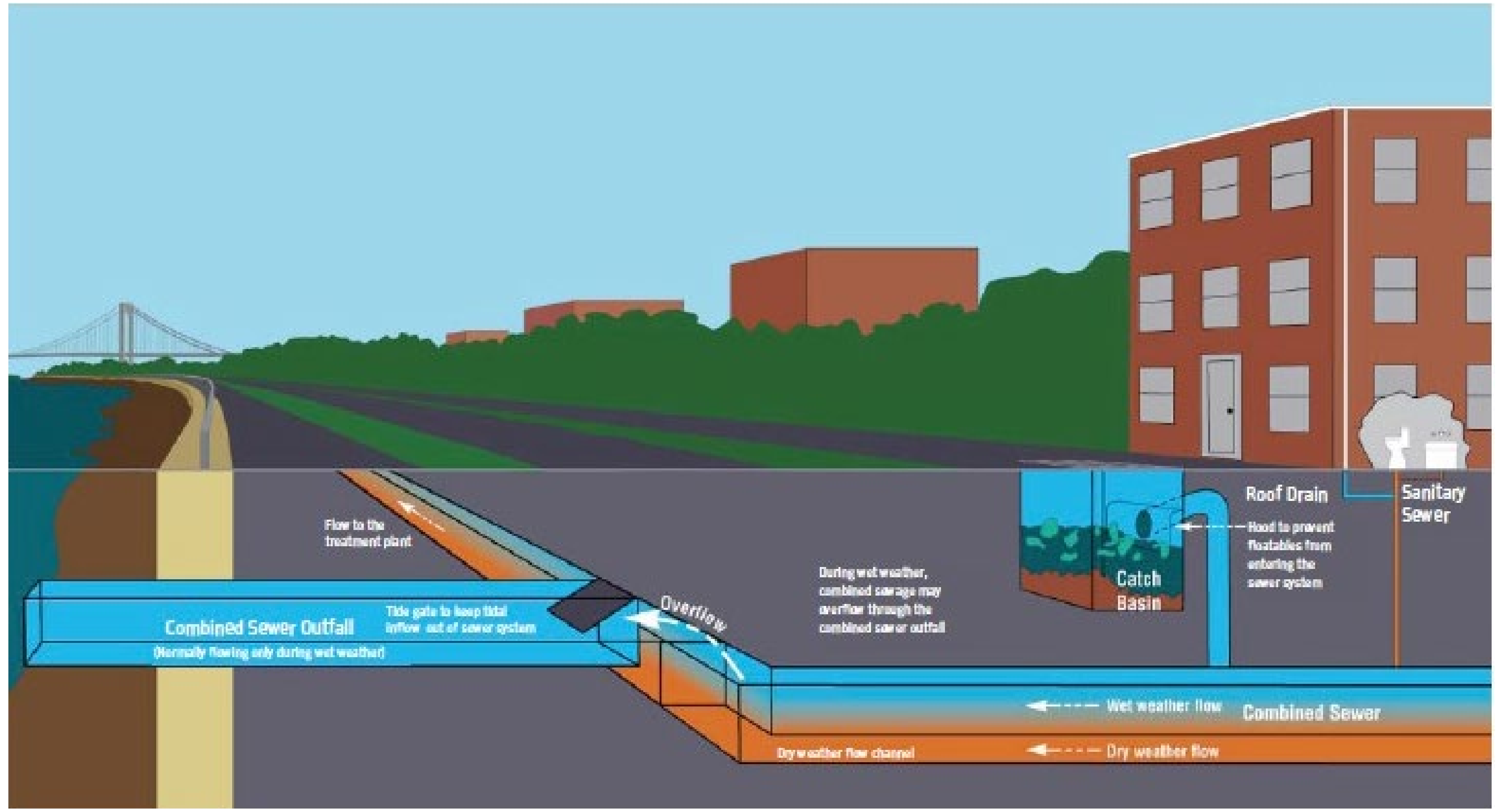

Figure 14:
Combined Sewer System Diagram

(Source: City of New York, 2008)

Detroit's sewer network is likely in need of a wide range of repairs. Service connections, especially in older areas, are notorious for misaligned joints, major cracks or breaks, and potentially significant tree root damage. All of these conditions lead to the development of major sources of infiltration (Camp Dresser & McKee, 2003). The existing map records for the Detroit sewer collection system are divided into the four maintenance districts shown below. The LEAP study area lies in the East district.

In an assessment of lateral sewer segment conditions conducted by CDM, lateral sewer lines were rated as being in excellent, good, or fair condition. Segments with major potential compromise to their structural or functional integrity were classified as "Needs Investigation". Within the East sewer district, 18% of lateral lines were rated as fair and 11.5% needed investigation (Camp Dresser & McKee, 2003). Typical sewer problems included corrosion, exfiltration, roots penetrating lines, sedimentation, and structural cracks (Camp Dresser & McKee, 2003).

In addition to the lateral lines, aging components of Detroit's sewer infrastructure also include CSO facilities. These include outfalls, outfall flow regulators, backwater gates, and in-system storage devices and system gates (Camp Dresser & McKee, 2003). In a recent assessment, consulting engineering firm CDM determined that three outfalls in the Jefferson-Chalmers neighborhood were in need of either an immediate inspection or inspection within 10 years time to assure continued proper functioning. One outfall flow regulator was also determined to be in need of immediate inspection. They also reported the need for inspection within five years for the backwater gate of one CSO facility (Camp Dresser & McKee, 2003).

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DWSD also currently operates 14 pump stations (Camp Dresser & McKee, 2003). The pump stations in the Jefferson-Chalmers neighborhood include the Conner Creek Pump Station, Freud Pump Station, and Lighthouse Point Pump Station (Figure 6) (Camp Dresser & McKee, 2003). According to CDM, Conner Creek is in need of 36 repairs with two repairs being classified as "Major" and "Immediately Needed". Freud is in need of 48 repairs with seven being classified as "Major" and "Immediately Needed". Lighthouse Point is in need of four repairs with three being classified as "Major" and "Immediately Needed" (Camp Dresser & McKee, 2003).

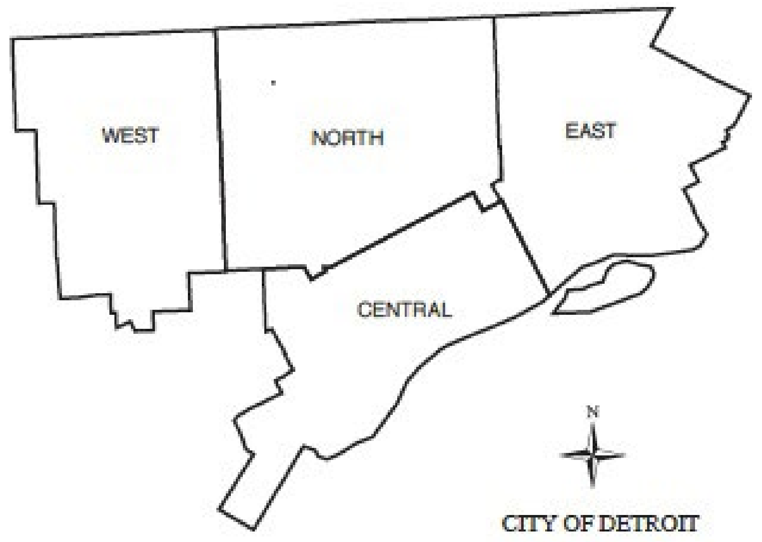

Figure 15: DSWD Sewer Maintenance Districts

(Source: Camp Dresser & McKee, 2003)

Implications of Stormwater Infrastructure Assessment

The need for the above-mentioned repairs and updates could contribute to increased risk of localized flooding due to storm sewer backups. The low-lying areas of the Jefferson-Chalmers neighborhood may be vulnerable to flooding due to its context within the surrounding sewer infrastructure network (see Figures 5-7 above). Located along the shoreline of the Detroit River and extending approximately one mile inland, a large portion of this neighborhood exists at a lower elevation than at the riverfront. This topography form a "bowl" shape which can prevent sewer water backing up into this portion of the neighborhood from leaving. Flooding in this area of extreme local low elevation is regularly reported following storm events according to sources at the Jefferson East Business Association – an effect that may be related to overtaxed or malfunctioning storm sewers.

The methodology behind Figure 7, which was used to display color-coded topography for the Jefferson-Chalmers neighborhood, involved displaying LiDAR DEM data obtained from the University of Michigan through ArcGIS's classified display feature. Color-coded classification was divided into ten categories in which elevation was displayed at one-foot intervals. Elevations ranged from 570 feet above sea level to 579+ feet above sea level. The elevation of 570 feet corresponded to there not being any point of elevation lower than 570 feet above sea level within Jefferson-Chalmers neighborhood study area boundary.

Localized flooding in the Jefferson-Chalmers neighborhood may also be related to the presence of several pump stations and CSO control structures bordering the noted area that is highly flood prone. Potential failure of a pump station or outfall within the Jefferson-Chalmers neighborhood could affect flows of stormwater being conveyed into the section of the DRI that runs under the study area. Flooding could be quite severe due to the extensive land area that makes up the effective storm sewer catchment upstream from the Jefferson-Chalmers neighborhood via the DRI.

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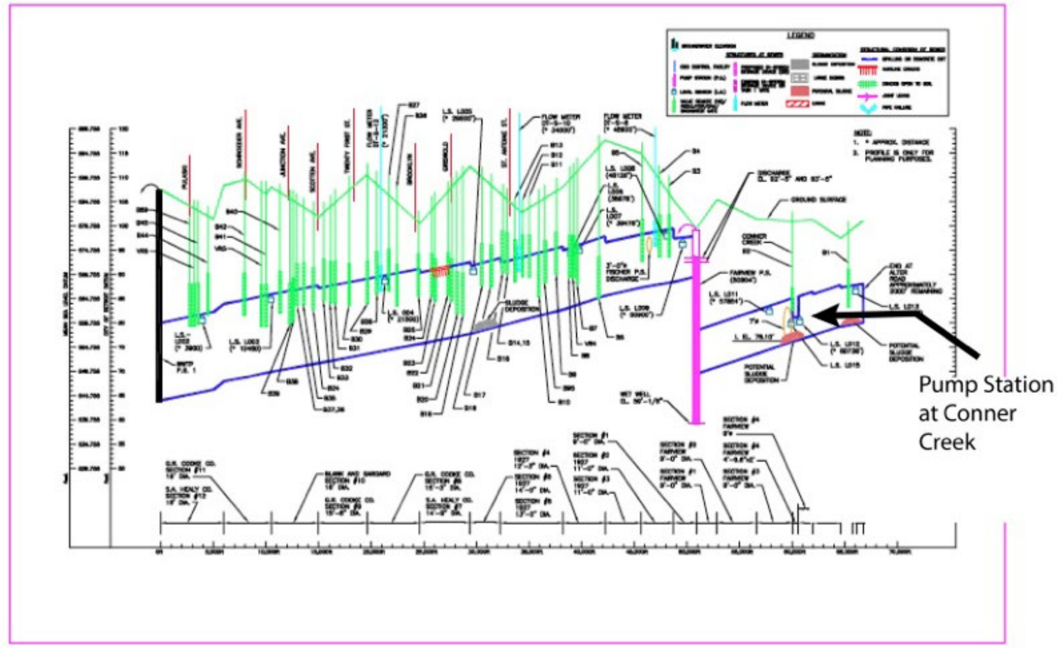
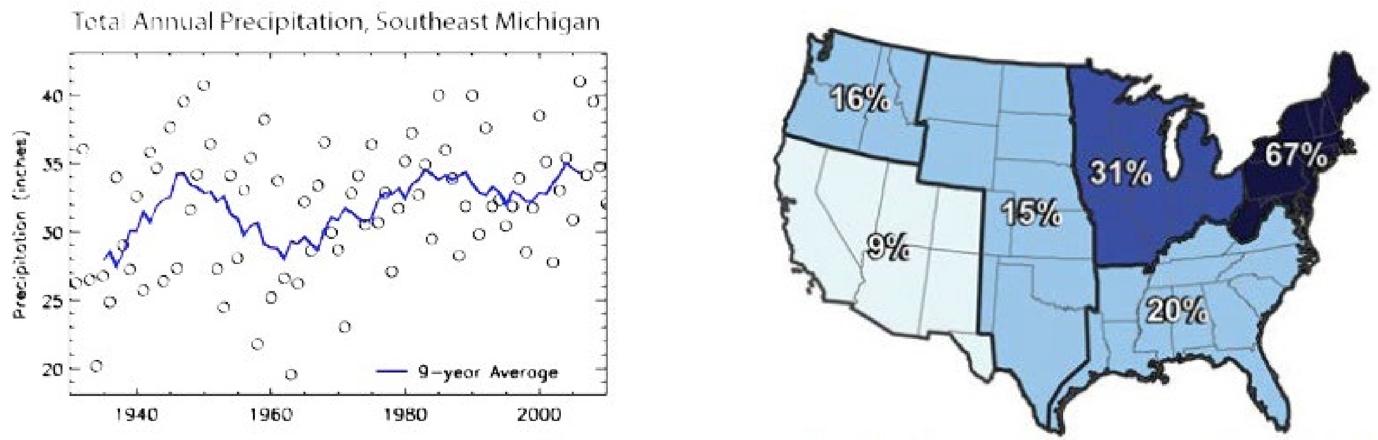


Figure 16:
DRI Elevation Profile. Note the presence of a pump station at Conner Creek that is required to pump storm water further down the DRI conveyance pathway. If this pump were not active or malfunctioning, storm water in the piped system could back up and flood portions of the Jefferson-Chalmers neighborhood.

(Source: Camp Dresser & McKee, 2003)

In addition to the Jefferson-Chalmers neighborhood being flood prone due to its low elevation and aging stormwater infrastructure, climate change may also impact potential flooding. As a generality, pipes that were sized to handle stormwater flows based on historic rainfall numbers may no longer be adequately sized to handle increased runoff volumes. According to the NOAA-funded GLISA initiative (Great Lakes Integrated Sciences and Assessment Center), Southeast Michigan has seen an 11% increase in total annual precipitation from the 1961-1990 average to the 1981-2010 average and most models project this trend to continue. The Midwest has also seen a 31% increase in the heaviest 1% of precipitation events from 1958 to 2007. Most climate models project trends in these extreme precipitation events will continue (GLISA, 2013).



Total Annual Precipitation from Southeast Michigan, 1930-2010. Open circles represent annual totals. The solid blue line is the 9 year running average. Total annual precipitaion increased by 11% from the 1961-1990 average to the 1981-2010 average. The Midwest has seen a 31% increase in the heaviest 1% of precipitation events from 1958 to 2007.

Figure 17: Plot on the left showing a gradual increase in annual precipitation in southeast Michigan over the last half century. Map on the right showing increases in extreme precipitation events across regions of the U.S.

(Source: GLISA, 2013)

Potential for Green Infrastructure

Green infrastructure is a relatively new and flexible term referring to systems designed to manage stormwater through the use or mimicry of a site's natural hydrologic processes as an alternative to piped stormwater infrastructure (EPA, 2014). Green infrastructure employs distributed source controls that incorporate vegetation, soils, and other natural processes. This mitigates stormwater runoff before it reaches piped infrastructure systems (NRC, 2009), thus decreasing in-sewer stormwater volumes and risks of storm sewer backups. This could potentially be a valuable strategy to limit flooding in the Jefferson-Chalmers neighborhood.

As previously mentioned, the Jefferson-Chalmers neighborhood is characterized by a high degree of vacant parcels (Figure 4). Due to Detroit's population loss trends, which limit resources for the upkeep of these land areas, vacant properties are considered a management burden for the city. However, these vacant parcels could potentially be seen as an asset if used to create a green infrastructure network for stormwater management (Austen et al. 2013). A large amount of vacant land lies to the north of the high flood risk area of the JEBA neighborhood. This area is also hydrologically upstream from the portions of the Jefferson-Chalmers neighborhood that are flood prone. In theory, this land could be converted to green infrastructure and leveraged to capture stormwater runoff before it enters sewers and is routed under the flood-prone JEBA neighborhood via the DRI. The conversion of these parcels could potentially free the city of two major financial burdens: the need to make costly upgrades and repairs to an aging storm sewer system, and the need for regular upkeep of the vacant parcels. Instead, the city could manage a series of low maintenance green infrastructure BMPs (Austen et al. 2013).

Determining Green Infrastructure Locations

In order to effectively determine which vacant lots to target for flood mitigation purposes within the highly flood prone areas of the Jefferson-Chalmers neighborhood (Figure 6), we must first determine the effective catchment area of the sewershed that will be contributing water to the section of the DRI that runs under the study area. By examining storm sewer master plans and hydrologic flow patterns across DWSD service areas, consulting engineering firm CDM was able to approximate the effective catchment areas of major trunk lines throughout the city (Camp Dresser & McKee 2003). Figure 6 is comprised of a map illustrating sewer catchment areas of trunk lines that convey stormwater to the portion of the DRI that runs under the JEBA neighborhood. No catchment area was included for the cities of Gross Point Park, Gross Point, and Gross Point Farms, which lie along the eastern edge of our site.

By comparing the effective catchment area of interest with the location of vacant parcels, we can begin to determine which vacant to first target in order to limit flooding in our Jefferson-Chalmers flood-prone area of interest due to storm sewer backups. Due to the overall north to south hydrologic drainage patterns of eastern Detroit (characterized by inland water draining to the low-lying Detroit River), we will want to target vacant land to the north of the Jefferson-Chalmers neighborhood and within the sewersheds outlined in Figure 4.

By altering the land of our study site north of Jefferson with strategically planned and placed green infrastructure, we can detain and infiltrate a high proportion of stormwater on site.

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Building a green infrastructure network within the area of highly vacant land gives us the advantage of few built obstacles needed to be worked around for a planned green infrastructure system. This act could serve to "lighten the load" borne by conventional pipe-based infrastructure. By reducing storm sewer contributions from a large tract of land, there is less total volume going into the piped system, which in turn lowers the potential for the system being overloaded during a large storm event. This ultimately should result in fewer storm sewer backups and CSOs. Utilizing large tracts of vacant land versus more conventional green infrastructure retrofit projects is a more cost effective solution to stormwater management. Retrofit projects have relatively limited volume capacities and are of relatively high cost for their overall small contributions to distributed stormwater management (i.e. pervious pavers, right-of-way rain gardens, manufactured devices, etc.). This is compared to the less costly and potentially much larger - in stormwater capacity - stormwater management contributions of green infrastructure using vacant lots (Austen et al. 2013).

Rather than placing green infrastructure in the most flood prone areas of the Jefferson-Chalmers neighborhood to limit flooding, it will be far more effective to detain and infiltrate stormwater in an area that is already serving this function by virtue of elevation (i.e. high elevation areas that are hydrologically upstream from the flood prone area). Instead, stormwater infrastructure should be planned in this area to efficiently convey stormwater offsite as quickly as possible by moving it into the nearby Detroit River (Figure 18). Ideally, untreated sewer backup water from a combined system should not be released directly into a water body, however, this option is justified if on-site stormwater detention is not an option and the area is at risk of local flood damage.

Based on the above considerations, a general stormwater management strategy to be applied in the Jefferson-Chalmers might be designed following the conceptual diagram below (Figure 18). Runoff originating upstream from the Jefferson-Chalmers neighborhood can be intercepted by extensive areas of green infrastructure source controls created by the repurposing of vacant parcels that lie north of Jefferson. Any stormwater reaching the neighborhood south of Jefferson via overland flows or via sewer backups can be conveyed rapidly off-site by a highly efficient conveyance mechanism such as a high capacity concrete-lined channel. Ideally, a more extensive source control network of green infrastructure measures would also be developed in the future that extends further north of our study site and throughout the entire sewershed depicted in Figure 5. This would reduce additional volumes of water entering the sewer network from further upstream areas that are hydraulically connected to the sewer infrastructure associated with the Jefferson-Chalmers neighborhood. This could help to further address Detroit's vacant land issues outside of our study site.

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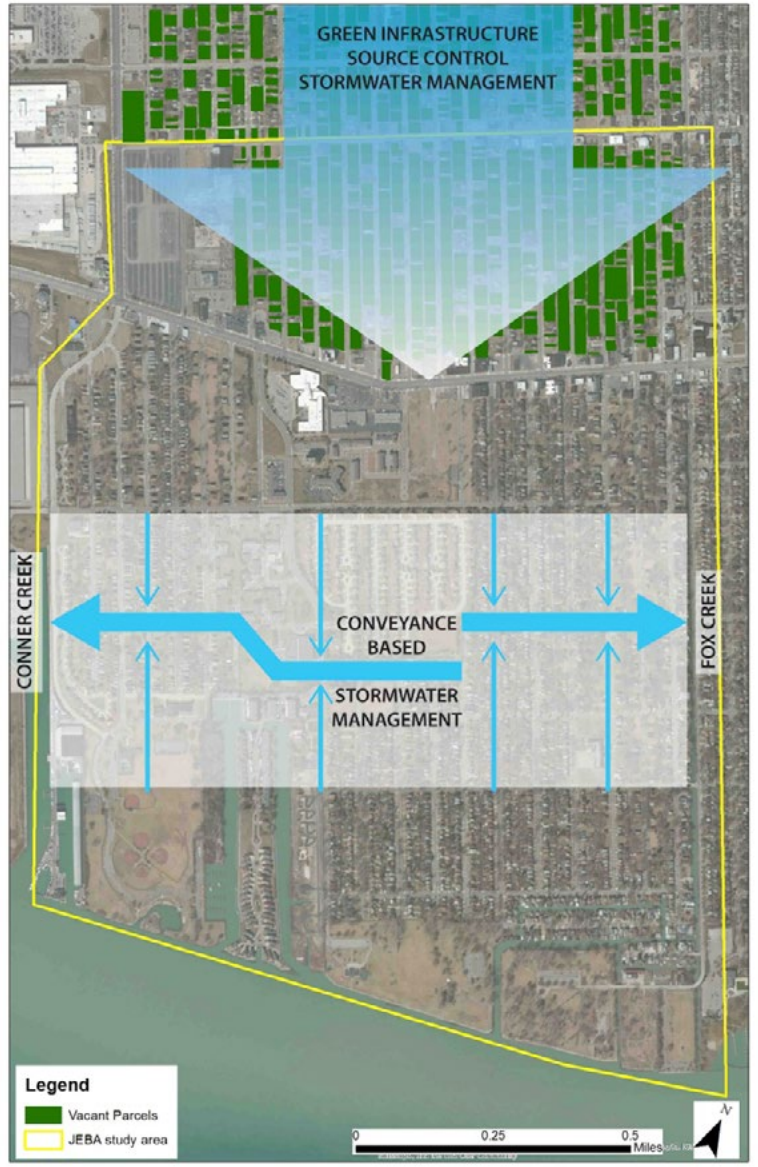

Figure 18:
Diagram of General Stormwater Management Strategy for the Jefferson-Chalmers Neighborhood.

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Selected vacant parcels from Detroit Residential Parcel Survey, 2009).

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Section V. Hydrologic Model for Siting Source Control Measures

Background

Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds. Source control measure implementation needs to be designed as a system that integrates structural and nonstructural control measures while incorporating watershed goals, site characteristics, development land use, construction erosion and sedimentation controls, aesthetics, monitoring, and maintenance. Stormwater cannot be adequately managed on a piecemeal basis due to its effects on habitat and water quality caused by the underlying complexity of associated hydrologic and pollutant processes (NRC, 2009).

To begin addressing the above elements in regard to source control networking, we developed a hydrologic model that demonstrates the most flood prone areas of our study site and the impact that converting vacant parcels in these areas can have on stormwater runoff volumes. The design and planning strategies developed in this master's project takes an approach to stormwater management via a networked system of a diverse array of green infrastructure stormwater controls. It should be noted that despite the importance of considering both nonstructural and structural green infrastructure measures, the master's project team focused exclusively on structural measures to address the state of vacant land in the city.

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Existing Stormwater Situation

According to current FEMA flood maps accessed on March 22, 2014, a large portion of the Jefferson-Chalmers neighborhood lies in the 100-year floodplain (Figure 19). Figure 7, which displays a representation of the neighborhood's topography, also tells us that the land area along the Detroit Riverfront is higher than the immediately adjacent inland area. In conversations with JEBA representatives, the master's project group has been told that this high-elevation shoreline character helps prevent river water from entering the neighborhood, but it also creates the issue of localized flooding where stormwater can be detained in the neighborhood.

LiDAR (Light Detection And Ranging) aerial imagery taken in the spring of 2010 with two-foot resolution, was used to create the DEM (Digital Elevation Model) that we used to display the topography of our study area in Figure 7. Among the most interesting findings from this map is that the ordinary high water of the river is 575 feet (not color coded in Figure 7 for display clarity) and the lowest elevation areas of the adjacent portions of the Jefferson-Chalmers neighborhood are 570 feet. This indicates that the surface water elevation of the river is higher than these inland areas. We can thus assume that because of its relatively low elevation and the current stormwater infrastructure engineering (Figure 6), our study site may act as a sink for stormwater arriving as overland flows from more northern and northwestern Detroit neighborhoods. It is important to note that the portion of the JEBA study area north of East Jefferson Avenue and lying outside of this low elevation stormwater sink area is highly vacant. This provides significant potential for the development of a green infrastructure network to mitigate the amount of stormwater reaching the flood prone southern portions of the neighborhood via overland flows. It should also be noted that the lowest areas of this localized sink are around Essex Avenue and Averhill Court, which run east west and terminates at the edges of the Jefferson-Chalmers neighborhood. Not far from the termini of both ends of Essex are CSO outlets leading into the canals of Fox and Conner Creeks along the Detroit River.

Figure 19:
100-year FEMA floodplain map of the study site accessed on March 22,2014.

(Source: msc.fema.gov – accessed March 22, 2014)

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Problem – Stormwater Flooding

According to the Jefferson Chalmers Neighborhood Stabilization Plan and JEBA neighborhood representatives, two types of flooding issues, river flooding and stormwater flooding, affect the neighborhood (Detroit Vacant Property Campaign, 2013). The high elevation riverfront is designed to prevent high river flows from reaching into the low-elevation portions of the Jefferson-Chalmers neighborhood as surface flows. However, the relatively higher riverfront creates a topographic condition that can impede overland flows of stormwater runoff originating further inland to reach the river. This suggests the need for a innovative and efficient means of transporting surface water flows to a river outlet upstream of the river.

JEBA representatives told us that local residents were consistently reporting basement flooding following heavy storm events. The combination of maintenance issues caused by an aging sewer infrastructure system, low topography, and the neighborhood's contextual relationship within Detroit's sewer infrastructure network suggests this area may experience such flooding in the future as well.

We suggest combining two different approaches to site interventions to help to relieve the problem: using green infrastructure to detain stormwater in upstream areas in order to reduce flooding in the Jefferson-Chalmers neighborhoods, and building an efficient conveyance system to increase the efficiency with which potential flood water is moved out of the neighborhood once it reaches and begins to settle in the low-elevation and high flood risk area of the neighborhood (Figure 18).

Analysis method

-General Methods

A good design for a green infrastructure network would mitigate issues related to stormwater management. To achieve this goal, decisions should be scientifically informed. A hydrological model and assessment was designed in this project as a basis for developing design interventions.

The hydrologic model and assessment is designed to answer the following questions: 1. Which areas notably contribute to flooding in the neighborhood? 2. Where are the flows of these flood-contributing areas most concentrated within the neighborhood? 3. How can BMPs affect the total volume of water yield for particular storm types?

To answer these questions, the process was broken down into four parts: the setup of a hydrologic model, a model sensitivity analysis, a design site impact assessment, and a design site impact evaluation (Figure 20). The model setup is the first and foremost part the analysis; it provides basic information for stormwater management, and all the following steps were built upon this part. The Model Sensitivity Analysis used altered model variables and data layers to test the robustness of the model. This also allowed us to establish a control storm for the site impact assessment. The design site impact assessment allowed us to estimate the stormwater output reduction caused by proposed green infrastructure design decisions. The design site impact evaluation was our final evaluation procedure and compared the results of the model sensitivity analysis with the site impact reduction to draw a conclusion on the stormwater mitigation performance.

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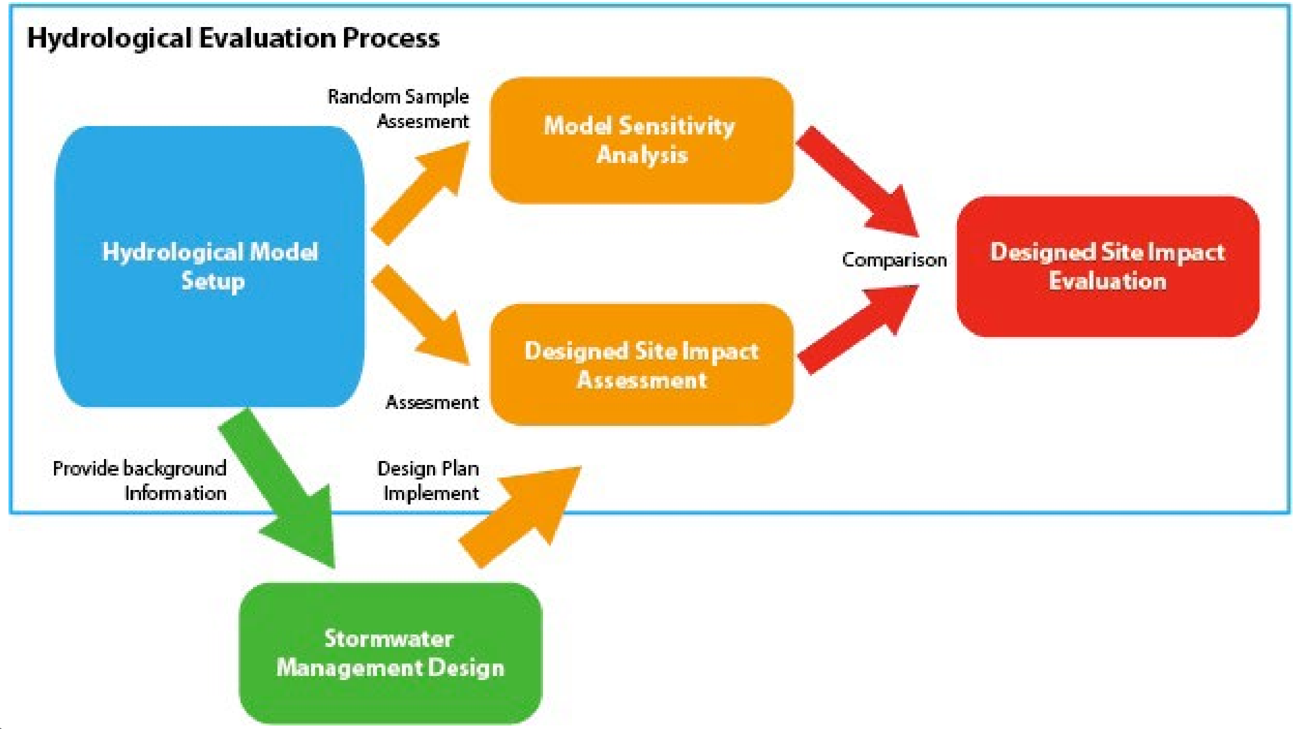

Figure 20:
Hydrologic Model and Assessment Process Diagram

-Hydrologic Model Precedents

The purpose of our hydrologic model for stormwater management planning is to provide an understanding of how runoff flows overland in order to inform the siting and design of infrastructure and utilities. Two methods that may contribute to effective future stormwater management solutions within our study area are managing runoff upstream of our site with source controls and utilizing efficient conveyance systems within the flood prone area by moving stormwater offsite as quickly as possible. In order to design an effective green infrastructure network for stormwater management, the main goal of our hydrologic model will be to examine the land upstream of our study site and identify the parts of our study area most likely to be in contact with high volume overland flows. By determining where these high volumes of overland flows are occurring, we can consider the potential for vacant land in these areas to serve as green infrastructure. This can allow JEBA neighborhood improvement funding to be strategic by backing projects that will create the biggest stormwater mitigation impact.

Background studies show that SUSTAIN (System for Urban Stormwater Treatment and Analysis Integration Model, US Environmental Protection Agency) and SWAT (Soil & Water Assessment Tool, Texas A&M University) are two existing models that can be used for this project. Further detail on these models can be found in Appendices 1 & 2.

Although SUSTAIN and SWAT are not suitable for this project, concepts from the theoretical documentation helped us to build our model. Both SUSTAIN and SWAT use watersheds as basic processing units within their hydrologic modeling interface. For our project, which is based on a DEM with 2-foot resolution, we were able to generate small watersheds similar to SUSTAIN and SWAT model outputs. Because these small watersheds could be sized to roughly that of a Detroit residential parcel, we deemed this scale appropriate for our hydrologic model because parcel-sized watersheds could help us to make land management decisions about the potential impact of vacant parcels on stormwater management. An alternative "grain-size" with which we could have used to create a hydrologic model was the original 2-foot cell size of DEM dataset. This could have provided information with much finer resolution, but it has crucial disadvantages:

- Too many cells make up the DEM to allow for time-effective modeling. Specifically, a half billion cells are used to represent a 12-square-mile area. Personal computers would need more than 10 years to run an analysis cell by cell. Less than half an hour is needed for a calculation of watershed accumulation.
- The watershed accumulation is based on a single D-8 algorithm, which is a deterministic method. When working at extremely fine scale, some random errors could change the whole stream pattern. Aggregating information to small watersheds acts as a smoothing operation, which minimizes the random errors in the dataset and makes the model more "noise"-resistant.
- The water accumulation algorithm is a simplified model to estimate the upstream area. When cell size is large (on the order of meters), the approximation is valid because the water flows in one direction at a meters scale. However, when the resolution goes down to much finer scale, we may need to use a multi-direction physical model to describe the water movement. This would be extremely complicated and unsuitable for this project. Small watersheds are at reasonable scale with valid stream flow assumptions and detailed enough information.

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-Watershed Delineation

A dynamic watershed delineation model (Figure 21) was created to represent the hydrologic relationships across our study site. The goal of the watershed delineation model was to locate upstream stormwater sources contributing to runoff into our study site following a 10-year, one-hour storm event (1.8 inches/hour). A short, intense storm mimics the area's well-documented rising trend of high intensity storm events that are likely related to climate change (GLISA, 2013). The model would then identify areas that exhibited high volume overland flows. The analysis process can be described as two phases. The first phase depended on geospatial analysis functions in ArcGIS where small-scale watersheds were generated through basic ArcGIS modules.

The second part was processed in R once the watersheds were delineated. Cumulative watershed overland flow volumes were calculated for successive watersheds in the study area based on their position or stream order in the watershed network. Two different methods were then used to evaluate where high-volume overland flows would occur. The first method is a simple approach where we calculated upstream area for each watershed in R programming. This method allows the number of upstream cells of the watershed to be the indicator for runoff volume being generated for each watershed. The second methodology uses the SCS Curve Number Procedure found in the SWAT model to assess ground water saturation within the local watersheds based on soil and groundcover. The measurement of overland flow volumes in this situation is total surface water volume not infiltrated and representing runoff passing over the area.

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In order to assess the total volume of runoff that will pass over a particular watershed, certain assumptions have been made.

- The storm sewers in the study area are unreliable and most stormwater will run off as above ground flow. The watershed accumulation model was only designed to simulate above ground water flows. In urban areas, much precipitation is typically conveyed to a receiving water body or treatment plant through well-maintained sewers. The hydrologic model and assessment used in this project cannot be considered a feasible methodology for predicting above ground stormwater flow if the storm sewers are assumed to be functioning.

- Water will flow uniformly through individual watersheds, and 100% of the flows will exit at a singular outlet. This assumption is an approximation. In reality, water will not flow uniformly in the watershed and may exit via an array of outlets. This assumption allows the model to link the land use type to water detention parameters.

- The higher the volume of overland flows that leave a watershed, the more runoff volume that can be expected to contribute to downstream flooding.

- The storm lasts for an hour and it covers the whole modeled area. The dynamic modeling process is very complex, the scope of this project only allows us to make this simplification.

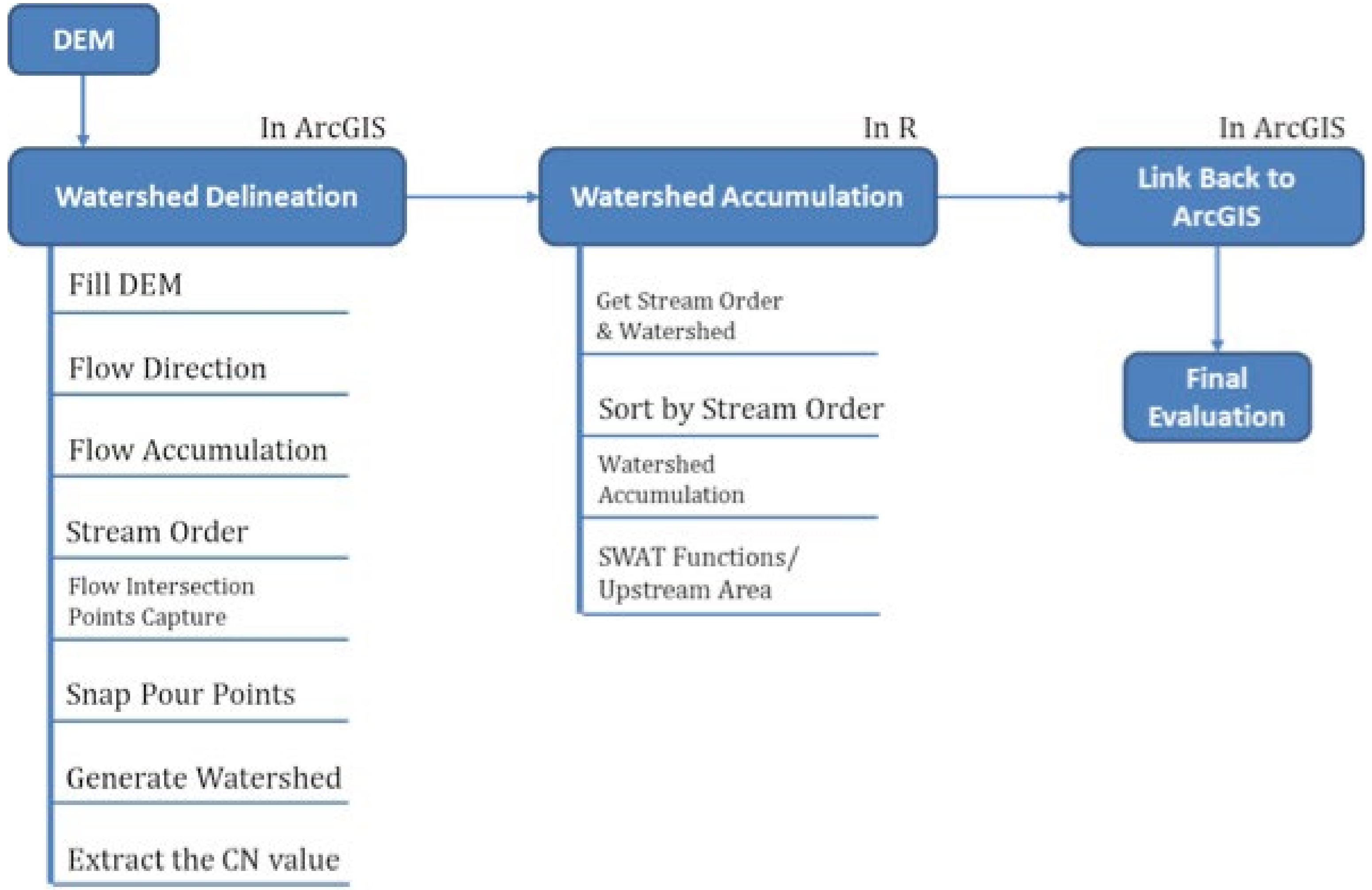

Figure 21:
Dynamic Watershed Delineation Model Methodology

-Hydrological functions

The process of overland stormwater runoff transport can be generalized in Figure 22 below, which was developed through the adaption of the theoretical model presented for water transport within documentation for SWAT methodology. Precipitation falls onto a catchment area in which a portion of the water in detained on-site (i.e. infiltration, detention based on topography, etc.). The remainder of the water will generate surface runoff to adjacent downstream watersheds. Arriving at the next watershed, the water will again experience onsite detention and generate surface runoff. The surface water flow will also experience evaporation and transmission loss over the course of several hours or days. However, our study models storms to last no longer than one hour, which is a relatively short time period. The model will therefore only use hydrological functions related to onsite detention and surface runoff generation.

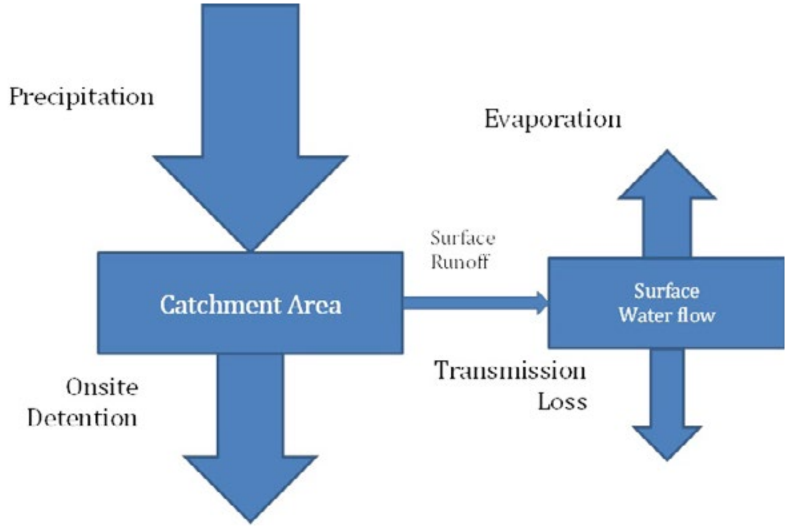

Figure 22:
Overland Stormwater Runoff Transport Process Diagram

-SCS Curve Number Procedure

As previously mentioned, our study employed two different methods for evaluating where high-volume overland flows would occur. The first was a simple relationship between land area and runoff volume generation, and the second involved the SCS Curve Number Procedure. This second method (See Appendix 1 for details) provides many advantages for the creation of a hydrologic model:

- The SCS Curve Number Procedure is a straightforward function. It is comparatively easy to handle, which makes it workable for our master's project.
- The function is based on an empirical observations. The model parameters are generalized information (i.e. landcover and soil type).
- This model requires less input information versus other comparable hydrologic models.

In the SCS procedure, we assign a runoff curve number (CN) to individual watersheds in a hydrologic model. This is based on National Land Cover Data (NLCD) and the soil group of the study area. A table given by SCS Engineering Division used to define land cover types (Appendix 1) (USDA, 1986). By plugging the Curve Number function into the SCS curve number procedure, we can find the water runoff volume generated by each small watershed.

In order to complete the analysis for determining which watersheds occupy areas experiencing high volumes of overland

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Class\ Value	Classification Description	Cell Count	Percentage	Curve NO.	Classification
Water					
11	**Open Water** - areas of open water, generally with less than 25% cover of vegetation or soil.	7310	14.92%	10	Water
Developed					
21 Open Space	**Developed, Open Space** - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.	3012	6.15%	79	Open Space
22 Low	**Developed, Low Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.	12631	25.79%	79	1 acre
23 Medium	**Developed, Medium Intensity** – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.	17424	35.57%	90	1/8 acre
24 High	**Developed High Intensity** -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.	7698	15.72%	94	Commercial & Business
Barren					
31 Barren	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.	5	0.01%	77	Poor C Bush
Forest					
41 Deciduous Forest	**Deciduous Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.	242	0.49%	73	Fair wood

Figure 23:
Land Cover Types

flows), cumulative overland flow volumes were linked with their associated watersheds. Watersheds were then categorized using a natural breaks classification method according to the amount of stormwater each watershed was expected to have flow from it as runoff after a storm event. Five categories of runoff volumes were created and ranged from low to high.

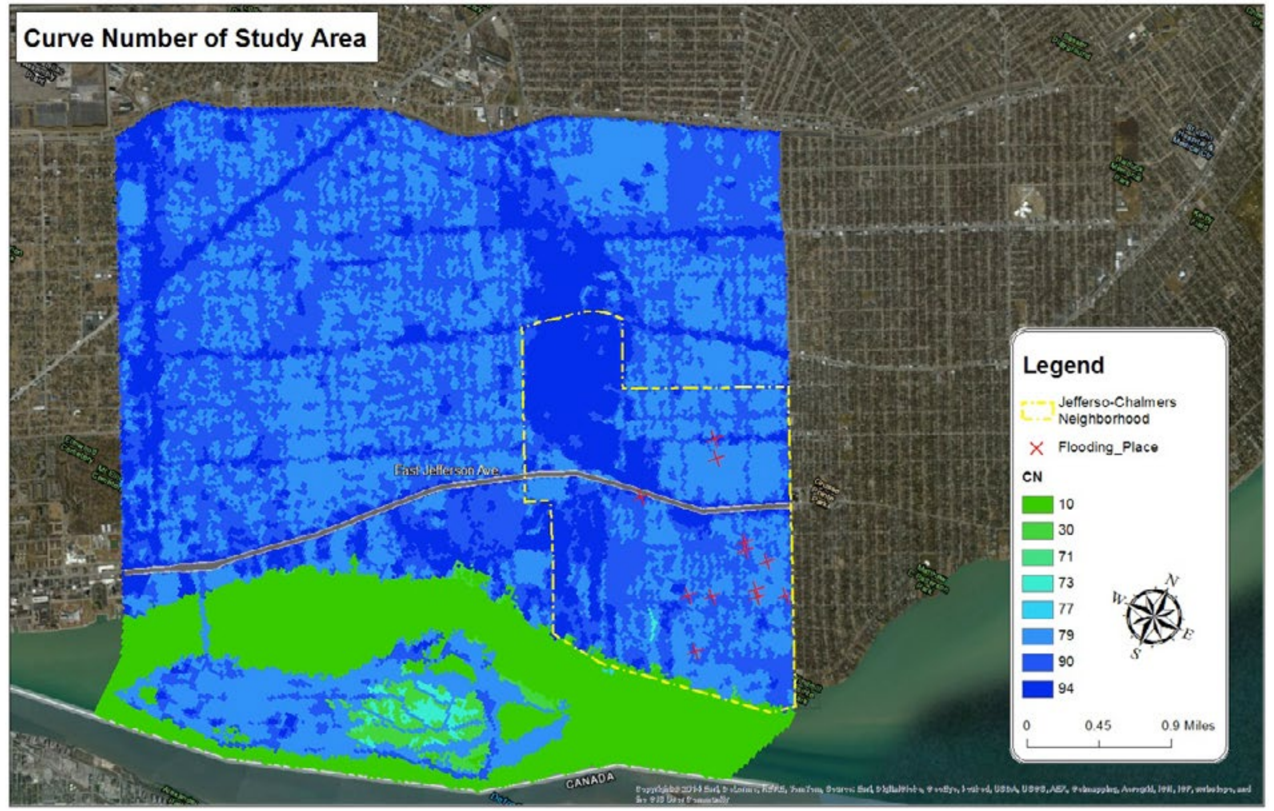

Figure 24:
Curve Number of Study Area in 2006

(Data Source: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Flooding Observation Report from JEBA, 2013; Curve Number Map created from National Land Cover Database 2006 and Michigan State Soil Database, 1994)

Results and Discussion

-Hydrologic Model

The maps below show that the two different methods used for evaluating where high-volume overland flows would occur produced slightly different patterns across our study site. A set of GPSed data points were generated by Justin Freid of the Jefferson East Business Association which correspond to flooded areas in the Jefferson Chalmers neighborhood following a storm on November 17, 2013. A total of 12 sites were reported to have noticeable flooding following a storm totaling 0.71 inches of precipitation. We used this as calibration data for our models.

Areas of our models associated with a high degree of runoff are also expected to be highly flood prone in downstream areas of the JEBA watershed network – particularly in areas of the neighborhood with topographic elevations lower than that of the Detroit Riverfront (Figure 7).

Comparing the locations of the field data with areas in our model where we would anticipate a high chance of being flood prone, the first method placed 4 out of 12 flooding observations in low elevation areas expected to come into contact with high degrees of runoff (Figure 25). Comparatively, the model based on the Curve Number Procedure placed 8 out of 12 records in these high flood prone areas (Figure 26). This leads us to believe that the model based on the SCS method is a superior model for demonstrating hydrologic relationships of stormwater within the JEBA study area.

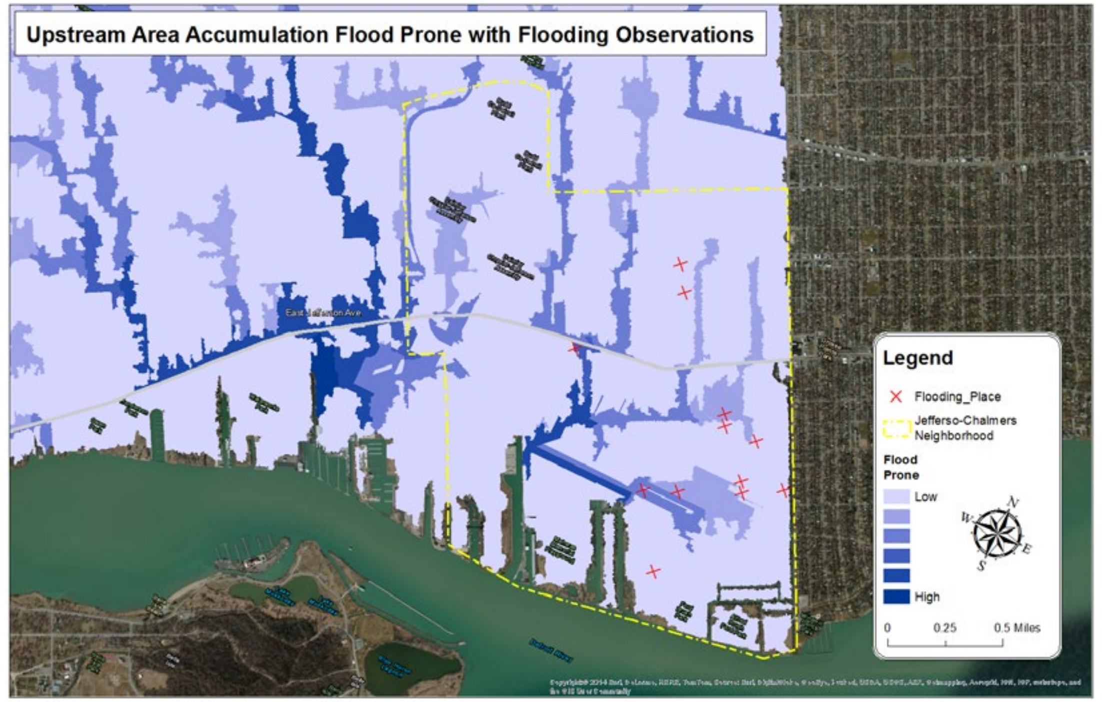

Figure 25:
Model Simulated Upstream Area Accumulation Flood Prone with Actual Flooding Observations Map

(Data Source: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Flooding Observation Report from JEBA, 2013; Upstream Area Accumulation Flood Prone Simulation by this project, 2014)

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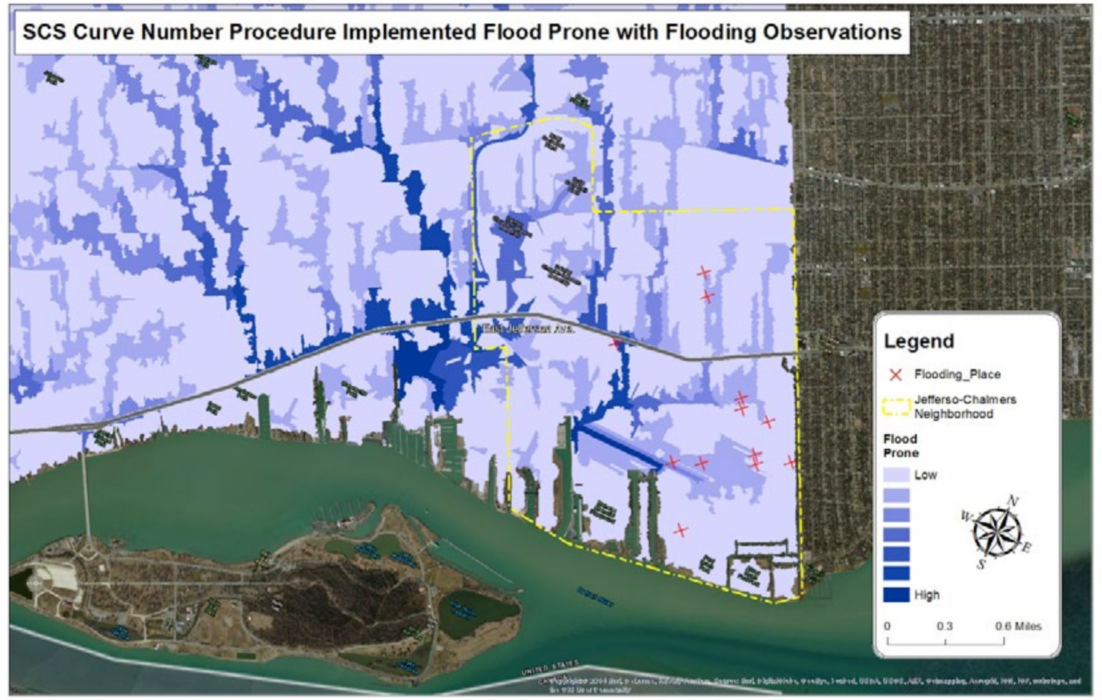


Figure 26:
Model Simulated SCS Curve Number Procedure Implemented Flood Prone with Actual Flooding Observations Map

(Data Source: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Flooding Observation Report from JEBA, 2013; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014)

Figure 27 shows a map displaying the results of the SCS-driven hydrologic model. Additionally, an approximate boundary has been drawn around the blocks in the neighborhood that are more flood prone due to their low elevation context within the neighborhood. Figure 28 below is a map with potential runoff volumes ranging from "med-low" to "highest" (see Figure 27) that have been extracted to demonstrate watersheds in the study area that will likely observe a higher degree of runoff flow following a storm. All vacant parcels in the Jefferson Chalmers neighborhood were also included in this map. Finally, Figure 29 below is a map displaying all vacant parcels that lie in the areas of Figure 28 indicating that they will observe a high degree of runoff following a storm. These vacant parcels indicate good opportunities where conversion to green infrastructure could be beneficial for flood reduction downstream. Additionally, stormwater detention should not be encouraged on vacant parcels lying within the "low elevation flood prone area". A key concept behind the use of source controls for stormwater management is to capture runoff upstream before it has the chance to make its way downstream and contribute to water quality issues and flooding. Instead, stormwater infrastructure should be planned in this area to efficiently convey stormwater offsite as quickly as possible by moving it into the nearby Detroit River.

Examining the Jefferson-Chalmers neighborhood's "bowl" shaped topography along with its position within the Detroit sewer network, it becomes clear that a source control approach for addressing the flooding issues within our study area will likely involve a green infrastructure design effort extending well-beyond the boundary of the Jefferson-Chalmers neighborhood. A multi-scalar approach to green infrastructure planning must be used. The Detroit River Interceptor (DRI), a major city stormwater collector, runs under the study site. The portion of

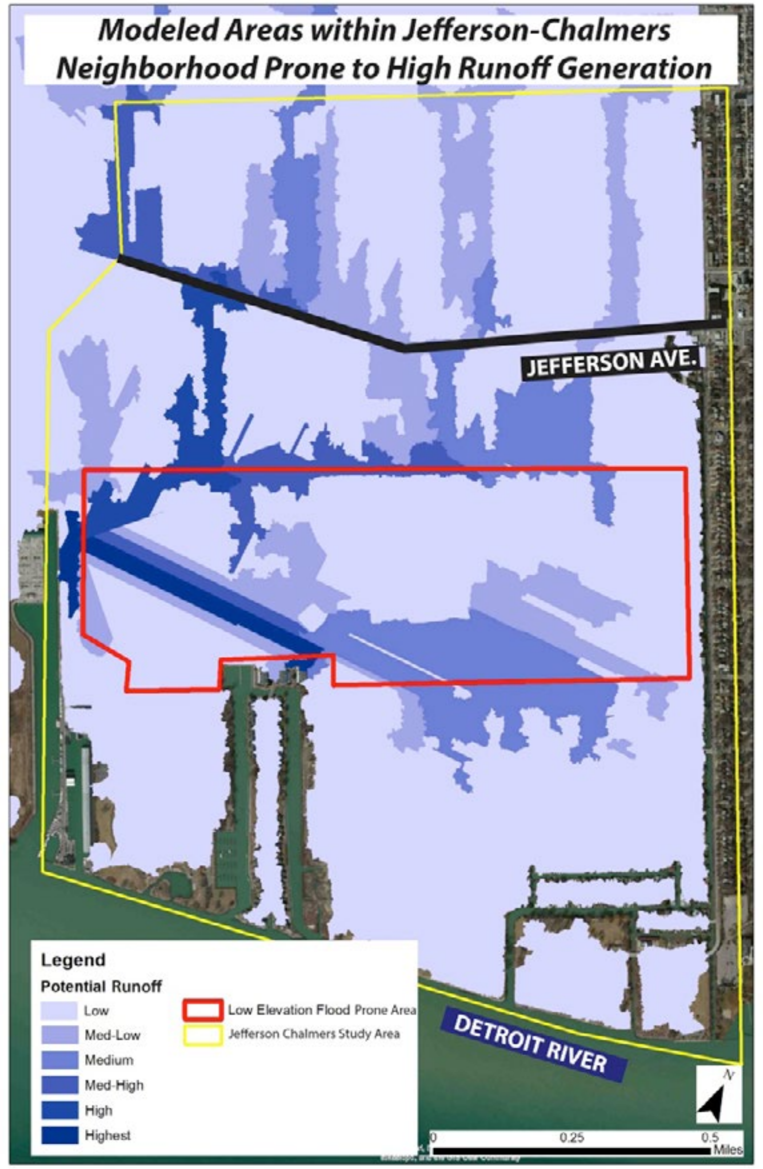


Figure 27:
Results of the SCS-driven Hydrologic Model within the Jefferson-Chalmers Neighborhood.

(Data Source: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014)

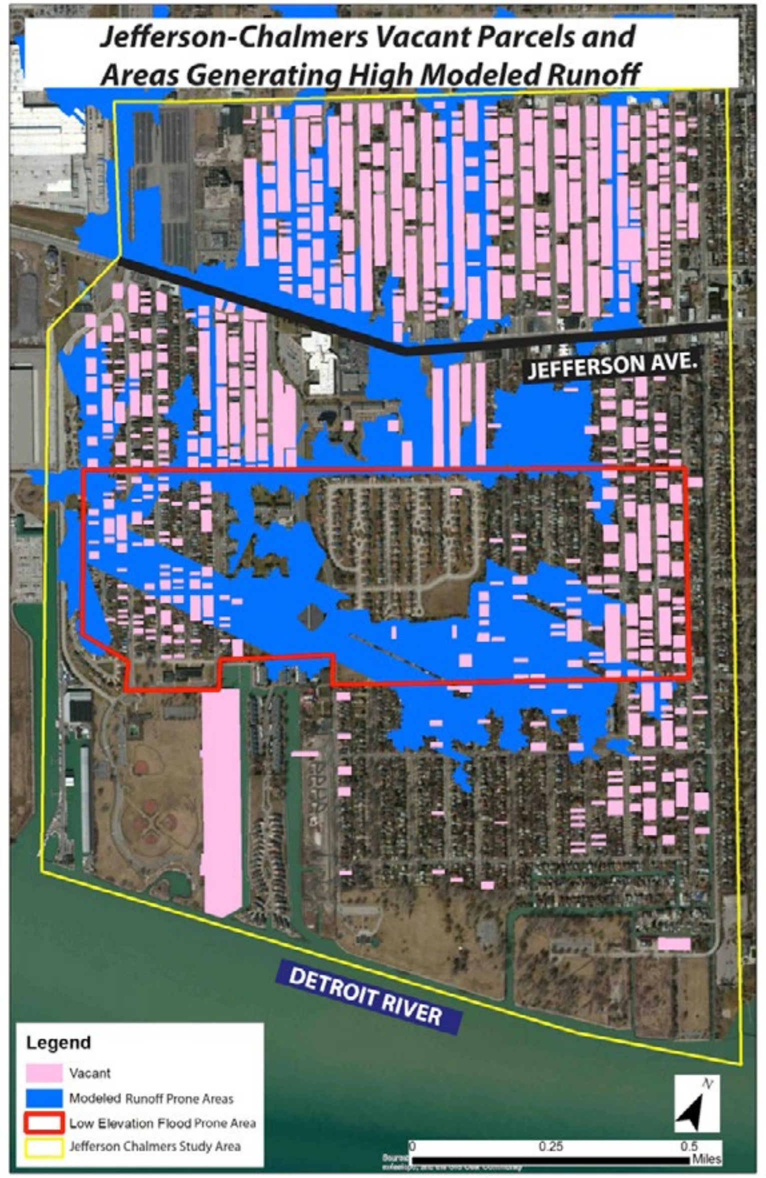
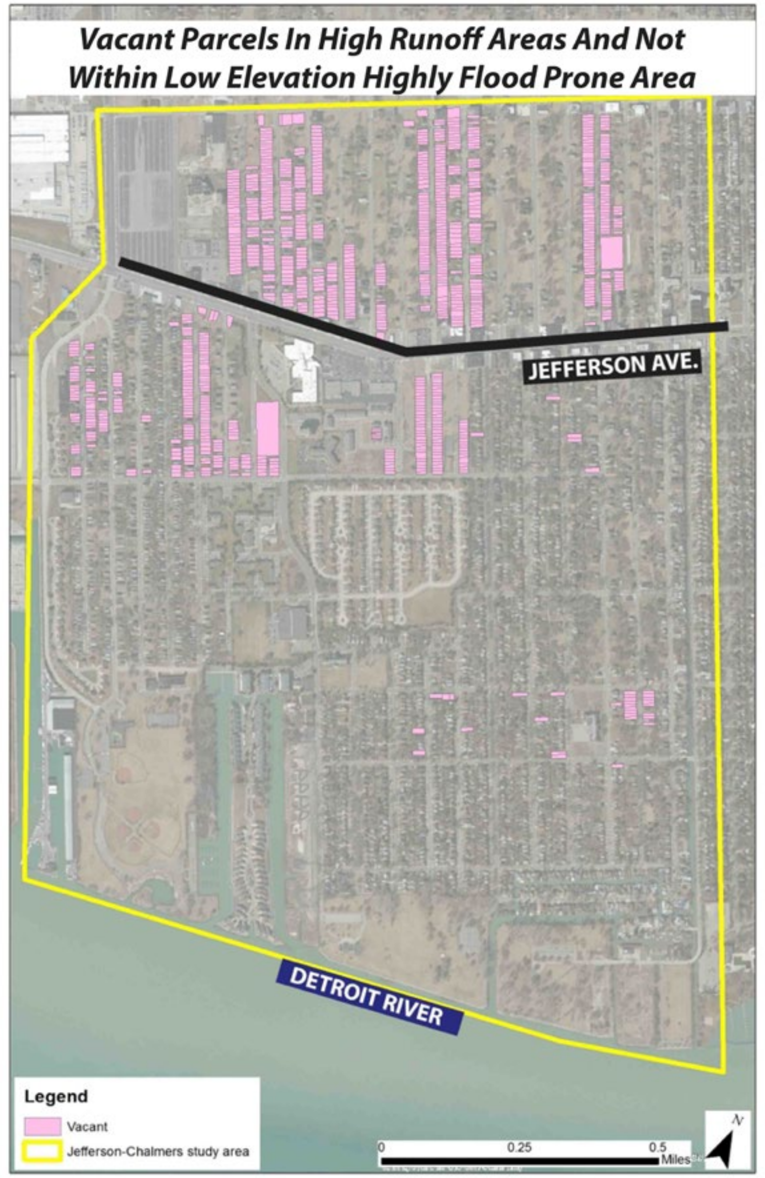


Figure 28:
Map displaying areas prone to generating high runoff amounts and all vacant parcels within the Jefferson-Chalmers neighborhood boundary.

(Data Source: Vacant parcels from Detroit Residential Parcel Survey, 2009; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014)

Figure 29:
Map displaying vacant parcels in high runoff areas and not within low elevation highly flood prone area (see Figure 28).

(Data Source: Vacant parcels from Detroit Residential Parcel Survey, 2009; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014)



the Detroit sewershed lying upstream and contributing water to the stretch of DRI routed under this neighborhood is extensive (Figure 5). This results in all intercepted runoff from the east side of the city being conveyed under the Jefferson-Chalmers neighborhood to the Conner Creek Pumping Station (Figure 6) (Camp Dresser & McKee, 2003). An examination of the location of the interceptor's path through the neighborhood also coincides with the portion of the Jefferson-Chalmers area lying at an unusually low elevation. Should a pump station or outfall within the JEBA neighborhood fail, or should a portion of the DRI running under the neighborhood be compromised, it will impede stormwater from exiting the area. In order to mitigate the possibility of future flooding caused by storm sewer backups in the Jefferson Chalmers neighborhood, city planners could scale up the approach to green infrastructure planning that was previously discussed within the context Jefferson-Chalmers neighborhood boundaries.

A green infrastructure planning approach was scaled up to an area occupying the geographic extents of the Lower Eastside Action Plan (LEAP) study area in Southeast Detroit. These extents were chosen because this was broadest scale dataset available to the master's project team that had all the necessary data layers for our model. It would have been ideal to use a dataset with coverage extents over the complete land area occupied by sewershed associated with the Jefferson-Chalmers neighborhood stormwater infrastructure (Figure 5).

Using a hydrologic model based on SCS methodology and runoff for a 10-year storm (1.8 inch/hour), we observe runoff patterns (Figure 30 below) and subsequently isolate areas that are prone to generating relatively high volumes of runoff (Figure 31). We could then strategically target vacant parcels within

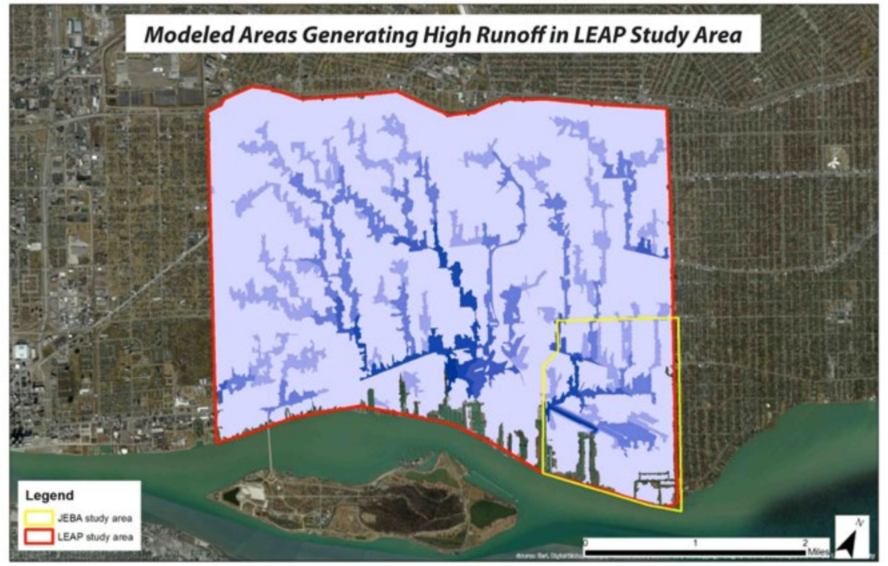


Figure 30:
Hydrologic model of runoff patterns across the LEAP study area. Darker blue areas represent locations prone to generating relative higher volumes.

(Data Source: Lower Eastside Action Plan boundary digitized from Austin et al. 2013; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014)

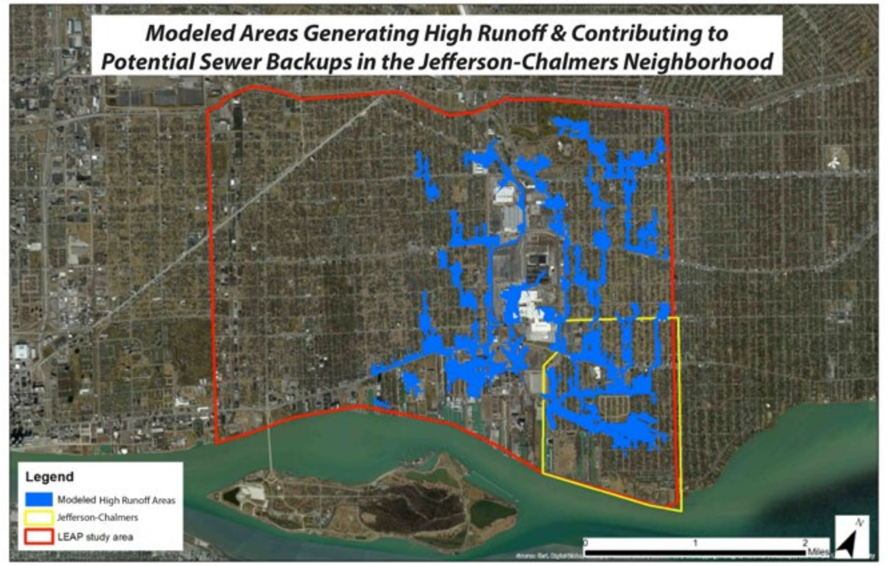


Figure 31:
Blue areas represent locations prone to generating relatively higher runoff volumes that are also in upstream areas of the sewershed contributing to runoff flows being conveyed through stormwater infrastructure under the Jefferson-Chalmers neighborhood.

(Data Source: Lower Eastside Action Plan boundary digitized from Austin et al. 2013; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014) these high runoff areas for green infrastructure (Figures 32 and 33). These projects could contribute to the reduction of runoff that may otherwise flow into the sewer, ultimately arriving under the Jefferson Chalmers neighborhood where it could back up out of sewers and flood low lying areas in the event of heavy rains or sewer system compromises.

The central concept of the above multi-scalar methodology for the effective planning of green infrastructure projects is the reliance on hydrologic relationships to plan source control networks. By modeling the likely pathway of stormwater runoff and determining where the highest volumes of flow will converge across the landscape, green infrastructure projects could be prioritized for areas where runoff volume mitigation is most needed.

The SCS Curve Number Procedure can also help us to understand both the water reduction dynamic and the potential relationship between the area of green infrastructure for stormwater control and runoff volume reduction. The figure 34 shows how runoff volumes are expected to change when different CNs are applied to a single watershed. An abrupt threshold can be observed at the point of capacity to detain water. This demonstrates that once these watersheds reach their saturation point for water detention, any more volume reaching the watershed will not be detained and will thus continue flowing downstream as runoff.

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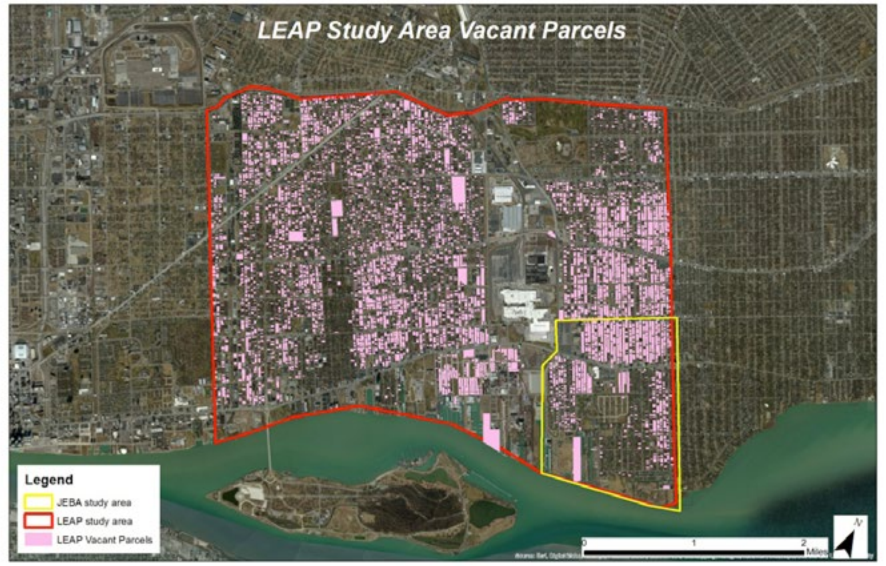

Figure 32:
LEAP Study Area Vacant Parcels

(Data Source: Lower Eastside Action Plan boundary digitized from Austin et al. 2013; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Vacant parcels from Detroit Residential Parcel Survey, 2009)

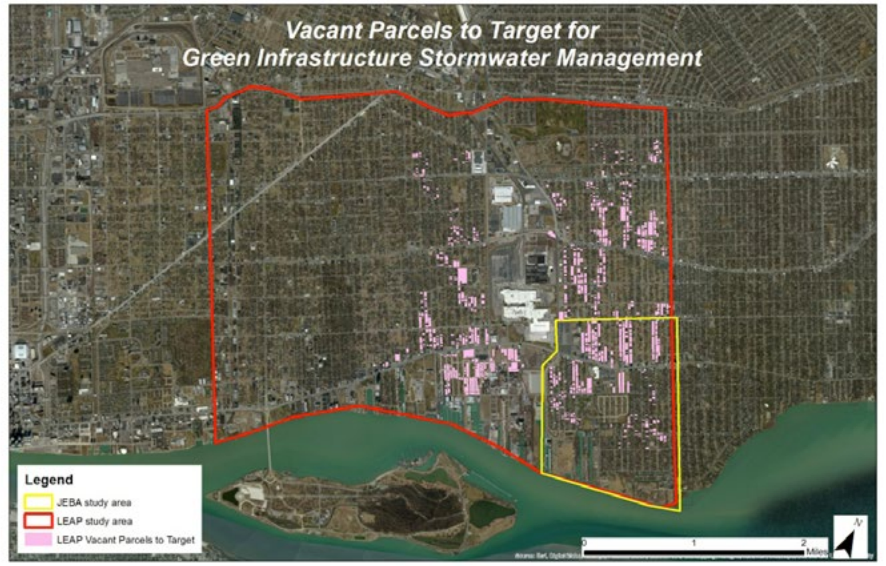

Figure 33:
Map displaying vacant parcels to be highest priority for green infrastructure conversion in the LEAP study area

(Data Source: Lower Eastside Action Plan boundary digitized from Austin et al. 2013; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Vacant parcels from Detroit Residential Parcel Survey, 2009)

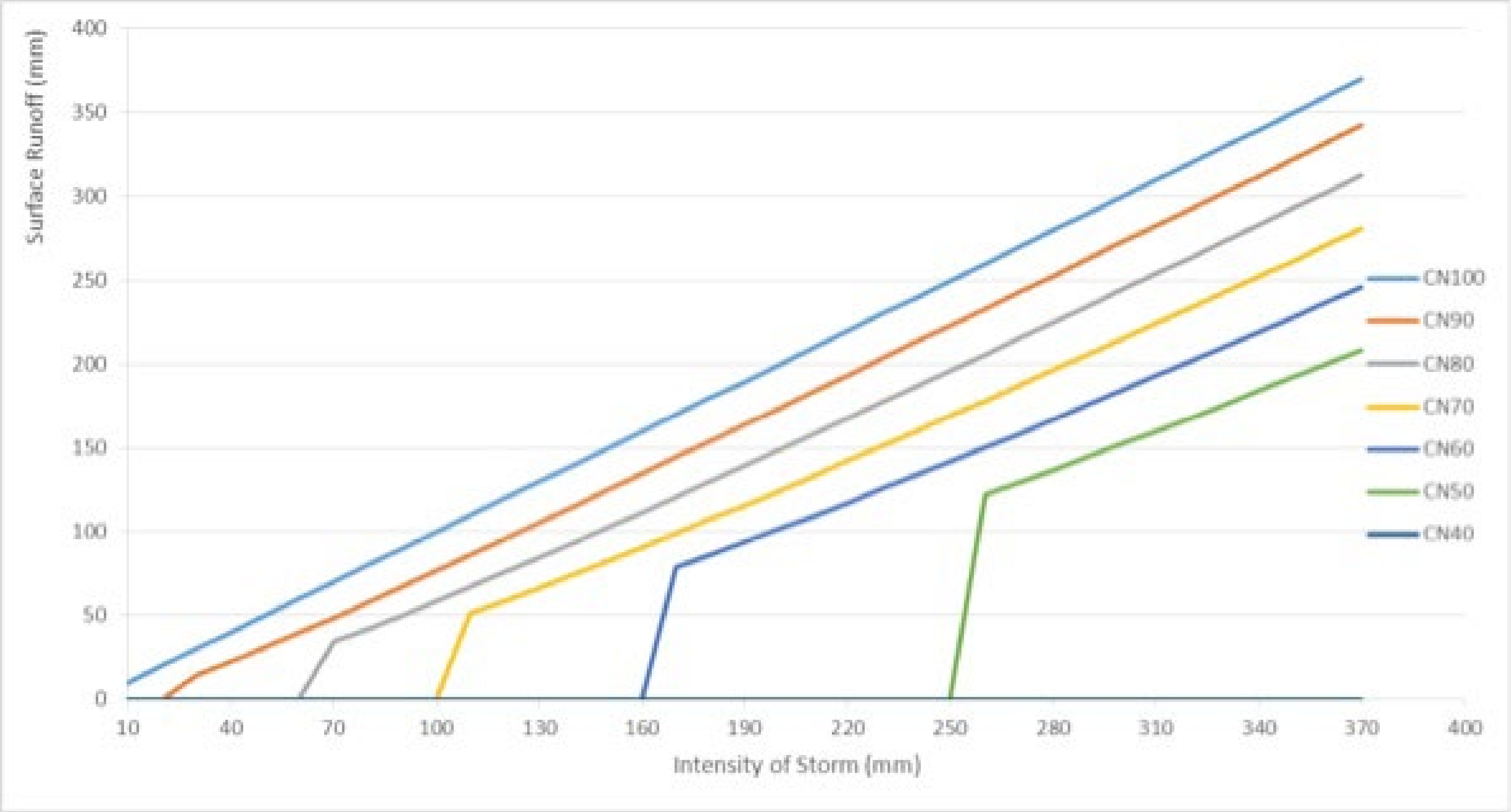

Figure 34:
Plot of ground flow generation from hydrologic model(different color lines are different CN)

-Model Sensitivity Analysis

A model sensitivity analysis was performed by comparing runoff flows generated by our modeled watersheds. Four simulated storms of varying strengths were used to test the sensitivity of the model: a 10 year 1-hour storm, a 25 year 1-hour storm, a 50 year 1-hour storm, and a 100 year 1-hour storm. According to The Rainfall Frequency Atlas of the United States (May 1961), the respective storms for the above mentioned intensities are 1.8 inches/hour, 2.0 inches/hour, 2.2 inches/hour, and 2.5 inches/hour. This set of storm intensities allowed us to perform a sensitivity analysis designed to check the robustness of the model. If the hydrological model has a structurally consistent response to these different storms, it is reasonable to assume that it will have a similar response structure to any storm event regardless of intensity. Our overall goal for this analysis is to assure when our model is used to evaluate the impact of green infrastructure source control measures for runoff and flow mitigation, results will reflect the impact of only these source control measures and not be dependent on any other variables.

Figure 36 below shows the different distributions of runoff generated by sampled watersheds falling throughout our model from more upstream to downstream areas. The sampled sites included areas from highly occupied neighborhood areas downstream to highly vacant land areas upstream. Figure 35 below displays the location of the sampled watersheds.

Although the response curve for each storm event varies slightly based on the modeled storm intensity, consistent similarities exist between the structural patterns of each curve. It can be observed that all four curves seem to produce a nearly identical

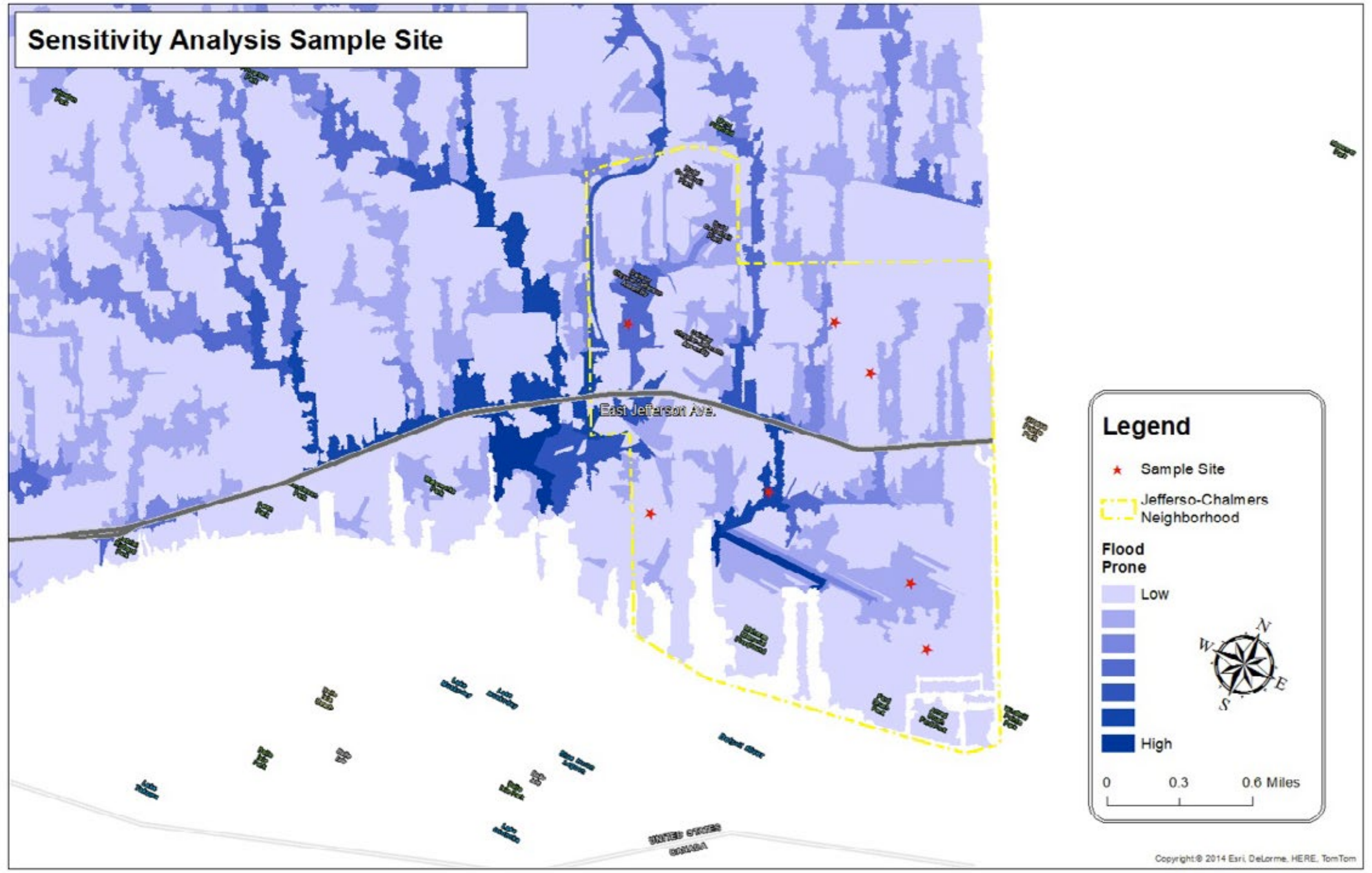

Figure 35:
Sample Site Location Map

(Data Source: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Sensitivity Sample Site Selection Based on Jefferson Chalmers Neighborhood Stabilize Plan in the Project, 2013; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014)

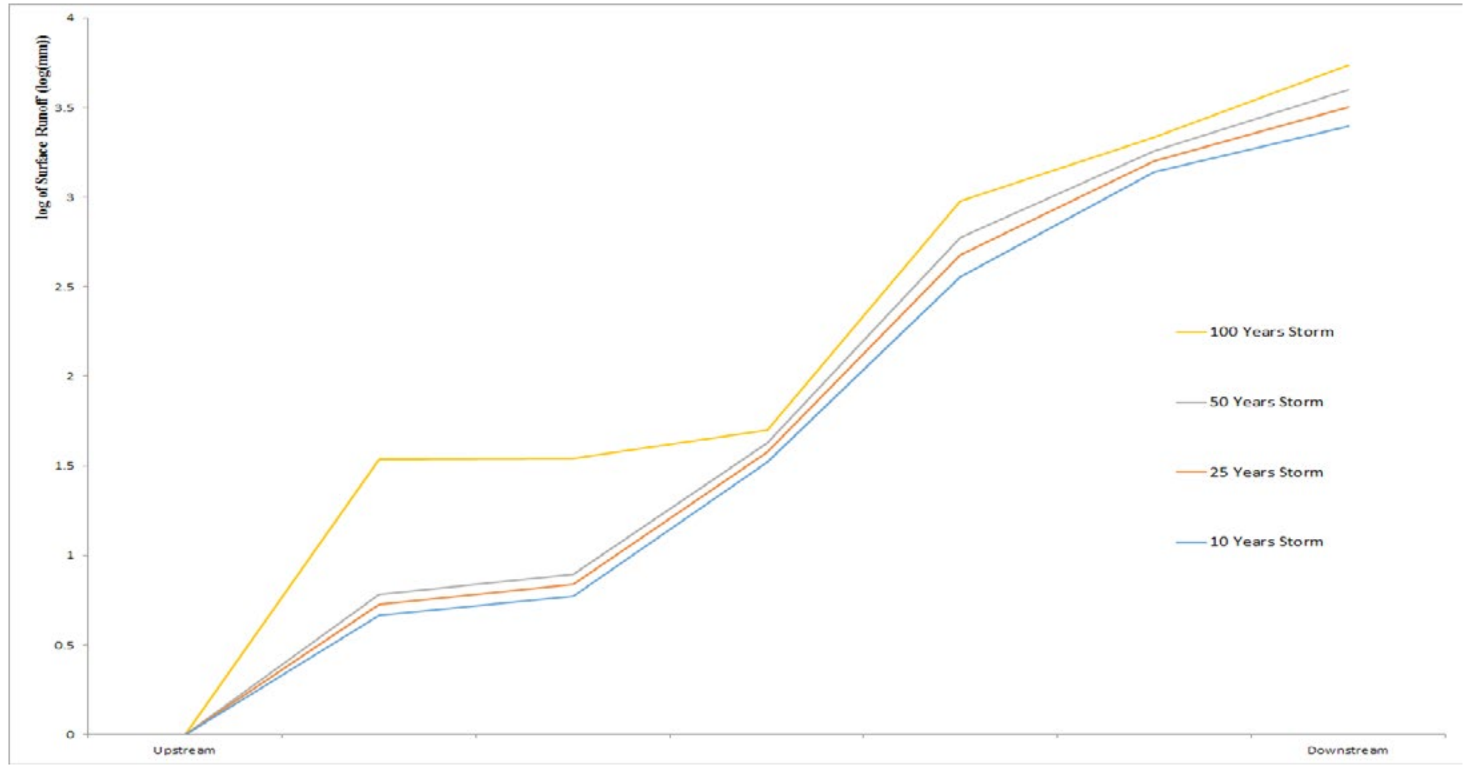

Figure 36:
Watersheds Surface Runoff Generation under Different Storm Event

pattern. The most prominent variance between the paths of the curves occurred in upstream areas during a 100-year storm event. This is because of the 100-year storm producing rainfall at a rate that exceeds the infiltration rate of upstream watersheds. These same upstream watersheds were able to more effectively infiltrate the rainfall generated during the other lesser intensity storm events which resulted in lower volumes of runoff being generated. Consistency in the overall runoff curve response patterns for each storm intensity indicates that our model runs in a predictable fashion. Our model can thus be considered a reliable tool to objectively assess the impact of green infrastructure design interventions within our study site on stormwater management. For the sake of project simplicity, we have decided to run all further analysis in this project based on a modeled 10-year, 1-hour storm event.

Another sensitivity analysis for assessing the potential impact of vacant land on stormwater management was performed by investigating the impact of turning vacant lots into other types of land cover with increased infiltration and runoff reduction potential. This would serve as a control group in our analysis to determine if strategically selecting green infrastructure sites could result in enhanced runoff reduction and create more effective stormwater management compared to the random sample. For this control group, we assumed that randomly selected vacant lots would be converted into urban woodlots on type A (well drained) soils (see SCS Curve Procedure in Appendix 1) to represent a land cover treatment with excellent stormwater management potential (CN = 65, see appendix 1). Four levels of conversion (100% vacant lots conversion, 50% vacant lots conversion, 25% vacant lots conversion, and 10% vacant lots conversion) were modeled to determine if a relationship existed between degree of source control creation and runoff reduction. Results are shown in the Table 1 below.

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-Designed Site Impact Assessment

The design site impact assessment allows us to estimate the water output reduction caused by proposed green infrastructure design decisions. Based on site analysis (discussed in section IV of paper), our source control-based approach for stormwater runoff management can be broken down into two strategies. The first strategy involves capturing runoff in green infrastructure source controls upstream of the Jefferson-Chalmers neighborhood flood-prone area. The second strategy pertains specifically to the previously identified highly flood-prone area and involves the use of an efficient stormwater conveyance channel to move water offsite and prevent flooding.

Figure 7 helped the master's project team to site a conveyance channel as part of the second strategy to be explored for runoff mitigation and stormwater management. The placement of the conveyance channel coincided with the areas of lowest elevations within the high-risk flood area. As can be observed from in Figure 7, these lowest elevation areas corresponded to the road footprints of Essex Avenue and Averhill Court. It was assumed that the conveyance channel would be sized adequately to convey all stormwater off site without its capacity becoming overwhelmed and leading to localized flooding. This concept was modeled by manipulating our DEM data and allowing the mapped footprint of the channel to have an infinite ability to receive runoff (Figure 37).

As expected, Figure 37 below indicates considerable hydrologic change regarding runoff volumes around the area of the conveyance pathway. Compared to the original watershed runoff generation map, the model indicates that water no longer collects in this area. Instead, runoff that would otherwise be collecting in this local sink is transported offsite and into the Detroit River.

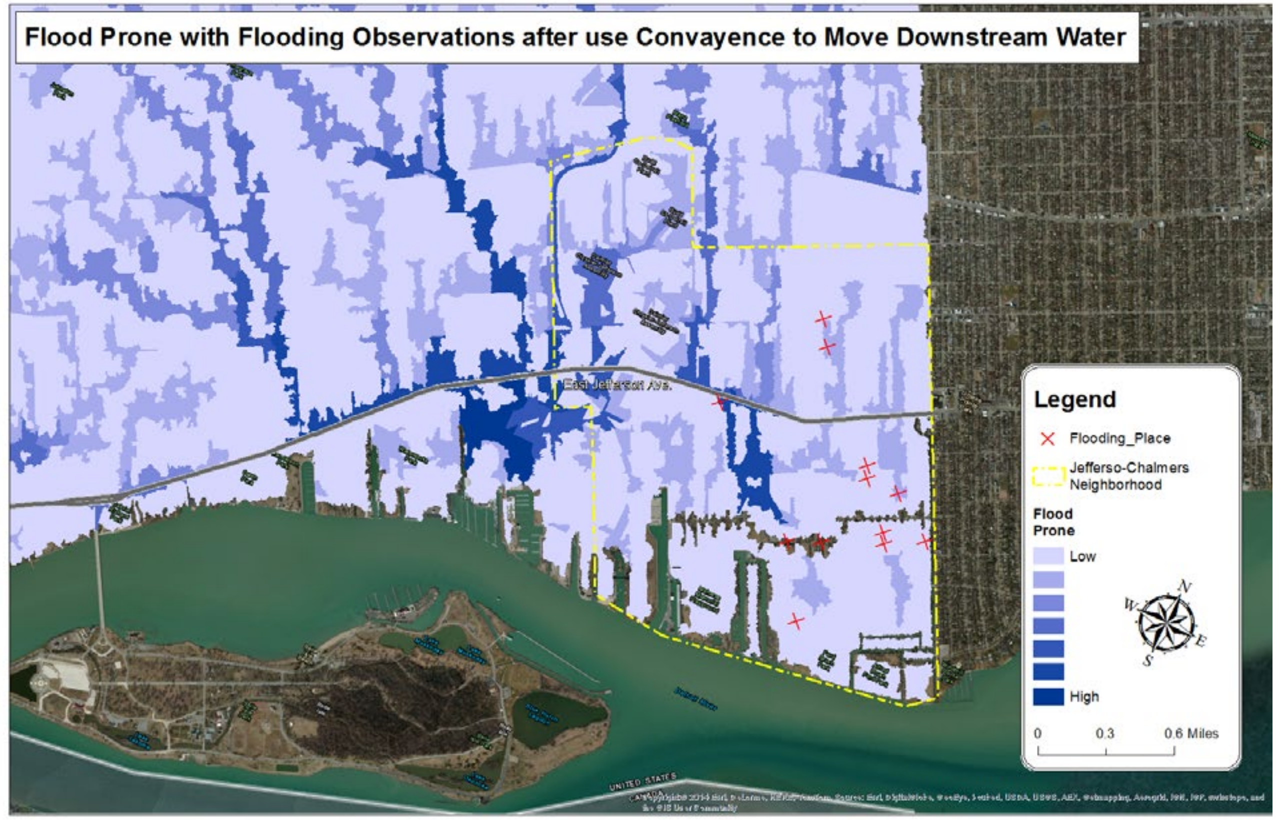

Figure 37:
Model Simulated SCS Curve Number Procedure Implemented Flood Prone after Fast Conveyance Channel Construction

(Dsta Source: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Flooding Observation Report from JEBA, 2013; Fast Conveyance Channel siting in this project, 2014; SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014)

Unit (mm*acre)	Total Amount of Water Generated	Amount of Ground Flow Reduction	Percentage of Ground Flow Reduction
Original	3888933.03	-	-
10% Vacant Lot	3858385.08	30547.95	0.79%
25% Vacant Lot	3824519.49	64413.55	1.66%
50 % Vacant Lot	3795490.04	93443.00	2.40%
100% Vacant Lot	3724045.67	164887.37	4.24%
Conveyance	2996020.85	892912.18	22.96%

Table 1:
Total Ground Flow Reduction

-Designed Site Impact Evaluation

To evaluate the impact of our planning decisions on stormwater management and runoff reduction, we compared runoff volumes projected in our original hydrologic model ("original" baseline condition) with runoff volumes projected following our project's proposed green infrastructure interventions. Table 1 below summarizes these findings. It can be observed that even when all vacant lots are converted to green infrastructure, there is only a ~4% reduction in runoff volume.

Higher reductions in modeled runoff volumes were observed when we proposed green infrastructure interventions on strategically chosen vacant parcels. Converting vacant parcels situated in watersheds we predicted to generate relatively higher runoff volumes resulted in greater runoff reduction compared to randomly chosen vacant parcels. When 50% of all vacant parcels were converted to green infrastructure source controls, we observed a 2.40% reduction with strategically chosen parcels. This is compared to a 1.23% reduction with randomly chosen parcels. The reason why the above percentages might seem low can be attributed to the processing area chosen to generate these numbers (see Appendix 3).

A significant 22.96% reduction was also observed in conjunction with the proposed conveyance channel in the highly flood prone portion of the Jefferson-Chalmers neighborhood.

Section VI. Design and Planning Recommendations for the Jefferson-Chalmers Neighborhood

Planning

Based on the above analysis of the Jefferson Chalmers neighborhood, the master's project team has developed a suite of planning strategies conveyed at the broad scale of this study area. The primary aims of these planning strategies are to improve stormwater management through green infrastructure source controls and strategic conveyance in order to mitigate flooding regularly reported in the Jefferson Chalmers neighborhood. Planning strategies were largely informed by the location of vacant land and CDAD future development trajectories currently supported by several of the community development organizations operating in the area. Additionally, planning strategies sought to complement goals outlined in numerous neighborhood stabilization plans authored and published by the Jefferson East Business Association – a community development organization with whom the master's project team worked on the project.

A number of crucial considerations regarding stormwater management strategies were revealed through our analysis. The presence of a high degree of vacant land north of Jefferson Avenue foments a unique opportunity to create a large area of green infrastructure source controls for stormwater management that is hydrologically upstream from most of the study area. Due to topographic anomalies and its unique position within the context of the Detroit combined sewer system, a large area of the neighborhood south of Jefferson Avenue is highly prone to flooding due to sewer backups. This has resulted in stormwater management planning strategies that emphasize a mix of stormwater management through both retention and conveyance (Figure 18).

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In order to create a more effective green infrastructure network to manage stormwater runoff, a hydrologic model was created to determine areas within our site that would observe the highest volumes of runoff following a storm event (Figure 27). By being better informed of where the most runoff is occurring, we could site green infrastructure in locations where they would retain the highest volumes of stormwater (Figures 28-29). This would prevent higher volumes of runoff from entering Detroit's sewer network, subsequently reducing the severity of potential sewer backups. Locations available for green infrastructure projects are dependent on the presence of vacant parcels, which can be converted into source controls.

The map below (Figure 38) illustrates the available parcels in the Jefferson Chalmers neighborhood that should be targeted for green infrastructure. All parcels lie in an area assumed to receive high runoff volumes during storm events (based on our hydrologic model), are situated outside the area south of Jefferson Avenue occupying an unusually low elevation that prevents this area from being considered for source control stormwater management, are parcels that lie within CDAD neighborhood typologies characterized by a high degree of open space, and exclude parcels that lie in spacious or traditional residential areas. Despite high levels of vacancy with good potential for stormwater management within some spacious residential areas, these parcels were not considered for the green infrastructure network. This was due to their potential to be revitalized as viable residential parcels in the event that the Jefferson Chalmers neighborhood can be stabilized. Additionally, a number of parcels have been added to those in the naturescape typology neighborhoods that were found to be optimal candidates for green infrastructure based on their status of currently being vacant and lying within our modeled areas receiving high potential runoff volume. Because the future vision of the CDAD naturescape typology constitutes completely depopulated areas dedicated to greenspace, all vacant parcels in these areas can be considered for use in green infrastructure systems.

A number of vacant land areas within the residentially viable portion of the study area south of Jefferson Avenue are proposed to be redesigned as parks to serve as amenities to surrounding neighborhood communities. Portions of these designated park areas assumed to receive high runoff volumes during storm events (according to our hydrologic model) would be designed to capture stormwater and serve as part of the comprehensive green infrastructure network acting to mitigate flooding in southern portions of the neighborhood. This allows these parks to function as multifunctional community amenities.

With loose boundaries of targeted vacant land demarcated, we can begin to observe how our planning efforts might begin to impact stormwater management throughout our study area. Large swaths of green infrastructure north of Jefferson Avenue are situated in areas assumed to receive high runoff volumes during storm events. Thus, large amounts of runoff can be intercepted before reaching Detroit's sewer network. The incorporation of green infrastructure for stormwater management within the proposed parks south of Jefferson (Figure 39) can also serve to mitigate the runoff from a location likely contributing more runoff to Detroit's sewers than anywhere else in the neighborhood (i.e. the Riverbend Shopping Center). There are no other instances in the study area where such high degrees of impervious surface exist. Roads and parking lots can be the most significant type of land cover with respect to stormwater. They constitute as much as 70 percent of total impervious cover in ultra-urban landscapes, and as much as 80% of the directly connected im-

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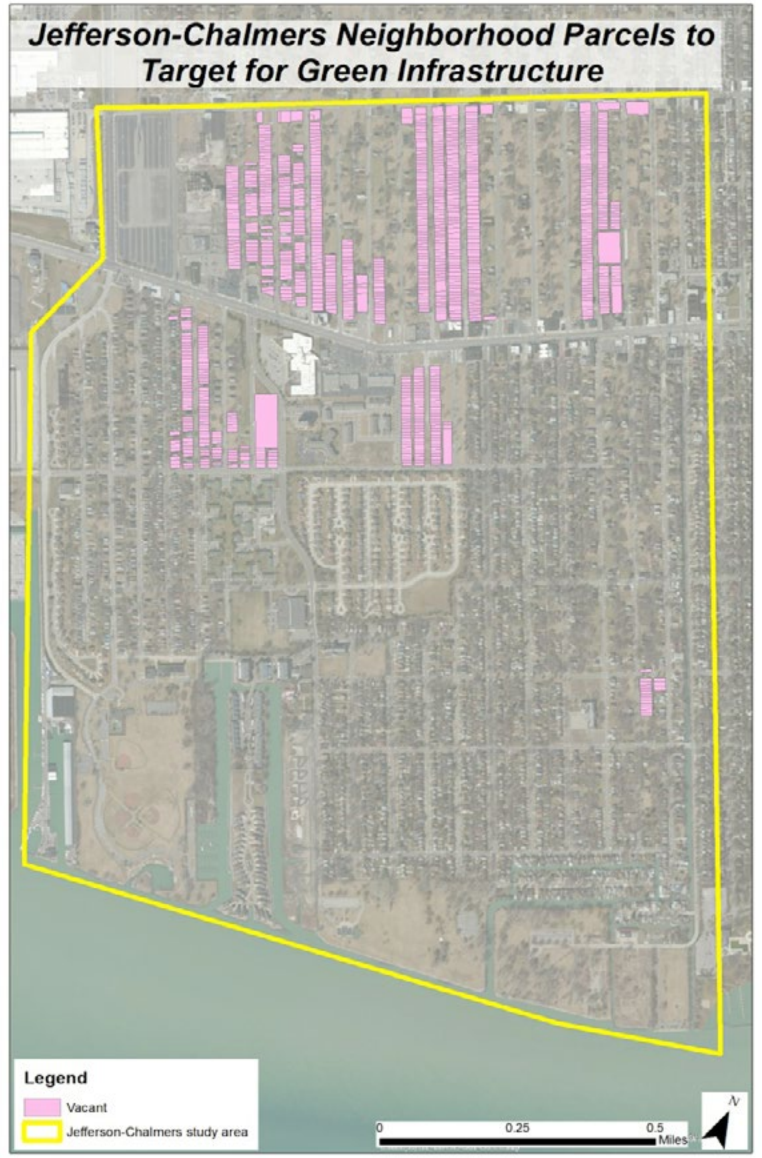

Figure 38:
Targeted parcels in Jefferson-Chalmers neighborhood for conversion to green infrastructure. Note the slight difference in parcels displayed above versus in Figure 29. Differences stem predominately from considerations based vacant parcels relative to surrounding CDAD neighborhood typoliges.

(Data Sources: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Vacant parcels from Detroit Residential Parcel Survey, 2009; Vacant parcels selected with data from SCS Curve Number Procedure Implemented Flood Prone Simulation by this project, 2014 & CDAD typology boundaries digitized from Community Development Advocates of Detroit, 2010)

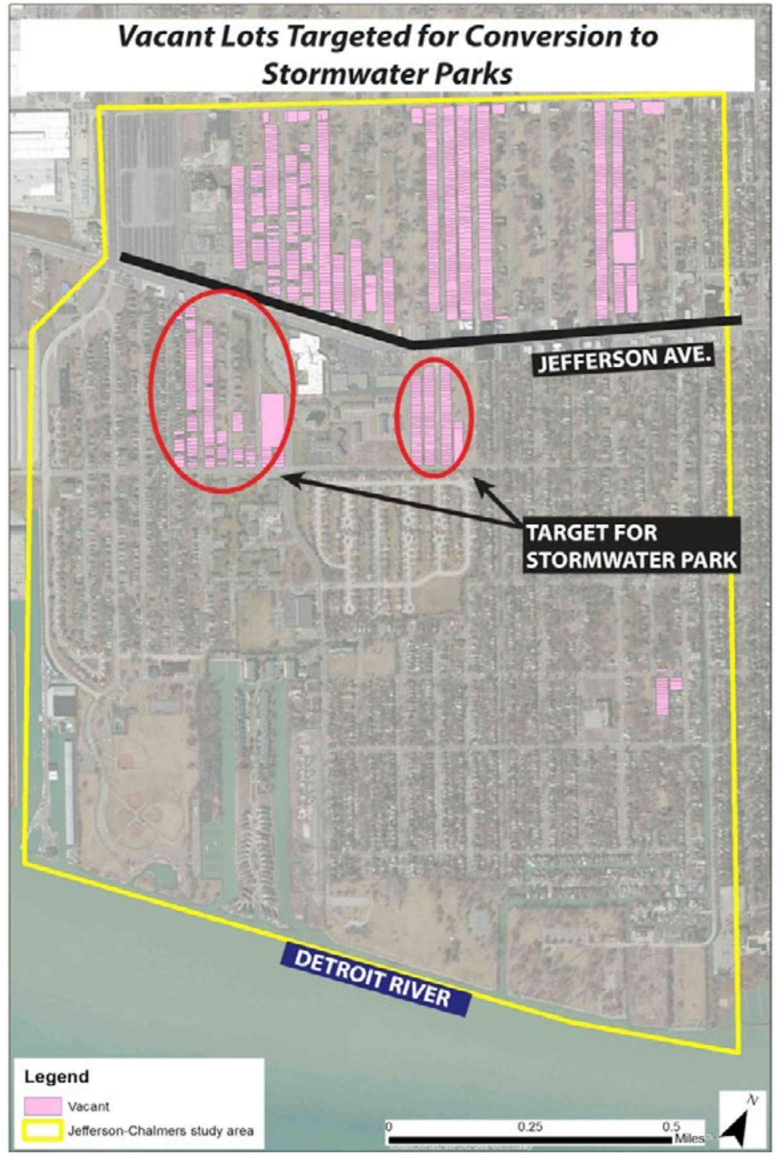

Figure 39:
Vacant Lots to Target for Conversion to Stormwater Parks

(Data Source: Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013; Vacant parcels from Detroit Residential Parcel Survey, 2009)

pervious cover (NRC, 2009). A swath of non-stormwater related greenspace has also been planned along the study area's eastern edge. The impetus for this specific planning intervention will be discussed more below.

Another aspect addressed with our stormwater planning efforts for the neighborhood's vacant land was the development of planning measures aimed to help mitigate the presence vacant parcels in the still highly occupied residential tracts south of Jefferson Avenue. As noted in the map above (Figure 40), a long swath of non-stormwater related greenspace has been planned along the study area's eastern edge. Such instances of additional non-stormwater vacant land interventions were planned to enhance the presence of land stewardship and care in healthy portions of the viable residential core of the Jefferson-Chalmers neighborhood that lie south of Jefferson Avenue. Vacant land falling within CDAD typology areas characterized by low density and greenspace oriented development (i.e. naturescape and urban homestead) was revitalized as open and recreational space. This significantly reduces the amount of neighborhood space characterized by dense vacancy in this residential core area.

Another neighborhood planning consideration yet to be addressed is the impact of the neighborhood's bowl-shaped topography and its affect on stormwater management. A large portion of the Jefferson-Chalmers study area exists at a lower elevation than at the riverfront (Figure 7). This area of extreme local low elevation regularly floods according to sources at the Jefferson East Business Association – an effect likely caused by overtaxed or malfunctioning storm sewers backing up. High likelihood of localized flooding is further increased by the presence of several pump stations and CSO control structures (figure 6) bordering the noted highly flood prone area of the neighborhood (Figure 7).

Figure 40:
Diagram of Source Controls Throughout Jefferson-Chalmers Neighbor-hood

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Figure 41:
Diagram of Conveyance Channel Locations

When planning a green infrastructure network, conventional wisdom might lead one to build green infrastructure in the most flood prone areas of the Jefferson-Chalmers neighborhood to limit flooding. However, this would be faulty logic as this area is already a local stormwater sink. There is no reason to detain and infiltrate stormwater in an area that is already serving this function by virtue of elevation. Instead, stormwater infrastructure in this area should be planned to efficiently convey stormwater offsite as quickly as possible by moving it into the nearby Detroit River. Ideally, untreated combined sewer backup water should not be released directly into a water body. However, this option is justified if on-site stormwater detention is not an option and the area is prone to local flood damage.

Based on the above considerations, a general conveyance-based stormwater management strategy might be designed following the conceptual diagram below. In the event of a storm event in which sewers begin backing up and allowing overland flows to settle in the low-elevation area shown above, a highly efficient conveyance mechanism such as a high capacity concrete-lined channel can be built into the lowest elevated areas of our site (see Figure 7). Our diagram below (Figure 41) positions such a conveyance channel along streets occupying these positions. Because city streets are often designed to have the lowest elevation relative to their immediate surroundings in order to effectively convey stormwater runoff into curbside sewer catch basins, it made sense for us to cite a conveyance channel in such locations. Essex Avenue and portions of Averhill Court are east-west oriented streets that run approximately through the center of the identified low-elevation and highly flood prone areas (Figure 7). They also occupy the lowest areas in our study site. Therefore, the footprints of these roads were chosen as the

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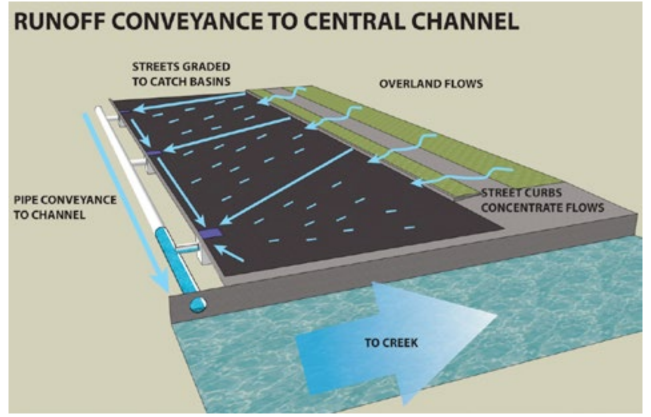

Figure 42:
Diagram of Runoff Conveyance to Central Conveyance Channel within Jefferson-Chalmers Neighborhood Flood Prone Area

Figure 43:
Greenway network through Jefferson-Chalmers neighborhood based on existing greenways, greenways proposed by the East Jefferson Corridor Collaborative, and greenways proposed within this master's project.

(Data Sources: Existing greenways and East Jefferson Corridor Collaborative proposed greenways digitized from East Jefferson Corridor Collaborative, 2010; Jefferson-Chalmers neighborhood boundary digitized from Detroit Vacant Property Campaign, 2013)

Figure 44:
Map illustrating the location of the proposed conveyance channel relative to the proposed and existing greenway network.

locations for our planned conveyance channels. It was assumed that water collecting in the low-elevation flood prone area would drain toward the conveyance channel via north-south oriented cross streets due to general sloping patterns of the existing roadway system already exhibiting this pattern. It is acknowledged however, that a degree of street re-grading will likely need to be completed in order to assure this drainage mechanism works completely as intended. Alternatively, successful drainage of north-south cross streets to the east west main conveyance channel could be accomplished through the installation of small underground pipe-based collector channels. These would be installed in right-of-ways to assure water is conveyed toward the main conveyance channel (Figure 42). This process could be carried out as part of future-scheduled road reconstruction projects, assuming Detroit's financial situation improves.

The planning of the above-depicted east-west conveyance channel cutting across the entirety of the Jefferson-Chalmers neighborhood also presents the opportunity to address the goals of improving walkability, streetscapes, and greenways. These goals were frequently discussed in both the Jefferson-Chalmers Neighborhood Stabilization Plan and the East Jefferson Stakeholder Outreach and Implementation Plan provided by our collaborators at the Jefferson East Business Association to help inform our planning efforts (East Jefferson Corridor Collaborative, 2010; Detroit Vacant Property Campaign, 2013). The master's project team has created a design for the conveyance channel that incorporates pedestrian and bike lanes running alongside this feature. In doing so, an east-west greenway with a complete-street-like character was generated to provide a central, multi-modal throughway connecting large portions of the study area's residential core. This conveyance channel-based thoroughfare also connects neighborhood populations to a

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Figure 45:
Existing and proposed greenway network in relation to assets outlined in the Jefferson-Chalmers Neighborhood Stabilization Plan.

(Data Sources: Neighborhood assets digitized from Detroit Vacant Property Campaign, 2013)) number of existing greenways in addition to a number of greenways that have been proposed by JEBA and other local community development organizations (East Jefferson Corridor Collaborative, 2010). Many of these greenway connections also happen to link with Jefferson Avenue and the entrances of the multiple parks that line the Jefferson-Chalmers riverfront. The greenway designed alongside the conveyance channel therefore functions to support the goals outlined by the above mentioned neighborhood stabilization plans involving the enhancement of access to key community amenities. The master's project team also suggests the future development of one additional north-south oriented complete green street along Lakeview Street that can be observed in the map below. The reasons for this suggestion include Lakeview having a 65' right of way compared to the typical 55' right of way of most the surrounding neighborhood streets, having its northern end terminate next to a proposed open and recreational park space discussed earlier in this section, and having its southern end terminate at the entrance of the riverfront's Alfred Brush Ford Park.

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Section VII. Design Overview

Conveyance Channel

Based on the aforementioned planning proposal to incorporate an efficient conveyance channel into a highly flood prone portion of the Jefferson-Chalmers neighborhood (Figure 41), the master's project team recommends that a channel be designed within the 60-foot right-of-way footprints of Essex Avenue and Averhill Court (Figure 7). To provide a more detailed example of how such a project might be designed and implemented, a proof of concept site has been included for the below identified area along the eastern portion of Essex Avenue (Figure 46).

The stretch of Essex Avenue in the proof of concept site displayed above (Figure 47) was measured to be approximately 2,000 feet in length (measure in Google Earth). Designs for a conveyance channel propose that the above 2,000 foot length of Essex be removed and a concrete lined conveyance channel constructed in its place. Vehicular bridges are designed at three intersections with the channel along Lakeview Street, Marlborough Street, and Ashland Street. Three non-vehicular pedestrian bridges are designed at three intersections with the channel along Chalmers Street, Philip Street, and Manistique Street (Figure 48). In order to convey water east and into Fox Creek, a minimum slope of 0.5% is proposed. This would necessitate a minimum channel depth of 10 feet at its outflow location into Fox Creek. The proposed channel design is 30-feet wide at bankfull. Precise sizing of channel dimensions will be assumed to accommodate the efficient drainage of all potential floodwaters. It is however recommended that a professional engineer be consulted to determine the channel's appropriate final sizing as the above-proposed dimensions are for conceptual purposes only.

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Figure 46:
Proof of Concept Site for Conveyance Channel

Figure 47:
Proof of Concept Site for Conveyance Channel (Fine Scale)

In order to enhance the multifunctional character of the proposed conveyance channel system, the master's project team utilized a design strategy to create a greenway and linear park network along the length of the project (Figures 43 and 44). We designed the channel to include 10-foot wide pedestrian and bicycle pathways along each of its banks (Figure 48). A number of vacant parcels also lie directly adjacent to the stretch of Essex Avenue to be replaced. It is proposed that these areas be converted into a series of pocket parks along the channel where local community members could gather. These parks are designed in a way that is informed by the neighborhood character in their immediate surroundings as defined by their assigned CDAD neighborhood typologies and levels of vacancy (Figure 49). The western end of the conveyance channel in this proof of concept site is characterized as "traditional residential" and has limited vacant land. Thus, proposed pocket parks take the form of a traditional paver-covered corner plaza sheltered by planted trees and a small maintained recreational turf-lawn for neighborhood children. The center-lying areas along the length of the channel are characterized by the "spacious residential" typology with a slightly higher presence of vacant land. Pocket parks in this area occupy more vacant parcels and are larger. Park design responds to the more vacant and open character of the surrounding neighborhood through a larger maintained turf field on one side of the channel and a row of planted trees within a low-maintenance no-mow meadow. Parks designed at the far East end of the channel fall in neighborhood areas with very high levels of vacancy and are characterized as "naturescape" and "urban homestead" CDAD typologies. Rows of trees surrounded by no-mow meadow were chosen for these pocket park areas to allow for low-levels of required maintenance. Tree species can be selected from those recommended for low-maintenance urban woodlots in Austin et al. 2013. All tree rows were planted at a "fight or flight distance"

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Figure 48:
Plan View of Conveyance Channel Replacing the Eastern Portion of Essex Avenue within the Jefferson-Chalmers Neighborhood.

Figure 49:
Vacant parcels and CDAD typologies in Areas Surrounding Proposed Conveyance Channel.

(Data Sources: Vacant parcels from Detroit Residential Parcel Survey, 2009; CDAD typology boundaries digitized from Community Development Advocates of Detroit, 2010)

Figure 50:
View of Conveyance Channel immediately after a Storm along Essex Avenue on the East Side of the Jefferson-Chalmers Neighborhood.

of at least 45 feet from park property lines along the channel to enhance the perception of public safety in these sparsely populated areas (Austin et al. 2013).

The image below (Figure 50) demonstrates what the above described conveyance channel might look like immediately following a storm event. Any local storm runoff or water from sewer backups would be conveyed to this central conveyance channel where it would be efficiently transported offsite. Typically, the below channel would be empty with its concrete bottom exposed and visible.

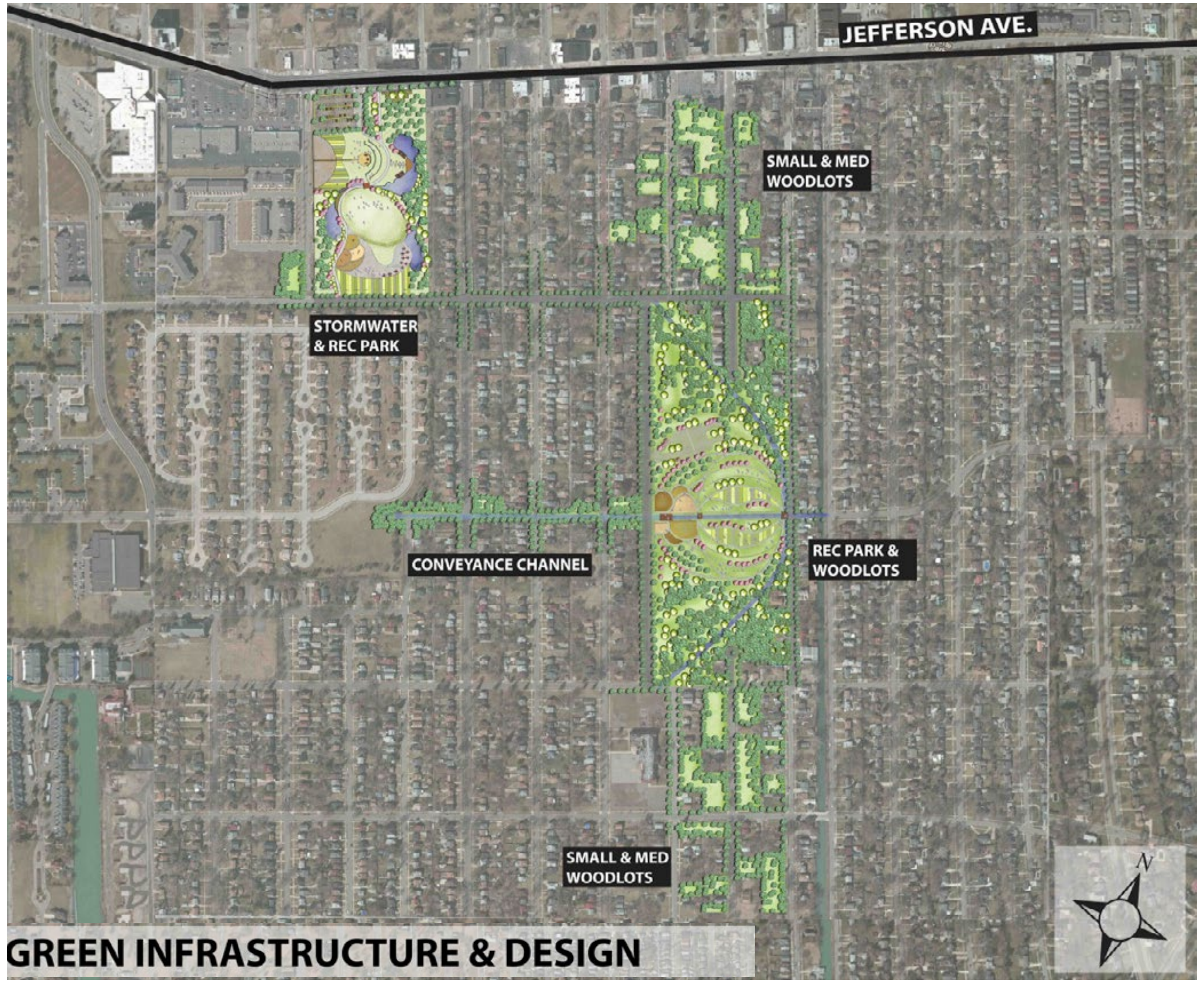
Of particular note in the below image are the steps making up the walls of the channel. This is to enhance public safety. Whereas steep sloping walls of a trapezoidal conveyance channel could pose a injury risk due to falls, the step-approach in the channel below mitigates this risk. It also allows the public a chance to interact with the channel form, using it as a place to sit and gather. Intermittent planters incorporated along the tops of the channel banks could also provide refuge and a degree of privacy to users sitting along the steps. The pedestrian and bicycle pathways can also be observed in the perspective. Additionally, views of one of the pocket park recreational lawns can be seen in the background.

Neighborhood Green Infrastructure Proof of Concept Design: Coupling Source Controls and Conveyance Strategies

In addition to our proof of concept design for the above detailed section of conveyance channel, we are also presenting a proof of concept for some of our proposed green infrastructure interventions within the portion of the Jefferson-Chalmers neighborhood outlined in Figure 51 below. This area was chosen because it contains portions of the neighborhood requiring the use of contrasting strategies for managing stormwater – source controls and conveyance-based controls.

Green infrastructure stormwater management interventions detailed in the following design plan (Figure 52) include a stormwater and recreation park adjacent to Riverbend Shopping Center, and small and medium sized woodlots for facilitating stormwater infiltration. Design of woodlots follow the design guidelines for small and medium-sized urban woodlots as described in Austin et al. 2013. These measures can be characterized as stormwater source controls and all of the above described interventions were sited outside of Jefferson-Chalmers neighborhood areas that are not flood prone due to low elevation (Figure 7). Within this flood prone area in the below plan (Figure 52), we can observe the presence of the aforementioned portion of the conveyance channel running west to east. Due to the limitations of source controls in this flood prone area, the below design uses efficient conveyance to mitigate potential flooding from sewer backup water settling in the area. Finally, a recreational park with woodlots is shown along the eastern side of the site. Although this area does not make significant contributions to flood control within the highly flood prone area (a small degree of infiltra-

Figure 51:
Proof of Concept Site



tion may be observed in the wooded areas), the design allows for large areas of vacant land to be converted into a community asset. Figure 53 below is comprised of a diagram of stormwater runoff flows and how the design conveyed in Figure 52 manages stormwater with a two pronged approach of source control retention and efficient conveyance.

Figure 52 (Left):
Illustrative plan of Source Control and Conveyance-based Stormwater Management Strategies within a Portion of the Jefferson-Chalmers Neighborhood.

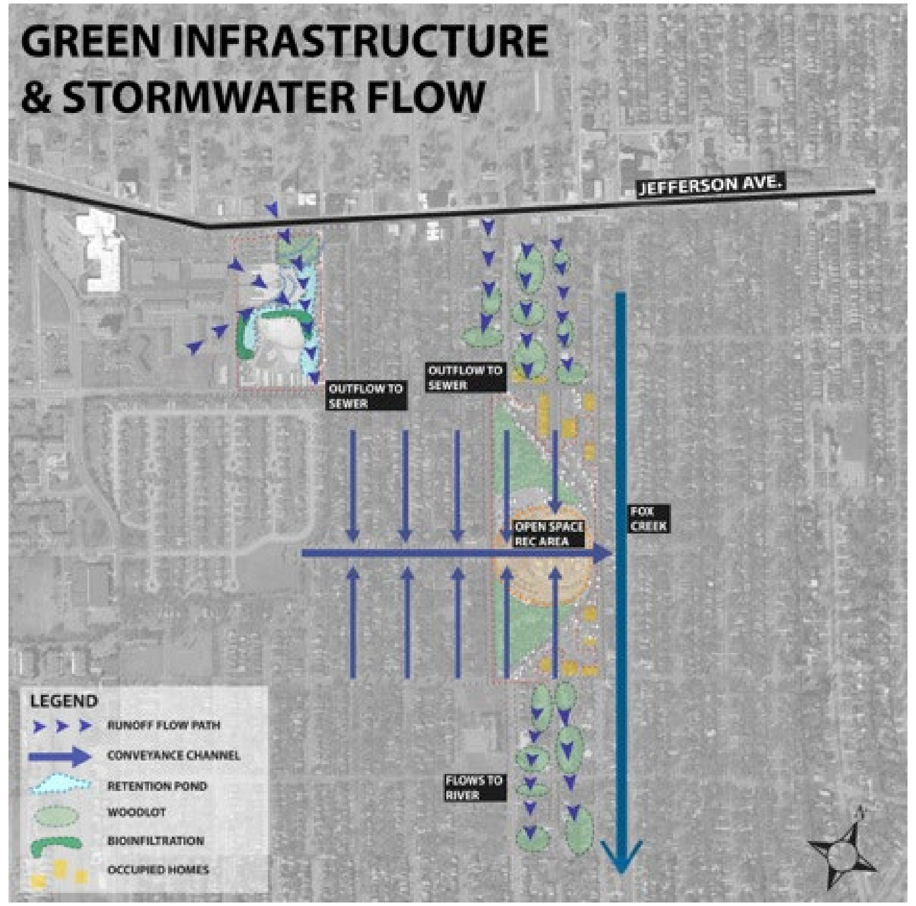


Figure 53 (Right):
Diagram of How Stormwater Runoff Flows are Affected by the Design Illustrated in Figure 52.

Section VIII. Conclusions

Green infrastructure can be a viable adaptive strategy for old cities with aging infrastructure as demonstrated in this report. However, the context of stormwater management strategies can inform limitations to differing types of interventions (i.e. source control-based vs. conveyance base). It also must be acknowledge that the scale of green infrastructure intervention can be large when attempting to address issues pertaining to stormwater management such as localized flooding.

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Section IX. Appendix

Appendix 1: SCS Curve Number Procedure – Empirical Model from 1950s

The SCS Curve Number Procedure is an empirical model developed in the 1950s. It categorizes how different combinations of land use, land cover, and soil type impact storm water infiltration by categorizing them into different curve numbers. Knowing the amount of precipitation and the curve number of a catchment allows you to calculate the amount of surface runoff. The original SCS curve number equation is:

$$\begin{cases} \dfrac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}. & \forall (R_{day} \geq I_a) \\ 0. & \forall (R_{day} \geq I_a) \end{cases}$$

Where Qsurf is accumulated runoff, Ia is initial abstraction, and S is the retention parameter. The retention parameter can be deconstructed further to the following equation:

$$S = 25.4(\frac{1000}{CN} \text{ -10})$$

“CN” in the above equation represents the curve number. CN, as explained above, is derived from the land use type and soil condition (See table below for more information on CN). According to the data layer from Michigan Geographic data library records, the whole study area is covered by the URBAN BLOUNT LENAWEE soil group, which has poor draining characteristics. Based on the description of the soil, local watersheds have a slow or moderately slow infiltration rate. According to the soil group description in the Curve number method, the curve number under soil group C will be applied.

NLCD 2006 data was used to generate the curve numbers. The NLCD has a very specific documentation of land use and land cover type. Land use type was linked to the corresponding curve number as the table shows below:

Table 2:1-2: Runoff curve numbers for other agricultural lands (from SCS Engineering Division, 1986)

Cover		Hydrologic Soil Group			
Cover Type	**Hydrologic condition**	**A**	**B**	**C**	**D**
Pasture, grassland, or range—continuous forage for grazing'	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay	----	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element'	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods—grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods'	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	----	59	74	82	86

Table 2:1-3: Runoff curve numbers for urban areas§ (from SCS Engineering Division, 1986)

Cover			Hydrologic Soil Group			
Cover Type	**Hydrologic condition**	**Average % impervious area**	**A**	**B**	**C**	**D**
Fully developed urban areas						
Open spaces (lawns, parks, golf courses, cemeteries, etc.)‡	Poor		68	79	86	89
	Fair		49	69	79	84
	Good		39	61	74	80
Impervious areas:						
Paved parking lots, roofs, driveways, etc. (excl. right-of-way)	----		98	98	98	98
Paved streets and roads; open ditches (incl. right-of-way)	----		83	89	92	93
Gravel streets and roads (including right-of-way)	----		76	85	89	91
Dirt streets and roads (including right-of way)	----		72	82	87	89

Table 2:1-3, continued: Runoff curve number for urban areas

Cover			Hydrologic Soil Group			
Cover Type	**Hydrologic condition**	**Average % impervious area**	**A**	**B**	**C**	**D**
Urban districts:						
Commercial and business		85%	89	92	94	95
Industrial		72%	81	88	91	93
Residential Districts by average lot size:						
1/8 acre (0.05 ha) or less (town houses)		65%	77	85	90	92
1/4 acre (0.10 ha)		38%	61	75	83	87
1/3 acre (0.13 ha)		30%	57	72	81	86
1/2 acre (0.20 ha)		25%	54	70	80	85
1 acre (0.40 ha)		20%	51	68	79	84
2 acres (0.81 ha)		12%	46	65	77	82
Developing urban areas:						
Newly graded areas (pervious areas only, no vegetation)			77	86	91	94

Soil Groups A, B, C, and D is defined as following by NRCS (U.S. Natural Resource Conservation Service):

A: (Low runoff potential). The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

B: The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well-drained to well-drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C: The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D: (High runoff potential). The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential soils that have a permanent water table, soils that have a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

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Appendix 2: Reasons for not using SUSTAIN or SWAT

The SUSTAIN model is designed for datasets with coarse spatial resolution. The extremely high-resolution dataset used in our project may cause the program to crash due to its high memory requirements.

Both the SUSTAIN and SWAT models require specific input files that are not currently available to our project team. Although they can be created through processes such as digitizing, we must consider the costs of a highly time-consuming digitization process versus the benefits of using this data.

The SUSTAIN model can only be run by the ArcMap 9.3 Service package 2 on a Windows XP operating system, which has limited flexibility and use. It is also a challenge getting access to those specific requirements.

The SWAT model is a water assessment tool with complex hydrological functions. The model does a great job assessing ground water flow volumes, but an evaluation of green infrastructure is not provided in the software. Output files from the SWAT model need further analysis in order to explore the full connection behind the dataset. The data export interface needed to get the output data from the model is also time consuming.

Appendix 3: Designed Site Impact Evaluation Processing Area

The LEAP study area was the processing area used for the hydrologic model and calculations associated with this project – not the Jefferson-Chalmers neighborhood and the associated upstream sewershed contributing to intercepted runoff being conveyed under the study area. This is because the original dataset we were working with on this project was primarily composed of coverages clipped to the LEAP study area boundary. We built our model based on these geographic extents and did not have adequate time to build a second model tailored specifically to the Jefferson-Chalmers neighborhood and its hydraulically connected sewershed. Large portions of the hydrologic model using the LEAP study area were also not hydrologically connected to the sewershed contributing stormwater to the sewer infrastructure conveying flows under the Jefferson-Chalmers neighborhood (Figures 5, 31, & 32). It is thus a reasonable assumption that we would compute a higher percentage of runoff reduction if our model was tailored specifically to the Jefferson-Chalmers neighborhood and associated upstream sewershed.

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