

# Measuring the Benefit of Green Infrastructure through the Development of Alternative Policy Scenarios

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Master's Thesis written by Bradford Kasberg

Primary Advisor Joan Nassauer

Secondary Bob Grese

## **ABSTRACT**

Detroit, Michigan, like other post-industrial cities, has the potential to convert vacant land into green infrastructure to support a shrinking population with strained infrastructure by reducing the overall amount of storm water entering sewer infrastructure. Alternative green infrastructure policies were developed that attempt to support what Joan Nassauer defines as “cues to care” to achieve normative goals that seek to perform, in addition to storm water management benefits, social and ecological benefits. Each of these normative policies resulted in a unique spatial pattern of green infrastructure development within the Cody Rouge neighborhood of Detroit. This study analyzes changes in storm water runoff capture capability of the resulting green infrastructure networks created by these alternative green infrastructure policies for the Cody Rouge neighborhood. Modest variations were found when comparing storm water runoff capture of the different policies. This study suggests that normative goals that seek to support ecological and social issues are able to be implemented within green infrastructure planning and design and that this integrated design may be necessary for shrinking cities to more holistically support its residents that live within highly vacant areas.

## INTRODUCTION

Some post-industrial cities throughout the Great Lakes states share a common legacy in their urban form. Following de-industrialization and the large-scale migration toward the suburbs, these post-industrial cities have rapidly lost population and economic activity. Detroit is no exception to this trend, as it has lost 61% of its residents since 1950 (Morrison & Dewar, 2012). This coincides with a decrease of manufacturing and retail jobs over a similar time period (Merx, 2008). This drastic reduction in population and employment propelled high vacancies of residential and commercial properties throughout the the City of Detroit in ways similar to other post-industrial cities. In the Orangelawn Avenue section of the Cody Rouge neighborhood of Detroit (Figure 1), the study area for this project, nearly 700 parcels are vacant, or exhibit a high likelihood of being vacant based on the Data Driven Detroit parcel inventory as of October 2015 (City of Detroit, Data Driven Detroit, 2015).

With high rates of vacancy in neighborhoods following a loss of population and jobs, post-industrial cities of the Great Lakes region face a problem that is often not addressed by current planning ideology and practice. These areas of disinvestment and depopulation have little in common with planning in which practitioners focus, “almost exclusively on controlling and shaping the effects of growth,” coined as a “bias towards growth” (Johnson, Hollander, & Hallulli, 2014; Morrison & Dewar, 2012). Depopulation and job loss also negatively impact those who stay, as the loss of ratepayers who migrated away from the city reduces capacity to support services across the city.

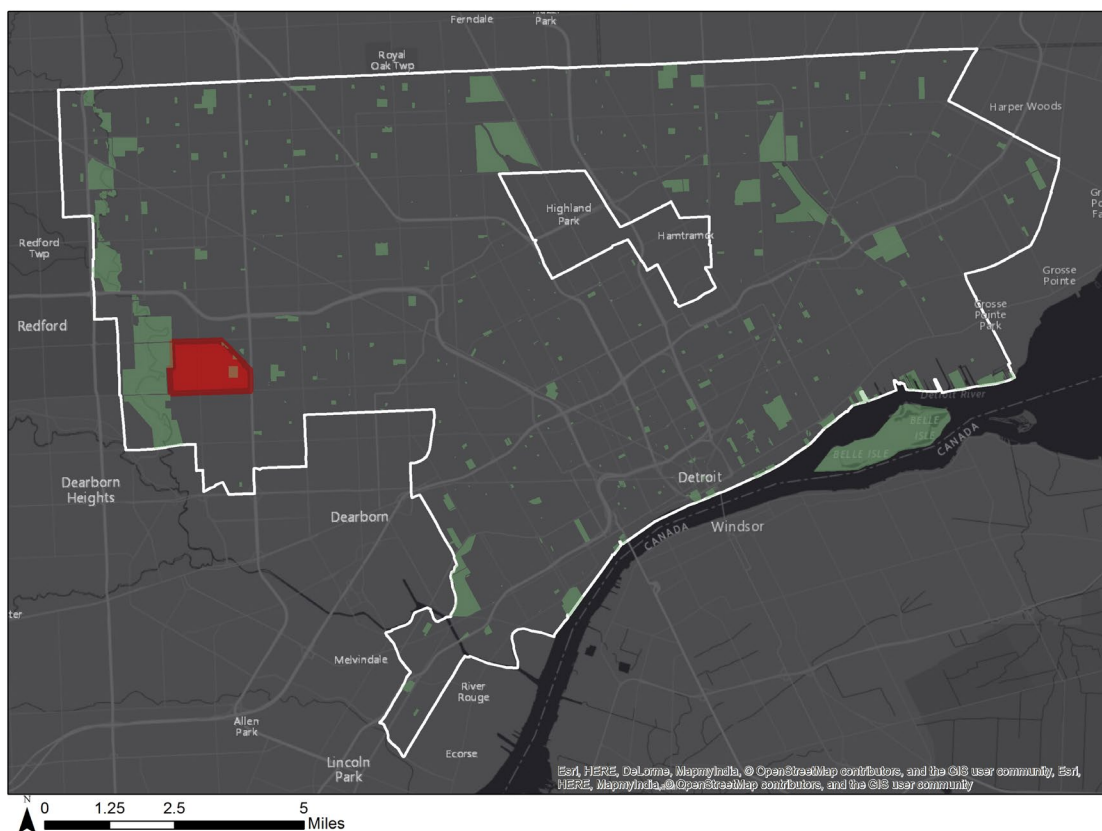
Post-industrial cities face several issues related to storm water management and their built form. In general, urban areas contain a large proportion of impervious surfaces. These surfaces limit the ability for urban areas to manage storm water through storage, infiltration, and recharge of the groundwater systems, all while increasing runoff (Li & Davis, 2009). This increase in runoff is sent through the storm water systems, which overflow when storm events exceed their carrying capacity. In older cities like Detroit, these systems are often sewers that combine storm water drains with sewer systems. In storm events that exceed carrying capacity the combined sewers overflow, releasing raw sewage into receiving waters. These instances are called combined sewage overflows (CSOs) and are a recognized systematic issue in storm water management and water quality, impacting human health and the health of the environment (Hill, 2009).

Detroit and other post-industrial cities have older storm water systems and often lack the resources to manage and repair these systems. Because of this, damaged and leaking systems can contribute as much as 25 percent of the storm water outfalls in dry weather, contributing significant pollution loads even when heavy rainfall events occur (National Research Council, 2009). Runoff in highly urbanized areas similar to Detroit typically contain high levels of pollutants such as oil, heavy

metals, salts, pathogens, and excess nutrients (Hill, 2009).

Further, runoff in Detroit drains into combined sanitary and storm water infrastructure, causing stress in high rainfall events on the system and eventually causing CSO events. This creates further contamination risk. While CSOs pose serious risks to the health of water systems, dry weather flow, which still captures the pollutants inherent to runoff regardless of CSOs, can negatively impact streams (National Research Council, 2009).

Fig. 1. Orangelawn Study Area Context Within the City of Detroit, Michigan



This project aims to explore how varying landscape patterns of green infrastructure can impact the efficiency of storm water management. In particular, varying landscape patterns are developed for bioretention systems, constructed on vacant land, capture surface runoff rather than mitigate or remove storm water already within the city's sewer infrastructure. These landscape patterns will consequently be analyzed for their ability to uptake storm water runoff from the storm

water network as a way to compare each pattern's efficiency in storm water runoff capture. In this study, the unit of measurement is the catchment.

To create varying landscape patterns, this study utilizes alternative future scenarios in order to spatially represent hypothetical green infrastructure implementation. These scenarios posit normative positions relating to social, cultural, and ecological goals inherent to the study area. Alternative future scenarios are hypothetical but plausible normative goals and/or politics that could be enacted; they are meant to examine spatial relationships and provide visual, data-driven hypothetical representations of alternative conditions (Nassauer & Corry, 2004). Each scenario emphasizes a different set of priorities for development, as a means to understand spatially, through GIS analysis, landscape patterns that emerge. These scenarios attempt to address issues, in varying degrees, the use of green infrastructure to maximize benefits for the community regarding the study area's vacant land, community networks, and environmental services.

Currently, Nassauer et al. (2015) are examining how residents of Cody Rouge perceive the conversion of the study area's highly vacant areas into green infrastructure. The research aims to understand how targeted investment of green infrastructure in vacant, blighted properties in a neighborhood can increase perceived safety and comfort for residents of the neighborhood. The first stage in this research included four test sites in which perception surveys and water quality sampling were conducted. In turn, this project aims to explore how this particular green infrastructure design can be implemented spatially on a larger scale through varying socially-driven normative scenarios, utilizing the concept of green infrastructure as positive providers of cues to care.

### *Why Green Infrastructure Bioretention?*

Addressing neighborhoods, cities, and regions in a state of decline requires a new framework for planning that recognizes that extensive repopulation and is an impractical assumption in post-industrial cities (Morrison & Dewar, 2012). Instead, efforts should be initiated to support current residents and mitigate the negative impacts associated with extensive vacancies in neighborhoods. Instead of "Smart Growth," a key framework for planners in the 21st century, post-industrial cities like Youngstown and Pittsburgh are looking at "right-sizing" as the framework in which they can better address the issues of decline. Schilling & Logan (2008) define "right-sizing" as the adjustment of land available for development through the replacement of vacant and abandoned properties with green infrastructure.

Green infrastructure should be considered in a context dependent on the built environment and social contexts in urban areas. Nassauer et al. (2008) discuss that, "design and planning of green infrastructure fails to recognize highly vacant neighborhoods as social systems, both long-term

storm water benefits and potential social benefits are at risk. Even highly vacant urban landscapes should be conceptualized as socio-ecological systems in research and practice.” Further, green infrastructure and right-sizing cities “will require politicians and planners to equitably balance residents’ immediate interests with long-term visions of community viability” while planning efforts that, “ameliorate blight should address resident’s needs and concerns, such as safety, job training, shelter and neighborhood cohesion” (Schilling & Logan, 2008).

Conventional methods of storm water management are called “grey infrastructure”, in reference to the emphasis on the construction of pipes and channels to transfer water. In contrast, “green infrastructure” is a new method of infrastructure emphasizing the infiltration and storage of water to imitate natural processes. This concept is broad- it can apply to large distributed systems of underground storm water cisterns, porous pavement, household rain gardens or rain barrels. These green infrastructure systems are typically composed of porous soils, vegetation, and/or porous hard surfaces in order to maximize the amount of capture and retention of water on site as possible, rather than delivering the water downstream as fast as possible as in grey infrastructure (United States Environmental Protection Agency, 2013).

Bioretention is the method of green infrastructure utilized throughout this study. Bioretention is the capture of storm water to be infiltrated and used on-site, in order to reduce the amount of generated runoff. This removes storm water from the centralized system ideally before it can enter the system. In the case of the TetraTech designed systems, systems capture more than the conventional ‘first flush’, generally the first ½” of runoff, which contains high amounts of sediments and pollutants (National Research Council, 2009). Capturing these runoff events in excess of the first flush can reduce the intensity of downstream runoff that can damage streams through high speed flows causing streambank erosion.

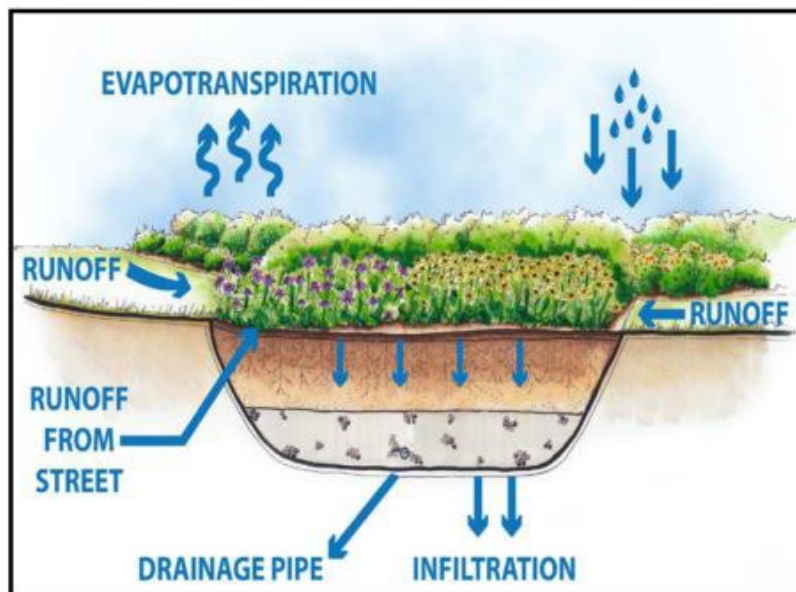
Through infiltration in the soil, uptake by plants, and slow-deterioration of pollutants, bioretention can physically remove some pollutants, though not all (Li & Davis, 2009). Some studies have found that bioretention systems are capable of capturing pollutants such as lead, copper, and zinc from runoff systems at very high rates (Davis et al, 2003). Not all pollutants are removed in this manner, and bioretention systems are susceptible to high accumulation of pollutants that are retained into the system or infiltrate deep into the soil column (National Research Council, 2009). However, concerns over the accumulation of pollutants in the soil of bioretention systems can be expected to evolve over time, allowing significant time for management practices to mitigate these issues. (Davis et al, 2003). Bioretention systems that also include a sediment collection device can further remove sediments from the system.

Vegetated bioretention, ranging from small rain gardens to large streetside swales, also improve the effectiveness of bioretention. Storm water collected on site is evapotranspired by

plants or infiltrates into the soil (Li & Davis, 2009). Plants are frequently found to improve pollutant reduction to an increased amount of uptake of pollutants like ammonia and nitrogen and they promote processes of denitrification and adsorption of pollutants to soil sediments (Hatt, Fletcher, & Deletic, 2008).

There are two similar bioretention designs utilized in this study. Across the study area, this design converts the foundation of a vacant, abandoned home into a bioretention system that reconfigures the storm sewers along the street to flow into the converted foundation. Essentially, after demolishing the vacant house, the foundation is converted into a large, rectangular basin with soil amendments and vegetation, as shown in Figure 2. The goal is to simultaneously address high rates of vacancy in the Cody Rouge neighborhood by converting vacant space into community space, while using a cost-effective method of installing large retention basins. This green infrastructure design focuses on, “keeping storm water separate from sanitary sewers and reducing the amount of storm water flowing to the combined system,” while recognizing that neighborhoods need to benefit from these designs (Nassauer et al., 2015).

Fig. 2. Bioretention Green Infrastructure System, From Nassauer et al. 2015



The second design used in this study occurs on the easement of several parcels along Orangelawn Avenue that have large setbacks from the street. The parcels along Orangelawn Avenue that will incorporate this second design are identified in Figure 3. Functionally very similar to the first design, the bioretention systems will be placed in the large setback along these parcels, rather than being converted from foundations of vacant housing.

Figure 3, Orangelawn Avenue Parcel Easements



### *Ecosystem and Social Services of GI*

Along with its ability to mitigate storm water flows and pollutant control, certain designs for green infrastructure can provide additional benefits. In some cases, vegetation and porous soil could provide habitat space (United States Environmental Protection Agency, 2013). Green infrastructure may also sometimes provide social benefits to neighborhoods as residents interact with green space. These may include “cultural services” such as aesthetic values, recreation, or sense of place to the neighborhoods green infrastructure occur (Daniel et al., 2012). In the context of highly vacant post-industrial cities, multifunctional green infrastructure systems, with particular focus on the provision of cultural services, are identified as a priority in the “right-sizing” process in post-Industrial cities like Detroit.

Identifying these environmental services is crucial to understanding the multifunctional nature of green infrastructure design. Ecosystem services, according to the EPA, are considered the, “life-sustaining benefits we see from nature” which include pollination, clean air, clean water, and flood control, among others (National Research Council, 2009).

The Millennium Assessment Report’s asserts that a, “dynamic interaction exists between



people and ecosystems, with the changing human condition serving to both directly and indirectly drive change in ecosystems and with changes in ecosystems causing changes in human well-being” (Millennium Ecosystem Assessment, 2005). In addition to the ecological performance and range of environmental services provided within a neighborhood, the perception of the relative quality, safety, and comfort of an area influences well-being.

In human-dominated landscapes, the perception of the quality and productivity of a landscape can impact well-being. A key aspect of aesthetic cultural services for green infrastructure (GI) is “cues to care”, or aesthetic design choices that convey a sense of order, management, and beauty over the landscape (Nassauer & Raskin, 2014). Cues to care can be small or large land management approaches that signify a place is being cared for. While these cues vary across communities, general signifiers of care in residential landscapes include mowed lawns, large trees, and flowers. There is much to gain in the sense of safety and comfort to the Cody Rouge neighborhood through the conversion of vacant, uncared for land into green infrastructure with clear signs that the landscape is being cared for, while addressing issues of excessive runoff and risk of pollution.

So-called “cues to care” (Nassauer, 1995) are management methods, design, and aesthetic choices that indicate within a community that a place is tended to and cared for. When these “cues to care” are present, individuals feel comfortable and safe. Cues to care frequently have similarities across varying communities, including mown lawn/turf, colorful flowers, neatness, fences, and clean edges (Nassauer, 1995).

### *Vacant Land*

Effects of vacant land are an important consideration in this study area and in the Great Lakes in general because of the sheer magnitude of vacancy in many post-industrial Great lakes communities. Studies suggest that proximity to vacant land, related to depopulation, has negative impacts on perceived quality of life (Johnson et al., 2014). Vacancies have further negative effects, as the presence of vacant and abandoned structures may reduce the value of neighboring land and creates a negative perception of a neighborhood’s safety and quality.

Vacant and blighted communities are perceived to be the locus of crime by both inhabitants and potential investors, and they also may overshadow positive aspects of neighborhoods with the potential for physical and mental health to be negatively impacted (Garvin, Branas, Keddem, Sellman, & Cannuscio, 2013). Further, vacancies tend to destabilize real estate markets because they reduce potential investments in neighborhoods, creating a cycle of disinvestment leading into further vacancies, and so on (Schilling & Logan, 2008). Therefore, the presence and intensity of

vacancy can be a signifier in a reduction in the—real or perceived—quality of life of a neighborhood.

The perception of safety within highly vacant urban neighborhoods is a critical factor influencing the potential for investment, further abandonment, and stress on current residents (Johnson et al., 2014). Vacant properties can overshadow, “positive aspects of neighborhood life and [undermine] the image or overall success of a community” (Garvin et al., 2013). In the Garvin et al. survey, vacant land was cited as a crime risk, as “participants felt vacant land attracted illegal activity”, with vacant structures encouraging illicit behaviors. Participants also felt that there was risk involved with walking past vacant lots due to the uncomfortable stigma around them. This perception also negatively impacted mental health, with many residents feeling depressed by the visual decay of their neighborhood. Aside from residents, potential investors also perceive vacant land as a higher risk due to negative perceptions of the quality of the neighborhood (Mallach and Brachmann, 2013).

It is important to note that highly vacant neighborhoods in post-industrial cities cannot “return to nature” and become highly productive ecosystems similar to pre-settlement conditions. Instead, they have altered biogeochemical processes, such as contaminant dispersal, new hydrologic functions, and new ecosystem patch dynamics. Further, social and/or human capital flows are altered due to changes in population impacting social services and civic infrastructure (Nassauer & Raskin, 2014; Schilling & Logan, 2008). Because of these changing social and ecological structures, the negative impact vacancy has on the mental and physical wellbeing of residents, and the reductions in investment potential of a neighborhood, Hoornbeek & Schwarz (2009) argue for careful assessment of optimizing vacant land and infrastructure, rather than creating new infrastructures.

#### *Problem Statement: Alternative Multifunctional Landscape Patterns for Green Infrastructure*

Varying patterns of green infrastructure on vacant residential properties could have different functional effects with different accompanying social and environmental benefits. The main objective of this study is to analyze how alternative GI landscape patterns, each aimed at different social benefits, would impact the amount of runoff captured in a green infrastructure network. Several green infrastructure network patterns are created for the Cody Rouge neighborhood in order to examine differences in spatial arrangement, with each scenario driven by different goals related to the potential for multidimensional functions of green infrastructure. These can help prioritize in each scenario where green infrastructure is likely to occur through a selection of vacant land based on spatial rules associated with the goals. A prioritization strategy is developed through spatial models inherent to each specific scenario.

This scenario-based spatial arrangement of green infrastructure networks was compared through a sensitivity analysis of runoff generated by each catchment across the study area. This analysis identified, across varying degrees of storm intensity, the runoff patterns per catchment in the study area. When overlaid with the resulting landscape patterns derived from the six scenarios, the green infrastructure networks can calculate how much runoff is available to be captured in the network.

A fundamental challenge for green infrastructure constructed in highly vacant neighborhoods is determining the optimum spatial arrangement across the watershed to simultaneously provide multiple human and biogeochemical services. A myriad of factors are at play in determining the landscape pattern of green infrastructure, including policy. To conceptualize how different desired functions, as expressed by policy, would impact the spatial distribution of green infrastructure in Cody Rouge, six alternative future policy scenarios were developed.

The six resulting green infrastructure spatial arrangements are analyzed through a sensitivity analysis of storm water runoff, generated from hydrologic modelling using ArcHydro tools in ArcGIS v10.3.1 to generate catchments in the highly urbanized neighborhood. Through this modelling, the Orangelawn area of Cody Rouge's storm water runoff potential can be analyzed on a per-catchment basis across the study area, allowing for each catchment's runoff potential to be investigated in varying storm intensities and scenarios.

## **METHODS**

### *Study Area*

The study area shown in Figures 4 and 5, a subset of the Cody Rouge neighborhood, is located along the Rouge River in Detroit. It is currently a residential neighborhood with high rates of vacant and abandoned properties. With high rates of vacancy, the perception of safety and community well-being are suffering from the unappealing appearance of these vacant properties. Perception of safety has real implications for residents and potential investors of a neighborhood. Additionally, the Cody Rouge neighborhood suffers occasionally from flooding and likely contributes negatively to water quality of the Rouge River.

The study area falls within a subset of the Cody Rouge neighborhood. Within this study area, storm water flows south and westward towards the Rouge River. The study area's subset of Cody Rouge is about 1.35 square miles, contains several parks, schools, and community centers, and is bounded by large commercial roads, a river, and a highway.

Because there are many vacant properties throughout the Cody Rouge neighborhood, nearly 700 vacant parcels as of October 2015 in the study area, this project investigates multiple modes of converting vacant land into green infrastructure systems that can capture and mitigate storm water. This method of green infrastructure development has the potential to address issues of perception and of water quality, as these designs are meant to be aesthetically pleasing interventions that can contribute to the neighborhood character.



## Scenario Development

The development of scenarios creates the normative or policy narrative to achieve specific goals. These normative or policy narratives in turn can define an hypothetical decision-making process for identifying which vacant parcels within the Orangelawn study area will be converted into green infrastructure. Each individual scenario has a different policy narrative; each policy narrative contains particular spatial criteria, and these spatial criteria are analyzed in relation to the parcels through GIS. Through this spatial analysis, parcels can be selected based on how well they match the narrative. The six scenarios vary in the way they prioritize vacant parcels for GI development. These prioritizations, including proximity to the Rouge River, proximity to schools and parks, density of vacant land within blocks, etc., are analyzed spatially using ArcGIS. The prioritizations and GIS analysis are represented in Table 1.

The first step in selecting parcels in any scenario was identifying parcel eligibility for green infrastructure implementation. Parcels were eligible if they were considered vacant or likely vacant, as determined through an aggregate of surveys conducted through Motor City Mapping. Further, the NEW-GI design requires two adjacent vacant parcels. This leaves a total of 368 parcels eligible in each scenario to be developed. The locations of vacant parcels are shown in Figure 6 and the eligible vacant parcels are shown in Figure 7.

In each scenario, 20 parcels were randomly selected in the scenarios for conversion to green infrastructure, as well as converting the same parcels along Orangelawn Avenue. While this is only slightly more than 5% of all eligible vacant parcels, only 20 parcels were selected for development because of the scale of development within this study area. More parcels would help generate more diverse results, but I judged that the cost estimate and scale of development for 20 parcels more reasonable for the City of Detroit to fund and construct without incurring excessive costs.

In scenario 5 only the parcels along Orangelawn Avenue are converted into green infrastructure, and in scenario 6 only the 20 green infrastructure parcels were included. Parcels are ranked in each scenario based on how well each parcel fits in each scenario's specific criteria, and then 20 parcels are randomly selected, with higher ranking parcels receiving a higher likelihood of selection.

All the locations of the selected parcels of each scenario are found in Figure 8.

Fig. 6. Orangelawn Vacant Parcels

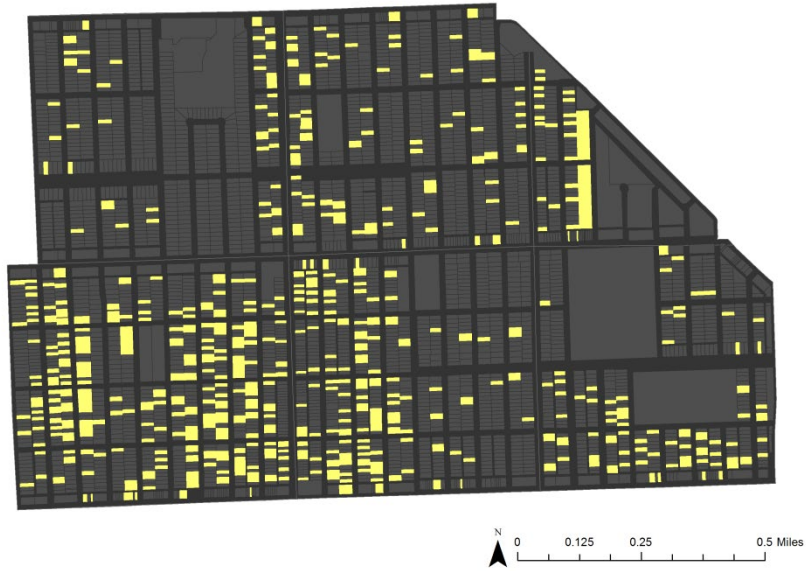


Fig. 7. Orangelawn Eligible Vacant Parcels

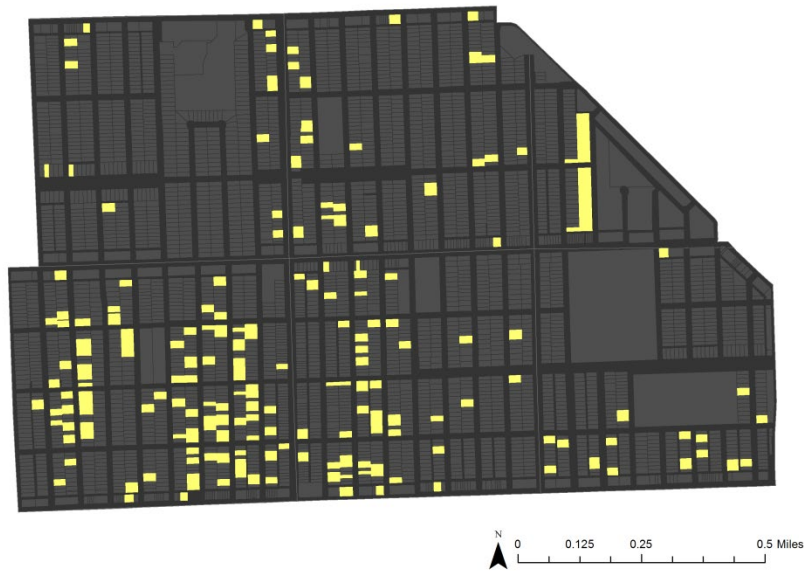


Table 1, Scenario Development

Scenario	Name	Purpose	Prioritized Parcels:
1	Rouge River Priority	Prioritizes proximity to Rouge River Parcels and parcels Captures runoff before reaching the Rouge River as a hypothetical "last chance" lower in the watershed	Parcels within 1,000', 2,000', and 3,000 ft of existing parks. Parcels that fall within higher stream orders. Include Orangelawn Avenue parcels.
2	Community Network	Focuses on community assets to enforce 'cues to care' in key areas	Parcels within 1,320' of commercial roads. Parcels within 1,320' of existing parks. Parcels within 1,320', 1,760', and 2,640' of schools. Parcels within blocks that have less than 30% vacancies. Include Orangelawn Avenue parcels.
3	Equal Distribution	Distributes GI across the study area to provide access to GI to as many households as possible	4-5 random parcels within the 6 block groups of the study area, with a minimum of 200' distance from each other. Include Orangelawn Avenue Parcels.
4	Random Distribution	Investigates whether any landscape pattern alters potential for stormwater capture	Random. Include Orangelawn Avenue Parcels.
5	Orangelawn Avenue Only	Investigates potential for the large easements along Orangelawn Avenue are for stormwater capture	Include Orangelawn Avenue Parcels.
6	Highest Runoff Only	Investigates whether runoff reduction as a priority can effectively reduce runoff	Select the 20 vacant parcels that occur within a unique catchment, in order of the highest runoff producing catchments



### *Scenario 1: Rouge River Priority*

The Rouge River Priority scenario focuses green infrastructure along the Rouge River and along lower parts of the watersheds of the Orangelawn study area. This scenario addresses the possibility of storm water capture near the edge of the Rouge River Park, in order to create an additional buffer of storm water interception between the neighborhood and the river. This buffer may provide social and ecological benefits, as this expands the open space network to the east, providing habitat space for wildlife and increasing connectivity to the parks, providing the environmental and social services identified by the Millennium Ecosystem Assessment.

Two methods of ranking proximity were used in this scenario, with a higher score representing a higher priority of development. First, proximity to existing green space—the Rouge River Park—was considered valuable in this scenario because it resulted in storm water capture immediately before runoff would reach the river. A multiring buffer was generated from the Rouge River parcels, with distances of 1,000, 2,000, and 3,000 feet. Vacant parcels within 1,000 feet of the Rouge River received a score of 3, between 1,000 and 2,000 feet a score of 2, and between 2,000 and 3,000 feet a score of 1.

The second criteria is a preference for vacant parcels that fall within higher-order ‘streams’ as identified through the hydrologic flow model generated by the high-resolution DEM and roads layer. Higher-order ‘streams’, while not necessarily occurring strictly in areas close to the Rouge River, represent places of higher accumulated flow which is of interest in storm water management. A stream order raster was calculated from the flow accumulation raster made in ArcHydro. Then a zonal statistic was calculated on this stream order raster to identify the highest stream order that occurs within each catchment of the study area. A second zonal statistic was then ran to identify the highest stream order that occurs within each parcel based on the catchments they occur in.

The parcels were given a final score by adding the multiring buffer score and the stream order score, with the multiring buffer score doubled to provide more priority to areas in close proximity to the Rouge River. This resulted in a score ranging from 2 – 12, which was reclassified into a 1 – 6 rank where 6 is the score which meets the most criteria for scenario 1. These scores then gave priority to the random selection of parcels.

### *Scenario 2: Community Connection*

The normative goal assumptions of scenario 2 emphasize community connectivity for

pedestrians- the scenario identifies the desire for a walkable neighborhood. The narrative emphasizes a policy that looks to address vacant land that negatively impacts the sense of comfort, safety, and connectivity to existing neighborhood, influenced by Hoornbeek & Schwarz (2009), Nassauer & Raskin (2014), and Schilling & Logan (2008). Positive community assets identified as suitable places to identify include places like parks, schools, churches, and commercial corridors. Through the conversion of targeted vacant parcels, pedestrian networks across residential spaces can be made to feel safer for the community.

Several criteria at play aim to emphasize proximity to community assets. First, roads that function as major arterial streets that are zoned as commercial and/or retail were identified as priorities for community walkability. These streets were given a 1/4 mile buffer, with any vacant parcel within the buffer receiving a score of 3. Parks were given a similar buffer and scoring system. Schools had a multiring buffer surrounding them, with buffers ranging from 0 to 1/4 mile, 1/4 to 1/3 of a mile, and from 1/3 to 1/2 of a mile. Parcels up to 1/4 a mile from the schools were given a score of 3, parcels between 1/4 and 1/3 of a mile were given a rank of 1, and parcels between 1/3 and 1/2 a mile were given a score of 1.

City blocks with relatively low rates of vacancy were prioritized for development in scenario 2. The individual scores for parks, schools, and proximity to major commercial roads within the Orangelawn neighborhood were then added together to create scoring distribution between 1 – 12. This was reclassified into a distribution of 1-6, with 6 being the score which meets the most criteria for scenario 2.

### *Scenario 3: Equal Distribution*

Equal distribution aims to provide blocks with a uniform distribution of green infrastructure. This policy proposes that this equal distribution can create small parks within blocks, helping to increase the cues to care within each block and providing a sense of ownership over each parcel. This would serve social needs such as green space, an improved sense of safety and comfort from the designs as well as ecological needs by ensuring that all areas in the neighborhood receive some sort of storm water mitigation. Compared to the first scenario that clusters green infrastructure around the low points of the watershed, an equal distribution can capture the first several inches of flow across a wider area.

### *Scenario 4: Random*

To test whether these policies impact storm water capture in a significant way, this policy envisions a process that distributes green infrastructure randomly across the neighborhood.

### *Scenario 5: Orangelawn Parcels Only*

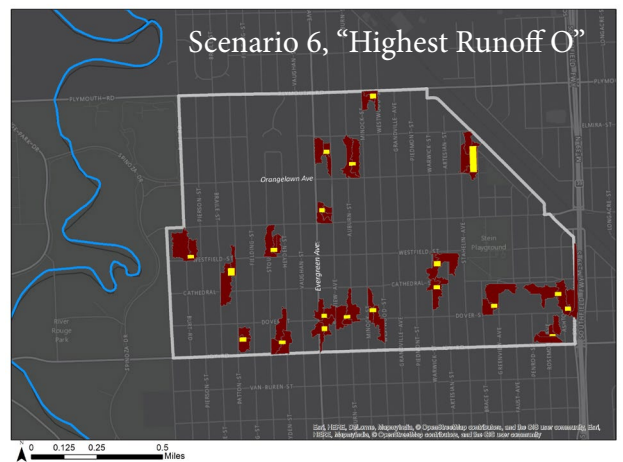
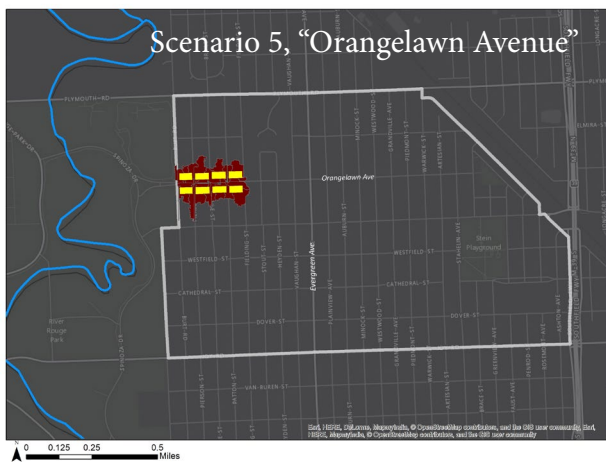
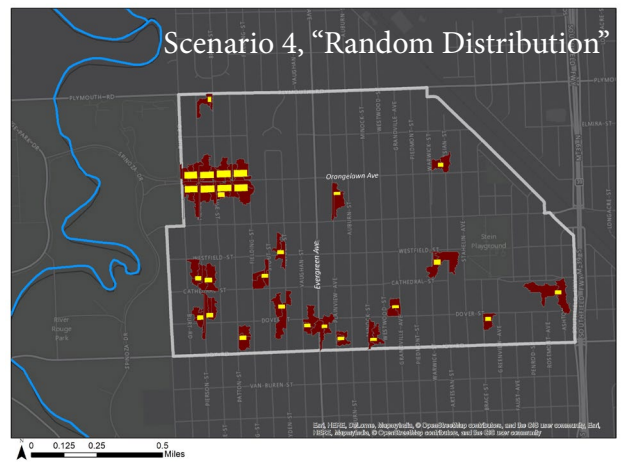
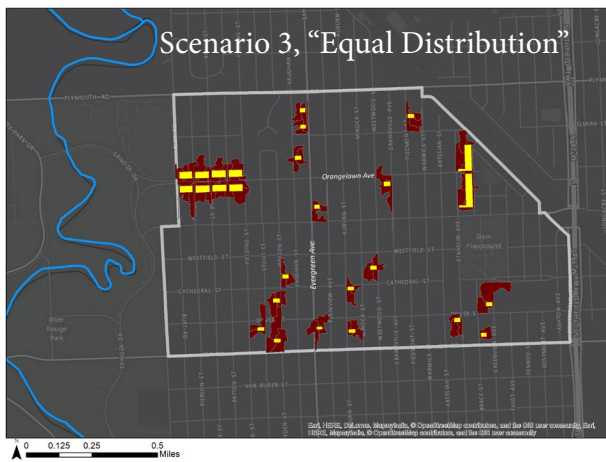
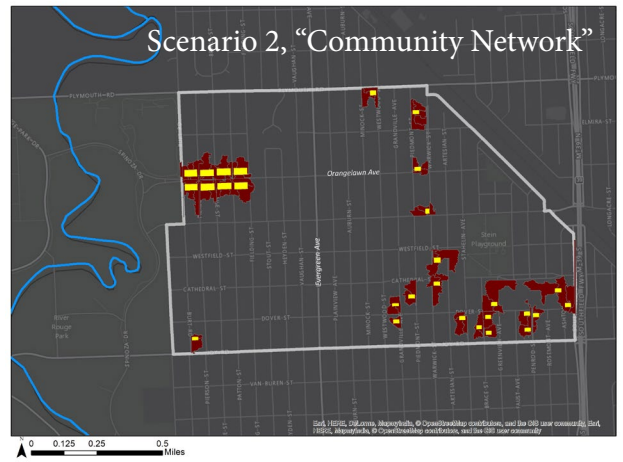
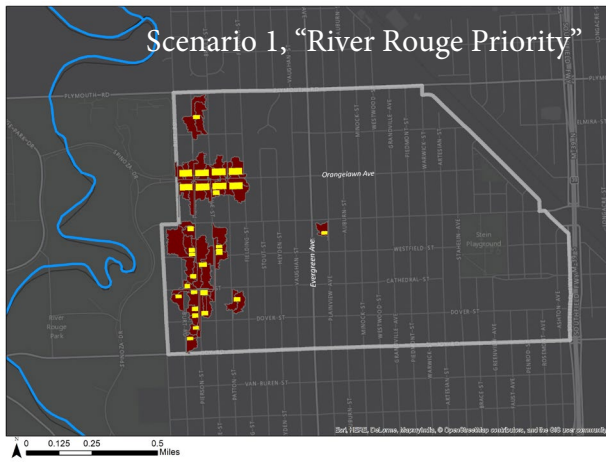
The parcels along Orangelawn have the large front yards that can be converted into green infrastructure. This policy envisions that only these parcels will be converted. By creating this scenario, we investigate how little to no action can impact storm water management.

### *Scenario 6: High-priority Catchments*

In this scenario, policy dictates that catchments with the highest amount of estimated runoff will be addressed with green infrastructure interventions. The purpose of this is to investigate whether or not variation in green infrastructure network patterns are as influential as targetting highest-runoff producing catchments. This was done by selecting the 20 vacant parcels that intersect the catchments with the largest estimated total runoff. It is important to note that this does not capture the top 20 catchments that produce runoff. Instead, this scenario targets the 20 catchments with large runoff totals that also have a vacant parcel within them.

In this scenario, no Orangelawn Avenue setbacks are converted into green infrastructure.

Fig. 8, Parcels Selected in Each Scenario and the Catchments That Occur Within Them



## *Hydrologic Flow Model*

To estimate runoff potential, a hydrologic flow model was developed that created small catchments, generally smaller than city blocks, in order to assess runoff on a catchment basis. Catchments within the study area are the best measurable unit within the study area because they create discrete spatial units which can generate an estimate of runoff based on the catchment's land cover and area. This allows for unique estimates of runoff to be generated across the catchment, allowing for a broader analysis of how specific areas of the study area generate runoff differently than others, based on the conditions of the built environment. The model is an adaptation of the model created by the 2013 master's project by Austin et al. which itself is derived from the general step-by-step process of the ArcHydro extension for ArcMap.

Catchment delineation was modeled based on surface conditions rather than underground drainage systems of stormsewers and larger pipelines for two reasons. First, the condition and performance capabilities of sewer lines in Detroit are difficult to assess, as the city lacks a system-wide analysis of its structures. Further, the green infrastructure system is designed to capture storm water before it enters any pipe in the sewer network, thereby avoiding issues related to the unknowns of the drainage system.

Identifying small catchments requires Digital Elevation Models (DEM)s to analyze surface elevations and conditions. Because this is a highly urbanized study area in an already relatively flat area, conventional coarse-grained DEM data cannot deliver the right level of data regarding surface conditions. To rectify this, a DEM using LiDAR data to calculate a 2-foot scale resolution can provide a detailed resolution for urban terrain.

The hydrologic model requires linear data to identify stream flow; linear flow data reconfigures the elevation data from the DEM. In less urbanized areas, this linear data would be existing streams and tributaries, but in the Orangelawn neighborhood roads data functions as the stream network. Surface water in urbanized areas are designed to flow along roadways and as such linear road data can provide the context to reconfigure surficial flow.

Nearly all of the model processing occurs within ArcHydro 10.1, an extension in ArcGIS. The only exception is the stream definition model exaggeration process unique to this study. This process was necessary because the flow accumulation raster created through ArcHydro 10.1 resulted in an inadequately sized series of catchments. To rectify this, the stream definition had an additional raster calculator process applied to it that exaggerated the values of flow accumulation, thereby creating more flow points in the raster, resulting in an increase in total catchments and an overall decrease in catchment size. After this raster calculation was completed, the process returns to the conventional method of delineating streams and watershed catchments outlined by the Austin et al. 2014 research project (Figure 9). Figure 10 shows the resulting catchment delineation from the hydrologic model flow chart.

Fig 9. Hydrologic Model Flow Chart Derived From Austin et al. (2013)

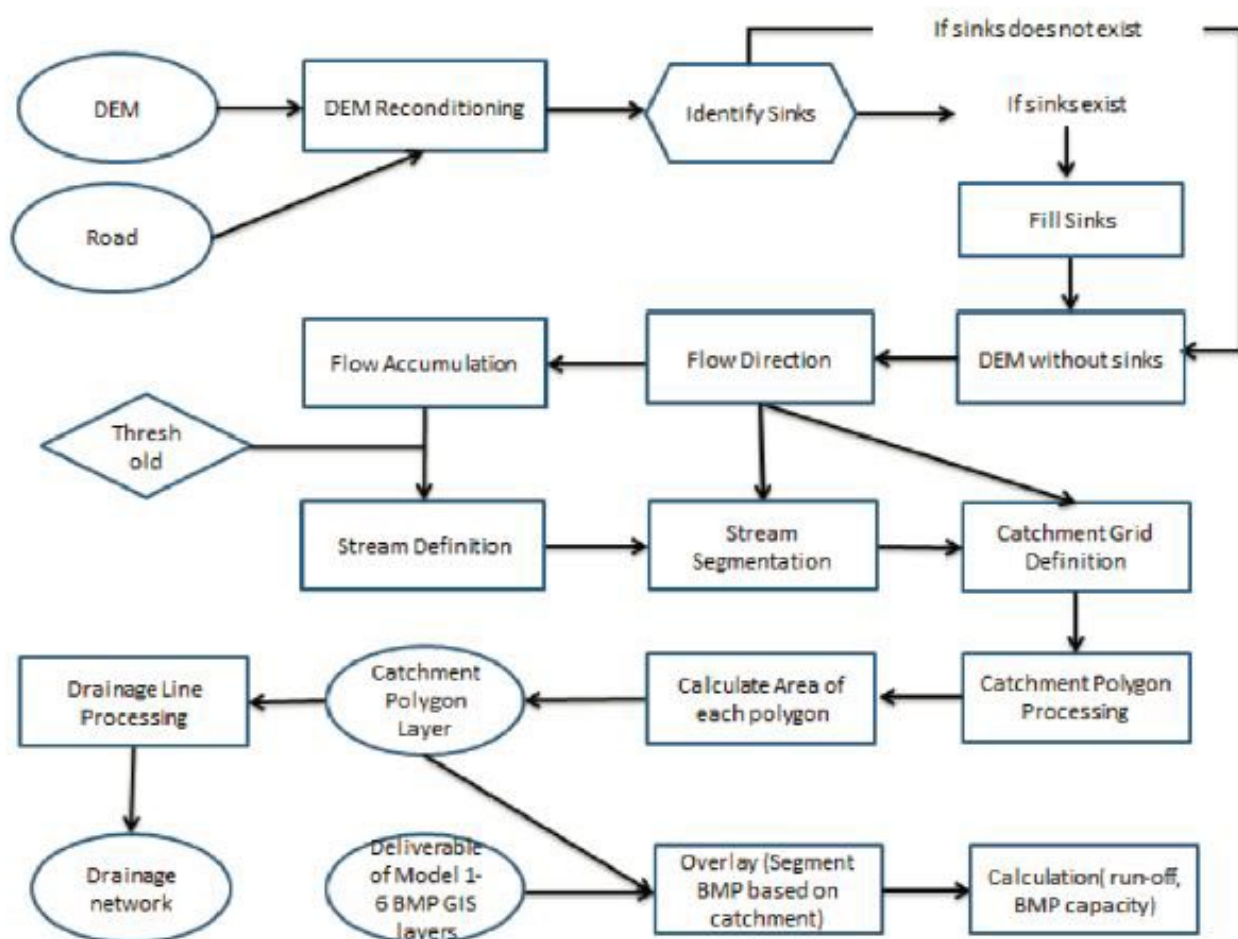
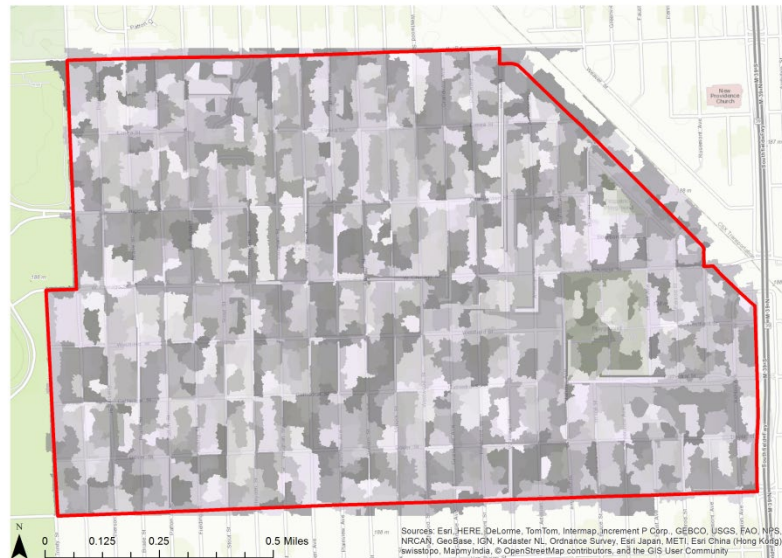


Fig. 10, Delineated Catchments of Study Area



### *Storm Water Runoff Calculation*

After delineating the catchments, the next step in the process requires calculating the runoff potential in each individual catchment. The rational method is used to calculate runoff in this study, define as:

$Q = C * i * A$ , where:  $Q$  = total runoff,  $C$  = runoff coefficient,  $i$  = rain intensity,  $A$  = area of catchment

To run a sensitivity analysis across storm events—in this case 2, 10, and 100 year storm events—rain intensities were derived from Herschfield (1961).

The runoff coefficient estimates the ratio of water that falls on a site compared to the amount of water that leaves the landcover where rain falls. This is calculated uniquely for each catchment. Using the 2005 Detroit Landcover assessment, which is a one meter resolution raster, provides a detailed level of land use suitable for assessing runoff. Land cover values include, “Trees”, “Lawn”, “Bare”, and “Urban”, the distribution of which within the study area is shown in Figure 11. Using

conventional runoff coefficients derived from the MDOT Stormwater Drainage Manual (2006), each land use type was assigned a particular coefficient. To create a total composite runoff coefficient for each catchment, each catchment's unique land covers were proportioned by their area within the catchment using the following equation:

$$C \text{ (composite coefficient)} = \frac{\sum(C \text{ individual area})(A \text{ individual area})}{(A \text{ total area})}$$

As mentioned above, the  $i$  value in the rational method is dependent on storm water intensity measurements. Using Hershfield (1961), intensities are identified for 2, 10, and 100 year storms. Intensities are a function of the storm interval (years), as well as length of storm duration (minute or hours). This study analyzes 2, 10, and 100 year storms in their respective 30 and 60 minute storm durations, resulting in 6 unique runoff calculations for the base scenario. For a 10-year storm with a duration of 30 minutes, the values for  $i$  would be 2.8 iph (inches per hour). This is factored into the rational formula through the method:

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

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

$$\text{Volume (10-year 30min)} = 2.8 \text{ AC} \times 30\text{min} \times 60 \text{ sec/min} = 5040 \text{ AC ft}^3$$

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

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

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

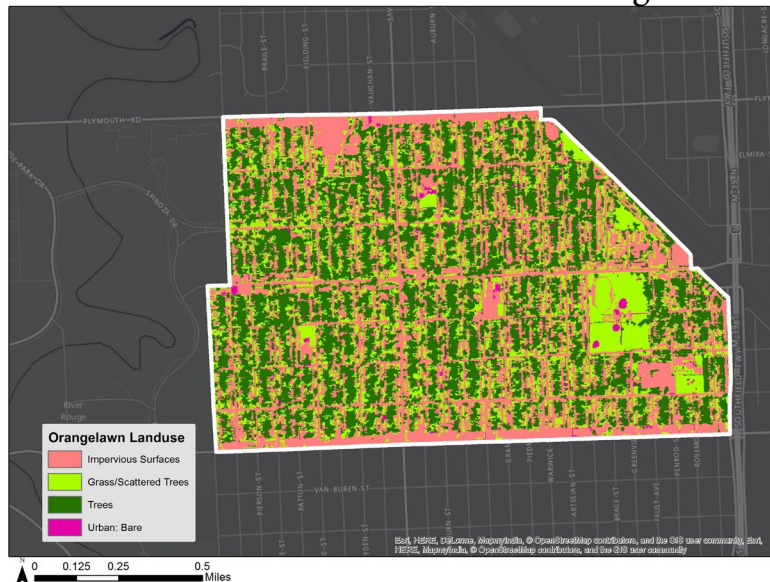
$$\text{Volume (10-year 30min)} = 1.8 \text{ AC} \times 60\text{min} \times 60 \text{ sec/min} = 6408 \text{ AC ft}^3$$

Using each catchment's varying  $C$  values and their respective area, total runoff derived from the rational equation varied according to storm intensity which remained constant across all catchments. This creates a sensitivity analysis across all 6 storm events. The catchments in this study benefit from a more accurate coefficient because some catchments are highly impervious, while others contain more permeable surfaces like tree and lawn cover, all of which are accurately captured in the 2005 Detroit land cover assessment.

The same method of calculation was used for 2 and 100 year storm events with the 30 minute and 60 minute durations. Those values are represented in Appendix A.



Fig. 11, Generalized 2012 Land Cover of the Orangelawn Study Area

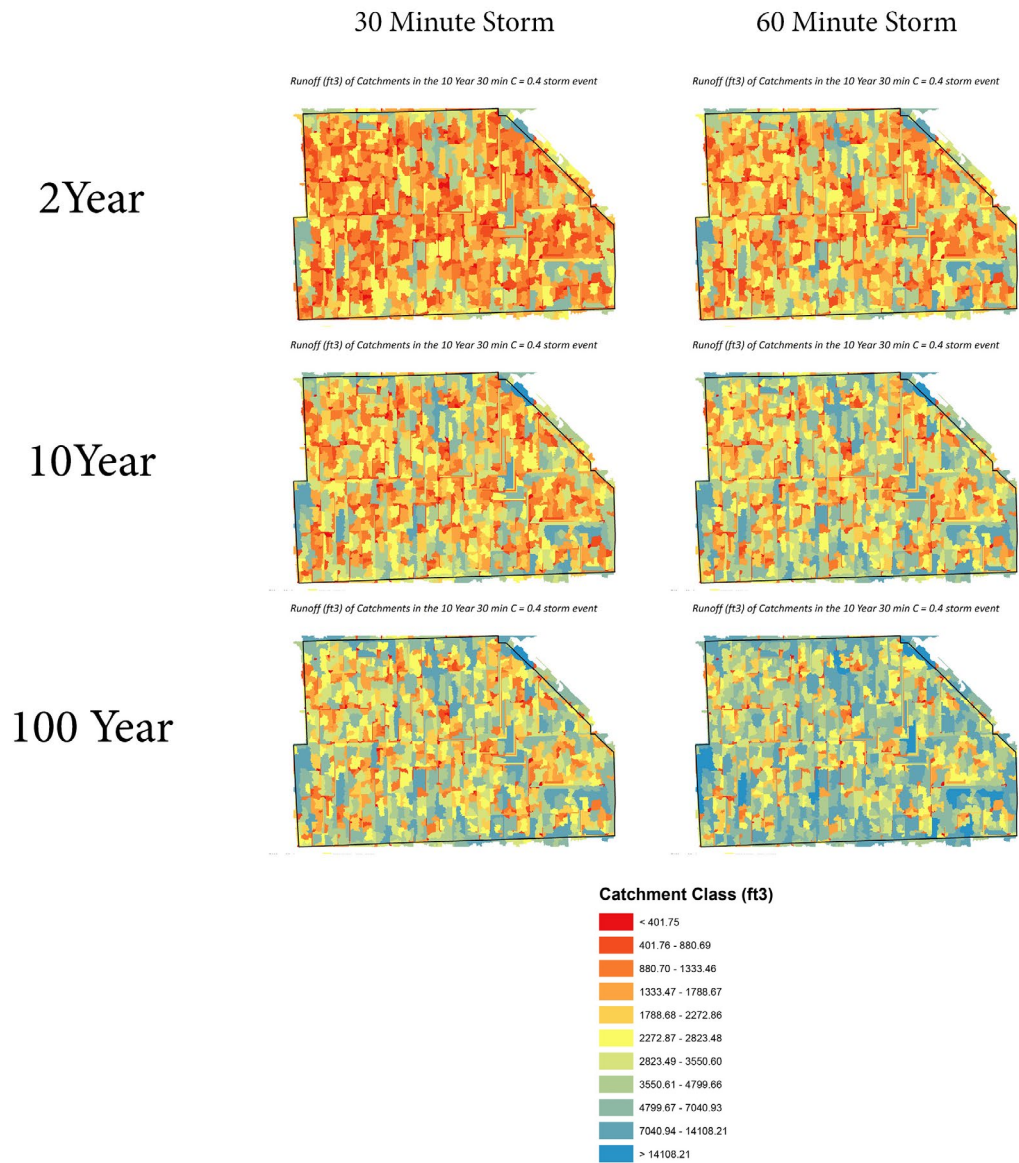


### *Catchment Classifications*

Using the rational equation, untreated storm water runoff was calculated in each catchment. To understand how runoff varied across catchments and storm group (6 groups – 3 storm intervals and 2 storm durations), the catchments were analyzed by their maximum runoff potential. Each storm event utilized the same classification scheme in order to interpret relationships across storm intensities and durations. The 10-year storm interval with a 30 minute duration was selected as the baseline for classifying runoff potential because it can be considered the median storm event in relation to 2 and 100 year storm events. Runoff totals for this event were classified into 10 classes utilizing natural breaks in ArcGIS. These are considered the baseline classifications, and any runoff exceeding the 10th class is placed within an 11th class. For the 10 year 30 minute storm, there would therefore be no catchments falling within the 11th catchment classification.

Results of the runoff classifications for the 6 storm events can be seen in Figure 12. Maps showing the spatial distribution of the catchment classifications clearly delineate the distribution of catchment classifications as they change in varying storm intensities and durations.

Fig. 12, Catchment Classifications of the Orangelawn Study Area in Varying Storm Events



## RESULTS

### *Treating Runoff*

The next phase of analysis investigates each scenario's spatial distribution of storm water management and the amount of storm water collected. The location of each of the six scenarios' green infrastructure are overlaid over the catchments in the 10 year, 30 minute storm in Figure 13. Frequently, green infrastructure is placed on parcels that intersect several catchments. The maximum retention of the green infrastructure is subtracted from the runoff generated by each catchment the infrastructure occurs in.

Further, these green infrastructure systems intake additional runoff from the street, increasing the range of potential runoff. The maps shown in Figure 11 show how each of the six scenarios impact runoff in a 10 year, 30 minute storm event, in relation to the base untreated scenario. All additional storm events can be seen in Appendix A.

Fig. 13, Storm Water Sensitivity Analysis of Each Scenario in a 10 Year, 30 Minute Storm

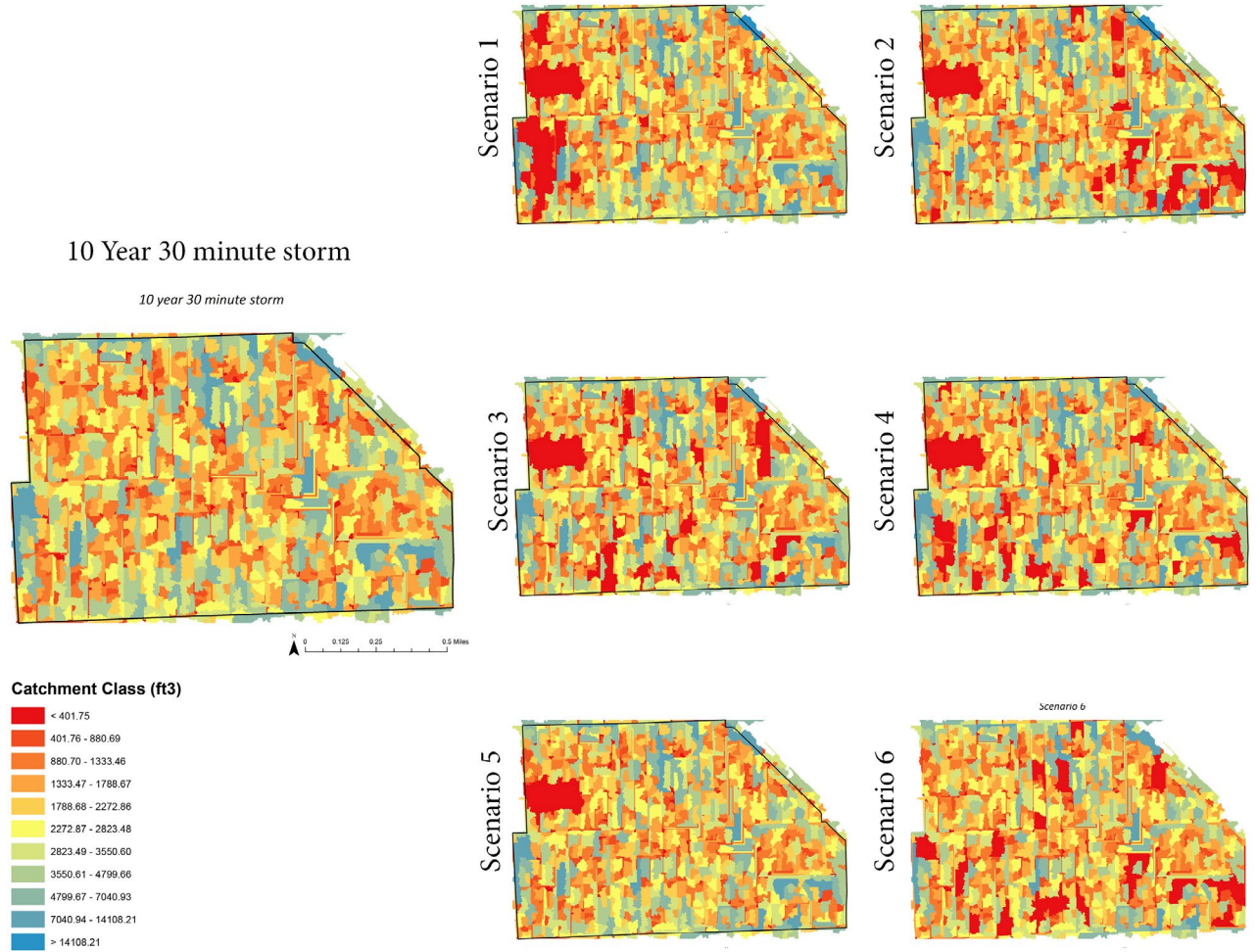


Table 1 shows the changed number of catchments in each classification for each scenario. The term “class” refers to the 11 groupings of runoff generated through GIS natural breaks classification.

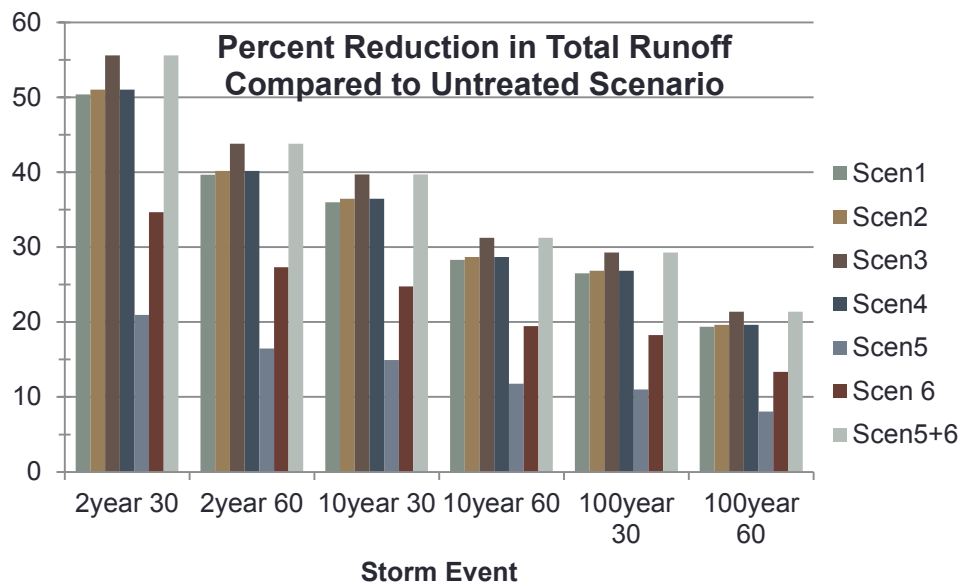
Table 2, Catchment Classification

<b>Number of catchments in each class during a 10 year 30 minute storm</b>								
Class	Runoff (ft3)	Untreated	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1	< 401.75	208	272	281	289	282	236	260
2	880.69	151	138	141	139	140	143	149
3	1333.46	206	192	197	191	191	200	201
4	1788.67	184	172	168	171	173	180	178
5	2272.86	149	142	140	138	143	146	143
6	2823.48	118	110	109	107	107	114	115
7	3550.60	94	88	86	87	86	93	89
8	4799.66	85	78	78	78	77	83	78
9	7040.93	49	49	46	45	46	49	36
10	14108.22	14	13	12	13	13	14	9
11	> 14108.22	0	0	0	0	0	0	0

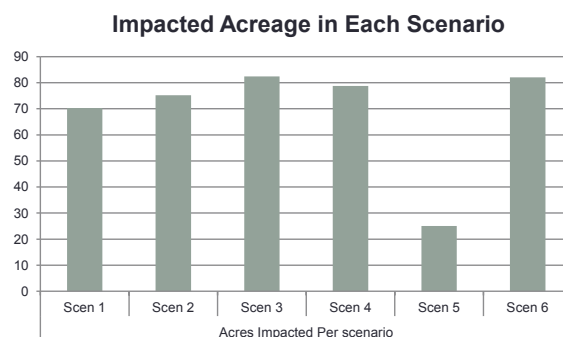
<b>Percent Decrease in Total Runoff Compared to Untreated Scenario</b>						
<b>Storm Events</b>						
Scenario	2yr, 30 min	2yr, 60 min	10yr, 30 min	10yr, 60 min	100yr, 30 min	100 yr, 60 min
1	50.3672198	39.6592283	35.976586	28.296191	26.509063	19.372008
2	51.0213394	40.1742831	36.443814	28.663674	26.853337	19.623592
3	55.6001775	43.7796675	39.714413	31.236055	29.263252	21.384684
4	51.0213394	40.1742833	36.443814	28.663674	26.853337	19.623592
5	20.9318316	16.4817572	14.951308	11.759456	11.016754	8.0507044
6	34.668346	27.2979103	24.763104	19.476599	18.246498	13.333979
5 + 6	55.6001776	43.7796674	39.714413	31.236055	29.263251	21.384684

Both the maps and the tables suggest that many catchments would not be treated for storm water runoff because they do not intersect with the proposed green infrastructure. Overall, minute differences in total acreage of impacted area in each scenario exist aside from scenario 5, which focuses only on the Orangelawn Avenue properties. Between the first 4 scenarios, the range of impacted area ranges between 70.23 and 82.36 acres; scenario 5 impacts only 25.03 acres and scenario 6 impacts 80.03 acres. Table 2 shows that scenario 3, the equal distribution of parcels within blocks, impacts the largest total area by catchment. The equal distribution scenario also contains the greatest percent reduction in total runoff in any scenario, with an average reduction of total runoff across all rain events of 36.8%, or an estimated 1,379,052.253 ft<sup>3</sup> of runoff in the 10 year, 30 minute storm. Following the equal distribution scenario are scenarios 2 and 4, which reduce nearly the same amount of runoff, both reducing by at about 33.8%. Scenario 3 captures an estimated 74,816 ft<sup>3</sup> more runoff than either scenario 2 or 4.

Table 2, Reduction In Runoff Within Catchments For Each Scenario



Difference in Runoff	
	<i>Runoff (ft3)</i>
<b>Scen1</b>	822976
<b>Scen2</b>	833664
<b>Scen3</b>	908480
<b>Scen4</b>	833664
<b>Scen5</b>	342016
<b>Scen 6</b>	566464
<b>Scen5+6</b>	908480



In the 10 year, 30 minute storm intensity, the equal distribution scenario captures an estimated 39.7% of the total untreated storm water runoff; scenarios 2 and 4 capture an estimated 36.4%.

Scenario 3, the “Equal Distribution” scenario, impacts the largest total area within the Orangelawn Avenue study area. Not surprisingly, this correlates to a larger amount of total runoff captured by its green infrastructure network. This is apparent in the ability for this green infrastructure design to capture surface runoff; scenarios with higher surface areas thereby will capture more surface runoff.

The only exception to this rule is scenario 6, the scenario that places 20 green infrastructure sites within the highest runoff-producing catchments in the study area that have vacant parcels in them. This scenario does not include any green infrastructure intervention on Orangelawn, reducing the amount of potential runoff capture by not including green infrastructure utilized in every scenario.

Despite the lack of additional green infrastructure within its network, scenario 6 has 82.04 acres of impacted area. However it captures nearly 25% less total runoff as compared to scenario 3 in a 10 year, 30 minute storm. When scenario 5 – the Orangelawn parcel only scenario—and scenario 6—the top 20 catchment scenario—are added together, they capture nearly the same amount of runoff as scenario 3. The combined scenario, which results in the same number of green infrastructure sites as scenarios 1 through 4, captures over 99.9% of the runoff as scenario 3 in three of the six storm events. The combined scenario also captures between 100 to 101% of the runoff in the other three events.

Scenario 3’s normative goals dictate that green infrastructure should be distributed relatively equally across the study area. Because of this, scenario 3 has a higher likelihood of each green infrastructure installment to occur within unique catchments. In contrast, scenarios 1 and 2 result in clustering of green infrastructure, resulting in multiple green infrastructure parcels overlapping on catchments. This inherently reduces the maximum effectiveness of each individual green infrastructure parcel.

Whether clustering is the stated purpose of the policy as in scenario 1, the Rouge River prioritization, or as a result of spatial implications of the built environment, as in scenario 2’s community connection prioritization, clustering of parcels is not inherently a negative outcome in and of itself. Scenarios 2 and 4 capture 94.6% of the runoff as compared to scenario 3’s equal distribution despite the relative clustering of parcels in scenario 2. Alternatively, the random

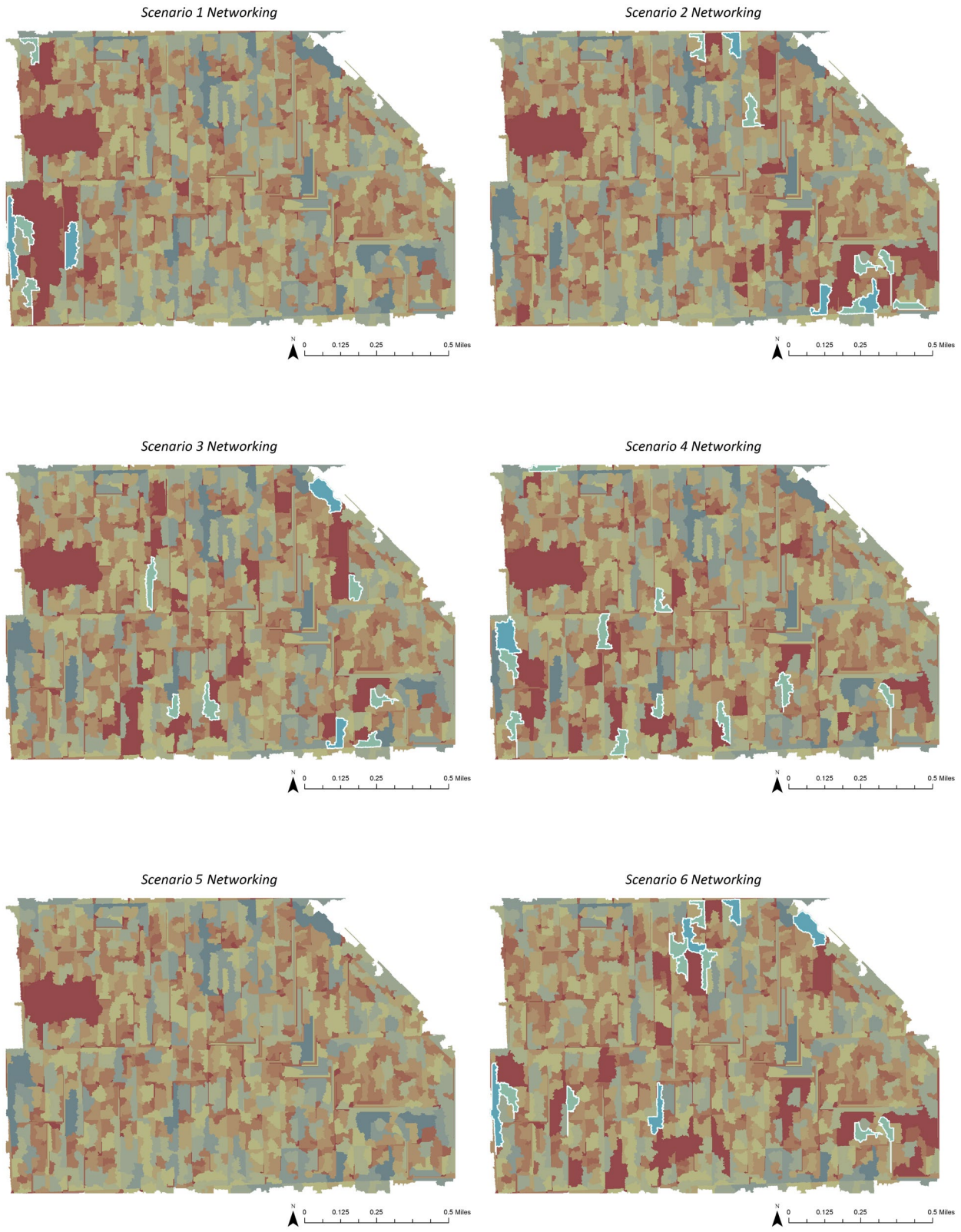
distribution of scenario 4 suggests that placement of green infrastructure is in and of itself not necessarily hindering storm water runoff capture in a significant way, as even scenario 1's substantial clustering of vacant parcels does not drastically reduce runoff capture. This suggests that considerations of social benefits of green infrastructure development can be implemented to achieve relatively similar levels of storm water runoff capture, as modest benefits were identified in this study.

Further, the equal distribution scenario was the most effective scenario, with the combined scenarios of 5 and 6 netting about an equal amount of runoff. Both result in a reduction of an estimated 39% of total runoff. Scenario 3 is a normative scenario hinged on social capital and green space access as a rationale for green infrastructure development; the combined scenario of 5 and 6 strictly addresses concerns of storm water.

In addition, investigating networking potential within each scenario can indicate potential for broader intervention in the landscape. In each scenario, catchments neighboring treated catchments have the potential to be intercepted within the system as well if alternative designs, such as trenches across streets, are implemented. Figure 14 shows, for each scenario, the neighboring catchments that fall within or above the 9th catchment class, with a minimum runoff of 4799.67 ft<sup>3</sup>. Again, scenario 3's equal distribution appears to perform well under this metric. However, scenarios 4 and 6 also contain significant networking opportunities. Scenario 6's performance in this metric is understandable given its prioritization of selecting high runoff producing catchments. Catchments with excessive runoff are likely to occur near other high runoff producing catchments due to the small scale nature of the catchments. This is because elements within the built environment that reduces the amount of runoff that can infiltrate into the soil, such as large roads, parking lots, or large buildings, generally occur at a scale greater than any single catchment.



Fig 4, Catchments With High Runoff that are Adjacent to GI Parcels in Each Scenario



**Catchment Class (ft3)**



## CONCLUSION

This project investigates the storm water management benefits in varying normative landscape scenarios of green infrastructure development in Detroit. It demonstrates how varying normative goals for design in a neighborhood, be they social or ecological, can impact storm water runoff capture. This research is rooted in previous work at the University of Michigan School of Natural Resources and Environment, specifically the 2013 Master's Project Austin et al. as well as research by Joan Nassauer and Margie Dewar, Nassauer et al. 2015. This project also derives the green infrastructure design and study area from Tetrattech's work in conjunction with research by Joan Nassauer.

Normative alternative future policy scenarios were generated based on hypothetical but plausible policies the City of Detroit could implement to enhance their storm water management systems. These policies aimed to address a myriad of social and ecological issues. Most important, these policies aimed to utilize the existing vacant parcels and the perception of safety, health, and wellness of communities.

These policies then generated spatial arrangements of green infrastructure. These spatial arrangements were then analyzed for their effectiveness in collecting storm water in varying degrees of storm intensities. The varying levels of storm water runoff mitigation were then compared to understand how the varying spatial arrangements, and their underlying normative policy scenarios, impacted the total runoff of the Cody Rouge neighborhood in Detroit. To analyze the runoff potential, hydrologic flow modeling was developed utilizing ArcHydro in ArcGIS. High-resolution digital elevation data and road networks drove the flow assessment in the Cody Rouge neighborhood because of the lack of comprehensive storm water system data.

Beyond those scenarios, the modest varying outcomes of runoff reduction suggest that there is room for the integration of non-storm water related drivers for green infrastructure implementation in the Cody Rouge neighborhood and beyond. There are considerable implications for social, ecological, and personal well-being and health regarding the existence and perception of vacant land. First, negative perceptions foster a lack of investment within a neighborhood, leading towards increasing vacancy and disinvestment. More importantly there are severe psychological distress associated with living in an environment one perceives as unsafe or unhealthy. It is clear that these factors need to be placed as prominently as mitigating strict runoff amounts.

This study suggests the potential for a more holistic integration of environmental and ecological services into the built environment, as the residents of the neighborhood stand to

benefit from the multidimensional benefits offered by these green infrastructure parcels. There are a variety of ways in which this can be implemented. Community participation in the planning, management, and design of green spaces can easily support the realization and sustainability of these multidimensional benefits. Further, assessments of green infrastructure potential across the region can factor in elements similar to the scenarios developed in this project to emphasize aspects of neighborhoods otherwise hidden when studying the flow of water and the condition of land cover.

As more data develops through studies of these green infrastructure parcels in Cody Rouge, more precise measurements of water quality improvement and community perceptions of these green infrastructure parcels can lead to a more complete quantification of ecological, hydrological, and social factors in ideal green infrastructure distribution.

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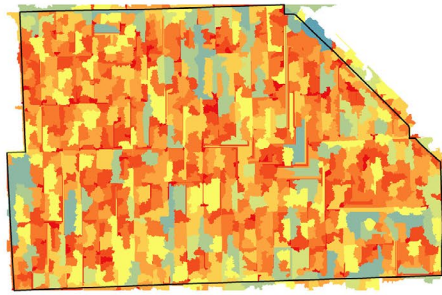
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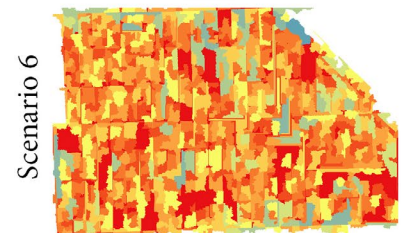
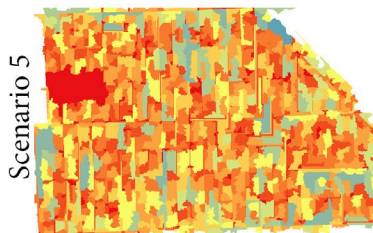
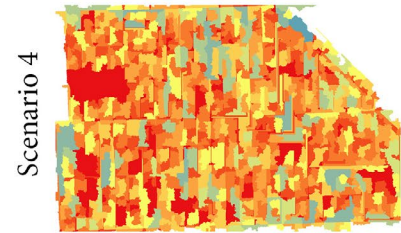
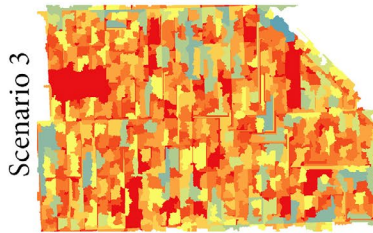
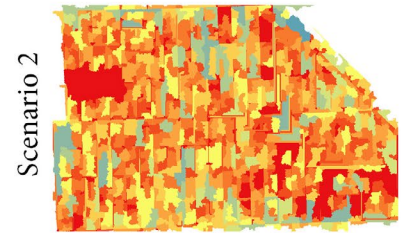
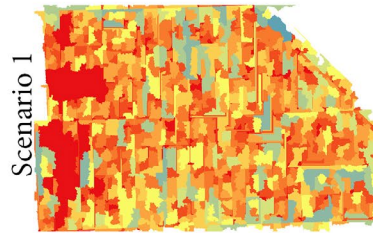
## APPENDIX A: Storm Water Calculation Per Catchment

### 2 Year 30 Minute Storm

Runoff (ft3) of Catchments in the 10 Year 30 min C = 0.4 storm event

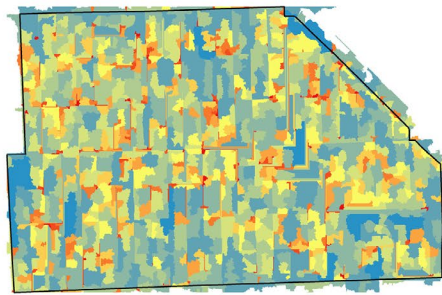


#### Catchment Class (ft3)



### 100 Year 60 Minute Storm

Runoff (ft3) of Catchments in the 10 Year 30 min C = 0.4 storm event



#### Catchment Class (ft3)

