RETHINKING RAINFALL: EXPLORING OPPORTUNITIES FOR SUSTAINABLE STORMWATER MANAGEMENT PRACTICES IN TURKEY CREEK BASIN AND DOWNTOWN KANSAS CITY

by

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A REPORT

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ABSTRACT

Kansas City's outdated sewer system is presently incapable of capturing and treating the increased runoff volumes in Turkey Creek Basin during rainstorm events. As a result, 2.66 billion gallons of untreated sewer system overflow is released annually into the Kansas River and nearby properties. In 2002, the Environmental Protection Agency issued a civil action requiring the City of Kansas City, Missouri, to take appropriate and necessary actions needed to prevent or minimize the discharge of untreated sewage. In response, the City of Kansas City adopted a comprehensive Overflow Control Plan intended to reduce sewer system overflow volumes in Turkey Creek Basin by 85% at a cost of approximately $244 million.

Initially, the City of Kansas City seriously considered implementing stormwater best management practices (BMPs) in place of sewer system improvements. Stormwater BMPs infiltrate, filter, store, and evaporate stormwater runoff close to its source, preventing stormwater runoff from reaching the sewer system. Subsequently, many BMPs were eliminated from the Overflow Control Plan and replaced with conventional sewer system technologies because of performance concerns. However, the Overflow Control Plan acknowledged that BMPs located on private property would indirectly benefit Kansas City's stormwater management strategy. Using geographic information system (GIS) analysis, suitability maps were generated for twelve different BMPs to determine suitable locations in Turkey Creek Basin for reducing stormwater runoff. Analysis concluded that the most effective strategy for sustainable stormwater management would be to locate BMPs at higher elevations within the watershed to prevent upland runoff from flooding sewer system pipes at lower elevations.

Areas having the highest suitability are located primarily on residential land, implying that Kansas City could benefit most from encouraging its residents to equip their properties with site-appropriate BMPs. This can be achieved through educational initiatives, policy adoption, and homeowner incentives. Therefore, policies and incentives targeting Kansas City's residents should be implemented to reduce sewer overflow volumes and prevent future costly improvements to Kansas City's sewer system.

rethinking rainfall

Exploring Opportunities for Sustainable Stormwater Management Practices in Turkey Creek Basin and Downtown Kansas City

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Abstract

Kansas City's outdated sewer system is presently incapable of capturing and treating the increased runoff volumes in Turkey Creek Basin during rainstorm events. As a result, 2.66 billion gallons of untreated sewer system overflow is released annually into the Kansas River and nearby properties. In 2002, the Environmental Protection Agency issued a civil action requiring the City of Kansas City, Missouri, to take appropriate and necessary actions needed to prevent or minimize the discharge of untreated sewage. In response, the City of Kansas City adopted a comprehensive Overflow Control Plan intended to reduce sewer system overflow volumes in Turkey Creek Basin by 85% at a cost of approximately $244 million.

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Introduce

View of Downtown Kansas City. Photo by: Missouri Division of Tourism, 2010.

> “The construction of green infrastructure and development of sustainable water management practices will be beneficial throughout the City.”

The City of Kansas City, Missouri Water Services Department
Overflow Control Plan, 2009

Dilemma and Thesis

Dilemma

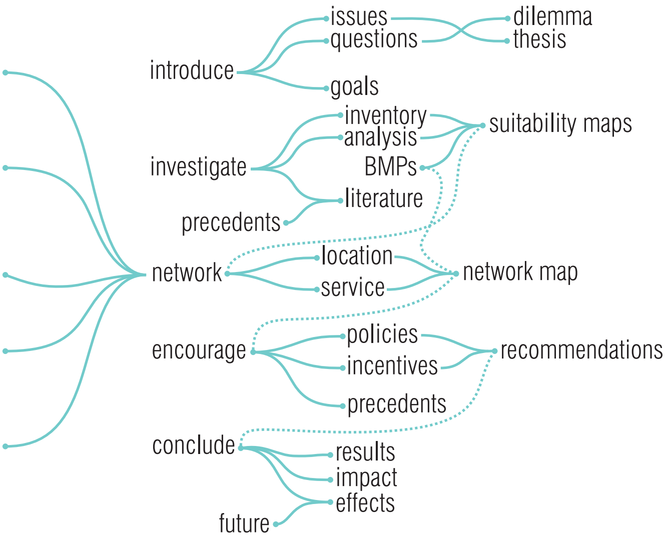
Conventional civil engineering of stormwater management systems are 19th century solutions being applied to 21st century puzzles. Rapid urbanization of the Kansas City Metropolitan area has left the outdated stormwater infrastructure incapable of capturing increased runoff volumes. As a result, this has led to numerous illegal discharges of untreated sewage into the Missouri River. However, instead of approaching the issue with new sustainable stormwater management practices, the City has opted to rely on conventional sewer system improvements likely to be inadequate for future runoff volumes.

Thesis

A departure from channelized sewer systems to a network of sustainable stormwater management practices located on privately-owned land can significantly reduce the volume of polluted stormwater illegally discharged into the Missouri River. Additionally, such an approach may encourage residents and businesses to adopt Best Management Practices of their own.

Work Plan

Efforts in fulfillment of a Master's Project began in the summer of 2012 and culminated in May of 2013. This document serves as a physical representation of the research, analysis, and design completed throughout those nine months. Progression of the project resulted in the establishment of five main phases, or chapters, that each represent a major advancement in the depth of the project. In consecutive order, these five chapters are: Introduce, Investigate, Network, Encourage, and Conclude. The project is linear in its development, suggesting a succession from one component of the project to the next (Figure 1). Each chapter builds on the information obtained from the previous chapter to reflect the project's linear progression.



introduce
issues
questions
goals
dilemma
thesis
investigate
inventory
analysis
BMPs
literature
precedents
suitability maps
network
location
service
network map
encourage
policies
incentives
precedents
recommendations
conclude
results
impact
effects
future

Introduction

In most of today's major cities, stormwater runoff is a major concern. Communities have tried relentlessly for centuries to control and manage stormwater successfully, yet today these forms of stormwater management continue to encounter failures. Urban growth has exacerbated these failures in stormwater management by promoting decentralized development at rates which exceed a city's effective stormwater management ability. To address urban stormwater concerns, municipalities have adopted stormwater management plans intended to alleviate issues associated with stormwater runoff. The term "stormwater management" can take on many different meanings depending on the application of the term. Some management programs are small, site-specific initiatives while others may be extensive, basin-wide initiatives affecting multiple municipalities. Furthermore, stormwater management may include as many or as few functions and components as necessary to meet the needs of a site. The development of these components may also vary in complexity and appearance.

Fundamentally, the purpose of stormwater management is to "keep people from the water, to keep the water from the people, and to protect or enhance the environment while doing so" (Debo and Reese, 1995). Municipalities worldwide have taken measures to prevent or limit people from inhabiting areas prone to flood damage. Non-structural measures intended to reduce water damages often include setbacks, property acquisitions, and additional regulations for areas located within floodplains. Preventing stormwater from reaching people incorporates both structural and non-structural practices either through channeling stormwater away from a site or capturing stormwater where it falls.

Urban communities have an extensive history of managing stormwater runoff for a variety of purposes. From the ancient Indus and Minoan practice of open channel drainage systems, to the 19th century practice of diverting stormwater underground through cement tunnels, stormwater management practices have been consistently relied upon to mitigate the perceived issues associated with stormwater (Burian et al., 2006). Historically, some stormwater management arrangements have combined infrastructure systems such as sanitary collection and stormwater runoff into a single conduit to reduce construction requirements.

Today, the practice of conveying sanitary wastewater (domestic, commercial, and industrial wastewaters) and stormwater in a single-pipe system is called a combined sewer system (CSS). Combined sewer systems are intended to transport sanitary wastewater to a sewage treatment plant where it is treated and then discharged into a water body. However, heavy rainfall or snowmelt can result in CSS volumes exceeding capacity for management at treatment plants. Therefore, CSS are designed to overflow occasionally; discharging untreated stormwater and sanitary wastewater into nearby water bodies. These overflows, referred to as combined sewer overflows (CSOs), include oils and greases from stormwater runoff and toxic wastes from sanitary wastewater. Approximately 772 cities in the United States operate with CSSs (U.S. Environmental Protection Agency, 2012).

Unlike CSS, systems which convey sanitary wastewater and stormwater in separate sewer channels are referred to as separate sewer systems (SSS). During heavy rainfall or snowmelt, stormwater runoff enters the stormwater sewer system and may either be treated at a city's treatment plant or discharged into nearby water bodies. However, *sanitary wastewater* is always transported to treatment facilities and treated before being discharged. Properly designed and operated SSSs provide better control and treatment of sanitary wastewater than do CSSs and reduce the impact of untreated sewage on those bodies of water receiving discharges. For developed areas with CSSs, replacing existing sewer systems with SSSs can be difficult to fund because of the need to upgrade and relocate existing infrastructure. Additionally, division between urban land use planning and stormwater management tends to be commonplace in many cities. The city of Kansas City, Missouri, is no exception.

Kansas City, Missouri, is located at the confluence of the Missouri and Kansas rivers and is part of a metropolitan area that expands into eastern Kansas (Figure 2). Established in 1821, Kansas City's excellent location along the Missouri River encouraged traders to settle and eventually became one of the Midwest's largest cities. With a current estimated population of 677,377 people, Kansas City ranks #37 in the United States' most populated cities and is expected to continue to rise steadily (U.S. Census Bureau, 2012). Like all cities, Kansas City's population increase is correlative to increased levels of development. Combined, Kansas City has become a highly urbanized environment and is experiencing difficulties in balancing urban development and nature conservation.

Figure 2: Location of Kansas City, Missouri. Figure by author.

Kansas City's downtown core straddles three watersheds, the Turkey Creek watershed, the Central Industrial District (CID) watershed, and the Northeast Industrial District (NEID) watershed. The majority of Kansas City's downtown core is located within the Turkey Creek watershed which is currently Kansas City's most problematic basin and the focus of this project (Figure 3). Stormwater has become incapable of infiltrating into the ground due to large amounts of impervious surface. Impervious land coverage is a fundamental characteristic of urban and suburban areas. Impervious surfaces can be defined as any material that prevents or reduces the infiltration of water into the soil (Ferguson et al., 1990; Sipes, 2010). Through urbanization, Kansas City's permeable land has been covered with impervious surfaces such as roads, parking lots, roofs, driveways, and sidewalks to accommodate the city's growth. The amount of impervious surfaces within a community directly correlates to the impact the community has on the site's hydrology, habitat structure, water quality, and biodiversity (Schueler et al, 2000).

When the hydrology of a watershed is altered, the watershed and its receiving water bodies begin to experience the impact. Streams capturing stormwater runoff may, upon development of a site, begin to convey larger volumes of runoff at a rate which receiving streams cannot accommodate without first widening their channels. This may prove disastrous for nearby properties or for receiving channels downstream. Development also causes disruptions to a watershed's floodplain when stormwater runoff is captured through constructed sewer networks; leaving the watershed's ecologically-sensitive floodplain environment in an unsaturated state. The reduction of permeable land capable of absorbing stormwater has had compounding effects for cities. Impervious surfaces reduce stormwater infiltration and

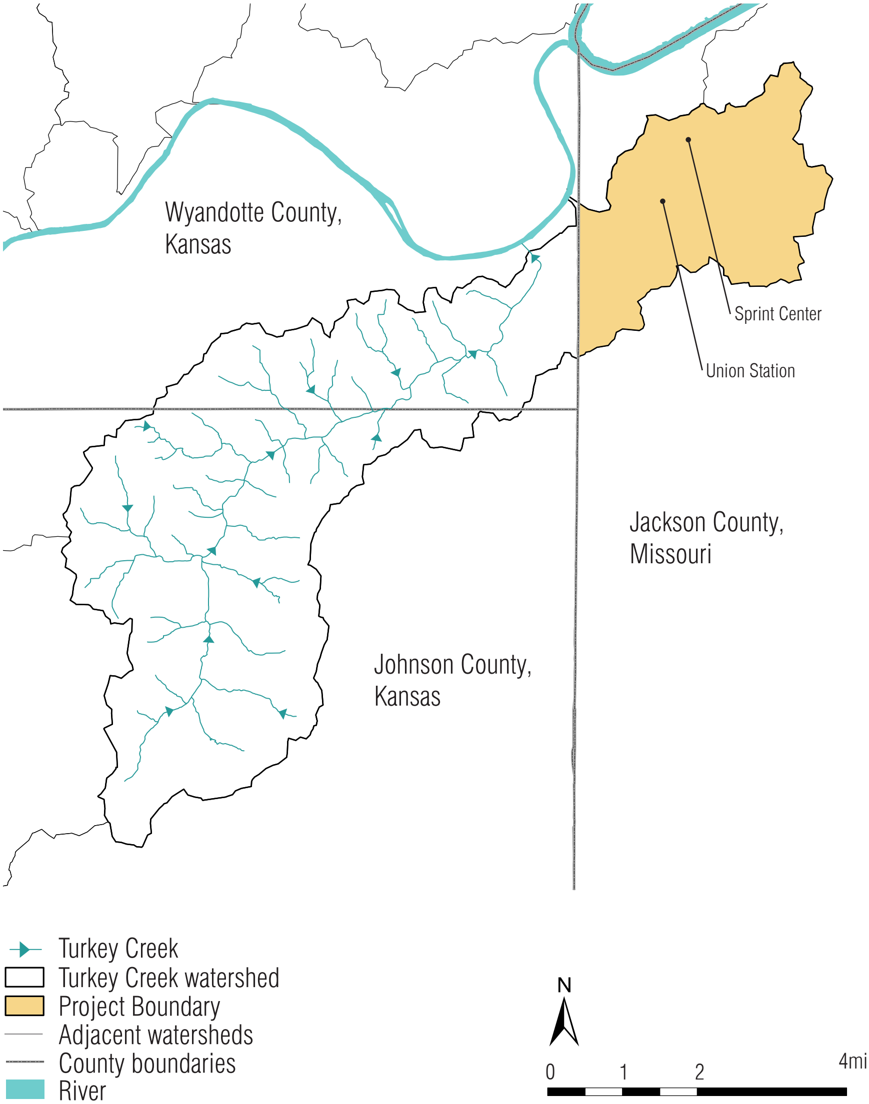


Figure 3: Project Boundary. Figure by author.

evapotranspiration, subsequently increasing the volume of stormwater runoff (Water Environment Federation, 2012). Combined, the landscape of Kansas City is continually subjected to changes it alone cannot accommodate with naturally occurring biological methods.

Instead, stormwater rushes over these impervious surfaces before entering Kansas City's sewer system. Although Kansas City's sewer systems were intended to efficiently transport and treat stormwater runoff, urbanization across Turkey Creek basin has increased impervious land cover, therefore decreasing infiltration and increasing the volume of stormwater runoff entering the sewer system. In addition, much of Kansas City's downtown sewer network is outdated structurally. Approximately 56 square miles within Kansas City south of the Missouri River are still served by CSS (City of Kansas City, Missouri, 2009). The mixture of toxic sewage and polluted runoff during rain events increases demand on Kansas City's water treatment facilities. As a result, polluted waters are commonly discharged into the Kansas River (U.S. v. KCMO, 2002).

Rethinking Rainfall focuses on the existing stormwater management issues in Kansas City, Missouri's Turkey Creek basin. Along with identifying the origins of the basin's stormwater management issues, I am proposing a departure from total reliance on conventional stormwater management practices (sewers and water treatment facilities). A few guidelines for this project shall be established. This project consists of two major components: 1) an analysis of locations best suited for mitigating stormwater runoff using biological methods of stormwater management; and 2) recommendations for implementing biological methods of stormwater management in Kansas City, Missouri, and the potential benefits of doing so. This project does not have site design intentions; meaning areas of opportunity for stormwater management that are identified through this project are not individually examined at the site scale. Because this is not a site design project, this project does not aim to provide detailed calculations of managed stormwater runoff volumes. Simply put, *Rethinking Rainfall* will provide a comprehensive analysis of Turkey Creek basin with recommendations for Kansas City's residents, City officials, and City planners to assist and guide future stormwater management improvements in the basin.

Goals

Four goals were developed to provide guidance and objectives during the progression of this project. Goals were developed based upon the possible outcomes of basin analysis, the potential benefits of the analysis, and the future use of the analysis. These goals are revisited in the conclusion of this book and compared to the project's results to determine the success of this project. The goals for this project are as follows:

- Maintain and improve Kansas City's urban design to optimize its environmental benefits for current and future generations.

- Identify areas of opportunity - land that is physically suitable for 12 different types of best management practices

- Design to reduce the volume and rate of stormwater runoff entering the combined sewer system.

- Suggest policies and incentives favorable to the private sector that encourage installation of best management practices

Investigate

Main Street during Kansas City storm event. Photo by: jaxonspictures, 2009.

"Earth as we know it came into being through its four great components: land, water, air, and life, all interacting in the light and energy of the sun. Although there was a sequence in the formation of the land sphere, the atmosphere, the water sphere, and the life sphere, these have so interacted with one another in the shaping of the Earth that we must somehow think of these as all present to one another and interacting from the beginning."

Thomas Berry
The Great Work: Our Way into the Future

United States of America v. The City of Kansas City, Missouri. 2002. Case 4:10-cv-00497

In 2002, Kansas City, Missouri's failure to address its aging sewer system resulted in a civil action filed by the EPA against the City claiming "numerous illegal discharges of pollutants…including discharges of raw sewage, and for violations of…permits issued to KCMO by the Missouri Department of Natural Resources" (US v. KCMO, 2002; p.1). The civil action required the City to take necessary actions needed to resolve the "imminent and substantial endangerment to the health of persons presented by KCMO's sewer system, resulting in discharges of raw sewage to homes, yards, parks, playgrounds, and streets" (US v. KCMO, 2002; p.2). The injunction also required the City to pay $600,000 in civil penalties to the United States for the violations.

The United States Environmental Protection Agency allows cities to discharge polluted stormwater and sewage with the appropriate permits. This is generally tolerable when cities with CSSs, such as Kanas City, Missouri, cannot accommodate the increased volumes of wastewater during storm events. However, cities are only allowed a limited volume of annual overflow before being fined. The civil action claims Kansas City's illegal discharges polluted the Missouri River, Kansas River, Fishing River, Wilkerson Creek, Rocky Branch Creek, Todd Creek, Blue River, Brush Creek, Penn Valley Lake, Line Creek, Round Grove Creek, Indian Creek, Hickman Mills Creek, Buckeye Creek, Rock Creek, Upper Shoal Creek, Walnut Creek, and other tributaries not mentioned by name.

Kansas City's unpermitted discharges of untreated sewage have resulted from "inadequate flow capacity due to aged and corroded pipes and force mains; illegal and improper cross-connections between sanitary and stormwater sewers; poor maintenance of collection systems including breaks and blockages in sewer pipes, force mains and manholes; and excessive infiltration and inflow to the sanitary sewers" (US v. KCMO, 2002; p.10).

The EPA recorded over 138 discharges from Kansas City's sewers between August 2002 and December 31, 2007. An estimated 4.6 million gallons of raw sewage was discharged into the Missouri River, Kansas River, Blue River, Brush Creek, Penn Valley Lake, and other unnamed tributaries (US v. KCMO, 2002; p.11-12). More so, between June 2, 2004 and June 30, 2005, the EPA recorded at least 766 incidents where raw sewage was discharged by Kansas City's sewer system onto public and private property, including streets, yards, public parks, and playground areas, and into buildings, including homes (US v. KCMO, 2002; p.13).

Untreated sewage contains a variety of disease-causing pathogens, including bacteria, viruses, parasitic organisms, and intestinal worms. The EPA claimed that until the City treated its sewage, the illegal discharges were "presenting an imminent and substantial endangerment to the health of persons" (US v. KCMO, 2002; p13).

Because of the danger presented, the United States issued an order requiring the City of Kansas City, Missouri:

> "1) to take measures (such as increasing sewer pumping and treatment capacity, improving operation and maintenance, and installing backflow devices) to prevent or minimize to the greatest extent possible the discharge of sewage into streets, yards, parks, playgrounds, buildings, and other areas where persons may come in contact with it when the discharge was caused by conditions in its Publicly Owned Treatment Works (POTW); 2) to develop a comprehensive response plan to follow when discharges occur caused by conditions in its POTW to clean up and disinfect the affected property by qualified personnel as promptly as possible so as to remove any endangerment to public health; 3) to improve public outreach and communications to notify the public of the occurrence and causes of backups and warn the public about the risks associated with contacting sewage; and 4) to take such other action as may be necessary" (US v. KCMO, 2002; p.14).

Kansas City, Missouri Water Services Department, 2009. Overflow Control Program - Overflow Control Plan.

Following the civil action brought forth by the EPA, the City of Kansas City, Missouri, began to develop a plan to help guide the City's efforts in addressing combined sewer overflows and flooding issues. The initiative was triggered, in part, by the EPA's civil action for injunctive relief and civil penalties against the City of Kansas City, Missouri, for illegal discharges of pollutants. To address the complaints brought forth by the EPA, each of Kansas City's 16 principal basins were individually monitored and evaluated. The 16 basins consisted of seven CSS basins located south of the Missouri River and nine SSS; four of which were located north of the Missouri River and the remaining five to the south.

Basins with CSSs were found to only capture 45% of wet weather flow, resulting in an overflow volume of 6.38 billion gallons across the seven basins. The Turkey Creek/CID basin was by far the largest contributor, releasing 2.66 billion gallons of overflow volume in a typical year (Table 1). In contrast, the nine basins with SSS were estimated to only have 190 million gallons of overflow in a modeled year (Kansas City, Missouri Water Services Department, 2009; p. 5-40, p.5-42).

The City identified three primary objectives of the Overflow Control Plan. These goals included:
1) Minimizing the loss of life and injury
2) Reducing property damage due to flooding
3) Improving water quality while maximizing economic, social, and environmental benefits

The Overflow Control Plan provides basin-specific proposals for each basin to develop a city-wide overflow control plan. The City reviewed nearly 300 different alternative solutions during the development of the plan, each of which were evaluated by cost, feasibility, ability to control overflows, and multi-benefit potential. For Kansas City's approximately 58-square miles of CSS, a combination of traditional grey infrastructure (sewer systems) and green infrastructure were explored as a means of reducing CSOs.

Basin	Typical Year Wet Weather Flow (billion gallons)	Existing Overflow Volume (billion gallons)	Capture of Wet Weather Flow (%)
Missouri River CSS Basin			
Downtown Airport	Data Not Available		
Turkey Creek/Central Industrial District	2.99	2.66	11%
Northeast Industrial District	1.12	0.89	21%
Subtotal, Missouri River Basins	4.11	3.55	14%
Blue River CSS Basins			
Town Fork Creek	0.88	0.34	61%
Brush Creek	1.83	1.46	20%
Subtotal, Brush Creek CSS Basin	2.71	1.80	34%
Gooseneck Creek	1.02	0.68	34%
Lower Blue River	0.62	0.21	66%
Middle Blue River	0.62	0.15	76%
Subtotal, All Blue River CSS Basins	4.97	2.83	43%
SSS Wet Weather from 87th Street	2.07	N/A	N/A
SSS Wet Weather from Round Grove	0.50	N/A	N/A
Subtotal, SSS Inflows to BRIS	2.56	N/A	N/A
City-Wide Totals	11.64	6.38	45%

Table 1: Kansas City's Combined Sewer System Performance in a Typical Year. (Adapted from Kansas City, Missouri Water Services Department, 2009; p.5-40).

The general objectives identified in the Overflow Control Plan included:

- Reducing the sources of wet-weather runoff and inflow through widespread implementation of both "green solutions" before the implementation of traditional, construction-intensive structural solutions such as capture facilities.
- Addressing flood protection needs as part of planning for CSOs.
- Providing a programmatic platform to facilitate implementation of a comprehensive green solutions initiative.
- Engaging the entire metropolitan community in a comprehensive effort to improve urban lakes, streams, and rivers.
- Maximizing use of the existing collection systems through improved operation and maintenance, coupled with an appropriate level of investment in continuing repair and replacement of system components as they age.
- Establishing an adaptive approach to long-term plans for structural solutions so that they can be modified to reflect the results and benefits of early efforts. i.e., green solutions and conventional source controls (Kansas City, Missouri Water Services Department, 2009; p. 2-7).

In 2004, eight basin engineers were engaged under contract to create a detailed analysis of each watershed contributing runoff to the city of Kansas City, Missouri (Kansas City, Missouri Water Services Department, 2009; p. 2-13). The selected basin engineers and their respective basins were:

- Black & Veatch: Turkey Creek, Northeast Industrial District, and Central Industrial District
- Camp, Dresser & McKee (CDM): Brush Creek, Town Fork Creek
- CH2M Hill: Gooseneck Creek, Lower Blue River
- HDR Engineers: Middle Blue River, Blue River South
- Bucher, Willis & Ratliff Corporation: Birmingham
- George Butler & Associates: Blue River Central, Blue River North, Little Blue River
- HNTB: Line Creek/Rock Creek
- Wade & Associates: Round Grove Creek

The Overflow Control Plan went through a series of modifications from 2002 - 2008 while suggestions and cost estimates were being explored for each basin. For the CSS basins, consideration was given to physical characteristics, measured flow/quality data, mathematical model runs, preliminary system capacity allocations, and available technologies. Technologies generally included source controls, Low-Impact Development (LID) – retrofit, inflow reduction, sewer system optimization, storage, physical/chemical treatment, and biological treatment (Kansas City, Missouri Water Services Department, 2009; p. 8-8). Although each basin had unique requirements, the ultimate goal was to provide similar or multi-basin solutions to create a comprehensive Master Plan.

Table 2 presents a summary of the estimated capital cost and CSO control performance of the submitted Overflow Control Plan.

Final estimates indicate the Plan will cost approximately $2.4 billion and take between 25 and 33 years to fully implement (Kansas City, Missouri Water Services Department, 2009; p.12-50). Funding for the plan will be accomplished through increased sewer rates and voter-authorized loans (Kansas City, Missouri Water Services Department, 2009; p.11-2). Fifty-eight percent of the total cost comes from improvements to the CSS basins, followed by 40 percent from improvements to the SSS basins, and 2% from "Program Initiatives" (Kansas City, Missouri Water Services Department, 2009; p.12-47). The City incorporated funding for program initiatives that promote the City's overall agenda to implement green solutions.

Basin	Typical Year Wet Weather Flow (billion gallons)	Existing Overflow Volume (billion gallons)	Proposed Overflow Volume (billion gallons)	Plan Complete Capture of Wet Weather Flow (%)	Estimated Capital Cost ($Million) 2008 dollars
Missouri River CSS Basin					
Downtown Airport					$17.28
Turkey Creek/CID	2.987	2.659	.0574	81%	$226.99
Northeast Industrial District	1.119	0.886	0.462	59%	$5.19
Subtotal, Missouri River Basins	4.105	3.545	1.035	75%	$249.47
Blue River CSS Basins					
Town Fork Creek	0.880	0.341	0.037	96%	$160.02
Brush Creek	1.830	1.456	0.022	99%	$462.51
Subtotal, Brush Creek CSS Basin	2.710	1.797	0.059	98%	$622.53
Gooseneck Creek	1.019	0.676	0.238	N/A	$10.25
Lower Blue River	0.622	0.211	0.076	N/A	$29.65
Middle Blue River	0.623	0.149	0.049	92%	$81.02
Subtotal, All Blue River CSS Basins	4.974	2.832	0.423	91%	$743.46
Blue River WWTP HRT	N/A	N/A	N/A	N/A	$45.93
Blue River WWTP Solids Handling	N/A	N/A	N/A	N/A	$161.03
Westside WWTP HRT	N/A	N/A	N/A	N/A	$61.42
CITY-WIDE TOTALS Without SSS Inflows to BRIS	9.08	6.38	1.46	88%	$1,261.31
SSS Wet Weather from 87th Street	2.065	N/A	N/A	N/A	N/A
SSS Wet Weather from Round Grove	0.499	N/A	N/A	N/A	N/A
Subtotal, SSS Inflows to BRIS	2.564	N/A	N/A	N/A	N/A
CITY-WIDE TOTALS With SSS inflows to BRIS	11.64	6.38	1.46	88%	$1,261.31
Programmatic Components					$48.00
Neighborhood Sewers in CSS Basins					$124.00
Estimated Capitol Costs for SSS Basins					$942.44
Estimated Total Capital Cost for Overflow Control Plan					$2.383.37

Table 2: Summary of Estimated Cost and Performance. (Adapted from Kansas City, Missouri Water Services Department, 2009; p.10-12).

Selected program initiatives include:

- Public Education and Outreach
- Enhanced Monitoring and Modeling
- Green Collar Jobs and Workforce Development
- Rain Gardens and Downspout Disconnects
- Blue River Watershed Management Plan

The Overflow Control Plan emphasizes the need for publicly- and privately-constructed green solutions in the 4,690 acre focus area of Turkey Creek basin. Currently, Turkey Creek Basin receives an average of 2.99 billion gallons of rain and snowmelt annually (Kansas City, Missouri Water Services Department, 2009; p.12-46), yet only has the capacity to capture 0.33 billion gallons. Multiple computer model runs were conducted by Black & Veatch to evaluate the effects of implementing all planned improvements for Turkey Creek basin. Modeling indicated that the improvements will reduce the typical year overflow volume in the basin by 78 percent. The overflow volume will be reduced from the existing level of 2.66 billion gallons to approximately 574 million gallons for a typical year (Kansas City, Missouri Water Services Department, 2009; p.12-39)

Proposed improvements include:

- Sewer separation of approximately 66 acres.
- Construction of approximately 10,600 linear feet of 48-inch force main.
- Replacement of gates at the Santa Fe Pumping Station and institution of real-time gate control to take advantage of additional system storage made available in ongoing CID storm drainage improvements.
- Construction of approximately 7,500 linear feet of 26-foot diameter deep-storage tunnel.
- Construction of a 30-million gallons per day (MGD) deep-tunnel pump station.
- Upgrade the Turkey Creek Pump Station capacity to 30 MGD.
- Construction of in-line storage gates for real-time control of depths in the OK Creek sewer to take advantage of available system storage.
- Basin-wide small-sewer rehabilitation

Although the Overflow Control Plan appears to be taking initiative to include green infrastructure in the management of the Turkey Creek basin, sustainable solutions are only a tiny fraction of the proposed plan for water management in the basin. Of the estimated $244 million capital cost for improvements within the basin, $9.47 million (or less than 4 percent of total capital costs) has been allocated for a single green solution (Kansas City, Missouri Water Services Department, 2009; p.12-40).

Black & Veatch, 2008. Overflow Control Program (OCP): Missouri River NEID/Turkey Creek Project Area - Preliminary Improvement Scenarios; Technical Memorandum.

During the creation of the Kansas City, Missouri Overflow Control Plan, the City hired Black & Veatch to develop stormwater management alternatives for Turkey Creek Basin. Black & Veatch is a global engineering, consulting, and construction company specializing in infrastructure development in energy and water. As basin engineers, Black & Veatch was responsible for developing basin-specific, stormwater management alternatives to reduce the occurrence of overflows within the basins.

The purpose of the Turkey Creek Basin Technical Memorandum was to document preliminary improvement scenarios which include: "reviewing the available technologies for CSO control; screening and selecting technologies that are viable for each basin; preparing a diversion structure/ CSO outfall consolidation plan; assembling screened technologies… [that would] focus on four overflows per year (Design Storm E: 1.80" total rain event) or approximately 85% capture of wet weather flows; evaluating preliminary alternatives including preparation of planning level cost estimates…; and reducing the range of preliminary alternatives for further hydraulic modeling and analysis" (Black & Veatch, 2008; p.2).The Turkey Creek Stormwater Master Plan determined in 2004 that Turkey Creek Basin's sewer system did not have the capacity to convey flows from a 2-year design storm. Based on hydraulic and hydrologic modeling simulations, Black & Veatch estimated the frequency of CSOs and CSO volumes in the basin. Next, a table of design storms was produced (Table 3) to assist in the development of CSO controls.

For Turkey Creek Basin, stakeholders identified minimizing property damage due to flooding and protecting water quality as very important factors. To determine possible control technology alternatives, stakeholders offered input on preferred technologies. Technologies which had the ability to store, convey, and treat the large CSO volumes, as well as be compatible with the recommended stormwater improvements, and provide multiple benefits were retained for additional performance analysis.

Many sustainable stormwater management practices were eliminated because their "impact may be small and cannot be precisely estimated or controlled" and therefore "would have little or no measurable benefit for CSO reduction or elimination" (Black & Veatch, 2008; p. 65). Black &

Design Storm	Return Period[1] (months)	Storm Depth (inches)	Peak Hourly Intensity (in/hr)	Storm Duration (hours)	Events Exceeding per Year[2]	Number of Events per Year[3]	Overflow Volume/ Event
A	0.33	0.28	0.16	6.00	36	18	N/A
B	0.67	0.52	0.25	8.75	18	6	N/A
C	1	0.86	0.38	12.25	12	6	N/A
D	2	1.40	0.60	16.75	6	2	52 MG
E	3	1.80	0.73	19.75	4	1	92 MG
F	4	2.00	0.82	21.00	3	1	120 MG
G	6	2.40	0.95	23.75	2	1	134 MG
H	12	2.90	1.2	26.75	1	1	162 MG

Notes:
1. Based on total event depth and peak hourly intensity.
2. Total number of events per year with total depths and peak hourly intensities equal to, or exceeding, the specified design storm depth and intensity.
3. Total number of events per year with the same, or very similar, depth/intensity/duration characteristics as the specified design storm.

Table 3: Design Storm Summary for Turkey Creek Basin. (Adapted from Black and Veatch, 2008; p.6)

Veatch did, however, note that BMPs placed on private property such as schools, institutions, and corporations, would detain and treat stormwater runoff and would indirectly benefit the Plan. It was recommended that green solutions be further pursued by both the City and the community.

Instead, Black & Veatch proposed three alternatives that focused primarily on installing a 7,500 foot-long deep tunnel system approximately 250 feet below ground. The 26-foot diameter deep tunnel would store approximately 30 million gallons to reduce overflows to six events per year (Black & Veatch, 2008; p.209). The main tunnel would traverse east-northeast through the center of the Turkey Creek basin following the Kansas City Terminal Railway Company right-of-way. Other proposed control technologies include in-line storage, combined sewer separation, and the installation of larger sewer pipes. See Figure 4 for location of proposed of improvements.

The 66-square acre sewer separation improvement near Penn Valley Park was the only green solution proposed by Black & Veatch. Following separation, only stormwater will discharge into the lake. Through GIS analysis, Penn Valley Park was identified as being the "most feasible site for green infrastructure because it has favorable topography and location in the watershed, it would eliminate a CSO, and it is in public ownership." It was estimated that the detention pond would be capable of storing nearly 5.9 million gallons for 48 hours (Black & Veatch, 2008; p.104).

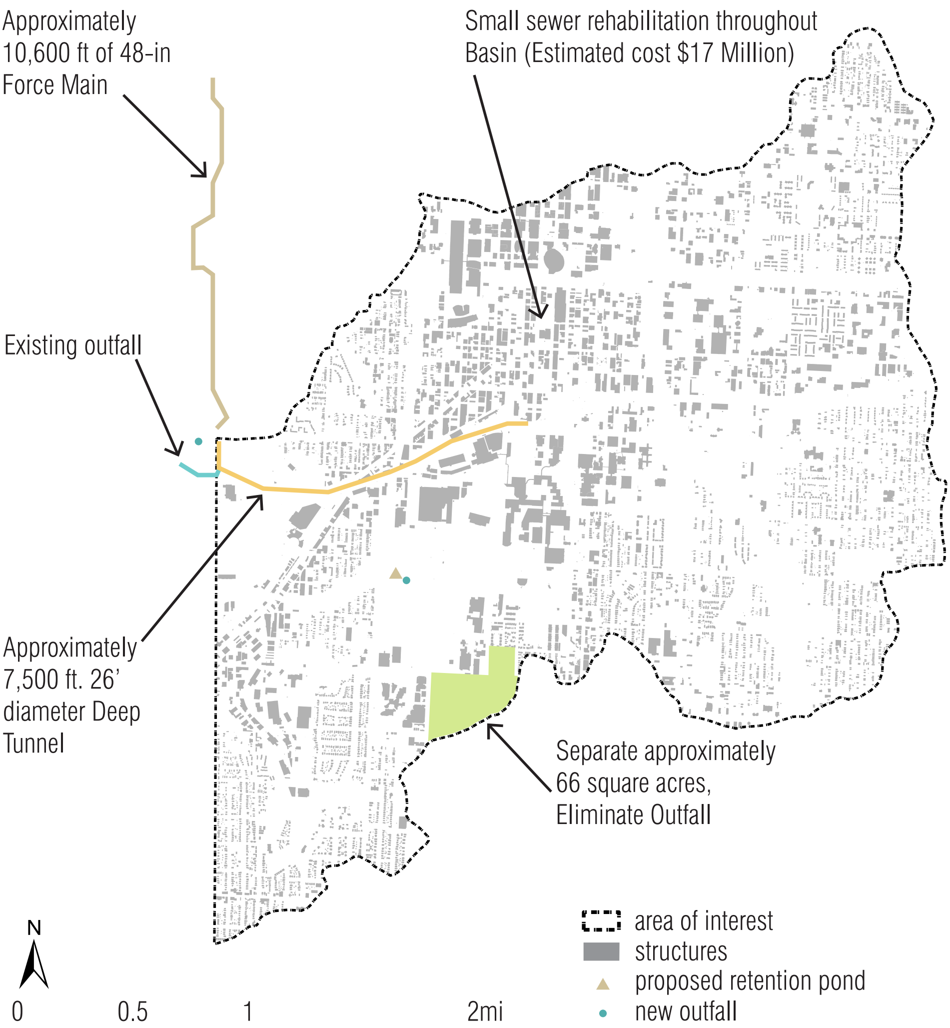


Figure 4: Black & Veatch Recommended Overflow Control Plan Alternative.

Site Inventory and Analysis

Turkey Creek Basin is approximately 4,558 acres in area and is one of Kansas City's oldest developed watersheds, containing a large portion of Kansas City's downtown urban core. The basin is best characterized by its large valley which runs east to west, physically splitting Kansas City's downtown core into two halves before reaching its point of lowest elevation at the confluence of the Kansas River (Figure 5). The location of the basin's valley has historically been problematic for developers looking to profit from land development in the immediate downtown area. Originally, the primary waterway for the basin was the OK Creek which once meandered through the basin's valley. It was later enclosed and rerouted by railroad companies in the early 1900's. The resulting sewer is now the primary conveyance system for the basin.

Because the conveyance system is located at lower elevations in Turkey Creek Basin, the majority of the basin's sewer network drains to this interceptor (Figure 6). During periods of moderate to heavy rainfall, the outdated conveyance system becomes inundated with the basin's stormwater, resulting in CSOs and/or discharges of untreated sewage into the Kansas River.

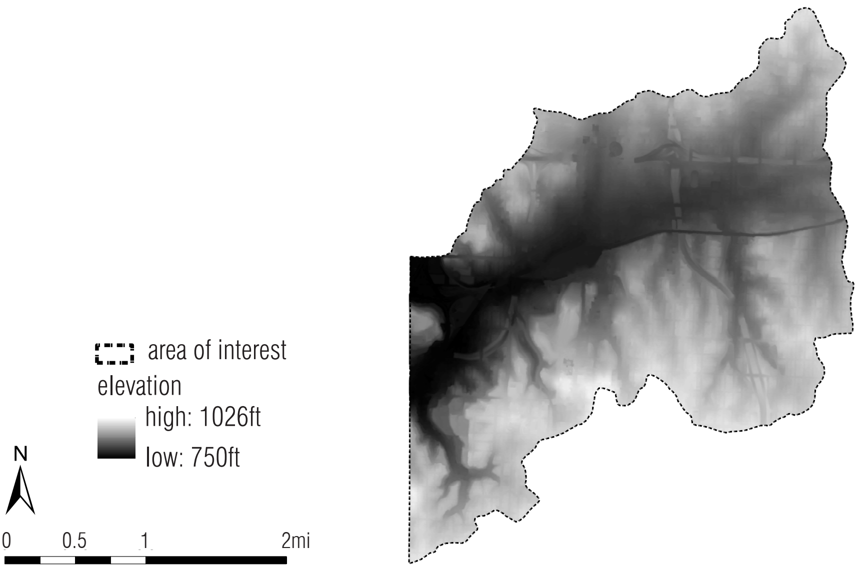


Figure 5: Digital Elevation Model (DEM)

Turkey Creek Basin is fully developed although many previously-developed but currently vacant lots are scattered around the urban core. Much of the development is office and commercial buildings with the remainder being medium to high density residential or mixed use development (Black & Veatch, 2008). Development has left the basin highly impervious, with approximately 55.7% of the basin covered by impervious surfaces as of 2005 (Figure 7) (Kansas City, Missouri Water Services Department, 2009). Lack of pervious surface area is contributing to increased stormwater runoff volumes.

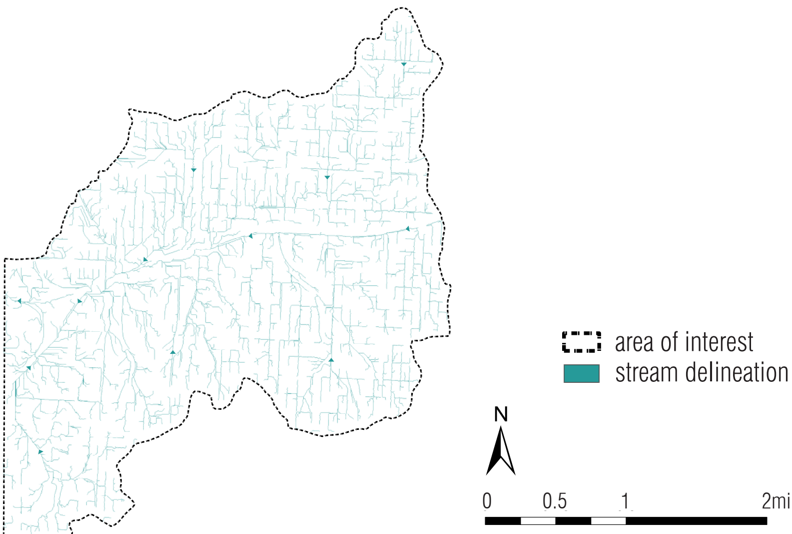


Figure 6: Stream Delineation

Figure 7: Impervious Surfaces

Most areas of woody vegetation are sporadically located in the southern half of the basin where the boundary of Kansas City's downtown is slightly less apparent (Figure 8). Vegetation is predominately composed of impaired deciduous woodlands and immature forests. Plots of mature vegetation tend to correspond with residential land use patterns. Soils across Turkey Creek Basin are classified as "Urban Land" soils (Figure 9). Urban Land soils are typical of developed areas and are comprised of filled and reworked soils. In some cases, urban soils may have traces of contaminants from prior land uses and will likely require amendments before any construction can occur (Environmental Protection Agency, 2011).

The majority of Turkey Creek Basin is comprised of privately-owned parcels belonging to residents, offices, and commercial and industrial businesses (Figure 10). These privately-owned parcels are located across the entire basin with no particular aggregation of private parcels. Right of ways, such as streets and interstates, are owned by the state or city unless otherwise specified. The single largest parcel of land is Penn Valley Park, which is owned by the City and the future location of a retention pond to assist in the stormwater management of the basin.

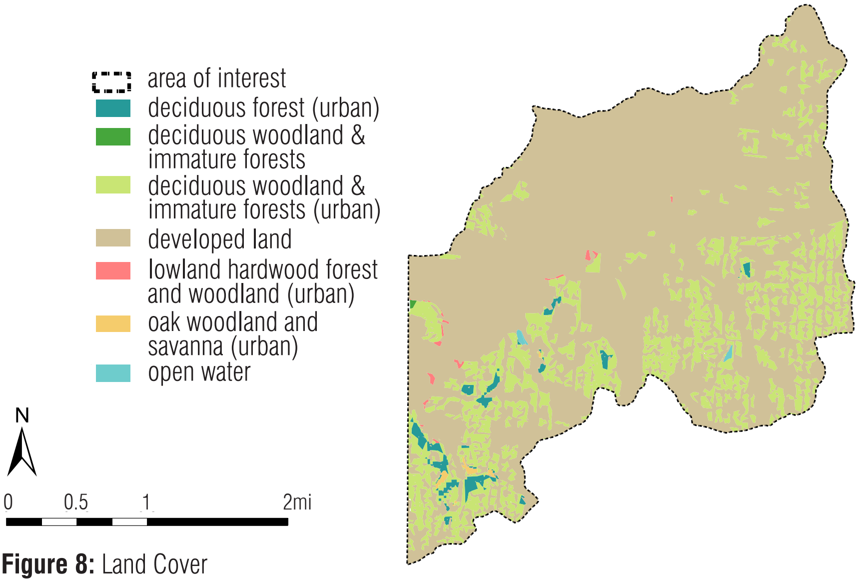


Figure 8: Land Cover

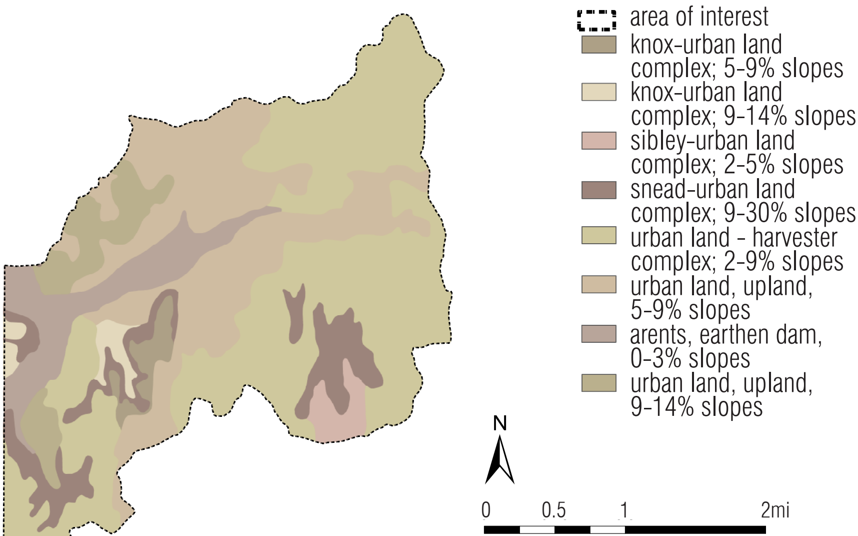


Figure 9: Soils

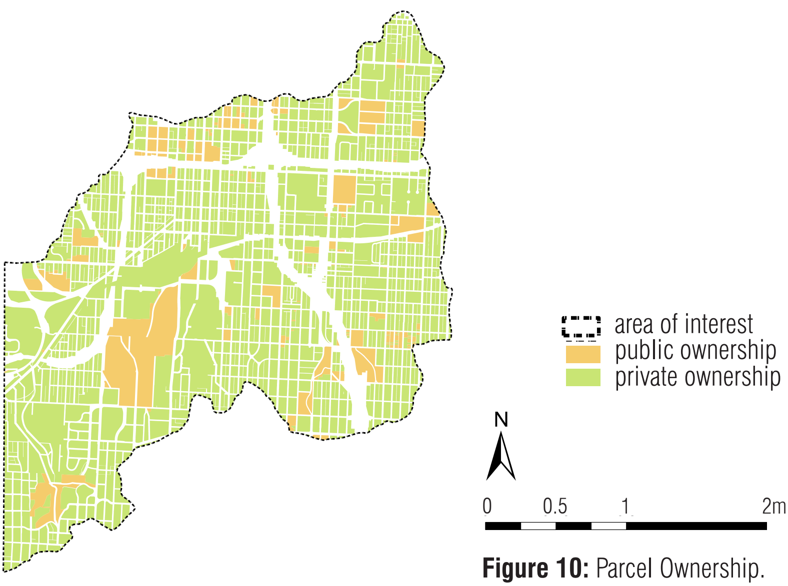


Figure 10: Parcel Ownership.

Identify

Downtown Kansas City. Photo by Richard Dickson, 2011

“As development continues in the watershed, the floodwater volumes and flood peaks are expected to increase. This will occur as less water soaks into the ground and more water runoff occurs from the increasing amount of land covered by impervious surfaces including buildings, roads and parking lots.”

Karen Kabbes, Amy L. Owens, and Michael A. Ports
Master Planning: Urban Stream Restoration - Upper Turkey Creek, Kansas City, KS

A New Approach to Stormwater Management

Although it is inevitable that Kansas City's ecosystems and infrastructure will be affected by increased runoff quantity and stormwater pollutants, opportunities are available to implement new and innovative stormwater management practices across Turkey Creek basin for stormwater management. Many cities across the world have recently opted to invest in new infrastructure technologies commonly referred to as best management practices (BMPs). According to *Sustainable Solutions for Water Resources*, best management practices are "site-specific applications that are recognized for their effectiveness in solving the problem at hand" (Sipes, 2010). The term, "best management practices," may be applied to a range of environmentally-conscious construction practices, however, for the purpose of addressing Kansas City's CSO problem, only stormwater BMPs will be examined.

Stormwater BMPs would provide added benefits such as water quality treatment, public amenities, and wildlife habitat while helping reduce the frequency and volume of Kansas City's CSOs. Additionally, BMPs would enhance the performance of existing overflow control practices. Stormwater BMPs incorporate a wide range of technologies, both structural and non-structural, and therefore can typically be applied to an existing site with minimal disturbance. However, to be successful, BMPs must be selected to fit the unique requirements of a site.

In practice, the selection of an appropriate BMP will depend upon the size of the site, local hydrology, and storage or treatment needs. Thus, the site must be thoroughly examined through multiple methods of analysis. Oftentimes, analysis takes place in person, allowing designers to experience site conditions first hand. This form of analysis is important to understanding the cultural characteristics of the site. A second form of site analysis includes the use of aerial imagery to record the physical characteristics of the site.

The most common application of aerial imagery analysis used by municipalities, city planners, and designers is geographic information system (GIS) software. GIS utilizes remote sensing data to map topography, vegetation, soils, and open space. These individual data sets can then be overlaid upon one another to create new and unique data. The data retrieved from GIS mapping may then be used by individuals to identify the characteristics of a site which may not be accurately represented otherwise. For large sites, GIS analysis is more appropriate, or more effective, than in-person site analysis. Due to the capabilities of GIS software, aerial imagery analysis will be utilized exclusively in determining suitable locations for stormwater BMPs across Turkey Creek basin. All source data used to generate BMP suitability maps was obtained from one or more of the following sources. Full citations are found in the Works Cited.

- City of Kansas City, Missouri; Department of City Planning and Development
- Mid-America Regional Council (MARC)
- Untied States Department of Agriculture
- Missouri Spatial Data Information Service

Best Management Practices

Stormwater BMPs are control measures taken to mitigate changes to both quantity and quality of urban stormwater runoff caused by increased impervious surfaces from land development. One of the primary goals of identifying suitable locations for stormwater BMPs is to reduce runoff volume and velocity by infiltrating rainfall to groundwater, evaporating and transpiring rainwater back into the atmosphere, detaining and treating runoff, and finding beneficial uses for the runoff. Stormwater BMPs incorporate simple and effective natural methods to decrease stormwater runoff using natural hydrology and vegetation. Typically, instead of sizeable investments in complex and costly engineering strategies, BMPs integrate open space, native landscaping, natural hydrology, and various other methods to reduce, detain, infiltrate, and treat runoff from developed land. By keeping stormwater on site and slowly releasing it, natural physical, chemical, and biological processes help reduce the volume of, if not eliminate, CSOs. Stormwater BMPs can also provide water quality treatment by removing pollutants that otherwise eventually reach waterbodies (Water Environment Federation, 2012). In these areas, BMPs are a critical component of a watershed approach to reduce overall water quality impacts from both CSOs and non-point source pollution.

Stormwater BMPs can be classified as “structural” (i.e., devices installed or constructed on a site) or “non-structural” (procedures, such as modified landscaping practices). There are a variety of BMPs available and selection typically depends on site characteristics, pollutant removal, and runoff reduction objectives. The U.S. Environmental Protection Agency (EPA) has published a list of recognized stormwater BMPs for use by local governments, builders and property owners. Of the EPA recommended BMPs, 12 have been selected for consideration in Turkey Creek basin to address Kansas City’s CSO dilemma. The 12 BMPs include, constructed wetlands, detention ponds, dry swales, filter strips, green roofs, infiltration trenches, native revegetation, permeable pavement, rain gardens, rainwater harvesting, retention ponds, and vegetated bioswales (Figure 11).

Figure 11: The 12 Best Management Practices (BMPs). Figure by author. (Sources: State of Vermont, 2013; Beall, 2010; Delaware Department of Transportation, 2007; City of Spokane, n.d.; United State Environmental Protection Agency, 2013; Sustainable Stormwater Management, 2007; Wetland Studies and Solutions, 2008; Philadelphia Water Department, 2013; How to Build a House Blog, 2012.)

Recognizing that no single BMP is a fix-all solution, the consideration of multiple BMPs allows for the possibility of wider application and therefore an increase in potential impact. Successful BMPs typically require multiple levels and types of analysis (i.e. suitability, cost, performance, maintenance, etc.). Using GIS software, suitable locations for each of the twelve BMPs were identified. Since suitability analysis was the only form of analysis extensively conducted, results represent suitable locations for BMP placement based strictly upon site conditions in Turkey Creek basin. This means that BMPs were located where they would create the least amount of disturbance to a site necessary for implementation.

A suitable location refers to areas of opportunity where a BMP could be placed based upon a number of selection factors. The number of factors contributing to the identification of a BMP's suitable locations will vary between BMPs. Some BMPs may only be affected by a few factors because of their wide-scale applicability. Other, more sensitive BMPs require extensive analysis of factors to identify areas which can support the BMP. Selection factors are grouped into six categories (Figure 12):

• Ownership: All publicly owned lands, including right-of-ways, will be omitted from GIS analysis since the City has already completed an analysis of BMP suitability on public parcels. Only privately-owned parcels will be considered for BMP placement.
• Site factors: Includes any physical characteristic of Turkey Creek basin.
• Applicability by land use: A BMP's relevancy to a specific land use type
• Proximity to flow accumulation: Distance to stormwater runoff paths
• Drainage area: Individual catchment areas which drain to a common point.
• Drainage points: Most downstream point of catchment area where flow accumulation should pool

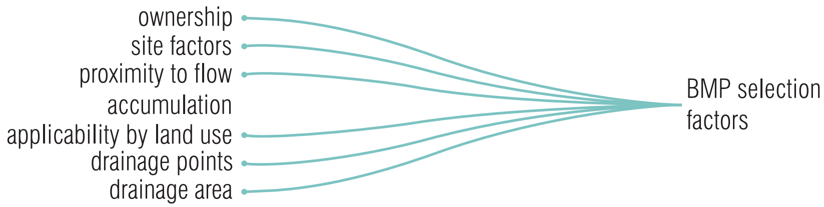


Figure 12: Structural BMP Selection Factors. Figure by author.

Ultimately, the objective of BMP suitability analysis is to determine areas of privately-owned land in Kansas City, Missouri, suitable for stormwater BMP service in Turkey Creek basin. A total of 12 objective goals were established to assist in the identification of applicable factors (Table 4). For guidance in defining the land use suitability objective and goals, *Smart Land-Use Analysis* by Margaret H. Carr and Paul D. Zwick was repeatedly referenced.

Each BMP was individually researched using a collection of municipal and institutional design manuals to determine applicable factors. Design manuals referenced during analysis are listed below. Full citations are found in the Works Cited.
• *Low Impact Development: a design manual for urban areas* by the University of Arkansas Community Design Center

• *Design of Urban Stormwater Controls* by the Water Environment Federation
• *Low Impact Development Manual for Michigan: A Design Guide for Implementors and Reviewers* by Southeast Michigan Council of Governments
• *BMP Manual of Best Management Practices for Stormwater Quality* by the Kansas City Metro Chapter of the American Public Works Association.
• *Low Impact Development* by the Metropolitan Government of Nashville and Davidson County.

Factors were then compared and contrasted between sources. After verifying the applicable factors for each goal, GIS models were created to simulate existing site conditions and influential factors. A total of 12 individual GIS models were created; one for each BMP. By simulating the unique conditions favorable to BMPs, a suitability map for each BMP was produced. Suitability maps visually identify areas of opportunity for BMPs within Turkey Creek basin. Specific applications of each BMP and their respective selection factors are discussed in the following pages. A side-by-side comparison of all 12 BMP highest suitability maps is provided at the end of the chapter in Figure 41.

Objective: Determine areas of privately-owned land in Kansas City, Missouri, suitable for stormwater BMP service in Turkey Creek Basin. Compare the resulting areas to derive appropriate locations for green infrastructure.	
Goals	
Goal 1	Identify lands most suitable for filter strips
Goal 2	Identify lands most suitable for permeable pavement
Goal 3	Identify lands most suitable for vegetated bioswales
Goal 4	Identify lands most suitable for dry swales
Goal 5	Identify lands most suitable for native revegetation
Goal 6	Identify lands most suitable for retention ponds
Goal 7	Identify lands most suitable for rainwater harvesting
Goal 8	Identify lands most suitable for infiltration trenches
Goal 9	Identify lands most suitable for detention ponds
Goal 10	Identify lands most suitable for rain gardens
Goal 11	Identify lands most suitable for constructed wetlands
Goal 12	Identify lands most suitable for green roofs

Table 4: Overall Statement of Intent

Filter Strips

A maintained strip of vegetation designed to slow runoff velocities and filter out sediment and other pollutants from urban stormwater runoff.

Filter strips are gently sloping areas that combine a grass strip and dense vegetation to filter, slow, and infiltrate stormwater runoff. Filter strips are best placed along roads and highways, small parking lots, and other impervious surfaces to capture stormwater runoff by converting it into sheet flow. By slowing stormwater runoff, plants can filter out sediment and other pollutants and provide some infiltration into soils (Figure 13). This reduces the likelihood of drainage systems and receiving water bodies being impacted by sediments and pollutants. Filter strips are also ideal buffer components of streams and vegetated corridors where stormwater runoff can be pretreated before reaching sensitive habitats (Southeast Michigan Council of Governments, 2008).

A suitability analysis of filter strips in Turkey Creek basin was performed to identify areas of opportunity. A total of six factors were considered in analysis, including slope, land cover, land cover buffer zone, impervious surfaces, soils, and property ownership (Table 5). Existing slopes are rated on a scale of one(1) to six(6) with one representing low suitability and six representing high suitability. Filter strips should be located on a lateral slope that does not exceed two percent to prevent stormwater runoff from laterally bypassing the strip (Prince George's County, Maryland, 1999). Slopes between zero and two percent received a rating of six (6), indicating high suitability. Steeper slopes are incrementally less suitable for filter strips and received lower ratings.

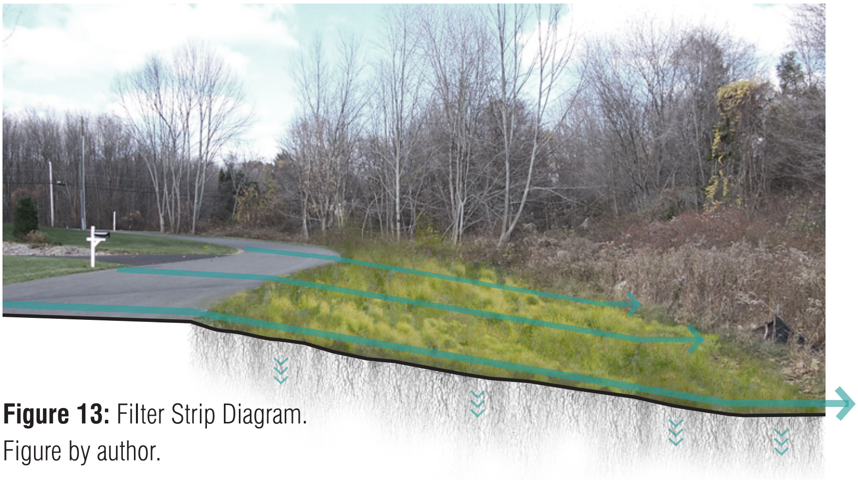


Figure 13: Filter Strip Diagram.
Figure by author.

Because filter strips require a large amount of open space to be properly implemented, highly developed areas limit the application of filter strips (Southeast Michigan Council of Governments, 2008). Therefore, suitability analysis aimed to protect existing clusters of established vegetation where stormwater likely collects. Unlike the scale rating used for slopes, land cover is rated on an inclusion or exclusion basis where zero(0) represents an exclusion of the data from further analysis and one(1) represents an inclusion of the data for further analysis. All vegetated land cover types

Goal 1	Identify lands most suitable for filter strips	
Objective 1.1	Determine lands physically suitable for filter strips	
Sub-objective 1.1.1	Identify optimal slope	Scale (1-6)*
	0% - 2%	6
	2% - 4%	5
	4% - 6%	4
	6% - 8%	3
	8% - 10%	2
	+10%	1
Sub-objective 1.1.2	Identify land covers	Scale (0-1)**
	Deciduous Forest (Urban)	1
	Deciduous Woodland and Immature Forests	1
	Deciduous Woodland and Immature Forests (Urban)	1
	Lowland Hardwood Forest and Woodland (Urban)	1
	Oak Woodland and Savanna (Urban)	1
	Open Water	1
	Developed Land	0
Sub-objective 1.1.3	Identify land cover buffer zone	Scale (0-1)**
	0 - 100 ft	1
	+100 ft	0
Sub-objective 1.1.4	Identify impervious surfaces	Scale (0-1)**
	Impervious	0
	Pervious	1
Sub-objective 1.1.5	Identify optimal soils	N/A
Objective 1.2	Identify lands politically suitable for filter strips	
Sub-objective 1.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-6) represents weight of variable data with (1) being the lowest and (6) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 5: Filter Strips Suitability Matrix

received a rating of one, while developed land received a rating of zero; excluding developed land from further suitability analysis.

Filter strips also require between 20’ and 100’ of buffer space to be effective (University of Arkansas Community Design Center, 2010). Analysis identified a 100’ buffer space surrounding vegetated land cover. Areas outside of the 100’ buffer received a rating of zero and were excluded from analysis. All impervious surfaces and public parcels also received a rating a zero and were excluded from further analysis. Soils would require special engineering before installing filter strips and therefore are not weighted.

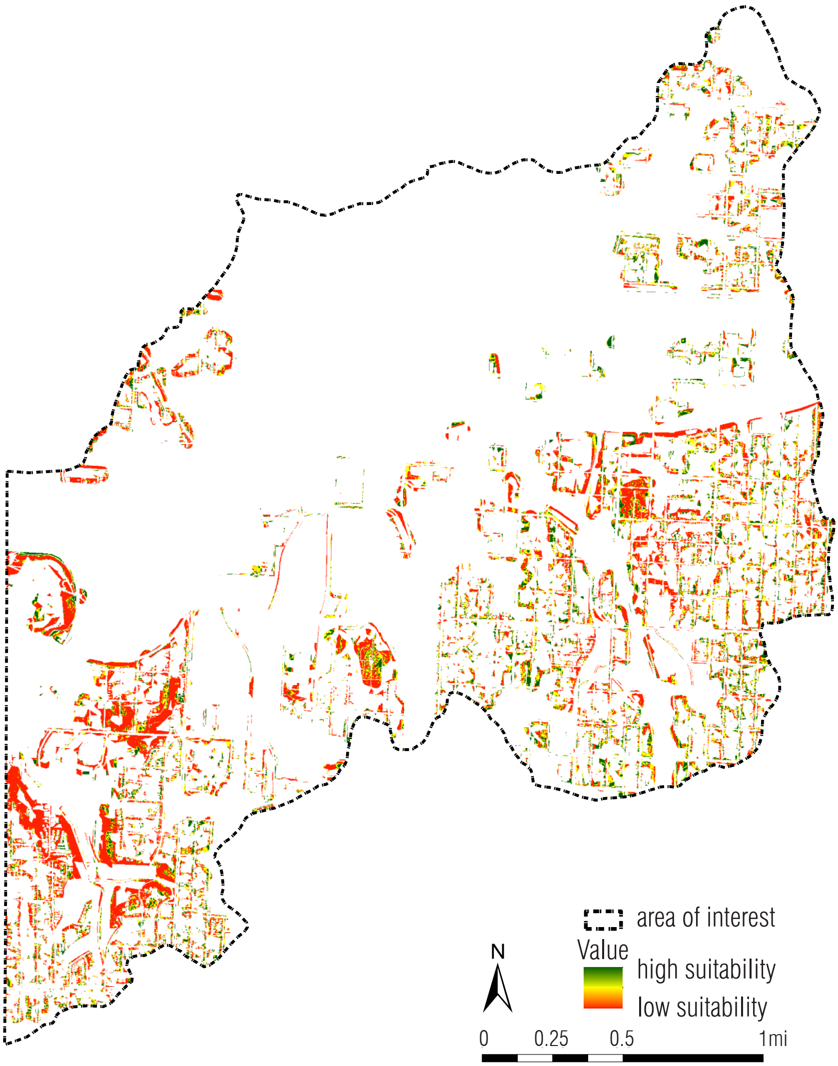


Figure 14: Filter Strips Suitability Map. Map by author.

All five factors were overlaid in GIS to identify areas suitable for filter strips in Turkey Creek basin. Approximately three quarters of land within the basin is excluded from analysis because the land is either highly developed or impervious. Suitable locations for filter strips are represented in Figure 14. Analysis reveals that many areas within the basin are low to moderately suitable for filter strips. This is likely a result of the basin's vegetated land cover being located on or near slopes where filter strips are ineffective. Areas of high suitability were extracted for easier recognition and are represented in Figure 15. The locations of areas of highest suitability coincide with land uses that are primarily residential and offer more open space for woody vegetation to establish.

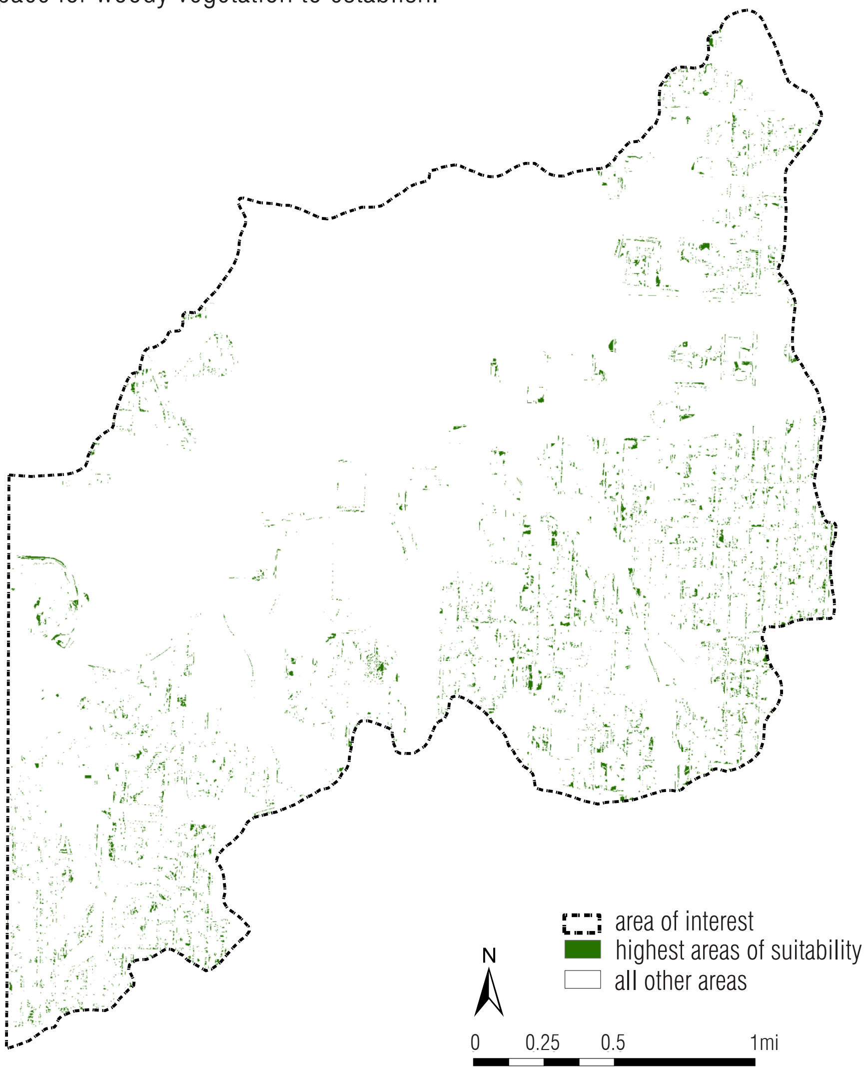


Figure 15: Filter Strips Highest Suitability Map. Map by author.

Permeable Pavement

Paving which provides load-bearing support for roads, plazas, and other paved areas while allowing water to vertically infiltrate through paved surfaces.

Permeable pavement allows for the infiltration of stormwater and the treatment of runoff from adjacent impervious areas by allowing the stormwater runoff to pass through an underlying aggregate structure where it is temporarily stored until it infiltrates the soil or is slowly released through an underdrain. Permeable pavement is most commonly used in areas of light vehicular traffic, such as parking lots, residential streets, and driveways, or areas of pedestrian foot traffic, such as sidewalks and plazas. Multiple types of permeable pavement are currently available, including pervious asphalt, pervious concrete, permeable interlocking concrete pavers, concrete grids, or reinforced grass (Water Environment Federation, 2012). Permeable pavement helps recharge groundwater and can remove up to 80% of runoff pollutants such as sediment, metals, and organic matter (Sipes, 2010; Ferguson, 2005).

A suitability analysis of permeable pavement in Turkey Creek basin was performed to identify areas of opportunity. A total of five factors were considered in analysis, including slope, setbacks, impervious surfaces, soils, and property ownership (Table 6). Existing slopes are rated on a scale of one(1) to nine(9) with one representing low suitability and nine representing high suitability. Steep slopes reduce the ability of permeable pavement to capture and store stormwater runoff and therefore received low suitability ratings (Metropolitan Government of Nashville and Davidson County, 2012). Slopes between zero and two percent are highly suitable for permeable pavement and received a rating of nine.

All other factors were rated on an inclusion or exclusion basis with zero(0) representing an exclusion of the data from further analysis and one(1) representing an inclusion of the data for further analysis. Because permeable pavement cannot support the same heavy weight loads that reinforced concrete can, the application of permeable pavement was limited to areas of light traffic currently paved with reinforced concrete or asphalt that could be successfully replaced with permeable pavement. These areas include sidewalks, parking lots, and driveways, and each received a rating of one. All other impervious areas, including right of ways, received a rating of zero and were excluded from further analysis.

Goal 2	Identify lands most suitable for permeable pavement	
Objective 2.1	Determine lands physically suitable for permeable pavement	
Sub-objective 2.1.1	Identify optimal slope	Scale (1-9)*
	0% - 1%	9
	1% - 2%	9
	2% - 4%	7
	4% - 8%	5
	8% - 10%	3
	10% - 15%	2
	15% - 20%	1
	20% - 25%	1
	+25%	1
Sub-objective 2.1.2	Identify setbacks	Scale (0-1)**
	Wells	
	0 - 100 ft	0
	+100 ft	1
	Structure setback from paved driveways	
	0 - 5 ft	0
	+5 ft	1
	Structure setback from paved parking lots	
	0 - 25 ft	0
	+25 ft	1
	Structure setback from paved sidewalks	
	0 - 10 ft	0
	+10 ft	1
Sub-objective 2.1.3	Identify impervious surfaces	Scale (0-1)**
	Structures	0
	Sidewalks	1
	Parking Lots	1
	Edge of Pavement	0
	Driveways	1
	Other	0
Sub-objective 2.1.4	Identify optimal soils	N/A
Objective 2.2	Determine lands politically suitable for permeable pavement	
Sub-objective 2.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-9) represents weight of variable data with (1) being the lowest and (9) being the highest, or most suitable
**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 6: Permeable Pavement Suitability Matrix

Permeable pavement must be setback from wells and structures because of the infiltration services permeable pavement provides. Setback distances for permeable pavement from structures vary depending upon application. Driveways retrofitted with permeable paving require a five foot minimum setback from structures. Parking lots retrofitted with permeable paving require a 25' setback from structures. And sidewalks retrofitted with permeable paving require a 10' setback from structures. All areas located inside of these setbacks received a rating of zero. Similarly, all areas within a 100' radius of wells received a rating of zero and were excluded from further analysis (Metropolitan Government of Nashville and Davidson County, 2012).

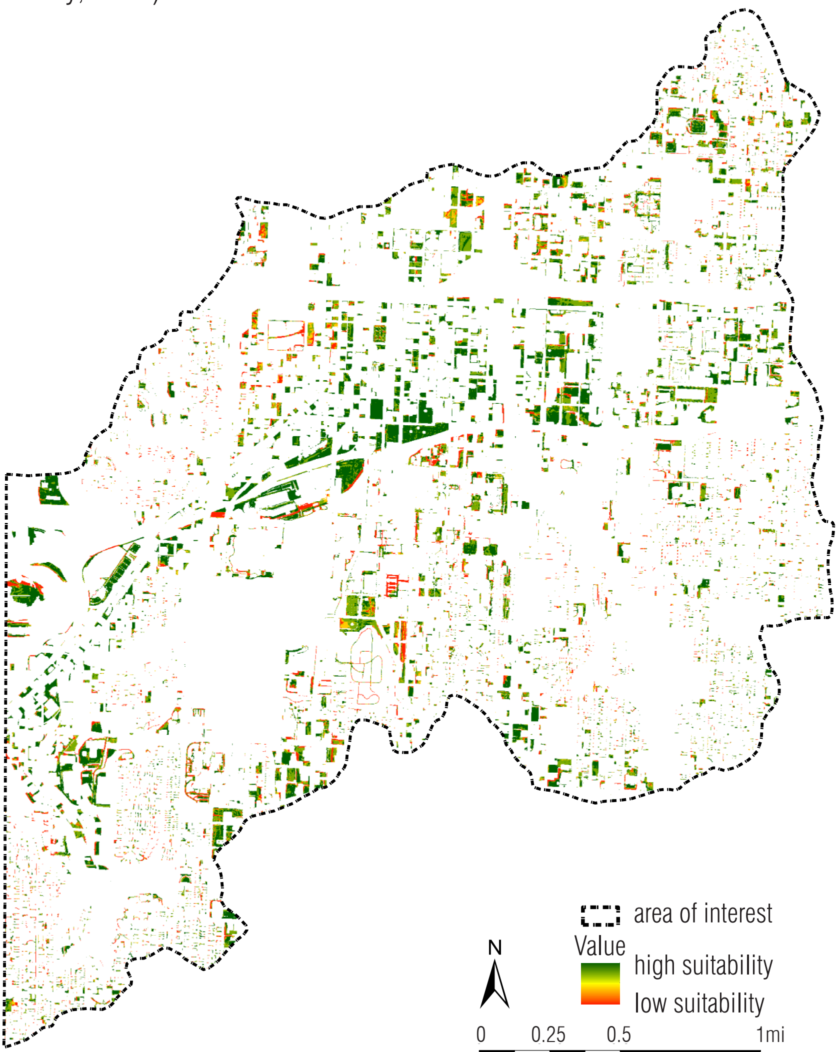


Figure 16: Permeable Pavement Suitability Map. Map by author.

All five factors were overlaid in GIS to identify areas suitable for permeable pavement in Turkey Creek basin. Suitable locations for permeable pavement are represented in Figure 16. Due to downtown Kansas City's large number of surface parking lots, analysis identified many areas across Turkey Creek basin suitable locations for permeable pavement. Areas of high suitability were extracted for easier recognition and are represented in Figure 17. Results indicate that permeable pavement is a viable option for reducing impervious cover throughout the basin and therefore subsequently reducing the amount of runoff entering the sewer system.

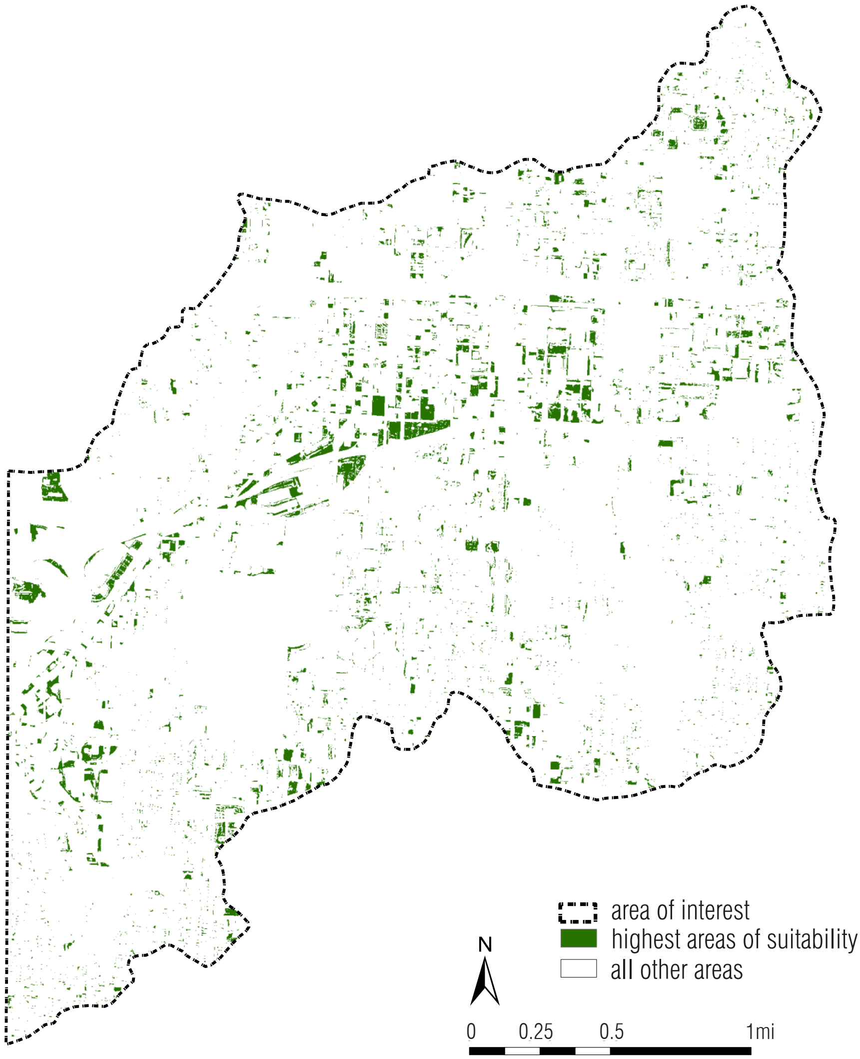


Figure 17: Permeable Pavement Highest Suitability Map. Map by author.

Vegetated Bioswales

A shallow stormwater channel that is densely planted with an assortment of grasses, shrubs, and trees designed to slow, filter, and infiltrate stormwater runoff.

The primary function of a vegetated bioswale is to treat stormwater runoff as it is conveyed. Vegetated bioswales are a popular alternative to conventional curb and gutter systems that transport contaminated stormwater runoff into sewer systems. Instead, vegetated bioswales slowly convey stormwater runoff, and in the process, promote infiltration through the use of engineered soil. Stormwater runoff infiltrates through the soil to a belowground perforated underdrain to prevent prolonged periods of standing water. The densely vegetated swale slows runoff velocities and provides treatment to polluted runoff in the process (Southeast Michigan Council of Governments, 2008). Vegetated bioswales are typically placed alongside roads and parking lots; however bioswales can also be placed in low-lying areas of a site to provide site drainage (University of Arkansas Community Design Center, 2010).

A suitability analysis of vegetated bioswales in Turkey Creek basin was performed to identify areas of opportunity. A total of six factors were considered in analysis, including slope, setbacks, proximity to flow accumulation, impervious surfaces, soils, and property ownership (Table 7). Existing slopes are rated on a scale of one(1) to nine(9) with one representing low suitability and nine representing high suitability. To convey stormwater, vegetated bioswales must be located on slopes between one and six percent (Southeast Michigan Council of Governments, 2008). Therefore, slopes between one and six percent received a rating of nine. Slopes steeper than six percent received lower suitability ratings because stormwater would be conveyed too quickly for bioswales to effectively filter stormwater.

All remaining factors were rated on an inclusion or exclusion basis with zero(0) representing an exclusion of the data from further analysis and one(1) representing an inclusion of the data for further analysis. Vegetated bioswales must be setback from wells and structures because of the infiltration services vegetated bioswales provide. Therefore, areas within a 100’ radius of wells and 10’ of structures received a rating of zero, and were excluded from further analysis (Metropolitan Government of Nashville and Davidson County, 2012). A 20’ buffer from the edge of street pavement was also included in analysis to account for bioswale placement alongside

Goal 3	Identify lands most suitable for vegetated bioswales	
Objective 3.1	Determine lands physically suitable for vegetated bioswales	
Sub-objective 3.1.1	Identify optimal slope	Scale (1-9)*
	0% - 1%	8
	1% - 2%	9
	2% - 3%	9
	3% - 4%	9
	4% - 5%	9
	5% - 6%	9
	6% - 8%	6
	8% - 12%	4
	+12%	1
Sub-objective 3.1.2	Identify setbacks	Scale (0-1)**
	Wells	
	0 - 100 ft	0
	+100 ft	1
	Structures	
	0 - 10 ft	0
	+10 ft	1
	Edge of Pavement	
	0 - 20 ft	1
	+20 ft	0
Sub-objective 3.1.3	Identify proximity to flow accumulation	Scale (0-1)**
	0 - 50 ft	1
	+50 ft	0
Sub-objective 3.1.4	Identify impervious surfaces	Scale (0-1)**
	Impervious	0
	Pervious	1
Sub-objective 3.1.5	Identify optimal soils	N/A
Objective 3.2	Identify lands politically suitable for vegetated bioswales	
Sub-objective 3.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-9) represents weight of variable data with (1) being the lowest and (9) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 7: Vegetated Bioswales Suitability Matrix

roads and parking lots. Areas located within the 20' buffer received a rating of one and were included for further suitability analysis. Finally, all impervious surfaces and public parcels received a rating of zero and were excluded from further analysis. Although a key factor, soils were not rated for this analysis but would still need to be amended accordingly before installing bioswales.

All six factors were overlaid in GIS to identify areas suitable for vegetated bioswales in Turkey Creek basin. Suitable locations for vegetated bioswales are represented in Figure 18. Vegetated bioswales are relatively suitable

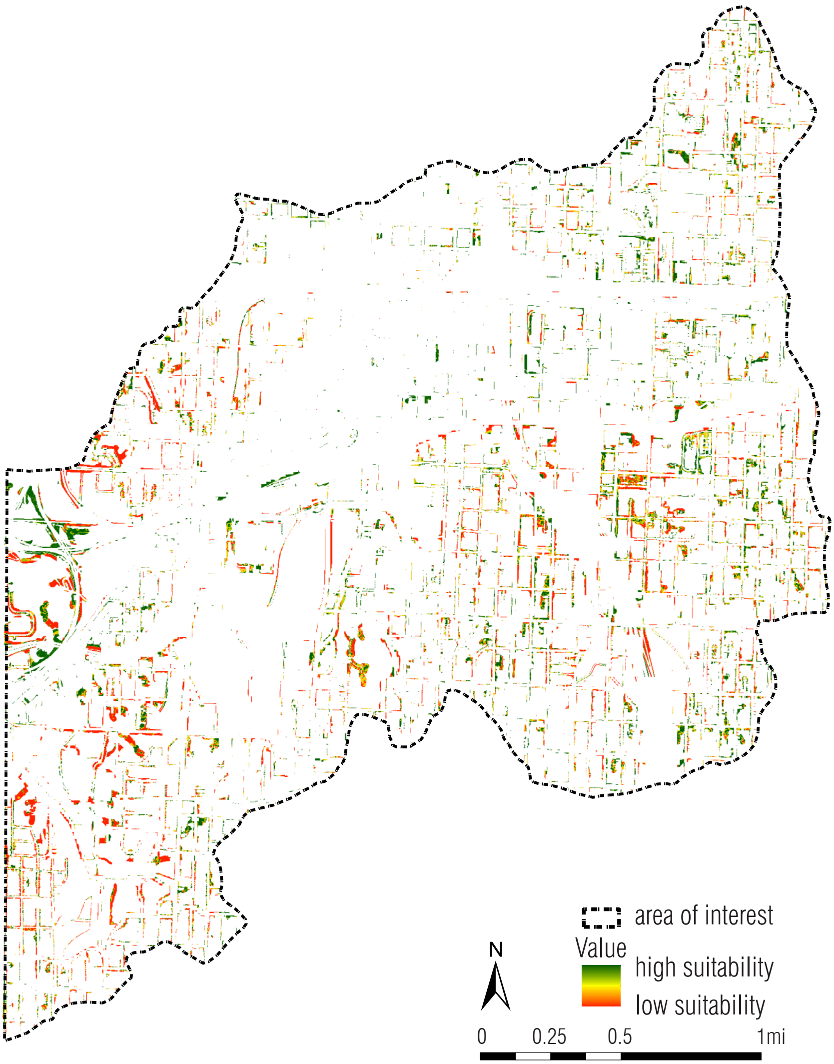


Figure 18: Vegetated Bioswales Suitability Map. Map by author.

throughout the basin. Existing slopes appear to be the primary limiting factor among suitable areas identified. Areas of high suitability were extracted for easier recognition and are represented in Figure 19. Turkey Creek basin appears to have a considerable amount of individual locations highly suitable for vegetated bioswales. Some identified areas may only be large enough to support a single bioswale according to Figure 19. Other identified areas appear to be capable of supporting a system of vegetated bioswales that extend a full city block in length.

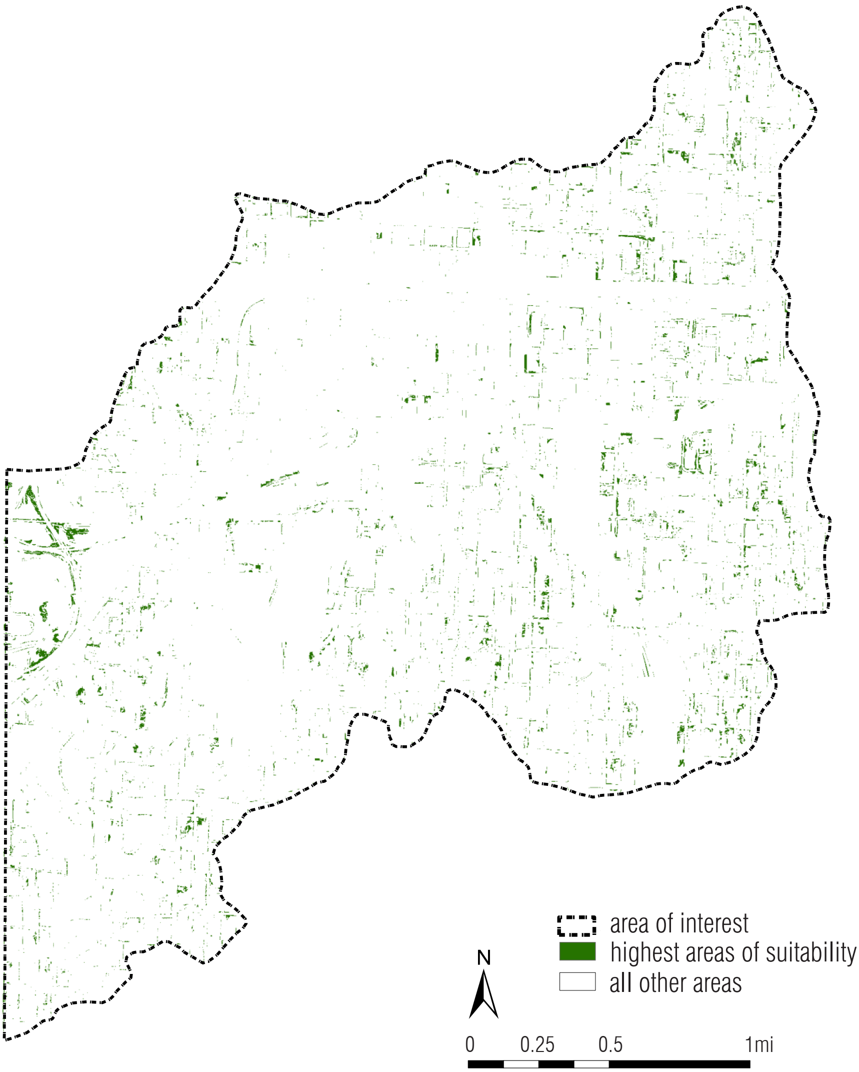


Figure 19: Vegetated Bioswales Highest Suitability Map. Map by author.

Dry Swales

An open grassed conveyance channel that filters, attenuates, and detains stormwater runoff as it moves to lower elevations.

Dry swales are commonly positioned alongside roadways or property lines as well as the perimeter of parking lots to filter and infiltrate stormwater runoff on-site. Effective dry swales require gentle longitudinal slopes and shallow runoff depths to increase contact with the vegetated surface and promote infiltration. Runoff collected in elongated dry swales takes a considerably longer time to reach outlet points, such as an overflow control system, and therefore delays the rate at which a site's runoff enters the sewer system. Swales may be vegetated with turf or native grasses, shrubs, trees, wetland plants, or a mixture of these vegetation types (Water Environment Federation, 2012). Existing roadside ditches and medians may also be converted into dry swales.

A suitability analysis of dry swales in Turkey Creek basin was performed to identify areas of opportunity. A total of six factors were considered in analysis, including slope, setbacks, proximity to flow accumulation, impervious surfaces, soils, and property ownership (Table 8). Existing slopes are rated on a scale of one(1) to nine(9) with one representing low suitability and nine representing high suitability. Slopes between one and two percent are highly suitable for dry swales and received a rating of nine because of the ability to detain runoff and promote infiltration (Metropolitan Government of Nashville and Davidson County, 2012). Steeper slopes are incrementally less suitable for dry swales.

All remaining factors are rated on an inclusion or exclusion basis where zero(0) represents an exclusion of the data from further analysis and one(1) represents an inclusion of the data for further analysis. Dry swales must be setback from wells and structures because of the infiltration services dry swales provide. Therefore, areas within a 100' radius of wells and 10' of structures received a rating of zero, and were excluded from further analysis (Metropolitan Government of Nashville and Davidson County, 2012). A 20' buffer from the edge of street pavement was also included in analysis to account for dry swale placement alongside roads and parking lots. Areas located within the 20' buffer received a rating of one and were included in further suitability analysis. All areas located outside the 20' buffer of parking lots and roadways received a rating of zero and were excluded from further analysis.

Goal 4	Identify lands most suitable for dry swales	
Objective 4.1	Determine lands physically suitable for dry swales	
Sub-objective 4.1.1	Identify optimal slope	Scale (1-9)*
	0% - 1%	8
	1% - 2%	9
	2% - 3%	7
	3% - 4%	6
	4% - 5%	5
	5% - 6%	4
	6% - 7%	3
	7% - 8%	2
	+8%	1
Sub-objective 4.1.2	Identify setbacks	Scale (0-1)**
	Wells	
	0 - 100 ft	0
	+100 ft	1
	Structures	
	0 - 10 ft	0
	+10 ft	1
	Parking Lots	
	0 - 20 ft	1
	+20 ft	0
	Edge of Pavement	
	0 - 20 ft	1
	+20 ft	0
Sub-objective 4.1.3	Identify proximity to flow accumulation	Scale (0-1)**
	0 - 50 ft	1
	+50 ft	0
Sub-objective 4.1.4	Identify impervious surfaces	Scale (0-1)**
	Impervious	0
	Pervious	1
Sub-objective 4.1.5	Identify optimal soils	N/A
Objective 4.2	Identify lands politically suitable for dry swales	
Sub-objective 4.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-9) represents weight of variable data with (1) being the lowest and (9) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 8: Dry Swales Suitability Matrix

Additional suitability analysis of dry swales considered the site's existing hydrologic patterns by identifying areas within 50' proximity of stormwater flow accumulation. All areas located inside the 50' buffer received a rating of one and were included in further suitability analysis. Finally, all impervious surfaces and public parcels received a rating of zero and were excluded from suitability analysis. Soils would require special engineering to be suitable for dry swales and therefore are not weighted.

All six factors were overlaid in GIS to identify areas suitable for dry swales in Turkey Creek basin. Suitable locations for dry swales are represented in

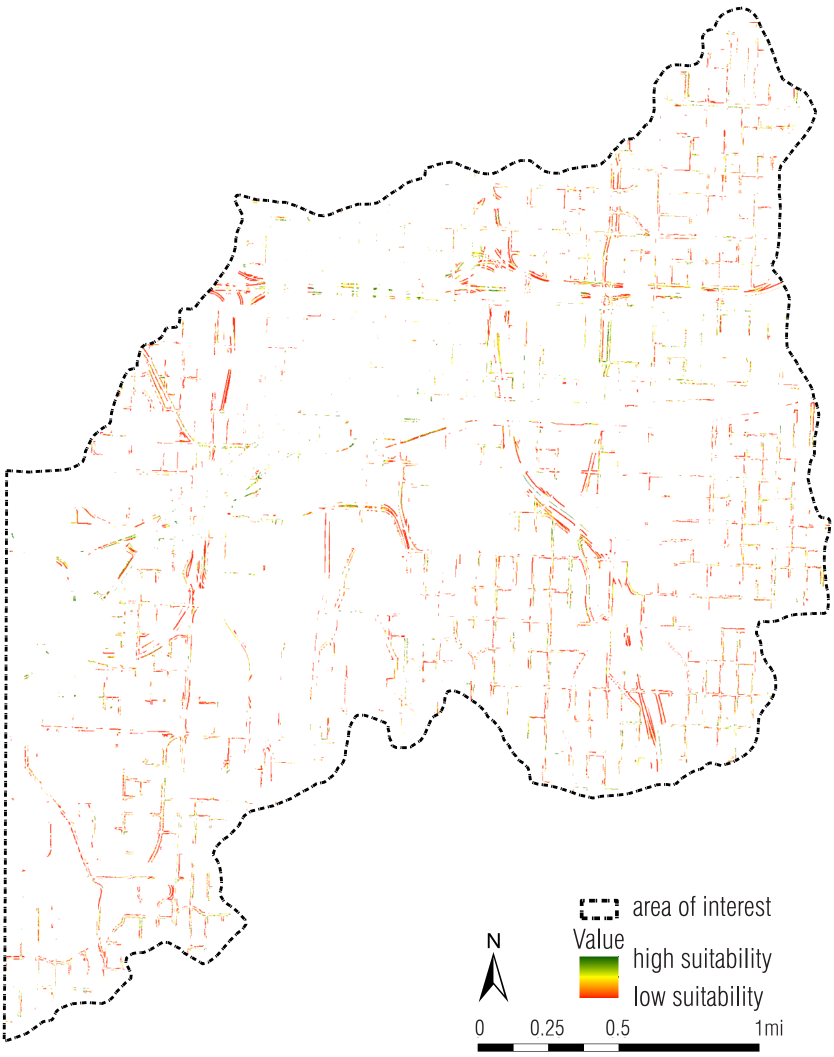


Figure 20: Dry Swales Suitability Map. Map by author.

Figure 20. Analysis concluded that much of the suitable area is moderate to poorly suitable. This is likely due to the existing terrain alongside roadways being too steep to support dry swales. Areas of high suitability were extracted for easier recognition and are represented in Figure 21. Highly suitable areas are sporadically located throughout Turkey Creek basin but are primarily found alongside artery roads and boulevards where open space is available. Ultimately, dry swales are not widely suitable for Turkey Creek basin. Other BMPs should be explored to assist dry swales in the management of stormwater runoff.

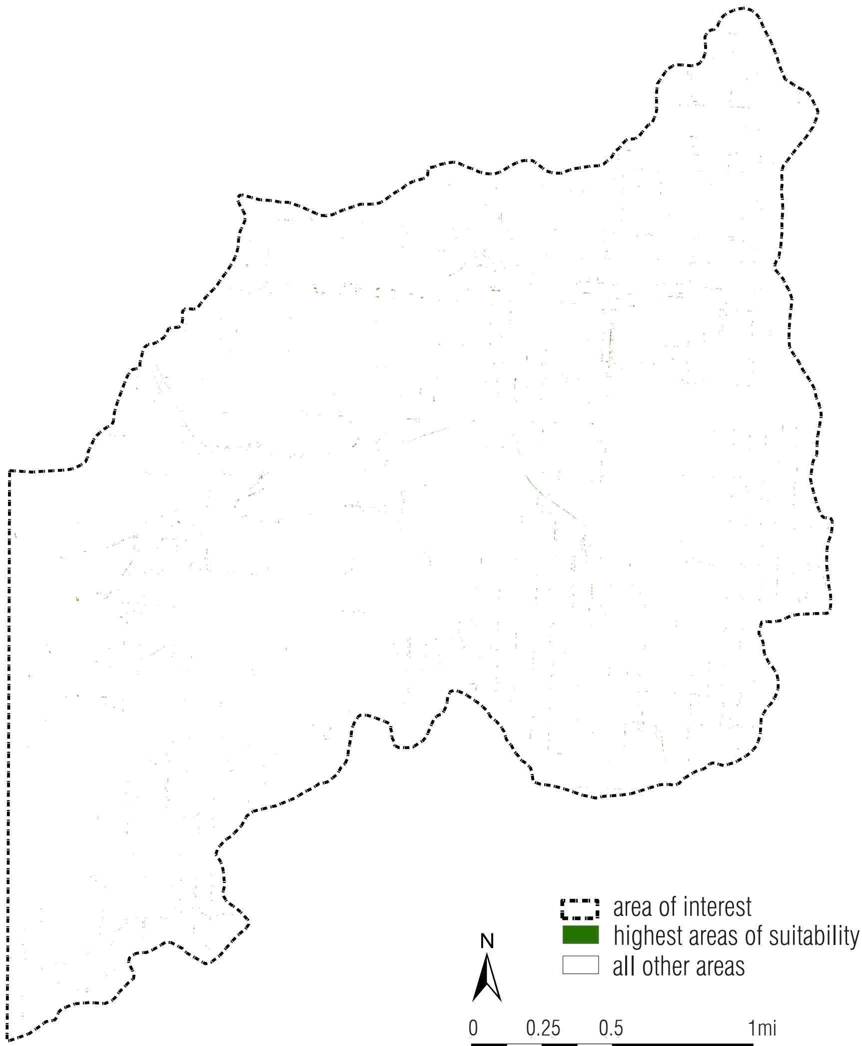


Figure 21: Dry Swales Highest Suitability Map. Map by author.

Native Revegetation

The planting of native species of vegetation that existed in a specific geographical region prior to development.

Using native plants to vegetate an area is an effective method of improving the quality and reducing the volume of a site's stormwater runoff. Native plant species should be from the same ecoregion as the project site. Compared to conventional lawn plantings, native species are typically more tolerant and resistant to pest, drought, and other local conditions. Additionally, the denser root systems of native species result in enhanced infiltration and transpiration (Southeast Michigan Council of Governments, 2008). Species native to Kansas City include various types of woody plants, tall grasses, and trees. Additional information relating to native plant

Goal 5	Identify lands most suitable for native revegetation	
Objective 5.1	Determine lands physically suitable for native revegetation	
Sub-objective 5.1.1	Identify optimal slope	Scale (1-9)
	0% - 5%	9
	5% - 10%	9
	10% - 15%	9
	15% - 20%	9
	20% - 25%	9
	25% - 35%	9
	35% - 45%	9
	+45%	1
Sub-objective 5.1.2	Identify land uses	Scale (1-9)
	Residential	9
	Mixed Use	9
	Industrial	9
	Commercial	9
	Office	7
Sub-objective 5.1.3	Identify land cover	Scale (1-9)
	Open Water	1
	Deciduous Woodland and Immature Forests (Urban)	4
	Developed Land	9
	Lowland Hardwood Forest and Woodland (Urban)	4
	Deciduous Forest (Urban)	4
	Deciduous Woodland and Immature Forests	2
	Oak Woodland and Savanna (Urban)	2

Table 9: Native Revegetation Suitability Matrix

species and their use in landscaping is available from the Missouri Prairie Foundation, at www.moprairie.org.

A suitability analysis of native revegetation in Turkey Creek basin was performed to identify areas of opportunity. Analysis did not account for the individual requirements of each plant species (i.e. soil, hydrologic regimes, sun exposure, aesthetics). Instead, analysis represents the general requirements of vegetation native to the Midwest. A total of seven factors were considered in analysis, including slope, land use type, land cover, surface aspect, impervious surfaces, soils, and property ownership (Table 9). Four of the seven factors (slope, land use, land cover, and surface aspect) were rated on a scale of one(1) to nine(9), with one representing low suitability and nine representing high suitability. Given the deep root structures of plant species native to the Midwest, native vegetation is suitable on slopes up to 45% (Southeast Michigan Council of Governments, 2008). All slopes from zero to 45% received a suitability rating of nine while slopes steeper than 45% received a low suitability rating of one.

Southern facing slopes received incrementally higher suitability ratings than slopes facing north, east, and west due to longer periods of sun exposure

Goal 5	Identify lands most suitable for native revegetation	
Sub-objective 5.1.4	Identify surface aspect	Scale (1-9)
	North	1
	Northeast	3
	East	5
	Southeast	7
	South	9
	Southwest	7
	West	5
	Northwest	3
Sub-objective 5.1.5	Identify impervious surfaces	Scale (0-1)
	Impervious	0
	Pervious	1
Sub-objective 5.1.6	Identify optimal soils	N/A
Objective 5.2	Identify lands politically suitable for native revegetation	
Sub-objective 5.2.1	Identify ownership of property	Scale (0-1)
	Private	1
	Public	0

*Scale (1-9) represents weight of variable data with (1) being the lowest and (5) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

for southern-facing slopes. Native vegetation is also widely suitable across land use types. Residential, mixed use, industrial, and commercial land use types received a rating of nine. Office land use received a moderately-high suitability rating of seven because the planting of native vegetation is limited given the lack of available open space. Finally, all impervious surfaces and public parcels received a rating of zero and were omitted from further analysis. Although soil suitability is crucial to the establishment of native plantings, soils will need to be amended to fit the unique requirements of the desired plant species.

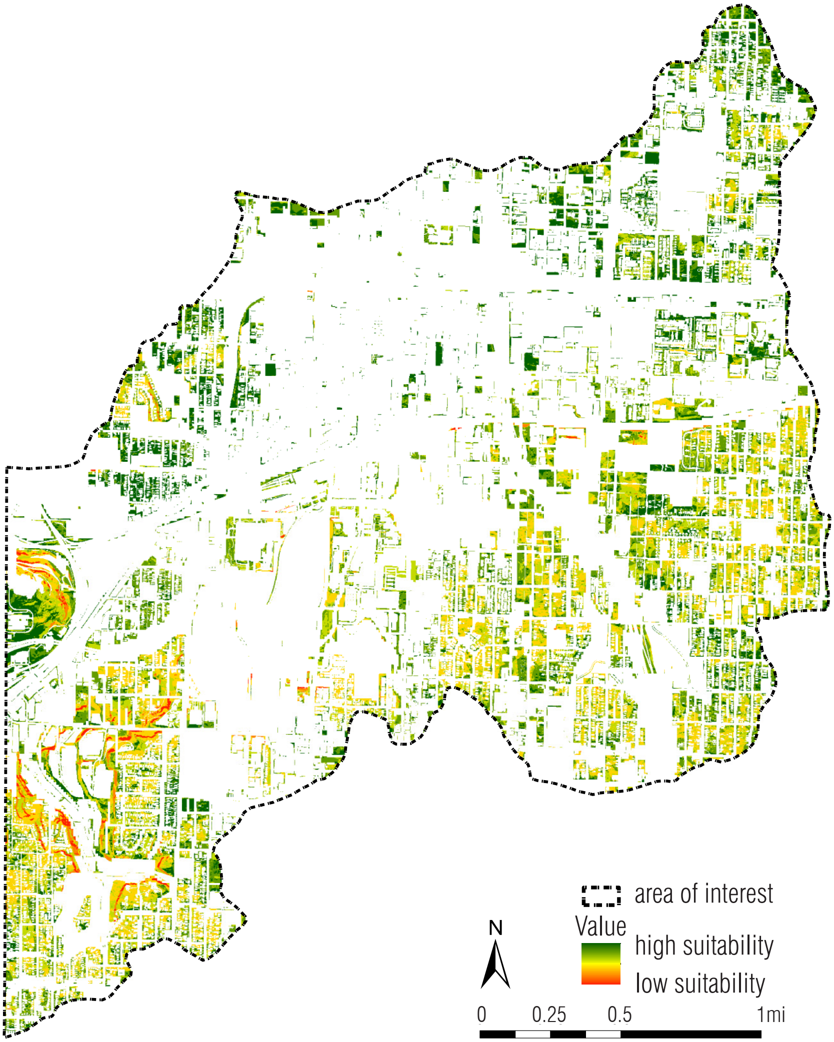


Figure 22: Native Revegetation Suitability Map. Map by author.

All seven factors were overlaid in GIS to identify areas suitable for native revegetation in Turkey Creek basin. Suitable locations for native revegetation are represented in Figure 22. Analysis reveals that a significant portion of Turkey Creek basin is suitable for native revegetation. Suitability for native revegetation is primarily moderate to high. Nearly all privately-owned open space and lawn could be replaced with native vegetation at varying levels of suitability. Areas of high suitability were extracted for easier recognition and are represented in Figure 23. Native revegetation is one of the most suitable BMPs for Turkey Creek basin given existing conditions and should be rigorously explored by Kansas City.

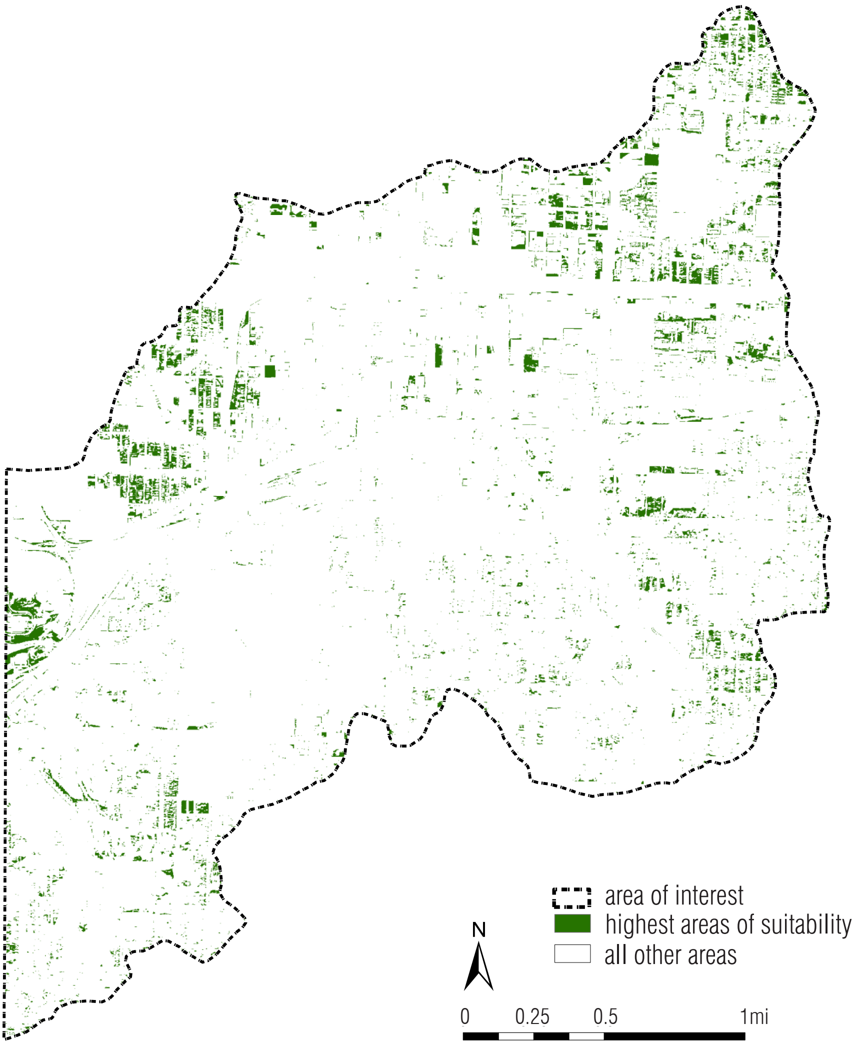


Figure 23: Native Revegetation Highest Suitability Map. Map by author.

Retention Ponds

A constructed stormwater pond that retains a permanent pool of water, with some biological treatment.

Retention ponds are designed to collect stormwater runoff in a permanent pool planted with aquatic vegetation that assists in the removal of pollutants. Retention ponds are commonly positioned in locations capable of maintaining a permanent pool of water throughout the year. To maintain a permanent pool, the bottom of the basin must be composed of relatively impervious soils and the drainage area should be large enough to provide sufficient runoff. Generally, a continual supply of rain, runoff, and groundwater is required to maintain permanent pool levels (Southeast Michigan Council of Governments, 2008). Thus, retention ponds tend to require a relatively large footprint to accommodate the runoff volumes contributed by the drainage area.

A suitability analysis of retention ponds in Turkey Creek basin was performed to identify areas of opportunity. A total of seven factors were considered in analysis, including slope, setbacks, proximity to drainage

Goal 6	Identify lands most suitable for retention ponds	
Objective 6.1	Determine lands physically suitable for retention ponds	
Sub-objective 6.1.1	Identify optimal slope	Scale (1-9)
	0% - 5%	8
	5% - 10%	9
	10% - 15%	8
	15% - 20%	7
	20% - 25%	6
	25% - 30%	5
	30% - 35%	4
	35% - 40%	2
	+40%	1
Sub-objective 6.1.2	Identify proximity to drainage points	Scale (1-9)
	0 - 10 ft	9
	10 - 20 ft	8
	20 - 30 ft	7
	30 - 40 ft	6
	40 - 50 ft	5
	50 - 60 ft	4

Table 10: Retention Pond Suitability Matrix

points, drainage area, impervious surfaces, soils, and property ownership (Table 10). Existing slopes and basin drainage points are rated on a scale of one(1) to nine(9) with one representing low suitability and nine representing high suitability. Slopes surrounding retention ponds should not exceed 10% (City of Eugene, Oregon, 2008). Therefore, slopes were classified into increments of five percent change with those slopes between five and 10% receiving a rating of nine. Suitability ratings for the remaining slopes were progressively lower for steeper and flatter slopes. Since all runoff drains to a few common drainage points in the basin, retention ponds would be best positioned at these locations. Hypothetical buffer zones arranged around these drainage points were used to rate suitable distances for retention ponds from drainage points. Areas within a 10' radius of drainage points

Goal 6	Identify lands most suitable for retention ponds	
Sub-objective 6.1.3	Identify setbacks	Scale (0-1)
	Wells	
	0 - 50 ft	0
	+50 ft	1
	Structures	
	0 - 20 ft	0
	+20 ft	1
	Stream	
	0 - 25 ft	0
	+25 ft	1
	Wetland	
	0 - 25 ft	0
	+25 ft	1
Sub-objective 6.1.4	Identify appropriate drainage area	Scale (0-1)
	0 - 5 ac	0
	+5 ac	1
Sub-objective 6.1.5	Identify impervious surfaces	Scale (0-1)
	Impervious	0
	Pervious	1
Sub-objective 6.1.6	Identify optimal soils	N/A
Objective 6.2	Identify lands politically suitable for retention ponds	
Sub-objective 6.2.1	Identify ownership of property	Scale (0-1)
	Private	1
	Public	0

*Scale (1-5) represents weight of variable data with (1) being the lowest and (5) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

received a rating of nine. Areas located further away from drainage points received lower suitability ratings.

All remaining factors were rated on an inclusion or exclusion basis with zero(0) representing an exclusion of the data from further analysis and one(1) representing an inclusion of the data for further analysis. To maintain a permanent pool, retention ponds must receive runoff from drainage areas five acres in size or larger (Southeast Michigan Council of Governments, 2008). Drainage areas smaller than five acres in size received a rating of zero and were excluded from further analysis. Furthermore, retention ponds must be setback 50' from wells, 20' from structures, 25' from streams,

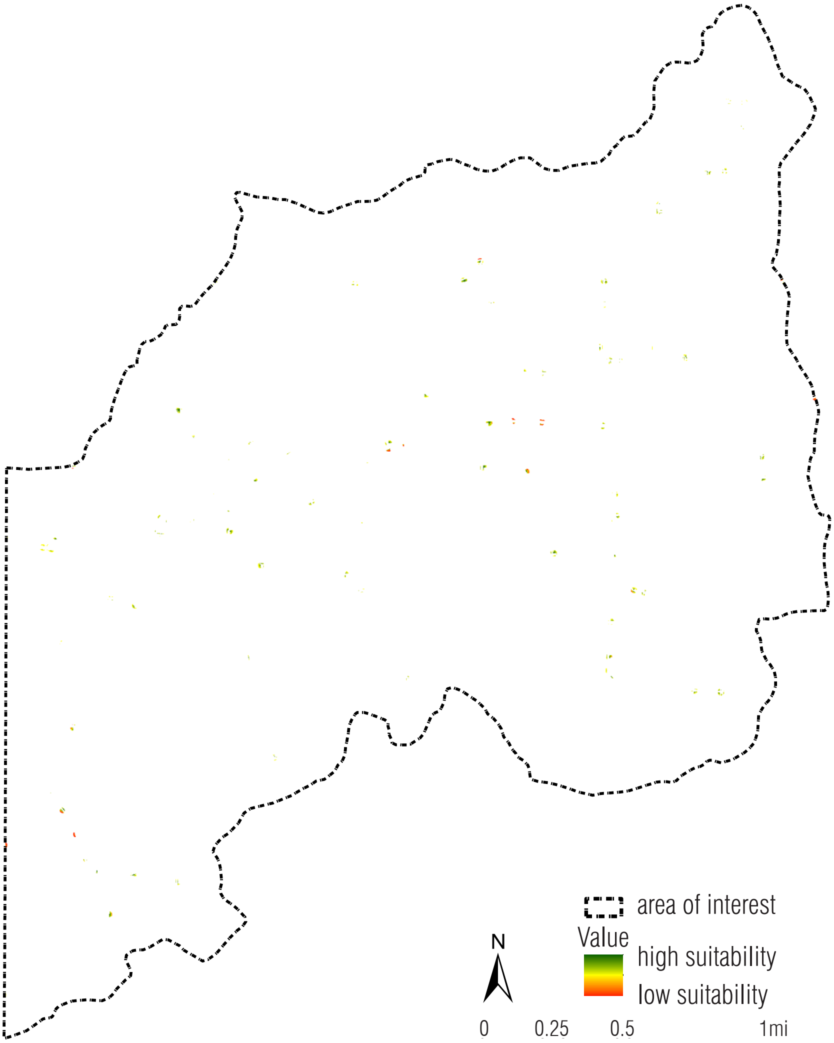


Figure 24: Retention Ponds Suitability Map. Map by author.

and 25’ from existing wetlands (City of Eugene, Oregon, 2008). All areas located inside these setbacks received a rating of zero and were also excluded from further analysis.

All seven factors were overlaid in GIS to identify areas suitable for retention ponds in Turkey Creek basin. As Figure 24 indicates, very few suitable locations for retention ponds exist in Turkey Creek basin due to drainage points being paved with impermeable material. Areas of high suitability were extracted for easier recognition and are represented in Figure 25. Retention ponds are not a suitable BMP for Turkey Creek basin given existing conditions.

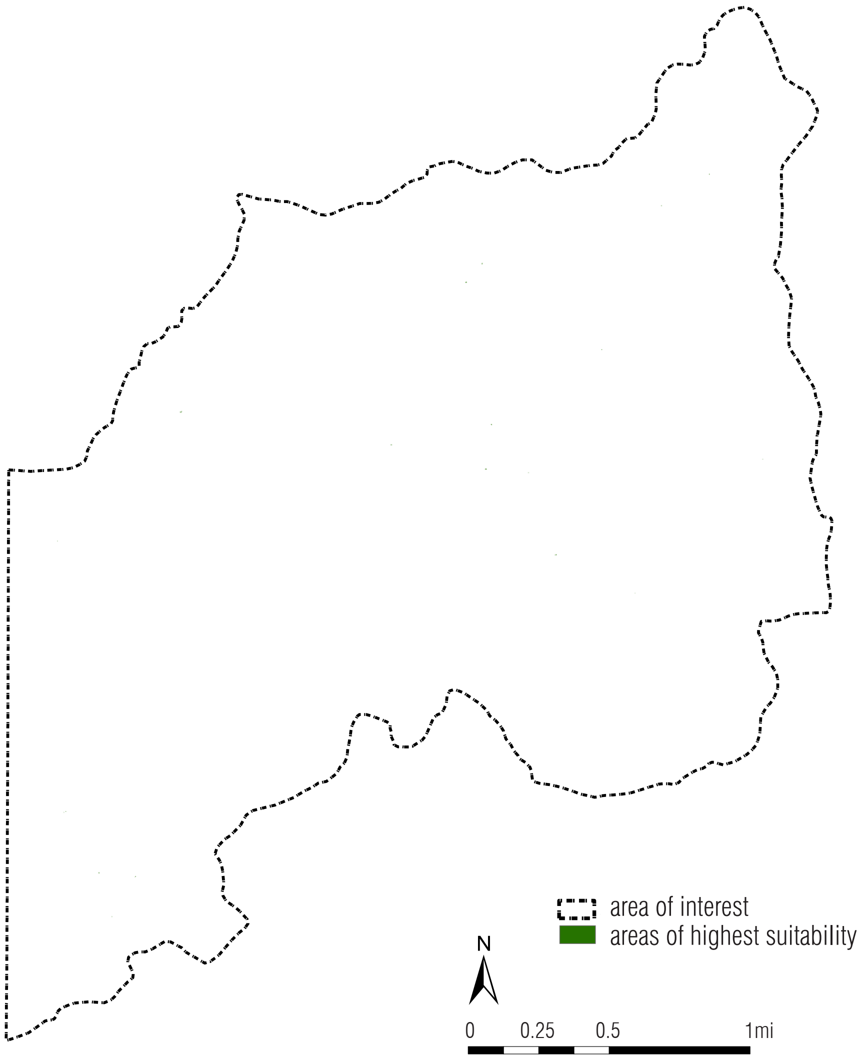


Figure 25: Retention Ponds Highest Suitability Map. Map by author.

Rainwater Harvesting

The use of an aboveground storage container that is directly connected with a roof downspout. Stormwater is diverted from the roof and stored for future use.

Rainwater harvesting refers to the use of a rain barrel connected to the downspout of a structure to capture stormwater for nonpotable water uses such as irrigation. Rainwater harvesting is most often incorporated at individual homes where stormwater can be reused for garden irrigation, including grass lawns, landscaped beds, trees, and other vegetated areas. Rain barrels can also be used in urbanized areas where the need for additional onsite irrigation exists. If deployment is significant in a watershed, rain barrels can reduce the amount of runoff and pollutants entering the sewer system by detaining stormwater on site. Pollutants captured by rain barrels are removed by settling and, if the captured runoff is directed to landscaped areas, through filtering and vegetative uptake (Water Environment Federation, 2012). Most rain barrels are relatively inexpensive compared to other BMPs and require little maintenance and preparation. Rain barrels are commercially available in many sizes, although most hold an average of 50 gallons of stormwater (University of Arkansas Community Design Center, 2010). For maximum effectiveness, rain barrels can be placed at every downspout. Once at capacity, any excess runoff should be directed to landscaped areas for infiltration.

A suitability analysis of rainwater harvesting in Turkey Creek basin was performed to identify areas of opportunity. A total of three factors were considered in the analysis, including land use, proximity to structures, and property ownership (Table 11). The small number of factors included in the analysis indicates that there are few limiting factors for rainwater harvesting. Land use types are rated on a scale of one(1) to five(5), with one representing low suitability and five representing high suitability. Although rainwater harvesting is feasible for all five land use types represented, suitability ratings were determined by considering rainwater harvesting's overall effectiveness per land use type. Residential land use received the highest suitability rating of five because captured stormwater can be reused to irrigate surrounding vegetation. Office land use received the lowest suitability rating of one because of the limited space surrounding office structures which would discourage use of large rain barrels. Mixed use, industrial, and commercial land use types received ratings of four, three, and two respectively.

Goal 7	Identify lands most suitable for rainwater harvesting	
Objective 7.1	Determine lands physically suitable for rainwater harvesting	
Sub-objective 7.1.1	Identify land uses	Scale (1-5)*
	Residential	5
	Mixed Use	4
	Industrial	3
	Commercial	2
	Office	1
Sub-objective 7.1.1	Identify proximity to structures	Scale (0-1)**
	0 - 10 ft	1
	+10 ft	0
Objective 7.2	Identify lands politically suitable for rainwater harvesting	
Sub-objective 7.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-5) represents weight of variable data with (1) being the lowest and (5) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 11: Rainwater Harvesting Suitability Matrix

All remaining factors were rated on an inclusion or exclusion basis with zero(0) representing an exclusion of the data from further analysis and one(1) representing an inclusion of the data for further analysis. Of the three factors used to determine rainwater harvesting suitability, proximity to structures is the most important factor. Rain barrels must be connected to a building's downspout to collect stormwater from the building's roof. Therefore, a buffer zone of 10' was determined to be a suitable distance to apply a rain barrel. All areas within 10' of a structure received a rating of one. All other areas outside of the 10' buffer zone received a rating of zero. Public parcels received a rating of zero and were excluded from further analysis as well.

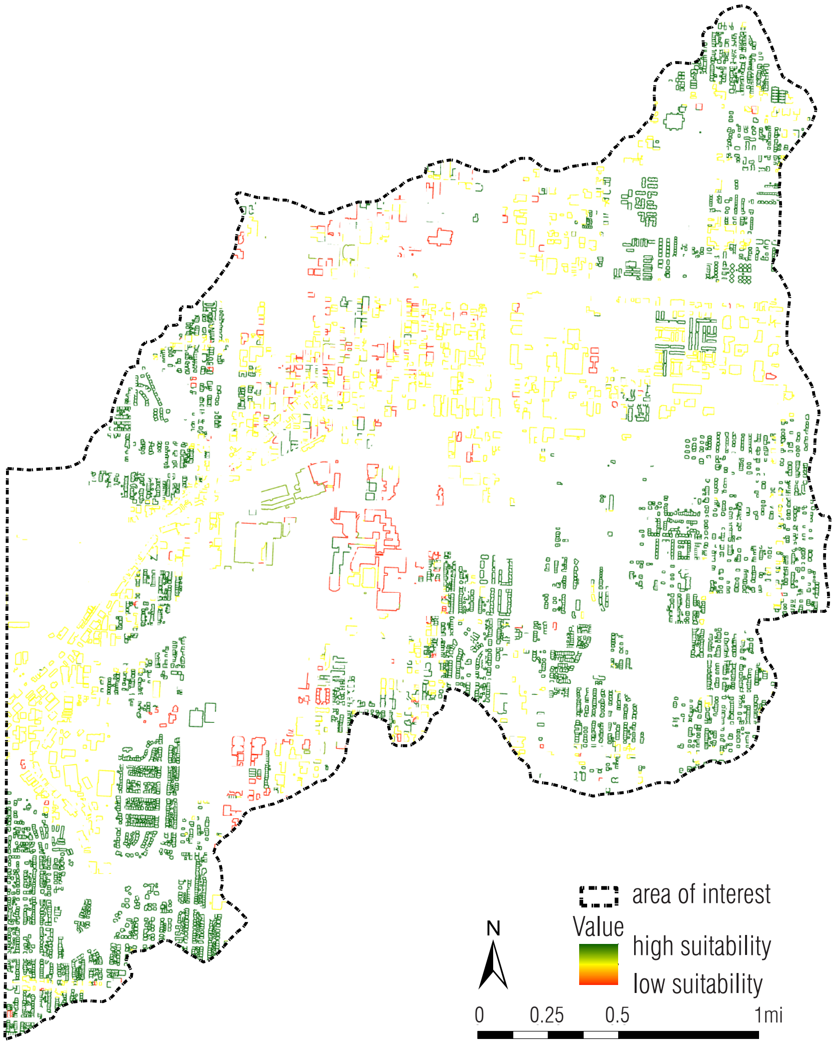


Figure 26: Rainwater Harvesting Suitability Map. Map by author.

All three factors were overlaid in GIS to identify areas suitable for rainwater harvesting in Turkey Creek basin. Suitable locations for rainwater harvesting are represented in Figure 26. Results indicate that rainwater harvesting is suitable in many locations across the basin. Areas of high suitability were extracted for easier recognition and are represented in Figure 27. Due to the small number of factors used for analysis, residential land uses directly correlate with areas of high suitability for rainwater harvesting. Rainwater harvesting appears to be a viable option for residential BMPs and should be further explored in Kansas City.

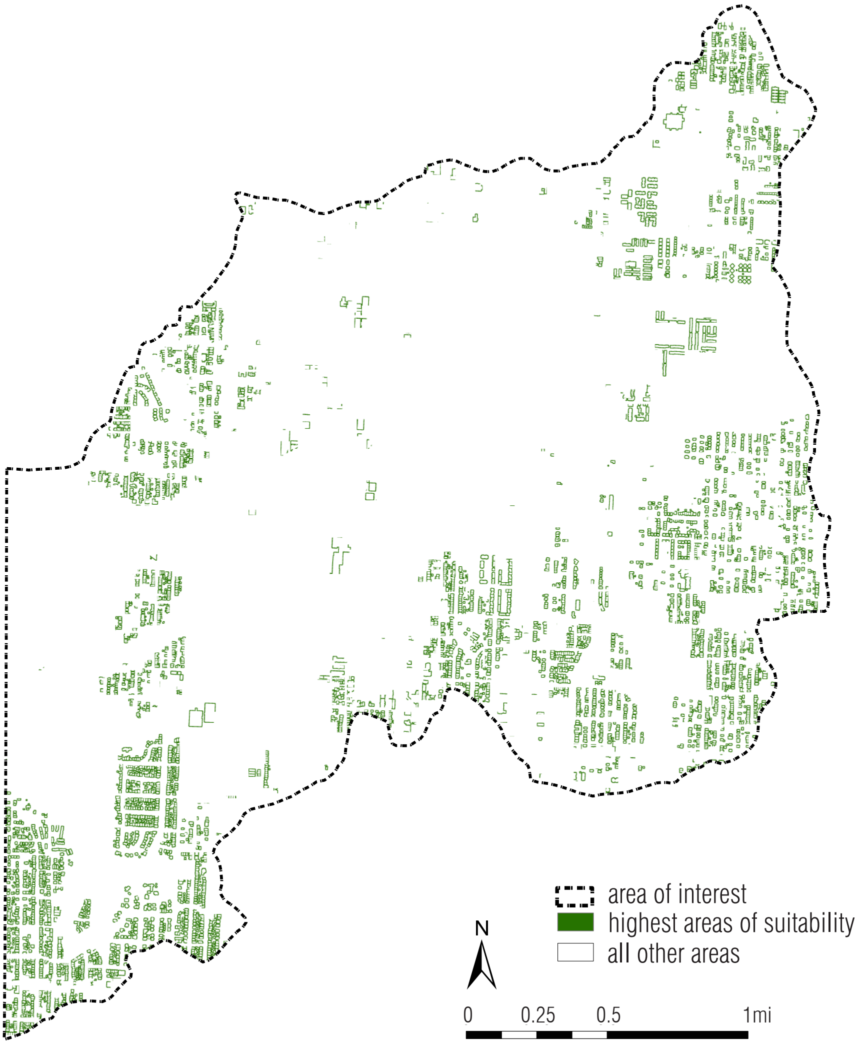


Figure 27: Rainwater Harvesting Highest Suitability Map. Map by author.

Infiltration Trenches

Small-scale, linear infiltration systems designed to collect and infiltrate stormwater runoff into the soil.

As the name suggests, the primary intent of infiltration trenches is to support the infiltration of stormwater runoff through an engineered trench with permeable soils over the length of 48 hours. Infiltration trenches are lined with a geotextile fabric and filled with gravel in place of the excavated soil (Water Environment Federation, 2012). The additional pore space created by the gravel allows for faster infiltration rates while the gravel filters particulates from the stormwater runoff. If installed as a system of multiple trenches, a perforated pipe placed under the gravel can convey excess runoff away from the heavily saturated soils during large storm events to prevent the trench from being flooded (Southeast Michigan Council of Governments, 2008).

Figure 28: Infiltration Trench Diagram. Diagram by author. Adapted from Sustainable Stormwater Management, 2007.

A total of six factors were included in the suitability analysis of infiltration trenches for Turkey Creek basin. The six factors include, slope, setbacks, impervious surfaces, proximity to flow accumulation, soils, and property ownership (Table 12). Existing slopes were rated on a scale of one(1) to five(5), with one representing low suitability and five representing high suitability. For infiltration to occur, trenches should be situated on a site with little or no slope (Southeast Michigan Council of Governments, 2008). Therefore, slopes between zero and two percent were determined to be highly suitable and received a rating of five. Slopes above five percent are less suitable and therefore received a rating of one.

Goal 8	Identify lands most suitable for infiltration trenches	
Objective 8.1	Determine lands physically suitable for infiltration trenches	
Sub-objective 8.1.1	Identify optimal slope	Scale (1-5)*
	0% - 2%	5
	2% - 5%	2
	5% - 10%	1
	10% - 15%	1
	+15%	1
Sub-objective 8.1.2	Identify setbacks	Scale (0-1)**
	Wells	
	0 - 50 ft	0
	+50 ft	1
	Structures	
	0 - 10 ft	0
	+10 ft	1
Sub-objective 8.1.3	Identify impervious surfaces	Scale (0-1)**
	Impervious surfaces	0
	Pervious surfaces	1
Sub-objective 8.1.4	Identify proximity to flow accumulation	Scale (0-1)**
	0 - 20 ft	1
	+20 ft	0
Sub-objective 8.1.5	Identify optimal soils	N/A
Objective 8.2	Identify lands politically suitable for infiltration trenches	
Sub-objective 8.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-5) represents weight of variable data with (1) being the lowest and (5) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 12: Infiltration Trench Suitability Matrix

All other factors were rated on an inclusion or exclusion basis with zero(0) representing an exclusion of the data from further analysis and one(1) representing an inclusion of the data for further analysis. Infiltration trenches must be set back from wells and structures because of the infiltration service the trenches provide. Areas within a 50’ radius of wells and a 10’ distance from structures received a rating of zero and were excluded from further analysis (Southeast Michigan Council of Governments, 2008). To improve the effectiveness of infiltration trenches, areas within 20’ proximity of stormwater flow accumulation received a rating of one. Finally, all impervious surfaces are unsuitable for infiltration trenches and received a rating of zero. In addition to impervious surfaces, public parcels also

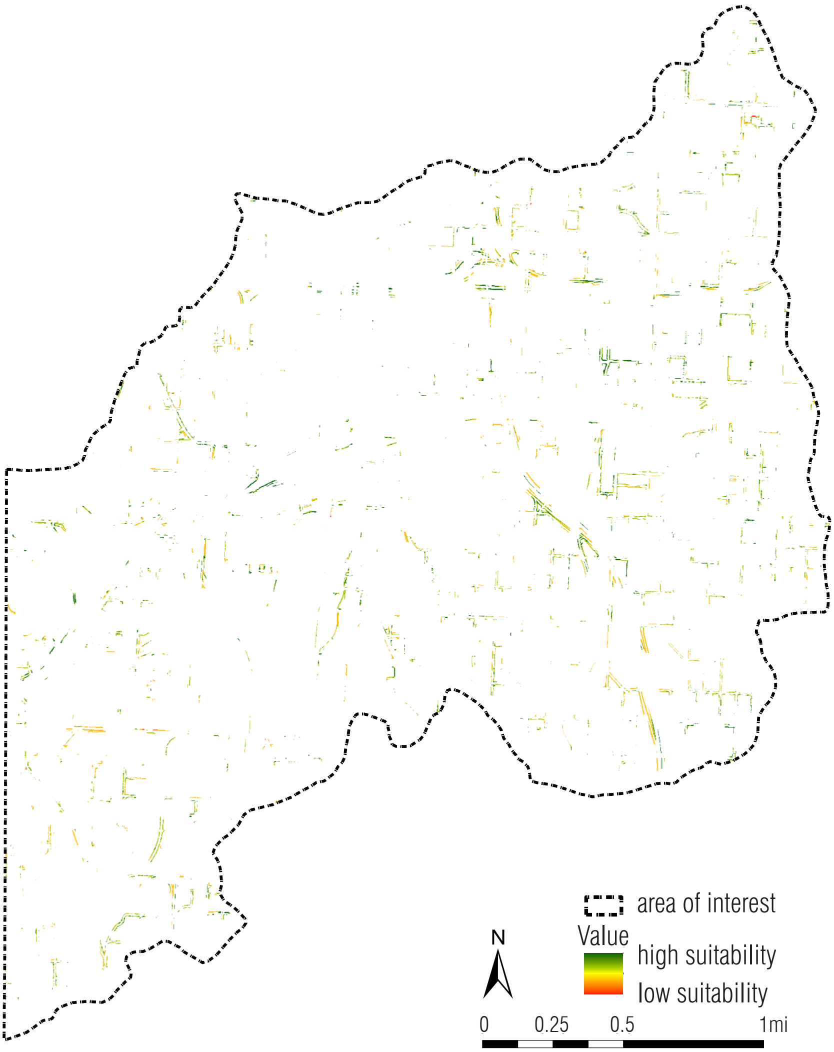


Figure 29: Infiltration Trenches Suitability Map. Map by author.

received a rating of zero and were excluded from further analysis. All soils would require special engineering to be suitable for infiltration trenches and therefore are not weighted.

All six factors were overlaid in GIS to identify suitable areas for infiltration trenches in Turkey Creek basin. Suitable locations for infiltration trenches are represented in Figure 29. Much of the suitable areas identified are classified as being moderate to highly suitable. Highly suitable areas were extracted from the suitability map for clarity and are represented in Figure 30. Ultimately, infiltration trenches are not widely suitable for Turkey Creek basin. Other BMPs should be explored to assist infiltration trenches in the management of stormwater runoff.

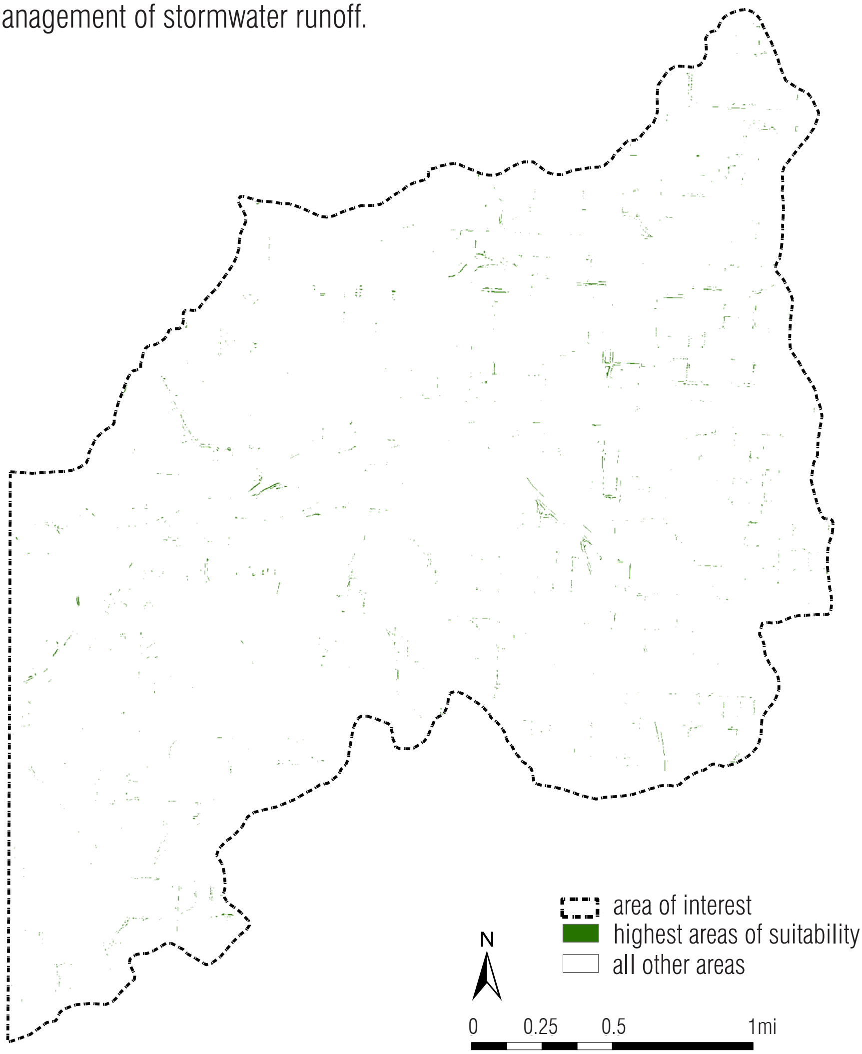


Figure 30: Infiltration Trenches Highest Suitability Map. Map by author.

Detention Ponds

Above-ground basins designed to intercept stormwater runoff for temporary containment and release contained stormwater into a sewer system or a receiving waterbody.

Detention ponds temporarily detain all, or a portion of stormwater runoff from each storm event by placing a controlled outlet at the bottom of the detention basin. The primary purpose of a detention pond is to provide stormwater runoff control to reduce the volume and rate at which runoff is entering the conveyance system. By detaining stormwater during large storm events, downstream habitats are less likely to experience degradation (University of Arkansas Community Design Center, 2010). Detention ponds are constructed by excavating existing soil to create a depression in the landscape and are usually planted with flood-tolerant grasses.

Detention ponds are designed to completely discharge stormwater, usually within 24 – 48 hours of a storm event. This allows stormwater treatment facilities to treat the detained stormwater at a later, more appropriate time instead of inundating the treatment facility with additional runoff and causing untreated water to be discharged into waterbodies. Although the primary function of detention ponds is to detain water for a short period of time, recent research has found that up to 30% of the average annual runoff volume may infiltrate through the soils or transpire while being detained (Strecker et al., 2001). Still, this requires permeable soils which haven't been compacted through urbanization.

A suitability analysis of detention ponds in Turkey Creek basin was performed to identify areas of opportunity. A total of seven factors were considered in analysis, including slope, setbacks, drainage area, drainage points, impervious surfaces, soils, and property ownership (Table 13). Existing slopes were rated on a scale of one(1) to five(5) with one representing low suitability and five representing high suitability. Gentle slopes between zero and five percent received a suitability rating of five for the purpose of installing a level basin. Steeper slopes are incapable of detaining stormwater and are more expensive to excavate and thus received lower suitability ratings (United States Environmental Protection Agency, 2006).

All other factors were rated on an inclusion or exclusion basis with zero(0) representing an exclusion of the data from further analysis and one(1) representing an inclusion of the data for further analysis. Detention ponds should be sufficiently setback at least 10’ from structures and at least 50’ from wells (Southeast Michigan Council of Governments, 2008). Areas inside of these setbacks received a rating of zero and were excluded from further analysis.

The location of a detention pond is imperative to its ability to capture stormwater runoff. As a general rule, detention ponds should be

Goal 9	Identify lands most suitable for detention ponds	
Objective 9.1	Determine lands physically suitable for detention ponds	
Sub-objective 9.1.1	Identify optimal slope	Scale (1-5)*
	0% - 5%	5
	5% - 10%	4
	10% - 15%	3
	15% - 20%	2
	+20%	1
Sub-objective 9.1.2	Identify setbacks	Scale (0-1)**
	Wells	
	0 - 50 ft	0
	+50 ft	1
	Structures	
	0 - 10 ft	0
	+10 ft	1
Sub-objective 9.1.3	Identify drainage area	Scale (0-1)**
	0 - 10 ac	0
	+10 ac	1
Sub-objective 9.1.4	Identify proximity to primary drainage points	Scale (0-1)**
	0 - 100 ft	1
	+100 ft	0
Sub-objective 9.1.5	Identify impervious surfaces	Scale (0-1)**
	Impervious	0
	Pervious	1
Sub-objective 9.1.6	Identify optimal soils	N/A
Objective 9.2	Identify lands politically suitable for detention ponds	
Sub-objective 9.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-5) represents weight of variable data with (1) being the lowest and (5) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 13: Detention Ponds Suitability Matrix

implemented in drainage areas at least 10 acres in size (University of Arkansas Community Design Center, 2010). Therefore, drainage areas larger than 10 acres in size received a rating of one and were included in further analysis. Since all runoff drains to a few common drainage points in the basin, detention ponds would be best positioned at these locations. Hypothetical buffer zones arranged around these drainage points were used to rate suitable distances for detention ponds from drainage points. Areas within a 100' radius of drainage points received a rating of one and were included in further analysis. All impervious surfaces and public parcels received a rating of zero and were excluded from further analysis.

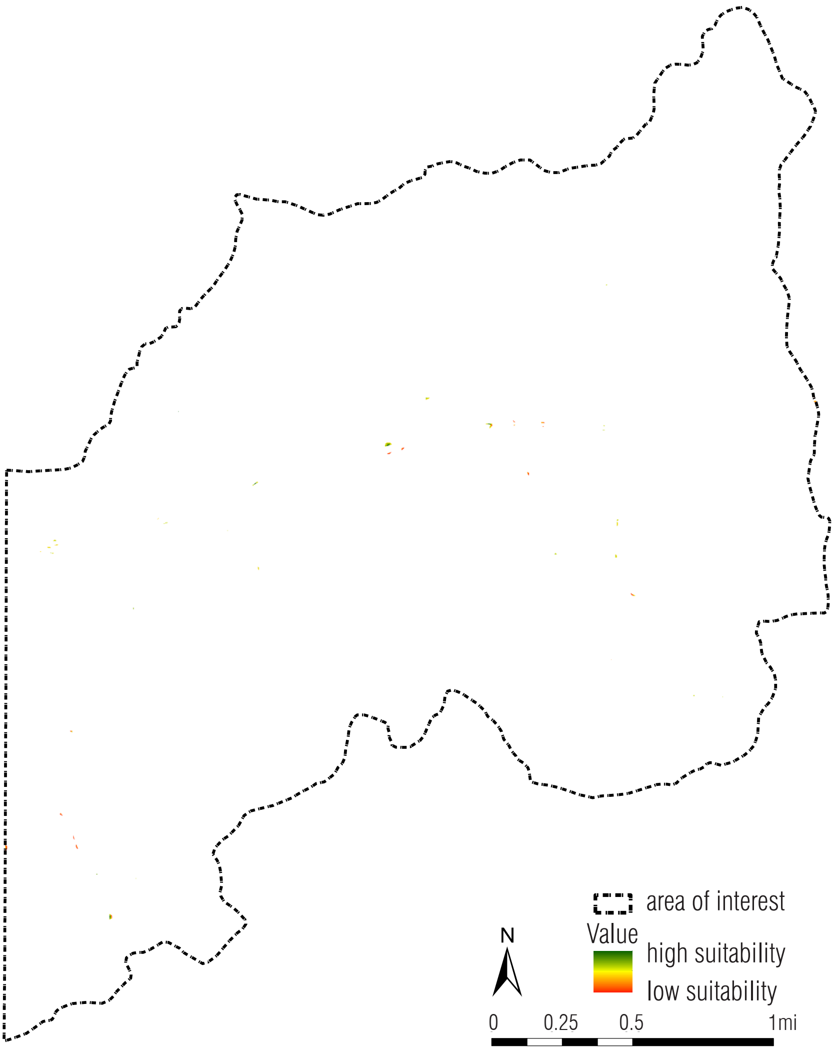


Figure 31: Detention Ponds Suitability Map. Map by author.

All seven factors were overlaid in GIS to identify areas suitable for detention ponds in Turkey Creek basin. Suitable locations for detention ponds are represented in Figure 31. Detention ponds require a large amount of space comparative to other BMPs. Since much of the basin is impervious, many of the drainage points are fully or partially covered with impervious cover. As a result, few locations in the basin are suitable for detention ponds. Areas of high suitability were extracted for easier recognition and are represented in Figure 32. Only a select few locations highly suitable for detention ponds exist. Detention ponds are not a suitable BMP for Turkey Creek basin given existing conditions.

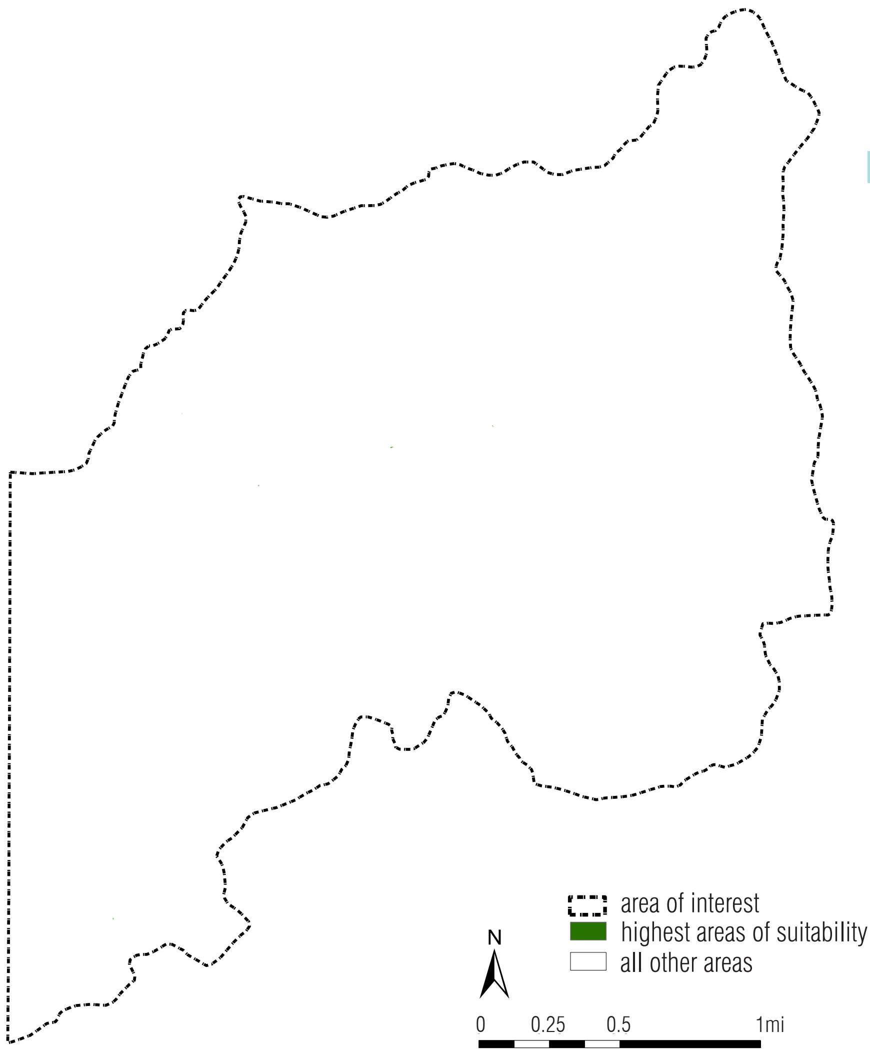


Figure 32: Detention Ponds Highest Suitability Map. Map by author.

Rain Gardens

A small excavated area planted with native wetland and prairie vegetation where stormwater collects and infiltrates.

Rain gardens are commonly promoted as native landscapes that enhance a site's aesthetic appearance while reducing stormwater runoff volumes and improving runoff quality. To do so, rain gardens are designed specifically to incorporate biological processes. By pooling stormwater within a planted area, water is allowed to infiltrate the soil and receive treatment using a combination of biologically-enhanced soils and native vegetation (Figure 33). Together, a rain garden's soil mixture and vegetation can increase the infiltration of stormwater and enhance a site's nutrient and water uptake while supporting transpiration (Water Environment Federation, 2012). Rain gardens are best applied at a relatively small scale and function well when integrated into impervious parking areas and low lying areas of a property (University of Arkansas Community Design Center, 2010).

A suitability analysis of rain gardens in Turkey Creek basin was performed to identify areas of opportunity. A total of seven factors were considered in analysis, including slope, land use, proximity to flow accumulation, setbacks, impervious surfaces, soils, and property ownership (Table 14). To determine the suitability of rain gardens, existing slopes and land use types were rated on a scale of one(1) to six(6), with one representing low

Figure 33: Rain Garden Diagram. Diagram by author. Adapted from United States Environmental Protection Agency, 2013.

suitability and six representing high suitability. A gentle slope is required for rain gardens to direct stormwater into the excavated ponding area (Metropolitan Government of Nashville and Davidson County, 2012).

Goal 10	Identify lands most suitable for rain gardens	
Objective 10.1	Determine lands physically suitable for rain gardens	
Sub-objective 10.1.1	Identify optimal slope	Scale (1-6)*
	0% - 1%	3
	1% - 2%	6
	2% - 3%	6
	3% - 4%	5
	4% - 5%	4
	+5%	2
Sub-objective 10.1.2	Identify land uses	Scale (1-6)*
	Residential	6
	Mixed Use	3
	Industrial	2
	Commercial	4
	Office	1
Sub-objective 10.1.3	Identify proximity to flow accumulation	Scale (0-1)**
	0 - 50 ft	1
	+50 ft	0
Sub-objective 10.1.4	Identify setbacks	Scale (0-1)**
	Wells	
	0 - 10 ft	0
	+10 ft	1
	Structures	
	0 - 10 ft	0
	+10 ft	1
Sub-objective 10.1.5	Identify impervious surfaces	Scale (0-1)**
	Impervious surfaces	0
	Pervious surfaces	1
Sub-objective 10.1.6	Identify optimal soils	N/A
Objective 10.2	Identify lands politically suitable for rain gardens	
Sub-objective 10.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-6) represents weight of variable data with (1) being the lowest and (6) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 14: Rain Gardens Suitability Matrix

Therefore, slopes between one and five percent received higher ratings, while slopes below one percent and above five percent received lower suitability ratings. Although rain gardens can typically be constructed on any land use, some land use types are better suited for rain gardens given the space requirements. Residential and commercial land use types received high suitability ratings, while mixed use, industrial, and office land uses received lower suitability ratings.

All remaining factors are rated on an inclusion or exclusion basis where zero(0) represents an exclusion of the data from further analysis and one(1) represents an inclusion of the data for further analysis. Rain gardens must

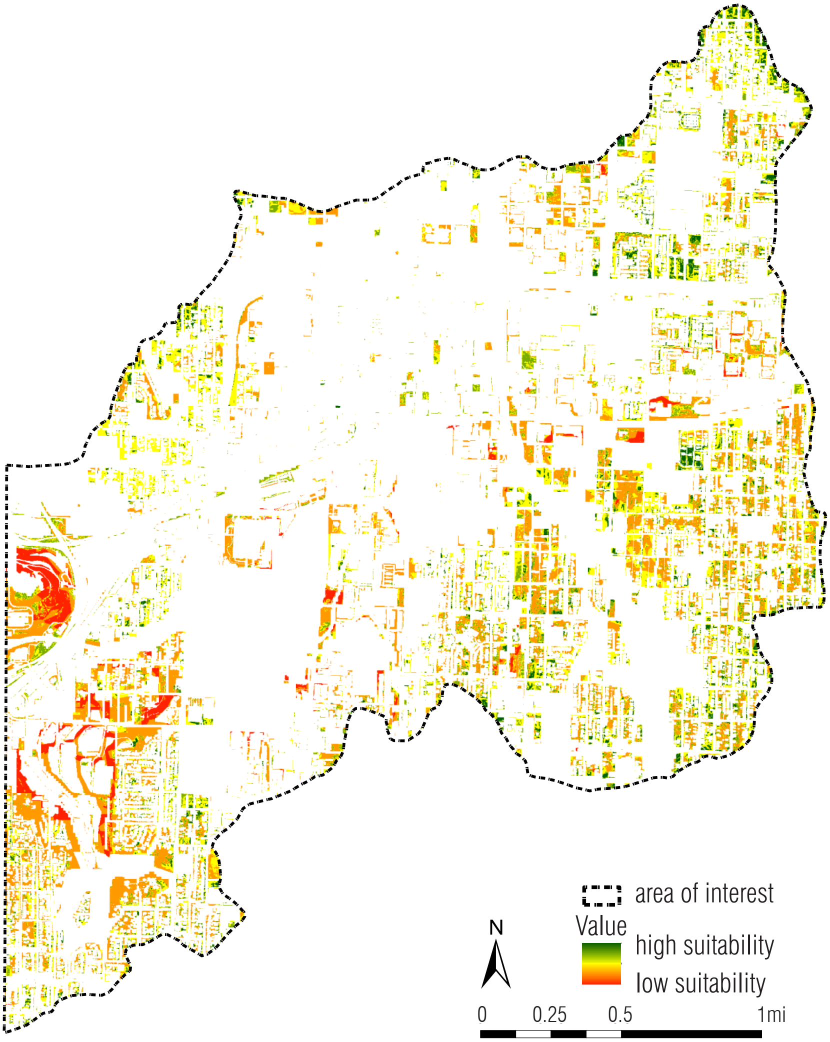


Figure 34: Rain Gardens Suitability Map. Map by author.

be setback 10’ from wells and structures because of the infiltration services rain gardens provide (Southeast Michigan Council of Governments, 2008). All areas located inside the 10’ setback received a rating of zero and excluded from further analysis.

All seven factors were overlaid in GIS to identify areas suitable for rain gardens in Turkey Creek basin. Suitable locations for rain gardens are represented in Figure 34. Analysis concluded that there are many locations in Turkey Creek basin which are moderately to poorly suitable for rain gardens. Areas of high suitability were extracted for easier recognition and are represented in Figure 35.

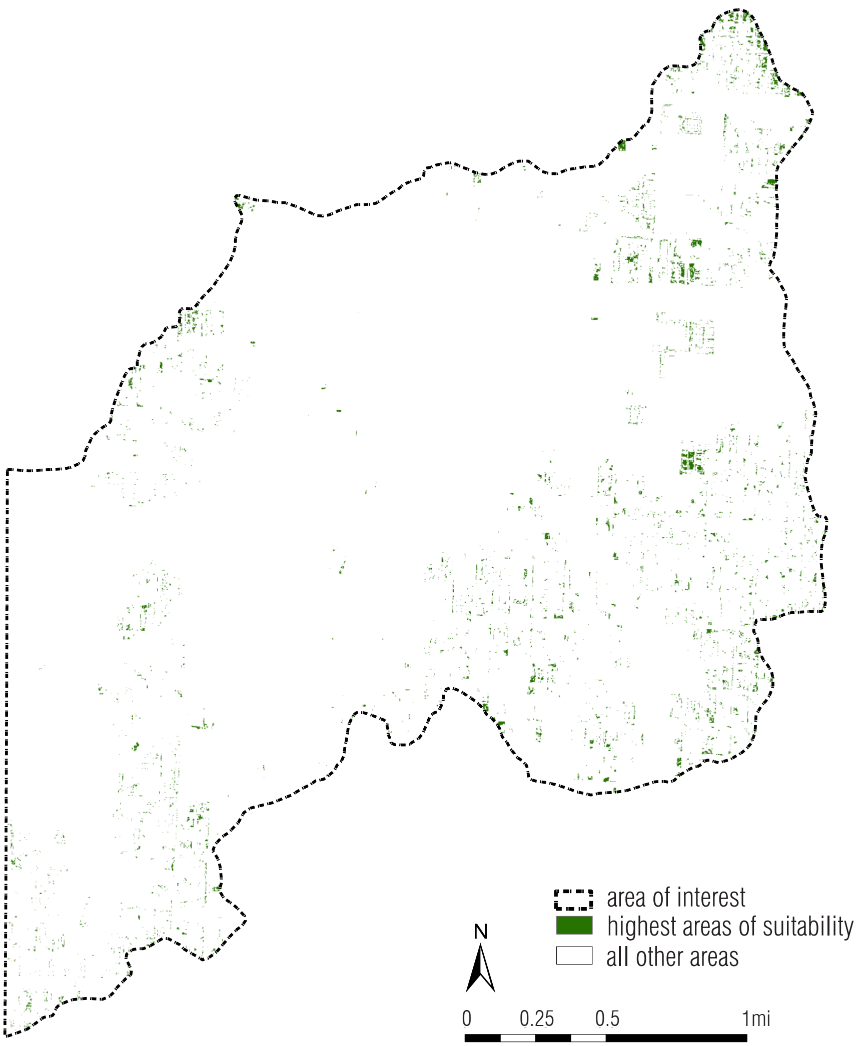


Figure 35: Rain Gardens Highest Suitability Map. Map by author.

Constructed Wetlands

Man-made marsh systems or swamps with permanent standing water that offer a full range of ecosystem services to treat polluted stormwater.

Constructed wetlands are artificial marshland areas developed through excavation and/or berming of soil to replicate the services and functions of naturally occurring wetlands. Constructed wetlands require reasonably large contributing drainage areas to maintain a permanent standing of water to properly function. Therefore, most constructed wetlands occur at lower elevations in watersheds and are typically sustained by stormwater runoff that originates from upland areas of land and travel to areas of lowest elevation; resulting in a ponding of stormwater (Figure 36). Through the incorporation of a diverse planting palette, constructed wetlands are capable of improving water quality by removing nutrients and urban pollutants such as oil and grease and some heavy metals from stormwater runoff (Southeast Michigan Council of Governments, 2008).

A suitability analysis of constructed wetlands in Turkey Creek basin was performed to identify areas of opportunity. A total of seven factors were

Goal 11	Identify lands most suitable for constructed wetlands	
Objective 11.1	Determine lands physically suitable for constructed wetlands	
Sub-objective 11.1.1	Identify optimal slope	Scale (1-6)*
	0% - 5%	2
	5% - 10%	3
	10% - 15%	4
	15% - 20%	5
	20% - 25%	6
	+25%	3
Sub-objective 11.1.2	Identify proximity to drainage points	Scale (1-6)*
	0 - 10 ft	6
	10 - 20 ft	5
	20 - 30 ft	4
	30 - 40 ft	3
	40 - 50 ft	2
	50 - 60 ft	1
Sub-objective 11.1.3	Identify appropriate drainage area	Scale (0-1)**
	0 - 5 ac	0
	+5 ac	1

Table 15: Constructed Wetlands Suitability Matrix

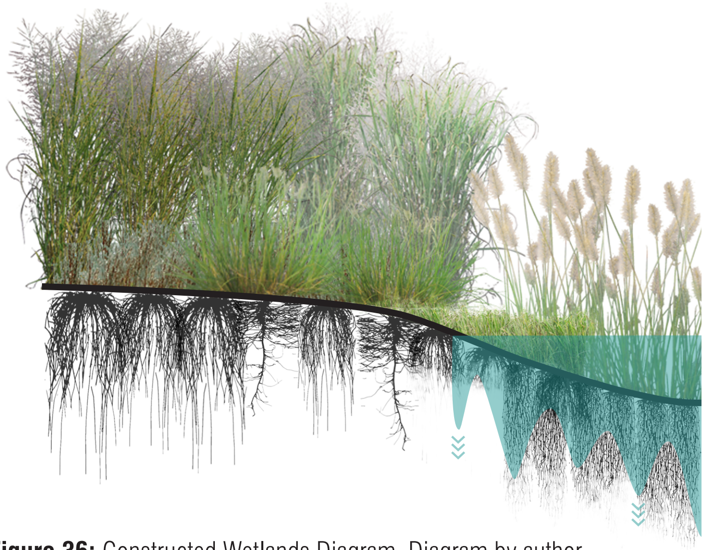


Figure 36: Constructed Wetlands Diagram. Diagram by author.

Goal 11	Identify lands most suitable for constructed wetlands	
Sub-objective 11.1.4	Identify setbacks	Scale (0-1)**
	Wells	
	0 - 100 ft	0
	+100 ft	1
	Structures	
	0 - 25 ft	0
	+25 ft	1
	Stream	
	0 - 25 ft	0
	+25 ft	1
	Wetland	
	0 - 25 ft	0
	+25 ft	1
Sub-objective 11.1.5	Identify impervious surfaces	Scale (0-1)**
	Impervious	0
	Pervious	1
Sub-objective 11.1.6	Identify optimal soils	N/A
Objective 11.2	Identify lands politically suitable for constructed wetlands	
Sub-objective 11.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-6) represents weight of variable data with (1) being the lowest and (6) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

considered in analysis, including slope, setbacks, proximity to drainage points, drainage area, impervious surfaces, soils, and property ownership (Table 15).Existing slopes and proximity from drainage points are rated on a scale of one(1) to six(6) with one representing low suitability and six representing high suitability. Slopes in and around wetlands should be between 20% and 25% (Southeast Michigan Council of Governments, 2008). Therefore, slopes between 20% and 25% received a rating of six. Areas within a 10' radius of drainage points are also highly suitable for constructed wetlands and received a rating of six.

All remaining factors are rated on an inclusion or exclusion basis where zero(0) represents an exclusion of the data from

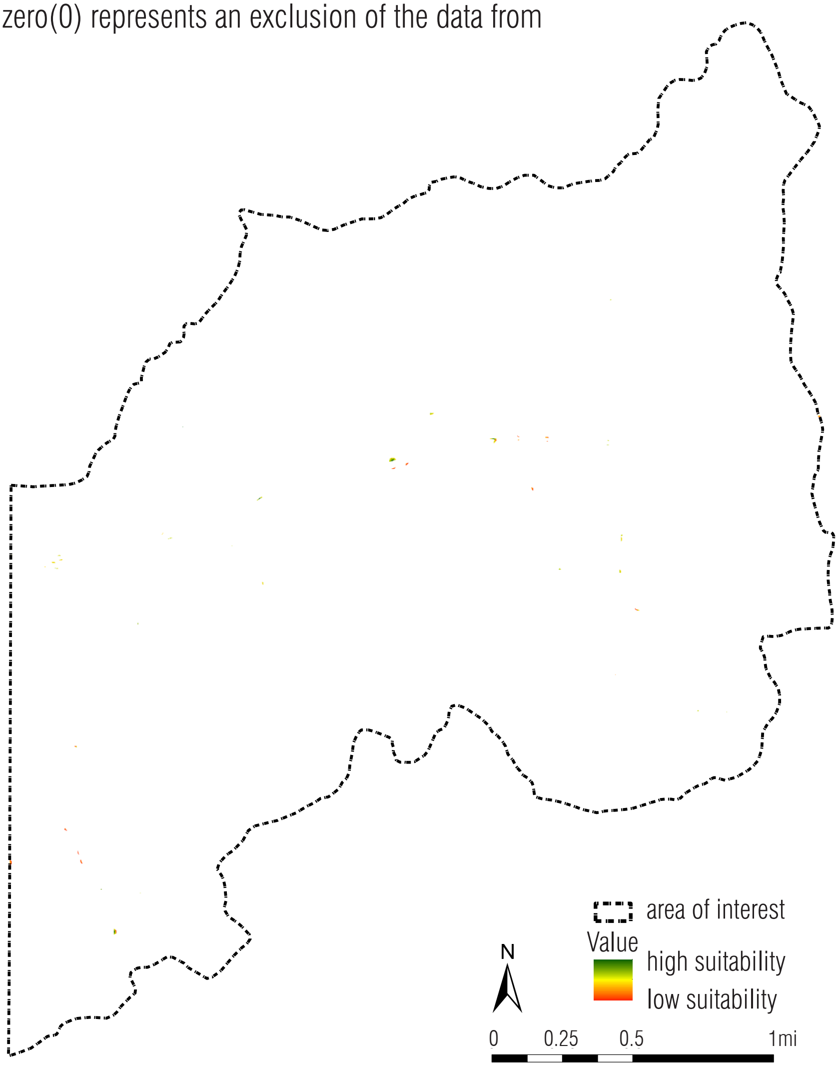


Figure 37: Constructed Wetlands Suitability Map. Map by author.

further analysis and one(1) represents an inclusion of the data for further analysis. Constructed wetlands require a minimum drainage area of five acres to be supported and a setback from wells, structures, streams, and existing wetlands (Southeast Michigan Council of Governments, 2008). All impervious surfaces and public parcels received a rating of zero and were excluded from further analysis.

All seven factors were overlaid in GIS to identify areas suitable for constructed wetlands in Turkey Creek basin. Suitable locations for constructed wetlands are represented in Figure 37. Analysis concluded that almost no suitable locations exist. No areas of high suitability exist, as represented in Figure 38.

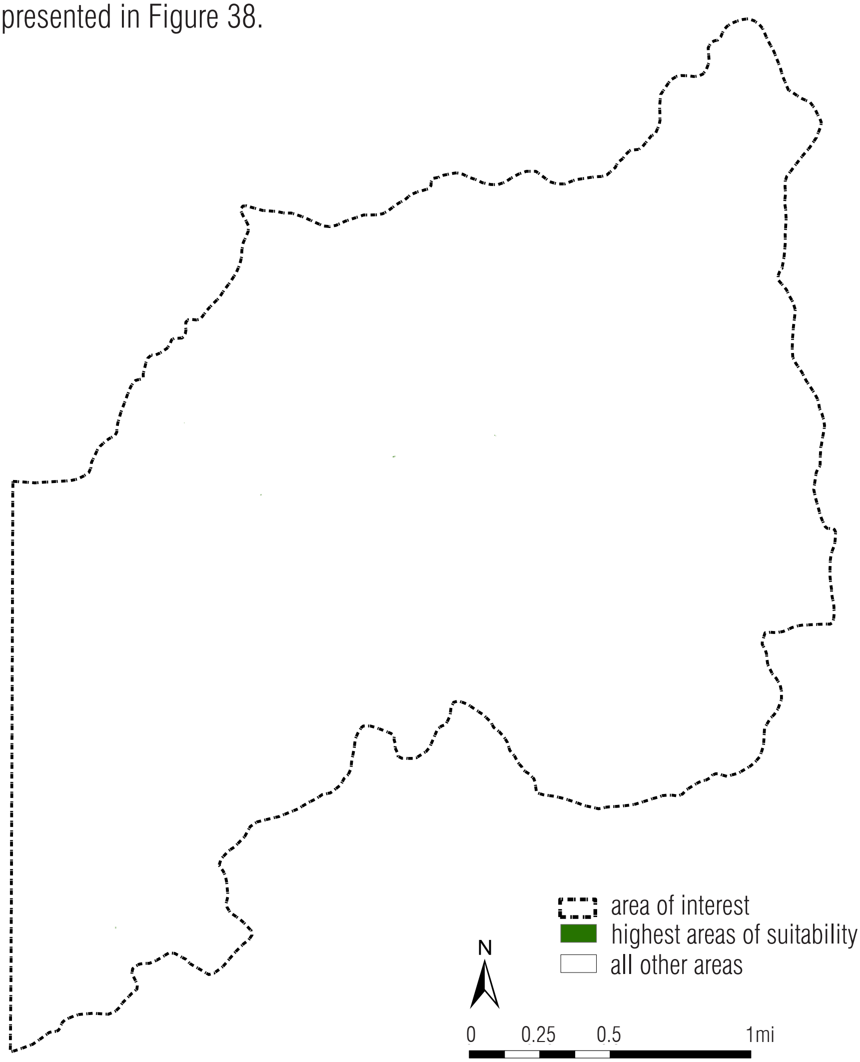


Figure 38: Constructed Wetlands Highest Suitability Map. Map by author.

Green Roofs

A roof that includes planted vegetation instead of traditional shingles, tiles, or other roofing materials.

Unlike buildings with impervious roofs which direct stormwater away from a structure, buildings with green roofs collect stormwater at its source, slow its release, and reduce its volume through transpiration from plants. Green roofs involve growing plants on rooftops, therefore replacing the vegetated footprint that was removed when the building was constructed. This allows the roof to function more like a vegetated surface which absorbs stormwater where it falls. By capturing and retaining stormwater, green roofs can prevent 60% of the annual precipitation that falls on them from entering the sewer system (Sipes, 2010).

Green roofs are becoming popular options for new buildings because of the multiple benefits green roofs offer. Besides capturing and retaining stormwater, green roofs also have the ability to provide a recreational component for people in urban areas where recreational space may be limited. For existing structures with impervious roofs, the roofs may be retrofitted to accommodate green roofs. The roof will need to be structurally designed to accommodate the additional load of the materials needed to sustain a green roof, including soil media, vegetation, and captured stormwater. Appropriate drainage and waterproofing are also necessary for proper functioning (Water Environment Federation, 2012).

A suitability analysis of green roofs in Turkey Creek basin was performed to identify areas of opportunity. A total of three factors were considered in analysis: land use, existing structures, and property ownership (Table 16). Land uses were rated on a scale of one(1) to five(5) with one representing low suitability and five representing high suitability. Green roofs are applicable on many types of structures and across a variety of land use types; however some land uses are more suitable for green roofs than others. Suitability analysis of green roofs did not distinguish between flat roofs and pitched roofs. Instead, analysis operated on the recognition that residential, industrial, and mixed use land uses were less likely than office and commercial land uses to invest in green roofs because of installation costs and structural concerns. Therefore, office and commercial land use types received a rating of five. Although it is possible to install green roofs on structures with pitched roofs, it is more difficult and requires additional structural support. Residential land uses received a suitability rating of one.

Goal 12	Identify lands most suitable for green roofs	
Objective 12.1	Determine lands physically suitable for green roofs	
Sub-objective 12.1.1	Identify land uses	Scale (1-5)*
	Residential	1
	Mixed Use	3
	Industrial	2
	Commercial	5
	Office	5
Sub-objective 12.1.2	Identify structures	Scale (0-1)**
	Structures	1
	No structures	0
Objective 12.1	Determine lands politically suitable for green roofs	
Sub-objective 12.2.1	Identify ownership of property	Scale (0-1)**
	Private	1
	Public	0

*Scale (1-5) represents weight of variable data with (1) being the lowest and (5) being the highest, or most suitable

**Scale (0-1) represents inclusion(1) or exclusion(0) of variable data from suitability map

Table 16: Green Roofs Suitability Matrix

All remaining factors are rated on an inclusion or exclusion basis where zero(0) represents an exclusion of the data from further analysis and one(1) represents an inclusion of the data for further analysis. Because green roofs require a structure, all structures within the basin were assumed to be suitable and received a rating of one. Since information on each building's structural integrity to support a green roof does not exist and would therefore require inspection from a qualified engineer, the structural integrity of buildings was excluded from the list of factors. Lastly, all public parcels received a rating of zero and were excluded from further analysis.

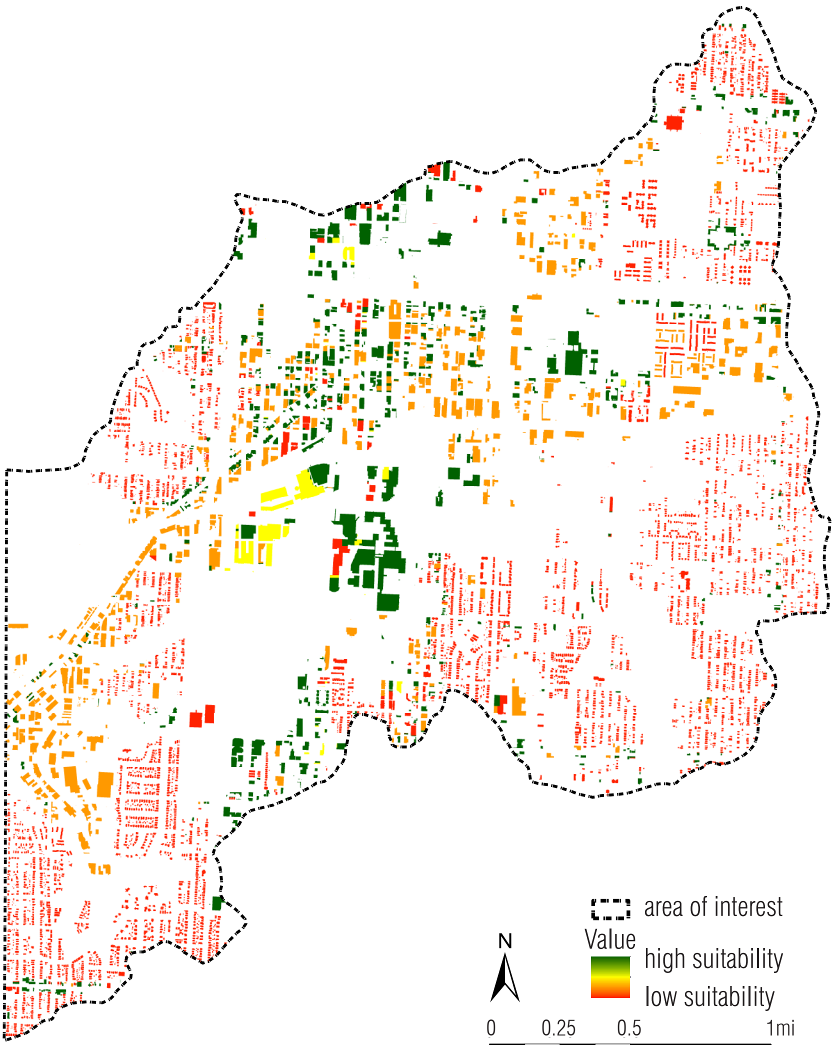


Figure 39: Green Roofs Suitability Map. Map by author.

All three factors were overlaid in GIS to identify areas suitable for green roofs in Turkey Creek basin. Suitable locations for green roofs are represented in Figure 39. Due to the few number of factors used, analysis suggests that green roofs are suitable at varying levels throughout the basin. Areas of high suitability were extracted for easier recognition and are represented in Figure 40. Analysis reveals that some of the areas with the highest amounts of impervious surfaces, such as downtown, have a considerable number of structures highly suitable for green roofs. This is important considering it is often difficult or nearly impossible to implement stormwater BMPs in Kansas City's highly urbanized downtown core.

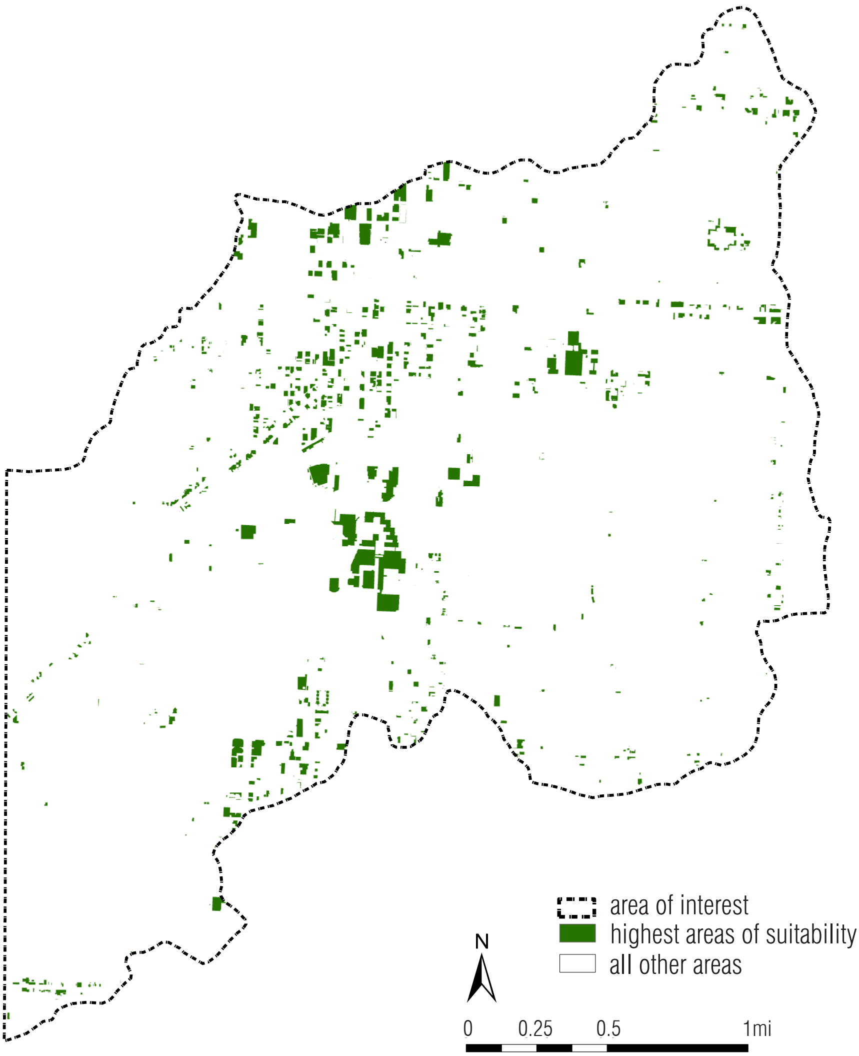


Figure 40: Green Roofs Highest Suitability Map. Map by author.

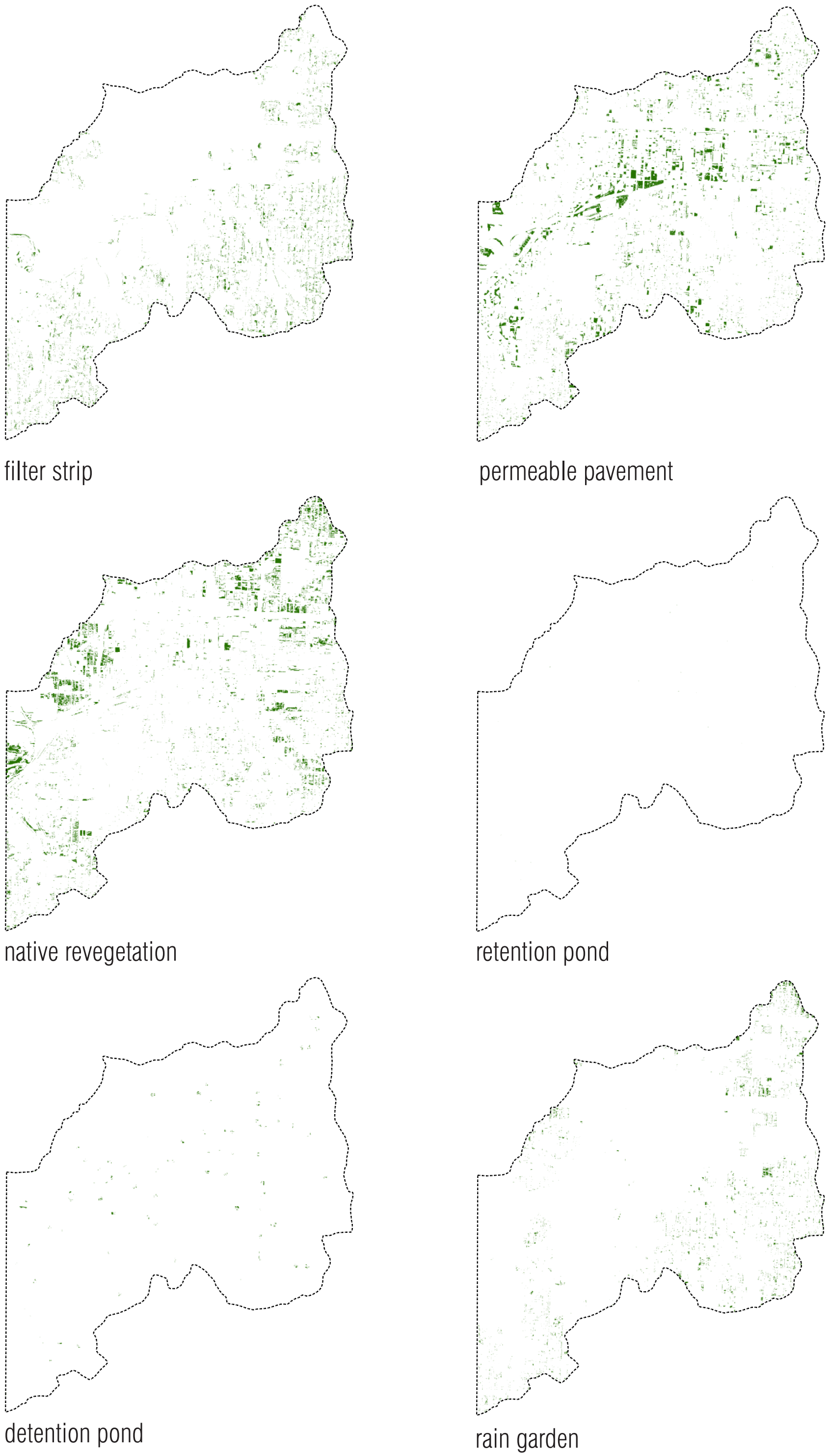
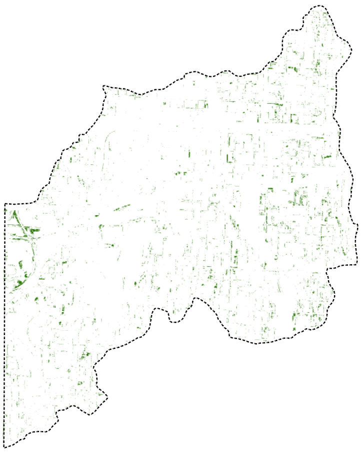
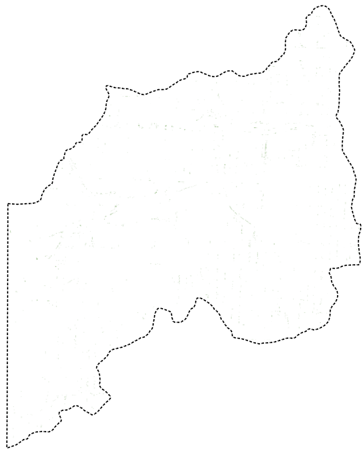


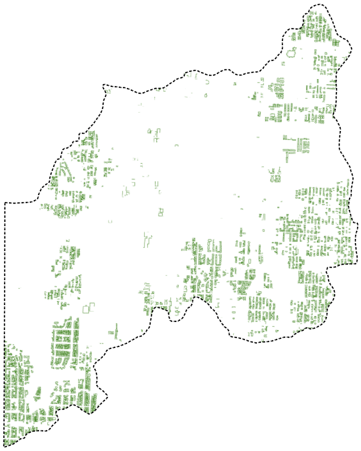
Figure 41: Visual Comparison of Highest Suitability Maps for Each BMP. Figure by author.



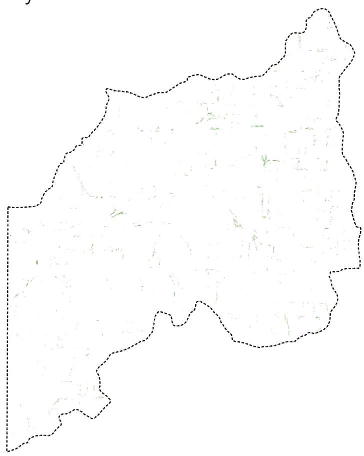
vegetated bioswale



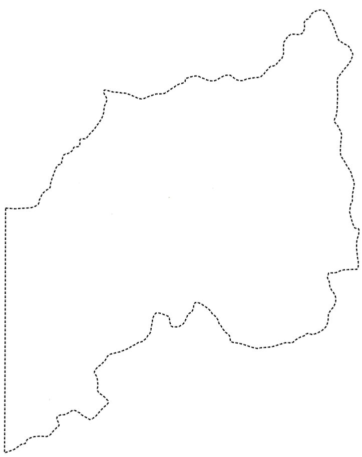
dry swale



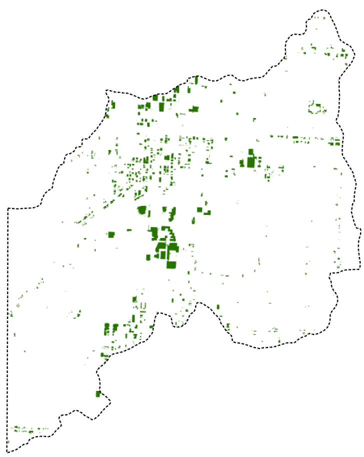
rainwater harvesting



infiltration trench



constructed wetland



green roof

Network

Main Street, Kansas City. Photo by Eric Bowers, 2005.

“The construction of green infrastructure and development of sustainable water management practices will be beneficial throughout the City.”

The City of Kansas City, Missouri Water Services Department
Overflow Control Plan, 2009

Developing a Network of Best Management Practices

No single best management practice will provide a comprehensive solution to Turkey Creek Basin's combined sewer overflow dilemma. In order for BMPs to have a noticeable impact on the volume and quality of stormwater runoff reaching the Kansas River and other waterbodies, a variety of BMPs must be integrated into the city's infrastructure throughout the basin. Contrary to the traditional practice of diverting stormwater runoff through a system of sewers to wastewater treatment plants, a distributed arrangement of BMPs across Turkey Creek basin could capture and treat polluted runoff through an ecological network. The goal of such a system is to sustain the basin's pre-development hydrologic pattern. Recently, commercial businesses and community establishments in Kansas City's downtown district have taken the initiative to install BMPs such as green roofs and native vegetation on their property. Despite these individual examples having a relatively low overall impact on the basin's stormwater runoff, extensive integration of BMPs on private properties across Turkey Creek basin would amount to a noticeable reduction in stormwater runoff volume and an improvement in runoff quality (Black & Veatch, 2008).

The purpose of developing a BMP Network in Turkey Creek basin is to provide a conceptual stormwater management plan intended to decrease the volume of stormwater runoff and increase ecological benefits. The Network should incorporate multiple BMPs with different levels of service. Using a combination of BMPs that slow, spread, and soak stormwater runoff assures full treatment capacity and resiliency in the Network. BMPs which simply control runoff volumes and retain stormwater should be accompanied by more vigorous BMPs that filter, infiltrate, and treat stormwater.

A dispersed spatial arrangement of various BMPs optimizes the full potential of the Network and avoids complications associated with concentrating BMPs on a single site. A distributed arrangement of BMPs means that stormwater runoff quality and quantity are cumulative and that each BMP provides compounding benefits to the overall Network. The objective of this step in the design development process is to establish a comprehensive arrangement of stormwater BMPs across Turkey Creek basin based on the twelve BMP suitability maps produced in the previous chapter. This chapter combines the twelve suitability maps to create a single composite map, or Network, of highly suitable BMP locations within the basin.

Unlike prior suitability analysis which used the basin's physical and political characteristics to determine a BMP's suitability, BMP analysis will consider a BMP's functionality within the Network to determine priority placement. The Network will operate as a self-regulating system, where all BMPs collectively work together to capture and treat stormwater runoff. To develop a BMP Network, two types of criteria were evaluated (Figure 42).

Figure 42: Network Selection Factors. Figure by author.

The first factor includes an assessment of the level of service provided by each BMP. The level of service a BMP offers refers to the mechanical and/or biological processes a BMP employs to serve its intended function in the management of stormwater. There are five different types of service provided by the twelve BMPs, including:

Detention: The temporary storage of stormwater runoff in ponds or basins to allow for a controlled discharge of stormwater at a later time.

Retention: The storage of stormwater runoff on site to allow for sedimentation of suspended solids.

Filtration: The removal of sediment from stormwater runoff through a porous media such as sand, a fibrous root system, or a man-made filter.

Infiltration: The vertical movement of stormwater runoff through soil and the subsequent recharging of groundwater

Treatment: Processes that utilize phytoremediation and other biological methods to treat contaminants in stormwater runoff.

The second factor includes a categorical analysis of the basin's topographic elevation. Surface elevation was determined using publicly-accessible data retrieved from satellites which remotely map the surface of the Earth. The resulting surface map is referred to as a digital elevation model (Figure 5). Surface elevation in Turkey Creek basin ranges from 750' at the lowest point, to 1026'. For the purpose of developing a BMP Network, surface elevations are organized into three classifications - upland, midland, and lowland areas.This piece of additional analysis ensures increased performance of BMPs by locating BMPs at the surface elevations within the Network which best correspond with the services the BMPs provide.

To determine the most suitable locations in the Network for the twelve BMPs, the level of service provided by each BMP was first identified by referencing *LID: a design manual for urban areas* by the University of Arkansas Community Design Center. Identifying the level of service for a given BMP is critical to appropriately locating the BMP at an elevation in the basin where the BMP can effectively provide its services. In this respect, the decision to place a BMP in the upland, midland, or lowland areas of the basin is dependent upon the services the BMP provides. All BMPs offer at least one of the five stormwater services which, at a minimum, attempt to reduce or delay the volume of stormwater runoff entering Kansas City's sewer system. Some BMPs provide additional services such as infiltration, filtration, and treatment of stormwater runoff through the incorporation of vegetation and a permeable soil layer. The five levels of service are illustrated in Figure 43. Although the decision to place a BMP in a specific location is not typically dependent upon the level of service a BMP offers, when creating a distributed arrangement of BMPs which function as a single system it is advantageous to place BMPs in locations which would most benefit from the desired level of service.

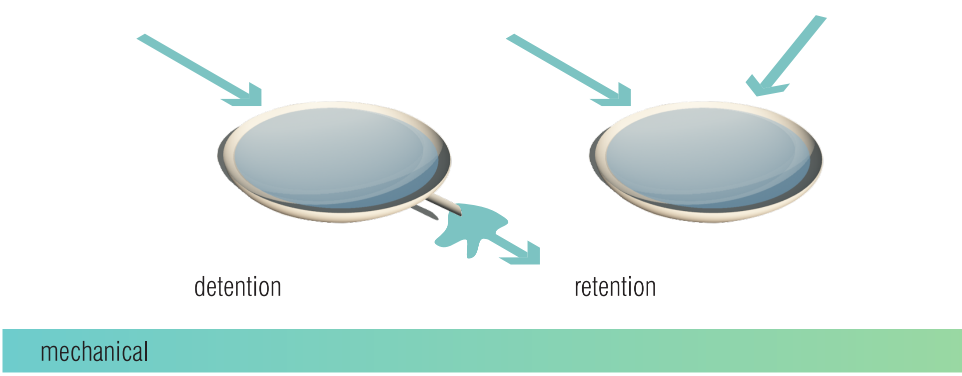
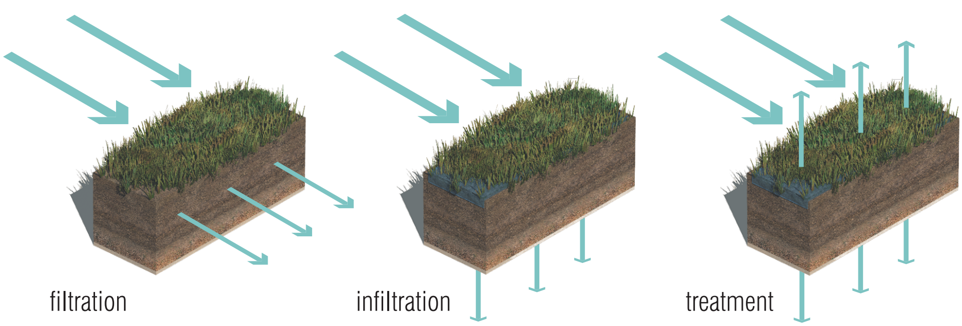


Figure 43: Services Provided by BMPs. Figure by author.

To increase the efficacy of the Network, each BMP should be placed at a surface elevation which best corresponds to its level of service. BMPs which offer filtration as a primary service are generally best suited in upland elevations to reduce the volume of runoff and sediment loads traveling to lower elevations in the basin. BMPs which offer treatment, infiltration, and detention as primary services are generally best suited in midland elevations where polluted runoff can saturate the ground and be treated through biological processes. Finally, those BMPs which offer retention as a primary service are generally best suited at lowland elevations where runoff begins to pool and treatment and evapotranspiration of polluted runoff can occur through the use of vegetation.

The following section contains the methodology used to group the 12 BMPs into upland, midland, and lowland categories. Grouping the 12 BMPs according to topographical elevation does not suggest that a BMP is not suitable at other elevations within the basin. Rather, by placing BMPs at elevations which are most favorable to their level of service, the Network shall function more efficiently and productively. This additional step helps to assure a successfully functioning Network composed of highly suitable BMP locations.



biological

Upland

Uplands are those areas of a watershed that are elevated above lower-lying areas, including midlands, lowlands, and floodplains. The upland areas act as the initial and primary point of stormwater management in a watershed. Permeable lands intercept and capture stormwater, reducing the total volume of runoff that travels downstream. The stormwater that reaches permeable land infiltrates into the soil and is either absorbed by plant roots or recharges local groundwater volumes. Meanwhile, vegetation filters sediment and other pollutants from stormwater runoff while also providing wildlife habitat and aesthetic values for the public. Stormwater which is not absorbed by upland areas ultimately reaches points of lower elevation due to the force of gravity. Because Turkey Creek basin is highly developed, the lowest elevations in the basin often become flooded and/or experience an overflow of raw sewage (Black & Veatch, 2008). For the BMP Network to be most effective in reducing the volume of stormwater runoff, integration of BMPs in upland locations near the source of runoff is essential.

The upland areas of Turkey Creek basin are roughly located in the basin's perimetral regions. Four of the 12 BMPs are most applicable in upland elevations based upon the services they provide. The four BMPs selected include filter strips, green roofs, permeable pavement, and rainwater harvesting. As Figure 53 indicates, all four BMPs are highly suitable in upland areas where capturing stormwater runoff at its source is crucial to reducing runoff volumes and sediment at lower elevations.

Filter strips are classified as an upland BMP because the primary service of a filter strip is to slow stormwater runoff and allow suspended sediments and debris loads to drop out of runoff flow. As a result, lower elevations see a reduction in runoff velocity and sediment. The absence of a filter strip's ability to effectively treat or reduce stormwater runoff through use of vegetation means that the delayed runoff should be treated by other BMPs in the Network. By locating filter strips at higher elevations in the basin to initially delay stormwater runoff, the runoff has a better opportunity to receive treatment before reaching the Kansas River and other sensitive habitats.

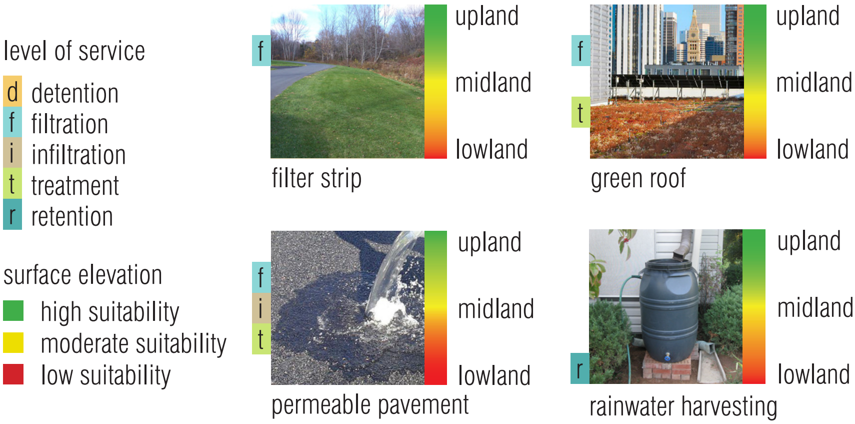


Figure 44: The Four Upland BMPs with their Respective Level of Service and Surface Elevation. Figure by author.

Green roofs are generally suitable at different topographical elevations within a basin because they are able to capture and treat stormwater at the source. Although a powerful BMP, green roofs are classified as an upland BMP because they are essentially a closed-loop system, independent of the services offered by BMPs at lower elevations. Similarly, permeable pavement also has the ability to capture stormwater at its source and provide treatment. Permeable pavement is classified as an upland BMP because of its ability to remove sediment and reduce runoff volumes.

Rainwater harvesting is classified as an upland BMP because stormwater is collected at its source. Since no biological process is involved and stormwater is essentially stored in a container for any given period of time, treatment and of the stormwater will be necessary. Therefore, upon release, harvested stormwater should be treated by BMPs at lower elevations in the Network.

To identify upland areas suitable for the placement of filter strips, green roofs, permeable pavement, and rainwater harvesting, a three step approach was followed utilizing the analysis capabilities of GIS. These steps were repeated for midland and lowland analysis.

Step 1: To delineate the upland areas of Turkey Creek basin, the digital elevation model was modified in GIS. A GIS analysis tool referred to as 'Fuzzy Membership' transforms data into a zero(0) to one(1) suitability scale. All data receiving a rating of zero is poorly suitable, and all data receiving a rating of one is highly suitable. All data falling between zero and one is moderately suitable respective to its value. The Fuzzy Membership tool was used to modify the digital elevation model to replicate perceived upland areas of the basin (Figure 54).

To do so, a contour representing the average perceived surface elevation of upland areas was selected as a datum point from which the Fuzzy Membership tool would compare the suitability of other contour elevations. Based upon topographic data derived from the digital elevation model, a contour elevation of 950' was selected to represent the average surface elevation of upland areas. The Fuzzy Membership tool assigned a rating of one to the 950' contour elevation; implying that areas within the 950' contour elevation are highly suitable upland areas.

Next, the Fuzzy Membership tool applied a suggested feather, or spread, to the selected contour elevation of 950'. The spread allows for the inclusion of similar contour elevations for the purpose of creating a range of elevations collectively referred to as upland areas. The closer a contour elevation is numerically to 950', the more suitable the contour elevation is within the upland area. Because some upland BMPs may be successfully placed in midland areas, the spread compensates by rating contour elevations which fall between the midland contour and the upland contour as suitable. Contour elevations identified as highly suitable represent the upland area of Turkey Creek basin.

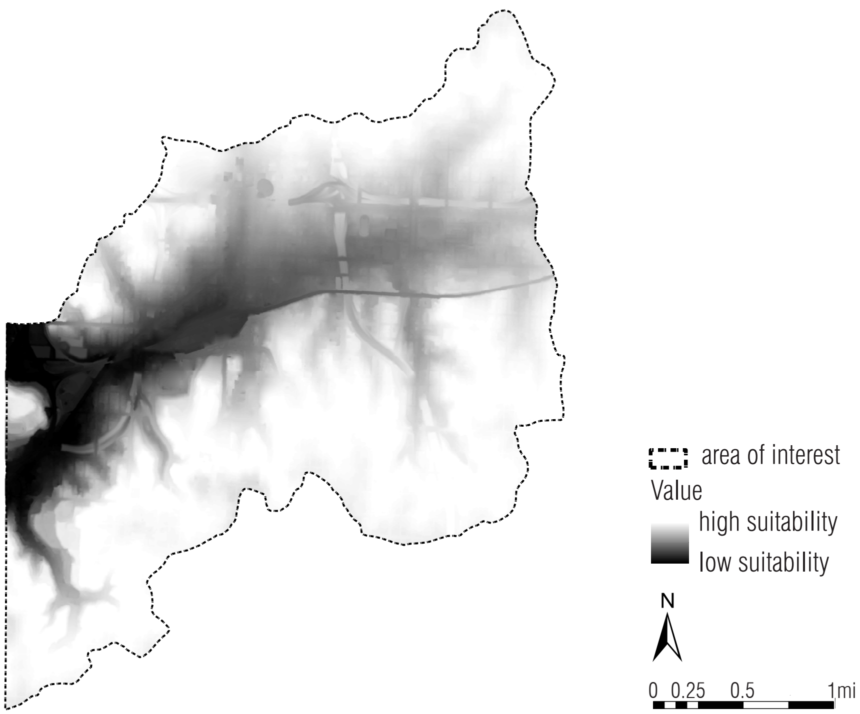


Figure 45: Upland Digital Elevation Model. Map by author.

Step 2: A GIS analysis tool referred to as 'Fuzzy Overlay' was then used to insure that the four upland BMPs were located exclusively in the highly suitable upland areas identified in Step 1. The Fuzzy Overlay tool allows the analysis of multiple inputs by overlaying the inputs and analyzing the relationships between the inputs. Similar to the Fuzzy Membership tool, the produced output transforms data into a zero(0) to one(1) scale. Data receiving a rating of zero have low suitability. Data receiving a rating of one are highly suitable. All data falling between zero and one is moderately suitable respective to its value.

For upland suitability analysis, a total of five inputs were inserted into the Fuzzy Overlay tool, including all four BMP highest suitability maps and the upland digital elevation model. The result is a single suitability map consisting of all highest suitability maps overlaid upon one another and superimposed on the upland digital elevation model. Figure 46 exhibits the suitability of upland BMPs across Turkey Creek basin. A correlation between upland BMPs and topographic elevation is noticeable. Upland BMPs located nearest to the 950' contour elevation received high suitability ratings.

Step 3: Upland BMP locations identified as having high suitability were extracted from the overlay map (Figure 47). Extracted locations are areas which represent the upland portion of the BMP Network.

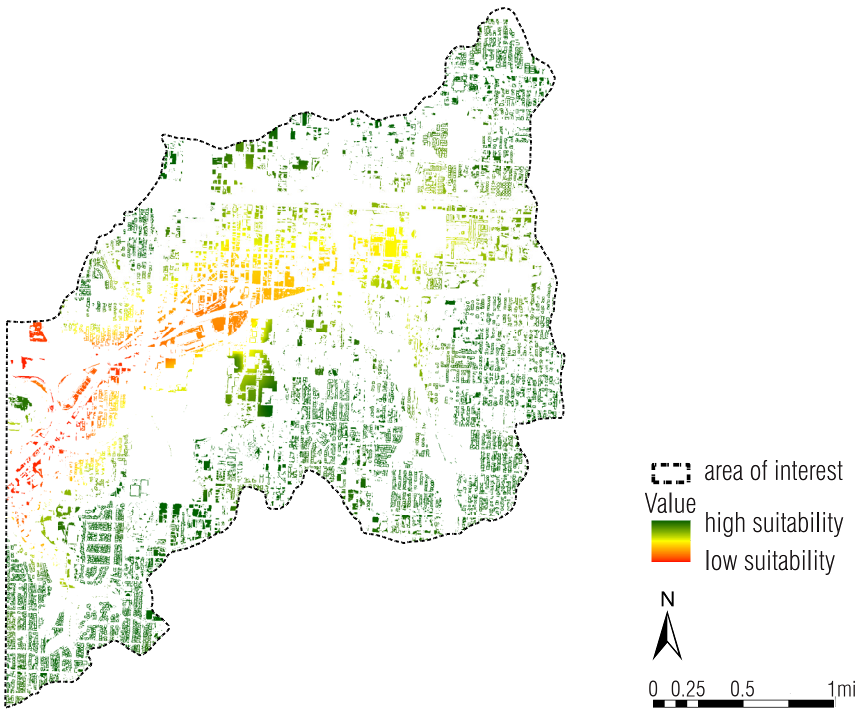


Figure 46: Upland Fuzzy Overlay Map. Map by author.

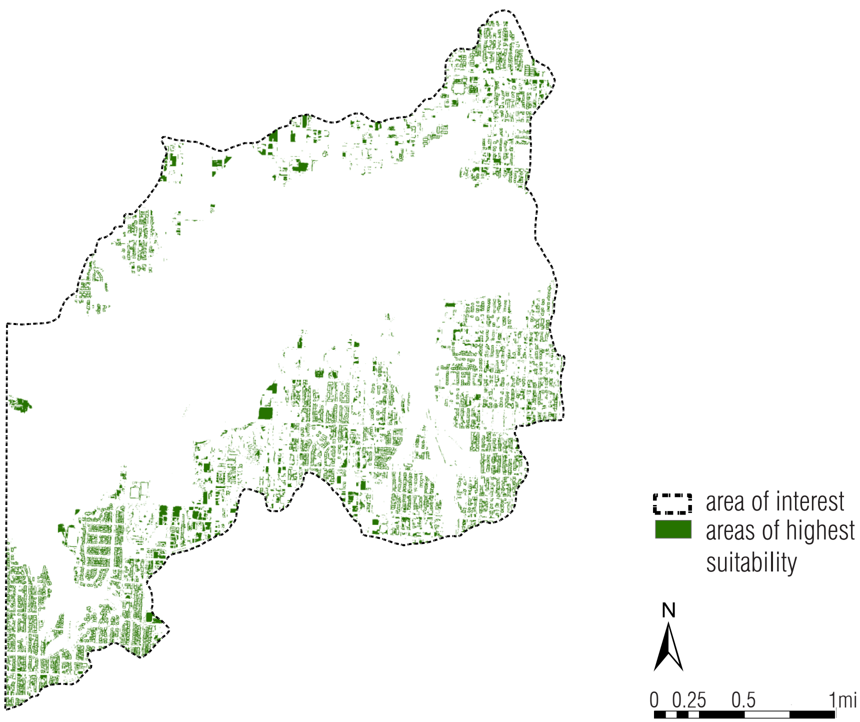


Figure 47: Upland BMP Highest Suitability Map. Map by author.

Midland

Midlands are those elevations of a watershed that are positioned lower than uplands and yet are still elevated above lowlands. In addition to receiving rainfall, midland areas also receive the stormwater runoff which did not infiltrate into the ground or was not captured in the upland areas. By the time stormwater runoff has reached midland areas, the runoff has become polluted with sediment and petroleum-based products. Similar to upland areas, stormwater that reaches permeable land infiltrates into the soil and is either absorbed by plant roots or replenishes groundwater volumes. However, the increased runoff volume caused by upland runoff compounds the effort to totally eliminate runoff. Subsequently, stormwater runoff which is not captured or infiltrated by midland areas ultimately travels to lower elevations in the basin. To compensate for any shortcomings in upland BMPs and further prevent increased runoff volumes, multiple BMPs should be integrated into the midland portion of the Network. More specifically, the selected BMPs should primarily provide infiltration and treatment services.

The midland areas of Turkey Creek basin roughly consist of the basin's valley shoulders and channels. Some midland areas fully extend to the basin's perimeter; primarily on the easternmost boundary of the watershed where the valley culminates. Half of the 12 BMPs are most applicable in midland elevations based upon the services they provide. The six BMPs selected include detention ponds, dry swales, infiltration trenches, native revegetation, rain gardens, and vegetated bioswales. As Figure 48 indicates, the six BMPs are highly suitable in midland areas where the infiltration and treatment of stormwater runoff are primary functions of stormwater management after having been filtered by upland BMPs.

While not the ideal BMP for midland areas, detention ponds are best placed at lower midland elevations, downstream of runoff. The primary service offered by detention ponds is stormwater detention which reduces the peak volume of runoff reaching lower elevations. Because detention ponds offer very little infiltration or treatment of stormwater runoff, lowland BMPs and other midlands BMPs must provide these services for stormwater which is temporarily detained by detention ponds.

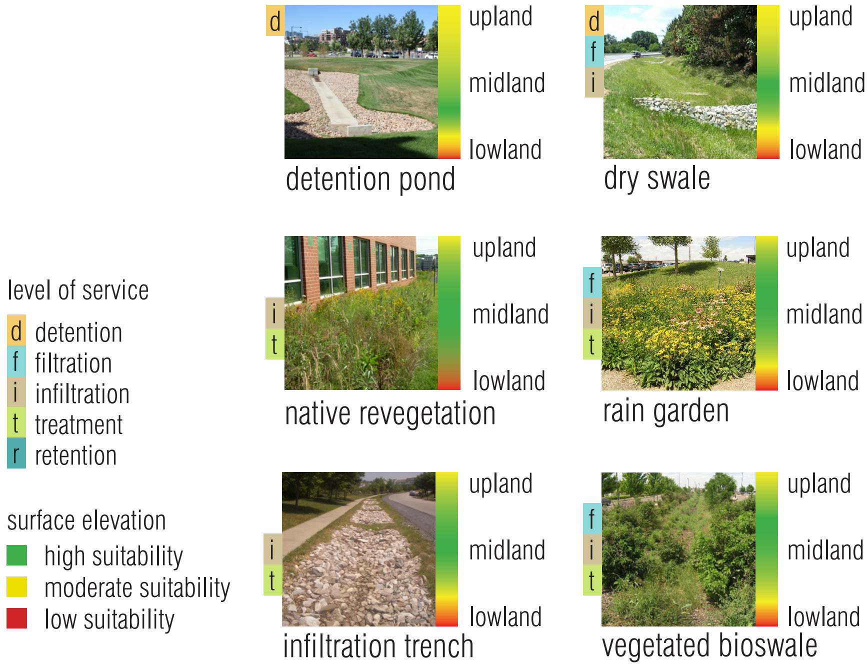


Figure 48: The Six Midland BMPs with their Respective Level of Service and Surface Elevation. Figure by author.

Dry swales should be placed downstream of flow control facilities and upstream of overflow basins. For this reason, dry swales are most appropriately located in midland elevations. Dry swales provide three services; detention, filtration, and infiltration. Therefore, dry swales should be paired with other BMPs which provide runoff treatment to offer a full range of service.

The remaining four BMPs, native revegetation, rain gardens, infiltration trenches, and vegetated bioswales are similar in that they are not restricted to midland areas and can generally be successfully implemented throughout the basin. Each of these four BMPs allow for the infiltration and treatment of stormwater runoff and function best when located downstream of those BMPs which provide filtration services. To develop a self-regulating Network, all four BMPs should be located in midland areas because of the infiltration and treatment services they provide.

To identify midland areas suitable for the placement of detention ponds, dry swales, infiltration trenches, native revegetation, rain gardens, and vegetated bioswales, the same three step approach that was used to identify upland BMPs was repeated.

Step 1: To delineate the midland areas of Turkey Creek basin, the digital elevation model was modified in GIS. Using the Fuzzy Membership tool, a modified model was created to replicate perceived midland areas of the basin (Figure 49). According to topographic data derived from the digital elevation model, a contour elevation of 850’ would appropriately represent the average surface elevation of midland areas given the basin’s high and low points of elevation. Using the Fuzzy membership tool, the 850’ contour was selected and a spread was applied outward from the contour. The spread allows for the inclusion of similar contour elevations for the purpose of creating a range of elevations collectively referred to as midland areas. Areas of the midland digital elevation model that are white are highly suitable midland elevations. Areas in black are poorly suitable midland elevations. Areas in grey are moderately suitable midland elevations.

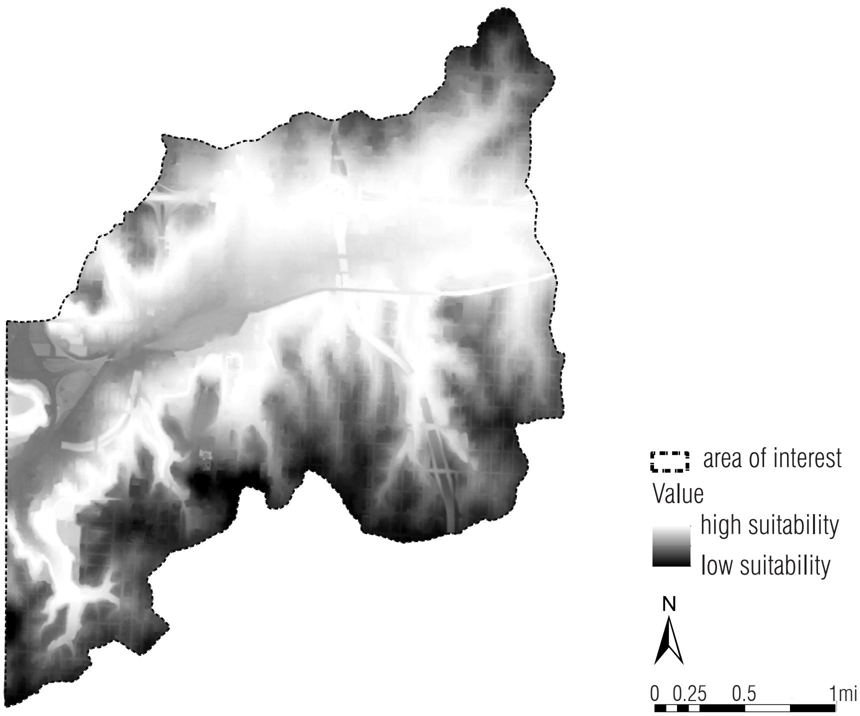


Figure 49: Midland Digital Elevation Model. Map by author.

Step 2: For midland suitability analysis, a total of seven inputs were inserted into the Fuzzy Overlay tool, including all six BMP highest suitability maps and the midland digital elevation model. The result is a single suitability map consisting of all highest suitability maps overlaid upon one another and superimposed on the midland digital elevation model. Figure 50 exhibits the suitability of midland BMPs across Turkey Creek basin. A correlation between midland BMP suitability and surface elevation is noticeable. Midland BMPs located nearest to the 850' contour elevation received high suitability ratings.

Step 3: Midland BMP locations identified as having high suitability were extracted from the overlay map (Figure 51). The extracted locations are the areas which represent the midland portion of the BMP Network.

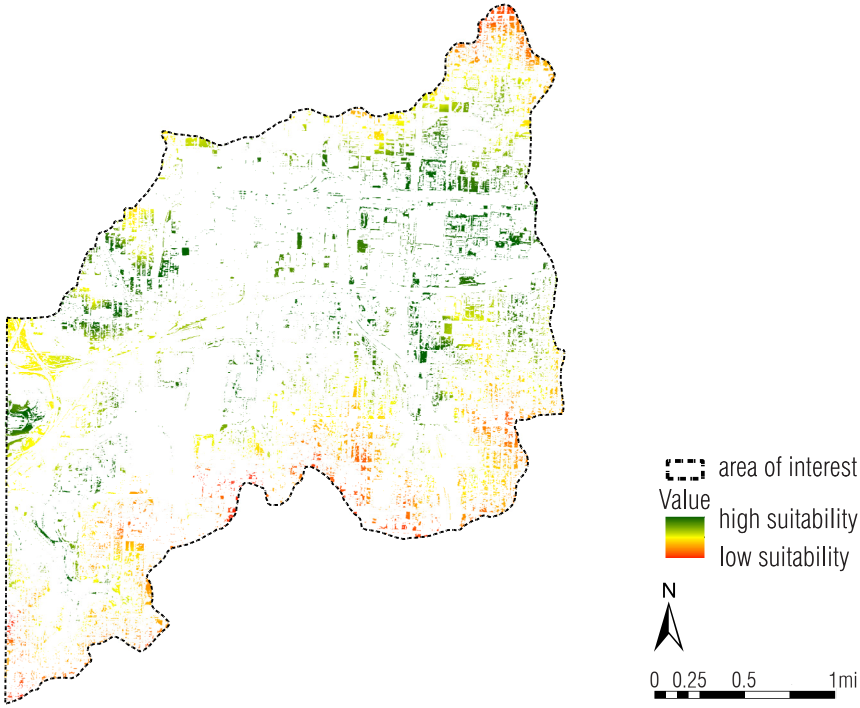


Figure 50: Midland Fuzzy Overlay Map. Map by author.

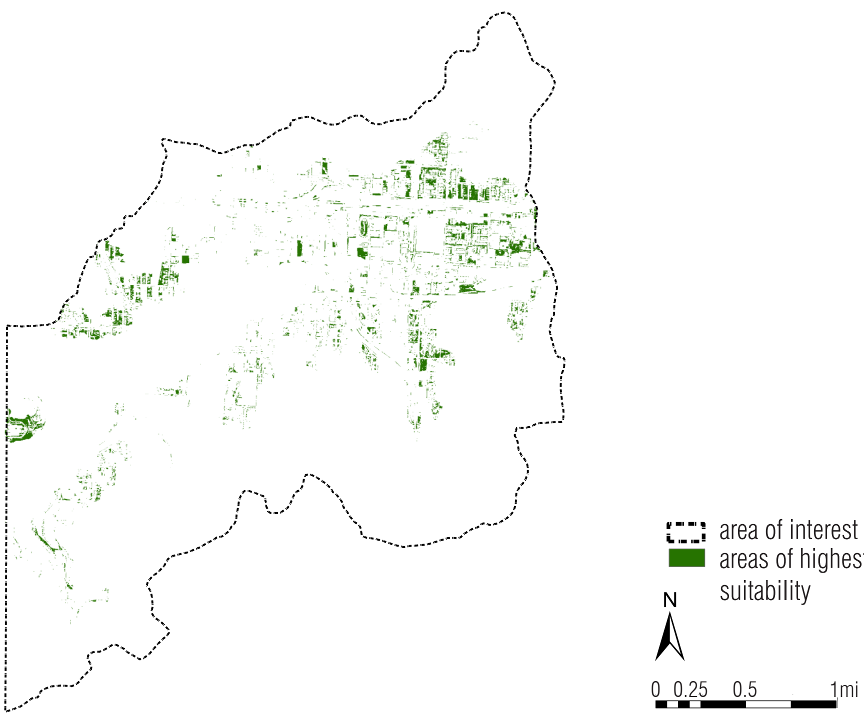


Figure 51: Midland BMP Highest Suitability Map. Map by author.

Lowland

Lowlands are those elevations of a watershed that are located at some of the lowest topographical points in a watershed; positioned lower than upland and midland areas. All runoff from upland and midland areas which did not infiltrate into the ground or was not captured subsequently reaches lowland areas causing frequent flooding of the area. The lowland areas provide the final opportunity to implement sustainable stormwater management practices in the watershed to reduce the volume and improve the quality of runoff reaching the sewer system and Kansas River. To do so, the BMPs selected to be included in the lowland portion of the Network should focus on retaining and treating accumulated volumes of stormwater runoff.

The lowland areas of Turkey Creek basin are located along the valley floor of the basin; primarily near the basin's mouth facing the Kansas River. The remaining two of the 12 BMPs are most applicable in lowland elevations based upon the services they provide. The two lowland BMPs include constructed wetlands and retention ponds. As illustrated in Figure 52, the two BMPs are highly suitable in lowland areas where stormwater runoff and precipitation can be retained and treated in large quantities indefinitely.

Retention ponds are usually constructed at the lowest point of a site, downstream of runoff. The primary services offered by retention ponds are stormwater retention and treatment which can significantly reduce the volume of runoff entering the sewer system. By retaining and treating large volumes of stormwater runoff from upland and midland areas, retention ponds can partially replace the need for new sewer systems and waste water treatment plants.

Out of all 12 Network BMPs, constructed wetlands should be located at the lowest elevations, just slightly higher than the elevation of receiving waterbodies. Constructed wetlands provide multiple services, including filtration, infiltration, treatment, and retention of stormwater. The range of services that constructed wetlands provide make constructed wetlands an excellent BMP to be situated in lowland areas and should function as the single end-of-the-line BMP for the Network.

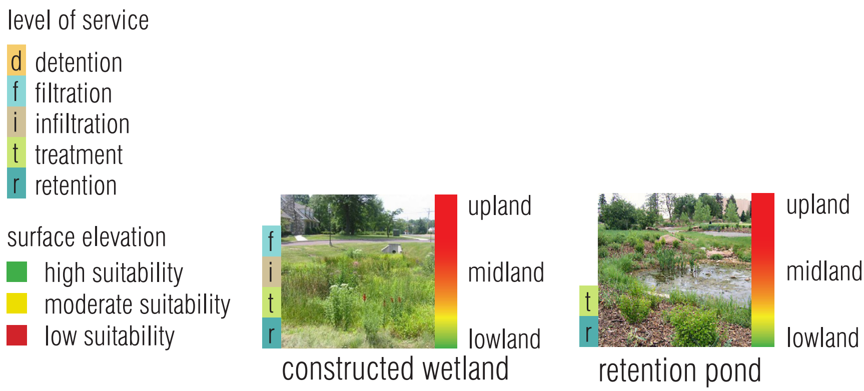


Figure 52: The Two Lowland BMPs with their Respective Level of Service and Surface Elevation. Figure by author.

To identify lowland areas suitable for the placement of constructed wetlands and retention ponds, the same three step approach that was used to identify upland and midland BMPs was repeated.

Step 1: To delineate the lowland areas of Turkey Creek basin, the digital elevation model was modified in GIS. Using the Fuzzy Membership tool, a modified model was created to replicate perceived lowland areas of the basin (Figure 53). According to data derived from the digital elevation model, a contour elevation of 750' would appropriately represent the average surface elevation of lowland areas given the basin's high and low points of elevation. Using the Fuzzy membership tool, the 750' contour was selected and a spread was applied outward from the contour. The spread allows for the inclusion of similar contour elevations for the purpose of creating a range of elevations collectively referred to as lowland areas.

Step 2: For lowland suitability analysis, a total of three inputs were inserted into the Fuzzy Overlay tool, including the two BMP highest suitability maps and the lowland digital elevation model. The result is a single suitability map consisting of the two highest suitability maps overlaid upon one each other and superimposed on the lowland digital elevation model. Figure 54 exhibits the suitability of lowland BMPs across Turkey Creek basin. Unlike the upland and midland suitability maps, the lowland suitability map hardly has any visible areas of suitability. This is due to the constructed wetlands and retention ponds having very few highly suitable locations in Turkey Creek basin as discussed in the previous chapter. Lowland BMPs located nearest to the 750' contour elevation received high suitability ratings.

Step 3: Lowland BMP locations identified as having high suitability were extracted from the overlay map (Figure 55). Results indicate that neither constructed wetlands nor retention ponds have a single highly suitable location in lowland areas. As a result, the Network will not consist of any BMPs placed in the lowland portion.

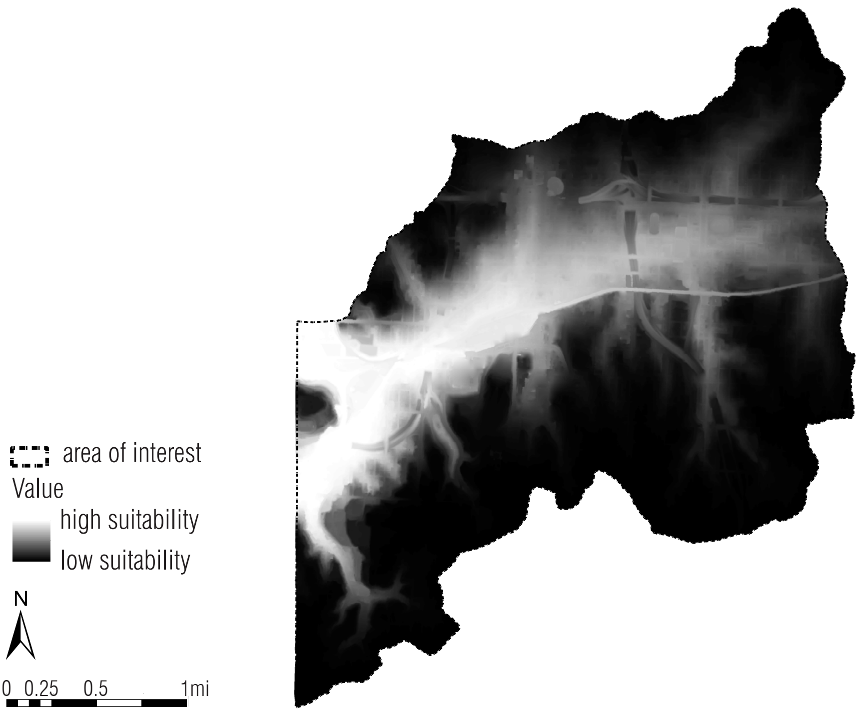


Figure 53: Lowland Digital Elevation Model. Map by author.

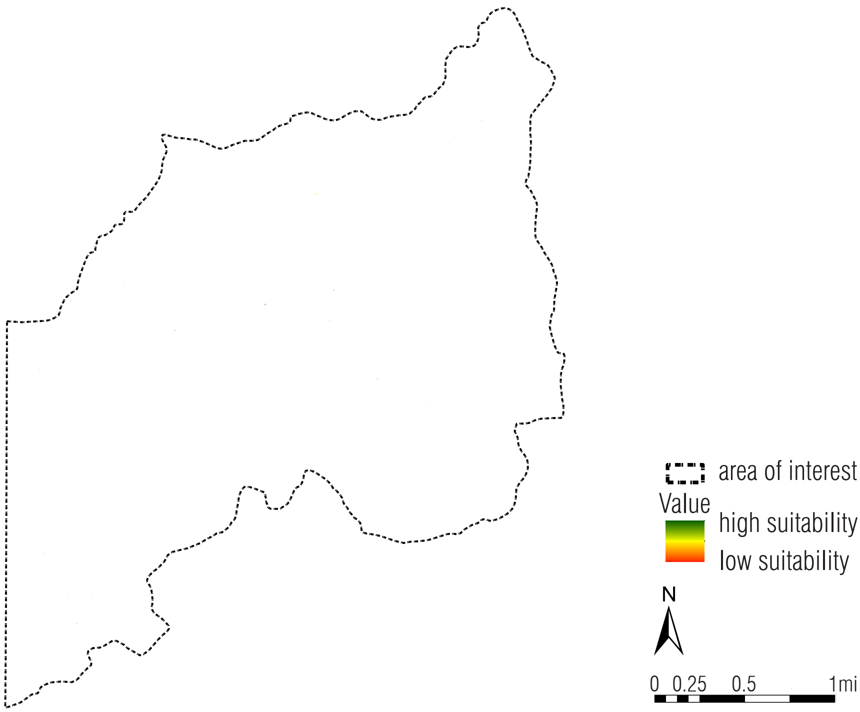


Figure 54: Lowland Fuzzy Overlay. Map by author.

Figure 55: Lowland BMP Highest Suitability. Map by author.

The Network

To create a Network of appropriately located BMPs, upland and midland suitability maps were merged. Due to the lowland suitability map producing no highly suitable locations, the lowland suitability map and its BMPs were omitted from the Network. Analysis suggests that the most effective locations to implement BMPs in Turkey Creek basin are in the upland and midland regions of the basin (Figure 56). By doing so, rainfall will be captured at its source location and subsequently treated in the BMP Network; reducing the total volume of stormwater runoff reaching lowland elevations. Because the urbanization of Turkey Creek basin does not support the effective use of lowland BMPs, it is encouraged that the remaining upland and midland BMPs be implemented to the highest extent possible.

Collectively, the total surface area identified as highly suitable for Network locations is 316.28 acres, or approximately seven percent of the basins total area. Further analysis of the Network data identified the exact locations of the 10 remaining BMPs in the Network (Figure 57). Through identification of individual BMPs, the private land owners and the City can reference the information to make accurate and informed decisions regarding the various BMPs suitable for any given property. By making informed design decisions supported by GIS analysis, private-property owners maximize the effectiveness of constructed BMPs and actively strengthen the Network's overall performance.

Turkey Creek basin engineer, Black & Veatch, estimates that a storm event which produces just 0.86" of stormwater results in 52 million gallons of CSO (Black & Veatch, 2008). A storm event of this size occurs on average once a month. Results of BMP land area requirements were obtained from the Network map. Collectively, the total area covered by Network BMPs totals 316.28 acres (Table 17). The BMP which represents the most land area of the Network is permeable pavement, which requires 66.11 acres. Dry swales represent the smallest land area in the Network, requiring 1.36 acres.

Using the land area requirements of each BMP, an estimated reduction in runoff volume was calculated for each BMP. Calculations were obtained by using the Green Value Calculator provided online by the Center for Neighborhood Technology. The Green Value Calculator functions by using

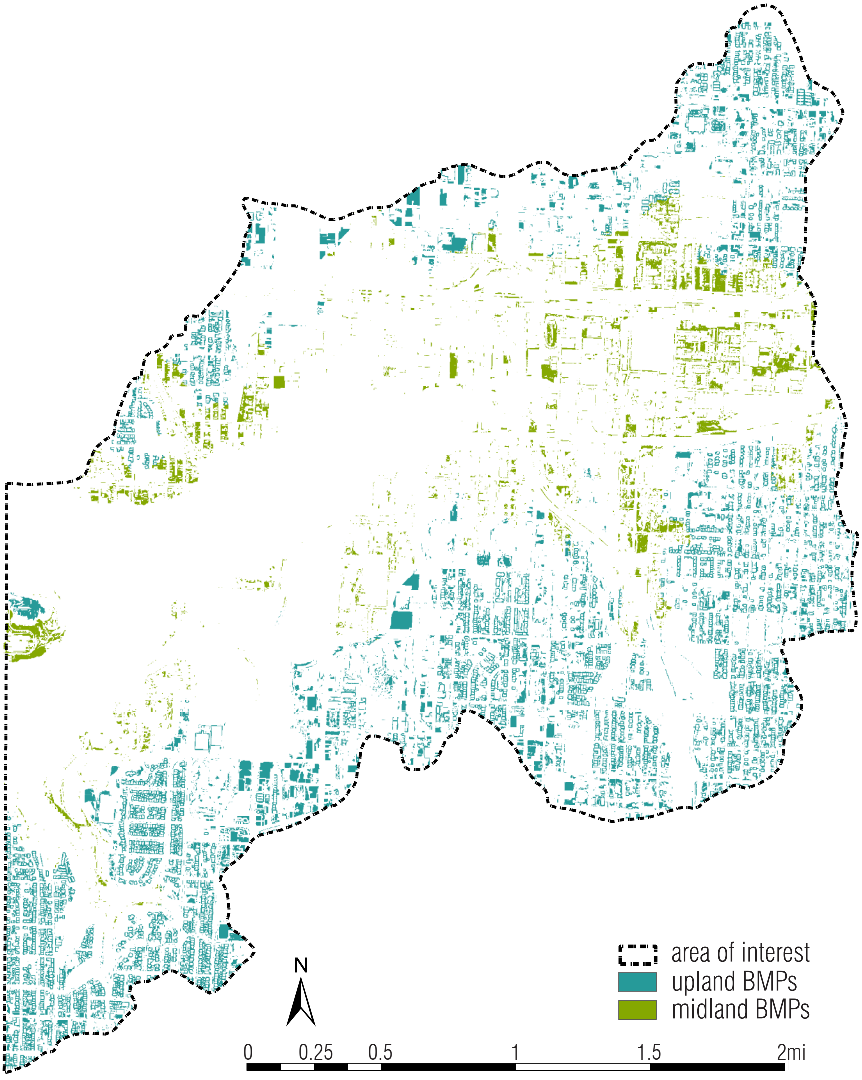


Figure 56: Proposed Network of BMPs for Privately-Owned Properties. Map by author.

a predefined algorithm to estimate the stormwater runoff volume reduced by a selected BMP. According to the Green Value Calculator, investment in the Network suggests that Turkey Creek basin could notice a significant reduction in stormwater runoff volumes entering the sewer system. Estimated reductions in runoff volume will, of course, depend upon the percentage of the Network completed. The results obtained from the Green Value Calculator were used to predict the reduction in runoff volume if only 20% of the land area identified for each BMP were converted into a functioning component of the Network. This is equivalent to 63.23 acres of highly suitable land.

If 20% of the identified land area in the proposed Network was converted into the respective BMP, Turkey Creek basin could expect an estimated 5,638,003 gallons of stormwater runoff to be captured, filtered, and treated by BMPs. This is equivalent to nearly 11% mitigation in runoff entering Kansas City's sewer system. Furthermore, this reduces the dependence and pressure on Turkey Creek Basin's only waste water treatment plant and results in fewer CSO occurrences and reduces CSO volumes. If 100% of the proposed Network was implemented, Kansas City could expect to see overflow volumes decrease by approximately 54% during a one month

Approximate reduction in stormwater runoff volume per BMP if only 20% of each Network BMP was implemented			
	total area identified (ac)	20% of identified area (ac)	total rainfall volume captured (gal)
detention ponds	2.47	0.49	79,825
dry swales	1.36	0.27	145,705
filter strips	60.97	12.19	1,390,262
green roofs	53.94	10.78	146,364
infiltration trenches	5.37	1.07	719,095
native revegetation	62.95	12.59	170,937
permeable pavement	66.11	13.22	719,958
rain gardens	8.89	1.78	24,139
rainwater harvesting	100,766 locations	20,153 locations	1,007,660
vegetated bioswale	54.22	10.84	1,236,058
constructed wetlands	n/a	n/a	n/a
retention ponds	n/a	n/a	n/a
total	316.28	63.23	5,638,003

Table 17: Approximate Reduction in Stormwater Runoff Volume for 20% of Network

design storm event that produces 0.86” of stormwater. Reference Appendix C for approximate reduction totals if 100% of the Network is completed. Results assume that all BMPs are regularly maintained and in proper functioning condition.

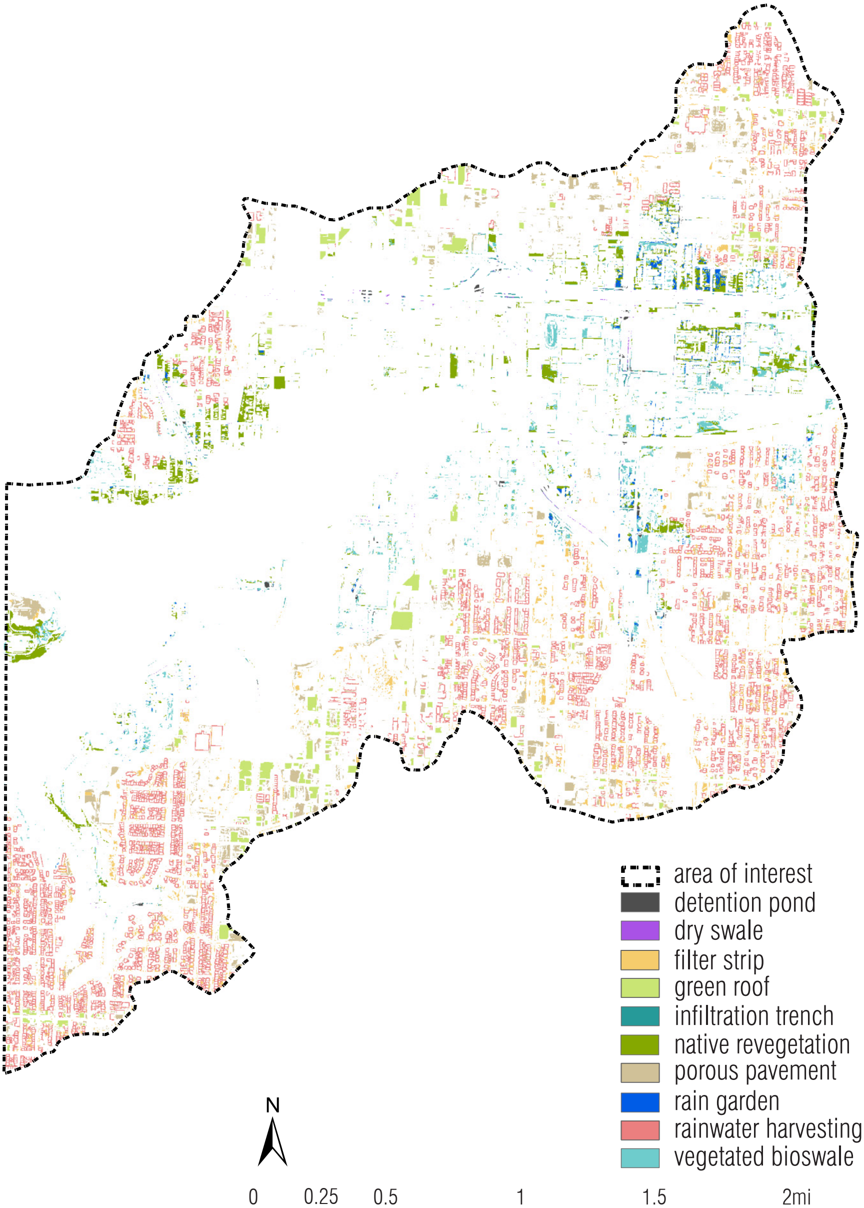


Figure 55: Proposed Network Map with Individual BMPs Identified. Map by author.

Encourage

 Rain garden at Kansas City's 18Broadway community garden. Photo by Maria Morton, 2011

“Whereas in the past, industrial economies were forced to contaminate or destroy the environment in service of the economy, today that equation is being reversed. Mutually codependent, the economy is now inseparable from the environment, and so are modes of production.”

Pierre Belanger
Landscape as Infrastructure, 2009

Development of a Stormwater Program

Many of the successful stormwater management programs around the nation are a combined effort between cities and private landowners and developers. Municipal governments such as the City of Portland and the City of Chicago have led by example through the installation of BMPs on publicly-owned buildings, right-of-ways, and parks. Doing so has created a public awareness and helped educate city residents of the benefits of stormwater BMPs. In turn, residents and business owners have become more accepting of BMPs, even voluntarily installing BMPs of their own (U.S. Environmental Protection Agency, 2010). Following in the steps of cities which have diligently integrated BMPs into the planning and design processes, Kansas City has begun taking initial steps to implement BMPs on public property as laid out in the City's Overflow Control Plan.

Of particular importance to the BMP Network are Kansas City's current efforts to implement BMPs within Turkey Creek basin. Kansas City's 2009 Overflow Control Plan acknowledges that "the construction of green infrastructure [i.e. best management practices] and development of sustainable water management practices will be beneficial throughout the city" (Kansas City, Missouri Water Services Department, 2009; p. 12-8). Despite Turkey Creek basin being responsible for the highest volume and occurrence of CSOs within Kansas City, selected improvements to the basin's sewer infrastructure reveal the City's continued preference for conventional stormwater management practices. Only a single BMP is included in selected improvements. Furthermore, the City does not plan to adopt a set of stormwater BMP policies until an undetermined later date when the impacts of the selected sewer improvements can be quantified (Kansas City, Missouri Water Services Department, 2009).

For Kansas City to meet the stormwater management objectives it set forth in the Overflow Control Plan and prevent future costly sewer system improvements, Kansas City should welcome the proposed BMP Network. A successful Network requires participation from property owners, developers, cities, and regulatory agencies in a comprehensive planning process. Each person and group of people has not only an important role in addressing Kansas City's CSO dilemma, but also an obligation to protect sensitive habitats and the land on which they live. Participation from private land owners is pivotal to the overall impact of the Network and ultimately the Network's success.

To assist in the realization of a BMP Network, Kansas City should develop stormwater BMP policies and incentives. Stormwater regulations from 12 cities within the contiguous United States were examined for possible application in Kansas City (Table 18). The dozen municipalities were chosen to represent a range in size, population, and geographic location to offer an inclusive view of stormwater regulations around the country. The intention of investigating stormwater management programs from multiple cities is to provide Kansas City with an improved understanding of available stormwater regulations currently in place across the country. Stormwater regulations are an important and necessary component of a city's stormwater management plan because they require and encourage citizens to take responsible measures to prevent stormwater runoff. Through the collection and comparison of each of the 12 community's stormwater BMP policies and incentives, appropriate recommendations for Kansas City have been made to encourage private investment in the Network and guide future policy development.

Municipalities
Wichita, Kansas
Philadelphia, Pennsylvania
Portland, Oregon
Seattle, Washington
San Jose, California
Santa Monica, California
Minneapolis, Minnesota
Columbus, Ohio
Olympia, Washington
Chicago, Illinois
Emeryville, California
Lenexa, Kansas

Table 18: The 12 Selected Municipalities

Stormwater Policy

Stormwater policies are regulations that cities may choose to implement to better manage stormwater at a local scale. By enforcing certain regulations, municipalities can better control the amount of stormwater runoff entering their sewer infrastructure and waste water treatment plants. Policies can be implemented on public and private land to equally insure that a City is meeting its policy objectives, and private landowners are held responsible, usually through the use of fees, for the runoff contributed from their property. Stormwater policies can also be used to require landowners to install BMPs to capture a specific amount of stormwater.

The 12 selected cities are currently implementing stormwater BMPs at three different scales to fulfill their stormwater management requirements. Scales include the watershed scale, neighborhood scale, and site scale. Not all of the municipalities are using BMPs at all three scales; however all incorporate a number of policies to address local stormwater concerns.

Common Policy Approaches					
Municipality	Public				
	Demonstration Projects	Street Retrofits	Capital Projects	Local Code Review	Education and Outreach
Wichita, KS	■			■	■
Philadelphia, PA	■	■	■	■	■
Portland, OR	■	■	■	■	■
Seattle, WA	■	■	■	■	■
San Jose, CA	■	■		■	
Santa Monica, CA		■	■	■	■
Minneapolis, MN		■	■		■
Columbus, OH			■		■
Olympia, WA	■	■		■	■
Chicago, IL	■	■	■	■	■
Emeryville, CA	■	■		■	
Lenexa, KS	■	■	■		■
Kansas City, MO	■		■		■

Table 19: Common Policy Approaches. Adapted from U.S. Environmental Protection Agency, 2010).

A total of nine stormwater policies and programs were identified as common approaches between the 12 cities although not every city currently incorporates all nine approaches into its stormwater management plan. Table 19 lists the 12 municipalities and identifies the common policy approaches utilized by each municipality. Common policy approaches are organized into 'public' and 'private' categories. The public category refers to policies and programs that apply to public agencies and can be implemented through public means such as city planning, development, and initiatives. The private category refers to policies and programs that apply to the private developers and private property owners.

Kansas City's stormwater policy approaches are also listed in Table 19 for comparison to the policies of the other 12 cities. Stormwater regulations are the single common denominator in all 13 cities. The cities which are most successful at managing stormwater incorporate a range of policies and approaches that focus on both public and private sectors.

Common Policy Approaches			
Private			
Stormwater Regulation	Stormwater Fee	Fee-based incentives	Other Incentives

Prior to drafting the Overflow Control Plan, Kansas City only had two stormwater policies, those being stormwater regulations and stormwater fees. The approved Overflow Control Plan added three additional policies: demonstration projects, capital improvements, and education and outreach. As a result, the City of Kansas City has installed multiple demonstration projects in adjacent watersheds and is currently gathering performance data. Capital projects are also under construction; most notably of which is the combined sewer separation at the southern edge of Turkey Creek basin. Although funds have been budgeted for education and outreach programs, the City has yet to establish any programs.

A further investigation of each municipality's list of stormwater policies reveals a trend in policy objectives. As shown in Table 20, some of the cities such as Lenexa, Kansas, and Philadelphia, Pennsylvania, require developers to manage a set volume of stormwater runoff created by impervious cover. This is referred to as a volume-based performance standard. Other cities, such as Wichita, Kansas, and Columbus, Ohio, require new development and redevelopment to contribute no more

Municipality			
	Post-Development to Meet Pre-Development Conditions	Volume-based Performance Standard	Process-based or Menu Approach
Wichita, KS	■		
Philadelphia, PA		■	
Portland, OR			■
Seattle, WA	■	■	■
San Jose, CA		■	
Santa Monica, CA		■	
Minneapolis, MN	■		
Columbus, OH	■		■
Olympia, WA		■	
Chicago, IL		■	
Emeryville, CA			■
Lenexa, KS		■	
Kansas City, MO (Recommended)		■	

Table 20: Stormwater Requirements. Adapted from U.S. Environmental Proection Agency, 2010).

stormwater runoff than what a site previously accounted for. Still, cities such as Portland, Oregon, and Emeryville, California, have taken a process-based or menu approach which requires developers to submit detailed calculations of expected runoff reductions. Communities may incorporate a single stormwater objective or multiple stormwater objectives depending on the needs of the city.

Cities which are less urbanized and have moderate to high development typically benefit most from a 'post-development to meet pre-development' policy objective. This is because developing on undeveloped land would require careful consideration of BMPs to meet policy requirements. Although there are portions of Kansas City that are not developed, Turkey Creek watershed is approximately 90% urbanized and therefore the benefits of such a policy structure would be limited (Kabbes et al., 2004).

Cities which have advanced stormwater policies currently in place often implement a 'process-based or menu approach' policy objective which requires detailed quantitative and qualitative calculations of runoff reduction. A process-based or menu approach can be a discouragement to communities who have little or no existing BMP programs. Typically, a community must already have wide-spread support for stormwater BMPs for such a policy objective to be successful. Therefore, it is especially difficult to successfully implement in communities without any former policies, such as Kansas City.

Finally, a 'volume-based performance' policy objective is generally found in communities concerned with reducing a specified volume of stormwater runoff and is the most common stormwater objective of the 12 municipalities. A volume-based performance standard requires a benchmark against which actual BMP performance is measured and

Stormwater BMP Incentives

Stormwater incentives are a resourceful tool municipalities can use to promote BMPs on private property. Typically, incentives are directed towards private property owners to encourage retrofits of existing sites to include BMPs where they do not already exist. Cities can encourage private developers and private landowners to include BMPs by providing incentives for both planned and existing developments. For existing developments, incentives can be used to encourage landowners to retrofit their sites with BMPs. Incentives can also be used to encourage developers to include BMPs when they are planning, designing, or constructing their projects.

To reduce CSOs and stormwater runoff across Turkey Creek basin, Kansas City should implement financial and non-financial incentives to encourage residential and non-residential property owners to implement BMPs. According to the U.S. Environmental Protection Agency, incentives can be organized into five categories by type of incentive (U.S. Environmental Protection Agency, 2009). The following are the five primary types of BMP incentives, along with a short description of each incentive type.

Fee Discount: Requires a stormwater fee that is based on impervious surface area. If property owners reduce the need for service by reducing impervious area and the volume of runoff discharged from the property, the municipality reduces the fee.

Development Incentives: Offered to developers during the process of applying for development permits. Examples include: zoning upgrades, expedited permitting, reduced stormwater requirements and increases in floor area ratios.

Grants: Provide direct funding to property owners and/or community groups for implementing a range of BMP projects and practices.

Rebates and Installation Financing: Provide funding, tax credits, or reimbursements to property owners who install specific BMPs. Often focused on BMPs needed in certain areas or neighborhoods.

Awards and Recognition Programs: Provide marketing opportunities and public outreach for exemplary projects and may include monetary awards.

Developing stormwater incentives requires a thoughtful approach. Cities must be mindful of the financial and human resources necessary to operate selected incentives. Municipalities may choose only a single incentive type or a combination of incentive types which they feel best fit their unique stormwater management plans and available resources. Since many incentives include the use of public funds to construct private BMPs, municipalities must structure incentives around current city budgets. Therefore, some incentives, unlike policies, are only offered for the amount of time the funds allow for. Keeping this in mind, municipalities may prefer to continually modify the terms of an incentive so as to prolong the incentive or make it more favorable to a selected group such as homeowners and small business owners.

To gain insight into the stormwater incentives other cities provide, the stormwater programs of the 12 municipalities previously referenced were examined for current or recent incentives (Table 20). The development of a municipality's stormwater management program appears to correlate with the number of incentive types the municipality offers. Cities such as Portland, Oregon, Seattle, Washington, and Chicago, Illinois, which are each considered to be leaders in sustainable stormwater management, offer four or five incentive types. Cities which are still relatively new to accepting sustainable stormwater management practices, such as Wichita, Kansas, Columbus, Ohio, and Lenexa, Kansas, only offer one or two incentive types.

As of May 2012, Kansas City was providing two stormwater incentives, both of which are classified as stormwater fee discount incentive types. The names of Kansas City's two stormwater incentives, along with a description of each incentive as provided by the City, are listed below (Kansas City, Missouri Water Services, 2012).

Program Name: Stormwater Fee Ratio Credit
Description: Properties that have a large pervious area to help absorb runoff from the runoff surface will be given a ratio credit, if the ratio of the total property area to the runoff surface area is at least 30:1. Properties that qualify shall be granted a 50% stormwater fee credit.

Program Name: Stormwater Fee Detention Credit
Description: Properties served by a privately owned, and properly maintained, detention structure shall be granted a stormwater fee credit. The amount of the credit shall be based on the reduction of stormwater runoff provided by the detention structures and be calculated according to guidelines established by the director of water services. The minimum credit shall be 10% and the maximum credit shall be 50%.

Municipality	Stormwater Fee Discounts	Development Incentives	Grants	Rebate/ Installation Financing	Awards/ Recognition
Wichita, KS	■				
Philadelphia, PA	■	■			■
Portland, OR	■	■	■	■	■
Seattle, WA	■	■	■	■	
San Jose, CA					
Santa Monica, CA			■	■	
Minneapolis, MN	■			■	
Columbus, OH	■				
Olympia, WA				■	
Chicago, IL		■	■	■	■
Emeryville, CA					■
Lenexa, KS			■	■	
Kansas City, MO	■				

Table 21: Stormwater Incentives.

Although it is evident that Kansas City is taking initiative to provide stormwater incentives to address stormwater management concerns, there are many issues with the City's current approach. First and foremost, Kansas City's stormwater incentives program is incomplete. By only providing two incentives, both of which are directed at commercial businesses and/or residential land uses, Kansas City is limiting the potential impact of incentives. Furthermore, the two incentives, possibly unintentionally, fail to encourage community activism and awareness. This defeats the purpose of an incentive which is to promote a practice or plan. Kansas City's ratio credit incentive is automatically determined and applied by the City using aerial photography analysis. By removing the application process, it is unlikely that private land owners are aware of other incentives. Secondly, Kansas City's detention credit does not meet the needs of the highly urbanized Turkey Creek basin. As previous GIS analysis shows, there are few suitable locations for detention ponds in Turkey Creek basin (Figure 17). This is due to high amounts of impervious cover and relatively low amounts of open space which can support the land requirements of detention ponds.

Policy and Incentive Recommendations

Like many other cities around the nation, Kansas City's stormwater management program has been guided by national policy for years. Policies such as the Federal Clean Water Act, while beneficial, have discouraged some cities from developing additional local stormwater regulations that better represent the changing dynamics of urbanized watersheds. Municipalities like Kansas City, which have viewed national stormwater policies as sufficient, have failed to advance local stormwater programs with time. With Kansas City's approval of the Overflow Control Plan and a proposed Network of BMPs identified here within, Kansas City must develop a set of policies and incentives that promote engagement and awareness among private developers and private landowners. Initiative and leadership must come from within Kansas City's City Council and Water Services Department. The development of a site-appropriate stormwater management program is imperative to the success of the Network and Kansas City's sewer infrastructure.

The diverse levels of urbanization found across Kansas City's 16 watersheds present a difficult challenge to the development of a stormwater management program. Generally, local stormwater programs are developed at a city-scale in an all-inclusive approach to stormwater management. However, in Kansas City's case, stormwater management demands vary at much smaller scales such as a watershed-scale. The demands for a highly-developed watershed, such as Turkey Creek basin, with intentions of implementing a Network of BMPs, would be considerably different from the demands of a suburbanized basin. Therefore, developing policies and incentives at a city-scale would undoubtedly ignore the demands of certain watersheds; as is currently the case. A one-size-fits-all approach would not benefit the diverse needs of the entire city. The development of stormwater regulations should be approached from a watershed-scale and be implemented at the city level. For this reason, recommendations are only reflective of the unique stormwater management demands of Turkey Creek basin yet may still be applied to other watersheds if applicable.

The recommendations listed for stormwater policy and incentives are intended to guide future development of local stormwater management programs. Recommendations were based upon existing site conditions, projected growth, and the incorporation of a BMP Network. Therefore, recommendations are informed, general suggestions that reflect the information brought forth in this document and should be further refined by the City before adoption.

Because of Kansas City's high amount of impervious cover, volume-based performance policies will prove most effective in reducing stormwater runoff volumes. Stormwater policy recommendations were developed through personal analysis and by reference to the current stormwater policies of the 12 municipalities and subsequently selecting policies which could be successfully applied in Kansas City. A list of stormwater policies currently provided in the 12 municipalities is located in Appendix B. Four guidelines for policy development have been created. Each guideline provides specific stormwater policy suggestions for private properties in Kansas City.

1. Review current zoning codes for regulatory barriers and simple improvements

    a. Connect zoning codes to Kansas City's stormwater management program.
    b. Amend zoning regulations to decrease parking requirements, increase building setbacks from protected habitats, and decrease max lot coverage areas.
    c. Remove storm sewer connection requirements and instead require private landowners to install BMPs to manage on-site stormwater to the greatest extent possible.
    d. Adopt site design requirements such as landscape requirements that integrate BMPs (Philadelphia, PA; Emeryville, CA).
    e. Water used for irrigation should not be allowed to runoff site (Santa Monica, CA).

2. Set volume-based performance standards

    a. Properties should manage the first half-inch or reduce imperviousness by 15% (Chicago, IL).
    b. Require new construction or retrofitted parcels to reduce runoff from impermeable surfaces by 0.75" (Lenexa, KS).

3. Promote the use of BMPs

    a. Require all new construction to incorporate BMPs on site; preferably Network BMPs (Portland, OR).
    b. Encourage residents and business owners to install widely-applicable BMPs such as rain barrels and native vegetation.
    c. Encourage and support community initiatives to promote BMPs.
    d. Permeable paving should be promoted as standard construction practice.

4. Enforce penalties to improve on-site stormwater management

    a. Increase stormwater utility fees
    b. Require private landowners to pay into a public stormwater fund when site runoff exceeds permitted volumes (Lenexa, KS). Use the money to fund Network education and outreach.

Although the benefits of stormwater BMPs are increasingly understood around the nation, incorporating BMPs into Kansas City's stormwater management program has presented municipal and regulatory challenges and has subsequently discouraged private landowners from voluntarily installing BMPs. Kansas City's lack of stormwater policy mixed with an absence of incentives only exacerbates the indifferent attitude many residents display towards BMPs. For Kansas City's new stormwater policies to be well received, policies should be paired with a wide range of incentives that provide private land owners and developers with immediate benefits. Stormwater incentive recommendations were developed through personal analysis and reference to the current stormwater incentives of the 12 municipalities (U.S. Environmental Protection Agency, 2009). Recommended incentives for Kansas City are listed below by incentive type.

1. Fee Discount

    a. Installation of Network BMPs for an applicable site may result in a stormwater fee discount.
    b. Properties not located within the Network may also be eligible to receive smaller stormwater fee discounts for installing BMPs.
    c. Properties which reduce impervious cover may receive

a percent fee reduction determined by the percent of impervious cover converted into permeable surface.

d. Properties which provide on-site management of stormwater may receive a percent stormwater fee discount determined by the volume of stormwater runoff reduced.

2. Development Incentives

    a. New development which incorporates BMPs into the design may receive zoning upgrades and expedited permitting (Chicago, IL).
    b. Developers may receive an increase in a building's floor area ratio for buildings constructed with a green roof (Chicago, IL).
    c. Business owners may receive a tax credit for installing a green roof on their building (Philadelphia, PA)

3. Grants

    a. Residential and commercial properties located within the Network which currently have stormwater flooding issues due to CSOs may receive grants for Network BMP installation.
    b. Schools, places of worship, and community organizations may receive grants to install BMPs (Portland, OR).

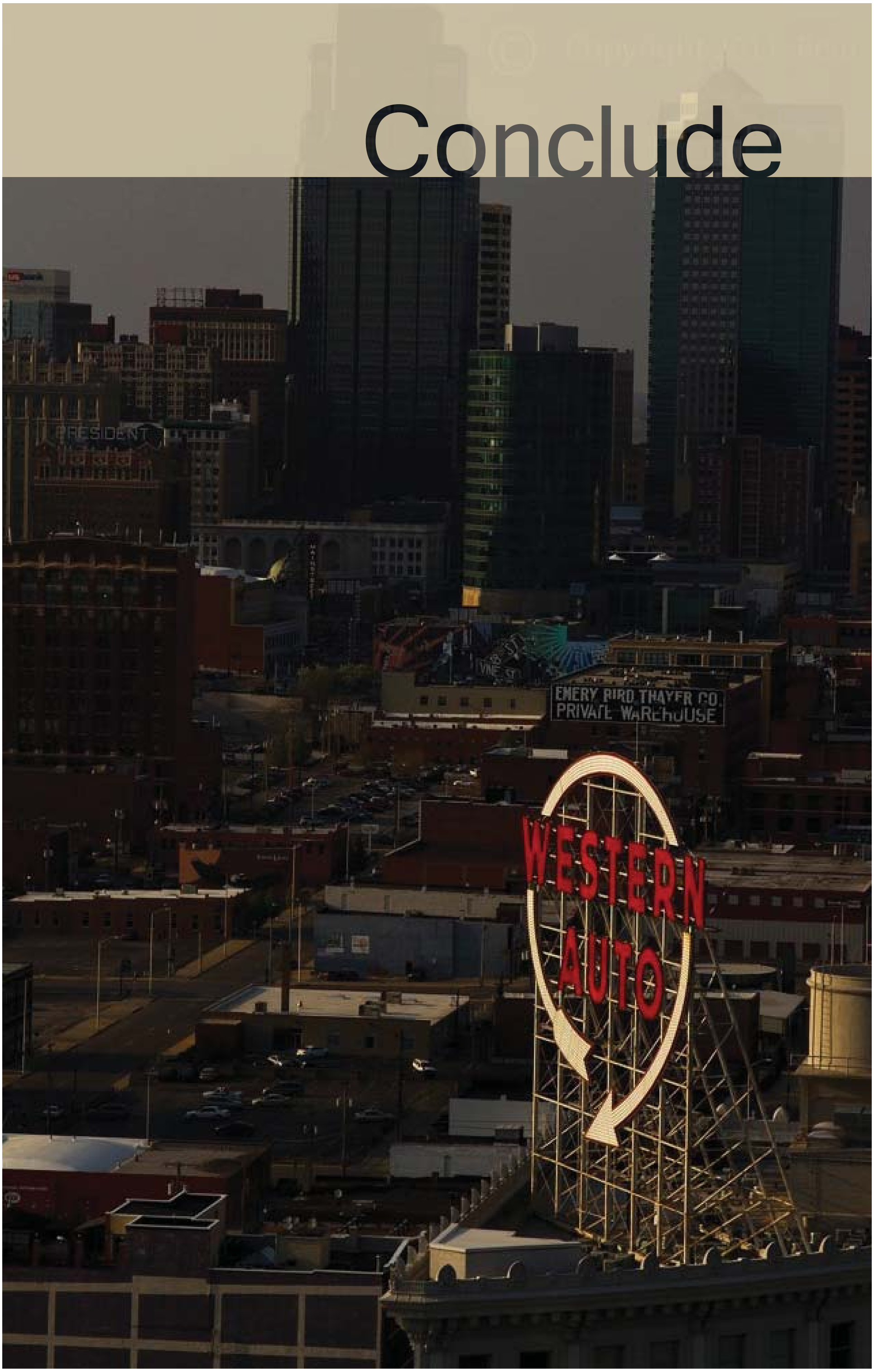
4. Rebates and Installation Financing

    a. Any property owner who installs Network BMPs may receive partial reimbursement for materials and installation costs.
    b. Small commercial businesses which install green roofs may receive partial reimbursement for materials and installation costs (Chicago, IL; Santa Monica, CA; Seattle, WA; Minneapolis, MN).

5. Awards and Recognition Programs

    a. Commercial and corporate businesses may qualify for free advertising with the installation of Network BMPs.
    b. Provide awards and recognition to institutions and non-profits which voluntarily adopt Network BMPs on-site.

Conclude



Downtown Kansas City at sunset. Photo by: Dave Rein, 2011.

“A new type of thinking is essential if mankind is to survive and move toward higher levels.”

Leonardo da Vinci
(Source Unknown)

Conclusion

Closing Remarks:
Kansas City, Missouri, is faced with a dilemma common to developed areas. Rapid urbanization of Kansas City has exceeded predicted development patterns causing unforeseen and unplanned predicaments in the management of stormwater. The undesirable circumstances have resulted in the adoption of a multi-billion dollar stormwater management plan. The plan, better known as the Kansas City Overflow Control Plan, was the result of decades of stormwater infrastructure neglect. The severity of the matter has compelled the City to select 'quick-fix' improvements instead of producing long-term, adaptive plans. As development continues in Turkey Creek basin, stormwater runoff volumes and pollution loads are expected to increase. This will occur as less water infiltrates the ground and more stormwater runoff occurs from the increased amount of land covered by impervious surfaces including buildings, roads, and parking lots. Consequentially, the conventional improvements selected for Turkey Creek basin will, in the near future, become antiquated and insufficient, requiring repairs and installation of larger sewer pipes once again.

A new approach to stormwater management is necessary if Kansas City wishes to free itself from the restraints of conventional sewer system infrastructure. Opportunities remain for Kansas City to incorporate stormwater best management practices moving forward. However, an honest concern subsists. If Kansas City accepts the Overflow Control Plan as a resolution to its combined sewer overflow issues and falls back into its lackadaisical mindset, Kansas City will find itself in a similar situation in the future. While the approved Overflow Control Plan may not include as many sustainable practices as originally desired, the opportunity to integrate BMPs still exists and will likely always exist given the growing need. To fully protect water resources, Kansas City needs to employ a wide range of land use strategies, based on local factors, including the adoption of a range of development policies, incorporating a network of BMPs, preserving critical ecological and buffer areas, and minimizing land disturbances.

The construction of BMPs would be beneficial should Kansas City continue to grow and develop. Results from suitability analysis discussed herein indicate that a considerable amount of private land in Turkey Creek basin is highly suitable for various stormwater BMPs. This is a noteworthy finding considering the City approved $244 million in sewer system improvements for Turkey Creek basin funded by sewer ratepayers and other additional revenues (Kansas City, Missouri Water Services Department, 2009). Had sewer ratepayers been encouraged to invest a comparable amount of money in BMP technologies over the past decade, it is possible the City could be focusing its time and funds elsewhere today.

That is not to say that private landowners should abandon current investments in BMPs. Rather, having identified suitable locations for BMPs in Turkey Creek basin; private landowners are now presented with a research-supported alternative to Kansas City's outdated sewer system to manage their stormwater. Residents are beginning to recognize the importance of each individual's role in the management of the city's stormwater. Although stormwater educational programs have not yet been developed by the City, the Turkey Creek basin community can immediately use the obtained results and sources provided herein to make informed design decisions regarding the management of runoff from their property. The establishment of a BMP Network is an attempt to provide motivated community members a comprehensive and feasible alternative to conventional stormwater management practices. All property owners can make changes to reduce stormwater runoff and pollutants from their site, maximizing the lifespan sewer infrastructure investment.

Findings suggest that if Kansas City were to fully implement a Network of BMPs strictly located on private land, an estimated 28 million gallons of stormwater runoff could be prevented or delayed from entering the Kansas City's sewer system during a single storm event. This is equivalent to a 54% reduction in Turkey Creek Basin's current combined sewer overflow volume for a storm that produces 0.86" of precipitation (Appendix C). The significance of the outcome suggests that a community effort would have both immediate and long-term beneficial impacts on sewer infrastructure and subsequently reduce pollutant levels in the Kansas River and other nearby water bodies. By implementing at least a portion of the Network, Kansas City residents will prolong the lifespan of the existing sewer system, ultimately saving tax payer money. Furthermore, construction of the BMP Network would be valuable to Turkey Creek Basin's ecology through the accommodation of natural processes and biologically-productive open space.

For BMPs to be most effective, the community should adhere to the

BMP Network map which identifies highly suitable locations for BMP implementation (Figure 67). Most importantly, BMPs should be located in upland and midland topographical regions to increase their impact by capturing and treating stormwater runoff at its source and prevent runoff from reaching lowland locations where a higher percentage of impervious cover exists. Additionally, the absence of highly suitable lowland BMPs emphasizes the importance of installing upland and midland BMPs.

To encourage completion of the Network, the City of Kansas City should develop and implement a collection of stormwater BMP policies and incentives. The few policies and incentives currently in place are outdated and unsuitable given the poor condition of the basin's sewer system infrastructure. While the success of the Network ultimately relies on private landowners taking initiative to incorporate BMPs, the City can increase the likelihood of private landowners investing in on-site stormwater management if the City provides adaptive incentives. Subsequently, the City could see reduced spending on sewer repairs and improvements if a moderate portion of the Network is completed. The need for a public-private partnership exists and both parties must respond with appropriate action. Through development of stormwater policies and incentives, the City can finally encourage private landowners to actively become part of the solution.

The research discussed herein suggests a pragmatic alternative to conventional stormwater management practices within Turkey Creek basin. Although there is no indication that sewer systems will, or can ever be completely replaced by stormwater BMPs, the benefits associated with incorporating BMPs into the stormwater management design process are immense. Nonetheless, Kansas City should use the presented results to progress towards an independent system of diverse treatment landscapes to manage stormwater, and away from its deteriorating sewer infrastructure.

Progress largely depends upon the degree of cooperation and collaboration that actually occurs at all levels to achieve shared goals. Integration of BMPs in recent years by private property owners represents a fundamental shift in the traditional approach to stormwater management. The adaptive spirit of inquiry is crucial in order to help the community both celebrate early successes and to learn from failures. The fundamental challenge to the community remains how to establish meaningful goals that help solve ongoing stormwater management problems while, at the same time, improve the quality of life for the overall community.

Limitations:
The use of stormwater BMPs is a nonconforming practice in Kansas City, making BMPs secondary to conventional means of stormwater management. Despite this, everyone involved in the drafting and implementation of Kansas City's Overflow Control Plan recognized the additional benefits that BMPs provide over conventional stormwater management practices. Unfortunately, a lack of local precedent, a perception of risk, and a steep learning curve for those involved, proved too much for Kansas City's Water Services Department to aggressively pursue. Subsequently, residents and business owners were also discouraged from pursuing the use of BMPs. This document is expected to serve as a guidebook for the City of Kansas City and its residents to assist in the development of stormwater BMP alternatives. This is not a design manual. Any resident, business, or City department interested in constructing a Network BMP should first consult the American Public Works Association (Kansas City Metro Chapter) stormwater BMP design manual, located at kcmetro.apwa.net.

The conclusions in this document are representative of the subjective methodology utilized for the project. To perform a computer-assisted suitability analysis of BMPs in Turkey Creek basin, the methodology required a personal evaluation of the design criteria in the referenced BMP design manuals. Because stormwater BMPs are still a relatively new practice in urban stormwater management and continue to evolve, performance data for each BMP type is still being documented by regulatory departments and municipal organizations. Therefore, no universal standard for BMP construction and design currently exists. To accommodate for the lack of consensus among BMP site factors, multiple design manuals, including the American Public Works Association stormwater BMP design manual, were compared to one another to identify commonalities between site factors for each BMP. The factors selected for BMP suitability analysis represent the most accurate consensus among the referenced design manuals. Site factors may be modified as new, more accurate design criteria is made available. This will adjust the outcome of the BMP suitability maps and Network map.

Furthermore, the GIS base data used in analysis ranges in age from six months to two years, therefore some results may not accurately represent current site conditions. In addition to computer-assisted suitability analysis, an in-person site analysis should be performed to confirm the site's suitability before constructing any Network BMPs.

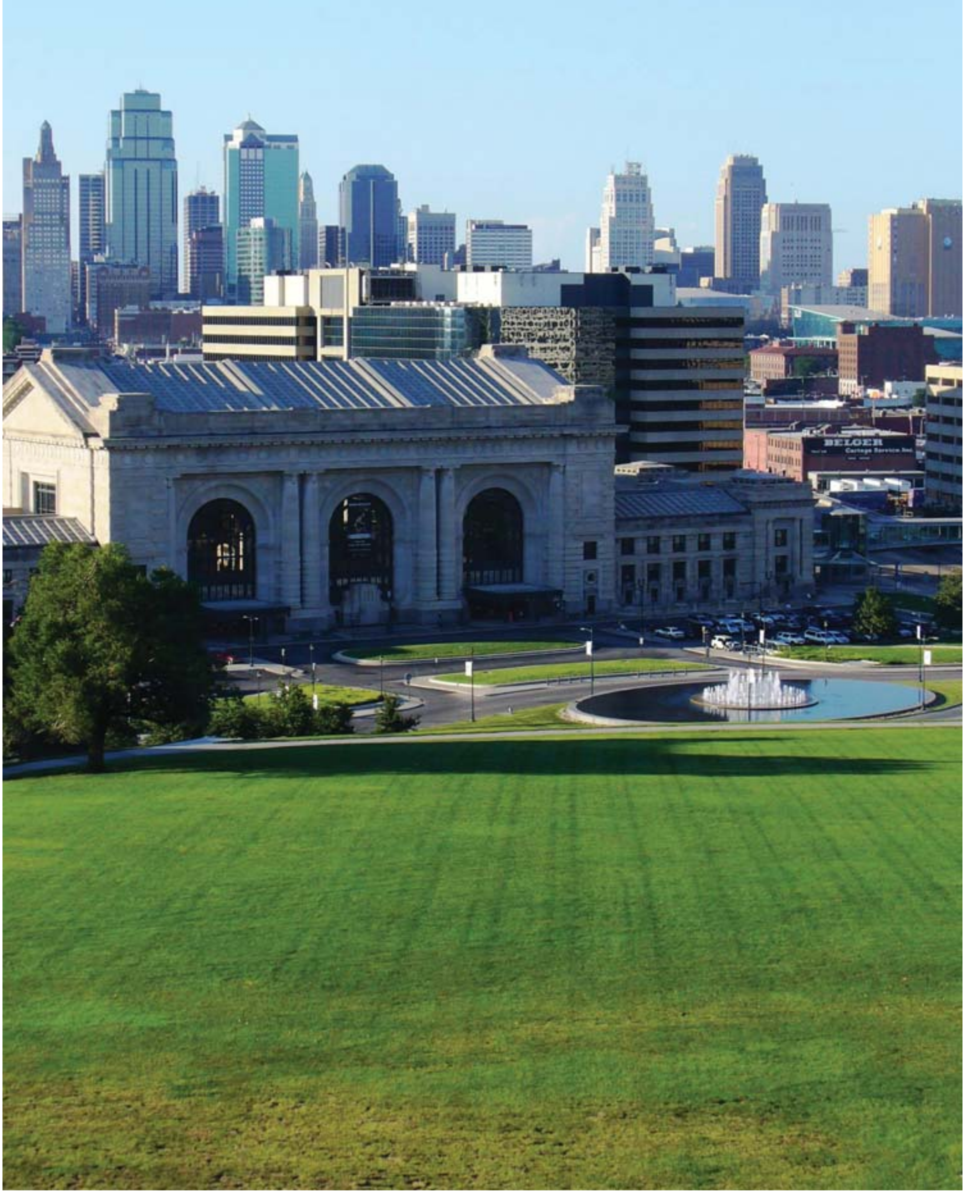
Moving Forward:
The BMP suitability analysis completed accounted for the physical suitability of stormwater BMPs on privately-owned lands within Turkey Creek basin. The final product was a Network of BMPs highly suitable given existing site conditions. While this information is necessary to identify suitable BMP locations in Turkey Creek basin, other forms of suitability analysis could be performed in addition to site suitability analysis. From a municipal and/or homeowner perspective, a BMP's physical suitability is only one of the many factors considered when making a decision to install a BMP. More often than not, upfront costs and maintenance requirements of BMPs have a considerable impact on the decision to install BMPs.

Had more time been available, the next logical step in BMP suitability analysis for Turkey Creek basin would be to compare costs, maintenance requirements, winter performance, and other influential factors of all 12 BMPs to identify new levels of suitability. These additional layers of data would create a dynamic, more refined Network. The additional analysis would also allow residents and business owners to identify suitable BMPs by a single factor, such as by cost or physical site conditions; or by a combination of factors, such as the least expensive BMP physically suitable for their property.

BMP Network suitability analysis could also be performed at larger scales. Using Turkey Creek basin as a model, the City may desire to replicate the methodology for the purpose of constructing a Network of BMPs in each watershed. This would likely require collaboration between the City of Kansas City and other nearby municipalities which are partially located within the same watershed(s). For smaller sites, a modification to the methodology would be required to yield accurate results.

Today, the use of GIS analysis should be an essential step in public stormwater management. Landscape architects and other design professionals must continue to use GIS to identify sustainable stormwater management opportunities and actively promote the integration of BMPs as common practice in urban stormwater management. For this to occur, projects such as *Rethinking Rainfall* must continue to promote GIS capabilities by providing public and private stakeholders with innovative solutions not commonly found in traditional approaches to stormwater management. Through a continued investigation of GIS analysis capabilities and stormwater BMPs, Kansas City and other municipalities can begin to plan ahead for future inevitable improvements to stormwater infrastructure.

Appendix & Works Cited



 Union Station with Downtown Kansas City in the background. Photo by Daniel Jeffries, 2008.

“We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect.”

Aldo Leopold
A Sand County Almanac, 1949

Appendix A

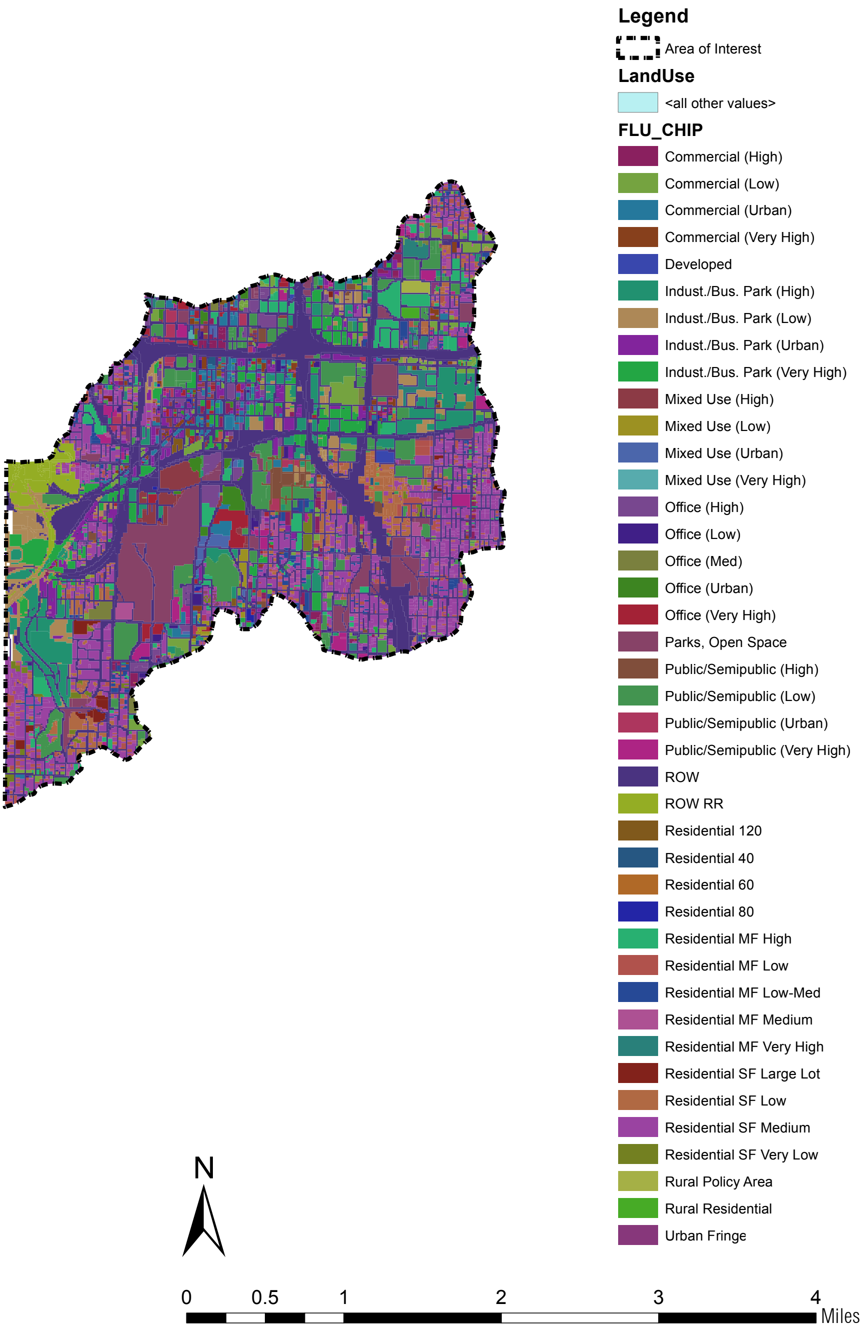


Figure 1: Land Use

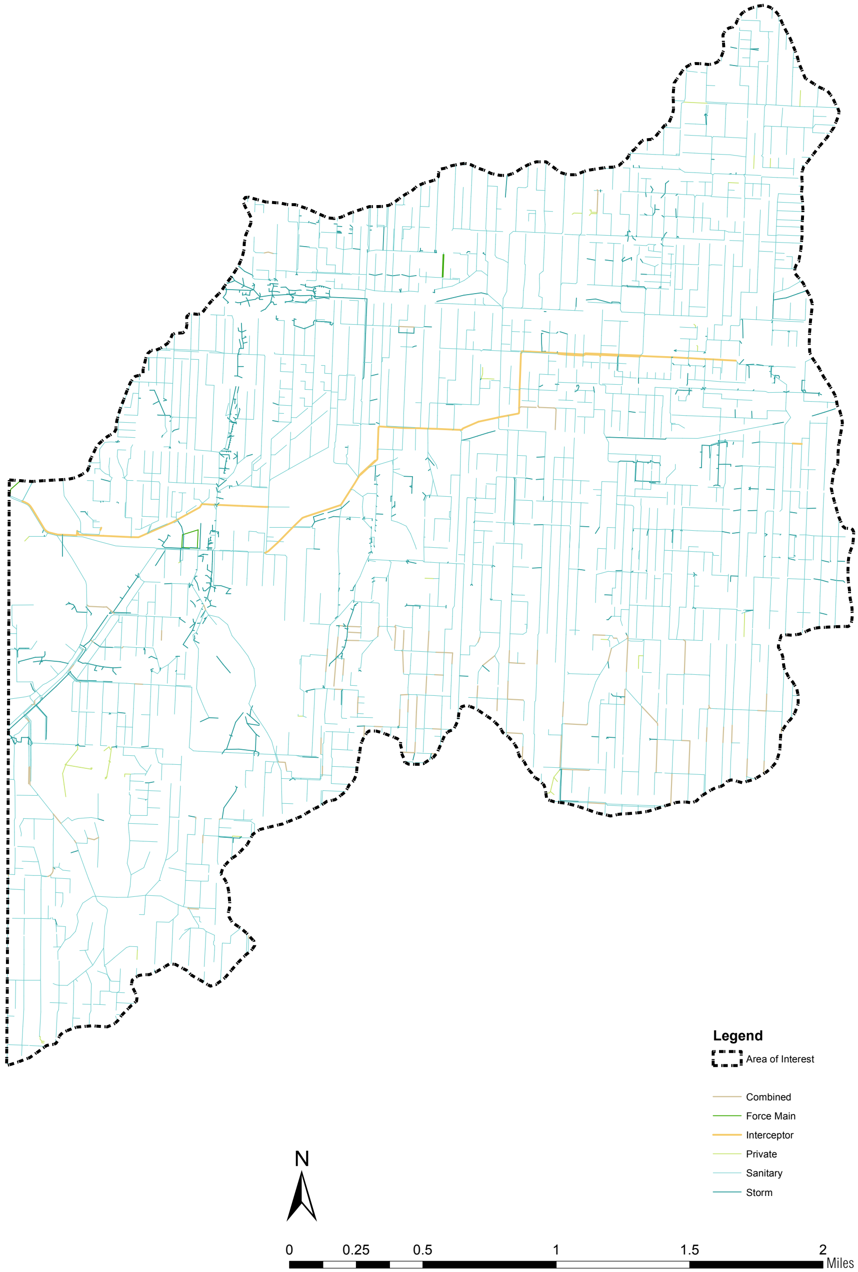


Figure 2: Sewers

Appendix B

Unique Policies of each Municipal Stormwater Management Plan	
Municipality	Stormwater Policy
Wichita, KS	1) Limit the proportion of the area of stormwater facilities to total site area through reduction of impervious surfaces via vertical construction and use of alternative parking surfaces to maximum extent practicable.
Philadelphia, PA	1) Four areas of focus and associated requirements: channel protection (control one year storm), flood protection (post-development conditions must be equal to pre-development), water quality (infiltrate/ manage first 1 inch from all directly connected impervious surfaces), and site design requirements to reduce imperviousness.
Portland,OR	1) Mandatory hierarchy for on-site infiltration or other practices to the maximum extent practicable.
Seattle, WA	1) All projects > 2000SF new and replaced impervious surfaces are required to compost amend all disturbed pervious areas, and implement green stormwater infrastructure practices to the maximum extent feasible. 2) For areas with >10,000 SF impervious flow control performance based thresholds must also be demonstrated; 3) For majority of Seattle creeks drainage basins site must achieve predeveloped pasture condition for peak and duration up to the 2-year flood frequency; 4) For CSO and capacity constrained systems peak control target for 2 year and 25 year flood frequency events must be demonstrated.
San Jose, CA	1) Control either 85 percent of 24-hour storm runoff event (using volume treatment control measures (TCMs)) or 10 percent of the 50-year peak flow rate (using flow TCMs), but must use landscape-based treatment and trees to maximum extent possible

Table 1: Unique policies of each municipality's stormwater management plan

Unique Policies of each Municipal Stormwater Management Plan	
Municipality	Stormwater Policy
Santa Monica, CA	1) 0.75-inch reduction of urban runoff from all impermeable surfaces through infiltration or treatment and release.
Minneapolis, MN	1) LID practices must be used to maximum extent practicable to meet quality and quantity requirements.
Columbus, OH	1) Provide on-site detention and water quality facilities 2) Post-development runoff rates must not exceed pre-development rates 3) Revising standards now based on pilot neighborhood project using green infrastructure
Olympia, WA	1) Control 91 percent of runoff volume infiltrated through on-site controls for quality 2) Post-development flow to meet predevelopment rates for quantity
Chicago, IL	1) Manage 0.5 inch runoff from all impervious surfaces or reduce imperviousness by 15 percent.
Emeryville, CA	1) Site design and source control measures, maximize pervious surfaces, and treatment using landscaping 2) Post-construction quality must meet pre-construction standards, to maximum extent practicable 3) Reporting on the amount of impervious surface created/replaced
Lenexa, KS	1) Manage 1.37 inches of water quality volume using LID treatment train approach; 2) Pay into system for quantity (used to fund regional projects)

Appendix C

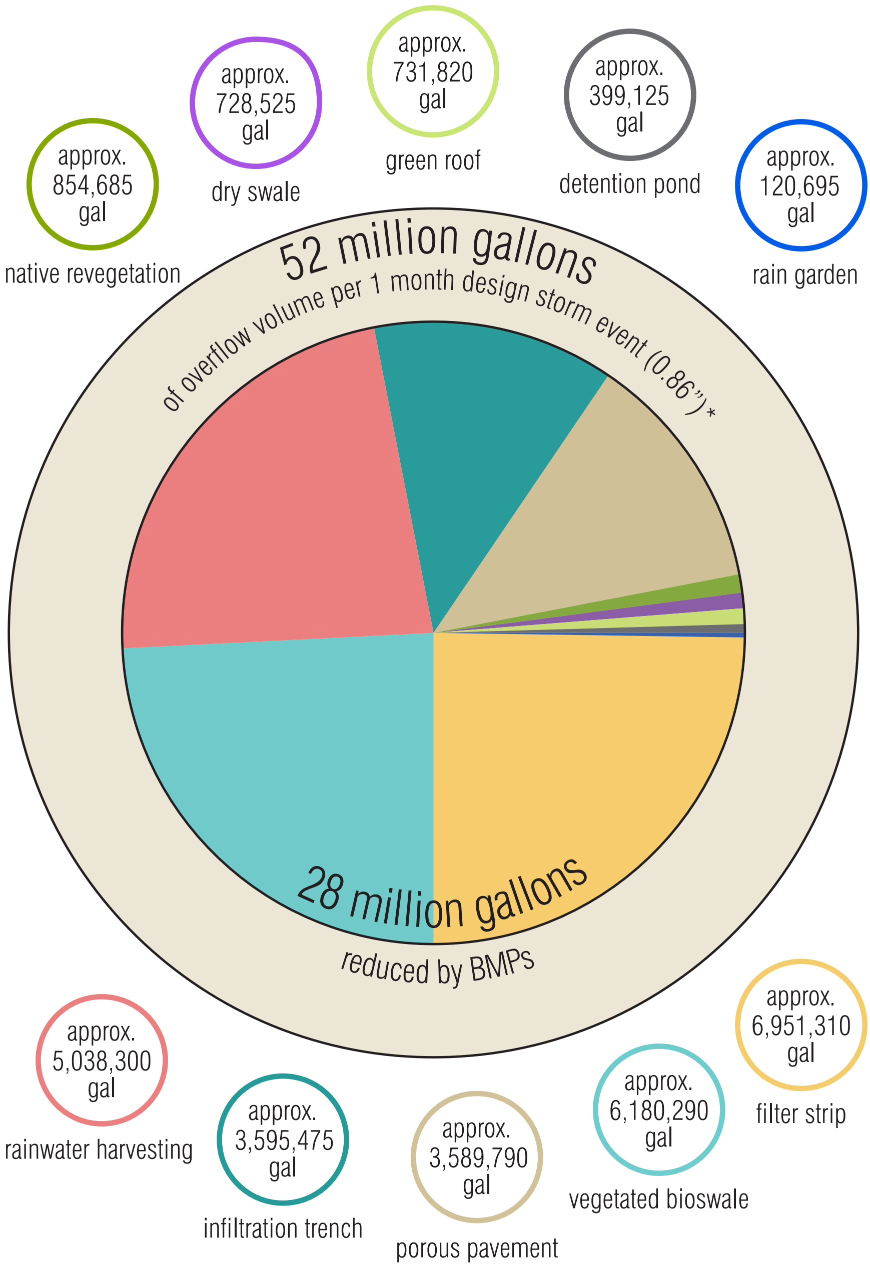


Figure 1: Comparison of CSO volume to runoff reduction if 100% of the Network were completed.

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1. (Southeast Michigan Council of Governments, 2008)
2. (Center for Neighborhood Technology, 2013)

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