BURNING BRIDGES | REINVENTING THE AMERICAN LAWN: A STRATEGIC APPROACH TO RESIDENTIAL STORMWATER MANAGEMENT

by

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A REPORT

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MASTER OF LANDSCAPE ARCHITECTURE

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Abstract:

Wildcat Creek watershed in Riley County, Kansas has been scene to increasingly severe and damaging flooding in recent years. Significant flood events in the summer of 2010 and 2011 have prompted the community to action. One of many areas of concern is addressed by this project in order to facilitate community efforts to reduce future flooding.

Residential stormwater best management practices (BMPs) implemented by property owners to reduce the amount of stormwater runoff entering the Wildcat Creek watershed is the focus of this project. An analysis of the residential development typology in the City of Manhattan within the Wildcat Creek watershed guides stormwater BMP implementation strategies.

GIS identified residential development types based on land use, land cover, and parcel size. Single family residential and high density multi-family developments are the areas of focus. Rational method stormwater calculations were conducted on one sample site selected from each of four areas identified as unique within the residential context. The four sample sites include large lot single family, small lot single family, traditional single family, and high density multi-family. The current stormwater runoff situation was constructed for residential areas of Manhattan within the Wildcat Creek watershed using these samples.

Sample sites were evaluated four times. Existing stormwater runoff amounts for each site were determined. A minimal BMP treatment in the form of rain gardens was applied. Then a moderate BMP treatment including rain gardens, rain barrels, and native plantings was applied. The fourth evaluation was on a high level of rainwater BMP treatment including rain gardens, rain barrels, cisterns, native vegetation, bioretention, and permeable paving.

Post-BMP runoff calculations were performed. The resulting data was compared to the pre-BMP stormwater data to determine the impact of varying degrees of BMP treatments.

This work produced a series of BMP strategies specifically suited to the Wildcat Creek watershed. These site specific strategies are a valuable resource for community members to help reduce flooding in the watershed. The resulting calculations are also valuable tools for community leaders determining the value of stormwater regulations that may require or promote stormwater BMPs in Manhattan.

Burning Bridges|Reinventing the American Lawn

A Strategic Approach to Residential Stormwater Management.

Chris Sanders
Landscape Architecture
Masters Report
Spring 2012

Committee:
Dr. Tim Keane - Major Professor
Professor Lee Skabelund
Dr. Stacy Hutchinson

Abstract

Wildcat Creek Watershed in Riley County, Kansas has been scene to increasingly severe and damaging flooding in recent years. Significant flood events in the summer of 2010 and 2011 have prompted the community to action. This project addresses one of the many areas of concern in the Wildcat Creek Watershed, in order to facilitate community efforts to reduce future flooding.

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Lee Skabelund and Stacy Hutchinson, for serving on my committee and helping mold this project with insights that helped to open my eyes to alternative possibilities.

Dedication

I dedicate this project to my mother for always pushing me to do more and never settle.

Introduction

Dilemma, Thesis, Scope

Introduction

Dilemma

As with many watersheds in the Midwestern United States, flooding is an important issue facing the Wildcat Creek watershed. Flooding within the Wildcat Creek watershed in the summers of 2010 and 2011 (see fig. 1.1) has prompted the formation of a graduate design group in the Department of Landscape Architecture and Regional and Community Planning at Kansas State University. The focus of the design group is to provide solutions to community members within the Wildcat Creek watershed that will help alleviate future flooding and property damages in the watershed.

Wildcat Creek is a unique watershed featuring six sub watershed types and portions of four urbanized areas. Urbanization, channelization, agricultural practices and natural processes all play a role in the flooding issue (Rosgen 2006). While no one solution is likely to solve all of these issues there are many ways to reduce flooding. The focus of this research will be residential stormwater runoff in the City of Manhattan, Kansas (see fig. 1.2). Currently little is done within the City of Manhattan to promote ecologically mindful stormwater best management practices (BMPs). Research by the U.S. Environmental Protection Agency shows that potential exists to reduce stormwater runoff and other ecological and economic inhibitors associated with the average Midwestern Lawn (US EPA 2004).

A one size fits all approach to stormwater management is not likely to work in the City of Manhattan. An array of residential housing types exists within the city. Distinguished by density, lot size, and zoning requirements each of the residential typologies within Manhattan will require unique stormwater management strategies. By approaching each of the residential types based on site specific suitability homeowners can be addressed in ways appropriate to their unique disposition. The questions that must be answered are: what are the different zoning categories in Manhattan and what is their stormwater BMP suitability? What BMP implementation strategies will promote a proactive response from both homeowners and policy makers? And what will the impacts of the proposed stormwater management strategy be on the Wildcat Creek watershed?

There exists an opportunity to educate the constituents of Manhattan on the effects of stormwater management techniques while promoting their implementation. Likewise, policy makers are in a position to engage the homeowners on the issue of stormwater management without alienating community members on the grounds of economics or politics. Through the application of stormwater management and implementation strategies appropriate to Manhattan, both homeowners and policy makers can be positively engaged and work towards a solution that is mutually beneficial.

Thesis

Implementing residential stormwater best management practices will reduce stormwater runoff and promote infiltration. The creation of strategic stormwater management guidelines for residential areas of Manhattan, Kansas within the Wildcat Creek watershed will provide an opportunity to reduce stormwater runoff and increase infiltration, thus, reducing the impact of residential developments on flooding within the Wildcat Creek watershed.

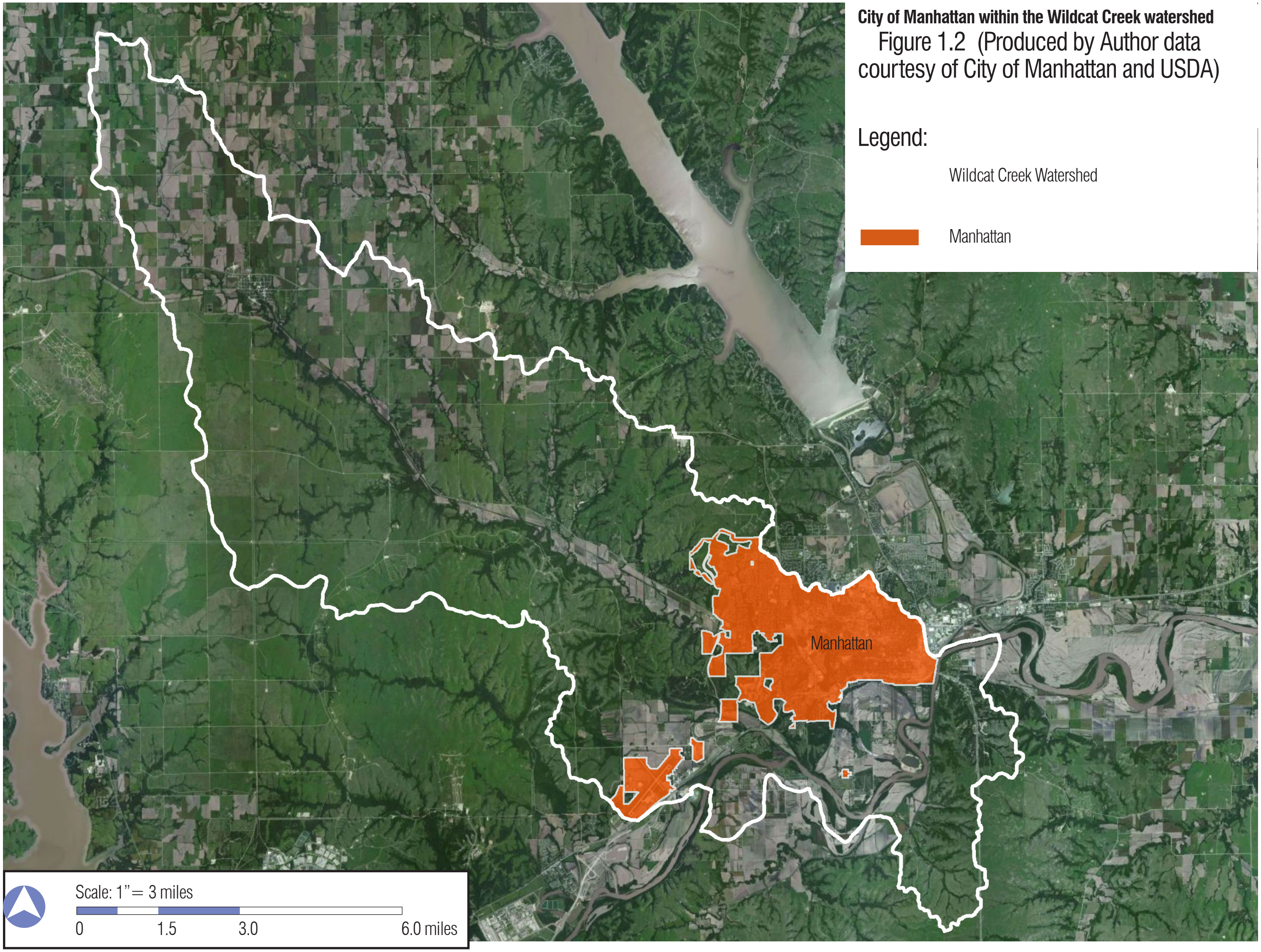
Scope

While the scope of this project will dictate an in-depth knowledge of the entire Wildcat Creek watershed, the City of Manhattan, Kansas is the primary focus of this project. HUC 12 boundaries for the Wildcat Creek watershed in combination with the city boundaries for Manhattan will serve as a site boundary. Within this larger boundary Manhattan zoning information will distinguish residential types (see fig. 1.3). This typology will serve as the framework for specific BMP strategies.

There are currently nine different residential zoning categories represented in the City of Manhattan. Eight of these categories are present in the Wildcat Creek watershed. These zoning categories represent single family residential as well as several levels of increased density residential (two-family, multiple-family, and four-family). From within these zoning categories this research project has established a residential typology that represents both single family and multi-family housing found within Manhattan. This typology will be used to calculate the potential impact of various levels of stormwater BMP implementation. Based on physical attributes and spatial relevance within the watershed four residential lot types will be evaluated. These lot types represent small lot single family residential, large lot single family residential, traditional single family residential and high density residential. One site from each of these residential types has been selected to explore BMP design possibilities. Four levels of BMP implementation are applied to each sample site to determine the effect varying degrees of BMP implementation will have on stormwater runoff quantities. Rational method stormwater calculations have been calculated for each site as it exists currently to determine a

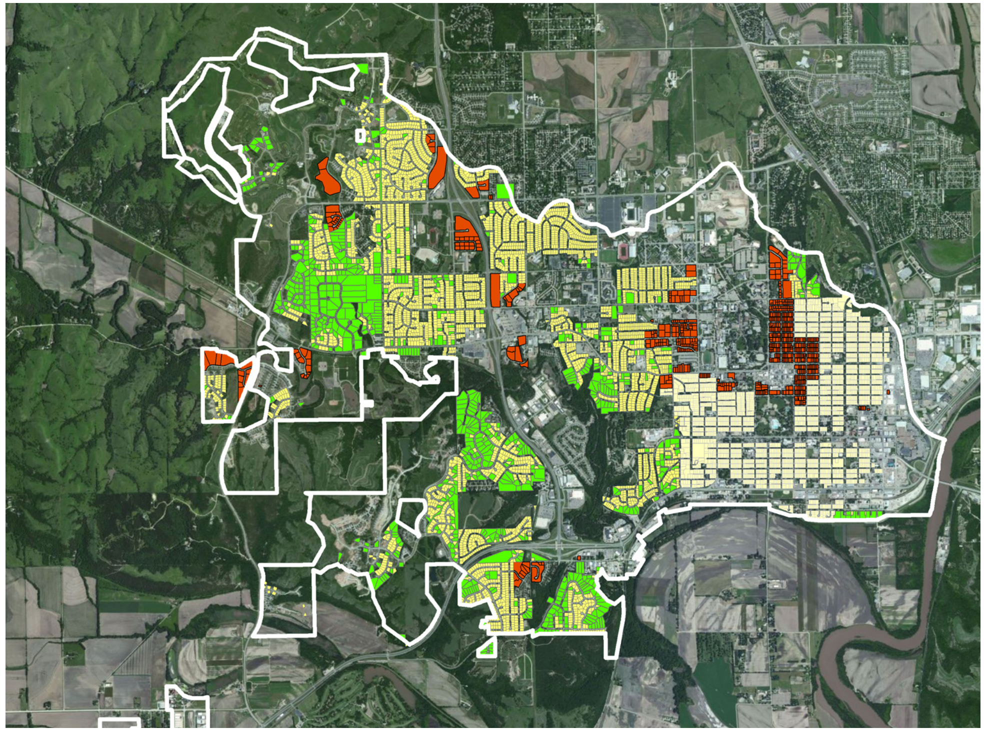
Wildcat Creek Flooding Summer 2011

Figure 1.1 (Photo courtesy of Ott, 2011):


City of Manhattan within the Wildcat Creek watershed
Figure 1.2 (Produced by Author data courtesy of City of Manhattan and USDA)
Legend:
Wildcat Creek Watershed
Manhattan
Manhattan
Scale: 1"= 3 miles
0
1.5
3.0
6.0 miles

baseline runoff amount. This runoff data has been extrapolated to show the stormwater impact of each residential type within Manhattan. These calculations were repeated after a low, moderate, and high level of BMP implementation is applied to each site. These calculations were then extrapolated and compared in different proportions to show the impact varying degrees of residential stormwater BMP implementation can have on the Manhattan area of the Wildcat Creek watershed.

In addition to watershed, city and site scale boundaries, stormwater BMPs require their own individual areas. An understanding of BMP sizing will be required as well. BMP sizing is important in determining site suitability so that BMPs will provide the level of performance needed to adequately handle the amount of stormwater encountered on each site.



Legend:

- Manhattan in Wildcat Creek Watershed
- Small Lot Single Family
- Large Lot Single Family
- Traditional Single Family
- High Density Multi-Family

Scale: N.T.S

Residential Development Areas Examined

Figure 1.3 (Produced by Author data courtesy of City of Manhattan and USDA):

Map showing the footprint of each of the four residential development types examined by this project in relation to the boundary of the City of Manhattan within the Wildcat Creek watershed.

The Project - Part I

Glossary, Process, Project Description/Development/Site Selection

Glossary

Bioretention Area

Figure 2.1 (USDA NRCS, 2012):

Example of bioretention area capturing runoff from paved area. This technique can be applicable in the Manhattan area. Primary difference between bioretention and rain garden is use of constructed soils in bioretention.

Acre Feet: The volume of one acre of surface area to a depth of one foot (66'x660'x1') or 43,560 cubic feet

Best Management Practice (BMP): Stormwater management practices that reduce the amount of stormwater runoff, increase infiltration, or increase stormwater lag times. BMPs Include structural and non-structural practices, as well as, maintenance procedures, and prohibition of activities. (MARC 2003)

Bioretention Area (fig. 2.1): Small vegetated areas that stormwater runoff is directed into allowed to pond and eventually infiltrate into the ground. Bioretention areas are made up of several components. Filter strips to introduce sheet drainage to system, ponding area for surface storage of runoff, organic mulch layer to protect against soil erosion, planting soil to support plant life in system, sand bed to facilitate drainage, plants for evapotranspiration and pollutant removal, and finally a water level control structure to remove excess water from system. Bioretention can be useful in recharging groundwater. (MARC 2003)

Cistern (fig. 2.2): Large container used to collect rooftop stormwater runoff for non-potable uses such as irrigation. Typically have 50-5000 gallon capacity (primary distinction between cisterns and smaller rain barrels). Can be above ground, fully or partially buried depending on site conditions and intended use. (Wilson and Company & Camp, Dresser and McKee 2009)

Dry Swale: A vegetated drainage channel or depression with an engineered soil matrix and under drains intended to slow stormwater runoff and promote infiltration while conveying runoff away from site. (MARC 2003)

Extended Dry Detention (EDDBs): Basin designed to retain stormwater runoff from 10-50 acres for up to 40 hours to allow for increased infiltration and reduction of overall stormwater runoff amounts. Area remains during extended periods without rainfall. (Wilson and Company & Camp, Dresser and McKee 2009)

Extended Wet Detention (EWDBs): Two part detention basins featuring a permanent pool that retains water at all times and an extended storage area that is usually dry. EWDBs allow for stormwater infiltration and reduction in runoff amounts as well as an extension in runoff lag times. (Wilson and Company & Camp, Dresser and McKee 2009)

Filter Strip: Grassed areas that accept sheet flow runoff from adjacent surfaces. Promote infiltration, filtration and slowing of stormwater runoff. Often used near large areas of impermeable surface and or/ to convey stormwater before discharge into swales or sewer systems. (MARC 2003)

HUC Boundary: Hydrologic unit code consisting of two to twelve digits depending on the level of definition. 2 digits: first level (region), 4 digits: second level (sub-region), 6 digits: third level (accounting unit), 8 digits: fourth level (cataloguing unit), 10 digits: fifth level (watershed), 12 digits: sixth level (sub-watershed). (USDA 2007)

Hydrologic Soil Groups (HSG's): TR-55 soil classification groups that classify soils based on infiltration qualities. The USDA has classified four HSG's group A, B, C, and D. (USDA 1986)

- Group A: low runoff potential and high infiltration rates. Often deep well drained sand or gravel.

- Group B: Moderate infiltration rates. Often moderately deep well drained soil with fine to moderately course texture.

- Group C: Low infiltration rates. Often soils with a layer that impedes downward transmission of water and moderately fine to fine textures.

- Group D: High runoff potential with very low infiltration rates. Often clay soils with high swelling potential, soils with permanently high water table, soils with a clay pan or clay layer near surface, and shallow soils over impervious material.

Impermeable: "Geologic formations that resist water percolating through them." (Bell, Eccles, Garber, Kerby & Swaffar, 2004) Buildings, pavement (impermeable), infrastructure, and rock are some examples of impermeable surfaces that don't collect water and create higher levels of runoff. (LOG+S Glossary)

Infiltration: Water seeping into the ground and creating moist soil, feeding plants through the root system, and preventing water from leaving the site. This is encouraged through the use of permeable materials, sandy soils, and vegetation. (LOG+S Glossary)

Infiltration Basin: Earthen structures that capture stormwater runoff and slowly allow infiltration over a period of time. Should drain within 72 hours to prevent mosquito breeding

Cistern

Figure 2.2 (Lake County, Illinois, 2006):

Example of above ground rain water cistern. Though this project utilized below ground cisterns above ground systems are applicable in Manhattan.

Native Kansas Plants

Figure 2.3 (Klataske, 2010):

Example of native Kansas vegetation found near Manhattan, KS.

Porous Asphalt

Figure 2.4 (Sturgis Michigan, 2011):

Example of porous paving that could be used in Manhattan area BMP strategies

Decorative Rain Barrels

Figure 2.5 (Rainscaping.org, 2011):

Example of decorative rain barrels that can be easily constructed by homeowner.

and odor. Best located near end of treatment train to prevent sedimentation. (MARC 2003)

Infiltration Trench: Excavated trenches filled with course granular material. Temporarily store stormwater runoff to allow infiltration. Only capable of handling small amounts of runoff typically used for first flush runoff values. (MARC 2003)

Lag Time (Time of Concentration): The time after the beginning of a rainfall event when all portions of a drainage basin are simultaneously contributing flow at the basin outlet (Iowa, 2008).

Low Impact Development (LID): Land development focusing on preserving or recreating natural landscape features resulting in point source stormwater management (U.S. Environmental Protection Agency, 2011).

Lot Coverage: The percentage of a lot that is covered by structures when viewed from above. Structures include but are not limited to: homes, enclosed patios, sheds, air conditioning units, and detached garages. Projecting roof eaves and gutters are considered part of the structure. (City of Manhattan n.d.)

Native Species (fig. 2.3): Plants and animals that have developed specific adaptations to exist in a particular region. (MARC 2003)

Porous Pavement (fig. 2.4): Pavement that allows water to infiltrate while maintaining stable platform for parking or driving. Examples include: porous asphalt, porous concrete, cobble pavers with porous joint material, and reinforced turf. Porous paving should be avoided in areas prone to sedimentation due to clogging of pores. (MARC 2003)

Predevelopment: Conditions that existed before the development of a site. For the purpose of this document, pre-development, will often refer to soil, vegetation, drainage, and other similar site features.

Rain Barrel (fig. 2.5): Small rainwater collection vessel (50-60 gallons) used to collect rooftop runoff to be reused for non-potable purposes. (Wilson and Company & Camp, Dresser and McKee 2009)

Rain Garden (fig. 2.6): Small depression planted with native wetland and prairie vegetation that collects local stormwater and facilitates infiltration. Commonly used in residential applications. (MARC 2003)

Stormwater Detention Facility: Structure that allows stormwater to be captured and slowly infiltrated or released at a later time. (MARC 2003)

Treatment Train: A series of biological and physical stormwater BMPs used in succession to treat stormwater quality and reduce physical volume of stormwater runoff. (MARC 2003)

Vegetated Swale (fig. 2.7): Densely vegetated, broad, shallow channels used to slowly convey stormwater and trap pollutants, promote infiltration, and reduce flow velocity. Requires a prepared soil filter bed. Can be wet or dry depending on site needs and client desires. (MARC 2003)

Vegetated Channel: Vegetated swale lacking prepared soil filter bed. Not intended to convey deep concentrated flow only effective for shallow concentrated flows. Often used along roads. (MARC 2003)

Watershed (Drainage, Basin, Catchment): Area of land that drains into a body of water. (MARC 2003)

Rain Garden

Figure 2.6 (City of Bloomington, 2012):

Example of residential rain garden constructed by homeowner. Rain gardens can serve both ecological and aesthetic function in residential landscape.

Vegetated Swale

Figure 2.7 (French, 2005):

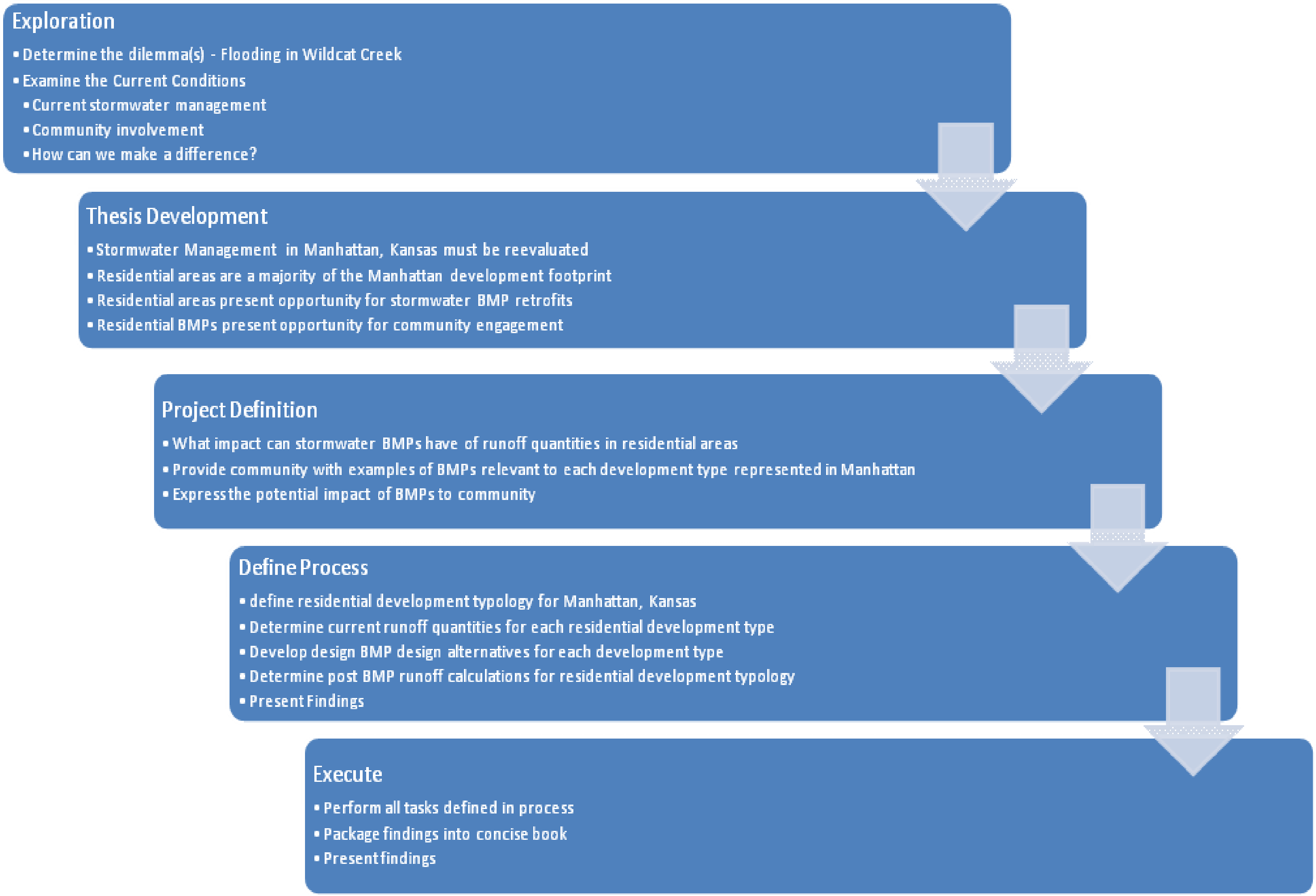
Vegetated swales promote stormwater infiltration while conveying runoff collected from adjacent areas.

Process

Project Process Diagram

Figure 2.8 (Produced by Author):

Diagram exploring the development and execution of this project.



Project Description/Development

Manhattan, Kansas has eight different classes of residential zoning (City of Manhattan). Based on the proportion of Manhattan within the Wildcat Creek watershed zoned in each residential type this project focuses on four types of residential development. Type one is small lot single family residential. Small lot single family lots are lots less than 20,000 square feet and feature a single dwelling unit. Type two is large lot single family. Large lot developments are single family lots greater than 20,000 square feet. Traditional single family lots make up the third development type. Traditional residential lots are lots within Manhattans Traditional Neighborhood Overlay District (TNO). Traditional Lots feature standard lot sizing of 50'x150' or roughly .17 acres and maximum lot coverage of 30%. Lot coverage is the amount of a lot when viewed from above that is covered in structures. The fourth and final residential type examined in this project will be the high density residential developments. High density developments are becoming increasingly prevalent in Manhattan as the need for housing increases. High density developments present different lot conditions and BMP opportunities than single family development.

Given the specific size and placement requirement of stormwater BMPs, determining residential types based on the physical attributes allows BMP placement strategies to be tailored to the suitability of specific housing types. The following descriptions describe each of the residential types as determined by this research. (Note: Calculations performed though Image analysis of GIS data provided by the City of Manhattan, Riley County, and the USDA NRCS)

Type 1: Small Lot Single Family Residential (Appendix A fig. A.1) – Type 1 is the largest of the five residential types in the Manhattan falling within the Wildcat Creek watershed accounting for 986.61 acres and 3784 lots. This makes the average lot in type 1, 11,357 square feet. Type 1 is comprised of single family residential parcels less than 20,000 square feet in size. 20,000 square feet is the size used in determining single family zoning subclasses in Manhattan, Kansas separating R and R-1 zoning classes from the larger R-S zoning class. Residential Type 1 is a combination of Manhattan zoning classes R (Single Family Residential), and R-1 (Single Family Residential). Portions of the previously stated zoning classes were excluded when drawing the Type 1 boundary to accommodate overlay districts, namely the Traditional Neighborhood Overlay (TNO). See Type 3 for further explanation of the TNO. Type 1 small lot residential accounts for 41.7% of the total developed area examined by this project making it the most influential development type in the watershed in terms of stormwater runoff.

Type 2: Large Lot Single Family Residential (Appendix A fig. A.2) – Type 2 is the second most influential development in terms of total acres encompassing 684.64 acres and 757 lots. The average lot size in type 2 developments is 39,554 square feet more than 3 times the average size of small lot residential developments in the area. Large lot development is significant in terms of BMP implementation as the size of a site directly impacts the size and placement of constructed BMPs. Large BMPs requiring constructed soils such as bioretention facilities and extensive grading such as bioswales are more easily accommodated on larger sites. Large lot developments in Manhattan are considered any single family lot of more than 20,000 acres and are primarily zoned as R-S (suburban single family residential). Large lot developments in Manhattan represent a unique condition in terms of land cover as well. Several areas within type 2 feature developments that are heavily wooded. While these developments will not be specifically focused on, it is important to note that alternative design solutions may need to be applied in these areas. For example, BMPs requiring grading are not well suited for the area under the drip line of a tree. Likewise, many native Kansas plants are not well suited to shade and would not be applicable in heavily wooded areas.

Type 3: Traditional Single Family Residential (Appendix A fig. A.3) – Type 3 TNO lots account for 403.79 acres in the project area roughly 17% of the total area. Type 3 developments are unique in several ways due to the requirements of the Traditional Neighborhood Overlay District in which they fall. First, the TNO regulates lot dimensions providing a relatively uniform lot dimension of 50'x150' or .17 acres. In addition to lot size lot layout and land cover are regulated in the TNO. Lot layouts are uniform with 14-25' front setbacks, garages and parking in the rear and alley access. Lots without alley access will have one curb cut to permit lot access. However, unlike other residential types the amount of pervious surface is regulated in the TNO. Lot coverage or the amount of the lot covered by structures when viewed from above is limited to 30% in the TNO. Drives are limited to 10 feet in width with limited length due to rear placement of garage structures. Parking adjacent to rear alley access is also allowed helping to limit the amount of paving used in the TNO. Street trees are regulated in the TNO as well with approval from the City Forester required to remove any street tree in the public right of way. In all, the TNO overlay helps to limit the highly developed impervious lots found in the high density multi-family development types.

Type 4: High Density Multi-family Residential (Appendix A fig. A.4) – High density multi-family developments are markedly less prevalent within the project area accounting for 290.73 acres or 12.3% of the total area. High density developments are becoming increasingly popular within the Manhattan area of Wildcat Creek watershed due to heightened demand from Kansas State University student and staff. Manhattan has implemented a Multi-family Redevelopment Overlay District adjacent to the Kansas State campus. This overlay district promotes the redevelopment of once traditional single family homes into high density apartment developments. Not only do these high density developments increase the overall lot coverage with larger buildings but the amount of impervious paving is increased to accommodate a much higher dwelling unit per lot ratio. While residential types 1-3 reflect an average of just over 1 DU per lot, development type 4 averages just over 9 DU per lot.

In each of the four residential types BMP treatments have been applied to accommodate varying degrees of stormwater management based on a two-year storm event. Certain BMPs will apply to all four of the residential development types while all four have a unique treatment train hierarchy based on site suitability. BMP physical feasibility was based on four categories: Size of drainage area, Space required for BMP, site slope, and requirement of supplemental watering and other care during times of low rainfall (MARC 2003).

Sample site selection is based on the dominant residential development types in the Manhattan portion of Wildcat Creek watershed. Single family developments overwhelmingly dominate the area. However, there is significant variance in the physical attributes of the single family lots in the project area. Using the four development types (small lot, large lot, traditional and high density residential) four sample sites, one from each development type, were selected to represent the general condition of Manhattan residential developments. These sample sites were evaluated using the rational method of stormwater calculation under four different stormwater treatment conditions.

The existing runoff volume was determined based on the current site conditions using the rational method of runoff estimation. Rational method estimation requires four key pieces of information. First, the site must be broken down by surface material and each surface and condition must be determined (i.e. turf grass with 7% slope). Next the area, in acres, of each surface type must be found. Once site conditions are determined the runoff coefficient of each surface must be determined. The coefficient tables used for this project can be found in the appendix of this document (see appendix E). The fourth piece of information needed is the rainfall intensity for the desired storm event and duration. For example, this project examines the runoff amounts accrued over one hour of a two-year storm event in Manhattan, Kansas. This amount is roughly 1.75 inches. Rainfall intensities can be found in numerous places, the table used for this project was developed for the state of Kansas and is located in the appendix (see appendix B). Once all four of these measures are acquired the calculations can be completed.

Rational method volume calculations use the formula: Q = A x C x I. Where, 'Q' is the discharge in acre inches per hour. 'A', is the area of the basin in acres. 'C', is the coefficient of runoff and 'I' is the intensity of rainfall in inches per hour. This equation was interpreted in two ways for this project.

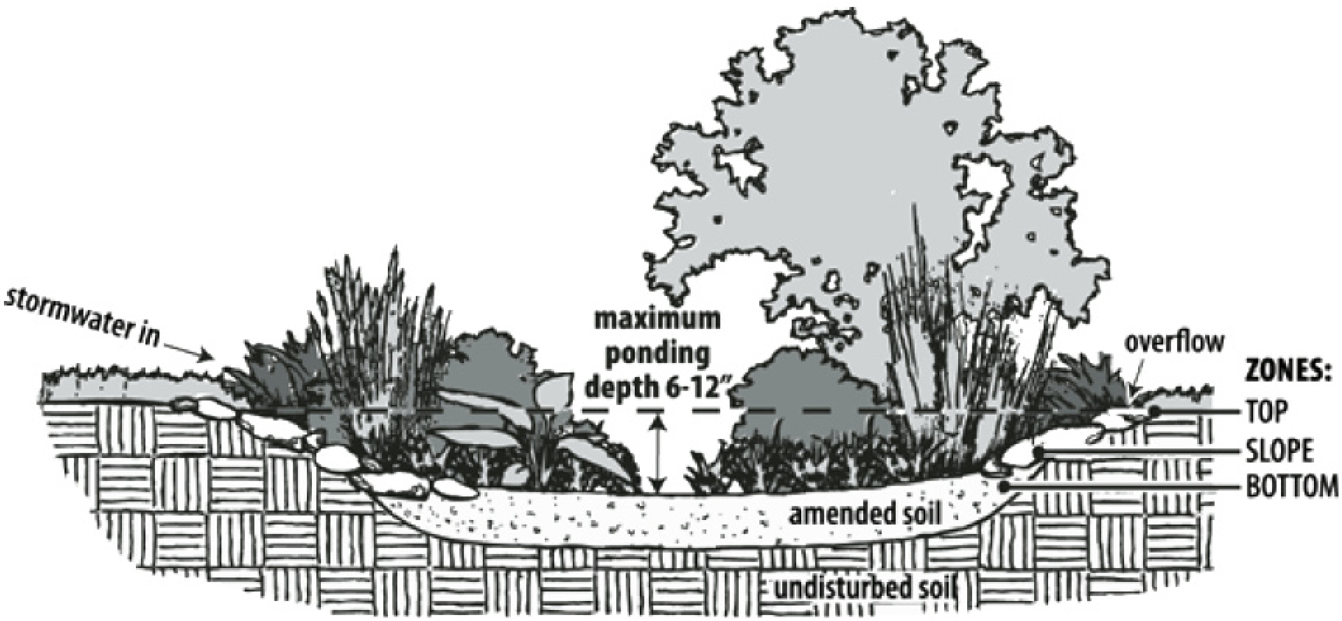
The first application of the rational method equation was to determine the overall runoff quantities for the four different residential development types in the project area. For this large scale application an adjusted runoff coefficient was determined for each development type. To develop the adjusted runoff coefficient each sample site was divided by surface cover type and the percentage of each type relative to the overall site was determined. The runoff coefficient for each of the surface types was then weighted by multiplying the coefficient by the percentage of the overall site the selected surface represents. Once the adjusted runoff coefficients (adj.C) for each surface type are determined they are added together to get the overall weighted average runoff coefficient for the development type represented by the respective sample site. It was important to determine the adjusted runoff coefficient for each development type to allow for efficient extrapolation of runoff calculations to the entire project area. Once the adjusted coefficient was determined the total area (A) of the residential development type was calculated using GIS data for the Manhattan area. Intensity (I) was then determined for one hour of a two-year storm event using the rain fall intensity charts in appendix B. Once 'A', adj.'C', and 'I' were determined a simple multiplication of the values provides the total runoff of the selected development type in the Manhattan portion of Wildcat Creek watershed.

The second application of the rational method equation was to determine site specific runoff quantities for each surface area on the sample sites. This calculation was less complicated than the city scale runoff estimation. To determine the quantity of runoff coming from each surface type 'A' is simply the area of the surface; 'C' is the coefficient for that specific surface type and 'I' is the intensity found in the previous calculation (1.75 inches per hour). Determining the runoff amounts associated with each surface on a selected site allows applications of BMPs suited to reduce runoff from the primary contributing areas. For example, if a site features a large amount of paving that contributes excess runoff, porous paving with underground storage may be able to capture, store and infiltrate the runoff that would normally enter the storm sewer system. In addition to source specific BMPs it is important to determine the overall runoff amount to achieve the 60, 80 and 100% runoff sequestration levels.

Once the base level of stormwater runoff from each sample site was determined BMP strategies were then applied to each site to achieve one of three goals. The thresholds established for this project are 60, 80, and 100% runoff mitigation. These thresholds are related to one of three levels of BMP implementation. Levels of implementation are low level, mid-level, and high level implementation. Each level has been determined based on the construction and fiscal demands of the BMPs included and the ability of a homeowner to implement these features. Low level BMP implementation consists of a rain garden or several rain gardens. Given the relatively easy nature of rain garden installation and low cost associated with this BMP, rain gardens are considered easily implemented on almost all sites in Manhattan. This project shows how rain gardens can be used to sequester 60% of a two-year storm event on residential sites in Manhattan. Mid-level BMP strategies include rain gardens, rain barrels and native plantings. Rain barrels are relatively easy to install and low cost, however, important considerations regarding overflow control are necessary. Native plantings fall within the moderate level BMP category as well due to the relatively simple nature of their implementation. Native plants are well adapted to the area requiring little supplemental water and fertilizer once they are established (EPA n.d). With proper site placement and minimal maintenance native plants can be a useful BMP with a low level of burden to the homeowner. Mid-level BMP strategies are used in this project to illustrate 80% runoff reduction for a two-year storm event. High level BMP strategies include all of the previously mentioned strategies as well as a few additional BMPs. These include cisterns, bioretention facilities, vegetated swales, and permeable paving. High level BMP strategies represent a level of implementation that will require significant time and monetary commitments. While high level BMP implementation strategies are recommended for reducing the highest level of stormwater runoff possible from a site scale perspective, it is accepted that many homeowners are not able to commit to the level of dedication required to achieve this level of BMP implementation. For the purposes of this project the High-level BMP strategies were used to achieve a 100% reduction of runoff from a two-year storm event.

BMPs used in this project were selected based on their applicability to the Manhattan area and the site conditions of the residential development types examined. Data from the Mid America Regional Council (MARC) and the BMP handbook they have assembled along with data from the Kansas Post Construction BMP Manual and the work of Marcus de la fleur on the 168 Elm Ave (MARC 2003 and de la fleur 2008). Pilot Project was used to determine applicability to the area and design criteria such as placement and sizing. A few things should be noted while examining the implementation strategies presented in the later portions of this report. First, rain gardens are sized assuming a maximum storage depth of 4inches to accommodate the native plantings used in these areas (Bachmann, 2006) (fig. 2.9). Rain Barrels are applied in three barrel units as used by Marcus de la fleur on the 168 Elm Ave. Pilot Project (de la fleur 2008). This application allows for substantial storage while maintaining flexibility in use by accommodating 165 gallons of water and three faucet locations tailored to specific uses (see fig. 2.10). Cisterns can be both above or below ground however, the designs examined in this project are underground systems (fig. 2.11). Permeable paving referenced in this project is assumed to include temporary underground storage capabilities to allow for 100% capture of stormwater falling on the surface and infiltration (see fig. 2.12). Also note that any water in excess of BMP design capacities will be assumed to overflow into currently in-place stormwater drainage networks and storm sewer system. Native vegetation referenced in the designs of this project are considered to be any healthy mix of native plants referenced in the MARC vegetation charts in Appendix C. The intent of this project is not to specify exact planting mixtures but rather present a framework for areas that could be converted to native plantings to promote infiltration (see fig. 2.13) .

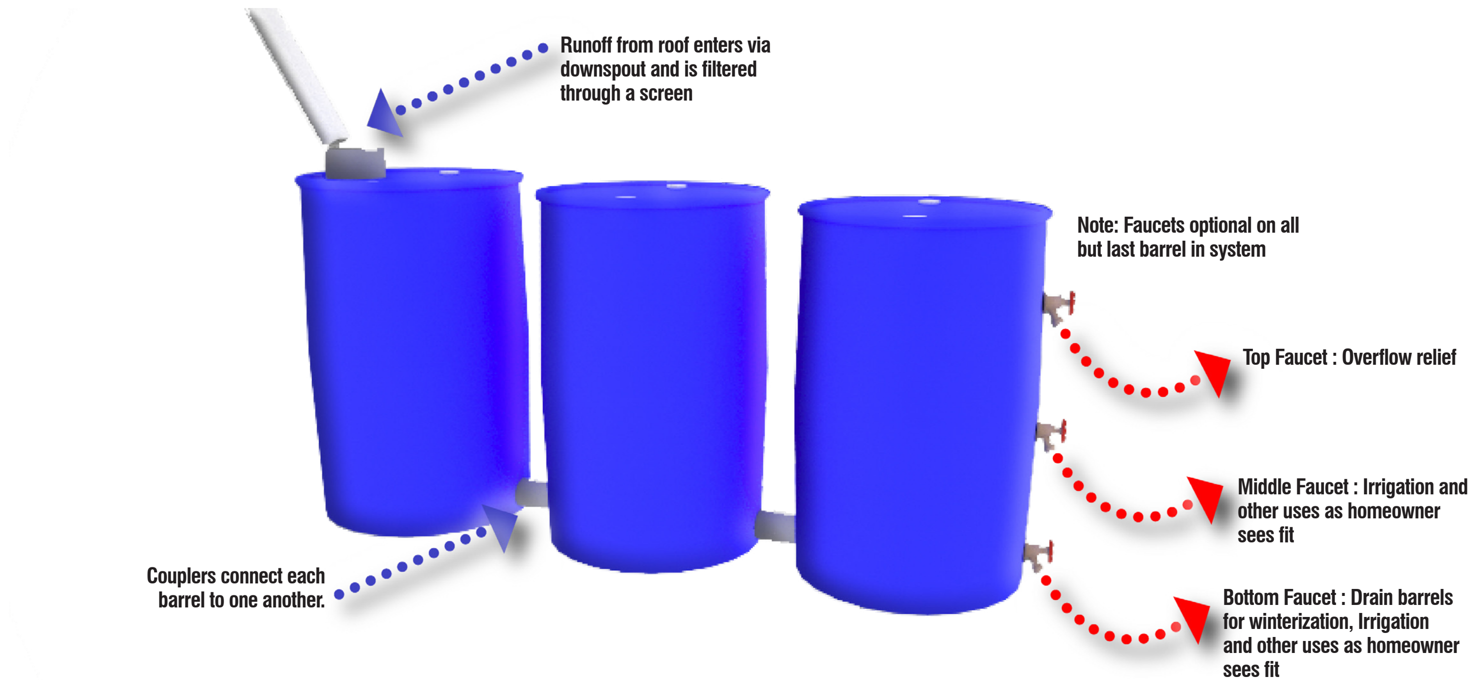
Stormwater runoff amounts from each level of BMP implementation for each of the four sample sites have been extrapolated to determine the overall stormwater runoff value of Manhattan residential developments. These calculations are important in allowing community leaders to see the impact of homeowner involvement. While all homeowners are not able to implement high level BMP strategies there is the potential for significant impacts on stormwater runoff by getting low level strategies from a high percentage of the population. This project will provides the data needed to evaluate what level of community involvement is necessary to have a positive impact on the Wildcat Creek flooding issue.



Section of Typical Rain Garden

Figure 2.9 (Drew, Yim, Lo & Liu, 2011):

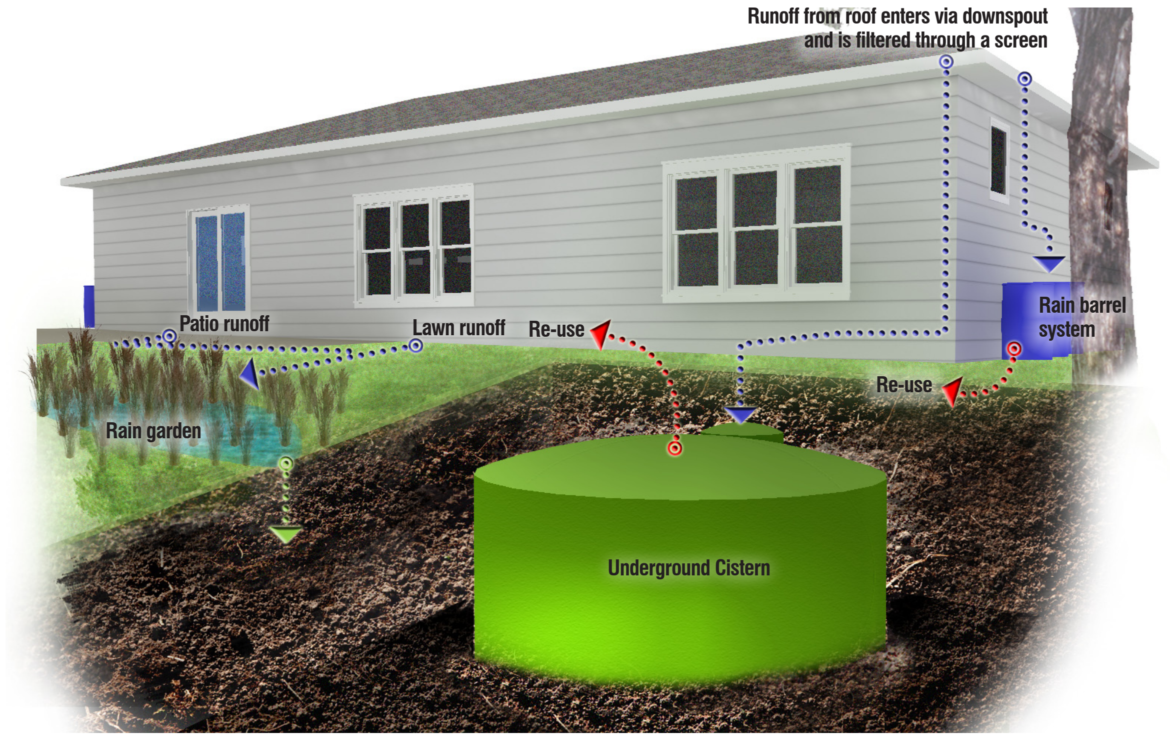
This section shows the essential elements of a typical rain garden. Note the amended soil will vary based on site conditions.



Rain Barrel System

Figure 2.10 (Adapted from de la fleur 2008):

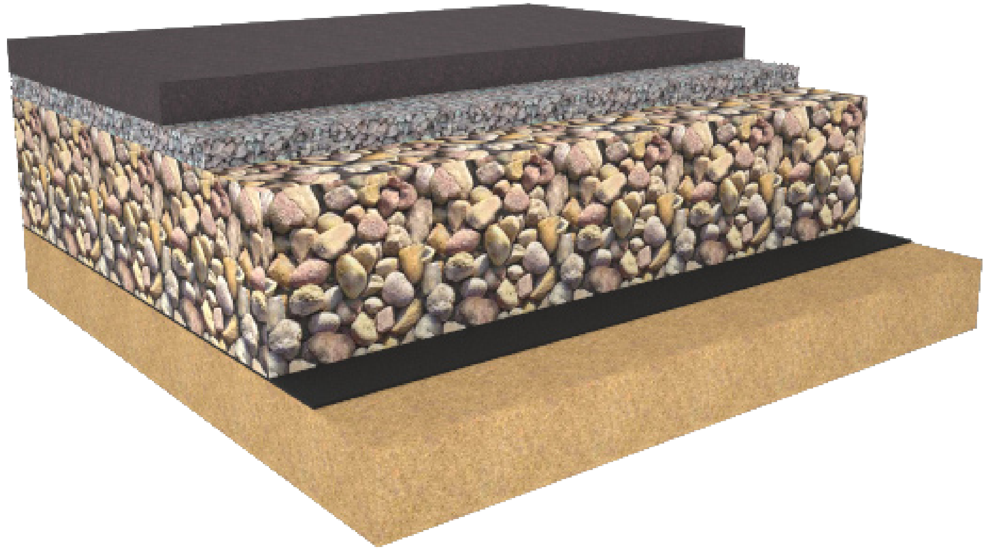
This diagram examines the 3-barrel rain barrel system used in the design alternatives for this project. This concept was used with success by Marcus de la fluer on his 168 Elm Ave project.



Cistern, Rain Barrel, Rain Garden

Figure 2.11 (Produced by Author):

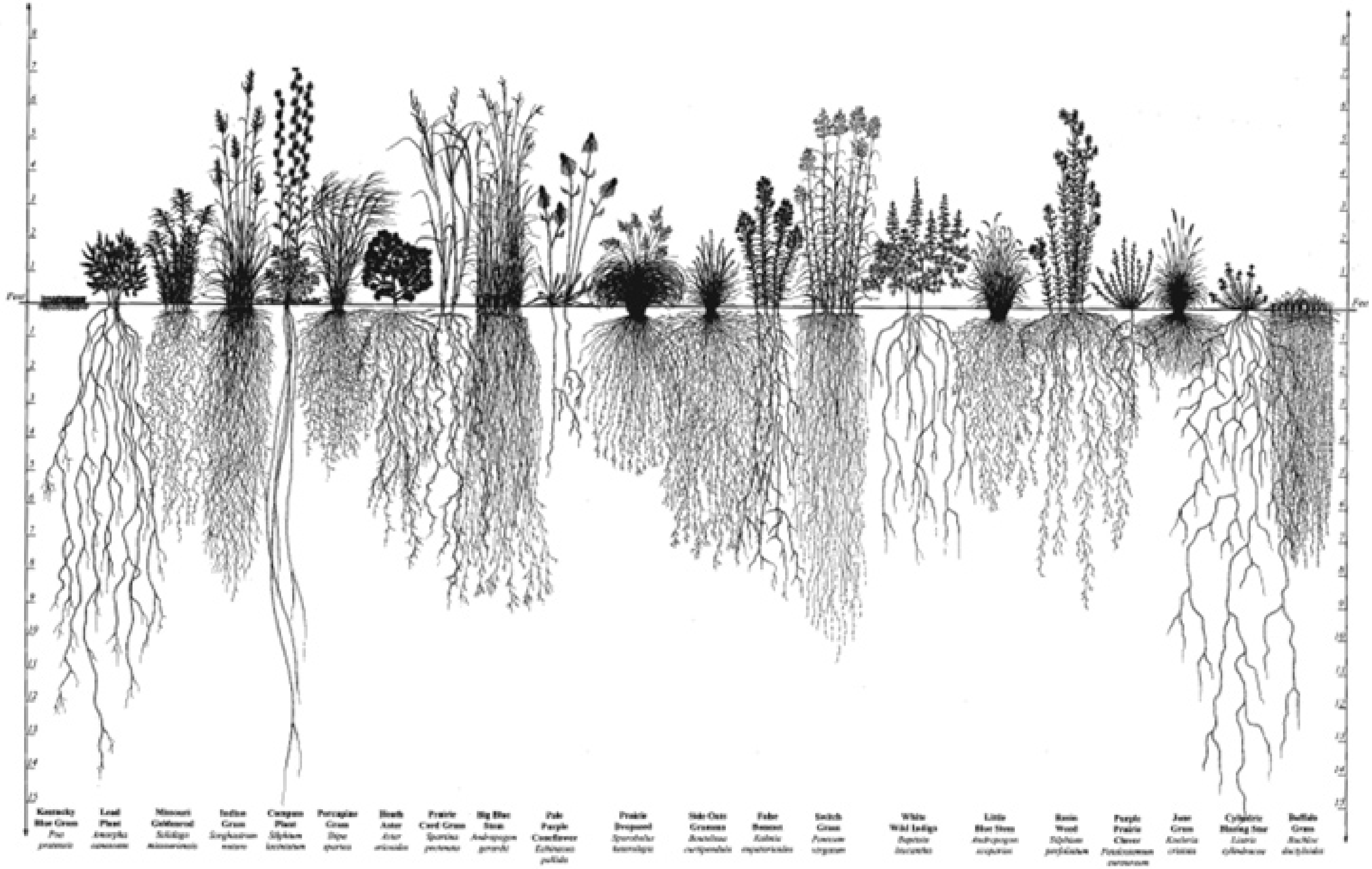
Diagram shows the stormwater sources of three common BMPs: cistern (roof), rain barrels (roof), and rain garden (lawn, patio). Diagram also shows the relationship of 2,000 gallon underground cistern (water pumped to surface for re-use) to house in small lot development type. Similar conditions would be expected in all four development types with site appropriate changes as necessary.



Porous Paving Diagram

Figure 2.12 (Produced by Author):

This diagram shows the typical materials and associated thicknesses of each in a porous paving application. It should be noted that inclusion of subgrade storage tanks to capture runoff is optional but not shown.



Comparison of Native Root Systems vs. Turfgrass:

Figure 2.13 (US EPA, 2008)

The Project - Part II

Application by development type

Inventory
Existing Conditions - Description, Strategy, Calculations
Low-level BMP strategies - Description, Strategy, Calculations
Mid-level BMP strategies - Description, Strategy, Calculations
High-level BMP strategies - Description, Strategy, Calculations

Application
Small Lot Single Family Residential

Development Type Inventory:

Area: 986.61 acres

Lots: 3784

Avg. Size: 0.26 acres

Sample Site Inventory:

Site: 2805 Nevada Street. Manhattan, Kansas

Area: 0.23 acres

Runoff: 100% - 0.0157 acre feet (5,105 gallons)

80% - 0.0124 acre feet (4,084 gallons)

60% - 0.0094 acre feet (3,063 gallons)

Surface Calculations:

Roof: Area - 0.0469 acres

Runoff - 0.0065 acre feet (2,115 gallons)

Paving: Area – 0.0244 acres

Runoff – 0.0034 acre feet (1,102 gallons)

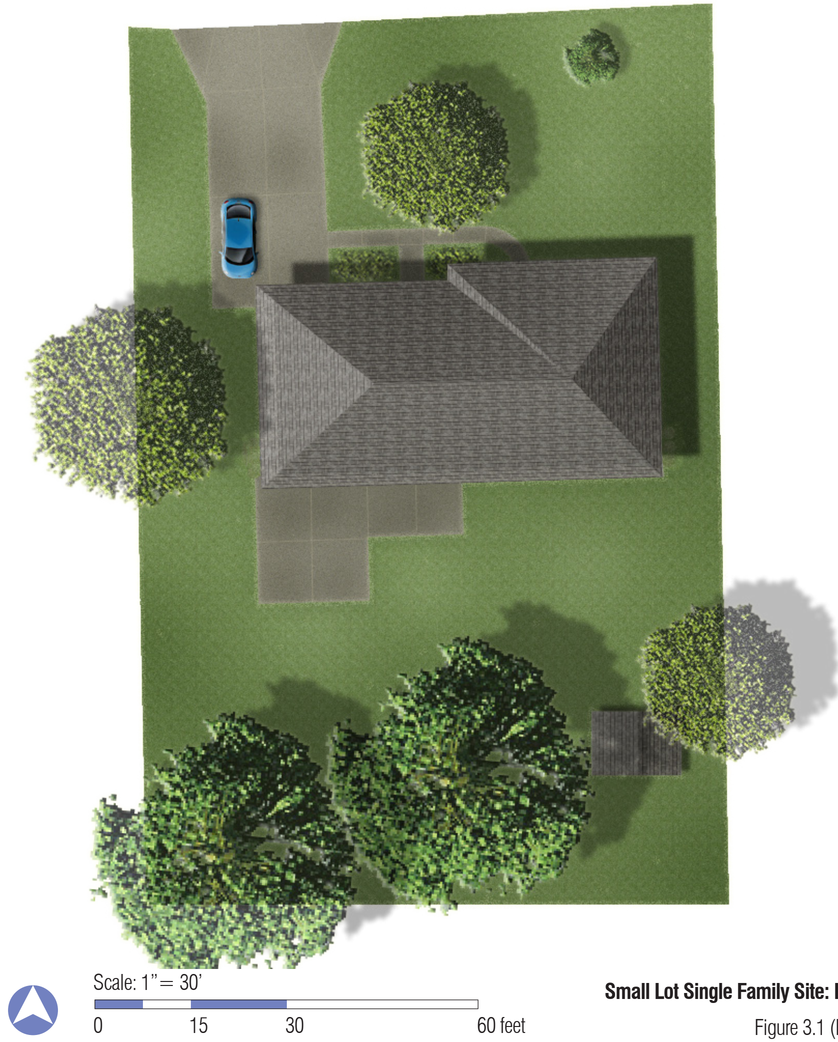
Lawn: Area – 0.1587 acres

Runoff - 0.0058 acre feet (1,885 gallons)

Existing Conditions (fig. 3.1): The small lot sample site is representative of the conditions found in a majority of these types of lots in Manhattan. As an established and aging development the sample site and the adjacent lots feature traditional suburban landscaping and mature tree cover. The site is dominated by turf grass with ornamental front tree plantings and several mature trees to the rear of the site. A small shed sits in the southwest portion of the rear lawn and a small patio sits adjacent to the rear entrance of the house. The house features a single car garage on the West side of the house with a drive appropriately sized to accommodate two vehicles (18'). The site is gradually sloped downhill from front to back with seven feet of elevation change. Slopes on a majority of the sample site fall between 0 and 6% while the southernmost area of the site features steeper slopes ranging between 10 and 15% (Appendix D fig. D.1). The southern portion of the site also has several mature trees.

Low-Level BMP Strategy (fig. 3.2): The small lot single family sample site is dominated by gently sloping lawn (69% of the site). This makes the area highly suitable for rain garden applications and easily capable of accommodating the low-level strategy goal of 60% runoff reduction. Though rain gardens are easily constructed by the homeowner in order to reach the 60% goal with strictly rain gardens the surface area dedicated to the BMPs must be relatively large (17% of the lawn area or 1230 square feet). This must be taken into consideration if the homeowner would prefer to retain large areas of open lawn space. Placement of the rain gardens was based on two primary factors. These factors are availability of open space without the removal of existing trees and adjacency to areas of impermeable surface. Trees are valuable pieces of the urban and suburban fabric and are a key piece of the Character of the City of Manhattan. Manhattan has earned the Tree City USA award for commitment to urban forestry for 29 years running (City of Manhattan). This project was conducted under the assumption that BMP retrofits should be incorporated into the landscape without dramatically altering the overall character thus; no trees were removed in the proposed BMP strategies. The 1230 square feet of rain garden needed to accomplish the 60% runoff reduction level was broken into four strategically placed gardens. The front lawn area features a 310 sq. ft. rain garden capturing runoff from the front lawn as well as the sidewalk and front areas of the roof. The side lawn to the west of the driveway is home to a 265 sq. ft. rain garden. This garden will capture water from the driveway as well as runoff from the front and side portion of the roof. Moving south along the west side of the site the third rain garden encompasses 320 sq. ft. and is positioned to capture runoff from the rear patio and roof. The fourth and largest of the four rain gardens is located centrally in the rear of the house. This garden is 335 sq. ft. and captures water from the patio, the rear portion of the roof, the shed and lawn areas north and adjacent to the rain garden. In all these rain gardens are capable of capturing and infiltrating 0.0094 acre feet or 3063 gallons of stormwater runoff that would typically exit the site. If all property owners in the small lot development type were to commit to low-level BMP strategies 13,140,000 gallons would be removed from the storm sewer system.

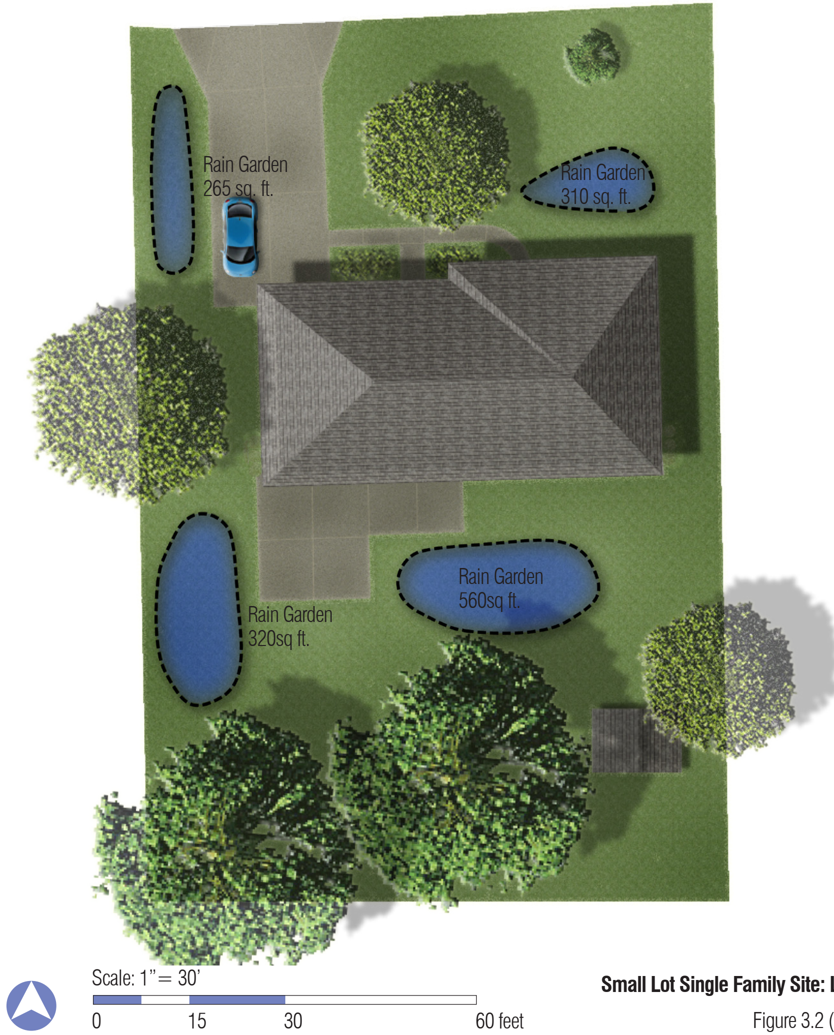
Mid-Level BMP Strategy (fig. 3.3): Mid-Level BMPs for the small lot single family development type include both rain gardens and rain barrels. Moving from low level to mid-level implementation increases the goal level of runoff reduction from 60 to 80 %. This increases the runoff quantity from 0.0094 acre feet to 0.0125 acre feet or 4084 gallons. To eliminate this quantity of runoff two sets of rain barrels are used along with slightly larger rain gardens than were used in the low level strategy. Using two sets of rain barrels (6 barrels) brings the storage capacity



Small Lot Single Family Site: Existing Conditions

Figure 3.1 (Produced by author):

of the barrel systems to 330 gallons. This storage will provide irrigation for both the lawn and the native plantings in the rain gardens in times of low precipitation. However, 330 gallons is far from the overall goal of 4084 gallons. Once the rain barrels are accounted for the remaining 3754 gallons of target runoff is captured by rain gardens in the same locations as the low-level implementation strategy. However, the size of these gardens has increased slightly to accommodate the additional runoff without compromising function. The total area of rain gardens needed in this level of implementation increases 275 square feet to 1505 total square feet. The rain garden located in the front lawn area of the site will remain 310 sq. ft. The same holds true for the rain garden to the west of the drive, it will remain at 265 sq ft. due to spatial constraints. As for the rear of the house, while the western most rain garden remains 320 sq. ft. the central rain garden increases in size to 610 sq. ft. This increase allows for a greater portion of the roof and patio runoff to be captured and infiltrated preventing it from leaving the site. Overall the mid-level implementation techniques limit the amount of construction that must take place in order to be successful. Rain barrels are relatively easy to construct from inexpensive materials and require a low number of man hours to complete. Rain

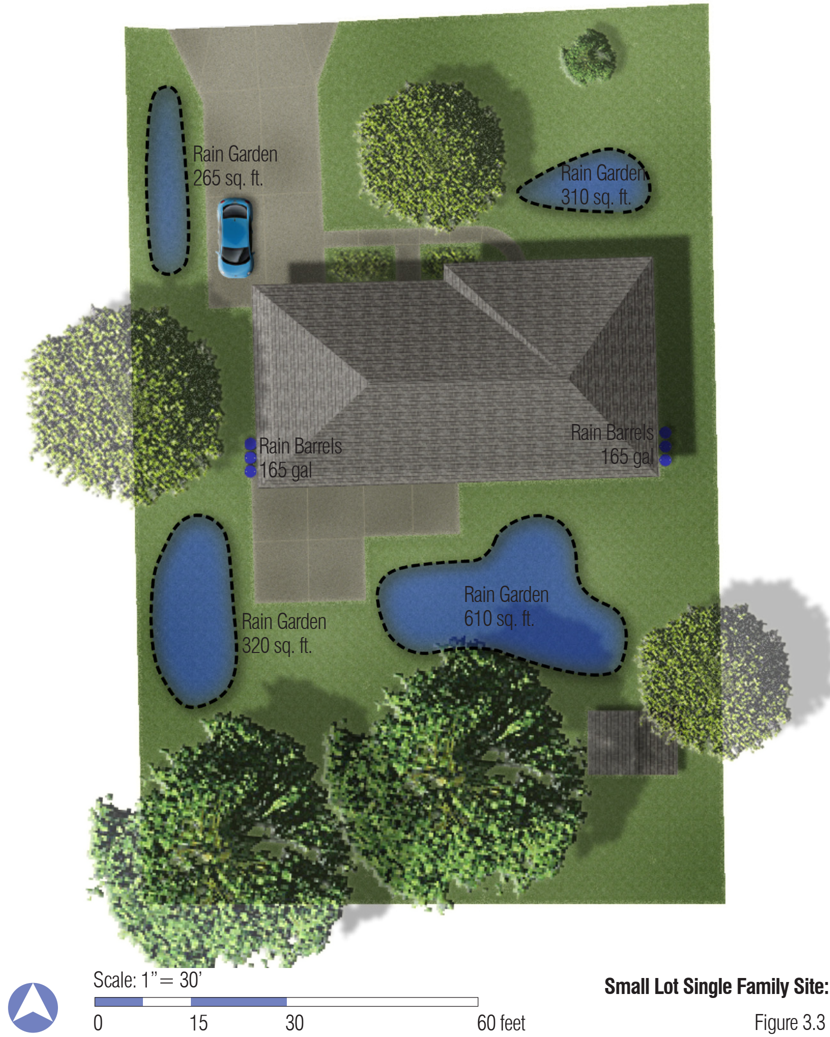


Small Lot Single Family Site: Low-Level Strategy

Figure 3.2 (Produced by author):

gardens can be installed by a property owner over the course of a few weekends with tools common to many homes and plants that can be purchased regionally. Mid-level strategies implemented in the small lot development area have the potential to capture 17,510,000 gallons of stormwater runoff.

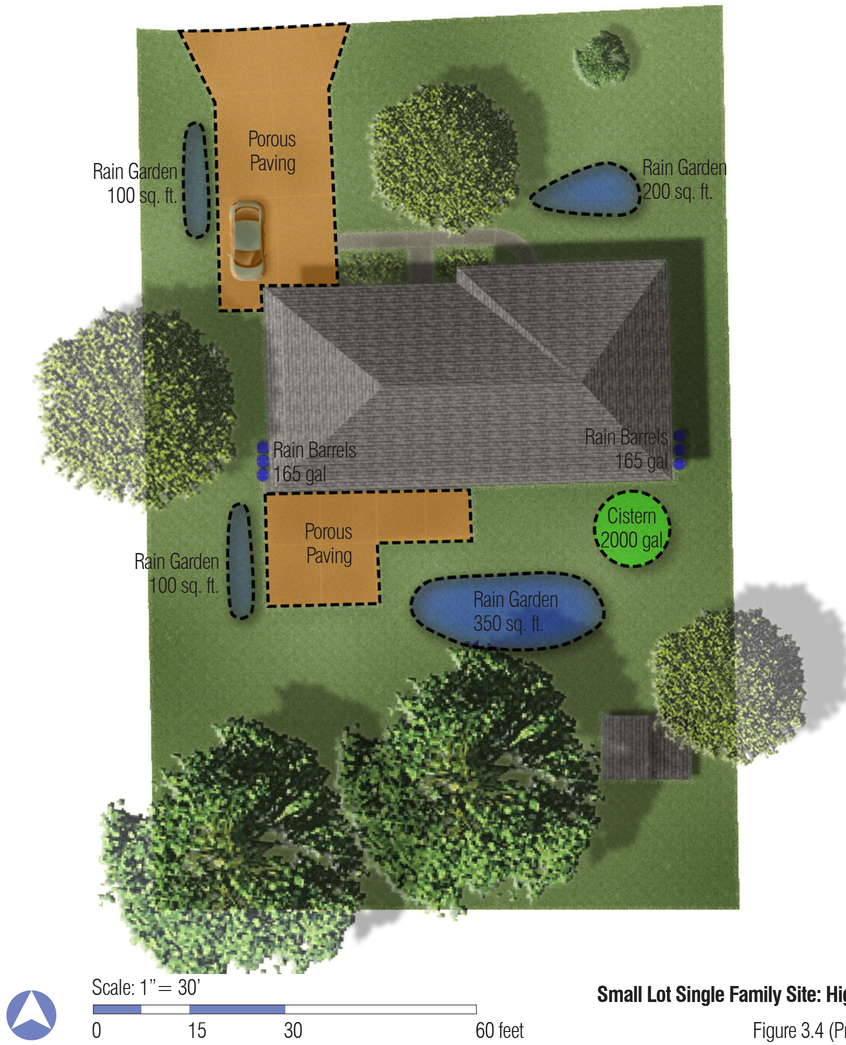
High-Level BMP Strategy (fig. 3.4): High-level BMP strategy is more construction intensive than the low and mid-level techniques. The addition of a cistern and porous paving with temporary storage capabilities requires excavation of several hundred cubic feet of earth in addition to the demolition and removal of the existing drive and patio. However, the high-level BMPs allow for 100% of the runoff from one hour of a two-year storm to be captured and re-used or infiltrated on site. Once again, rain barrels account for 330 gallons of temporary storage for easy re-use. A cistern is installed in this strategy capable of holding the additional 1785 gallons of runoff from the roof that the rain barrels are not able to capture. To ensure adequate storage a 2000 gallon cistern would be recommended for this design. Porous paving is the next addition to this level of implementation. Both the Driveway and the patio were replaced with porous paving and temporary underground storage. The attenuation tanks used to store water under



Small Lot Single Family Site: Mid-Level Strategy

Figure 3.3 (Produced by author):

the paving areas have a minimum capacity of 1160 gallons as this is the amount of water that would fall on these surfaces during one hour of a two-year storm event. After the removal of both the roof runoff and the paving runoff through rain barrels, the cistern, and permeable paving there is 1830 gallons of runoff left to capture. This remaining stormwater is captured using rain gardens. The rain gardens were placed in the same locations as in the low and mid-level strategies, however, their sizes were reduced accordingly as the amount of runoff was reduced. In this level of implementation the front rain garden was reduced to 200 sq. ft. a reduction of 100 sq. ft. Both the rain gardens on the western most portion of the site were reduced to 100 sq. ft. While the central rear rain garden was reduced to 350 sq. ft. and focused to the south to increase the amount of lawn area draining into the garden. In all these four BMPs capture 100% of the amount of rain 1 hour of a two-year storm would deposit on the site. High-level strategies applied to the entire small lot development area in Manhattan would result in the removal of 21,890,000 gallons of runoff from the sewer system and Wildcat Creek. A street view of the high-level BMP strategy can be seen in figure 3.5.



Small Lot Single Family Site: High-Level Strategy

Figure 3.4 (Produced by author):

Small Lot Single Family Site: Street View of High Level BMP Strategy

Figure 3.5 (Produced by author):

Application

Large Lot Single Family Residential

Development Type Inventory:
- Area: 644.71 acres
- Lots: 710
- Avg. Size: .91 acres

Sample Site Inventory:

Site:	431 Pottawatomie Ave. Manhattan, Kansas
Area:	1.47 acres
Runoff:	100% - 0.0649 acre feet (21,140 gallons)
	80% -0.0519 acre feet (16,912 gallons)
	60% - 0.0389 acre feet (12,684 gallons)

Surface Calculations:

Roof:	Area - 0.0492 acres
	Runoff – 0.0068 acre feet (2,221 gallons)
Gravel:	Area – 0.1580 acres
	Runoff – 0.0115 acre feet (3,753 gallons)
Paving:	Area – 0.0045 acres
	Runoff – 0.0006 acre feet (204 gallons)
Lawn:	Area – 1.2583 acres
	Runoff – 0.0459 acre feet (14,962 gallons)

Existing Conditions (fig. 3.6): Large lot single family developments represent the second largest residential development in the Manhattan area. Large lot developments represent a unique opportunity from a stormwater BMP perspective. Averaging almost an acre in size the large lot developments present an opportunity to apply large BMPs not suited to smaller sites. On the large lot sample site for example 1.26 acres of open lawn provide ample space to plant native prairie plants found in the Manhattan area. The large lot sample site is located on the south side of Manhattan just north of the levee sheltering the city from the Kansas River. Paving is one of the largest contributors of runoff in the watershed due to its prevalence in all types of developments in the form of parking. However, the large lot sample site features a surprisingly small amount of paving due to the use of gravel for the driveway and parking area. Gravel reduces the runoff coefficient of these areas from .95 to .50. This simple exchange of materials reduces the amount of runoff from these surfaces alone by 3,389 gallons during one hour of a two-year storm. A large majority of the site is suitable for BMP implementation as the site is mostly open and slopes are relatively gentle 0-5% (fig. D.2). However, some development limitations do exist. Several mature trees are located near the house and a series of four evergreens create a windbreak along the road to the east of the site, limiting the ability to implement BMPs in these areas. A large swale exists to the south of the site just north of the levee creating steep slopes (10%+) that limit the ability to implement many types of BMPs.

Low-level BMP Strategy (fig. 3.7): Given the scale of the large lot sample site and the design flexibility this size provides, areas producing large amounts of runoff are specifically targeted for BMP implementation. In order to achieve the 60% runoff reduction goal for the low-level BMP strategy, rain gardens must capture and infiltrate 12,684 gallons of water. With the 4 inch free board design depth 5,100 square feet of rain gardens are needed to capture the desired quantity. 5,100 square feet is more rain garden area than implemented on any other sample site designs, however, given the substantially larger lot area in the large lot sample site these rain gardens are easily accommodated. Three rain gardens capture runoff from the parking area and the drive preventing it from entering the large swale to the south of the site. The first of these gardens is located on the southeast edge of the parking area and is 1,000 square feet in surface area. The other two gardens in this area cover 500 square feet each and are linear in shape. Located adjacent to the driveway on the southern edge, these gardens capture the runoff from the driveway and could be combined or broken in any number of configurations to appease the homeowner. A fourth rain garden covering 1,000 square feet is located on the northeast corner of the house capturing runoff from the patio area the roof and the sidewalk as well as lawn areas adjacent to the house. The fifth and final rain garden is located in the northeast corner of the lot adjacent to both the northern property line and the evergreens to the east. This garden captures the runoff from the large front lawn and prevents it from entering the roadside swales bordering the property. In addition to capturing runoff from each of the problematic areas on the site the rain gardens work as visual accents to spaces that can be planted in decorative styles if the homeowner desires. If every homeowner in Manhattan within the Wildcat Creek watershed were to implement these low-level BMPs 5,558,000 gallons of stormwater could be captured and infiltrated on site.

Mid-level BMP Strategy (fig.3.8): Mid-level BMP implementation on the large lot sample site allows the homeowner to maintain a generally traditional lawn space

Large Lot Single Family Site: Existing

Figure 3.6 (Produced by Author):

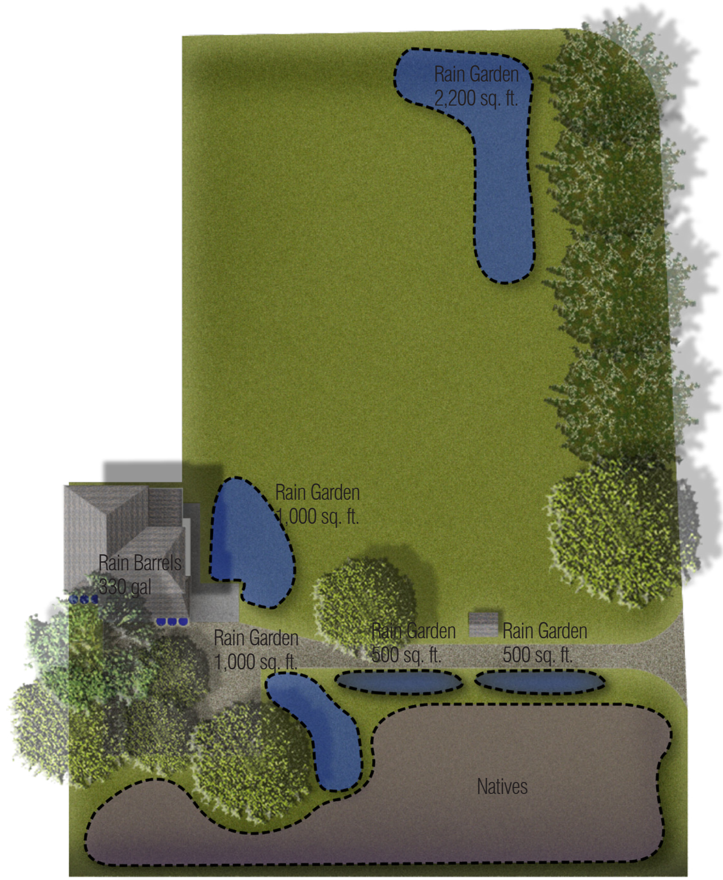
while infiltrating 80% of the runoff created in one hour of a two-year storm event. Three sets of rain barrels were used in this strategy totally 9 barrels or 495 gallons of water. These barrels capture water from the roof and allow the homeowner to easily reuse it for non-potable applications around the site. Rain barrels are responsible for capturing 5% of the stormwater runoff in this strategy. Native plants were implemented in this level of strategy as well. The southern swale area adjacent to the levee was converted into native prairie plantings totaling 13,350 square feet. This area allows for an additional 20% of stormwater runoff to be infiltrated without posing a significant aesthetic change to the property due to its location. By planting the natives on the slope to the south of the house it is slightly hidden from view to people passing by the property on the road. Strategically placing BMPs to minimize public view of a landscape that may not be accepted by all members of the community may be an important tactic to some homeowners, especially those wishing to reduce the stormwater runoff from their property while maintaining a traditional lawn aesthetic. Rain gardens in the mid-level strategy maintain the same positions and size as in the low-level strategy for the most part. The northeastern rain garden, framing the lawn area, increased

Large Lot Single Family Site: Low-Level Strategy

Figure 3.7 (Produced by Author):

in sized by 100 square feet for a total of 2,200 square feet. Though spatially and aesthetically the mid-level strategy maintains a minimalist approach if each large lot homeowner were to implement these strategies 7,410,000 gallons of stormwater runoff can be infiltrated on site during one hour of a two-year storm event. For some perspective, mid-level strategies on just the large-lot single family developments in the Manhattan area would reduce the amount of stormwater runoff produced by roughly the equivalent of 11 Olympic-sized swimming pools.

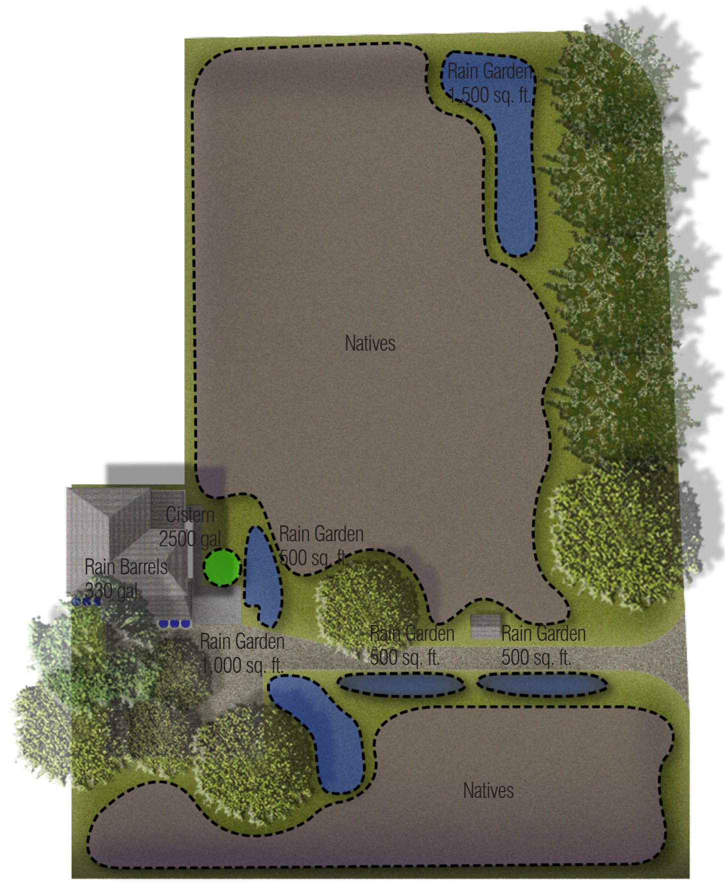
High-level BMP Strategies (fig.3.9): High-level BMP implementation on the large lot sample site involves four stormwater BMPs. Two rain barrel units (6 barrels) account for 330 gallons and provide the homeowner quick access to non-potable water for various applications around the residence. A cistern accounts for the remaining 2,221 gallons of roof runoff. In this design scheme the cistern is sized for 2,500 gallons to accommodate slightly more than one hour of a two-year storm event. Native plantings were applied to the entire turf area of the site (1.26 acres). Simply replacing the turf grass with native prairie grass reduced the site runoff by 42%. Rain gardens on the site remain in the same locations as in the



Large Lot Single Family Site: Mid-Level Strategy

Figure 3.8 (Produced by Author):

other two implementation strategies in order to capture runoff from problem areas on the site. The Sizes of the three rain gardens along the south edge of the drive and parking area remain the same as these areas will continue to produce a relatively large amount of the sites runoff. The rain garden to the northeast of the house is reduced to 500 square feet to account for the capture of the roof runoff by the cistern. Likewise the rain garden in the northeast corner of the site is reduced to 1,500 square feet to account for the reduction in runoff from the lawn areas. The result of these four BMPs is the capture or infiltration of 100% of the runoff produced by one hour of a two-year storm event. Extrapolation of this level of BMP implementation across the entire development type would reduce the amount of runoff entering the watershed by 9,265,000 gallons every hour of a two-year storm event. A street view of the high-level BMP strategy for the large lot sample site can be seen in figure 3.10.



Scale: 1"= 80'

0 40 80 160 feet

Large Lot Single Family Site: High-Level Strategy

Figure 3.9 (Produced by Author):

Large Lot Single Family Site: Street View of High Level BMP Strategy

Figure 3.10 (Produced by Author):

Application

Traditional Single Family Residential

Development Type Inventory:
- Area: 443.72 acres
- Lots: 2,207
- Avg. Size: 0.20 acres

Sample Site Inventory:

Site:	812 Laramie Street. Manhattan, Kansas
Area:	0.17 acres
Runoff:	100% - 0.0101 acre feet (3,299 gallons)
	80% - 0.0081 acre feet (2,639 gallons)
	60% - 0.0061 acre feet (1,979 gallons)

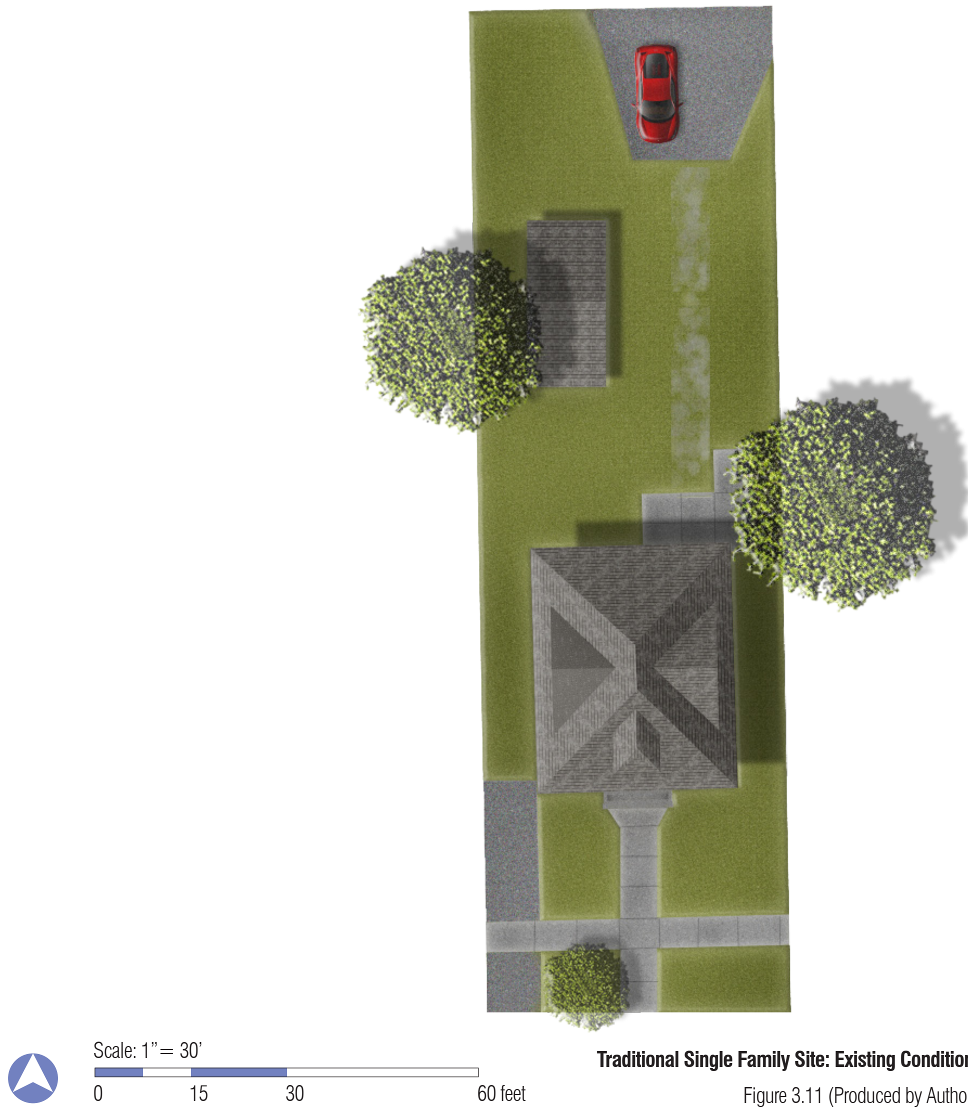
Surface Calculations:

Roof:	Area – 0.0337 acres
	Runoff – 0.0047 acre feet (1521 gallons)
Gravel:	Area – 0.0205 acres
	Runoff – .0009 acre feet (293 gallons)
Paving:	Area – 0.0033 acres
	Runoff – 0.0005 acre feet (150 gallons)
Lawn:	Area – 0.1125 acres
	Runoff – 0.0041 acre feet (1336 gallons)

Existing Conditions (fig. 3.11): The City of Manhattan's Traditional Family Overlay District (TNO) encompasses the type 3 developments and enforces design regulations that create a unique condition not found in any of the other development type in Manhattan. By limiting the amount of site coverage allowed in the TNO the overall amount of stormwater runoff is reduced. Traditional development sites are a majority lawn, with lawn comprising roughly two-thirds of the sample site. In contrast to the lawn the next largest surface type is the roof accounting for roughly 20% of the site. Gradual slopes between 0-5 percent allow for the implementation of BMPs across the entire site without limitations. Manhattan traditional lots feature gravel parking areas and lack large areas of pavement. This lack of paving increases the overall infiltration of the traditional development type. Trees are prevalent throughout the traditional development type with both mature and adolescent specimens scattered throughout. However, the traditional development sample site features two young trees within the parcel boundary and two more over hanging trees near the property line. Tree cover is a limiting factor in this project for both rain gardens and native grasses. One additional consideration when designing in the traditional development type is the visibility of features in the front of the property. The sample site features a front parking space, which would require a special allowance to construct under the current TNO guidelines. TNO development guidelines specify that all parking must be located in the rear of the house as to create uniform street frontage and in turn a larger palette to convey stormwater BMP design to the general public.

Low-level BMP Strategy (fig. 3.12): Once again, low-level strategies in this project solely utilize rain gardens to achieve the desired 60% runoff reduction. Traditional single family developments are easily retrofitted with rain garden BMPs due to the large percentage of open space on the developments. 800 square feet of rain garden are required to capture the 1979 gallons of water that represent 60% of the runoff from one hour of a two-year storm event on the traditional development type. Due to the narrow width of the traditional lots (50 feet) rain gardens are focused in the front and rear of the site. The southeastern corner of the front lawn is the location of the first of four rain gardens in the low-level strategy. Oriented around an existing low point on the site, this rain garden is 300 square feet and captures water from the roof as well as the eastern portions of the front and side lawn area. Centrally located in the front lawn, between the paved path leading from the street to the house and the gravel parking area, the second rain garden covers an area of 80 square feet. This garden captures water from the parking area and front lawn as well as the roof. Moving to the rear of the site, the largest rain garden is located just south of the rear parking area in another existing low point. This rain garden is 310 square feet and works to capture runoff from the gravel parking area the rear lawn and the roof. The final rain garden is located in the northwest corner of the lot and covers 110 square feet. Runoff from the parking area and the storage shed are captured in this garden. In all, the low-level strategy addresses each primary source of runoff on the site maximizing the effectiveness of the BMPs. Given 100% implementation of low-level BMPs on traditional single family developments in the Manhattan portions of Wildcat Creek 5,164,745 gallons of water can be removed from the storm sewer system and infiltrated on site.

Mid-level BMP Strategy (fig. 3.13): In a similar fashion to the small lot single family mid-level strategy the traditional mid-level strategy incorporates rain barrels and slightly enlarged rain gardens. The mid-level BMP strategy captures 80% of the traditional site runoff equating to 2639 gallons. Two sets

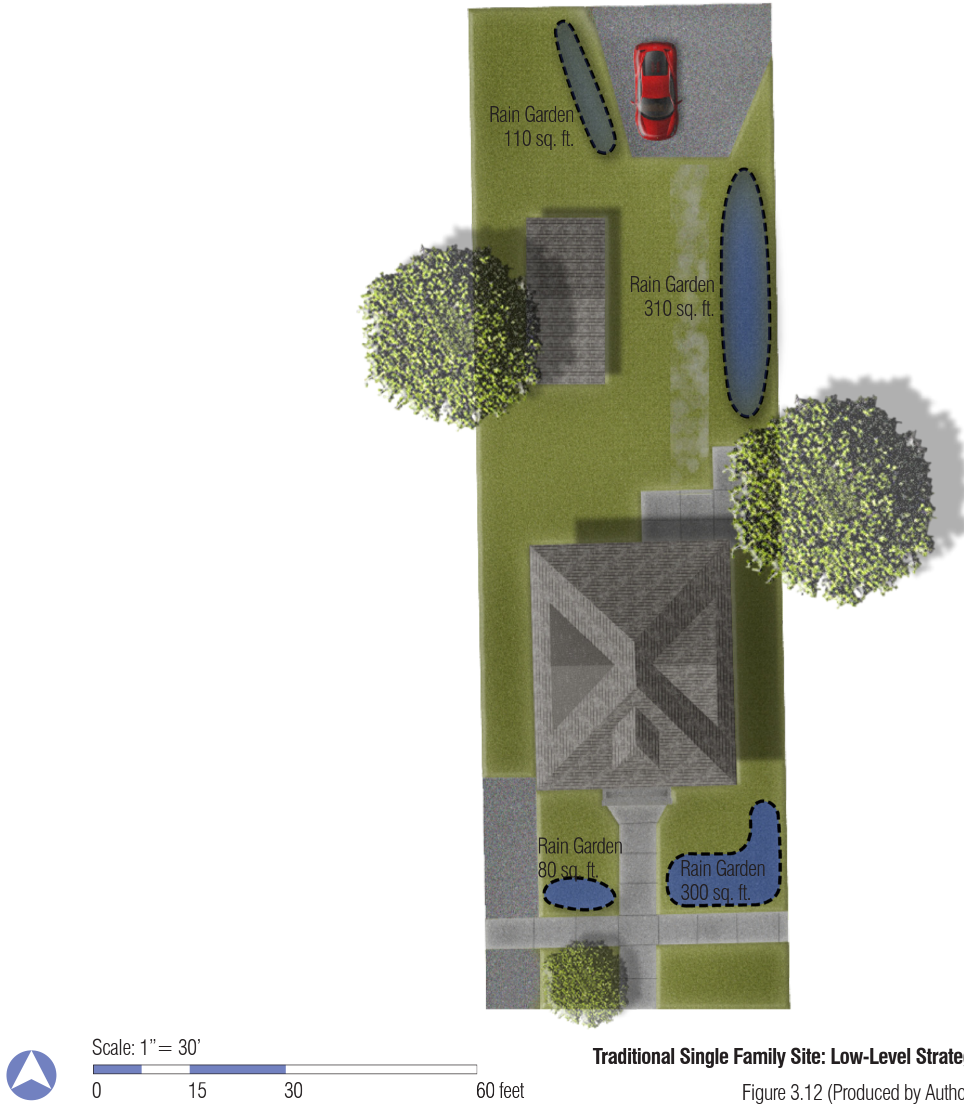


Traditional Single Family Site: Existing Conditions

Figure 3.11 (Produced by Author):

of rain barrels capture 330 gallons of runoff from the roof of the house. Rain gardens account for the remaining 2339 gallons. In the front portion of the site, the first rain garden remains the same as in the low-level strategy accounting for 380 square feet. Moving to the rear of the house the large rain garden on the eastern portion of the site remains 310 square feet. The final rain garden is repositioned from the northwest corner of the lot and moved south to the area between the shed and the house. This move allows the garden to be enlarged to 240 square feet, an addition of 130 square feet and 360 gallons of holding capacity. Repositioning the fourth rain garden to the south allows an additional amount of roof runoff to be directed into this garden helping to reduce the effects of the concentrated roof runoff. In total if mid-level strategies applied to all traditional single family developments in the project area have the potential to infiltrate 6,886,327 gallons of stormwater runoff on site.

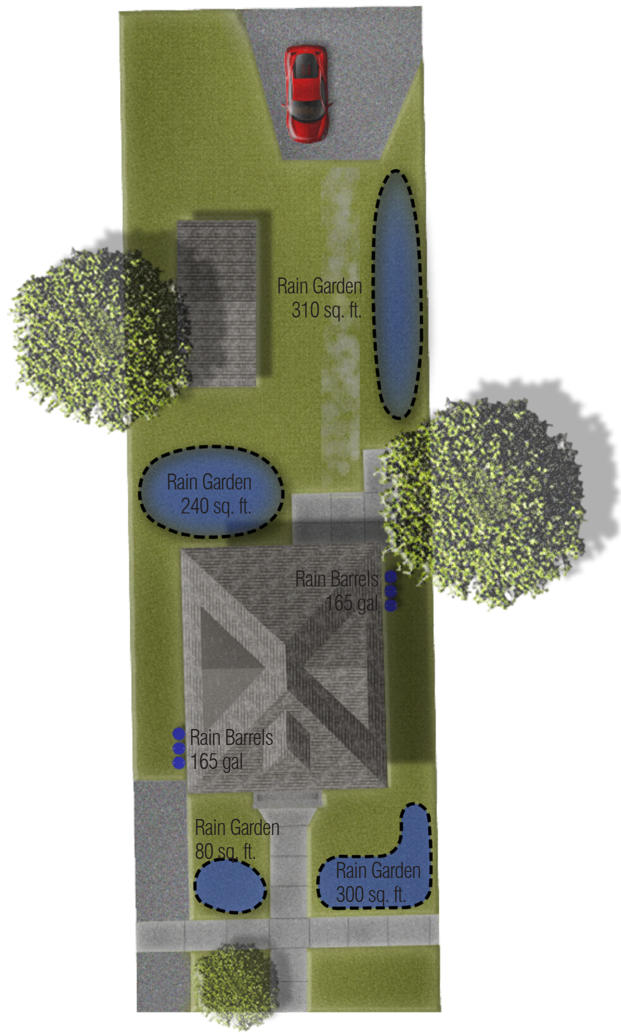
High-level BMP Strategy (fig. 3.14): As with the large and small lot single family developments, the high-level strategy for the traditional development type captures 100% runoff attributed to one hour of a two-year storm event (3299 gallons) and allows for on site infiltration or reuse. The traditional development high-level strategy incorporates



Traditional Single Family Site: Low-Level Strategy

Figure 3.12 (Produced by Author):

rain barrels, a cistern, native plantings, and rain gardens; given the relatively small amount of pavement on the traditional sample site porous paving was not used in this design. Rain barrels, again, account for 330 gallons of roof runoff. However, the high-level strategy captures the remaining roof runoff (1,191 gallons) in a cistern. This design calls for a 1500 gallon cistern to allow for a small amount of excess water that may not be accounted for in these estimations. By capturing the roof runoff in its entirety the spatial needs of the rain gardens is greatly reduced. This reduction is reflected in the sizing of the rain gardens. While the primary frontal rain garden remains 300 square feet to accommodate the front and side lawn, the secondary rain garden is reduced to 50 square feet. In the rear of the house the primary rain garden on the eastern portion of the site is reduced 10 square feet to 300 sq. ft., while the second rain garden is completely removed. In order to add an extra level of infiltration, native vegetation was incorporated into this level of BMP implementation. Working as a buffer strip for the rain gardens in the front of the house, two plantings of 110 square feet are located along the north edge of each rain garden. In combination with the proposed rain gardens the native plantings in the front of the house effectively eliminate



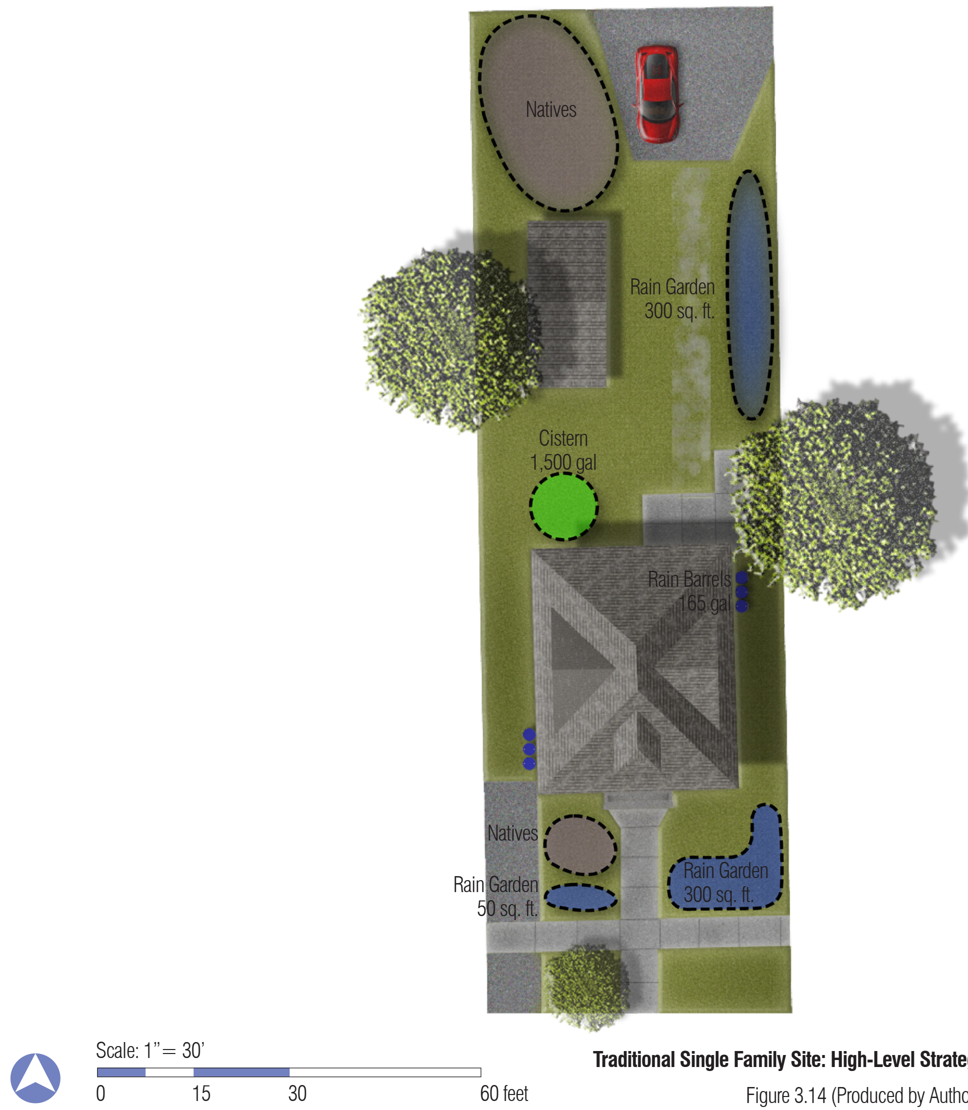
Scale: 1" = 30'

0 15 30 60 feet

Traditional Single Family Site: Mid-Level Strategy

Figure 3.13 (Produced by Author):

turf grass from the front lawn. This drastic change places stormwater BMPs center stage making them highly visible. In the rear of the house to the north of the shed a third patch of native grasses covers 810 square feet and helps to infiltrate water from the rear parking areas and the shed. High-level BMP strategies capturing 100% of a 2-year storm event over the course of one hour provide the opportunity to reduce runoff by 8,608,000 gallons in traditional development types. A street view of the high-level BMP strategy on the traditional single family sample site can be seen in figure 3.15.



Traditional Single Family Site: High-Level Strategy

Figure 3.14 (Produced by Author):

Traditional Single Family Site: Street View of High Level BMP Strategy

Figure 3.15 (Produced by author):

Application

High Density Multi-Family Residential

Development Type Inventory:
- Area: 290.73 acres
- Lots: 619
- Avg. Size: 0.47 acres

Sample Site Inventory:
- Site: 1015 Kearney Street. Manhattan, Kansas
- Area: 0.34 acres
- Runoff: 100% - 0.0445 acre feet (14,490 gallons)
  - 80% - 0.0356 acre feet (11,592 gallons)
  - 60% - 0.0267 acre feet (8,695 gallons)

Surface Calculations:
- Roof: Area – 0.1046 acres
  - Runoff – 0.0145 acre feet (4,722 gallons)
- Paving: Area – 0.1905 acres
  - Runoff – 0.0264 acre feet (8,600 gallons)
- Walks: Area – 0.0180 acres
  - Runoff – 0.0026 acre feet (847 gallons)
- Lawn: Area – 0.0269 acres
  - Runoff – 0.0010 acre feet (320 gallons)

Note: Due to the high density developments found in type 4 developments the 60, 80, 100% runoff sequestration levels could not be achieved with the BMP strategies applied to other development types. Application of BMPs suited to this development type exposed a pattern of runoff reduction that resulted in roughly 30% reduction increments. For this reason the BMP strategies for high density development types will be: Low-level (33%), Mid-level (63%), High-level (99 %).

Existing Conditions (fig. 3.16): High density multi-family developments in Manhattan are unique from any other residential development types. Where a majority of Manhattan is dominated by lawn space and tree cover, the high density development type is predominantly impervious. Lots in type 4 developments are often occupied by large buildings and parking areas with small amounts of turf grass or planting beds accenting building approaches. Trees in this development type are often relegated solely to street tree applications. Open areas of pervious surface are near nonexistent and runoff rates are enormous when compared to other development types. The sample site selected for the high density multi-family development type is located in the City of Manhattans Multi-family Redevelopment Overlay District (M-FRO). The M-FRO district is intended to provide high-density, campus oriented housing for students and faculty at Kansas State University and is located directly adjacent to campus (City of Manhattan 2010). Properties in this area are zoned for multi-family development but must meet additional requirements as specified by the M-FRO to ensure that high density infill is in keeping with the surrounding developments. These requirements include setbacks, lot sizing, development heights, and design standards (lot and building features). The sample site chosen is representative of the style of development that has occurred in the M-FRO over the last 5 years. The sample site is .34 acres, a combination of two traditional style lots found in the area. In combining two traditional lots the dimensions of the development grow to 100’x150’ allowing for larger building foot prints and an increased amount of on site parking. Of the .34 acres on the sample site, .31 acres (92%) are covered in impermeable surfaces, roof and paving in this case. Small amounts of turf grass are located along the north edge of the site and small mulched planting beds border the building along the north side. Slopes on the site are generally shallow between 0-6 percent however; along the north edge of the site, steeply sloped turf grass areas reach as high as 15 percent slopes (Appendix - D fig. D.4). Parking on the site is less than required by the City of Manhattan based on occupation. This makes eliminating excess parking to incorporate pervious surfaces such as rain gardens of bioretention areas impossible. By prohibiting structured parking in the M-FRO but requiring at least one parking stall for each bedroom the City of Manhattan is promoting the construction of pervious surface and contributing to the flooding issues in Wildcat Creek.

Low-level BMP Strategy (fig. 3.17): The low-level strategy for the high density development type employs one stormwater BMP to capture roughly one third of the runoff leaving the entire site. A 5,000 gallon cistern is capable of capturing 100% of the rainwater that falls on the roof of the building on the sample site. Roughly 4,722 gallons of runoff leaves the 630 square foot roof, equating to 33% of the total runoff produced on the site. Though low-level strategies for type 4 development only account for one-third of the runoff leaving these developments, if all sites in the development type employed these strategies 4,041,000 gallons of water would be captured for reuse on these sites.

Mid-level BMP Strategy (fig. 3.18): Roughly 63% (5,439 gallons) of the runoff produced by one hour of a two-year storm

Multi-family Site: Existing Conditions

Figure 3.16 (Produced by Author):

event on the high density sample site can be captured through the use of permeable paving with temporary underground storage. Not including sidewalks, 56% (.1905 acres) of the sample site is paved. Porous paving captures the water that falls on these areas and allows it to slowly infiltrate over time effectively removing a large amount of runoff while maintaining the functionality of traditional paving. Applied throughout the entire high density development area, porous paving could remove 7.744,000 gallons of runoff from the watershed.

High-level BMP Strategy (fig. 3.19): Four BMPs are used in the high-level BMP strategy for the high density sample site. In addition to cisterns and porous paving as found in the low and mid-level strategies, native plantings and rain barrels are incorporated into the high-level strategy for the high density development type. Native plants replace the turf grass areas along the northern edge of the site. In addition to reducing runoff by 1.33% (128 gallons), natives will help to stabilize the steep slopes where they are located. Native plant species have much deeper and more dense root systems than turf grass species promoting infiltration and soil stability (see fig. 2.13). Rain barrels as applied in other development types are employed in two, three-barrel sets capturing

Multi-family Site: Low-Level Strategy

Figure 3.17 (Produced by Author):

330 gallons of water (2.3%). When applied to the entire high density development type in Manhattan areas of the Wildcat Creek watershed these BMPs could capture 12,230,000 gallons of water. Even though the type 4 high-level strategy is not a net zero runoff plan it allows the capture of more would-be runoff than both the traditional and large-lot development high-level strategies. Increases in runoff within the multi-family development area is not due to a larger area in fact the high density development type is the smallest development type examined. However, due to the impervious nature of the high density developments, current conditions produce a much higher level of runoff than any other development type examined in this project. A street view perspective of the high-level BMP strategy on the multi-family sample site can be seen in figure 3.20.

Multi-family Site: Mid-Level Strategy

Figure 3.18 (Produced by Author):

Multi-family Site: High-Level Strategy

Figure 3.19 (Produced by Author):

High Density Muli-Family Site: Street View of High Level BMP Strategy

Figure 3.20 (Produced by author):

Conclusions

Findings and suggestions

Conclusions
Summary of Findings
Extrapolations

Site scale data was extrapolated to represent each development type in order to determine the overall impact residential stormwater BMPs in the Manhattan area would have on the Wildcat Creek watershed. A five step process provides valuable information that can be used to guide future stormwater regulations within the City of Manhattan.

Step one of the extrapolation process was to determine the overall footprint of each development type. GIS information provided by the City of Manhattan allowed for accurate area calculations to be made for each development type. These area calculations were made using parcel data and account for the total area of land contained within each development type within the private domain. Thus, roads and right of ways were excluded as areas outside of the influence of homeowners. In all, the residential development types studied accounted for 2,365.77 acres within the city of Manhattan. Area calculations showed development type 1, small lot single family, to be the most prevalent development type in the city. Small lot developments accounted for 986.61 acres (42% of total) and 3,784 lots. Development type 2, large lot single family, was found to be the second most common development type accounting for 644.71 acres (27% of total) and 710 lots. Traditional single family developments ranked third in terms of overall area accounting for 443.72 acres (19% of total) and 2,207 lots. Last but certainly not least in terms of runoff was the high density multi-family development type. High density developments cover 290.73 acres (12% of total) and 619 lots. Having determined the areas of each development type attention was turned to the next step of the extrapolation process.

Step two is to determine the adjusted runoff coefficient for each development type. This coefficient was determined using the area calculations from each sample site. Total areas for each different surface type were measured using ArcGIS and the latest aerial imagery available through the ArcGIS Online search function (2012). Once each surface type was measured, the percentage of the total site each surface represented was determined by simply dividing the surface area by the total lot area. Surface percentages were then multiplied by the runoff coefficients found in table E.1 In appendix E. The resulting value gives a weighted coefficient for each surface type. An adjusted runoff coefficient can be found by simply adding each surface types weighted coefficient. This adjusted runoff coefficient can then be used to perform rational method runoff calculations on entire development types.

Step three is the calculation of rational method runoff calculations for each development type.

Using the equation: Q = A x Adj. C x I.

Where:

Q = amount of runoff in acre inches/hour

A = area in acres of the development type

Adj. C = weighted average coefficient for each development type

I = the rainfall intensity for one hour of a two year storm event in Manhattan, Kansas (1.75 in/hr.)

These calculations for each development type can be found in appendix F.

Step four: once runoff calculations for each development type were completed the runoff units must be adjusted to show the information in units commonly used by design professionals and the general public. The rational method equation provides data in Acre inches. For the purposes of this project runoff quantities will be expressed in Acre feet and gallons. It should be noted that for rain garden calculations, these units were converted to cubic feet and cubic inches in order to determine the volume required to contain the desired runoff quantities.

Step five, the final step, is to determine the value of each level of stormwater BMP implementation on a development type scale. For this project the values are 60, 80 and 100 percent of the development runoff totals except for the high density development type which uses 33, 63, and 99 percent values. To determine each percentage the overall total is simply multiplied by the decimal value (i.e. 60% = 0.60)

Once the calculations were complete, the resulting values painted a picture of the runoff impact on Wildcat Creek of residential development in Manhattan and more specifically the impact development density has on runoff quantities (Table F.3). High density developments proved to be the biggest contributor of runoff per developed acre of all four development types with an average runoff quantity of .13 acre feet per acre (42,617 gallons per acre). This is largely attributed to the high density of development and use of impervious surfaces severely limiting infiltration. Small lot single family developments are the second highest runoff contributing residential development type. Type 1 lots contribute an average of 0.07 acre feet of runoff per acre (22,187 gallons per acre). This can be attributed to the low level of regulation the city places on these developments as far as development density and design. For example there are no lot coverage limitations for many of these areas resulting in large percentages of roof coverage. Coming in third from a runoff per acre perspective was the traditional single family development type. Averaging 0.06 acre feet of runoff per acre (19,400 gallons per acre), traditional single family developments are just slightly less problematic than small lot developments. The small reduction in runoff from small lot developments may be attributed to the 30% lot coverage limitations and strict parking regulations present in the Traditional Neighborhood Overlay District. By limiting the amount of impervious surface a homeowner can develop on their property the City has effectively limited the amount of unabated runoff being produced in the TNO. Large lot single family developments produced the least amount of stormwater runoff per acre with an average of 0.04 acre feet per acre (14,371 gallons per acre). This is in large part due to the low development density of these areas. For example the sample site for this project was only 3.7% impermeable surface including the house, shed, and parking areas.

Development density plays a critical role in land management and resource utilization. It is not an efficient use of land to house the entire population of even a small city like Manhattan in low density developments such as the large lot developments examined in this project. However, it is also not sustainable to think that high density developments come without an ecological cost. Each area of impervious surface developed reduces the amount of water that is naturally infiltrated and increases the amount of water entering the Wildcat Creek watershed at an unnaturally rapid pace. This increase in flow is not natural and not sustainable and will result in increasing flood levels as infiltration rates decline. As high density developments become increasingly important the ability to supplement imperviousness with design through concepts such as stormwater BMPs becomes more prevalent. Through BMPs it is possible to simulate natural infiltration rates and reduce the negative impact developments have on infiltration, in turn reducing the flooding intensity in areas such as Wildcat Creek

BMPs serve a second role, equally as important as stormwater management, BMPs help to reduce the carbon footprint of the residential lawn. Reduction in the carbon footprint of a property is a multifaceted result of BMP implementation. Reduced emissions, increased biomass, and lowered maintenance requirements and cost equate to both financial and ecological benefits provided by BMPs.

Ecological benefits attributed to native vegetation are undeniable. There are three critical reasons native vegetation is ecologically more viable than traditional turfgrass or other urban surface types.

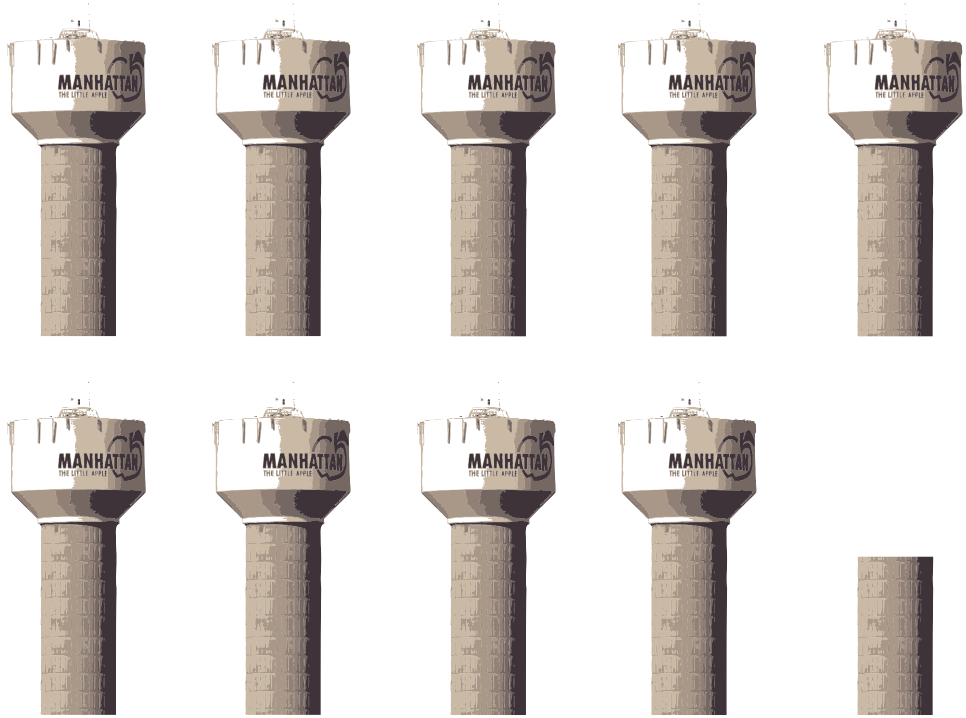
First, native plants are adapted to the soils represented in their natural ranges. Soil adaptation reduces the need for artificial fertilizers and increases soil ecology (Reeves and Hedlund 2006). Soil nutrients are a limiting factor of plant growth, by establishing biologically diverse plantings comprised of native plant species the nutrients in the soil such as nitrogen are used to their fullest extent (Tillman 2006). Diverse plantings in turn reduce the need for supplemental fertilizers by targeting available nutrients opposed to a monoculture such as bluegrass that targets one nutrient group (Purdue 2010). In addition to reduction in fertilizers, native plantings adaptation to site conditions reduce the need for herbicides by out competing invasive species.

Second, native plants produce a much higher level of biomass both above and below the surface (see fig. 2.13). The increased root depth and mass of native plants promotes soil stability. The presence of substantial root depth not only reduces erosion potential by increasing soil stability but promotes infiltration by reducing the potential for soil compaction. Thus the implementation of native plantings lead to reductions in both runoff and erosion promoting stream health.

The third reason native plantings are ecologically beneficial is the reduced level of maintenance when compared to traditional turfgrass applications. Native plants require a much lower schedule of maintenance than traditional turfgrass. Where turfgrass requires mowing every few weeks to maintain a proper grooming standard, healthy native plants require only one mowing or burning per year. Similar to gardens and other plantings weeding is required once native areas are established to prevent invasive species and undesired species such as shrubs and trees from taking over areas. However, weeding is a pollutant free maintenance regime that requires little to no monetary commitement. Reduction in lawn maintenance through the implementation of natives is hugely important from a carbon reduction standpoint but is equally critical to a homeowner from an economics perspective.

Turfgrass maintenance is hugely expensive for several reasons. $5.25 billion is spent annually on fertilizers derived from fossil fuels, many of which are imported. This adds increased burden to the already strained economy in the United States. In addition to fertilizers, $700 million is spent on pesticides alone when native plants are capable of promoting natural pest control through biodiversity (Purdue 2010). Turfgrass maintenance expense does not end with fertilizers and pesticides. Lawn mowers alone consume 580 million gallons of gas per year in the United States (Purdue 2010). With the cost of one gallon of gas lingering near four dollars, Americans spend $2.320 billion mowing turfgrass every year. Fuel is but a fraction of the $25 billion total Americans spend on lawn care annually (Purdue 2010). The U.S. Environmental Protection Agency estimates that over a ten year span the average maintenance cost of an acre of native landscape is roughly one-fifth the cost of an acre of turfgrass (US EPA 2008). From a fiscal responsibility perspective it is easy to see why natives are a far superior alternative to traditional turfgrass lawns. From a common sense perspective this last series of statistics may make the situation a bit more clear. Purdue University has found that 30-60% of all freshwater used in the United States is used for irrigation (Purdue 2010). For every acre of turfgrass in the Midwest alone 325,848 gallons of water are used each summer for irrigation (US EPA 2008). Yet Manhattan allows upwards of 52 million gallons of stormwater to fall on residential areas and runoff into Wildcat Creek with little thought about capturing and reusing this water to offset irrigation needs. To put this quantity into perspective all of the water towers servicing the city of manhattan have only a 5.5 million gallon capacity (see fig. 4.1). Allowing the 52 milion gallons of stormwater to runoff into the sewer system to be lost forever is not only an injustice to the environment but it is an injustice to the homeowner. Economically it makes little sense for a homeowner to allow stormwater to fall on his or her property and runoff into the storm sewer system, only to then pay to irrigate their lawn with city water.

Given the evidence it is clear that more must be done to utilize stormwater BMPs in the Manhattan area. Specifically residential stormwater BMPs which have the opportunity to have positive impacts both economically and ecologically. Residential stormwater BMPs economically reduce the cost of utility maintenance as well as irrigation costs. These same BMPs have an ecological impact by increasing biodiversity, increasing infiltration, reducing the carbon footprint of developed areas, and reducing pollutants. For these reasons residents of Manhattan and the Wildcat Creek watershed must re-evaluate their approach to residential stormwater management.



Potential Runoff Captured by High-Level BMP Strategies

Figure 4.1 (Created by Author adapted from image by McNeill):

High-level BMP strategies applied to residential developments in the Manhattan areas of Wildcat Creek watershed have the potential to reduce stormwater runoff by 52,000,000 gallons. The water towers that service the city of Manhattan hold 5,500,000 gallons (City of Manhattan, 2009). In turn, by achieving 100% participation in high-level BMP applications runoff reduction levels would equal the entire storage capacity of Manhattans water towers more than 9 times.

Recommendations

Residential developments are an important factor in trying to reduce stormwater runoff in developed areas such as Manhattan. The primary factor differentiating residential developments from other development types is the limited influence government has on the use of private property. Given the results of this project it is important that the city of Manhattan take action to address stormwater runoff in the residential areas of the city. It is recommended here that residential stormwater BMPs be implemented in the city of Manhattan to reduce the amount of runoff entering Wildcat Creek. These BMPs should be used to offset the imperviousness created by new development as well as existing development.

While no one singular solution will solve the flooding issues of the Wildcat Creek watershed it is important to consider all facets of the problem and the contributing factors. This project focused on the contributions of a growing residential presence in the watershed. As the population of Manhattan continues to grow the need for residential developments will continue to rise. If nothing is done to address the stormwater runoff burden caused by these developments it is certain the flooding intensity and frequency in the Wildcat Creek watershed will continue to increase. Significant amounts of runoff can be prevented from rapidly entering the creek through the implementation of the BMPs examined in this project (fig. 4.1 & tables F.3 & F.4). It is not an easy proposition to regulate what homeowners can do with their property but the benefits of these BMPs are worth the effort. The idea of the 'carrot' and the 'stick' should be carefully examined by policy makers within the city government. 'Carrot' or reward oriented policy such as tax reduction incentives are a tried and true way of promoting homeowner participation in city programming. Similar approaches could be used in Manhattan to promote the implementation of BMP retrofits on existing residential properties. These incentives should be based on the level of participation in BMP strategies. For example, any homeowner achieving a level of runoff reduction equivalent to 60% of the pre-BMP total will receive a reduction in personal property tax for the life of the BMP. This approach provides homeowners with an incentive to take action in helping to reduce their personal runoff contributions to the watershed. In the case of new developments BMPs could be required on runoff differential basis. In other words the level of BMP implementation could be dictated by the amount of runoff created by the proposed development in comparison to what was created by the pre-development condition. In a sense this type of policy would pass the savings generated by the city onto homeowners for reducing their use of stormwater infrastructure.

On the other side of the coin, 'stick' oriented approaches to community engagement involve penalties for lack of participation. Several instances of this style of policy making can be found in policies around the country and abroad. Germany, for example, has made site scale flood reduction planning federal law. Existing properties are required to meet maximum runoff standards and all new developments to implement BMPs. The goal of the German legislature is to reduce the likelihood of 100-year floods thus reducing flood damage and environmental impacts of developments (Berlin, 2005). In this type of community engagement a homeowner would be assessed a penalty for not reducing stormwater runoff. For example, an infrastructure tax could be assessed to each homeowner based on the amount of runoff leaving their property. This tax would be used to maintain stormwater infrastructure and develop new infrastructure and stormwater BMPs to offset the runoff produced by properties choosing not to participate in BMP implementation programs. In essence, the stick approach would ensure the reduction of stormwater runoff through both point source and non point source BMPs and would ensure funding through taxation. Historically increased taxes are unpopular and this approach should be pursued with caution. The fact exists however, that as flood damage increases so too will the cost of flood damages. The question that must be asked is: which is less costly; BMPs, taxes or flood damage?

It is important to understand that residential and other BMPs are not holistic solutions to the flooding in the Wildcat Creek Watershed. While BMPs will help reduce local flooding and signifigantly improve water quality and conservation, it is critical that other influences are addressed as well. Agricultural lands upstream from Manhattan in conjunction with other land uses and regional climate are important factors in the flooding of Wildcat Creek Watershed. More information and analysis on Wildcat Creek Watershed and additional flood mitigation strategies see the link in Appendix H.

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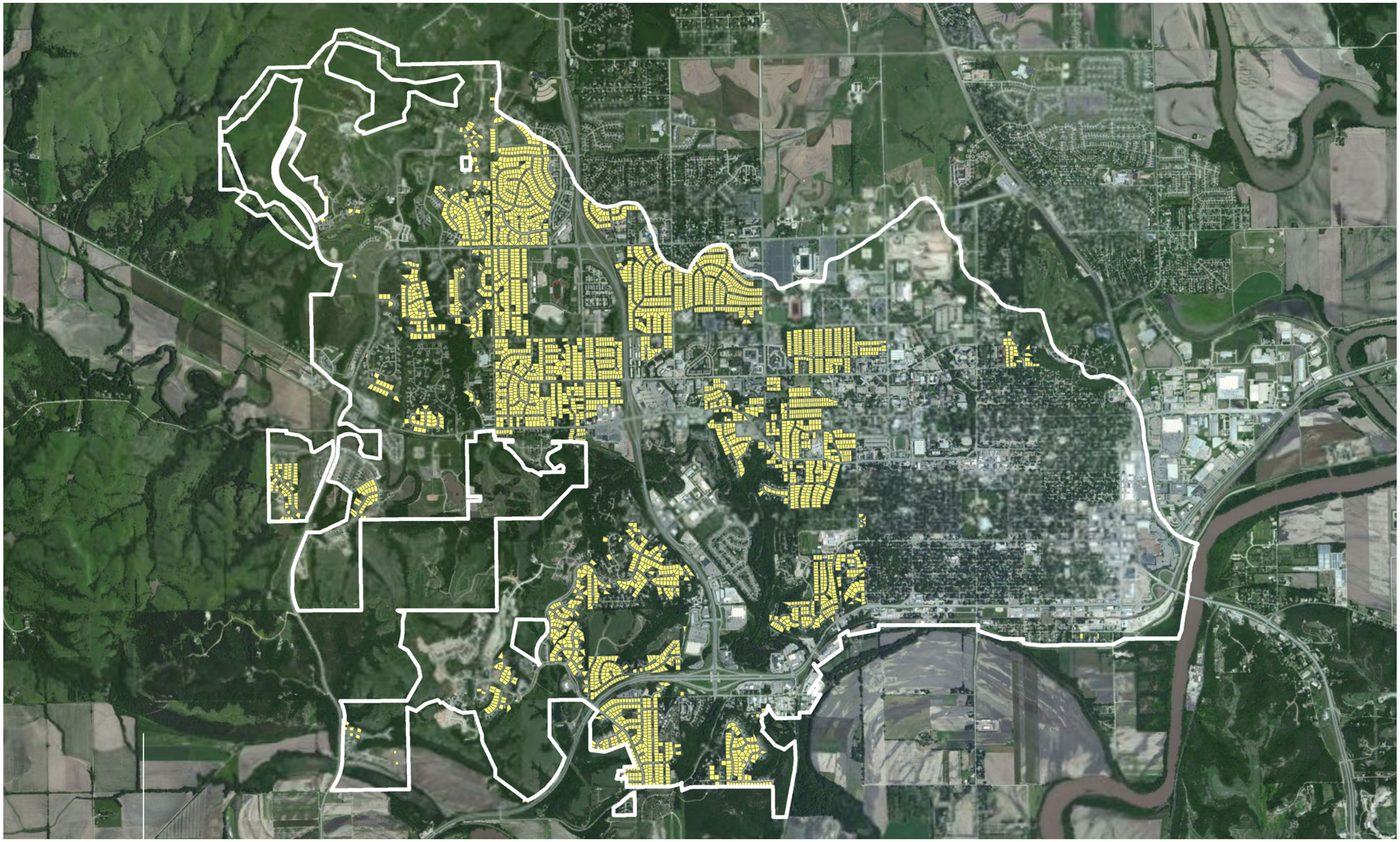
Appendices

A - Typology
B - Precipitation
C - Vegetation
D - Slopes
E - Coefficients
F - Runoff Calculations
G - Literature Review

Appendix A - Residential Typology (maps)

Small Lot Single Family Residential Development in Manhattan, Kansas



Legend:

Manhattan in Wildcat Creek Watershed

Small Lot Single Family

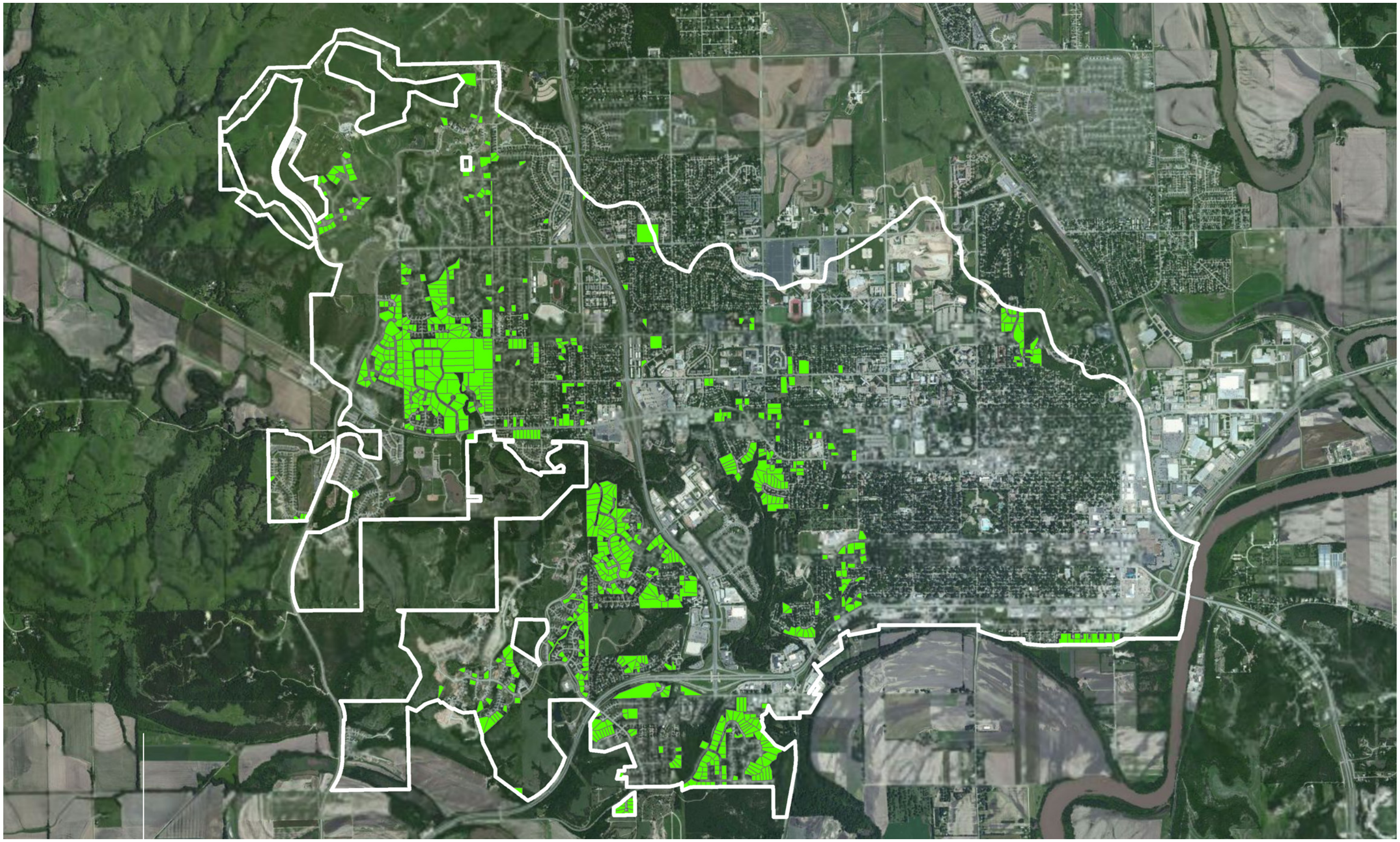
Scale: 1" = 1 mile

0 0.5 1.0 2.0 miles

Small Lot Single Family Residential Development Footprint

Figure A.1 (Produced by Author data courtesy of City of Manhattan and USDA)

Small Lot Single Family Residential Development in Manhattan, Kansas



Legend:

Manhattan in Wildcat Creek Watershed

Small Lot Single Family

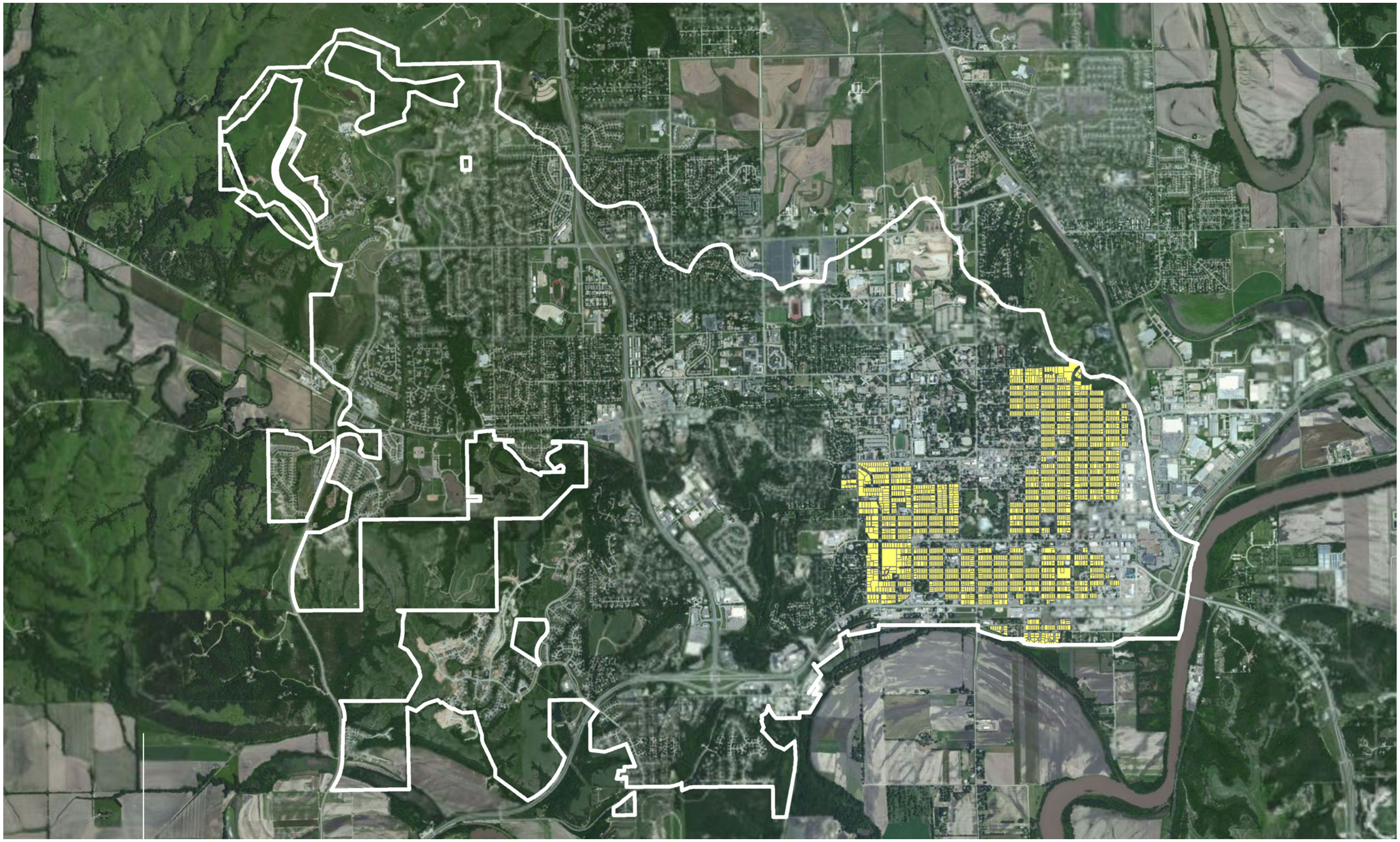
Scale: 1" = 1 mile

0 0.5 1.0 2.0 miles

Large Lot Single Family Residential Development Footprint

Figure A.2 (Produced by Author data courtesy of City of Manhattan and USDA)

Traditional Single Family Residential Development in Manhattan, Kansas



Legend:

Manhattan in Wildcat Creek Watershed

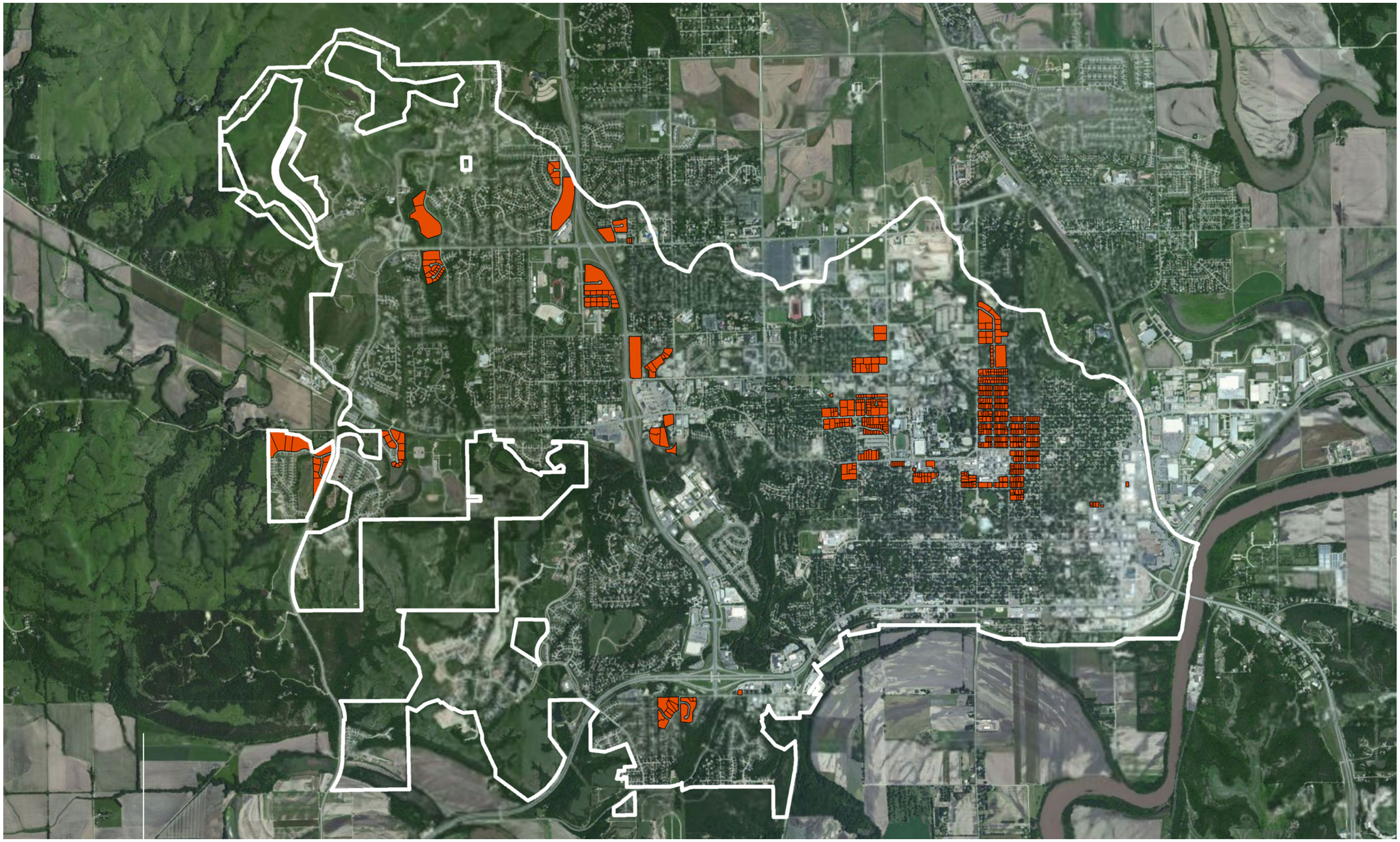
Traditional Single Family

Scale: 1" = 1 mile

0 0.5 1.0 2.0 miles

Traditional Single Family Residential Development Footprint
Figure A.3 (Produced by Author data courtesy of City of Manhattan and USDA)

High Density Multi-Family Residential Development in Manhattan, Kansas



Legend:

Manhattan in Wildcat Creek Watershed

Multi-Family

Scale: 1" = 1 mile

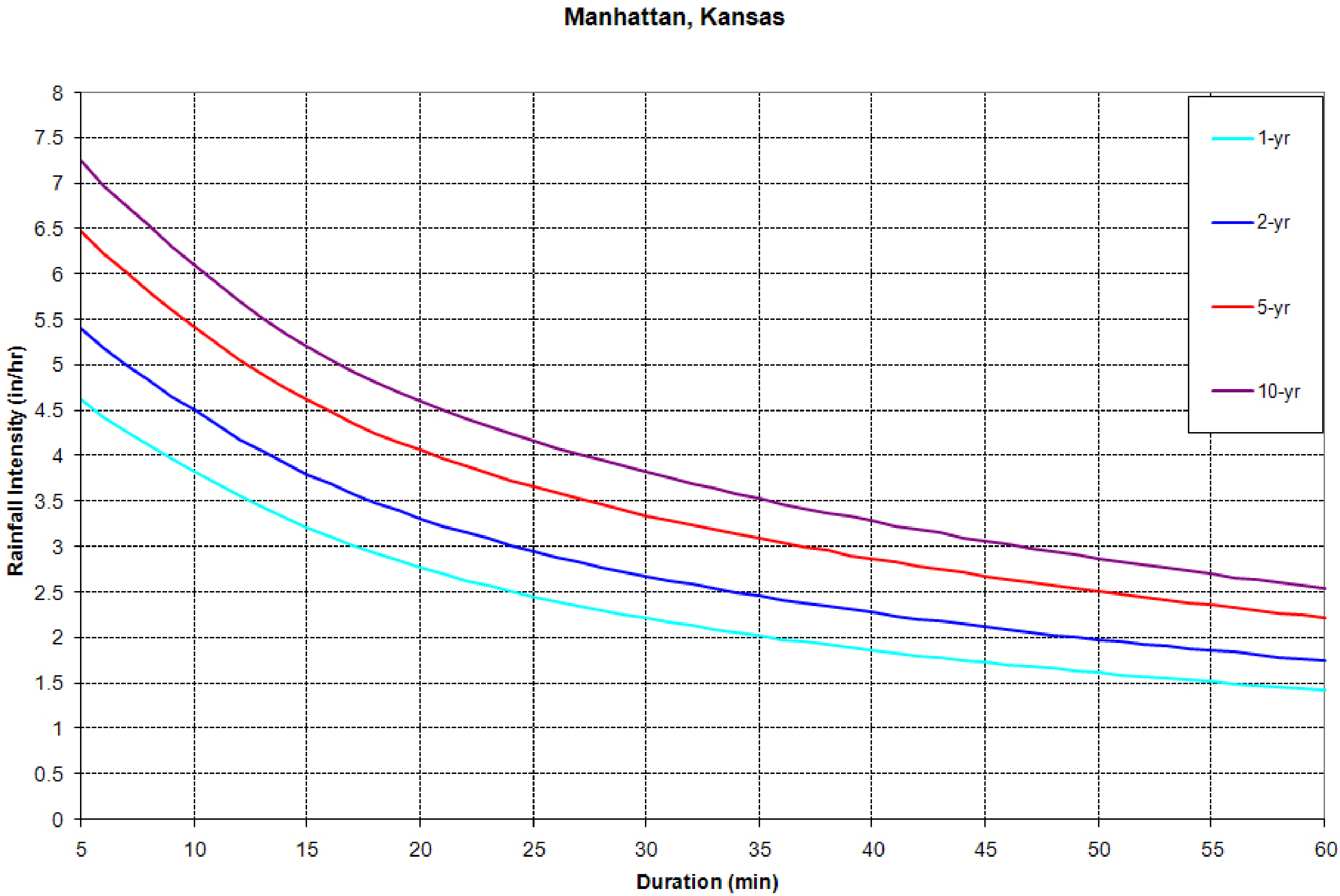
0 0.5 1.0 2.0 miles

High Density Multi-Family Residential Development Footprint

Figure A.4 (Produced by Author data courtesy of City of Manhattan and USDA)

Appendix B - Precipitation

Rain Fall Intensity Charts For Manhattan, Kansas



Rain Fall Intensity for Key Storm Events in Manhattan, Kansas
Figure B.1 (Wilson and Company & Camp, Dresser and McKee 2009)

Appendix C - Vegetation

Recommended Plants for Stormwater BMPs

RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
GRASSES																	
Prairie Cordgrass (Spartina pectinata)	P	W	T	G/BG	M/S	X		X	X	X	X			X	X	X	
Switchgrass (Panicum virgatum)	P	W	T	G	M/S	X	X	X	X	X	X			X	X	X	X
Western Wheatgrass (Pascopyrum smithii)	P	C	M	G/YG	M/S	X	X		X					X			X
Indian Grass (Sorghatrum nutans)	P	W	T	G	D/M	X	X	X	X	X	X	X		X		X	X
Big Bluestem (Andropogon gerardii)	P	W	T	G	M	X	X	X	X	X	X			X	X	X	X
Little Bluestem (Schizachyrium scoparium)	P	W	M	BG/G	D/M	X	X	X	X	X	X	X		X		X	X
Side Oats Grama (Bouteloua curtipendula)	P	W	M	P/G	D/M	X	X	X	X	X	X	X		X			
Canada Wildrye (Elymus canadensis)	P	C	T	G	D/M	X	X		X	X	X	X					
Virginia Wildrye (Elymus virginicus)	P	C	M	G	M	X	X	X	X	X	X			X	X	X	
Buffalograss (Buchloe dactyloides)	P	W	S	BG/G	D/M/S	X	X		X	X	X	X	X	X			
Redtop (Agrostis gigantea)	P	C	T	R/G	D/M/S	X	X		X	X	X	X					
Bermuda (Cynodon dactylon)	P	W	S	G	D/M/S		X		X	X	X	X	X	X			X
Blue Grama (Bouteloua gracilis)	P	W	S	BG	D	X	X		X	X	X	X	X	X			
Hairy Grama (Bouteloua hirsuta)	P	W	S	BG	D	X	X		X	X	X	X	X	X			
Alta or Kentucky 31 Fescue (Festuca elatior var. arund.)	P	C	M	G	D/M/S	X	X		X	X	X	X		X			X
Kentucky Bluegrass (Poa pratensis)	P	C	S	BG	D/M	X	X		X	X	X	X		X			X
Perennial Ryegrass (Lolium perenne var. derby)	P	C	M	G	D/M	X	X		X	X	X	X		X			X

Table C.1 (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Red Creeping Fescue (Festuca rubra)	P	C	S	G/R	D/M	X	X		X	X	X	X		X			X
Prairie Dropseed (Sporobolus heterolepsis)	P	W	M	G	D/M	X	X		X	X	X	X		X			
Saltgrass (Distichlis stricta)	P	W	S	G	M/S		X	X	X	X	X	X	X	X		X	
Vine Mesquite (Panicum obtusum)	P	P	S	G	M/S		X	X	X	X	X	X	X	X		X	
Timothy (Phleum pratense)	P	C	M	G	M	X	X		X	X	X						X
Bottlebrush Grass Hystrix patula (Elymus hystrix)	P	C	M	G	M		X		X	X	X			X			
Woodland Brome Bromus pubescens	P	C	M	G	M		X		X	X	X			X			X
Seed Oats (Avena sativa)	A	C	T	G/BG	D/M	X			X								X
Annual Rye (Lolium multiflorum)	A	C	M	G	D/M	X			X								X
Winter Rye (Secale cereale)	A	C	T	G	D/M	X			X								X
FORBS AND LEGUMES																	
Illinois Bundleflower (Desmanthus illinoensis)	P	W	M	G/BR	M	X	X		X					X			
Purple Coneflower (Echinacea purpurea)	P	W	M	P	M	X	X		X					X	X	X	
Leadplant (Amorpha canescens)	P	W	M	B	M	X	X		X					X	X	X	
Showy Goldenrod (Solidago speciosa)	P	W	T	Y	M	X	X		X	X				X	X	X	
Maximillian Sunflower (Helianthus maximillianii)	P	W	T	Y	M	X	X		X	X				X	X	X	
Prairie Blazingstar (Liatris pycnostachya)	P	W	M	P/R	M	X	X		X	X				X	X	X	
Black-eyed Susan (Rudbekia hirta)	A/P	W	M	Y	M	X	X		X	X				X	X	X	

Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs																	
Plant Species	**Annual/Perennial**	**Cool/Warm**	**Short/Medium/Tall**	**Leaf/Stem/Flower Color**	**Moist/Wet/Salt Tolerant**	**Riparian Buffer**	**Dry Swale**	**Wet Swale**	**Filter Strip**	**Infiltration Basin**	**Infiltration Trench**	**Sand Filter**	**Pervious Pavement**	**Bioretention**	**Rain Garden**	**ED Wetland**	**Phased Const.**
Purple Prairie Clover (Dalea purpurea)	P	W	M	P	M	X	X		X	X				X	X	X	
Common Dayflower (Commelina communis)	P	W	S	B	M	X	X		X	X				X	X	X	
Cut-leaf Coneflower (Rudbeckia laciniata)	P	W	T	Y	D/M	X	X		X	X				X	X	X	
Shrubby Cinquefoil (Potentilla fruticosa)	P	W	S	Y	M	X	X		X	X				X	X	X	
Wild False Indigo (Baptisia alba var. macrophylla)	P	W	M/T	W/Y	M	X	X		X	X				X	X	X	
Showy Tick Trefoil (Desmodium canadense)	P	W	S/M	P	M/D	X	X		X	X				X	X	X	
Showy Sunflower (Helianthus lateriflorus)	A/P	W	T	Y	D/M	X	X		X	X				X	X	X	
False Sunflower (Heliopsis helianthoides)	P	W	M	Y	D/M	X	X		X					X	X	X	
Rough Blazing Star (Liatris aspera)	P	W	M	P/R	D/M	X	X		X					X	X	X	
Joe Pyeweed (Eupatorium maculatum)	P	W	M	P	M/W	X	X	X	X					X	X	X	
Boneset (Eupatorium perfoliatum)	P	W	T	W	W			X						X	X	X	
Sneezeweed (Helenium autumnale)	P	W	S	Y	M/W	X	X	X	X					X	X	X	
Prairie Cinquefoil (Potentilla arguta)	P	W	S	Y	D/M	X	X		X					X	X	X	
Heart-leaved Alexander (Zizia aptera)	P	W	S	Y	D/M	X	X		X					X	X	X	
Swamp Milkweed (Asclepias incarnata)	P	W	T	P/PK	M/W	X	X	X	X					X	X	X	
Marsh Aster (Aster puniceus)	P	W	M/T	W/Y	W			X						X	X	X	
Great Blue Lobelia (Lobelia siphilitica)	P	W	M	B	M/W	X	X	X	X					X	X	X	

Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Common Water Horehound (Lycopus americanus)	P	W	S	W	W		X	X						X	X	X	
Common Mountain Mint (Pycnanthemum virginianum)	P	W	M	W	M/W	X	X	X	X					X	X	X	
Cup Plant (Silphium perfoliatum)	P	W	T	Y	M/W	X	X	X	X					X	X	X	
Purple Meadow Rue (Thalictrum dasycarpum)	P	W	M	P	M/W	X	X	X	X					X	X	X	
Blue Vervain (Verbena hastata)	P	W	S	P/B	M/W	X	X	X	X					X	X	X	
Canada Anemone (Anemone canadensis)	P	W	S	W	M/W	X	X	X	X					X	X	X	
Cream Gentian (Gentiana alba)	P	W	M	W	D/M	X	X		X					X	X	X	
Showy Evening Primrose (Oenothera speciosa)	P	W	S	W	D/M	X	X		X					X	X	X	
Indian Blanket (Gaillardia pulchella)	A	W	S	R/Y	D/M	X	X		X					X	X	X	
Nodding Onion (Allium cernuum)	P	C	S	PK	D/M	X	X		X					X	X	X	
Cream False Indigo (Baptisia bracteata)	P	W	S	W	D/M	X	X		X					X	X	X	
White Prairie Clover (Dalea candida)	P	C	S	W	D/M	X	X		X					X	X	X	
Golden Alexanders (Zizia aurea)	P	W	M	Y	M/W	X	X	X	X					X	X	X	
Sky Blue Aster (Aster azureus)	P	W	M	B	D/M	X	X		X					X	X	X	
Blue Wild Indigo (Baptisia australis)	P	W	M	B	D/M	X	X	X	X					X	X	X	
Wild Bergamot (Monarda fistulosa)	P	W	M/T	P/B	D/M	X	X		X					X	X	X	
Smooth Penstemon (Penstemon digitalis)	P	W	M	W	M/W	X	X	X	X					X	X	X	

Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Ohio Spiderwort (Tradescantia ohiensis)	P	W	M	B	D/M/W	X	X	X	X					X	X	X	
Slender Mountain Mint (Pycanthemum tenuifolium)	P	W	S	W	D/M	X	X		X					X	X	X	
Wild Columbine (Aquilegia canadensis)	P	W	M	R	D/M	X	X		X					X	X	X	
False Solomon's Seal (Smilacina racemosa)	P	W	S/M	W	D/M	X	X		X					X	X	X	
Hoary Vervain (Verbena stricta)	P	W	M	P/PK	D/M	X	X		X					X	X	X	
Common Milkweed (Asclepias syriaca)	P	W	M	PK	M	X	X	X	X					X	X	X	
Partridge Pea (Cassia fasciculata)	A	W	S	Y	D/M	X	X		X					X	X	X	
Bush Clover (Lespedeza capitata)	P	W	M	B	D/M	X	X		X					X	X	X	
Compass Plant (Silphium laciniatum)	P	W	T	Y	D/M	X	X		X					X	X	X	
Stiff Goldenrod (Solidago rigida)	P	W	M/T	Y	D/M	X	X		X	X				X	X	X	
Buttererfly Milkweed (Asclepias tuberosa)	P	W	M	OR	D/M	X	X		X	X				X	X	X	
Whorled Milkweed (Asclepias verticillata)	P	W	S	W	D/M	X	X		X	X				X	X	X	
Smooth Blue Aster (Aster laevis)	P	W	M	P/B	D/M	X	X		X	X				X	X	X	
Western Sunflower (Helianthus occidentalis)	P	W	M	Y	D/M	X	X		X	X				X	X	X	
Spotted Berfgamot (Monarda punctata)	P	W	M	Y/P	D	X	X		X	X							
Yellow Coneflower (Ratibida pinnata)	P	W	M	Y	D/M	X	X		X	X				X	X	X	
New England Aster (Aster novae-angliae)	P	W	M/T	B	M/W	X	X		X	X				X	X	X	

Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Thimbleweed (Anemone cylindrica)	P	W	S	G	D/M	X	X		X	X				X	X	X	
Heath Aster (Aster ericoides)	P	W	S/M	W	D/M	X	X		X	X				X	X	X	
Silky Aster (Aster sericeus)	P	W	S	P/B	D	X	X		X	X							
New Jersey Tea (Ceanothus americanus)	P	W	S/M	G/BR	D/M	X	X		X	X				X	X	X	
Alum Root (Heuchera richardsonii)	P	W	S	GR	D/M	X	X		X	X				X	X	X	
Prairie Smoke (Geum triflorum)	P	W	S	R	D/M	X	X		X	X				X	X	X	
Wild Lupine (Lupinus perennis)	P	W	S	B	D	X	X		X	X							
Large Flowered Beard Tongue (Penstemon grandiflorus)	P	W	M	P/B	D	X	X		X	X							
Downy Phlox (Phlox pilosa)	P	W	S	PK	D/M	X	X		X	X				X	X	X	
Blue-eyed Grass (Sisyrinchium campestre)	P	W	S	B	D	X	X		X	X							
Old Field Goldenrod (Solidago nemoralis)	P	W	S	Y	D	X	X		X	X							
Riddell's Goldenrod (Solidago riddellii)	P	W	S/M	Y	M/W	X	X	X	X	X				X	X	X	
Flowering Spurge (Euphorbia corollata)	P	W	S	W	D/M	X	X		X	X				X	X	X	
Prairie Spiderwort (Tradescantia bracteata)	P	W	S	B	D/M	X	X		X	X				X	X	X	
WETLAND SPECIES																	
Blueflag (Iris virginica)	P	W	S/M	B	M/W			X						X	X	X	
Arrowhead (Sagitaria fasciculate & latifolia)	P	W	S/M	W	M/W									X	X	X	
Needle Spikerush (Eleocharis acicularis)	P	W	S	BR	M/W			X						X	X	X	

Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs																		
Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Rice Cutgrass (Leersia oryzoides)	P	W	S	GR	M/W			X						X	X	X	
Bulrush var. Olney's (Scirpus americanus)	P	W	T	GR	M/W			X						X	X	X	
Common Spikerush (Eleocharis acicularis)	P	W	S	BR	M/W			X						X	X	X	
Cardinal Flower (Lobelia cardinalis)	P	W	M	R	M/W			X						X	X	X	
White Water Lilly (Nymphaea odorata)	P	W	S	W	W									X		X	
Wild Calamus (Acorus calamus)	P	W	M	W	W			X						X	X	X	
Bottlebrush Sedge (Carex hystricina)	P	W	M	BR	M/W			X						X	X	X	
Pointed Broom Sedge (Carex scoparia)	P	W	M	BR	M/W			X						X	X	X	
Dark Green Rush (Scirpus atrovirens)	P	W	M	GR	M/R			X						X	X	X	
Wool Grass (Scirpus cyperinus)	P	W	M	GR	M/W			X						X	X	X	
Great Bulrush (Scirpus validus creber)	P	W	T	GR	M/W			X						X	X	X	
Common Spike Rush (Juncus effusus)	P	W	S	BR	M/W			X						X	X	X	
Wood Sedge (Carex rosea)	P	W	S	GR	M/W	X								X		X	
Smartweed (Polygonum spp.)	P	W	S/T	BR	M/W			X						X	X	X	
Angelica (Angelica atropurpurea)	P	W	M	GR/W	M/W			X						X	X	X	
Water Hemlock (Cicuta maculata)	P	W	T	Y	W									X	X	X	
Barnyard Grass (Echinochloa crusgalli)	P	W	M	GR	M/W			X						X	X	X	X

Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs																	
Plant Species	**Annual/Perennial**	**Cool/Warm**	**Short/Medium/Tall**	**Leaf/Stem/Flower Color**	**Moist/Wet/Salt Tolerant**	**Riparian Buffer**	**Dry Swale**	**Wet Swale**	**Filter Strip**	**Infiltration Basin**	**Infiltration Trench**	**Sand Filter**	**Pervious Pavement**	**Bioretention**	**Rain Garden**	**ED Wetland**	**Phased Const.**
Fowl Manna Grass (Glyceria striata)	P	W	M/T	GR	W			X						X	X	X	
Germander, Wood Sage (Teucrium canadense)	P	W	M	W/P	M	X										X	
Woodland Sedge (Carex blanda)	P	W	S/M	GR	M	X										X	
Pen Sedge (Carex pensylvanica)	P	W	S/M	GR	M			X						X	X	X	
Woodland Sedge (Carex sparganioides)	P	W	S/M	GR	M			X						X	X	X	
Winged Loosestrife (Lythrum alatum)	P	W	S	B/P	W			X						X	X	X	
Common Bur Reed (Sparganium eurycarpum)	P	W	M/T	BR	W			X						X	X	X	
Iron Weed (Vernonia fasciculata)	P	W	M	R/PK	M/W									X	X	X	
Culver's Root (Veronicastrum virginicum)	P	W	M/T	W	M/W			X						X	X	X	
Blue Joint Grass (Calamagrostis canadensis)	P	W	M/T	GR/Y	M/W			X						X	X	X	
TREES																	
Sycamore (Platanus occidentalis)					M/W	X								X		X	
Hackberry (Celtis occidentalis)					D/M	X								X		X	
Shagbark Hickory (Carya ovata)					D/M	X											
Red bud (Cercis canadensis)					D/M	X								X		X	
Black Cherry (Prunus serotina)					D/M	X								X		X	
White Oak (Quercus alta)					D	X										X	
Black Walnut (Juglans nigra)					D/M	X										X	

Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs

Plant Species	Annual/Perennial	Cool/Warm	Short/Medium/Tall	Leaf/Stem/Flower Color	Moist/Wet/Salt Tolerant	Riparian Buffer	Dry Swale	Wet Swale	Filter Strip	Infiltration Basin	Infiltration Trench	Sand Filter	Pervious Pavement	Bioretention	Rain Garden	ED Wetland	Phased Const.
Eastern Red Cedar (Juniperus virginiana)					D/M/S	X								X		X	
Red Maple (Acer rubrum)					M/W/S	X								X		X	
Bur Oak (Quercus macrocarpa)					M/S	X								X		X	
Eastern Cottonwood (Populus deltoides)					D/M/S	X		X						X		X	
River Birch (Betula nigra)					M/W	X		X						X	X	X	
Hazelnut (Corylus americana)					D/M	X								X		X	
Pin Oak (Quercus palustris)					M/W/S	X		X						X		X	
Red Elm (Ulmus rubra)					D/M	X								X		X	
Green Ash (Fraxinus pennsylvanica subintegerrima)					M/W	X								X	X	X	
Red Oak (Quercus rubra)					D/M	X								X		X	
Basswood (Tilia americana)					D/M	X								X		X	
Boxelder (Acer negundo)					M/S	X		X						X		X	
SHRUBS AND VINES																	
Streamco Willow (Salix purpurea)				GR/Y	M/W	X		X						X	X	X	
Sandbar Willow (Salix exigua)				GR/Y	M/X	X		X						X	X	X	
Rough-leaved Dogwood (Cornus drumondii)				W	D/M	X	X		X	X				X	X	X	
Coralberry (Symphocarpus orbiculatus)				PK	D/M	X	X		X	X				X	X	X	
Wild Plum (Prunus americana)				W	D/M	X	X		X	X				X		X	

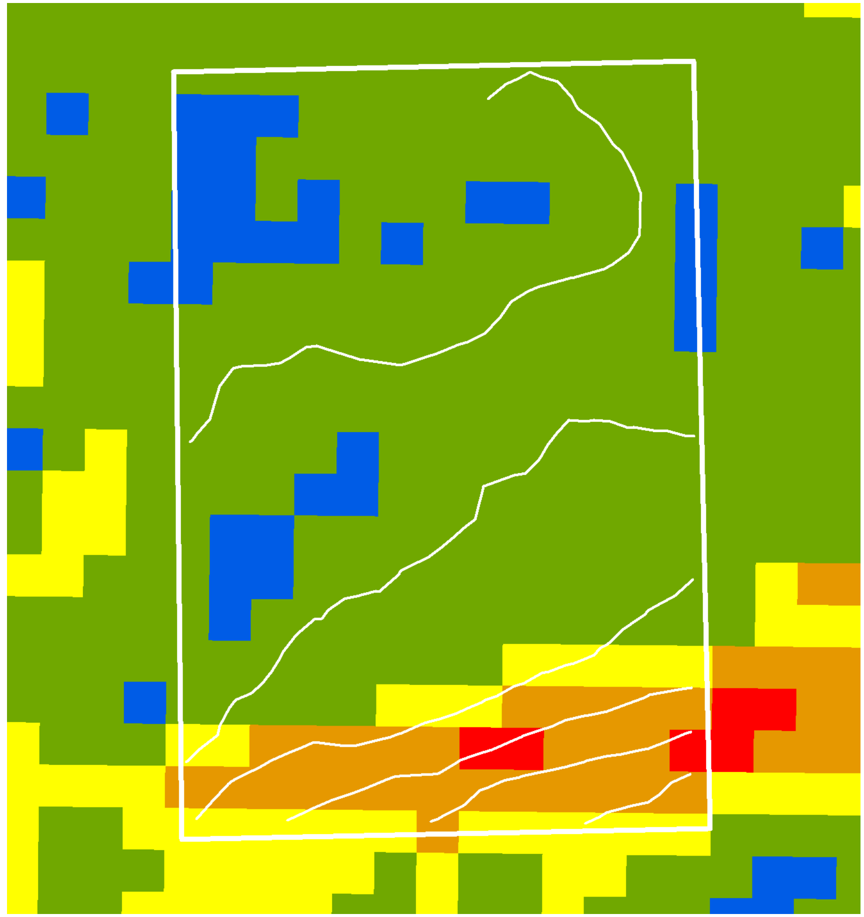
Table C.1 Cont. (MARC 2003)

RECOMMENDED PLANT MATERIALS FOR BMPs																	
Plant Species	**Annual/Perennial**	**Cool/Warm**	**Short/Medium/Tall**	**Leaf/Stem/Flower Color**	**Moist/Wet/Salt Tolerant**	**Riparian Buffer**	**Dry Swale**	**Wet Swale**	**Filter Strip**	**Infiltration Basin**	**Infiltration Trench**	**Sand Filter**	**Pervious Pavement**	**Bioretention**	**Rain Garden**	**ED Wetland**	**Phased Const.**
Elderberry (Sambucus canadensis)				W	M	X	X	X	X	X				X		X	
Flame-leaf Sumac (Rhus glabra)				R	D/M	X	X		X	X				X		X	
Red-osier Dogwood (Cornus stolonifera)				W	D/M	X	X	X	X	X				X		X	
Chokecherry (Prunus virginiana)				W	D	X	X		X					X			
Common Buckthorn (Rhamnus carthartica)				Y	D	X	X		X	X				X		X	
Button Bush (Cephalanthus occidentalis)				w	M/W			X						X	X	X	
Gray Dogwood (Cornus racemosa)				W	D/M	X	X		X	X				X		X	

Table C.1 Cont. (MARC 2003)

Appendix - D

Sample Site Slopes



Legend:

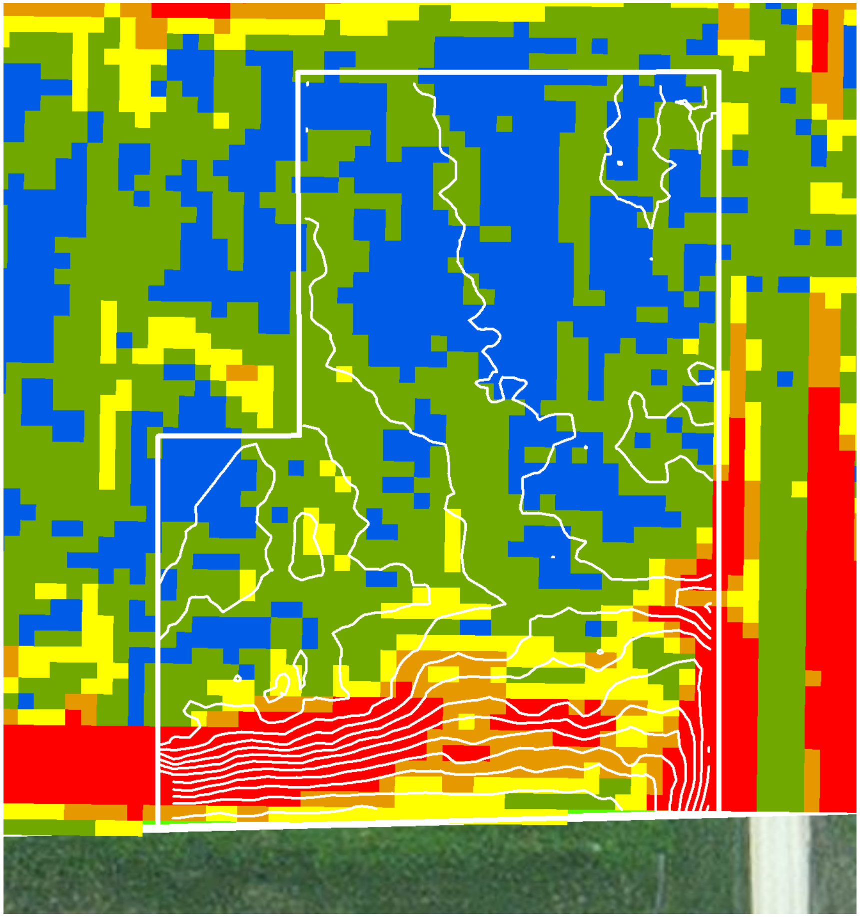
- Site Boundary/Contours
- 0-2%
- 2-6%
- 6-10%
- 10-15%
- 15%+

Scale: 1" = 30'

0 15 30 60 feet

Small Lot Single Family Site: Slopes

Figure D.1 (Produced by author):



Legend:

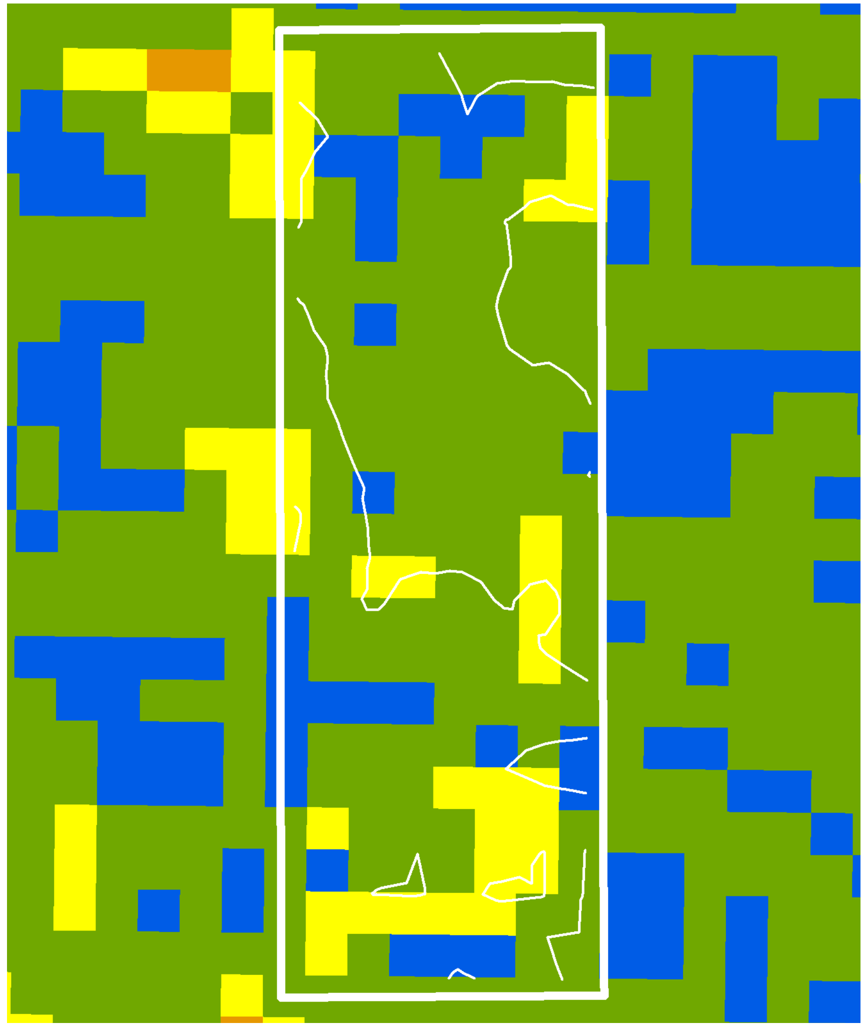
- Site Boundary/Contours
- 0-2%
- 2-6%
- 6-10%
- 10-15%
- 15%+

Scale: 1" = 80'

0 40 80 160 feet

Large Lot Single Family Site: Slopes

Figure D.2 (Produced by author):



Legend:

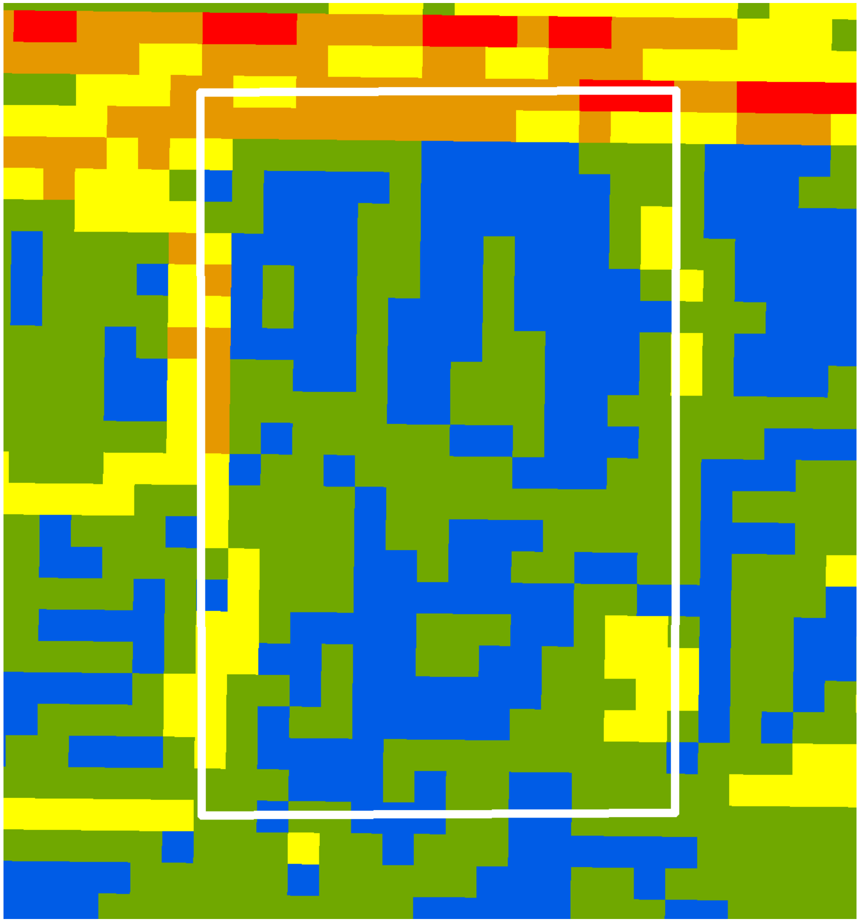
- Site Boundary/Contours
- 0-2%
- 2-6%
- 6-10%
- 10-15%
- 15%+

Scale: 1" = 30'

0 15 30 60 feet

Traditional Single Family Site: Slopes

Figure D.3 (Produced by author):



Legend:

- Site Boundary/Contours
- 0-2%
- 2-6%
- 6-10%
- 10-15%
- 15%+

Scale: 1" = 40'

0 20 40 80 feet

Multi-Family Site: Slopes

Figure D.4 (Produced by author):

Appendix E - Runoff Coefficients

Runoff Coefficients		
Material		Coefficient (c)
Streets		
	asphalt	0.70-0.95
	concrete	0.80-0.95
	brick	0.70-0.85
Drives and Walks		0.75-0.85
Roofs		0.75-0.95
Lawns		
	sandy soil, gradient $\leq$ 2%	0.05-0.10
	sandy soil, gradient $\geq$ 7%	0.15-0.20
	heavy soil, gradient $\leq$ 2%	0.13-0.17
	heavy soil, gradient $\geq$ 7%	0.25-0.35
Unimproved (native)		0.10-0.30
Gravel		0.35-0.70

Runoff Coefficients

Table E.1 (Addapted From: Dunne & Leupold, 1978 and American Iron and Steel Institute, 1980)

Appendix F - Calculations

Surface Runoff Calculations (By Site)							
Site	Material	Area (acres)	Coefficient (c)	Rainfall Intensity Two-year storm (in/hr)	Runoff Quantity (acre inches)	Runoff Quantity (acre feet)	Runoff Quantity (gallons)
Small Lot Single Family							
	Roof	0.0469	0.95	1.75	0.0779	0.0065	2115.4478
	Paving	0.0244	0.95	1.75	0.0406	0.0034	1101.5136
	Lawn	0.1587	0.25	1.75	0.0694	0.0058	1885.7005
Large Lot Single Family							
	Roof	0.0492	0.95	1.75	0.0818	0.0068	2221.0847
	Paving	0.0045	0.95	1.75	0.0075	0.0006	204.6829
	Lawn	1.2583	0.25	1.75	0.5505	0.0459	14948.6036
	Gravel	0.1580	0.5	1.75	0.1382	0.0115	3753.2245
Traditional Single Family							
	Roof	0.0337	0.95	1.75	0.0560	0.0047	1521.3528
	Paving	0.0033	0.95	1.75	0.0055	0.0005	150.3295
	Lawn	0.1125	0.25	1.75	0.0492	0.0041	1336.5000
	Gravel	0.0205	0.3	1.75	0.0108	0.0009	292.2480
Multi-Family							
	Roof	0.1046	0.95	1.75	0.1739	0.0145	4722.0623
	Paving	0.1905	0.95	2.75	0.4977	0.0415	13514.1785
	Sidewalks	0.0188	0.95	3.75	0.0668	0.0056	1814.7888
	Lawn	0.0269	0.25	4.75	0.0320	0.0027	868.6995

Surface Runoff Calculations

Figure F.1 (Produced by Author):

Weighted Runoff Coefficients (By Site)					
Site	Material	Area (acres)	Percent of Total Area	Coefficient (c)	Weighted Coefficient (adj.c)
Small Lot Single Family					
	Roof	0.0469	0.2039	0.95	0.1937
	Paving	0.0244	0.1061	0.95	0.1008
	Lawn	0.1587	0.6900	0.25	0.1725
Development Type (adj. C)					0.4670
Large Lot Single Family					
	Roof	0.0492	0.0335	0.95	0.0318
	Paving	0.0045	0.0031	0.95	0.0029
	Lawn	1.2583	0.8560	0.25	0.2140
	Gravel	0.1580	0.1075	0.5	0.0538
Development Type (adj. C)					0.3025
Traditional Single Family					
	Roof	0.0337	0.1982	0.95	0.1883
	Paving	0.0033	0.0194	0.95	0.0184
	Lawn	0.1125	0.6618	0.25	0.1655
	Gravel	0.0205	0.1206	0.3	0.0362
Development Type (adj. C)					0.4084
Multi-Family					
	Roof	0.1046	0.3076	0.95	0.2922
	Paving	0.1905	0.5603	0.95	0.5323
	Sidewalks	0.0188	0.0552	0.95	0.0524
	Lawn	0.0269	0.0792	0.25	0.0198
Development Type (adj. C)					0.8967

Weighted Runoff Coefficients

Figure F.2 (Produced by Author):

Development Type Runoff Extrapolations						
Site	Area (acres)	Weighted Coefficient (adj.c)	Rainfall Intensity Two-year storm (in/hr)	Runoff Quantity (acre inches)	Runoff Quantity (acre feet)	Runoff Quantity (gallons)
Small Lot Single Family	986.61	0.4670	1.75	806.3070	67.1923	21894690.6865
Large Lot Single Family	644.71	0.3025	1.75	341.3159	28.4430	9268189.7966
Traditional Single Family	443.72	0.4084	1.75	317.0879	26.4240	8610294.0797
Multi-Family	290.73	0.8967	1.75	456.2272	38.0189	12388524.6552
Total	2365.77	2.0746	1.75	1920.9380	160.0782	52161699.2180

Development Type Runoff Extrapolations

Figure F.3 (Produced by Author):

Implementation Level Runoff Extrapolations					
Site	BMP Implementation	Runoff Quantity (acre inches)	Runoff Quantity (acre feet)	Runoff Quantity (gallons)	Runoff Quantity (cubic feet)
Small Lot Single Family					
	High (100%)	806.3070	67.1923	21894690.6865	2926894.4917
	Mid (80%)	645.0456	53.7538	17515752.5492	2341515.5933
	Low (60%)	483.7842	40.3154	13136814.4119	1756136.6950
Large Lot Single Family					
	High (100%)	341.3159	28.4430	9268189.7966	1238976.7936
	Mid (80%)	273.0527	22.7544	7414551.8373	991181.4349
	Low (60%)	204.7896	17.0658	5560913.8780	743386.0762
Traditional Single Family					
	High (100%)	317.0879	26.4240	8610294.0797	1151028.9264
	Mid (80%)	253.6703	21.1392	6888235.2638	920823.1411
	Low (60%)	190.2527	15.8544	5166176.4478	690617.3558
Multi-Family					
	High (98.73%)	450.4332	37.5361	12231190.3920	1635072.3697
	Mid (62.50%)	285.1420	23.7618	7742827.9095	1035065.5637
	Low (32.6%)	148.7301	12.3942	4038659.0376	539890.1980
Total					
	High	1915.1440	159.5953	52004364.9548	6951972.5813
	Mid	1456.9107	121.4092	39561367.5597	5288585.7330
	Low	1027.5566	85.6297	27902563.7753	3730030.3250

Implementation Level Calculations

Figure F.4 (Produced by Author):

Appendix G - Literature Review

Synthesis

Flooding in the Wildcat Creek watershed is a complex issue that will take a multitude of water management strategies working in conjunction to solve. Residential stormwater management is one component of the whole solution that should be considered. Comprehensive residential stormwater best management plans are rarely implemented in the Midwest. However, a solid foundation of information to support stormwater BMP implementation can be found by drawing from a multitude of sources in both the public and private sector.

Comprehensive regional scale planning efforts to include water sensitive design are examined by Carmon and Shamir in their publication titled, Water-sensitive Planning: Integrating Water Considerations into Urban and Regional Planning. In this piece they explore the concept of integrating stormwater best management into larger stormwater plans as a way to address stormwater at appropriate scales. For example, while retaining large areas of native landscape and natural drainage systems is an ideal solution, many common urban development practices eliminate this as a workable solution. Thus, using stormwater BMPs and design strategies to produce pseudo natural drainage systems is a plausible solution. Integration of water sensitive design into all aspects of the urban fabric is critical to alleviating stormwater management issues such as the flooding of Wildcat Creek. Water Sensitive Planning touches on concepts paralleled by the Mid America Regional Council (MARC) in their 2003 publication, Manual of best management practices for stormwater quality. It is here that the step from regional planning to neighborhood and parcel scale solutions is made. Both MARC and Carmon and Shamir share strategies that can be considered point source stormwater management. Point source stormwater management is addressing stormwater at its point of contact with the earth or within close proximity thereof. An example of this is addressing stormwater in small amounts through infiltration techniques such as rain gardens and permeable paving rather than condensing stormwater through impermeable water conveyance facilities such as curb and gutter or piped sewers. By addressing stormwater runoff near its source the chances for greater infiltration and reduction of stormwater runoff quantities increase.

While the flooding of Wildcat Creek is an important issue to the residents of the watershed, stormwater management in the state of Kansas and the rest of the country is becoming an increasingly important issue. The Environmental Protection agency has seen to this by establishing the National Pollutant Discharge Elimination System (NPDES) permit program (Wilson and Company & Camp, Dresser and McKee). Part of this program requires municipalities to implement stormwater quality management programs. The state of Kansas has adhered to this requirement and in the process created a Post Construction BMP Manual using Wilson and Company & Camp, Dresser and McKee as consultants. The Kansas BMP manual serves to assist Kansas Stormwater Consortium Phase II cities in meeting NPDES criteria. Manhattan, Kansas is a city addressed in the manual. The Kansas BMP manual is an important resource as it addresses many critical issues involved in BMP planning. Most important of these issues are specifications for structural and non-structural BMPs, as well as, hydrologic, soil, and vegetation information for the City of Manhattan. When coupled with the MARC BMP manual the Kansas BMP manual proves to be an invaluable resource.

Credibility is a critical part of any attempt to influence policy making. The MARC and Kansas BMP manuals provide a level of credibility in that they are commissioned by credible local sources and address very regionally specific BMP strategies. In addition to credibility, these manuals mesh well with the U.S. Department of Agriculture's Technical Release 55 (TR-55). The USDA TR-55 Urban Hydrology for Small Watersheds manual is a widely accepted method to calculate stormwater runoff volume, discharge rates, hydrographs, and storage volumes. Integration of the MARC, Kansas, and USDA manuals will lend a high level of credibility and accuracy to the Wildcat Creek watershed residential BMP implementation strategy.

In addition to the specific sources referenced above residential stormwater BMPs in the Wildcat Creek watershed portion of Manhattan, Kansas will be well served by fundamental literature known to many Landscape Architects. Joan Nassuer's Messy Ecosystems, Orderly Frame, has served to inspire me in my attempt to integrate natural systems and functioning landscapes into residential America. Likewise Dunham-Jones served as my first exposure to the notion of retrofitting in her Suburban Retrofits, Demographics, and Sustainability. Dramsted, Olson, and Forman further inspired these notions of integrating ecology into suburban areas in an attempt to create meaningful corridors and promote biodiversity in their work titled Landscape ecology principles in landscape architecture and land-use planning. These and other sources that have influenced the thinking behind my residential stormwater management plan are explored below.

Reviews:

Carmon, Naomi and Shamir, Uri. (2009). Water-sensitive Planning: Integrating Water Considerations into Urban and Regional Planning. Water and Environment Journal. 181-191. doi: 10.1111/j.1747-6593.2009.00172.x

Keywords: Stormwater Management, Planning, Integration, Sustainability, Water Resources

Water-sensitive planning (WSP) is a culmination of 15 years of research into ways of integrating water considerations into planning and development efforts. The overall goal is to improve user environments, improve water quality, and reduce the negative impacts of stormwater. WSP has developed into national and municipal guidelines and planning directives and highlights suggested practices and paradigms. They propose using every aspect of an urban environment to maximize water integration. This includes all green space both public and private as well as planning streetscapes to consider their use as drainage ways. The idea of "the 3Ms of stormwater management" is highlighted in WSP (minimize difference in runoff before and after development, minimize the difference in discharge before and after development, minimize pollutant load). BMPs are included in the WSP ideology with suggested guidelines (reduce impervious areas/increase pervious, intersperse impervious with pervious areas, pass runoff through vegetated patches and or through the ground, on-site infiltration, make each yard into a micro-catchment, direct runoff form roofs and impervious areas to pervious areas, maintain soil permeability). WSP also addresses regional planning and legal action.

WSP is an extremely useful place to start planning in the Wildcat Creek watershed. By implementing the ideas proposed in the WSP idea we can greatly impact the watershed in a positive way.

Dramstad, W. E., Olson, J. D., & Forman, R. T. T. (1996). Landscape ecology principles in landscape architecture and land-use planning. Washington D.C.: Island Press.

Keywords: Patches, edges, boundaries, corridors, ecology

Wenche E. Dramstad, James D. Olson, and Richard T. Forman present a comprehensive evaluation of the importance of landscape ecologies in the modern world in their book, Landscape Ecology Principles in Landscape Architecture and Land-Use Planning. Landscape ecology is becoming an increasingly important part of the planning profession as prior negligence of natural resources and poor planning begins to catch up with society (Dramstad, Olson, Forman 9-16). Dramstad, Olson, and Forman approach the concept of landscape ecologies in pieces, exploring each part for its importance to the whole. Patches, edges and boundaries, corridors and connectivity, and have been identified as key pieces of landscape ecologies that warrant deeper exploration (Dramstad, Olson, and Forman 2). As such these topics serve as the organizing structure for the paper and will in turn serve to organize this review thereof.

Patches are the individual components of the mosaic that comprise the overall landscape of the earth (Dramstad, Olson, and Forman 17). Patches occur in many different shapes and sizes, for this reason patches serve a plethora of unique functions. This large variance in size and placement provides the possibility for patches to perform functions that work to benefit as well as harm overall ecologies (Dramstad, Olson, and Forman 19). The individual nature of patches places an increased importance on each patch. Like the ingredients in a cookie, each patch serves a purpose. Removal of any individual patch creates a gap in the overall mosaic of the landscape, thus, stressing the integrity of the natural ecologies. These gaps can come in any number of forms, such as a suburban development in the heart of a large expanse of forest, or the substitution of natural riparian buffers for industrial sites. On the contrary patches can be added to the mosaic to increase the resilience of the landscape. An example of this would be the establishments of smaller ecological corridors between larger patches to promote biodiversity and strong ecosystems. These linkages relate strongly to the next piece of landscape ecology as defines by Dramstad, Olson, and Forman, edges and boundaries.

Edges and boundaries are the conditions that define patches within the landscape (Dramstad, Olson, and Forman 27). Edges are the areas around patches that serve as a transition from one patch to another. These patches can take on many different appearances and functions. Edges can range from zones of high biodiversity between two unique ecosystems to abrupt changes such as hedge rows and fence lines. Humans have a large impact on patches as well as edges and boundaries given political juxtapositions with the natural landscape, super imposed boundaries can greatly affect how natural boundaries and edges are treated (Dramstad, Olson, Forman 28-32).

Corridors and connectivity has a strong correlation to the treatment of edges and boundaries both natural and man made. Corridors are linkages between the patches in a landscape that allow for the movement of things between the patches. Ecological corridors may serve as migration paths for animals or be a simple as paths connecting food sources in a forest. Dramstad, Olson, and Forman explain that man made barriers may serve as connections or blockages. Take highway corridors for example, they not only serve to move humans and resources but ditches along highways may serve as easy game trails. However the same highway creates a distinct area of low biodiversity that may isolate ecologies on either side (Dramstad, Olson, and Forman 35-40).

Upon exploring each of these elements; patches, edges and boundaries, and corridors and connectivity, their relationship is apparent. These relationships can be synthesized into the mosaics that make up the landscape (Dramstad, Olson, and Forman 41-46). These mosaics can vary greatly based on scale and region. The mosaic of Manhattan Kansas is very different from the mosaic of the flint hills region though they share the same geographic location. For this reason the selection of frame, scale, and reference for the mosaic in which we design has a great impact of the overall ecological considerations of our designs. This is an incredibly important correlation between landscape architecture and landscape ecologies that we must consider in every aspect of our work to ensure that the profession of landscape architecture takes a place at the forefront of design in the near future.

Hale, Thurston W. (2006). Opportunity Costs of Residential Best Management Practices for Stormwater Runoff Control. Journal of Water Resources Planning and Management. 89-96. doi: 10.1016/ (ASCE) 0733-9496(2006)132:2(89)

Keywords: BMPs, Opportunity Costs, Stormwater Management, Urban Stormwater

Thurston examines the viability of using economic incentives to promote the use of small scale stormwater BMPs. They propose using a market based incentive system to trade allowance for runoff reductions. This system would promote stormwater BMPs in a privatized urban area. Opportunity costs of installing the BMPs are considered especially landowner valuation of the land that makes up their parcel.

This article sheds light on a topic of possibly great importance to the Wildcat Creek watershed. The privatization of land in the developed areas creates a significant road block for any kind of residential BMP implementation. By examining the costs and possible incentives of such BMPs we learn valuable information on overcoming these issues.

Jacobson, Carol R. (2011). Identification and quantification of the hydrological impacts of imperviousness in urban catchments: A review. Journal of Environmental Management, 92(6), 1438-1448. doi:10.1016/j.jenvman.2011.01.018

Keywords: Drainage, Catchment Basins, Permeability

Carol Jacobson addresses the impact of impervious surfaces in artificial urban drainage systems. By examining the impacts of urbanization on natural drainage systems Jacobson helps to expose the true impact of impervious surfaces in urban areas. Mapping and detailed imagery play an important role in the ability to accurately depict the areas that are examined to more accurately determine the impacts on the hydrology. Where the impacts of urbanization play an important role in the article the methods with which water flow is modeled are closely examined.

This article plays a role specific to the modeling and categorization of urban drainage. It may not be of prime importance to all aspects of the Wildcat Creek group it may be used as a support role in some areas of study.

Jia, Haifeng; Ma, Hongtao; Wei, Mingiie. (2011). Urban Wetland Planning: A Case Study in the Beijing Central Region. Ecological Complexity, 8(2), 213-221. doi:10.1016/j.ecocom.2011.03.002

Keywords: Detention, Flood Control, Urban Drainage, Wetlands, Water Quality, Water Purification

This case study examines the use of urban wetlands from a planning standpoint. A good amount of information about urban wetland loss and the benefits of those wetlands are presented. Several facets of urban wetland are highlighted including water purification and the efficiency of wetlands to purify runoff before it reenters the water column. Spatial distribution and area requirements of urban wetlands needed to effectively make an impact are defined. This is an interesting insight into how much is needed to make a change from not only a water management standpoint but also an ecological and microclimate standpoint. This article also examines cultural impacts of wetlands in urban areas which is especially important from a designer's perspective. I believe the incorporation of wetlands within the urban areas of the wildcat creek watershed will take a large amount of proof and good salesmanship by the planners and designers. Documents such as this that take a multifaceted approach to justifying the use of wetlands and other BMP's will prove to be especially important pieces of evidence.

This source may be limited by the difference in climate between Manhattan and Beijing. However, the unique perspectives presented including cultural impacts may have an especially important impact on designs in the wildcat creek watershed.

Karamouz, Mohammad; Hosseinpour, Ana; Nazif Sara. (2011). Improvement of Urban Drainage System Performance under Climate Change Impact: Case Study. Journal of Hydrologic Engineering, 16(5), 395-412. doi:10.1061/(ASCE) HE. 1943-5584.0000317

Keywords: Climate Change, Urban Drainage Systems, Infrastructure, Water Cycle, anthropogenic factors

This source is a case study examining BMP's in an urban area. The idea is to develop a system for selecting the optimal BMP scheme for an area. The study examines several facets of storm water management. Levels of infiltration in sediment basins, the amount of sediment disposal and construction in stream right of ways are all areas of examination in this reading. The most interesting aspect of this study is the accommodation of climate change in their urban flood studies and the use of an algorithm to accurately estimate water levels and effects. This system is tested on the city of Tehran in Iran. In its final evaluation feasibility assessment of BMP's is created that accounts for cost and several other issues. The study shows there is a correlation between using an analytical system for BMP selection and the overall effectiveness of the system.

This source may be limited by the difference in climate between Manhattan and Tehran. However, the overall objective of using a model to accurately determine which storm water BMP's to use in an urban area is very useful to our work here in the Wildcat Creek watershed.

Kazemi, Fatemi. Beecham, Simon. Gibbs, Joan. (2011). Streetscape Biodiversity and the Role of Bioretention Swales in an Australian Urban Environment. Landscape and Urban Planning, 139-148. 101(2) doi: 10.1016/j.landurbplan.2011.02.006.

Keywords: Bioretention swale; Biodiversity; Water Sensitive Urban Design; Low impact Development; Urban landscape; Green space

This study looks at the potential biodiversity impacts of bioretention swales from the perspective of developing a Water Sensitive Design or Low impact Design. The authors compared nine swales and nine corresponding traditional green spaces (turf grass). They measured Biodiversity through sweep net analysis of invertebrates. Bioretention swales proved to have increased species, species richness, and diversity.

This source could prove to be valuable as a quantitative source of information about the effects of bioswales on an urban area. By showing improvement this source is proof of the added benefits of stormwater BMPs.

Larson, Rebecca A and Safferman, Steven I. Storm Water Best Management Practices that Maximize Aquifer Recharge. Journal of Green Building 3(1) 126-138.

Keywords: Stormwater Management, Pollutant Removal, BMPs, Infiltration, Groundwater recharge, low-impact development, biological uptake

Stormwater infiltration can help to recharge aquifers and increase the available supply of fresh water. This is especially important here in Kansas where the Ogallala aquifer is quickly depleting and the livelihood of many people depend on the regeneration of the aquifer. This source examines the effect that specific storm water BMPs have on aquifer regeneration. The BMPs examined are bioretention areas, grassed swales/ filter strips, infiltration trenches, porous pavement, rain barrels, and wet detention ponds. The authors organize these BMPs into a series of tables that allow for comparative analysis of the BMPs as well as a table for site specific cost comparisons.

This source is a quality tool for our work in the Wildcat Creek watershed. Not only is freshwater availability an important issue in the area but the format if the research increases its viability. By presenting the BMPs in a metric form that compares cost and ecological impact it will be a powerful tool to convince landowners of the benefits of stormwater BMPs.

Mid-America Regional Council and American Public Works Association. (2003). Manual of Best management Practices for Stormwater Quality.

Keywords: Best management practices, Storm-water management

Mid-America Regional Council (MARC) has developed a stormwater management manual to guide in the development of . MARC data is particularly useful to work within the Wildcat Creek watershed due to the regional proximity of Kansas City to Manhattan, Kansas. While the primary goal of the manual is to improve water quality several key ideas are expressed that are relevant to managing stormwater quantity. Key ideas pertinent to reducing runoff levels in Manhattan will be summarized below.

Key Ideas/Points:

-(pg11) Site infiltration can be maintained by preserving existing pervious surfaces (Open space, vegetation, native species are primary targets). While most of the areas of Manhattan affected by my project will be disturbed sites, areas that are slated for future development will benefit from preservation strategies such as this.

-(pg12) Structural BMPs such as infiltration galleries and bioretention areas help to slow runoff and promote runoff. These strategies will help to remove stormwater from Manhattan's traditional storm sewer system and allow for more natural infiltration as well as an increase in lag times. Reduction in runoff amounts and increased lag times will reduce a storm events potential to cause flooding in urban areas and downstream.

-(pg13) MARC introduces the idea of a treatment train approach to BMP placement. By using several BMPs in succession the amount of stormwater that is infiltrated can be increased. This idea can be applied to residential lots by following the idea of treating runoff at the source (impervious surfaces) then capturing remaining runoff in larger collection type BMPs (Rain gardens, infiltration swales, retention areas).

-Hierarchy of stormwater BMPs.

1. Preservation and promotion of natural hydrology
2. Engineered stormwater treatment and Infiltration
    - Engineered swales
    - Sand filters
    - Infiltration trenches
    - Bioretention filters
3. On-site detention and treatment
    - Extended detention ponds
    - Wetland treatment systems
    - Pervious pavement
    - Wet ponds

-Standard of >12% impervious surface requires stormwater BMPs

-Hydrologic Soil Groups (TR-55 method) of post development areas is assumed to be one group higher than pre-development, unless soil treatment plan in provided to document otherwise. This is highly relevant to Manhattan where a majority of areas within the Wildcat Creek boundaries are in the post development phase.

Conclusion:

The MARC stormwater BMP manual is an informative resource to assist in the implementation of stormwater BMPs, specifically in the Midwest. As a document focused specifically on the Midwest the MARC manual provides region specific information and data that pertains to the Wildcat Creek and Manhattan, Kansas. The MARC manual will be a valuable resource for developing BMP strategies for type of residential development found in the Wildcat Creek watershed of Manhattan.

Park, Daeryong. Loftis, Jim C. and Roesner, Larry A. (2011). Performance Modeling of Storm Water Best Management Practices with Uncertainty Analysis. Journal of Hydrologic Engineering, 332-344. doi: 10.1061/(ASCE)HE.1943-5584.0000323.

Keywords: Storm water; Best management practice; International Stormwater BMP Database; k-C model; Uncertainty analysis; Derived distribution method; Latin hypercube sampling; First-order second-moment

This paper focuses on accounting for the uncertainty found in Best Management Practice performance modeling. By accounting for variables known to differentiate the authors were able to factor uncertainty into the performance calculations. This resulted in a 95% confidence interval on the performance data rendered.

This source may be important to someone focusing on extremely detailed analysis of BMP performance. But requires built BMPs to study thus reducing its value to our group.

Urban Creeks Council. 427 13th Street, Oakland, CA 94612. (510)356-0591

http://www.urbancreeks.org/index.html

Keywords: Urban Creeks, Restoration, Case Studies, Community Involvement

The Urban Creeks Council is a California based non-profit organization specializing in urban stream restoration. They focus on preservation, protection, and restoration of urban creeks and riparian habitats. Though this resource is not a literary source they provide real world experience in our topic area. Their website provides links to all of the projects they have completed as well as resources.

Urban Creeks Council's website provides resources such as annotated references related to projects as well as complete project data (i.e.: maps, legislature, field notes, photos, technical data etc…). This site may prove to be an important source for case study information and technical references to find relevant information related to urban watersheds.

Veith, Tamie L. Wolfe, Mary Leigh. Heatwole, Conrad D. (2003). Optimization Procedure for Cost Effective BMP Placement at a Watershed Scale. Journal of the American Water Resources Association, 1331-1343. 39(6)

Keywords: Best Management Practices, Case Studies, Cost analysis, Non Point Pollutants, Watershed management, Performance Evaluation, Water Pollution

This article looks at how to optimize both the environmental impact as well as economic impact of BMPs in agricultural areas at a watershed scale. By using computer programming to calculate algorithms in combination with ArcView analysis the authors developed a modular system for BMP optimization. ArcView was used to calculate non point source pollutants from agricultural areas. This works in conjunction with the Clean Water Act that works to solve water pollution through implementation of BMPs and cultural alternatives (new farming techniques) to illuminate or reduce non point source pollution (pollution that is carried into watersheds.

Though it uses complex computer programming this source could be useful in working with the agricultural areas within the Wildcat Creek watershed. As with other sources related to the placement of BMPs this source emphasizes the need to understand the variables possible when selecting and placing BMPs in a watershed.

Young, Kevin D. Dymond, Randel L. Kibler, David F. (2011). Development of an Improved Approach for Selecting Storm-Water Best Management Practices. Journal of Water Resources Planning and management, 92(6), 268-275. doi:10.1016/(ASCE)WR.1943-5452.0000110.

Keywords: Best management practices, Storm-water management, Algorithms, Geographic information system, Hydrologic modeling.

This paper focuses on ways to select BMPs for stormwater mitigation though mathematical analysis. Several strategies are used to guide the selection process.

1. Evaluation of the most common factors influencing the selection of urban BMPs;
2. Development of a GIS to depict physical site characteristics influencing BMP selection;
3. Development and automation of the AHP decision support algorithm;
4. Application of the AHP algorithm to a demonstration site; and
5. Modeling of various runoff management strategies on the demonstration site.

The AHP algorithm noted in the paper is the summation of a research project done by the US Environmental Protection Agency. It is used to evaluate and rank BMPs based on a wide range of criteria. The end product of this paper is the development of selection criteria based on computer data and analysis of site factors.

This source could be useful in determining BMPs for use in the Wildcat Creek watershed. By borrowing methodology identified in this paper we can provide analytical backing for decisions related to BMPs.

WARSSS

Watershed Analysis

Wildcat Creek watershed (approx. 99 square miles) in Riley County, Kansas had significant flooding in recent years. A watershed assessment of river stability and sediment supply (WARSSS, Rosgen, 2006) of Wildcat Creek was performed to determine locations that are contributing to the flooding. WARSSS is split into three levels: reconnaissance level assessment (RLA), rapid resource inventory for sediment and stability consequence (RRISSC), and prediction level assessment (PLA). The evaluation completed for Wildcat Creek focuses on the RLA and RRISSC level scale and criteria. The RLA level focuses on creating sections by similar land use and land cover to get an overall understanding of the watershed. The RRISSC level divides the watershed into 19 sub-watersheds and takes a more detailed approach to the assessment. The WARSSS assessment is typically done on smaller watershed scale, but was adapted to fit the entire Wildcat Creek watershed.

The assessment provided the foundation for master's reports. The reports focused on potential solutions to the flooding and improving Wildcat Creek watershed.

The following Link can be used to View the Watershed Assessment of River Stability and Sediment Supply (WARSSS) analysis performed by the Wildcat Creek watershed group.

https://krex.k-state.edu/dspace/handle/2097/13605