# A green infrastructure retrofit for the upper campus creek watershed parking lots

by

Victor Sobotka

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF LANDSCAPE ARCHITECTURE

Department of Landscape Architecture and Regional Community Planning
College of Architecture, Planning, and Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2022

Approved by:

Major Professor
Jessica Canfield

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## Abstract

Flash flooding and poor water quality are significant issues for Campus Creek. Studies have shown that green infrastructure can mitigate certain stormwater runoff related issues like flooding and poor water quality, but there are opportunities to further explore how retrofitting parking lots on campus with green infrastructure can make a difference. Thus, this project explores how the northwestern parking lots of the Campus Creek Watershed can be retrofitted with green infrastructure to help reduce stormwater runoff quantity, peak rate, and pollutant load.

The study area was selected because it is located within the headwaters of the watershed. The specific parking lots of focus include Bill Snyder Stadium, Peter's Recreation Center, and the northern portion of the Jardine Apartment Complex. The opportunities and constraints of each site were studied through site analysis.

The proposed green infrastructure solutions included bioretention, rainwater harvesting mechanisms, tree canopy, and permeable pavement. The solutions were designed in areas where they could have the most beneficial impact on stormwater management.

Once the design of the green infrastructure solutions was complete, additional modeling was conducted to determine their effectiveness. This project found that the proposed green infrastructure measures, together, can decrease annual runoff quantity by 54.5%, annual pollutant load by 84.7%, and the peak rate of runoff by 81% for a 5-Year Storm (3 hour duration), 10-Year Storm (2 hour duration), 25-Year Storm (90 minute duration), 50-Year Storm (1 hour duration), and 100-Year Storm (30 minute duration).

Victor Sobotka

2022


# A Green Infrastructure Retrofit for the Upper Campus Creek Watershed Parking Lots

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Major Professor:
Jessica Canfield, PLA, ASLA

Supervisory Committee:
Lee Skabelund, PLA, ASLA
Trisha Moore, Ph.D.

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These findings show the potential effectiveness of retrofitting campus parking lots with green infrastructure. Although green infrastructure was proven effective, future research should continue to focus on cost effectiveness, long-term maintenance, and overall viability of implementing green infrastructure across the Kansas State University campus.

# Acknowledgements

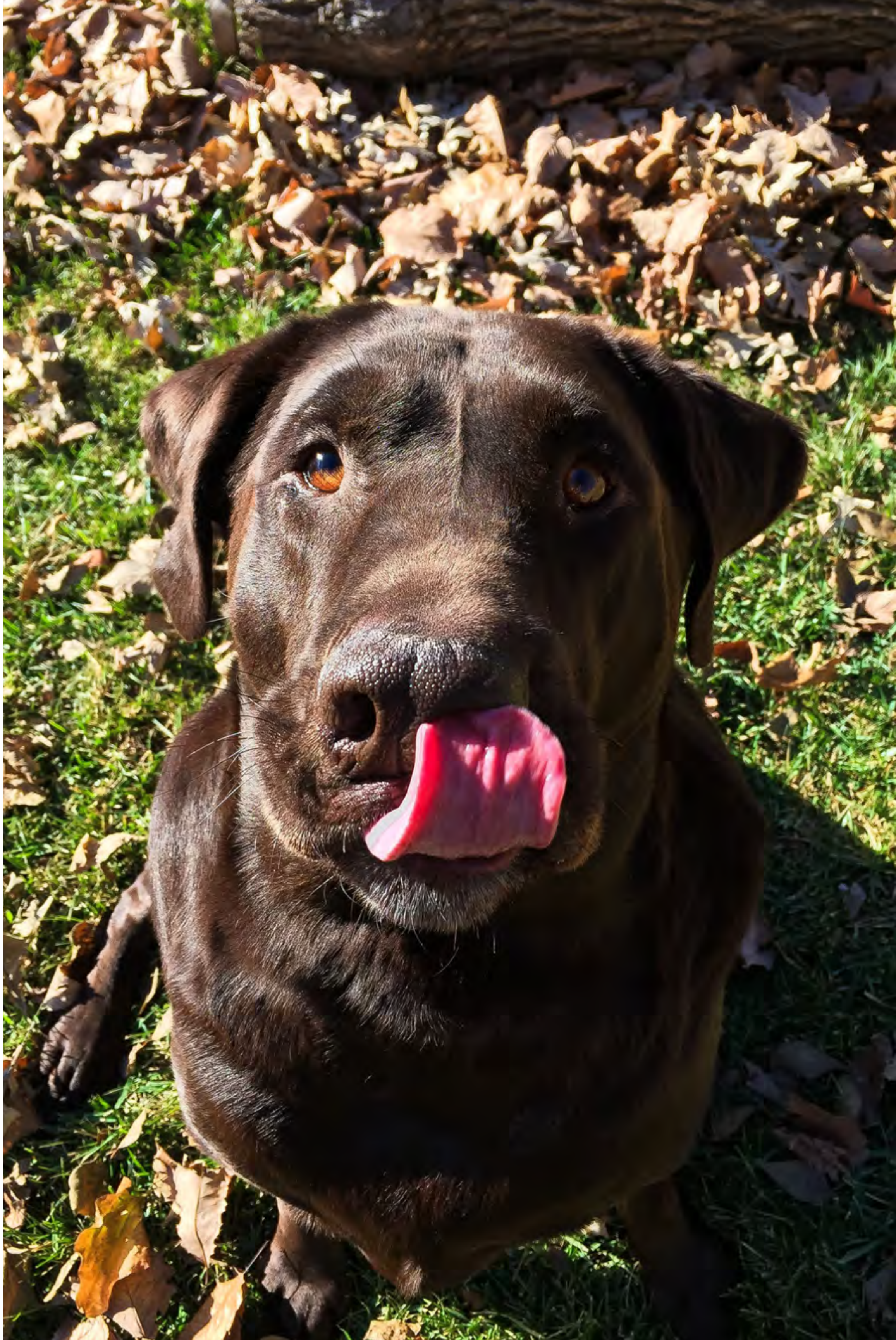
I would love to thank my entire family for their constant support. This project, let alone my entire college career, would not have been achievable up to this point without my mother, father, brother, and all of my aunts, uncles, and cousins endlessly supporting my every move. My future beyond this project will be spent giving back to all of you for believing in me, even when everything was stacked against us.

I also need to recognize the invaluable assistance given to me by the LARCP faculty. Regards to Jessica Canfield for her patience and endless genius that ensured the completion of this project. Deepest thanks to Blake Belanger, Anne Beamish, Katie Kingery-Page, Jon Hunt, Lee Skabelund, Kirby Barrett, Howard Hahn, Frank Hammond, Hyung Jin Kim, La Barbara Wigfall, Stephanie Rolley, Trisha Moore and last but never least Tim Keane for securing my confidence and reminding me of the value of patience.

## Dedicated to...

Mick. The goodest boy.

Mick and Vic forever.



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## Introduction

Figure 1.1. Campus Creek Watershed

# Introduction

The 400-acre Campus Creek Watershed lies within Kansas State University Campus in Manhattan, Kansas (see Figure 1). The watershed is approximately 49% impervious surface. Due to the watershed being heavily urbanized, there is little flood storage capacity. After storm events, untreated runoff flows quickly into the Campus Creek stream channel. This leads to bank erosion and water quality issues along with localized flooding (Albracht et al. 2014).

**A** Stormwater runoff from the northwest portion of the watershed is a major contributor to the channel's flow (see Figure 1.3). This area includes the Peter's Recreation Center, the East Bill Snyder Stadium parking lot, and almost all of the Jardine Apartment Complex. The East Stadium parking lot is the largest parking lot at Kansas State with an area of approximately 16 acres, 7.1 acres of which is within the Campus Creek Watershed. Jardine contains 8 major parking lots with streets that double as parking. The Peter's Recreation Center contains two parking lots, one on the north side and another on the south. Edward's Hall is also surrounded by parking. All of the previously stated areas combine their runoff into a series of storm sewers that meet and create Campus Creek.

**B** The Campus Creek channel originates south of the Veterinary Medicine building where all runoff from the northwestern portion of the watershed converges. Secondary branch channels are located east of the Vet-Med building. They are lined with concrete and have bridges for circulation overtop. All of the channels converge where the creek flows into an underground culvert at Jardine Avenue.

**C** After daylighting south of Claflin Road, the creek flows in an open air channel, lined with vegetation along its banks. This area of the watershed is more aesthetically pleasing than other portions of the creek. The creek progresses southwest before entering a storm drain at North Manhattan Avenue.



Figure 1.2. Campus Creek Watershed.

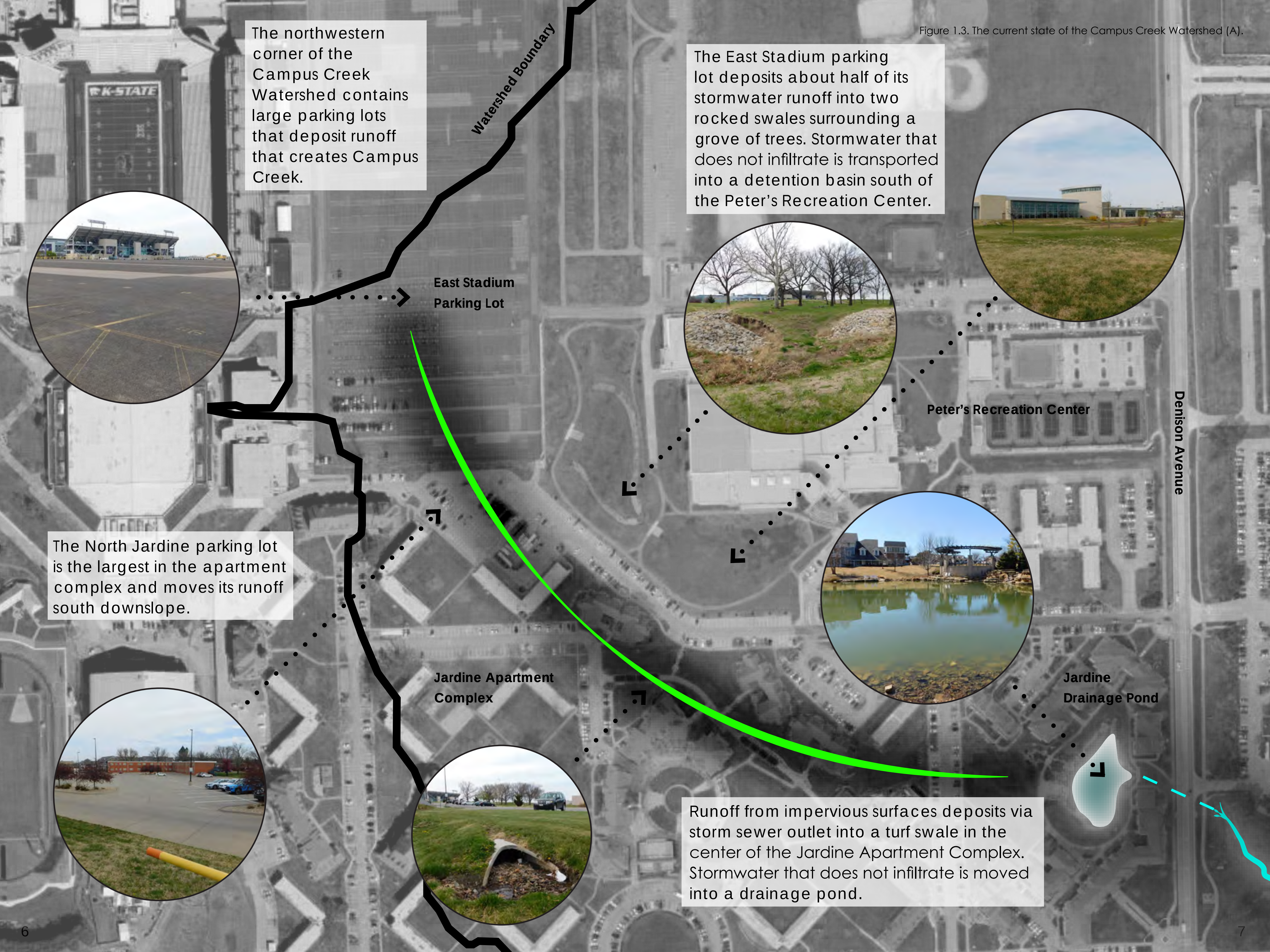



Figure 1.3. The current state of the Campus Creek Watershed (A).

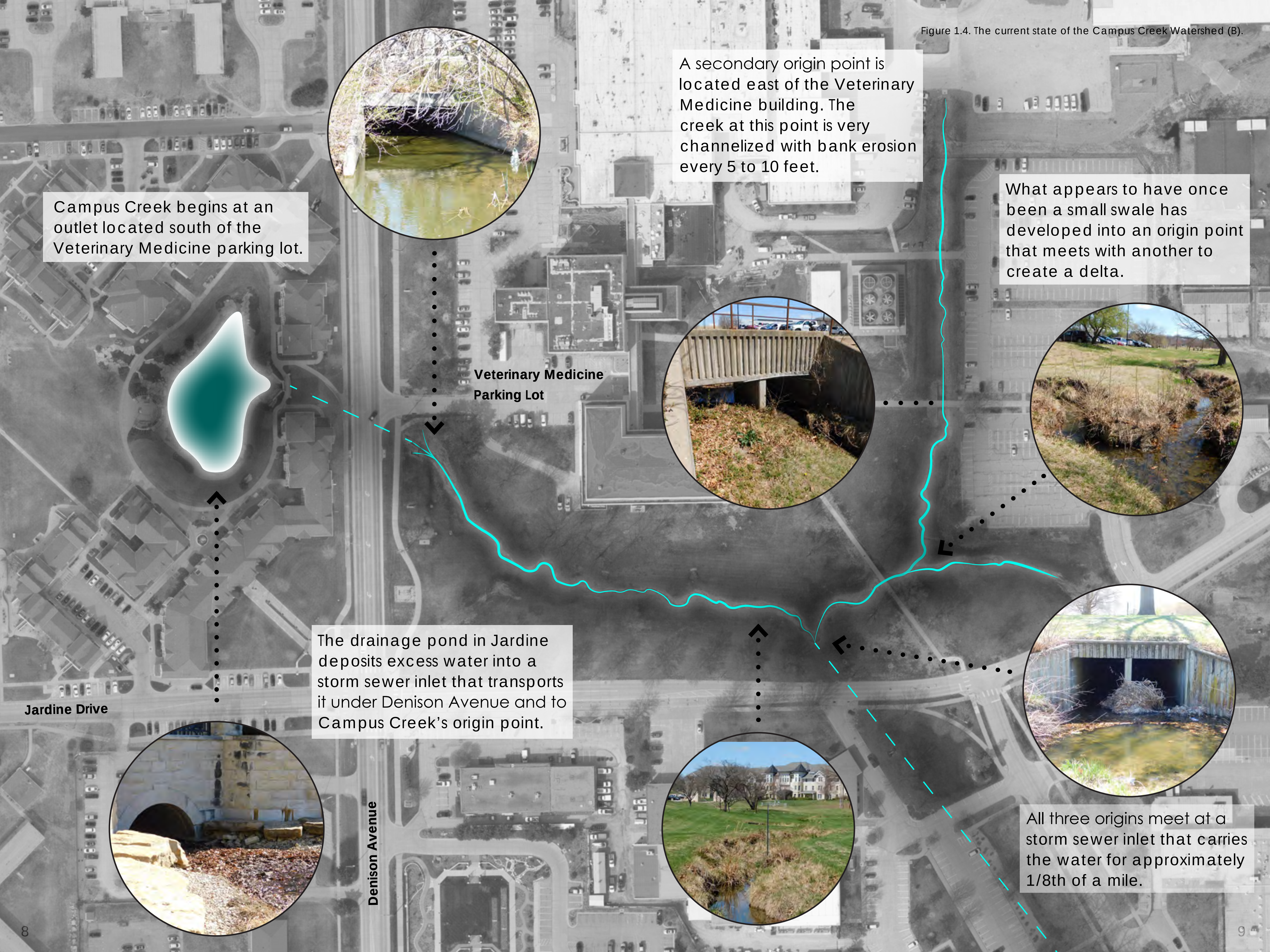



Figure 1.4. The current state of the Campus Creek Watershed (B).


Figure 1.5. The current state of the Campus Creek Watershed (C).

## Main Dilemmas

According to the US Environmental Protection Agency (EPA), stormwater runoff is a major cause of water pollution and flood related issues in urban areas. Runoff can carry trash, bacteria, metals, and other harmful pollutants through storm drains into local waterbodies like Campus Creek. Rainstorms can cause severe flooding that leads to property damage, risk of injury, and increased erosion within the channel (US EPA 2022). As depicted in Figures 1.3 through 1.5, the main issues impacting Campus Creek are:

- Poor Water Quality
- Littering
- Bank Erosion
- Flooding
- High Ratio of Impervious Surface
- Channelization

Issues of poor water quality, erosion, and flooding can be reduced through the use of green infrastructure. Green infrastructure includes a range of solutions that use plant or soil systems, permeable pavement, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or surface waters (EPA 2022).

Given that Campus Creek originates from stormwater runoff from imperviou surfaces, there is an opportunity and need to implement green infrastructure in the watershed headwaters. By retrofitting with green infrastructure solutions, infiltration and filtration can occur before runoff ever reaches the creek.

Therefore, this project will propose green infrastructure solutions to address stormwater runoff from the impervious focus areas defined in Figure 1.6.

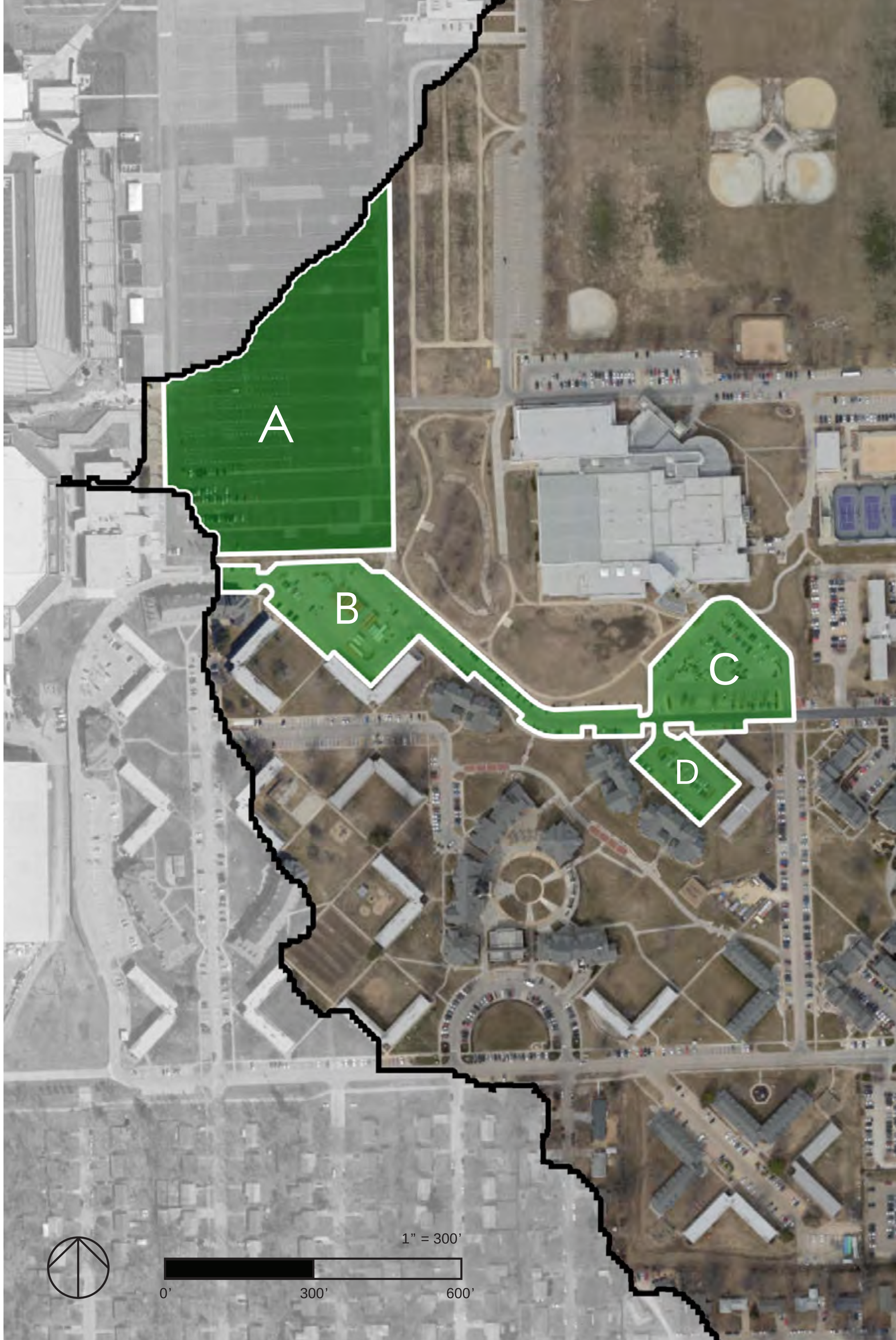



Figure 1.6. Project Focus Areas.

| | |
|---|---|
| A | East Stadium Parking Lot |
| B | North Jardine Parking Lot |
| C | South Recreation Parking Lot |
| D | Mid-Jardine Parking Lot |

# Focus Area Rationale

The northwestern portion of the watershed was chosen as a focus area because of its amount of impervious surfaces, and a series of opportunities it has for retrofitting with green infrastructure.

Approximately half of the East Stadium parking lot is located within the Campus Creek Watershed boundaries, as depicted in Figure 1.6. On-site observations confirmed a clear drainage path from the East Stadium parking lot downslope to a grove of trees, two rock swales, and a detention basin south of the Peter's Recreation Center. Therefore, there is an opportunity to closely analyze the East Stadium parking lot and propose green infrastructure solutions that are suitable for the area.

There is a clear drainage path through Jardine's turfgrass landscape. On-site observations confirmed locations of storm sewer inlets and outlets that take water from the parking lots and deposit it into some of these turfgrass areas. Therefore, there is an opportunity to analyze the landscape and propose green infrastructure solutions that are suitable for the area.

The general Jardine area contains almost 300 trees, but the parking lots are barren of canopy cover, so there is an additional opportunity to increase the amount of trees within the focus areas.

Figure 1.7. Depressed drainage area in Central Jardine.

Figure 1.8. Flowering crabapple trees within a Jardine parking lot.

Figure 1.9. Bioswales and trees that take on drainage from the East Stadium parking lot

Figure 1.10. Detention basin south of the Peter's Recreation Center that takes on drainage from the East Stadium parking lot.

The following research questions are addressed...

## How can the northwestern parking lots of the Campus Creek Watershed be retrofitted with green infrastructure to help reduce stormwater runoff quantity, peak rate, and pollutant load?

- How much stormwater runoff is produced by the focus areas?
- How much stormwater is being intercepted by the trees in the focus areas?
  - Can this number be improved?
- Is green infrastructure currently being utilized to reduce runoff from the university parking lots? If so, where?
- How much of the existing tree canopy in the focus areas overhangs impervious surfaces?
- How many years will it take newly planted trees to achieve a canopy that to some degree covers adjacent parking lot impervious surface?
- What types of green infrastructure can address the stormwater management needs of the focus areas?
  - Where can they be implemented effectively?
- What environmental services are being provided by parking lot trees?
  - Can more trees be planted within the focus areas? If so, where?
  - What effect will newly planted trees have?

This project uses a **Mixed Method** approach to inform the development of a **Projective Design**



# Project Goals

A **Learn about the process of retrofitting an impervious area with green infrastructure.**

B **Determine which types of green infrastructure are suitable for a retrofit in the chosen parking lots.**

C **Demonstrate how green infrastructure can reduce stormwater runoff from parking lots.**

D **Demonstrate how trees can reduce stormwater runoff from parking lots.**

# Chapter 2

## Background

Figure 2.1. Tree located on the north courtyard of Seaton Hall at Kansas State University.

To understand green infrastructure, the following themes were also researched to understand stormwater management overall. Themes include gray infrastructure, green infrastructure, and the process of retrofitting.

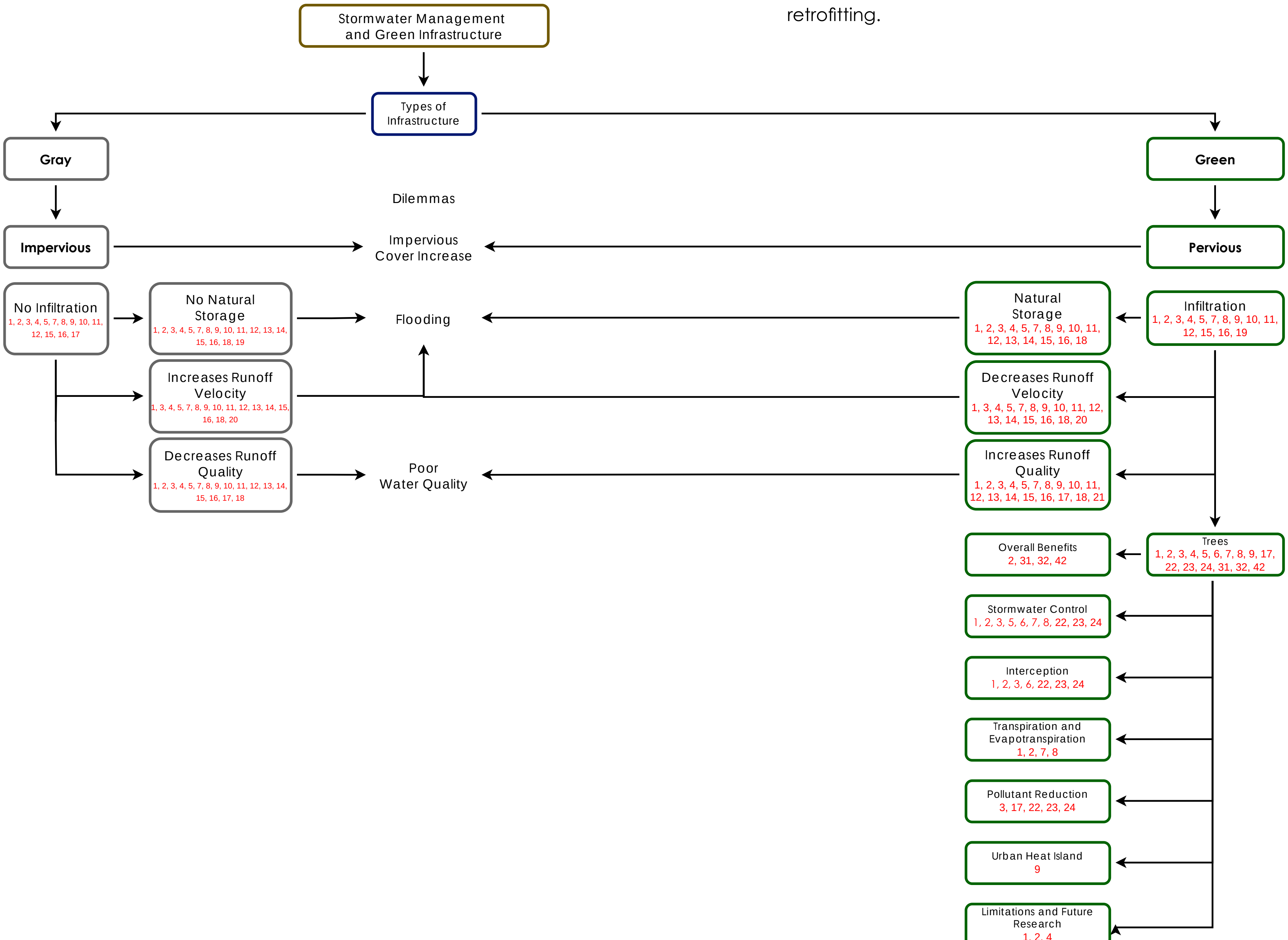



Figure 2.2. Primary Literature Map.

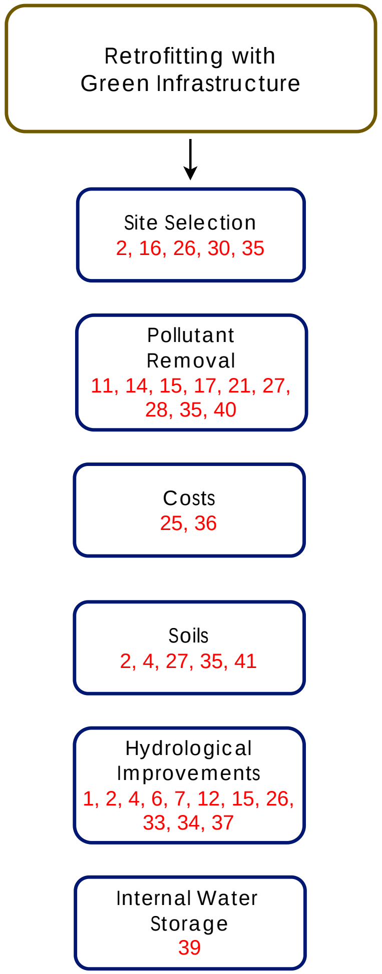



Figure 2.3. Discussion Literature Map.

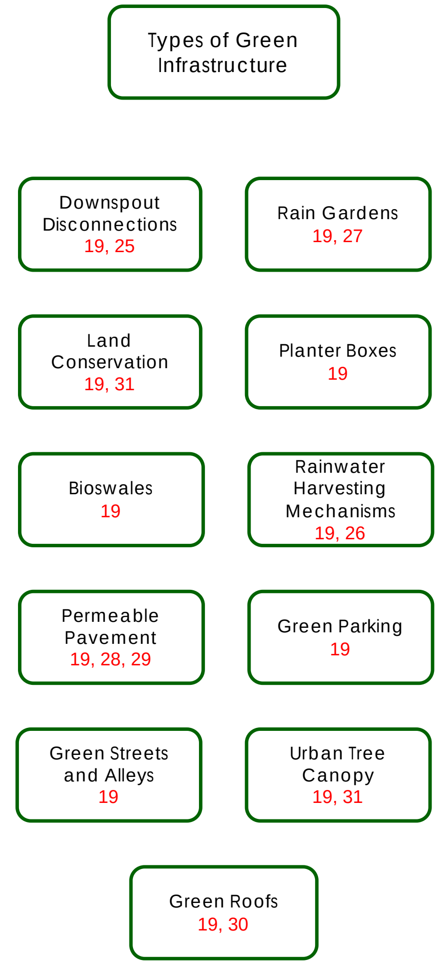



Figure 2.3. Green Infrastructure Literature Map.

## 2.1 Gray Infrastructure

Gray infrastructure is a term used to describe buried pipes, dams, seawalls, roads, and water treatment plants and storm sewers (Berland et al. 2017). For hundreds of years, gray infrastructure was considered the best way to manage stormwater in the United States (Benedict and McMahon 2006). Infrastructure designed to manage stormwater and waste began to be implemented in the mid-to-late 1800s. The early systems consisted of mostly canals, but by the mid-1900s they evolved into sewers designed in conjunction with sewage or wastewater treatment. There are two categories of gray infrastructure: combined and separate. Combined gray infrastructure carries wastewater from residential, commercial, and industrial sources in the same conveyance structure or pipe. Because of this, they can overflow during floods due to limited storage capacity. Separate gray infrastructure can be found in urban/renewed areas and carries stormwater and sewage in two separate structures. Unfortunately, in most cases, untreated stormwater flows into downstream waterbodies (Berland et al. 2017), thus increasing pollutant loads to surface waters (Berland et al. 2017, Szota et al. 2018, Johnson et al. 2021, Lefevre et al. 2014, Liu et al. 2014).

Gray infrastructure, as noted, is impervious which means stormwater runoff cannot infiltrate into the soil. This leads to **increased velocity of runoff** (Dagenais et al. 2018, Beidokhti and Moore 2021, Hynicka and Caraco 2017, Szota et al. 2019) and **increased pollutant loads** into local water supplies (Dagenais et al. 2018, Beidokhti and Moore 2021, Szota et al. 2019). Flooding is a result of increased runoff velocity (Dagenais et al. 2018, Szota et al. 2019). Increased pollutant load is a result of a lack of filtration (Berland et al. 2017, Dagenais et al. 2018, Szota et al. 2019, LeFevre et al. 2014). Pollutants that can contaminate runoff via gray infrastructure include toxic metals, nutrients, suspended solids, pathogens, pesticides, and petroleum hydrocarbons (Dagenais et al. 2018, LeFevre et al. 2014).

In the late 1980s and 1990s, more natural approaches to stormwater management began to be developed (Benedict and McMahon 2006, Berland et al. 2017). Gray infrastructure improvements and maintenance are very expensive and often not effective at reducing runoff in the long run, while also limiting the degree of hydrological losses (infiltration, transpiration, exfiltration, filtration, etc.) that occur in non-urban landscapes (Berland et al. 2017). Hence, the need for a more natural approach, green infrastructure. **Low Impact Development (LID)**, also known as sustainable urban drainage, is a land planning and engineering design approach that implements small-scale hydrologic controls with integrated pollutant treatment (using plants and soils) to compensate for land development impacts on hydrology and water quality (US EPA 2015).

Green infrastructure is a form of LID and is an interconnected network of natural areas and other open spaces that conserve natural ecosystem values and functions, sustain clean air, and water, and provide a wide array of benefits to people and wildlife (Benedict and McMahon 2006). Taking a green infrastructure approach facilitates conservation activities and adds value to a project's results.

Figure 2.4. Gray Infrastructure at the North Jardine Parking Lot at Kansas State University.

## 2.2 Green Infrastructure

Green infrastructure can be implemented in numerous ways to fit the context of a site within its urban and ecoregional setting. If an area is anticipating growth, a green infrastructure plan should be put together to pre-identify lands for conservation, restoration (Benedict and McMahon 2006), retrofitting, or enhancement (McFarland et al. 2019, Thiagarajan et al. 2018). It is important to note that green infrastructure will never completely replace gray infrastructure in urban settings as some stormwater pipes will likely be needed to safely remove and convey heavy rainfall and runoff away from impervious areas. Urban areas can be retrofitted with green infrastructure to decrease the risk of stormwater overflow within existing gray infrastructure (Berland et al. 2017, Thiagarajan et al. 2018).

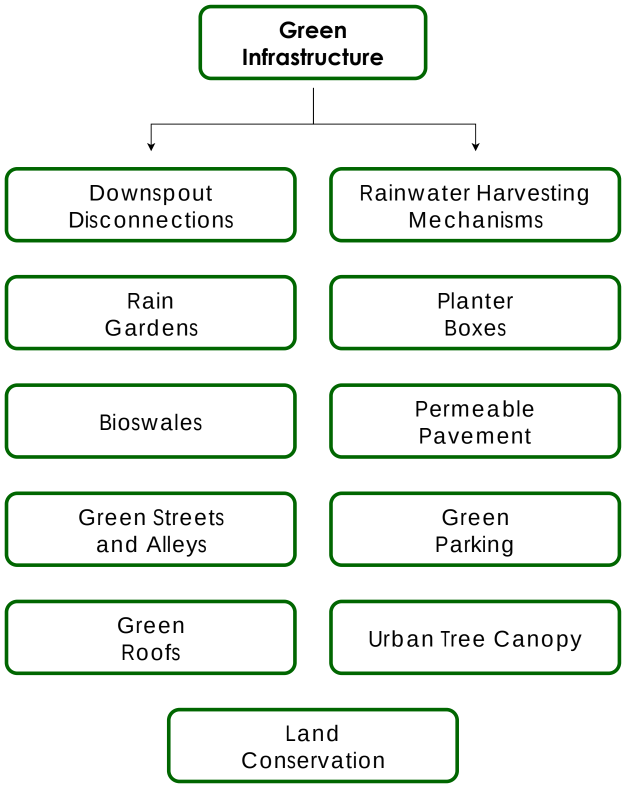



Figure 2.5. Types of Green Infrastructure.
Source: US EPA 2015



Green infrastructure can be in the form of:

- Downspout Disconnections
    - Rooftop drainage pipes that move rainwater into rain barrels, cisterns, or permeable areas (Foster et al. 2011, US EPA 2015).
- Rainwater Harvesting Mechanisms
    - Rain barrels, commercial building cisterns, ground level pits, and subsurface storage in existing and/or mediated soils and geologic formations meant to slow down runoff and collect rainwater for future use (Garcia-Cuerva et al. 2018, US EPA 2015).
- Rain Gardens
    - Small, shallow, depressed areas of plantings that collect stormwater runoff from roofs, streets, and sidewalks. These features may also be called bioretention cells (a term that typically implies that the feature is created using engineered or mediated soils). Designed to copy the natural ways water flows and absorb water into the land to reduce pollution (Sharma and Malaviya 2021, US EPA 2015).
- Planter Boxes
    - Urban rain gardens with vertical walls that can be open or closed at the bottom. Typically found in downtown areas to collect and absorb runoff from rooftops, streets, sidewalks, and parking lots. Highly suitable for areas with limited space (US EPA 2015).
- Bioswales
    - Found along curbs and in parking lots. Use vegetation, rock, or mulch to slow down and filter stormwater (US EPA 2015).
- Permeable Pavements
    - Permeable pavement allows rain to infiltrate and be stored and treated where it falls. They can be made of pervious concrete, porous asphalt, or permeable interlocking pavers. Considered to be cost effective if land value is high and flooding/icing is an issue (Abdollahian et al. 2018, Sansalone, Kuang, and Ranieri 2008, US EPA 2015).
- Green Streets and Alleys
    - Green streets and alleys integrate green infrastructure elements into their design to store and filter stormwater. Can be in the forms of permeable pavements, bioswales, planter boxes, and trees (US EPA 2015).
- Green Parking
    - Permeable pavements can be installed in certain sections of parking lots to complement nearby trees, rain gardens or bioswales along medians or around the perimeter of a parking lot (US EPA 2015).

- Green Roofs
    - Green roofs are covered with growing media and vegetation to enable rainfall infiltration and evapotranspiration of stored water. They can be cost effective in dense urban areas if land values are high and within large industrial/office buildings where stormwater management expenses are high (Skabelund and Brokesh 2013, US EPA 2015).
- Urban Tree Canopy and Associated Soil Systems
    - Trees absorb stormwater in leaves, branches, and roots. The larger a network of trees and soils is, the larger the impact (US EPA 2015, Cappiella, Wright, and Schueler 2005).
- Land Conservation
    - Water quality and flooding can be addressed by protecting natural, open spaces. The conserved land can also provide recreational opportunities for city residents located adjacent to the land in question. Natural areas that should be conserved include riparian areas, wetlands, woodlands, grasslands, and steep hillsides (US EPA 2015, Cappiella, Wright, and Schueler 2005).

All of the different forms of green infrastructure have similar traits, including the slowing, filtering, and absorbing of stormwater where it falls (US EPA 2015). During rain events, as noted, stormwater runoff is produced by impervious surfaces and is sloped towards an inlet that guides water to another location (Asadian and Weiler 2009). Potential destinations include water treatment facilities, streams, rivers, ponds, etc. Stormwater runoff, if directed into a green infrastructure, will infiltrate into the ground before entering an inlet to another destination (Berland et al. 2017, Thom et al. 2020). It's important to note that only tree canopy, land conservation, permeable pavement, rain gardens, and bioswales increase infiltration.

During infiltration, other hydrological processes can take place like evapotranspiration, deep percolation (filtering), recharge, and redistribution. Infiltration stores water temporarily, thus, slowing down runoff and delaying its travel to the next destination (Berland et al. 2017, Szota et al. 2019, Liu et al. 2014), which can prevent flooding by decreasing the peak discharge of the destination in question (Liu et al. 2014, Thom et al. 2020, Vijayaraghavan et al. 2021). Peak discharge represents the peak rate of runoff and is typically referred to in cubic feet per second (Weaver 2003).



Using bioretention drastically increases the runoff time of concentration. For example, a 44,000 square foot parking lot was found to generate approximately 16 times more runoff than a meadow of the same size. The total time of concentration, depending on the rain event, is between 5 and 10 minutes. The addition of a bioretention facility in front of the drainage outlet will increase the time of concentration from 15 minutes to several hours depending on the size, duration, and intensity of the storm event(s), therefore, slowing down surface runoff and reducing flood risk (Liu et al. 2014).

Transpiration is the movement of water along the soil-plant interface as soil water is taken up by the plants and lost through leaf surfaces to the atmosphere (Berland et al. 2017, Carlyle-Moses and Gash 2011). While runoff is stored, it can be utilized by the plant material. The runoff undergoes a process called evapotranspiration; the evaporation (process of liquid turning into gas) of water from plants (Berland et al. 2017, Hynicka and Caraco 2017). As a result, evapotranspiration allows more infiltrated water to be stored in substrates the next time it rains, further decreasing: (1) flood risk (Hynicka and Caraco 2017), (2) total water disseminated to the surrounding soil/underdrain, (3) pollutant load (Berland et al. 2017), and (4) urban heat island effects via evaporative cooling (Johnson et al. 2021, Berland et al. 2017).

Figure 2.6. Green Infrastructure at the engineering building at Kansas State University.

## 2.3 Trees as Green Infrastructure

As noted, impervious surfaces on the built landscape reduce the number of hydrological losses (infiltration, transpiration, etc.). Green infrastructure can leverage the properties of soil and vegetation to enhance detention capacity (Xiao and McPherson 2016), thus, managing stormwater volume (Berland et al. 2017, Vijayaraghavan 2021, Szota et al. 2019). Trees are excellent candidates for increasing the losses from the urban hydrological cycle because they can provide dense vegetation within a small footprint. Their root systems can also capture and pump lots of water through the tree, with some of it returning to the atmosphere. Therefore, there is a need to direct more attention to understanding the role of urban trees as stormwater control measures (Berland et al. 2017).

Rainfall partitioning processes are the most studied processes of urban tree canopies in regulating stormwater runoff and include throughfall, interception, and stemflow. Throughfall is the amount of rainfall that reaches the ground through the canopy (Beidokhti and Moore 2021). Interception is the amount of rainfall remaining on the canopy surfaces and is evaporated later on (Berland et al. 2017, Beidokhti and Moore 2021). Stemflow is the precipitation that is delivered to the base of the tree along the trunk (Beidokhti and Moore 2021). Individual tree species contain different amounts of precipitation partitioning and identifying those differences is still an area for future study (Berland et al. 2017, Beidokhti and Moore 2021 Xiao and McPherson 2002). However, Beidokhti and Moore (2021), created a series of regression models to represent the tree types instead of their individual species. Trees are categorized by leaf type: Deciduous-Leafless, Deciduous-Leafed, Evergreen-Broadleaf, and Evergreen-Needleleaf. Trees are also categorized by smooth bark and rough bark.

Because of their size in comparison to other plants, trees can also exhibit much higher degrees of transpiration and evapotranspiration, especially if they are established. Recent studies have shown that established urban trees that were retrofitted with infiltration trenches transpired 17% of total annual stormwater runoff generated (Thom et al. 2020). Another study found that the best performing system can retain 43.7% of runoff as long as nearby inlets remain unblocked by sediment/debris and suggests that younger trees surrounded by impervious surfaces or growing in dry climates can benefit more from stormwater infiltration interventions (Szota et al. 2019).

Forms of green infrastructure outside of trees can be integrated to further complement one another. Trees can enhance the capacity of bioretention by regulating the soil moisture content (Berland et al. 2017, Szota et al. 2019). Trees can also improve water quality and have been found to reduce nutrient concentrations in runoff (Berland et al. 2017).

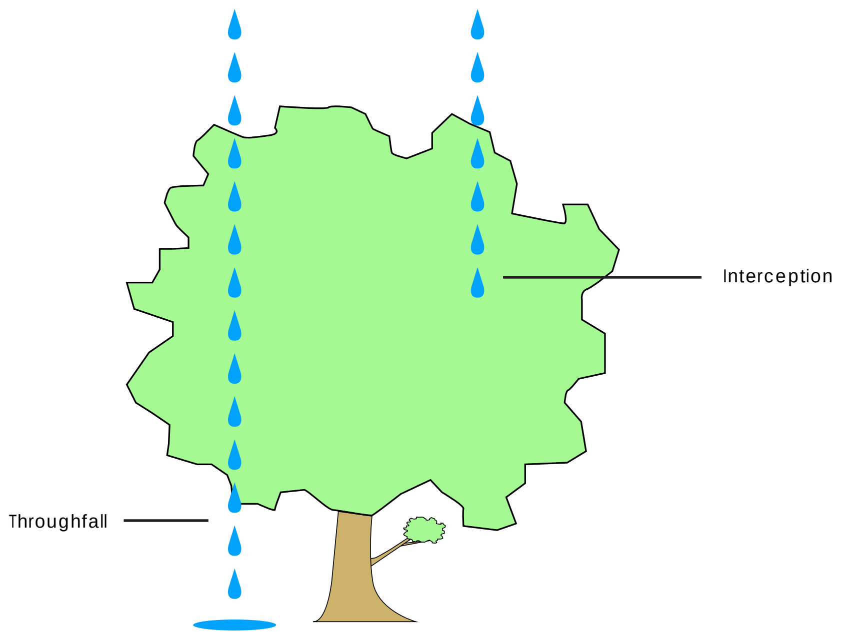



Figure 2.7. Rainfall interception and throughfall of trees.

## 2.4 Retrofitting with Green Infrastructure

### Site Selection

As noted, green infrastructure can support existing gray infrastructure, but it is important to observe the cultural and physical environment to determine the suitability of certain interventions (Benedict and McMahon 2006, McFarland et al. 2019). Garcia-Cuerva et al. (2018) selected locations for green infrastructure located within socioeconomically underprivileged or marginalized communities that also had the potential for outreach. Outreach meaning the proposed green infrastructure was in close proximity to areas of high foot traffic, therefore, the public had the opportunity to become more familiar with green infrastructure. Kansas State University contains several green infrastructure solutions within campus that are accompanied by informative signage that enhances the quality of the landscape as it attracts passersby who are unfamiliar with green infrastructure and its benefits.

Cultural properties can identify general areas, while physical properties identify more specific sites. There are three main hydrological zones within small watersheds. The contributing zone is located in the upper watershed, ahead of the point of origin of a waterbody and contributes three types of stormwater runoff: (1) overland flow, (2) interflow (water moving laterally through soil), and (3) groundwater. The contributing zone is where stormwater capture and retention are most desirable to prevent flooding in the lower watershed (Marsh 2010, McFarland et al. 2019).

The collection zone is where flood issues are greater due to groundwater saturation and pooling. Small scale stormwater management is good for the collection zone to improve water quality and decrease runoff quantity. The conveyance zone is the lowest section of the watershed and runoff is at the lowest quality and highest volume, therefore, green infrastructure installation is difficult due to runoff speed and high-water tables (Marsh 2010, McFarland et al. 2019).

### Pollutant Removal

The process of pollutant removal is far more complex. Dissolved pollutants are more available now than in the past due to widespread air pollution and contamination of urban surfaces (Novotny 1995), therefore, impacting receiving water bodies quicker (LeFevre et al. 2015). Common pollutants include copper, petroleum hydrocarbons, phosphorus (P), zinc, nickel, nonylphenols, and low molecular weight PAHs (McFarland 2019, LeFevre et al. 2015). The most common of particles found is phosphorus and the dissolved fraction of phosphorus in stormwater can reach 90% in some cases (LeFevre et al. 2015, Marvin et al. 2020). Pollutants are captured via settling and filtration in most stormwater treatment practices. In typical bioretention designs, removal of dissolved nutrients will happen through a combination of adsorption, precipitation, ion exchange, and biological processes (LeFevre et al. 2015, Sharma and Malaviya 2020). Phosphorus (P) remains a dominant pollutant because many media that contains organic matter and a high P index can become a source of P instead of a filter for P (LeFevre et al. 2015, Marvin et al. 2020).

According to McFarland et al. (2019), when a combined sewer overflow (CSO) occurs, untreated human and industrial waste discharges into receiving waters, therefore, exposing the public and local wildlife to pollution and health hazards. Green infrastructure's ability to treat stormwater before entering sewers can prevent pollution related issues from occurring. See Table 2.1 for descriptions of primary pollutants in stormwater runoff. See Table 2.2 for the pollutant removal processes occurring within different types of green infrastructure.

| Contaminant | Description | Sources |
|---|---|---|
| Pathogens | Disease-causing microorganisms that cause public health concerns | Fecal matter and wastewater from agriculture |
| Natural Organic Matter | Organisms (plant and animal) and their associated waste. Cause dissolved oxygen in water to decrease | Food waste, decaying animal/plant matter, and fecal matter |
| Synthetic Organic Chemicals | Chemicals for human use that is usually toxic and persistent in soil and water environments | Car byproducts (oil, fuel, exhaust) |
| Nutrients | Nitrogen and phosphorus used for agriculture. Causes eutrophication (nutrient build up) and algal blooms. | Fertilizer, manure, pet waste, soil erosion, leaf/lawn litter |
| Heavy Metals | Common pollutant from residential, industrial, and commercial use. Can heavily impact aquatic life. | Tire wear, metallic road structures, traffic signs |
| Sediments | Smaller solids that impact aquatic life by reducing light penetration in water bodies. Can also fill in voids for small-life habitat. | All types of land use |
| Pharmaceuticals and personal care products (PPCPs) | Products used to improve human quality of life. | Pharmaceuticals, antibiotic resistant genes, disinfectants |

Table 2.1. Pollutant sources and descriptions.
Adapted from McFarland et al. (2019).

| | Pathogens | Natural Organics | Synthetic Organics | Nutrients | Heavy Metals | Sediment | PPCPs |
|---|---|---|---|---|---|---|---|
| **Detention Basin** | Retention, infiltration | Vegetation, retention, infiltration | Vegetation, Retention | Sparse vegetation | Sparse vegetation, retention, infiltration | Settling | Sparse vegetation, infiltration |
| **Rainwater Harvesting** | Retention | Retention | - | - | Retention | Settling | - |
| **Bioswale** | Infiltration | Vegetation, infiltration | Vegetation | Sparse vegetation | Sparse vegetation, infiltration | Settling | Sparse vegetation, infiltration |
| **Rain Garden** | Infiltration | Vegetation, infiltration | Vegetation | Heavy vegetation | Heavy vegetation, infiltration | Settling and Catchment | Heavy vegetation, infiltration |
| **Green Roof** | Infiltration | Vegetation, infiltration | Vegetation | Heavy vegetation | Heavy vegetation, infiltration | Settling and Catchment | Heavy vegetation, infiltration |
| **Permeable Pavement** | Retention | Retention, infiltration | - | - | Retention, infiltration | Settling and Catchment | Infiltration |

**Highly Effective** **Moderately Effective** **Mildly/Not Effective**

Table 2.2. Pollutant removal processes by green infrastructure. Adapted from McFarland et al. (2019).

Internal Water Storage (IWS) is the subsurface layer of media within bioretention that provides more storage for water. According to A. Brown et al. (2009), creating an IWS layer is inexpensive and simple and requires a 90-degree PVC upturned elbow attached to the underdrain to create an outlet that's elevated (NCDEQ 2018). The depth of the IWS zone is dependent on the permeability of the soil (less permeable, closer to surface; highly permeable, farther from surface), and assuming that the IWS layer is in the appropriate spot, the total nitrogen removal can be increased from 35 to 60 percent and total phosphorous removal can be increased to between 45 and 60 percent (A. Brown et al. 2009). It's important to note that the previously stated pollutant removal estimates reflect the sandhills and coastal plains of the eastern United States.

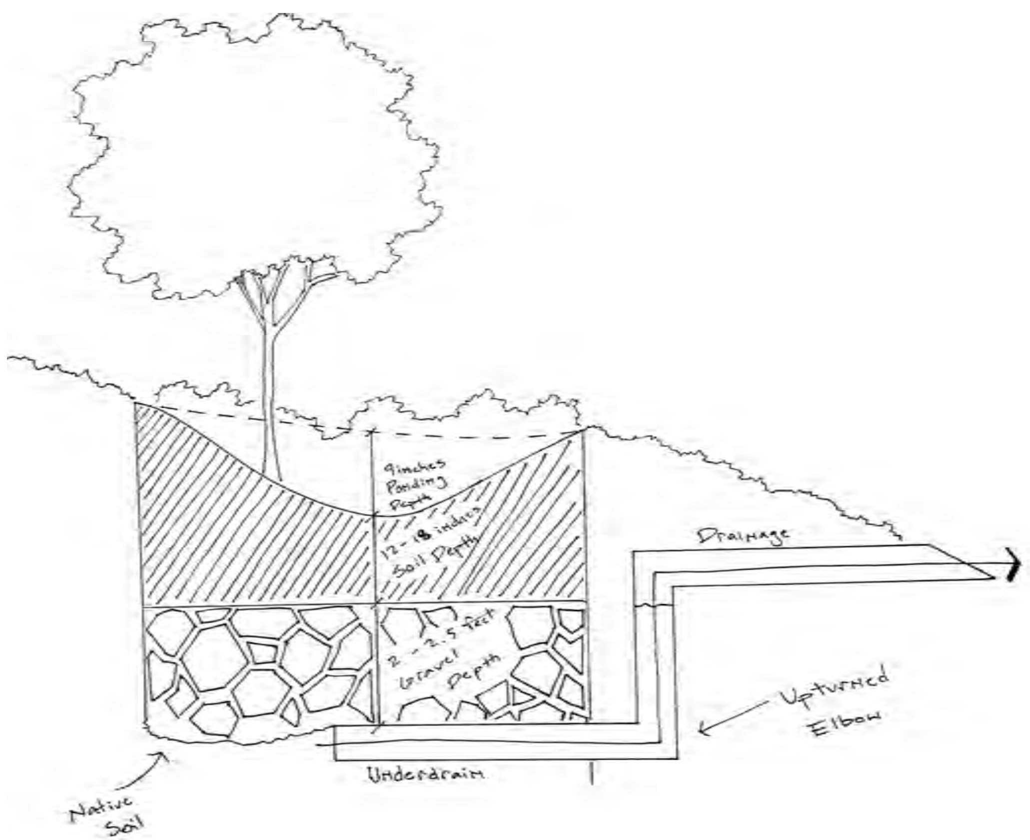



Figure 2.8. Sketch of bioretention featuring an underdrain with an upturned elbow for Internal Water Storage.

### Soils

As noted, the performance of green infrastructure solutions like bioretention is dependent on soil properties. Soils are composed of sand, silt, and clay and the distribution of particles determines the soil's quality. Urban areas often contain poor soils due to high frequencies of disturbance like mixing, removal, and replacement (McFarland et al. 2019). Soil characteristics that indicated poor quality include low infiltration rates and poor drainage. Infiltration and drainage of soils is attributed to high clay content in relation to the other particles; this leads to ponding in level areas, erosion from runoff on hills, and inadequate moisture for plant growth (McFarland et al. 2019, USDA n.d.). Water favors the large pores within sandy soil and when they are absent, management practices should be altered to improve soil quality. Szota et al. (2019) found that soil type had significant effects as sandy clay retained more stormwater than clay sites and also has a higher hydraulic conductivity (ease with which fluid can move through pores) that allows water to exfiltrate to surroundings faster.

According to the USDA, infiltration rates can be improved by: (1) avoiding soil disturbance and equipment operation, (2) subsoiling to break up existing compacted layers, and (3) adding organic materials like manure to bind to soil particles and increase porosity/infiltration. It's important to note that organic matter promotes use by soil biota like earthworms that can continuously create pores connecting to the surface (USDA n.d.).

The USDA also provides an organic matter guide for educators. Organic matter is made of three parts: (1) plant residue and small living soil organisms, (2) decomposing organic matter, and (3) stable organic matter. The organic matter can increase nutrient exchange, moisture retention, infiltration, and reduce compaction. Climate and texture of soil are the two primary factors that impact organic matter in soil, and they cannot be altered. Climate and texture effect the rate of decomposition of organic matter. The colder and less humid the temperature, the slower decomposition occurs (and vice versa). The higher the aeration of soil can increase oxygen levels which increase the rate of decomposition (and vice versa).



### Hydrological Improvements

Retrofitting existing impervious areas to include green infrastructure can reduce the total runoff deposited into receiving waters and alleviate flood related issues as a result. Time of concentration is one aspect of green infrastructure that was previously outlined and refers to the speed runoff travels at. Runoff volume reduction is another aspect of green infrastructure (not all types of green infrastructure) that can effectively retain water and exfiltrate it into the ground. Thiagarajan et al. (2018) retrofitted 13.38 square miles of a single-family residential neighborhood using permeable pavement (49% of existing impervious surface), vegetated swales (46.07 square meters), rain harvesting mechanisms (757.08 liters of storage each), planter boxes (2.2 square miles), rain gardens (43 cubic meters), and additional trees/flower beds and found that total runoff was reduced by 56 billion liters annually in the whole neighborhood if each parcel had the previously stated green infrastructure installed. In addition, the study also concluded that the retrofit was affordable (regarding long-term benefits) and easy to maintain.

Zadehesmaeil (2019) conducted a study of the Boardwalk parking lot (22,922.9 square meters) in Ontario, Canada and retrofitted the area to incorporate 14,550 square meters of green infrastructure. The author concluded that the proposed green infrastructure reduced hydrological discharge by 25.7% with a $368,650 reduction (over a 100-year life cycle) in total costs of the conventional stormwater management system it complements.

# Chapter 3

## Methodology

Figure 3.1. A tree blooming in spring at Kansas State University.

# 3.1 Research Design

**Data Collection**

To inform the development of a projective design, this project included multiple phases of site analysis and modeling. Site analysis was split into two phases: (1) inventory mapping, and (2) modeling. Site inventory was split into two scales: (1) the watershed scale, and (2) the parking lot scale. In this case, the Campus Creek Watershed, and the parking lots of focus (see Figure 3.2). The site inventory was organized into Physical, Natural, and Social/Cultural attributes that apply to a projective design. Modeling was separated into three phases at the parking lot scale, two of which occurred post-site inventory, and the third occurred post-projective design. The phases are: (1) Existing Conditions, (2) a Reference Model, and (3) Future Conditions. Phase 1 of the modeling process established a baseline for improvement within the focus areas. Phase 2 established the possibility for improvement by comparing the focus areas to another site that contains more tree canopy while being smaller than the focus areas. Phase 3 established the effectiveness of the projective design by comparing it to the baseline established in phase 1.

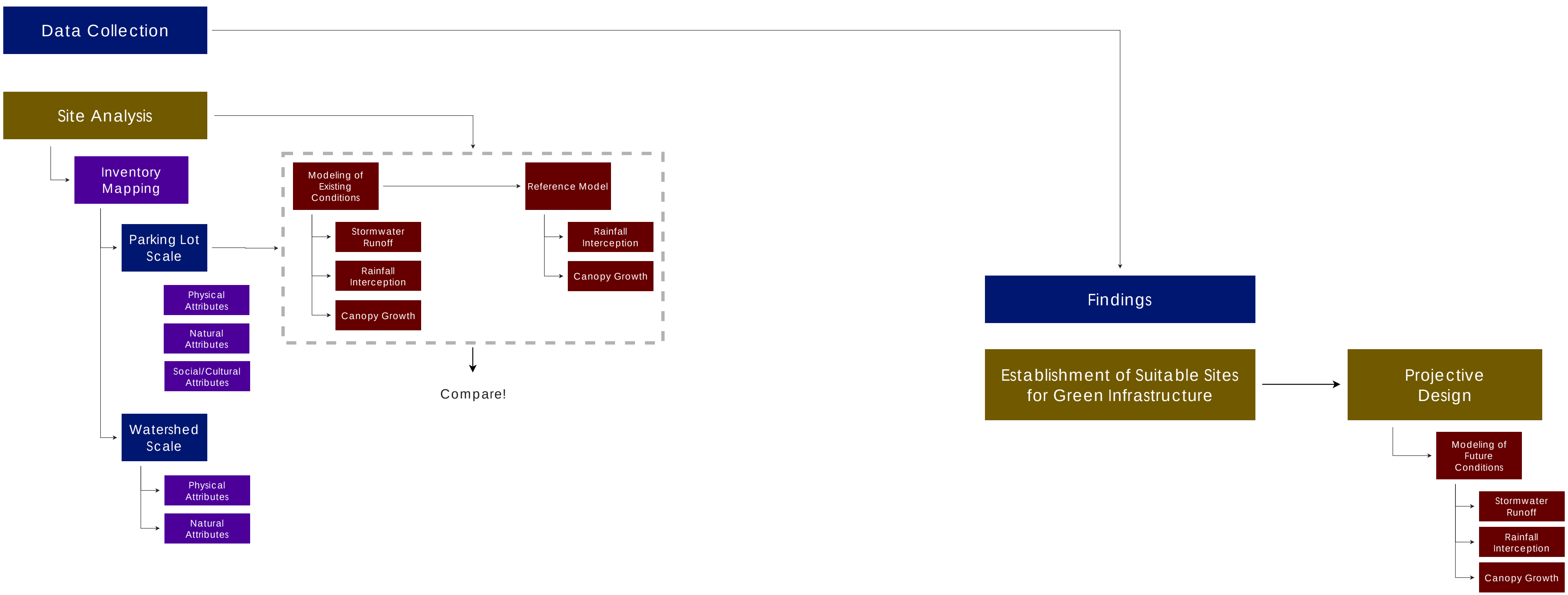



Figure 3.2. Research Design

# 3.2 Site Analysis

**Inventory Mapping | Campus Creek Watershed Scale**

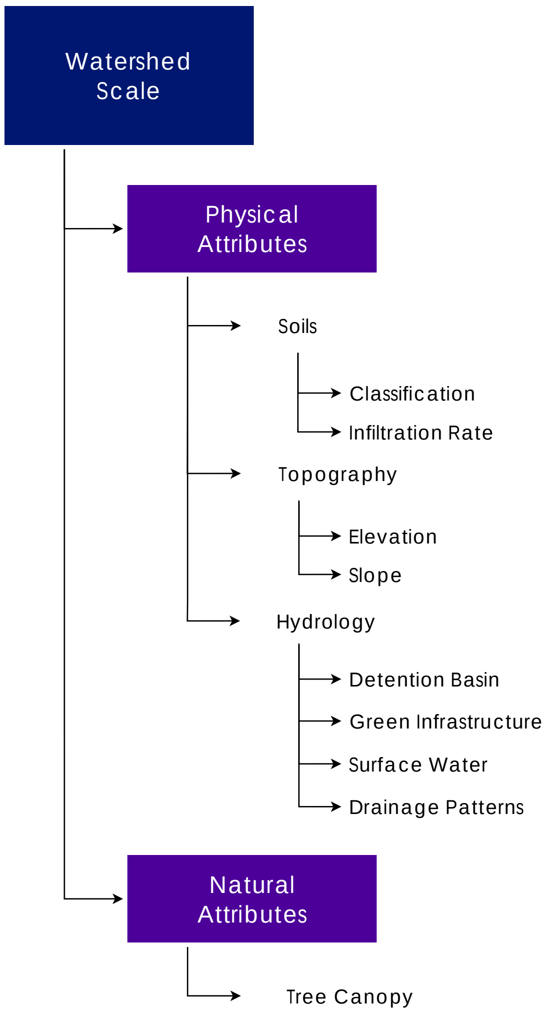



Figure 3.3. Watershed Analysis Attributes

## At the watershed scale, physical and natural attributes were examined...

**Soil classification** was examined to identify existing infiltration rates of the Campus Creek Watershed and to accordingly inform green infrastructure design. Soil infiltration refers to the soil's ability to allow water movement into and through the soil profile, thus, allowing soil to temporarily store water for use by vegetation. Different soil types contain varying infiltration rates (USDA).

**Topography** was examined to establish the direction of water flow. Slope was observed to understand the speed at which stormwater travels across impervious surfaces. Understanding topography helps recognize the appropriate areas to implement green infrastructure by indicating depressed softscape areas within the waterflow path. Topography and hydrology were mapped together as they influence one another in terms of drainage patterns.

**Hydrologic patterns** of the whole watershed reinforced any information gained from the topography analysis in terms of drainage patterns. Review of topography established the paths water takes to reach existing green infrastructure, detention basins, and surface water locations. Mapping of hydrologic patterns also helped understand the size of the watershed in relation to the size of Campus Creek.

**Tree canopy** was examined to understand the distribution of trees in relation to the impervious cover within the Campus Creek Watershed. The runoff generated by impervious cover is often directed into drainage outlets that deposit the water directly into Campus Creek. As noted, trees can absorb and filter, or infiltrate stormwater runoff before it reaches the creek, therefore, mapping out the locations of canopy reinforced the need for an increase within the focus areas.

# 3.2 Site Analysis

**Inventory Mapping | Parking Lot Scale**

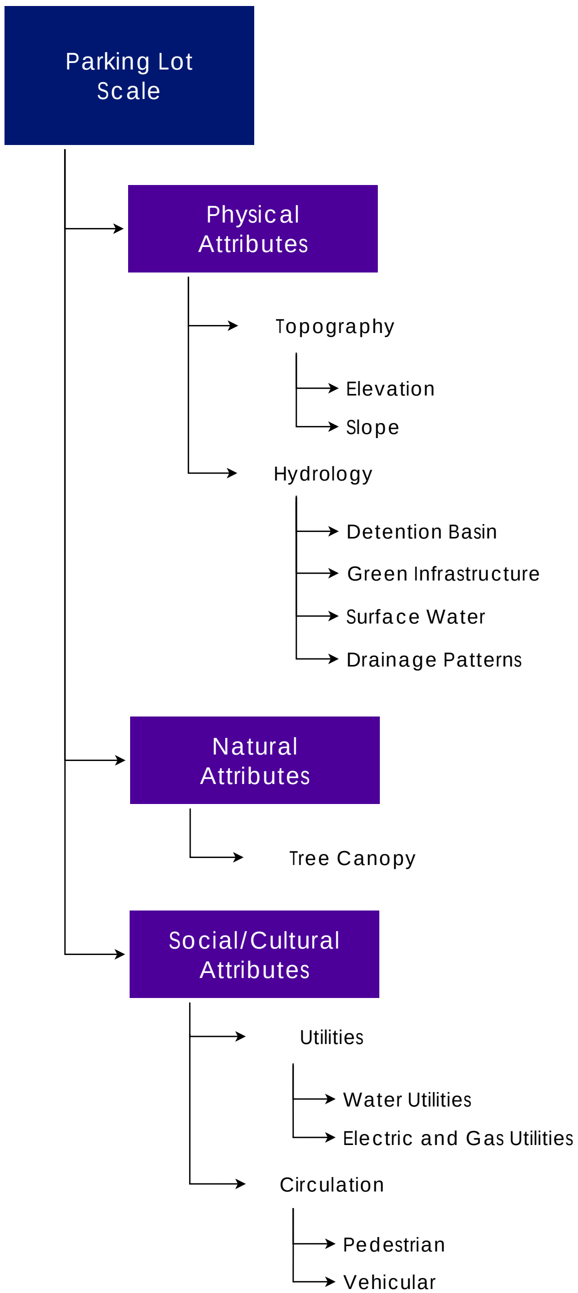



Figure 3.4. Parking Lot Analysis Attributes



## At the parking lot scale, physical, natural, and social/cultural attributes were examined...

**Topography** was examined at a smaller scale to establish the direction of waterflow within the focus areas. At the parking lot scale, topography, hydrology, and water utilities were mapped together. Topography indicated low points within the softscape adjacent to the focus areas that are suitable for green infrastructure implementation. **Hydrologic patterns** of the focus areas reinforced any information gained from the topography analysis in terms of water flow direction and addressed relationships between nearby green infrastructure. **Storm water utilities** indicated where storm sewer inlets and outlets were located and further informed the path stormwater takes underneath the surface and where it resurfaces.

**Tree canopy** was examined to understand the distribution of trees in relation to the impervious cover within the focus areas. At the parking lot scale, tree canopy can be examined to note if the trees are being utilized to intercept, or filter and absorb stormwater runoff.

**Utility** conflicts can determine the viability and type of green infrastructure to be implemented. If conflicts are present, then green infrastructure implementation may not be cost-effective in the event that repairs, or removal of utilities is needed. Utility mapping includes identifying the location of all storm sewer utilities, storm sewer inlet and outlet locations, gas utilities, and electrical utilities.

**Circulation** was examined to understand adjacent streets, traffic volume, and pathways that can influence the size and location of green infrastructure. Parking lots with a higher capacity/square footage but with less use compared to other parking lots may be more viable for green infrastructure implementation as they are less likely to interfere with typical traffic patterns but still produce more runoff (i.e., Bill Snyder Stadium east parking lot). At the parking lot scale, traffic patterns can influence where people park their cars, therefore producing another opportunity for tree planting and green infrastructure (i.e., shade and pollutant production from cars).

Note: that soils were analyzed at the watershed scale and not the parking lot scale due to a lack of site specific data.

# 3.3 Modeling

**Models** are simplifications of reality and are used to make predictions and generate new knowledge. Using data generated from the Site Analysis phase, future conditions were modeled for two scenarios: future conditions **without** green infrastructure, and future conditions **with** green infrastructure. Modeling was conducted at the parking lot scale for (1) stormwater runoff, (2) rainfall interception, and (3) canopy growth. The models can only be conducted at the parking lot scale as this project's scope is only within the northwestern region of the Campus Creek Watershed. Below are the first two phases of the modeling process. The first phase (left) was a model of existing conditions to establish a baseline for improvement within the focus areas. The second phase (right) was a reference model of the West Memorial Stadium parking lot. The reference model was generated to demonstrate the possibilities of a design solution with more tree canopy. The West Memorial Stadium parking lot contains a significant amount of canopy cover, therefore, modeling results from its existing conditions, in terms of rainfall interception and canopy growth, were compared to the project focus areas to show the benefits of having trees as a green infrastructure solution in parking lots.

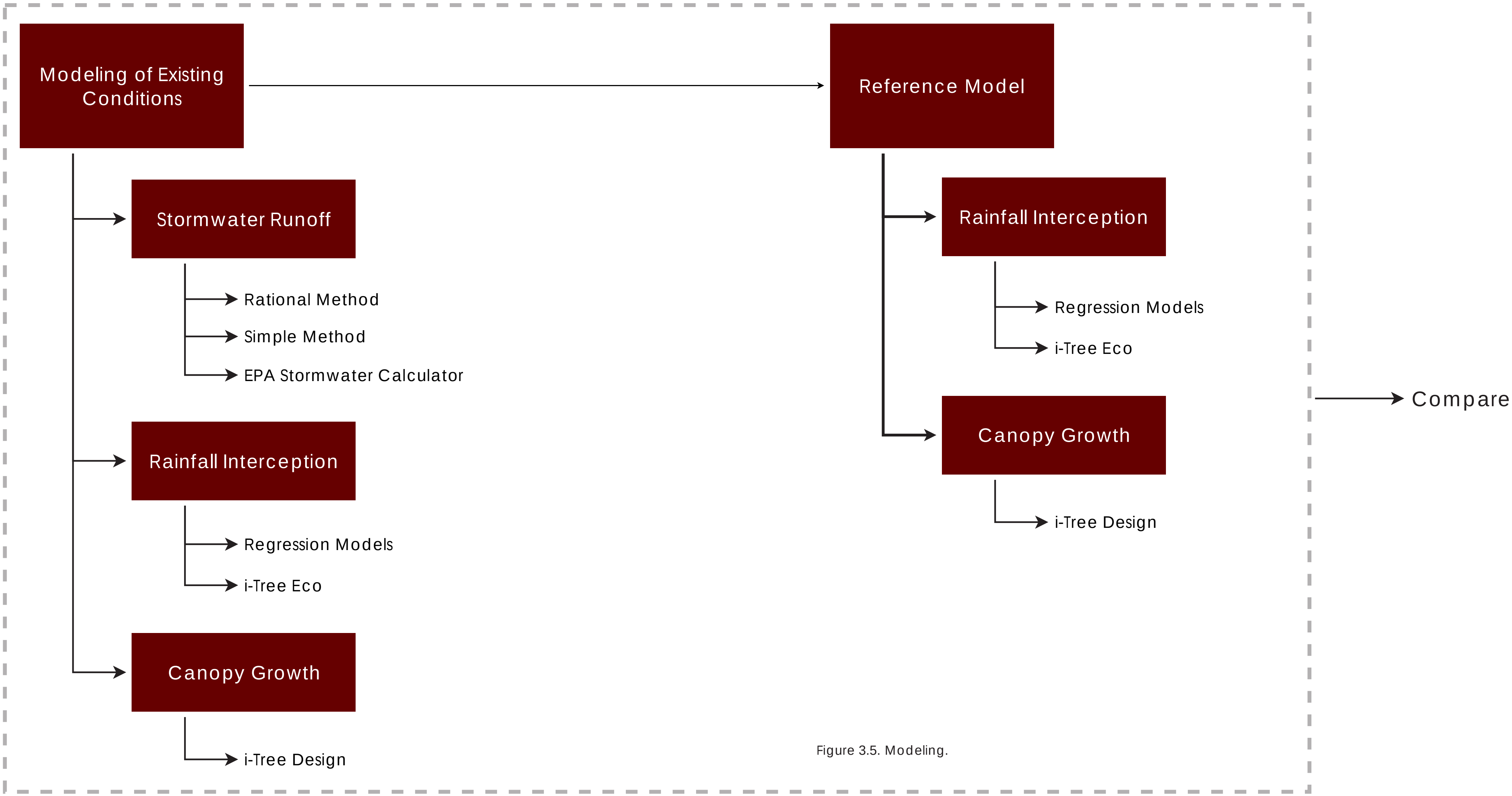



Figure 3.5. Modeling.

# 3.3 Modeling

### Rainfall Interception

As noted in the Background Chapter, rainfall interception is the amount of rainfall remaining on the canopy surfaces and is evaporated after or during a storm event (Berland et al. 2017, Beidokhti and Moore 2021). Although interception is a factor of the regression models produced by Beidokhti and Moore (2021), it was modeled separately to produce data specific to interception and examine the value of canopy that covers impervious surface, therefore, results were different than that produced by the other models stated on the previous page.

*i-Tree* uses the area of tree cover and local weather data to estimate rainfall interception. A local standardized removal rate is multiplied by the tree cover logged and produces a total effect from the trees (cubic meters) (Nowak 2020). i-Tree will be utilized as it is a peer-reviewed software suite provided by the USDA Forest Service.

*Regression Models* created by Beidokhti and Moore (2021) were developed by conducting a meta-regression analysis of existing precipitation partitioning studies of urban areas. In statistical modeling, regression analysis is a set of statistical processes for estimating the relationships between a dependent variable and one or more independent variables (Beers 2021). In simpler terms, regression analysis is a way of mathematically sorting out the impact of one thing on something else (Gallo 2015). In this case, the dependent variable is rainfall partitioning (interception, throughfall, and stemflow), and the independent variables are leaf types and bark types.

Every leaf and bark type has a different regression model that represents its ability to allow rainfall to:

1. Fall through its canopy (throughfall)
2. Stop rainfall from falling through its canopy (interception)
3. Allow rainfall to flow down its trunk (stemflow)



Models were created for the leaf and bark types instead of individual trees because of the immense amount of tree species.

The leaf types are:

- Deciduous Leafed
- Deciduous Leafless
- Evergreen Broadleaves
- Evergreen Needleleaf

The bark types are:

- Smooth Bark
- Rough Bark

For this project, five storms were modeled for rainfall interception:

1. Standard Storm (1.0-inch depth; 6 hour duration)
2. Water Quality Storm (1.10-inch depth; no duration)
3. 10-Year Storm A (2.92-inch depth; 2 hour duration)
4. 10-Year Storm B (4.94-inch depth; 24 hour duration)
5. 50-Year Storm (5.57-inch depth; 6 hour duration)

# 3.3 Modeling

### Canopy Growth

The time it takes for a tree canopy to grow and cover the adjacent impervious surface was modeled to aid in the selection of species, to understand the time it takes for a canopy to intercept water before it touches the hardscape beneath it. The results also reinforced the findings of the previously stated regression models.

> *i-Tree* uses a series of regression equations and laws to calculate leaf area for different types of settings. i-Tree uses a set of equations to calculate tree biomass for 50 – 60 tree species and plans to add more (Nowak 2020).

### Stormwater Runoff

**Stormwater runoff** was calculated to estimate the total amount of runoff produced by the individual parking lots for five design storms. Understanding how much stormwater runoff is produced revealed the need for interventions (i.e., green infrastructure and increased tree canopy), and also provided a baseline for comparison after the projective design has been carried out. Five design storms were modeled: (1) 5-Year Storm (.92 inches/hour rainfall intensity; 3-hour duration), (2) 10-Year Storm (1.48 inches/hour rainfall intensity; 2-hour duration), (3) 25-year Storm (2.23 inches/hour in rainfall intensity, 1.5-hour duration), (4) 50-Year (3.39 inches/hour rainfall intensity; 1-hour duration), and (5) 100-Year Storm (5.56 inches/hour rainfall intensity; 0.5-hour duration).

> The *Rational Method* of stormwater runoff modeling estimates peak runoff rates for catchment areas of less than 200 acres (Albracht et al. 2014).

> The *Simple Method* of stormwater runoff modeling estimates stormwater runoff pollutant loads for urban areas as a product of annual runoff volume and pollutant concentration. The Simple Method allows the investigator to break up land uses into specified areas and calculate annual pollutant loads for each of them (CWP 2015).

> The *EPA National Stormwater Calculator (SWC)* is a software application that can estimate rainwater amounts and the frequency of runoff from a specific site using green infrastructure as low impact development controls. The software uses the Storm Water Management Model (SWMM) as its computational engine. SWMM has been in continuous use for over 40 years and accesses several national databases for soil, topography, rainfall, and evaporation information. The SWC can also provide cost estimates and develop various climate scenarios (US EPA 2014). SWC will be used to calculate the total annual runoff quantity.

Note: The stormwater runoff calculations conducted using the above methods reflect a different set of storms than that of the regression model calculations. The Stormwater Runoff calculations are meant to gain an overall understanding of how much runoff is produced by the parking lots, while the regression model calculations are meant to understand how trees perform during storm events of varying intensities. It's also important to reiterate that the Standard Storm is mentioned on Page 27 of the Kansas Water Pollution Control Permit for Kansas and the Water Quality Storm represents the 90$^{th}$ percentile storm for this part of Kansas.

# 3.3 Modeling

### Assumptions and Limitations

All modeling tools contain assumptions and limitations. Models are simplifications of reality; therefore, certain variables have to be assumed to allow models to produce results. This section will restate the tools to be used, their purpose, and their associated assumptions that inform the projective design.

*The EPA Stormwater Runoff Calculator (SWC)*, as noted, is a software application created by the Environmental Protection Agency (EPA). It can estimate the annual amount of rainfall and the frequency of runoff generated by a specific site. It can also apply Low-Impact-Development (LID) controls to model the reductions they will have on existing conditions. The software requires user inputs regarding: (1) Location, (2) Soil Type, (3) Soil Drainage, (4) Topography, (5) Precipitation, (6) Evaporation, (7) Climate Change, (8) Land Cover, and (9) LID Controls. The SWC contains the least number of assumptions compared to the other models because of their required input fields that are designed to eliminate as many limitations as possible; therefore, assuming that the user fills all of the data fields, assumptions can be kept to a minimum. For this project, assumptions will reflect the proposed LID Controls. The SWC has a separate set of LID Control specific input fields that specify their design.

**Downspout Disconnections** are the practice of directing runoff from impervious areas, such as roofs or parking lots, into pervious areas like lawns or gardens. The SWC requires a user input of the capture ratio. The capture ratio represents the ratio of pervious area receiving the runoff to the impervious area that generates the runoff. For example, if 10,000 square feet of roof area is diverted into a 5,000 square foot rain garden, the capture ratio is 5,000 / 10,000, or 50%. If the capture ratio field is not specified, it is assumed to be a 100% capture ratio.

**Rain Harvesting Systems** take runoff from rooftops and convey it to a cistern tank where it can be used for non-potable water uses. The harvesting system is assumed to consist of a given number of fixed-sized cisterns per 1000 square feet of rooftop area to be captured. The water from each cistern is also assumed to be withdrawn at a constant rate and infiltrated on-site. The user input fields required to specify the proposed rain harvesting systems are: (1) cistern size (gallons), (2) emptying rate (gallons/day), (3) number of cisterns per 1000 square feet. If the user input fields are not specified, then cistern size is assumed to be 100 gallons with an emptying rate of 50 gallons per day with 4 total cisterns per 1000 square feet.



**Rain Gardens** are shallow depressions filled with engineered soil mix that can support vegetative growth and capture runoff. The user input fields are: (1) ponding height (inches), (2) soil media thickness (inches), (3) soil media conductivity (inches/hour), and (4) capture ratio. If the user input fields are not specified, ponding height is assumed to be 6 inches with 12-inch-deep soil media and a conductivity of 10 inches/hour. The capture ratio is assumed to be 5%.

**Green Roofs** (or vegetated roofs) are bioretention systems placed on roof surfaces that capture and temporarily store rainwater in soil. The user input fields are: (1) soil media thickness (inches), and (2) soil media conductivity (inches/hour). If the user input fields are not specified, then soil media is assumed to be 4 inches deep with 10 inches/hour in soil conductivity.

**Street Planters** consist of concrete boxes filled with soil that can support plant growth. A gravel bed is located beneath the soil to provide more storage. The user input fields are: (1) ponding height (inches), (2) soil media thickness (inches), (3) soil media conductivity (inches/hour), (4) gravel bed thickness (inches), and (5) capture ratio. If the user input fields are not specified, then the SWC assumes a ponding height of 6 inches, soil media thickness of 18 inches, soil media conductivity of 10 inches/hour, a gravel bed thickness of 12 inches, and a capture ratio of 6%.

**Infiltration Basins** are shallow depressions filled with grass or vegetation to capture runoff and infiltrate it into the soil. The SWC assumes that the infiltration rate in the basin is the same as the site's native soil, which must be inputted via the user in the Soil Drainage fields specified earlier in the model. The user input fields are: (1) basin depth (inches), and (2) capture ratio. If the user input fields are not specified, then basin depth is assumed to be 6 inches with a 5% capture ratio.

**Permeable Pavement** is an excavated area filled with gravel and paved over with porous concrete or asphalt mix. They can also be designed with modular block pavers. With an ideal design, rainfall would immediately pass through the pavement into an aggregate storage layer below where it can infiltrate native soils. The user input fields are: (1) pavement thickness (inches), (2) gravel layer thickness, and (3) capture ratio. If the user input fields are not specified, then the SWC assumes a pavement thickness of 6 inches with 18 inches of gravel and a 100% capture ratio.

# 3.3 Modeling

### Assumptions and Limitations

*i-Tree Eco* is a modeling software utilizes a complete inventory of trees to assess them for structure (e.g., leaf area), function (e.g., gas exchange), service (e.g., pollution removal), benefits (e.g., cleaner air), and value (e.g., reduced health care costs) (Nowak 2020). This project specifically focuses on structure (leaf area), and services (water intercepted).

**Leaf area** is the amount of surface area of leaves on a tree. Cumulative amount of leaf area per unit of ground is known as the Leaf Area Index (LAI). Leaf area is an important variable in estimating biomass, air pollution removal, carbon storage and sequestration, and other subjects that i-Tree is designed to model. i-Tree utilizes a series of regression equations to represent the tree types and uses the user inputted DBH and total tree height. The estimation error in calculating leaf area and biomass is unknown therefore i-Tree uses a series of species-specific shading coefficients to mitigate assumptions and increase the accuracy of results. i-Tree currently has over 50 species-specific tree biomass equations and is adding more. If a tree is inputted and i-Tree does not contain a tree biomass equation for it, then it uses an equation for a tree of similar traits (Nowak 2020).

**Rainfall interception** is the amount of rainfall that is stopped by a tree's canopy and never reaches the ground beneath because its evaporated directly from the canopy. i-Tree Eco can estimate rainfall interception, evaporation from leaf surfaces, potential evapotranspiration, transpiration, and avoided runoff values (Nowak 2020). Interception is modeled using an improved Rutter methodology (Valente et al. 1997). The model assumes that precipitation is uniformly distributed over the area, and that precipitation is partially intercepted by leaves and the remainder reaches the ground. Some portion of the precipitation is evaporated, and the remainder drops to the ground when it exceeds the maximum capacity of water storage of leaves. See Hirabayashi (2015) for a more in-depth description of the rainfall interception assumptions utilized in i-Tree Eco.

**Canopy growth** can be modeled in i-Tree Design using the base growth rate. Open grown tree growth rates were developed based on measured street tree growth (Fleming 1988, Frelich 1992, Nowak 1994b) and use the equation below:

*Standard Growth = measured growth x (153/number of frost-free days of measurement)*

According to Nowak (2020), the average diameter growth rate for open-grown trees with 153 frost free days is 0.33 in/year. To determine a local base growth rate, the standard growth rate was adjusted based on the local length of growing:

*Base Growth = standard growth x (number of frost-free days in area/153)*

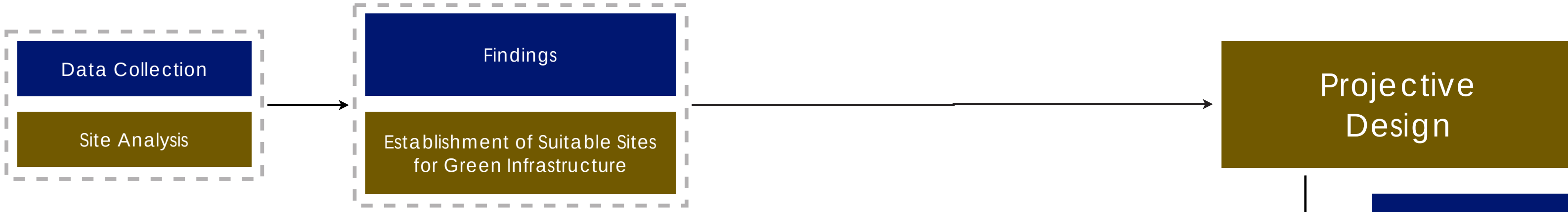
Based on the data generated from the previous two equations, the average diameter growth rate of open-grown trees with 153 frost free days are set to 0.23 in/yr for slow growing species, 0.33 for moderate growing species, and 0.43 in/yr for fast growing species. Because there is very limited data on growth in urban areas, growth rates are estimates.

Tree competition was factored in using crown light exposure. Light exposure measurements are based on the number of sides that are exposed to sunlight wherein if 0 to 1 side of a tree receiving sunlight, then the tree is in a closed or nearly closed canopy. 2 to 3 sides represent park conditions and 4 to 5 represents open-grown areas.

Tree condition adjusts growth rates based on the percentage of crown dieback. Base growth rates are multiplied by 1 – (percentage of dieback). For example, a tree with 60 percent dieback will have a base growth rate multiplied by 0.4

Total tree height adjusts growth rates as it represents age. As a tree approaches the maximum height, their associated growth rate will decrease. Therefore, the growth rates are adjusted as a ratio between the current height of the tree and the average height at maturity for the species.

# 3.4 Projective Design




The Site Analysis phase of the project resulted in an identification of sites for future green infrastructure solutions and the types of green infrastructure to be implemented. After the green infrastructure sites and types were established, the Projective Design was split into two categories: (1) the main project, and (2) demonstration projects; both of which contribute to one final projective design. To assess the quality of the design, the modeling phase occured again, and was compared to the original model of existing conditions to demonstrate its effectiveness.

The figure below depicts the dilemmas addressed in the research question, and the associated modeling tools that were used to address it.

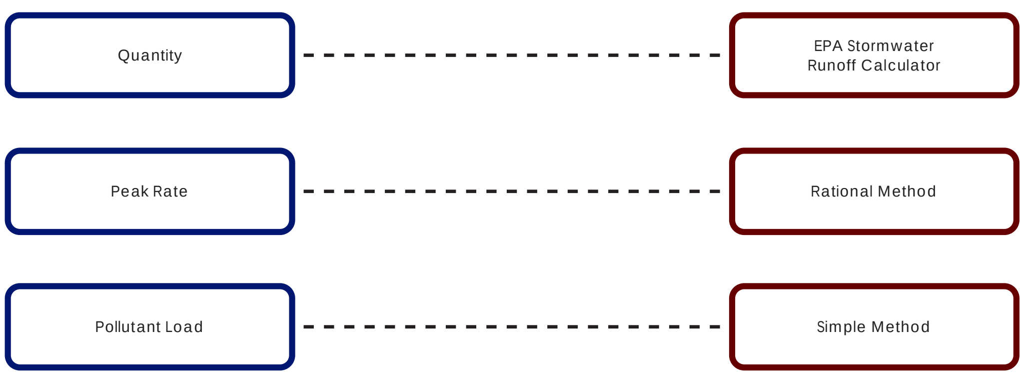



Figure 3.7. Runoff modeling tools and what they address.

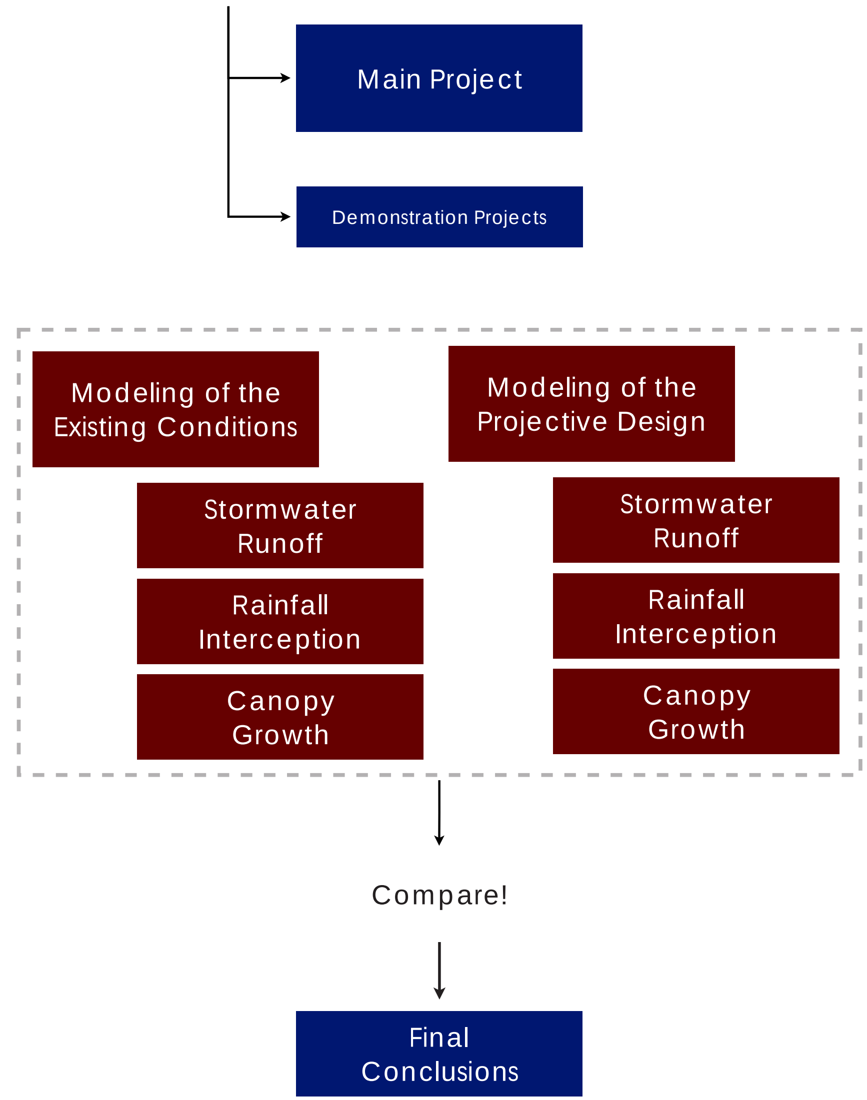



Figure 3.6. Projective Design Process.

# Chapter 4

Findings

Existing Conditions

Figure 4.1. Squirrel perched on the branches of a tree at Kansas State University.

# 4.1 Research Design

As noted in Chapter 3, this project collected site analysis data through inventory mapping and modeling of existing conditions. Inventory was completed at the watershed scale and parking lot scale; Modeling was conducted at the parking lot scale. The data generated from the site analysis identified sites that were suitable for future green infrastructure implementation and then the projective design was carried out (see chapter 5).

Chapter 4 begins with watershed scale inventory mapping of Campus Creek Watershed characteristics like total impervious cover, tree canopy cover, and parking lot area. After watershed characteristics were established, inventory mapping of the attributes listed in Chapter 3 were conducted.

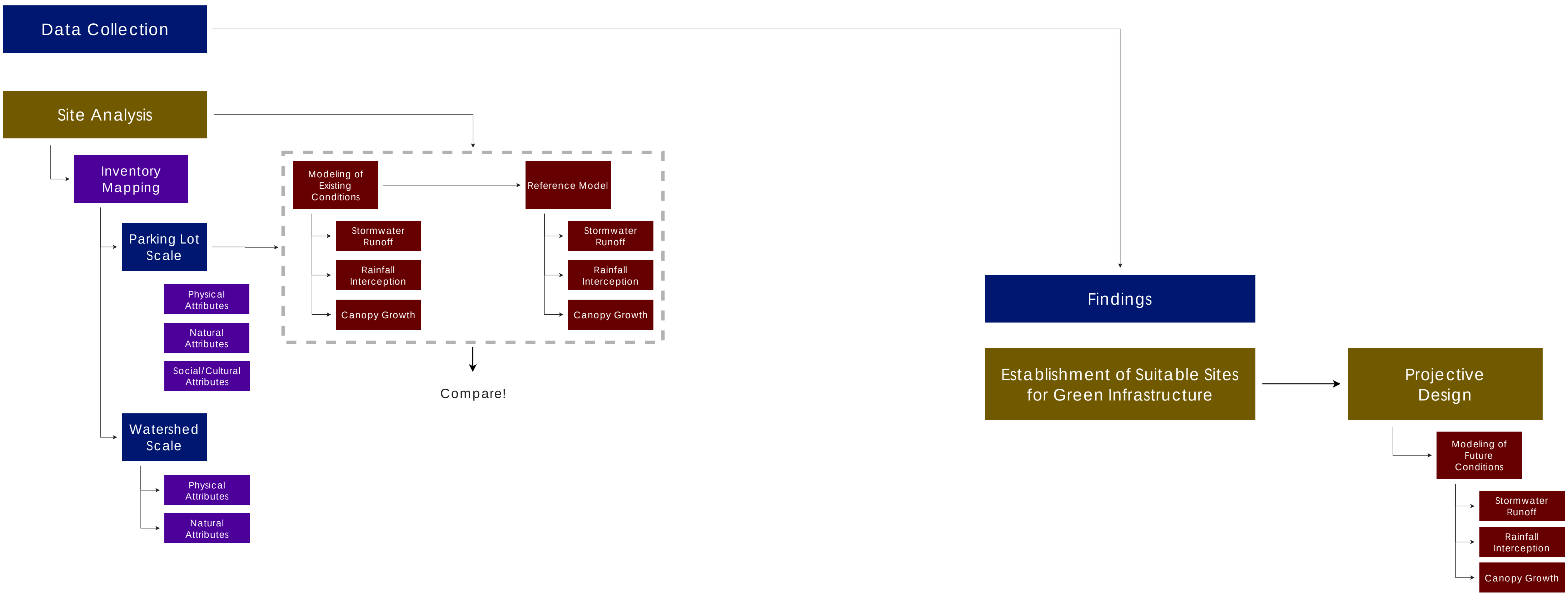
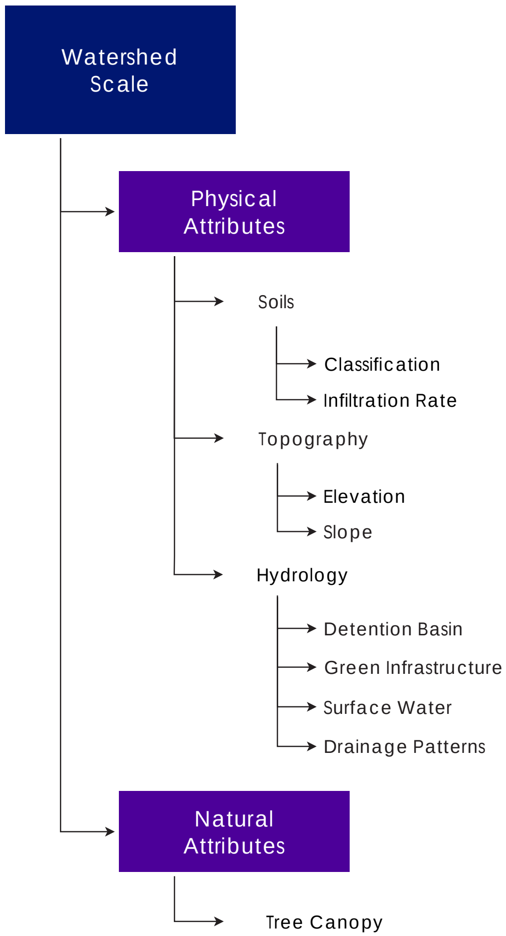



Figure 4.2. Research Design

# 4.2.1 Watershed Scale Analysis




***+/- 400 acres***

Figure 4.3. Watershed Analysis Attributes.

Figure 4.4. Campus Creek Watershed Boundaries.

# 4.2.1 Watershed Scale Analysis

## Watershed Characteristics

The Campus Creek Watershed contains approximately 14% tree canopy cover (approximately 56 acres). Most of the existing canopy is located within the campus core area in the southern sectors of the watershed. The northern and northwestern areas are very barren in comparison to the south, and offer an opportunity to increase canopy cover.

***14% Tree Canopy Cover***
***+/- 56 acres***

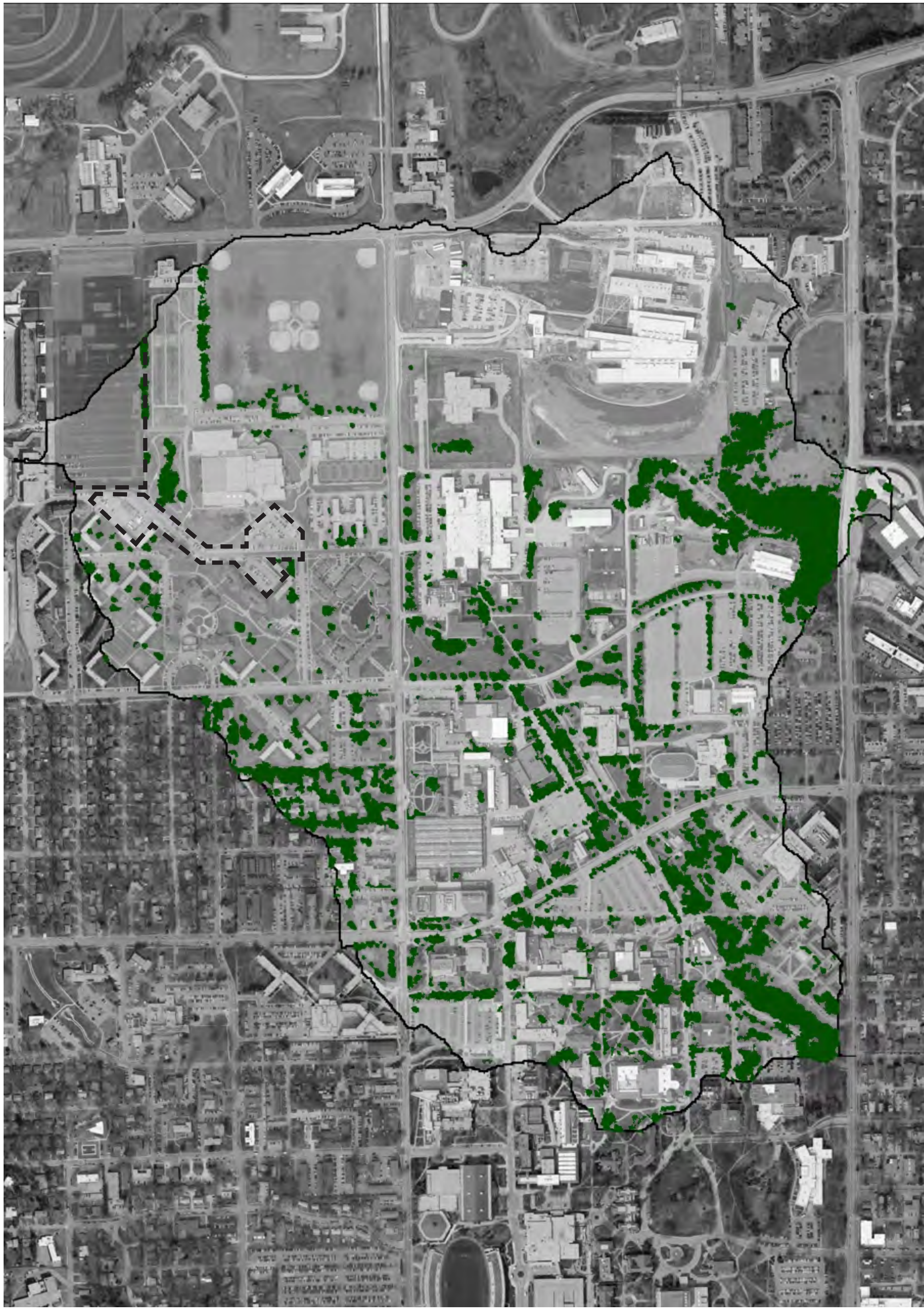


Figure 4.5. Campus Creek Watershed Tree Canopy.

## 4.2.1 Watershed Scale Analysis

### Watershed Characteristics

The Campus Creek Watershed contains approximately 49% impervious cover (approximately 200 acres). According to McFarland et al. (2019), replacing natural land cover with impervious surfaces decreases on-site infiltration and increases stormwater runoff. Watersheds that exceed 12% impervious surface commonly experience negative impacts on receiving waters; 30% of impervious surfaces result in degradation that becomes severe. These findings indicate a need to address the Campus Creek Watershed's impervious surfaces using green infrastructure.

***49% Impervious Cover***
***+/- 200 acres***

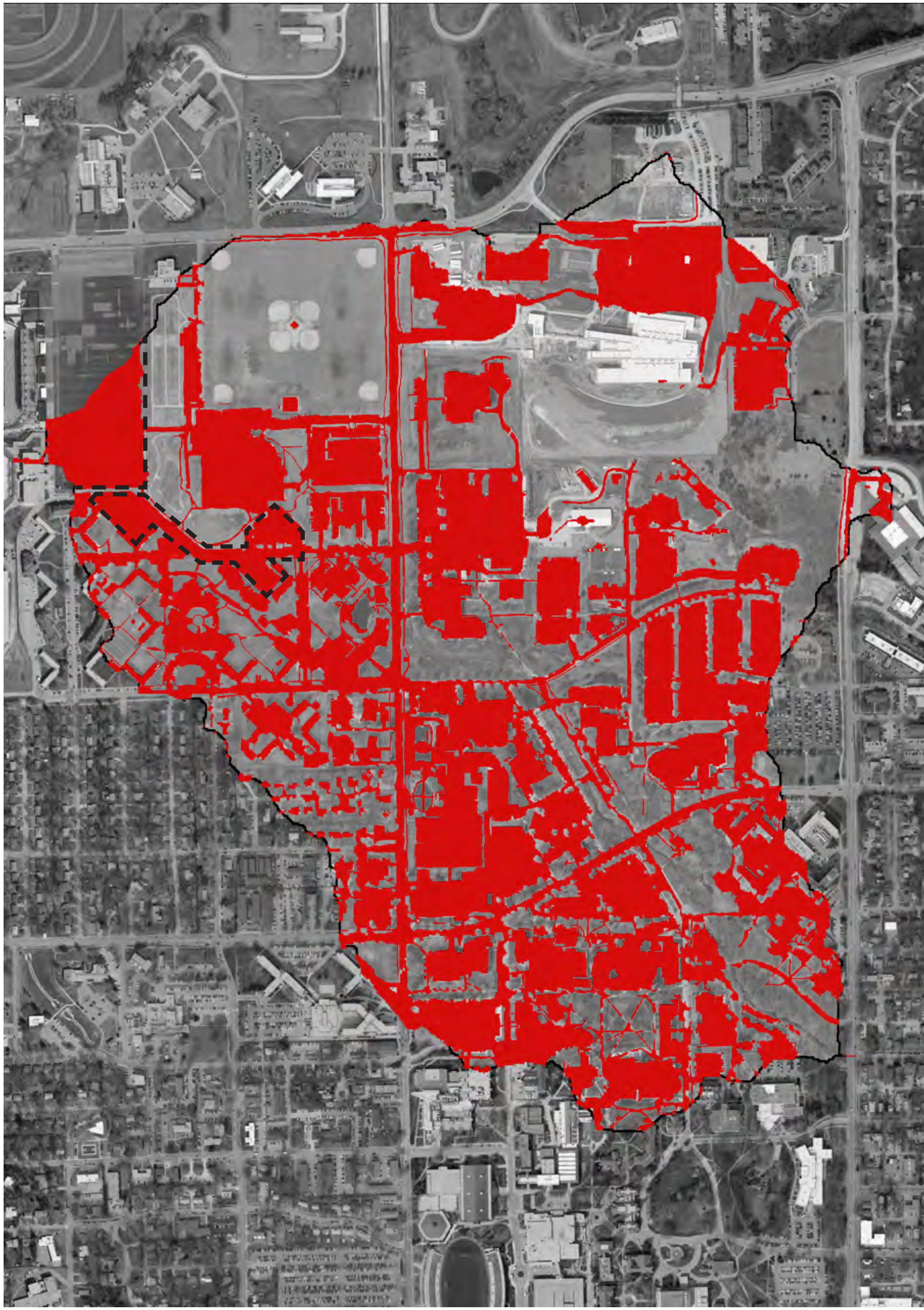


Figure 4.6. Campus Creek Watershed Impervious Cover.

# 4.2.1 Watershed Scale Analysis

## Watershed Characteristics

As noted, the Campus Creek Watershed contains approximately 49% impervious, 31% of that impervious surface is parking (approximately 62 acres). The focus areas (dashed line) embody approximately 5.62% (approximately 11.23 acres) of the total impervious surfaces within the watershed, all of which contribute stormwater runoff to Campus Creek.

***15.5% Parking Lot Impervious Cover +/- 62 acres***

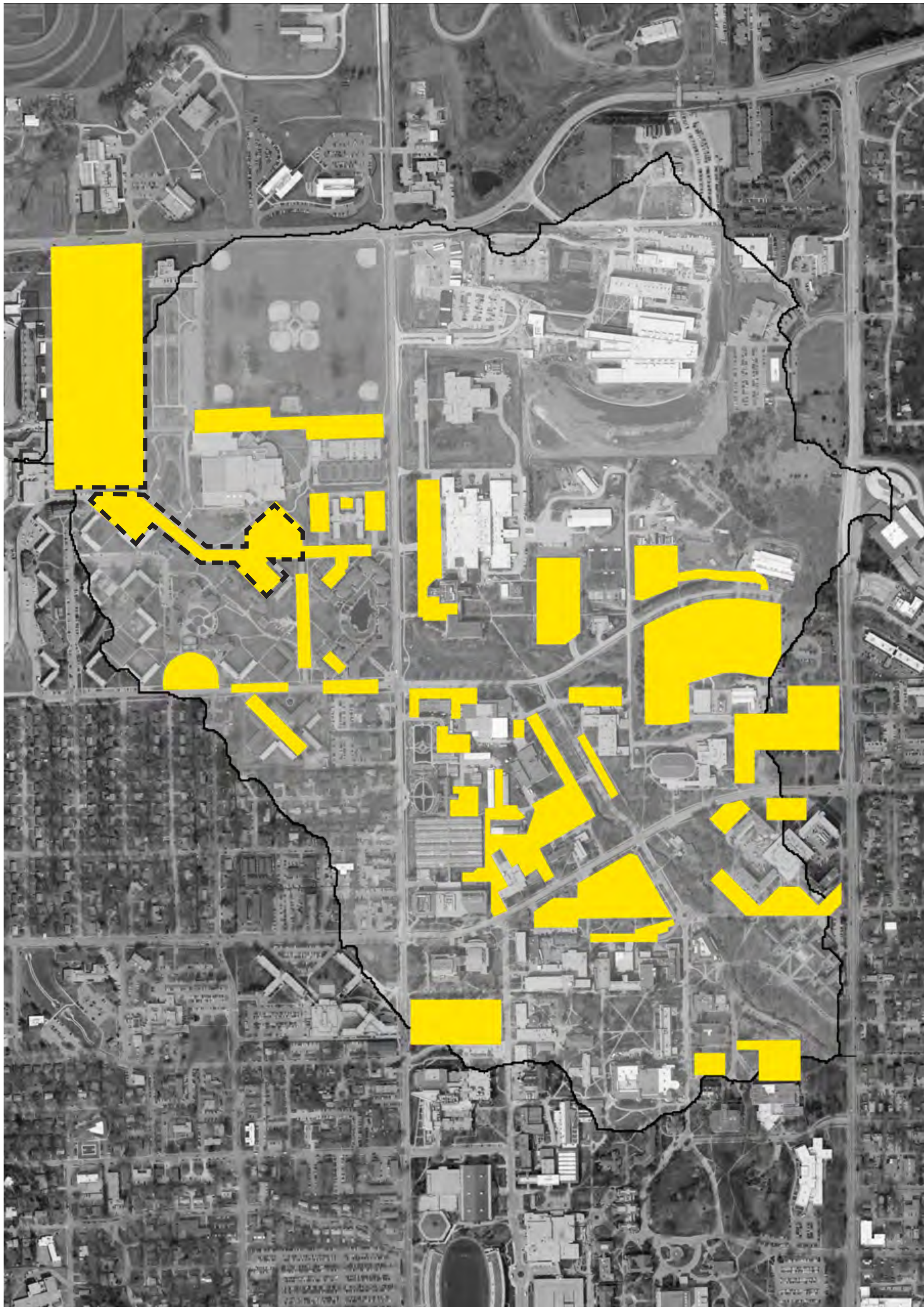


Figure 4.7. Campus Creek Watershed Parking Lots.

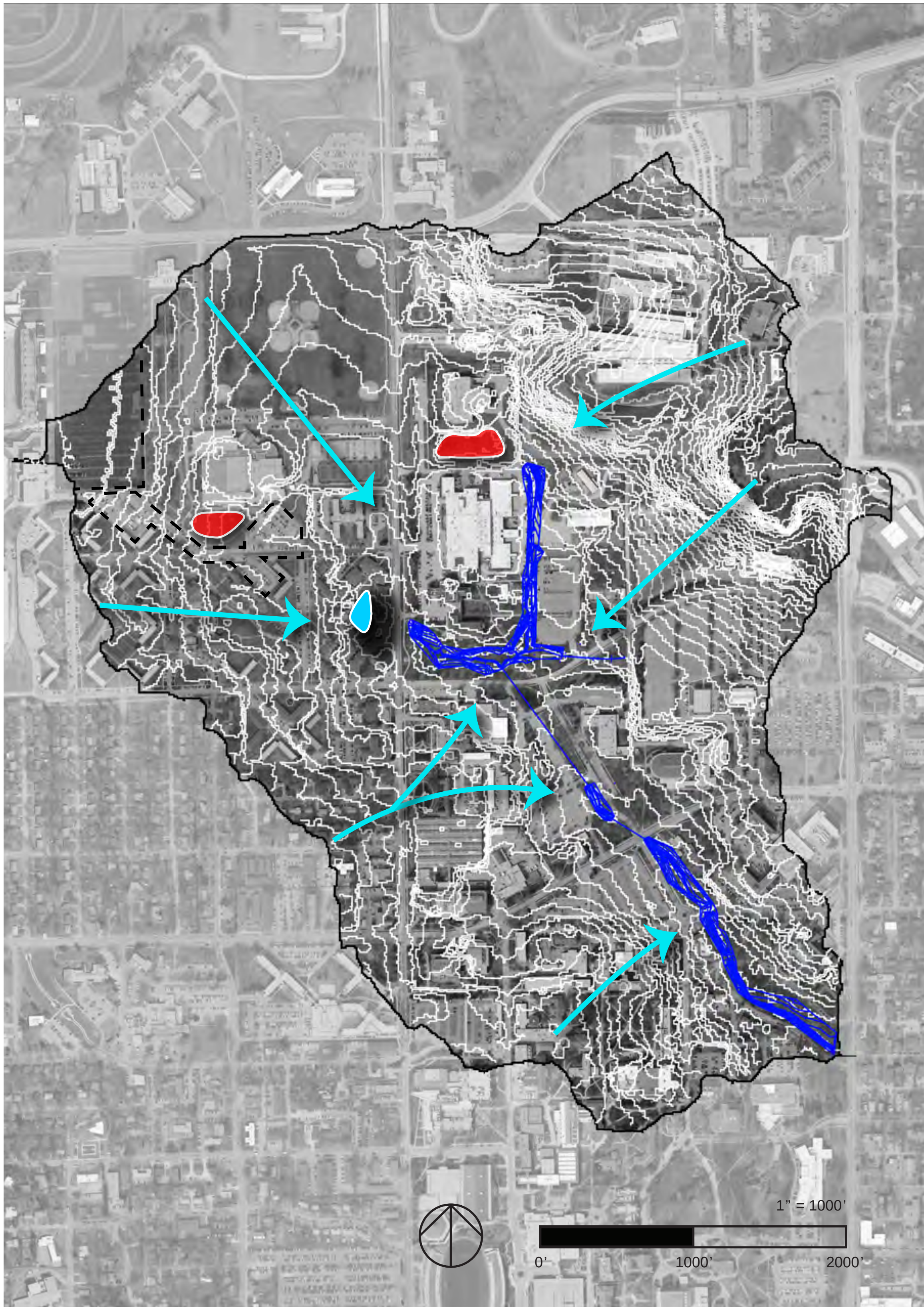
# 4.2.1 Watershed Scale Analysis

## Topography and Hydrology

**Topography and Hydrologic Drainage Patterns** were mapped to understand the distance and paths water takes to inevitably get into Campus Creek, and the interactions the water has with existing impervious surfaces.

**Detention Basins** are located in three locations in the northern portion of the watershed and, according to the Kansas State University Stormwater Management Plan, they are being utilized to temporarily store stormwater runoff, not only from impervious surface but also from pervious surface after their soils have become saturated. One of the drainage basins is located south of the Peter's Recreation Center and directly adjacent to the focus areas, thus, implying that this detention area is suitable for further green infrastructure implementation. According to the Kansas State University Stormwater Management Plan, the Recreation Center Detention Basin takes on runoff from not only the East Stadium parking lot, but also the recreation fields to the north of the recreation complex.

**Surface Water** indicates the drainage pond located within the Jardine Apartment Complex. According to the Groundskeeper for Housing and Dining at Kansas State University, most of the stormwater runoff in the northwestern sector of the watershed drains directly into this pond and during major rain events, the pond's water level will rise drastically. This pond also serves as the transition before runoff is delivered into Campus Creek.




**Legend**

Campus Creek Channel

Drainage Pattern

Surface Water

Detention Basins

Focus Area

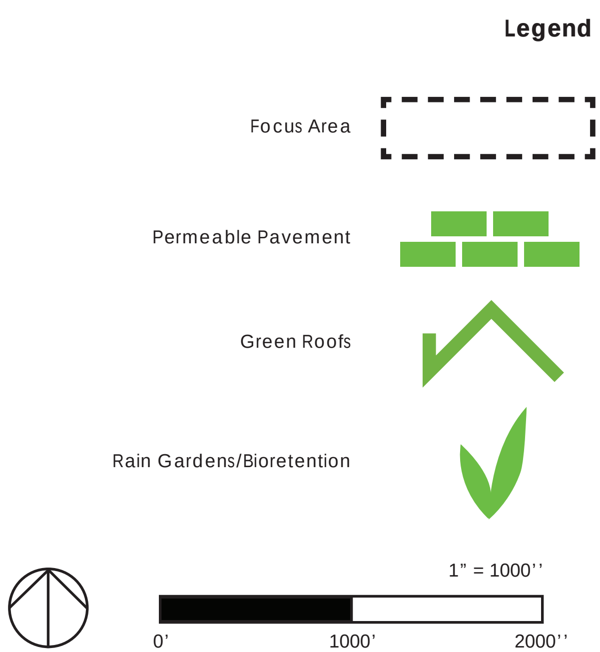
Figure 4.8. Campus Creek Watershed Topography and Hydrology.
Source: LiDar

# 4.2.1 Watershed Scale Analysis

## Existing Green Infrastructure

**Existing Green Infrastructure** shows rain gardens, bioswales, and green roofs are located on the Kansas State University campus. Most are located in the southern portions of the watershed, or right outside of it.

Figure 4.9 shows that the northwestern portion of the watershed, near the focus areas, contains no green infrastructure solutions. Therefore, providing an opportunity for future implementation to address the stormwater management needs of the area. The existing green infrastructure demonstrates the willingness of Kansas State University to explore different stormwater management techniques.



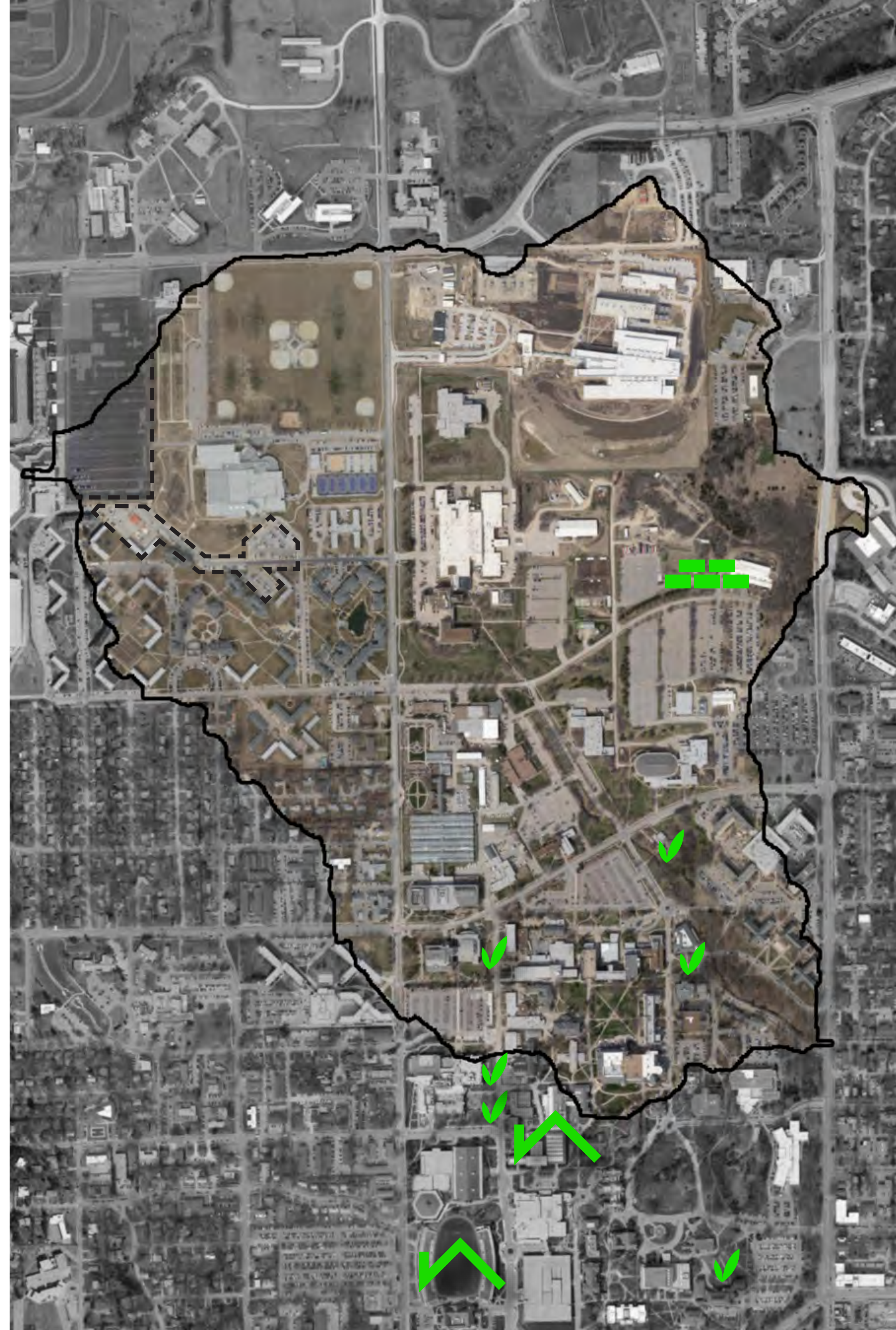



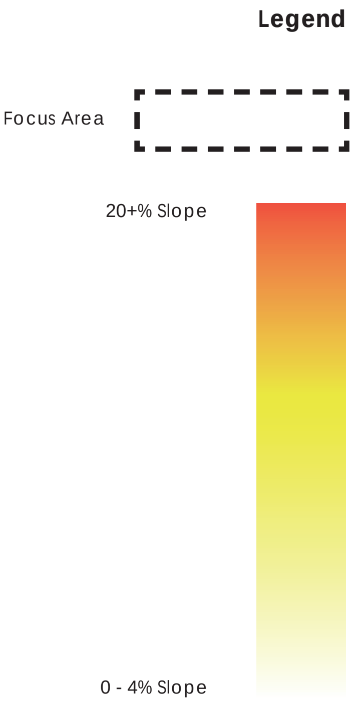
Figure 4.9. Campus Creek Watershed Green Infrastructure.

# 4.2.1 Watershed Scale Analysis

## Slope

The slope map in Figure 4.10 depicts slopes ranging from a shallow 0 to 4 percent, to a more steep 20+ percent. The flatter areas of the Campus Creek Watershed are rmostly impervious cover while almost all steeper slopes of 10 percent or more have softscape cover. This is particularly noticeable in the northeastern portion of the watershed where the National Biological and Agro-Defense Facility (NBAF) was recently built at the highest elevation within the watershed, therefore pushing for steeper slopes around its footprint.

The flattest region of the watershed is the northwestern portion of the watershed where the focus areas are located. These areas have slopes of less than 10 percent, again, indicative of the amount of impervious surface in the area. Because of the shallower slopes in this area, runoff moves much slower, therefore, increasing the potential for green infrastructure solutions to be implemented to increase infiltration in the area. Although there is no evidence of a pooling issue near the focus areas, shallow slopes do present the possibility of stormwater pooling.



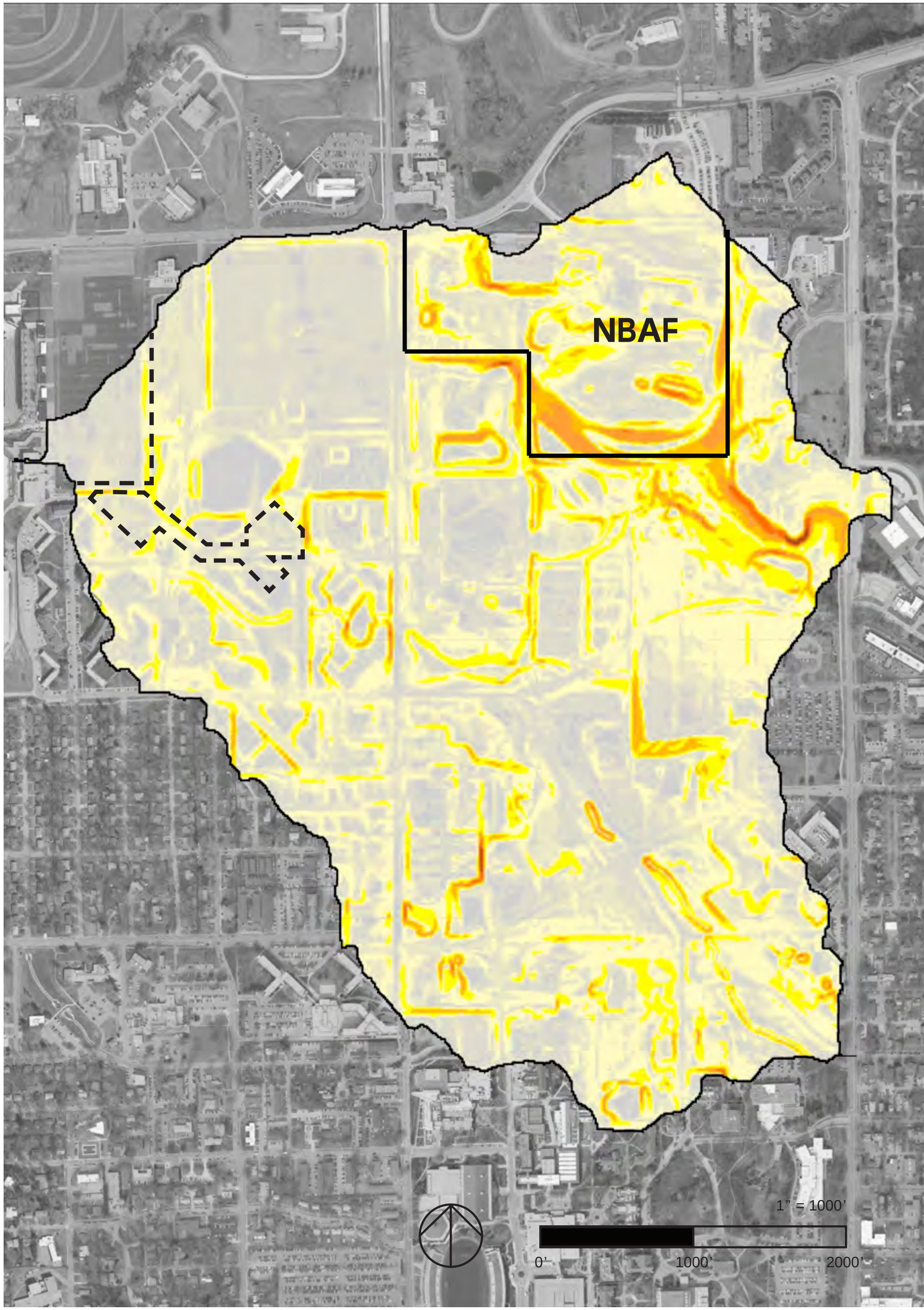




Figure 4.10. Campus Creek Watershed Slope.
Source: ArcGIS

# 4.2.1 Watershed Scale Analysis

## Soil Classifications and Infiltration Rates

According to a series of soil surveys conducted for the Campus Re-Envisioned Project for the Campus Creek Watershed, the soils are silty loam to silty clay loam in texture; both of which present low infiltration rates and increase the amount of stormwater runoff produced.

The focus areas are within the smolan silty loam and smolan silty clay loam soil classifications. Therefore, if bioretention solutions are to be proposed in the area, they must follow a set of guidelines to improve soil infiltration rates. According to the NRCS, necessary guidelines include:

- Avoid soil disturbance and equipment use when the soils are wet
- Use subsoil to break up compacted layers
- Use a continuous, no-till cropping system
- Apply organic material
- Use perennials, ground cover, and woody species

**Legend**

Focus Area

Smolan Silty Loam

Ivan & Kennebec Silty Loam

Wymore Silty Clay Loam

Smolan Silty Clay Loam

Wymore Silty Clay Loam

Tully Silty Clay Loam

Wymore-Kennebec Complex

Clime-Sogn Complex

Clime Silty Clay Loam

Chase Silty Clay Loam

Steady-State Infiltration Rates (in/hr)

| | |
|---|---|
| Sand | > 0.8 |
| Sandy and Silty | 0.4 - 0.8 |
| Loam | 0.2 - 0.4 |
| Clayey | 0.04 - 0.2 |
| Sodic Clayey | < 0.04 |

Table 4.1. Soil Infiltration Rates
Source: USDA n.d.

Note: Soils were analyzed at the watershed scale and not the parking lot scale due to a lack of site scale data.

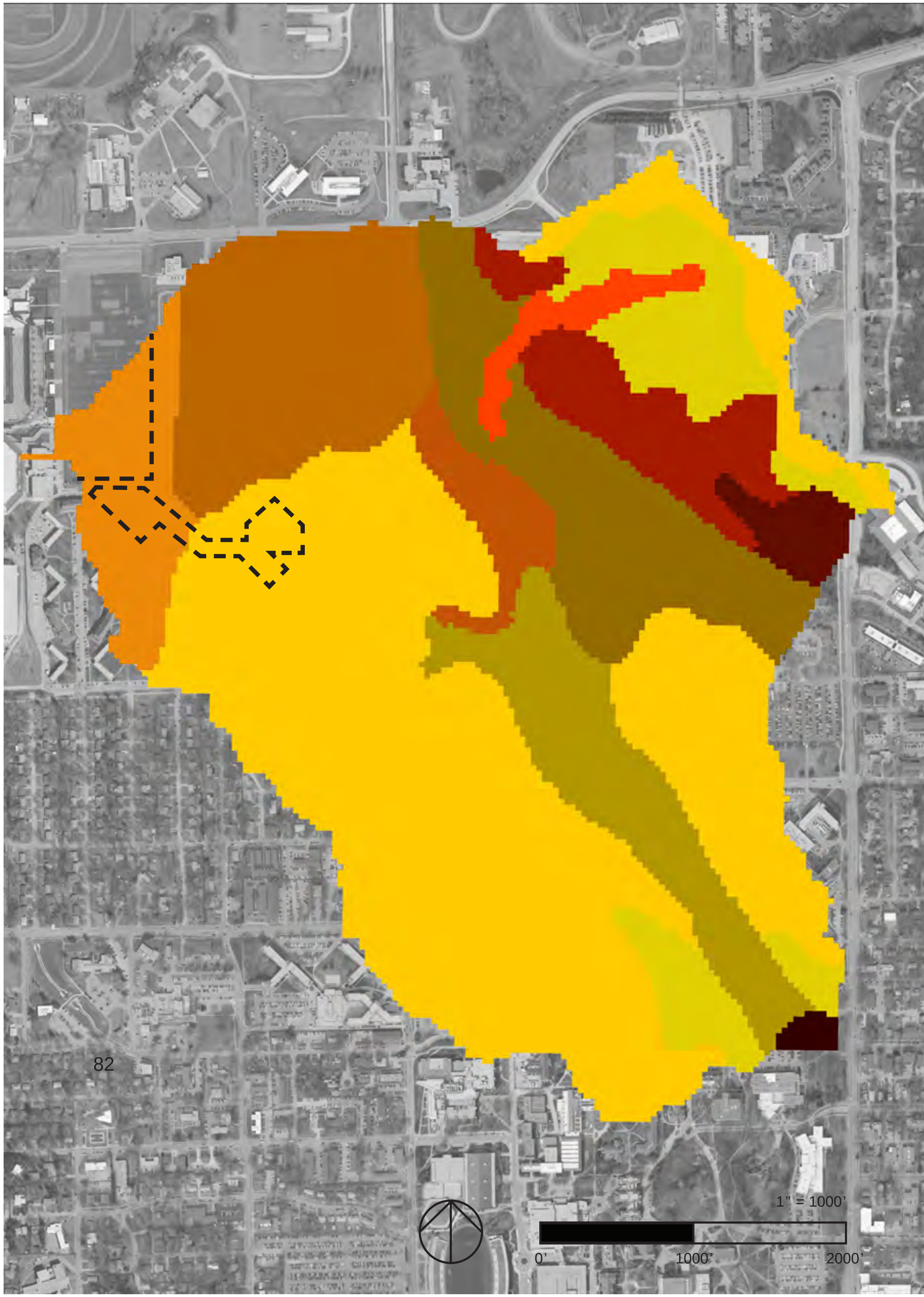



Figure 4.11. Campus Creek Watershed Soils.
Source: Campus Creek Watershed Assessment Report and the USDA Web Soil Survey

# 4.2.2 Parking Lot Scale Analysis

Site analysis was conducted at the parking lot scale to further understand the interactions between the stormwater runoff and Campus Creek, but at this scale, moreso the interactions between the hardscape and softscape. At the parking lot scale, topography and hydrology will guide the project by clearly defining the pathways that stormwater runoff travel down to get to Campus Creek and provide a more developed idea of what the individual focus areas need in order to address their stormwater management needs. In addition, to topography and hydrology, electric and gas utilities, and circulation will finalize what forms of green infrastructure will be utilized, and where they will be placed.

| | |
|---|---|
| A | East Stadium Parking Lot |
| B | Mid-Jardine Parking Lot |
| C | North Jardine Parking Lot |
| D | South Recreation Parking Lot |

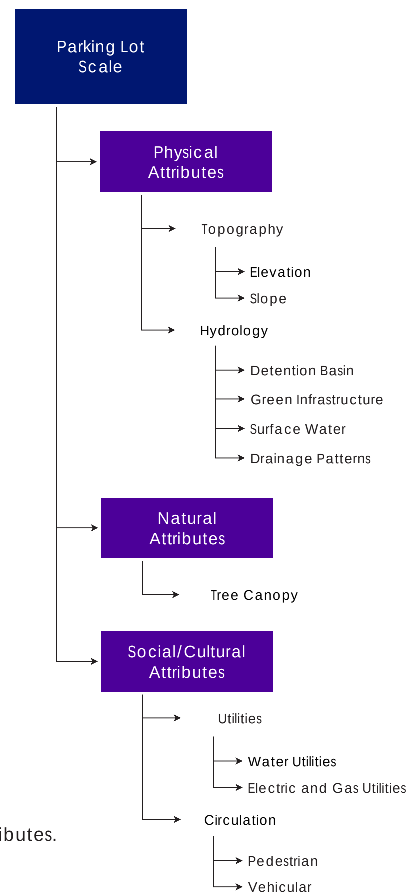



Figure 4.12. Parking Lot Analysis Attributes.


Figure 4.13. Project Focus Areas.

# 4.2.2 Parking Lot Scale Analysis

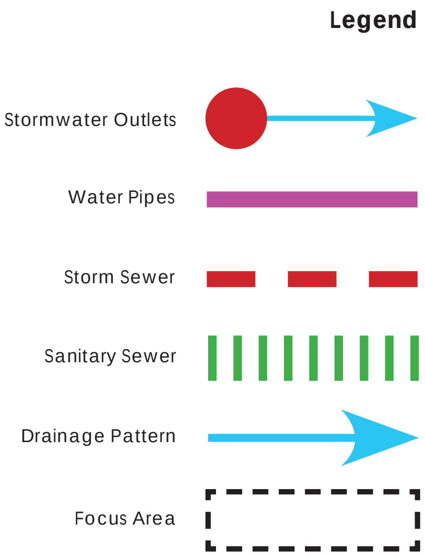
## A | East Stadium Parking Lot

**Topography and Hydrology**

The East Stadium parking lot encompasses a total area of approximately 16 acres, 7.1 acres of which are within the Campus Creek Watershed boundaries. The site contains underground sanitary sewer lines, storm sewer lines, and water pipes, all of which overlap one another. Two storm drains in the southeast corner of the parking lot move water into a small depressed area, and into another drain that moves stormwater into two rocked swales. The swales take water around a grove of trees and into another drain that deposits it into the detention basin south of the Peter's Recreation Center. The storm sewer lines also appear to travel from underneath Bill Snyder Stadium, which implies that runoff from beyond the watershed is being deposited into the same area.

Figure 4.14. East Stadium parking lot storm sewer outlet.

Figure 4.15. Rock swales that take on drainage from the East Stadium parking lot.



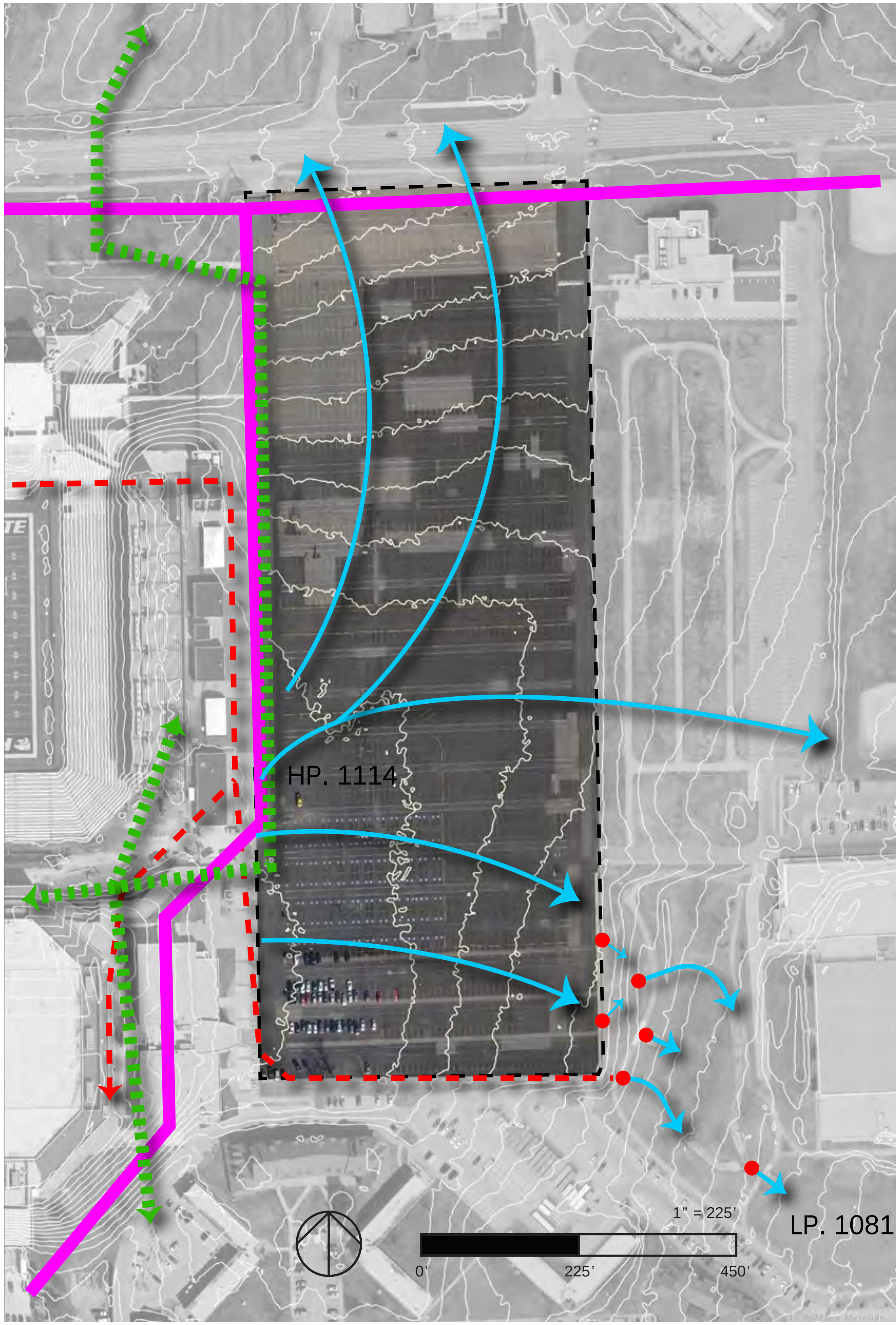




Figure 4.16. East Stadium Parking Lot Hydrology.
Source: LiDar

# 4.2.2 Parking Lot Scale Analysis

## A | East Stadium Parking Lot

**Electrical and Gas Utilities**

The East Stadium parking lot contains electrical utilities along the perimeter, but no gas utilities. The lines in Figure 4.17 represent the general area of the utility with a 15 foot buffer as well to increase legibility.

According to Figure 4.17, telephone lines travel north-south along the west edge of the lot and turn to the east at the southwestern edge. They mimic the same line as the storm sewer lines depicted in Figure 4.16 on the previous page, but extend beyond the drainage outlet and continue past the Peter's Recreation Center. The underground electrical lines surround the parking lot perimeter and cut across the southeastern and north eastern edges. According to Figure 4.16, stormwater runoff drains to the southeastern corner, therefore, providing an opportunity for permeable paving in that area.

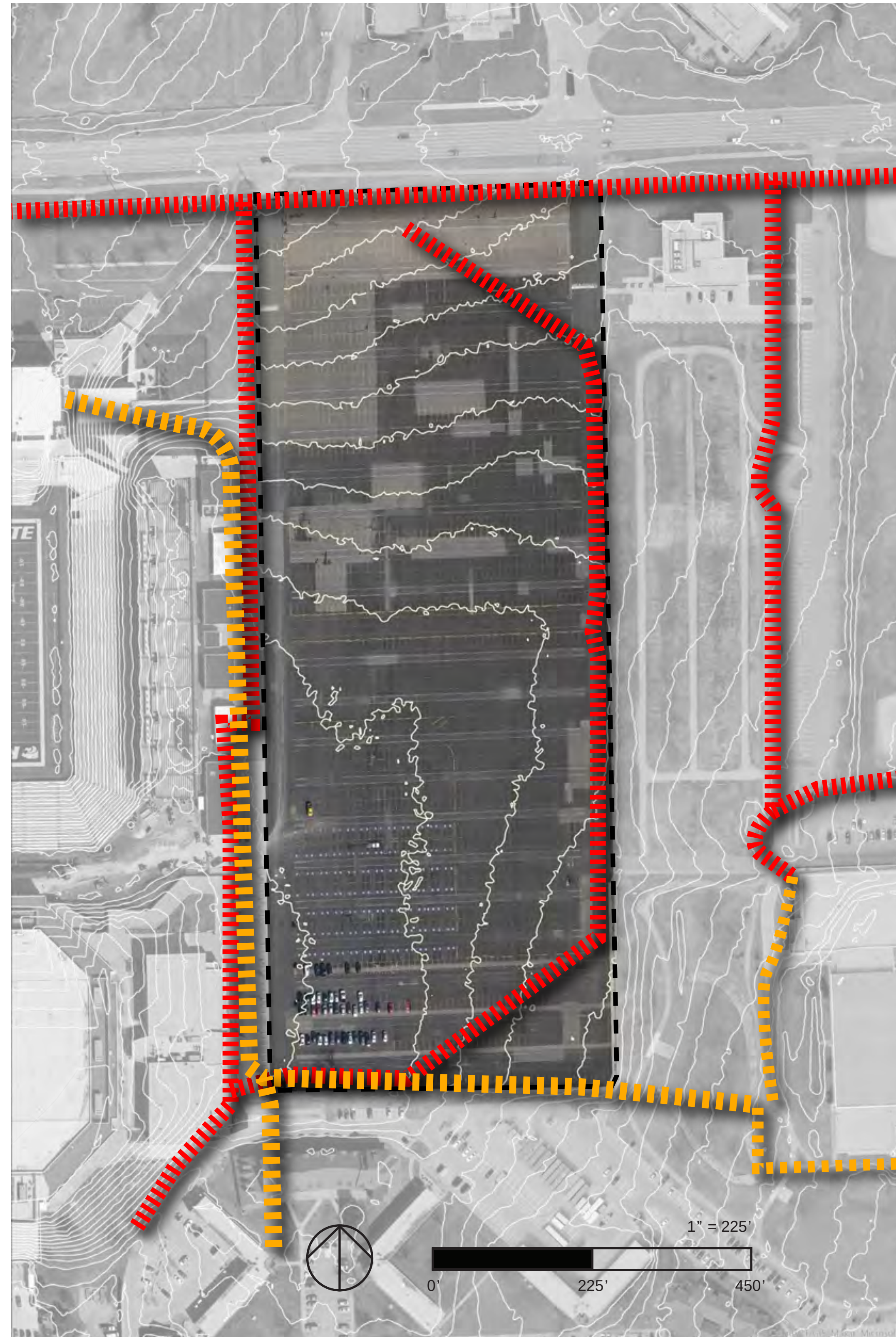



Figure 4.17. East Stadium Parking Lot Electric and Gas Utilities

# 4.2.2 Parking Lot Scale Analysis

## A | East Stadium Parking Lot

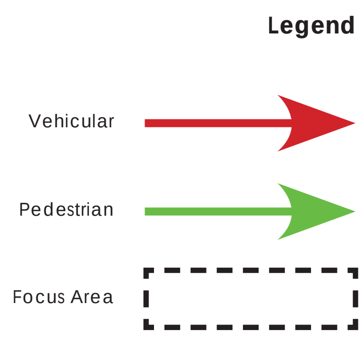
**Pedestrian and Vehicular Circulation**

The East Stadium parking lot is designed to house hundreds of vehicles for home football games, which are less than 10 days per year. During those days, traffic volume increases drastically in both pedestrian and vehicular form, therefore, the parking lot contains two primary vehicular entry points to the north and a secondary entry point to the east, leading into the northern Peter's Recreation Center parking lot.

During those same days, pedestrians inhabit the entire area as tailgating is taking place not only within the parking lot, but also right outside its eastern border, north of the Peter's Recreation Center.

Due to the amount of revenue brought in by the Bill Snyder Football Stadium and Bramlage Coliseum, it is unlikely that K-State Athletics would give up parking spots to make room for parking islands with bioretention or tree canopy. In terms of green infrastructure types, it is more realistic to consider permeable paving within this parking lot.

It's important to note that the southeastern corner of the parking lot houses an ATA bus stop utilized by Jardine residents, according to on-site observation.



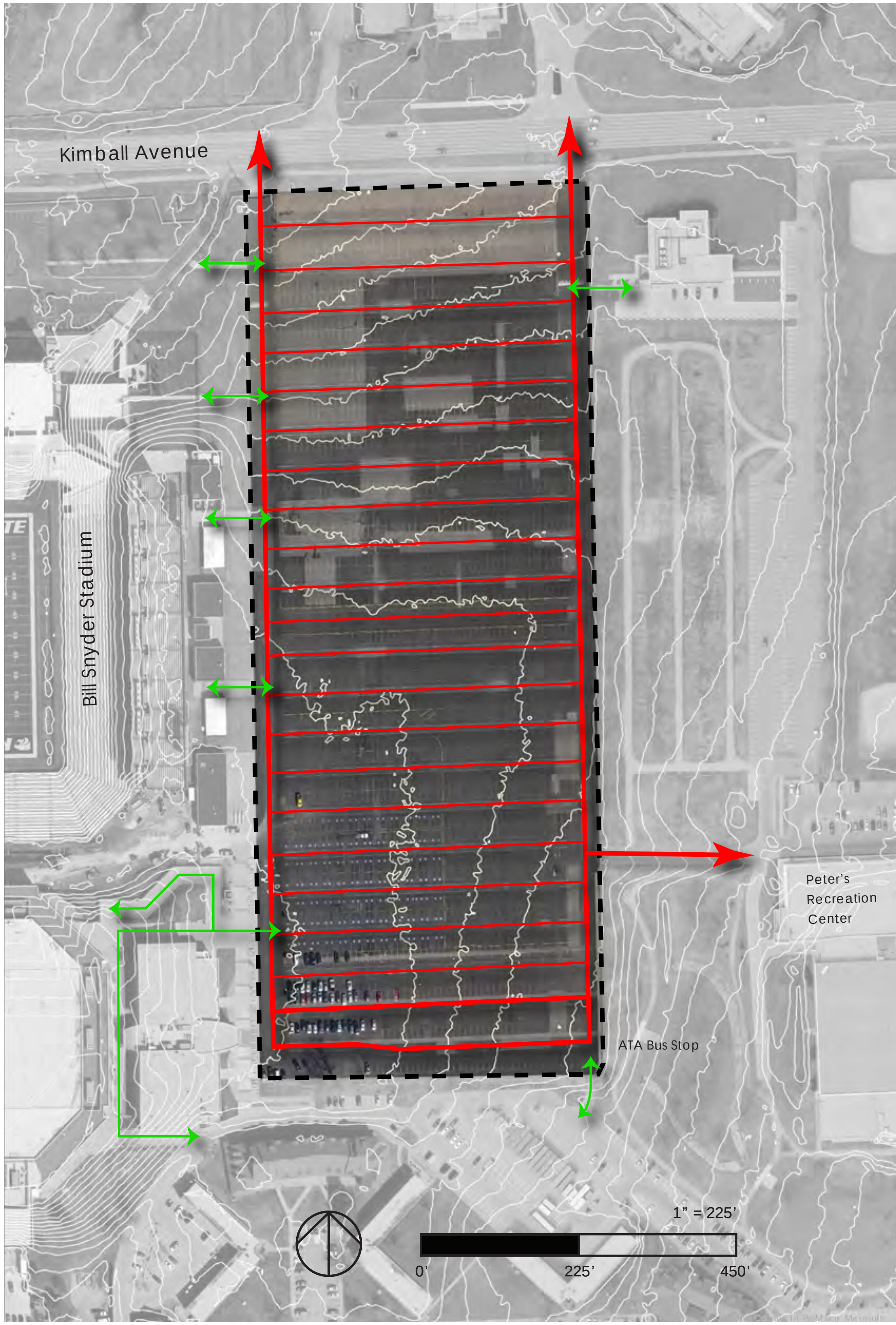




Figure 4.18. East Stadium Parking Lot Circulation.

# 4.2.2 Parking Lot Scale Analysis

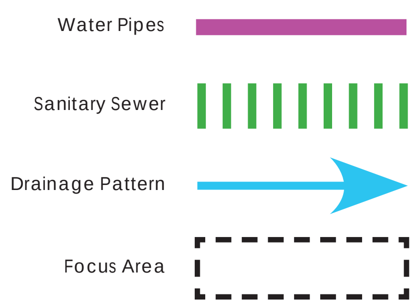
## B | Mid-Jardine Parking Lot

**Topography and Hydrology**

The Mid-Jardine parking lot encompasses approximately .56 acres, making it the smallest of all of the focus areas. According to Figure 4.19, there are sanitary sewer lines and water pipes traveling underneath the lot, but there are no storm sewers, as was confirmed during a site visit to the focus area. Therefore, stormwater runoff travels downslope to the north, through the entrance of the lot, and the travels east down the street, and into two stormdrains at the bottom of the street.


Figure 4.19. Mid-Jardine Parking Lot Hydrology.
Source: LiDar

**Legend**

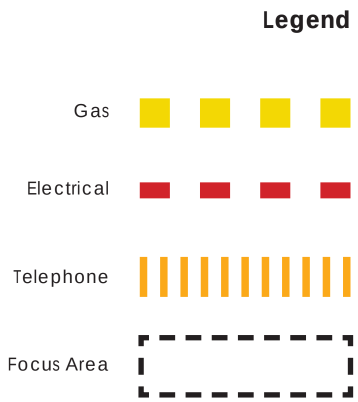



# 4.2.2 Parking Lot Scale Analysis

## B | Mid-Jardine Parking Lot

**Electrical and Gas Utilities**

In addition to water utilities, there are also electric and gas utilities, all of which respond to the building footprints adjacent to the parking lot. Electrical utilities appear to the east and west and mimic the building footprint of the easternmost apartment building. Power utilities travel underneath both parking islands and all three of the utilities travel under the southern most parking island. It's important to note that both islands also contain lightpoles, therefore, eliminating the ability to install bioretention or trees in the parking islands.



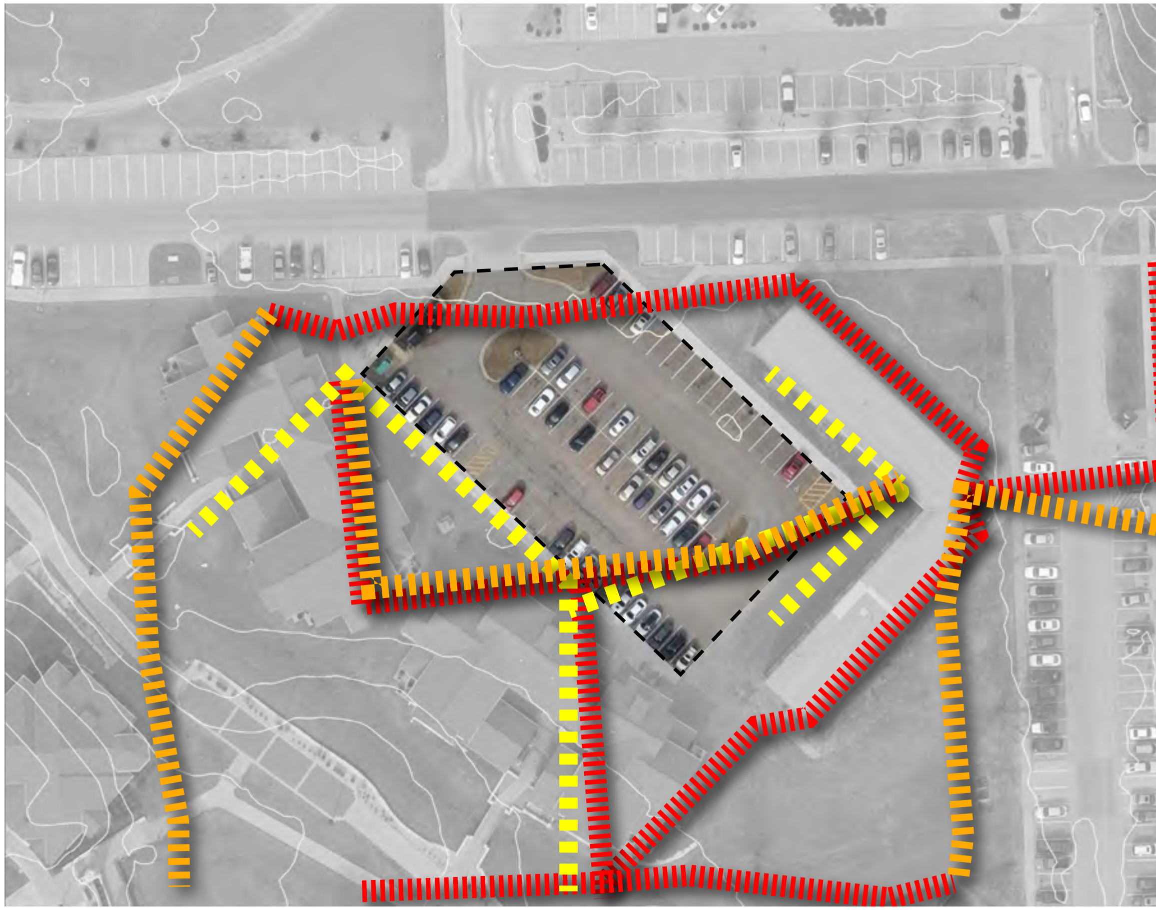



Figure 4.20. Mid-Jardine Parking Lot Electric and Gas Utilities.

# 4.2.2 Parking Lot Scale Analysis

## B | Mid-Jardine Parking Lot

**Pedestrian and Vehicular Circulation**

The Mid-Jardine parking lot accomodates multi-family residential parking, therefore, pedestrian circulation is direct, to and from the residential buildings adjacent to it. To the south, are two newer apartment buildings with a pathway that cuts through the ground floor of the building, to a bridge that crosses the Jardine drainage ditch.

Vehicular circulation is representative of the size of the lot and the graphic on the opposite page depicts a single loop that returns to the only entrance. The vehicular circulation is also representative of the proximity of the buildings to the parking lot itself. The parking lot is squeezed inbetween the buildings with very limited softscape. If there is softscape, it contains underground utilities, as was depicted on the previous two analysis.

The Mid-Jardine parking lot contains very little softscape free of utilities for bioretention or tree canopy and the utilities also eliminate the possibility of future permeable paving implementation. Since there are no storm sewers, and stormwater runoff drains towards Denison Avenue, the Mid-Jardine parking lot is not suitable for any future green infrastructure implementation.


Figure 4.21. Mid-Jardine Parking Lot Circulation.

**Legend**

Vehicular

Pedestrian

Focus Area

# 4.2.2 Parking Lot Scale Analysis

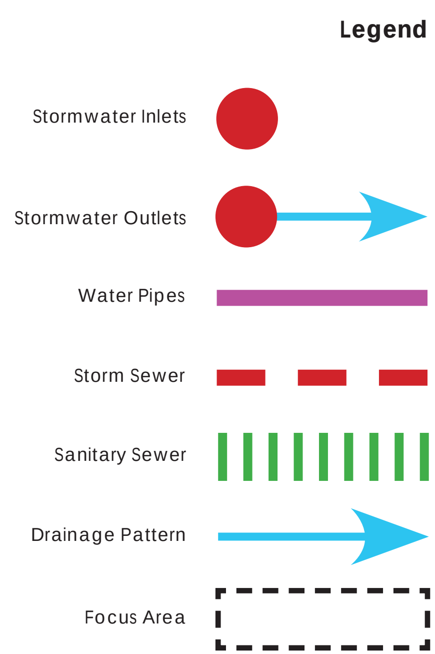
## C | North Jardine Parking Lot

**Topography and Hydrology**

The North Jardine parking lot encompasses a total area of approximately 2.18 acres and like the other focus areas, contains a wide assortment of underground utilities. The most current utility information available confirms the locations of sanitary sewer lines and water pipes, but does not map any storm sewer lines even though there are four storm drains onsite (confirmed during a site visit).

According to the head groundskeeper for Housing and Dining at Kansas State University, the four storm drains connect together and dump into a drainage ditch located in the center of the Jardine Apartment Complex; the storm sewer outlet is depicted in Figure 4.22 and 4.23. It's important to note that the storm sewer lines on the opposite page are not confirmed as updated utility maps are not available. Therefore, the connections between each storm drain are not entirely accurate, except where they inevitably drain to as depicted in Figure 4.24.

Figure 4.22 (top) and 4.23 (bottom). North Jardine Parking Lot Stormwater Outlets.



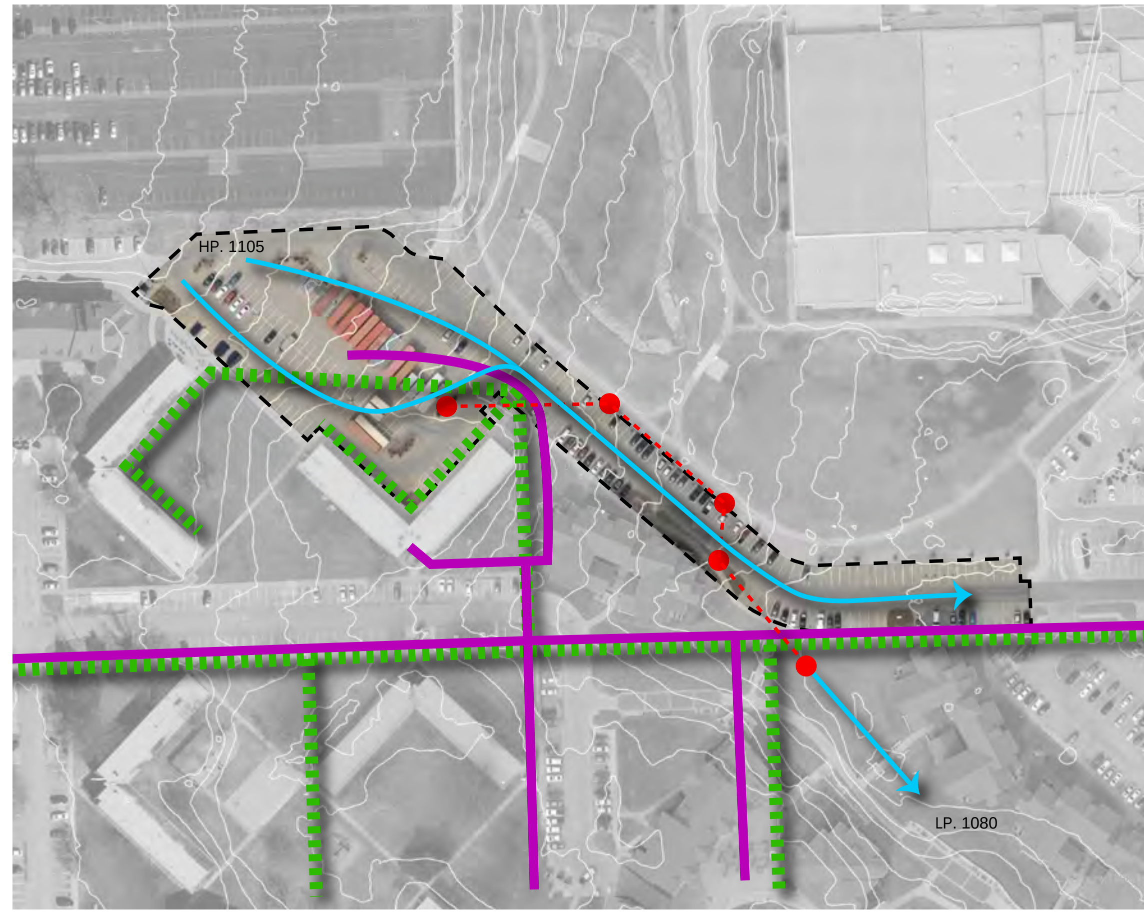




Figure 4.24. North Jardine Parking Lot Hydrology.
Source: LiDar

# 4.2.2 Parking Lot Scale Analysis

## C | North Jardine Parking Lot

**Electrical and Gas Utilities**

Like the other focus areas, there is an abundance of power and gas utilities present in and around the North Jardine parking lot. Electrical, gas, and telephone utilities, again, mimic the buildings they accomodate, but the vital difference between the North Jardine parking lot and the Mid-Jardine parking lot is their size. As noted, the North Jardine parking lot is approximately 2.18 acres in comparison to the .56 acres of the Mid-Jardine parking lot, therefore, there is more room for future interventions. Also, the Mid-Jardine parking lot was surrounded on 3 sides by residential buildings while the North Jardine parking lot only contains buildings on its south side, thus, ensuring that no electrical and gas utilities have to pass underneath the parking lot to reach the other side.

According to Figure 4.25, and the water utility map on the previous page, the northern parking islands are free of any underground utilities and are within the path of drainage downslope, thus, making them suitable for future bioretention or tree canopy implementation

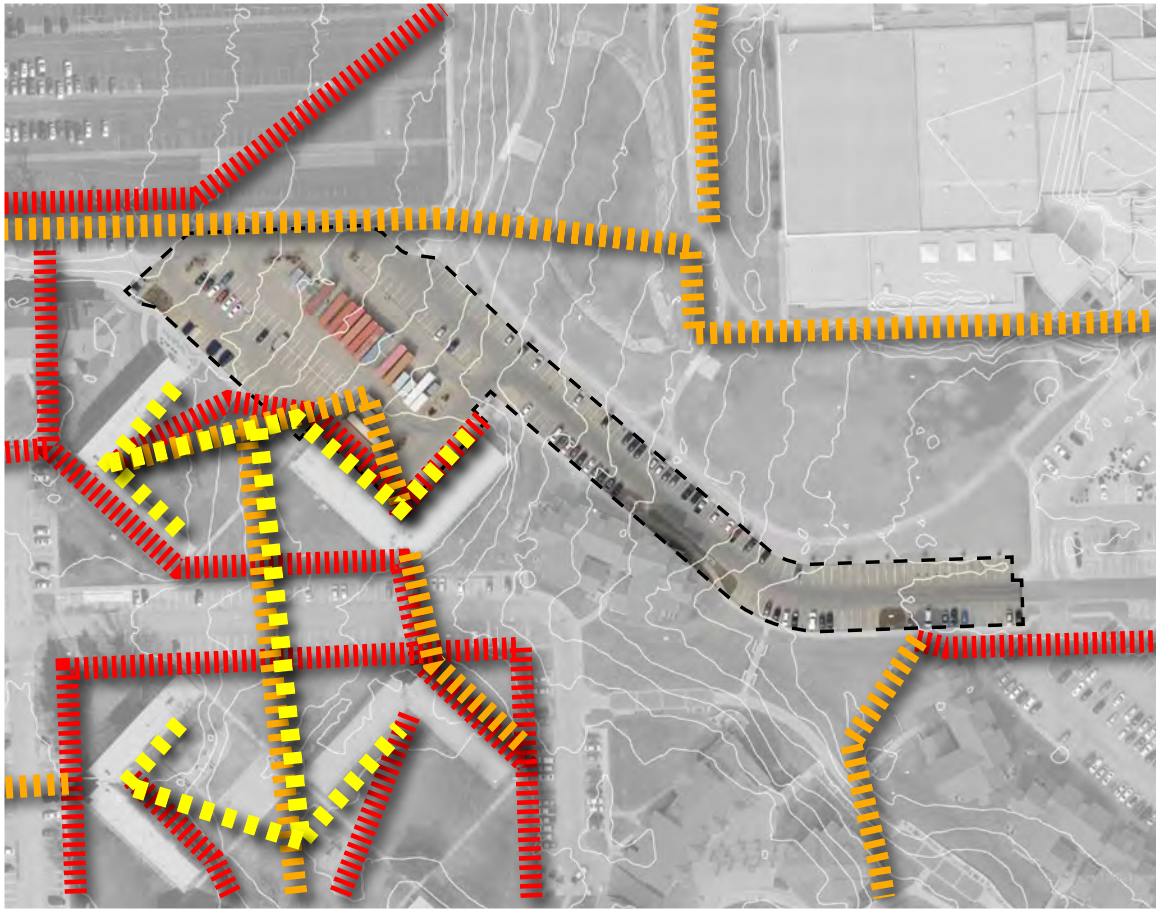


Figure 4.25. North Jardine Parking Lot Electric and Gas Utilities.

**Legend**

Gas

Electrical

Telephone

Focus Area

# 4.2.2 Parking Lot Scale Analysis

## C | North Jardine Parking Lot

**Tree Canopy**

The North Jardine parking lot contains nine Flowering Crabapples. As depicted in Figure 4.27, the crabapples appear to be in good condition but they are also very small. Crabapples are short-lived small trees that grow to approximately 15 to 20 feet in height with a similar width. Because these trees are located within parking islands they most likely will not be able to grow beyond the edge of the plant bed because cars need to be able to park there and because of their short lifespan, they most likely will not last more than 50 to 60 years. It’s important to note that a several evergreen trees align the northeastern edge of the parking lot, but due to their size and distance from the curb, they will not be considered in this project as they do not directly address the stormwater runoff of the North Jardine parking lot.

Figure 4.26. A view of the North Jardine parking lot looking east from the East Stadium parking lot.

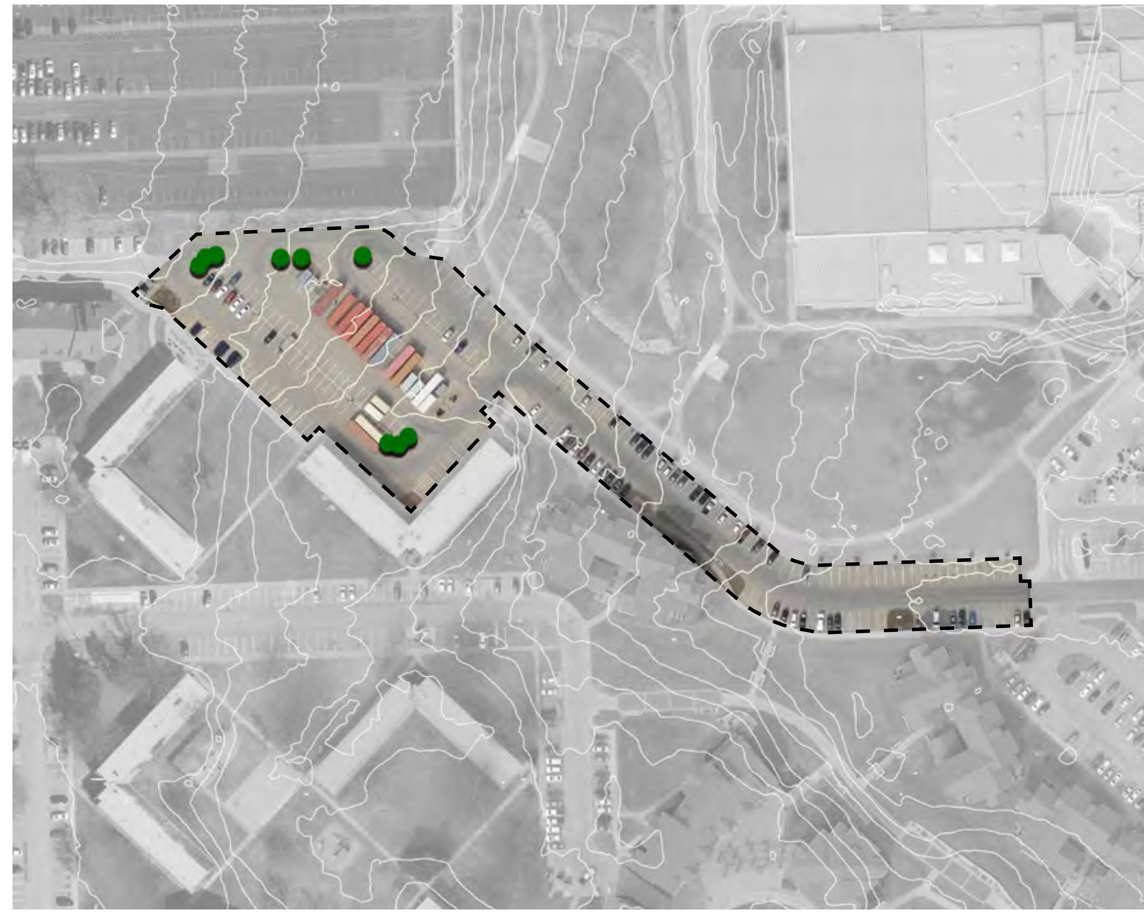


Figure 4.27. North Jardine Parking Lot Tree Canopy.

**Legend**

Tree Canopy

Focus Area

1” = 200’

0’ 200’ 400’

# 4.2.2 Parking Lot Scale Analysis

## C | North Jardine Parking Lot

**Pedestrian and Vehicular Circulation**

Like the Mid-Jardine parking lot, the North Jardine parking lot accomodates multi-family residential parking. In comparison to the Mid-Jardine parking lot, the North Jardine parking lot only accomodates two buildings instead of three, therefore, the lot often appears empty given it is almost four times the size of the Mid-Jardine parking lot.

Pedestrian circulation is more common in this lot, especially during football season. Many students walk to the stadium on gamedays, and the trails provided through the Jardine Apartment Complex in addition to the trails provided southwest of the Peter's Recreation Center, provide a short cut for students and families on their way to the game. Therefore, there is an opportunity to provide more aesthetic appeal to the parking lot as it accomodates a more informal form of pedestrian circulation in comparison to the other focus areas.

The North Jardine parking lot is suitable for both on and off-site green infrastructure solutions, particularly in the form of bioretention and tree canopy.

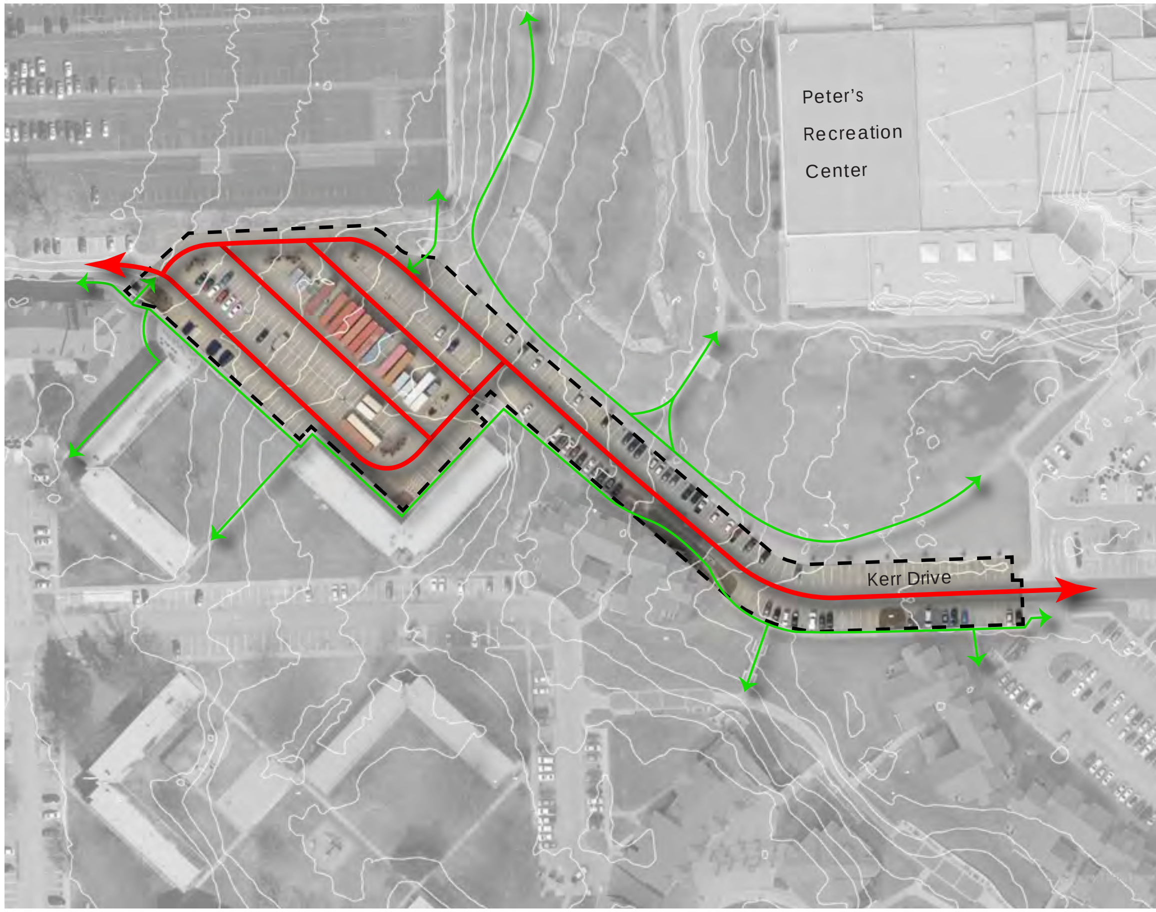



Figure 4.28. North Jardine Parking Lot Circulation.

**Legend**

Vehicular

Pedestrian

Focus Area

1" = 200'

0' 200' 400'

# 4.2.2 Parking Lot Scale Analysis

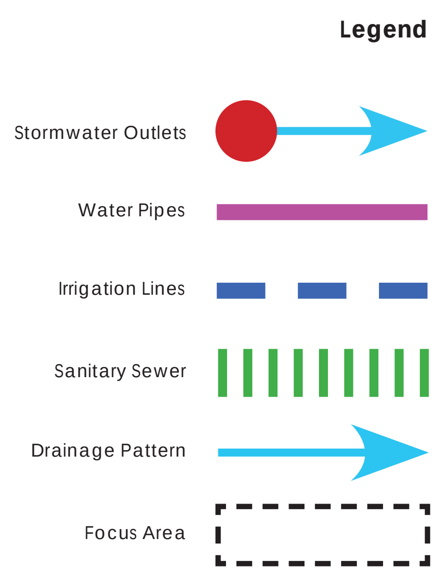
## D | South Recreation Parking Lot

**Topography and Hydrology**

The South Recreation parking lot encompasses approximately 1.39 acres. According to the most current utility information, the parking lot is completely free of underground water utilities, but it's important to note that there is a stormwater outlet located at the southeast corner of the lot (see Figure 4.29). It is unconfirmed as to where this drain originates at, therefore it is not mapped in the figure opposite of this page.

There are no other stormwater inlets within the South Recreation parking lot, therefore, implying that runoff from the parking lot meets with the runoff from the southeastern storm outlet and moves downslope to a drain at the bottom of Kerr Drive. This is also the case for the Mid-Jardine parking lot.

Figure 4.29. South Recreation Parking Lot southeastern stormwater outlet.



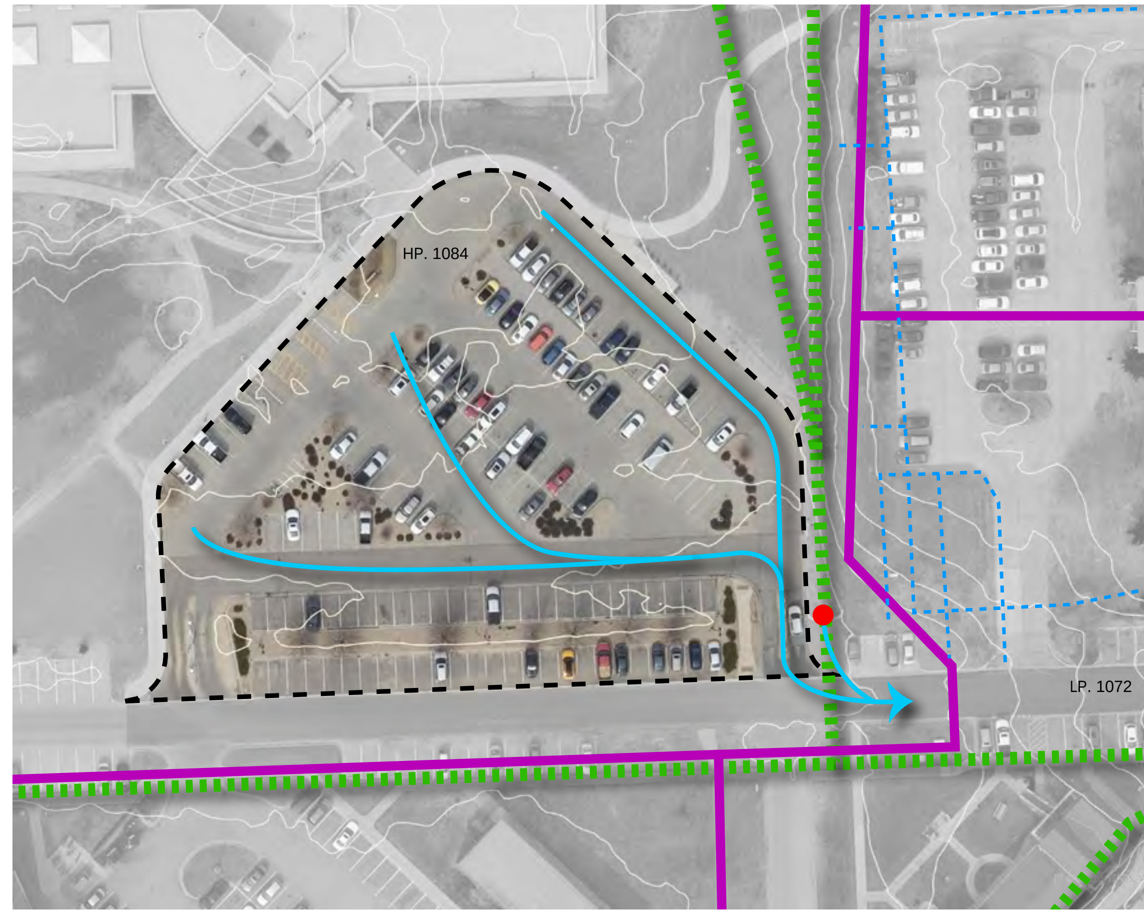




Figure 4.30. South Recreation Parking Lot Hydrology.
Source: LiDar

# 4.2.2 Parking Lot Scale Analysis

## D | South Recreation Parking Lot

**Electrical and Gas Utilities**

As noted, the South Recreation parking lot accomodates a different land use than the other focus areas, therefore, electrical utilities also do not travel underneath the parking lot. There is one telephone line that travels across the northern corner of the parking lot and connects to Edwards Hall to the east. There are electrical utilities farther north, but the closest to the focus area are across Kerr Drive at the Mid-Jardine parking lot.

Due to the lack of utilities within the South Recreation parking lot, all of the parking islands are suitable for future green infrastructure implementation.

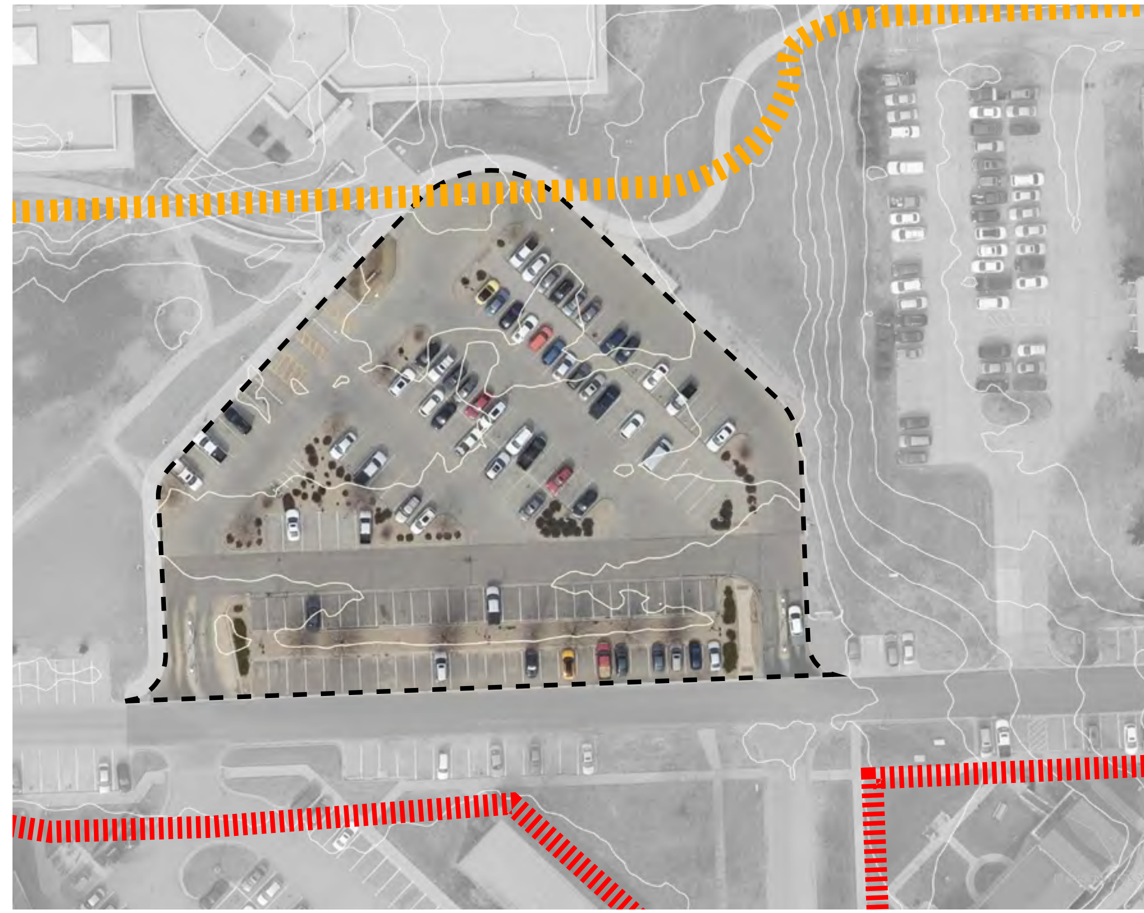


Figure 4.31. South Recreation Parking Lot Electric and Gas Utilities.

**Legend**

Electrical

Telephone

Focus Area

# 4.2.2 Parking Lot Scale Analysis

## D | South Recreation Parking Lot

**Tree Canopy**

The South Recreation parking lot contains seven Lacebark Elm trees (also referred to as Chinese Elm trees) and seven Eastern Red Cedar trees. The trees appear to be older than the crabapples located in the North Jardine parking lot and they are also tree species that are more suitable for parking lots. The Lacebark Elm can grow to approximately 40 to 50 feet in height with a spread of 35 to 45 feet; the Eastern Red Cedar can grow to approximately 40 to 50 feet in height with a spread of 10 to 20 feet at maturity. Because of their size, the South Recreation parking lot will have more benefits provided by their trees due to their ability to intercept rainfall in comparison to the North Jardine parking lot trees.

Figure 4.32. South Recreation parking lot tree canopy.

**Legend**

Tree Canopy

Focus Area

1” = 80’

0’ 80’ 160’

# 4.2.2 Parking Lot Scale Analysis

## D | South Recreation Parking Lot

**Pedestrian and Vehicular Circulation**

The South Recreation parking lot is perhaps the busiest among the focus areas as it accomodates a commercial use that is popular among Kansas State University students and faculty. Vehicular circulation is angled 45 degrees to the northwest and southeast with two access points into the lot on the south side.

Pedestrian circulation within the parking lot boundaries tends to mimic vehicular circulation with one pathway within and one along the perimeter all reflecting a 45 degree angle to the northwest and southeast. The South Recreation parking lot also grants access to the trails leading to the Bill Snyder Stadium which implies that during football season, many visitors will pass through the South Recreation parking lot.

This increase in pedestrian traffic volume is another reason to provide more aesthetic appeal and shade to not only the parking lot but also its adjacent pathways.

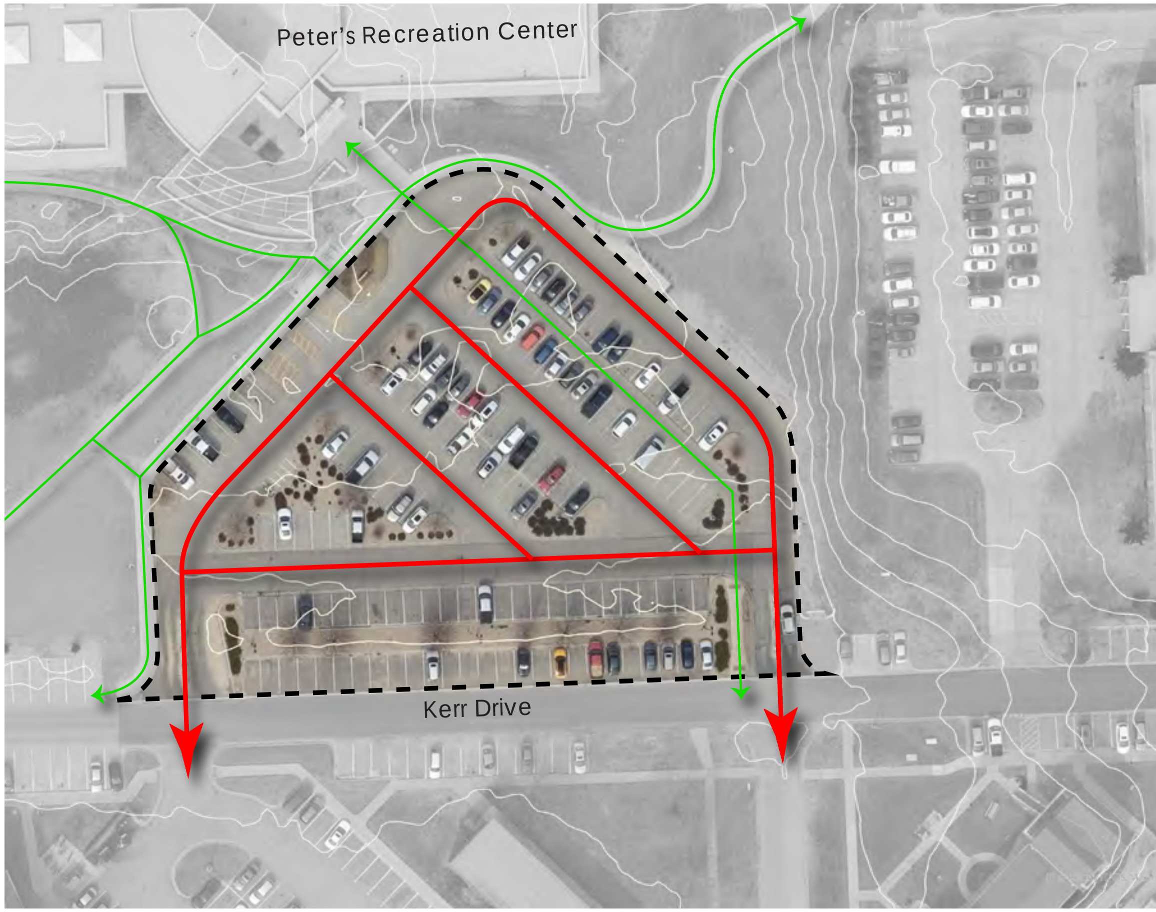



Figure 4.33. South Recreation Parking Lot Circulation.

**Legend**

Vehicular

Pedestrian

Focus Area

# 4.3 Modeling

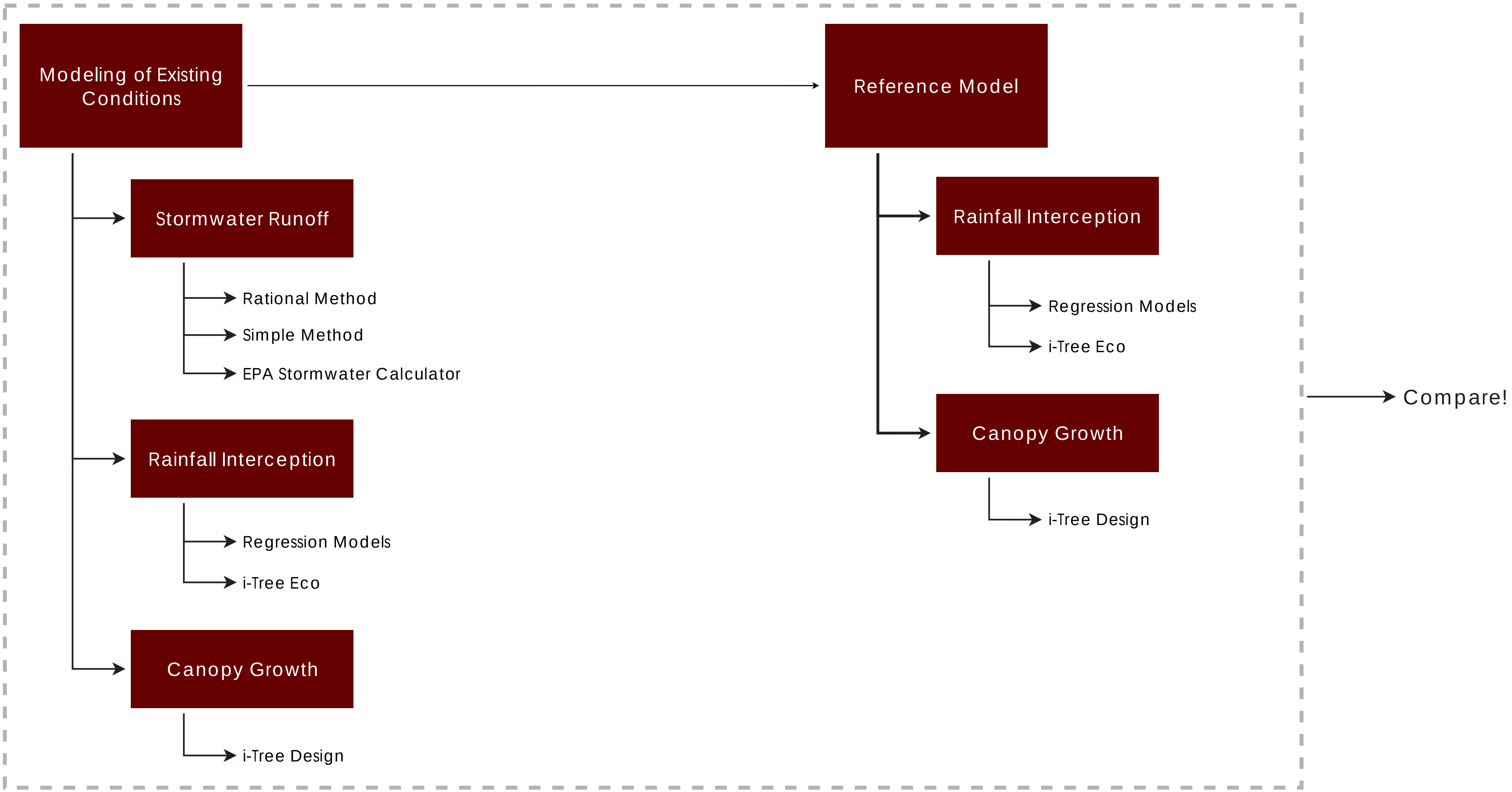



Figure 4.34. Modeling

# 4.3.1 Runoff Calculations

Runoff calculations were conducted on existing conditions to establish a baseline for the projective design and reinforce the need for green infrastructure.

**The Rational Method** was used to estimate the peak runoff in cubic feet per second for each catchment area and parking lot. The findings are proportional to the size of the parking lot being analyzed (e.g., the East Stadium Parking Lot is the largest parking lot, therefore, producing the most runoff). In every storm event the East Stadium Parking Lot produces over 75 percent more runoff than any of the other parking lots. See Appendix D for work.

**The Simple Method** was used to estimate the pollutant loads for each of the parking lots and their associated land uses in pounds per year. The findings are, again, proportional to the size of the analyzed parking lot. See Appendix E for work.

**Zinc (Zn)** is the most abundant pollutant in this scenario. Zinc can be deposited into nearby waterbodies via stormwater runoff if the runoff comes in contact with galvanized metal, motor oil, hydraulic fluid, and tire dust (Golding 2008).

**Lead (Pb)** is one of the metals of greatest water quality concern as it was once used as an additive in gasoline. The USEPA has water quality criteria for pollutant concentrations and widespread soil contamination from lead can often cause soils adjacent to roads, highways, parking lots, etc., to violate these criteria (Jones-Lee and Lee 2000).

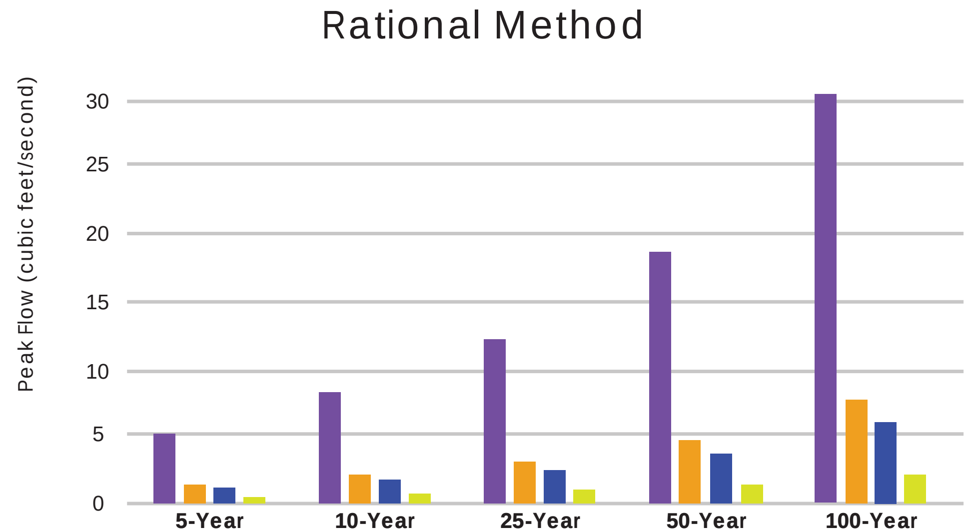
**Copper (Cu)** is used for electrical wiring, plumbing, air conditioning tubing, and roofing. According to the State of Connecticut Department of Environmental Protection, most of their major rivers exceed the copper water quality criteria several times throughout the year and this leads to negative impacts on aquatic life.

**F. Coli** is short for fecal coliform and is a form of bacteria that is found in fecal matter, particularly pet, livestock, and wildlife waste, in this case (Minnesota Pollution Control Agency 2020).

**Nitrogen (TN)**, according to Wang et al. (2022), can be found in road and roof runoff.

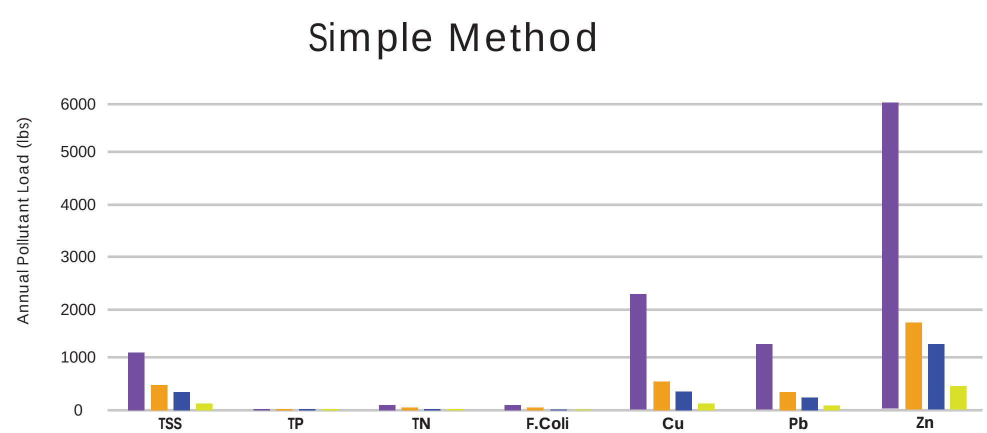
**Phosphorus (TP)** is a common component of agricultural fertilizers, manure, and organic waste (Minnesota Pollution Control Agency 2021).

**Total Suspended Solids (TSS)** comprises both inorganic and organic material and is one of the most common contaminants found in urban stormwater runoff. They originate from many sources including dust, litter, and other deposits on or from impervious surface. Erosion at construction sites is also a major source of solids. A high TSS can increase turbidity, limit aquatic plant growth, and reduce penetration of light within water.




| | 5-Year | 10-Year | 25-Year | 50-Year | 100-Year |
|---|---|---|---|---|---|
| East Stadium | 0.23 | 8.41 | 12.67 | 19.26 | 31.58 |
| North Jardine | 1.30 | 2.10 | 3.16 | 4.80 | 7.88 |
| South Recreation | 1.02 | 1.65 | 2.48 | 3.77 | 6.18 |
| Mid-Jardine | 0.33 | 0.54 | 0.81 | 1.23 | 2.02 |

Figure 4.35. Estimated peak rate of the focus areas produced via the Rational Method of runoff calculation (Appendix i).




| | TSS | TP | TN | F.Coli | Cu | Pb | Zn |
|---|---|---|---|---|---|---|---|
| East Stadium | 1166.30 | 6.5 | 82.1 | 77.75 | 2202.99 | 1209.5 | 6004.22 |
| North Jardine | 348.24 | 1.93 | 24.5 | 23.22 | 657.8 | 361.14 | 1792.81 |
| South Recreation | 246.40 | 1.37 | 17.34 | 16.43 | 465.42 | 255.52 | 1259.4 |
| Mid-Jardine | 95.30 | 0.53 | 6.7 | 6.35 | 179 | 98.8 | 490.5 |

Figure 4.36. Estimated pollutant load of the focus areas via the Simple Method of runoff calculation. (Appendix ii).

# 4.3.2 Rainfall Interception

i-Tree Eco

Interception is the amount of rainfall remaining on tree canopy surfaces and is evaporated after or during a rain event (Beidokhti and Moore 2021). i-Tree Eco allows its users to input a complete inventory of trees and model the benefits of them in terms of carbon sequestration, avoided runoff, pollutant removal, and more. i-Tree requires the tree species, and its diameter at breast height (DBH), but has optional fields that can provide for more accurate modeling results and are listed below (fields used for this project are highlighted in red).

### General Site Fields

- Tree Address
- Land Use
- Strata/Area
- Status
- Street Tree/Non-Street Tree
- Map (GPS) coordinates
- Public/Private

### Management Fields

- Maintenance Recommended
- Maintenance Task
- Sidewalk Conflict
- Utility Conflict
- Pests
    - Sign & Symptoms of Tree Stress
    - Sign & Symptoms of Foliage
    - Sign & Symptoms of Branches
- User Tree ID

### Tree Detail Fields

- Total Tree Height
- Crown Size
    - Height to Live Top
    - Height to Crown Base
    - Crown Width
    - Percent Crown Missing
- Crown Health
- Crown Light Exposure
- Energy (Building Interactions)
    - Distance to Building
    - Direction to Building

Crown size and health are highly recommended fields because of their influence on the accuracy of the modeling results, but they could not be documented as the inventories were conducted during leafless months. Therefore, i-Tree assumes the leaf area based off the species and DBH measurements.

In this case, tree inventories were done for the North Jardine and South Recreation parking lots. The Mid-Jardine and East Stadium parking lots were not modeled because they currently do not have any tree canopy cover.

The South Recreation parking lot contains seven Chinese Elm trees growing to a height of 40 to 60 feet with an equal spread at maturity. The South Recreation parking lot also contains seven Eastern Redbud trees that grow to between 20 and 30 feet tall with a similar canopy spread. The North Jardine parking lot contains 9 Flowering Crabapples growing to 20 feet in height with a 15 foot canopy spread, therefore, the South Recreation parking lot intercepts almost four times more water than the North Jardine parking lot because of its larger tree species in higher quantities.

C | North Jardine Parking Lot

| Tree Species | DBH | Water Intercepted (cubic feet per year) |
|---|---|---|
| Flowering Crabapple | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 4.8 | 19.2 |
| | 5.1 | 25.7 |
| | 4.8 | 40.8 |
| | 4.8 | 40.8 |
| **Total** | | **240.12** |

Table 4.2. Estimated rainfall intercepted by the Trees in the North Jardine Parking Lot.

Figure 4.37. Existing tree canopy in the North Jardine Parking Lot.

D | South Recreation Parking Lot

| Tree Species | DBH | Water Intercepted (cubic feet per year) |
|---|---|---|
| Chinese Elm | 7.6 | 21.5 |
| | 4.5 | 12.1 |
| | 5.7 | 19.5 |
| | 8.9 | 48.1 |
| | 6.7 | 20.6 |
| | 5.1 | 9.2 |
| | 5.1 | 12.6 |
| Eastern Redbud | 10.8 | 93.8 |
| | 9.9 | 101.2 |
| | 11.5 | 137.9 |
| | 6.7 | 35.5 |
| | 11.8 | 91 |
| | 9.9 | 81.2 |
| | 10.5 | 51.9 |
| **Total** | | **736.1** |

Table 4.3. Estimated rainfall intercepted by the Trees in the South Recreation Parking Lot.

Figure 4.38. Existing tree canopy in the South Recreation Parking Lot.

# 4.3.2 Rainfall Interception

Regression Models

Alireza Nooraei Beidokhti and Trisha Lynn Moore (2021) conducted a meta-data analysis of the effects of precipitation, tree phenology, leaf area index, and bark characteristics on the throughfall rates of urban trees. Throughfall is the amount of rainfall that reaches the ground through the tree canopy, with or without contacting canopy surfaces. The results of the meta-data analysis lead to the development of a series of regression models that can represent the amount of throughfall associated with the different tree types (see Table 4.4), not the individual species. In this case, the tree types are split by leaf characteristics and bark characteristics (characteristics used in this model are highlighted in red):

**Leaf Types**

- Deciduous Leafless
- Deciduous Leafed
- Evergreen Broadleaf
- Evergreen Needleleaf

**Bark Types**

- Rough Bark
- Smooth Bark

For this project, the goal is to model the amount of rainfall captured per storm event for Deciduous Leafed-Rough Bark Trees, therefore, the following equation is presented (Appendix G):

**Volume captured = (Rainfall - Throughfall) x Leaf Area**

The models were conducted for five storm events:

**Standard Storm**

| | | |
|---|---|---|
| Depth | 1.0 inch | Stated on Page 27 of the Kansas Water Pollution Control Permit for Stormwater Management (KDHE 2019) |
| Duration | 6 hours | |

**Water Quality Storm**

| | | |
|---|---|---|
| Depth | 1.10 inches | Stated in Section 4: Structural BMP construction for Kansas as the 90th Percentile Rain Event (MARC 2012) |
| Duration | ----- | |

**10 Year (A)**

| | | |
|---|---|---|
| Depth | 2.92 inches | Rain events that are more likely to produce flood related issues |
| Duration | 2 hours | |

**10 Year (B)**

| | |
|---|---|
| Depth | 4.94 inches |
| Duration | 24 hours |

**50 Year**

| | |
|---|---|
| Depth | 5.57 inches |
| Duration | 6 hours |

Throughfall was determined for **Deciduous Leafed - Rough Bark** trees using the formula below:

**TH = -0.49 + 0.77(P)**

P = Precipitation

| Storm Event | Throughfall |
|---|---|
| Standard | .28 |
| Water Quality | .36 |
| 10 Year (A) | 1.76 |
| 10 Year (B) | 3.31 |
| 50 Year | 3.79 |

Table 4.4. Estimated throughfall for deciduous leafed-rough bark trees.

Percentage of total rainfall intercepted by Deciduous Leafed - Rough Bark trees

**Volume captured (%) = (Rainfall - Throughfall)/Rainfall**

| Storm Event | % Rainfall Captured |
|---|---|
| Standard | 72% |
| Water Quality | 67% |
| 10 Year (A) | 39.7% |
| 10 Year (B) | 33% |
| 50 Year | 32% |

Table 4.5. Estimated throughfall (%) for deciduous leafed-rough bark trees.

C | North Jardine Parking Lot

| Storm Event | Rainfall Volume Captured (cubic feet per storm event) |
|---|---|
| Standard | 833.76 |
| Water Quality | 856.92 |
| 10 Year (A) | 1343.28 |
| 10 Year (B) | 1887.54 |
| 50 Year | 2061.24 |

Table 4.6. Rainfall volume captured per storm event for the North Jardine parking lot trees.

Figure 4.39. Existing tree canopy in the North Jardine parking lot.

D | South Recreation Parking Lot

| Storm Event | Rainfall Volume Captured (cubic feet per storm event) |
|---|---|
| Standard | 3094.56 |
| Water Quality | 3180.52 |
| 10 Year (A) | 4985.68 |
| 10 Year (B) | 7005.74 |
| 50 Year | 7650.44 |

Table 4.7. Rainfall volume captured per storm event for the South Recreation parking lot trees.

Figure 4.40. Existing tree canopy in the South Recreation parking lot.

See Appendix G for Regression calculations

# 4.3.3 Canopy Growth

i-Tree Design

Canopy growth was modeled to understand the size that different tree species can achieve after certain periods of time. All tree species grow at different rates and to different sizes, therefore, understanding the amount of time it takes for an urban tree to cover the impervious surface adjacent to it can aid in selection of tree species and can also justify the need for more or different tree canopy.

i-Tree Design allows users to model tree canopy growth over a 60 year time frame and requires the tree species, its current DBH or circumference, the current condition, and its exposure to sunlight. The modeling software can also calculate the impact the inventoried trees have on the cooling and heating utility bills of buildings they're adjacent to. The graphics on this page depict canopy size at 30 and 60 years of growth and utility benefits were not modeled as none of the inventoried trees are close enough to a building to provide said benefits.

C | North Jardine Parking Lot

Figure 4.41. North Jardine tree canopy growth over 30 years.

Figure 4.42. North Jardine tree canopy growth over 60 years.

Note: The Mid-Jardine and East Stadium parking lots were not modeled for canopy gowth as they do not contain trees.

Findings

The North Jardine parking lot contains eight Flowering Crabapple trees. The Flowering Crabapple is a small and short lived tree that typically grows to approximately 20 feet in height with a 15 foot canopy spread, so if the trees live to 60 years, their canopies will only cover the adjacent impervious cover by one to five feet since their beds are between 10 to 20 feet in width. It's important to note that even if the canopies covered the adjacent impervious cover, they will most likely be pruned as the Flowering Crabapples are short trees located within a parking lot, so allowing their canopies to grow beyond the bed will hinder the ability for a car to be parked adjacent to it. Therefore, Flowering Crabapple are a poor parking lot tree.

The South Recreation parking lot contains Chinese Elm and Eastern Red Cedars both of which grow higher and wider than the Flowering Crabapple, thus, allowing for the trees to provide more benefits since they will eventually cover the adjacent impervious surface, proving that Chinese Elms and Eastern Red Cedars are adequate parking lot trees.

D | South Recreation Parking Lot

Figure 4.43. South Recreation tree canopy growth over 30 years.

Figure 4.44. South Recreation tree canopy growth over 60 years.

# 4.3.4 Reference Model

## West Memorial Stadium Parking Lot

The West Memorial Stadium parking lot will be modeled to demonstrate the benefits of having a large amount of trees that cover their adjacent impervious cover. The West Memorial Stadium parking lot contains 147 trees of 11 different tree species. The trees are planted in long 10-foot-wide islands (see Figure 4.47) and appear to be in good condition while being over 30-years-old according to the most recent aerial imagery (1991). It's important to note that the reference model is intended to compare rainfall interception between the focus areas and the West Memorial Stadium parking lot and will not compare overall runoff reductions by bioretention because the reference model site does not contain bioretention, just a large amount of tree canopy cover.

The data was drawn from an existing tree inventory done in the late 1990s and was cross referenced in the field. The original inventory states that there were 157 trees in the parking lot but there are now 147 due to new development or failure. Due to time constraints and limited resources, DBH of the individual trees was calculated as an average of 25% of each species and then made uniform among all of the trees of that species. For example, there are 24 Littleleaf Linden trees within the parking lot, therefore, 6 of the 24 trees were measured for DBH, then the average of the 4 measurements (15.6) determined the DBH for all of the Littleleaf Linden trees within the West Memorial Stadium parking lot. Therefore, the results are not as accurate as they could be but still imply the benefits of having large amounts of tree canopy cover.

Figure 4.45. West Memorial Stadium parking lot.

Figure 4.46. West Memorial Stadium parking lot tree canopy cover.

Figure 4.47. Root flare of a Littleleaf Linden tree within the West Memorial Stadium parking lot.

# 4.3.4 Reference Model

Rainfall Interception | i-Tree Eco

Interception is the amount of rainfall remaining on tree canopy surfaces and is evaporated after or during a rain event (Beidokhti and Moore 2021). i-Tree Eco allows its users to input a complete inventory of trees and model the benefits of them in terms of carbon sequestration, avoided runoff, pollutant removal, and more. i-Tree requires the tree species, and its diameter at breast height (DBH), but has optional fields that can provide for more accurate modeling results. Due to time constraints, as noted, the DBH was calculated as an average of 25% of the tree species in question and crown width and dieback could not be documented as the inventory was conducted during leafless months.

| Tree Species | # of Trees | DBH | Individual Interception | Total Water Intercepted (cubic feet per year) |
|---|---|---|---|---|
| Littleleaf Linden | 24 | 15.6 | 156.9 | 3795.6 |
| Red Maple | 15 | 12.7 | 66.2 | 993 |
| Green Ash | 18 | 14.2 | 158.0 | 2844 |
| Flowering Crabapple | 25 | 17.3 | 98.9 | 2472.5 |
| Royal Purple Smoketree | 2 | 11.5 | 38.4 | 76.8 |
| Eastern Redbud | 9 | 7.9 | 34.8 | 313.2 |
| American Elm | 4 | 12.7 | 103.8 | 415.2 |
| Black Walnut | 2 | 10.2 | 76.1 | 152.2 |
| Chinese Elm | 2 | 14.6 | 113.2 | 226.4 |
| Hackberry spp. | 7 | 14.3 | 143.3 | 1003.1 |
| Goldenrain Tree | 20 | 11.1 | 107.7 | 2154 |
| Siberian Elm | 13 | 9.2 | 57.2 | 743.6 |
| **Total** | | | | **15879.8** |

Table 4.8. The West Memorial Stadium Parking Lot trees and the total water they intercept.

| Parking Lot | Lot Area (acres) | Total Trees | Total Water Intercepted (cubic feet per year) |
|---|---|---|---|
| North Jardine | 2.12 | 9 | 240.12 |
| South Recreation | 1.41 | 14 | 736.1 |
| East Stadium | 7.1 | 0 | 0 |
| Mid-Jardine | .57 | 0 | 0 |
| **Total** | **11.2** | **23** | **976.22** |
| **West Memorial Stadium** | **6.7** | **147** | **15879.8** |

Table 4.9. Comparison of lot area, total trees, and total water intercepted per year between the focus areas and the reference model (West Memorial Stadium Parking Lot).

The West Memorial Stadium Parking Lot contains 147 trees within a 6.7 acre area with a total of 15,879.7 cubic feet of rainfall being intercepted every year. The North Jardine and South Recreation Parking Lots intercept a total of 976.22 cubic feet of rainfall every year; which is approximately 93.8 percent less than the West Memorial Parking Lot. **The parking lots of focus encompass a total area of 11.2 acres which is approximately 40 percent larger than the West Memorial Stadium Parking Lot, yet they only contain 22 trees between them.**

**93.8%**

more rainfall being intercepted by the West Memorial Stadium parking lot trees!

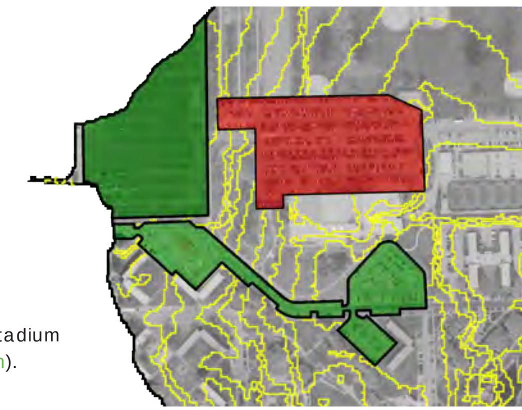


Figure 4.48. Size comparison of the West Memorial Stadium parking lot (red) in relation to the focus areas (green).

As noted, the trees referenced in the West Memorial Stadium parking lot are planted in long 10-foot-wide parking islands ranging between 300 and 350 feet (see Figure 4.47). There are also trees planted along its borders. The North Jardine, South Recreation, and Mid-Jardine parking lots don't contain the space for islands of this design, but the East Stadium parking lots does.

Figure 4.49. The West Memorial Stadium parking lot tree canopy.

# 4.3.4 Reference Model

Rainfall Interception | Regression Models

Alireza Nooraei Beidokhti and Trisha Lynn Moore (2021) conducted a meta-data analysis of the effects of precipitation, tree phenology, leaf area index, and bark characteristics on the throughfall rates of urban trees. Throughfall is the amount of rainfall that reaches the ground through the tree canopy, with or without contacting canopy surfaces. The results of the meta-data analysis lead to the development of a series of regression models that can represent the amount of throughfall associated with the different tree types, not the individual species. In this case, the tree types are split by leaf characteristics and bark characteristics (characteristics used in this model are highlighted in red):

**Leaf Types**

- Deciduous Leafless
- Deciduous Leafed
- Evergreen Broadleaf
- Evergreen Needleleaf

**Bark Types**

- Rough Bark
- Smooth Bark

For this project, the goal is to model the amount of rainfall captured per storm event for Deciduous Leafed-Rough Bark Trees, therefore, the following equation is presented (Appendix G):

**Volume captured (%) = (Rainfall - Throughfall)/Rainfall x Leaf Area**

The models were conducted for five storm events:

| | | |
|---|---|---|
| **Standard Storm** | | Stated on Page 27 of the Kansas Water Pollution Control Permit for Stormwater Management (KDHE 2019) |
| Depth | 1.0 inch | |
| Duration | 6 hours | |
| **Water Quality Storm** | | |
| Depth | 1.10 inches | Stated in Section 4: Structural BMP construction for Kansas as the 90th Percentile Rain Event (MARC 2012) |
| Duration | ----- | |
| **10 Year (A)** | | |
| Depth | 2.92 inches | Rain events that are more likely to produce flood related issues |
| Duration | 2 hours | |
| **10 Year (B)** | | |
| Depth | 4.94 inches | |
| Duration | 24 hours | |
| **50 Year** | | |
| Depth | 5.57 inches | |
| Duration | 6 hours | |

| Storm Event | Rainfall Volume Captured (cubic feet per storm event) |
|---|---|
| Standard | 52355.52 |
| Water Quality | 53809.84 |
| 10 Year (A) | 84350.56 |
| 10 Year (B) | 118527.08 |
| 50 Year | 129434.48 |

Table 4.10. Rainfall volume captured per storm event for the West Memorial Stadium parking lot trees.

**90+%**

more rainfall being intercepted by the West Memorial Stadium parking lot trees for every storm event!

| Storm | Parking Lot | Lot Area (acres) | Total Trees | Rainfall Volume Captured (cubic feet/storm event) |
|---|---|---|---|---|
| Standard | North Jardine | 2.12 | 9 | 833.76 |
| | South Recreation | 1.41 | 14 | 3094.56 |
| | East Stadium | 7.1 | 0 | 0 |
| | Mid-Jardine | .57 | 0 | 0 |
| | **Total** | **11.2** | **23** | **3928.32** |
| | **West Memorial Stadium** | **6.7** | **147** | **52355.52** |
| Water Quality | North Jardine | 2.12 | 9 | 856.92 |
| | South Recreation | 1.41 | 14 | 3180.52 |
| | East Stadium | 7.1 | 0 | 0 |
| | Mid-Jardine | .57 | 0 | 0 |
| | **Total** | **11.2** | **23** | **4037.44** |
| | **West Memorial Stadium** | **6.7** | **147** | **53809.84** |
| 10 Year (A) | North Jardine | 2.12 | 9 | 1343.28 |
| | South Recreation | 1.41 | 14 | 4985.68 |
| | East Stadium | 7.1 | 0 | 0 |
| | Mid-Jardine | .57 | 0 | 0 |
| | **Total** | **11.2** | **23** | **6028.95** |
| | **West Memorial Stadium** | **6.7** | **147** | **84350.56** |
| 10 Year (B) | North Jardine | 2.12 | 9 | 1887.54 |
| | South Recreation | 1.41 | 14 | 7005.74 |
| | East Stadium | 7.1 | 0 | 0 |
| | Mid-Jardine | .57 | 0 | 0 |
| | **Total** | **11.2** | **23** | **8893.28** |
| | **West Memorial Stadium** | **6.7** | **147** | **118527.08** |
| 50 Year | North Jardine | 2.12 | 9 | 2061.24 |
| | South Recreation | 1.41 | 14 | 7650.44 |
| | East Stadium | 7.1 | 0 | 0 |
| | Mid-Jardine | .57 | 0 | 0 |
| | **Total** | **11.2** | **23** | **9711.68** |
| | **West Memorial Stadium** | **6.7** | **147** | **129434.48** |

Table 4.11. Rainfall volume captured per storm event for the West Memorial Stadium parking lot trees in comparison to the focus areas.

# 4.3.4 Reference Model

Canopy Growth | i-Tree Design

Canopy growth was modeled to understand the size that different tree species can achieve after certain periods of time. All tree species grow at different rates and to different sizes, therefore, understanding the amount of time it takes for an urban tree to cover the impervious surface adjacent to it can aid in selection of tree species and can also justify the need for more or different tree canopy.

Figure 4.50 depicts canopy size at 60 years of growth.

Figure 4.50. The West Memorial Stadium Parking Lot tree canopy after 60 years.

According to the most recent aerial imagery, the West Memorial Stadium Parking Lot contained the current trees in 1991 (31 years). As depicted in Figures 4.51 through 4.53, many of the trees were planted in 10-foot-wide parking islands and appear to be very healthy as all of them now cover the adjacent impervious surfaces, thus, providing shade and intercepting rain that would otherwise contribute to runoff.

Figure 4.51. Littleleaf Linden and Red Maple trees in the West Memorial Stadium Parking Lot.

Figure 4.52. Littleleaf Linden root flare within a 10-foot-wide parking island.

Figure 4.53. Littleleaf Linden canopy cover.

## 4.3.4 Reference Model

Canopy Growth | i-Tree Design

North Jardine

South Recreation

West Memorial Stadium

Figure 4.54 (top), 4.55 (middle), 4.56 (bottom). Canopy cover comparisons between the North Jardine, South Recreation, and West Memorial Stadium parking lots.

**...current growth...**

**1,158**

**square feet of tree canopy**

**...in an 87,000 square foot parking lot**

**1.3% Canopy Cover**

**4,298**

**square feet of tree canopy**

**...in a 61,500 square foot parking lot**

**6.9% Canopy Cover**

**72,716**

**square feet of tree canopy**

**...in a 290,000 square foot parking lot**

**25% Canopy Cover**

**...94+% more canopy cover!**

Note: All square footages of canopy cover were estimated via Google Earth aerial imagery.

## 4.4

## Suitable Sites

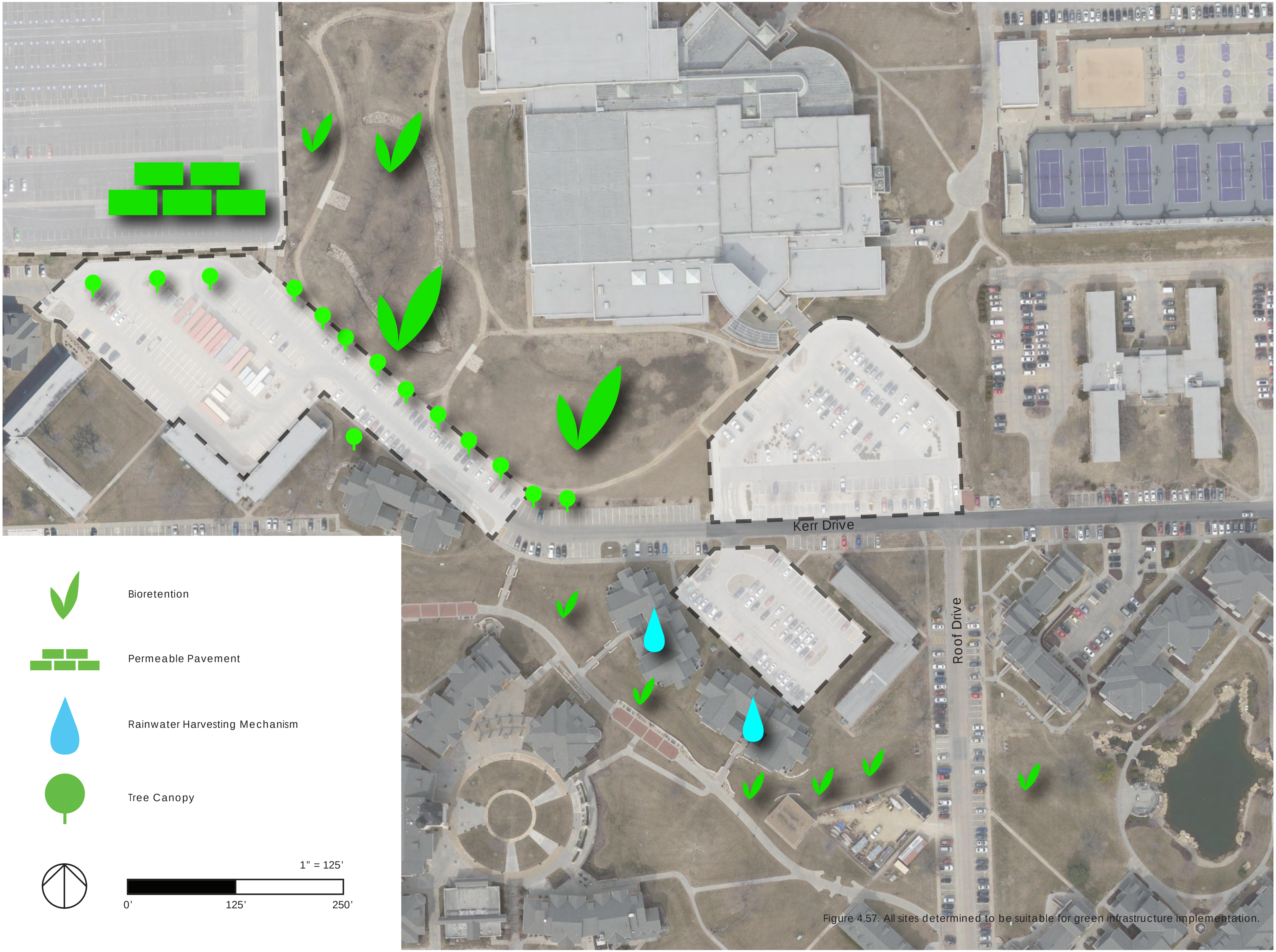


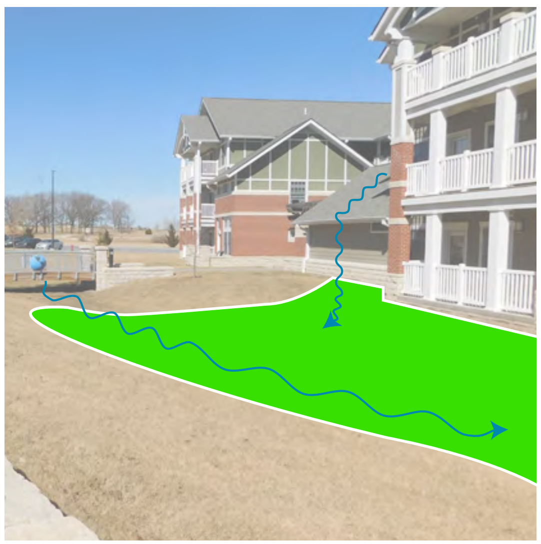

Figure 4.57. All sites determined to be suitable for green infrastructure implementation.

# 4.4.1 Suitable Sites

Bioretention | North Jardine Parking Lot

The following locations have been designated for future bioretention implementation to address the stormwater runoff produced by the North Jardine parking lot. The sites are located within the drainage ditch that cuts through the center of the Jardine Apartment Complex. Each site avoids utility conflicts, is located within a depressed area, is located within the path of drainage of the North Jardine parking lot, is located within close proximity of the downspouts of nearby structures, and also avoids any circulation conflicts.

To clarify, bioretention is a term used to describe a depressed softscape area containing vegetation that is meant to slow down, filter, or temporarily store stormwater runoff.



### Suitability Criteria

- Topography and Hydrology
  - Drainage Direction
- Utilities
  - Storm Sewer Inlet Locations
  - Storm Sewer Outlet Locations
  - Sanitary Sewer Conflicts
  - Water Pipe Conflicts
  - Power Utility Conflicts
- Circulation
  - Pedestrian Circulation Conflicts
  - Vehicle Circulation Conflicts

Figure 4.58. Depressed lawn area suitable for future green infrastructure implementation.

Figure 4.59. Bioretention sites to address North Jardine Parking lot runoff

1" = 125'

0' 125' 250'

Suitable Area

Water Related Utilities

Power and Gas Utilities

Surface Drainage

Note: Figure 4.59 depicts sanitary sewer, storm sewer, and water pipes under the same line as they all follow the same paths. The same technique was applied to power and gas utilities for the same reasons and because it aids in readability.

# 4.4.1 Suitable Sites

Bioretention | East Stadium Parking Lot

The following locations have been designated as potential sites for future bioretention implementation. The entire area contains little to no utility or circulation conflict while also responding to hydrological patterns of the East Stadium parking lot. The sites located to the west, closer to the parking lot, currently contain a large grove of trees that is assumed to have been implemented for the soul purpose of addressing the runoff produced by the East Stadium parking lot. The existing detention basin to the south of the recreation center now takes on not only the east stadium parking lot runoff, but also the runoff from the recreation fields to the north of recreation center. Therefore, increasing stress on the detention basin. Therefore, of the sites presented, the detention basin south of the recreation center appears to be more suitable for future improvement. It is also important to note that the three sites to the north are currently vegetated by trees, thus, reinforcing the suitability of southern detention basin.

Figure 4.60. South Recreation Detention Basin Suitable for future green infrastructure implementation.

**Suitability Criteria**

- Topography and Hydrology
    - Drainage Direction
- Utilities
    - Storm Sewer Inlet Locations
    - Storm Sewer Outlet Locations
    - Sanitary Sewer Conflicts
    - Water Pipe Conflicts
    - Power Utility Conflicts
- Circulation
    - Pedestrian Circulation Conflicts
    - Vehicle Circulation Conflicts

Note: Figure 4.61 depicts sanitary sewer, storm sewer, and water pipes under the same line as they all follow the same paths. The same technique was applied to power and gas utilities for the same reasons and because it aids in readability.

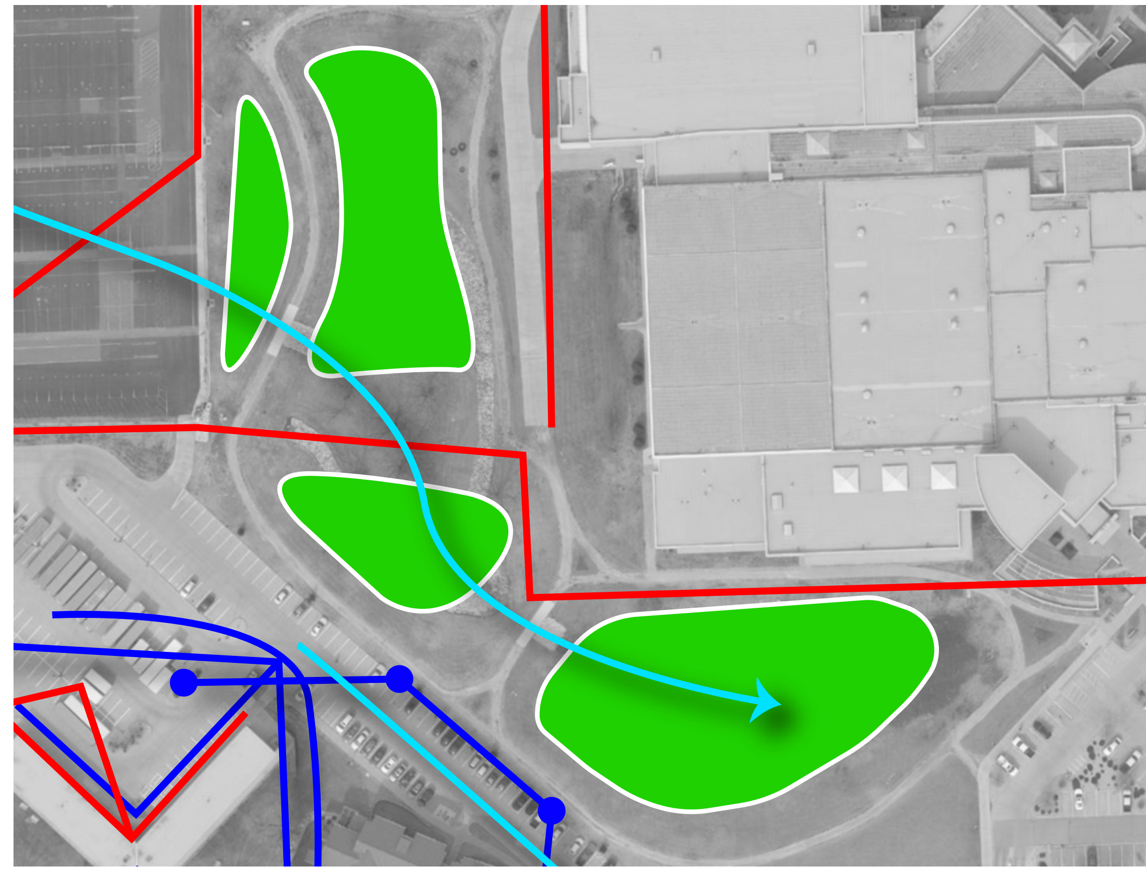


Figure 4.61. Bioretention site to address East Stadium Parking lot runoff


Suitable Area

Water Utilities

Power and Gas Utilities

Surface Drainage

# 4.4.2 Suitable Sites

Tree Canopy | North Jardine Parking Lot

The following sites have been designated as suitable spots for future tree plantings. The area contains a series of water, electric, and gas utilities, therefore, the sites depicted in the graphic opposite of this page contain no underground or above ground constraints. As shown in Figure 4.62 (below), the parking islands currently contain Flowering Crabapple trees that are to be considered as the only site limitation because of their tree characteristics. Flowering crabapple trees are short-lived, small trees that grow to 20 feet in height and 15 feet in width, therefore, they will most likely not cover the adjacent impervious cover and if they do, they are likely to be pruned to make room for cars to park. This project will examine the possibility of relocating the North Jardine crabapple trees to another location and planting larger species in their place.

**Suitability Criteria**

- Topography and Hydrology
  - Drainage Direction
- Utilities
  - Storm Sewer Inlet Locations
  - Storm Sewer Outlet Locations
  - Sanitary Sewer Conflicts
  - Water Pipe Conflicts
  - Power Utility Conflicts
- Circulation
  - Pedestrian Circulation Conflicts
  - Vehicle Circulation Conflicts

Figure 4.62. North Jardine Parking Island Suitable for future green infrastructure implementation.

Note: Figure 4.63 depicts sanitary sewer, storm sewer, and water pipes under the same line as they all follow the same paths. The same technique was applied to power and gas utilities for the same reasons and because it aids in readability.

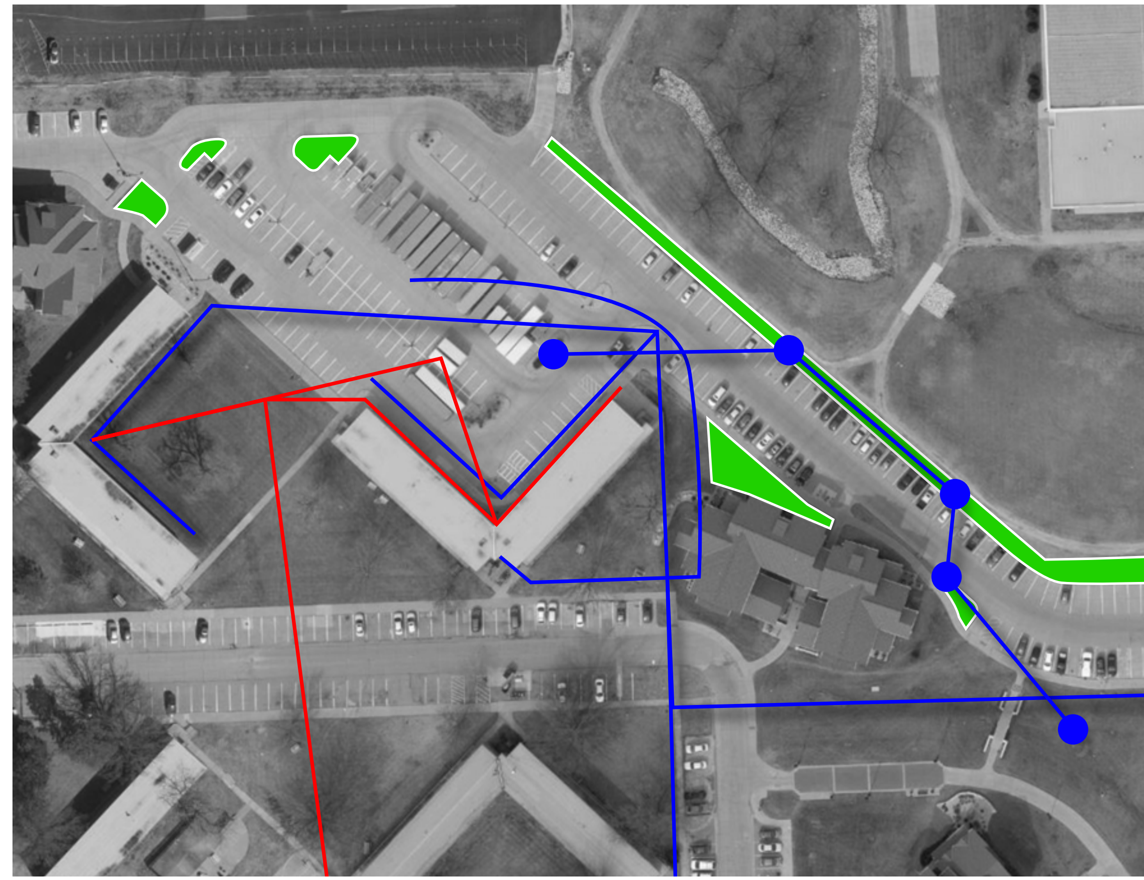


Figure 4.63. Increased tree canopy sites to address North Jardine Parking lot runoff

1” = 125’

0’ 125’ 250’

Suitable Area

Water Related Utilities

Power and Gas Utilities

# 4.4.3 Suitable Sites

Rainwater Harvesting Mechanisms

The following sites are suitable for rainwater harvesting mechanisms because of their close proximity to the drainage swale that was designated as suitable for future bioretention as seen in Figure 4.65, therefore, providing ease of access when the vegetation adjacent needs water. Each of the sites are located in direct contact with a downspout directing water from the adjacent roofs into the turf at the base of the structures.

Figure 4.64. Suitable site for a future cistern at the Jardine Apartment Complex.

### Suitability Criteria

- Topography and Hydrology
    - Drainage Direction
- Utilities
    - Storm Sewer Inlet Locations
    - Storm Sewer Outlet Locations
    - Sanitary Sewer Conflicts
    - Water Pipe Conflicts
    - Power Utility Conflicts
- Circulation
    - Pedestrian Circulation Conflicts
    - Vehicle Circulation Conflicts

Figure 4.65. Sites suitable for a future rainwater harvesting mechanism.


Suitable Area

# 4.4.4 Suitable Sites

Permeable Pavement

The following site is suitable for future permeable pavement installation. As shown in Figure 4.66, power and water utilities frame the suitable area, and conveniently outline the low point at the southeast corner of the East Stadium parking lot. Permeable pavement in this sector of the parking lot will increase infiltration and reduce total runoff into the grove and detention basin to the southeast that the East Stadium parking lot drains into. Increasing infiltration and reducing runoff can efficiently reduce the runoff pollutant load and peak rate. It's important to note that the established suitable area surrounds an existing ATA bus stop, therefore, there is opportunity to utilize new paving as a landmark location for pedestrians waiting for their bus.

**Suitability Criteria**

- Topography and Hydrology
    - Drainage Direction
- Utilities
    - Storm Sewer Inlet Locations
    - Storm Sewer Outlet Locations
    - Sanitary Sewer Conflicts
    - Water Pipe Conflicts
    - Power Utility Conflicts
- Circulation
    - Pedestrian Circulation Conflicts
    - Vehicle Circulation Conflicts

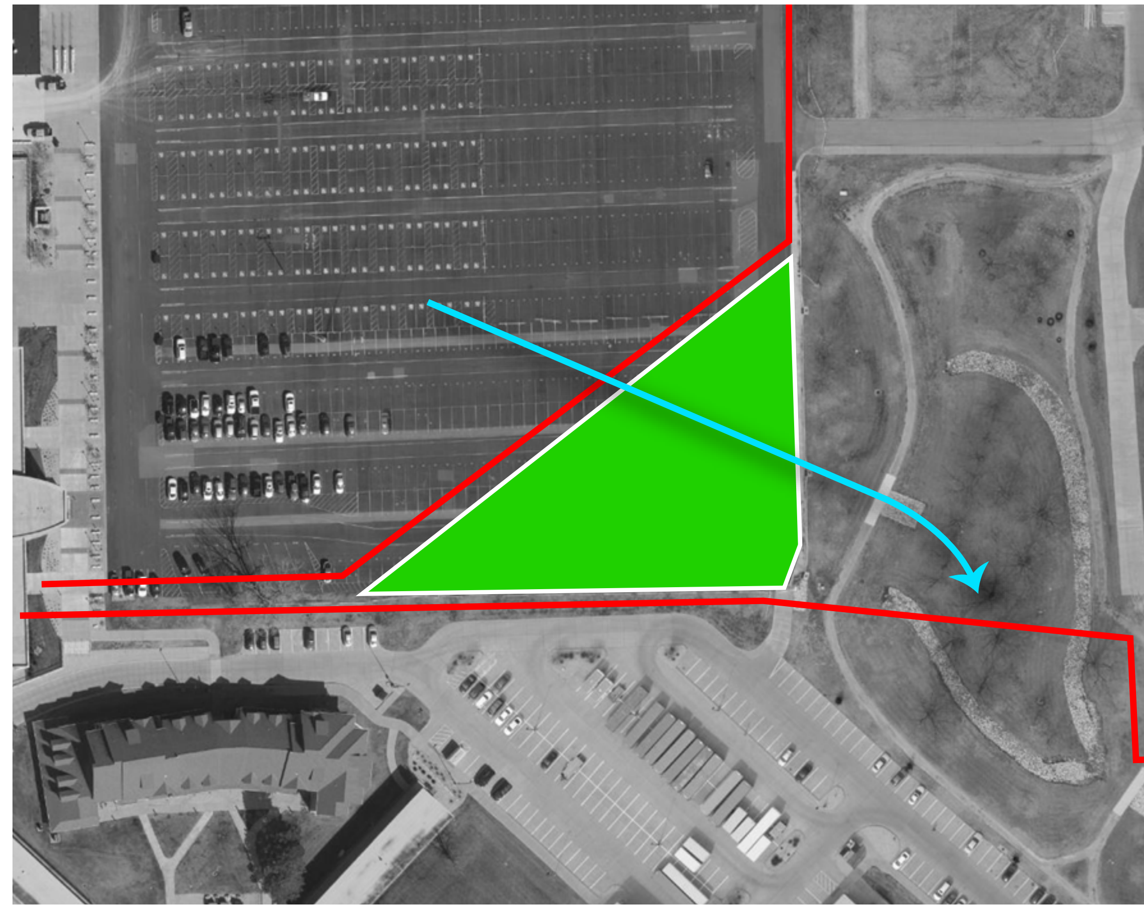
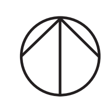


Figure 4.66. Suitable site for permeable pavement to address East Stadium parking lot runoff



1" = 125'

0' 125' 250'

Suitable Area

Power and Gas Utilities

Surface Drainage

# 4.5 Chapter Summary

This chapter depicted site analysis in the form of inventory mapping at the watershed and parking lot scale. Modeling of existing conditions was done at the parking lot scale, and again for the West Memorial Stadium parking lot. The West Memorial Stadium parking lot was modeled because it contains over 140 trees of several species, all of which cover their adjacent impervious cover. The results of the focus area models were compared to the reference model to demonstrate the stormwater management possibilities of having more tree canopy.

Site analysis in the form of inventory mapping and modeling established a set of sites that are suitable for future green infrastructure implementation. The South Recreation parking lot is not suitable for green infrastructure implementation because utility conflicts, and drainage patterns. The South Recreation parking lot also already contains 14 trees that are covering their adjacent impervious cover, therefore, there is no area adjacent or within the parking that is suitable for green infrastructure. The Mid-Jardine parking lot is not suitable because of utility conflicts, drainage patterns, and limited space. The parking lot is tightly packed between three structures, all of which contain underground utilities that mimic their perimeters. See Figure 4.68 to see where stormwater runoff generated by the South Recreation and Mid-Jardine parking lots is moved.

How can the northwestern parking lots of the Campus Creek Watershed be retrofitted with green infrastructure to help reduce stormwater **runoff quantity**, **peak rate**, and **pollutant load**?

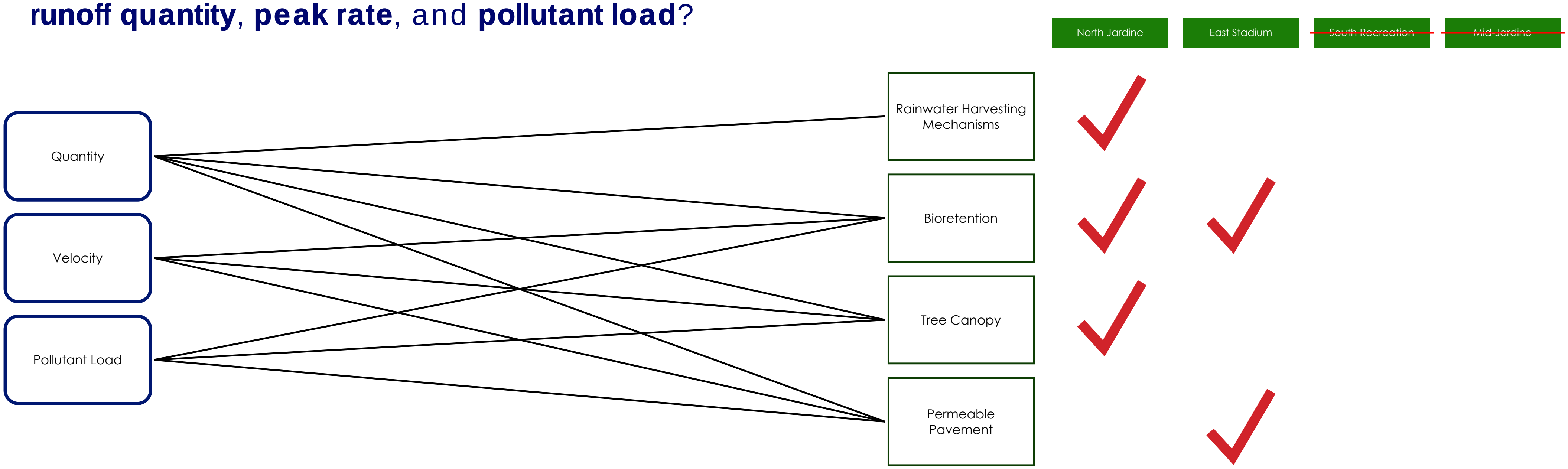



Figure 4.67. Site suitability and the associated dilemma that the proposed green infrastructure practices address.

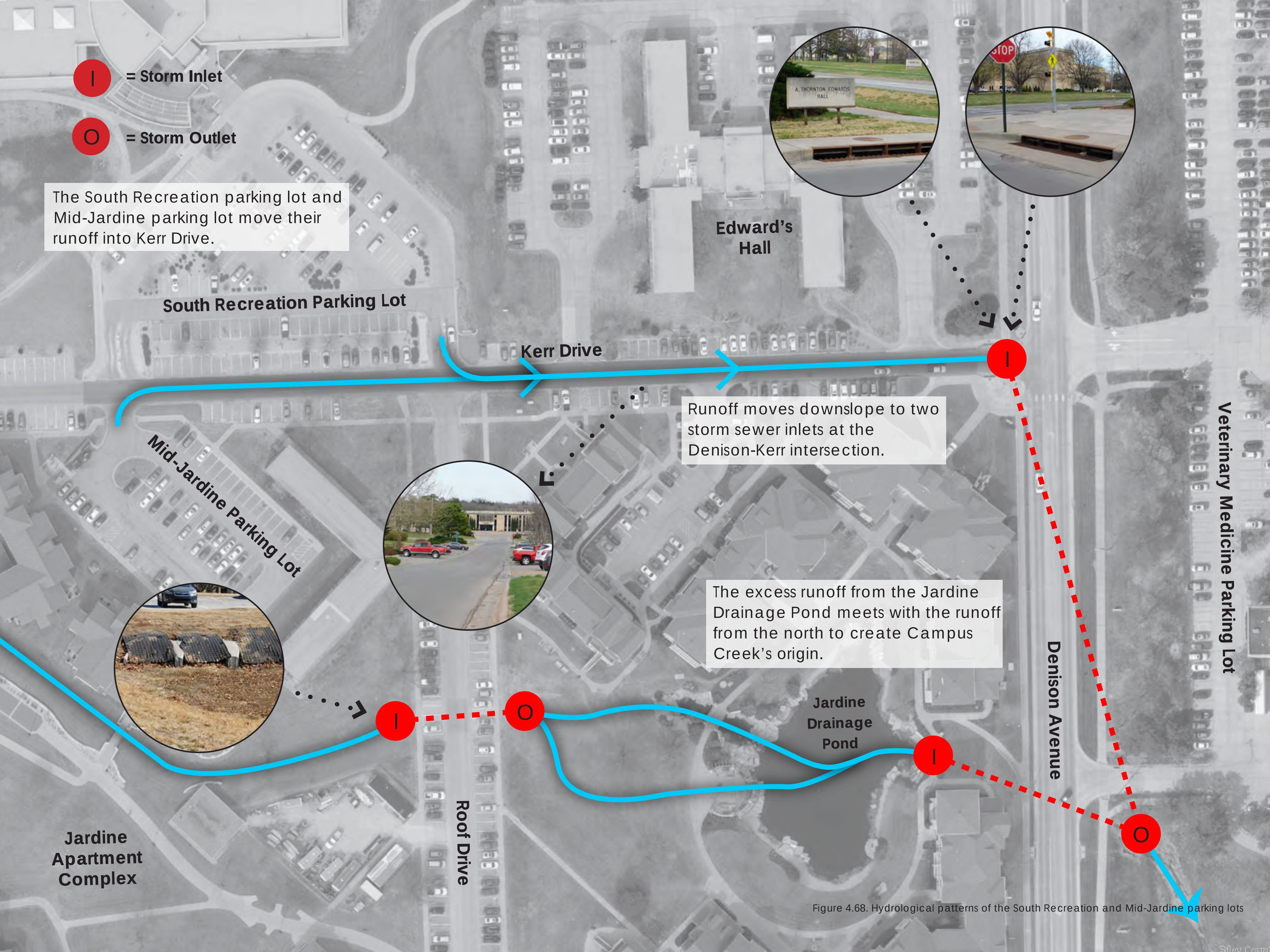



Figure 4.68. Hydrological patterns of the South Recreation and Mid-Jardine parking lots

# Chapter 5

Projective Design

**Main Project**

Bioretention

Figure 91. Jardine Apartment Complex drainage pond.

# 5.1 Projective Design Introduction

A projective design is a proposed design solution that is informed by research. In this case, the research was site analysis, as stated previously. There are two types of projective design: design experiments and experimental design. A design experiment is set within a given context and the investigation applies design-based strategies to examine possibilities. Experimental design is the development of new landscape compositions that can be applied in different settings (Deming and Swafield 2011).

In this instance, the final product is a design experiment because the project addresses specific focus areas to explore the possibilities of runoff improvements using various green infrastructure solutions. To restate the primary research question:

How can the northwestern parking lots of the Campus Creek Watershed be retrofitted with green infrastructure to help reduce stormwater **runoff quantity**, **peak rate**, and **pollutant load**?

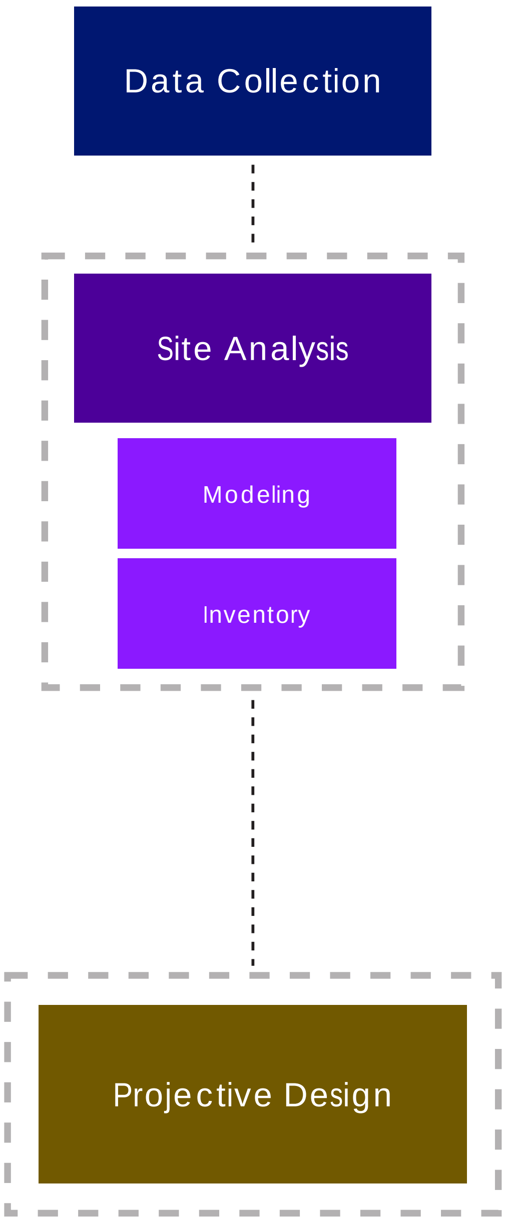



Figure 5.1. Research Design leading to a Projective Design.

# 5.1 Projective Design Introduction

Documentation Metrics

A set of design metrics have been established for each of the green infrastructure solutions to be implemented. The Campus Rainworks Challenge is a green infrastructure design competition hosted by the US EPA. It seeks to engage with young professionals at colleges and universities in the US to kickstart a dialogue regarding the need for innovative stormwater management techniques. The competition brief provides a set of metrics that all projects can choose to follow. The metrics have been adapted for use in this project to reflect the various green infrastructure solutions proposed. Each metric falls into a broader category, categories are described below and their associated metrics can be found in Figure 5.2. (US EPA 2021)

**Stormwater Management** metrics reflect reduction or improvements to impervious surfaces and overall runoff reduction in total runoff depth, annual pollutant load, or peak flow. The stormwater management metrics presented will model performance based off a 1-year, 24-hour storm, as is recommended by the EPA.

**Integrated Water Management** metrics demonstrate the reductions in potable water use and landscape water requirements of green infrastructure solutions.

**Other Ecosystem Services** embodies a wider range of benefits ranging from preservation, restoration, tree canopy benefits, and plant diversity.

| Green Infrastructure Type | Category | Metric |
|---|---|---|
| Rain Water Harvesting Mechanisms | Stormwater Management | Reduction in directly connected impervious area (square feet) |
| | Integrated Water Management | Reduction in potable water use (gallons/year captured) |
| Bioretention | Stormwater Management | Change in stormwater peak rate from existing conditions |
| | Other Ecosystem Services | Area of protected or restored native plant communities (square feet) |
| | | Change in plant diversity (before and after plant lists) |
| | Integrated Water Management | Reduction in potable water use (gallons/year captured) |
| Tree Canopy | Other Ecosystem Services | Increase in canopy cover (10 years after installation) (square feet) |
| | | Air pollutant removal by trees (lbs/year) |
| | | Carbon dioxide sequestered by new trees (lbs/year) |
| Permeable Pavement | Stormwater Management | Reduction in impervious area (square feet) |
| | | Change in stormwater peak rate from existing conditions |

Figure 5.2. Documentation metrics of projective green infrastructure designs.
Source: Campus Rainworks Campaign Brief.

# 5.1 Projective Design Introduction

## Design Goals

The final projective design reflects four sets of goals, all of which were also adapted from the Campus Rainworks Challenge. The goals were used to establish the effectiveness of the design in terms of (1) Performance, (2) Design, (3) Implementation, and (4) Resilience.

**Performance** criteria reflect the design's ability to address stormwater needs on site.

**Design** criteria determine the environmental, social and economic effects of the proposed green infrastructure solutions.

**Resilience** criteria reflect the environmental priorities at the local, state, and regional scale while also evaluating the plant selection and forms of green infrastructure proposed.

Category → Performance

Goals →
- The design effectively uses green infrastructure practices to capture and treat stormwater runoff on site (e.g., through infiltration, evapotranspiration, or harvest and reuse) and improves local water quality?
- The predicted performance is quantified and supported by modeling and calculations. Calculations include the design storm managed and/or the annual reduction in runoff volume.
- Additional benefits (water/energy conservation, flood management, heat island reduction...) are identified and in any way quantified.
- The design references the appropriate local and/or state design standards.

Figure 5.3. Performance goals.

Category → Design

Goals →
- The design components convey the functionality and value of the design with a cohesive, multi-disciplinary perspective.
- The selected green infrastructure approaches address multiple campus environmental, social, and economic objectives (e.g., water resource management goals, public health benefits, educational and recreational opportunities).
- The design complements efforts to address areas of environmental, economic, and social needs within the broader community or region.

Figure 5.4. Design goals.

Category → Resilience

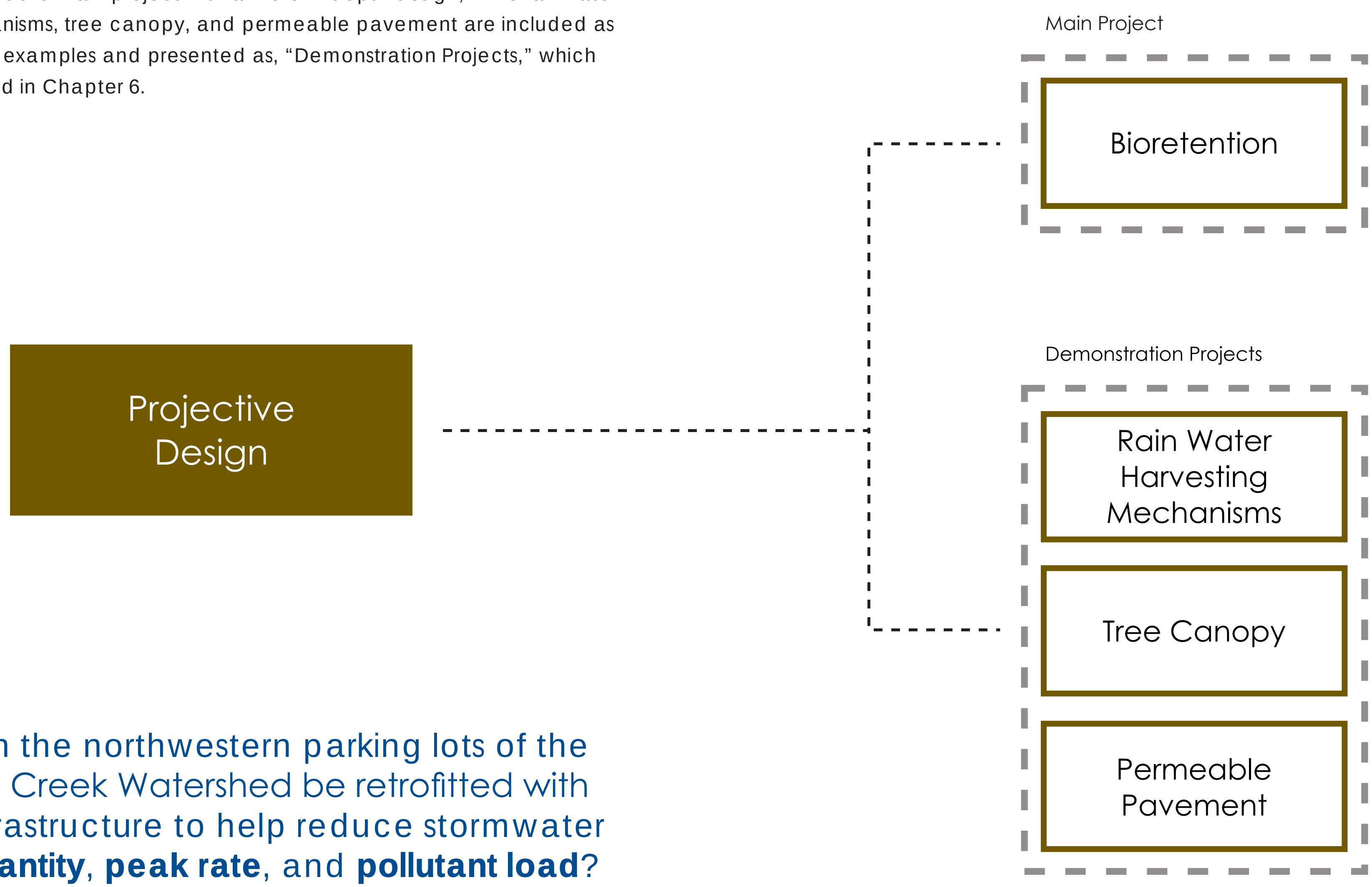
Goals →
- The design incorporates priorities included in local, state, regional, or national climate resiliency initiatives, sustainability plans, adaptation plans, or climate action plans.
- Where applicable, the project includes regionally appropriate, native vegetation that will provide ecosystem services that integrate the natural and built environments.
- The design incorporates elements of stormwater capture and use for non-potable water applications to offset and replace potable water demand.

Figure 5.5. Resilience goals.

# 5.1 Projective Design Introduction

Design Types

The final projective design demonstrates retrofitting the study area with four types of green infrastructure: (1) Bioretention, (2) Rain Water Harvesting Mechanisms, (3) Tree Canopy, and (4) Permeable Pavement. However, site analysis confirmed that bioretention solutions are the most applicable and beneficial for the study area. Thus, bioretention is the main project with a more in-depth design, while rainwater harvesting mechanisms, tree canopy, and permeable pavement are included as more conceptual examples and presented as, “Demonstration Projects,” which are further detailed in Chapter 6.




How can the northwestern parking lots of the Campus Creek Watershed be retrofitted with green infrastructure to help reduce stormwater **runoff quantity**, **peak rate**, and **pollutant load**?

Figure 5.6. Types of Green Infrastructure to be designed.

# 5.2.1 Sizing

All areas suitable for bioretention were determined based off site analysis of topography, hydrological patterns, underground utilities, and pedestrian and vehicle circulation. Upon determining these sites, design development took place to explore, and maximize the performance of the proposed green infrastructure solutions.

The sites determined to be suitable embody a total square footage of 12,971 for the North Jardine parking lot, and 80,000 for the East Stadium parking lot. Therefore, if all of the suitable sites were to be retrofitted with bioretention, it would effectively address the stormwater management needs of the parking lot focus areas and then some. It's important to reiterate that due to utility, and circulation conflicts, and an analysis of existing hydrological patterns, the South Recreation and Mid-Jardine parking lots are not suitable for bioretention implementation within a 1/4 mile radius as all drainage from both parking lots is deposited into storm drains that deliver the water into Campus Creek across Denison Avenue.

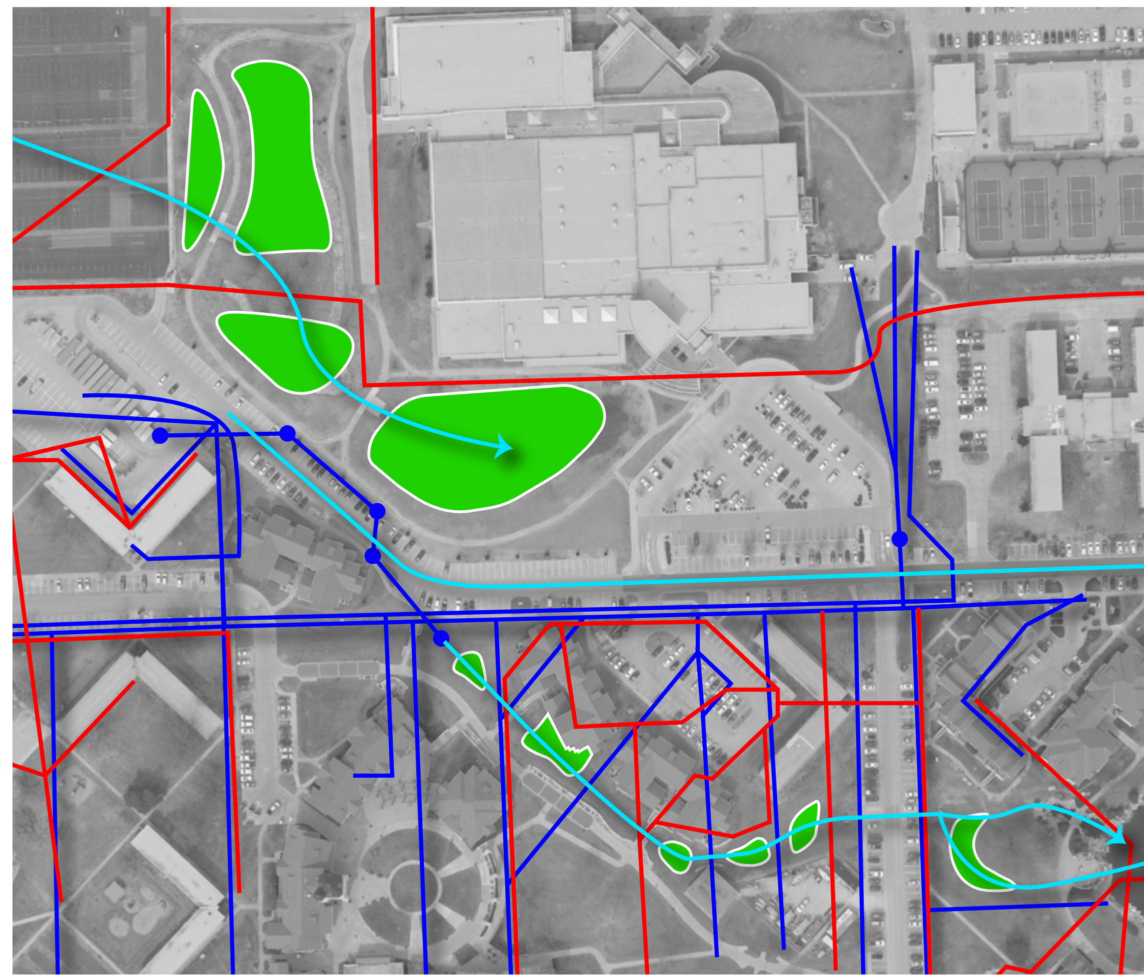
| Parking Lot | Area (sf) | Bioretention Size (9" depth) (sf) |
|---|---|---|
| North Jardine | 87,120 | 2,904 |
| East Stadium | 304,920 | 10,164 |

Table 5.1. Nine inch deep rain garden sizing for a 1-inch storm for each focus area. Sizes determined using the guide provided in Appendix X.

This project will explore maximizing the amount of bioretention installed to also maximize benefits. Doing so can:

- Ensure plant survival my further mitigating the speed of runoff and amount of runoff
- Address storms of higher depth and duration
- Maximize reductions in peak rate, pollutant loads, and quantity of runoff

Note: See Appendix X for the rain garden sizing guide used for this project



**Legend**

Suitable Area

Water Utilities

Power and Gas Utilities

Surface Drainage

Figure 5.7. All suitable sites for future bioretention implementation.

## 5.2.2 Design Development

Figures 5.8 depicts further design development of the bioretention areas in terms of the layering in the North Jardine bioretention sites. The need for an underdrain and internal water storage was explored as the bioretention sites also serve as a form of vegetated bioswale, but were pulled from the design as they may be counterintuitive regarding the mitigation of runoff quantity and peak rate. Instead, each bioretention cell will focus on retaining stormwater and exfiltrating it into the soil below.

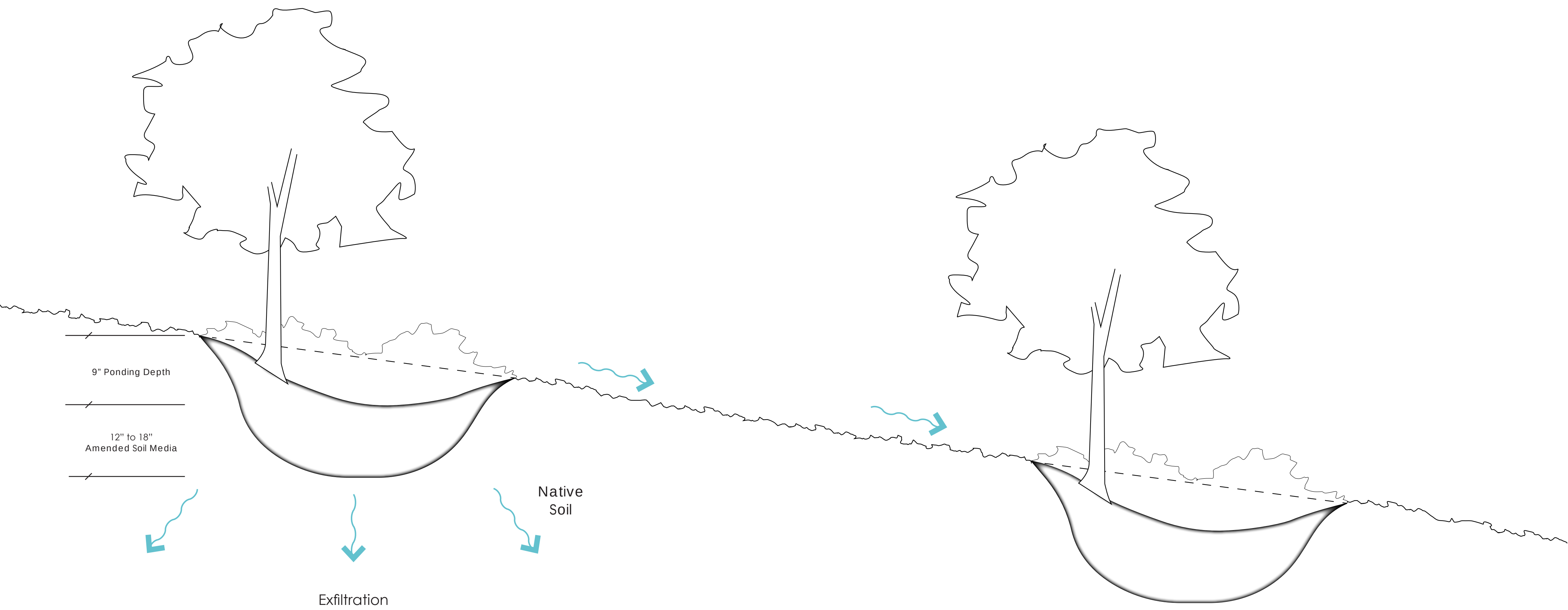



Figure 5.8. Conceptual development of North Jardine bioretention cells.

## 5.2.2 Internal Water Storage

Figure 5.9 depicts the North Jardine bioretention cells designed to address the stormwater management needs of the North Jardine parking lot. In section (Figure 5.10), the proposed bioretention cells are better represented as a means of slowing down and absorbing stormwater runoff.

As stormwater runoff drains across the landscape, large quantities will be intercepted by each bioretention cell, thus, reducing the runoff quantity. Passage by stormwater runoff into each bioretention cell will also reduce the peak rate before reaching the Jardine drainage pond as runoff has a more indirect route in comparison to existing conditions.

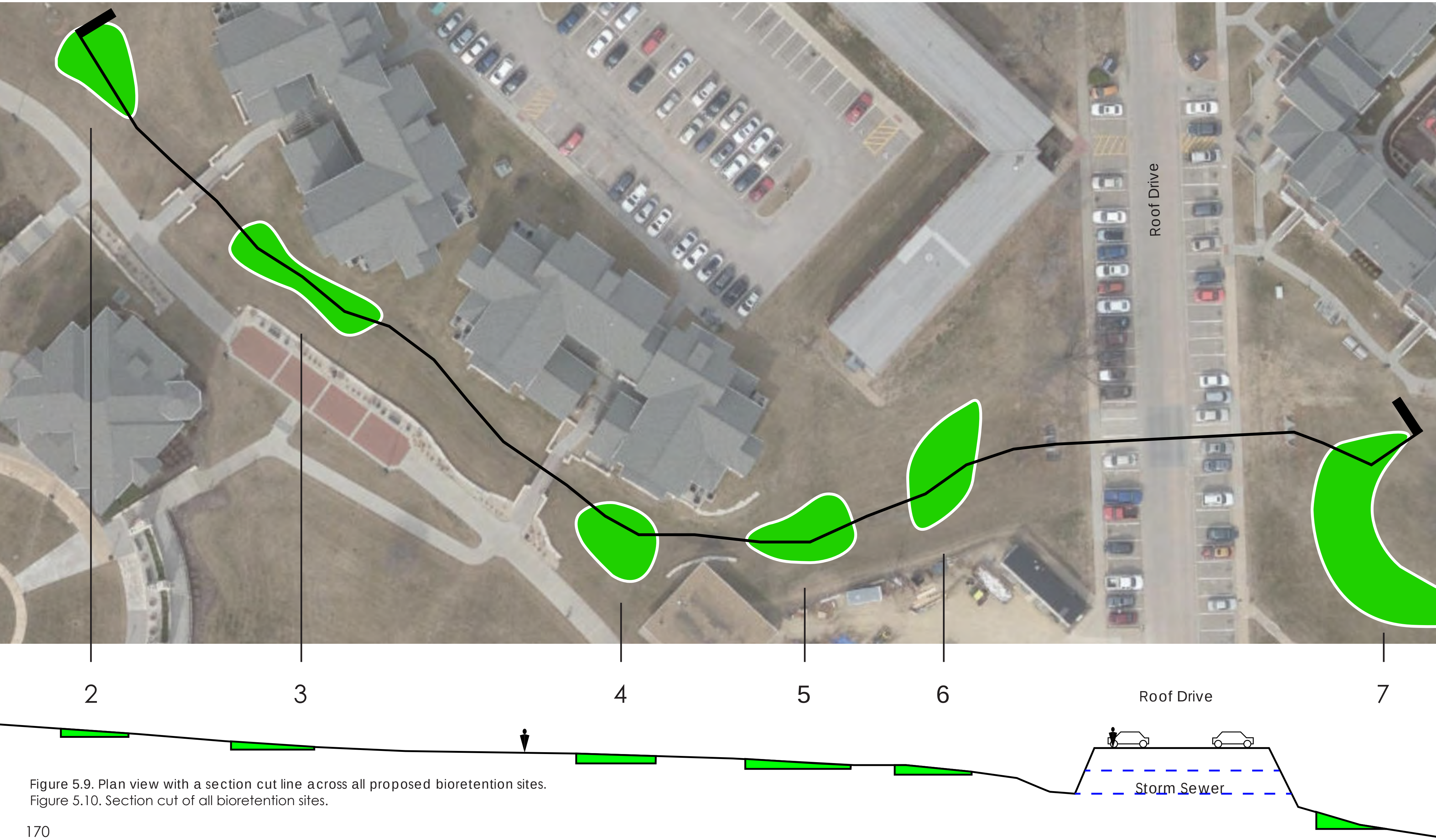



Figure 5.9. Plan view with a section cut line across all proposed bioretention sites.
Figure 5.10. Section cut of all bioretention sites.

## 5.2.3 Soils

**Soils** are one of the most detrimental properties of a bioretention cell as they directly influence the success of plant material, and the effects of runoff. Soil texture is one of the primary factors affecting infiltration rates, but texture cannot be changed quickly. Texture of soil reflects the ratio of silt, sand, and clay. A high clay content typically has slow infiltration rates, unless there is a time of drought. Otherwise, water favors sand for its large pores. See section 2.4 for more soil information.

The focus areas contain high clay content and high runoff potential, therefore, this project seeks to enhance and maintain soil at bioretention sites to ensure the long-term survival of the plant material and further increase benefits. According to the USDA, there are a series of management practices that can be conducted on site to preserve or enhance soil infiltration rates:

Avoid soil disturbance and equipment operation during a period of soil saturation

Subsoil to break up compacted layers

**Utilize organic matter on a cyclical basis**

Figure 5.11. Basic soil management.
Source: USDA n.d.

**Organic Matter** consists of three parts including small plant residues and small living organisms, decomposing organic matter, and stable organic matter (see section 2.4 for more organic matter information). This project will utilize plant residue and decomposition to enhance the soil quality and infiltration. The primary factor affecting soil organic matter is climate; decomposition happens faster in warm/humid climates, and slower in colder ones. Decomposition also occurs faster when soils are saturated and well aerated (USDA n.d.). This project will seek to maximize soil quality through the use of select organic materials during specific times of year.

Organic Material to be utilized is **crop residue** (leaves, husks, stems, stalks, etc.). As noted in Chapter 1, Kansas State is a Tree Campus, therefore, autumn months produce immense amounts of leaf litter. Kansas State is also well known for its College of Agriculture. Utilizing these two characteristic of Kansas State University can allow for a supply of crop residue that can be distributed in the bioretention cells and enhance soil quality.

It's important to note that mulch is used in most landscapes to enhance soil quality but will not be utilized in the proposed bioretention cells because of their purpose. The bioretention is meant to slow down, capture, and retain runoff, therefore, mulch is likely to wash away downslope as the bioretention cells are located directly within the drainage path of the North Jardine parking lot runoff.

Distributing crop residue within the bioretention cells is most suitable during **autumn and winter months** as rain is less likely to wash away the organic material and potentially clog sewer inlets that will inevitably take runoff into Campus Creek.

# 5.2.4 Plants

Now that bioretention sites have been designated, plants have been chosen, and depths have been established, the design must progress into a more realistic concept. All vegetated space has its own water requirements and it's important to prepare for future water needs as the proposed bioretention areas will be installed without an irrigation system. The EPA provides a Water Budget Tool that has access to national databases for precipitation information. The tool requires the location, total square feet of landscaped area, and exact square footages of shrubs, trees, groundcover, turf grass, permeable hardscape, non-vegetated softscape, and water features of any kinds. Using this information, the tool can estimate the monthly baseline water requirement and monthly landscape water allowance (LWA) based on the peak watering month. The peak watering month refers to the month that the landscape will experience the most drought.

Figure 5.12 is a map of all of the bioretention sites to be proposed and an identifying number assigned to them. The opposite page depicts the peak watering month, average monthly evapotranspiration, and average monthly rainfall of Manhattan according to the EPA. Pages 176 through 181 depict the established plant pallette, the distribution of plants across their boundaries, and the total landscape water requirement needed in gallons per month. Table 5.2 on the next page depicts the chosen plant pallette and Table 5.3 depicts the same pallette categorized as shrubs, trees, and ground cover plants as these are the fields that the Water Budget Tool requires. In this instance, perennials, annuals, biennials, and grasses are included in the shrub category.

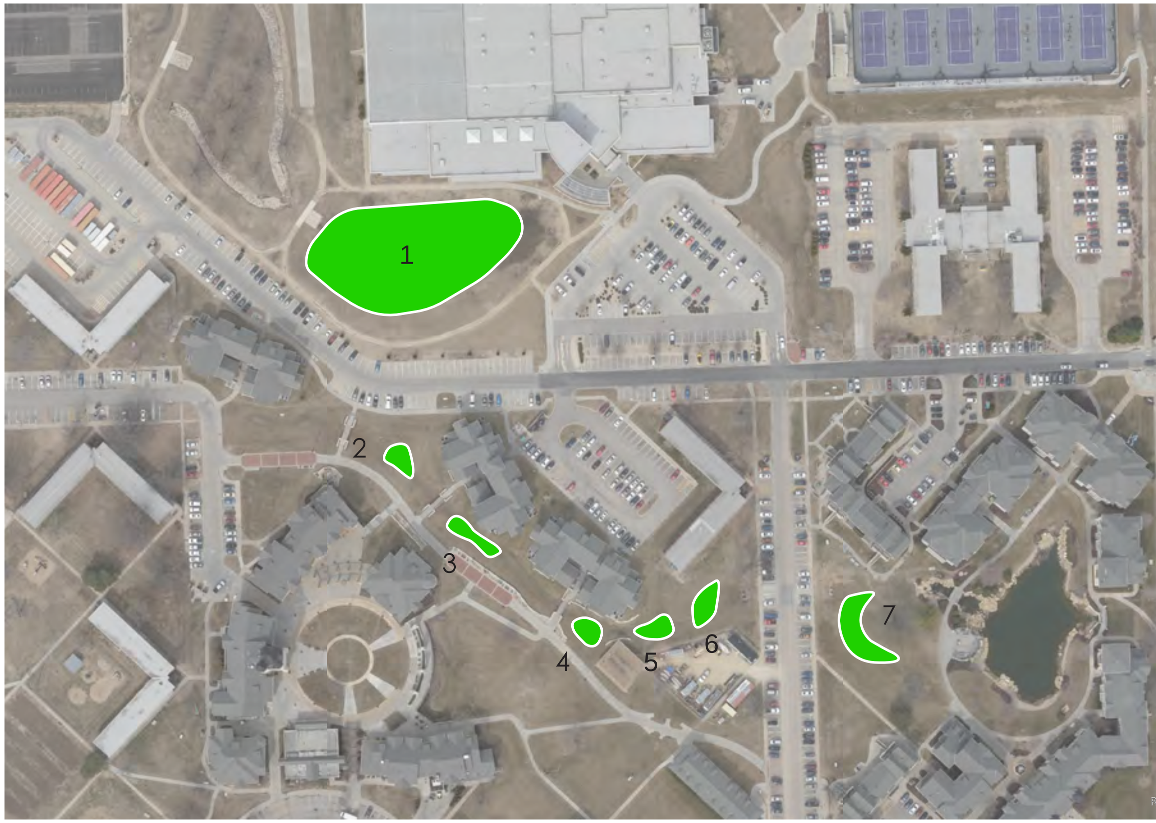
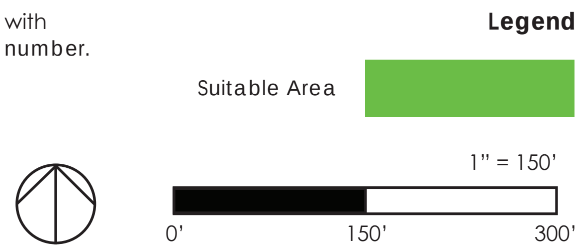



Figure 5.12. Final sites to be retrofitted with bioretention and their associated site number.




## Peak Watering Month — July

| | |
|---|---|
| Average Monthly Evapotranspiration | 7.95 inches/month |
| Average Monthly Rainfall | 3.20 inches/month |

# 5.2.4 Plants

Planting in a Post-Wild World by Rainer and West (2015) provides a series of frameworks for plant design. In this instance, Heiner Luz's Zeigeleipark strategy will be utilized as it focuses on the ornamental potential of designed plant communities. Luz's strategy provides a layered approach to plant design and layers are described below. The plant pallette can be found on the opposite page (Table 5.2). The chosen plants are common rain garden plants of both dry and wet tolerance and are also native to Kansas.

"**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area."

"**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area."

"**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area."

"**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area."

Note: The planting design methods above reflect Pages 172 and 173 of Planting in a Post-Wild World by Thomas Rainer and Claudia West.

| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

Table 5.2. Bioretention plant pallette.
Source: Rain Gardens by Gregg Eyestone
K-State Research and Extention, Riley County Agent, Horticulture

## 5.2.4 Plants

Note: Table 5.2 on the previous page depicts the chosen plant pallette and Table 5.3 depicts the same pallette categorized as shrubs, trees, and ground cover plants as these are the fields that the Water Budget Tool requires. In this instance, perennials, annuals, biennials, and grasses are included in the shrub category.

| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
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| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
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| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
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| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

| Plant Type | Scientific Name | Common Name |
|---|---|---|
| Shrubs | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Asclepias incarnata | Swamp Milkweed |
| | Liatris | Gayfeather |
| | Oenothera macrocarpa | Missouri Primrose |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |
| | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Trees | Taxodium distichum | Bald Cypress |
| | Betula nigra | River Birch |
| | Quercus bicolor | Swamp White Oak |

Table 5.3. Finalized plant selection converted into shrub, ground cover, and tree categories.

# 5.2.5 Potable Water Use

As noted previously, the table below depicts the total square footage, plant distribution in square feet, the landscape water allowance, and the landscape water requirement for each of the established sites for future bioretention implementation. **Monthly baseline** represents the amount of water a typical landscape would use during the peak watering month. **Landscape Water Allowance (LWA)** refers to the amount of supplemental water allotted for the designed landscape. **Landscape Water Requirement (LWR)** refers to the amount of water the landscape would need during the peak watering month, in this case, that month is July.

| Site | Total Square Feet | Plant Distribution (square feet) | | LWA (gallons/month) | LWR (gallons/month) |
|---|---|---|---|---|---|
| 1 | 30,000 | Shrubs | 18,000 | 104,004 | 21,089 |
| | | Trees | 6,000 | | |
| | | Ground Cover | 6,000 | | |
| 2 | 1,700 | Shrubs | 1,020 | 5,894 | 1,195 |
| | | Trees | 400 | | |
| | | Ground Cover | 280 | | |
| 3 | 2,500 | Shrubs | 1,500 | 8,667 | 1,757 |
| | | Trees | 500 | | |
| | | Ground Cover | 500 | | |
| 4 | 1,000 | Shrubs | 600 | 3,467 | 703 |
| | | Trees | 200 | | |
| | | Ground Cover | 200 | | |
| 5 | 850 | Shrubs | 510 | 2,947 | 598 |
| | | Trees | 200 | | |
| | | Ground Cover | 140 | | |
| 6 | 2,000 | Shrubs | 1,200 | 6,934 | 1,406 |
| | | Trees | 600 | | |
| | | Ground Cover | 200 | | |
| 7 | 5,000 | Shrubs | 3,000 | 17,334 | 3,515 |
| | | Trees | 1,000 | | |
| | | Ground Cover | 1,000 | | |
| **Total** | **43,050** | **Shrubs** | **25,830** | **149,245** | **30,263** |
| | | **Trees** | **8,900** | | |
| | | **Ground Cover** | **8,320** | | |

**Monthly Baseline = 213,207 gallons/month**

**Does the designed landscape meet the water budget?**

**YES. The LWR is an 86% reduction in water use from the baseline.**

Table 5.4. Established bioretention sites and their associated landscape water requirements based off of the average monthly rainfall, total square footage, and plant distribution by square footage.

Table 5.4 states that the established bioretention sites would require approximately 30,263 gallons of water per month. Sites 2 through 7 are located adjacent to rainwater harvesting mechanisms that can capture approximately 4,800 gallons of water during a storm event of 1 inch in depth. Sites 2 through 7 will require approximately 9,173 gallons of water per month. Excluding storm events that will also provide necessary water needs to the bioretention sites, and assuming that the bioretention sites are properly designed, it is safe to say that the rainwater harvesting mechanisms proposed will reduce the potable water use by storing runoff for future use. Site 1 is the detention basin located south of the Peter's Recreation Center and takes on more runoff than any of the other sites.

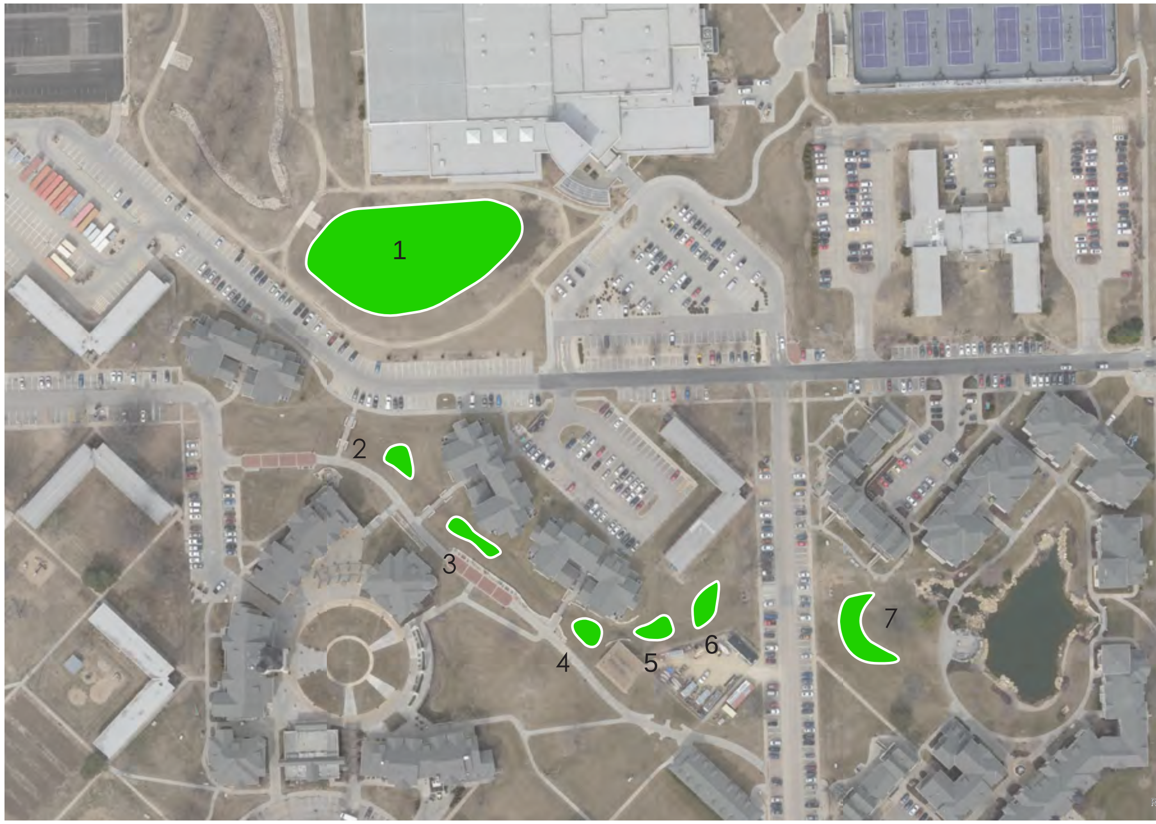



Figure 5.13. Final sites to be retrofitted with bioretention and their associated site number.

**Legend**

Suitable Area

1" = 150'

0' 150' 300'

# 5.3 Final Design

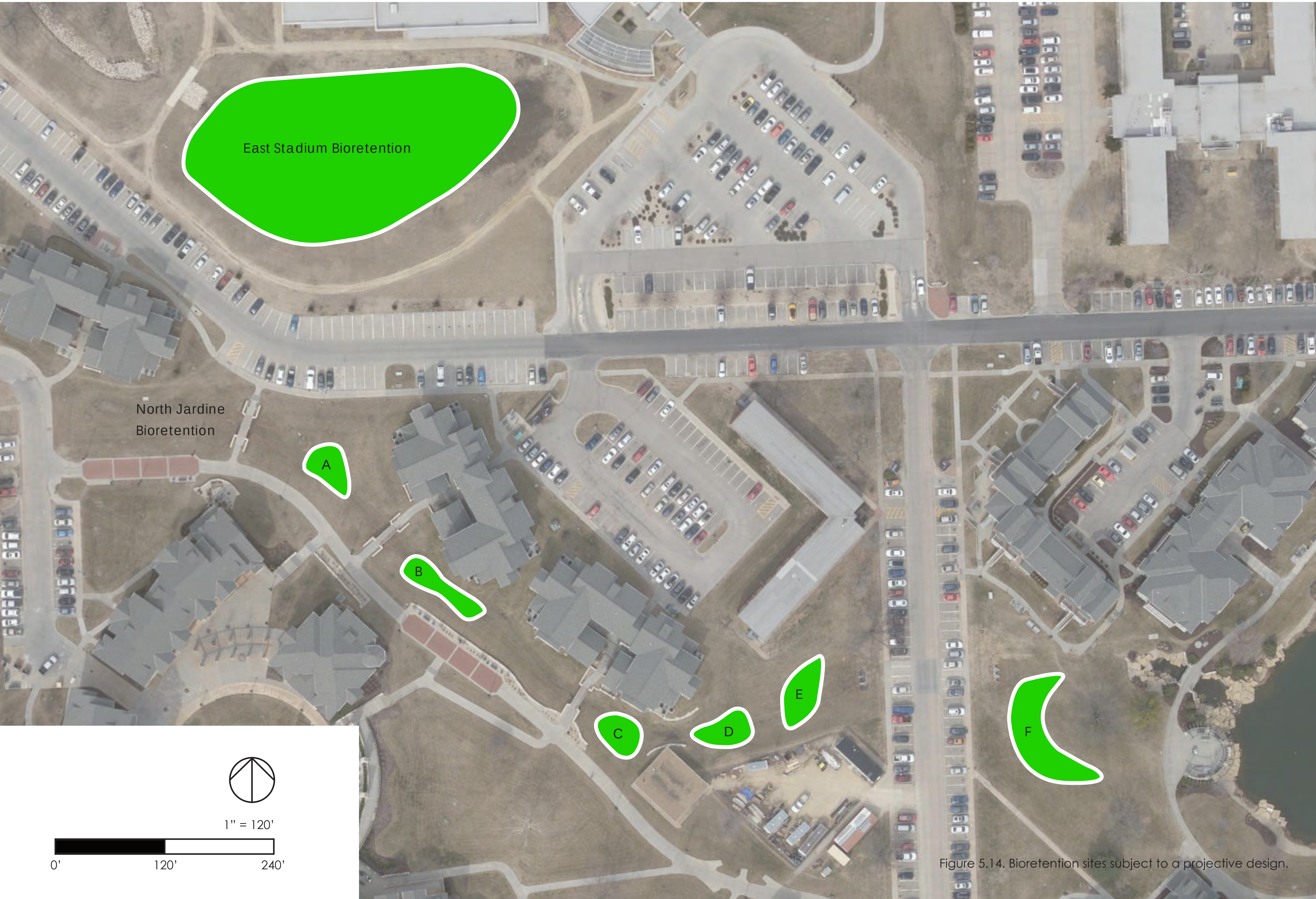



Figure 5.14. Bioretention sites subject to a projective design.

# 5.3.1 East Stadium Bioretention

A set of wet and dry tolerant species have been identified for the bioretention areas. The plants are native to Kansas and are organized using Heiner Luz's Zeigeleipark strategy for plant design. This design strategy emphasizes a 'wild' aesthetic that organizes plant material into layers that represent plant aesthetics and function. Below are the restated layers of the Zeigeleipark strategy for plant design and Table 5.2 depicts the chosen plant pallette.

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.

**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

# 5.3.1 East Stadium Bioretention

It is important to note that the planting plan and renderings presented are designed to represent overall groupings and distribution of plant material and not the placement of individual plants.

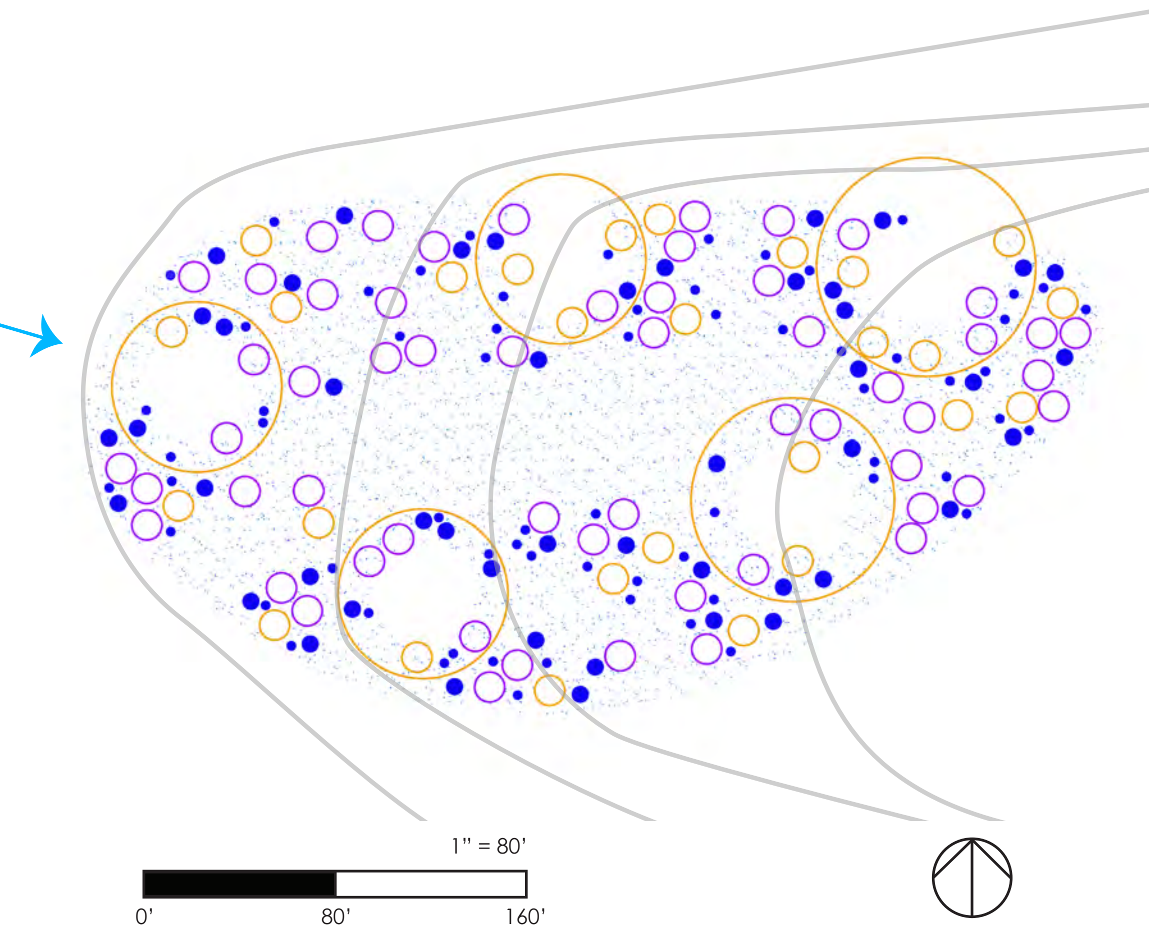



Figure 5.15. East Stadium Bioretention Planting Plan and Palette.

| Plant Layers | Scientific Name | Common Name |
| --- | --- | --- |
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

# 5.3.1 East Stadium Bioretention

Structural Framework

| | |
|---|---|
| Panicum virgatum | Switch Grass |
| Schizachyrium scoparium | Little Bluestem |
| Sporobolus heterolopsis | Prairie Dropseed |
| Liatris aspera | Tall Blazing Star |
| Rudbeckia hirta | Black-Eyed Susan |
| Silphium laciniatum | Compass Plant |
| Zizia aurea | Golden Alexander |
| **Taxodium distichum** | **Bald Cypress** |
| **Betula nigra** | **River Birch** |
| **Quercus bicolor** | **Swamp White Oak** |

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

Seasonal Theme

| | |
|---|---|
| Aster novae-angliae | New England Aster |
| Chelone glabra | White Turtlehead |
| Eupatorium perfoliatum | Boneset |
| Mimulus ringens | Monkey Flower |
| Sagittaria latifolia | Arrowhead |
| Solidago gigantean | Giant Goldenrod |
| Verbena hastata | Blue Vervain |
| Achillea sp. | Yarrow |
| Asclepias tuberosa | Butterfly Weed |
| Baptisia bracteata | Plains Wild Indigo |
| Dalea purpurea | Purple Prairie Clover |
| Echinacea purpurea | Purple Coneflower |
| Hemerocallis | Daylily |
| Ratibida columnifera | Mexican Hat |
| Asclepias incarnata | Swamp Milkweed |
| Oenothera macrocarpa | Missouri Primrose |
| Zizia aurea | Golden Alexander |

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.



Figure 5.16. East Stadium Bioretention Structural Framework Plants.

Figure 5.17. East Stadium Bioretention Seasonal Theme Plants.

# 5.3.1 East Stadium Bioretention

| | | |
|---|---|---|
| Dynamic Filler | Acorus calamus<br>Juncus<br>Lopelia cardinalis | Sweet Flag<br>Rush<br>Cardinal Flower |

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

Figure 5.18. East Stadium Bioretention Dynamic Filler Plants.

| | | |
|---|---|---|
| Ground Cover | Carex spp.<br>Spartina pectinata<br>Equisetum | Sedge<br>Prairie Cordgrass<br>Horsetail |

**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

Figure 5.19. East Stadium Bioretention Ground Cover Plants.

# 5.3.1 East Stadium Bioretention

The bioretention site installed to address the East Stadium parking lot runoff is located south of the Peter's Recreation Center and will provide a new natural amenity for students and staff at Kansas State University. The new garden is located adjacent to a series of walkways designed to guide visitors to Bill Snyder Stadium on gameday, therefore, the new bioretention will not only absorb, infiltrate and filter stormwater runoff, but it will also capture the pedestrian's eye. In addition to passersby, Kansas State students and staff visiting the recreation center can walk a very short distance to a contemplative space when in need of rest after a work out.

The previous site was desolate of any vegetation; the new site is lush and wild and compliments the newly planted trees in the North Jardine parking lot. Together, they both address stormwater management needs of the area while providing aesthetic appeal that was otherwise absent in the original site.

Figure 5.22. A view of the East Stadium Bioretention from the Recreation Center Entrance.

Figure 5.20. A view of the East Stadium Bioretention from the southern walkway looking North.

# 5.3.2 North Jardine Bioretention

Site A

It is important to note that the planting plan and renderings presented are designed to represent overall groupings and distribution of plant material and not the placement of individual plants.

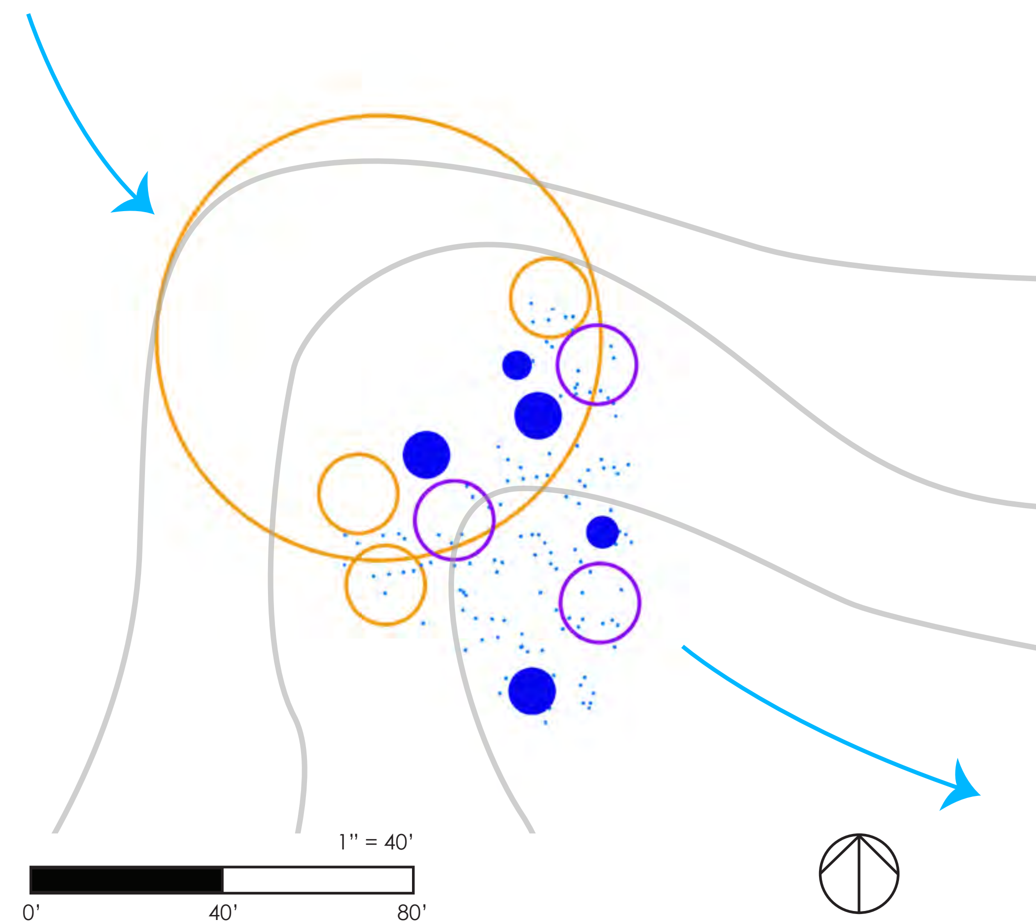



Figure 5.22. North Jardine Bioretention Site A Planting Plan and Palette.

| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

# 5.3.2 North Jardine Bioretention

Site A

Structural Framework

| | |
|---|---|
| Panicum virgatum | Switch Grass |
| Schizachyrium scoparium | Little Bluestem |
| Sporobolus heterolopsis | Prairie Dropseed |
| Liatris aspera | Tall Blazing Star |
| Rudbeckia hirta | Black-Eyed Susan |
| Silphium laciniatum | Compass Plant |
| Zizia aurea | Golden Alexander |
| **Taxodium distichum** | **Bald Cypress** |
| **Betula nigra** | **River Birch** |
| **Quercus bicolor** | **Swamp White Oak** |

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

Seasonal Theme

| | |
|---|---|
| Aster novae-angliae | New England Aster |
| Chelone glabra | White Turtlehead |
| Eupatorium perfoliatum | Boneset |
| Mimulus ringens | Monkey Flower |
| Sagittaria latifolia | Arrowhead |
| Solidago gigantean | Giant Goldenrod |
| Verbena hastata | Blue Vervain |
| Achillea sp. | Yarrow |
| Asclepias tuberosa | Butterfly Weed |
| Baptisia bracteata | Plains Wild Indigo |
| Dalea purpurea | Purple Prairie Clover |
| Echinacea purpurea | Purple Coneflower |
| Hemerocallis | Daylily |
| Ratibida columnifera | Mexican Hat |
| Asclepias incarnata | Swamp Milkweed |
| Oenothera macrocarpa | Missouri Primrose |
| Zizia aurea | Golden Alexander |

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.

Figure 5.23. North Jardine Bioretention Site A Structural Framework Plants.

Figure 5.24. North Jardine Bioretention Site A Seasonal Theme Plants.

# 5.3.2 North Jardine Bioretention

Site A

| | | | |
|---|---|---|---|
| Dynamic Filler | | Acorus calamus<br>Juncus<br>Lopelia cardinalis | Sweet Flag<br>Rush<br>Cardinal Flower |

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

| | | | |
|---|---|---|---|
| Ground Cover | | Carex spp.<br>Spartina pectinata<br>Equisetum | Sedge<br>Prairie Cordgrass<br>Horsetail |

**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

Figure 5.25. North Jardine Bioretention Site A Dynamic Framework Plants.

Figure 5.26. East Stadium Bioretention Ground Cover Plants.

# 5.3.2 North Jardine Bioretention

Site B

It is important to note that the planting plan and renderings presented are designed to represent overall groupings and distribution of plant material and not the placement of individual plants.

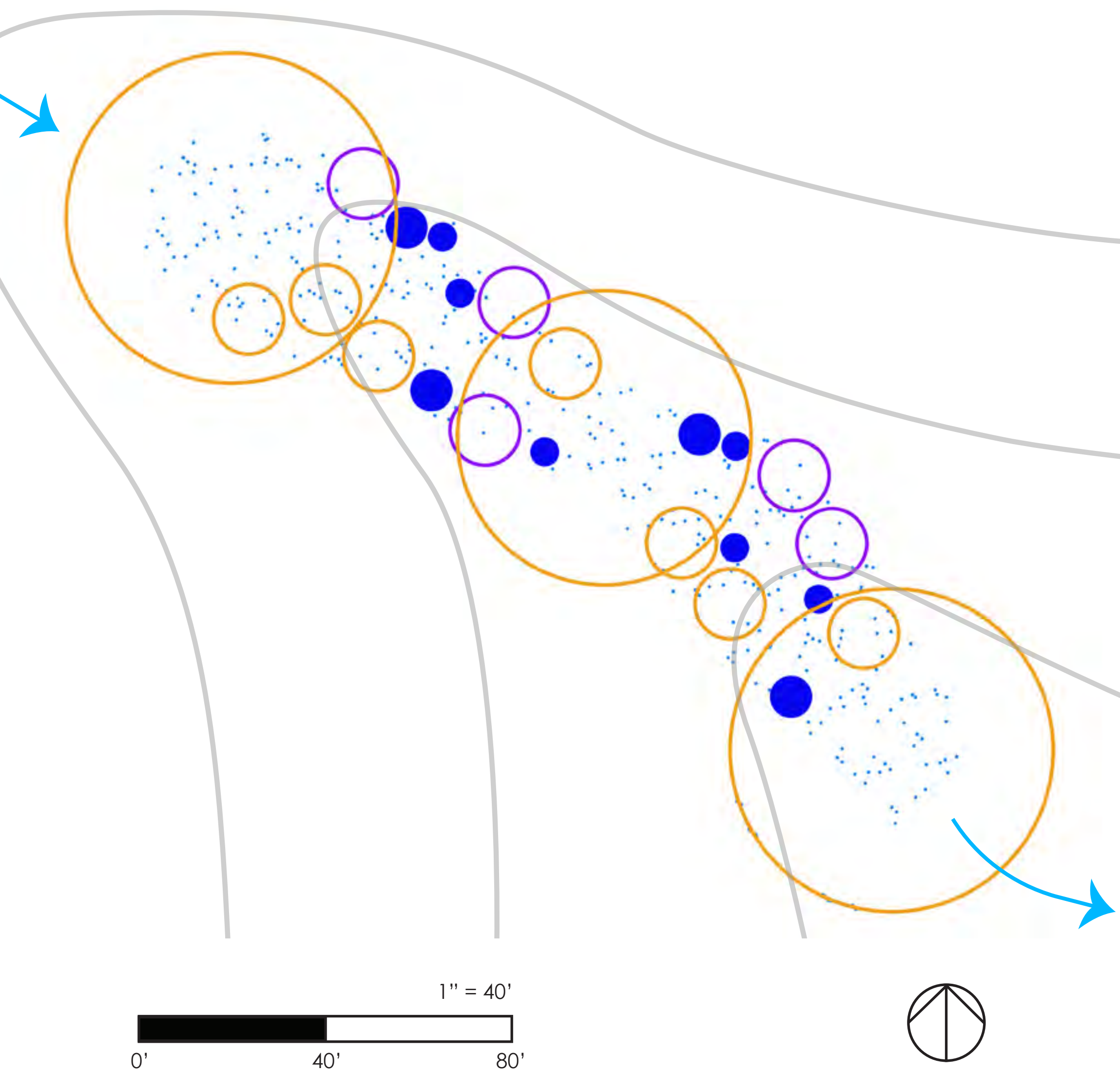



Figure 5.27. North Jardine Bioretention Site B Planting Plan Palette.

| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

# 5.3.2 North Jardine Bioretention

Site B

Structural Framework

| | |
|---|---|
| Panicum virgatum | Switch Grass |
| Schizachyrium scoparium | Little Bluestem |
| Sporobolus heterolopsis | Prairie Dropseed |
| Liatris aspera | Tall Blazing Star |
| Rudbeckia hirta | Black-Eyed Susan |
| Silphium laciniatum | Compass Plant |
| Zizia aurea | Golden Alexander |
| **Taxodium distichum** | **Bald Cypress** |
| **Betula nigra** | **River Birch** |
| **Quercus bicolor** | **Swamp White Oak** |

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

Seasonal Theme

| | |
|---|---|
| Aster novae-angliae | New England Aster |
| Chelone glabra | White Turtlehead |
| Eupatorium perfoliatum | Boneset |
| Mimulus ringens | Monkey Flower |
| Sagittaria latifolia | Arrowhead |
| Solidago gigantean | Giant Goldenrod |
| Verbena hastata | Blue Vervain |
| Achillea sp. | Yarrow |
| Asclepias tuberosa | Butterfly Weed |
| Baptisia bracteata | Plains Wild Indigo |
| Dalea purpurea | Purple Prairie Clover |
| Echinacea purpurea | Purple Coneflower |
| Hemerocallis | Daylily |
| Ratibida columnifera | Mexican Hat |
| Asclepias incarnata | Swamp Milkweed |
| Oenothera macrocarpa | Missouri Primrose |
| Zizia aurea | Golden Alexander |

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.

Figure 5.28. North Jardine Bioretention Site B Structural Framework Plants.

Figure 5.29. North Jardine Bioretention Site B Seasonal Theme Plants.

# 5.3.2 North Jardine Bioretention

Site B

| | | |
|---|---|---|
| Dynamic Filler | Acorus calamus<br>Juncus<br>Lopelia cardinalis | Sweet Flag<br>Rush<br>Cardinal Flower |

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

Figure 5.30. North Jardine Bioretention Site B Dynamic Filler Plants.

| | | |
|---|---|---|
| Ground Cover | Carex spp.<br>Spartina pectinata<br>Equisetum | Sedge<br>Prairie Cordgrass<br>Horsetail |

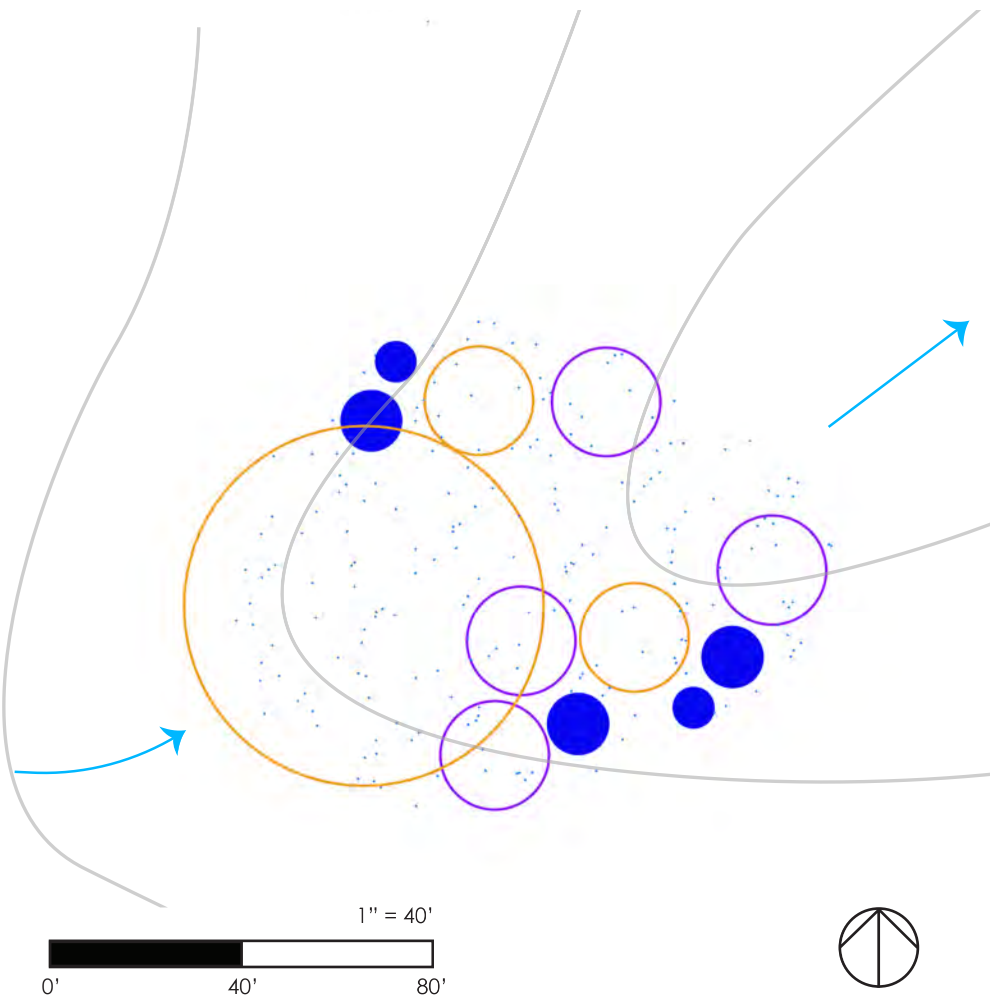
**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

Figure 5.31. North Jardine Bioretention Site B Ground Cover Plants.

# 5.3.2 North Jardine Bioretention

Site C

It is important to note that the planting plan and renderings presented are designed to represent overall groupings and distribution of plant material and not the placement of individual plants.




| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

Figure 5.32. North Jardine Bioretention Site C Planting Plan and Palette.

# 5.3.2 North Jardine Bioretention

Site C

Structural Framework

| | |
|---|---|
| Panicum virgatum | Switch Grass |
| Schizachyrium scoparium | Little Bluestem |
| Sporobolus heterolopsis | Prairie Dropseed |
| Liatris aspera | Tall Blazing Star |
| Rudbeckia hirta | Black-Eyed Susan |
| Silphium laciniatum | Compass Plant |
| Zizia aurea | Golden Alexander |
| **Taxodium distichum** | **Bald Cypress** |
| **Betula nigra** | **River Birch** |
| **Quercus bicolor** | **Swamp White Oak** |

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

Seasonal Theme

| | |
|---|---|
| Aster novae-angliae | New England Aster |
| Chelone glabra | White Turtlehead |
| Eupatorium perfoliatum | Boneset |
| Mimulus ringens | Monkey Flower |
| Sagittaria latifolia | Arrowhead |
| Solidago gigantean | Giant Goldenrod |
| Verbena hastata | Blue Vervain |
| Achillea sp. | Yarrow |
| Asclepias tuberosa | Butterfly Weed |
| Baptisia bracteata | Plains Wild Indigo |
| Dalea purpurea | Purple Prairie Clover |
| Echinacea purpurea | Purple Coneflower |
| Hemerocallis | Daylily |
| Ratibida columnifera | Mexican Hat |
| Asclepias incarnata | Swamp Milkweed |
| Oenothera macrocarpa | Missouri Primrose |
| Zizia aurea | Golden Alexander |

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.

Figure 5.33. North Jardine Bioretention Site C Structural Framework Plants.

Figure 5.34. North Jardine Bioretention Site C Seasonal Theme Plants.

# 5.3.2 North Jardine Bioretention

Site C

| | | |
|---|---|---|
| Dynamic Filler | Acorus calamus<br>Juncus<br>Lopelia cardinalis | Sweet Flag<br>Rush<br>Cardinal Flower |

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

Figure 5.35. North Jardine Bioretention Site C Dynamic Filler Plants.

| | | |
|---|---|---|
| Ground Cover | Carex spp.<br>Spartina pectinata<br>Equisetum | Sedge<br>Prairie Cordgrass<br>Horsetail |

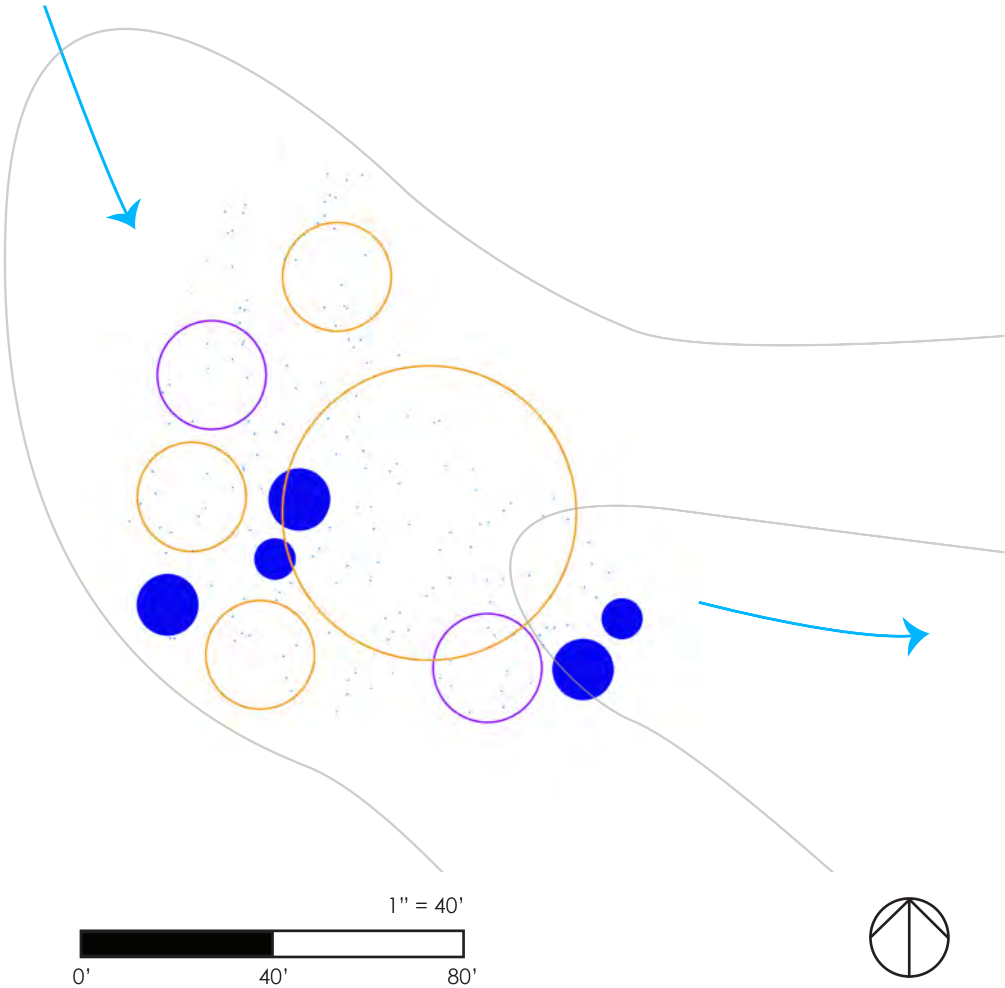
**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

Figure 5.36. North Jardine Bioretention Site C Ground Cover Plants.

# 5.3.2 North Jardine Bioretention

Site D

It is important to note that the planting plan and renderings presented are designed to represent overall groupings and distribution of plant material and not the placement of individual plants.




| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

Figure 5.37. North Jardine Bioretention Site D Planting Plan and Palette.

# 5.3.2 North Jardine Bioretention

Site D

Structural Framework

| | |
|---|---|
| Panicum virgatum | Switch Grass |
| Schizachyrium scoparium | Little Bluestem |
| Sporobolus heterolopsis | Prairie Dropseed |
| Liatris aspera | Tall Blazing Star |
| Rudbeckia hirta | Black-Eyed Susan |
| Silphium laciniatum | Compass Plant |
| Zizia aurea | Golden Alexander |
| **Taxodium distichum** | **Bald Cypress** |
| **Betula nigra** | **River Birch** |
| **Quercus bicolor** | **Swamp White Oak** |

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

Seasonal Theme

| | |
|---|---|
| Aster novae-angliae | New England Aster |
| Chelone glabra | White Turtlehead |
| Eupatorium perfoliatum | Boneset |
| Mimulus ringens | Monkey Flower |
| Sagittaria latifolia | Arrowhead |
| Solidago gigantean | Giant Goldenrod |
| Verbena hastata | Blue Vervain |
| Achillea sp. | Yarrow |
| Asclepias tuberosa | Butterfly Weed |
| Baptisia bracteata | Plains Wild Indigo |
| Dalea purpurea | Purple Prairie Clover |
| Echinacea purpurea | Purple Coneflower |
| Hemerocallis | Daylily |
| Ratibida columnifera | Mexican Hat |
| Asclepias incarnata | Swamp Milkweed |
| Oenothera macrocarpa | Missouri Primrose |
| Zizia aurea | Golden Alexander |

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.

Figure 5.38. North Jardine Bioretention Site D Structural Framework Plants.

Figure 5.39. North Jardine Bioretention Site D Seasonal Theme Plants.

# 5.3.2 North Jardine Bioretention

Site D

| | | | |
|---|---|---|---|
| Dynamic Filler | | Acorus calamus<br>Juncus<br>Lopelia cardinalis | Sweet Flag<br>Rush<br>Cardinal Flower |

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

Figure 5.40. North Jardine Bioretention Site D Dynamic Filler Plants.

| | | | |
|---|---|---|---|
| Ground Cover | | Carex spp.<br>Spartina pectinata<br>Equisetum | Sedge<br>Prairie Cordgrass<br>Horsetail |

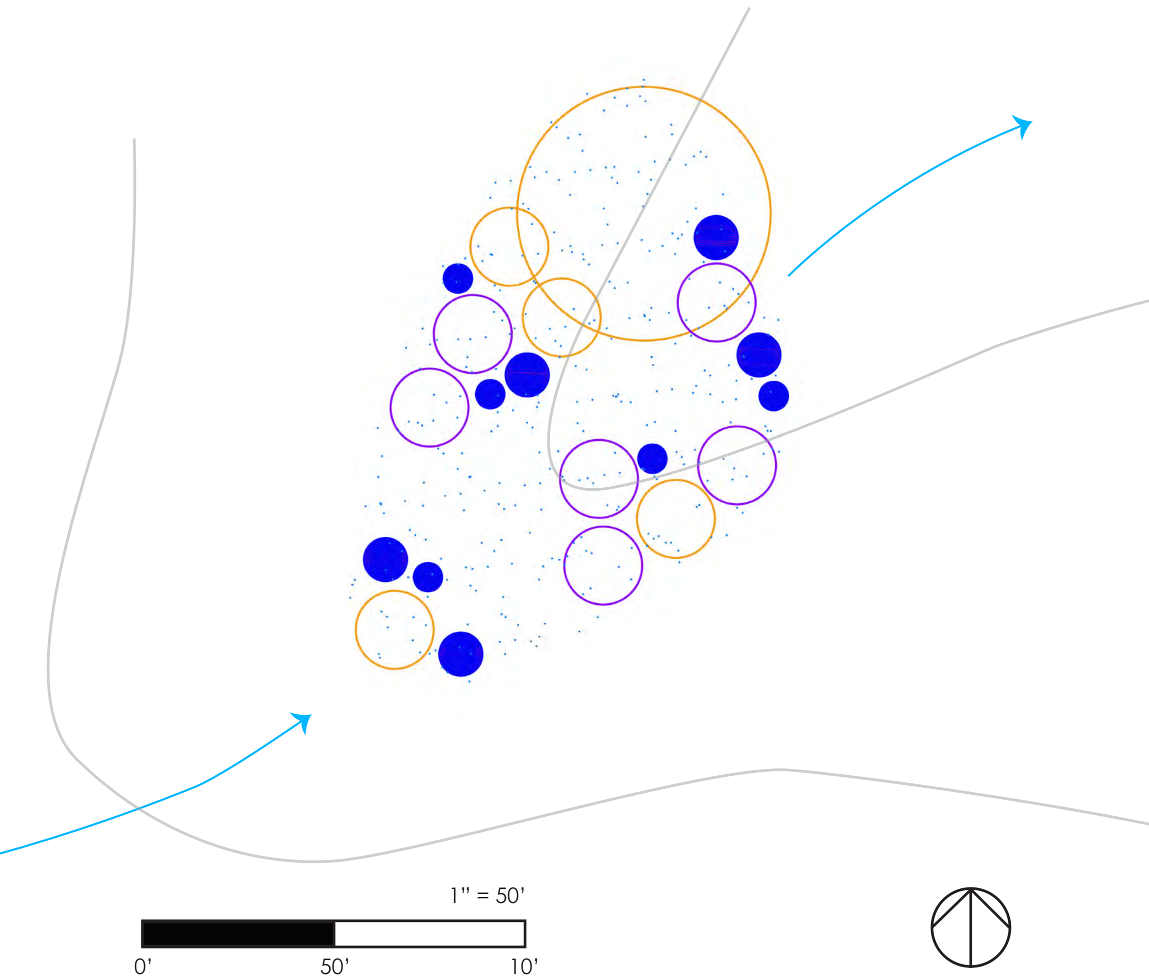
**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

Figure 5.41. North Jardine Bioretention Site D Ground Cover Plants.

# 5.3.2 North Jardine Bioretention

Site E

It is important to note that the planting plan and renderings presented are designed to represent overall groupings and distribution of plant material and not the placement of individual plants.




| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

Figure 5.42. North Jardine Bioretention Site E Planting Plan and Palette.

# 5.3.2 North Jardine Bioretention

Site E

Structural Framework

| | |
|---|---|
| Panicum virgatum | Switch Grass |
| Schizachyrium scoparium | Little Bluestem |
| Sporobolus heterolopsis | Prairie Dropseed |
| Liatris aspera | Tall Blazing Star |
| Rudbeckia hirta | Black-Eyed Susan |
| Silphium laciniatum | Compass Plant |
| Zizia aurea | Golden Alexander |
| **Taxodium distichum** | **Bald Cypress** |
| **Betula nigra** | **River Birch** |
| **Quercus bicolor** | **Swamp White Oak** |

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

Seasonal Theme

| | |
|---|---|
| Aster novae-angliae | New England Aster |
| Chelone glabra | White Turtlehead |
| Eupatorium perfoliatum | Boneset |
| Mimulus ringens | Monkey Flower |
| Sagittaria latifolia | Arrowhead |
| Solidago gigantean | Giant Goldenrod |
| Verbena hastata | Blue Vervain |
| Achillea sp. | Yarrow |
| Asclepias tuberosa | Butterfly Weed |
| Baptisia bracteata | Plains Wild Indigo |
| Dalea purpurea | Purple Prairie Clover |
| Echinacea purpurea | Purple Coneflower |
| Hemerocallis | Daylily |
| Ratibida columnifera | Mexican Hat |
| Asclepias incarnata | Swamp Milkweed |
| Oenothera macrocarpa | Missouri Primrose |
| Zizia aurea | Golden Alexander |

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.

Figure 5.43. North Jardine Bioretention Site E Structural Framework Plants.

Figure 5.44. North Jardine Bioretention Site E Seasonal Theme Plants.

# 5.3.2 North Jardine Bioretention

Site E

| | | | |
|---|---|---|---|
| Dynamic Filler | | Acorus calamus<br>Juncus<br>Lopelia cardinalis | Sweet Flag<br>Rush<br>Cardinal Flower |

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

| | | | |
|---|---|---|---|
| Ground Cover | | Carex spp.<br>Spartina pectinata<br>Equisetum | Sedge<br>Prairie Cordgrass<br>Horsetail |

**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

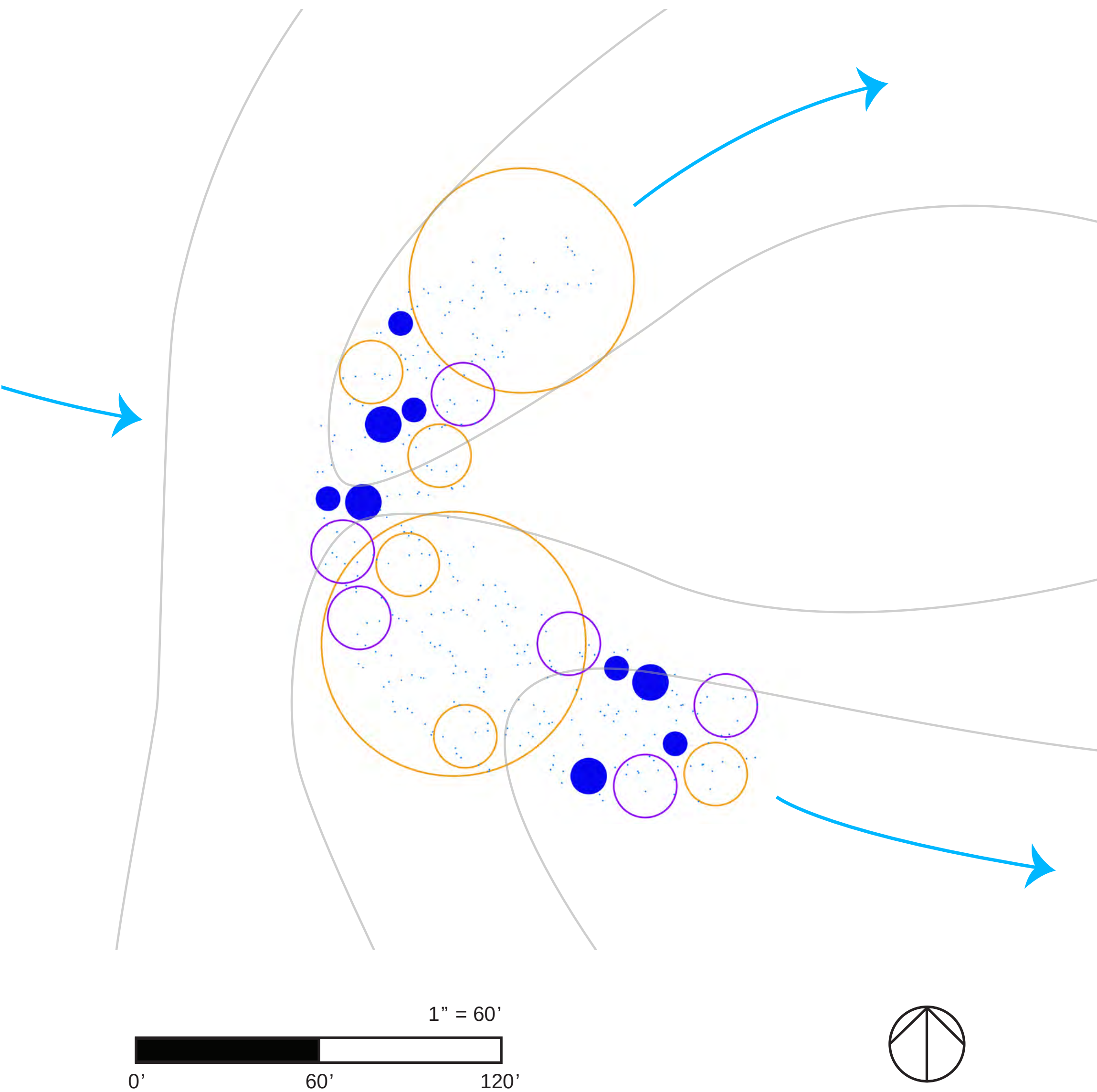
Figure 5.45. North Jardine Bioretention Site E Dynamic Filler Plants.

Figure 5.46. North Jardine Bioretention Site E Ground Cover Plants.

# 5.3.2 North Jardine Bioretention

Site F

It is important to note that the planting plan and renderings presented are designed to represent overall groupings and distribution of plant material and not the placement of individual plants.




| Plant Layers | Scientific Name | Common Name |
|---|---|---|
| Structural Framework | Panicum virgatum | Switch Grass |
| | Schizachyrium scoparium | Little Bluestem |
| | Sporobolus heterolopsis | Prairie Dropseed |
| | Liatris aspera | Tall Blazing Star |
| | Rudbeckia hirta | Black-Eyed Susan |
| | Silphium laciniatum | Compass Plant |
| | Zizia aurea | Golden Alexander |
| | **Taxodium distichum** | **Bald Cypress** |
| | **Betula nigra** | **River Birch** |
| | **Quercus bicolor** | **Swamp White Oak** |
| Seasonal Theme | Aster novae-angliae | New England Aster |
| | Chelone glabra | White Turtlehead |
| | Eupatorium perfoliatum | Boneset |
| | Mimulus ringens | Monkey Flower |
| | Sagittaria latifolia | Arrowhead |
| | Solidago gigantean | Giant Goldenrod |
| | Verbena hastata | Blue Vervain |
| | Achillea sp. | Yarrow |
| | Asclepias tuberosa | Butterfly Weed |
| | Baptisia bracteata | Plains Wild Indigo |
| | Dalea purpurea | Purple Prairie Clover |
| | Echinacea purpurea | Purple Coneflower |
| | Hemerocallis | Daylily |
| | Ratibida columnifera | Mexican Hat |
| | Asclepias incarnata | Swamp Milkweed |
| | Oenothera macrocarpa | Missouri Primrose |
| | Zizia aurea | Golden Alexander |
| Ground Cover | Carex spp. | Sedge |
| | Spartina pectinata | Prairie Cordgrass |
| | Equisetum | Horsetail |
| Dynamic Filler | Acorus calamus | Sweet Flag |
| | Juncus | Rush |
| | Lopelia cardinalis | Cardinal Flower |

Figure 5.47. North Jardine Bioretention Site F Planting Plan and Palette.

# 5.3.2 North Jardine Bioretention

Site F

Structural Framework

| | |
|---|---|
| Panicum virgatum | Switch Grass |
| Schizachyrium scoparium | Little Bluestem |
| Sporobolus heterolepis | Prairie Dropseed |
| Liatris aspera | Tall Blazing Star |
| Rudbeckia hirta | Black-Eyed Susan |
| Silphium laciniatum | Compass Plant |
| Zizia aurea | Golden Alexander |
| **Taxodium distichum** | **Bald Cypress** |
| **Betula nigra** | **River Birch** |
| **Quercus bicolor** | **Swamp White Oak** |

**Structural Framework Plants** are large plants that form the visual structure of the plant pallette. Structural framework plants include trees, shrubs, and upright growing grasses and perennials, and large-leaved perennials. Plants in this layer are long-lived and have unique forms while they remain competitive and stress-tolerant. Structural framework plants embody 10 to 15 percent of the plant area.

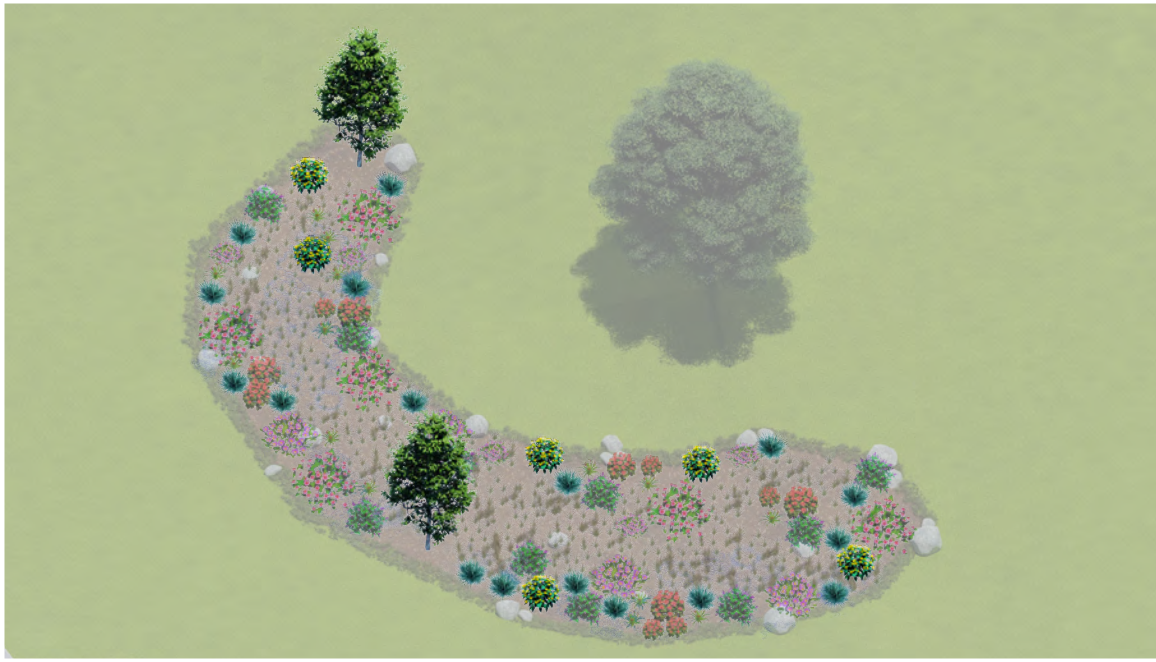


Figure 5.48. North Jardine Bioretention Site F Structural Framework Plants.

Seasonal Theme

| | |
|---|---|
| Aster novae-angliae | New England Aster |
| Chelone glabra | White Turtlehead |
| Eupatorium perfoliatum | Boneset |
| Mimulus ringens | Monkey Flower |
| Sagittaria latifolia | Arrowhead |
| Solidago gigantean | Giant Goldenrod |
| Verbena hastata | Blue Vervain |
| Achillea sp. | Yarrow |
| Asclepias tuberosa | Butterfly Weed |
| Baptisia bracteata | Plains Wild Indigo |
| Dalea purpurea | Purple Prairie Clover |
| Echinacea purpurea | Purple Coneflower |
| Hemerocallis | Daylily |
| Ratibida columnifera | Mexican Hat |
| Asclepias incarnata | Swamp Milkweed |
| Oenothera macrocarpa | Missouri Primrose |
| Zizia aurea | Golden Alexander |

**Seasonal Theme Plants** are at a moderate height at maturity and become visually dominant during their blooming season. When they are not in bloom, they become green plants that support the structural framework with long to medium lifespans and embody 25 to 40 percent of the plant area.

Figure 5.49. North Jardine Bioretention Site F Seasonal Theme Plants.

# 5.3.2 North Jardine Bioretention

Site F

| | | |
|---|---|---|
| Dynamic Filler | Acorus calamus<br>Juncus<br>Lopelia cardinalis | Sweet Flag<br>Rush<br>Cardinal Flower |

**Dynamic Filler Plants** are short-lived species that temporarily fill gaps and grow quickly. They also have little competition tolerance and embody 5 to 10 percent of the plant area.

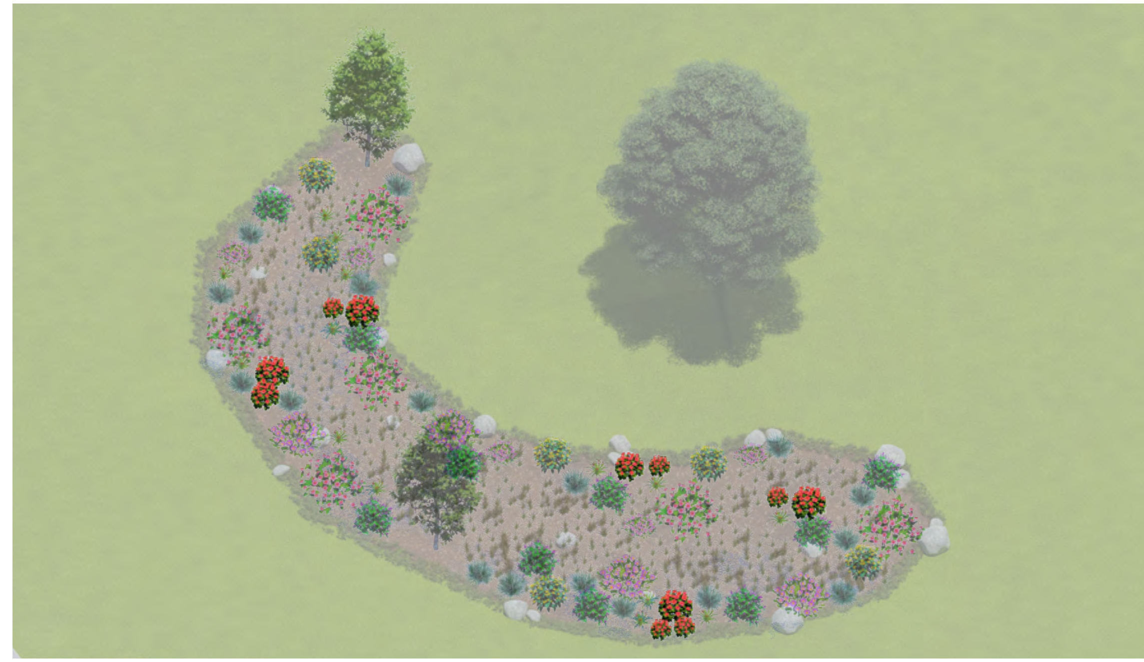


Figure 5.50. North Jardine Bioretention Site F Dynamic Filler Plants.

| | | |
|---|---|---|
| Ground Cover | Carex spp.<br>Spartina pectinata<br>Equisetum | Sedge<br>Prairie Cordgrass<br>Horsetail |

**Ground Cover Plants** are low, shade-tolerant species used to cover the ground between points. Ground cover provides erosion control and a source of nectar for pollinators while being stress tolerant. Ground cover plants are the most abundant and cover about 50 percent of the plant area.

Figure 5.51. North Jardine Bioretention Site F Ground Cover Plants.

# 5.3.3 North Jardine Bioretention

Renderings

The bioretention site installed to address the North Jardine parking lot runoff is located in a central drainage area within the apartment complex. The new gardens are strategically placed in locations free of utility or pedestrian circulation conflicts. The original site was already a depressed swale-like area designed to move runoff, and was also conveniently located next to pedestrian bridges, sidewalks, and apartment buildings. Therefore, providing a new experience for Jardine residents.

As noted, the original site was a depressed lawn area, the new plantings provide a new garden-like aesthetic that creates a new amenity for Jardine residents. The entire area serves as pedestrian circulation during football season for people walking to Bill Snyder Stadium. Thus, the new garden aesthetic will draw the eye of passersby and increase the overall aesthetic appeal of the Jardine Apartment Complex.

Figure 5.53. A view of the North Jardine Bioretention looking South.

Figure 5.52. A view of North Jardine bioretention site B looking west.

Figure 5.54. A view of the North Jardine Bioretention looking north.

Figure 5.55. Jardine Apartment Complex bioretention from an aerial view looking south.

# Chapter 6

## Projective Design

### Demonstration Projects

Rainwater Harvesting

Tree Canopy

Permeable Pavement

Figure 6.1. Trees located on the Weigel Library Terrace north of Seaton Hall at Kansas State University.

# 6.1.1 Rainwater Harvesting

Sizing

The graphic opposite of this page depicts sites that are suitable for a future rainwater harvesting mechanism. The sites are suitable for their proximity to downspouts, but also their proximity to the suitable bioretention areas visualized on the previous page. According to Texas Tanks, a well known cistern installation company, a storm with a 1 inch depth can produce approximately 600 gallons of water per 1000 square feet of roof. The total roof catchment area is approximately 8,000 square feet. The table below depicts the amount of water produced by the roof area and how large of a cistern is needed.

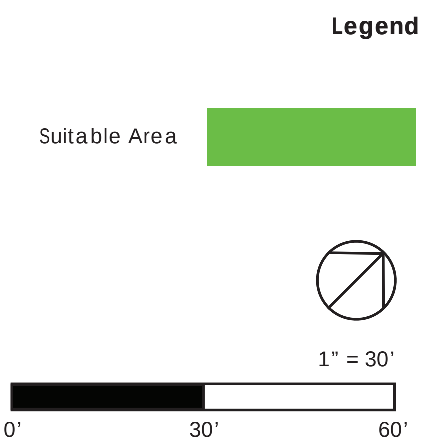
| Roof Area (sf) | Gallons of Runoff | Gallons of Storage |
|---|---|---|
| 8,000 | 4,800 | 5,000 |

Table 6.1. Total roof area, the amount of runoff produced for a 1" deep storm, and the amount of gallons produced.

To mitigate the need to wire all downspouts into one large 5,000 gallon cistern, exploration into having several cisterns at every downspout has taken place. Figure 6.2 depicts the building footprint of the two buildings adjacent to the drainage area where future bioretention will be installed, and where smaller, separate cisterns can be placed.

| # | Cistern Size (gallons) |
|---|---|
| 1 | 830 |
| 2 | 830 |
| 3 | 500 |
| 4 | 500 |
| 5 | 830 |
| 6 | 830 |
| 7 | 1,200 |
| 8 | 500 |
| **Total** | **6,020** |

Table 6.2. All cisterns and their associated sizes. Source: Texas Tanks website.



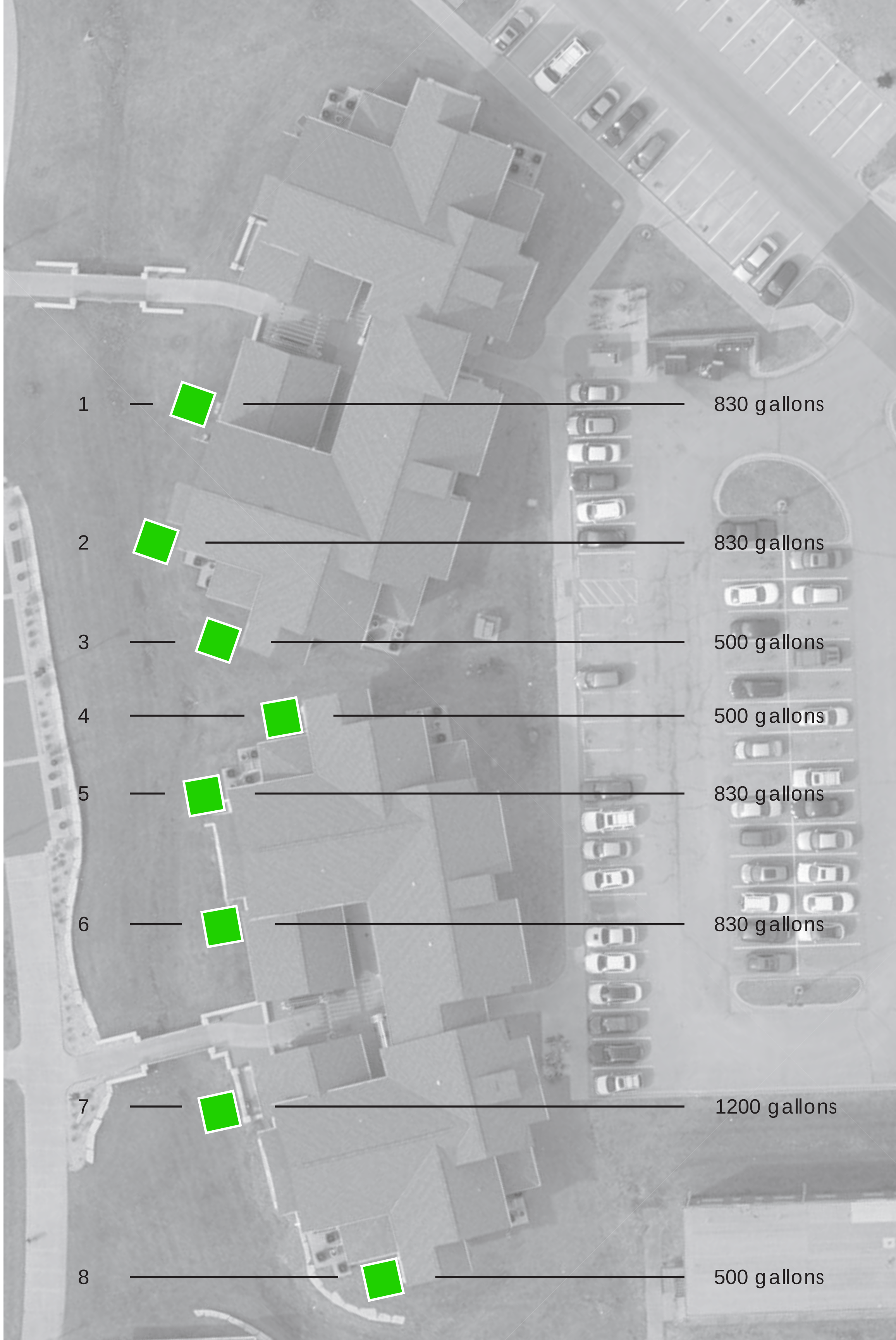




Figure 6.2. All cisterns and their associated sizes.

# 6.1.2 Rainwater Harvesting

Water Distribution

It's important to note the proximity to each rainwater harvesting mechanism and the bioretention and note how this can be used to an advantage. Figure 6.3 depicts the elevation change between the proposed rain water harvesting mechanism and the adjacent bioretention. Utilizing the elevation change can alleviate the need for a more advanced pumping mechanism to deliver stored water to the bioretention site and instead use gravity to do so. Figure 6.5 (next page) depicts the utilization of a simple hose bibb faucet strategically placed at the bottom of the cistern. Each cistern will have its own hose that can be wired to the faucet and guided to any of the nearby bioretention sites.

The maintenance crew for Housing and Dining at Kansas State University is short staffed according to their managing groundskeeper, Thomas Fish. Therefore, the proposed cistern design will allow for the least amount of maintenance and the most ease of access for the current maintenance crew, thus, mitigating additional stress.

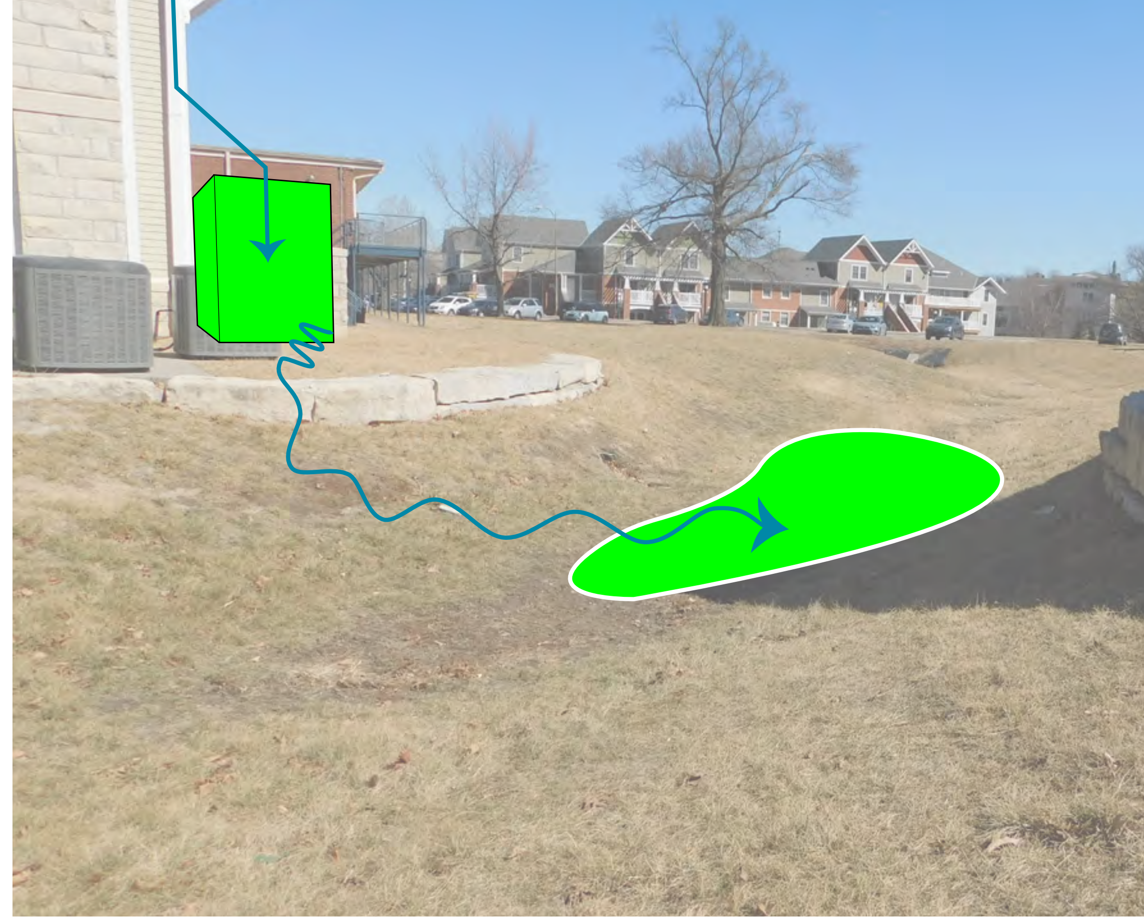


Figure 6.3. Interaction between rainwater harvesting mechanism and bioretention.

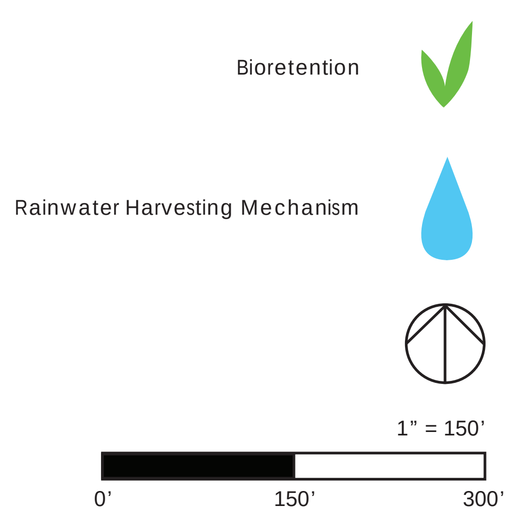



Figure 6.4. Proposed bioretention and rain water harvesting sites.

# 6.1.2 Rainwater Harvesting

Water Distribution

**A** Rainwater is guided into gutter.

**B** Gutter guides rainwater into downspout connection.

**C** A filter at the bottom of the downspout prevents debris from entering cistern.

**D** Rainwater collects within the cistern. A hose is conveniently located on the outside of the tank.

**E** An overflow pipe located at the top of the cistern in the event that the cistern reaches full capacity.

**F** A hose bibb faucet located at the bottom of the cistern allows for easy access to stored rainwater with the additional access via hose.

**G** A bioretention cell located at the low point adjacent to the rainwater harvesting mechanism utilizes the overflow water and the stored water.

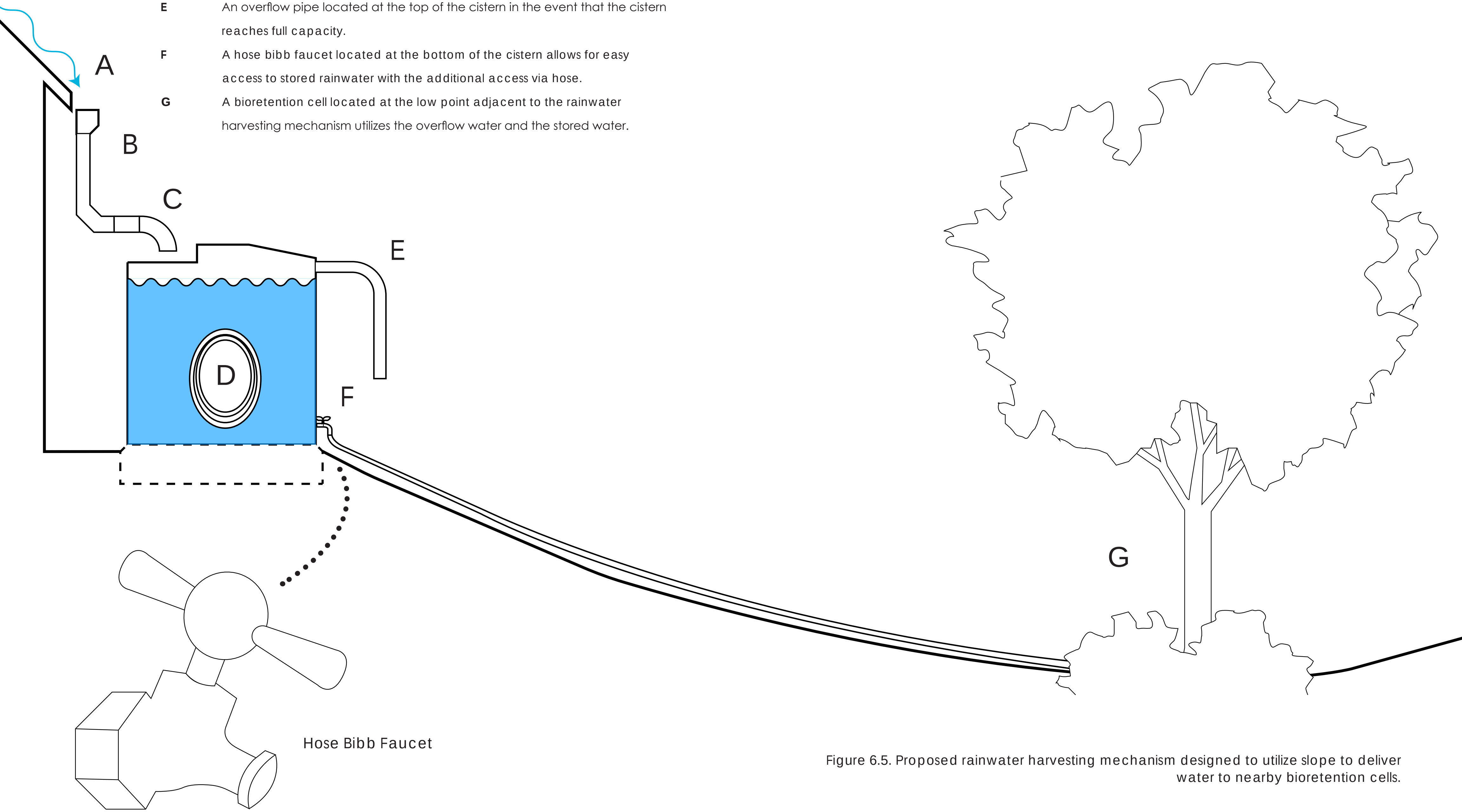



Figure 6.5. Proposed rainwater harvesting mechanism designed to utilize slope to deliver water to nearby bioretention cells.

# 6.1.3 Rainwater Harvesting

Perspective Renderings

The proposed rainwater harvesting mechanisms are placed adjacent to the proposed bioretention and have the opportunity to provide an educational opportunity to passersby as they are also in close proximity to pedestrian circulation. Rain Water Harvesting is a relatively unknown concept and ensuring that pedestrians can see the benefits in real time can support the future implementation of more of them.

Each cistern is connected to an existing roof downspout that will store runoff for future use, and their strategic placement will offer easy access to the newly installed bioretention. The stainless steel design reflects the design Texas Tanks provides, and offers a unique contrast between the natural and artificial. Both of which rely on one another.

Figure 6.7. A view of the rainwater harvesting mechanisms and their proximity to pedestrian circulation.

Figure 6.6. A view of the rainwater harvesting mechanisms and their proximity to bioretention.

# 6.2.1 Tree Canopy Increase

Suitable Area and Parking Island Exploration

The graphic below depicts all sites suitable for an increase in tree canopy. It's important to note that the East Stadium, South Recreation, and Mid-Jardine parking lot are not suitable for a potential increase in tree canopy due to utility and circulation conflicts, and a lack of softscape/parking islands. Therefore, exploration into an increase in tree canopy will be focused on the North Jardine parking lot as it contains parking islands and adjacent softscape free of utility or circulation conflicts. Figures X and X explore extending select parking islands to provide more room for growth. It's important to note that the suitable parking islands contain small Flowering Crabapple trees. Perhaps there is an opportunity to relocate them to a place where they can grow larger, and the parking islands can be replanted with a taller and wider tree species that has potential to cover the adjacent impervious surfaces.

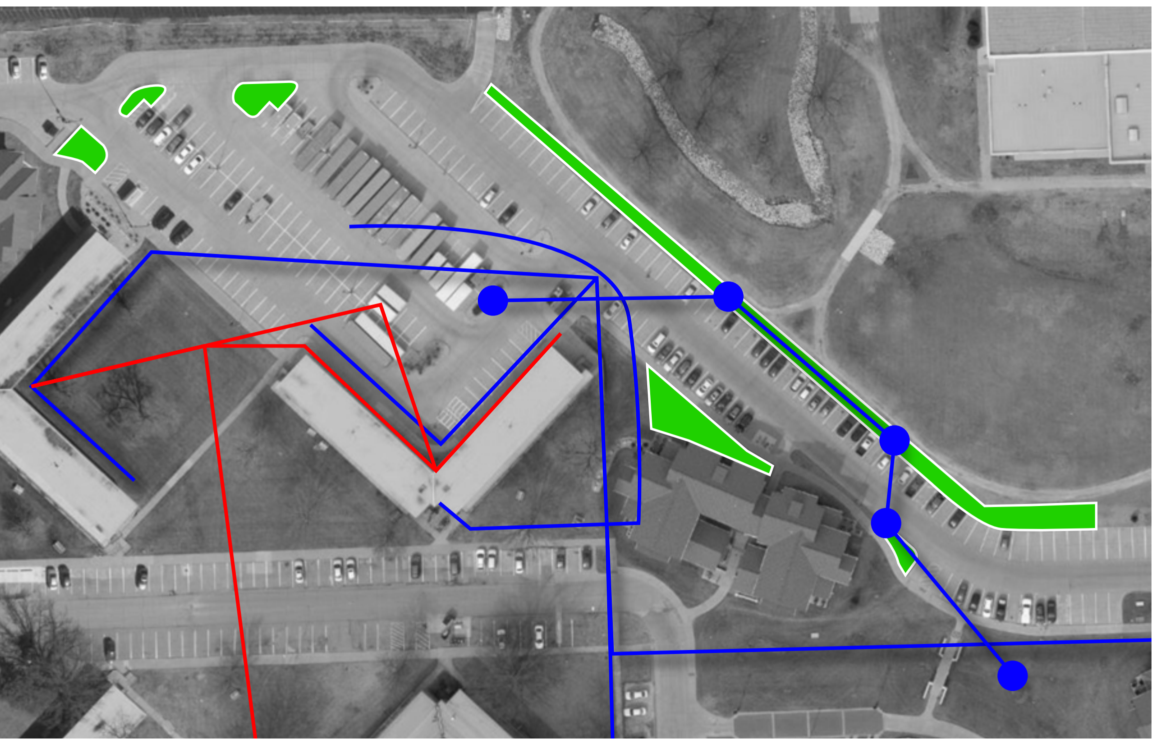


Figure 6.8. Site suitable for future tree plantings.

**Legend**

1" = 125'

0' 125' 250'

| | |
|---|---|
| Suitable Area | (green) |
| Water Utilities | (blue line) |
| Power and Gas Utilities | (red line) |

Figure 6.9. North Jardine parking islands that could be extended to accomodate more trees.

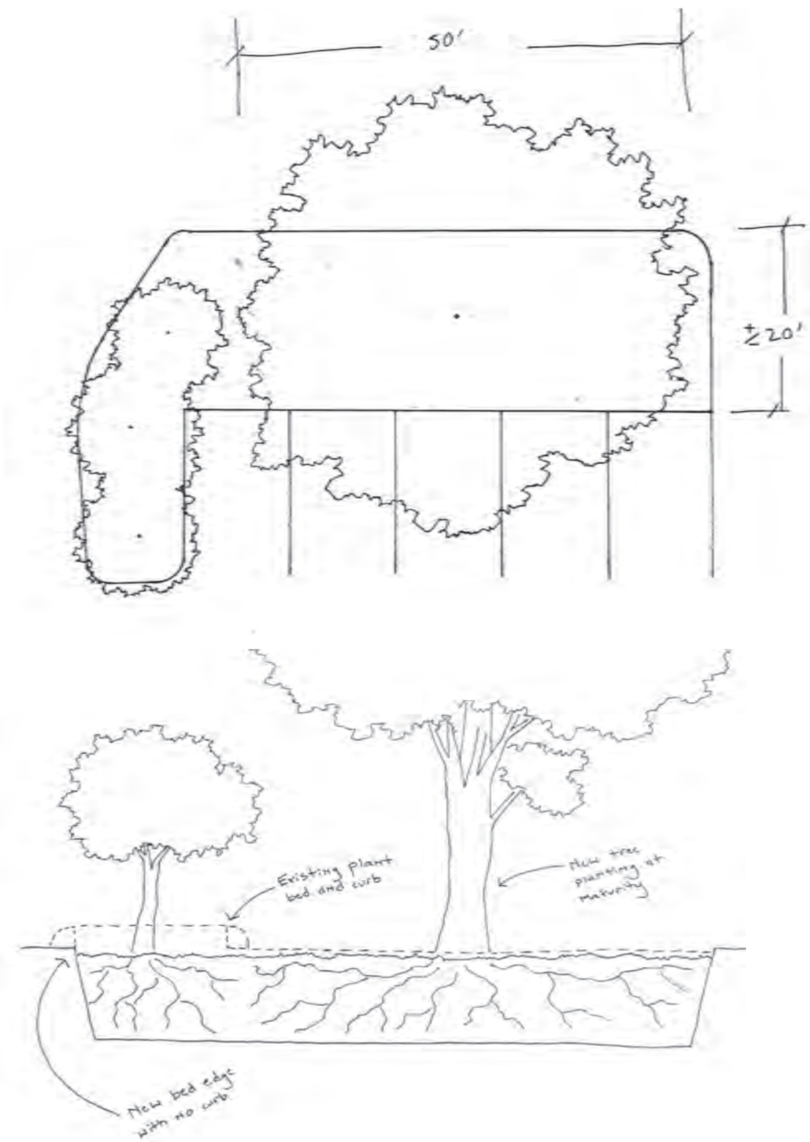



Figure 6.10. Exploration of dimensions and potential canopy cover in the future.

# 6.2.2 Tree Canopy Increase

Planting

Figure 6.8 depicts the suitable sites for future tree plantings within and adjacent to the North Jardine parking lot. The development of the design explores the idea of relocating the Flowering Crabapple trees to the site depicted in Figure 6.11. The Flowering Crabapples will be relocated as they are not a good tree for intercepting rainwater before it hits impervious surface. The reason these trees are not good for rainfall interception is because they do not grow large enough to do so and within parking lot settings, are likely to be pruned even if they did eventually cover the adjacent impervious surface. Therefore, relocating them to a more open softscape will allow them to grow to their full potential while their previous locations will be replaced with trees that can better intercept rainfall.

Replacement trees will be **Thornless Honeylocust**, **Kentucky Coffeetree**, and **Sawtooth Oak**. The Thornless Honeylocust was chosen for its ability to grow up and out while producing little to no fruit. Kentucky Coffeetree was chosen for its drought tolerance, spread, and moderate fruit production. The Sawtooth Oak was also chosen for its spread, but also for its ability to adapt to many soil conditions. All of the trees offer a range of autumn colors with the Honeylocusts and Coffeetree turning yellow, and the Sawtooth turning golden-red. The new tree plantings will also offer a contrast to the rest of Jardine's parking lots that currently contain Flowering Crabapples or no canopy.

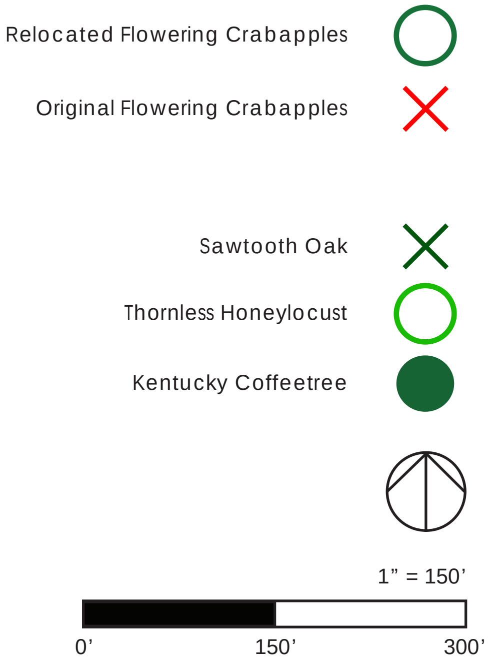



Figure 6.11. Proposed relocation of the existing Flowering Crabapples at the North Jardine parking lot.

Figure 6.12. Proposed tree plantings for the North Jardine parking lot.

# 6.2.3 Tree Canopy Increase

Structural Cell Exploration

In most urban settings, street trees are often not given an appropriate amount of room to expand their root systems. If an inadequate amount of room does not kill the tree, it will certainly limit its growth. In this project, the goal is to maximize the proposed trees performance and the best way to do this is by ensuring there is adequate space for root growth. A more expansive root system will lead to a larger and healthier canopy spread. The graphics on this page explore the possibility of installing structural cells to maximize root health.

Structural cells (SC) are a form of suspended pavement. Suspended pavement consists of frames/columns and decks with a combined strength designed to exceed the loading requirements for pavement. The spaces inbetween the columns can be filled with soils and allow tree roots to grow underneath the pavement without threatening the structural integrity of the pavement itself. Figure 6.13 depicts the six proposed trees to be planted in the North Jardine parking islands and the area underground that could be retrofitted with SCs. Utilizing a structural cell will allow the newly planted trees to grow beyond their existing potential. It's important to note that structural cells costs approximately $65 per cell (ASLA 2009) and in addition to upturning existing concrete, a structural cell installation would be very expensive.

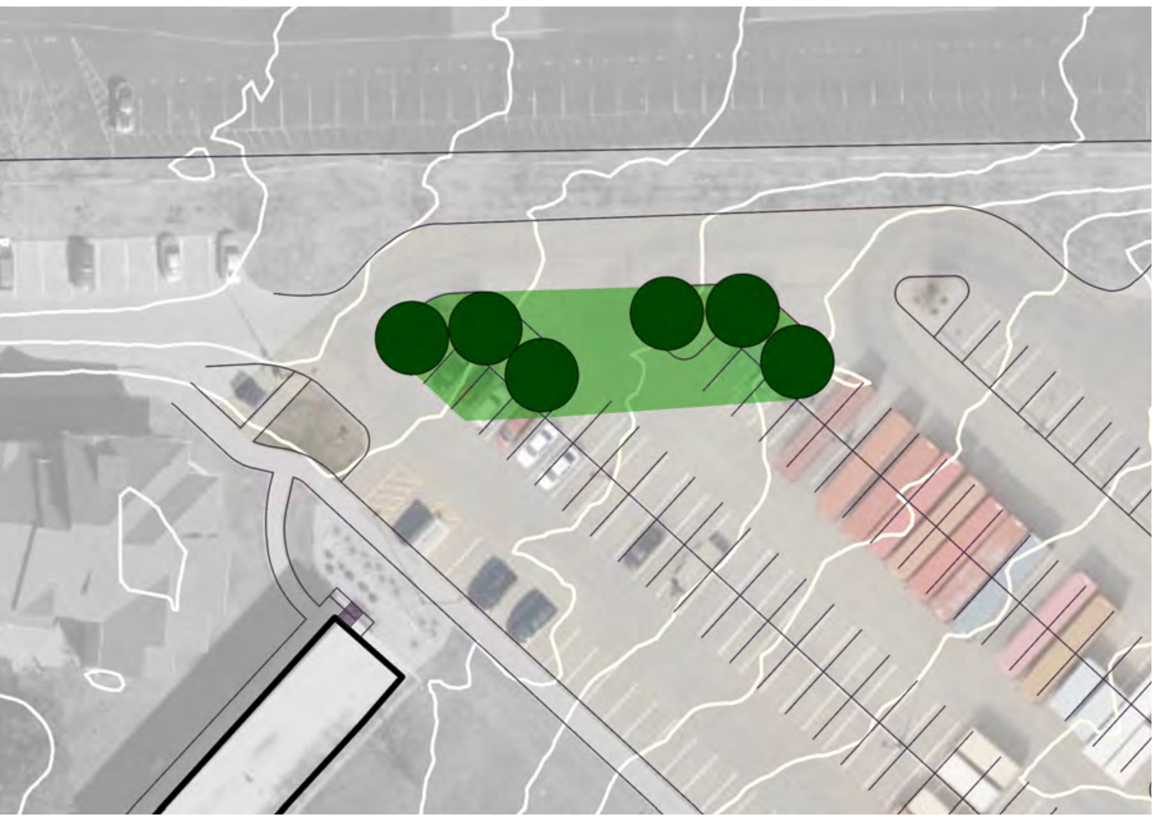
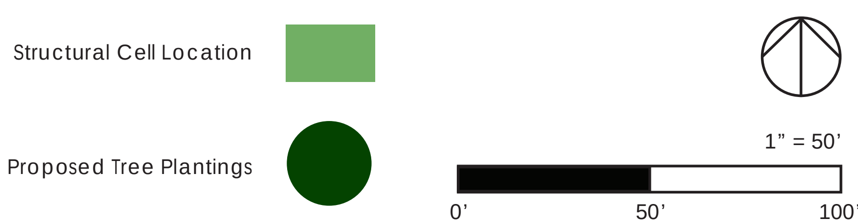


Figure 6.13. Proposed tree plantings and the area suitable for future structural cell installation.



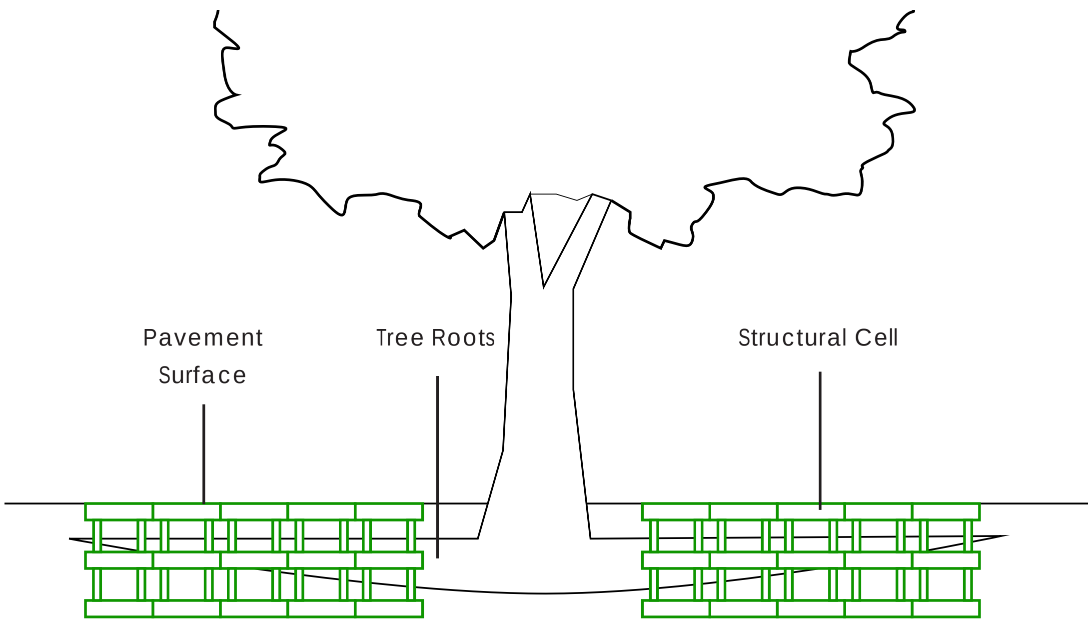




Figure 6.14. Diagram depicting the relationship between tree roots and the structural cells.

# 6.2.4 Tree Canopy Increase

Renderings


Figure 6.15. Proposed tree canopy in the North Jardine parking lot.

# 6.2.4 Tree Canopy Increase

Renderings

The proposed tree plantings within and adjacent to the North Jardine parking lot provide a new aesthetic in contrast to the rest of the Jardine Apartment complex. At maturity, the proposed trees are expected to provide significantly more shade that is beneficial for pedestrians using the area for parking, or pedestrians on foot and on their way to Bill Snyder Stadium for a football game.

The removal of the curb allows for stormwater to enter the parking islands and be utilized by the newly planted trees. The increase in canopy cover will intercept more water and further reduce stormwater runoff while aesthetically complementing other proposed green infrastructure in the area.

Figure 6.17. A view of the North Jardine treeline.

Figure 6.16. A view from the northwestern corner of the parking lot, looking east.

# 6.2.4 North Jardine Tree Increase

Perspective Renderings

The newly proposed trees, as noted, contrast with the rest of the Jardine Apartment Complex parking lots; most of which contain small flowering crabapples. The new trees are Thornless Honeylocusts, Kentucky Coffeetrees, and Sawtooth Oaks and they all provide a new assortment of autumn colors. Kansas State University is apart of Tree Campus USA, so providing a new set of trees and increasing biodiversity in the area contributes to that status while aligning with the rest of campus regarding autumn aesthetics.

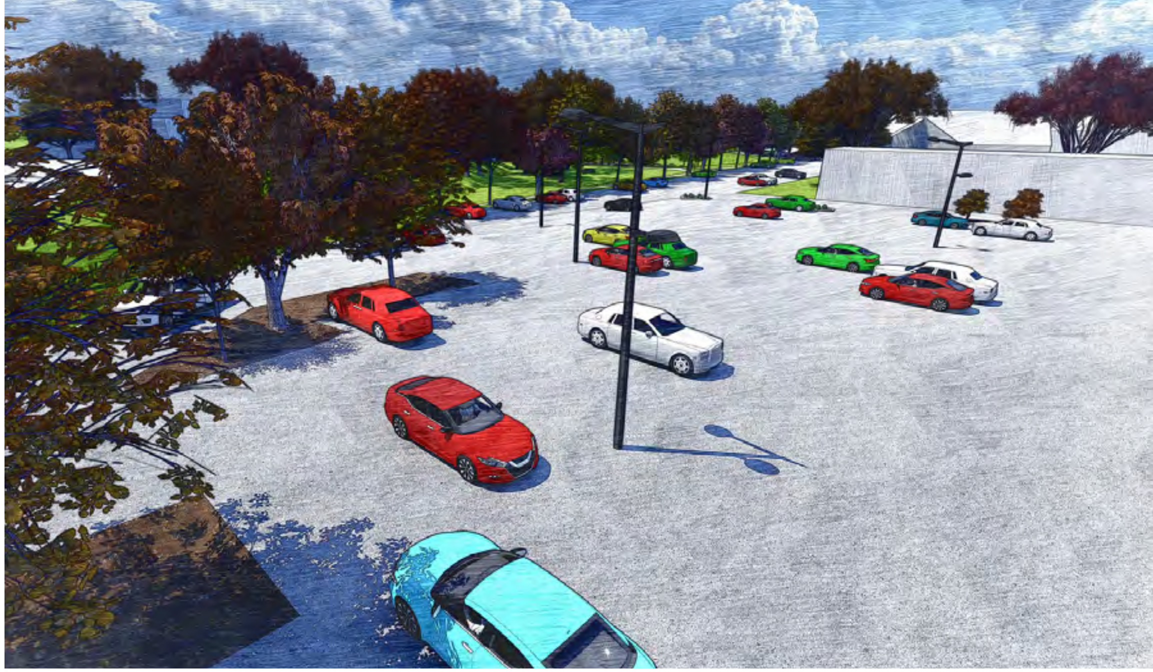


Figure 6.19. An aerial view of the North Jardine parking lot trees.

Figure 6.18. A view from the northwestern corner of the parking lot, looking east.

# 6.3.1 Permeable Pavement

Suitable Area and Design Exploration

The graphic below depicts the area determined to be suitable for future permeable paving. Due to the barren nature of the East Stadium parking lot, the amount of runoff it produces, and the existing hydrological patterns, the East Stadium parking lot is more suitable for permeable paving than the other forms of green infrastructure that this project explores. Figures X and X depict design exploration into the possibility of future permeable pavement installation. Permeable pavement is simple in principle but there are limitations to every site based off existing site conditions. In this case, the primary limitation is soil with a high clay content and a high runoff potential.

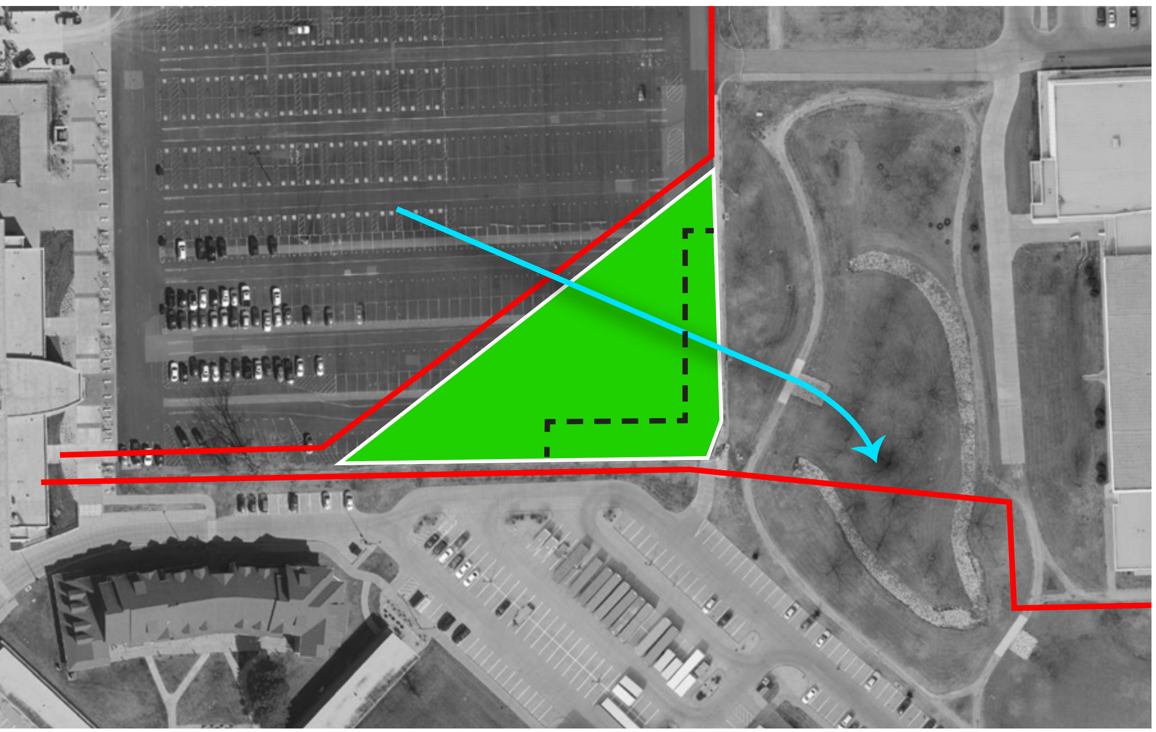


Figure 6.20. Site suitable for permeable pavement.

**Legend**

Suitable Area

Surface Drainage

Power and Gas Utilities

Project Area

1" = 150'

0' 150' 300'

Permeable pavement allows stormwater to infiltrate through pathways in the pavement surface. The stormwater can be filtered once it reaches the underlying aggregate and eventually reaches the soil subgrade. Permeable pavement is used to control stormwater quanity and quality while accommodating pedestrians and vehicles. It's important to note that permeable pavement design is very extensive and this project does not have the resources to pursue a more accurate design beyond this progress on this page.
See Appendix X for a more in-depth description of the process.

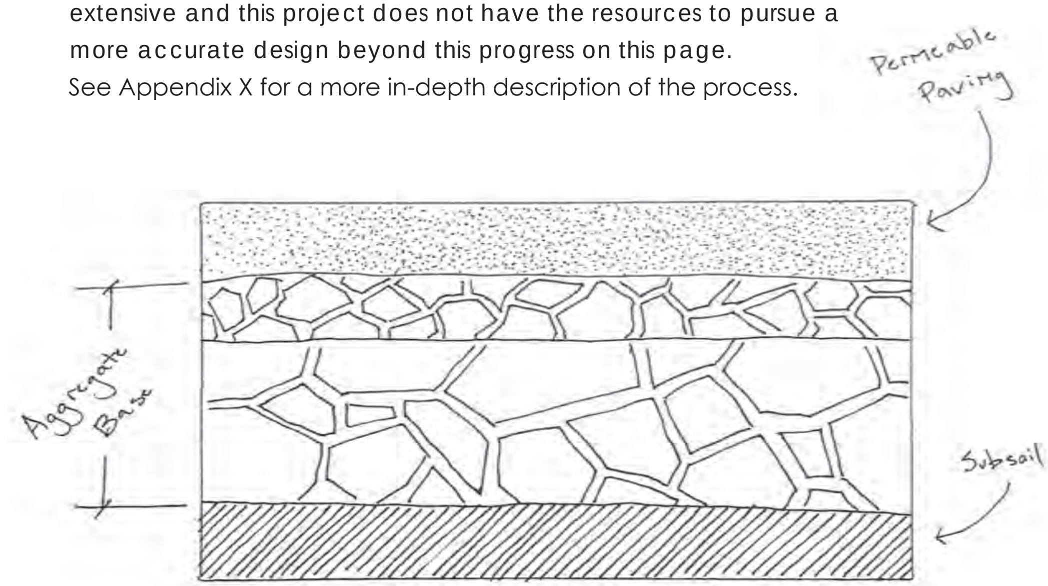



Figure 6.21. Conceptual permeable pavement section.

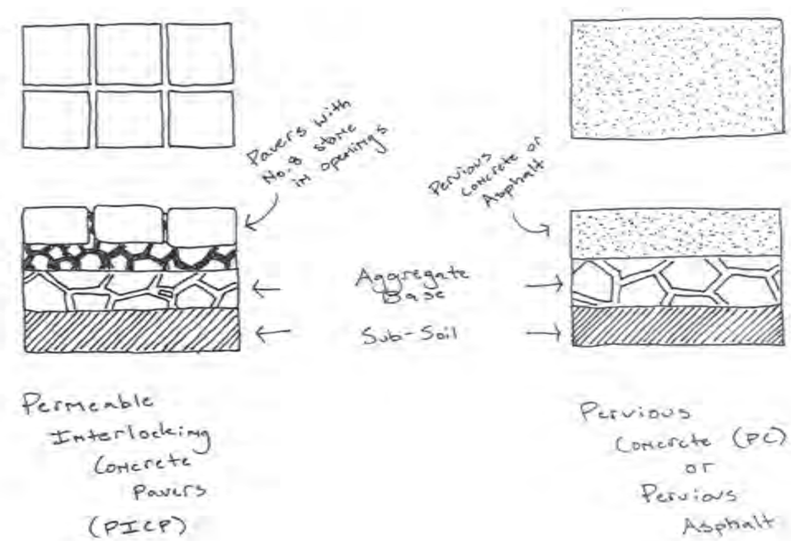



Figure 6.22. Permeable paving types conceptualized.

# 6.3.2 Permeable Pavement

Renderings

Permeable pavement is used within a proposed ATA bus stop. This suggested demonstration design, would provide pedestrians with a multi-use amenity, while helping lessen stormwater runoff.

Figure 6.24. The atmosphere of the new bus stop outlined by permeable paving.

Figure 6.23. An aerial view of permeable paving that doubles as a bus stop.

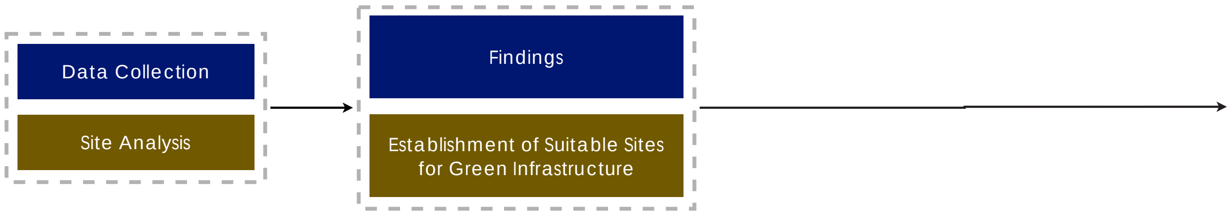
## Chapter 7

Projective Design

**Findings**

Figure 7.1 Aerial of proposed green infrastructure.

# 7.1 Modeling Introduction




As noted in Chapter 3, the projective design phase of this project was split into (1) the main project (bioretention) and (2) demonstration projects (rainwater harvesting mechanisms, tree canopy, and permeable pavement). All of the projects contributed to one final projective design that was modeled to compare to the existing conditions. Below are the tools that were used to answer the research question:

How can the northwestern parking lots of the Campus Creek Watershed be retrofitted with green infrastructure to help reduce stormwater **runoff quantity**, **peak rate**, and **pollutant load**?

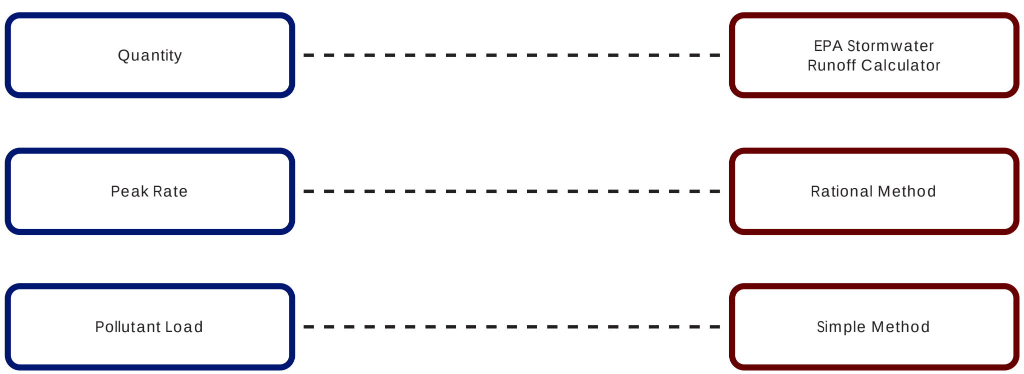



Figure 7.2. Modeling tools and the dilemma they address.

This chapter begins with modeling reductions in runoff quantity using the EPA National Stormwater Runoff Calculator. Then, modeling reductions in peak rate using the Rational Method, and finally, reductions in pollutant load using the simple method.

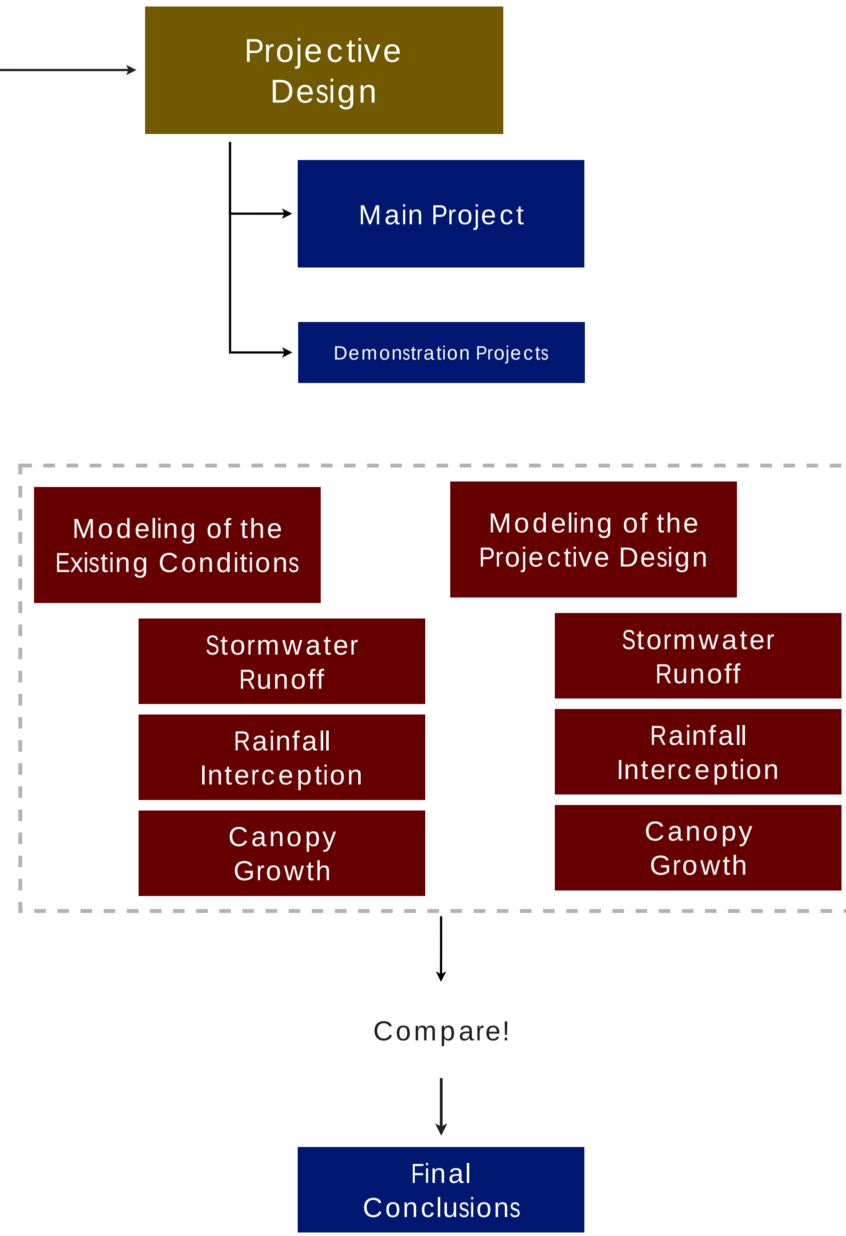



Figure 7.3. Projective Design methodology.

# 7.2 Runoff Quantity

The EPA National Stormwater Runoff Calculator

The EPA has developed a National Stormwater Calculator that can estimate the amount of stormwater runoff generated from a defined sector of land under various development scenarios over long-term periods. The final report refers to local soil conditions, topography, land cover, and meteorology; the software can also apply different types of low impact development (LID) practices and estimate the amount of stormwater runoff captured and retained on-site. The National Stormwater Calculator can also analyze across a series of climate change scenarios: (1) no change, (2) Hot/Dry, (3) Median, and (4) Warm/Wet. It is important to note that this model is separate of the rainfall interception, and canopy growth models because it estimates the annual runoff quanity of green infrastructure. This model will reflect the same designed storms modeled for peak rate. The other models are specific to urban tree canopy. The software requires the following inputs to generate final reports:

**Location**

Zip Code
Site Area (optional)

**Soil Type**

| | |
|---|---|
| A | Low Runoff Potential |
| B | Moderately Low Runoff Potential |
| C | Moderately High Potential |
| D | High Runoff Potential |

**Soil Drainage**

| | | | | | |
|---|---|---|---|---|---|
| < | 0.01 inches/hour | | | | |
| > | 0.01 inches/hour | to | < | = | 0.1 inches/hour |
| > | 0.1 inches/hour | to | < | = | 1.0 inches/hour |
| > | 1.0 inches/hour | | | | |

**Topography**

| | |
|---|---|
| Flat | (2% Slope) |
| Moderately Flat | (5% Slope) |
| Moderately Steep | (10% Slope) |
| Steep | (15+% Slope) |

**Precipitation**

Select a rain guage location to use as a source of hourly rainfall data

**Evaporation**

Select a weather station to use as a source for evaporation rates

Note: Tree canopy benefits were modeled separately from the other green infrastructure solutions because the EPA Stormwater Calculator does not have a field for tree canopy, but has a field for street planters. Therefore, the six proposed trees located within the North Jardine parking islands were modeled as 'street planters.'

The proposed bioretention cells in the Jardine Apartment Complex fall under the category of 'rain garden' in this model.

See Appendix X for the user inputs for the EPA National Stormwater Runoff Calculator

**Climate Change**

No Change
Hot/Dry
Median Change
Warm/Wet

| | |
|---|---|
| Near Term | 2020 - 2049 |
| Far Term | 2045 - 2074 |

**Land Cover**

% Forest
% Meadow
% Lawn
% Desert
% Impervious

**LID Controls**

% Disconnection
% Rain Harvesting
% Rain Gardens
% Green Roofs
% Street Planters
% Infiltration Basins
% Permeable Pavement

Design Storm for Sizing (inches)

# 7.2 Runoff Quantity

Below are the model boundaries, they reflect the parking lots that the green infrastructure solutions were designed for, and the associated area they drain into. Focus Area A is the North Jardine parking lot, and Focus Area B is the East Stadium parking lot. Below each figure are the user inputs entered into the EPA National Stormwater Runoff Calculator.

It's important to note that the proposed green infrastructure solutions were designed for the parking lots of focus and not the entire drainage area that actually dumps into the suitable sites. See Figures X through X on Page X to see the entire drainage area the proposed green infrastructure solutions realistically take on.

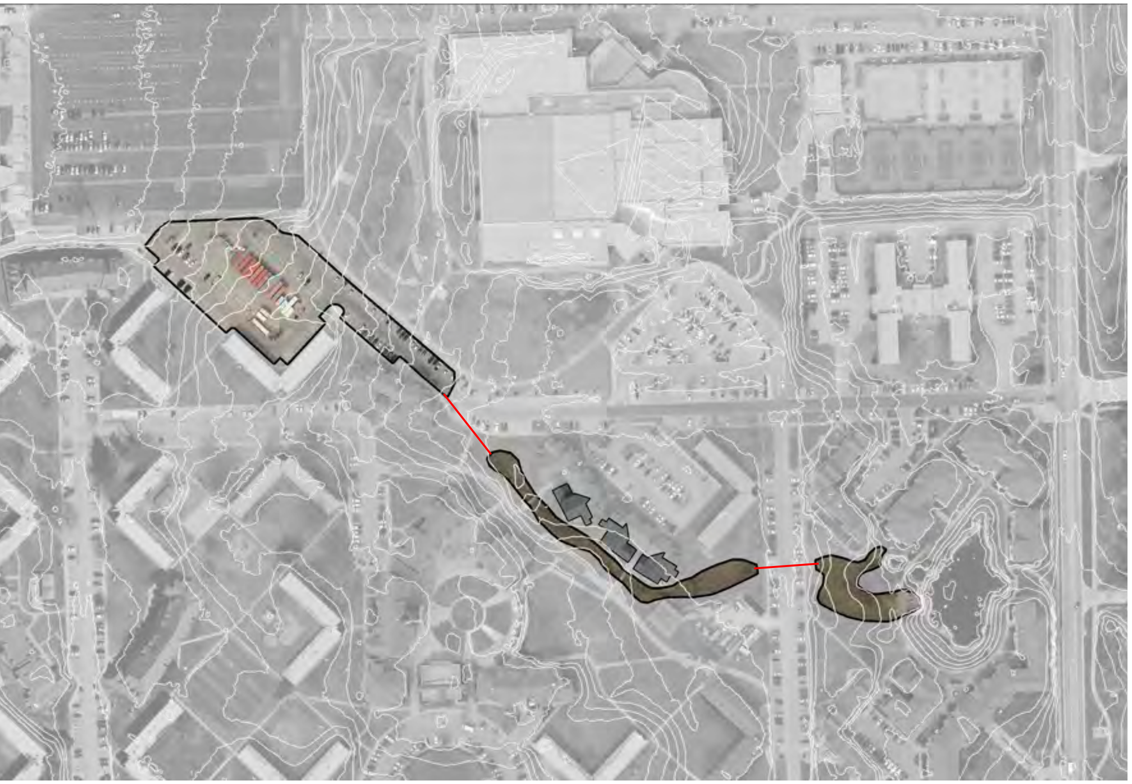


Figure 7.4. North Jardine Focus Area.

1" = 350'

0' 350' 700'

| | |
|---|---|
| **Total Area** | **2.50 acres** |
| **Land Cover** | |
| Forest | **0%** |
| Meadow | **0%** |
| Lawn | **25%** |
| Desert | **0%** |
| Impervious | **75%** |
| **Low-Impact Development** | |
| Disconnection | **0%** |
| Rain Harvesting | **7.1%** |
| Rain Gardens | **70%** |
| Green Roofs | **0%** |
| Street Planters | **2.1%** |
| Infiltration Basins | **0%** |
| Permeable Pavement | **0%** |

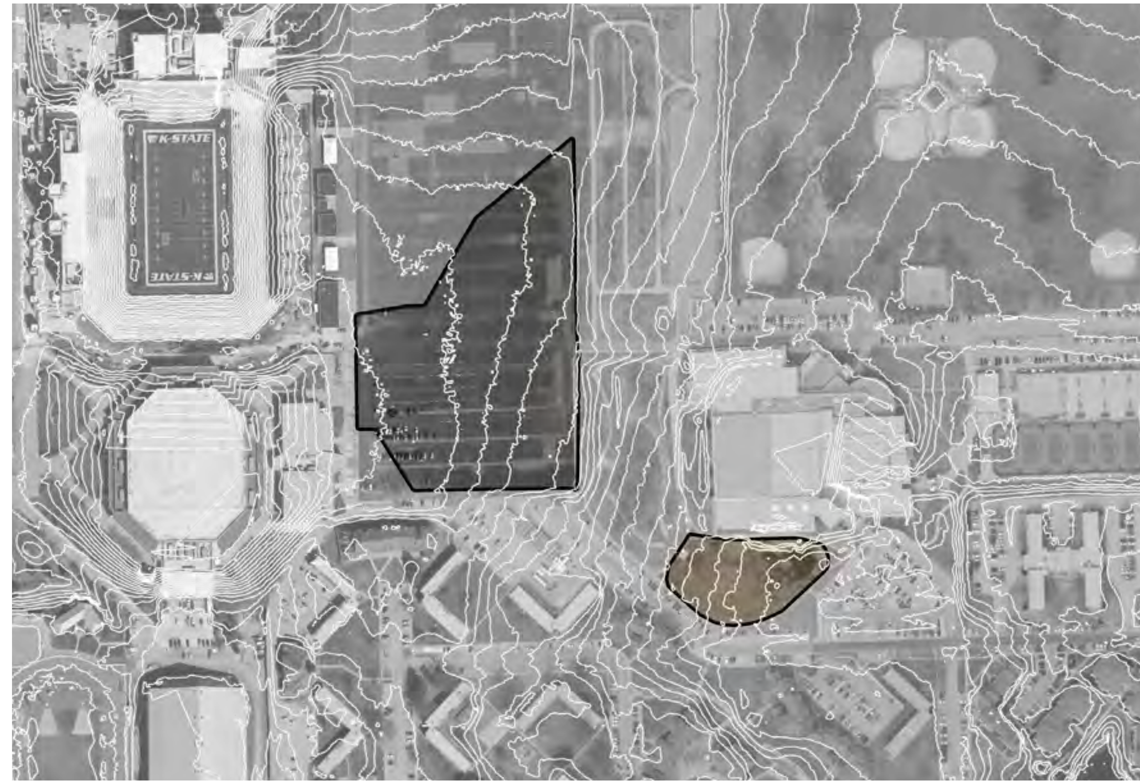


Figure 7.5. East Stadium Focus Area

1" = 550'

0' 550' 1100'

| | |
|---|---|
| **Total Area** | **10.70 acres** |
| **Land Cover** | |
| Forest | **0%** |
| Meadow | **0%** |
| Lawn | **16%** |
| Desert | **0%** |
| Impervious | **84%** |
| **Low-Impact Development** | |
| Disconnection | **0%** |
| Rain Harvesting | **0%** |
| Rain Gardens | **5%** |
| Green Roofs | **0%** |
| Street Planters | **0%** |
| Infiltration Basins | **0%** |
| Permeable Pavement | **95%** |

# 7.2 Runoff Quantity

North Jardine Focus Area

1" = 350'

0' 350' 700'

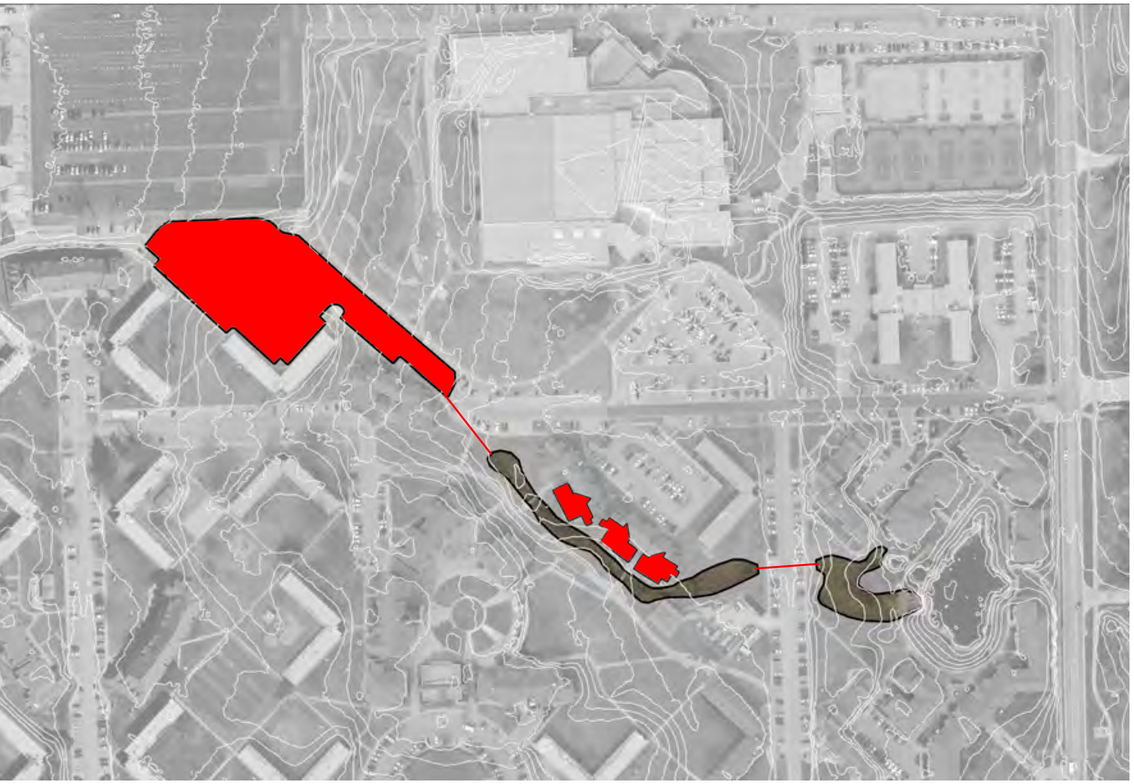


Figure 7.6. North Jardine Focus Area Impervious Cover.

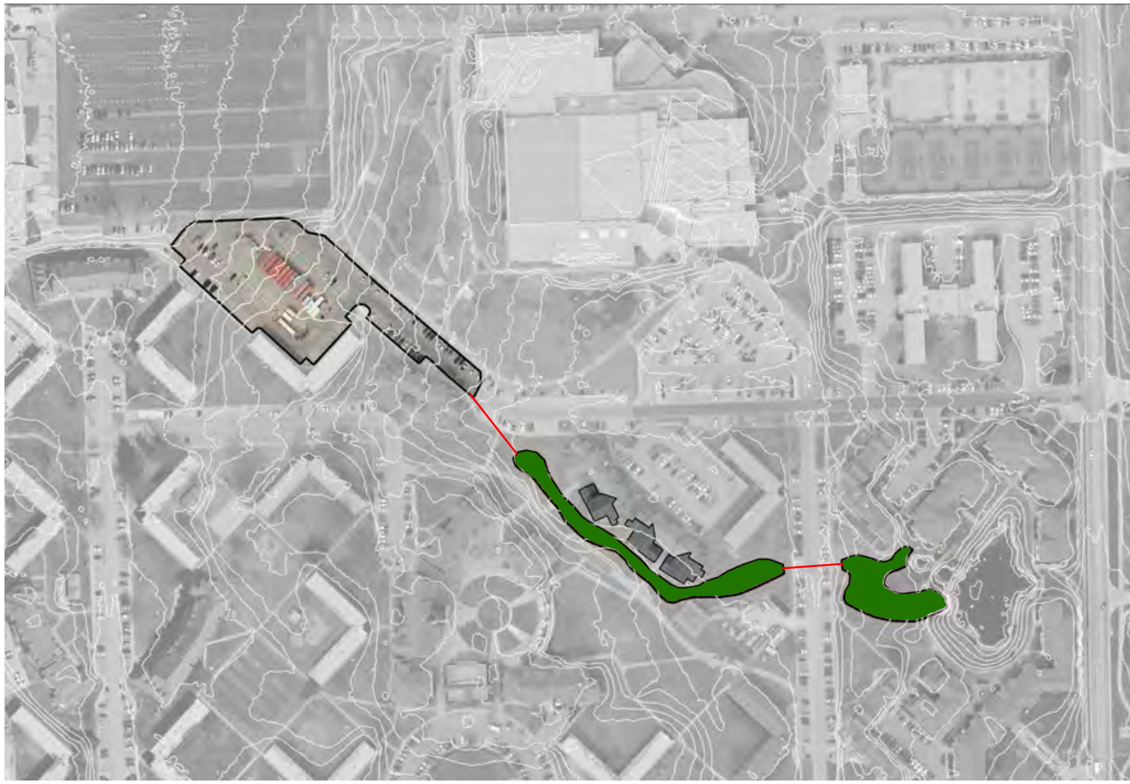


Figure 7.7. North Jardine Focus Area Lawn Cover.

***75% Existing Impervious Cover***
***+/- 1.86 acres***
***+/- 81,100 square feet***

***25% Existing Lawn Cover***
***+/- .61 acres***
***+/- 26,630 square feet***

# 7.2 Runoff Quantity

North Jardine Focus Area

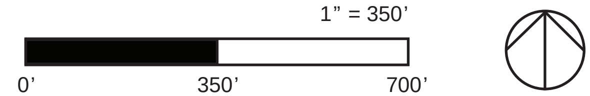



Figure 7.8. North Jardine Focus Area Proposed Bioretention.

***Proposed Bioretention***

***Addresses***

***70% of Drainage from***

***Impervious Surface***

***.29 acres***

***12,971 square feet***

Figure 7.9. North Jardine Focus Area Rainwater Harvesting Mechanisms.

***Proposed Rainwater Harvesting***

***Addresses***

***7.1% of Drainage from***

***Impervious Surface***

***8 Cisterns***

***6,000+ gallons of storage***

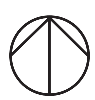
# 7.2 Runoff Quantity

North Jardine Focus Area

Figure 7.10. North Jardine Focus Area Street Planters.

1” = 350’

0’ 350’ 700’



***Proposed Street Planters Address***

***2.5% of Drainage from***

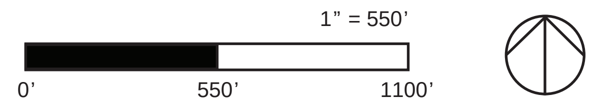
***Impervious Surface***

***.1 acres***

***4,440 square feet***

# 7.2 Runoff Quantity

East Stadium Focus Area



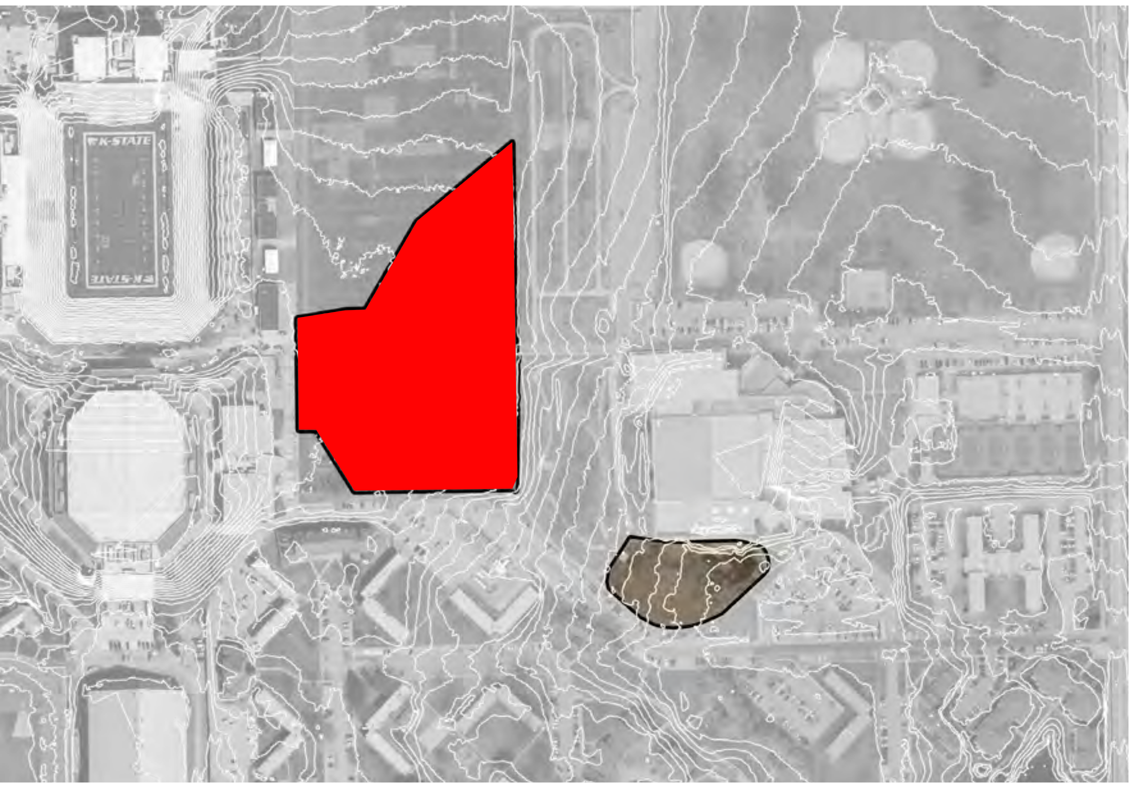



Figure 7.11. East Stadium Focus Area Impervious Cover.

Figure 7.12. East Stadium Focus Area Lawn Cover.

***84% Existing Impervious Cover***
***+/- 7.20 acres***
***+/- 313,277 square feet***

***16% Existing Lawn Cover***
***+/- 1.33 acres***
***+/- 57,821 square feet***

# 7.2 Runoff Quantity

East Stadium Focus Area

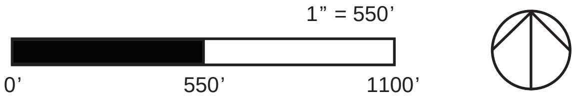



Figure 7.13. East Stadium Focus Area Proposed Permeable Pavement.

**Proposed Permeable Pavement Addresses**

**95% of Drainage from**

**Impervious Surface**

**.31 acres**

**13,500 square feet**

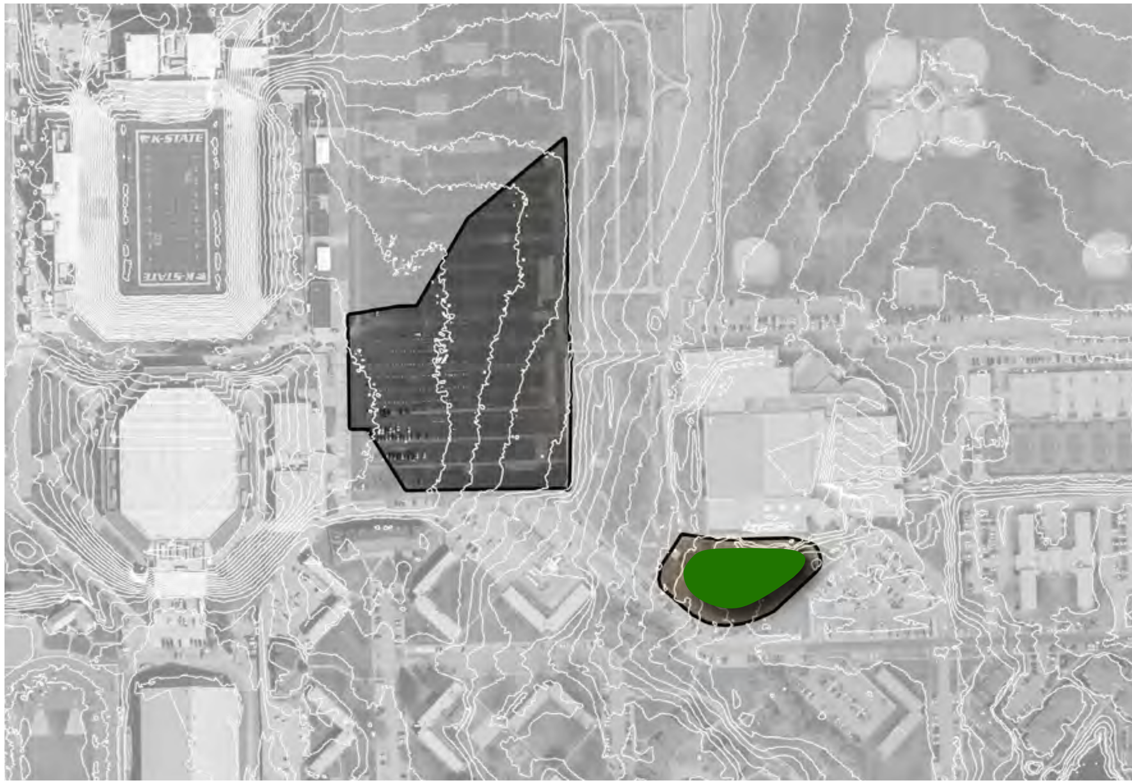


Figure 7.14. East Stadium Focus Area Proposed Bioretention.

**Proposed Bioretention Addresses**

**5% of Drainage from**

**Impervious Surface**

**.69 acres**

**30,000 square feet**

# 7.2 Runoff Quantity

North Jardine Focus Area Results

Existing conditions in the North Jardine area where green infrastructure was proposed primarily consisted of turf grass and impervious surfaces (e.g., the North Jardine parking lot). The soil in the area (and most of the watershed) is very high in clay content, therefore, limiting infiltration.

See Appendix H for more information regarding the existing conditions in comparison to the projective design.

The proposed green infrastructure includes bioretention cells that address the North Jardine parking lot impervious surface. The design assumed amended soils and with an addition of low maintanence, hardy plant material, **infiltration is increased by 38%** and the **annual runoff quantity is reduced by 46%**.

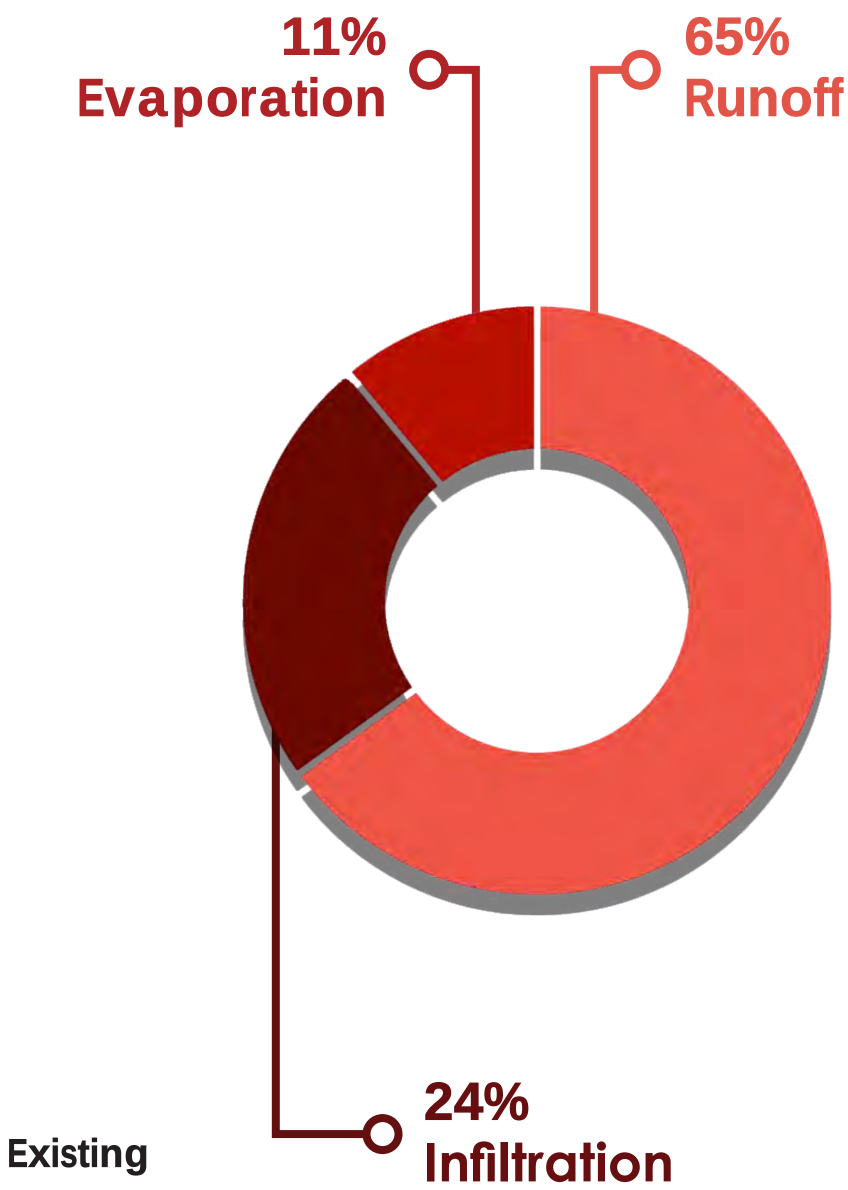



Figure 7.15. Runoff quantities of the North Jardine Existing Conditions.

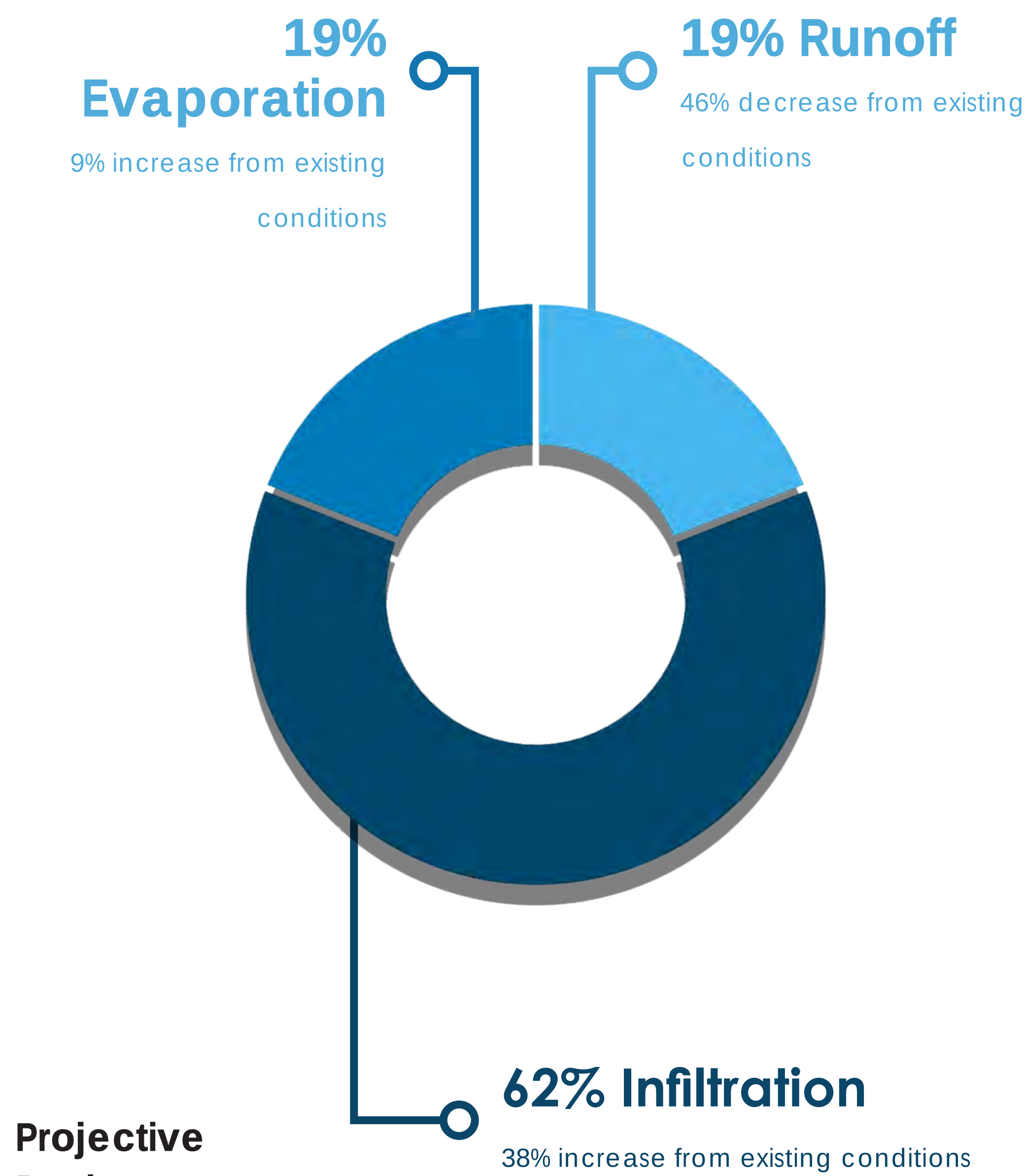



Figure 7.16. Runoff quantities of the North Jardine Projective Design.

# 7.2 Runoff Quantity

East Stadium Focus Area Results

Existing conditions in the East Stadium area are primarily impervious surface located in the East Stadium parking lot. There is a detention basin south of Peter's Recreation Center where bioretention was proposed. As noted, the soil in the area is high in clay content, limiting infiltration. The detention basin is mostly turf grass.

See Appendix H for more information regarding the existing conditions in comparison to the projective design.

The proposed green infrastructure includes one bioretention cell that addresses the East Stadium parking lot impervious surface. The design assumed amended soils and with an addition of low maintanence, hardy plant material, **infiltration is increased by 63%** and the **annual runoff quantity is reduced by 63%**.

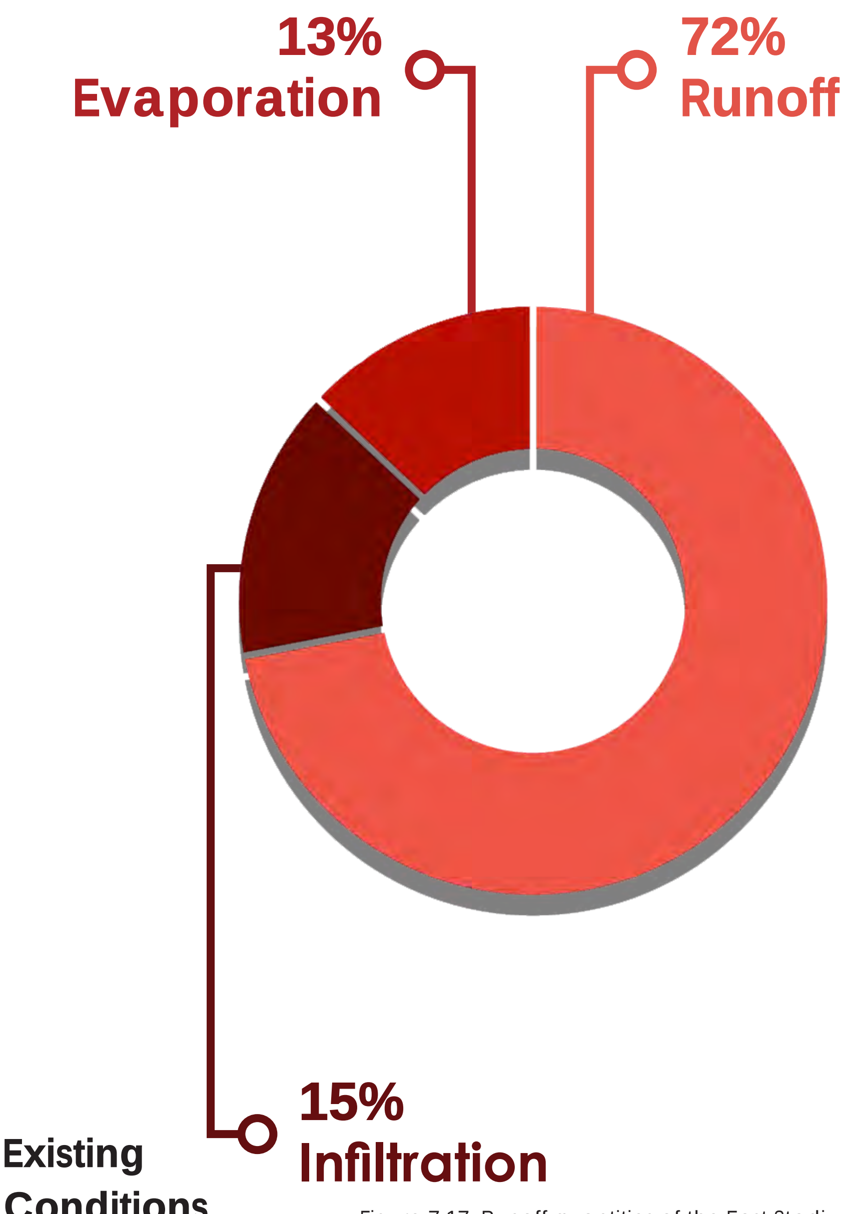



Figure 7.17. Runoff quantities of the East Stadium Existing Conditions.

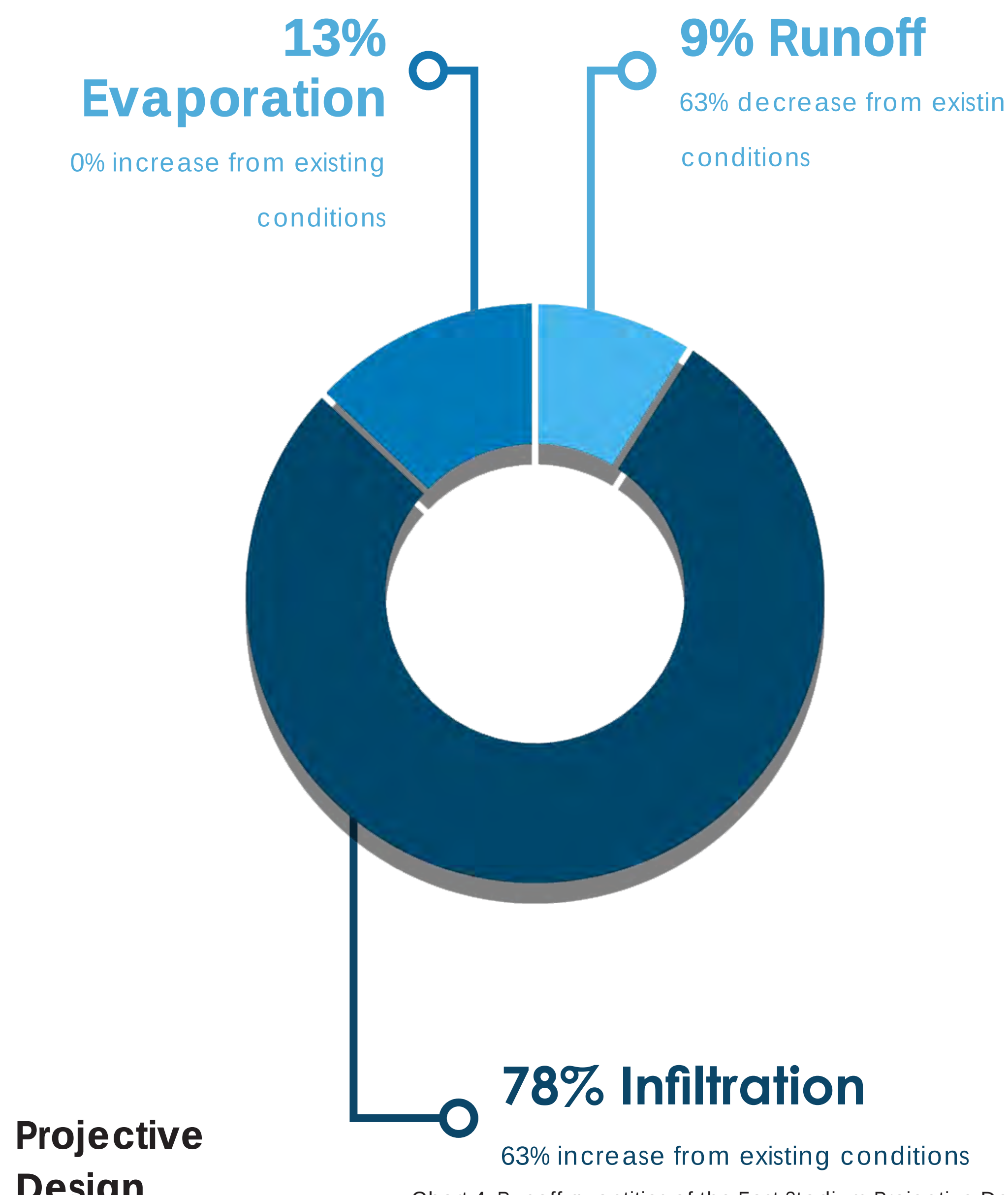



Chart 4. Runoff quantities of the East Stadium Projective Design.

# 7.3 Pollutant Load

Simple Method

**The Simple Method** was used to estimate the pollutant loads for each of the parking lots and their associated land uses in pounds per year. The findings presented in Chapter 4 and Figure 7.19 depict the pollutant loads generated by the focus areas' existing conditions. Figure 7.20 depicts the reduced pollutant loads Post-Projective Design. The reductions in pollutant load are stated below:

**Total Suspended Solids (TSS)**
East Stadium: 95% decrease
North Jardine: 77% decrease

**Phosphorus (TN)**
East Stadium: 92% decrease
North Jardine: 77% decrease

**Nitrogen (TN)**
East Stadium: 92% decrease
North Jardine: 77% decrease

**F.Coli**
East Stadium: 92% decrease
North Jardine: 77% decrease

**Copper (Cu)**
East Stadium: 92% decrease
North Jardine: 77% decrease

**Lead (Pb)**
East Stadium: 92% decrease
North Jardine: 77% decrease

**Zinc (Zn)**
East Stadium: 92% decrease
North Jardine: 77% decrease

**East Stadium**
92.4% average decrease in all pollutants

**North Jardine**
77% average decrease in all pollutants

See Appendix E for Simple Method Calculations

## Existing Conditions

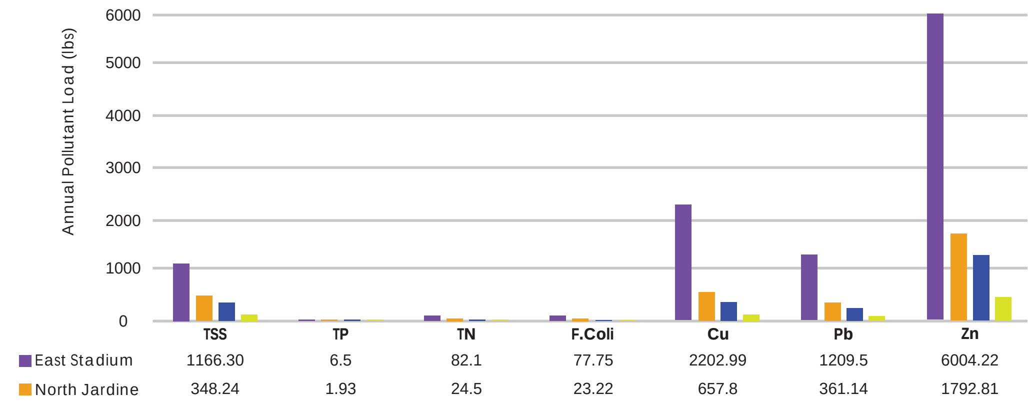



Figure 7.19. Estimated pollutant load of the focus areas (existing conditions) via the Simple Method of runoff calculation (Appendix ii).

## Projective Design

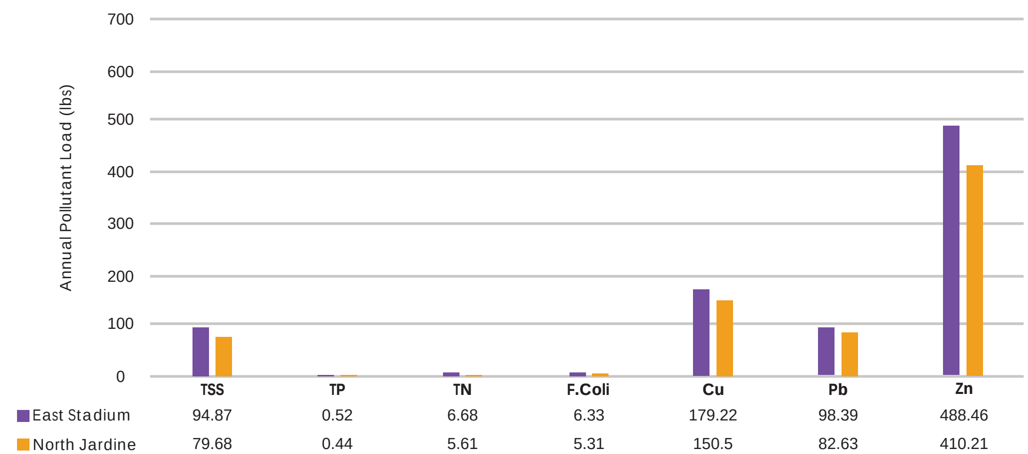



Figure 7.20. Estimated pollutant load of the proposed Projective Design via the Simple Method of runoff calculation (Appendix ii).

# 7.4 Peak Rate

Rational Method | North Jardine Bioretention

**The Rational Method** was used to estimate the peak rate for each of the parking lots and their associated land uses in pounds per year. The findings presented in Chapter 4 and Figure 4.35 depict the peak rates generated by the focus areas' existing conditions. Figure 7.21 depicts the reduced peak rates Post-Projective Design. It's important to note that peak rate was recalculated to reflect the reductions by bioretention and permeable pavement, not rainwater harvesting mechanism and tree canopy. This was done because, at the time of this project, runoff coefficients to represent rainwater harvesting mechanisms and tree canopy were not developed.

In Figure 7.21, 5-Year, 10-Year, and 25-Year storms appear to have zero discharge in comparison to the reductions in the 50-year and 100-Year storms. This is because the proposed bioretention cells will be able to completely retain the runoff from these storms. The proposed bioretention cells can do this because the infiltration rate in inches per hour is greater than the rainfall intensity.

**Peak Rate = 0**

if

**rainfall intensity is less than the infiltration capacity**

Infiltration capacity represents both the infiltration rate (inches/hour) AND how much water the soil can hold.

The 50- and 100-Year storms were calculated using a runoff coefficient representative of grass in good condition. This project takes a qualitative approach to final peak rate calculations because soil assumptions must be made. This project assumes an ideal infiltration rate of 1 to 2 inches per hour and good soil, therefore, the runoff coefficient of grass in good condition is representative of the proposed bioretention cells during the 50- and 100-Year storms.

See Appendix D for Rational Method Calculations

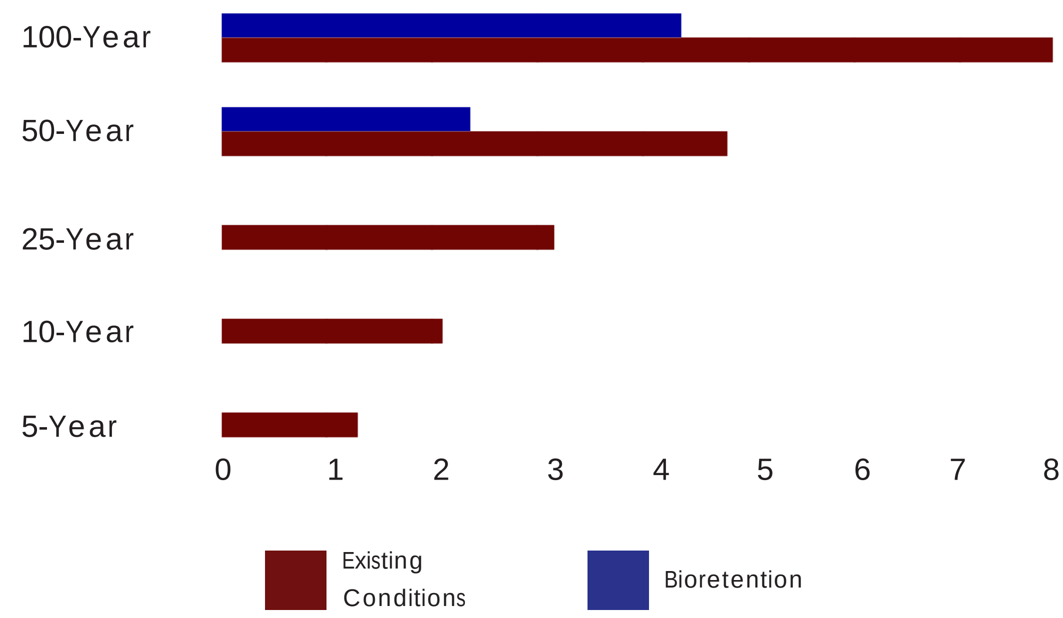



Figure 7.21. Estimated peak rate of the proposed North Jardine bioretention via the Rational Method of runoff calculation (Appendix ii).

The proposed North Jardine bioretention cells **decrease the peak rate of runoff by an average of 79.1%**.

# 7.4 Peak Rate

Rational Method | East Stadium Bioretention and Permeable Pavement

As noted, peak rate was recalculated to reflect the reductions by bioretention and permeable pavement, and this was done because runoff coefficients to represent the other proposed green infrastructure solutions (e.g., rainwater harvesting mechanisms and tree canopy) were unknown at the time of this project.

This project refers to Bean (2005) for a runoff coefficient that represents permeable pavement (0.44). Regarding bioretention, the results reflect the same outcome of the North Jardine bioretention cells with zero discharge during 5-, 10-, and 25-Year storms.

The proposed East Stadium bioretention cell **decreases the peak rate of runoff by an average of 83%**.

The proposed East Stadium permeable pavement **decreases the peak rate of runoff by an average of 45%**.

**Together, the proposed green infrastructure solutions reduce the peak rate of runoff by 64%.**

See Appendix D for Rational Method Calculations

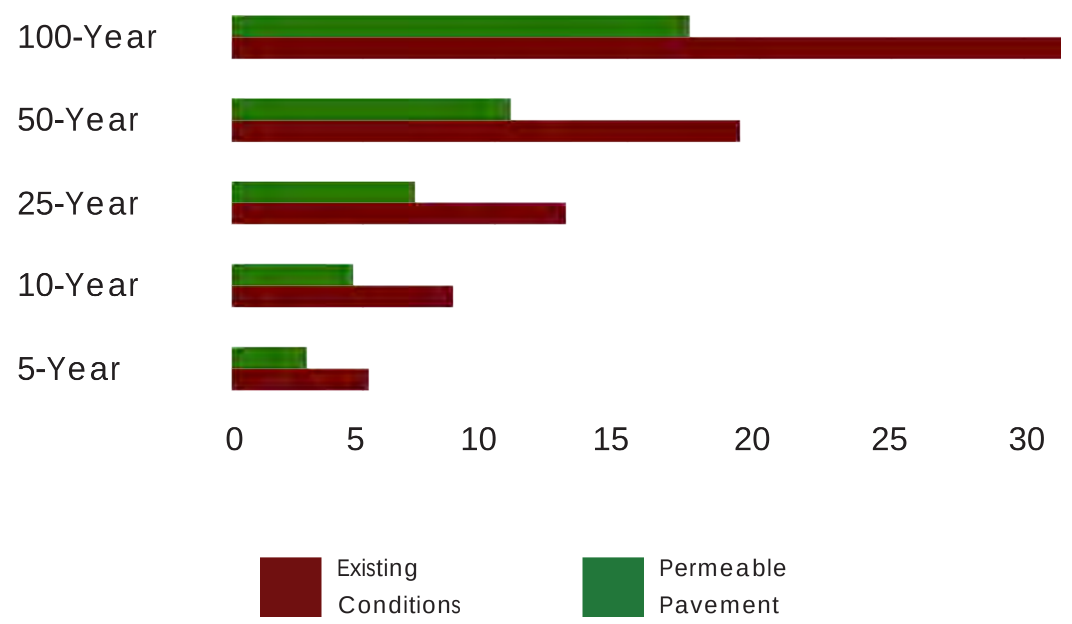



Figure 7.22. Estimated peak rate of the proposed East Stadium permeable pavement via the Rational Method of runoff calculation (Appendix ii).

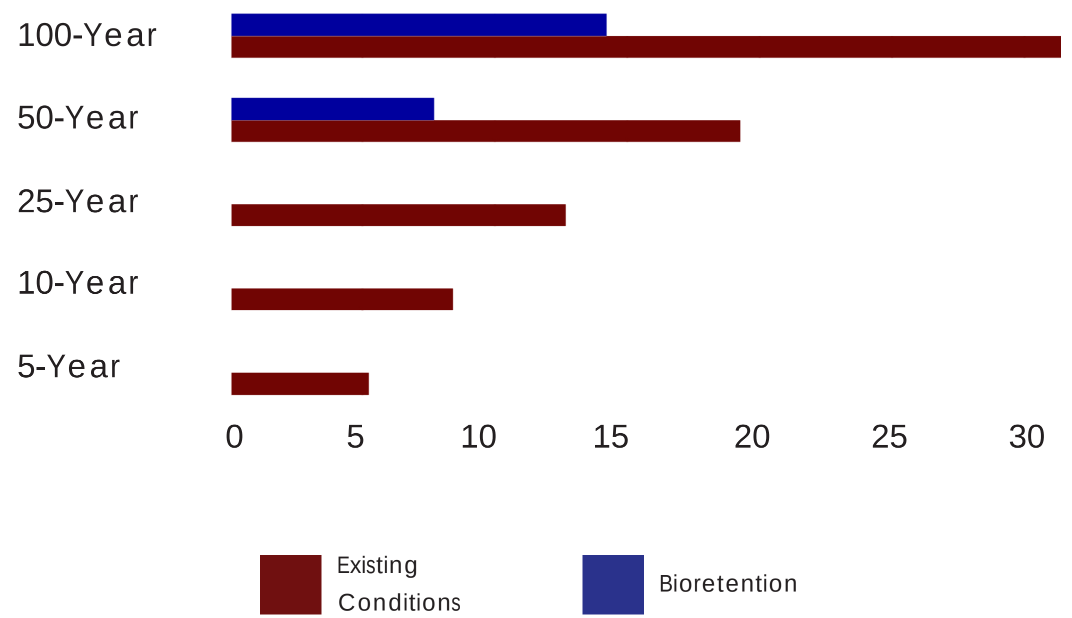



Figure 7.23. Estimated peak rate of the proposed East Stadium bioretention via the Rational Method of runoff calculation (Appendix ii).

# 7.5 Rainfall Interception

i-Tree Eco

In Chapter 4, rainfall interception models were conducted using i-Tree Eco to estimate the amount of water intercepted in cubic feet per year. The models were conducted on the North Jardine parking lot and South Recreation parking lot, but site analysis confirmed that there wasn't any suitable area for significant tree canopy increase within the South Recreation parking lot. Therefore, only the North Jardine parking lot was redesigned to accomodate more trees, and the proposed tree increase is modeled in this section.

i-Tree Eco allows its users to input a complete inventory of trees and model the benefits of them in terms of carbon sequestration, avoided runoff, pollutant removal, and more. i-Tree requires the tree species, and its diameter at breast height (DBH), but has optional fields that can provide for more accurate modeling results and are listed below (fields used for this project are highlighted in red).

### General Site Fields

- Tree Address
- Land Use
- Strata/Area
- Status
- Street Tree/Non-Street Tree
- Map (GPS) coordinates
- Public/Private

### Tree Detail Fields

- Total Tree Height
- Crown Size
  - Height to Live Top
  - Height to Crown Base
  - Crown Width
  - Percent Crown Missing
- Crown Health
- Crown Light Exposure
- Energy (Building Interactions)
  - Distance to Building
  - Direction to Building

### Management Fields

- Maintenance Recommended
- Maintenance Task
- Sidewalk Conflict
- Utility Conflict
- Pests
  - Sign & Symptoms of Tree Stress
  - Sign & Symptoms of Foliage
  - Sign & Symptoms of Branches
- User Tree ID

Crown size is a highly recommended field because of its influence on the accuracy of the modeling results, but it could not be documented as the inventory is hypothetical. Therefore, i-Tree assumes the leaf area based off the species and DBH measurements.

The North Jardine parking lot originally contained eight Flowering Crabapple trees that cover approximately 1,158 square feet of the 87,000 square foot parking lot (1.3% canopy cover) (see Table X). The redesigned parking lot contains 30 trees that cover approximately 33,000 square feet of the 87,000 square foot parking lot (38% canopy cover) (see Table X) at 30 years of age. According to i-Tree Eco, the estimated total canopy area is approximately 67,000 square feet at 30 years of age, but most of the new plantings are located along the eastern edge of the parking lot, where only half of the tree will cover the impervious surface, therefore, the canopy area provided was cut in half to more accurately represent the amount of canopy that is covering the parking lot.

It is important to note that because the new tree plantings are being hypothetically modeled, all of the DBH inputs are assumed to be 6 - 12 inches, their heights are assumed to be anywhere between 30 to 50 feet, and their crown health is assumed to contain a 10% dieback. Given that the trees are planted in the less suitable conditions of a parking lot, a 10% dieback is a safe assumption as long as they are also assumed to be properly maintained. i-Tree Eco uses the assumed DBH, height measures, and dieback to estimate the total canopy area.

Note: Tree canopy benefits were modeled separately from the other green infrastructure solutions because the EPA Stormwater Calculator does not have a field for tree canopy as trees do not fall under an LID category.

# 7.5 Rainfall Interception

i-Tree Eco

**Before Redesign**

| Tree Species | DBH | Water Intercepted (cubic feet per year) |
|---|---|---|
| Flowering Crabapple | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 5.4 | 22.9 |
| | 4.8 | 19.2 |
| | 5.1 | 25.7 |
| | 4.8 | 40.8 |
| **Total** | | **200.4** |

Table 7.1. Estimated rainfall interception of the North Jardine parking lot trees via i-Tree Eco.

Figure 7.24. North Jardine parking lot before a redesign with more trees.

**After Redesign**

| Tree Species | DBH (inches) | Water Intercepted (cubic feet per year) |
|---|---|---|
| Sawtooth Oak (x8) | 6 - 12 | 984.8 |
| Thornless Honeylocust (x10) | 6 - 12 | 738.0 |
| Kentucky Coffeetree (x10) | 6 - 12 | 816.0 |
| Flowering Crabapple (x4) | 5.4 | 91.6 |
| **Total** | | **2630.4** |

Table 7.2. Estimated rainfall interception of the proposed North Jardine parking lot trees via i-Tree Eco.

The proposed North Jardine trees **increase the rainfall interception by 2,430 cubic feet per year.**

Figure 7.25. North Jardine parking lot after a redesign with more trees.

# 7.5 Rainfall Interception

Regression Models

Alireza Nooraei Beidokhti and Trisha Lynn Moore (2021) conducted a meta-data analysis of the effects of precipitation, tree phenology, leaf area index, and bark characteristics on the throughfall rates of urban trees. Throughfall is the amount of rainfall that reaches the ground through the tree canopy, with or without contacting canopy surfaces. The results of the meta-data analysis lead to the development of a series of regression models that can represent the amount of throughfall associated with the different tree types (see Table X), not the individual species. In this case, the tree types are split by leaf characteristics and bark characteristics (characteristics used in this model are highlighted in red):

**Leaf Types**

- Deciduous Leafless
- Deciduous Leafed
- Evergreen Broadleaf
- Evergreen Needleleaf

**Bark Types**

- Rough Bark
- Smooth Bark

For this project, the goal is to model the amount of rainfall captured per storm event for Deciduous Leafed-Rough Bark Trees, therefore, the following equation is presented (Appendix X):

**Volume captured = (Rainfall - Throughfall) x Canopy Area**

The models were conducted for five storm events:

**Standard Storm**

| | | |
|---|---|---|
| Depth | 1.0 inch | Stated on Page 27 of the Kansas Water Pollution Control Permit for Stormwater Management (KDHE 2019) |
| Duration | 6 hours | |

**Water Quality Storm**

| | | |
|---|---|---|
| Depth | 1.10 inches | Stated in Section 4: Structural BMP construction for Kansas as the 90th Percentile Rain Event (MARC 2012) |
| Duration | ----- | |

**10 Year (A)**

| | | |
|---|---|---|
| Depth | 2.92 inches | Rain events that are more likely to produce flood related issues |
| Duration | 2 hours | |

**10 Year (B)**

| | |
|---|---|
| Depth | 4.94 inches |
| Duration | 24 hours |

**50 Year**

| | |
|---|---|
| Depth | 5.57 inches |
| Duration | 6 hours |



Throughfall was determined for **Deciduous Leafed - Rough Bark** trees using the formula below:

**TH = -0.49 + 0.77(P)**

P = Precipitation

| Storm Event | Throughfall |
|---|---|
| Standard | .28 |
| Water Quality | .36 |
| 10 Year (A) | 1.76 |
| 10 Year (B) | 3.31 |
| 50 Year | 3.79 |

Table 7.3. Estimated throughfall rates of deciduous leafed - rough bark trees.

Percentage of total rainfall intercepted by Deciduous Leafed - Rough Bark trees

**Volume captured (%) = (Rainfall - Throughfall)/Rainfall**

| Storm Event | % Rainfall Captured |
|---|---|
| Standard | 72% |
| Water Quality | 67% |
| 10 Year (A) | 39.7% |
| 10 Year (B) | 33% |
| 50 Year | 32% |

Table 7.4. Estimated rainfall captured (%) by deciduous leafed - rough bark trees.

Please note the change in canopy area that will determine the increase in rainfall interception:

| Parking Lot | Canopy Area (square feet) |
|---|---|
| Pre-Redesign | 1158 |
| **Post-Redesign** | **95,000** |

Table 7.5. Canopy area increase according to i-Tree Eco.

Note: The increase in canopy area assumes proper maintenance and good growing conditions after 20 years of growth.

# 7.5 Rainfall Interception

Regression Models

| Storm Event | Rainfall Volume Captured (cubic feet per storm event) |
|---|---|
| Standard | 833.76 |
| Water Quality | 856.92 |
| 10 Year (A) | 1343.28 |
| 10 Year (B) | 1887.54 |
| 50 Year | 2061.24 |

Table 7.6. Rainfall volume captured per storm event for the North Jardine parking lot trees before a redesign.

Figure 7.26. North Jardine parking lot before a redesign with more trees.

| Storm Event | Rainfall Volume Captured (cubic feet per storm event) |
|---|---|
| Standard | 68400 |
| Water Quality | 70300 |
| 10 Year (A) | 110200 |
| 10 Year (B) | 154850 |
| 50 Year | 169100 |

Table 7.7. Rainfall volume captured per storm event for the North Jardine parking lot trees after a redesign.

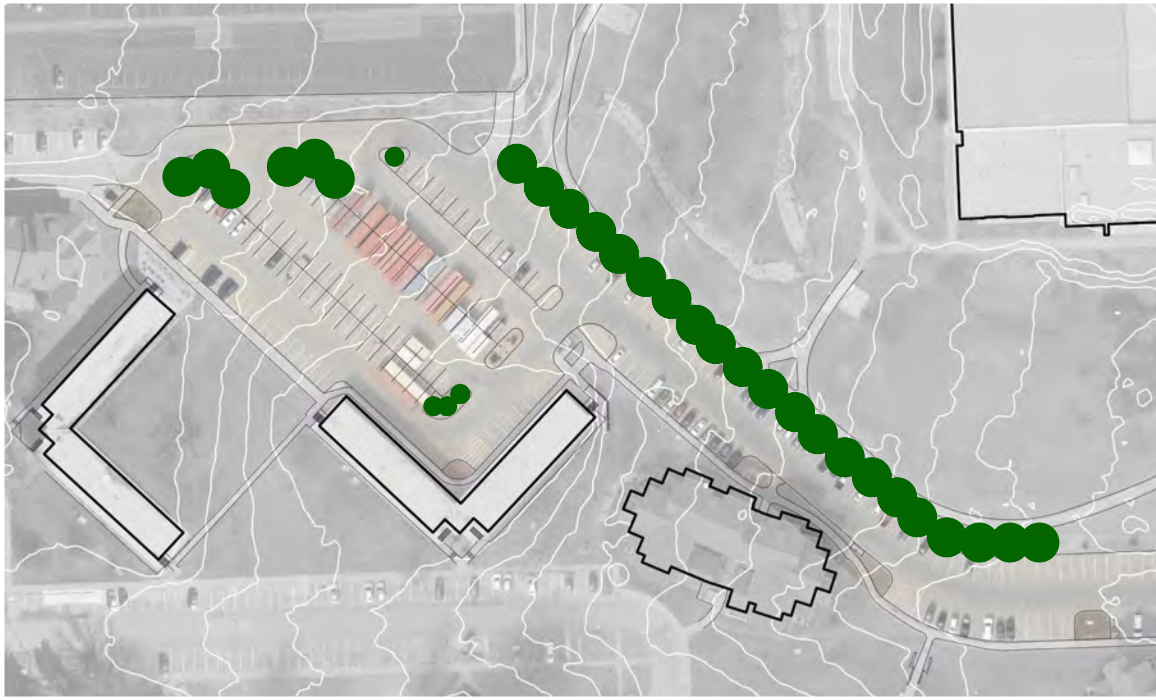


Figure 7.27. North Jardine parking lot after a redesign with more trees.

Note: The dramatic change in rainfall interception results produced by the regression models in comparison to i-Tree Eco is due to different assumptions and model variables. See section 3.3 for descriptions of each model's limitations and assumptions.

# 7.6 Canopy Growth

i-Tree Design

Canopy growth was modeled to understand the size that different tree species can achieve after certain periods of time. All tree species grow at different rates and to different sizes, therefore, understanding the amount of time it takes for an urban tree to cover the impervious surface adjacent to it can aid in selection of tree species and can also justify the need for more or different tree canopy.

i-Tree Design allows users to model tree canopy growth over a 60 year time frame and requires the tree species, its DBH or circumference, the current condition, and its exposure to sunlight. This project proposes Sawtooth Oak trees (8), Thornless Honeylocust trees (10), and Kentucky Coffeetrees (10). For this model, the assumption is made that the trees are new plantings ranging from 1 to 3 inches in DBH. For the i-Tree Design input, the DBH will be inputted at 1.5 inches with full sun for all of the newly proposed trees.

Findings

The figures below depict the North Jardine parking lot canopy cover after a redesign at 30 years and 60 years. As shown below, the new trees will cover significantly more area in comparison to the existing site. It's important to note that the existing Flowering Crabapple trees (red) will grow larger but not to their full potential, as their width will be pruned because of their short height. The proposed Sawtooth Oak, Thornless Honeylocust, and Kentucky Coffeetrees will grow higher and will be able to also grow wider as a result.

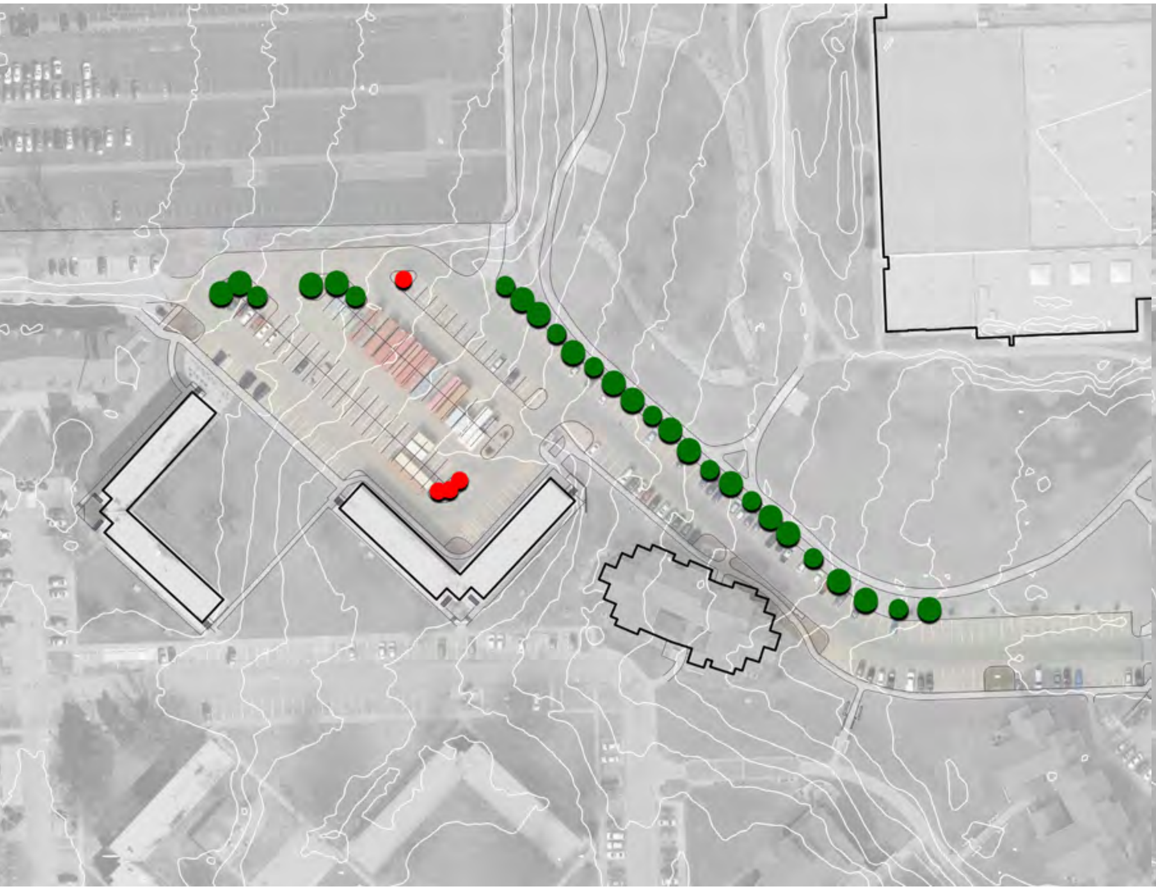


Figure 7.28. North Jardine parking lot redesign at 30 years of growth.

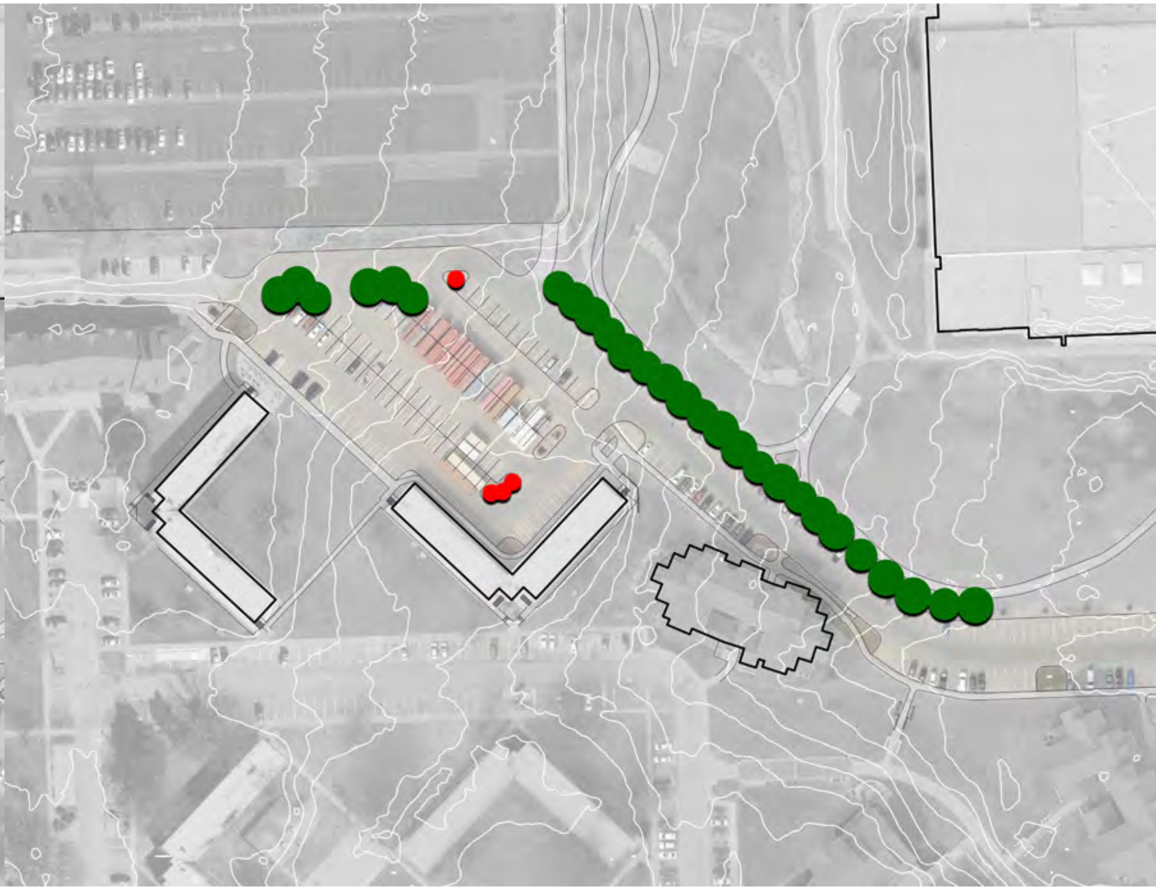


Figure 7.29. North Jardine parking lot redesign at 60 years of growth.

# 7.7 Documentation Metrics

Final Projective Design

*Rain Water Harvesting Mechanisms* were proposed for two buildings adjacent to the proposed bioretention sites. Using the EPA Water Budget Tool, users can estimate the amount of water needed for a garden, and assuming that the bioretention cells are designed correctly, the rainwater harvesting mechanisms should provide sufficient water and contribute to an **86% reduction in potable water use**. The impervious area the downspouts were originally connected to is now connected to the rainwater harvesting mechanisms, resulting in a **5,782 square foot reduction in directly connected impervious area**.

*Bioretention* cells were proposed to address the stormwater management needs of the North Jardine parking lot and the East Stadium parking lot. Through an elaborate design process supported with research, the proposed bioretention cells can **decrease the peak rate by 79% for the North Jardine parking lot**, and **83% for the East Stadium parking lot**. They also provide **42971 square feet of restored native plant communities** and a **100% change in plant diversity** as the original site was turf grass.

*Tree Canopy* increase was proposed in the North Jardine parking lot to explore the change in rainfall interception, and other ecosystem services. The proposed tree canopy will cover an additional **4,304 square feet in 10 years** and the new trees will also remove approximately **15.4 lbs of air pollutants every year** and an **826 pounds of carbon will be sequestered every year**.

*Permeable Pavement* was proposed in the East Stadium parking lot because of its large size in relation to its associated drainage area. Approximately 8,566 square feet of impervious area was replaced with permeable paving, leading to a **45% decrease in the peak rate**.

| Green Infrastructure Type | Category | Metric |
|---|---|---|
| Rain Water Harvesting Mechanisms | Stormwater Management | **5,782 reduction** in directly connected impervious area |
| | Integrated Water Management | **2.8% reduction** in potable water use |
| Bioretention | Stormwater Management | **North Jardine: 79% decrease in peak rate** **East Stadium: 83% decrease in peak rate** |
| | Other Ecosystem Services | **42,971 square feet** of protected or restored native plant communities (square feet) |
| | | **100% Change** in plant diversity |
| | Integrated Water Management | **86% reduction** in potable water use |
| Tree Canopy | Other Ecosystem Services | **4,304 square feet** more leaf area after 10 years |
| | | **15.375 lbs/year** air pollutant removal by trees (lbs/year) |
| | | **826 lbs/year** carbon sequestered by new trees |
| Permeable Pavement | Stormwater Management | **8,566 square foot reduction** in impervious area |
| | | **45% decrease in peak rate** |

Figure 7.30. Final documentation metrics for the projective design.

# 7.8 Design Goals

In 5.4, design goals were established and adapted from the Campus Rainworks Competition.

**Performance** goals reflect the design's ability to address stormwater needs on site. The modeling results for pollutant load, infiltration increase, runoff decrease, and rainfall interception all state that the performance goals have been met.

**Design** goals determine the environmental, social and economic effects of the proposed green infrastructure solutions. The various green infrastructure designs required in-depth research and modeling to ensure their effectiveness. Research included a small review of the Kansas State University Stormwater Management Plan.

**Resilience** goals reflect the environmental priorities at the local, state, and regional scale while also evaluating the plant selection and forms of green infrastructure proposed. Each proposed bioretention cell contains a completely native plant palette designed to be as low maintenance as possible; in addition, all rainwater harvesting mechanisms are strategically placed to reduce potable water use and replace the need for underground irrigation systems.

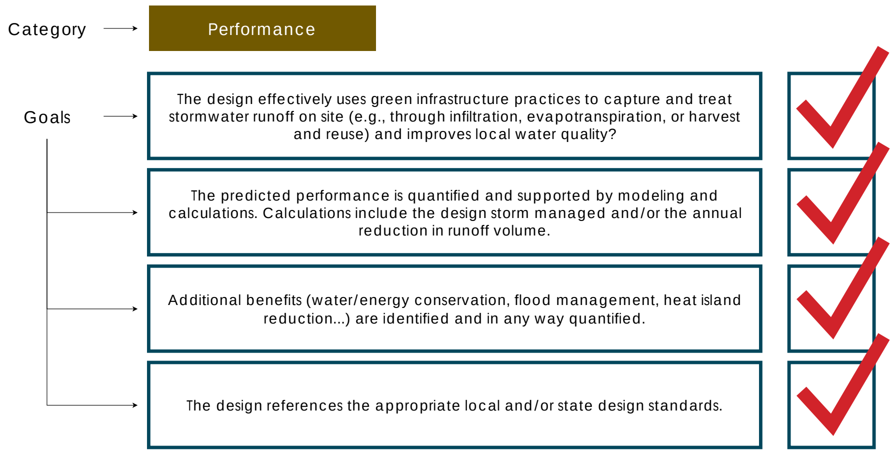


Figure 7.31. Performance Goals met.

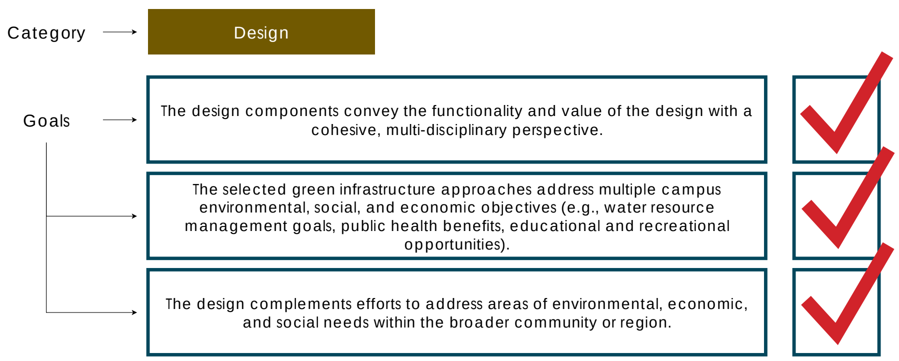


Figure 7.32. Design Goals met.

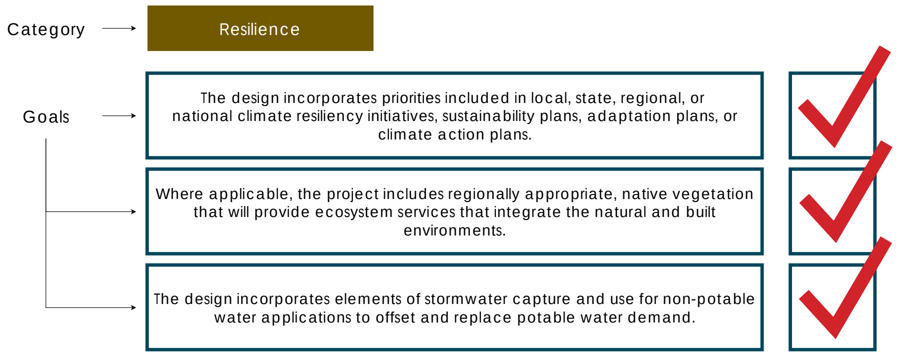


Figure 7.33. Resilience Goals met.

How can the northwestern parking lots of the Campus Creek Watershed's be retrofitted with green infrastructure to help reduce stormwater **runoff quantity**, **peak rate**, and **pollutant load**?

| | | |
|---|---|---|
| Quantity | • • • • • • • • • • • • • • • • • • • | An average annual **54.5% decrease in runoff quantity** via Bioretention, Rain Water Harvesting, and Permeable Pavement. |
| Peak Rate | • • • • • • • • • • • • • • • • • • • | An average **81% decrease in runoff peak rate.** |
| Pollutant Load | • • • • • • • • • • • • • • • • • • • | An average annual **84.7% decrease in Pollutant Load** |

# Chapter 8

## Conclusion

Figure 8.1. Aerial view of Projective Design.

# Conclusion

Project Summary

Campus Creek has the potential to be restored, providing ecological benefits and a socio-cultural amenity for the university.

This project's aim was to use green infrastructure to lessen downstream impacts on Campus Creek. The focus area has a high ratio of impervious surface, primarily parking lots, and poor soils, therefore, high quantities of runoff are produced after storm events, which cause flash floods. Runoff from parking lots carries many pollutants downstream, and, as a result, Campus Creek's water quality is in poor condition. Green infrastructure includes a range of measures that can infiltrate, absorb, and filter stormwater before it enters a waterbody. Due to Campus Creek's degraded state, proposing a series of green infrastructure measures that work together can effectively reduce the quantity, peak rate, and pollutant load of stormwater runoff generated from the focus area. This alone will not restore the health of Campus Creek, but future, ongoing impacts can be lessened.

Site Analysis was conducted in the form of Site Inventory and Modeling. Site Inventory was done to learn everything physically possible about both the watershed and the parking lots of focus while also establishing forms of green infrastructure to install that would utilize existing conditions. Modeling was done to understand existing benefits and to provide a baseline for improvement.

Bioretention was the area of focus for this project and supplementary green infrastructure measures like rainwater harvesting mechanisms, increased tree canopy, and permeable pavement were proposed to create one cohesive network of innovative stormwater management techniques.

Modeling was conducted again, but with the proposed green infrastructure measures applied. **Findings indicated a 54.5% decrease in total annual runoff quantity, an 81% decrease in the peak rate of runoff, and an 84.7% decrease in the annual pollutant load generated.**

The findings indicate that retrofitting with green infrastructure can effectively reduce the stress on a local waterbody and do so efficiently. This project proves that proposed green infrastructure measures can be modeled prior to installation via various modeling tools like the EPA Stormwater Runoff Calculator.

People in any urban area can apply the same steps taken in this project to establish a baseline for improvement in their area and assign locations for future green infrastructure measures. Although this project was conducted with prior knowledge of site analysis, green infrastructure, and the effects runoff have in urban areas, it is important to note that anyone can find this knowledge using online resources like the EPA website which offers all kinds of information regarding stormwater management along with tools.

# Conclusion

## Project Limitations

The primary challenge faced during this project was maximizing the effects of the green infrastructure measures while trying to remain realistic. Unfortunately, the cost of installing and maintaining over 40,000 square feet of bioretention, 8 rainwater harvesting mechanisms, and approximately 13,500 square feet of permeable pavement far outweigh the benefits in the eyes of a university. Bioretention provides natural benefits with aesthetic appeal but ensuring that plant material establishes itself in clay soil is a complex process without an irrigation system and soil remedies. Therefore, rainwater harvesting mechanisms were a viable alternative to irrigation since structures were located nearby, but cisterns include another level of maintenance in addition to the bioretention. Permeable pavement requires an exuberant amount of maintenance to ensure peak performance regarding stormwater runoff infiltration. All the maintenance that accompanied the proposed green infrastructure measures could not realistically be addressed with the existing maintenance crew for Housing and Dining at Kansas State University. With no ability to establish a dollar value in runoff reduction benefits, it is unrealistic to install green infrastructure measures that require a set dollar value in maintenance annually.

In addition to maintenance limitations, there are also limitations to the proposed bioretention cells. The combined measures were specifically designed to address the stormwater management needs of the parking lots of focus when the proposed bioretention cells take on runoff from all of the structures, sidewalks, and turf grass within the drainage area. Therefore, it is important to note that regarding the parking lots of focus alone, the proposed measures do drastically reduce their runoff quantity, peak rate, and pollutant load. Regarding the entire drainage area of the proposed measures, the runoff quantity, peak rate, and pollutant load is reduced by significantly less than the parking lots alone. Thus, raising more questions as to the overall viability of such installations in urban areas.

## Future Research

Although there is significant literature regarding green infrastructure, there are still questions in terms of overall viability in retrofits. Universities like Kansas State have interest in the value of amenities like sports and the revenue they bring in. Kansas State University has spent millions on improving the total capacity of sporting events, perhaps there is an opportunity to improve stormwater management in conjunction with sporting improvements.

Kansas State University put together a master plan in 2012 with supplemental master plans for future development and stormwater management. The stormwater management master plan outlined a set of projects that implement new gray infrastructure on campus and pipe excess runoff into existing detention basins. Using the methodology in this project, there is an opportunity to propose green infrastructure that reflects the needs outlined in the stormwater management master plan, and do so in a way that can support sporting venues and inform the public at the same time. This has already been done at the Memorial Stadium in the form of green roofs. Can it be done at Bill Snyder Stadium?

# Conclusion

Reflection

This project has reinforced to me the need and opportunity for landscape architecture projects to be interdisciplinary, especially those that deal with green infrastructure. The expertise of other professionals, like environmental engineers, civil engineers, biologists, agronomists, and horticulturalists help strengthen project outcomes. This project would not have been possible without the expertise of my committee members, who provided necessary input and perspectives.

Landscape architecture as a profession is very broad in its capabilities. I became interested in landscape architecture because I wanted to design the skate parks of the future. Less than three years later, my focus has diverted to addressing mother nature as a living being with rights like the rest of us. Keeping this in mind, how can humans raise nature to a level wherein its far more respected than it is now and how can we do so via landscape design?

My change in focus over the last 5 years has proven how diverse of a profession landscape architecture can be while also establishing the need to learn to communicate across professions. This project in particular required me to expand my knowledge away from design and moreso into **function**. Collaborating with Dr. Trisha Moore, PhD, in the Department of Biological and Agricultural Engineering and learning how to prove that a landscape can provide far more than aesthetics was the biggest takeaway from this project.

Personally, I now know what questions to ask when approached with a new project and how I can use the project as a new avenue for data collection among other professions. As my career continues on, I'd like to use this project as a precedent for the possibilities of green infrastructure design and I see myself revisiting the same methodology in a new environment and bringing it to life.

I also was fortunate enough to experience a shift at Kansas State University during the last two months of this project. In late March of 2022, Kansas State installed permeable pavement along the same path I walk my dog every day. They also improved several bioswales on the same path and put in signage to inform passersby of the value of green infrastructure. Projects like this one are responsible for the recognized value in nature.


Figure 8.2. Bioswale signage at Kansas State University.

Figure 8.3. Permeable pavement at Kansas State University.

# Appendices

# Appendix A

Text References

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# Appendix D

Rational Method Runoff Calculations | Existing Conditions

## East Stadium Parking Lot

Q = CiA

Where:

- Q = Peak Flow (cubic feet per second)
- C = Runoff Coefficient
  - 0.80 (Commercial)
  - 0.65 (Multi-Family Residential)
- I = Rainfall Intensity (inches/hour)

| Storm Event | Duration (Hr) | Rainfall Intensity (inches/hour) |
|---|---|---|
| 5-Year | 3.00 | .92 |
| 10-Year | 2.00 | 1.48 |
| 25-Year | 1.50 | 2.23 |
| 50-Year | 1.00 | 3.39 |
| 100-Year | 0.50 | 5.56 |

*Rainfall intensity numbers provided by the NOAA Precipitation Frequency Data Server*

- A = Subcatchment Area (Acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

*Area estimates established using Google Earth Aerial Imagery*

5-Year Storm

Q = .80 * .92 * 7.1

Q = 5.23 cfs

10-Year Storm

Q = .80 * 1.48 * 7.1

Q = 8.41 cfs

25-Year Storm

Q = .80 * 2.23 * 7.1

Q = 12.67 cfs

50-Year Storm

Q = .80 * 3.39 * 7.1

Q = 19.26 cfs

100-Year Storm

Q = .80 * 5.92 * 7.1

Q = 31.58 cfs

## North Jardine Parking Lot

Q = CiA

Where:

- Q = Peak Flow (cubic feet per second)
- C = Runoff Coefficient
  - 0.80 (Commercial)
  - 0.65 (Multi-Family Residential)
- I = Rainfall Intensity (inches/hour)

| Storm Event | Duration (Hr) | Rainfall Intensity (inches/hour) |
|---|---|---|
| 5-Year | 3.00 | .92 |
| 10-Year | 2.00 | 1.48 |
| 25-Year | 1.50 | 2.23 |
| 50-Year | 1.00 | 3.39 |
| 100-Year | 0.50 | 5.56 |

*Rainfall intensity numbers provided by the NOAA Precipitation Frequency Data Server *

- A = Subcatchment Area (Acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

*Area estimates established using Google Earth Aerial Imagery*

5-Year Storm

Q = .65 * .92 * 2.18

Q = 1.30 cfs

10-Year Storm

Q = .65 * 1.48 * 2.18

Q = 2.10 cfs

25-Year Storm

Q = .65 * 2.23 * 2.18

Q = 3.16 cfs

50-Year Storm

Q = .65 * 3.39 * 2.18

Q = 4.80 cfs

100-Year Storm

Q = .65 * 5.56 * 2.18

Q = 7.88 cfs

### South Recreation Parking Lot

Q = CiA

Where:

- Q = Peak Flow (cubic feet per second)
- C = Runoff Coefficient
  - 0.80 (Commercial)
  - 0.65 (Multi-Family Residential)
- I = Rainfall Intensity (inches/hour)

| Storm Event | Duration (Hr) | Rainfall Intensity (inches/hour) |
|---|---|---|
| 5-Year | 3.00 | .92 |
| 10-Year | 2.00 | 1.48 |
| 25-Year | 1.50 | 2.23 |
| 50-Year | 1.00 | 3.39 |
| 100-Year | 0.50 | 5.56 |

*Rainfall intensity numbers provided by the NOAA Precipitation Frequency Data Server *

- A = Subcatchment Area (Acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

*Area estimates established using Google Earth Aerial Imagery*

5-Year Storm

Q = .80 * .92 * 1.39

Q = 1.02 cfs

10-Year Storm

Q = .80 * 1.48 * 1.39

Q = 1.65 cfs

25-Year Storm

Q = .80 * 2.23 * 1.39

Q = 2.48 cfs

50-Year Storm

Q = .80 * 3.39 * 1.39

Q = 3.77 cfs

100-Year Storm

Q = .80 * 5.56 * 1.39

Q = 6.18 cfs

### Mid-Jardine Parking Lot

Q = CiA

Where:

- Q = Peak Flow (cubic feet per second)
- C = Runoff Coefficient
  - 0.80 (Commercial)
  - 0.65 (Multi-Family Residential)
- I = Rainfall Intensity (inches/hour)

| Storm Event | Duration (Hr) | Rainfall Intensity (inches/hour) |
|---|---|---|
| 5-Year | 3.00 | .92 |
| 10-Year | 2.00 | 1.48 |
| 25-Year | 1.50 | 2.23 |
| 50-Year | 1.00 | 3.39 |
| 100-Year | 0.50 | 5.56 |

*Rainfall intensity numbers provided by the NOAA Precipitation Frequency Data Server *

- A = Subcatchment Area (Acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

*Area estimates established using Google Earth Aerial Imagery*

5-Year Storm

Q = .65 * .92 * .56

Q = .33 cfs

10-Year Storm

Q = .65 * 1.48 * .56

Q = .54 cfs

25-Year Storm

Q = .65 * 2.23 * .56

Q = .81 cfs

50-Year Storm

Q = .65 * 3.39 * .56

Q = 1.23 cfs

100-Year Storm

Q = .65 * 5.56 * .56

Q = 2.02 cfs

# Appendix D

Rational Method Runoff Calculations | Projective Design

Peak rate was not recalculated for the South Recreation parking lot and Mid-Jardine parking lot because they were not subject to a Projective Design.

## East Stadium Parking Lot | Bioretention

Q = CiA

Where:

- Q = Peak Flow (cubic feet per second)
- C = Runoff Coefficient
- I = Rainfall Intensity (inches/hour)

| Storm Event | Duration (Hr) | Rainfall Intensity (inches/hour) | Runoff Coefficient |
|---|---|---|---|
| 5-Year | 3.00 | .92 | 0 |
| 10-Year | 2.00 | 1.48 | 0 |
| 25-Year | 1.50 | 2.23 | 0 |
| 50-Year | 1.00 | 3.39 | .32 |
| 100-Year | 0.50 | 5.56 | .36 |

*Rainfall intensity numbers provided by the NOAA Precipitation Frequency Data Server*
*Runoff coefficients for grass in condition were used to represent bioretention*
*Runoff coefficients for grass sourced from M. McEnroe, et al. 2013*

- A = Subcatchment Area (Acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |

*Area estimates established using Google Earth Aerial Imagery*

<u>5-Year Storm</u>

Q = 0 * 0.92 * 7.1

Q = 0 cfs

<u>10-Year Storm</u>

Q = 0 * 1.48 * 7.1

Q = 0 cfs

<u>25-Year Storm</u>

Q = 0 * 2.23 * 7.1

Q = 0 cfs

<u>50-Year Storm</u>

Q = 0.32 * 3.39 * 7.1

Q = 7.70 cfs

<u>100-Year Storm</u>

Q = 0.36 * 5.56 * 7.1

Q = 14.20 cfs

## North Jardine Parking Lot | Bioretention

Q = CiA

Where:

- Q = Peak Flow (cubic feet per second)
- C = Runoff Coefficient
- I = Rainfall Intensity (inches/hour)

| Storm Event | Duration (Hr) | Rainfall Intensity (inches/hour) | Runoff Coefficient |
|---|---|---|---|
| 5-Year | 3.00 | .92 | 0 |
| 10-Year | 2.00 | 1.48 | 0 |
| 25-Year | 1.50 | 2.23 | 0 |
| 50-Year | 1.00 | 3.39 | .32 |
| 100-Year | 0.50 | 5.56 | .36 |

*Rainfall intensity numbers provided by the NOAA Precipitation Frequency Data Server*
*Runoff coefficients for grass in condition were used to represent bioretention*
*Runoff coefficients for grass sourced from M. McEnroe, et al. 2013*

- A = Subcatchment Area (Acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |

*Area estimates established using Google Earth Aerial Imagery*

<u>5-Year Storm</u>

Q = 0 * 0.92 * 2.18

Q = 0 cfs

<u>10-Year Storm</u>

Q = 0 * 1.48 * 2.18

Q = 0 cfs

<u>25-Year Storm</u>

Q = 0 * 2.23 * 2.18

Q = 0 cfs

<u>50-Year Storm</u>

Q = 0.32 * 3.39 * 2.18

Q = 2.36 cfs

<u>100-Year Storm</u>

Q = 0.36 * 5.56 * 2.18

Q = 4.36 cfs

# Appendix D

Rational Method Runoff Calculations | Projective Design

Peak rate was not recalculated for the South Recreation parking lot and Mid-Jardine parking lot because they were not subject to a Projective Design.

## East Stadium Parking Lot | Permeable Pavement

Q = CiA

Where:

- Q = Peak Flow (cubic feet per second)
- C = Runoff Coefficient
  - Permeable Pavement = 0.44
- I = Rainfall Intensity (inches/hour)

| Storm Event | Duration (Hr) | Rainfall Intensity (inches/hour) |
|---|---|---|
| 5-Year | 3.00 | .92 |
| 10-Year | 2.00 | 1.48 |
| 25-Year | 1.50 | 2.23 |
| 50-Year | 1.00 | 3.39 |
| 100-Year | 0.50 | 5.56 |

*Rainfall intensity numbers provided by the NOAA Precipitation Frequency Data Server*
*Runoff coefficients for permeable pavement sourced from Bean 2005, Page 146, Table 3*

- A = Subcatchment Area (Acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |

*Area estimates established using Google Earth Aerial Imagery*

5-Year Storm

Q = 0.44 * 0.92 * 7.1

Q = 2.87 cfs

10-Year Storm

Q = 0.44 * 1.48 * 7.1

Q = 4.62 cfs

25-Year Storm

Q = 0.44 * 2.23 * 7.1

Q = 6.96 cfs

50-Year Storm

Q = 0.44 * 3.39 * 7.1

Q = 10.59 cfs

100-Year Storm

Q = 0.44 * 5.56 * 7.1

Q = 17.37 cfs

## Total Reductions

North Jardine Parking Lot

| Storm Event | Existing Conditions | Bioretention | Reduction |
|---|---|---|---|
| 5-Year | 1.30 | 0 | 100% |
| 10-Year | 2.10 | 0 | 100% |
| 25-Year | 3.16 | 0 | 100% |
| 50-Year | 4.80 | 2.36 | 50.83% |
| 100-Year | 7.88 | 4.36 | 44.67% |
| | | **Average % Reduction** | **79.1%** |

East Stadium Parking Lot

| Storm Event | Existing Conditions | Bioretention | Permeable Pavement |
|---|---|---|---|
| 5-Year | 5.23 | 0 | 2.87 |
| 10-Year | 8.41 | 0 | 4.62 |
| 25-Year | 12.67 | 0 | 6.96 |
| 50-Year | 19.26 | 7.70 | 10.59 |
| 100-Year | 31.58 | 14.20 | 17.37 |

| Storm Event | Permeable Pavement Reductions | Bioretention Reductions |
|---|---|---|
| 5-Year | 45.12% | 100% |
| 10-Year | 45.07% | 100% |
| 25-Year | 45.07% | 100% |
| 50-Year | 45.02% | 60.02% |
| 100-Year | 45.00% | 55.03% |
| **Average % Reduction** | **45.05%** | **83.01%** |
| | **64.03%** | |

# Appendix E

Simple Method Runoff Calculations | Existing Conditions

L = 0.226 * R * C * A

Where:

- L = Annual Load (lbs)
- R = Annual Runoff (inches)
  - o 26.92 inches *provided by the EPA Stormwater Runoff Calculator*
- C = Pollutant concentration (mg/l)
  *provided by New York State Stormwater Management Design Manual*

| Pollutant | Concentration |
|---|---|
| TSS | 27 mg/l |
| TP | 0.15 mg/L |
| TN | 1.9 mg/l |
| F. Coli | 1.8 1,000col/ml |
| Cu | 51 ug/l |
| Pb | 28 ug/l |
| Zn | 139 ug/l |

- A = Area (acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

- 0.226 = Unit Conversion Factor

Calculations

| Pollutant | Equation | Annual Load (lbs) |
|---|---|---|
| TSS | 0.226 * 27 * 26.92 * 7.1 | 1166.30 |
| TP | 0.226 * 0.15 * 26.92 * 7.1 | 6.5 |
| TN | 0.226 * 1.9 * 26.92 * 7.1 | 82.1 |
| F. Coli | 0.226 * 1.8 * 26.92 * 7.1 | 77.75 |
| Cu | 0.226 * 51 * 26.92 * 7.1 | 2202.99 |
| Pb | 0.226 * 28 * 26.92 * 7.1 | 1209.5 |
| Zn | 0.226 * 26.92 * 139 * 7.1 | 6004.22 |

L = 0.226 * R * C * A

Where:

- L = Annual Load (lbs)
- R = Annual Runoff (inches)
  - o 26.92 inches *provided by the EPA Stormwater Runoff Calculator*
- C = Pollutant concentration (mg/l)
  *provided by New York State Stormwater Management Design Manual*

| Pollutant | Concentration |
|---|---|
| TSS | 27 mg/l |
| TP | 0.15 mg/L |
| TN | 1.9 mg/l |
| F. Coli | 1.8 1,000col/ml |
| Cu | 51 ug/l |
| Pb | 28 ug/l |
| Zn | 139 ug/l |

- A = Area (acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

- 0.226 = Unit Conversion Factor

Calculations

| Pollutant | Equation | Annual Load (lbs) |
|---|---|---|
| TSS | 0.226 * 27 * 26.92 * 2.18 | 348.24 |
| TP | 0.226 * 0.15 * 26.92 * 2.18 | 1.93 |
| TN | 0.226 * 1.9 * 26.92 * 2.18 | 24.5 |
| F. Coli | 0.226 * 1.8 * 26.92 * 2.18 | 23.22 |
| Cu | 0.226 * 51 * 26.92 * 2.18 | 657.8 |
| Pb | 0.226 * 28 * 26.92 * 2.18 | 361.14 |
| Zn | 0.226 * 26.92 * 139 * 2.18 | 1792.81 |

# Appendix E

Simple Method Runoff Calculations | Existing Conditions

L = 0.226 * R * C * A

Where:

- L = Annual Load (lbs)
- R = Annual Runoff (inches)
  - o 26.92 inches *provided by the EPA Stormwater Runoff Calculator*
- C = Pollutant concentration (mg/l)
  *provided by New York State Stormwater Management Design Manual*

| Pollutant | Concentration |
|---|---|
| TSS | 27 mg/l |
| TP | 0.15 mg/L |
| TN | 1.9 mg/l |
| F. Coli | 1.8 1,000col/ml |
| Cu | 51 ug/l |
| Pb | 28 ug/l |
| Zn | 139 ug/l |

- A = Area (acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

- 0.226 = Unit Conversion Factor

Calculations

| Pollutant | Equation | Annual Load (lbs) |
|---|---|---|
| TSS | 0.226 * 27 * 26.92 * 1.39 | 246.4 |
| TP | 0.226 * 0.15 * 26.92 * 1.39 | 1.37 |
| TN | 0.226 * 1.9 * 26.92 * 1.39 | 17.34 |
| F. Coli | 0.226 * 1.8 * 26.92 * 1.39 | 16.43 |
| Cu | 0.226 * 51 * 26.92 * 1.39 | 465.42 |
| Pb | 0.226 * 28 * 26.92 * 1.39 | 255.52 |
| Zn | 0.226 * 26.92 * 139 * 1.39 | 1259.4 |

L = 0.226 * R * C * A

Where:

- L = Annual Load (lbs)
- R = Annual Runoff (inches)
  - o 26.92 inches *provided by the EPA Stormwater Runoff Calculator*
- C = Pollutant concentration (mg/l)
  *provided by New York State Stormwater Management Design Manual*

| Pollutant | Concentration |
|---|---|
| TSS | 27 mg/l |
| TP | 0.15 mg/L |
| TN | 1.9 mg/l |
| F. Coli | 1.8 1,000col/ml |
| Cu | 51 ug/l |
| Pb | 28 ug/l |
| Zn | 139 ug/l |

- A = Area (acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |
| South Recreation | 1.39 |
| Mid-Jardine | .56 |

- 0.226 = Unit Conversion Factor

Calculations

| Pollutant | Equation | Annual Load (lbs) |
|---|---|---|
| TSS | 0.226 * 27 * 26.92 * .56 | 95.3 |
| TP | 0.226 * 0.15 * 26.92 * .56 | .52 |
| TN | 0.226 * 1.9 * 26.92 * .56 | 6.7 |
| F. Coli | 0.226 * 1.8 * 26.92 * .56 | 6.35 |
| Cu | 0.226 * 51 * 26.92 * .56 | 179 |
| Pb | 0.226 * 28 * 26.92 * .56 | 98.80 |
| Zn | 0.226 * 26.92 * 139 * .56 | 490.5 |

# Appendix E

Simple Method Runoff Calculations | Projective Design

Pollutant load was not recalculated for the South Recreation parking lot and Mid-Jardine parking lot because they were not subject to a Projective Design.

## North Jardine Parking Lot

L = 0.226 * R * C * A

Where:

- L = Annual Load (lbs)
- R = Annual Runoff (inches)
  - 5.99 inches *reduced average annual runoff depth via the EPA Stormwater Runoff Calculator for the North Jardine parking lot*
- C = Pollutant concentration (mg/l)

| Pollutant | Concentration |
|---|---|
| TSS | 27 mg/l |
| TP | 0.15 mg/L |
| TN | 1.9 mg/l |
| F. Coli | 1.8 1,000col/ml |
| Cu | 51 ug/l |
| Pb | 28 ug/l |
| Zn | 139 ug/l |

- A = Area (acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |

- 0.226 = Unit Conversion Factor

Calculations

| Pollutant | Equation | Annual Load (lbs) |
|---|---|---|
| TSS | 0.226 * 27 * 5.99 * 2.18 | 79.68 |
| TP | 0.226 * 0.15 * 5.99 * 2.18 | 0.44 |
| TN | 0.226 * 1.9 * 5.99 * 2.18 | 5.61 |
| F. Coli | 0.226 * 1.8 * 5.99 * 2.18 | 5.31 |
| Cu | 0.226 * 51 * 5.99 * 2.18 | 150.5 |
| Pb | 0.226 * 28 * 5.99 * 2.18 | 82.63 |
| Zn | 0.226 * 139 * 5.99 * 2.18 | 410.21 |

Reduction

| Pollutant | Existing Conditions | Projective Design | Reductions |
|---|---|---|---|
| TSS | 348.24 | 79.68 | 77.12% |
| TP | 1.93 | 0.44 | 77.20% |
| TN | 24.50 | 5.61 | 77.10% |
| F. Coli | 23.22 | 5.31 | 77.13% |
| Cu | 657.80 | 150.5 | 77.12% |
| Pb | 361.14 | 82.63 | 77.12% |
| Zn | 1792.81 | 410.21 | 77.12% |
| | | **Average % Reduction** | **77.13%** |

## East Stadium Parking Lot

L = 0.226 * R * C * A

Where:

- L = Annual Load (lbs)
- R = Annual Runoff (inches)
  - 2.19 inches *reduced average annual runoff depth via the EPA Stormwater Runoff Calculator for the East Stadium parking lot*
- C = Pollutant concentration (mg/l)

| Pollutant | Concentration |
|---|---|
| TSS | 27 mg/l |
| TP | 0.15 mg/L |
| TN | 1.9 mg/l |
| F. Coli | 1.8 1,000col/ml |
| Cu | 51 ug/l |
| Pb | 28 ug/l |
| Zn | 139 ug/l |

- A = Area (acres)

| Parking Lot | Area (Acres) |
|---|---|
| East Stadium | 7.1 |
| North Jardine | 2.18 |

- 0.226 = Unit Conversion Factor

Calculations

| Pollutant | Equation | Annual Load (lbs) |
|---|---|---|
| TSS | 0.226 * 27 * 2.19 * 7.1 | 94.87 |
| TP | 0.226 * 0.15 * 2.19 * 7.1 | 0.52 |
| TN | 0.226 * 1.9 * 2.19 * 7.1 | 6.68 |
| F. Coli | 0.226 * 1.8 * 2.19 * 7.1 | 6.33 |
| Cu | 0.226 * 51 * 2.19 * 7.1 | 179.22 |
| Pb | 0.226 * 28 * 2.19 * 7.1 | 98.39 |
| Zn | 0.226 * 139 * 2.19 * 7.1 | 488.46 |

Reduction

| Pollutant | Existing Conditions | Projective Design | Reductions |
|---|---|---|---|
| TSS | 1166.30 | 94.87 | 94.87% |
| TP | 6.5 | 0.52 | 92.00% |
| TN | 82.1 | 6.68 | 91.86% |
| F. Coli | 77.75 | 6.33 | 91.86% |
| Cu | 2202.99 | 179.22 | 91.86% |
| Pb | 1209.5 | 98.39 | 91.87% |
| Zn | 6004.22 | 488.46 | 91.86% |
| | | **Average % Reduction** | **92.31%** |

# Appendix F

Permeable Pavement Design

This project refers to the NCDEQ (North Carolina Department of Environmental Quality) Stormwater Design Manual for guidance on permeable pavement design. According to the manual, the municipal development code for permeable pavement contains 13 Municipal Development Codes (MDC) to ensure that the permeable pavement meets the necessary criteria.

**MDC 1** requires a **soil investigation** to establish the hydraulic properties within the proposed footprint and elevation.

**MDC 2** requires that the design meets two SHWT requirements.
The minimum separation between the lowest point of the subgrade surface and the SHWT shall be: (1) two feet for infiltrating pavement systems; however, the separation may be reduced to no less than one foot if the applicant provides a hydrogeologic evaluation that demonstrates that the water table will subside to its pre-storm elevation within five days or less; and (2) one foot for detention pavement systems.

**MDC 3** requires that the permeable pavement is not installed in areas where toxic pollutants are stored or handled.

**MDC 4** requires that the soil subgrade surface has a slope of less than or equal to two percent.

**MDC 5** requires that the aggregate base materials are used.

**MDC 6** requires that the pavement surface has a demonstrated infiltration rate of at least 50 inches per hour using a head less than or equal to 4 inches.

**MDC 7** requires that runoff from adjacent areas meets these requirements: (1) the maximum ratio of additional built-upon area that may drain to permeable pavement is 1:1; (2) runoff from adjacent pervious areas shall be prevented from reaching the permeable pavement except for incidental, unavoidable runoff from stable vegetated areas.

**MDC 8** requires that infiltrating permeable pavement systems shall be designed to dewater the design volume to the bottom of the subgrade surface within 72 hours.

**MDC 9** requires that the pavement is equipped with a minimum of one observation well placed at the low point of the system.

**MDC 10** requires that the system is designed to detain water for a period of two to five days.

**MDC 11** requires that edge restraints are installed around the perimeter or permeable interlocking pavers and grid pavers.

**MDC 12** requires that the soil subgrade for permeable pavement shall be graded when there is no precipitation.

**MDC 13** requires that after installation, the pavement is protected from sediment deposition unitl the site is completed and stabilized, and an infiltration permeability test is conducted and certified post-stabilization.

As noted, MDC 5 requires that permeable pavement uses an aggregate base. The NCDEQ Stormwater Design Manual provides an equation to establish the necessary of aggregate needed for the design volume. The equation is presented below:

$$D_{wq} = \frac{P\,(1+R)}{n}$$

| | | | |
|---|---|---|---|
| where: | Dwq | = | Depth of aggregate |
| | P | = | Rainfall depth (water quality storm) |
| | R | = | Aa/Ap ratio of the additional BUA to permeable pavement area |
| | N | = | Percent voids, unitless decimal |

In this project, the above variables are:

| | | | |
|---|---|---|---|
| where: | Dwq | = | TBD |
| | P | = | 1.1 inches |
| | R | = | 0.06 |
| | N | = | Percent voids, unitless decimal |

Due to resource and time constraints, this project will not be able to assign an aggregate depth as variable N (percent voids) cannot be accurately calculated because it requires a series of tests to determine the percentage of voids within it. See the next page for a more in-depth description of this process.

# Appendix F

Permeable Pavement Design

Below is the process to establish the bulk density and void percentage of aggregate per the ASTM Standard.

**Tools** required are: (1) a balance, (2) tamping rod, (3) cylindrical metal measure, (4) shovel/scoop, (5) equipment for measuring volume of measure.

**Step 1: Determination of Volume of Measure**

a. Evaluate the mass of the plate glass and measure the nearest 0.05 kg.

b. Place a thin layer of grease on the rim of the measure to prevent leakage of water.

c. Fill the measure with water and cover it with the plate glass in a manner to remove bubbles and excess water.

d. Determine the mass of the water, plate glass, and measure to the nearest 0.05 kg.

e. Measure the temperature of the water to the nearest 0.5 degrees Celsius and specify its density.

f. Calculate the volume, V, of the measure using the following expression:

V = (W - M) / D

F = D / (W - M)

where:

V = Volume of the measure, m3

W = Mass of the water, plate glass and measure, kg

M = Mass of the plate glass and measure, kg

D = Density of the water for the measured temperature, kg/m3

F = Factor for the measure, 1/m3

**Step 2: Test Procedure**

a. Take the weight of the empty measure (W) to the nearest 0.05 kg.

b. Fill the measure in three layers and compact the aggregate in the three layers using one of the three methods based on aggregate size.

Method A: Rodding

Method B: Jigging

Method C: Shoveling

c. Finally, determine and record the mass of the measure plus its contents to the nearest 0.05 kg.

**Step 3: Calculations**

a. Calculation of Compacted Bulk Density of Aggregate

Bulk Density (M) = (G - T) / V

Bulk Density (M) = (G - T) / F

where:

M = Bulk density of aggregate, kg/m3

G = Mass of the aggregate plus the measure, kg

T = Mass of the measure, kg

V = Volume of the measure, m3

F = Factor for measure

b. Void Content

% of Voids = 100 [(S x W) - M] / (S x W)

where:

M = Bulk density of the aggregate, kg/m3

S = Bulk specific gravity

W = Density of water, 998 kg/m3

# Appendix G

Regression Models | Existing Conditions

Throughfall Equation for Deciduous Leafed – Rough Bark trees

-0.49 + 0.77(P)

Where:

P = Precipitation Depth (inches)

| Storm Name | Duration | Depth (inches) |
|---|---|---|
| Standard | 6 hours | 1.0 |
| Water Quality | -- | 1.10 |
| 10 – Year (A) | 2 hours | 2.92 |
| 10 – Year (B) | 24 hours | 4.94 |
| 50 – Year | 6 hours | 5.57 |

Throughfall

| Storm Name | Equation | Throughfall |
|---|---|---|
| Standard | -0.49 + 0.77(1.0) | **.28** |
| Water Quality | -0.49 + 0.77(1.10) | **.36** |
| 10 – Year (A) | -0.49 + 0.77(2.92) | **1.76** |
| 10 – Year (B) | -0.49 + 0.77(4.94) | **3.31** |
| 50 – Year | -0.49 + 0.77(5.57) | **3.79** |

Equation for Total Rainfall Captured (% per storm event)

(Rainfall – Throughfall) / Rainfall

| Storm Name | Equation | Rainfall Captured (%) |
|---|---|---|
| Standard | (1.0 - .28) / 1.0 | **72%** |
| Water Quality | (1.10 - .36) / 1.10 | **67%** |
| 10 – Year (A) | (2.92 – 1.76) / 2.92 | **39.7%** |
| 10 – Year (B) | (4.94 – 3.31) / 4.94 | **33%** |
| 50 – Year | (5.57 – 3.79) / 5.57 | **32%** |

Equation for Total Rainfall Captured (cubic feet per storm event)

(Rainfall – Throughfall) * Canopy Area

Canopy Area

| Parking Lot | Canopy Area (square feet) |
|---|---|
| North Jardine | 1,158 |
| South Recreation | 4,298 |
| West Memorial Stadium (Reference Model) | 72,716 |

*Canopy area was estimated using Google Earth Imagery*

North Jardine

| Storm Name | Equation | Rainfall Captured (cubic feet) |
|---|---|---|
| Standard | (1.0 - .28) * 1,158 | **833.76** |
| Water Quality | (1.10 - .36) * 1,158 | **856.92** |
| 10 – Year (A) | (2.92 – 1.76) * 1,158 | **1,343.28** |
| 10 – Year (B) | (4.94 – 3.31) * 1,158 | **1,887.54** |
| 50 – Year | (5.57 – 3.79) * 1,158 | **2,061.24** |

South Recreation

| Storm Name | Equation | Rainfall Captured (cubic feet) |
|---|---|---|
| Standard | (1.0 - .28) * 4,298 | **3,094.56** |
| Water Quality | (1.10 - .36) * 4,298 | **3,180.52** |
| 10 – Year (A) | (2.92 – 1.76) * 4,298 | **4,985.68** |
| 10 – Year (B) | (4.94 – 3.31) * 4,298 | **7,005.74** |
| 50 – Year | (5.57 – 3.79) * 4,298 | **7,650.44** |

West Memorial Stadium (Reference Model)

| Storm Name | Equation | Rainfall Captured (cubic feet) |
|---|---|---|
| Standard | (1.0 - .28) * 72,716 | **52,355.52** |
| Water Quality | (1.10 - .36) * 72,716 | **53,809.84** |
| 10 – Year (A) | (2.92 – 1.76) * 72,716 | **84,350.56** |
| 10 – Year (B) | (4.94 – 3.31) * 72,716 | **118,527.08** |
| 50 – Year | (5.57 – 3.79) * 72,716 | **129,434.48** |

# Appendix G

Regression Models | Projective Design

Canopy Area of the North Jardine Parking Lot after 20 years = 95,000 square feet

*New Canopy Area after 20 years provided by i-Tree Eco*

| **Storm Name** | **Equation** | **Rainfall Captured (cubic feet)** |
|---|---|---|
| Standard | (1.0 - .28) * 95,000 | **68400** |
| Water Quality | (1.10 - .36) * 95,000 | **70300** |
| 10 – Year (A) | (2.92 – 1.76) * 95,000 | **110200** |
| 10 – Year (B) | (4.94 – 3.31) * 95,000 | **154850** |
| 50 – Year | (5.57 – 3.79) * 95,000 | **169100** |

# Appendix H

EPA National Stormwater Calculator Results

Percent reductions in runoff quantity presented in Chapter 5 reflect an average of annual runoff reduced across all three storms.

## North Jardine Parking Lot

5-Year Storm

| | Existing Conditions | Projective Design |
|---|---|---|
| Average Annual Rainfall (inches) | 33.31 | 33.31 |
| Average Annual Runoff (inches) | 21.69 | 6.6 |
| Days per Year with Rainfall | 0.8 | 0.8 |
| Days per Year with Runoff | 0.4 | 0.2 |
| Percent of Wet Days Retained | 50 | 75 |
| Smallest Rainfall w/ Runoff (inches) | 3.76 | 4.48 |
| Largest Rainfall w/o Runoff (inches) | 3.24 | 3.73 |
| Maximum Rainfall Retained (inches) | 0.76 | 2.34 |

10-Year Storm

| | Existing Conditions | Projective Design |
|---|---|---|
| Average Annual Rainfall (inches) | 33.38 | 33.38 |
| Average Annual Runoff (inches) | 21.68 | 6.36 |
| Days per Year with Rainfall | 0.6 | 0.6 |
| Days per Year with Runoff | 0.2 | 0 |
| Percent of Wet Days Retained | 66.67 | 100 |
| Smallest Rainfall w/ Runoff (inches) | 3.73 | 0 |
| Largest Rainfall w/o Runoff (inches) | 3.91 | 4.48 |
| Maximum Rainfall Retained (inches) | 1.01 | 2.73 |

25-Year Storm

| | Existing Conditions | Projective Design |
|---|---|---|
| Average Annual Rainfall (inches) | 34.99 | 34.99 |
| Average Annual Runoff (inches) | 22.66 | 6.73 |
| Days per Year with Rainfall | 0.48 | 0.48 |
| Days per Year with Runoff | 0.16 | 0 |
| Percent of Wet Days Retained | 66.67 | 100 |
| Smallest Rainfall w/ Runoff (inches) | 3.99 | 0 |
| Largest Rainfall w/o Runoff (inches) | 3.91 | 4.85 |
| Maximum Rainfall Retained (inches) | 1.01 | 2.73 |

## East Stadium Parking Lot

5-Year Storm

| | Existing Conditions | Projective Design |
|---|---|---|
| Average Annual Rainfall (inches) | 33.31 | 33.31 |
| Average Annual Runoff (inches) | 24.09 | 3.0 |
| Days per Year with Rainfall | 0.8 | 0.8 |
| Days per Year with Runoff | 0.6 | 0.2 |
| Percent of Wet Days Retained | 25 | 75 |
| Smallest Rainfall w/ Runoff (inches) | 3.24 | 4.48 |
| Largest Rainfall w/o Runoff (inches) | 2.98 | 3.73 |
| Maximum Rainfall Retained (inches) | 0.48 | 2.07 |

10-Year Storm

| | Existing Conditions | Projective Design |
|---|---|---|
| Average Annual Rainfall (inches) | 33.38 | 33.38 |
| Average Annual Runoff (inches) | 24.11 | 2.88 |
| Days per Year with Rainfall | 0.6 | 0.6 |
| Days per Year with Runoff | 0.4 | 0.1 |
| Percent of Wet Days Retained | 33.33 | 83.33 |
| Smallest Rainfall w/ Runoff (inches) | 3.73 | 4.48 |
| Largest Rainfall w/o Runoff (inches) | 3.24 | 3.91 |
| Maximum Rainfall Retained (inches) | 0.68 | 2.54 |

25-Year Storm

| | Existing Conditions | Projective Design |
|---|---|---|
| Average Annual Rainfall (inches) | 34.99 | 34.99 |
| Average Annual Runoff (inches) | 25.18 | 3.15 |
| Days per Year with Rainfall | 0.48 | 0.48 |
| Days per Year with Runoff | 0.24 | 0 |
| Percent of Wet Days Retained | 50 | 100 |
| Smallest Rainfall w/ Runoff (inches) | 3.62 | 0 |
| Largest Rainfall w/o Runoff (inches) | 3.91 | 4.85 |
| Maximum Rainfall Retained (inches) | 0.68 | 2.54 |

# Appendix I

i-Tree Eco | Forecast Results

Forecast is a separate component of i-Tree Eco that runs independently and allows users to see future conditions of the inputted tree inventory over a chosen time period in years. Forecast compiles data into composition and structure (canopy area, leaf area, tree biomass, etc.), and benefits (carbon sequestration, carbon storage, etc.). The model assumes 150 days per year without frost, 3% base annual mortality rate for healthy trees, 13.1% base annual mortality rate for sick trees, and 50% base annual mortality rate for dying trees. The assumptions can be altered for specific scenarios. Forecast was ran to see future tree conditions and benefits after 60 years.

# Appendix I

i-Tree Eco | Forecast Results

North Jardine Parking Lot | Existing Conditions

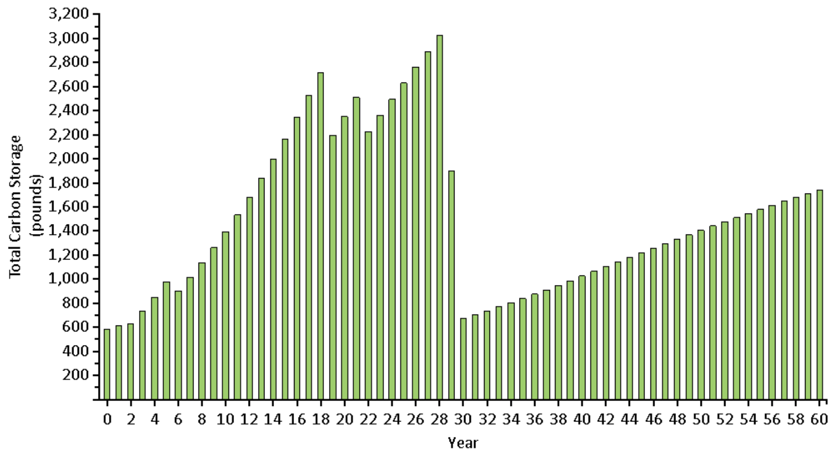



Figure X. Total Carbon Storage for the North Jardine Parking Lot Existing Conditions.

North Jardine Parking Lot | Projective Design

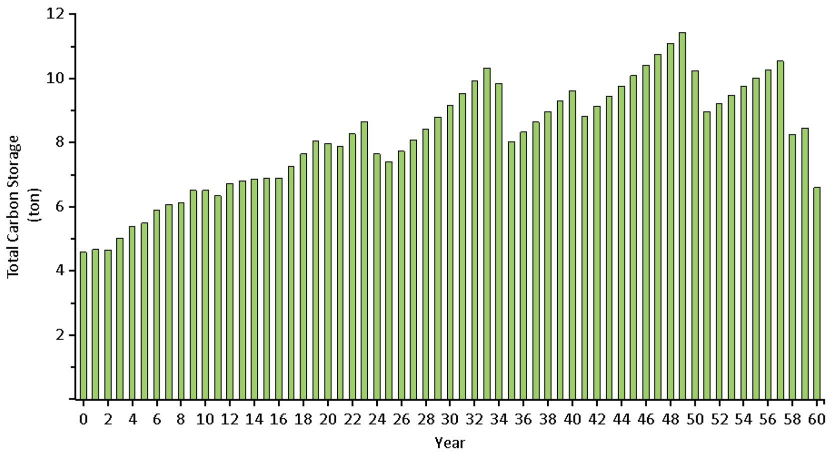



Figure X. Total Carbon Storage for the North Jardine Parking Lot Projective Design

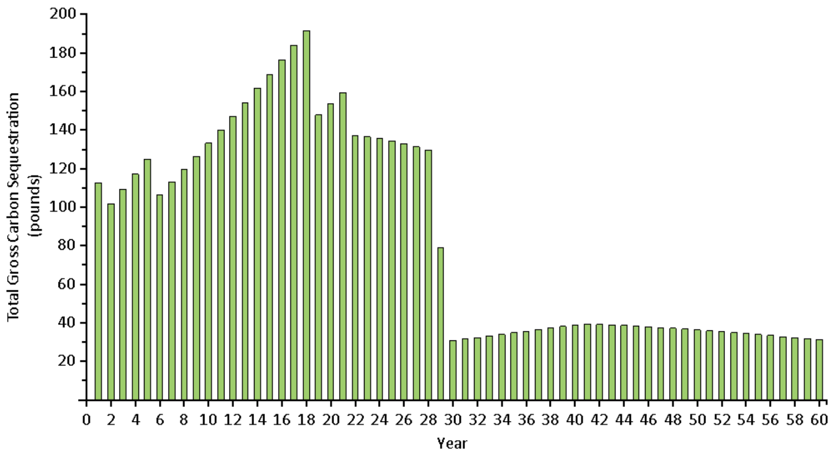



Figure X. Total Carbon Sequestration for the North Jardine Parking Lot Existing Conditions.

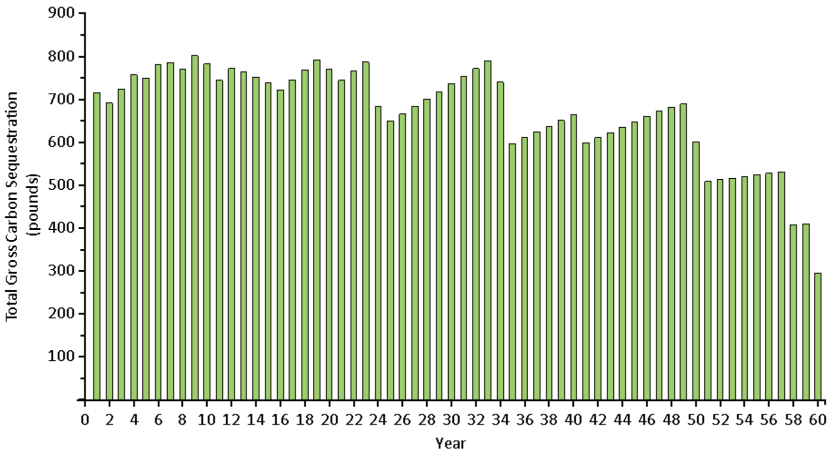
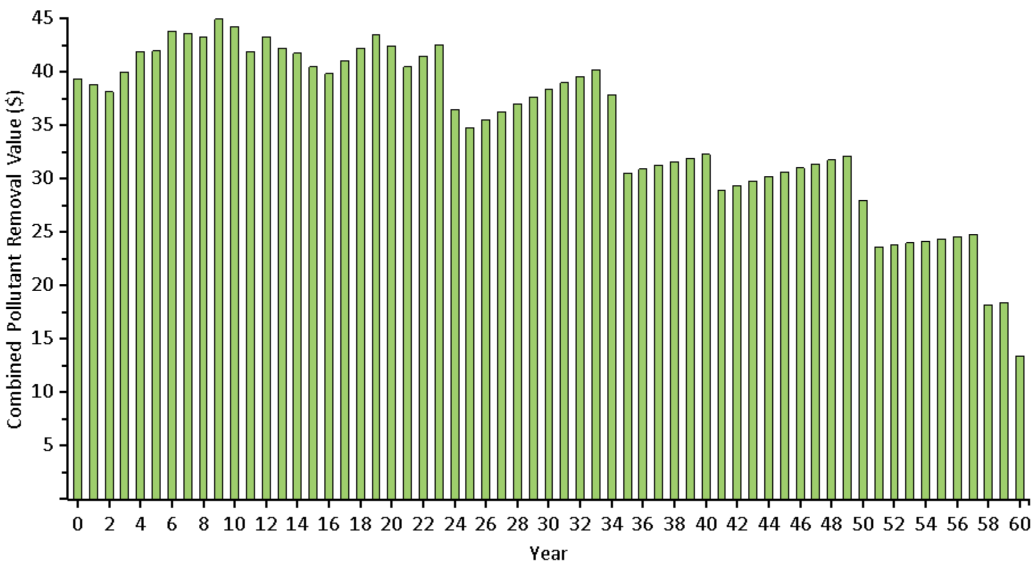



Figure X. Total Carbon Sequestration for the North Jardine Parking Lot Projective Design.

# Appendix I

i-Tree Eco | Forecast Results

North Jardine Parking Lot | Projective Design




| Tree ID | Species Name | DBH (in) | Replacement Value ($) | Carbon Storage (lb) | Carbon Storage ($) | Annual benefits: Gross Carbon Sequestration (lb/yr) | Gross Carbon Sequestration ($/yr) | Avoided Runoff (ft³/yr) | Avoided Runoff ($/yr) | Carbon Avoided (lb/yr) | Carbon Avoided ($/yr) | Pollution Removal (oz/yr) | Pollution Removal ($/yr) | Energy Savings ($/yr) | Total Annual Benefits ($/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 2 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 3 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 4 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 5 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 6 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 7 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 8 | Sawtooth oak | 9.0 | 1,442.89 | 371.2 | 31.66 | 35.1 | 2.99 | 28.6 | 1.91 | N/A | N/A | 11.2 | 1.80 | N/A | 6.71 |
| 9 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 10 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 11 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 12 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 13 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 14 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 15 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 16 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 17 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 18 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 19 | Thornless honeylocust | 9.0 | 1,260.28 | 282.3 | 24.08 | 24.8 | 2.11 | 17.1 | 1.15 | N/A | N/A | 6.7 | 1.08 | N/A | 4.34 |
| 20 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 21 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 22 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 23 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 24 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 25 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 26 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 27 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 28 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 29 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| 30 | Kentucky Coffee tree | 9.0 | 1,223.76 | 282.3 | 24.08 | 24.8 | 2.11 | 19.0 | 1.27 | N/A | N/A | 7.4 | 1.19 | N/A | 4.57 |
| | **Total** | | **38,868** | **9,181** | **783** | **826** | **70** | **626** | **42** | **N/A** | **N/A** | **246** | **39** | **N/A** | **152** |

Carbon storage and gross carbon sequestration value is calculated based on the price of $0.08528 per pound.
Due to limits of available models, i-Tree Eco will limit carbon storage to a maximum of 7,500 kg (16,534.7 lbs) and not estimate additional storage for any tree beyond a diameter of 254 cm (100 in). Whichever limit results in lower carbon storage is used.
Avoided runoff value is calculated by the price $0.067/ft³. The user-designated weather station reported 44.7 inches of total annual precipitation. Eco will always use the hourly measurements that have the greatest total rainfall or user-submitted rainfall if provided.
Energy saving value is calculated based on the prices of $130.20 per MWH and $11.34 per MBTU. Trees less than or equal to 10ft/3m tall or further than 60ft/18m away from buildings do not provide energy benefits to nearby buildings.
Pollution removal value is calculated based on the prices of $0.72 per pound (CO), $1.25 per pound (O3), $0.24 per pound (NO2), $0.10 per pound (SO2), $37.48 per pound (PM2.5), $3.39 per pound (PM10*).
Replacement value is the estimated local cost of having to replace a tree with a similar tree.
A value of zero may indicate that ancillary data (pollution, weather, energy, etc.) is not available for this location or that the reported amounts are too small to be shown.

Figure X. Total Total Pollutant Removal (dollar value) for the North Jardine Parking Lot Projective Design

Figure X. Total Total Pollutant Removal Summary for the North Jardine Parking Lot Projective Design

# Appendix J

Rain Garden Design Guide

The rain garden guide on this page is adapted from the "How to Install a Rain Garden" guide created by the Alabama Watershed Stewards. The guide provides a specific square footage of rain garden required to address a drainage area during a storm of one-inch depth.

## Rain Garden Size

1. Calculate total parking lot area.

   ______ ft. x ______ ft. = ______ ft.$^2$

2. Calculate total rooftop area (if there is a structure within the drainage area)

   ______ ft. x ______ ft. = ______ ft.$^2$

3. Add any additional impervious area in square feet.

   ______ ft. x ______ ft. = ______ ft.$^2$

   ______ ft. x ______ ft. = ______ ft.$^2$

   ______ ft. x ______ ft. = ______ ft.$^2$

   ______ ft. x ______ ft. = ______ ft.$^2$

   ______ ft. x ______ ft. = ______ ft.$^2$

   ______ ft. x ______ ft. = ______ ft.$^2$

   ______ ft. x ______ ft. = ______ ft.$^2$

4. Set ponding depth to either 3 or 6 inches

   ______ ft.$^2$ total area to be treated ÷ ______ (divide by 10 for 3 inches of depth or 20 for 6 inches of depth) = _____ ft.$^2$ total rain garden area

   At 3 inches, ponding depth = _____ ft.$^2$ total rain garden area

   At 6 inches, ponding depth = _____ ft.$^2$ total rain garden area

*If mulch is to be added, ponding depth must be in addition to mulch depth. For example, if ponding depth is 6 inches but 3 inches of mulch is to be added, total depth is 9 inches*

5. Set length and width dimensions to reflect total rain garden area calculated in #4 and the context of the site.

   ______ ft. x ______ ft.

# Appendix K

Glossary

**Bioswales** Found along curbs and in parking lots. Use vegetation or mulch to slow down and filter stormwater ((US EPA, 2015).

**Channel** The bed where a natural stream of water runs.

**Channelization** The reconstruction of a natural waterway so as to flow in a different path.

**Circulation** Movement or passage.

**Downspout Disconnections** Rooftop drainage pipes that move rainwater into rain barrels, cisterns, or permeable areas (US EPA, 2015).

**Detention Basin** Also known as an infiltration basin, shallow depressions filled with grass or other natural vegetation that capture runoff from adjoining areas and allow it to infiltrate soil (US EPA, 2015).

**Erosion** The group of natural processes, including weathering, dissolution, abrasion, corrosion, and transportation, by which material is worn away from the earth's surface.

**Evaporation** The conversion of a solid or liquid by heat into vapor.

**Evapotranspiration** Combined processes of evaporation, sublimation, and transpiration of the water from the earth's surface into the atmosphere.

**Gray Infrastructure** Buried pipes, dams, seawalls, roads, water treatment plants, and storm sewers.

**Green Infrastructure** An interconnected network of natural areas and other open spaces that conserve natural ecosystem values and functions, sustain clean air and water, and provide a wide array of benefits to people and wildlife (Benedict and McMahon, 2006).

**Hydrology** The study of the properties, distribution, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

**Impervious** Artificial structures - such as water resistant pavement made from materials like asphalt, concrete, brich, or stone.

**Interception** The amount of rainfall remaining on the canopy surfaces and is evaporated later on.

**Landscape Water Allowance** An efficient allotment of water that the landscape can be designed to use during the location's peak watering month.

**Landscape Water Requirement** The amount of water the landscape would need during the peak watering month.

**Leaf Area** The amount of surface area (one-sided) of leaves on a tree.

**Low-Impact Development (LID)** A land planning and engineering design approach that implements small-scale hydrologic controls with integrated pollutant treatment to compensate for land development impacts on hydrology and water quality.

**Modeling** Simplifications of reality used to generate new knowledge.

**Peak Watering Month** Month wherein a landscape reaches peak water needs.

**Permeable Pavement** Permeable pavement allows rain to infiltrate and be stored and treated where it falls. They can be made of pervious concrete, porous asphalt, or permeable interlocking pavers (US EPA, 2015).

**Pervious** A surface that allows the percolation of water into the underlying soil such as grass, mulched groundcover, and vegetated areas.

# Appendix K

Glossary

**Planter Boxes** Urban rain gardens with vertical walls that can be open or closed at the bottom. Typically found in downtown areas to collect and absorb runoff from rooftops, streets, sidewalks, and parking lots. Highly suitable for areas with limited space (US EPA, 2015).

**Projective Design** A design informed by other research strategies.

**Rain Gardens** Small, shallow depressed areas of planting that collect stormwater runoff from roofs, streets, and sidewalks. These features may also be called bioretention cells. Designed to copy the natural ways water flows and absorb water into the land to reduce pollution (US EPA, 2015).

**Rainfall Partitioning** Process by trees of regulating stormwater runoff. Includes throughfall, interception, and stemflow.

**Rainwater Harvesting Mechanisms** Rain barrels, commercial building cisterns, ground level pits, and subsurface storage in existing and/or mediated soils and geologic formations meant to slow down runoff and collect rainwater for future use (US EPA, 2015).

**Rational Method** A method of calculating peak flows/rates of stormwater runoff from small drainage areas of less than 200 acres.

**Regression** A technique for predicting the value of a dependent variable as a function of one or more independent variables in the presence of random error.

**Throughfall** The amount of rainfall that reaches the ground through the tree canopy.

**Transpiration** The act or process of transpiring, through the stomata of plant tissue.

**Urban** of, relating to, characteristic of, or constituting a city.

**Urban Heat Island Effect (UHI)** When the air temperature is significantly higher in urban areas.

**Simple Method** A method of calculating the annual pollutant load from the stormwater runoff of a drainage area.

**Soil Infiltration** Downward entry of water into soil. Infiltration rate is expressed in inches per hour.

**Stemflow** Precipitation that is delivered to the base of the tree along the trunk.

**Stormwater Runoff** Precipitation that flows across land.

**Watershed** The area draining into a river, river system, or other body of water.