Greening parking lots to decrease stormwater runoff and improve water quality

by

Natalie Kerner

A REPORT

submitted in partial fulfillment of the requirements for the degree

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

KANSAS STATE UNIVERSITY
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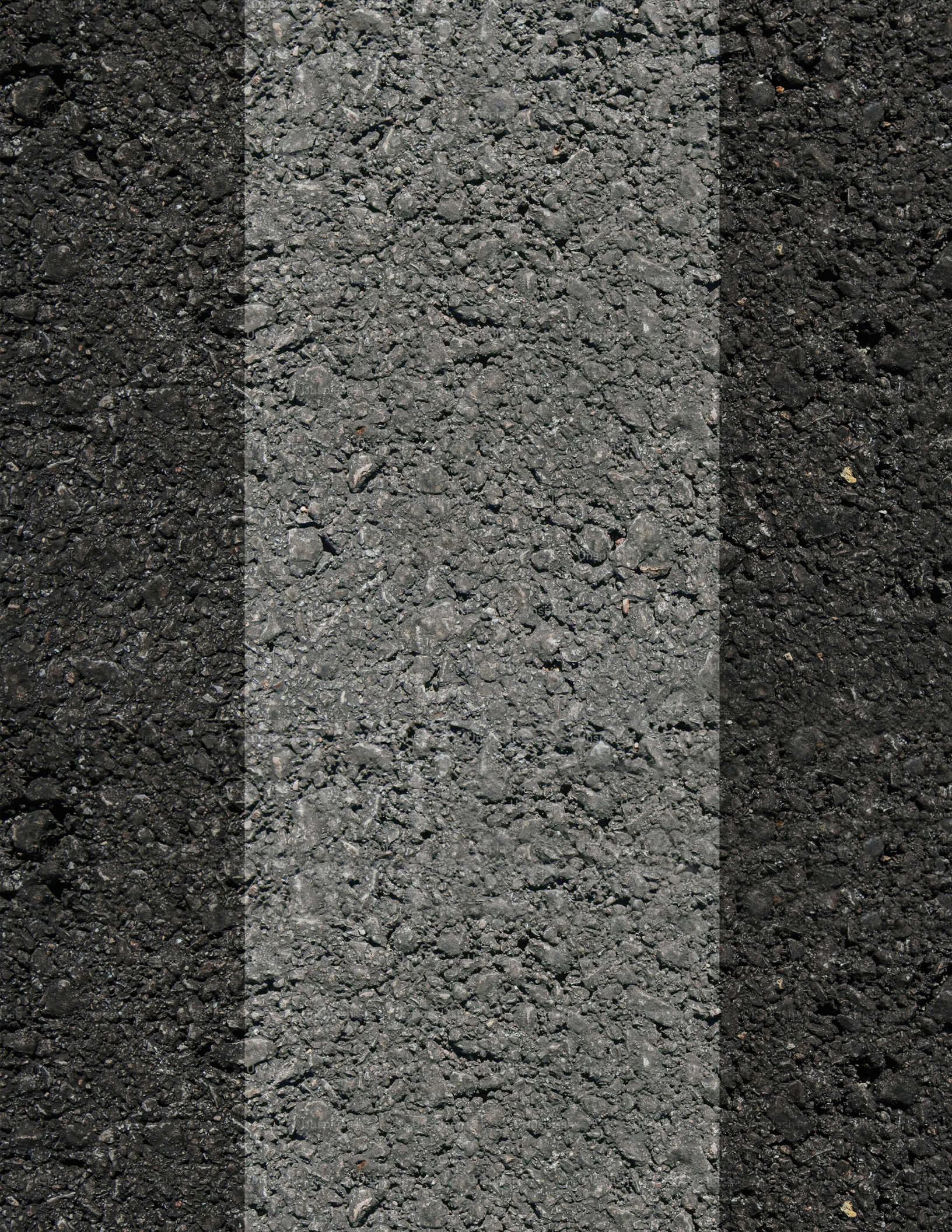
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Abstract

As society becomes increasingly more reliant on vehicular transportation, the demand for sufficient storage, or parking lots, continues to grow. To satisfy this demand, property owners and developers commonly budget to maximize space to meet the need for parking during peak rush times. This results in a sweeping stretch of impervious paving, often with many spots left empty. The areas that may come to mind are parking areas for shopping malls and stadiums that are frequently never filled or sit vacant half of the year. The effects of these spaces are significantly damaging to the surrounding environment as they can cause high volumes of runoff and degrade the water quality that is directed downstream. However, these environmental impacts can be reduced through implementing more green infrastructure. Gray infrastructure has historically been more commonly used in directing stormwater using its structural network to quickly move water toward nearby water bodies. Alternatively, green infrastructure is a system that manages stormwater by imitating the natural water cycle. This study aims to explore the different types of green infrastructure, and how they can be implemented in parking lots to best mitigate their environmental impacts. Research into successful existing systems, stormwater runoff quality testing, and precedent studies will all inform a projective design to address stormwater management around Bill Snyder Stadium and Chester E. Peters Recreation Complex at Kansas State University.

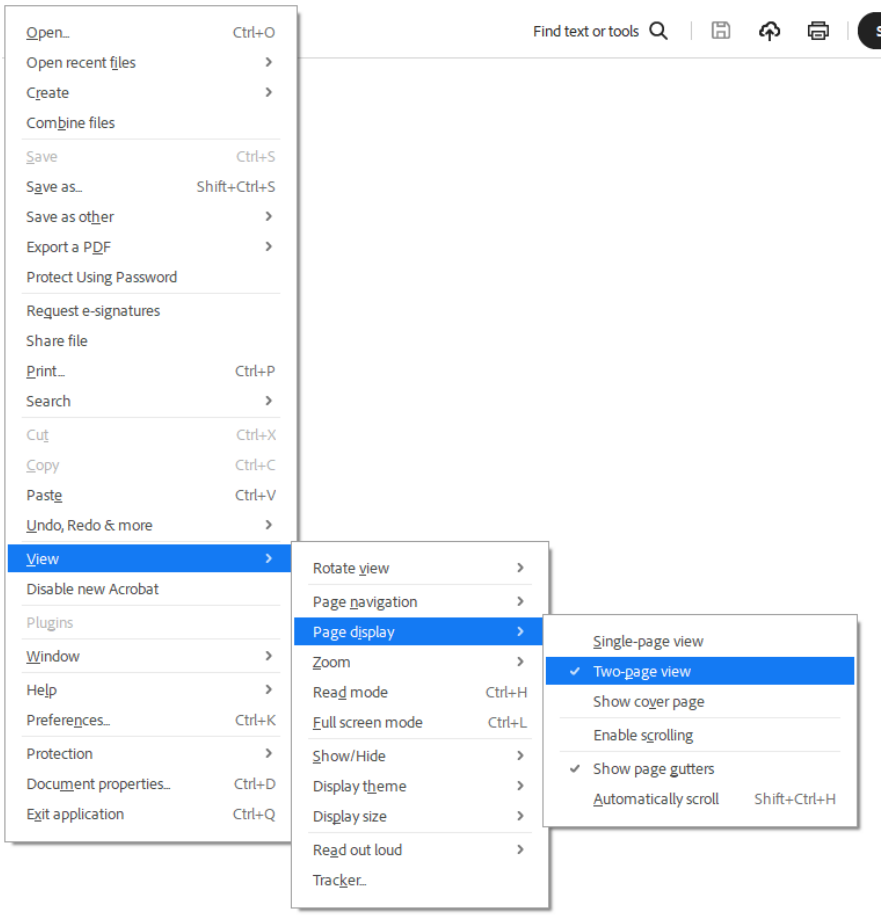




Greening Parking Lots to Decrease Stormwater Runoff and Improve Water Quality

Natalie Kerner | Spring 2025

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Greening Parking Lots to Decrease Stormwater Runoff and Improve Water Quality

A report 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 & Design
Kansas State University

Master's Project Committee:
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ABSTRACT

As society becomes increasingly more reliant on vehicular transportation, the demand for sufficient storage, or parking lots, continues to grow. To satisfy this demand, property owners and developers commonly budget to maximize space to meet the need for parking during peak rush times. This results in a sweeping stretch of impervious paving, often with many spots left empty. The areas that may come to mind are parking areas for shopping malls and stadiums that are frequently never filled or sit vacant half of the year. The effects of these spaces are significantly damaging to the surrounding environment as they can cause high volumes of runoff and degrade the water quality that is directed downstream. However, these environmental impacts can be reduced through implementing more green infrastructure. Gray infrastructure has historically been more commonly used in directing stormwater using its structural network to quickly move water toward nearby water bodies. Alternatively, green infrastructure is a system that manages stormwater by imitating the natural water cycle. This study aims to explore the different types of green infrastructure, and how they can be implemented in parking lots to best mitigate their environmental impacts. Research into successful existing systems, stormwater runoff quality testing, and precedent studies informs a projective design to address stormwater management around Bill Snyder Stadium and Chester E. Peters Recreation Complex at Kansas State University.

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01 INTRODUCTION



Figure 1.2—Drainage outlet between parking lot and Chester E Peter's Recreation Complex. 2024. Photograph by Natalie Kerner. Manhattan, KS.

STATEMENT OF PROBLEM

Despite being one of "the most commonly regularly used public outdoor open space," (Ben-Joseph 2012, p. 4), the parking lot is often an afterthought regarding design and budget. Hundreds of millions of Americans use it daily to get to their desired destination. With significant events such as football games hosting thousands of people and massive buildings serving multiple businesses, the demand for parking in these situations is high to accommodate the peak flow/times of fans, workers, and customers. However, what about when there is no game or when workers and customers are at home in the evening? This results in a desolate void of space, large areas of asphalt devoid of greenery, absent of any form of life. Parking lots are becoming more prevalent as society becomes more automobile-dependent, creating higher social isolation, urban sprawl, and prioritization of vehicular infrastructure over pedestrian and public transit.

Not only do very large parking lots cause social reverberations, these mostly impermeable warm-season heat islands also negatively impact the environment. The volume of stormwater runoff from these long stretches of paved, impervious surface overwhelms the outdated gray infrastructure that was not built to transport these higher amounts of water. Even if flooding does not occur, there are pollutants from the vehicles and other sources left on the asphalt surface that contaminate the water. This water can then pollute downstream bodies of water, damaging the local ecology. To adequately address the issue of something many people use every day, it is critical to learn and understand how they came about. Parking's origins traces back farther than one may think, long before the invention of the first automobile.

IMPORTANCE

The environmental impact of parking lots is a pressing issue as automobile dependency is present now more than ever. With the efficiency and convenience of driving and parking, the construction of parking lots will likely continue to grow. Recent studies have found "that 500 million surface parking spaces exist in the United States alone—a number that increases daily" (Ben-Joseph 2012, p. 13). The associated effects will only worsen as climate change causes more frequent and intense storms and heat waves. This dilemma is critical in landscape architecture and one that designers, engineers, ecologists, and many other professions can collaborate to create solutions.

PURPOSE

Currently, there are little to no green infrastructure interventions on the surface parking lots at Kansas State University. This results in heavier flooding and degraded water quality that pollutes connected surface waters. With surface parking lots lasting up to 40 years (Rehan 2016, pg 30), there is an opportunity and a need for better, eco-centric design. There are various types of green infrastructure that can be implemented depending on the kind of treatment goals, in addition to space and budget limitations.

RESEARCH QUESTION

How can green infrastructure be implemented on the large surface parking lots at Bill Snyder Stadium to mitigate stormwater runoff and improve water quality?



Figure 1.3—Flooded storm sewer inlet on Kansas State University campus parking lot. 2024. Photograph by Natalie Kerner. Manhattan, KS.

GLOSSARY

Best Management Practice (BMP): “a practice, or combination of practices, that is determined to be an effective and practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals.” (North Carolina Forest Service 2017, "Defining BMPs" section)

Green infrastructure: “the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters.” (US EPA 2024a, " 2019 Clean Water Act..." section)

Groundwater recharge: “Hydrologic process where water moves down (infiltrates) from the ground surface or the bottom of a waterway into an underlying aquifer. Recharge can occur naturally via infiltration of surface water and precipitation through rivers, streams, lakes, wetlands, and open space, or through a more intentional manner by diverting and conveying water to engineered infiltration ponds, spreading basins, flooding of agricultural lands, and injection wells.” (California Department of Water Sources 2024, para. 4).

Nutrients: “water-soluble nitrates and phosphates that cause excessive growth of algae and other water plants, which deplete the water's oxygen supply. This kills fish and, when found in drinking water, can kill young children.” (Lenntech 2024, para. 5)

Soluble pollutants: “acids, salts and toxic metals. Large quantities of these compounds will make water unfit to drink and will cause the death of aquatic life.” (Lenntech 2024, para. 4)

Total suspended solids (TSS): “refers to waterborne particles that exceed 2 microns in size. Any particle that is smaller than 2 microns, on the other hand, is considered a total dissolved solid (TDS). The majority of total suspended solids comprise of inorganic materials; however, algae and bacteria may also be considered TSS.” (Campbell 2021, "What are Total Suspended Soilds" section)

Urban heat island effect: “urbanized areas that experience higher temperatures than outlying areas. Structures such as buildings, roads, and other infrastructure absorb and re-emit the sun’s heat more than natural landscapes such as forests and water bodies. Urban areas, where these structures are highly concentrated and greenery is limited, become “islands” of higher temperatures relative to outlying areas.” (US EPA 2024c, para. 1)

02 BACKGROUND



Figure 1.4— Ford Motor Co. Rouge Plant Parking Lot, 1953. (Jewell 2018) Used Under Creative Commons Attribution Non-commercial.

Parking Background & Use

Controlled parked vehicle regulations date back as far as 2,000 years ago to the Roman Empire: "...vehicles such as chariots and large carts were prohibited from entering the commercial district of large cities during certain hours because of congestion. Special zones (parks) were designated for storing these vehicles." (Ben-Joseph 2012, p. 53).

Originally, Roman road construction consisted of flat and crushed stone, gravel, and coarse sand mixed with lime. This was utilized around Europe until the late 18th century. The 1700s significantly improved the design of roads, incorporating crowned streets with curbs that distinguished pedestrian vs. carriageway paths (Ben-Joseph 2012, p. 59). The unpaved streets of the 1800s paired with the lack of sanitation and drainage systems highlighted the need for cleaner and quicker transportation methods. After the invention of the automobile in the late 1880s, more designs were created and more factories to produce them.

By the 1940s, 23 million vehicles were registered across the United States. During the 20th century, as suburbia grew, central business districts declined and were replaced with surface lots to entice suburbanites back to city centers. Property owners did not consider investing in their parking lots because they expected the use to change. The result was numerous under-designed lots that lasted decades. These poorly maintained spaces set the precedent for future lots to be constructed (Ben-Joseph 2012, p. 73-76).

As surface lots continued to be constructed, and their permanence recognized, zoning, regulations, and design for these spaces were established. It was not until as recently as the 2000s that green parking techniques were embraced and encouraged by the Environmental Protection Agency (EPA) (Ben-Joseph 2012, p. 93).

Environmental Impact

As surface parking lots evolved, their functional improvements impacted the environment in profound ways. The combination of impervious surface and gray infrastructure can cause or contribute to the high volume of polluted stormwater runoff, flooding, habitat disruption, and urban heat island effects. According to the EPA, it is estimated that almost 25 million acres of impervious surface cover the continental United States (US) and that approximately 70 million acres of land will be newly developed in the US by 2025 (US EPA 2008a, p. 44).

Flooding

With this sea of paved space, more gray infrastructure has typically been implemented with it. Most gray infrastructure has been built with the intention of quickly and efficiently carrying water to receiving water bodies through gutters, drains, and pipes (US EPA 2008a, p. 2). These systems often get overwhelmed with the volume of runoff from impervious surfaces and sometimes need costly repairs and upgrades. When gray infrastructure fails, flooding can occur, and surrounding infrastructure can become degraded. Also, with higher velocity and volume of runoff, aquatic ecosystems and wildlife can be damaged and disrupted by diminishing light transmission, reducing plant growth, and altering food supplies.



Water Quality

As impervious surfaces expand and issues with gray infrastructure worsen, obstacles extend far beyond just capacity—with degraded water quality a major issue.

A study on the Clemson University campus collected stormwater runoff from a campus parking lot (McQueen et al 2010, "2.1 Sampling Location" section). To discern if the poor water quality affected local aquatic wildlife, researchers measured the toxicity by observing the sensitivity of species of water flea, *Ceriodaphnia dubia Richard* and fathead minnow, *Pimephales promelas Rafinesque* (McQueen et al 2010). Final results found that “this campus parking lot stormwater (CPLSW) include: pH, alkalinity, total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), oil and grease (O/G), aluminum (Al), cadmium (Cd), copper (Cu), iron (Fe), nickel (Ni), lead (Pb), and zinc (Zn)” (McQueen et al 2010).

The study also found that the fish species were more sensitive to the polluted runoff water than the species of water flea. It was found that the survival of the minnow species decreased by 92% and the survival of the water flea species decreased by 15% of the samples (McQueen et al 2010, " 3.3. Toxicity measurements of campus parking lot stormwater" section). The samples collected from the first part of the storm event were typically more toxic than those collected later. Overall the toxicity of the species ranged from “no detectable toxicity to complete mortality” (McQueen et al 2010, "4. Discussion" section).



Figure 1.5—Mallard in polluted water. (rjp 2007) Used Under Creative Commons Attribution Non-commercial.

Groundwater Recharge

In addition to being a threat to aquatic life, the growth of parking lot impervious surfaces also inhibits groundwater recharge. As an integral part of a watershed's natural hydrological cycle, groundwater recharge is:

> "an important hydrologic process where water moves down (infiltrates) from the ground surface or the bottom of a waterway into an underlying aquifer. Recharge can occur naturally via infiltration of surface water and precipitation through rivers, streams, lakes, wetlands, and open space, or through a more intentional manner by diverting and conveying water to engineered infiltration ponds, spreading basins, flooding of agricultural lands, and injection wells." (California Department of Water Sources 2024, para. 4).

Some of the associated impacts of obstructing groundwater recharge are "water tables are lowered, reducing streamflow during dry periods, depleting water supplies, and exacerbating the negative impacts of droughts" (US EPA 2008a, 3). These effects are especially concerning when "groundwater accounts for approximately 97% of fresh water on Earth" (Healy 2010, p. 1).

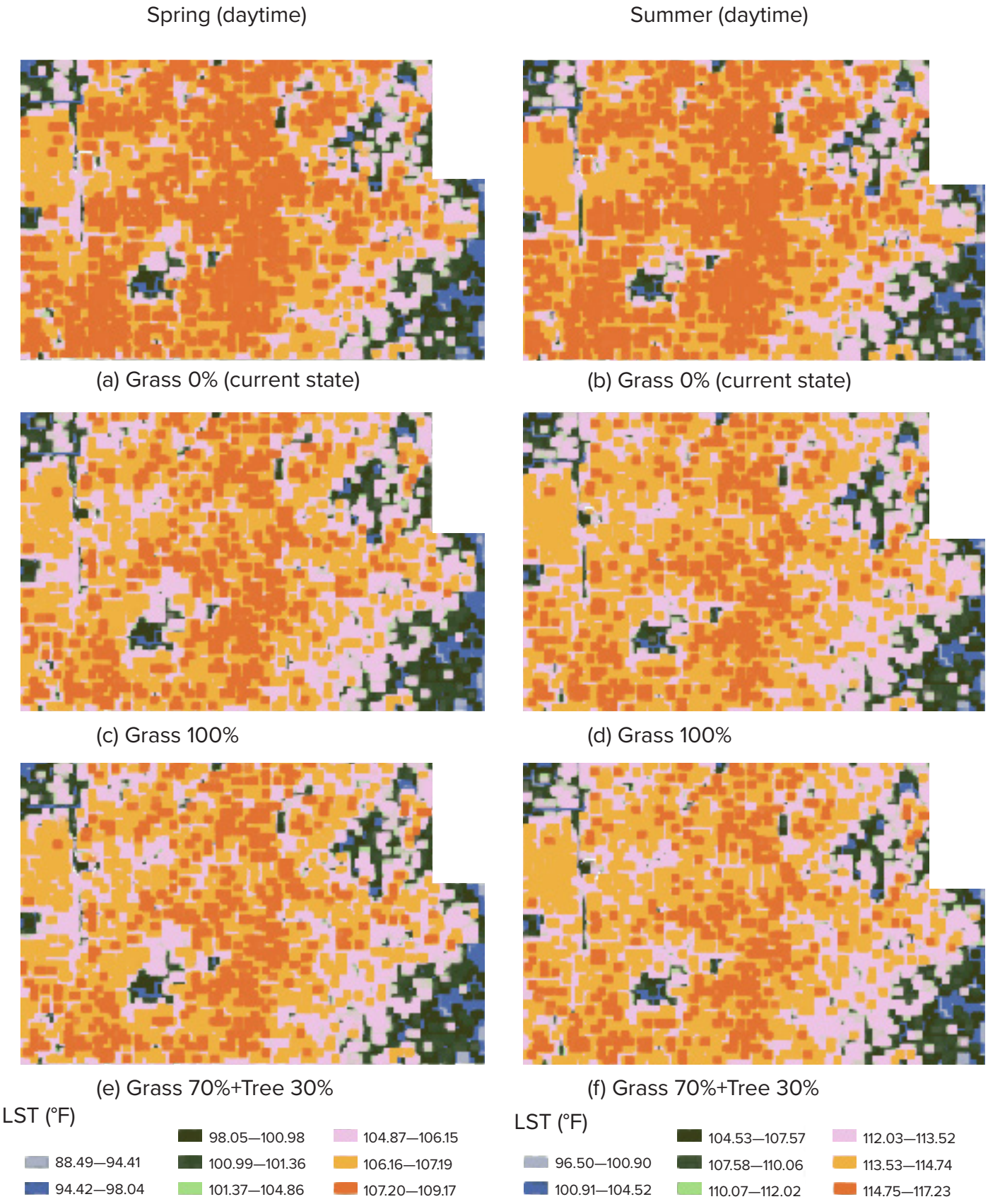


Figure 1.6.—Diagram in Spatial distribution of simulated land surface temperature (LST) in spring (left figures) and summer (right figures) for the green parking lot scenarios. Kerner, Natalie. Adapted from Map graphic by Onishi et al. 2010. Reproduction allowed for educational or non-profit purposes only.

Urban Heat Island Effect

The impact of impervious surfaces extends beyond hydrological concerns, surface parking lots also heavily contribute to the urban heat island effect. The urban heat island effect can cause temperatures in cities to be 35°—41° Fahrenheit higher than those in surrounding areas (Onishi et al 2010, para. 1). The higher amounts of impervious surfaces and lower amounts of natural land cover cause this effect.

A study was conducted in a city in Japan to test the change in land surface temperature after replacing parking lots with grasses and trees. In this study, “planting vegetation means covering (i.e., replacing) surfaces of the parking lots with grass and/or trees” (Onishi et al 2010, "Results" section). Two scenarios were simulated where scenario 1 had “planting grass from 10 to 100% at intervals of 10%” (Onishi et al 2010, "Results" section) and scenario 2 had “planting 30% trees and 70% grass in parking lots” (Onishi et al 2010, "Results" section). The study found that the land surface temperature was lowest at vegetated areas and highest at commerce and residential areas, where many parking lots are located.

Not only can surface parking lots heat up the surrounding areas, but also the temperature of the stormwater runoff that goes downstream. This, in turn, can increase the temperature of the water bodies downstream, affecting plant growth and wildlife.



Figure 1.7—Community College Rain Garden Pottstown II. (Montgomery County Planning Commission's photostream 2012). Used Under Creative Commons Attribution Non-commercial.



Green Infrastructure Solutions

While all of these effects of surface parking lots are cause for concern, there are solutions to mitigate these effects, the most widely implemented being green infrastructure. According to the EPA, green infrastructure employs “plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters” (US EPA 2024a, " 2019 Clean Water Act..." section).

There are many different types of green infrastructure with different benefits and designs including bioswales, permeable paving, detention and retention basins, and more. The United States Environmental Protection Agency established a ‘Green Parking Lot Resource Guide’ (2008a) to spotlight planning and design concepts, environmental benefits, and cost-effectiveness for green parking lots. Prior to this guide, information on green parking lots was dispersed across disciplines. This manual provides an overview of green parking lots. The following section will briefly overview commonly used green infrastructure techniques.

BIOSWALE

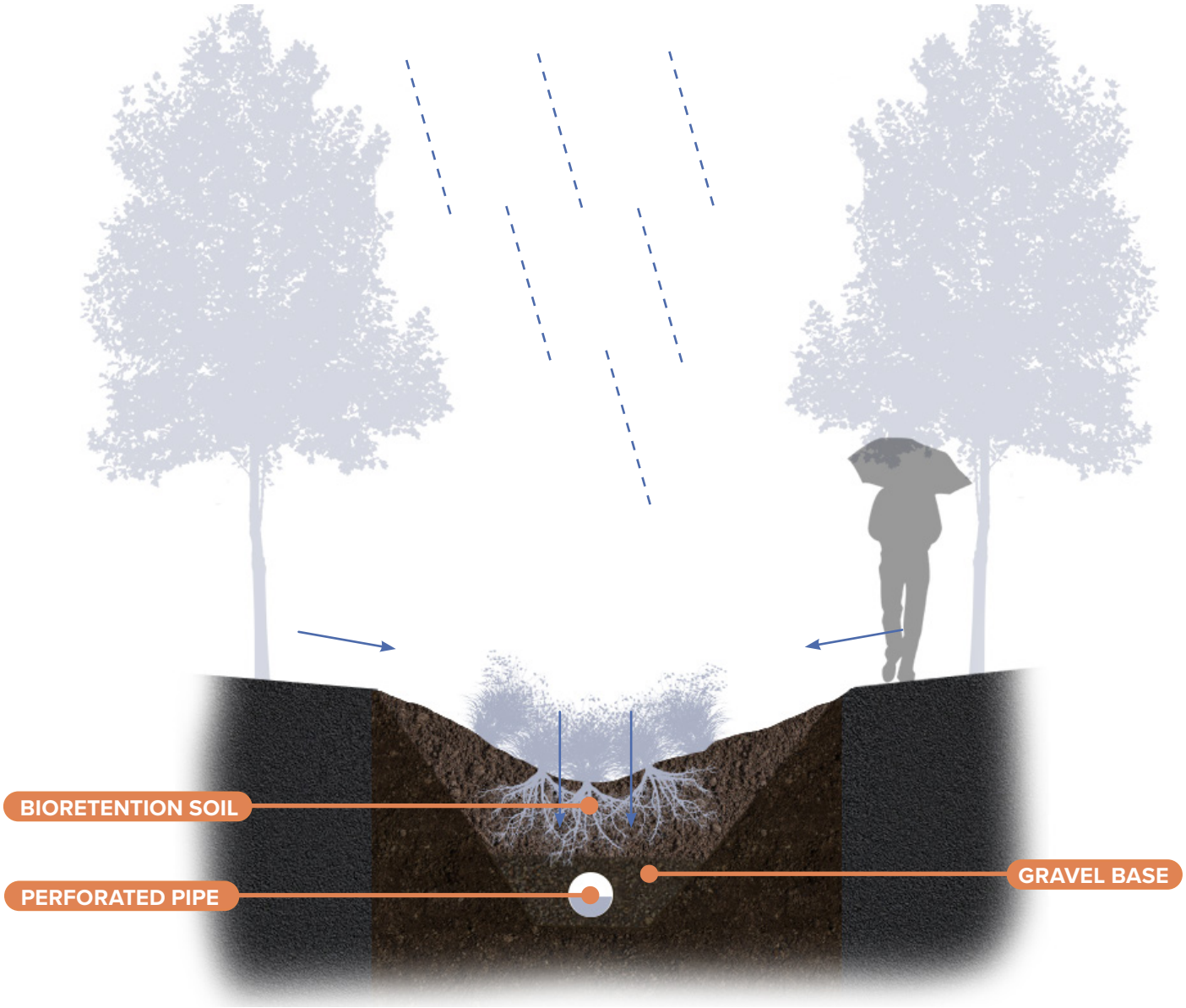


Figure 1.8—Bioswale diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

One type of green infrastructure is a **swale, or bioswale**—"open channels or depressions with dense vegetation used to transport, decelerate, and treat runoff" (US EPA 2008a, p. 15). Bioswales require more area than 'V' or 'U'-shaped ditches or buried stormwater pipes, but are very effective at slowing and infiltrating runoff. They are typically not designed to hold water, but instead slowly direct water into a larger bioretention or detention area. Bioswales can filter some of the toxins out of stormwater runoff before it reaches the basin. This type of green infrastructure can be a grassed channel, dry swale, or wet swale.

Grassed channels are often used to decelerate water transportation through soil-protecting its grass vegetation, one or more check dams, and a pretreatment forebay. Dry swales are designed to hold water temporarily, typically including permeable material and an underdrain system. In contrast, wet swales usually do not include a filter bed or underdrain system and commonly contain wetland vegetation (Massachusetts Department of Environmental Protection 2008, p. 79). Depending on the type of swale, the maintenance may vary from annual or as necessary treatment (removing sediment) or monthly treatment (such as mowing) (Massachusetts DEP 2008, p. 78).

SPACE REQUIREMENT:	• Dependent on required water quality volume • Bottom width 2-8ft
DESIGNED FOR:	• Treat required water quality volume and convey runoff from 10-year storm event
EFFECTIVENESS:	• 70% TSS removal
MAINTENANCE:	• Twice a year: Inspect vegetation and slopes are not eroding • At least once a year: Remove sediment and debris • As necessary: re-seeding
COST:	• Average $6.60 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Can be used to replace more expensive curb and gutter systems • Water quality and quantity control , reducing driving hazards
LIMITATIONS:	• Can be higher maintenance • Typically treat smaller areas

Table 1. Bioswale General Information. All information in table from Massachusetts Department of Environmental Protection (2008, p. 77-82) unless listed otherwise

STORMWATER MANAGEMENT GOALS

INFILTRATION

WATER QUALITY

WATER STORAGE

BIORETENTION AREA / RAIN GARDEN

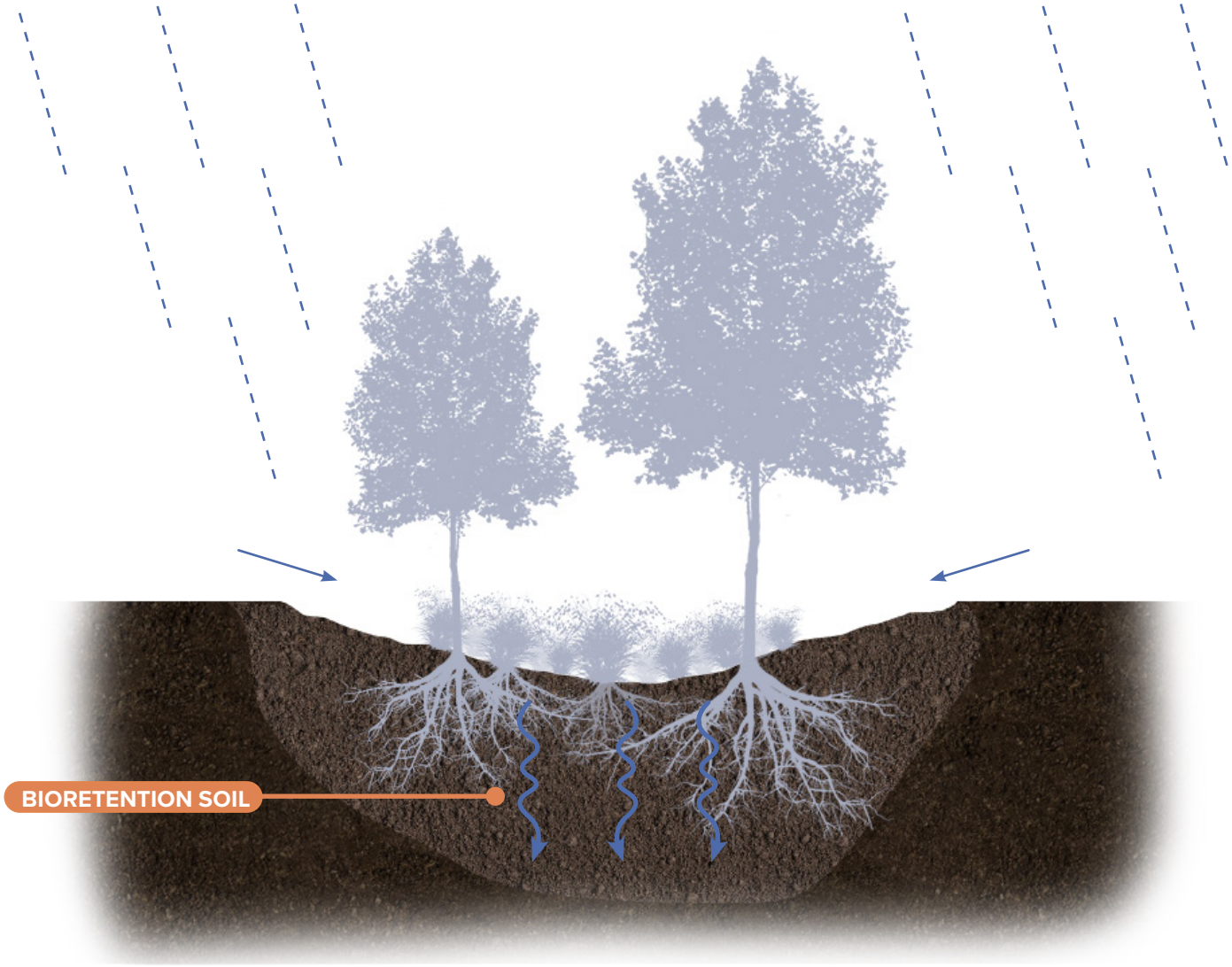


Figure 1.9—Bioretention area diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

Another type of green infrastructure is **bioretention areas**, or **rain gardens**. "Bioretention areas include shallow ponding areas with riparian edges and are often used in the parking lot islands" (US EPA 2008a, p. 15). Rain gardens also encourage groundwater recharge because they allow stormwater runoff to collect and slowly seep into the ground. Rain gardens are ideal if there is limited space for green infrastructure design in parking lots as they are more concentrated areas.

Apart from the environmental benefits, rain gardens can also add aesthetic value to the surrounding area and provide a habitat for wildlife and insects. These systems are most effective at removing total suspended solids (TSS) with pretreatment such as vegetated filter strips (Massachusetts Department of Environmental Protection 2008, p. 25). Maintenance can range from inspecting and removing trash monthly to pruning and removing dead vegetation annually (Massachusetts DEP 2008, p. 24).

SPACE REQUIREMENT:	• Size of bioretention area should be 5%-7% of the area draining to it • Soil media depth of 2-4ft
DESIGNED FOR:	• Treating stormwater before infiltration
EFFECTIVENESS:	• 80%-90% of TSS removal • Can provide groundwater recharge
MAINTENANCE:	• Mowing 2-12 times per year • Monthly: Inspect/Remove trash • Annually: Fertilize, remove dead vegetation, prune
COST:	• Average $33.20 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Depth of soil depends on proposed vegetation • Can provide shade and absorb noise
LIMITATIONS:	• Requires considerable landscaping/maintenance • Not suitable for larger drainage areas

Table 2. Bioretention Area/Rain Garden General Information. All information in table from Massachusetts Department of Environmental Protection (2008, p. 23-28) unless listed otherwise

STORMWATER MANAGEMENT GOALS

INFILTRATION

WATER QUALITY

WATER STORAGE

DRY DETENTION BASIN

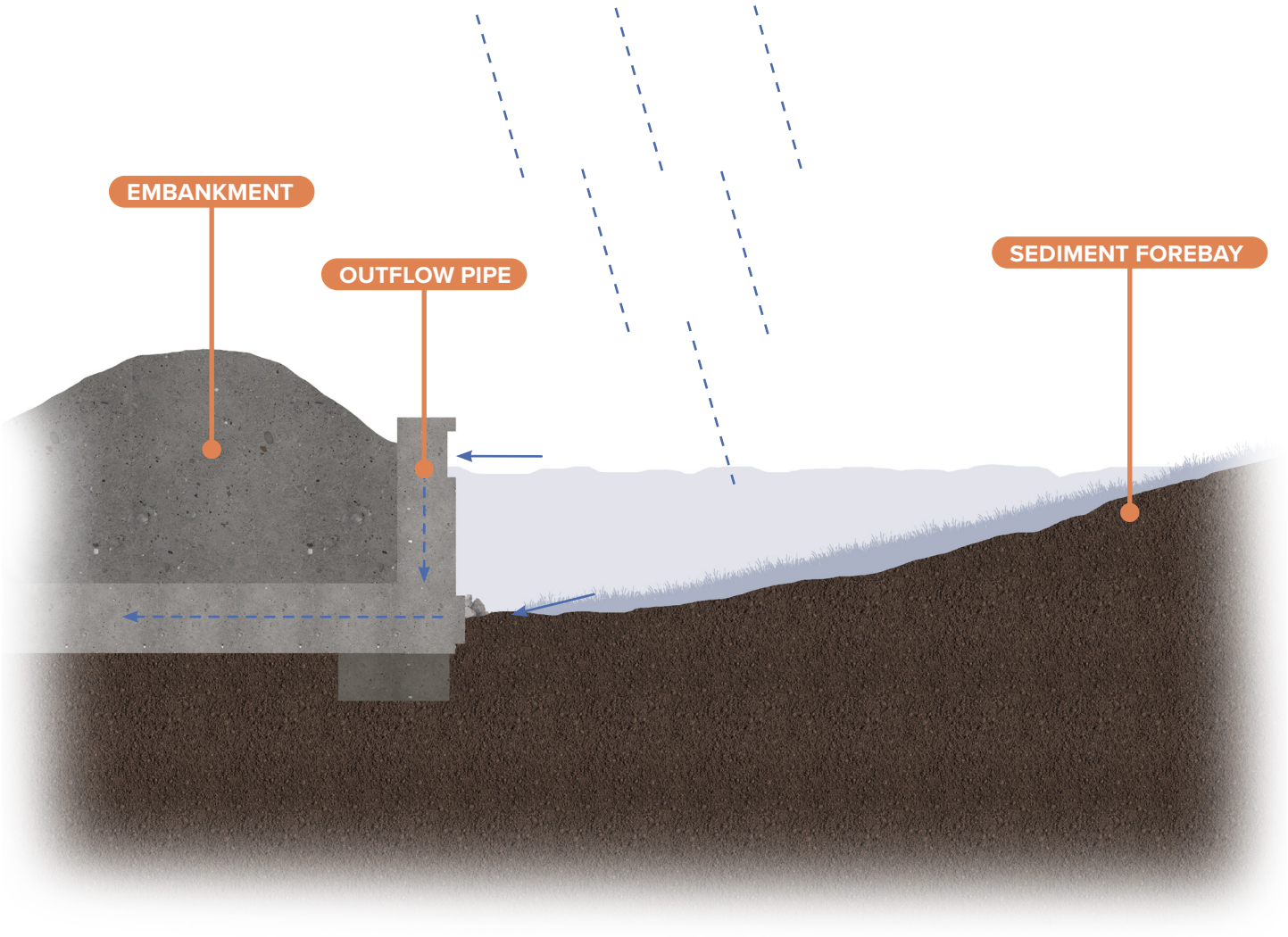


Figure 1.10—Dry detention basin diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

Similarly, a **dry detention basin** is a "vegetated basin with controlled outlets, designed to detain runoff (lowering flows and reducing velocity) for a short amount of time (e.g. 24 hours or less), partially removing pollutants before the water is discharged" (US EPA 2008a, p. 15). Per its name, dry detention basins typically stay dry between storm events. Extended dry detention basins are typically not applicable to watershed areas of less than ten acres (Massachusetts Department of Environmental Protection 2008, p. 51).

These basins are most effective at removing absorber pollutants over soluble pollutants (Massachusetts Department of Environmental Protection 2008, p. 49). Maintenance may include removing debris, mowing, and examining outlets for clogging at least twice a year. Dry detention basins are the least costly BMP that addresses stormwater quality and quantity (Massachusetts DEP 2008, p. 49).

SPACE REQUIREMENT:	• Large land area requirement—dependent on storage capacity and maximum rate of runoff released from basin
DESIGNED FOR:	• Temporary stormwater detention • Allows controlled release from downstream • Empty out completely in less than 24 hours
EFFECTIVENESS:	• No TSS removal • Provides no groundwater recharge
MAINTENANCE:	• At least once a year: Operation inspection • At least twice a year: Mowing and sediment/trash/debris removal from sediment forebay • At least once every 10 years: Remove polluted sediment from basin
COST:	• Average $59.83 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Controls peak runoff flows for 2-year and 10-year storm events • Low costs
LIMITATIONS:	• Poor pollutant removal & groundwater recharge • Large space requirement • Susceptible to clogging

Table 3. Dry Detention Basin General Information. All information in table from Massachusetts Department of Environmental Protection (2008, p. 108-111) unless listed otherwise

STORMWATER MANAGEMENT GOALS

- INFILTRATION
- WATER QUALITY
- WATER STORAGE

WET RETENTION BASIN

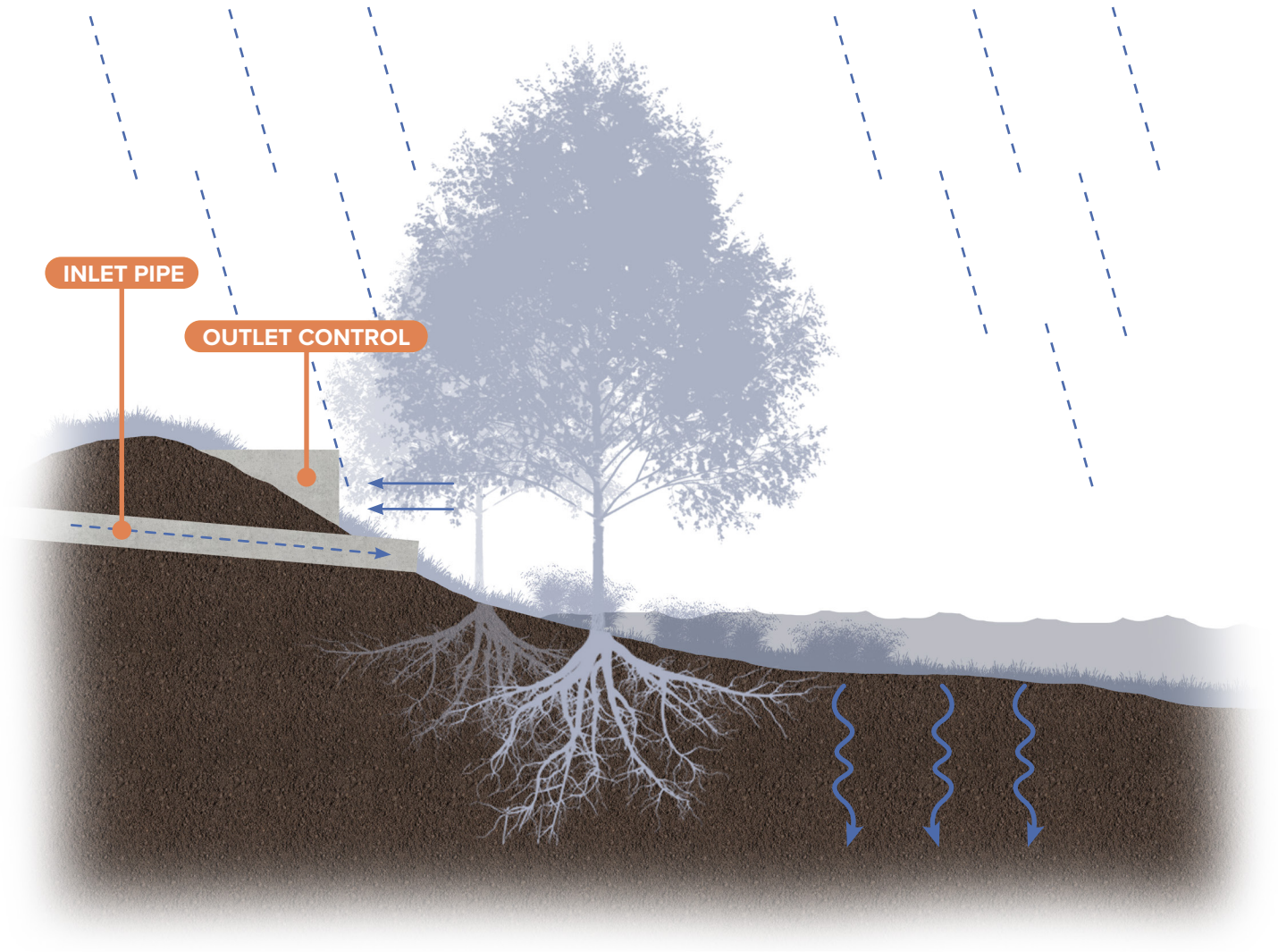


Figure 1.11—Wet retention basin diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

Wet retention basins are "designed to capture, filter, store, and infiltrate stormwater, and have storage capacity adequate for flood volumes of water" (US EPA 2008a, p. 16). These basins successfully control water because they capture and hold a permanent pool of water (US EPA 2008a, p. 16).

Like rain gardens, wet retention basins go beyond environmental advantages in beautifying the surrounding area and establishing a habitat for wildlife and insects. They most effectively remove solid and soluble pollutants, TSS, nutrients, and metals. Wet retention basins must be tended to at least once or twice a year by mowing to ensure they function as intended (Massachusetts Department of Environmental Protection 2008, p. 64).

SPACE REQUIREMENT:	• Minimum 20 acre drainage area • 3-6 ft pool depth • 0.25 acre minimum surface area
DESIGNED FOR:	• Uses permanent pool of water to allow sediments to settle and remove soluble pollutants
EFFECTIVENESS:	• 80% TSS removal with sediment forebay • No groundwater recharge
MAINTENANCE:	• Annually: Operation inspection • Bianually: Mowing, removing sediment/trash/ debris from sediment forebay • Every 10 years: Remove sediment from basin
COST:	• Average $22.08 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Capable of removing TSS and soluble pollutants, nutrients, and metals • Sediment removal required less often than other BMPs
LIMITATIONS:	• Infiltration and groundwater recharge is minimal • Potentially high maintenance requirements

Table 4. Wet Retention Basin General Information. All information in table from Massachusetts Department of Environmental Protection (2008, p. 63-67) unless listed otherwise

STORMWATER MANAGEMENT GOALS

- INFILTRATION
- WATER QUALITY
- WATER STORAGE

INFILTRATION SYSTEMS

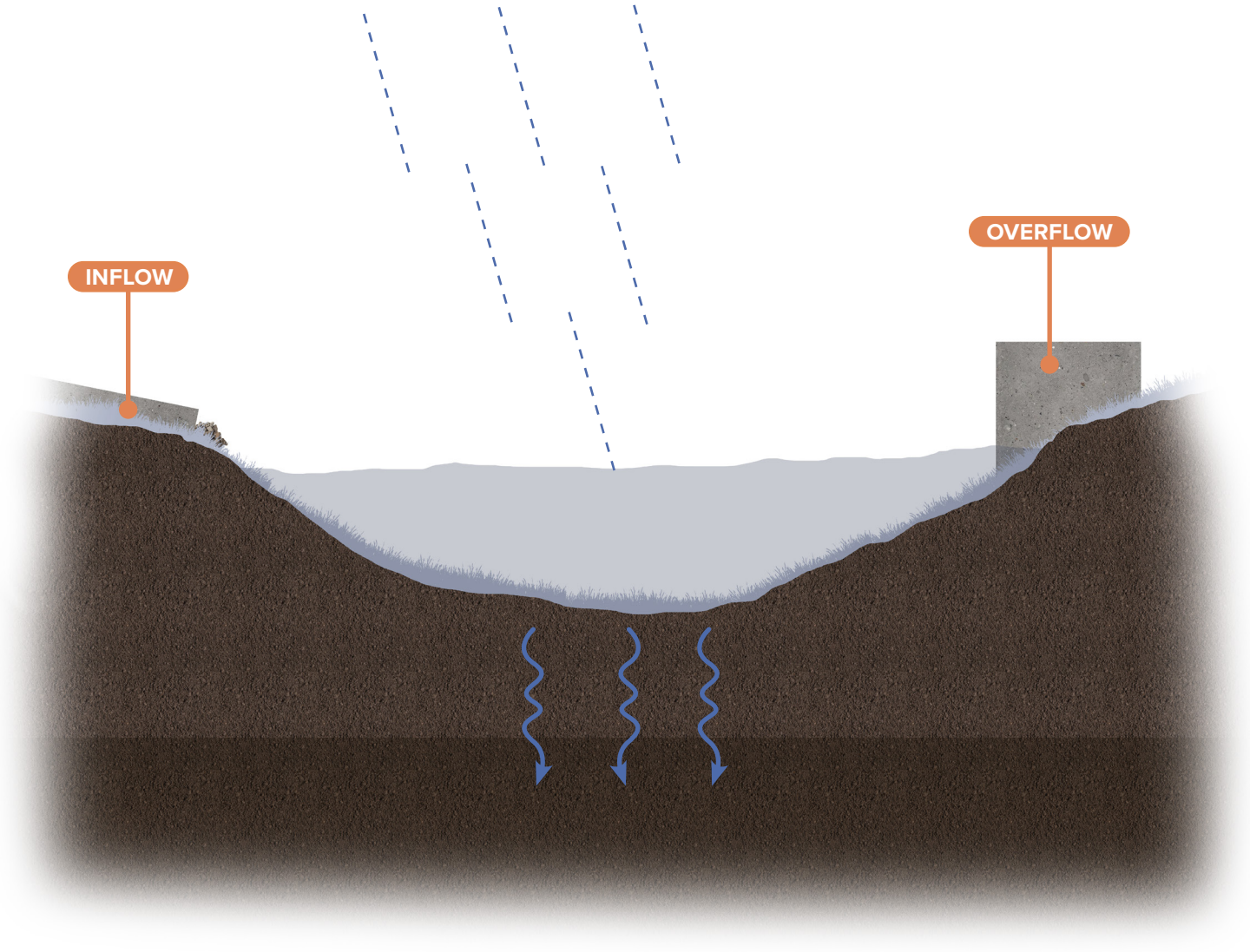


Figure 1.12—Infiltration systems diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

Infiltration systems are "designed to capture and retain stormwater runoff, allowing water to gradually infiltrate into the ground over a period of hours or days, depending on the design" (US EPA 2008a, p. 16). An **infiltration basin** is a depression in the ground that typically stretches across an expansive area. These basins are typically built to work jointly with other green infrastructure techniques such as permeable paving with underground gravel storage areas, bioretention areas, filter strips or swales, so the stormwater is directed into the infiltration basins. According to the US EPA (2008a, p. 16), infiltration trenches are "shallow excavated ditches lined with filter strips and filled with stone to form a subsurface basin, where water is stored until it infiltrates into the soil." These infiltration systems significantly decreased runoff in addition to promoting groundwater recharge by allowing the water to seep down to the aquifers. Infiltration basins and trenches are also effective for pollutant removal when paired with other BMPs, such as swales. They are most successful at filtering out TSS and many other contaminants, but not as effective in removing particulate pollutants. Maintenance requirements may include mowing twice a year and examining to ensure they are working as designed twice a year (Massachusetts Department of Environmental Protection 2008, p. 87).

SPACE REQUIREMENT:	• Dependent on site/existing conditions and context: minimum separation from seasonal high groundwater of at least 2 ft
DESIGNED FOR:	• Temporary stormwater storage that slowly exfiltrates through permeable soil
EFFECTIVENESS:	• 80% TSS removal rate with pretreatment • Provides groundwater recharge
MAINTENANCE:	• Twice a year: Preventative maintenance, inspection, and mowing • Every other month recommended or at least twice a year (ideally after every major storm event): inspect and clean pretreatment devices
COST:	• Average $9.48-$27.56 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Suitable parent soils should have infiltration rate of 0.17 inches per hour • Reduces local flooding • Preserves natural water balance
LIMITATIONS:	• Improper siting, poor pretreatment, design, and lack of maintenance can cause poor performance • Not suitable for high loads of sediment and pollutants

Table 5. Infiltration Systems General Information. All information in table from Massachusetts Department of Environmental Protection (2008, p. 86-92) unless listed otherwise

STORMWATER MANAGEMENT GOALS

INFILTRATION

WATER QUALITY

WATER STORAGE

CONSTRUCTED WETLANDS

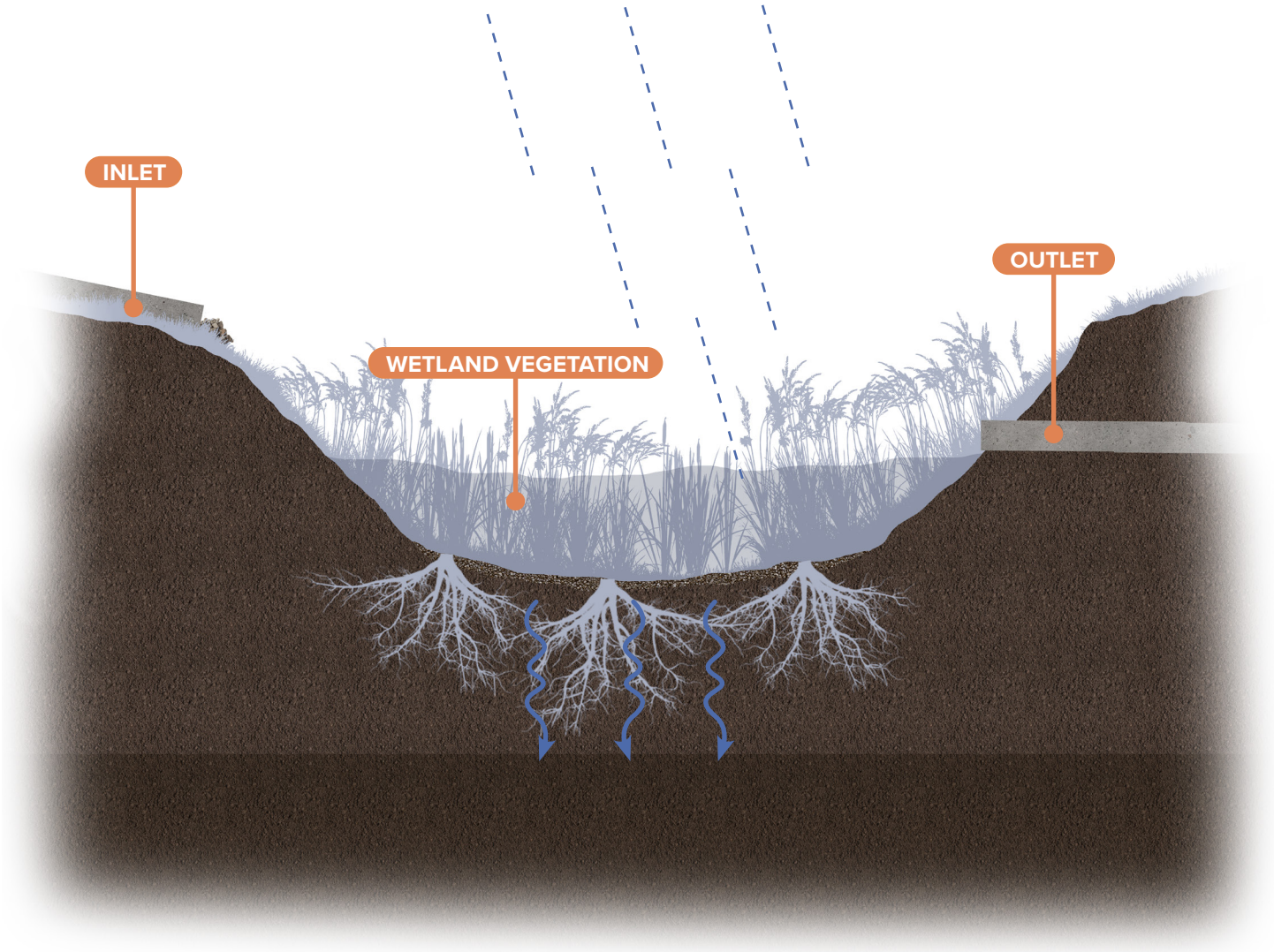


Figure 1.13—Constructed wetlands diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

A more intricate type of green infrastructure is **constructed wetlands**. These systems aim to capture, filter, and store stormwater (US EPA 2008a, p. 16). Constructed wetlands are built to mimic the natural water cycle at a smaller scale—complete with wetland vegetation and channels. These systems have many benefits—though the construction cost may be costly, the maintenance cost is relatively low. Once vegetation is established, constructed wetlands are highly effective at pollutant removal including oil and grease, total suspended solids, and phosphorous. These networks provide aesthetic value to surrounding areas, and act as a habitat for wildlife (Massachusetts Department of Environmental Protection 2008, p. 36). Constructed wetlands typically require a large amount of space, and are usually not suited for urban areas. The wetlands must be inspected a couple of times a year to ensure they function as designed and clean out sediment forebays (Massachusetts Department of Environmental Protection 2008, p. 37).

SPACE REQUIREMENT:	• Depth can range from 6" to 6' below normal pool elevation depending on water quality volume • Requires large contributing drainage areas—ten acres minimum • Pocket type wetlands for smaller drainage areas
DESIGNED FOR:	• Maximize removal of pollutants from stormwater runoff through wetland vegetation uptake, retention, and settling • Temporarily store runoff in shallow pools that support conditions suitable for growth of wetland plants
EFFECTIVENESS:	• 80% TSS removal with pretreatment • Higher removal efficiences than dry extended detention basins • One of the most effective treatment practices • Provides no groundwater recharge
MAINTENANCE:	• Twice a year first three years: Wetland inspection • Annually: Clean out forebays • Once every 10 years: Clean out sediment in basin/wetland systems
COST:	• Average $8.28 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Lower maintenance costs in most cases • Provides wildlife habitat • Enhances aesthetics
LIMITATIONS:	• Typically requires more land • Higher construction costs • Potentially higher maintenance

Table 6. Constructed Wetlands General Information. All information in table from Massachusetts Department of Environmental Protection (2008, p. 36-48) unless listed otherwise

STORMWATER MANAGEMENT GOALS

INFILTRATION

WATER QUALITY

WATER STORAGE

POROUS PAVEMENT

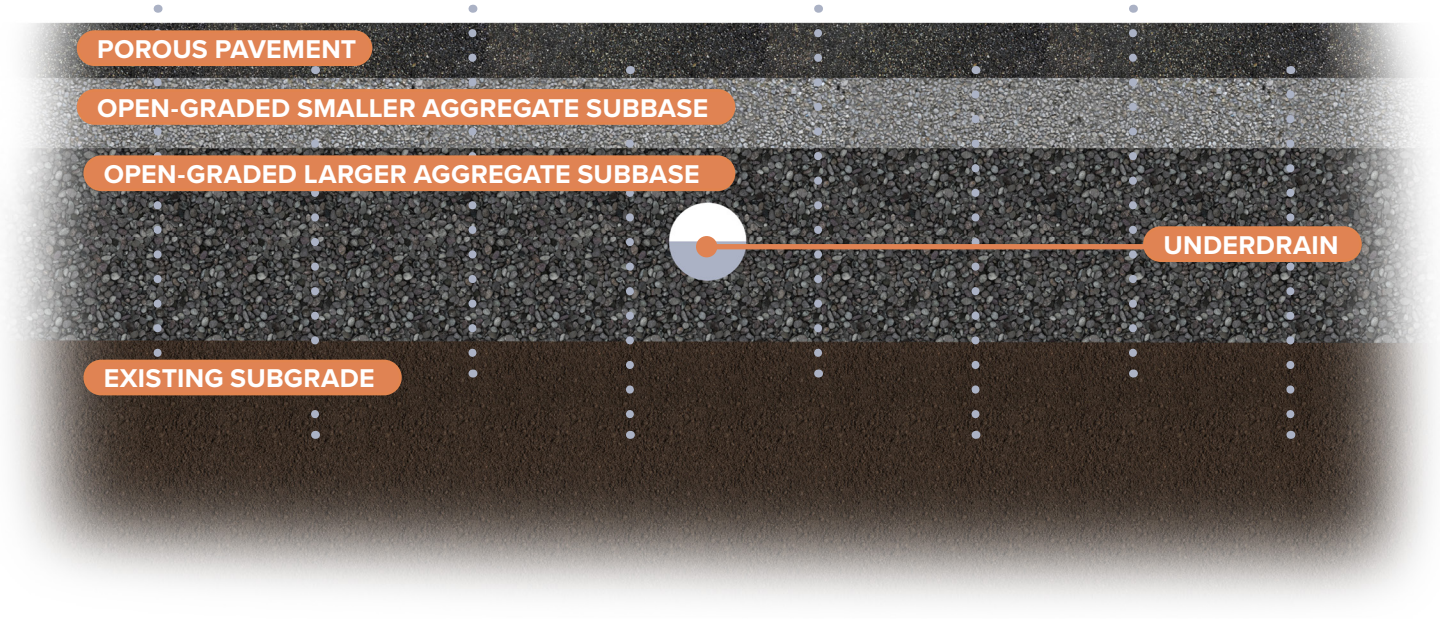


Figure 1.14—Porous pavement diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

Another method for mitigating adverse environmental impacts from impervious surfaces is alternative parking pavement materials such as porous pavement and alternative pavers. These alternatives allow the stormwater to infiltrate the pavement, reducing runoff volume. Permeable pavement is meant to treat smaller storm events ranging from 0.5—1.5 inches (US EPA 2008a, p. 24). However, a site must be designed with a proper ratio of infiltration area to impervious area with permeable soil (between 0.5 to 3 inches per hour). While ideal for pollutant removal and smaller storm events, alternative paving materials alone are not enough to combat extreme flooding (US EPA 2008a, p. 25).

Porous pavement is a "permeable pavement surface, often built with an underlying stone reservoir, which temporarily stores stormwater before it infiltrates into the underlying soil" (US EPA 2008a, p. 22). In conventional paving, there are usually finer aggregates that do not allow water to infiltrate. In porous paving, those finer aggregates are eliminated, and the larger aggregates are bonded with an asphalt or Portland cement binder, allowing water to infiltrate. Underneath the porous paving is an overflow control structure that ensures water does not overflow to the pavement level. Porous asphalt was developed in the 1970s by the Franklin Institute. It "consists of an open-grade coarse aggregate, bonded together by a typical asphalt cement in which fine aggregates have been reduced or eliminated, allowing water to move through the small voids created" (EPA 2008a, p. 23). The Florida Concrete Association developed pervious concrete, and similarly, it contains a mixture of Portland cement, uniform open-graded coarse aggregate, and water (US EPA 2008a, p. 23). However, pervious concrete can be more durable than porous asphalt, especially in hot weather conditions. According to the EPA (2008a, p. 23), it is "considered by experts to be the most effective and affordable technique for addressing stormwater management from development." porous pavement is typically applied in low to medium vehicular traffic areas.

SPACE REQUIREMENT:	• Surface area can vary, but depths are typically around 27 in. depth of varying aggregate materials and subbases before native soil
DESIGNED FOR:	• Replacing traditional pavement, allowing runoff to infiltrate directly into soil while receiving water quality treatment
EFFECTIVENESS:	• 80% TSS removal (0.5-1in water quality volume drain within 72 hrs) • Provides groundwater recharge
MAINTENANCE:	• As needed: Monitor drainage, clean using power washer and vacuum to prevent clogging, assess exfiltration • Annually: Surface inspection for deterioration, assess exfiltration
COST:	• Average $5.91 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Reduces stormwater runoff volume from paved surfaces • Can last decades if properly designed, installed, and maintained
LIMITATIONS:	• Prone to clogging • Frequent maintenance required

Table 7. Porous Pavement General Information. All information in table from Massachusetts Department of Environmental Protection (2008, p. 118-121) unless listed otherwise

STORMWATER MANAGEMENT GOALS

- INFILTRATION
- WATER QUALITY
- WATER STORAGE

ALTERNATIVE / PERMEABLE PAVERS

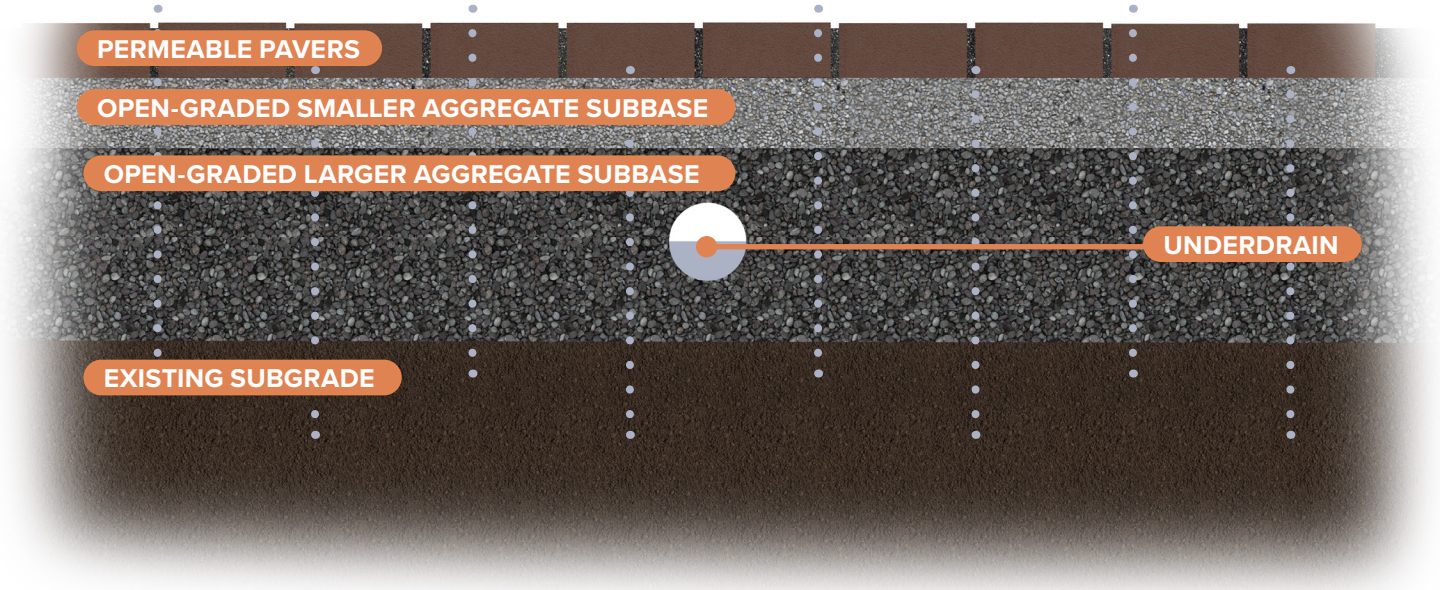


Figure 1.15—Permeable pavers diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.

Another alternative to parking pavement is **alternative pavers**. These are "interlocking concrete blocks [with permeable openings]or synthetic fibrous grids with open areas filled with grass, sand, or gravel" (US EPA 2008a, p. 23). The gaps between the pavers allow stormwater from the parking surface to collect and infiltrate the storage bed (typically sand or crushed stone) and eventually into the subgrade soils. If planned and installed appropriately, permeable pavements can last 15 to 20 years, which is similar to the required resurfacing of conventional asphalt (which is needed around every 20 years).

There are many factors to consider when implementing permeable paving including slope, traffic volume, subgrade, land use, soil, infiltration and drainage characteristics, and groundwater conditions (US EPA 2008a, p. 24). Clogging in permeable paving is a common issue that can be avoided by installing a perimeter trench connected to the stone reservoir to treat overflow onto the surface. Another common problem is the contamination and compaction of the soil beneath the permeable paving over time from vehicles and heavy equipment. These issues can also be avoided with proper maintenance, typically a high-pressure hose to clear out clogging and vacuuming at least two to four times a year. Grid pavers will require less maintenance than porous asphalt as they do not clog as easily. Parking lots with higher traffic volumes will also require more maintenance as more vehicles track more soils and particulates onto the lot.
There is limited data on permeable pavement system removal rates. For porous pavement, the US EPA observed the Purdue University Engineering Department's Long-Term Hydrologic Impact Assessment which found that "the range of pollutant removal effectiveness for porous pavement, showing a removal effectiveness of at least 65 percent for suspended solids, nitrogen, pathogens, and metals; and at least 30 percent of phosphorus" (US EPA 2008a, p. 28).

A study from the University of Washington on the long-term effectiveness of alternative pavers found that "concentrations of copper in runoff from alternative pavers were roughly 80 percent lower than those found in the runoff from conventional asphalt, and zinc concentrations were at least 40 percent lower. Also, motor oil was detected in 89 percent of the runoff samples from conventional asphalt, while no motor oil was detected in any samples that infiltrated through sections of alternative pavers" (US EPA 2008a, p. 28).

SPACE REQUIREMENT:	• Surface area can vary, but depths are typically around 27 in. depth of varying aggregate materials and subbases before native soil
DESIGNED FOR:	• Replacing traditional pavement, allowing runoff to infiltrate directly into soil while receiving water quality treatment
EFFECTIVENESS:	• 80% TSS removal (0.5-1in water quality volume drain within 72 hrs) • Provides groundwater recharge
MAINTENANCE:	• As needed: Monitor drainage, clean using power washer and vacuum to prevent clogging, assess exfiltration • Annually: Surface inspection for deterioration, assess exfiltration
COST:	• Average $5.91 per square foot (International Stormwater BMP Database 2022)
SPECIAL FEATURES:	• Reduces stormwater runoff volume from paved surfaces • Can last decades if properly designed, installed, and maintained
LIMITATIONS:	• Prone to clogging • Frequent maintenance required

Table 8. Permeable Pavers General Information. All information in table from (Massachusetts Department of Environmental Protection 2008, p. 118-121) unless listed otherwise

STORMWATER MANAGEMENT GOALS

- INFILTRATION
- WATER QUALITY
- WATER STORAGE

Green Infrastructure Economic Benefits

While all of these green infrastructure interventions are beneficial to the environment, they can also have significant economic benefits. The most notable advantage is the reduced gray infrastructure construction and maintenance costs (Thurston 2011, p. 55). Green infrastructure systems are more sustainable than gray infrastructure systems because they simulate the natural water cycle. Gray infrastructure may cause flooding in concentrated areas and require costly repairs if broken or worn down. Green infrastructure also increases land and property values (Thurston 2011, p. 50).

It can be difficult to accurately quantify the economic benefits of green infrastructure as elements such as the operation and maintenance of the projects are site-specific and non-market benefits can be hard to monetize such as air quality and aesthetic value (Thurston 2011, p. 103). *Economic Incentives for Stormwater Control*, edited by Hale Thurston, outlines various economic analyses for green infrastructure represented in different case studies.

One example is the capital cost assessment which evaluates and estimates the impacts of development standards and fee before implementing the system. This analysis calculates and compares the costs of BMPs implementation and the costs of traditional gray infrastructure implementation (Thurston 2011, p. 105).

This publication also defines multiple equations for calculating water quality volume, total construction costs, land-area requirements, operating and maintenance costs, and total present costs. Similar equations are given on the effectiveness of contaminant removal, including runoff fraction treated, pollutant loading, and fraction of contaminants removed (Thurston 2011, p. 35-42). Such water quality improvements reduce needed downstream cleanup and costs.



Figure 1.16—Parking lot at El Rio de Los Angeles State Park, with native plants, infiltration areas, and permeable pavers. (Boyd 2007). Used Under Creative Commons Attribution Non-commercial.

Green Infrastructure Funding

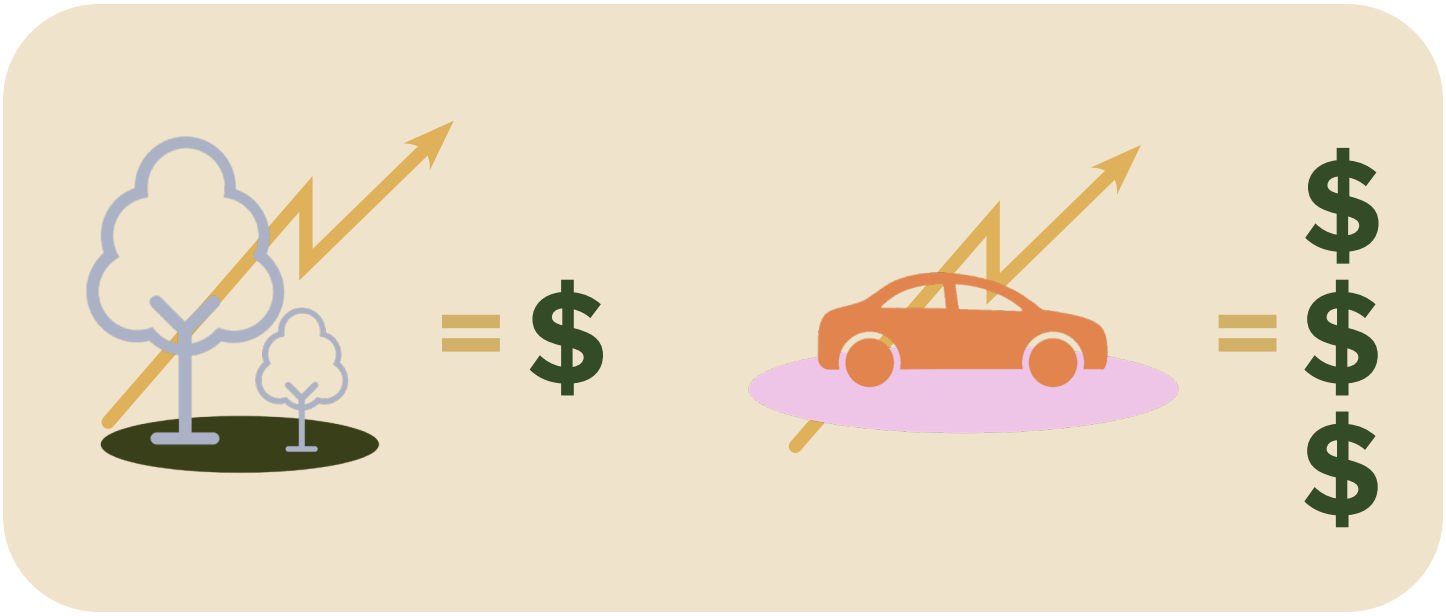
Communities are often hesitant to take on green infrastructure projects due to obtaining funding sources and given financial constraints. There also may be a lack of information and understanding benefits of green infrastructure, paired with a mentality of 'existing system works adequately most of the time—why change it?'. Communities may be more inclined to implement green infrastructure projects if they see what their surrounding areas could be. Awareness of funding options for these projects may also appeal to communities. There are three main types of funding sources for implementing green infrastructure projects in communities (EPA 2008b, p. 1).

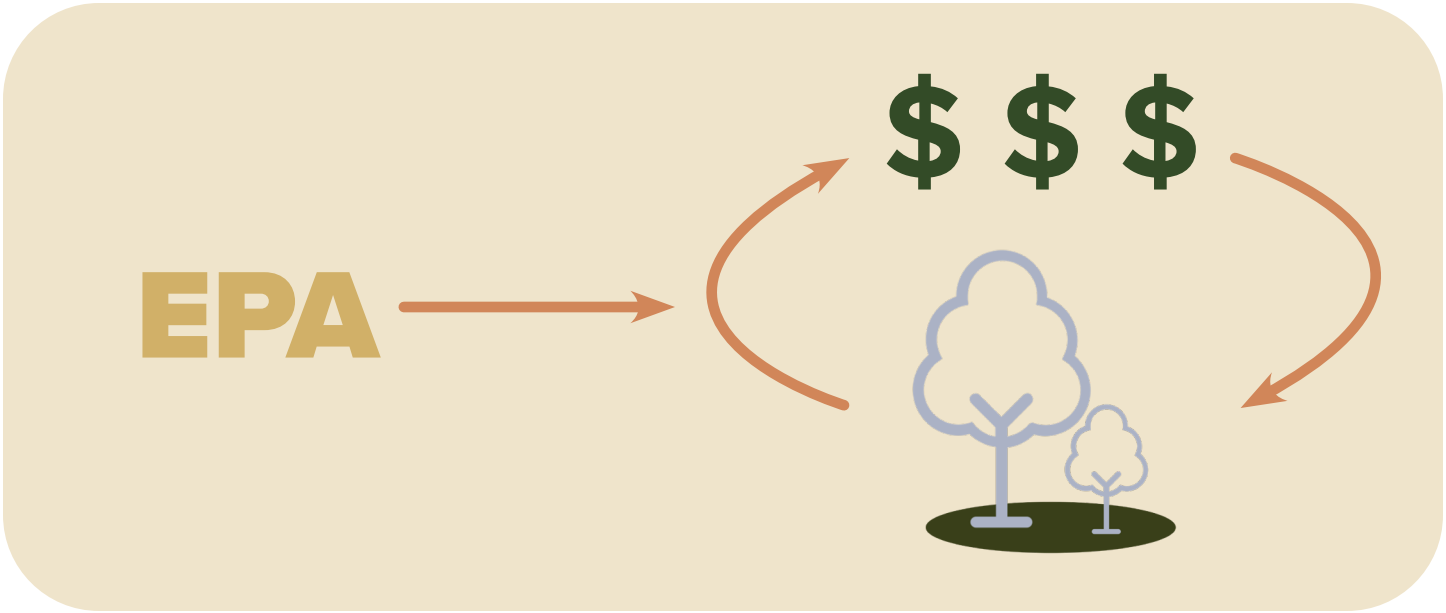
The first is **stormwater fees**, which create a revenue stream to allocate costs for the increasing investment most communities will need to control stormwater runoff. Stormwater user fees were typically collected in general tax funds, however the fees ended up being used to fix the stormwater management in areas that generate the most runoff. For the billing process, stormwater fees can be separated from general funds. An impervious surface-based billing system is an effective method for calculating stormwater fees (EPA 2008b, p. 2-6).

Another common funding source is **federal or state loan programs**. The EPA Clean Water State Revolving Fund (CWSRF) is a significantly valuable financing program that can provide funding for stormwater management projects. "In 2007 alone, $5.3 billion was provided to fund a wide variety of projects that protect or improve national water quality." (EPA 2008b, p. 11). Essentially, EPA grants provide funds for the nation's CWSRF program. States can provide additional matching funds which are loaned to various water quality projects. The loans are typically paid off over around 20 years, starting about a year after project completion. The loan payments plus interest are fed into the fund and used for new stormwater management projects (EPA 2008b, p. 11-14).

Finally, **grant programs** exist that can be issued to communities to implement green infrastructure projects. However, they are typically only enough to fund smaller, local projects. They can be useful as seed money for a project, but typically not sufficient enough for long-term funding for a project and its maintenance, though national groups are working to increase that amount (EPA 2008b, p. 1).

Figure 1.17 (Right)—Green infrastructure funding diagram. Natalie Kerner, 2025. Diagram in Adobe Photoshop.


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Figure 1.18—Manchester Beach. (Vargas 2009). Used Under Creative Commons Attribution Non-commercial.

Green Infrastructure Incentives

Some municipalities in the United States use incentives to implement green infrastructure. One of the most common types is a **stormwater fee discount**—municipalities require a stormwater fee based on the impervious surface amount (EPA 2009, p. 2-3). Essentially, the municipalities lower the fee if property owners minimize the amount of impervious surface area, which lessens the volume of runoff.

There are also **development incentives**, such as zoning upgrades, expedited permitting, etc., which are offered to developers amid the application process for development permits (Thurston 2011, p. 6).

Some **grants** supply direct funding to property owners/community groups for implementing green infrastructure into their projects and practices (EPA 2009, p. 4).

Rebates and installation financing are typically reserved for specific interventions needed in certain areas (EPA 2009, p. 4). These will supply funding, tax credits, or reimbursements to property owners who implement specific green infrastructure interventions.

Finally, some programs issue **marketing opportunities and recognition** for exceptional projects that may provide monetary awards (EPA 2009, p. 5).

Discussion

In summary, large areas of impervious surface parking lots have significant adverse impacts on the environment. Most notably, these spaces contaminate water quality and generate a large volume of stormwater runoff which can contribute to flooding issues. Pollutants such as oil and grease from cars, total suspended solids, and certain metals can be collected in the runoff, contaminating streams and rivers. In addition to stormwater management issues, surface parking lots can also produce an urban heat island effect and prevent groundwater recharge systems. However, landscape architects can design solutions to these issues by implementing green infrastructure systems in projects, and making these methods more commonly utilized in the practice.

03 METHODOLOGY

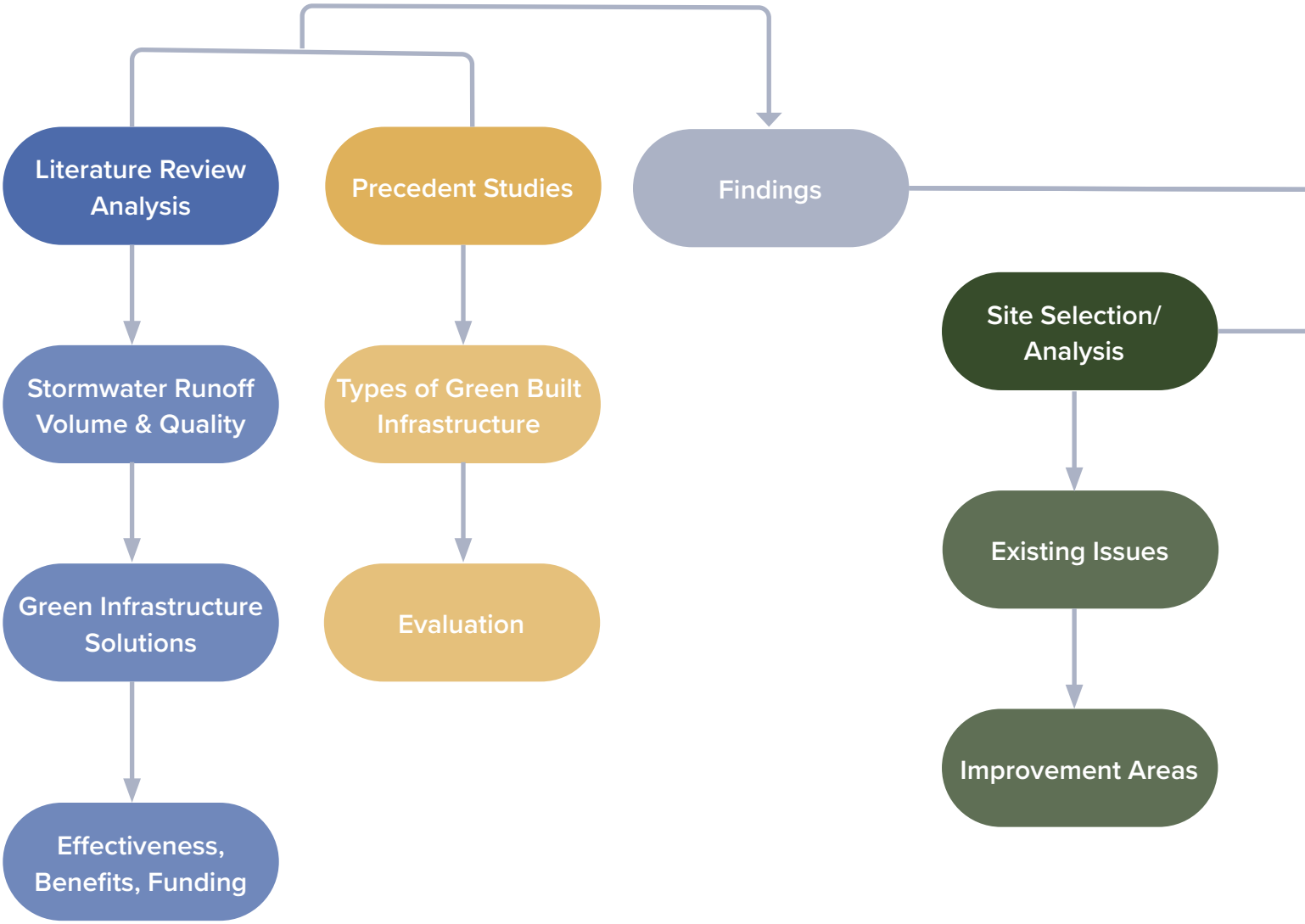
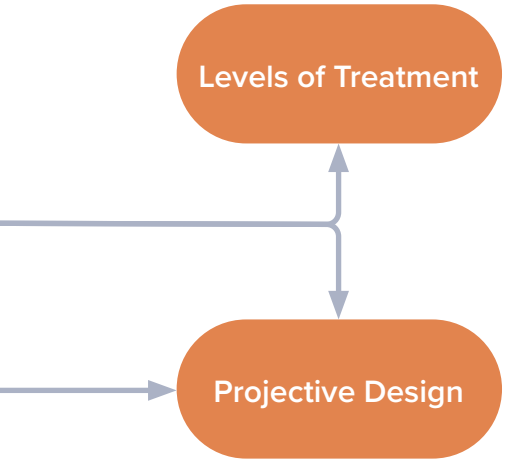


Fig. 2.1—Methodology framework diagram. Natalie Kerner, 2025. Diagram in Adobe InDesign



This study employs a methodology that includes an analysis of the literature review and a series of precedent studies. The literature review analysis synthesizes key findings related to stormwater runoff volume and quality, green infrastructure solutions, and their effectiveness, benefits, and funding. These insights are then applied to the projective design for the parking lot south of the Kansas State University Practice Facility, ensuring an evidence-based approach to sustainable site development.

Additionally, precedent studies of built green parking lots inform the design process by examining the implementation and performance of green infrastructure elements such as permeable paving and bioretention cells. These case studies provide valuable applications that guide the integration of sustainable stormwater management strategies within the proposed design.

ASCE Headquarters

PRECEDENT 01



Fig. 2.2—After Photos of ASCE Parking Lot. (ASCE Foundation 2025). Used with permission.

LOCATION: Reston, Virginia (American Society of Civil Engineers Headquarters

CONTEXT: Suburb of Washington, D.C.—Difficult Run Watershed

COMPLETED DATE: November 2020

SIZE/SCOPE: 6,000 sq. ft impervious asphalt surfaces could be replaced with permeable pavers

DESIGN TEAM: Chair—Matt Jones, PE, LEED, AP BD+C, Senior Principal, Magnusson Klemencic Associates (MKA) (Shuster 2021, para. 2)

STAKEHOLDERS: ASCE, Guests of headquarters building include: professional engineers, educators, students, and policy officials

COST/FUNDING: Donations from members, ASCE foundation donors, and others; in-kind and materials donations

With donations cost: $440,000

Without donation cost: $700,000

(Shuster 2021, "Rubber meets the road" section)

ISSUE ADDRESSED: 80% of Chesapeake Bay's tidal regions partially or fully impaired by toxic contaminants (due to highly urbanized context)
When 1 inch of rain falls on 1 acre of impervious surface coverage, (Chesapeake Bay Foundation) estimates that it generates about 27,000 gallons of stormwater runoff (Shuster 2021, para. 3)

GREEN INFRASTRUCTURE USED









Fig. 2.3a & 2.3b—Construction Photos: Permeable Pavers. (ASCE Foundation 2020) Used with permission.

Fig. 2.4a & 2.4b—Construction Photos: Stormcrete Precast Porous Concrete. (ASCE Foundation 2020) Used with permission.

Permeable Interlocking Concrete Pavement (24 spots at front of building)

- Built using Interlocking Concrete Pavement Institute's Foundation for Education and Research guidelines
- 80mm thick, 100x200mm solid concrete pavers, spaced 10mm apart
- Joints filled with permeable aggregate to trap sediment
- Water flows into stone base/subbase, acting as a reservoir
- 300mm thick base/subbase of open-graded aggregate (~40% porosity) stores ~100mm of water while infiltrating it into the soil
- Designed to handle 100-year storm event
- Sloped soil subgrade with 30mm thick, 200mm high PVC vertical check dams (spaced every 5m) to detain/infiltrate water

(Shuster 2021, "Let it flow" section)

Stormcrete Precast Porous Concrete Panels (11 parking spots in another area)

- Made by Porous Technologies LLC
- Concrete mix with uniform coarse aggregate gradation and minimal fine aggregates 15-20% interconnected voids for stormwater infiltration
- Water flows into the soil and into the FocalPoint biofiltration system (by ACF Environmental)
- FocalPoint uses high-flow media for rapid treatment in a compact footprint
- Removes TSS, phosphorus, nitrogen, oils, grease, and bacteria
- Treated runoff flows through an outlet pipe to an existing storm drain
- Domed overflow riser manages larger storm events

(Shuster 2021, "Let it flow" section)



Fig. 2.5—Construction Photos: Filterra Unit. (ASCE Foundation 2020). Used with permission.

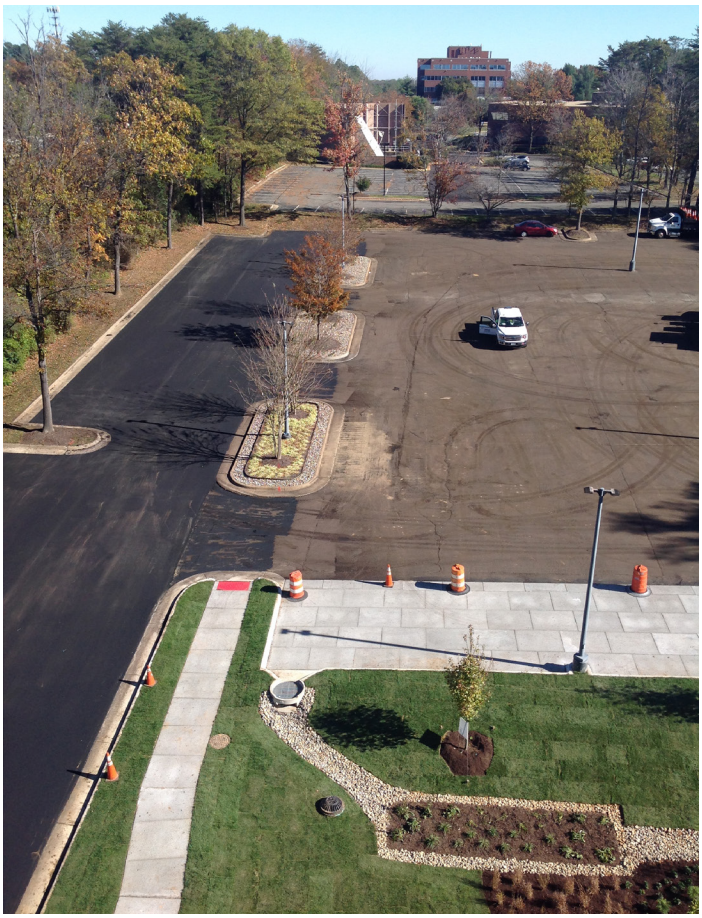


Fig. 2.6—Construction Photos: Milling & Paving. (ASCE Foundation 2020). Used with permission.

Filterra Biofiltration Unit (Contech Engineered Solutions LLC)

- 13x7 ft filtering unit placed in sidewalk near front steps
- Runoff enters through an existing curb inlet (not pavers)
- Water flows through a specialized filter-media mixture within a landscaped concrete container
- Captures and immobilizes pollutants, which decompose or are incorporated into system's biomass
- Treated runoff is discharged

(Shuster 2021, "Let it flow" section)

Asphalt Repaving (105,750 sq ft of parking lot)

- Used 1,241 tons of asphalt mixed with recycled tires (Asphalt Plus LLC)
- 11 lb of Elastiko crumb rubber per ton (~722 recycled tires kept from landfills)
- Rubber stiffens asphalt mix, reducing cracking and slowing crack progression
- More durable, requires less maintenance, and uses less material than standard pavement

(Shuster 2021, "Rubber meets the road" section)

Vegetated Courtyard

- Pavers engraved with names of ASCE Foundation donors and members
- Educational signage installed

(Shuster 2021, "Rubber meets the road" section)

BEFORE





Fig. 2.7a & 2.7b—Before Photos of the ASCE Headquarters Parking Lot. (ASCE Foundation 2020). Used with permission.

AFTER



Fig. 2.8a & 2.8b—After Photos of the ASCE Parking Lot. (ASCE Foundation 2020). Used with permission.

Kortright Centre

PRECEDENT 02

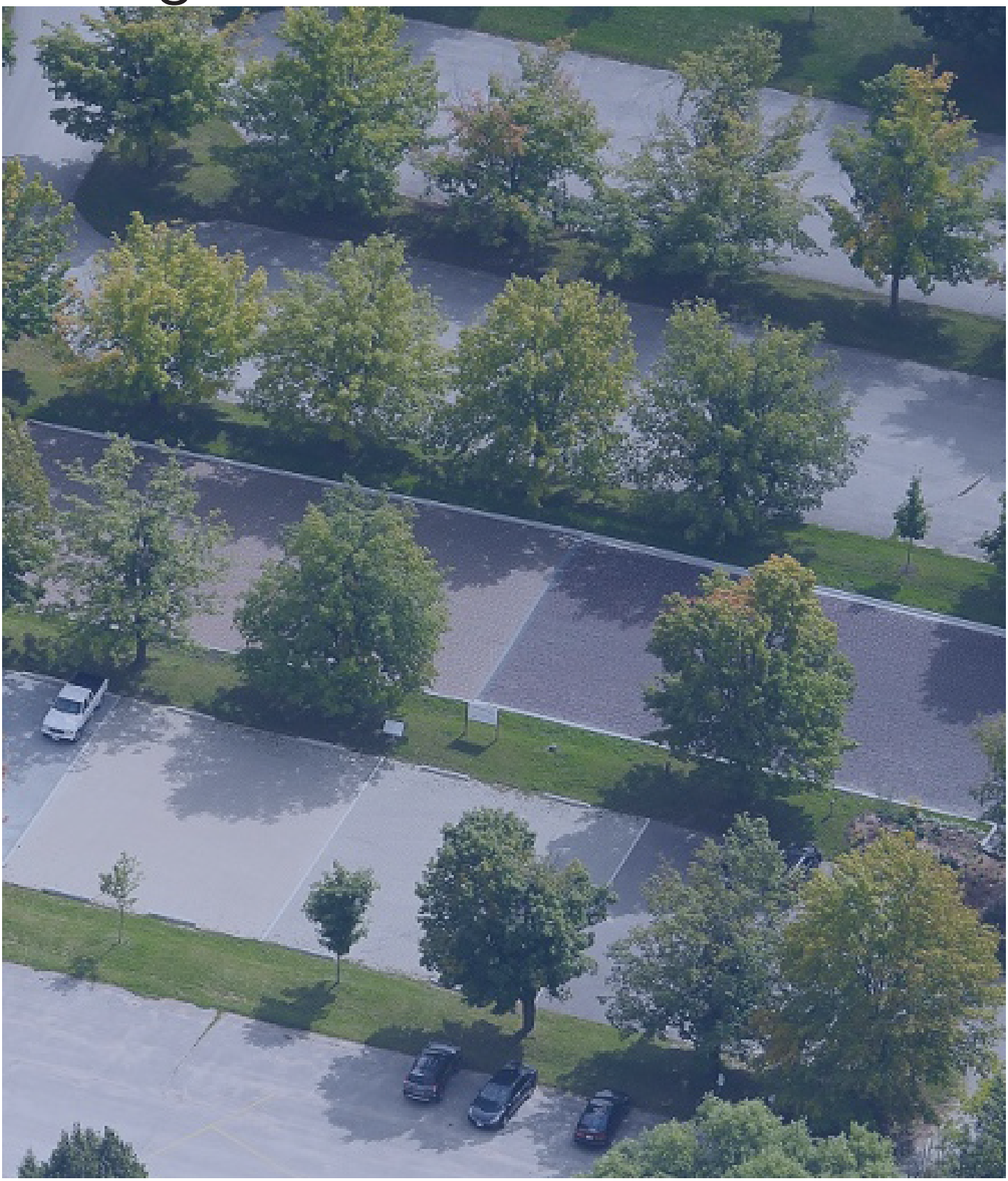


Fig. 2.9—Kortright Centre Green Parking Lot. (Kortright Centre 2019). Courtesy of Toronto and Region Conservation Authority.

LOCATION: Vaughan, Ontario, Canada (Kortright Centre for Conservation)

CONTEXT: Conservation Area/Parks & Suburbs

COMPLETED DATE:
Phase I: 2010—2012, University of Guelph doctoral research thesis in collaboration with STEP (evaluated hydrologic quality and functional performance of different types of concrete permeable pavements)

Phase II: July 2012—December 2014, initiated by STEP with support from Cement Association of Canada, and Interlocking Concrete Pavement Institute (extended earlier study with focus on evaluating long term performance of pavements and documenting direction and magnitude of changes in performance over time)
(Sustainable Technologies Evaluation Program 2015, iv)

SIZE/SCOPE: 4 pavement plots—each roughly 2,475 ft^2

DESIGN TEAM:
Phase I: University of Guelph doctoral research thesis students & Sustainable Technologies Evaluation Program (STEP)

Phase II: STEP and support from Cement Association of Canada and Interlocking Concrete Pavement Institute
(Sustainable Technologies Evaluation Program 2015, iv)

STAKEHOLDERS: Kortright Centre; Guests include various professionals, educators, students, and visitors

COST/FUNDING: Financial support for extended monitoring program (July 2012—December 2014) provided by Cement Association of Canada, Interlocking Concrete Paving Institute, and STEP program partners (Region of Peel, York Region and the City of Toronto)
In-Kind Monitoring & Research Services: University of Toronto

Phase I Financial Support:

- Great Lakes Sustainability Fund
- Toronto and Region Remedial Action Plan
- Ontario Ministry of the Environment Best in Science Program
- Ontario Ministry of Transportation
- City of Toronto
- Region of Peel
- York Region
- Metrus Development Inc.
- Interlocking Concrete Paving Institute
- Aecon Group Inc.

In-Kind Services and Materials Donations

- Urban Ecosystems Limited (Engineering consulting services)
- Brown's Concrete (AquapaveTM)
- Unilock (Eco-Optiloc)
- Lafarge (Ultra Pervious concrete)
- Hanson (sampling vault)
- Ontario Ministry of the Environment (laboratory services)
- Armtec (pipes)
- Condrain (construction services)
- Dufferin Aggregates (aggregate base)
- Layfield Plastics (liner)

(Sustainable Technologies Evaluation Program 2015, iii)

ISSUE ADDRESSED:

- Monitor and evaluate clean water, air and energy technologies
- Assess barriers and opportunities to implementing technologies
- Develop tools, guidelines and policies, and
- Promote broader use of effective technologies through research, education and advocacy

(Sustainable Technologies Evaluation Program 2015, iv-vi)

GREEN INFRASTRUCTURE USED:

Cell 1

- Asphalt (drained by catchbasin in center of lot)

Cell 2

- AquaPave permeable pavers (drained by perforated pipe)

Cell 3

- Eco-Optiloc permeable pavers (drained by perforated pipe)

Cell 4

- Hydromedia pervious concrete (drained by perforated pipe)

Each permeable pavement cell is drained by a perforated pipe placed 20in below the surface at an interface between open-graded subbase layer and native soil.

As water infiltrates the permeable surfaces, separately sealed pipes conveys the water to a downstream monitoring vault where automated samplers, flow meters, and temperature sensors are housed (Sustainable Technologies Evaluation Program 2015, p. 3-6).

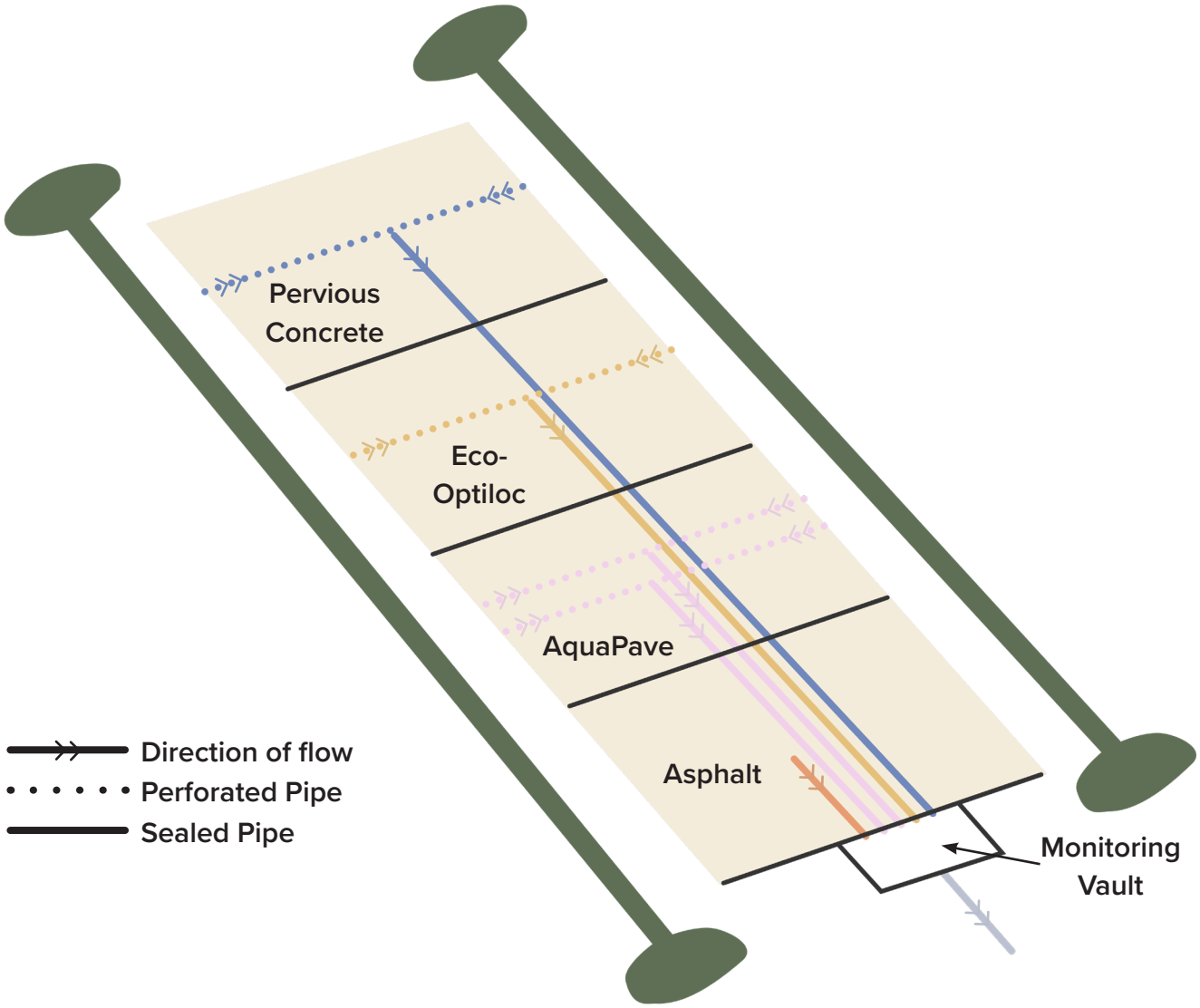
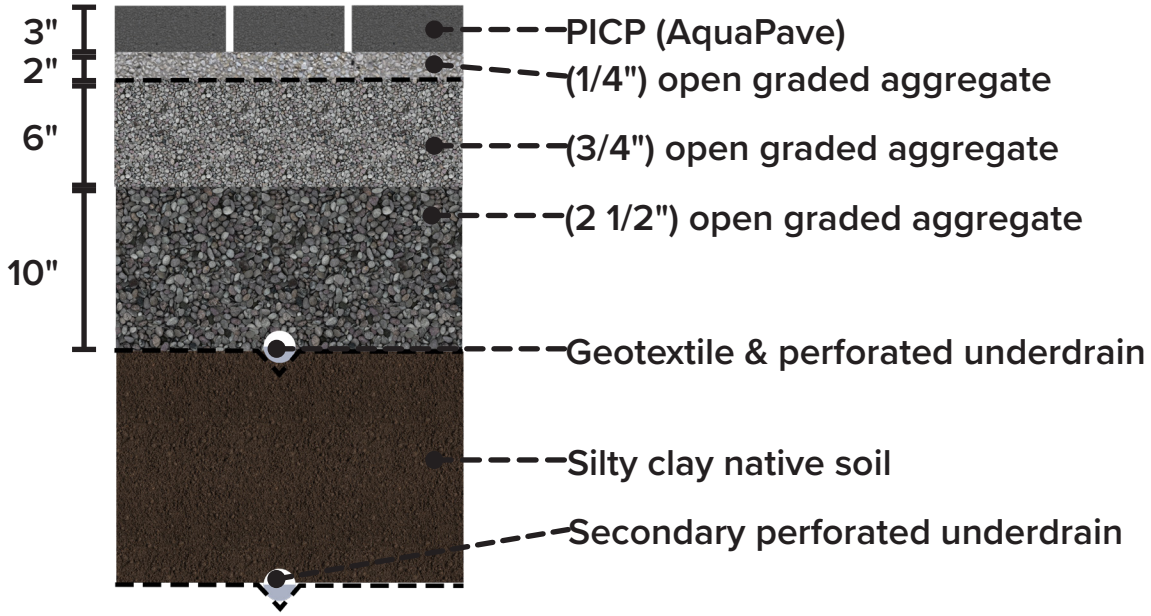
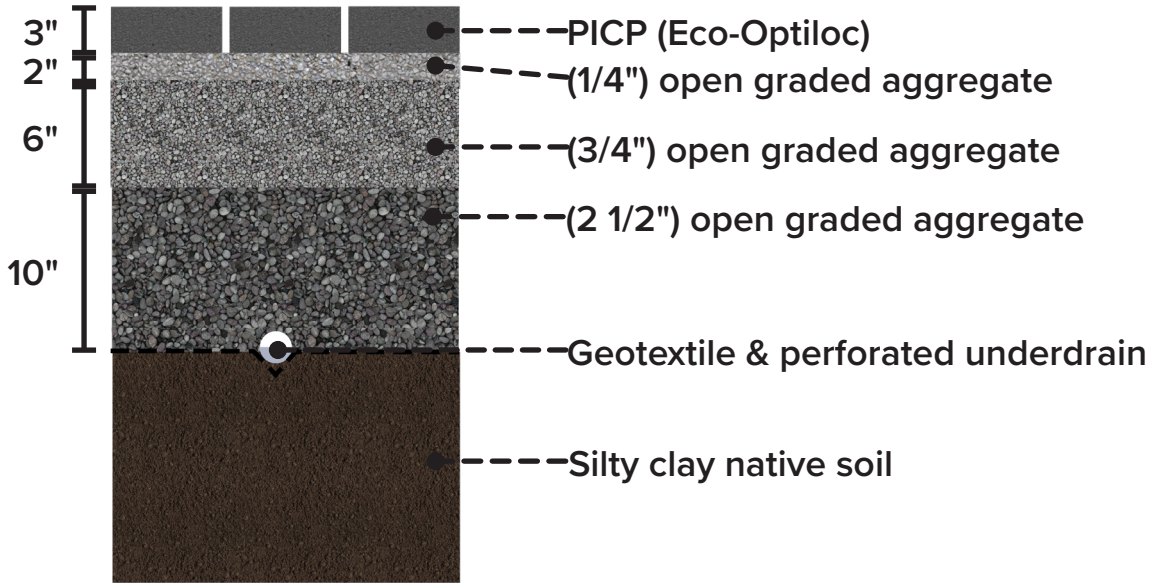
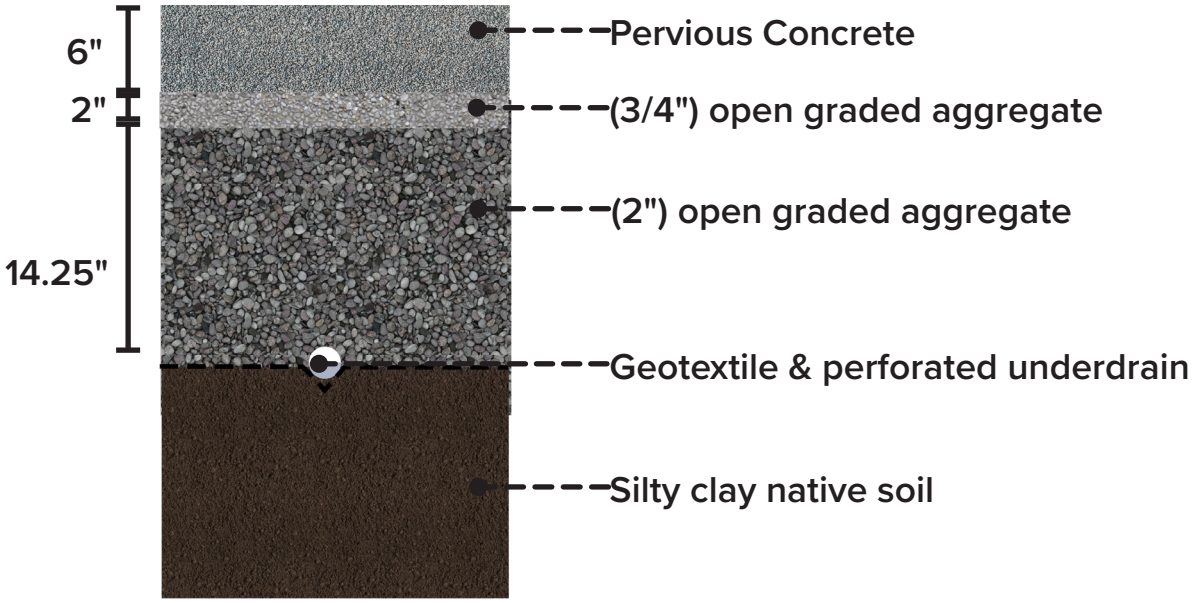


Fig. 2.10—Adapted from *Five Year Performance Evaluation of Permeable Pavements*: [Figure 2.2: Schematic of Kortright permeable pavement showing the monitoring vault] (Kortright Centre 2019). Diagram in Adobe Illustrator by Natalie Kerner. 2025.


3"
2"
6"
10"
PICP (AquaPave)
(1/4") open graded aggregate
(3/4") open graded aggregate
(2 1/2") open graded aggregate
Geotextile & perforated underdrain
Silty clay native soil
Secondary perforated underdrain


3"
2"
6"
10"
PICP (Eco-Optiloc)
(1/4") open graded aggregate
(3/4") open graded aggregate
(2 1/2") open graded aggregate
Geotextile & perforated underdrain
Silty clay native soil


6"
2"
14.25"
Pervious Concrete
(3/4") open graded aggregate
(2") open graded aggregate
Geotextile & perforated underdrain
Silty clay native soil

Additional Considerations

- The subbase layers of open-graded aggregate provide storage for around 4in of rain event.
- The pavement cells are hydraulically separated by concrete curbs and seepage collars to prevent cross flow among cells.
- Underdrains for each cell are fitted with flow restrictors to control the rate of drawdown after storm events and prolong the period over which infiltration can occur. Full drawdown of runoff for large events occurred within 48 hours or less.
- A Mirafi Filter Weave® 500 geotextile was placed below the base as a separation layer
- An Inbitex® geotextile with an apparent opening size of 0.145 mm and a flow rate of 4500 L/min/m2 was placed between the bedding and base aggregate layers of the AquaPave pavement
- Beneath the AquaPave cell a second perforated pipe is placed to evaluate the potential impact of stormwater infiltrated through native soils on groundwater quality

(Sustainable Technologies Evaluation Program 2015, p. 3-6)

It is important to note that the pervious concrete has around 30% void space, while the Eco-Optiloc has around 12% open space, and AquaPave has only 2-4% open space (Sustainable Technologies Evaluation Program 2015, p. 9).

Fig. 2.11a, 2.11b, 2.11c (Left)—Adapted from *Five Year Performance Evaluation of Permeable Pavements*: [Figure 2.3: From [top to bottom], cross sections of the AquaPave (AP) Eco – Optiloc (EO) and pervious concrete (PC) pavements]. (Kortright Centre 2019) Diagrams in Adobe Photoshop by Natalie Kerner. 2025.



Fig. 2.12— Kortright Centre Green Parking Lot. (Kortright Centre 2019). Courtesy of Toronto and Region Conservation Authority.

MONITORING:

Precipitation Monitoring

- A tipping bucket rain gauge (200 meters south of the facility) and a backup gauge (500 meters north) measure rainfall.

Flow Measurement

- Tipping bucket flow gauges track low flows
- For higher flows, a clamp-on ultrasonic flow meter is used.
- Two pressure transducers in pavement wells measure water levels below the pavement.

Infiltration Rates

- Surface infiltration rates are measured annually (18 tests per pavement type) using ASTM C1701 standards, conducted before and after maintenance. Measurements begin after a winter operation for certain pavements and soon after installation for others.

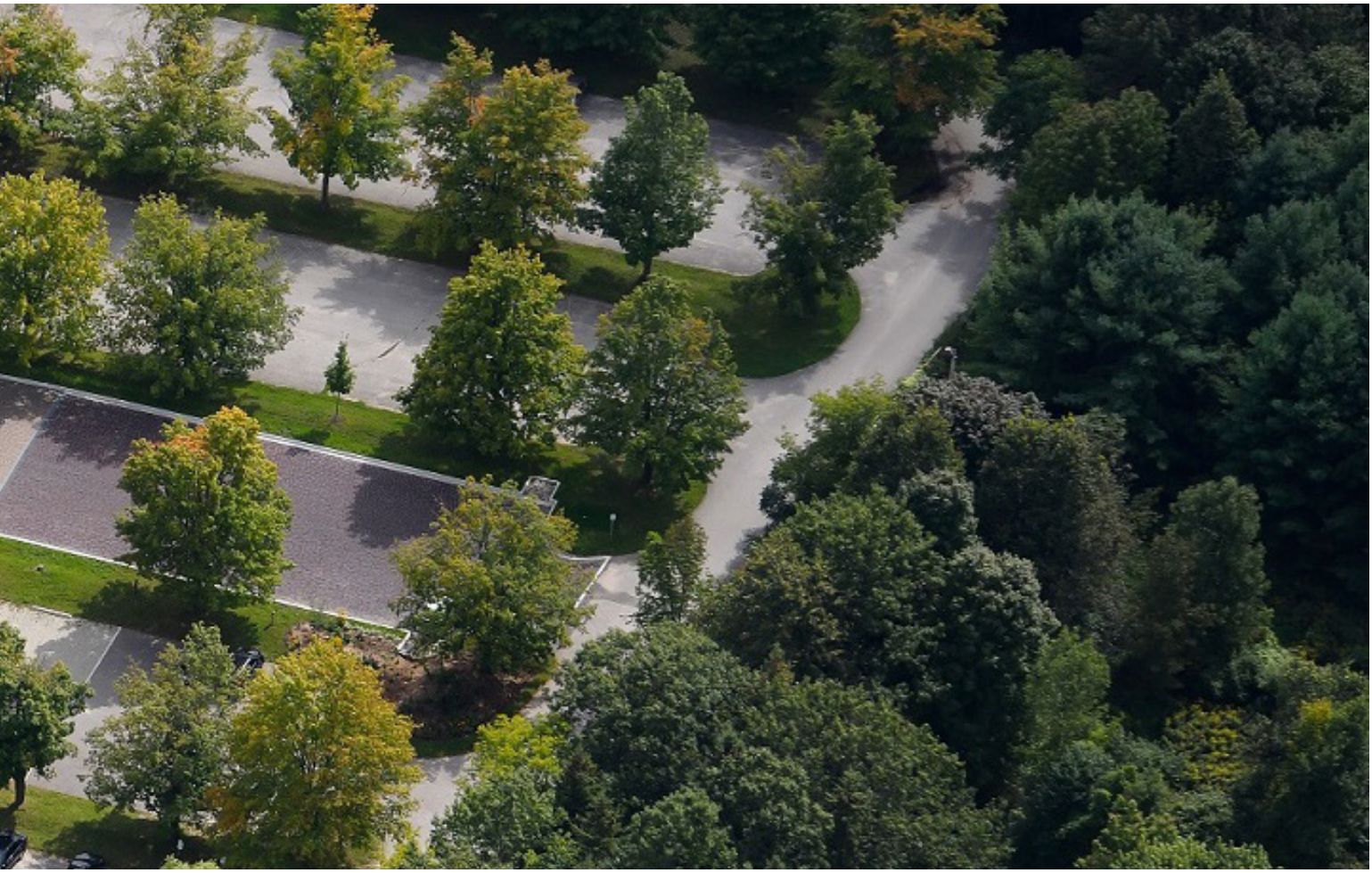
Water Quality Monitoring

- Water discharged from underdrains of permeable pavements and asphalt is sampled during rain and snow events.
- Samples are proportioned by flow volume and sent to the Ontario Ministry of the Environment (OMOE) Laboratory for analysis (e.g., solids, nutrients, metals, etc.).
- Water temperatures are recorded to assess the thermal impact on stream ecosystems.

Elevation Monitoring

- Elevation of pavements and asphalt is surveyed annually to assess the effects of freeze-thaw conditions and traffic, but this monitoring was discontinued after two years.

(Sustainable Technologies Evaluation Program 2015, p. 6)



CHALLENGES:

- It should be noted that traffic enters the parking area primarily from the east entrance. Therefore, dirt and sediment on tires from outside areas is more likely to be deposited on PC and the neighboring EO pavement because these are closer to this entrance. Sand was not used for winter maintenance on the permeable pavement plots and asphalt control; only salt (NaCl)
- Reductions in infiltration over time may occur if fines clogged the geotextile or native soils below the granular base. Further compaction of the subgrade soils may also occur as the pavement ages, which may also affect infiltration.
- Cold season outflow volumes were also available but flow reductions calculated from comparison to the asphalt reference could not be verified to be accurate because, as mentioned earlier, some of the snow that fell on the asphalt pavement may have been plowed to the permeable pavement plots, or vice versa (Sustainable Technologies Evaluation Program 2015)

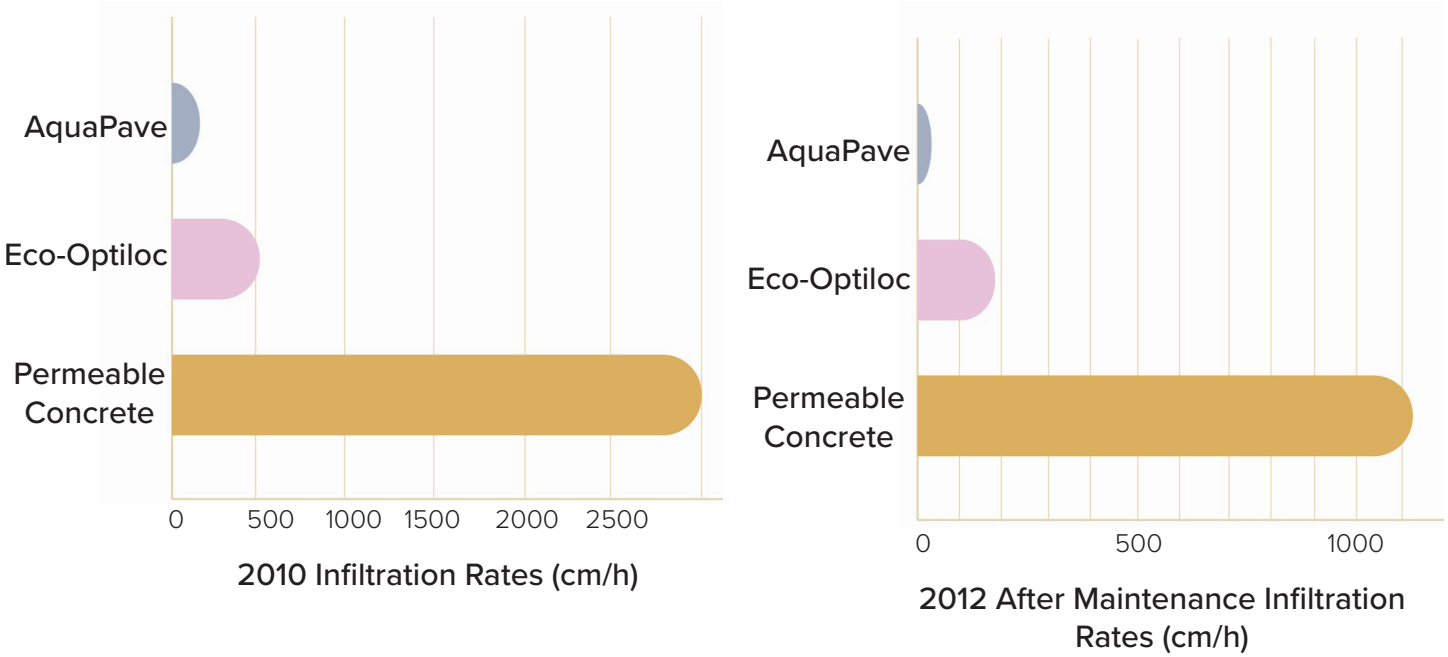


Fig. 2.13—Adapted from *Five Year Performance Evaluation of Permeable Pavements:* [Figure 4.1: Surface Infiltration Rates]. (Kortright Centre 2019). Diagram in Adobe Illustrator by Natalie Kerner. 2025.

EVALUATION:

Surface Infiltration

- Surface infiltration rates of permeable pavements were measured every spring between 2010 and 2014 as well as before and after the pavements were cleaned in 2012 by Elgin Whirlwind vacuum truck.
- 2010 infiltration rates highest on pervious concrete, then Eco Optiloc, then AquaPave.
- By 2012, infiltration rates declined (87%, 81%, 49%).
- Vacuum maintenance showed significant improvement infiltration rates on Permeable Interlocking Concrete Pavements, but not PC Pavement (which was highest infiltration rate).
    - Even after pavements cleaned, infiltration rates still continued to decline between 2010 and 2014 (Sustainable Technologies Evaluation Program 2015, p. 9-10).
- It is likely that permeable concrete displays higher infiltration rates due to its higher void space of 30%, while the permeable paving infiltration rates are lower because they have less open space (12% or less). (Sustainable Technologies Evaluation Program 2015, p. 9-10)



40% - 52%

STORMWATER VOLUME
REDUCTION RATE

Volume Reduction

- To assess the extent of changes, the volume of stormwater reduced by the permeable pavements was calculated during the warm season (April to November) from 2010 to 2014.
- It should be noted that the permeable pavement underdrains are equipped with control valves to help detain the water for up to 48 hours after a rain event. All efforts were made to ensure these control valves were maintained at the same settings throughout the monitoring period to minimize influences on volume reduction rates.
- On an annual basis, warm season volume reduction rates ranged between 40% and 52%. Year to year differences may be attributed to variations in the size and durations of events. (Sustainable Technologies Evaluation Program 2015, p. 11-12)
- Data indicate that infiltration into the native soils beneath the pavements has remained relatively constant over the first five years of operation, suggesting that infiltration into the native soils may not be strongly influenced by pavement age, and that the geotextile between the base and native soils is not inhibiting the transfer of water to the soils below.
- In the previous study, which covers the first 22 months of monitoring, peak flows were reduced by an average of 91% relative to the asphalt pavement, and stormwater was released over a longer time period (Sustainable Technologies Evaluation Program 2015, p. 11-12).

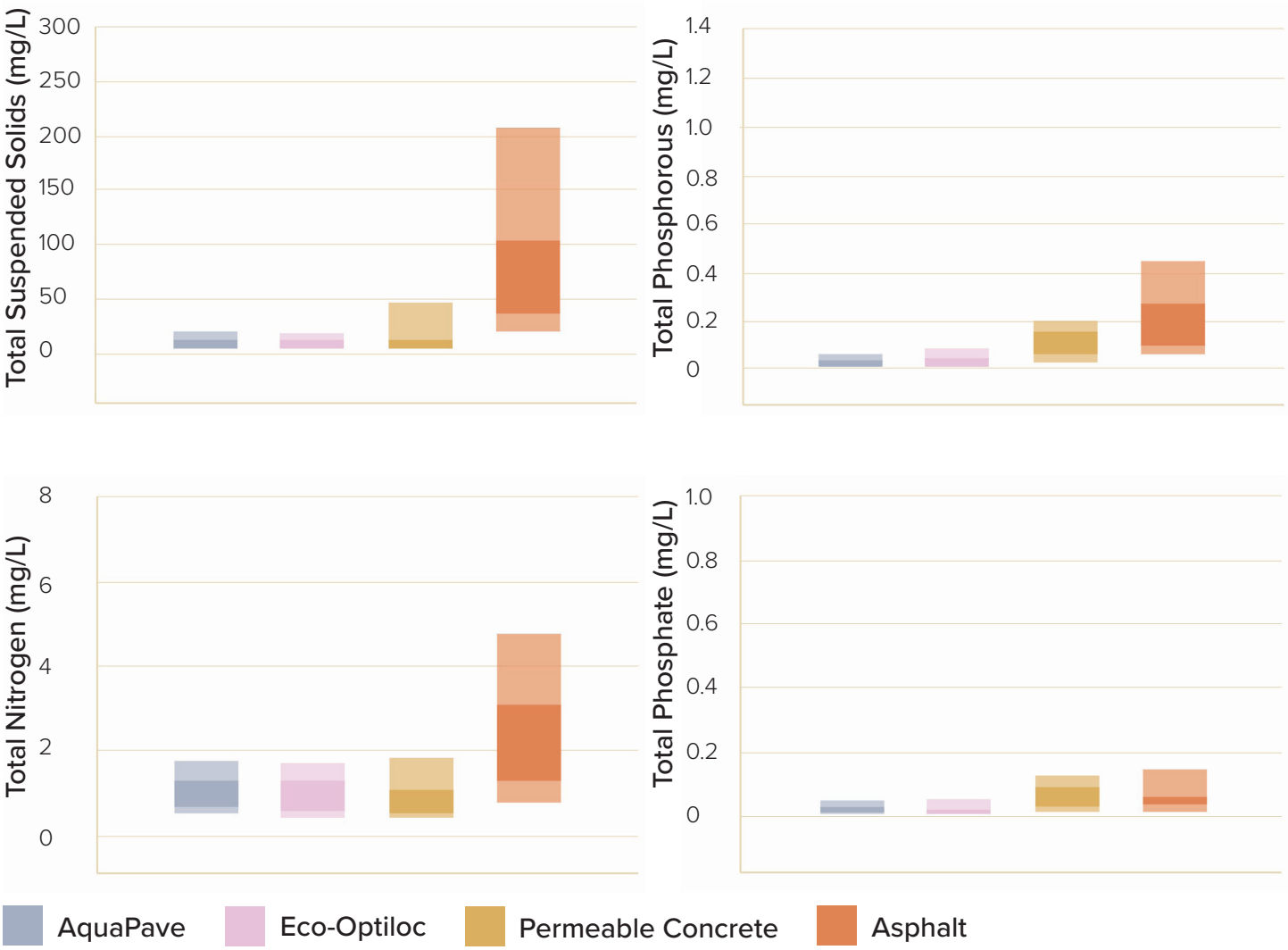


Fig. 2.14—Adapted from *Five Year Performance Evaluation of Permeable Pavements:* [Figure 4.4: Box plots of TSS and selected nutrient concentrations over the 2010-2014 study period]. (Kortright Centre 2019). Diagram in Adobe Illustrator by Natalie Kerner. 2025.

Water Quality

- By 2014, over 250 samples had been collected for water quality analysis. Samples were analyzed for **solids**, **nutrients**, **metals**, **road salt constituents**, and **general chemistry**.

(Sustainable Technologies Evaluation Program 2015, p. 13-16)

Concentrations

- Asphalt vs permeable paving
  - Asphalt runoff concentrations were mostly higher than concentrations from the permeable pavements: includes TSS, total phosphorous, total nitrogen, total kjeldahl nitrogen, ammonia nitrogen, iron and zinc.
  - Oil and grease was detected above method detection limiting over 83% of asphalt samples, but in less than 6% of permeable pavement samples
  - Copper also had lower concentrations in permeable pavement samples

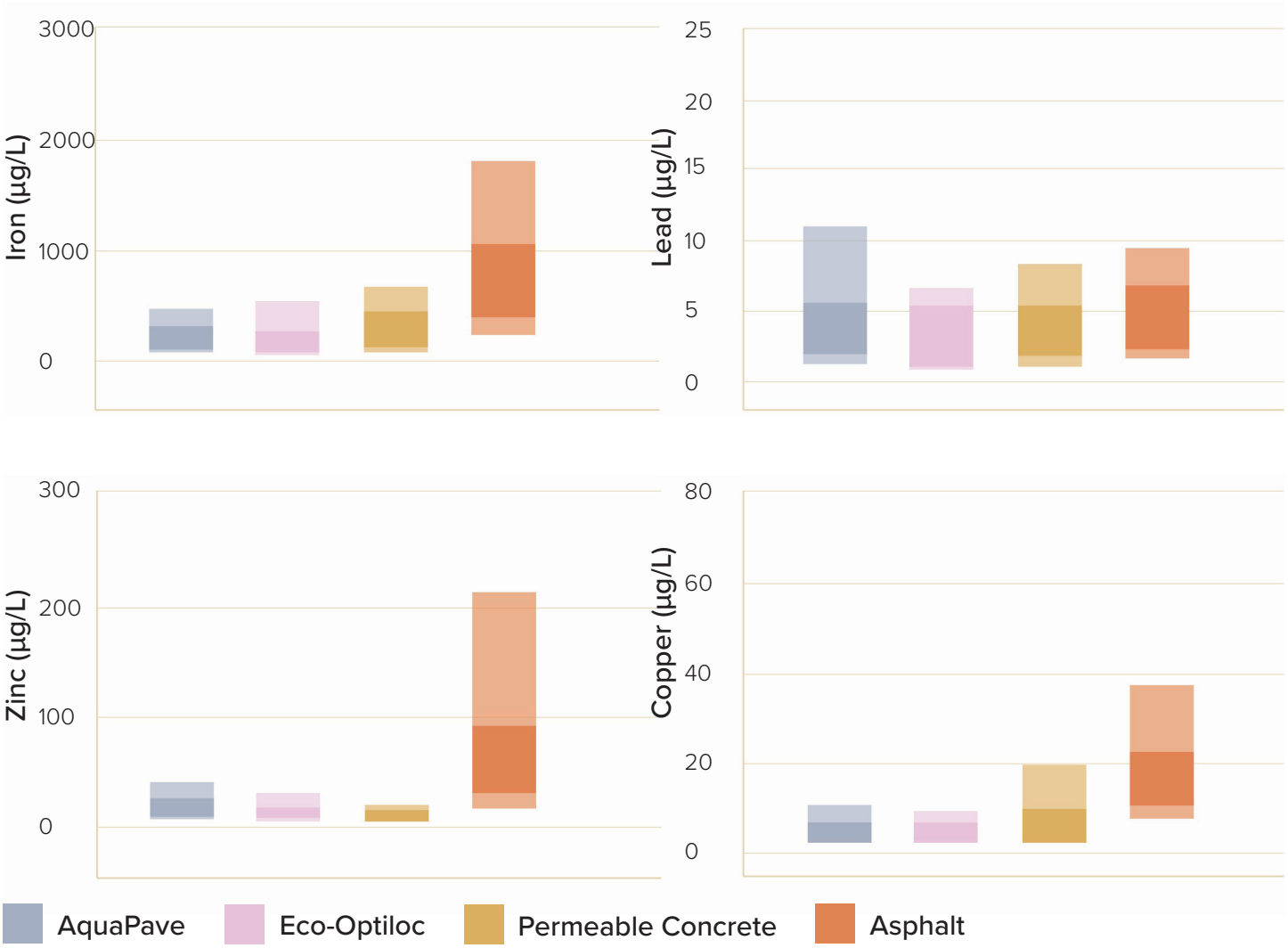


Fig. 2.15— Adapted from *Five Year Performance Evaluation of Permeable Pavements:* [Figure 4.5: Box plots of selected metal concentrations over the 2010-2014 study period]. Diagram in Adobe Illustrator by Natalie Kerner. 2025.

- Relative to asphalt pavement, permeable pavement had higher concentrations of nitrate, potassium, strontium, pH and alkalinity
  - Potassium and strontium in runoff are of little concern because they are not a threat to receiving waters at observed concentrations
  - pH/alkalinity from permeable concrete was high first 2 years, but then fell within acceptable ranges for protection of aquatic life

(Sustainable Technologies Evaluation Program 2015, p. 13-16)

- Eco-Optiloc vs AquaPave
  - Difference between these pavers was size of joints between pavers, joint stabilizing material, and presence of Inbitex geotextile below open graded bedding of AquaPave
  - Both reduced concentration of pollutants in stormwater runoff, and mass load of pollutants discharged downstream
  - It is hypothesized that high initial pH of the PC effluent may have contributed to high phosphate concentrations since phosphorus availability is lowest at pH between 7.5 to 8.0 and increases at values above and below this level (Sustainable Technologies Evaluation Program 2015, p. 13-16).



Fig. 2.16—Kortright Centre Green Parking Lot: Permeable Paving. (Kortright Centre 2019). Courtesy of Toronto and Region Conservation Authority.

Groundwater Contamination

- As seen in Fig 2.11, the research facility includes underdrains at the interface between the base and native soils, as well as one additional underdrain below the native soil for the AquaPave cell. The second underdrain was installed to monitor the water quality that infiltrates into the groundwater, and assess how concentrations change over time as pollutants build up in the native soils
    - Results showed that there was little difference in water quality between the two underdrains. Total suspended solids concentrations in the lower underdrain were initially higher than the upper underdrain, but decreased over time.
- The concentration of stormwater pollutants in the upper and lower underdrains of the AP pavement are compared to drinking water standards. Most pollutants were well below the limits for drinking water, with the exception of chloride, sodium, total dissolved solids, iron and lead (Sustainable Technologies Evaluation Program 2015, p. 19-21).

Surface Elevation

- The surface of the permeable pavements and asphalt were surveyed with a total station for elevation changes twice a year from November 2009 to June 2012, and once each in 2013 and 2014. Over the 5 year period, there have been no significant movements in the surface of the four pavement cells, and no signs of slumping or heaving (Sustainable Technologies Evaluation Program 2015, p. 24)



Thermal Loading

- As stated, expanses of dark impervious surfaces in urban areas generates thermal pollution by increasing the temperature of runoff, however green infrastructure practices such as permeable pavements can help mitigate these effects
- To understand the thermal characteristics of runoff from the asphalt and permeable pavements, four events that were preceded by maximum air temperatures between 27 and 35^{0}C [80^{0} and 95^{0}F] were selected for analysis
    - Results show that maximum outflow temperatures from the permeable pavement were consistently lower than asphalt runoff, while event mean temperatures were similar or higher.
- On July 13th, asphalt runoff event mean temperature was over 5^{0}C [41^{0}F] lower than that of permeable pavement outflows. The much lower asphalt temperatures during this event occurred because rain fell during the night, when air temperatures dropped to 11^{0}C [52^{0}F]. Also, permeable pavement outflows occur over a much longer time period allowing for additional heating from solar radiation during the day. Despite lower asphalt runoff event mean temperatures, the thermal loads from the permeable pavement were 36 to 61% lower than the asphalt pavement, due primarily to lower runoff volumes (Sustainable Technologies Evaluation Program 2015, p. 21-23)

Heifer International

PRECEDENT 03



Fig. 2.17—Heifer International Green Parking Lot. (Heifer International 2025). Used with permission for educational or non-profit purposes only.

LOCATION: Little Rock, Arkansas

CONTEXT: Industrial, Urban, Arkansas River to North

COMPLETED DATE: 2006

SIZE/SCOPE: 94,000 ft^2 office building

DESIGN TEAM:
BNIM

STAKEHOLDERS: Heifer International

COST/FUNDING: $188 per ft^2

ISSUE ADDRESSED:
The land where Heifer International's headquarters sits is a former industrial waste site that we rehabilitated into a wetlands habitat. Crews removed leaky storage tanks, stripped polluted soil and hauled away debris. Ecologists then conducted testing to make sure all contaminants were cleared. The cleanup was among the largest land recoveries of its kind ever completed in Arkansas. About 75,000 tons — or 4,500 truckloads — of contaminated soil was removed from the site (Heifer International 2025, "The Site" section).

GREEN INFRASTRUCTURE USED:

Parking Lot Materials

- Gravel Pave system and Bioswales in lot design, reducing the 60% originally impervious surface
  - Gravel pave system constructed of 100% recycled material (90% post-industrial + 10% post-consumer)
  - System consists of sandy gravel base, covered with filter fabric to contain sand and restrict plants from growing through, and topped with layer of crushed gravel
    - Maintenance for gravel pave requires roughly 8 hours a month
- Aisles and driveways of lot paved with concrete rather than asphalt
  - Concrete is 90% recycled cement w/ top layer made of locally produced concrete (reducing materials transport impacts)
  - Light color + reflectivity of concrete helps reduce HIE compared to asphalt
- Heifer employees helped recycle brick pavers from buildings that previously occupied the site including for the laid in circular driveway and sidewalks of lot
- Reused on-site 70% of soil removed for construction of parking lot
- Energy efficient lighting used to illuminate parking area
- All parking lot materials purchased from local dealers within 500 miles of site
  - Supports local economy + reduces transportation emissions

(EPA 2008a, p. 31)

Innovative Stormwater Management

- Conventional parking would have channeled runoff into adjacent Arkansas River
- Heifer parking lot designed to avert runoff via creation of closed loop water collection system
- Guides stormwater into open space medians, and bioswales, and ultimately into constructed wetlands
- Includes 5 bioswales (15,795 sq ft, or .36 acres)
  - 3-ft deep sand filtration basins + native flora that slow + filter water
  - Within 24 hrs, any remaining water in bioswales that does not infiltrate into soil slowly drains via sub-surface drainage system into retention basin + circulated to man-made wetland surrounding the building
- Wetlands store 750,000 gallons of water and are designed to mimic natural system
- Fluctuating water levels at certain times of year
- Retention basin and wetlands provide irrigation water for landscaping and wetlands provide habitat for wildlife (birds, watersnakes, dragonflies, butterflies, turtles, and frogs)
- Indigenous plants not require pesticide; provide food + shelter to wildlife
- Plant species should be able to sustain under natural rainfall events (not require irrigation)
- Combination of sprinkler + drip irrigation used in bioswales and cistern with 32,000 gallon storage capacity
  - Cistern mainly used to supply bathroom facilities + HVAC
- When stormwater management system fully operational, all irrigation water will come from recycled site water system or captured rainwater

(EPA 2008a, p. 31-32)



Fig. 2.18—Heifer International Green Parking Lot. (Heifer International 2025). Used with permission for educational or non-profit purposes only.

Reduced Automobile Reliance

- Promotes alternative transport/commuting
- Local bus system route change for improved public transportation access for employees
- Company subsidizes cost of public transit, provides on-site bike racks, + encourages participation in organizations 'commuting program'
- 6 premium parking spots for carpooling or hybrid vehicles
- The city's plan for new bike trail (connects North Little Rock to Little Rock, Arkansas) will lead to Heifer site

(EPA 2008a, p. 31)

04 PROJECTIVE DESIGN



Fig. 3.1—Tailgating at Bill Snyder Stadium. Photograph by Natalie Kerner. 2024. Manhattan, KS.

KANSAS STATE UNIVERSITY STADIUM PARKING LOT

Kansas State University parking lots present a significant challenge in stormwater management, as they generate substantial runoff with degraded water quality. This is true for the K-State Stadium Southeast Parking Lot, south of the K-State Football Practice Facilities and east of Bramlage Coliseum.

This chapter explores a projective design approach that integrates green infrastructure solutions to mitigate these environmental impacts while enhancing the site's functionality and aesthetics. Informed by a comprehensive literature review and precedent studies, the proposed design incorporates permeable pavements, bioswales, and vegetated retention areas to reduce runoff volume and improve water quality. Additionally, the design responds to the site's unique context, considering the high-traffic demands of Bill Snyder Stadium and the residential needs of the nearby Jardine Apartments. By balancing sustainability with practical usability, this project aims to transform the parking lot into a model for resilient urban infrastructure.



The projective design is part of a larger plan created for the Campus Rainworks Competition put on by the EPA. This report focuses solely on the parking lot area southeast of Bill Snyder Stadium, however is designed to work with the rest of the proposed interventions. The design was also created with the intention of feasibility within Kansas State University's goals and budget constraints.

The overall site design begins with green infrastructure implementations in the north east parking lot (highlighted in Fig. 3.2). Stormwater runoff is directed into the swale system beginning west of the Chester E. Peters Recreation Complex, trailing through the garden space, ultimately leading to the constructed wetlands southeast of the Recreation Complex. This integrated green infrastructure design will improve the water quality of the Campus Creek, mitigate flooding, and alleviate pressure on the gray infrastructure systems.

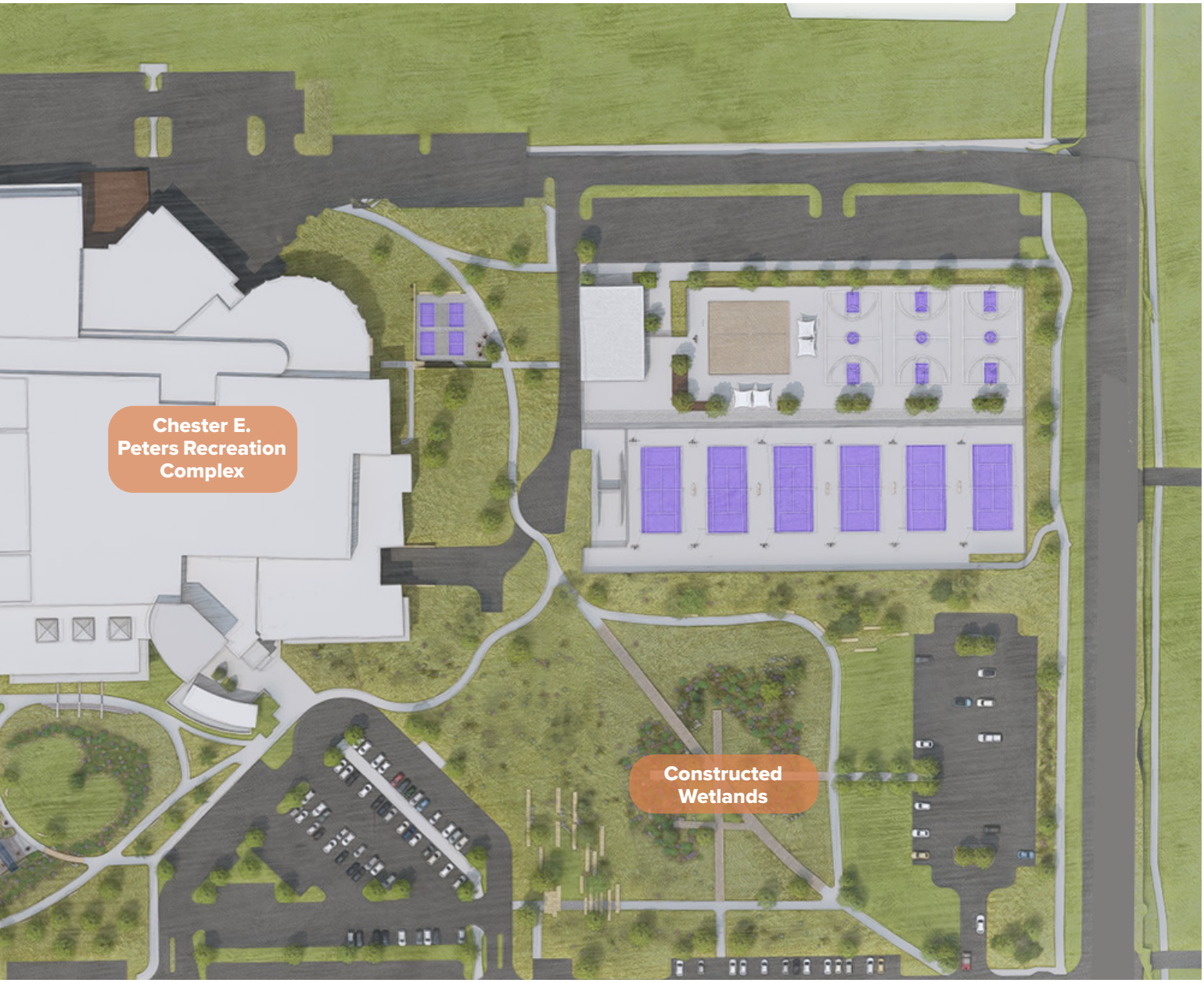


Fig. 3.2—Stadium and Peters Rec Area Site Plan. Created by Devin Tilley, 2025. Plan in Lumion & Photoshop.

SITE ANALYSIS



Fig. 3.3—Aerial Photo of K-State Campus & Project Area Context. Adapted from Google Earth 2025. Diagram in Adobe Illustrator by Natalie Kerner. 2025.

The focus area for this project is the southeast parking lot for Bill Snyder Stadium on the Kansas State University Campus in Manhattan, Kansas. The overall surrounding context is largely campus buildings, roadways, parking lots, a large hospital complex, and residential development.

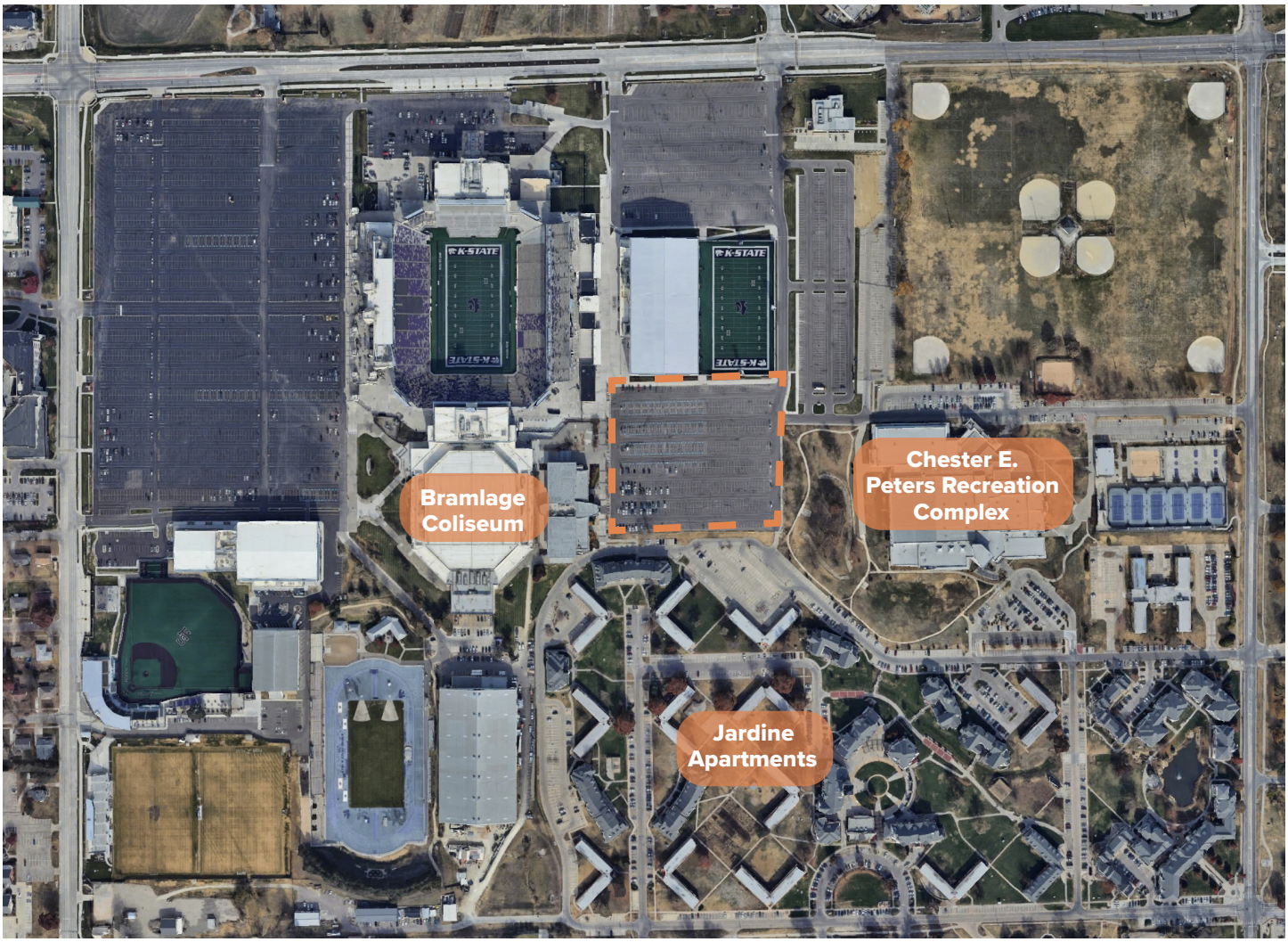


Fig. 3.4—Aerial Photo of K-State Campus & Project Area Context. (Adapted from Google Earth 2025). Diagram in Adobe Illustrator by Natalie Kerner. 2025.

The immediate context includes multiple parking lots for to accommodate for the stadium, Chester E. Peter's Recreation Center, Bramlage Coliseum, and Jardine Apartments. At about 38 acres, these expanses of surface parking are highly concentrated in this area. K-State football games generate a high volume of vehicular traffic on gamedays, but the rest of the year the large parking lots stand mostly empty, with partial use for the K-State basketball games and other events.

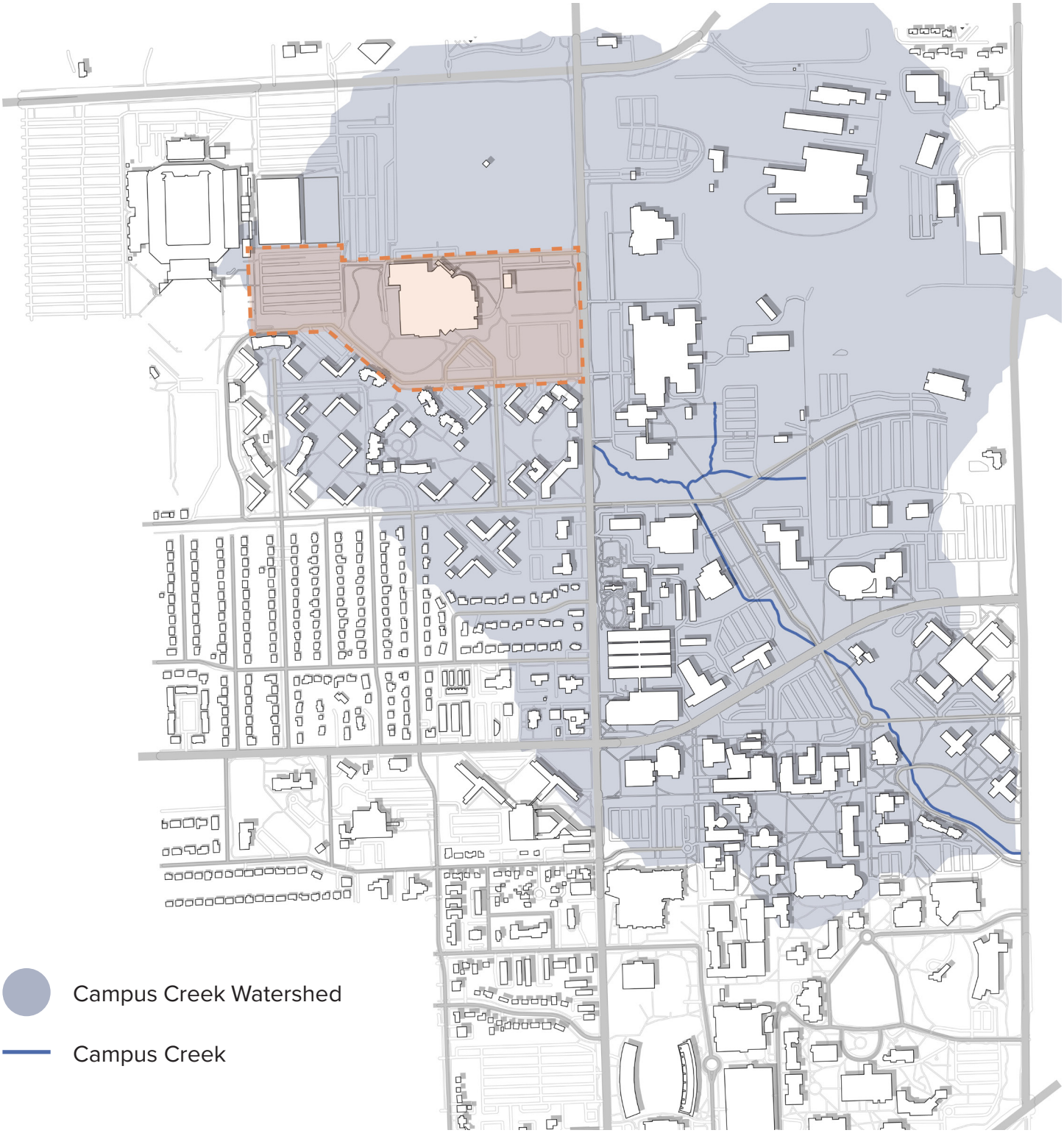


Fig. 3.5—Upper Campus Creek Watershed Diagram. Adapted from "Watershed Diagram" by Lukas Freelove, 2025. Diagram in Adobe Illustrator.

WATERSHED

The site sits at the northwest branch of the Campus Creek Watershed, heavily contributing to the degradation of the Campus Creek. As discovered in the literature review, large areas of impervious surfaces create high volumes of stormwater runoff.



Fig. 3.6—Existing Green Infrastructure on K-State Campus. Adapted from "Existing Green Infrastructure Diagram" by Lukas Freelove, 2025. Diagram in Adobe Illustrator.

EXISTING GREEN INFRASTRUCTURE

There are other green infrastructure projects around campus, however the only one around the site is a swale to the west of Chester E. Peters Recreation Complex which flows into a detention basin south of the Recreation Complex. However, the swale is heavily degraded and eroded and large rocks have been placed along the length of each swale but do not increase its effectiveness. Sediment-laden stormwater from the swales moves into the regularly mowed detention basin.

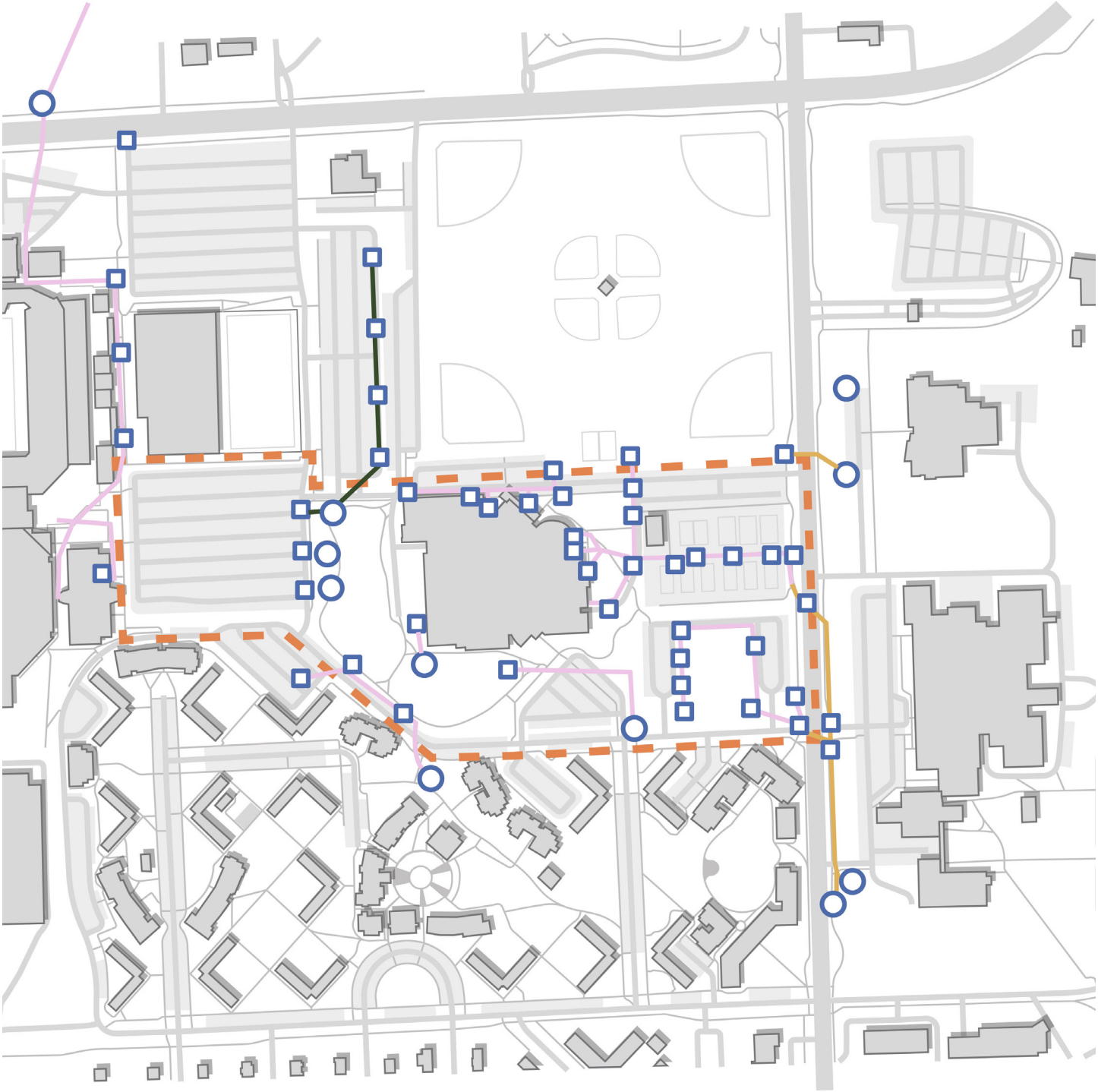


Fig. 3.7—Existing Gray Infrastructure on Site. Adapted from "Existing Gray Infrastructure Diagram" by Lukas Freelove, 2025. Diagram in Adobe Illustrator.

Current Green Infrastructure

Stormwater Inlets

Stormwater Discharge Points

Stormwater Pipes

Inefficient Stormwater Pipes Per 2013 Report

Probable Locations

Site Boundaries

CURRENT GRAY INFRASTRUCTURE

The current gray infrastructure moves stormwater runoff towards the southeast of the site, and ultimately into Campus Creek. On the east edge of the parking lot, three inlets collect the stormwater runoff from the surface. This runoff is piped to three outlets on the west side of the recreation complex and flows through the swales.

This part of campus is vital when considering green infrastructure projects, because it is at the head of the watershed and therefore affects all connecting waterways within the watershed. There is also a significant portion of campus showcased with the Bill Snyder Stadium, Bramlage Coliseum, and Chester E. Peters Recreation Center. This would be an ideal area to display that Kansas State University's campus is both socially and environmentally positive.

CALCULATIONS

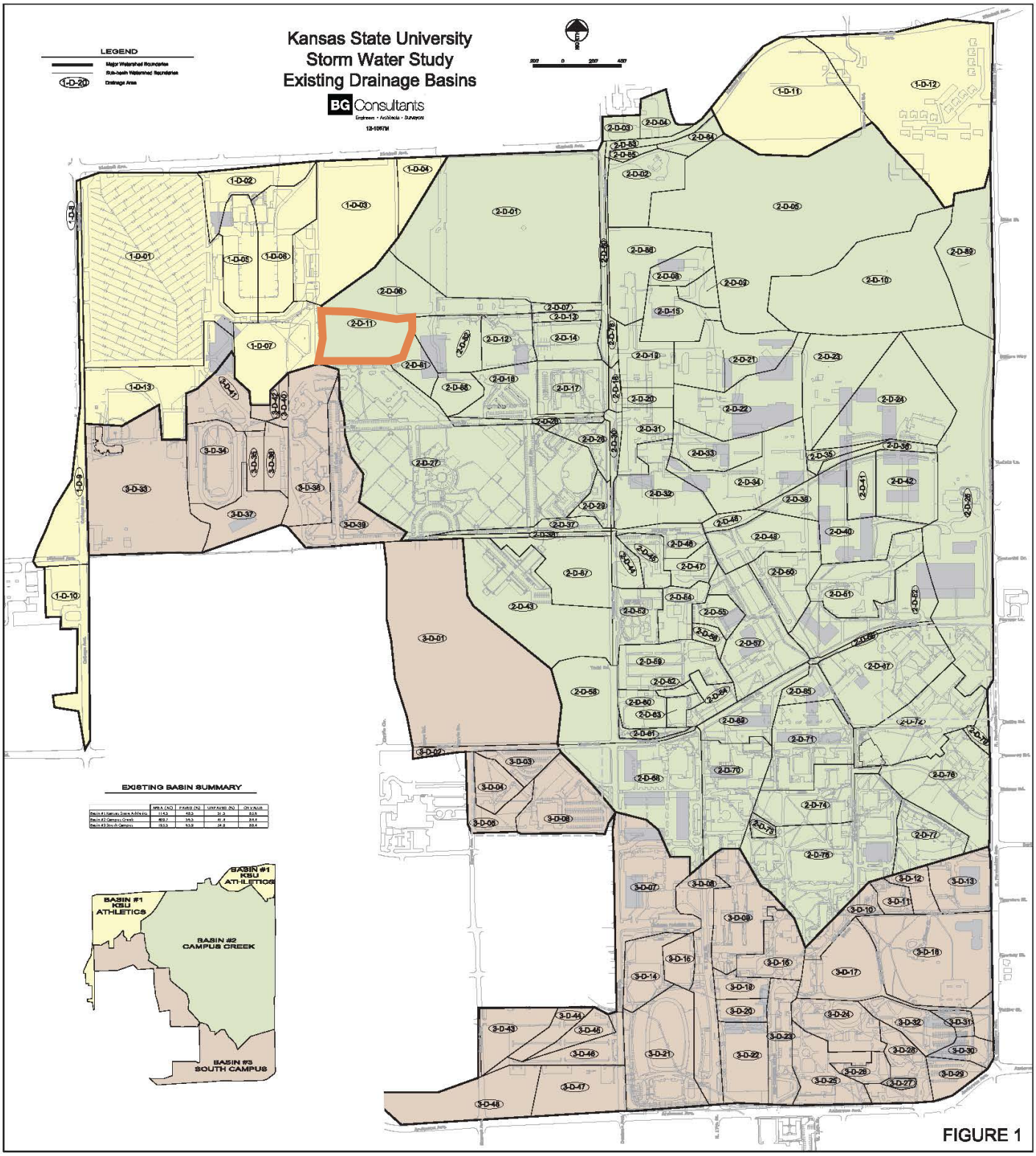


Fig. 3.8—Kansas State University Stormwater Study Existing Drainage Basins. (BG Consultants 2013).

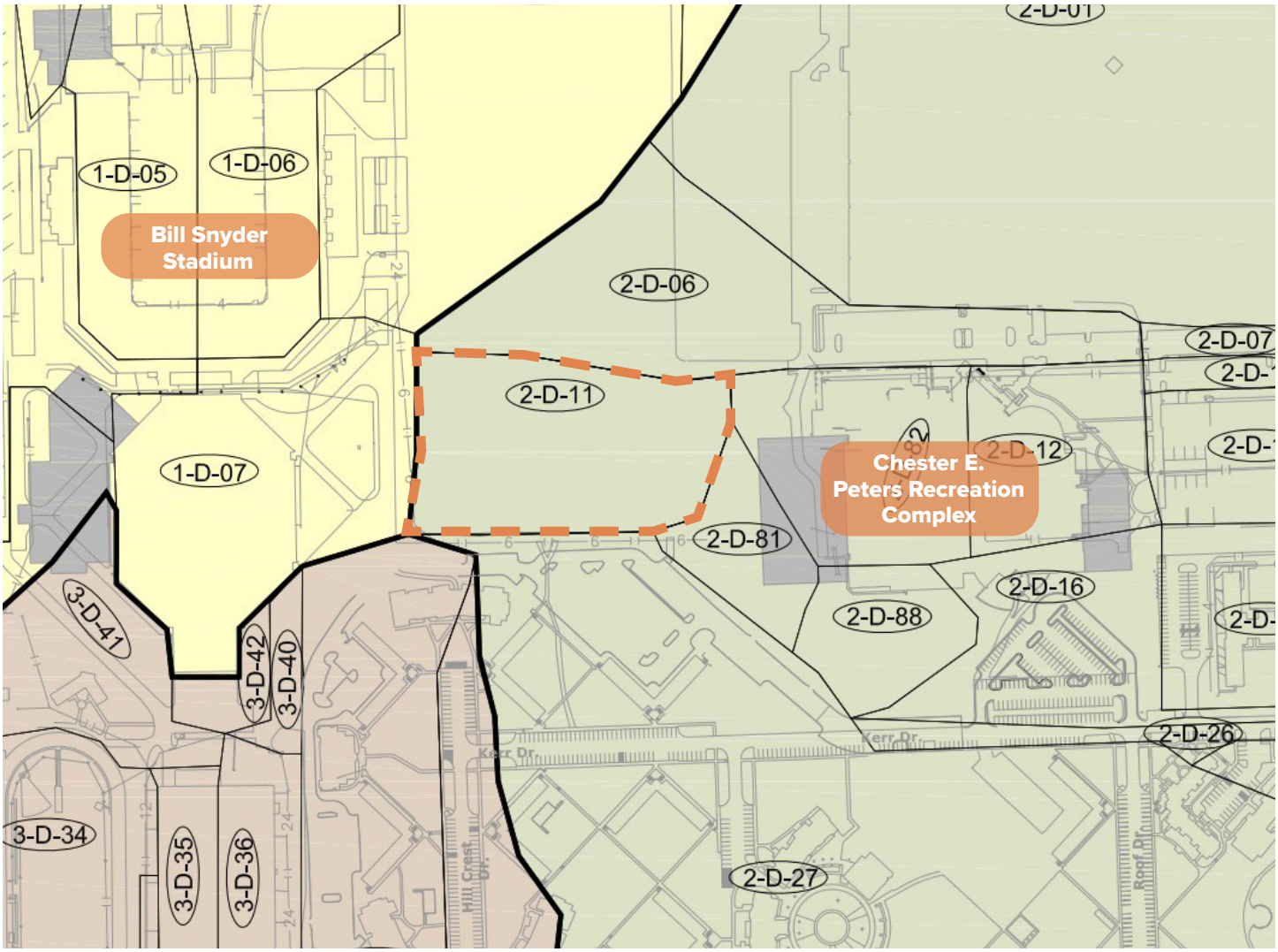


Fig. 3.9—Kansas State University Stormwater Study Existing Drainage Basins 2-D-11. (BG Consultants 2013).

The site is within the 2-D-11 drainage area within the larger major Campus Creek Watershed. The area is drainage area is 4.94 acres, 89% of it being impervious. The average slope is 1.82%, draining from the northwest to the southeast (BG Consultants 2013, "Figure 1").

USGA Streamstat

EDWARDS HALL

2-yr, 60 min		5-yr, 60 min		10-yr, 60 min		20-yr, 60 min	
Weighted CN	89	Weighted CN	89	Weighted CN	89	Weighted CN	89
P (mm)	40	P (mm)	51	P (mm)	60	P (mm)	73
I (mm)	6.3	I (mm)	6.3	I (mm)	6.3	I (mm)	6.3
S (mm)	31.7	S (mm)	31.7	S (mm)	31.7	S (mm)	31.7
Q (mm)	17.3	Q (mm)	26.1	Q (mm)	33.7	Q (mm)	45.2
Area (m^2)	486900	Area (m^2)	486900	Area (m^2)	486900	Area (m^2)	486900
WQv (m^3)	**8439**	WQv (m^3)	**12716**	WQv (m^3)	**16423**	WQv (m^3)	**21995**

Count	Type	CN	Area Cover (Decimal)	CN*Area Cover	Weighted CN	NOTES
2	Soybeans	80	0.004140787	0.33126294	**89**	For bioretention WQv ponding depth is ~9in, for CSW ~15in
1	Alfalfa	80	0.002070393	0.16563147		Or .23 to .38m
2	Other Hay/Non Alfalfa	80	0.004140787	0.33126294		
74	Developed/Open Space	85	0.15320911	13.02277433		
151	Developed/Low Intensity	85	0.3126294	26.57349896		
151	Developed/Med Intensity	95	0.3126294	29.69979296		
72	Developed/High Intensity	95	0.149068323	14.16149068		
2	Deciduous Forest	70	0.004140787	0.289855072		
2	Mixed Forest	70	0.004140787	0.289855072		
26	Grassland/Pasture	75	0.053830228	4.037267081		
483	**<-TOTAL COUNT**					

Q = Precipitation Excess (runoff mm)
P = Cumulative Precipitation (mm)
S = Potential Maximum Retention
CN = Curve Number

ArcGIS Pro #1

EDWARDS HALL

2-yr, 60 min		5-yr, 60 min		10-yr, 60 min		20-yr, 60 min	
Weighted CN	90	Weighted CN	90	Weighted CN	90	Weighted CN	90
P (mm)	40	P (mm)	51	P (mm)	60	P (mm)	73
I (mm)	5.5	I (mm)	5.5	I (mm)	5.5	I (mm)	5.5
S (mm)	27.7	S (mm)	27.7	S (mm)	27.7	S (mm)	27.7
Q (mm)	19.1	Q (mm)	28.2	Q (mm)	36.1	Q (mm)	47.8
Area (m^2)	486900	Area (m^2)	486900	Area (m^2)	486900	Area (m^2)	486900
WQv (m^3)	**9296**	WQv (m^3)	**13747**	WQv (m^3)	**17569**	WQv (m^3)	**23277**

Count	Type	CN	Area Cover (Decimal)	CN*Area Cover	Weighted CN	NOTES
83	Developed/Open Space	85	0.16468254	13.99801587	**90**	For bioretention WQv ponding depth is ~9in, for CSW ~15in
152	Developed/Low Intensity	85	0.301587302	25.63492063		Or .23 to .38m
177	Developed/Med Intensity	95	0.351190476	33.36309524		
88	Developed/High Intensity	95	0.174603175	16.58730159		
1	Barren	70	0.001984127	0.138888889		
1	Mixed Forest	70	0.001984127	0.138888889		
2	Grassland/Pasture	75	0.003968254	0.297619048		
504	**<-TOTAL COUNT**					

ArcGIS Pro #2

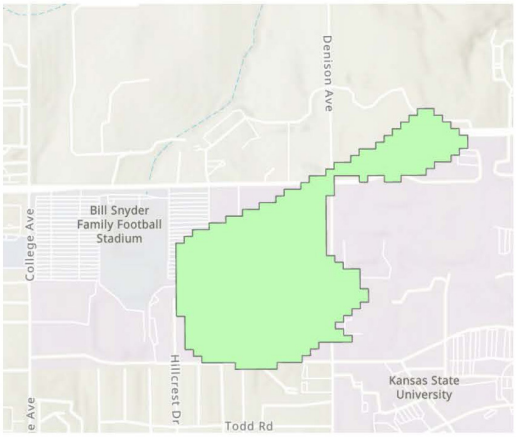
EDWARDS HALL

2-yr, 60 min		5-yr, 60 min		10-yr, 60 min		20-yr, 60 min	
Weighted CN	90	Weighted CN	90	Weighted CN	90	Weighted CN	90
P (mm)	40	P (mm)	51	P (mm)	60	P (mm)	73
I (mm)	5.7	I (mm)	5.7	I (mm)	5.7	I (mm)	5.7
S (mm)	28.3	S (mm)	28.3	S (mm)	28.3	S (mm)	28.3
Q (mm)	18.8	Q (mm)	27.9	Q (mm)	35.8	Q (mm)	47.4
Area (m^2)	486900	Area (m^2)	486900	Area (m^2)	486900	Area (m^2)	486900
WQv (m^3)	**9176**	WQv (m^3)	**13604**	WQv (m^3)	**17411**	WQv (m^3)	**23100**

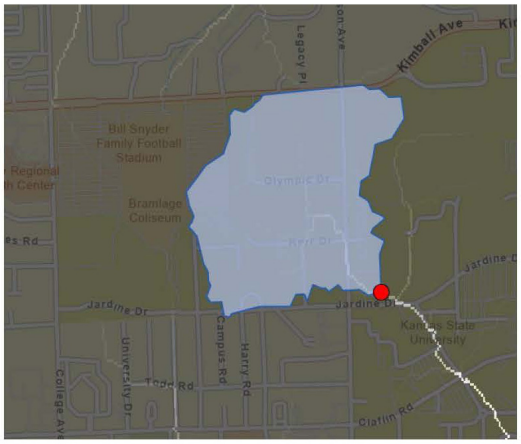
Count	Type	CN	Area Cover (Decimal)	CN*Area Cover	Weighted CN	NOTES
80	Developed/Open Space	85	0.173535792	14.7505423	**90**	For bioretention WQv ponding depth is ~9in, for CSW ~15in
142	Developed/Low Intensity	85	0.30802603	26.18221258		Or .23 to .38m
158	Developed/Med Intensity	95	0.342733189	32.55965293		
77	Developed/High Intensity	95	0.1670282	15.86767896		
1	Barren	70	0.002169197	0.151843818		
1	Mixed Forest	70	0.002169197	0.151843818		
2	Grassland/Pasture	75	0.004338395	0.32537961		
461						

Fig. 3.10—Stormwater Calculations and Map Diagrams for the Stadium and Peters Recreation Drainage Area. Adapted from an Excel Spreadsheet prepared by Monavarian, Alireza Monavarian.

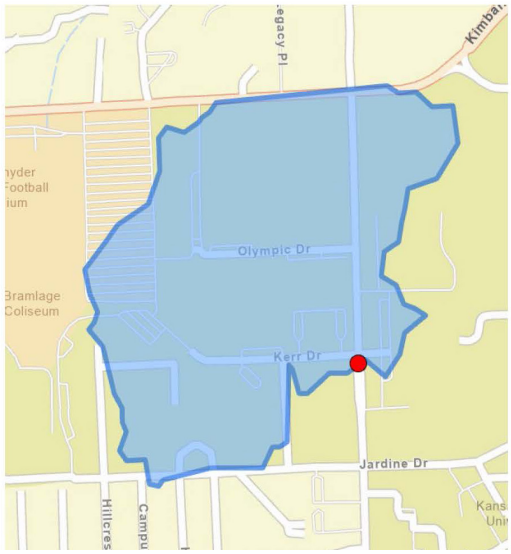
Watershed delineation done in both ArcGIS Pro and USGS Stream Stat, similar watershed area produced.



Watershed delineation done in both ArcGIS Pro and USGS Stream Stat, similar watershed area produced.



Watershed delineation done in both ArcGIS Pro and USGS Stream Stat, similar watershed area produced.



Calculations were developed by Kansas State University biological and agricultural engineering student, Alireza Monavarian, to determine the stormwater runoff volume or water quality volume (WQv) for 2-yr, 5-yr, 10-yr, 20-yr 60 minute storm events for the site. This was beneficial for the design team as we sought to reduce flooding, swale and downstream erosion, and improve campus creek water quality. Water quality volume is, "the amount of stormwater runoff from any given storm that should be captured and treated in order to remove a majority of storm water pollutants on an average annual basis" (Ohio EPA 2018).

The TR-55 curve method was used with ArcGIS Pro and USGA Streamstat to delineate the watersheds. Figure 3.10 shows the stormwater calculations using three different modeling approaches.

Without reducing the amount of parking spaces significantly, it is unlikely that any green infrastructure implemented in the parking lot would accommodate for the very high water quality volume levels. However, it is possible for an optimized, space-efficient solution to alleviate most of the 2-year to 5-year 60 minute storm events.

GREEN INFRASTRUCTURE DESIGN



Fig. 3.11—K-State Stadium Southeast Parking Lot Site Plan. Rendered in Lumion and Adobe Photoshop by Natalie Kerner, 2025.

PERMEABLE PAVING STRIPS

BIORETENTION CELLS

Adapted from Monavarian's proposed approaches, the proposed site design features a central promenade that enhances the visitor experience by creating a more inviting and pedestrian-friendly environment. This mall, composed of permeable paving and lined with plantings (excluding drive aisles), aligns with the existing sidewalk to the south, seamlessly connecting to the Jardine Apartments.

To improve stormwater management, the parking space divider lines will incorporate permeable paving with an underdrain system that directs runoff to a bioretention cell. From there, collected water will be conveyed through a drainage system to bioswales located east of the parking lot, facilitating infiltration and thus improving water quality.

On the southern edge of the site, a new sidewalk is proposed to guide pedestrian movement toward the Bramlage Coliseum entrance. Adjacent to this sidewalk, a retaining wall and staircase will provide both functional and aesthetic enhancements including stormwater management. The terraced planters will function as level-spreaders, slowing down and infiltrating stormwater into amended soils, and nourishing the trees and other vegetation. In front of the retaining wall, large sculptural Kansas State University letters will serve as a landmark, reinforcing the entryway's significance and enhancing the gameday and tailgating experience.



Fig. 3.12—Entrance Perspective of the K-State Stadium Southeast Parking Lot Site Plan. Rendered in Lumion and Adobe Photoshop by Natalie Kerner, 2025.

The water directed from the permeable paving system to these bioretention cells supports the growth of the vegetation. The large trees provide ample shade, creating a cooler, more inviting walkway for people to walk and tailgate.



In this proposed system, stormwater flows across the asphalt towards the strips of permeable paving. The lip curb on the southern side of the 4' permeable paving strips allows the water to continue to flow from east to west along these strips. The water flows into the bioretention cells at the ends of these permeable paving strips.

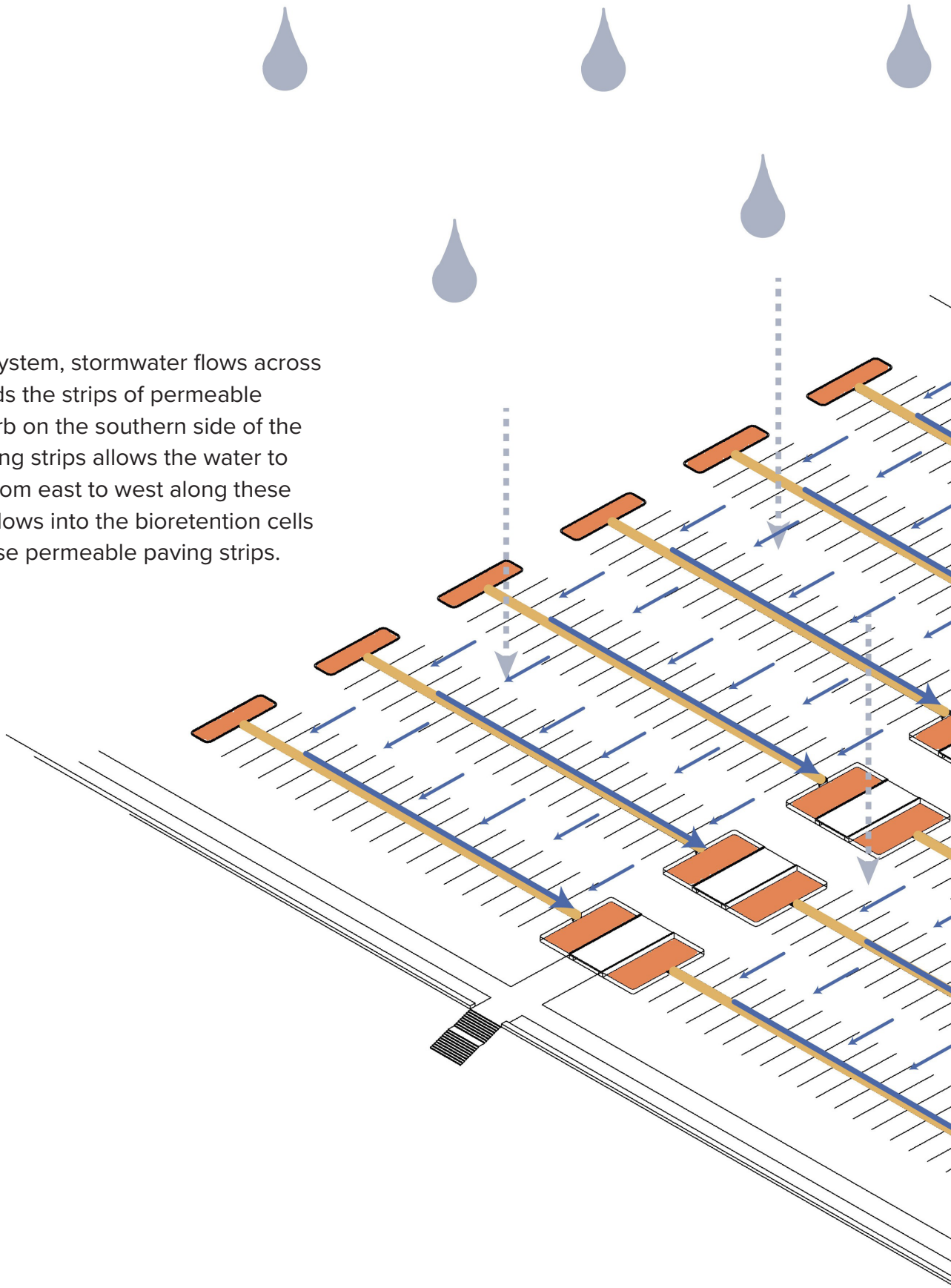
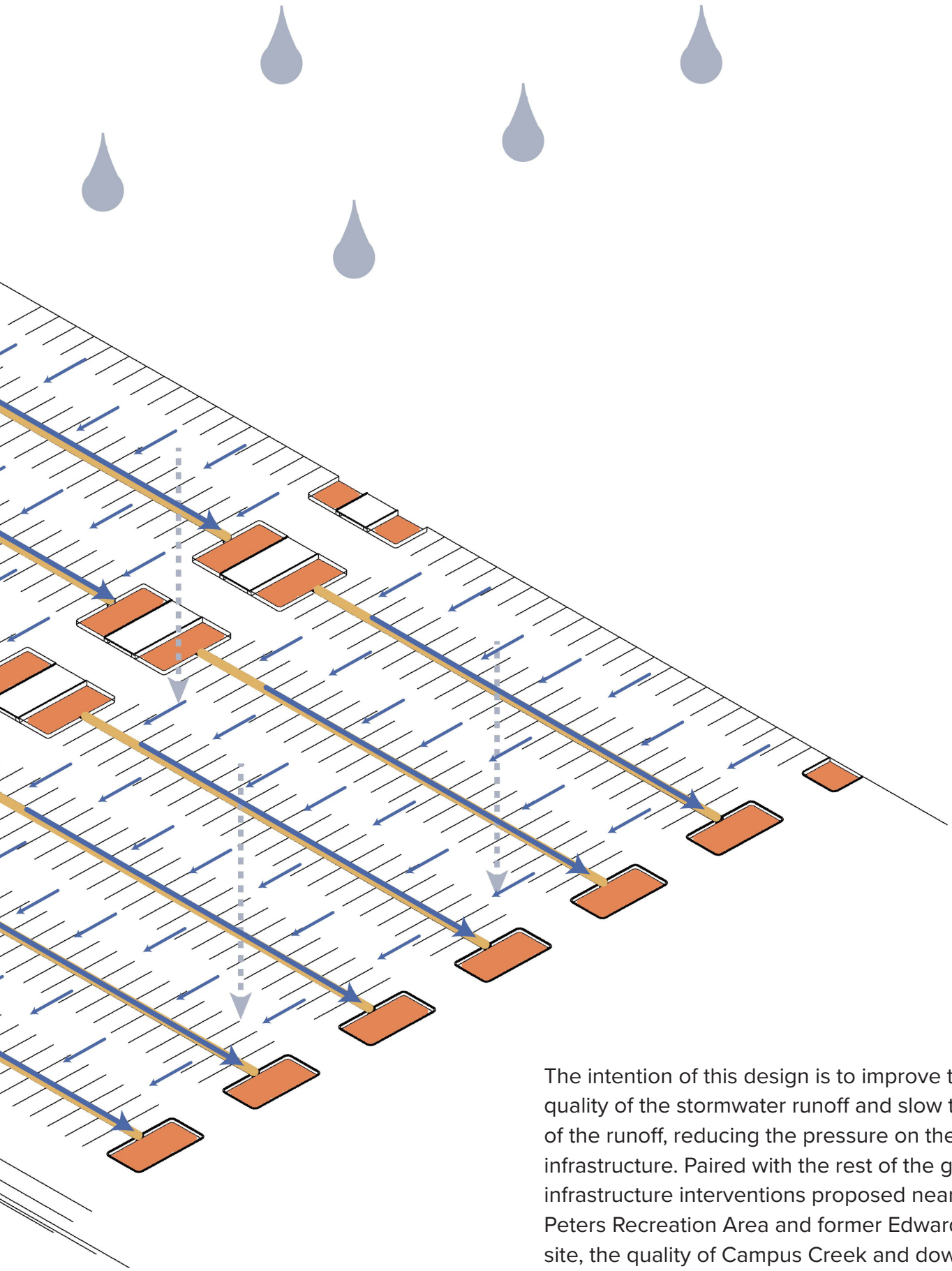


Fig. 3.13—Parking lot water flow diagram. Diagram in Adobe Photoshop by Natalie Kerner. 2025.



The intention of this design is to improve the quality of the stormwater runoff and slow the speed of the runoff, reducing the pressure on the gray infrastructure. Paired with the rest of the green infrastructure interventions proposed near the Peters Recreation Area and former Edwards Hall site, the quality of Campus Creek and downstream water bodies should greatly improve.

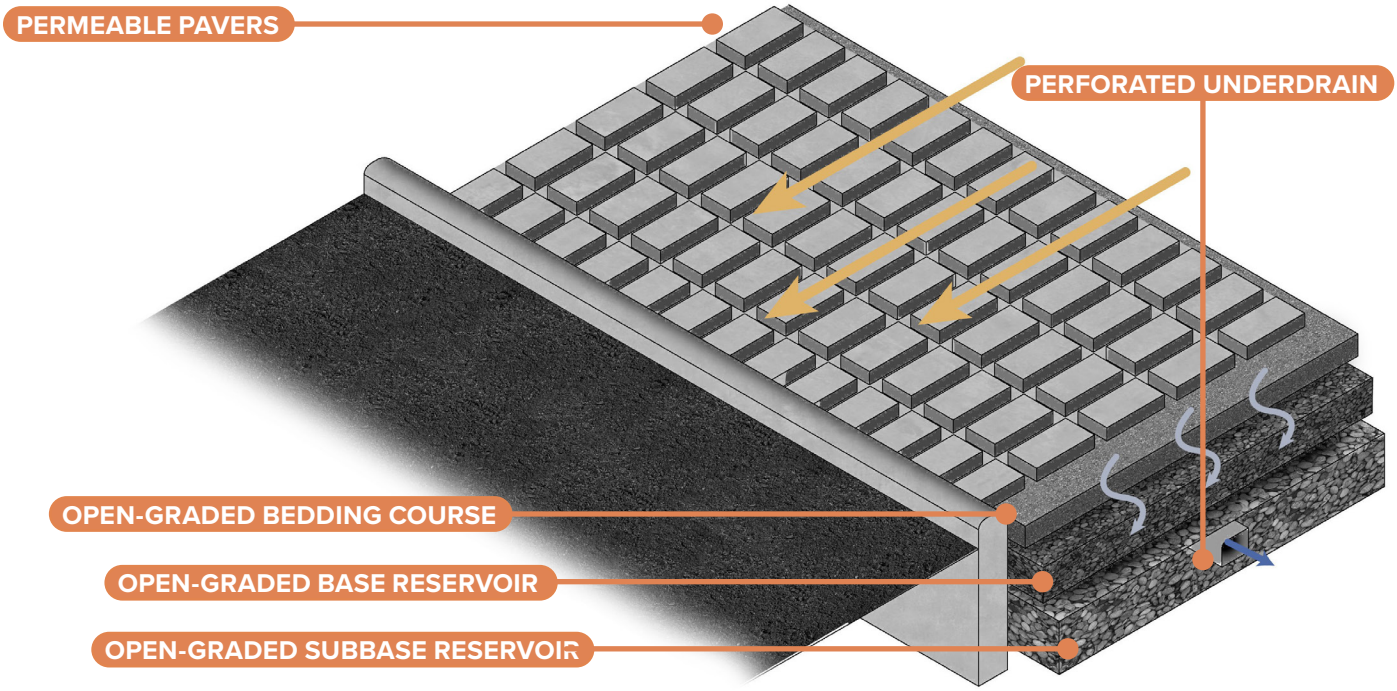


Fig. 3.14—Permeable paving water flow diagram. Diagram in Adobe Photoshop by Natalie Kerner. 2025.

The permeable paving system allows water to infiltrate through the gravel subbases and into a perforated pipe that leads to the bioretention cells. The lip curb on the south ensures that the stormwater slows enough to infiltrate the system, instead of the stormwater flowing right over it.

The system will require power washing and vacuuming as needed to prevent clogging and ensure that it is functioning properly.

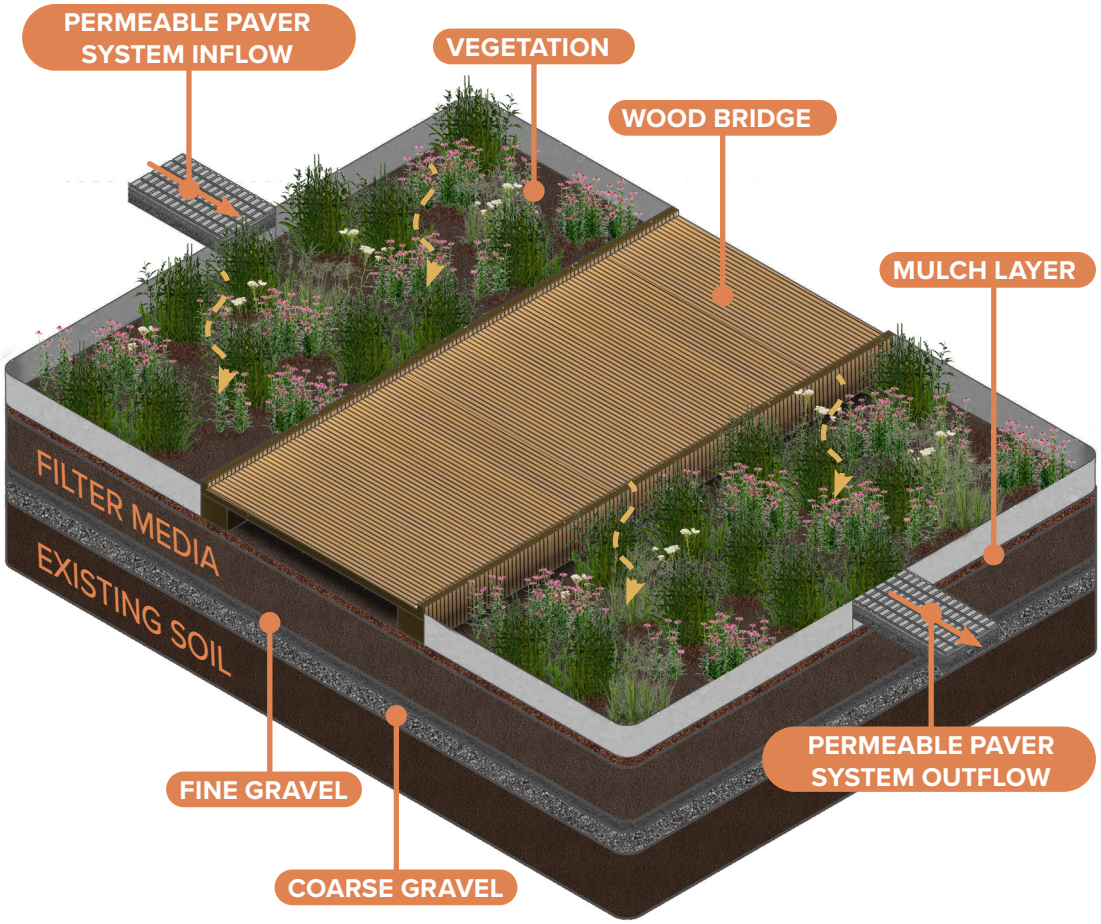


Fig. 3.15—Bioretention cell water flow diagram. Diagram in Adobe Photoshop by Natalie Kerner. 2025.

After flowing through the permeable paving system into the bioretention cell, the stormwater infiltrates into the soil. The water also supports the vegetation in the bioretention cell. There is a perforated pipe under the permeable paving system on the other side as well. This also acts as a pipe inlet, in order to prevent flooding and over-saturating the plants.

Maintenance will be required including monthly inspections and trash removal. Annual removal of dead vegetation, and pruning is necessary for optimal performance.

06 CONCLUSION



Fig. 4.1—Germantown_Acad_Parking. (Montgomery County Planning Commission 2016).

SUMMARY

While parking lots serve as essential infrastructure for modern transportation, their widespread prevalence comes with significant social and environmental consequences. While vehicular-centered infrastructure is prioritized, pedestrian-focused infrastructure and public transit systems are neglected, contributing to urban sprawl and social isolation. Additionally, their impervious surfaces contribute to high volumes of stormwater runoff, pollution, and ecological degradation. As automobile dependency continues to rise and parking infrastructure expands, these issues will only become more severe, especially in the face of climate change. Addressing this challenge requires a multidisciplinary approach, bringing together landscape architects, ecologists, and many other professions to develop more sustainable and adaptive solutions for the future of parking and urban design.

This report illustrates that green infrastructure solutions takes many forms and can be adapted to size and budget limitations. The projective design for the Bill Snyder Stadium parking lot at Kansas State University serves as an example that green infrastructure can be implemented in a way that still accommodates for high capacities, but also reduces runoff and improves water quality. The design only takes away around 100 parking spots.

LIMITATIONS

It is necessary to address the limitations within this report. The projective design was created with the intention of feasibility within the University's needs and budget. A few meetings with campus planning and facilities took place to ensure that these areas were observed in the design. However, further meetings and collaboration with multiple disciplines would be very important.

There are many sources that discuss green infrastructure types and costs. This report only covers a small range of that literature. Naturally, with abundant literature on green infrastructure, there is conflicting information. Details such as costs, maintenance, and performance will vary depending on location, context, etc.

FUTURE RESEARCH

While the implementation of green infrastructure in parking lots is an improvement from the standard of acres of impervious surface, there is an opportunity that these spaces be used for more than just storing cars. Activating these lifeless spaces could have many benefits socially, economically, and environmentally. There are already existing activities such as farmers markets, pop-up shops, and tailgating. However, paired with green infrastructure techniques, these activities could grow and become more widespread. Further research regarding these issues would be a very helpful addition to the green infrastructure literature.



Fig. 4.2—Green parking lot perspective at sunset. Rendered in Lumion and Adobe Photoshop by Natalie Kerner. 2025.



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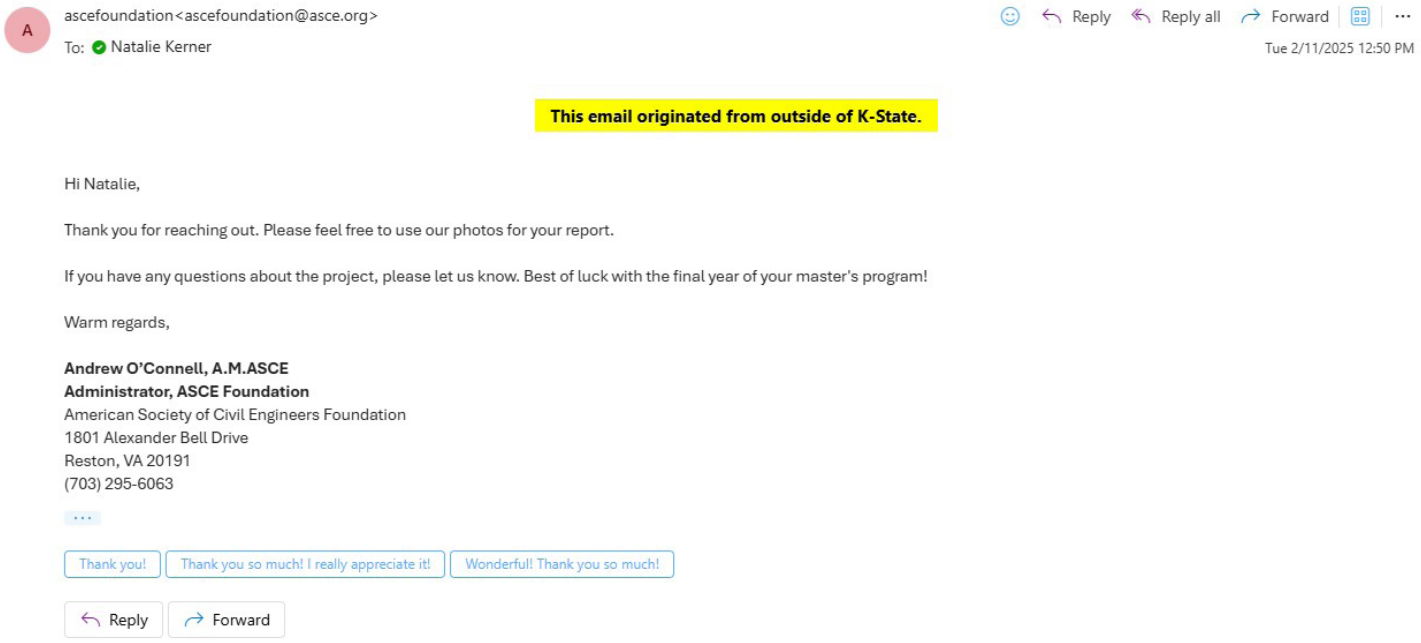
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IMAGE PERMISSIONS



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To: Natalie Kerner

Reply Reply all Forward
Tue 2/11/2025 12:50 PM

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Hi Natalie,

Thank you for reaching out. Please feel free to use our photos for your report.

If you have any questions about the project, please let us know. Best of luck with the final year of your master's program!

Warm regards,

Andrew O'Connell, A.M.ASCE
Administrator, ASCE Foundation
American Society of Civil Engineers Foundation
1801 Alexander Bell Drive
Reston, VA 20191
(703) 295-6063

...

Thank you! | Thank you so much! I really appreciate it! | Wonderful! Thank you so much!

Reply Forward

AJ

Afiya Jilani<Afiya.Jilani@trca.ca>

To: Natalie Kerner

Reply | Reply all | Forward

Fri 2/28/2025 11:42 AM

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You can use the images from the linked page. Please attribute them as "Courtesy of Toronto and Region Conservation Authority."
Thank you and have a good weekend.

Afiya Jilani (She/Her)
Specialist, Communications & Media Relations
Communications, Marketing and Events | Corporate Services

T: (416) 661-6600
C: (647) 386-0303
E: afiya.jilani@trca.ca
A: 5 Shoreham Drive, Toronto, ON, M3N 1S4 | trca.ca

Toronto and Region Conservation Authority

GREATER TORONTO'S TOP 2025 EMPLOYERS

From: Natalie Kerner <nckerner@ksu.edu>
Sent: February 19, 2025 3:24 PM
To: Afiya Jilani <Afiya.Jilani@trca.ca>
Subject: Re: New submission from TRCA Media Request Form

EXTERNAL SENDER

Thank you! | The changes have been made. | Will do, thanks!

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DR

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Kind regards,

Shunta' Stubbs
Donor Services Representative
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