exceeding intent:

A precedent library of exemplary **GREEN STORMWATER INFRASTRUCTURE** PROJECTS

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TEAM MEMBERS

MELIORA DESIGN
Michele Adams, PE, LEED AP
Chelsea Fitzpatrick

ANDROPOGON ASSOCIATES
Lauren Mandel, PLA, ASLA
Loretta Desvernine

ROOFMEADOW
Melissa Muroff, Esq.
Kate Farquhar, MLA

SITEGreen SOLUTIONS
Steve Benz, PE, LEED Fellow, Hon, ASLA

INDIGO JLD
Joyce S. Lee, FAIA, LEED Fellow

SITE: PHOENIX PARK PHASE I
PHOTO CREDIT: © Camden County Municipal Utilities Authority

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EXECUTIVE SUMMARY

Green stormwater infrastructure (GSI) occupies the nexus of environmental sustainability, adaptability, resilience, social equity, and a vibrant economy.

GSI, for the purposes of this library, is defined as soil-water-plant systems that intercept stormwater, infiltrate a portion of it into the ground, evaporate a portion of it into the air, and/or in some cases release a portion of it slowly back into the sewer system.

In addition to stormwater management and improved water quality, GSI provides benefits such as beautified communities, improved public health, creation of ecological habitat, and enhanced local economic vitality.

SITE: U.S. Coast Guard Headquarters
PHOTO CREDIT: © Andropogon Associates

These environmental, social, and economic benefits (the triple bottom line) are what makes GSI the preferred approach over centralized and decentralized gray infrastructure, and why cities and municipalities like Philadelphia have incorporated GSI into their portfolios to meet Clean Water Act goals and regulations. Philadelphia is leading the nation with its comprehensive stormwater management plan, *Green City, Clean Waters,* which focuses heavily on GSI, and includes regulations and incentives for developers, stormwater fees for property owners, and a defined target and timeline for achieving GSI "greened acre" goals. Because of increasing investment, especially in Philadelphia, GSI is a strong emerging industry.

In order to continue to increase public and private investment in GSI and ensure that it is incentivized and facilitated as much as possible, additional information is needed on the degree to which GSI performs – environmentally, socially, and economically.

Engineering and design professionals, developers and property owners, and regulators agree that there is a significant need for more data on the performance of GSI projects, and for that data to be publicly available. With broader understanding on the performance of best management practices (BMPs) such as rain gardens, stormwater tree trenches, porous pavement, and green roofs, industry professionals can continue to improve the design and performance of these tools; developers and property owners can increase their knowledge-base on the value of investing in GSI; and regulatory agencies can expand the performance metrics used to approve and credit GSI projects.

To address this need, the Sustainable Business Network of Greater Philadelphia's (SBN) GSI Partners and the Delaware Valley Green Building Council (DVGBC), with team of leading industry professionals, have developed the following precedent library of exemplary GSI designs, systems, and approaches to inform the approval of more green and innovative stormwater management projects in Philadelphia. With greater understanding of how GSI performs, performance metrics and calculation methods can be updated, designs can continue to improve, and there can be more comfort and confidence from the development community that GSI is an effective and affordable way to meet city regulations.

The precedent library is a collection of highly effective GSI projects from urban areas across the country that have been selected for their ability to demonstrate the dynamic performance capacity of different types and classes of GSI practices, and their application at a range of project types and scales. Case studies discuss the degree to which these projects are exceeding their intents - environmentally, economically, and/or socially. This collection of case studies is complimented by peer-reviewed research that further defends the degree to which GSI performs.

This library will be used to support the successful implementation of *Green City, Clean Waters*, and to increase the industry's collective knowledge on the performance of GSI.

ABOUT THE ORGANIZATIONS

THE SUSTAINABLE BUSINESS NETWORK OF GREATER PHILADELPHIA (SBN)
sbnphiladelphia.org

GREEN STORMWATER INFRASTRUCTURE (GSI) **PARTNERS**
gsipartners.sbnphiladelphia.org

DELAWARE VALLEY GREEN BUILDING COUNCIL (DVGBC)
dvgbc.org

SITE: Lurie Garden
PHOTO CREDIT: © Lurie Garden

THE SUSTAINABLE BUSINESS NETWORK OF GREATER PHILADELPHIA is a non-profit membership organization of 400 locally-owned sustainability-minded businesses, and works to build a just, green, and thriving economy in the Greater Philadelphia region. We accomplish this by growing and educating a broad base of local, independent businesses and educating policymakers and the public.

SBN supports *Green City, Clean Waters* and its triple-bottom line approach, and through the GSI Partners, SBN is working to maximize the local economic, environmental, and social impact of the plan.

GREEN STORMWATER INFRASTRUCTURE PARTNERS is a signature initiative of SBN working to advance the local GSI industry, innovation, and the local economy as it relates to GSI. Formed in 2012 in response to Philadelphia's ambitious and innovative stormwater management plan, *Green City, Clean Waters,* the GSI Partners advocate for the greenest approaches to be facilitated and incentivized as much as possible, and for the public and private investment to remain as local as possible. Members include locally-owned engineering and landscape architecture firms; landscape design, build, and maintenance firms; and material suppliers whose services and products pertain to GSI. Many members are recognized locally, regionally, and nationally as industry experts.

DELAWARE VALLEY GREEN BUILDING COUNCIL is a mission-based non-profit organization working to foster transformative impact in our communities through green building education and advocacy. We represent over 500 individual members in southeastern Pennsylvania and the state of Delaware who work in the building, construction, design and manufacturing industries.

DVGBC's members from the landscape architecture and civil engineering communities occupy the leading edge in green infrastructure solutions to stormwater management. Practitioners from the region have been long-time leaders on the U.S. Green Building Council's Technical Advisory Group for the LEED Stormwater Management credits and the Sustainable Sites Initiative, and as such, have helped to share the leading voluntary standard in the practice.

DVGBC has a keen interest in supporting Philadelphia's *Green City, Clean Waters* plan and seeing its implementation succeed fully. Over the past three years, DVGBC has gathered leading practitioners from the field to learn from their experience with stormwater management projects in Philadelphia and discuss ways to support more innovative and vegetated solutions to stormwater management.

GSI STRATEGIC METHODS

Green Stormwater Infrastructure presents strategic methods which – if widely deployed – facilitate the restoration of natural hydrologic cycles.

Additional environmental benefits derive from or link to the potential for restoring hydrologic cycles.

SITE: KIDZOOU
PHOTO CREDIT: © Halkin Mason Photography

In 2009, Nancy Stoner of the Natural Resources Defense Council delivered testimony to the U.S. Congress with a comprehensive list detailing the goals and benefits of GSI and its role in addressing urban stormwater runoff.

PER STONER, THIS LIST INCLUDES:

SOURCE WATER PROTECTION – Green infrastructure practices provide pollutant removal benefits, thereby providing some protection for both ground water and surface water sources of drinking water. In addition, green infrastructure provides groundwater recharge benefits by putting stormwater back into the ground and enhances surface water quality by redirecting the high volume and velocity flows that scour streams and muddy drinking water sources.

CLEANER WATER – Percolation of stormwater through soil, uptake by vegetation, and water reuse reduce the volumes of stormwater runoff and, in combined systems, the volume of combined sewer overflows, as well as reduce concentrations of pollutants in those discharges.

ENHANCED WATER SUPPLIES – Most green infiltration approaches involve allowing stormwater to percolate through the soil where it recharges the groundwater and the base flow for streams, thus ensuring adequate water supplies for humans and more stable aquatic ecosystems. In addition, capturing and using stormwater conserves water supplies.

COMMUNITY BENEFITS – Trees and plants improve urban aesthetics and community livability by providing recreational and wildlife areas. Studies show that property values are higher, homes sell faster, and crime is reduced when trees and other vegetation are present.

HEALTH BENEFITS – Studies show that people who have access to green infrastructure in their communities get more exercise, live longer, and report better health in general. Exposure to green infrastructure (even through a window) improves mental functioning, reduces stress, and reduces recovery time from surgery.

COST AVOIDANCE – Green infrastructure saves capital costs associated with paving, curb and gutter, building large collection and conveyance systems, and digging big tunnels and centralized stormwater ponds; operations and maintenance expenses for treatment plants, pumping stations, pipes, and other hard "gray" infrastructure; energy costs for pumping water around; cost of treatment during wet weather; and costs of repairing the damage caused by stormwater, such as streambank restoration.

MODERATED IMPACTS OF CLIMATE CHANGE – Climate change impacts and effects vary regionally, but green infrastructure techniques provide adaptation benefits for a wide array of circumstances, by conserving and reusing water, promoting groundwater recharge, reducing surface water discharges that could contribute to flooding.

REDUCED FLOODING – Green infrastructure both controls surface flooding and stabilizes the hydrology so that peak stream flows are reduced.

CLEANER AIR – Trees and vegetation improve air quality by filtering many airborne pollutants and can help reduce the amount of respiratory illness. Green infrastructure approaches that facilitate shorter commute distances and the ability to walk to destinations also reduce vehicle emissions.

REDUCED URBAN TEMPERATURES – Summer city temperatures can average 10°F higher than nearby suburban temperatures. High temperatures are also linked to higher ground level ozone concentrations. Vegetation creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air.

WILDLIFE HABITAT – Stream buffers, wetlands, parks, meadows, green roofs, and rain gardens increase biodiversity within the urban environment.

INCREASED ENERGY EFFICIENCY – Energy efficiency not only reduces costs, but also reduces generation of greenhouse gases.

INTRODUCTION

Per the Environmental Protection Agency (EPA), non-point source pollution is the leading remaining cause of water quality problems.[1] In particular, non-point source water pollution from combined sewer overflows (CSOs) as well as stormwater runoff from municipal separate sewer systems is a persistent problem because it is impossible to attribute to specific individuals or institutions. An innovative, cost-effective, and wide-scale approach to how land surface is developed and occupied is essential to address effectively non-point source pollution and improve water quality.

SITE: SHOEMAKER GREEN
PHOTO CREDIT: © Andropogon Associates

More than 700 older U.S. cities like Philadelphia have combined sewer systems, where both stormwater and wastewater are collected via a complex underground network of pipes and tunnels, and carry them to wastewater treatment facilities.[2] However, due to increased development and impervious surfaces, the capacity of the system is regularly overwhelmed during wet weather events. To prevent street level flooding and sewage backups, the system is designed so that all excess stormwater and waste water overflow into rivers and streams, a phenomenon called a combined sewer overflow (CSO). Increasingly stringent water quality regulations at the federal and state levels have necessitated that cities like Philadelphia take action to reduce the number of CSO events.[3]

Philadelphia, like other cities, also has a separate sewer system. A separate sewer system consists of two different sewer pipes; one transports sanitary sewage to treatment plants and the other carries stormwater to a nearby receiving river or stream.[4] "Hard surfaces prevent rainwater from soaking into underlying soils. During rainstorms, impervious surfaces produce stormwater runoff surges that mobilize a wide range of pollutants including fertilizers, pesticides, oils, metals, trash, and bacteria. An estimated 10 trillion gallons per year of this polluted mix flows uninhibited and untreated into local waterways."[5]

Stormwater management is important to prevent the pollution from both combined sewer overflows and discharges from separate sewer systems. The traditional "gray" approach to stormwater management involves the construction of a subsurface network of large pipes and tunnels that hold stormwater during wet weather events, and slowly release it back into the system at a rate that the treatment plants can manage. This approach is extremely costly; it was estimated that Philadelphia would need to invest $8 - $10 billion to build a traditional subsurface gray system that could meet EPA regulations.[6] Federal affordability policies constrained Philadelphia's ability to raise water rates more than certain amount in any given year and therefore delayed the City's projected timeline for compliance.

These real cost concerns, along with an appreciation for the affect land use has on water quality, created the impetus for Philadelphia to look to green infrastructure for possible solutions. In 2009, Stratus Consulting was commissioned by the Philadelphia Water Department to do a triple bottom-line analysis comparing the traditional approach to stormwater management and green stormwater infrastructure. The final report shows that "the net present-value of the benefits from green infrastructure greatly outweigh those of traditional gray infrastructure."[7] For example, managing runoff from 50 percent of impervious surfaces in Philadelphia with green stormwater infrastructure would provide an estimated net benefit of $2.85 billion. The traditional gray infrastructure option, proxied by a 30-foot tunnel, would provide an estimated net benefit of only $122 million.[8]

Many cities and municipalities across the country are adopting GSI into their portfolios to meet EPA Clean Water Act regulations due to its affordability, adaptability, and significant triple bottom line benefits,[9] especially when compared to the cost/benefit of the traditional centralized "gray" approach of large subsurface pipes and tunnels. Philadelphia is leading the country with *Green City, Clean Waters*, a long term control plan adopted in June 2011 that prioritizes the use of green stormwater infrastructure to meet federal regulations. The plan is estimated to cost between $1.2 and $2.4 billion. To be sure, GSI is an affordable approach to meeting EPA regulations and provides significant additional environmental, social, and economic benefits as well.

To demonstrate clearly the value and benefits of GSI as compared to gray infrastructure, this precedent library provides an introduction to GSI best management practices, followed by comprehensive case studies from high-performing GSI projects from across the country with applicability in Philadelphia. In addition, the library includes a literature review, obtained from publications and peer-reviewed research, that presents evidence in support of GSI and the case studies presented.

BEST MANAGEMENT PRACTICES

GSI works by replicating the components of a natural hydrologic balance, where much of the annual rainfall is intercepted by vegetation and absorbed by soils, to be returned to the atmosphere via evapotranspiration, or returned to the groundwater via infiltration. Very little runoff occurs in a natural landscape, where vegetation and soils work together in a balanced system. In urban areas, GSI practices work together to emulate nature in restoring a hydrologic balance.

GSI, for the purposes of this library, is defined as soil-water-plant systems that intercept stormwater, infiltrate a portion of it into the ground, evaporate a portion of it into the air, and/or in some cases release a portion of it slowly back into the sewer system. Integrating GSI into a highly developed area such as Philadelphia requires a decentralized and creative approach to planning and design. The following best management practices (BMPs) are examples of green infrastructure practices featured in this library.

- APPLICABLE to a given case study
- NOT APPLICABLE to a given case study

Not applicable	Applicable	Not applicable	Applicable	Applicable	Not applicable	ACME AT TROLLEY SQUARE
Not applicable	Not applicable	Applicable	Applicable	Applicable	Not applicable	CENTRAL WHARF PLAZA
Applicable	Applicable	Applicable	Not applicable	Applicable	Applicable	CIRA GREEN
Applicable	Applicable	Applicable	Not applicable	Applicable	Applicable	KIDZOOU
Applicable	Applicable	Applicable	Not applicable	Applicable	Applicable	KROC CENTER OF PHILADELPHIA
Applicable	Applicable	Not applicable	Not applicable	Not applicable	Applicable	KROON HALL
Not applicable	Not applicable	Not applicable	Applicable	Applicable	Not applicable	LURIE GARDEN
Not applicable	Applicable	Not applicable	Not applicable	Applicable	Not applicable	PALMISANO PARK
Not applicable	Applicable	Not applicable	Applicable	Applicable	Not applicable	PANTHER HOLLOW
Not applicable	Applicable	Applicable	Applicable	Applicable	Not applicable	PHOENIX PARK PHASE I
Not applicable	Applicable	Applicable	Applicable	Applicable	Applicable	SHOEMAKER GREEN
Applicable	Applicable	Not applicable	Not applicable	Applicable	Applicable	SIDWELL FRIENDS MIDDLE SCHOOL
Applicable	Applicable	Applicable	Not applicable	Applicable	Applicable	STROUD WATER RESEARCH CENTER
Applicable	Applicable	Not applicable	Not applicable	Applicable	Applicable	U.S. COAST GUARD HEADQUARTERS
Not applicable	Applicable	Not applicable	Applicable	Applicable	Applicable	WASHINGTON CANAL PARK

GREEN ROOFS, or living roofs, are vegetated roof cover atop a building or buried structure that mimics the hydrologic functions of surface vegetation. Green roofs consist of a layered assembly above the waterproofing membrane that generally includes a protection layer, drainage layer, lightweight growing medium, and plants. These systems can be designed to support multiple, simultaneous objectives ranging from stormwater management to provision of social spaces and/or wildlife habitat.

BIORETENTION areas are vegetated, shallow surface depressions that use the interaction of plants, soils and microorganisms to store, treat, and reduce runoff volume, and to reduce the flow rate of stormwater runoff. Bioretention areas include engineered or modified soils that facilitate the movement of stormwater through the soils. Plants are a critical component of this BMP and improve soil structure and porosity through the establishment of root systems and microbial communities.

POROUS PAVEMENT consists of a permeable surface typically composed of asphalt, concrete, pavers, reinforced turf, or rubber play surface over a subsurface composed of open graded stone storage or infiltration bed. Stormwater drains through the surface of these systems and is temporarily stored before it infiltrates into underlying soils.

TREE TRENCH systems are comprised of an underground infiltration system that supports the trees on the surface. Tree trenches are often linear BMPs that accept, store, treat, and infiltrate street runoff. These BMPs provide increased canopy cover, enhanced tree health, and longevity, as well as enhanced site aesthetics.

SOIL STORAGE within BMPs temporarily stores stormwater in pore spaces between soil particles. Soil storage capacity varies depending on physical and chemical properties of the soil. Engineered or modified soils in GSI systems are typically designed for high soil storage, which helps absorb and detain water and improves residence time.

CISTERNS may be above- or below-ground storage tanks made from a variety of materials including wood, concrete, plastic, stone, or modular storage units. They are often used for the storage and reuse of captured stormwater runoff from rooftops and other impervious surfaces. This BMP provides volume reduction, can reduce potable water needs, and may be used as a visible tool for public awareness and education.

ACME AT TROLLEY SQUARE

PHOTO CREDIT: © Meliora Design

ACME AT TROLLEY SQUARE began as an economic redevelopment effort to revitalize and maintain an important and walkable local food source within an urban community, while also reinvigorating an important urban intersection for pedestrians. The initial source of funding originated from an Urban Heat Island grant, but GSI became the tool for meeting a multitude of project and city goals, including reducing localized intersection flooding.

Comprised of a bioswale, a tree trench, a bioretention area, and subsurface infiltration beds; and with 19 shade trees, and more than 2,800 shrubs and smaller perennial plants, the 9,000 square foot system captures an estimated 70 percent of the site's annual rainfall, providing relief to the city's combined sewer system. This project helps to preserve the integrity of the region's drinking water and reduce the urban heat island effect.

PROJECT IMPACT

- Reduces runoff and improves water quality through vegetation that absorbs and filters rainwater
- Offers shade and improves air quality through vegetation that filters air pollutants and absorbs greenhouse gases
- Provides a "face lift" to an urban commercial development
- Revitalizes the intersection through streetscape improvements

PROJECT STATISTICS

GENERAL

LOCATION: Wilmington, DE

YEAR CONSTRUCTED: 2010

TOTAL PROJECT AREA: 9,000 SF

TYPE OF DEVELOPMENT: Retrofit

PRIOR LAND USE CONDITIONS: Parking Lot

CLIENT: Delaware Center for Horticulture (DCH)

OWNER: ACME Markets

PARTNERS: City of Wilmington Office of Economic Development

PROJECT TEAM:

- Salix Design Studio (Landscape Architect)
- Meliora Design (Civil Engineer)

CONSTRUCTION + MAINTENANCE TEAM:

- All Seasons Landscaping (General Contractor)

COST

- Construction cost: $180,000

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: As a retrofit project, this site did not have any stormwater requirements to meet. Instead, the property owner now receives credits for managing runoff within this combined sewer overflow area.

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: No

IMAGE CREDITS
All © Meliora Design

APPROACH

DESIGN

With a limited construction budget, the goal of this project was to manage as much of the stormwater runoff as possible without significantly changing the parking lot circulation or number of parking spaces. All of the stormwater runoff on site flowed to one inlet in a deep bowl at the east end of the parking lot causing frequent flooding. To alleviate this issue, a series of stormwater features were designed across the site.

A bioswale sits in the center of the lot, where water sheet flows into the vegetated system. Water that bypasses the bioswale, drains to a tree trench that has several feet of continuous soil to maximize tree growth. The tree trench also maximized the volume of water stored without a deep excavation using modular storage blocks, which have ~ 90 percent void space, rather than stone. This subsurface infiltration bed also manages the overflow runoff that is piped from the bioswale. At the low point of the site where flooding was occurring, sits a large bioretention area. This area was intentionally designed not to infiltrate using a liner due to contaminated soils that were discovered during construction. Instead, this retention system filters water through the engineered soils and vegetation before slowly draining back to the sewer system. With six BMP features 2,270,975 gallons of water each year- or enough to fill the Acme Building to a depth of 13 feet- is prevented from entering the City's combined sewer system and instead is allowed to infiltrate on site.

CONSTRUCTION

While excavating to install the bioretention areas, the contractors discovered that the soils were contaminated with petroleum hydrocarbons, as this was the site of an old gas station. The contaminated soils were removed within the extent of excavation and disposed of in a safe manner. This bioretention area was then lined to prevent water from infiltrating through the soils below and spreading the contamination to the groundwater table.

POST CONSTRUCTION + MAINTENANCE

Maintenance for this stormwater system is largely related to upkeep of the landscaping. There have been some difficulties with the upkeep of the vegetation in the bioretention area, and much of the bed bottom is now bare. DCH is currently seeking funding to revegetate the area and provide regular maintenance for all of the systems at the ACME.

FINDINGS

ENVIRONMENTAL Prior to the installation of these stormwater measures, all of the stormwater runoff from the ACME at Trolley Square site, the vast majority of which is impervious, drained to the combined sewer system, frequently overloading the wastewater treatment plant. Now, a large percentage of the volume of water running off from the site is stored, filtered, and infiltrated where it is generated, reducing the pollution that enters waterways when there is a precipitation event. The project creates animal habitat and provides shade, reducing the urban heat island effect.

SOCIAL By having the stormwater management system directly in the public eye, the systems at ACME serve as an educational opportunity for patrons of the store and people traveling around the site. There is educational signage, as described by Pam Sapko, former Executive Director of DCH, "The site incorporates a permanent interpretive sign explaining how the parking lot system works and how it improves water quality. The public education value of this high-traffic installation is immeasurable." Thousands of people will learn about the environmental benefits of green infrastructure as a result of this signage. The public also benefits from the beautification of the site, brining nature into this dense urban area. When looking at the parking lot from afar, one passerby said, "I remember what this used to look like. It was terrible. It's so much better now."

ECONOMIC The ACME at Trolley Square was considering closing its doors prior to the project to revitalize and renovate both the interior and exterior of the property. The Wilmington Department of Economic Opportunity teamed with the DCH in this effort, providing funding for interior renovations while DCH secured a grant from the Delaware Department of Agricultural Forest Service for Urban Heat Island Mitigation that supported the exterior stormwater retrofit. These efforts helped to revitalize this commercial space that is iconic to downtown Wilmington.

TAKEAWAYS

- Retrofitting parking lots is a cost-effective way to revitalize a commercial area that needs a lift. By working with the existing layout to incorporate greening and stormwater management that is distributed throughout the parking lot, complete repaving was avoided.

CENTRAL WHARF PLAZA

PHOTO CREDIT: © Charles Mayer

CENTRAL WHARF PLAZA is a highly performing, micro-forest plaza that connects Boston's historic waterfront to the Inner Harbor. Located near the acclaimed New England Aquarium, this plaza is used by student groups, downtown commuters and workers, as well as tourists. Aside from stormwater management, this plaza serves other essential roles including providing shade for all of the individuals passing through, and offering vital connectivity from downtown to the harbor. However, this plaza provides more than a gathering space for individuals; it validates the environmental benefits of an urban tree canopy, having twenty-five trees of assorted oak species that shade 94 percent of the site. Central Wharf Plaza contains several design elements beyond what found in a typical urban plaza including pervious surfaces, a continuous sand-based structural soil layer, and intelligent irrigation systems. With carefully chosen planting practices, and design features, Central Wharf Plaza has become a model for innovative and effective urban tree planting.

PROJECT IMPACT

- Prevents 369,000 gallons of stormwater runoff per year from entering the city's combined sewer system
- Captures 100 percent of the rainfall that falls on-site (with the exception of extreme rainfall events)
- Infiltrates rainfall from the 25-year, 24-hour storm
- Intercepts 87,000 gallons of rainwater annually with the site's tree canopy

PROJECT STATISTICS

GENERAL

LOCATION: Boston, MA

YEAR CONSTRUCTED: 2007

TOTAL PROJECT AREA: 13,100 SF

TYPE OF DEVELOPMENT: New Development

PRIOR LAND USE CONDITIONS: Transportation; Traffic hub

CLIENT: Frog Pond Corporation

PROJECT TEAM:

- Reed Hilderbrand, LLC (Landscape Architect)
- Chan Krieger Sieniewicz (Architect)
- Vanasse Hangen Brustlin (Civil - Stormwater Engineer)
- ARUP (Structural MEP Engineer)
- Pine Swallow Environmental (Soil Scientist)
- LAM Partners (Lighting Designer)

CONSTRUCTION + MAINTENANCE TEAM:

- Turner Construction (Construction) Management - General Contractor)
- ValleyCrest (Landscape Contractor)

COST

- Construction cost: Confidential

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: This project was designed to meet the City of Boston's Stormwater Management Regulations in 2007.

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: This site has been studied for urban heat island effect, carbon sequestration, stormwater management, tree growth rates, in addition to public use and safety.

IMAGE CREDITS
All © Charles Mayer

APPROACH

DESIGN

This tiny plaza, shaded by 25 oak trees demonstrates a replicable urban forest design. Stormwater management practices on site include:

1) Granite pavers with permeable joints, stonedust, and planting soils cover approximately 10,000 square feet of the site (75 percent). The pavers allow stormwater to infiltrate through, while supporting continued use of the paths.

2) Excess runoff that is not captured through the pavers is collected through twelve slot drains, which is then directed to trees for passive irrigation.

3) Flood bubblers were installed with a rain sensor to adjust level of irrigation while watering the trees. Moisture sensors allow for irrigation depending on soil moisture.

4) The sand-based structural soil provides consistent distribution of moisture across the site as well as an unobstructed root zone for the trees.

CONSTRUCTION

This plaza was initially a difficult location, due to the conditions above and below grade. Since the vicinity was near the harbor, plant selection had to be carefully selected to tolerate both winds and salt content. Due to the site previously being a part of the bay, the sub-soils and fill underground would not be able to support normal groundwork without ample settlement. Lastly, underground utilities posed a challenge to the construction of the site.

The team worked with city agencies to expand the site to over 13,000 square feet, which provided this space with unity. Specific species of trees were chosen, including Red and Pin Oaks for their resistance to wind and salt. In addition, a specific soil mix was created to accommodate the settling soils and revamp tree growth. Spanning grade beams were installed to ensure the support of the benches and catenary posts; shallow footings and a sand- based structural soil accommodated the seat walls and stairs. The design team continues their relationship with the client ensure maintenance decisions are successful.

POST CONSTRUCTION + MAINTENANCE

Following construction, the condition of the trees began to decline due to the stress of being moved from their native soil biology. A soil biologist confirmed the best solution to the tree biology was to activate the latent biology of the manufactured soil using compost tea and mycorrhizal applications. This treatment aided in the recreation of the soils native biology, encouraging root growth and nutrient uptake. The soil biology is now a systematic maintenance application that is used to regulate the health of the trees.

FINDINGS

ENVIRONMENTAL The average ground-level temperature following construction was reduced by 10.4°F through tree canopy, which covers approximately 94 percent of the site. Roughly 369,000 gallons of annual stormwater runoff is prevented from entering the city's combined sewer system, and is now infiltrated on site. Twenty-five oak trees eliminate about 3,600 pounds of carbon annually. When the trees reach full maturity at about 33 years, they will eliminate almost 13,000 pounds of carbon, and intercept almost 87,000 gallons of rainwater each year. Due to improved soil volume available per tree (1,500 cubic feet), tree growth rate on-site is 54 percent higher when compared to a typical urban oak tree.

SOCIAL Central Wharf Plaza provides pedestrian connectivity between the Rose Fitzgerald Kennedy Greenway and the Inner Harbor waterfront. The site welcomes about 280 pedestrians per hour and is a key location for downtime in relaxation in the area. About 22 percent of plaza visitors were observed spending an average of 12 minutes in the plaza. Pedestrian safety increased and car accidents decreased in streets surrounding the plaza, falling from 6 reported pre-construction to 1 report post-construction. Community events are held in this plaza including World Oceans Day, hosted by the New England Aquarium.

ECONOMIC Design components considered for this project greatly improve the conditions for root growth, tree health, size, and longevity. Central Wharf Plaza has an annual mortality rate of 1.6 percent compared to a 4.3 percent average among typical urban street trees. This means that if the site used a typical urban street tree design, 23 of the 25 trees would have to be replaced over 23 years, whereas only 9 trees would have to be replaced over the same time frame in this plaza.

TAKEAWAYS

- Soil biology plays a key role in the performance of urban landscapes.
- Carefully designed soils are an integral part of green infrastructure systems.
- A healthy soil ecosystem has a diverse population of soil organisms.
- In order to have the highest performance of plant and tree species on site, routine maintenance of soils will continue to provide species with the nutrients they need, providing healthy trees for evapotranspiration.

CIRA GREEN

PHOTO CREDIT: © Albert Vecerka for ESTO

CIRA GREEN is the first publicly accessible elevated landscape in Philadelphia, and offers a novel approach to stormwater management that enhances plant performance and treats rainfall. This elevated park enhances evapotranspiration by prolonging rainwater availability to plants, preventing hundreds of thousands of gallons of rainwater from entering the Philadelphia sewer system every year. The most novel aspect of the design is the coupling of thin detention cisterns (conceived as 'pancake'-like) beneath permeable paving with adjacent planted roof areas that receive outflow from the 'pancake' cisterns. This hybrid stormwater strategy provides enhanced runoff volume reduction through evapotranspiration, additional runoff rate reduction, and water quality treatment. Cira Green is the first blue-green roof featuring 'pancake' cisterns in the nation. Since it's opening, Cira Green has featured an event hosted by the Democratic National Convention, received coverage by Channel 6 news, and been the subject of educational tours during the American Institute of Architects National Convention and the Urban Land Institute Conference.

PROJECT IMPACT

- Prevents more than 700,000 gallons of stormwater runoff from discharging to the combined sewer system each year
- Contains the capacity to store 20,000 gallons of rainfall in a two-inch thick 'pancake' cistern

PROJECT STATISTICS

GENERAL

LOCATION: Philadelphia, PA

YEAR CONSTRUCTED: 2015

TOTAL PROJECT AREA: 1.2 acres

TYPE OF DEVELOPMENT: Redevelopment

PRIOR LAND USE CONDITIONS: Commercial

CLIENT: Brandywine Reality Trust

PROJECT TEAM:

- Roofmeadow (Landscape Architect)
- Erdy McHenry (Architect)

CONSTRUCTION + MAINTENANCE TEAM:

- Hunter Roberts Construction (General Contractor)
- Sean's Landscaping (Landscape)

COST

- Construction cost: $2.66 Million
- Annual maintenance cost: $34,000 / year minimum

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: Cira Green was designed to meet, and exceed, Philadelphia Water Department regulations in 2015. Cira Green's fusion of intensive green roofs, permeable paving, and thin "pancake cisterns" results in a hydrologically integrated site that manages the first 2 inches of rainfall; prevents over 700,000 gallons of stormwater runoff from discharging into the sewer, and facilitates 1) extended stormwater detention of up to 72 hours, 2) water quality treatment, and 3) runoff volume reductions via evapotranspiration (ET).

INFILTRATION POSSIBLE: No, additional ground-level stormwater management practices (BMPs) would have had to be installed elsewhere on the site. The cost and logistics of such ground-level BMPs, plus the added value of the amenity space, justified the investment in a blue-green roof.

MONITORING EQUIPMENT ON SITE: No formal monitoring has been implemented, however observations confirm that the systems are fully operating. Trees, shrubs, perennials, grasses, and lawns are lush; drains are clear; and people are flocking to the site.

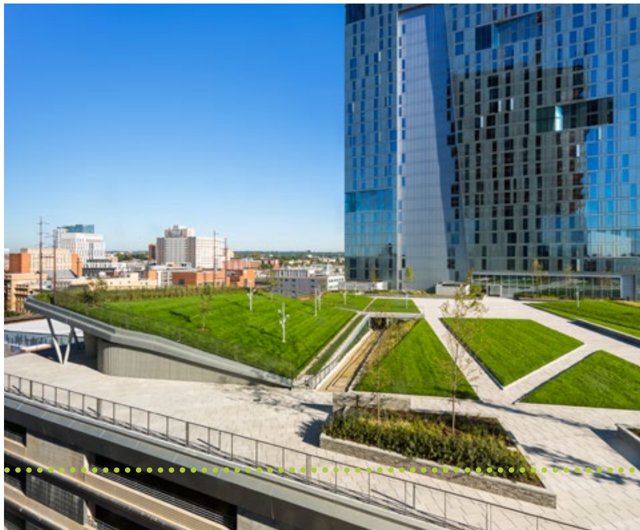


IMAGE CREDITS
All © Albert Vecerka for ESTO

APPROACH

DESIGN

Cira Green is a blue-green landscape on structure that constitutes a new paradigm for urban living. The park combines three BMPs within its footprint: green roofs, permeable pavers and integrated 'pancake' cisterns. The concept of 'pancake' cisterns beneath the pervious pavers was developed to allow the project to meet and exceed Philadelphia's stormwater regulations while also achieving the client's vision of a vibrant, highly programmable public park servicing a dense urban area. Inlets from the 'pancake' cisterns to the green roof are strategically located along the curbs allowing stormwater to move from the cistern to the green roof. Removable lids allow for the observation of conditions at the inlets and for fine adjustments of weirs. Water discharging to the green roof fills a basal granular layer to a depth of 2 inches before overflowing to the roof drains. Retention of water in the root zone makes plantings more drought resistant and reduces irrigation requirements. As a result, the plants have longer active growth cycles and evapotranspire greater amounts of moisture into the atmosphere, further reducing runoff discharge from the roof.

The project aimed to exceed stormwater regulation requirements while offering an irresistible, accessible urban park. For the space to realize that potential, more pavement was required than regulations allowed. The blue-green BMP was developed to meet seemingly incompatible imperatives and combines three benefits:

1) extended detention of the first 2 inches of rainfall,
2) water quality treatment
3) runoff volume reductions via ET.

A fundamental distinction of this design concept is that rooftop ET substitutes for infiltration, producing significant runoff volume reductions. Contact with media and plant roots produce real-time uptake of detained water.

CONSTRUCTION

The project is constructed on a completely flat deck. The pavement, curbs, walls, artificial terrain, planters, and sloped zones had to be built to very close tolerances to produce the desired pattern of runoff management and flow.

POST CONSTRUCTION + MAINTENANCE

A detailed maintenance plan is intended to promote vigorous plant growth, ensure adequate irrigation, and protect trees from wind uplift. Maintenance of the roof requires horticultural knowledge of native and adapted trees, shrubs, perennials, and grasses for appropriately timed pruning and propagation.

FINDINGS

ENVIRONMENTAL Cira Green is located on the west bank of the Schuylkill River on what was previously a parking deck. The blue-green roof creates a habitat that emphasizes plants that are durable enough to withstand the extreme weather conditions typical of elevated landscapes. The plant palette is composed of tough, drought tolerant plants, most of which are native to the region. What could have been a concrete deck filled with cars is now a visually appealing amenity that sustains birds, crickets, and butterflies. The topographic form calms wind, trees offer shade, and enhanced evapotranspiration by plants throughout the roof offers environmental cooling.

SOCIAL Cira Green has seen an event hosted by the Democratic National Convention and receptions for local design and advocacy groups. Countless students have toured Cira Green and city agencies across the country have provided city representatives the opportunity to visit the roof. The potential for food vendors, a beer garden, concerts, art fairs and a farmers' market are all currently under consideration. In its first year, Cira Green was featured in over 1,300 personal Instagram photos.

ECONOMIC Financial benefits to the client include stormwater credits, enhanced leasing potential of the adjacent buildings and leasing of the park for events. At Cira Green, the long-term potential for profit stems from the park's fundamental role as a spectacular place that serves the public year-round.

TAKEAWAYS

- Publicly accessible elevated park landscapes enrich densely urban areas and should be considered an important complement to traditional greenspace.
- Pancake cisterns – which support walkways and plazas without sacrificing stormwater management - overcome the problem of structural loading associated with water retention on structure.
- Small grade variations can result in construction challenges where thin paving and planting systems are featured.
- Maintenance procedures to clear plaza and walkways of snow must be closely monitored to prevent overloading the structure.
- Ongoing remediation of dog waste has become an unavoidable aspect of maintaining Cira Green.

KIDZOOU

PHOTO CREDIT: © Halkin Mason Photography

KIDZOOU at the Philadelphia Zoo sets a new standard in stormwater management and sustainability practices for the Zoo as a whole. KidZooU transformed the former historic pachyderm building and elephant yard into a new indoor/outdoor children's zoo where water and its role in supporting the environment is a key feature for education. The design provides a venue for children to discover the natural world through exposure and interaction with animals and plants in a setting that references the natural and agricultural landscapes of Southeastern Pennsylvania. The project met the requirements of the Philadelphia Water Department and achieved LEED Gold certification. In 2014, the project was recognized by DVGBC as one of the three "Groundbreaker" Sustainability projects. The project also won the 2014 Exhibit of the Year Award from the Association of Zoos and Aquariums.

PROJECT IMPACT

- Captures more than 1-inch of runoff from impervious surfaces
- Reduces the volume of runoff in the 2-year, 3.3-inch rainfall to less than pre-development conditions
- Reduces flooding and improves water quality through volume management
- Creates habitat

PROJECT STATISTICS

GENERAL

LOCATION: Philadelphia, PA

YEAR CONSTRUCTED: 2013

TOTAL PROJECT AREA: 2 acres

TYPE OF DEVELOPMENT: Retrofit

PRIOR LAND USE CONDITIONS: Zoo Exhibit

CLIENT: The Philadelphia Zoo

PROJECT TEAM:

- Viridian Landscape Studio (Landscape Architect)
- SMP Architects (Architect)
- Meliora Design (Civil - Stormwater Engineer)
- CVM (Structural Engineer)
- Arora Engineers, Inc. (Electrical Engineer)
- Bruce E. Brooks & Associates (HVAC & Plumbing Engineer)
- David Nelson & Associates, LLC (Lighting Design)

CONSTRUCTION + MAINTENANCE TEAM:

- W.S. Cumby (General Contractor)

COST

- Construction cost: $3.3 Million

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The proposed stormwater management system was designed to meet Philadelphia Water Department Regulations in 2013. This design reduced site impervious by 35 percent, greater than the required 20 percent by the Water Department. As a result, the project was exempt from channel protection and flood control requirements. Stormwater management facilities provide capacity to capture and infiltrate the first inch of runoff from the impervious surfaces. Overall, the stormwater management system will reduce peak flow rates and provide water quality and volume control through the use of vegetative systems and subsurface infiltration beds.

A permitting challenge unique to the Zoo is the management of stormwater runoff from outdoor animal holding areas. These areas represent a substantial portion of the Zoo campus, and are both a source of stormwater runoff and subject to the Philadelphia Stormwater Management requirements. However, these areas contain animal waste and cannot easily be managed by GSI systems without consideration of human contact and animal waste management. Per regulations, runoff from these areas cannot be directed to rain gardens, infiltration beds, etc. Rather than seek an exemption to stormwater requirements for these animal holding areas at KidZooU, the Zoo proactively managed additional stormwater from existing, unmanaged impervious areas to offset any animal holding areas that could not be captured.

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: No

IMAGE CREDITS
All © Halkin Mason Photography

APPROACH

DESIGN

GSI components at KidZooU include:

1) 4,672 square feet of green roof
2) Two stormwater infiltration beds (5,600 square feet)
3) Four rain gardens (approx. 865 square feet)
4) Two level spreaders
5) Two 3,000-gallon cisterns that capture roof runoff for reuse in flushing toilets

The retrofit of this site had several unique challenges. After many years of the heavy foot traffic of large animals, the soils on-site were heavily compacted. This necessitated designing the infiltration beds below the compacted soil, while the final site grade was raised several feet. Several bioretention areas were designed to store and filter stormwater runoff from new paths before the runoff enters the stone beds. The drainage piping system and other site utilities had to avoid a maze of existing utilities, and had to be carefully installed using air-spading to protect the roots of large mature trees that were to remain. Two 3,000-gallon cisterns capture runoff from the roof areas for reuse in flushing toilets both in the refurbished pachyderm building and in the new restroom building. These cisterns reuse approximately 69,600 gallons of rainfall each year to flush toilets, however, no regulatory credit was applied due to uncertainties in the approval process and requirements at the time. Three green roofs were installed on new structures, and a small area of porous bonded aggregate pavement was installed near the chicken yard.

CONSTRUCTION

The construction of KidZooU was carefully staged to work within the exhibit limits while the Zoo was still open to the public. Tree protection fence was placed to prevent construction traffic around existing trees, and a geothermal well system was installed prior to other site work to manage the well spoils in settling pools. An existing water line that was several feet off from its surveyed location caused a field change to the shape of the bed, and this same infiltration footprint required soil scarification to meet the minimum infiltration rate.

POST CONSTRUCTION + MAINTENANCE

After construction, the landscaped areas had a temporary irrigation system watering the plants to help with establishment. With dense plantings and fences, visitors were excluded from the landscaped areas, so foot traffic did not damage the vegetation or compact the soils. Once plants were established, there is little maintenance required in the rain gardens other than occasional weeding and checking the water quality inserts in the drain basins for leaves and mulch.

FINDINGS

ENVIRONMENTAL By managing stormwater runoff from impervious surfaces, this project reduces combined sewer overflows, improves water quality, and promotes groundwater recharge. Heat island effect was reduced by planting over 120 trees. Canopy coverage was also preserved by protecting existing mature trees, and implementing specific construction practices to ensure tree survival and long-term health. New green spaces were created, planted in native species, and intended to provide food sources for migrating birds and butterflies. The true benefits of this approach were seen in the Fall of 2015 when migrating monarch butterflies were observed feeding and resting on milkweed.

SOCIAL The new exhibit not only allows interaction between children and animals, but features educational displays highlighting the benefits of the water management. The importance of water for animals is reinforced throughout KidZooU, including experiences to increase visitor awareness of the human impacts to water and the connectivity of water needs and uses. In part because of the water messaging and the facility site design, KidZooU received the 2014 "Exhibit of the Year" Award from the Association of Zoos and Aquariums.

ECONOMIC It is difficult to quantify all of the economic benefits to the Zoo of an improved campus landscape as a result of GSI practices and reduced localized flooding, however both the KidZooU award and the campus improvements have positively impacted the Zoo's number of visitors as well as donor support, furthering their educational impacts. Cisterns that capture rainwater for use in the toilets reduce water consumption costs.

TAKEAWAYS

- Creating a water management strategy that mimics nature is possible, even on a pre-developed site with numerous obstacles. This water management strategy works as a system; with various components that manage runoff where it is generated, and filter it with both structural and natural means. All of this was accomplished with the constraints of working around existing utilities and structures and protecting existing trees.

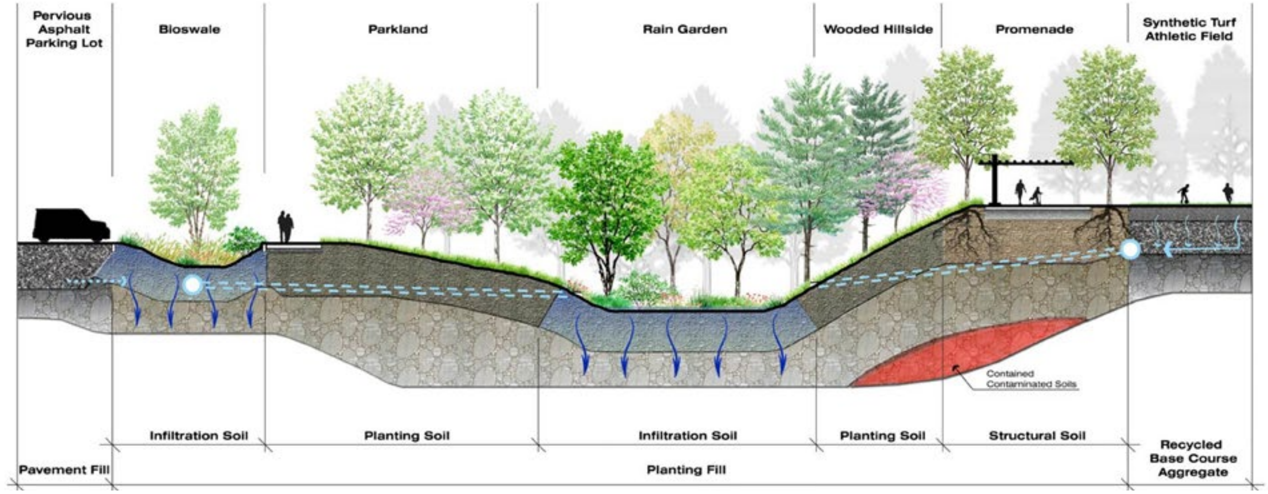
KROC CENTER OF PHILADELPHIA

PHOTO CREDIT: © Andropogon Associates

KROC CENTER OF PHILADELPHIA, in Philadelphia's Hunting Park neighborhood, demonstrates the successful repurposing of an abandoned, post-industrial 13-acre brownfield site and parking lot into a richly-programmed, publicly accessible high-performance landscape using green stormwater infrastructure and a zero net waste approach to site construction. The Kroc Center's dynamic landscape and community center offer a universally accessible, transit-oriented, multi-functional campus that accommodates gatherings, urban agriculture, and passive and active recreation. The former void space in the center of the low-income neighborhood is now a magnet for activity. A key facet of the project's sustainable design strategy is stormwater management through green stormwater infrastructure and re-use.

PROJECT IMPACT

- Re-uses 100 percent of the water-quality volume from the site and the building
- Reduces the rate of stormwater runoff by 98 percent, 97 percent, and 64 percent for the 2-, 10-, and 100-year storms, respectively, when compared to pre-development conditions
- Saves more than $70 million in gray stormwater infrastructure costs by deploying green infrastructure



PROJECT STATISTICS

GENERAL

LOCATION: Philadelphia, PA

YEAR CONSTRUCTED: 2010

TOTAL PROJECT AREA: 13 acres

TYPE OF DEVELOPMENT: Brownfield / Contaminated Soils / Utilities / Right-of-way

PRIOR LAND USE CONDITIONS: Contaminated industrial landscape and parking lot

CLIENT: The Salvation Army

PROJECT TEAM:

- Andropogon Associates (Landscape Architect)
- MGA Partners (Architect)
- PZS Architects (Architect of Record)
- Duffield Associates (Civil-Stormwater Engineer)
- CVM (Structural Engineer)
- Irrigation Consultants, Inc. (Irrigation Design)

CONSTRUCTION + MAINTENANCE TEAM:

- TN Ward (General Contractor)
- Sharps Landscaping Inc. & Volunteers (Landscape Maintenance)

COST

- Construction cost: $6.9 Million
- Annual maintenance cost: Unknown

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: All of the BMPs were designed to provide the capacity to store the 1-inch water quality volume and to release stored runoff at a controlled rate as required at the time by the Philadelphia Water Department.

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: Data is currently collected through observation, monitoring, and inspections.

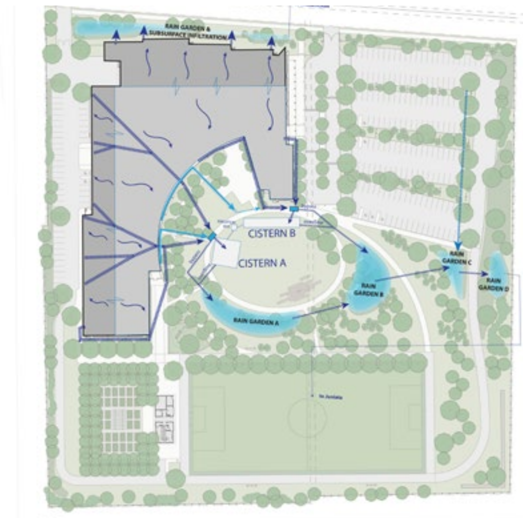


IMAGE CREDITS
All © Andropogon Associates

APPROACH

DESIGN

The Kroc Center of Philadelphia's design goals were to:

1) Reinvigorate a post-industrial brownfield site to become a richly- programmed, publicly accessible landscape.

2) Strive for a "zero net waste" approach to site construction.

3) Manage stormwater through conveyance, detention, filtration, infiltration, and re-use.

CONSTRUCTION

Construction practices emphasized careful material stockpiling and re-use within a challenging brownfield environment. In fact, nearly 100 percent of the site's existing hardscape was recycled and re-used on-site. These types of contaminated sites often require an importation of specialized soil to support plant growth and stormwater management. Unfortunately, the soil brought onto the site differed significantly from that which was specified, resulting in one of the project's most impactful construction challenges.

POST CONSTRUCTION + MAINTENANCE

The project's landscape maintenance goals are to:

1) Maintain plant biodiversity

2) Prevent and/or mitigate invasive plant species establishment.

This maintenance is achieved through a combination of professional landscape contractors and volunteers. One challenge has been improper mowing of the rain garden.

FINDINGS

ENVIRONMENTAL The redevelopment project reduced impervious surfaces on the site by 43 percent, from 9.26 acres to 5.30 acres. The four rain gardens filter and infiltrate stormwater runoff from the building and porous parking lot. One lined rain garden is on the street side of the building; the other three are unlined. The rain gardens are designed as wet plant communities. Carved granite runnels capture air conditioner condensate and carry it to a cistern and rain gardens. The landscape was designed as native plant communities with upland, lowland and wet habitats. Dragonflies, bees, other insects and some bird species have been observed on the site post-planting.

SOCIAL The site's community center is a highly diversified headquarters offering recreational facilities, job training, and educational and spiritual programs for the adjacent neighborhoods. The landscape supports this programming with sports fields, gardens, and an urban farm. The small urban farm dedicates a third of an acre to growing produce and has an outdoor classroom for educational programs.

The site is strategically located in a socio-economically depressed neighborhood in an effort to create recreational, social, and educational opportunities for underserved community members.

ECONOMIC Engineers estimate over $70 million in stormwater infrastructure savings over the life of the project due to the elimination of municipal impact fees and the dramatic reduction in conventional conveyance infrastructure. The site contained approximately 2,700 cubic yards (cy) of asphalt, 2,410 cy of concrete, 7,020 cy of aggregate stone sub-base, and 370 cy of railroad ballast. These materials were recycled and integrated into the construction of the parking areas, synthetic turf base, lawn base, paths, and structural fill. By determining the equivalent performance capabilities of the type of aggregate debris, each could be specified for maximum benefit at the site. This effort saved $575,000 in disposal fees and prevented 12,500 cy (17,500 tons) of material from entering landfills.

TAKEAWAYS

- Better integration between the building, site and landscape design could have yielded greater costs savings through downsized mechanical and drainage systems.
- Continuous yearly monitoring paired with an aggressive invasive species management plan is critical to the success of habitat restoration.

KROON HALL

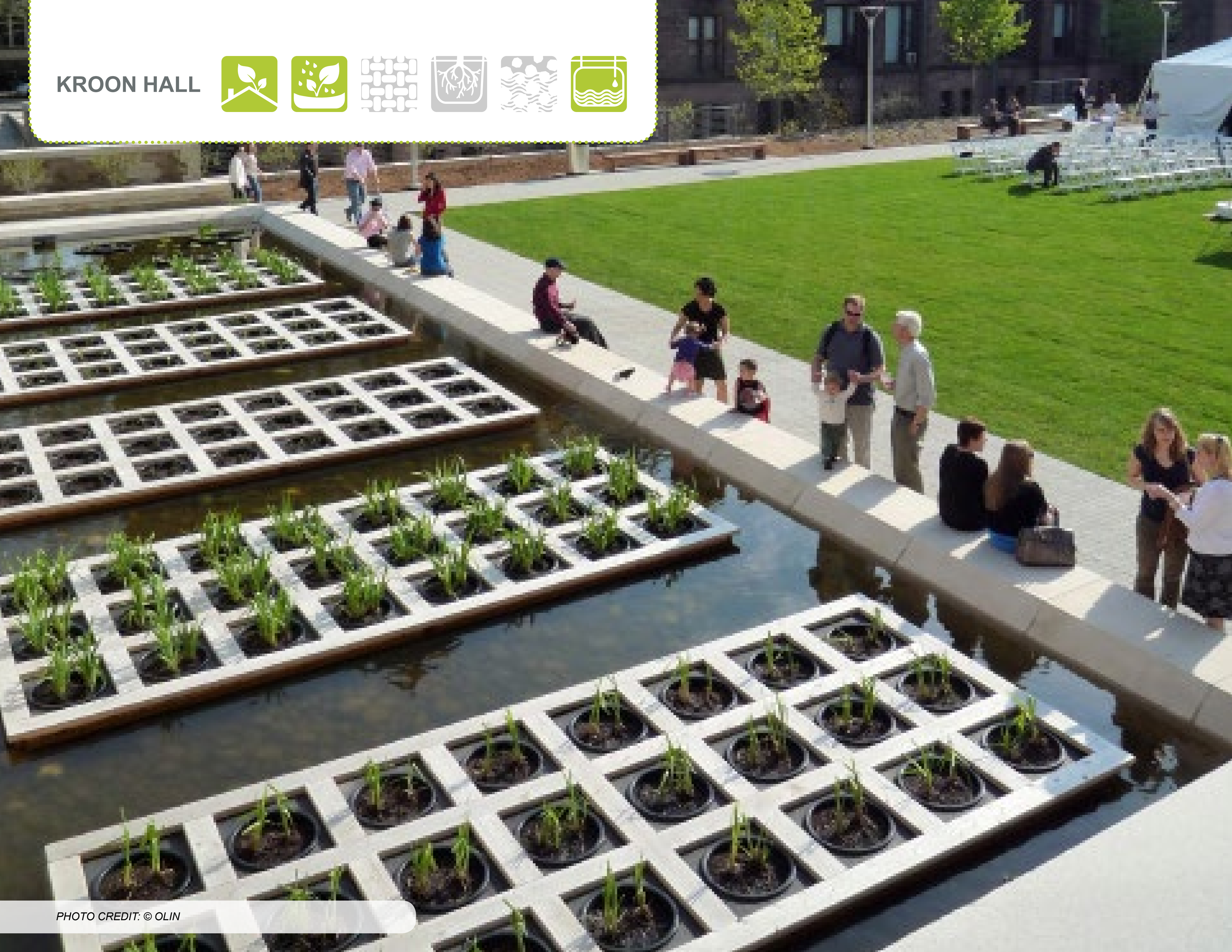
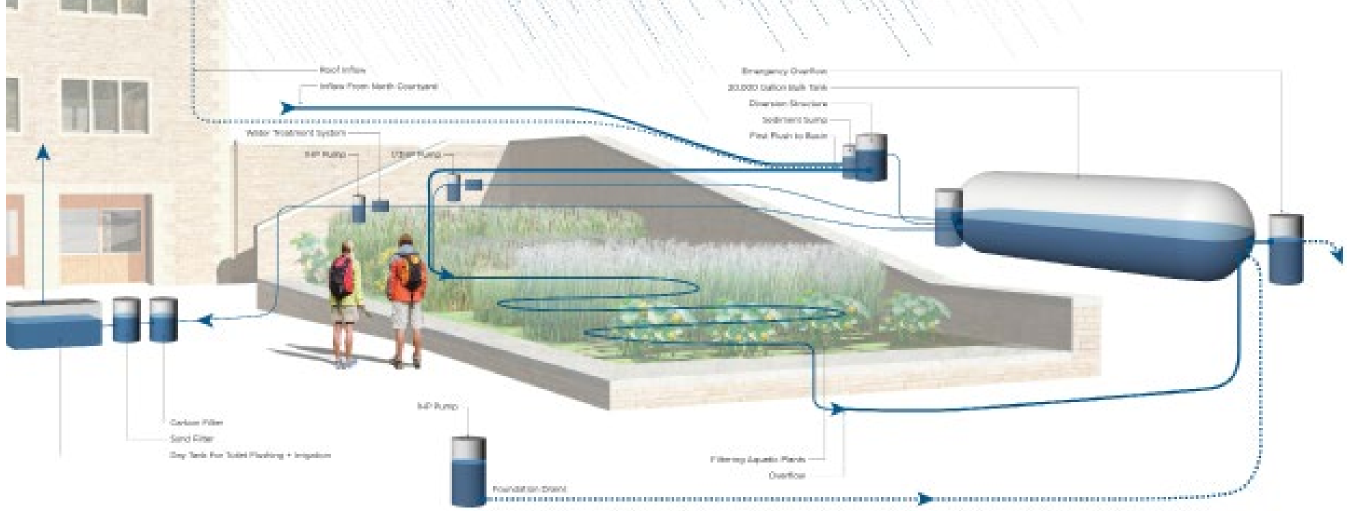


PHOTO CREDIT: © OLIN

KROON HALL and the site's green space transformed from a decommissioned power plant, parking lot, and patchwork of service roads, are a highly visible center for the study of environmental science on Yale's Science Hill Campus. Prior to redevelopment, the existing boiler plant on the Kroon Hall was removed. Today, graduation, happy hour, alumni events, and other school activities are commonly scheduled for the courtyard. Green stormwater infrastructure components include a rainwater harvesting system and cleansing pond that in turn provide water for landscape irrigation and indoor toilet flushing demands.

PROJECT IMPACT

- Reduces runoff volume through rainwater harvesting
- Reduces stormwater peak runoff rates off-site
- Cleanses the first flush through aquatic plantings
- Diverts the first flush to a rainwater re-use system
- Reduces stormwater volume and improves water quality entering the combined sewer



PROJECT STATISTICS

GENERAL

LOCATION: New Haven, CT

YEAR CONSTRUCTED: 2009

TOTAL PROJECT AREA: approx. 1.7 acres

TYPE OF DEVELOPMENT: Redevelopment

PRIOR LAND USE CONDITIONS: Grayfield

CLIENT: Yale School of Forestry and Environmental Studies

PROJECT TEAM:

- OLIN (Landscape Architect)
- Hopkins Architects (Architect)
- Nitsch Engineering (Civil Engineer)
- ARUP (Structural Engineer)
- Atelier Ten (Environmental Building Engineer)

CONSTRUCTION + MAINTENANCE TEAM:

- Turner Construction (Construction Company)

COST

- Budget: $33.5 Million
- Construction cost: $200,000*
- Annual maintenance cost: $6,000

*estimated stormwater management elements

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The City of New Haven had significant combined sewer overflow (CSO) mitigation targets for the project to achieve. Exceeding these requirements for CSO reduction was a major design objective.

INFILTRATION POSSIBLE: Infiltration was not possible, as the site was placed over an underground service dock. As such the site was effectively a green (landscape) and blue (water management) roof.

MONITORING EQUIPMENT ON SITE: Monitoring of the system is not currently in place, however the stormwater management system was designed with the potential to engage the academic community of the Yale School of Forestry and Environmental Studies (FES) in performance monitoring.

IMAGE CREDITS
All © OLIN

APPROACH

DESIGN

Kroon Hall's site features an innovative application of rainwater treatment, storage, and reuse. It includes a landscape water feature that utilizes plants to cleanse stormwater through phytoremediation. The first inch of stormwater runoff collected from Kroon Hall's rooftop and site is diverted to this water feature. Treated stormwater is directed to a subsurface 20,000-gallon cistern, from which it is continually recycled through the water feature by a small pump. The rainwater harvesting cistern is optimized to permanently store and reuse the volume of rainwater captured from rainfall events that generate one inch of precipitation or less, which accounts for 90 percent of the average annual rainfall. Water harvested in the cistern is available for reuse in the building for toilet flushing and to irrigate portions of the landscape. Potable water use is reduced 75 percent below baseline via waterless urinals, dual-flush toilets, and other features. No potable water backup is available to supplement the irrigation for the landscape. The system is projected to save Yale 634,000 gallons of water per year and to contribute to improved water quality and reduced stormwater discharge to overtaxed city sewers. Additionally, more than 50 percent of potable water is heated via solar hot water heaters. The project is LEED Platinum-certified.

CONSTRUCTION

This brownfield site encountered challenges including contaminated soils, working around campus utilities, and buried structures, including a relocated steam line. The design engineers had limited role during construction and consequently a few minor questions remain about whether certain construction details were completed, for example whether foundation drain discharge lines are connected to the rainwater re-use system as designed.

POST CONSTRUCTION + MAINTENANCE

Integration with Yale's campus and connection to the surrounding New Haven community was a design priority. Kroon Hall and its surrounding courtyards and terraces serve as accessible public spaces on an urban university campus. With an estimated 60 percent of the occupants using public transport and automobile-free commuting, a campus shuttle bus stop was located near the site, as well as numerous bicycle racks. Additionally, no on-site parking is provided, promoting walking to the site and encouraging interaction with the campus and city.

FINDINGS

ENVIRONMENTAL Native plantings were used to support wildlife and minimize potable water waste. In the constructed water feature, floating rafts were planted with native aquatic plants specially selected to remove pollutants carried by the stormwater that recycles through the system. These supplement the project's terrestrial landscape design to feature twenty-five varieties of native, adaptive plantings that serve wildlife and improve air quality.

SOCIAL Integration with Yale's campus and connection to the surrounding New Haven community was a design priority. Kroon Hall and its surrounding courtyards and terraces serve as accessible public spaces on an urban university campus. With an estimated 60% of the occupants using public transport and automobile-free commuting, a campus shuttle bus stop was located near the site, as well as numerous bicycle racks. Additionally, no on-site parking is provided, promoting walking to the site and encouraging interaction with the campus and city.

ECONOMIC While the water savings from rainwater harvesting have not been calculated in financial terms, the system saves over a half a millions of gallons of potable water per year. Additionally, Kroon Hall was designed to reduce energy consumption through the building orientation, solar panels, and sensors that adjust artificial light. The Kroon Hall site is designed as a service dock for a portion of the Science Hill campus, providing efficient service vehicle access and distribution of goods and materials through this service node.

TAKEAWAYS

- The design for stormwater performance is just the first step in a successful implementation. While designers are not usually involved after the construction ends, their involvement during constriction greatly affects the ongoing performance of the green stormwater infrastructure system.
- The GSI system at Kroon Hall remains a largely untapped resource for post-occupancy monitoring within the FES curriculum. While the stormwater system was designed to accommodate monitoring by the FES students, to date the rainwater harvesting system has been the subject of only one student research project. Integrating this site into the school curriculum would foster research collaborations and ensure this valuable resource is utilized to the fullest.

LURIE GARDEN

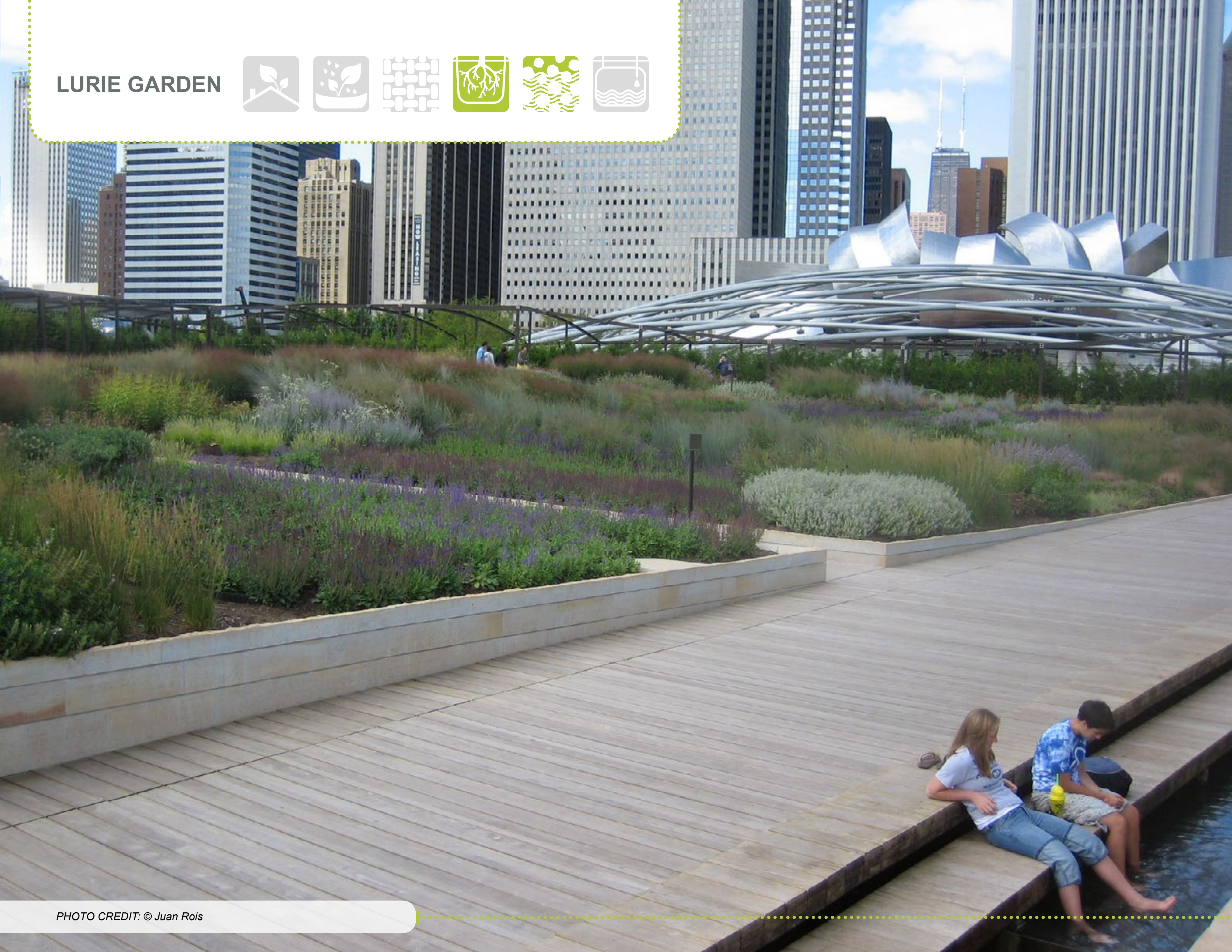


PHOTO CREDIT: © Juan Rois

LAURIE GARDEN, in downtown Chicago, replaced 3-acres of surface parking lots with a lush botanical garden and urban wildlife habitat atop a sub-grade parking structure. The garden occupies the southeast corner of Millennium Park, one of the largest landscapes on structure in the world. Inspired by Chicago's geographic siting within the Midwestern prairie, the garden features native and adapted plant species and locally-sourced limestone. This rich habitat attracts pollinators, birds, and more than 10,000 visitors annually who come to see the garden's stunning seasonal displays of color and scent. The Lurie Garden's plants and green roof media work to reduce stormwater runoff by 60 percent, or nearly 100,000 gallons annually.

PROJECT IMPACT

- Reduces stormwater runoff by 60 percent as compared to the site's previous land use
- Supports more than 250 plant varieties, more than 60 percent of which are native to the Midwest
- Provides habitat for more than 27 observed bird species

PROJECT STATISTICS

GENERAL

LOCATION: Chicago, IL

YEAR CONSTRUCTED: 2004

TOTAL PROJECT AREA: 3 acres

TYPE OF DEVELOPMENT: Redevelopment

PRIOR LAND USE CONDITIONS: Surface parking lot and rail-yard

CLIENT: Millennium Park, Inc.

PROJECT TEAM:

- Gustafson Guthrie Nichol, Ltd. (Lead Landscape Architect)
- Terry Guen Design Associates, Inc. (Local Landscape Architect)
- KPFF Consulting Engineers (Structural-Civil Engineer)
- McDonough Associates (Parking Garage Engineer)
- Piet Ouldolf (Perennial Planting Design)
- Jeffrey L. Bruce & Company, LLC (Irrigation Design)

CONSTRUCTION + MAINTENANCE TEAM:

- Spectrum Strategies (General Contractor)

COST

- Construction cost: $9 Million
- Maintenance endowment: $10 Million

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The project was designed to meet the Chicago Deptartment of Water Management regulations.

INFILTRATION POSSIBLE: No

MONITORING EQUIPMENT ON SITE: At this time, no specific stormwater monitoring happens at Lurie Garden.

IMAGE CREDITS
clockwise from top: © Gustafson Guthrie Nichol, Ltd., © Oyama Bryan, © Gustafson Guthrie Nichol, Ltd

APPROACH

DESIGN

The Lurie Garden's primary design goals were to:

1) Increase public open space in downtown Chicago by 3-acres.
2) Provide a biodiverse botanic garden atop a sub-grade parking structure.
3) Gain design inspiration from Chicago's history and citizens.
4) Ensure the garden could accommodate crowds of up to 10,000 people.
5) Reduce stormwater runoff by 60percent.

CONSTRUCTION

To achieve the project's design goals, the Lurie Garden incorporates regional, hardy materials – soil, plants, limestone, and steel – designed and engineered to endure in a heavily-trafficked, constructed environment. Additionally, 35,000 perennials (240 varieties) and 5,800 woody plants (14 varieties) were planted, more than 60 percent of which are Midwestern natives.

POST CONSTRUCTION + MAINTENANCE

The Lurie Garden's botanical and ecological success is dependent upon a rigorous maintenance program that is funded by a philanthropic $10 million endowment by Ann Lurie. This endowment enables the garden's maintenance program to operate independently of Chicago's municipal park budget, which historically fluctuates.

FINDINGS

ENVIRONMENTAL By converting previously impervious cover into surfaces that are 66 percent pervious, the Lurie Garden reduces stormwater runoff by 60 percent, or nearly 100,000 gallons annually. The garden's use of native and adapted plants reduces necessary irrigation, with periodic irrigation deployed during drought. The plantings attract bees, butterflies, and more than 27 species of birds, according to counts by garden staff. The garden additionally benefits the environment by sequestering more than 55 tons of carbon annually in 46 new shade trees and the more than 1,600 trees that comprise the garden's perimeter shoulder hedge. No insecticides, fungicides, or herbicides are needed to maintain the garden due to the biodiverse, native plant selection. In addition to monitoring/tracking bird visitation to the Garden, the following are monitored and tracked:

1) Pest insect and/or disease occurrence
2) Occurrence of Illinois listed exotic invasive organisms
3) Annual soil physical and chemical analysis

SOCIAL The Lurie Garden is a significant tourist destination within Millennium Park, which received four million visitors from 38 countries and 48 states in 2015. Programs provide adult and family workshops, guided walks, and other educational opportunities to nearly 10,000 visitors annually. On certain days, up to two staff members and four volunteers are on hand in the garden to answer questions. Additionally, the Lurie Garden has sparked a renewed interest in residential native plantings through the garden's extensive educational and volunteer programs.

ECONOMIC Reducing stormwater runoff by 60 percent with green roof media and plants eliminated the need for an on-site stormwater detention facility, saving an estimated $159,000. The Lurie Garden additionally saves $17,800 in annual irrigation costs (890,000 gallons of water) by using native and adapted plant species instead of the turf and concrete path design outlined in the site's original master plan. The garden also contributes to Millennium Park's $2.6 billion in estimated visitor spending and $1.4 billion in projected residential development between 2005 and 2015.

TAKEAWAYS

- Diverse native plant selection can reduce irrigation demand, thereby conserving potable water and saving money on irrigation.
- An endowment can function as a reliable method of financing a public project's operations and maintenance budget.

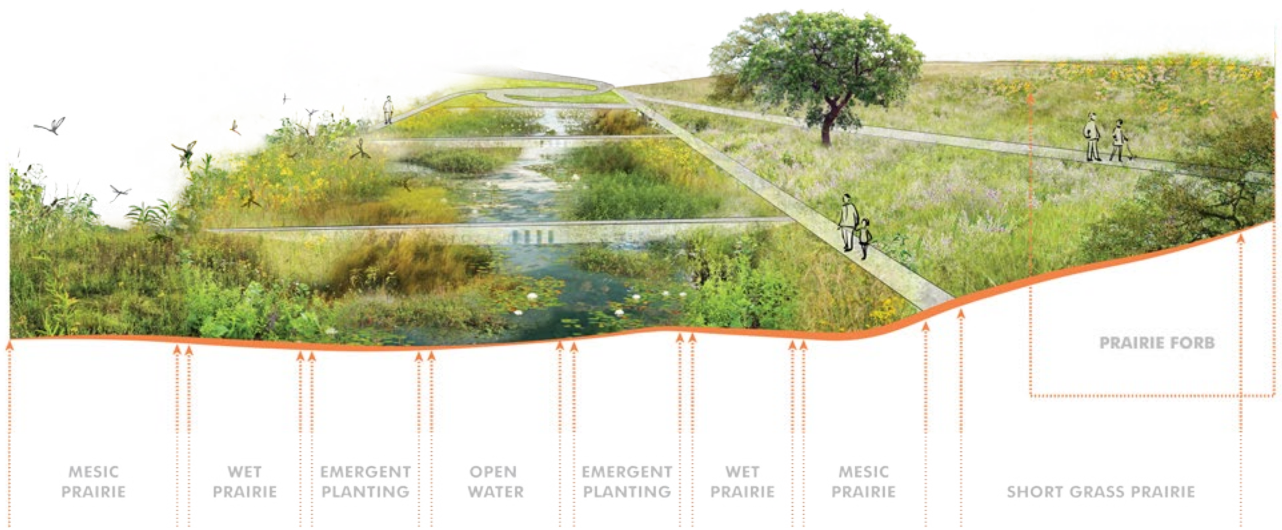
PALMISANO PARK

PHOTO CREDIT: © Robert Sit for Site Design Group, Ltd.

PALMISANO PARK (Stearns Quarry) is a 27 acre redevelopment project, 380 foot deep former limestone quarry turned landfill. The quarry began operation in the 1830s, and contributed stone to many of Chicago's first building and infrastructure projects. In 1969, the quarry was closed and the site was used as a municipal landfill for clean construction debris. The quarry/landfill site was transferred to the Chicago Park District, which, in collaboration with the Open Lands Commission, began converting the site into a public space. The park design reveals its past land use by keeping a quarry wall exposed. Through the sculpting of a unique landform affectionately called Mount Bridgeport, the park's hilltop reaches 33-feet above street level and covers landfill materials while providing an elevation point for people to view the surrounding neighborhood and downtown Chicago. The park space tapers to a series of wetlands that cleanse water and lead to a pond tucked against the quarry wall. The park is well-used and beloved by the neighborhood and also serves as a destination park for the Chicago area and beyond.

PROJECT IMPACT

- Manages rainwater for the 100-year, 24-hour storm on-site (5.56 million gallons) through bioswales, wetland cells, and a retention pond
- Saves 10.5 million gallons of potable water and $34,700 annually by deploying native, drought tolerant prairie plants
- Diverts more than 4,280 cubic feet of material from landfills by reusing 78 boulders found on-site and repurposing local sidewalk and foundation debris



PROJECT STATISTICS

GENERAL

LOCATION: Chicago, IL

YEAR CONSTRUCTED: 2010

TOTAL PROJECT AREA: 27 acres

TYPE OF DEVELOPMENT: Redevelopment

PRIOR LAND USE CONDITIONS: Landfill; Brownfield with contaminated soils

CLIENT: Chicago Park District

PROJECT TEAM:

- Site Design Group, Ltd (Landscape Architect)
- Weston Solutions, Inc. (Civil-Environmental Engineer)
- Farruggia Gibisch Reis, Inc. (Structural Engineer)
- Kowalenko & Bilotti, Inc. (Environmental Engineer)
- Continental Associates (Electrical Engineer)
- Applied Ecological Services (Wetland Engineer)

CONSTRUCTION + MAINTENANCE TEAM:

- Clauss Brothers, Inc. (General Contractor)
- Midwest Fence Corporation (Metalwork)

COST

- Construction cost: $10 Million

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The project was designed to meet the Chicago Department of Water Management regulations.

INFILTRATION POSSIBLE: No

MONITORING EQUIPMENT ON SITE: Minimal monitoring of dissolved oxygen and total suspended solids were conducted by the Illinois Institute of Technology. Dissolved oxygen levels and total suspended solids in water are good indicators of the health of an ecosystem and species living in the water. While testing both dissolved oxygen and total suspended solids yielded results showing slight improvement throughout the wetland cells, the results are unable to conclusively state an improvement throughout the entire water system. This is in part due to two water sources present at location one and to unknown inputs into the pond. Additionally, limitations of this method include the focused, single event testing does not reflect overall water quality improvement or trends in water quality over a period of time.

IMAGE CREDITS
clockwise from top: © Site Design Group, Ltd,
© Ron Gordon for Site Design Group, Ltd

APPROACH

DESIGN

The sloped topography of this site conveys all stormwater through 3.6 acres of terraced wetlands into a 2 acre retention pond. Water is mechanically recirculated by a pump from the pond through the wetland system, ensuring regular flow through the system. Per regulations previously stated, Palmisano Park's stormwater management features are prohibited from releasing uncontrolled water off-site during a 100 year, 24 hour storm. To meet this requirement, the landfill was capped, preventing water infiltration. Over Palmisano Park's 27 acres, the 100 year, 24 hour storm event would accumulate over 5.5 million gallons. The park's native planting, bioswales, and wetland treatment cells enhance water quality through infiltration and absorption of total suspended solids or additional pollutants. Plant mixes in wetlands and bioswales also help to improve water quality.

An interesting aspect of Palmisano Park is that it was constructed without trees. The tight construction budget, and required costs of landfill closure requirements the project team removed trees from the initial implementation. Trees have since been planted and will be important to future management of heat island, air quality, habitat, and quality of life.

CONSTRUCTION

During construction, the Chicago Park District asked the landscape architect to consider money-saving strategies, including reusing concrete from the demolition of adjacent sidewalks. The terraced wetland treatment system in the project was originally designed with limestone, however the recycled concrete served as a cost effective alternative. As a result, the waterfall terraces and stairs are completely made with the recycled concrete material. This solution had the benefit of saving the client from buying new limestone and eliminating transportation and disposal fees for the concrete.

POST CONSTRUCTION + MAINTENANCE

As part of the continuing process to transform the park into a nature preserve, controlled plantings of more native vegetation and prescribed burns have been conducted to help foster new growth. Prescribed burns are an important land management tool in the removal of invasive species, and the promotion of growth of native plants. Prairie plants are not destroyed during a prescribed burn, as their extensive root systems grow deep in to the soil. Nutrients are recycled back into the soil after a prescribed burn, typically resulting in a positive response from native vegetation in the following growing season.

FINDINGS

ENVIRONMENTAL The Park's 22 acres of native wetland and prairie ecosystems contain 8 different native plant mixes including wet prairie, emergent planting, submergent planting, mesic prairie, short grass prairie, tall grass prairie, prairie forb, and native swale. Beyond managing stormwater, these systems provide habitat for resident and migratory birds, such as downy woodpeckers, crows, cardinals, sparrows, blue jays, and finches. Occasionally, coyotes and foxes have been sighted in the park.

SOCIAL The addition of Palmisano Park doubles park space in the Bridgeport community to 54 acres (4% percent of the land area). Programming and activities that take place in the park include stewardship days, ecological education, camping, catch and release fishing, fossil hunting, passive recreation, music, and an air and water show. Fossils found on-site are part of the Field Museum of Natural History's collection. Additionally, this park has over 1.7 miles of paths, nature trails and boardwalks.

Since its completion in 2010, Palmisano Park has had a positive impact on the Bridgeport community. Through a survey of 122 community members, 94 percent of the respondents reported stronger community relations, aesthetic improvements, and opportunities for nature exploration.

ECONOMIC By using native warm season prairie plants instead of turf, the park saves $34,000 in annual irrigation costs, and over $87,000 in annual maintenance costs. The most significant contribution to the maintenance savings was the cost difference between weeding native prairie versus mowing lawn. In addition, the surrounding community saw an average of $34,000 increase in sales price for homes within two blocks of the park.

TAKEAWAYS

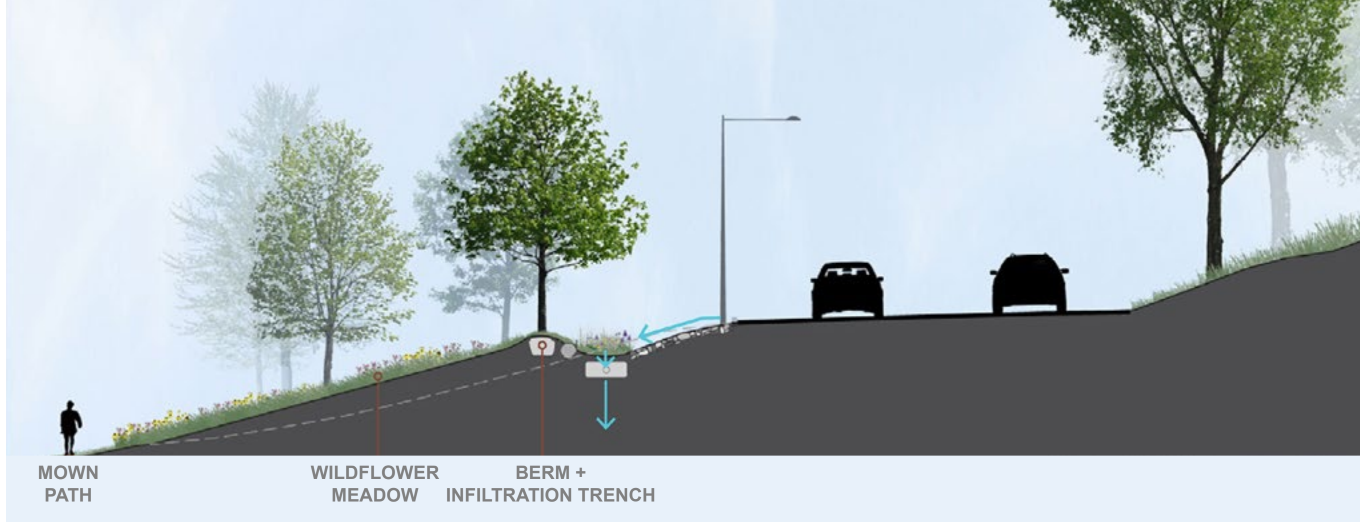
- While a typical park in the Chicago area might replicate a characteristic Midwestern prairie park design, Palmisano Park represented something new, and was initially not well supported by the community. By constructing a physical model of the park to better explain the various areas of the park, the landscape architect gained support over time for the contemporary design.

PHOTO CREDIT: © Meliora Design

PANTHER HOLLOW pilot projects features the first installations completed under the recommendations of the Panther Hollow Watershed Plan, which focuses on restoring the natural hydrologic regime of the watershed through the implementation of GSI. Downstream of the park, the combined sewer overflow (CSO) outfall from this watershed was one of Pittsburgh's most challenging with respect to CSO discharge volume. What's more, when the watershed headwaters were diverted to the combined sewer, the streams within the park were deprived of their baseflow. To remedy these challenges, the initial GSI installations included two distinct site designs. At Beacon Street, street runoff is directed to two new tree trenches that infiltrate during small storms and overflow during larger storms to a restored meadow area within the park. Integrated paths that run through the meadow connect the neighborhood to the park. The second pilot project, located on the Bob O'Connor Golf Course in the park, includes retentive grading berms with pockets of modified soil and grasses. The berms capture runoff from the golf course, allowing it to infiltrate and restore base flow to the stream. These landscape-based GSI practices are currently being monitored by faculty and students at the University of Pittsburgh.

PROJECT IMPACT

- Reduces stormwater runoff volume by approximately 50,000 gallons per year through tree trench infiltration (which will increase to 65,000 gallons per year once construction corrections are complete)
- Manages approximately 565,000 gallons of rainwater per year in a 3-acre meadow
- Captures a combined approximately 1,640,000 gallons of rainwater per year through tree trenches, meadow conversion, and golf course retentive berms



PROJECT STATISTICS

GENERAL

LOCATION: Pittsburgh, PA

YEAR CONSTRUCTED: 2015

TOTAL PROJECT AREA: 16 acres

TYPE OF DEVELOPMENT: Retrofit

PRIOR LAND USE CONDITIONS: Road right of way and lawn

CLIENT: Pittsburgh Parks Conservancy

PROJECT TEAM:

- Andropogon Associates (Landscape Architect)
- Meliora Design (Civil Engineer)

CONSTRUCTION + MAINTENANCE TEAM:

- Eisler Landscape (General Contractor)

COST

- Construction cost: $458,000
- Annual maintenance cost: approximately $3,500

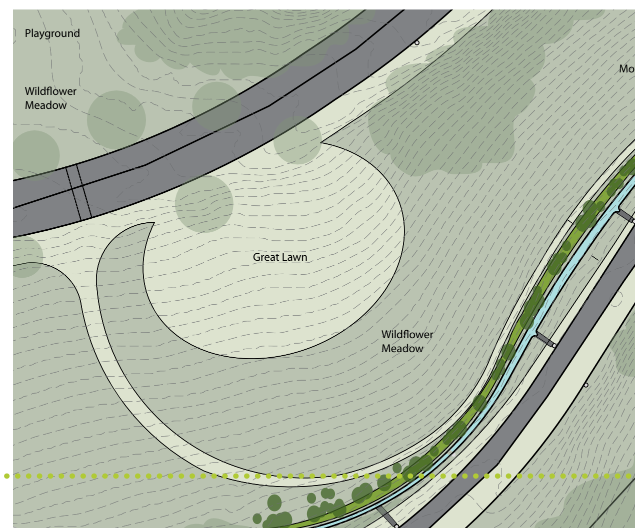
DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: There were no regulatory requirements to manage stormwater. The project goals were to capture the first inch through a mix of static storage, soil improvements, and land use changes that support infiltration and evapotranspiration. Land use changes are an important component of the GSI system and provide much of the stormwater reduction.

INFILTRATION POSSIBLE: Yes, but at a slow rate. Measured rates were below 0.5 inches per hour and would be excluded by most stormwater regulations.

MONITORING EQUIPMENT ON SITE: The University of Pittsburgh is approximately a year into monitoring infiltration in the tree trenches and recently began monitoring infiltration in the golf course. Initial estimates of infiltration in the tree trenches appear to average approximately 0.1 inches per hour, a rate that is slower than design estimates. In addition to on-site monitoring, long-term stormwater modeling has been conducted using both EPA SWMM and WinSLAMM, informed by the measured infiltration rates to date. Combined, the meadow and trenches will perform as proposed in the original watershed plan after construction corrections are made within the next 6 months. Interestingly, the structural tree trenches provide less volume reduction that the land use changes associated with the lawn to meadow conversion.

IMAGE CREDITS
clockwise from top: © Andropogon Associates, © Meliora Design, © Andropogon Associates



APPROACH

DESIGN

The watershed was modeled in EPA's SWMM during the investigation phase. The model indicated that a significant amount of runoff was being generated by lawns and other pervious surfaces, in particular, the steep maintained lawns within the park. The meadow restoration project aims to reduce runoff generated on a 3-acre lawn through land cover changes. The golf course retentive grading project aims to achieve a similar effect, however since a wholesale land cover change is not appropriate, the capacity of the isolated meadow installations are amplified by prepared soils and artificial depression. The tree Trench project aims to divert runoff generated on a half-acre roadway and an adjacent 2.5-acre lawn to the infiltration trenches, and direct overflows from that system to the restored meadow where it will have another opportunity to infiltrate.

Project goals:

1) Increase the health of the watershed by restoring stream baseflow and improving ecological conditions

2) Reduce flows to the combined sewer and associated overflows

3) Gather community support and participation in watershed restoration

4) Demonstrate replicable pilot projects

CONSTRUCTION

At the Beacon Street infiltration trenches, lower than expected infiltration rates were encountered during construction. This project was not required to meet any regulatory requirements for stormwater, therefore it was installed as designed. As a result, the actual amount of runoff currently managed is less than originally intended. Additionally, existing sewer pipes were found to be deeper than indicated on the survey. This small discrepancy impacted the entire conveyance design. To resolve this issue, the contractor installed vertical bends on the existing pipes to raise the pipe elevation and connect the existing sewer pipes to the new inlets at the elevation specified in the design documents. The construction corrections will ultimately result in meeting the original design intent for volume reduction, after accounting for lower infiltration rates.

POST CONSTRUCTION + MAINTENANCE

During the planning process, there were conversations with the golf course that they would have to adjust their mowing routine to accommodate the new naturalized plantings in the retentive grading areas. They were on board during the planning process, but did not adjust their mowing after construction. The parties involved will have to continue to work together to come to compromise that will satisfy the needs of the golf course, and the project's goals of runoff management and naturalized plantings.

FINDINGS

ENVIRONMENTAL A comprehensive ecological assessment was prepared for the larger Panther Hollow watershed. A strategic planting plan, designed for success, is a critical component of the hydrological process and thus a stormwater master plan. A native wildflower and grass meadow was installed as part of this project. The native plant communities along with soil biota work to help infiltrate and transpire stormwater in addition to mitigating the heat island effect, providing rich habitat, improving air and water quality and sequestering carbon.

SOCIAL Raising awareness around watershed issues was an important goal of the project. Changing the health of the watershed takes action at many levels from an individual homeowner's rain garden to a large scale park intervention. A stakeholder engagement strategy was designed to reach a broad range of communities to increase watershed awareness, build consensus around issues, and work together to improve the health of the Panther Hollow Watershed.

ECONOMIC The GSI components throughout the Panther Hollow Watershed reduce the runoff entering Pittsburgh's combined sewer system, therefore reducing public expenditure on stormwater infrastructure and maintenance. Financial benefits also include reduced mowing and maintenance for a meadow.

TAKEAWAYS

- Ensure all stakeholders fully understand how the proposed project will impact their use of the area. The golf course management and maintenance staff did not understand how the change in land cover would affect the use and maintenance tasks, and as a result have continued to mow the native and ornamental grasses planted around the retentive grading areas. This will restrict the biological processes that can enhance runoff reduction in a landscape stormwater practice.

PHOENIX PARK PHASE I

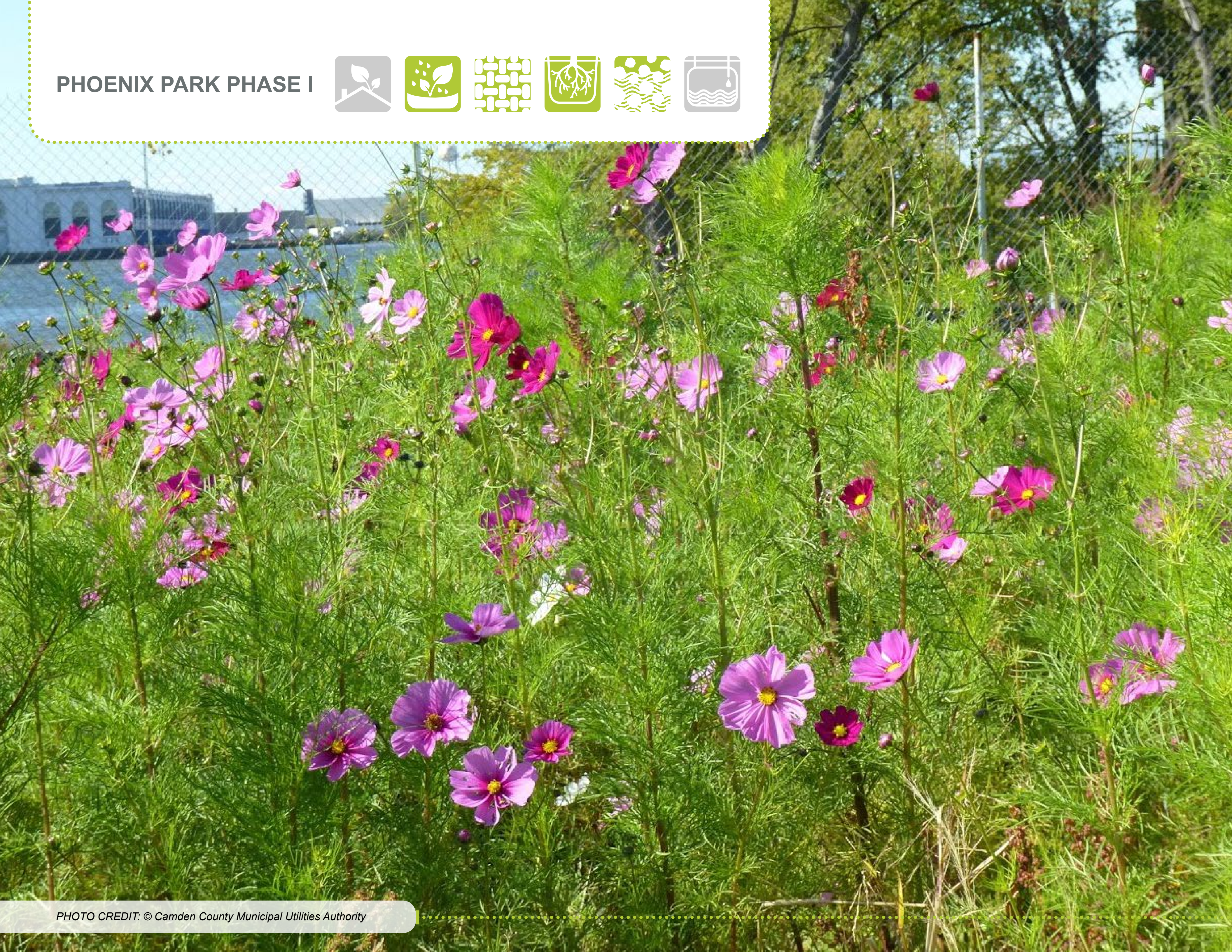


PHOTO CREDIT: © Camden County Municipal Utilities Authority

PHOENIX PARK, PHASE I has transformed a 5.3-acre brownfield previously occupied by a vacant industrial building into a waterfront park, through the concerted effort of committed partners leveraging funding from Federal, State, and County sources,. Once a blight on one of New Jersey's most challenged communities, this abandoned parcel turned park now offers a welcome escape for community members. Upon project completion, Phoenix Park is expected to manage over 5 million gallons of stormwater annually and provides green space and a recreational areas with access to the Delaware River for a neighborhood that had been cut off from the river for generations.

This project, along with others completed by CCMUA, was recognized by the U.S. Environmental Protection Agency and the Environmental Council of the United States as one of the ten most innovative uses of Federal water infrastructure funding in the country.

PROJECT IMPACT

- Prevents neighborhood flooding
- Reduces combined sewer overflows
- Promotes infiltration in greenspace planted with trees, shrubs, and grasses
- Enhances water quality through a constructed living shoreline, with native aquatic plants and freshwater mussels

PROJECT STATISTICS

GENERAL

LOCATION: Camden, NJ

YEAR CONSTRUCTED: 2015

TOTAL PROJECT AREA: 5.3 acres

TYPE OF DEVELOPMENT: Redevelopment

PRIOR LAND USE CONDITIONS: Brownfield, vacant industrial building

CLIENT: Camden County Municipal Utilities Authority

PARTNERS:

- Camden SMART
- Camden City
- Cooper's Ferry Partnership
- NJ Tree Foundation
- NJ Department of Environmental Protection
- Rutgers University

PROJECT TEAM:

- Rutgers Cooperative Extension Water Resources Program
- Kupper/JMT (Planning and Design)
- Environmental Resolutions, Inc. (Environmental Monitoring)

CONSTRUCTION + MAINTENANCE TEAM:

- Mount Construction (Construction)

COST

- Construction cost: $3 Million

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: This project was designed to meet the City of Camden, New Jersey's Stormwater Managment Regulations in 2015.

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: No stormwater monitoring is currently being conducted at this site.

IMAGE CREDITS
All © Camden County Municipal Utilities Authority

APPROACH

DESIGN

Phoenix Park's design goals were to manage stormwater and to provide green space and a recreational area with access to the Delaware River for the neighborhood that had historically been cut off from the river. Street flooding from the city's combined sewer system was a health, safety, and quality of life problem that needed to be addressed. Phoenix Park's GSI components, including rain gardens, trees, flowering meadow, and pervious pavement all manage stormwater, alleviate flooding, and provide passive recreational amenities in the park. Stormwater runoff within this industrial area can be easily contaminated with gasoline, motor oil, and other motor vehicle fluids; sewage; and other pollutants. The intent of this effort is to reduce flooding by repairing damaged infrastructure and creating opportunities for stormwater to naturally filter back into the ground so it doesn't flow over streets and collect in flood-prone neighborhoods.

In addition to landscape based GSI components, Phoenix Park also utilizes permeable pavement, and slope and bank protection were installed along the shoreline of the Delaware River.

CONSTRUCTION

There was a large amount of demolition debris, which was tested for contamination. Ultimately, the Department of Environmental Protection removed 500 to 600 cubic yards of contaminated concrete and asphalt from the site as part of the remediation. During the construction process, uncontaminated concrete and soil were crushed and used for site fill and grading.

POST CONSTRUCTION + MAINTENANCE

The next phase of the park has been funded through the EPA and includes a shoreline restoration project, with a focus on open access for fishing, and wildlife habitat restoration, providing a home for shorebirds and mussels. This living shoreline with native aquatic plants and freshwater mussels are expected to result in the filtration and treatment of about 500,000 gallons of river water per day when fully implemented.

FINDINGS

ENVIRONMENTAL Phoenix Park is a replicable example the possibilities for restoration of the approximate 300 brownfields in Camden, New Jersey. Through depaving and planting the new park improves local air quality and habitat, and reduces urban heat island effect with trees, grasses, and flowering plants.

SOCIAL Phoenix Park was given its name as a symbol of rising success from a crumbled industrial facility. The park serves as an oasis for residents, reconnecting residents of the Waterfront South neighborhood with the Delaware River waterfront, and providing a passive and active recreation space for the community to enjoy.

ECONOMIC Camden County bought the former abandoned industrial site using an $800,000 Open Space grant.

Additional grants and low- or no-interest loans from the New Jersey Environmental Infrastructure Trust Fund and state Department of Environmental Protection helped pay for the park. New Jersey Environmental Infrastructure Trust, Camden County Open Space Trust Fund, has also designated Phoenix Park Phase 1 as a New Jersey Department of Environmental Protection (NJDEP) Supplemental Environmental Project.

TAKEAWAYS

- With a set of committed partners via the Camden SMART collaborative team of organizations, it was possible to create a sizable green infrastructure installation as a significant stormwater management measure, and an opportunity for residents of the Waterfront South neighborhood to experience a park setting on their waterfront, amidst the surrounding heavy industry. The enthusiasm for the project has allowed it to be extended—and funded—with a riparian restoration component at the water's edge, and a living shoreline.

SHOEMAKER GREEN

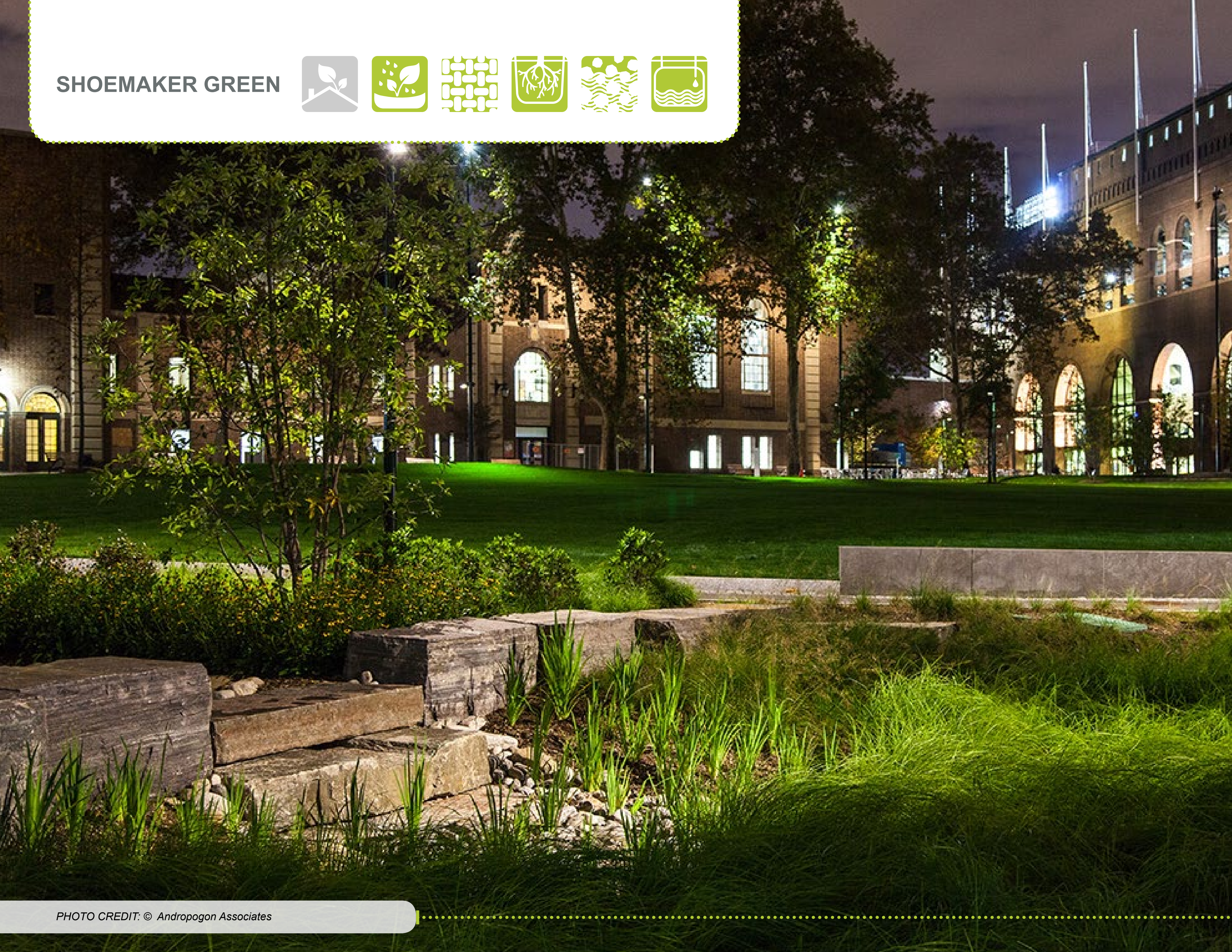


PHOTO CREDIT: © Andropogon Associates

SHOEMAKER GREEN is a 2.75-acre urban greenspace at the University of Pennsylvania in Philadelphia, that demonstrates the successful implementation of an ecologically-rich, high-occupancy, non-infiltrating landscape. The greenspace, which is popular with university students, faculty, and neighbors, opened to the public in 2012, concurrent with the start of a five-year landscape performance monitoring investigation. The longitudinal study, conducted by the university and the project's landscape architect and ecological planner, Andropogon Associates, has resulted in preliminary findings related to hydrology, soils, vegetation, and social use. Shoemaker Green was designed to manage a 1-inch rain event (as required by local regulations), but monitoring has found that the non-infiltrating landscape effectively manages more than three-times that amount due to soil storage and evapotranspiration.

PROJECT IMPACT

- Receives stormwater regulatory credit for capturing the 1-inch rainfall event
- Manages the 3.16-inch rainfall event according to post-occupancy performance monitoring
- Supports more than 100,000 people within integrated hardscape and softscape stormwater management areas during an annual 3-day event

PROJECT STATISTICS

GENERAL

LOCATION: Philadelphia, PA

YEAR CONSTRUCTED: 2012

TOTAL PROJECT AREA: 2.75 acres

TYPE OF DEVELOPMENT: Redevelopment

PRIOR LAND USE CONDITIONS: Grayfield; Utilities; Right-of-way; Buried structures

CLIENT: University of Pennsylvania

PROJECT TEAM:

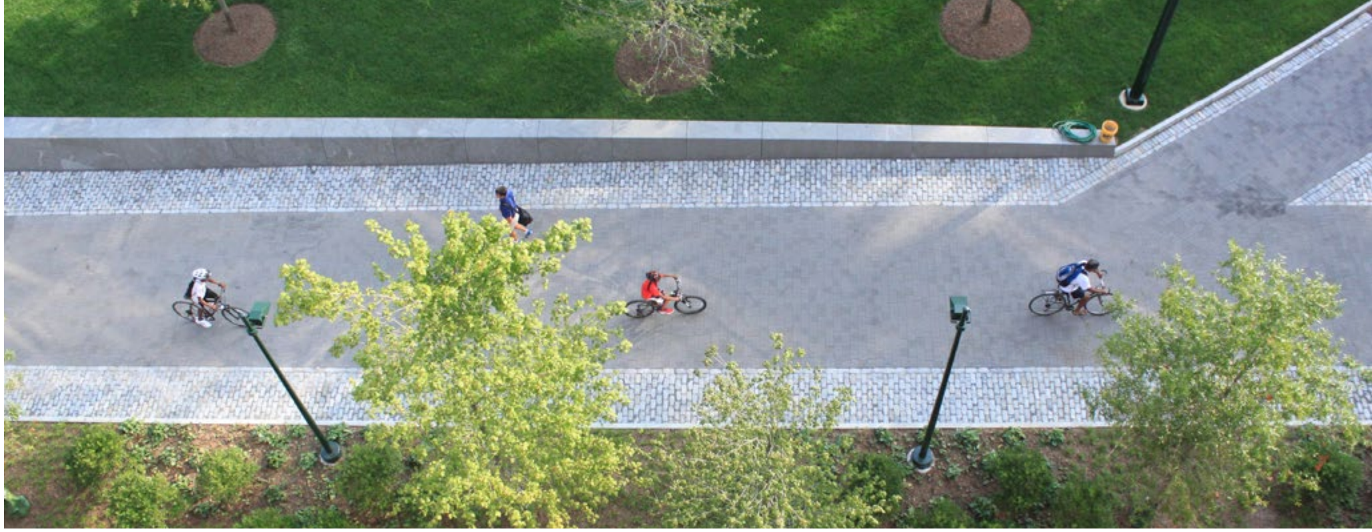
- Andropogon Associates (Landscape Architect)
- Meliora Design (Civil-Stormwater Engineer)
- Stantec (Civil-Utilities Engineer)
- Keast and Hood (Structural Engineer)
- Craul Land Scientists (Soil Scientist)
- Irrigation Consulting Inc. (Irrigation Design)

CONSTRUCTION + MAINTENANCE TEAM:

- P. Agnes (General Contractor)
- Ecological Landscape Management (Biological Amendments)
- Fiorella Woodworking (Woodwork)
- Brickman Landscaping (Landscape Maintenance)
- Andropogon Associates / University of Pennsylvania (Landscape Performance Research)

COST

- Construction cost: $8.5 Million
- Annual maintenance cost: Unknown



DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The non-infiltrating project was designed to store the 1-inch water quality volume and to release stored runoff at a controlled rate, as required by the Philadelphia Water Department (PWD) in 2012.

INFILTRATION POSSIBLE: No

MONITORING EQUIPMENT ON SITE: In 2012 Andropogon initiated an on-going, five-year landscape performance study at Shoemaker Green in collaboration with the University of Pennsylvania's Earth and Environmental Science and Facilities departments. The monitoring effort targets water (quality, quantity, plant transpiration rates); soil (compaction, infiltration, biology, moisture, pH, organic matter); plants (vigor, species suitability); and human use (occupancy, behavior). Additionally, a professor and graduate student from the university's School of Design are currently conducting additional research for a Landscape Architecture Foundation 2016 Case Study Investigation.

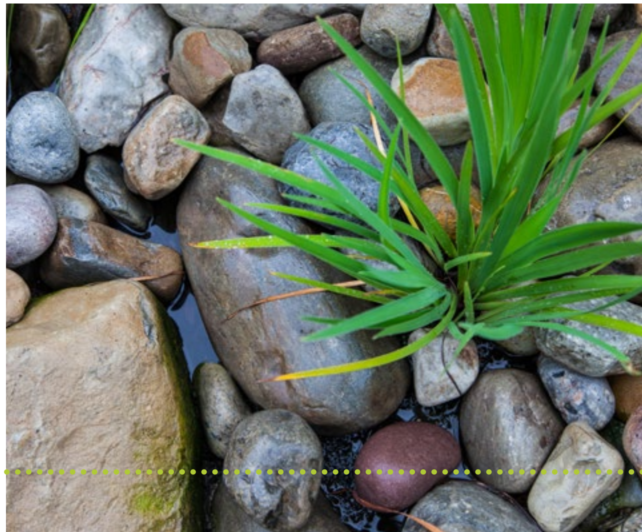


IMAGE CREDITS
All © Andropogon Associates

APPROACH

DESIGN

Shoemaker Green's designers aimed to:

1) Extend the campus' existing open space pattern.
2) Create an accessible green space that provides urban habitat.
3) Provide students and faculty with an on-campus "living laboratory" for academic research.

During design, infiltration proved to be the most influential variable. The site rests atop approximately 30-feet of urban fill (i.e. building foundation, rubble, degraded soils) in addition to the buried tennis courts, half of which remain intact. Due to the urban fill's inconsistent composition, pre-construction infiltration testing found extreme infiltration variability across the site, ranging from 0.48 to 16,941 inches/hour. To minimize the risk of sinkhole development and associated sub-structural failure, the design team decided to pursue a non-infiltrating design approach by using a liner at the base of the new landscape. The site functions like a stormwater "bathtub," or high-performing green roof, that relies upon evapotranspiration and stormwater capture with re-use for irrigation.

CONSTRUCTION

Construction was unusually smooth, aside from a glitch with the rain garden weir elevation that required trouble shooting in the field by the landscape architect and execution by the contractor. The weir within the rain garden's natural stone weir wall was too high when installed, due to irregularities in the stone. As a result, reducing the rain garden's ponding depth required chiseling the stone to drop the weir opening to its intended elevation.

POST CONSTRUCTION + MAINTENANCE

A key component of the maintenance regime involves regular application of compost tea and de-compaction after large events in the lawn area. Consequently, the research team monitors the soil biology, plant robustness, and soil compaction to better understand the effectiveness of this regiment. In 2014, additional site monitoring identified that the irrigation system was accidentally set to more than eight times the designed rate, at which point the maintenance contractor was able to resolve the issue by re-programming the system.

FINDINGS

ENVIRONMENTAL With 48,665 square feet of disconnected impervious area and a one-inch storm management requirement, Shoemaker Green is required to manage 3,412 cubic feet (25,523 gallons) of stormwater. The university, however, requested that greenspace additionally manage runoff from the adjacent athletic facility buildings – 21,255 cubic feet (159,000 gallons) – plus air conditioner condensate from the buildings. In 2013, the wettest year since construction, the site directly received 4,172,050 gallons of stormwater. During the largest single rain event, the site effectively managed 3.16 inches of water, more than three times that required by the Philadelphia Water Department (PWD). Researchers attribute the added management to soil storage and evapotranspiration, neither of which are currently given full credit by PWD. Additionally, the project aimed to increase biodiversity by building soil; supporting diverse, native plant species; creating micro-habitats with varying moisture and shade regimes; and providing potential songbird and pollinator corridor connections.

SOCIAL Shoemaker Green supports (and withstands compaction by) more than 100,000 people during an annual three-day hosted by the university. The site is open to the public, so anyone is free to enjoy the open lawn or naturalized green space. Social monitoring conducted by the research team found that people perform varied active and passive activities in Shoemaker Green all year round, and males more commonly occupy the space than females. The site also offers educational opportunities by providing professors and students with an on-campus outdoor laboratory.

ECONOMIC In January of 2013, a grant in the amount of $11,140 was awarded to the Department of Earth and Environmental Studies. The monies were provided to purchase equipment and any necessary laboratory testing, no staffing costs were included. Additional financial benefits may relate to increased property value and marketing/PR.

TAKEAWAYS

- Purposely specified engineered soils and plant species can support increased stormwater management, particularly in urban landscapes.
- Increased capacity achieved through soil storage and evapotranspiration should be recognized and incentivized by more municipalities to encourage investment in green infrastructure.

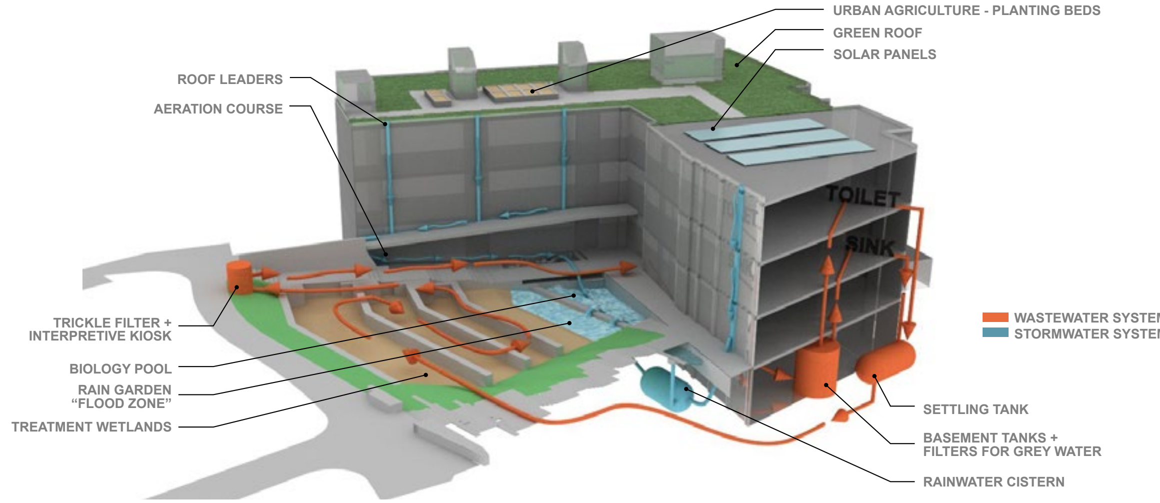
SIDWELL FRIENDS MIDDLE SCHOOL

PHOTO CREDIT: © Andropogon Associates

SIDWELL FRIENDS MIDDLE SCHOOL is the world's first LEED-NC Platinum K-12 school building and embodies its founding Quaker philosophy: to educate and guide students in developing social and environmental awareness. The renovation and addition to the 50-year-old 33,000 square foot brick school building sought to extend the learning environment into the landscape with a green roof, outdoor classroom, biology pond, butterfly meadow, and Washington D.C.'s first constructed wetland. Water conservation played a central role in the project design with a closed-loop wastewater system and underground cistern that collects roof runoff, stores it, and supplies water to the biology pond during dry summer months. The campus achieved recognition from the National Wildlife Federation as a wildlife habitat for its use of native plantings, which attract birds and insects to the middle school courtyard.

PROJECT IMPACT

- Integrates 100 percent of the LEED Platinum school building's water utility systems with the site
- Treats 100 percent of stormwater and wastewater on-site
- Supports more than 80 plant varieties native to the Chesapeake Bay region



PROJECT STATISTICS

GENERAL

LOCATION: Washington, D.C.

YEAR CONSTRUCTED: 2007

TOTAL PROJECT AREA: 1.5

TYPE OF DEVELOPMENT: Grayfields; Utilities

PRIOR LAND USE CONDITIONS: Redevelopment

CLIENT: Sidwell Friends School

PROJECT TEAM:

- Andropogon Associates (Landscape Architect)
- Kieran Timberlake Associates, LLP (Architect)
- Biohabitats, Inc. (Environmental Engineer)
- Vika, Inc. (Civil Engineer)
- CVM Engineers (Structural Engineer)
- Bruce Brooks Associates (MEP Engineer)
- Furbish (Green Roof Engineer)
- GreenShape LLC (Sustainability Consultant)
- Integrative Design Collaborative (Sustainability Consultant)
- Natural Systems International (Wastewater Consultant)

CONSTRUCTION + MAINTENANCE TEAM:

- Hitt Contracting, Inc. (General Contractor)

COST

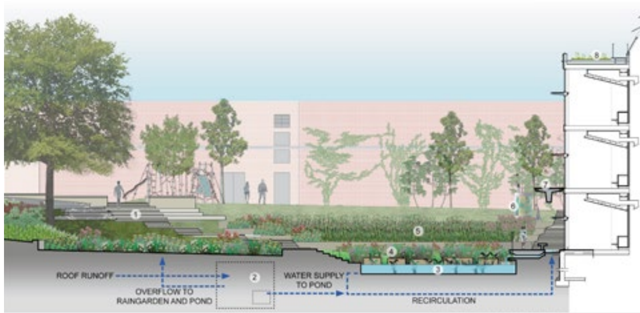
- Construction cost: $4 Million

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The project was designed to meet the regulations that preceded the Washington D.C. 2013 Rule on Stormwater Management and Soil Erosion and Sediment Control.

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: Students are engaged in monitoring constructed wetland performance and air, biology pond, and soil temperatures. The site's only installed equipment with monitoring capacity are the cistern and a rooftop rain gauge.



1. OUTDOOR CLASS ROOM
2. CISTERN
3. POND
4. RAIN GARDEN
5. WETLANDS FOR WASTEWATER TREATMENT
6. TRICKLE FILTER WITH INTERPRETIVE DISPLAY
7. RAMP TO SECOND FLOOR ENTRY
8. GREEN ROOF

IMAGE CREDITS
All © Andropogon Associates

APPROACH

DESIGN

The project's primary design goals were to:

1) Design a LEED Platinum school building with integrated stormwater and wastewater treatment systems that also serve as an outdoor laboratory.

2) Treat all stormwater and wastewater on-site.

3) Protect existing, mature trees.

4) Provide students with a rooftop classroom with access to green roofs, rooftop agriculture, and solar panels.

Achieving these goals required a closed loop rainwater harvesting and re-use system that deploys green roofs, bioswales, rain gardens, biological wastewater treatment (with a trickling filter and UV treatment), and terraced constructed wetlands.

CONSTRUCTION

A high level of coordination was required to construct an integrated building and landscape, particularly within the site's confined courtyard. Part of this coordination involved the protection of mature trees, which required siting utilities close to the building and installing pathways that would not damage tree roots via compaction.

POST CONSTRUCTION + MAINTENANCE

Maintenance of the Middle School landscape requires comprehensive knowledge of native plant stewardship and wetland maintenance. Post-construction challenges have required trouble-shooting performance issues with the green roofs and wetland, which have led to a better understanding of the systems.

FINDINGS

ENVIRONMENTAL Native plantings, including more than 80 species native to the Chesapeake Bay region, were planted instead of lawn, eliminating the need for irrigation and use of pesticides. Plant species in the courtyard and elsewhere on the middle school grounds include red maple, sassafras, oxeye sunflower, turtlehead and milkweed. The plant selection aimed to provide habitat for select endangered animal species, including the snowy owl and the monarch butterfly.

SOCIAL The Middle School campus design fosters ecological awareness through its landscape features, which middle school students interact with on a daily basis through the school lavatories, studying the health of the systems in Environmental Studies class, giving tours to visitors, or through passive exposure. A rooftop classroom offers students a range of applied learning opportunities, including vegetable gardening, green roof technology, stormwater management, and stewardship; and interpretive signage and scientific art further educates and inspires.

ECONOMIC Sidwell Friends Middle School is nationally recognized as a leader in sustainable school design. The campus design and sustainability ethos have helped attract distinguished students/alumni with potential affiliated donors, including Archibald Roosevelt, Charles Lindberg, Nancy Reagan, Julie Nixon Eisenhower, Tricia Nixon Cox, Bill Nye, Chelsea Clinton, Malia Obama, and Sasha Obama.

TAKEAWAYS

- Sustainable landscapes can have a positive impact on school identity and lead to a higher understanding of ecological awareness in students, faculty, staff, and visitors.
- Complex projects of this scale are difficult to implement using a standard design-bid-build process, which does not foster collaboration. When feasible, a negotiated bid with a general contractor or a construction manager may be preferable.

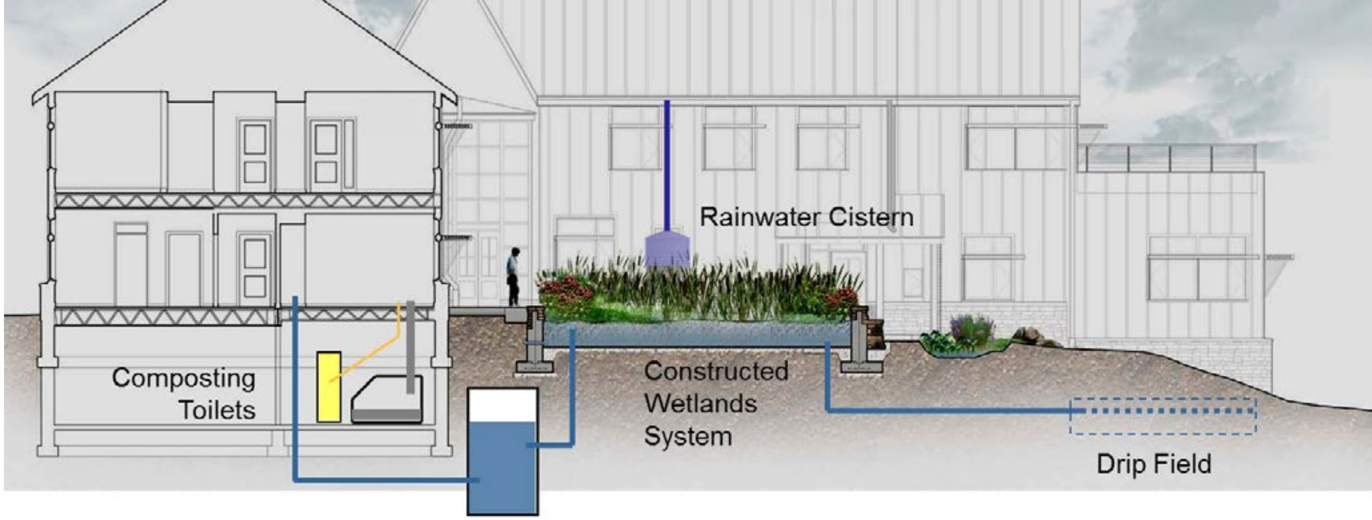
STROUD WATER RESEARCH CENTER

PHOTO CREDIT: © Andropogon Associates

STROUD WATER RESEARCH CENTER is one of the premier freshwater research institutions in the world., In 2012, Stroud expanded their campus to include the Moorhead Environmental Complex, a new LEED Platinum educational facility designed with the theme of "getting the water right." The project site of just over an acre restores the natural water balance and hydrology for over 2 acres of previously disturbed landscape through a system of green stormwater infrastructure (GSI) measures. This high-performance site includes stormwater management components that restore the natural water balance of the campus, creating outdoor gathering spaces and educational opportunities. The building and site work together to meet integrated, regenerative water goals, in addition to mitigating previous flooding and erosion issues. Other design components include a focus on sustainable water use and treatment, the use of recycled and locally sourced materials, energy efficiency, and indoor environmental quality.

PROJECT IMPACT

- Manages the 3.24-inch storm using decentralized green infrastructure
- Controls peak rate for 2-year through 100-year rainfall events



PROJECT STATISTICS

GENERAL

LOCATION: Avondale, PA

YEAR CONSTRUCTED: 2012

TOTAL PROJECT AREA: 3.26 acres

TYPE OF DEVELOPMENT: Retrofit

PRIOR LAND USE Conditions: Parking and former agriculture areas (mushroom house)

CLIENT: Stroud Water Research Center

PROJECT TEAM:

- Andropogon Associates (Landscape Architect)
- M2 Architecture (Architect)
- Meliora Design (Civil Engineer)
- Bruce Brooks (Mechanical Engineer)
- Biohabitats (Wetland Wastewater)
- Consilience (Owner's Representative)

CONSTRUCTION + MAINTENANCE TEAM:

- Nason Construction (Construction Manager)
  ThinkGreen (Landscape Contractor)

COST

- Construction cost: $5.6 Million

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The regulatory stormwater management requirements for this project included peak rate control for the 2-year through 100-year storm events, and retention of the net increase in runoff volume for the 2-year event (between and existing and proposed conditions), as defined in the Pennsylvania Stormwater Manual. Because much of the site was already disturbed, the net increase in runoff volume was not significant. Stroud elected to provide much more volume management by using a baseline condition of natural woodlands, and to mitigate the runoff from both existing conditions as well as the new building. The design strives to replicate natural (woodland) hydrologic conditions with no increase in runoff volume for the 2- year storm as compared to woodland (approximately 2.5 inch volume management).

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: Currently, there is no monitoring of BMPs on site.

IMAGE CREDITS
All © Andropogon Associates

APPROACH

DESIGN

The goals of this project were to:

1) Build a new education building.
2) Extend the campus' existing open space pattern.
3) Create an accessible green space and urban habitat.
4) Provide students and faculty with a "living laboratory" for academic research.

Stormwater management was based on a low impact development approach that strives to incorporate a number of landscaped-based stormwater practices to manage water close to where it is generated. The BMPs are constructed as a connected system allowing rain from small storms to be fully managed on-site by the landscape. The system includes: 9 rain gardens, 4,800 square feet of porous brick pathways, vegetated swales, 3 level spreaders that disperse runoff across restored meadows, a green roof, a large infiltration trench, 5,000 gallons in cisterns for water re-use, no-mow lawn areas, and restored native meadows and woodland plantings. In addition, all wastewater is cleansed by a wetland treatment system that returns the treated water to the aquifer at a cleaner level than the groundwater drawn from an on-site water supply well.

CONSTRUCTION

Construction practices focused on limiting site disturbance and soil compaction. The stormwater system is comprised of a network of distributed components relying heavily on the accurate construction elevations and grading. A construction challenge with regards to site protection was the numerous sub-contractors and personnel who did not adhere to all site protection requirements.. Ultimately, landscape and soil restoration measures were required to establish the desired stormwater system performance and landscape.

POST CONSTRUCTION + MAINTENANCE

Long-term maintenance is always a challenge. A three-day design charrette was held very early in the design phase, including Stroud maintenance staff as well as campus users. Their input informed design decisions and provided them with an understanding of campus GSI components and maintenance needs. Stroud maintenance staff also provided input during the construction process. This direct involvement of staff during design and construction has led to a staff that understands both the intent and design of the GSI components. Stroud has successfully maintained these

FINDINGS

ENVIRONMENTAL The site is planted with native species. Existing lawns were replaced with meadow or no-mow lawn, and riparian buffers were planted. The soils in the rain gardens and meadows were amended with compost and planted with native, low maintenance vegetation. The stormwater features at this site provide habitat for native species. Stroud measures nitrate levels in the groundwater from their on-site well, which has shown high nitrate levels as a result of past agricultural activities. The nitrate levels in the discharge from the on-site wastewater wetland system are lower than groundwater levels and meet drinking water criteria for nitrates.

SOCIAL Staff and students at Stroud were engaged in a 4-day long design charrette to define environmental goals and implement their vision into the final design. Since that time, the Stroud facility has served as an educational center for both students and working professionals. This includes training sessions for professionals such as teachers, PA DEP, county conservation district employees, staff and their counterparts from other states and regions.

ECONOMIC The funding sources were all private with the exception of a $239,000 Growing Greener grant for construction and monitoring of the wetland wastewater treatment system. Site and landscape materials were primarily obtained within 100 miles of the site.

TAKEAWAYS

- The treated wastewater from the wetland wastewater treatment system is exceeding intent, the outflow from the system is of higher overall quality and lower nitrate levels than the water withdrawn from the on-site well. The wastewater system returns the water to the aquifer cleaner than it was withdrawn.
- While there is no stormwater monitoring data, the frequent stormwater discharges from the site have been eliminated. Stroud Director, Bern Sweeny, refers to the "before" and "after" photographs of the facility as documentation that the GSI approach is performing. The "before" photograph shows flooding and runoff during a typical rainfall event; the "after" photograph indicates the improved site runoff at the end of Hurricane Sandy.

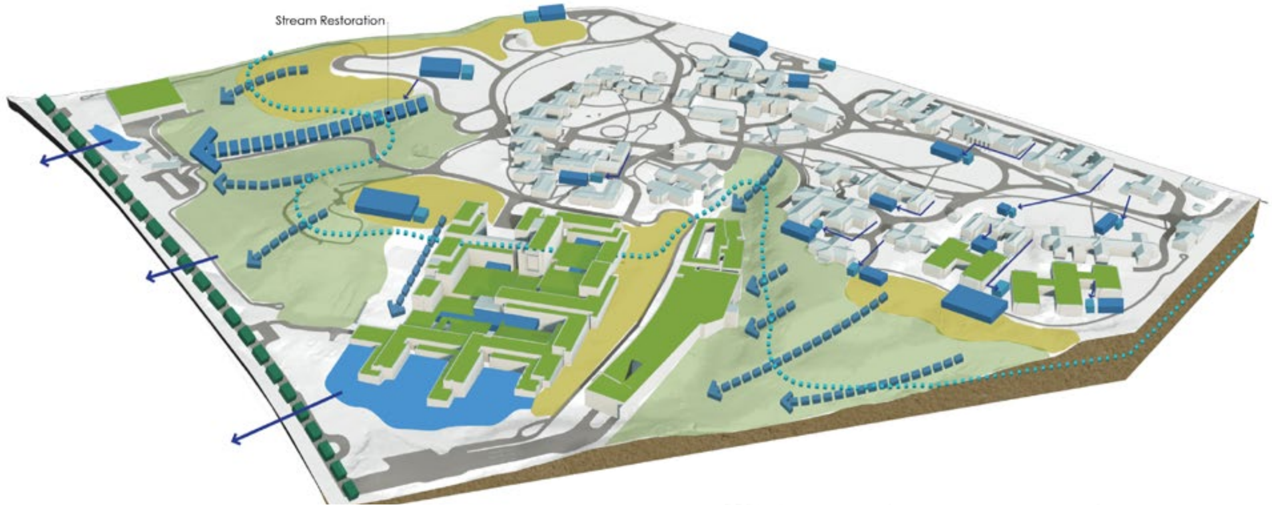
U.S. COAST GUARD HEADQUARTERS

PHOTO CREDIT: © Andropogon Associates

The **U.S. COAST GUARD HEADQUARTERS** (USCG) in Washington D.C. contains 32-acres of high-performance landscapes at grade and on rooftops. These landscapes were designed for maximum integration with the building systems through harvesting, treating, and reusing stormwater that is generated from both the site and buildings. In addition to green roofs, the stormwater management system includes wet ponds, bioswales, and step pools to handle stormwater runoff from the entire campus to treat the 2-year, 15-year, 100-year storms, and beyond to accommodate future development. The overall landscape structure of the site is organized around a series of courtyards, edges, and green roofs that create a green veil over the building and provide continuity in the landscape between the existing woodlands that surround the site and the historical campus to the east. This site organization preserves the Green Bowl, a series of bluffs and escarpments that surround Washington D.C..

PROJECT IMPACT

- Manages 2-, 15-, and 100-year storms exclusively through rooftop and at-grade green infrastructure
- Detains 424,000 gallons of water (1.7 inches) within 9.2-acres of green roofs
- Intercepts 230,000 gallons of water annually through the site's planted tree canopy



PROJECT STATISTICS

GENERAL

LOCATION: Washington, D.C.

YEAR CONSTRUCTED: 2013

TOTAL PROJECT AREA: 32 acres

TYPE OF DEVELOPMENT: Grayfield; Contaminated Soils; High Water Table

PRIOR LAND USE CONDITIONS: New development within an historic hospital campus

CLIENT: General Services Administration, US Department of Homeland Security

PROJECT TEAM:

- Andropogon Associates (Landscape Architect)
- HOK (Landscape Architect of Record)
- Perkins & Will (Architect)
- WDG Architects (Architect of Record)
- McKissack & McKissack (Garage and CUP Architect)
- Quinn Evans (Historic Architect)
- Loiederman Soltesz Associates, Inc. (Civil Engineer)
- Cagley & Associates (Structural Engineer)
- Girard Engineering (MEP Engineer)
- ECS (Geo Technical Engineer)
- HOK (Sustainable Design and LEED Consultant)

CONSTRUCTION + MAINTENANCE TEAM:

- Clark Construction (General Contractor)
- Valley Crest (Landscape Contractor + Maintenance)

COST

- Construction cost: $28.9 Million (Site + Green Roofs)

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The project was designed to meet the following local and national stormwater management requirements:

1) Washington D.C. 2013 Rule on Stormwater Management and Soil Erosion and Sediment Control

2) DCMS4 Municipal Separate Storm Sewer System (MS4) National Pollutant Discharge Elimination System (NPDES)

3) Energy Independence and Security Act (EISA), Section 438, which requires complete capture the entire 95th percentile storm or return of the site to pre-development hydrologic characteristics.

INFILTRATION POSSIBLE: Yes

MONITORING EQUIPMENT ON SITE: Surface temperature was measured using HOBO temperature pendant data loggers (UA-001-08) installed in perforated 2 inch diameter PVC pipe with end caps. The site's ongoing green roof media and plant coverage monitoring does not involve permanent monitoring equipment.

IMAGE CREDITS
All © Andropogon Associates

APPROACH

DESIGN

The project's primary design goals were to:

1) Create a high-performance, closely integrated building and site within a sloped landscape, which minimally impacted the surrounding historic campus.

2) Provide a healthy work environment for employees.

3) Sustainably manage stormwater, including meeting water quality goals exclusively using green roofs and a pond. Achieving the third goal involved 18 green roofs (totaling 9.2-acres), a 2.4-acre stormwater retention pond with ecologically valuable vegetated shelves, and bioswales with check dams.

CONSTRUCTION

A meticulously coordinated effort was required to construct such a large, integrated project. One of the most taxing landscape construction challenges involved Canada geese herbivory of young plants. Goose protection was not included in the construction drawings nor the specifications, although it could have prevented vegetation losses along the pond in particular.

POST CONSTRUCTION + MAINTENANCE

Effective maintenance of the ground landscape and green roofs requires a high labor hour commitment, and corresponding financial resources. Challenges have included improper mowing of tall grasses, weed pressure, and lack of access to certain green roof areas.

FINDINGS

ENVIRONMENTAL The USCG green roofs capture and store up to 424,000 gallons of water, or 100 percent of the 95th percentile storm (1.7 inches), while two years after planting, the site's planted tree canopy intercepts an additional 230,000 gallons of water annually Researchers have found that compared to a traditionally designed office complex, USCG is up to eight times more biodiverse; average surface temperatures are 1.6 degrees cooler on average and up to 15 degrees cooler at peak times; and carbon sequestration is four times higher.

SOCIAL USCG offers employees and visitors a rich landscape to occupy when approaching the buildings and during breaks. Views of vegetation are also provided, which have been linked in studies to increased work performance, happiness, and mental health.

ECONOMIC The green infrastructure installed at USCG is expected to generate a minimum of 89,667 U.S. Department of Energy and Environment Stormwater Retention Credits based on estimates for the stormwater capture of the extensive green roof (16,667 credits) and the 985 planted trees (73,000 credits).

TAKEAWAYS

- Native plant material was difficult to find locally in large quantities, so more advanced plant procurement coordination and contract growing would have been beneficial.
- A system based approach to design, which can produce functional and beautiful benefits, is achievable on a large-scale project.

WASHINGTON CANAL PARK

STORMWATER STRATEGY

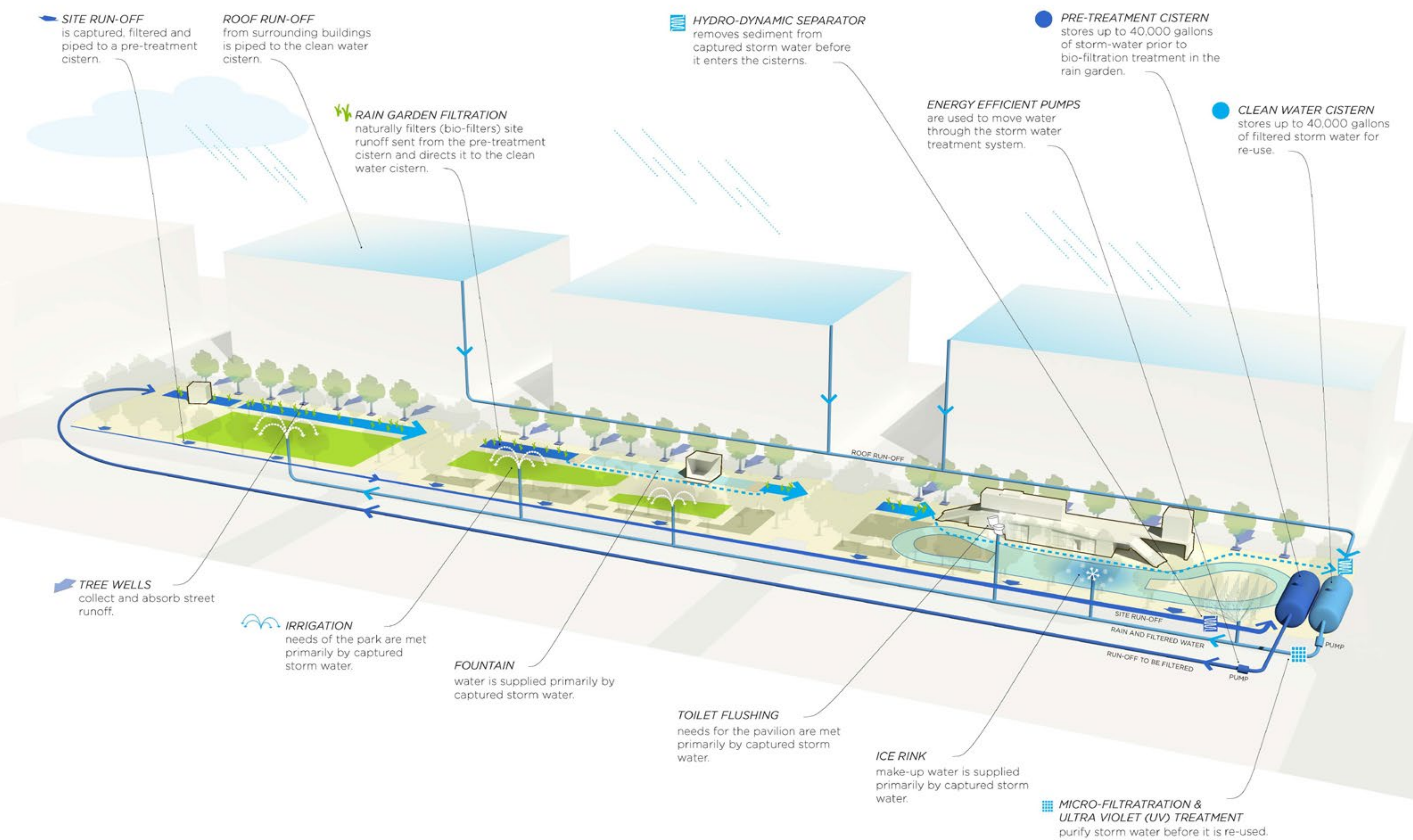


PHOTO CREDIT: © OLIN

WASHINGTON CANAL PARK is a linear, three - block, urban park situated in the Capitol Riverfront neighborhood of southeast Washington, D.C., a rapidly developing mixed-use community with 4,700 residents, over 32,000 daytime employees, and almost 3 million annual visitors. A unique public-private partnership provided funding for the park. Formerly a parking lot for District school buses, the site is the location of the historical Washington City Canal system that once connected the Potomac and Anacostia Rivers. The design evokes this heritage through a linear rain garden and three pavilions reminiscent of floating barges that were once seen in the canal. The largest of the three pavilions, located at the southern end of the park, houses a full service restaurant and skate rental for the seasonal ice rink. Responding to the developer's desire to create a park demonstrating modern sustainable strategies, the restaurant building is covered with an accessible vegetated green roof and is heated and cooled utilizing a ground source heat pump. The linear rain garden and bioretention tree pits along the perimeter of the site collect, filter, and direct stormwater runoff into underground cisterns. This water is reused for the park's two interactive water features, as well as the ice skating rink and landscape irrigation. In addition, the stormwater infrastructure was designed to collect rainwater from the roofs of future adjacent buildings, creating a neighborhood-scale stormwater management system.

PROJECT IMPACT

- Reduces stormwater impacts to the combined sewer
- Re-uses rainwater for park uses through a holistic stormwater management system
- Demonstrates a first-of-its-kind stormwater reuse system in Washington D.C.

PROJECT STATISTICS

GENERAL

LOCATION: Washington, DC

YEAR CONSTRUCTED: 2012

TOTAL PROJECT AREA: 3 acres

TYPE OF DEVELOPMENT: Redevelopment

PRIOR LAND USE CONDITIONS: Brownfield

CLIENT: WC Smith

PROJECT TEAM:

- OLIN (Landscape Architect)
- Vika Capitol, LLC (Civil Engineer)
- Nitsch Engineering (Civil-Stormwater Engineer)
- SK&A Structural Engineers, PLLC (Structural Engineer)
- Joseph R. Loring & Associates, Inc. (MEP Engineer)
- Studios Architecture (Pavilion Architect)
- Environmental Consultants and Contractors,
- Inc. (Environmental Consultant)
- Atelier Ten (Environmental Design & Lighting Design)
- Bonestroo/Stantec (Ice Rink and Fountain Design Engineer)
- David Hess (Sculptor)

CONSTRUCTION + MAINTENANCE TEAM:

- James G. Davis Construction Corporation (Construction)

COST

- Construction cost: $20 Million
- Annual maintenance cost: $400,000 for the entire park

DESIGN / PERFORMANCE

STORMWATER REQUIREMENTS: The project had to comply with DDOE (District Department of Environment) criteria for CSO reduction. The parks holistic green infrastructure solution reduced stormwater volume from the site and three adjacent development parcels to below-pre-development conditions. In addition to stormwater reduction and water quality enhancement, the use of harvested rainwater in the play fountains required the team to perform a health risk assessment for DDOE's approval. Canal Park now is a model for other projects in the District to follow when re-using stormwater for potential human contact.

INFILTRATION POSSIBLE: Infiltration systems were not feasible at Canal Park due to the brownfield soils and concern for pollutant transport. Additionally, the site was located on urban fill, which contained a wide range of debris and unsuitable soils.

MONITORING EQUIPMENT ON SITE: No monitoring of stormwater is being performed.

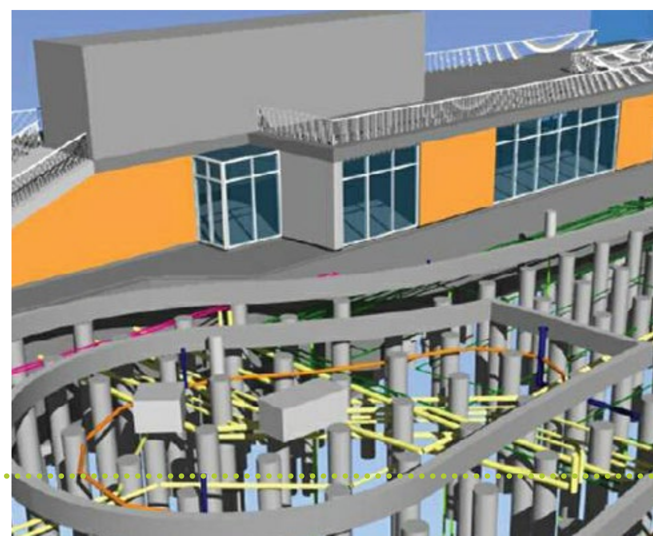


IMAGE CREDITS
All © OLIN

APPROACH

DESIGN

The park needed to attract visitors from around the city while retaining the interest of the local residents and numerous day-time office workers who were crucial to keeping the park active. The design needed to serve people of various ages, and diverse social and economic backgrounds, while also providing a connection to the canal's historic legacy. Environmental sustainability was a priority, with a goal of developing an innovative stormwater management system that considered runoff from surrounding buildings not yet built. Stormwater management provides the wellspring for much of this dynamic park's programming needs. The park features 6,000 square feet of linear rain gardens and 46 bioretention tree pits around the perimeter of the site capture, detain, and treat stormwater runoff. Two underground cisterns located under the south block hold up to 80,000-gallons of water collected from the park and neighboring streets. Two interactive water features and an on-site ice skating rink, utilize stormwater runoff captured and treated on site. Additionally, the treatment system (bioretention, filtration and ultraviolet disinfection) for the reused stormwater targets contaminants identified as potential risks.

CONSTRUCTION

Canal Park was constructed on the former site of a 3 city block parking lot. A maze of utilities was present, and the park is surrounded by city streets. Two streets cross the park itself. There were many construction issues for the project due to its complexity of design in a highly-urban environment. The design was complicated by the inclusion of an ice rink, two interactive/play fountains, and a tavern/restaurant using geothermal heat pumps.

POST CONSTRUCTION + MAINTENANCE

Canal Park has an ongoing and robust maintenance plan. Maintenance of the BMPs include regular removal of trash and selective removal of vegetation from the landscape. To maintain quality, water in the reuse system is tested weekly and only organic, biodegradable products are used to maintain vegetation on-site. Park maintenance is a funded activity. Due to the complexity of all the park infrastructure systems the maintenance activities involve managing and monitoring equipment (such as pumps and control systems) as well as the landscape BMPs.

FINDINGS

ENVIRONMENTAL In addition to BMPs, over 150 trees and hundreds of shrubs and flowers were installed within the park, greatly increasing the area's biodiversity and vegetated biomass. The linear rain gardens are planted with a range of native and adapted species transitioning from woody shrubs and trees at the northern end, to shallow herbaceous plants in the south, and provide much-needed new urban habitat areas.

SOCIAL The park is open to the public and is programmed for several events throughout the year. Post-occupancy studies have shown that Canal Park is a region-wide attraction, as well as a neighborhood community asset for workers and residents of the DC Navy Yard District. The study was conducted from May 2013 to April 2014. The study was designed to answer questions posed by the design team about how design features might support social functions and questions posed by the client about how the park was functioning for visitors. On-site observations, time-lapse photography, and stakeholder surveys and interviews were conducted during this time.

ECONOMIC Canal Park is a part of the District's Capital Riverfront Development Plan. As such, it is an integral element in a regional economic development plan for the Navy Yard district. Its stormwater management system was designed to receive runoff from three adjacent development parcels, intended to provide an economic incentive to the developers of the parcels.

TAKEAWAYS

- When the park first began operation, park management received constant complaints regarding the "dirty" appearance of the water in the toilets. Despite their best efforts to explain this sustainable practice, public dissatisfaction remained high and park management decided to revert to traditional methods.
- Since the park was completed, adjacent redeveloped parcels have not connected to the system. The discrepancies between the way the system was designed and the way it's currently performing demonstrate that no matter how well a feature is designed, public perception and economic circumstances can still play an important role in how it will perform.

LITERATURE REVIEW

The need for data and information on the performance of GSI projects has emerged as a significant need. Comprehensive data will support industry professionals to continue improving the design and performance of these tools, developers and property owners to gain greater knowledge of the value that investing in GSI offers, and regulatory agencies to expand the performance metrics used to approve GSI projects.

This literature review focuses on current publications, and peer-reviewed research regarding triple bottom line - environmental, social and economic - benefits of GSI. Research themes presented in this review reflect and support the case studies featured in this library and include reduced stormwater runoff, air quality, climate change, and urban heat island effect, soils and vegetation, habitat and biodiversity, recreation, crime and violence, employee and student health and productivity, and local economic impact.

ENVIRONMENTAL

Research demonstrates that the environmental benefits of green stormwater infrastructure are significant and extend well beyond its fundamental goal of reducing stormwater runoff and improving water quality.

REDUCED STORMWATER RUNOFF

- Empirical studies of green roof stormwater retention performance have found that green roofs can retain anywhere from 40 to 80 percent of annual precipitation. For example, a green roof in Chicago with an area of 5000 square feet, using a 60% retention rate, can reduce runoff by more than 71,000 gallons annually.[10]
- Well-designed bioretention and infiltration features capture all or nearly all of the precipitation which falls on the feature and its related drainage area. For example, a site in Chicago with an infiltration area of 2000 square feet and a drainage area of 4000 square feet, using an 80% retention rate, can reduce runoff by almost 114,000 gallons annually.[11]
- Several studies have shown that pervious pavement can infiltrate anywhere from 80 to 100% of the rain that falls on a site….For example, a permeable pavement feature in Chicago, with an area of 5000 square feet, using an 80% retention rate, can reduce runoff by almost 95,000 gallons annually.[12]
- A study focused on quantifying stormwater management benefits of trees and green roofs through greening models found "With the intensive greening scenario, installing 55 million square feet of green roofs in the CSS area [of Washington D.C.] would reduce CSO discharges by 435 million gallons or 19% each year... Reductions in untreated discharges in the CSS area are over 22% for the intensive greening scenario."[13]
- A research study completed at a Department of Land, Air, and Water Resources, University of California aimed to determine the performance of engineered soils and trees in a bioswale concluded that the bioswale system "reduced runoff by 88.8% and total pollutant loading by 95.4%. The engineered soil provided a better aeration and drainage for tree growth than did the control's compacted urban soil. The superior performance of the bioswale demonstrated its potential use for large-scale application in parking lots and roadsides to reduce runoff and support tree growth."[14]

AIR QUALITY, CLIMATE CHANGE, AND URBAN HEAT EFFECT

- A 2009 Stratus report indicated significant reductions in seasonal ozone, sulfur dioxide, nitrogen oxides, and carbon dioxide from the increased trees that would result from managing runoff from 50 percent of impervious surfaces in Philadelphia with green stormwater infrastructure.[15]
- "Although many studies agree that [other] vegetative infrastructure elements such as bioswales, rain gardens and other bio-infiltration techniques can provide considerable air quality benefits, there is currently a lack of scientific research measuring and quantifying the direct air pollution uptake potential of these practices."[16]
- "In addition to green roofs, trees, and bioretention and infiltration practices, permeable pavement can also improve air quality and reduce atmospheric CO2. Permeable pavement reduces the amount of water treatment needed by allowing stormwater to infiltrate on site, in turn reducing air pollution

and CO_2 emissions from power plants. It also decreases ground level ozone formation and helps to lower pavement surface temperatures by reducing the amount of heat absorbed. This helps to cool the air and decrease the amount of energy needed for cooling. It also mitigates the urban heat island effect."[17]

- "Research synthesized in a Michigan State University report offers average carbon sequestration values provided by extensive green roofs' aboveground biomass[18]…Using the data from that report, it is possible to arrive at an estimated range of carbon sequestration per square foot for similarly implemented extensive green roofs….the hypothetical 5,000 square foot extensive green roof would sequester between about 166 and 172 pounds of carbon annually, or an average of 169 pounds of carbon per year." [19]
- 100 medium trees of various species are capable of sequestering 44,400 pounds of carbon dioxide annually.[20]
- "Although many studies agree that vegetative infrastructure such as bioswales, rain gardens, and other bio-infiltration techniques can provide a considerable amount of carbon sequestration benefit, there is a current lack of scientific research measuring and quantifying the sequestration potential of those practices."[21]
- "Various studies have estimated that trees and other vegetation within building sites reduce temperatures by about 5°F when compared to outside non-green space. At larger scales, variation between non-green city centers and vegetated areas has been shown to be as high as 9°F. Likewise, recent studies done on permeable pavement have found that it reduces or lowers the negative impacts of UHI through its porosity, which serves to insulate the ground better and allow more water evaporation. Both of these effects aid in cooling temperatures and mitigating the UHI effect."[22]
- "One study, evaluating the benefit of reduced extreme-heat events, estimates that, at a city level, 196 premature fatalities can be avoided in Philadelphia (over a 40-year period) by integrating green infrastructure throughout the city landscape to address its combined sewer overflows (McPherson et al 2006; Akbari et al 1992; Stratus 2009). According to figures from the USEPA (n.d.b), the value of a statistical life (VSL) is $7.4 million (in 2006 dollars). Thus, applied to the Philadelphia study, reductions in UHI-related fatalities could save over $1.45 billion."[23]
- "The Lawrence Berkeley Lab Heat Island Group estimates that each one degree Fahrenheit increase in peak summertime temperature leads to an increase in peak demand of 225 megawatts, costing ratepayers $100 million annually (Chang 2000)."[24]

SOILS AND VEGETATION

- In a study between 2009 and 2011, researchers at Villanova University quantify evapotranspiration rates of a green roof and found "[t]he average daily ET was observed to range from 1 to 10 mm/day depending on season, temperature, relative humidity, solar radiation, and antecedent moisture condition."[25]
- A study aimed at investigating the effect of tree roots on infiltration in compacted soils showed that tree roots "penetrated the more compacted soil, increasing infiltration rates by an average of 153%." The study concluded that "some species may be effective tools for increasing water infiltration and enhancing groundwater recharge" in infiltration best management practices.[26]
- A study on the characteristics and performance of bioretention systems for the removal of several heavy metals showed "[r]eductions in concentrations of all metals were excellent (> 90%) with specific metal removals of 15 to 145 mg/m2 per event. Moderate reductions of TKN, ammonium, and phosphorus levels were found (60 to 80%). Little nitrate was removed, and nitrate production was noted in several cases. The importance of the mulch layer in metal removal was identified. Overall results support the use of bioretention as a stormwater best management practice and indicate the need for further research and development."[27]
- "The sand based bioretention systems provide an excellent LID stormwater system for high density urban sites. However, it is essential that the systems are constructed with 80 or more percent sand, and that at least 70 percent or more of the sand be uniformly graded medium to coarse sand."[28]
- "Native plant landscapes can infiltrate as much as 25 times more rainwater than turf grass, reducing stormwater pollution while promoting groundwater recharge."[29]
- "Tree canopies reduce soil erosion by diminishing the impact of raindrops on barren surfaces and by improving soil strength and stability through encouraging the build-up of soil organic matter and the action of tree roots (CUFR, 2002; Nisbet et al., 2004)."[30]

HABITAT AND BIODIVERSITY

- "Ecological economists recognize two aspects of habitat which are preconditions for the provision of a whole array of ecosystem services. First, habitat is living space for both resident and migratory species. Second, habitat provides nurseries for species which live their adult lives elsewhere….[However, few contingent valuation studies have been conducted that examine the] habitat value of urban green space."[31]

SOCIAL

Green stormwater infrastructure provides community and neighborhood benefits for all its users, workers and residents. Health is a significant benefit and could be a driver for community planning. The Public Health field has recognized "Place Matters",[32] the physical environment having demonstrable effect on the nation's health. There is also agreement among professionals that once capital improvement on the environment is made, the positive health impact can be permanent when the performance level of the project improvement is high.

COMMUNITY AMENITIES AND RECREATION

- "In one study, Philadelphia, Pennsylvania, estimated an increase of almost 350 million recreational trips (over a 40-year period) when utilizing green infrastructure within the proposed implementation of its Green City Clean Waters plan to control stormwater. The 2009 monetized present value of these added trips could amount to over $520 million (Stratus 2009)".[33]
- Estimates on "user days" from the 2009 Stratus report offers a helpful starting point for valuing improved recreation from green infrastructure and increased vegetation.
    - One additional vegetated acre provides an estimated 1,340 user days per year
    - One additional vegetated acre provides an estimated 27,650 user days over a 40-year period
    - One user day provides an estimated $0.71 in present value for 40-year project period

  The Stratus report translated these increased user days to an approximate economic benefit of $951.40 for each additional vegetated acre per year and about $19,631.50 for each additional vegetated acre over a 40-year project period.[34]
- "Another approach to valuing recreation is determining the avoided costs in connection to health benefits. An example of this would be studies that correlate lowered medical expenses with increased levels of routine physical activity. In a 2000 study, researchers found that when previously inactive adults regularly incorporated moderate physical activity into their routines, annual mean medical expenditures were reduced by $865 per individual (Pratt et al. 2000)."[35]
- "Biodiversity loss has negative effects on several aspects of human wellbeing, such as food security, vulnerability to natural disasters, energy security, and access to clean water and raw materials. It also affects human health, social relations, and freedom of choice."[36]
- In a Philadelphia-based study, researchers conducted a decade-long difference-in-difference analysis of the impact of a vacant lot greening program on health and safety outcomes. The study found decreased levels of self-reported high stress around newly greened vacant lots. [37]

CRIME AND VIOLENCE

- A study done by the Landscape and Human Health Laboratory at the University of Illinois at Urbana/Champaign (UIUC) found that, "Exposure to green surroundings reduces mental fatigue and the feelings of irritability that come with it. . . . Even small amounts of greenery . . . helped inner city residents have safer, less violent domestic environments." (Kuo and Sullivan 2001b).[38]
- Some researchers also look at the linkages between increased urban greening and crime. A 2001 study by Sullivan and Kuo found that increased greening and reduced crime.[39] Another study conducted from 2000 to 2012 in Philadelphia specifically investigated the health and safety effects of urban green stormwater infrastructure projects. Results show consistent and statistically significant reductions in narcotics possession (18%–27% less) within 16th-mile, 8th-mile, quarter-mile, and half-mile distances from the GSI sites. Narcotics manufacture and burglaries were also significantly reduced at multiple scales.[40]

EMPLOYEE AND STUDENT HEALTH AND PRODUCTIVITY

- Workers in environments that incorporate natural elements reported 15% higher level of well-being, were 6% more productive, and were 15% more creative than those who work in environments devoid of nature.[41]
- A study of high school students in Illinois found that students with a view of trees were able to recover their ability to pay attention and bounce back from stress more readily than those who looked out on a parking lot or had no view of windows at all.[42]

ECONOMIC

Green stormwater infrastructure boasts as array of economic benefits, both direct and indirect. From local, small business job growth to increased property values, the economics of green stormwater infrastructure makes a compelling case for its proliferation.

- The local GSI industry is believed to be experiencing double-digit annual growth, and conservatively represents annual economic impact of almost $60 million within the city of Philadelphia, currently supporting 430 local jobs and generating nearly $1 million in local tax revenues.
- Philadelphia Water has projected that it will invest anywhere from $1.2 to 2.4 billion in stormwater infrastructure projects over the life of GCCW, and is inducing additional private GSI projects through regulation and incentives. Conservatively, these investments will produce a $3.1 billion impact in the Philadelphia economy, supporting about 1,000 jobs per year and generating $2 million per year in local tax revenues for the entire 25-year period.
- It is estimated that proximity to a GSI feature produces a 10+ percent increase in house value, which means that the 496 GSI projects that have been completed in GCCW's first five years have yielded an aggregate $1.3 billion increase in citywide property value, producing an annual increase of $18 million in property tax for the City of Philadelphia and its public schools.[43]
- "Several empirical studies have shown that property values increase when an urban neighborhood has trees and other greenery. For example, one study reported an increase in property value of 2–10 percent for properties with new street tree plantings in front (Wachter 2004; Wachter and Wong 2008). Another study done in Portland, Oregon, found that street trees add $8,870 to sale prices of residential properties and reduce time on market by 1.7 days (Donovan and Butry 2009)."[44]

APPENDIX A - ENDNOTES

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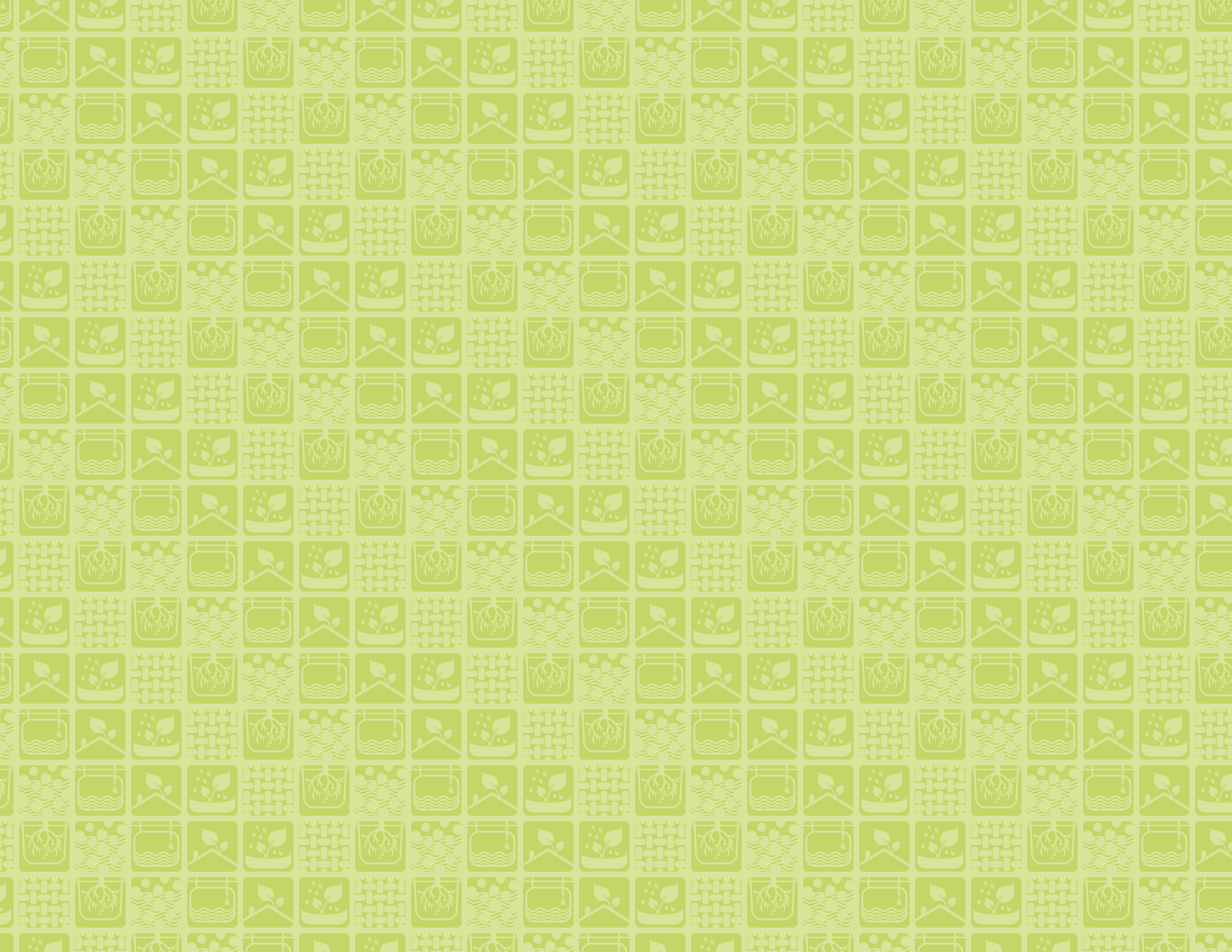
RUBRIC REVIEWERS: Bryan Astheimer, LEED AP BD+C Re:Vision Architecture + Jeremy Chadwick, Philadelphia Water Department

RANKING	ENVIRONMENTAL BENEFITS	SOCIAL BENEFITS	ECONOMIC BENEFITS	INNOVATION	MONITORING
HIGH	The project's stormwater management features are mostly or entirely bio-infiltration, bio-retention, green roofs, and/or porous pavement. The stated design intent was to manage stormwater, as well as incorporate native plantings; create or improve habitat and/or biodiversity; create or preserve greenspace/open space;and/or otherwise provide additional ecological value. Monitoring data and/or anecdotal evidence shows that this project is performing well above its stated design intent re: stormwater management.	A. The project was intended for public access, and provides an exceptional number of demonstrable social benefits and/or educational components for its users, planned or not.	A. A significant amount of grant funding and/or in-kind donations were leveraged for the completion of this project/to expand its scope. B. A significant number of contracts for the design, build, maintenance elements of the project were awarded to local firms. (Local is defined as privately held firms headquartered in the same metropolitan area as the project location.) C1. Private projects: i. Significant demonstrable return on investment for the client, especially as it relates to the overall cost of the project, ie. stormwater fee credits, increased property value, etc. C2. Public projects: i. Significant demonstrable return on investment for the client, especially as it relates to the overall cost of the project ii. Significant demonstrable increase of surrounding property value.	Few of any of the project's stormwater management features are traditional/typical, with many pioneering applications of best management practices relative to peer projects that were constructed at the same time.	Monitoring is currently conducted on site. The data fully defends the perfomance narrative in one or more of the other categories.
MEDIUM	The project's stormwater management features are mostly or entirely bio-infiltration, bio-retention, green roofs, and/or porous pavement. The stated design intent was to manage stormwater, as well as incorporate native plantings, and/or create or improve habitat and/or biodiversity. Monitoring data and/or anecdotal evidence shows that this project is performing moderately above its stated design intent re: stormwater management.	A. The project was not intended to have public access. The project has private users, and/or provides a moderate number of demonstrable social benefits and/or educational components for its users, planned or not. B. The project was intended for public access, and provides a moderate number of demonstrable social benefits and/or educational components for its users, planned or not.	A. A moderate amount of grant funding and/or in-kind donations were leveraged for the completion of this project/to expand its scope. B. A moderate number of contracts for the design, build, maintenance elements of the project were awarded to local firms. (Local is defined as privately held firms headquartered in the same metropolitan area as the project location.) C1. Private projects: i. Moderate demonstrable return on investment for the client, especially as it relates to the overall cost of the project, ie. stormwater fee credits, increased property value, etc. C2. Public projects: i. Moderate demonstrable return on investment for the client, especially as it relates to the overall cost of the project ii. Moderate demonstrable increase of surrounding property value	Most of the project's stormwater management features are traditional/typical, with a few pioneering applications of best management practices relative to peer projects that were constructed at the same time.	Monitoring is currently conducted on site. The data moderately defends the perfomance narrative in one or more of the other categories.
LOW	The project's stormwater management features are mostly or entirely bio-infiltration, bio-retention, green roofs, and/or porous pavement. The stated design intent was primarily to manage stormwater. Monitoring data and/or anecdotal evidence shows that this project is performing at or below its stated design intent.	A. The project was not intended to have public access. The project has zero users, or provides few if any demonstrable social benefits and/or educational components for its users, planned or not.	A. Little to no grant funding and/or in-kind donations were leveraged for the completion of this project/to expand its scope. B. Little to no contracts for the design, build, maintenance elements of the project were awarded to local firms. (Local is defined as privately held firms headquartered in the same metropolitan area as the project location.) C1. Private projects: i. little to no demonstrable return on investment for the client, especially as it relates to the overall cost of the project, ie. stormwater fee credits, increased property value, etc. C2. Public projects: i. little to no demonstrable return on investment for the client, especially as it relates to the overall cost of the project ii. little to no demonstrable increase of surrounding property value.	All of the project's stormwater management features are traditional/typical relative to peer projects that were constructed at the same time.	A. No monitoring is currently conducted on site. B. The data contradicts/does not defend the perfomance narrative in one or more of the other categories.




TREE TRENCH


GREEN ROOFS


BIORETENTION


POROUS PAVING


CISTERN


SOIL STORAGE