Growing Together:
A Community Food Forest for Stormwater Management at Andrew Hamilton School

University of Pennsylvania

Student Team D18

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Abstract

The Andrew Hamilton School (AHS) is located only two miles from the University of Pennsylvania, but the differences between the two locations are pronounced. With a lack of green space, access to fresh and healthy foods, and stormwater management systems, AHS is in need of sustainable and food-producing green stormwater infrastructure (GSI) that would benefit both the students and the community of West Philadelphia. Our design will lower the school's stormwater fee, mitigate flooding in the community, alleviate the urban heat island effect, and provide access to fresh healthy food for students and the surrounding community. We propose a plan that will incorporate a green roof, rain gardens, raised beds, a food forest, and permeable pavers. To improve students' engagement with GSI, our project will also incorporate educational signage, the development and implementation of both watershed-focused and nutrition-oriented curricula, and a mural created by the school's students depicting the role of water in urban sustainability and resilience. In addition to collaborating with the school's leadership and students, we have worked with the School District of Philadelphia, the Philadelphia Water Department, the Netter Center for Community Partnerships, Students for Environmental Equity, and the Philadelphia Orchard Project to form a multidisciplinary team to design and eventually implement the GSI plan. The students and community partners will work together with the school to transform it into a sustainable community hub that provides food and helps mitigate neighborhood-wide flooding using GSI.

Introduction

We want our green infrastructure design to not only sustainably manage stormwater but also provide social, economic, and environmental benefits to students and local community members. The school is located in a food desert, which means there is a lack of access to fresh produce and other nutritious food at affordable prices, with only one to five grocery stores for every 1,000 residents. Additionally, Philadelphia's property wealth is just over $188,000 per pupil, which is around half of Pennsylvania's average, and 63.5% of school revenue comes from local property taxes. With 85.16% of students at AHS being economically disadvantaged, this puts stress and limits on school resources.

The parking lot surrounding the school frequently floods during minor storms, and there is little green space or vegetation at the school to manage stormwater naturally. The school falls within a combined sewer overflow area, meaning that whenever it rains, rainwater and raw sewage are mixed into the same pipe. When the rainfall volume totals above 1.5 inches in a single wet weather event, an overflow of the system is triggered, which discharges raw sewage directly into local waterways. The sewer outfall for the school's site is located just north of Eastwick, a historically marginalized Black community in Philadelphia which experiences chronic issues with both flooding and pollution. Therefore, the lack of on-site stormwater management at the school not only negatively impacts the school's students and staff, but also downstream communities. Additionally, the school is located in an area which is in the hottest 10% of the city, with an average temperature that is 3.8 degrees Fahrenheit above other neighborhoods. This creates an urban heat island effect with temperatures which can be dangerous for children.

In considering all of these factors, we aim to create a green infrastructure plan that will address stormwater management issues, engage and educate the local community and students, grow healthy, freely available nutritious foods, and provide extensive environmental co-benefits. Our design has taken into account soil profiles, water flow and drainage, current use of the area, cost, food availability, permitting, local stormwater regulations, and many other factors to create a design that includes fruit-bearing trees, raised beds, rain gardens, permaculture food forests, disconnection of the faculty parking lot, pervious pavers, a green roof, educational signage, and environmental curriculum development.

City-Wide and Neighborhood Context

Although parts of Philadelphia are in a new era of growth, rejuvenation, and progress, Philadelphia retains its unfortunate title of the poorest big city in America. As of 2019, the city's poverty rate sat at 23.3%, with the unemployment rate breaking past 15% in August this year. (Inga, 2020) These economic hardships are not evenly distributed across the city, with the northern and western neighborhoods bearing the brunt of it. Sitting on the corner of 57th and Spruce, in the heart of Cobbs Creek in West Philadelphia, AHS is in an area code that underperforms compared with the City of Philadelphia by basic economic indicators. Between 2009-2013, 47% of individuals fell below the poverty line (Duchneskie, 2018). Additionally, according to the 2018 American Community Survey 5-Year Estimates, the median household income in Cobbs Creek is $32,746, which is over $10,000 less than the median city-wide household income of $43,744. Additionally, 44.2% of children below the age of 18 in the neighborhood are living below the poverty line – nearly 10% higher than Philadelphia overall. As Cobbs Creek's residents are 93.1% Black, these economic indicators and demographic make-up led the Pennsylvania Department of Environmental Protection to classify the area as an Environmental Justice Area (PA Department of Environmental Protection, 2020).

An average of 63.5% of Philadelphia's school funding comes from property taxes. Looking at these statistics side by side, it is clear that AHS is under tight financial pressure. AHS does not have the budget to provide its enrolled students with access to green spaces that higher income communities and school districts across the city can access.

AHS also underperforms compared to the rest of the city by educational standards. AHS is a K-8 school with 615 students. The school's demographics generally align with those of Cobbs Creek. 90.2% of the school's students are Black. 612 of the 615 students at the school meet the income criteria to receive free lunch. Based on standardized test scores, only 15% of the students are proficient in mathematics and only 35% are proficient in languages (Area Vibes, 2016).

Indicators created by Greatschools.org, a national nonprofit whose mission is to empower parents' decision making to provide opportunities to their children, rates AHS as a two out of ten on their test scores. This score ranks the school far below the state average. They also provide a low equity score, a two out of ten, stating that "disadvantaged students may be falling far behind other students in the state" and the school may have "large achievement gaps" (GreatSchools.org, 2020).

Site Analysis

The school sits upon a 2.94 acre lot. The footprint is largely impervious; 87,487 square feet of the 95,659 square foot lot are impervious surfaces. The lot contains a 32,081.62 sq. foot school building, a 14,130.84 sq. foot faculty parking lot, and a 32,042.63 sq. foot school yard that is made up of a basketball court and blacktop (Google Maps, n.d.). The only permeable surfaces of note within the site are three small plots of grassy area adjacent to the faculty parking lot, and other smaller areas near the western and northern edges of the site.

A national stormwater calculator report with data provided by the Philadelphia Franklin Institute estimates an average annual rainfall of 50.18 inches over the last twenty years. Of this rainfall, 27.17 inches is stormwater runoff. There is an average of 77.34 days per year with rainfall. Of these wet weather days, 57.43 of them result in runoff. As climate change leads to increased precipitation in the mid-Atlantic United States, the amount of rainfall and, thus, runoff is expected to only increase.

The large impermeable surface footprint of the school results in high monthly fees. The City of Philadelphia, which charges a stormwater fee in addition to a water usage fee, charges the school a monthly fee of $1,065.13 for their stormwater runoff.

Currently, the lot surrounding the school building is split into two sections: a parking area for staff and a play area for the students including a basketball court, running track, and space to line up before and after school. There is also limited vegetation around the school, with small grass sections between the sidewalk and the building on the western, northern, and eastern sides, two trees in the middle of the play area, and three trees along the eastern side. There is a depressed area between the parking lot and the building on the eastern side that frequently floods and retains water. There are four existing drains: two in the play area and two in the faculty parking lot.

Site Analysis: Soil

In conjunction with Princeton Hydro, we collected soil samples and conducted a soil analysis. The results show that the majority of soil tested is silt loam, which is the ideal soil type for food production as it both retains some moisture and provides enough drainage to prevent over-saturation of the soil.

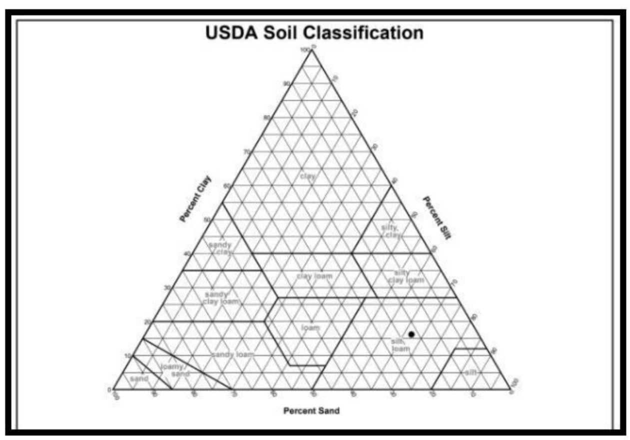

Figure 1. Andrew Hamilton School soil test results. Princeton Hydro, 2020.

Site Analysis: Water

The school experiences frequent on-site nuisance flooding in several areas. In addition to this, AHS is in a combined sewer overflow area and is connected by sewer infrastructure to a buried historic stream that was converted into a sewer. The sewer feeds into the nearby Cobbs Creek, which drains into the Delaware River. When the amount of rainfall in a given storm event exceeds 1.5”, the sewer system becomes overloaded and releases a mixture of raw sewage and stormwater into Cobbs Creek, which flows into the Delaware River. The combined sewer outfall is just upstream of the predominantly Black community of Eastwick, which already experiences chronic issues with both pollution and severe flooding. Thus, any water which we can keep out of the combined sewer system onsite will help to alleviate environmental justice issues in the adjacent community.

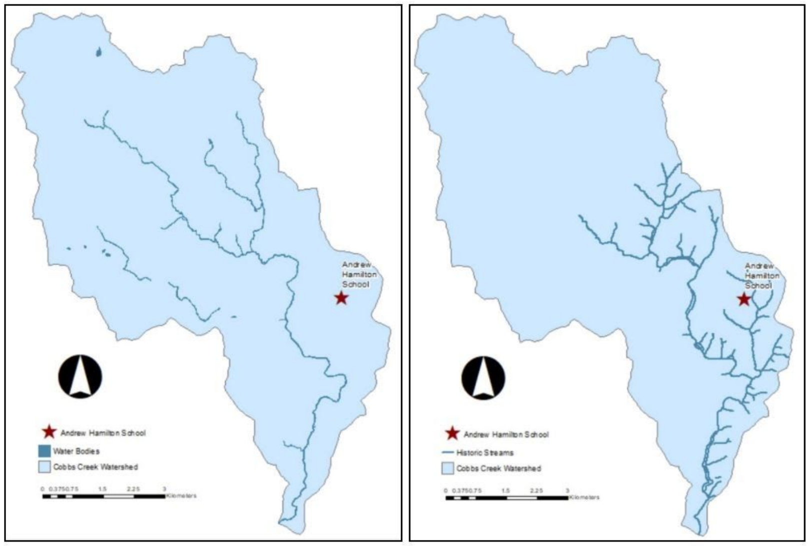

Figure 2. Andrew Hamilton School in the Cobbs Creek watershed with modern water bodies (left) and historic water bodies (right). Created using data from the USGS and the City of Philadelphia, 2020.

Project Goals

This proposal has seven goals which aim to benefit the environment, students of the school, and the surrounding community:

Goal 1: Improve the water quality of Cobbs Creek and the Delaware River by reducing the amount of runoff that will drain into the sewer and watershed

Goal 2: Increase resilience and offset the effects of these severe weather events at the school and nearby environmental justice communities by reducing impermeable surfaces and implementing rainwater capture mechanisms

Goal 3: Create a liminal space between the school and the surrounding community through gardens that offer mental health benefits to the students and neighborhood residents by providing a peaceful place of respite and connection to nature

Goal 4: Provide students and community members with access to fresh fruit and vegetables, and instill knowledge about healthy eating habits, nutrition, and a connection to their food supply

Goal 5: Address the environmental injustices inherent in the neighborhood by offsetting the urban heat island effect and increasing equitable access to green space

Goal 6: Provide meaningful engagement experiences with students to incorporate their ideas in the design process

Goal 7: Design GSI-oriented curricula to improve STEM education opportunities and foster environmental stewardship

Community Engagement and Education

Extensive community engagement was conducted during this proposal. From the very beginning, the school's principal and faculty were involved in the site selection and design process through multiple phone calls, site visits, and email exchanges. Through this relationship we were able to engage the local school district. The school district is planning to repave the parking lot and are obligated to implement stormwater management practices due to local stormwater management regulations. They have agreed to utilize our project's design, and we plan to continue engaging with them throughout implementation.

The students of AHS were directly engaged through curricula that were designed in tandem with our project team and the school's faculty. For example, one series of lessons evoked feedback in the design and plant selection to be used in the green infrastructure. After conducting a poll during a class at Hamilton, we received direct feedback from the students about which food-producing plants they would be most interested in growing. The results of that poll (for perennial plants) were: apples, strawberries, blueberries, blackberries, raspberries, peaches, and cranberries. Working with the students, we selected tomatoes, squash, herbs, mushrooms, corn, cabbage, grapes, potatoes, and sorrel to plant in the raised garden beds. Beyond the plant selection process, other lesson plans used the project as a starting point to discuss agricultural science and industry, food deserts, environmental impacts of farming and food production, environmental justice, healthy lifestyles, and community-based agriculture.

We also worked closely with the Netter Center for Community Partnerships and the Philadelphia Orchard Project to assist our efforts in engaging the students, creating connections with the community, planning and caring for the GSI installations, and implementing GSI-oriented curricula. The Netter Center, which works to enable civic and community engagement between the University of Pennsylvania and the West Philadelphia community, has led local efforts in implementing green infrastructure and food education into school curricula; this served as a model for our engagement strategy with the students. Additionally, the Netter Center will hire part-time staff members to maintain the garden spaces and will continue to build out curricula utilizing the rain gardens and food forest. The Philadelphia Orchard Project, a local non-profit that helps plant permaculture orchards in low-income communities, is assisting with the installation and maintenance of the food forest.

Working with the Netter Center over the last few months, Students for Environmental Equity (SEE) has built amazing classroom connections with the students at AHS. SEE is a group of undergraduate and graduate fellows at the University of Pennsylvania who develop educational curricula and activities to connect classroom content with environmental equity. Focusing on issues of environmental injustice, the Fellows planned engagements in Language Arts/Social Studies classrooms and Math/Science classrooms to connect the bigger issues of the world to the community garden these students hope to bring on site. Luckily, the imaginings for this project started the year prior with a group of now 7th graders, and so this year's engagements started with a recap of how these students wanted to see a food forest come to life at their own school. To build a strong foundation, the Fellows prepared presentations around native and invasive species, organic and genetically modified foods, and came full circle to discuss examples of youth environmental activism, to show these students that their voices matter and they can bring change to their communities as well.

Design Solutions

To address issues of runoff, our design includes various filtering methods around the drains. Both of the drains in the play area will have a ring of pervious pavers with subsurface storage surrounding them. We chose not to place vegetation around these drains because it would interfere with the students lining up before and after recess. In addition to managing these drains with permeable pavers, our design takes advantage of the fact that the school is scheduled to resurface the faculty parking lot within the year. The school district and the engineering firm they have contracted with for the parking lot project have agreed to regrade the lot so that the entire surface slopes toward a drain. The slope will channel runoff into a rain garden in the play area adjacent to the parking lot in accordance with our design. This will manage all of the runoff from the parking lot surface. At the entrance of the parking lot, there will be an oil-absorbing filter in the drain to catch spills from vehicles and prevent polluted runoff from interfering with plant growth in the connected rain garden.

We will install several rain gardens throughout the property amounting to a total surface area of 1650 sq ft, as well as a 11,140 sq ft extensive green roof. We will also depave the area between two existing tree pits to be part of a larger rain garden design in the area adjacent to the school's basketball court; currently these tree pits are at the same elevation as the rest of the yard, so they do not manage much stormwater. We will deepen those planted areas to include subsurface water storage and provide increased growing space for native plants.

The most important part of our design is our inclusion of various food-producing plants to combat the food desert, including fruit trees, annual vegetables, and herbs. A perennial food forest will be installed around the perimeter of the school; native fruit-bearing trees and shrubs will be placed in the rain gardens in the school yard; and annual vegetable crops will be planted in 36 raised beds to the east of the school.

Our design features various ways to engage the community. We will create a safe and relaxing green space with benches; a picnic table; and educational signs on rain gardens, soil infiltration, and groundwater recharge which will provide an interface for students to learn about GSI. To incorporate art into the design, a mosaic mural depicting water with poetry written by the students will be opposite the raised beds, and the UN Sustainable Development Goals will be painted on the pavement next to where students line up every morning.

Design Solution: Overall Co-benefits

GSI not only manages stormwater, but also provides extensive social, environmental, and financial co-benefits. On-site GSI can provide an opportunity for students to engage in hands-on projects spanning several disciplines: landscape architecture, ecological design, biology, public health, environmental studies, engineering, urban conservation, and more. Additionally, five of six recent studies found that exposure to natural areas in urban environments improve cognitive functioning, boost attentional capacity, and improve working memory (Kondo et al., 2018). These cognitive benefits could have a positive effect on students' academic performance.

In addition to providing learning opportunities for students, connections between humans and urban green spaces can benefit physical health and reduce blood pressure (U.S. EPA, n.d..) One literature review that analyzed studies pertaining to the relationship between urban green spaces and health found a negative association between urban green spaces and mortality, resting heart rate, and violence (Kondo et al., 2018).

More co-benefits are linked to health. Noise pollution, or excess noise, can lead to myriad health issues, including hearing impairment, sleep disturbance, and hypertension. It can also lead to decreased scholastic performance (Rowe, 2011). Noise pollution is particularly prevalent in urban areas due to the presence of tall buildings, concrete and other hard surfaces, street canyons, and high ambient noise due to traffic. Green spaces can help to offset noise pollution by reducing the surface area of hard materials, as well as by reducing noise through both their vegetation and growing substrate that absorbs sound waves (Rowe, 2011; The value of green infrastructure, 2010). Because of these qualities, green spaces can be a valuable resource in reducing urban noise pollution and its negative effects on the students and surrounding community.

Greened urban spaces can also provide a habitat for animals and insects in urban areas that have been largely stripped of the natural spaces they need to survive (The science of sustainability, n.d.). They can do this by creating "stepping stones" or "islands" of habitat space (Adams & Marriott, 2008). They can additionally create "corridors" through urban spaces that can connect otherwise isolated habitat areas (Wilkinson & Dixon, 2016). Such stepping stones, islands, or corridors can provide spaces for wildlife to rest, feed, nest, or raise their young (Wilkinson & Dixon, 2016).

Green spaces also have extensive financial co-benefits. For example, in 2009, the Philadelphia Water Department (PWD) implemented a parcel-based stormwater fee program for all non-residential properties. The fee associated with impervious land cover is significantly higher than the fee for previous land cover. This program is designed to incentivize the conversion of impervious surface area to pervious surface area using green infrastructure such as green roofs and rain gardens. If a property manages the first inch of runoff from a storm event, the property owner can achieve up to an 80% reduction in stormwater fees (Natural Resources Defense Council, 2013.) PWD also offers a tax credit which covers 50% of green roof installation costs, up to $100,000 per project (Natural Resources Defense Council, 2013).

Design Solution: Green Roof

One major part of our design is a green roof. Green roofs can manage air pollution, carbon emissions, building energy usage, and the lifecycle of the roof itself. Air pollution is ubiquitous in urban areas, and can have deadly effects on human health (Rowe, 2011). The most common health consequences of exposure to air pollution are respiratory illnesses and cardiovascular disease (Rowe, 2011). Two separate studies found that a single square foot of green roof can filter 0.04 pounds of dust and other particulate matter from the air per year (Adams & Marriott, 2008). Green roofs accomplish this feat via several different methods: dry deposition; the sequestration and storage of carbon; reduced energy demand and subsequently lowered energy production emissions and air pollution; and the slowing of ozone formation by lowering ambient temperatures (U.S. EPA, 2008).

One of the main contributors to climate change is the release of carbon dioxide into the atmosphere. Green roofs can reduce atmospheric carbon in two ways: by sequestering carbon in their roots and surrounding substrate, and by reducing the energy consumed by the building beneath them through insulation. The first method is only temporary, as the amount of carbon a green roof or rain garden can absorb is finite and will reach a carbon-neutral point after a few years (Rowe, 2011). The second benefit regarding energy usage, however, will persist throughout the lifetime of the green roof.

Green roofs provide heating and cooling savings by insulating buildings from wide swings in temperature (Framework energy savings, 2020). They accomplish this by shading roof surfaces, creating thermal insulation through heat retention in their growing media, and using the evapotranspiration process to cool the air surface above the building (U.S. EPA, 2008). A cooler roof creates energy use savings by decreasing the movement of heat into and out of the roof's surface (Wilkinson & Dixon, 2016). Green roofs also create energy savings during the winter by using their insulation properties to prevent the loss of heat from the building to the atmosphere (Wilkinson & Dixon, 2016).

Green roofs can provide additional savings for buildings with rooftop air conditioning systems (Natural Resources Defense Council, 2013). Green roofs can reduce the ambient temperature of the roof by 32 – 33.26°F and thereby lower the temperature of the system's air intake, which improves the efficiency of the system (Framework energy savings, 2020).

Although the upfront cost of a green roof is on average twice that of a traditional roof, the total life cycle costs of the roof must be taken into consideration. The typical lifespan of a traditional gray roof is 20 years. The lifespan of a green roof is double to triple that: about 40 years on average (Wilkinson & Dixon, 2016). This is due to several factors, including the reduction of ultraviolet damage from sunlight to the roof membrane and of damage caused by widely fluctuating temperatures (Acks, 2006; Duffield Associates, 2013). This extension of the roof's service life recoups the cost of installation in the long term and represents significant cost savings over time.

Design Solution: Rain Gardens

The design for the schoolyard incorporates several rain gardens, which are incredibly effective in offsetting stormwater. Plants and soils are selected specifically to maximize infiltration and storm water retention (Asleson et al 2009). Because of these properties, rain gardens help to establish patterns of hydrological flow that closely resemble undeveloped watersheds, thereby slowing the rate and intensity of runoff draining into nearby water bodies or sewer systems (Vineyard et al. 2015).

In addition to managing stormwater, rain gardens can alleviate the urban heat island effect (UHIE), which refers to the phenomenon that urban areas tend to have higher ambient temperatures than suburban and rural areas. The UHIE can contribute to premature fatalities as well as health issues including respiratory difficulties, heat stroke, and exhaustion (The value of green infrastructure, 2010). The City of Philadelphia has experienced numerous excessive heat events, which have contributed to as many as 100 premature fatalities per season. These excessive heat events will only increase in duration and intensity as climate change accelerates (A triple bottom line, 2009).

Dark impervious surfaces such as the existing schoolyard can reach up to 190 degrees Fahrenheit when exposed to direct sunlight, while vegetated surfaces usually only reach about 70 degrees Fahrenheit under the same conditions (The science of sustainability, n.d.). This is due to two main factors. First, vegetation retains moisture and releases it during the evapotranspiration process, which provides ambient cooling. Second, the larger plants and trees in rain gardens create shade, which reduces surface temperatures of the surrounding paved areas, in turn reducing the heat that is both transmitted into the paved surface and re-emitted into the atmosphere (The science of sustainability, n.d.; U.S. EPA, 2008).

Rain gardens also have the added benefit of sequestering carbon. Trees and other plants included in the garden are extremely effective in capturing carbon from the air. Over a 30 year life span, rains garden sequester an average of -75.5 ± 68.4 kg CO2 eq. M^{-2} (Kavahei et al, 2018). As emissions continue to increase, sequestering carbon whenever possible is essential in mitigating the effects of climate change.

Design Solution: Raised Beds

We will install 36 raised beds to the east of the school. Although the amount of stormwater managed by raised beds is only equal to the surface area of the bed, by using compost instead of urban soils, as is the case in this project, we can double their infiltration rate (Gittleman, Farmer, Kremer, & Mcphearson, 2016). Additionally, the use of compost-filled raised garden beds are an identified best practice for installing green infrastructure in unsuitable or polluted urban soils, especially when the crops are intended for urban agriculture, to ensure safe consumption (US EPA, 2011). Raised beds also provide several other benefits: easy access to growing spaces for students with disabilities, which may make bending or kneeling difficult; the opportunity for students to learn about the life cycle of plants and to incorporate nutrition education into the school's curriculum; and the alleviation of the food desert phenomenon which AHS experiences.

Design Solution: Permeable Pavers

Our design also includes rings of permeable pavers atop subsurface storage around the two main drains in the schoolyard. We had originally intended to place rain gardens around each one, but realized that the area around the drain is where the students line up after recess, so it was not feasible for a green space. Concrete and asphalt roadways, sidewalks, and parking lots make up a large portion of impervious surfaces in cities and directly contribute to storm water runoff related issues, such as combined sewer overflows. The use of permeable pavers helps to offset these negative effects by allowing stormwater to infiltrate the paver's surface and be absorbed into the ground. Additionally, permeable pavers have been shown to reduce turbidity of runoff by up to 80% as well as substantially reduce pollutants such as copper and zinc (Blackbourn 2011).

Design Solution: Food Forests

As part of our design, we will work with the Philadelphia Orchard Project to transform the neglected weedy areas around the perimeter of the school into intensive permaculture food forests; meaning that we will plant fruit-bearing trees and shrubs, perennial herbs and flowers, and hardy groundcover. All plants will be both edible and native to Pennsylvania. The deep roots of permaculture food forests will help retain and evapotranspirate far more stormwater than those of the existing scrub grasses and weeds which currently occupy those neglected spaces. Since the food forest spaces will be on the edges of the schoolyard, they will be readily accessible to both students and community members, creating a valuable connection to both nature and nutrition for all.

Design Performance

Our design combines several methods for stormwater management, including infiltration, evapotranspiration, and reuse through harvest and, thus, funnels stormwater into three outcomes: drained into the ground, evaporated off vegetation or surface, and taken up by plants' roots. Using a combination of the programs Rhino and Google Earth, we found the square footage data for the property. We have increased protected or restored soils by 46.53% and protected or restored 25,675.00 sq. ft of native vegetation while reducing impervious surfaces by 27.67% (Table 1). By implementing rain gardens and a green roof, we have increased shade cover of hardscape areas by 47.32%. This has also shaded 15,500 sq. ft of the roof and has reduced the building's energy consumption by 2,329.30 kWhs in electricity and by 15.5 Therms per year in gas usage. These electricity and gas usage savings will add up to $366.54 per year in total energy savings (Green roof, n.d.) (Table 2).

Surface Characteristics	Prior	After	Change	Change %
Reduction in Overall Impervious Area (sq. ft)	72,365.00	52,345.00	-20,020.00	27.67%
Reduction in Directly Connected Impervious Area (sq. ft)	12,455.00	0.00	-12,455.00	100.00%
Area of protected or restored soils (sq. ft)	9,713.41	14,233.41	4,520.00	46.53%
Area of protected or restored native plants (sq. ft)		25,675.00		

Table 1. Changes in characteristics of impervious surfaces and content of surfaces from before implementation and after.

Vegetation	Prior	After	Change	Change %
Roof Area Shaded by Vegetation (%) sq.ft	0.00	15,500.00	15,500.00	
Hardscape Area Shaded by Vegetation	1,120.00	1,650.00	530.00	47.32%
Building Electricity Consumption (KWh)			-2,329.30	
Particulate Matter Removed by Trees & Green Roof (lbs/yr)	14.33	656.37	642.04	4481.64%
Carbon Dioxide Sequestered (lbs CO2/yr) *mid point used for calculation	396.50	3,857.61	3,461.11	872.92%

Table 2. Changes in vegetation and vegetation-impacted hardscape characteristics before and after implementation.

Vegetation is vital to carbon sequestration and the removal of other air pollutants, such as particulate matter, sulfur dioxide, and carbon monoxide. According to the Center for Neighborhood Technology and American Rivers, the range of carbon that can be sequestered by a green roof is 0.0332 lbs C/sq. ft to 0.0344 lbs C/sq. ft. Since our proposed green roof design has a total area of 15,500 square feet, the total annual carbon sequestration of the green roof will be between 514.60 C/sq. ft and 533.20 C/sq. ft (The value of green infrastructure, 2010). Each tree is also estimated to sequester 13 lbs of carbon when young and 48 lbs when mature (Trees Improve Our Air Quality, n.d.). Each square foot of rain garden also sequesters an average of about 0.52 lbs each year, with a total of 2,327.21 lbs/yr (Kavahei et al, 2018). Thus, our design sequesters a total of 3,857.61 lbs per year. A mature tree can also remove about 1.1 lbs of particulate matter (PM) per year and, in addition to the 0.04 lbs/sq. ft of PM a green roof can remove, our design will remove 656.37 lbs each year (EnviroAtlas Interactive Map, n.d.; Air quality, n.d.).

The City of Philadelphia mandates that, in order to receive a stormwater management fee reduction, a site must manage the first 1.5” of rainfall. The current site runoff volume in a hypothetical 24-hour storm is 204.52 cubic meters, or 54,028 gallons. As shown in Figure 3, after managing the site with the green roof, rain gardens, porous pavement, and raised beds, the total runoff volume for the site will be 79.09 cubic meters, or 20,893 gallons. This totals a 62.96% reduction in runoff volume (Model my watershed, n.d.). We have also calculated a decrease in runoff depth and peak stormwater flow by 19% and 27% respectively, as well as an increase in annual groundwater recharge by 35% using the NJGS GSR 32 model and the rational method through the NOAA Atlas 14 model (Table 3). Considering this, we estimate that the school will be able to achieve the maximum allowed stormwater fee reduction of 80%.

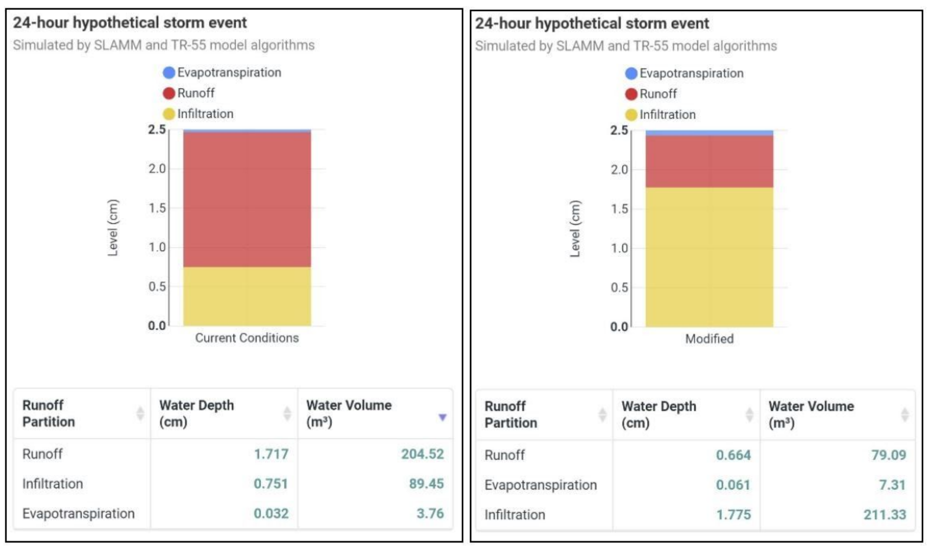

Figure 3. Andrew Hamilton School current stormwater runoff profile before BMP installation (left) and after BMP installation (right). Model My Watershed. (2020).

Water & Runoff Characteristic	Prior	After	Change	Change %	Model
Runoff Depth (in/year)	35.80	29.00	-6.80	19.00%	NJGS GSR 32 model
Stormwater Peak Flow (cubic ft/s/acre)	4,317.00	3,142.00	-1,175.00	27.00%	Rational Method using NOAA
Annual Groundwater Recharge (gallons/yr)	55,019.00	84,358.00	29,339.00	35.00%	NJGS GSR 32 model

Table 3. Changes between water and runoff characteristics from before and after implementation.

The design will further produce a variety of annual and perennial fruits and vegetables, as well as herbs. Our partnership with the Philadelphia Orchard Project will allow for the installation of 10 species of trees, 10 species of shrubs and vines, and 25 perennials and ground cover species, including the species selected by the students. All of these will be food-producing varieties.

Pollutant Type	Pollutant Load Before BMPs	Pollutant Load After BMPs	Percent Reduction
Total suspended solids (TSS)	27.75 lbs/acre/yr	4.88 lbs/acre/yr	82.41%
Total nitrogen	0.60 lbs/acre/yr	0.11 lbs/acre/yr	82.44%
Total phosphorus	0.03 lbs/acre/yr	0.01 lbs/acre/yr	61.54%

Table 4. Water quality pollutant loads before and after proposed BMP installation. Model My Watershed. (2020).

Table 4 shows the water quality pollutant load both before and after the installation of the proposed best management practices (BMPs), as calculated using the Model My Watershed tool. With the installation of a green roof, permeable pavers, rain gardens, and raised bed gardens, the reduction of all pollutant types is over 61%.

Project Phasing & Maintenance Plan

<table>
<tr><th></th><th>JAN-MAY</th><th>JUN-AUG</th><th colspan="2">SEP-DEC</th></tr>
<tr><td>2020</td><td colspan="2">Not applicable</td><td>Conducted site assessment
Conducted meetings with students, faculty, and staff at AHS
Developed project design
Identified grants</td><td>Applied for AHS to be POP Project Site
Finalizing design with School District of Philadelphia (SDP) and Philadelphia Orchard Project (POP)</td></tr>
<tr><td rowspan="2">2021</td><td colspan="4">Apply for grants</td></tr>
<tr><td>Install & plant raised beds
Hire part-time staff to maintain garden spaces & coordinate programming
Install environmental monitoring tools</td><td>Harvest spring crops
Create community food distribution program
Coordinate summer educational programs
Sow and harvest summer crops</td><td colspan="2">Submit engineering plans to SDP
Install orchard food forest
Implement 6th - 8th grade garden-oriented curriculum
Plant fall and winter crops</td></tr>
<tr><td>2022</td><td colspan="2">Work with SDP to install rain gardens, permeable pavers & green roof</td><td colspan="2">Expand curriculum to include STEM education on GSI</td></tr>
<tr><td>2023 - 2025</td><td>Expand curriculum to other grades</td><td colspan="3">Begin harvesting and distributing fruit from orchard spaces as trees mature, continue planting and harvesting from raised beds</td></tr>
</table>

Table 5. Phasing plan.

Cost and Maintenance

Looking at our budget, the price points are taken from the Center for Neighborhood Technology (CNT), and can be found in Table 6 below.

Item	Sub-components	Square Footage	Item/Materials Cost	Cost per Sq Ft	Installation Cost	Annual Maintenance Cost Per Sq Ft	Quantity	Total Cost
Tree	N/A	N/A	$175.00	-	-	$20.00	1	$195.00
Vane grates	N/A	N/A	$349.00	-	$2,725.00	-	1	$3,074.00
Raingardens	N/A	1650	-	$5.15	-	$0.31	1	$8,497.81
Permeable pavers	N/A	127	-	$5.30	-	$0.01	1	$673.11
Green roofs (Extensive)	N/A	11140	-	$8.00	-	$0.02	1	$89,120.02
Raised beds		32			$4,706.00	-	36	$4,706.00
	Irrigation	32	-	$2.50	-	-	36	$2,880.00
	Native Plants	32	-	$0.02	-	-	36	$23.04
	Small hoops (set of 6)	32	$22.99	-	-	$0.03	36	$57.55
	Row cover (~10' x 12')	N/A	$15.99	-	-	-	1	$15.99
Additional Expenses		N/A	-	-	-	-		$0.00
					Total Cost with 10% Contigency			$120,166.77

Table 6. Cost estimates for GSI installation and maintenance.

The row for each component of our project has a breakdown between installation costs as well as maintenance costs. As we can see from the budget proposal, the maintenance costs that we have for our project have been adjusted for yearly cost in order to smoothly integrate them into our financial model, which is discounted annually. To make sure no budget constraint arises in the future, we have decided to implement a contingency percentage of 10% of our total budget.

For the green roof maintenance, our estimate for cost per square foot is by far the largest of our components and sits at $20 per square foot. The maintenance schedule for a hypothetical green roof is complicated and depends on the temperature and precipitation of the region along with the time of year. When considering the precipitation of a region, Philadelphia is well above the national precipitation average of 38 inches annually, and does not require routine irrigation, with only prolonged temperatures above 85 degree Fahrenheit possibly carrying the risk of supplemental watering. Therefore, this unexpected minor maintenance does not necessitate the inclusion of an irrigation system for our green roof and does not need to be included in our budget, and falls into the 10% contingency. Since our green roof is under 5,000 square feet, the estimated annual man-hours for inspection and spot weeding, which will occur every four weeks, is only 10 to 20 hours.

The financial feasibility for this project is calculated by taking our installation costs, discounted future and an estimated 80% savings against a discount factor of 0.83% to form a Discounted Cash Flow (DCF) Model. The discount factor of 0.83% was selected since 0.83% is the Ten Year Risk Free Treasury Rate as of December. We feel comfortable using the risk free rate since we are dealing with a public high school that has no associated risks. Our starting benchmarks for installation costs, savings, the estimated life of use, and maintenance were taken from a comparable environmental retrofit out of Texas before our case specifics were integrated. We can see that this project will turn a positive NPV by Year 14, which is before the estimated life of use (30 years) ends. Thus, this project is not only financially viable but productive even without the potential social and environmental co-benefits. AHS is particularly interested in beginning installation within the 2021 calendar year, which informs our chosen 2021 starting point.

In 2051, which is the Year 30 for the project, the accumulated value will be $131,698.27, which is also the NPV of this project, and the project's IRR will be around 8.798%. Figure 4 represents the change of accumulated value in the 30-year period. Table 7 shows the analytical methods we used for determining the projected project value over time.

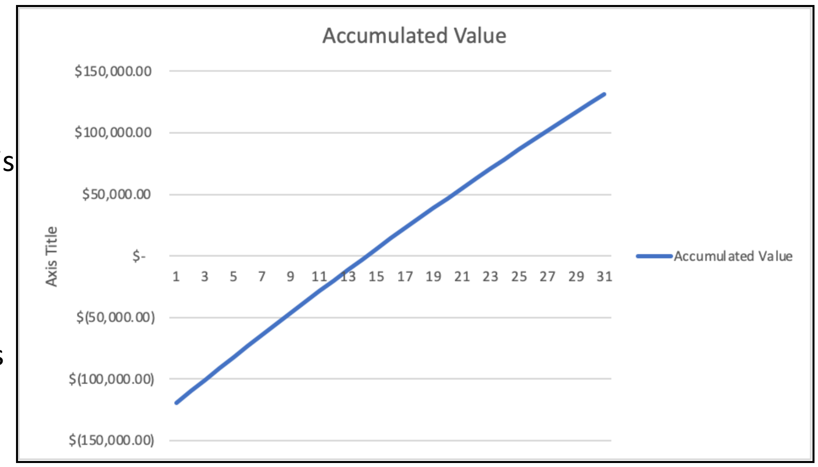

Figure 4. Accumulated value of GSI.

Valuation									
**Assuming the project will start in 2021 and will be completed before 2022 rainy season*									
Discounted Cash Flow									
Project Life	*0*	*1*	*2*	....	*13*	*14*	....	*29*	*30*
	2021	2022	2023	....	2034	2035	....	2050	2051
Annual Saving from the project	$0.00	$10,560.00	$10,560.00	....	$10,560.00	$10,560.00	....	$10,560.00	$10,560.00
(+) Total Saving (80% of Total)	$0.00	$10,560.00	$10,560.00	....	$10,560.00	$10,560.00	....	$10,560.00	$10,560.00
Expenses									
(-) Operation & Maintenance Cost	0	$ (1,000.00)	$ (1,000.00)	....	$ (1,000.00)	$ (1,000.00)	....	$ (1,000.00)	$ (1,000.00)
(-) Total Investment	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
(=) Total Cash Flow	$ -	$ 9,560.00	$ 9,560.00	....	$ 9,560.00	$ 9,560.00	....	$ 9,560.00	$ 9,560.00
Dicount Factor	0.83%	0.83%	0.83%	....	0.83%	0.83%	....	0.83%	0.83%
Discount Factor Per Year	99.2%	99.2%	99.2%	....	99.18%	99.2%	....	99.2%	99.2%
Accmulated Discount Factor	99.2%	98.36%	97.55%	....	89.07%	88.34%	....	78.04%	77.40%
Value of the Saving from Project @ 2020 Oct	$ -	$ 9,403.26	$ 9,325.85	....	$ 8,515.32	$ 8,445.23	....	$ 7,460.45	$ 7,399.04
Accumulated Value	$ (119,177.60)	$ (109,774.34)	$ (100,448.48)	....	$ (2,794.26)	$ 5,650.97	....	$ 124,299.24	$ 131,698.27
Net Present Value	$ 131,698.27								
Internal Rate of Return (From now to 2051)	8.798%								

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}$$

Table 7. GSI valuation model.

Funding

We have identified multiple sources of government funding to cover the various costs associated with both the planning and implementation of this project. A significant source of support will be the Pennsylvania Department of Environmental Protection, which has instituted more than 30 grant and rebate programs to support projects that protect the state's waterways and natural environment. A number of these programs directly aid schools, including DEP's Environmental Education Grants Program, Growing Greener Program, and Nonpoint Source Management Grant Program under Section 319(h) of the federal Water Pollution Control Act. The City of Philadelphia's Water Department has also created a 25-year plan to revitalize our waterways via land-based approaches and GSI projects. This plan is supported by multiple funding mechanisms, including the Stormwater Management Incentive Program (SMIP) for planning and construction of stormwater projects on non-residential properties in Philadelphia.

There are also 15 regional foundations with a specific interest in managing water resources and supporting sustainable development projects. This includes the William Penn Foundation, which has a dedicated funding stream for regional watershed protection and GSI projects, as well as the Exelon Foundation, which supports environmental projects based in the West Philadelphia community. All of these funders have supported similar projects within the area, and we have begun outreach to several potential funders in order to share our concept for AHS. In combination, the government sources can provide up to $500,000 and the foundation sources can provide an average of $200,000 in support.

Additionally, the Philadelphia Orchard Project has committed to purchasing plant materials and signage for the food forest areas, and the Netter Center will purchase all materials needed for the raised garden bed construction, planting, and maintenance. This will help to significantly defray upfront implementation costs.

References

10 Year Treasury Rate. (2020, December 4). Retrieved December 7, 2020, from https://ycharts.com/indicators/10_year_treasury_rate

A triple bottom line assessment of traditional and green infrastructure options for controlling CSO events in Philadelphia's watersheds. (2009, August 24). Stratus Consulting, Inc. Retrieved from https://www.epa.gov/sites/production/files/2015-10/documents/gi_philadelphia_bottomline.pdf

Acks, K. 2006. A Framework for Cost-Benefit Analysis of Green Roofs: Initial Estimates. Green Roofs in the Metropolitan Region: Research Report. C. Rosenzweig, S. Gaffin, and L. Parshall (Eds.)

Adams, S., Marriott, D. (2008). Cost benefit evaluation of ecoroofs.. City of Portland Environmental Services. Retrieved from https://www.portlandoregon.gov/bes/article/261053

Air quality. (n.d.). Retrieved December 10, 2020, from https://www.urbangreenbluegrids.com/air/

Asleson, B. C., Nestingen, R. S., Nieber, J. L., Hozalski, R. M., & Gulliver, J. S. (2009). Performance Assessment of Rain Gardens. *Journal of the American Water Resources Association, 45*(4), 1019-1031. doi:https://doi-org.proxy.library.upenn.edu/10.1111/j.1752-1688.2009.00344.x

Area Vibes. (2016). Andrew Hamilton School. Retrieved December 07, 2020, from https://www.areavibes.com/philadelphia-pa/schools/hamilton+andrew+school-421899005185/

Average energy prices - Philadelphia, Camden, Wilmington. (2020). Bureau of Labor Statistics. Retrieved from https://www.bls.gov/regions/mid-atlantic/news-release/averageenergyprices_philadelphia.htm

Bitzkie, G., & Howell, R. (2014). Large Scale Rainwater Collection at Texas Public Schools. Retrieved December 7, 2020, from https://www.hillcountryalliance.org/wp-content/uploads/2014/06/Large-Scale-Rainwater-Collection-at-Texas-Public-Schools.pdf

Blackbourn, S. (2011). Road Runoff Water-Quality Mitigation by Permeable Modular Concrete Pavers. Journal of Irrigation and Drainage Engineering., 137(11), 720–729. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000339

Duchneskie, J. (2018, December 19). Map: Income and Poverty in the Philadelphia Region. Retrieved from http://media.inquirer.com/storage/special_projects/income_and_poverty_in_the_philadelphia_region.html

EnviroAtlas Interactive Map. (n.d.). Environmental Protection Agency. Retrieved December 10, 2020, from https://enviroatlas.epa.gov/enviroatlas/interactivemap/

Framework and tools for quantifying green infrastructure co-benefits and linking with triple bottom line analysis, co-benefit technical paper: Enhanced aesthetics and community livability, as reflected in increased property values. (2020, February 4). Corona Environmental Consulting, LLC.

Getter, K.L., Rowe, D.B., Robertson, G.P., Cregg, B.M., Andresen, J.A. (2009). Carbon sequestration potential of extensive green roofs. Environmental Science & Technology 43 (19), 7564-7570. DOI: 10.1021/es901539x

Gittleman, M., Farmer, C. J., Kremer, P., & Mcphearson, T. (2016). Estimating stormwater runoff for community gardens in New York City. *Urban Ecosystems, 20*(1), 129-139. doi:10.1007/s11252-016-0575-8

GreatSchools.org. (2020). Explore Hamilton Andrew School in Philadelphia, PA. Retrieved December 07, 2020, from https://www.greatschools.org/pennsylvania/philadelphia/2132-Hamilton-Andrew-School/

Green roof resources. (n.d.) Green Roof Plants. Retrieved from https://www.greenroofplants.com/for-industry-professionals/

Green roofs. (n.d.). Philly Watersheds. Retrieved from http://archive.phillywatersheds.org/whats_in_it_for_you/residents/green-roofs

Hydrology. (2014, December 8). The City of Philadelphia. Retrieved from https://www.opendataphilly.org/dataset/hydrology

Kavehei, E., Jenkins, G.A., Adame, M.F., Lemckert, C. (2018). Carbon sequestration potential for mitigating the carbon footprint of green stormwater infrastructure. Renewable and Sustainable Energy Reviews, Volume 94,Pages 1179-1191, Retrieved December 10, 2020 from https://doi.org/10.1016/j.rser.2018.07.002

Kondo, M.C., Fluehr, J.M., McKeon, T., Branas, C.C. (2018, March 3). Urban green space and its impact on human health. International Journal of Environmental Research and Public Health. DOI: 10.3390/ijerph15030445

Liu, K., Baskaran, B. (2005). Thermal performance of extensive green roofs in cold climates. National Research Council Canada. Retrieved from https://nrc-publications.canada.ca/eng/view/accepted/?id=11095d5f-ac30-41f3-9340-2f2382ba40de

Model my watershed. (n.d.). *WikiWatershed, Stroud Water Research Center.* Retrieved from https://modelmywatershed.org/project/

National stormwater calculator. (n.d.) United States Environmental Protection Agency. Retrieved from https://www.epa.gov/water-research/national-stormwater-calculator

Natural Resource Defense Council. (2013). The green edge: How commercial property investment in green infrastructure creates value. Retrieved from https://www.nrdc.org/sites/default/files/commercial-value-green-infrastructure-report.pdf

PA Department of Environmental Protection. (2020). PA Environmental Justice Areas. Retrieved December 07, 2020, from https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages /PA-Environmental-Justice-Areas.aspx

Rowe, B. (2011). Green roofs as a means of pollution abatement. Environmental Pollution. 159(8-9):2100–2110.

Saffron, I. (2020, October 14). How Philadelphia became the nation's poorest big city, and how we can fix it: Inga Saffron. Retrieved from http://www.inquirer.com/business/philadelphia-poverty-unemployment-racism-education-upskilling-20201013.html

Stormwater grants. (n.d.). City of Philadelphia Water Department. Retrieved from https://www.phila.gov/water/wu/stormwater/Pages/Grants.aspx.

The science of sustainability. (n.d.). The University of Chicago Library. Retrieved from https://www.lib.uchicago.edu/collex/exhibits/science-sustainability/green-roofs/construction-components-green-roofs/

The value of green infrastructure: A guide to recognizing its economic, environmental and social benefits. (2010). Center for Neighborhood Technology and American Rivers. Retrieved from http://www.americanrivers.org/newsroom/resources/thevalue-of-green-infrastructure

Trees Improve Our Air Quality. (n.d.). Urban Forestry Network. Retrieved from http://urbanforestrynetwork.org/benefits/air%20quality.htm#:~:text=Young%20trees%20absorb%20CO2%20at,to%20support%20two%20human%20beings.

United States Environmental Protection Agency. (2008). Green Roofs. In: Reducing urban heat islands: Compendium of strategies. Retrieved from https://www.epa.gov/heat-islands/heat-island-compendium

United States Environmental Protection Agency, Region 5. (2011). *Evaluation of Urban Soils: Suitability for Green Infrastructure or Urban Agriculture* (No. 905R11003). EPA. Retrieved December 9, 2020, from https://nacto.org/docs/usdg/evaluation_of_urban_soils_epa.pdf

United States Environmental Protection Agency. (n.d.). Using green roofs to reduce heat islands. Retrieved from https://www.epa.gov/heat-islands/using-green-roofs-reduce-heat-islands

Useful climate information for Philadelphia: Past and future. (2014, August). Prepared for the Philadelphia Mayor's Office of Sustainability by ICF Incorporated, L.L.C. Retrieved from https://www.phila.gov/media/20160505145605/Useful-Climate-Science-for-Philadelphia.pdf

Vineyard, D., Ingwersen, W. W., Hawkins, T. R., Xue, X., Demeke, B., & Shuster, W. (2015). Comparing Green and Grey Infrastructure Using Life Cycle Cost and Environmental Impact: A Rain Garden Case Study in Cincinnati, OH. *JAWRA Journal of the American Water Resources Association, 51*(5), 1342-1360. doi:10.1111/1752-1688.12320

Wilkinson, S. J., Dixon, T. (2016). Green roof retrofit : Building urban resilience. Chichester, West Sussex, United Kingdom: John Wiley & Sons, Ltd.