Getting to Green:
Connected Spaces for Environmental Justice and Stormwater Management at Sayre High School

University of Pennsylvania

Team Number D9

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Abstract

Sayre High School, located in the Cobbs Creek neighborhood of West Philadelphia, has many assets; an onsite health center, a small garden program, and beautiful student-created murals all serve to create a vibrant community hub. However, the school lacks green stormwater infrastructure (GSI), access to healthy food, green space, and places for students to gather. To address this discrepancy, we propose a project which will leverage the lived experiences and local expertise of community residents alongside the technical skills of University of Pennsylvania students to co-design, fund, and ultimately implement a GSI installation at the school which will also act as a green space for recreation and gathering while providing a multitude of nutritional, environmental, health, and educational co-benefits. Design elements will include a green roof, rain gardens, permeable pathways, bioswales, tree trenches, a greenhouse, and raised beds.

Existing Challenges

Sayre High School falls within a combined sewer overflow (CSO) area, meaning that during rain events, stormwater and wastewater mix into the same pipes. During rain events, that mixture will overload the combined sewer system, and the excess will overflow into the local waterways. The sewer outfall for Sayre is located just north of Eastwick, a historically marginalized Black community in Philadelphia which experiences chronic issues from flooding and pollution (Statistical Atlas, 2018; US EPA, n.d.). Therefore, the lack of onsite 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 summer temperature that is up to 7.8 degrees Fahrenheit above other neighborhoods. These temperatures, created by an urban heat island effect, have the potential to be dangerous to children.

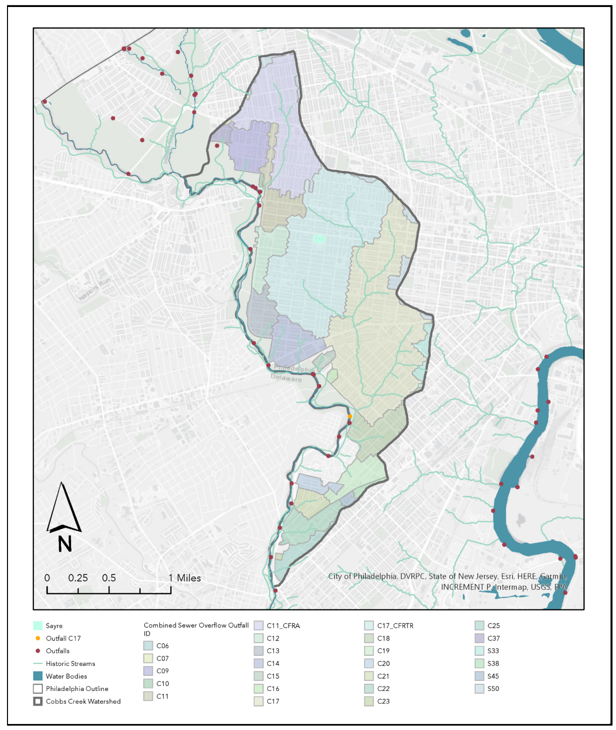

Figure 1. Sewersheds of the Cobbs Creek Watershed.

The school is also located in a food desert, which means there is a lack of access to fresh produce and other nutritious food at affordable prices. Additionally, according to the 2018 American Community Survey, the median household income in the Cobbs Creek neighborhood is $32,746; over $10,000 less than the median city-wide household income of $43,744. 44.2% of children below the age of 18 in the neighborhood are living below the poverty line – nearly 10% higher than Philadelphia overall (American Community Survey, 2018). As Cobbs Creek's residents are 93.1% Black, these economic indicators and demographics compelled the Pennsylvania Department of Environmental Protection to classify the area as an Environmental Justice Area.

Sayre's student body follows the pattern of Cobbs Creek; 90.9% of the school is Black, and all but one student met the threshold for free lunch eligibility. The school has a 45% four-year graduation rate (compared to an 86% state average) and a 16% college matriculation rate in 2019 (School District, 2021).

According to the Philadelphia School District's website, Sayre's educational attainment scores lag behind their local counterparts, with 0% of students attaining Proficient or Advanced levels on the state standardized math exam and only 11% of students attaining Proficient or Advanced levels on the state standardized English exam (School District, 2021). When looking at standardized test scores, Sayre lags significantly behind Pennsylvania state averages. Results for the 2019 Keystone Exams - Pennsyvlania's public school standardized testing system - scored Sayre students at between 8-16% proficient across literature, algebra, and biology, while the state averages hover around 70% (Pennsylvania Department of Education, 2019). Several studies have shown that exposure to green spaces, including GSI, can boost students' scores (Kuo et al. 2019).

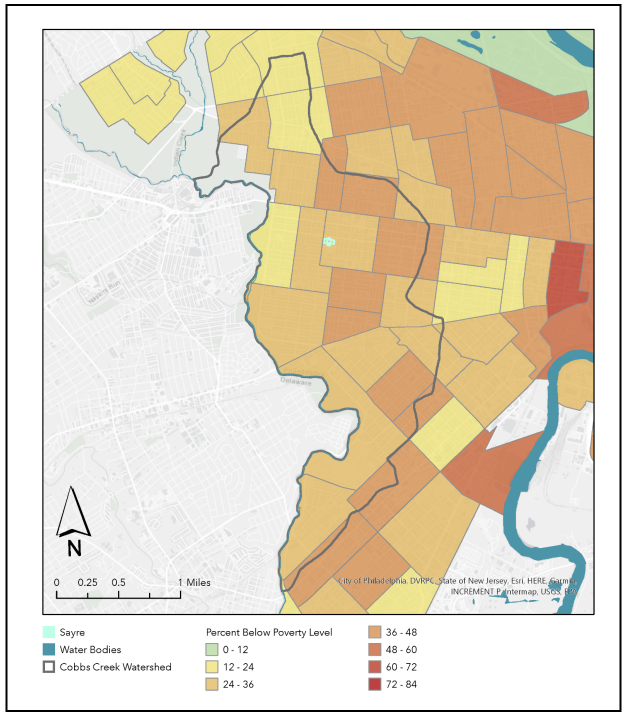

Figure 2. Poverty Levels.

Overall, the school has issues with combined sewer overflows, heat, food access, poverty, and education. To mitigate these challenges, GSI can lower the school's stormwater fee, mitigate flooding, alleviate the urban heat island effect, beautify public spaces, provide valuable STEAM education opportunities, and provide access to fresh healthy food for students and the surrounding community.

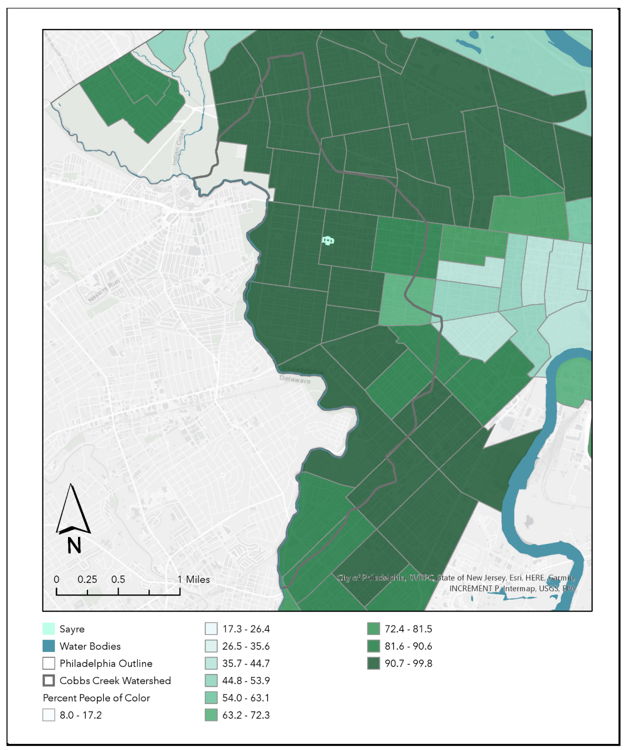

Figure 3. Percent People of Color.

In addition to collaborating with the school's leadership and students to realize their vision, we will work with the School District of Philadelphia, the Sayre Health Center, the Philadelphia Water Department, the Netter Center for Community Partnerships, the Water Center at Penn, Penn Praxis, and the Philadelphia Orchard Project to form a multidisciplinary team to co-design and eventually implement the GSI plan. Together, this team of students, teachers, community members, and experts will work together to co-create a Sayre High School that provides safe, green, food-producing spaces for generations of students to come.

Environmental Benefits of GSI: Stormwater Runoff Mitigation

Runoff from stormwater is a considerable source of pollution in urban water bodies. Impervious surfaces typical in an urban landscape block rainwater from seeping into the ground, causing the water runoff to flow instead into stormwater drains. The runoff amasses trash, bacteria, heavy metals, and other contaminants from the roadways which often pollute local water bodies from CSOs (US EPA, 2021). In a natural area, only 10% of rain will become runoff. However, if 75% or more of land becomes impervious, 55% of rainfall becomes runoff (US EPA, 2003). Therefore, replacing impermeable surfaces with GSI can reduce the amount of runoff, which can have profound downstream impacts; indeed, diverting just 10% of stormwater runoff from sewage systems into GSI can prevent 90% of floods (Wilkinson & Dixon, 2016).

Environmental Benefits of GSI: Climate Change Adaptation, Mitigation, and Resilience

Urban resilience is "the ability of an urban system…to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" (Meerow et al., in Wilkinson & Dixon 2016). The disturbances to urban landscapes caused by accelerating climate change are multitudinous, ranging from increasingly frequent and severe rainfall events to extreme heat events. Such extreme weather conditions can threaten not only property and infrastructure, but also human life. Creating adaptable systems which can address the full spectrum of extreme weather events caused by climate change will be crucial in addressing current and future threats to life and property in urban areas. One such adaptable system is that of GSI, which can filter polluted stormwater, reduce ambient air temperatures, and alleviate flooding events (Enhancing, 2014). Additionally, GSI can reduce the amount of carbon dioxide in the atmosphere. For example, rain gardens are shown to sequester carbon at an average rate of -75.5 ± 68.4 kg CO_2 eq. M^{-2} over 30 years (Kavehei et al., 2018).

Environmental Benefits of GSI: Urban Heat Island Effect

The urban heat island effect (UHIE) is the phenomenon that occurs when the temperature of the city is higher than the surrounding suburban temperatures. The impacts of this effect range from increased energy usage to severe health issues: heat strokes, exhaustion, or respiratory issues can all occur at high temperatures. Low income communities are at greater risk of experiencing health related issues from poor housing conditions, such as small living areas and a lack of air conditioning (US EPA, 2014a). According to a recent report, there were 137 heat-related deaths in Philadelphia between 2006 and 2018 (Philadelphia Office of Sustainability, 2019). Philadelphia can get up to 21 degrees Fahrenheit hotter than nearby rural areas and is 3.8 degrees warmer on average in the summer

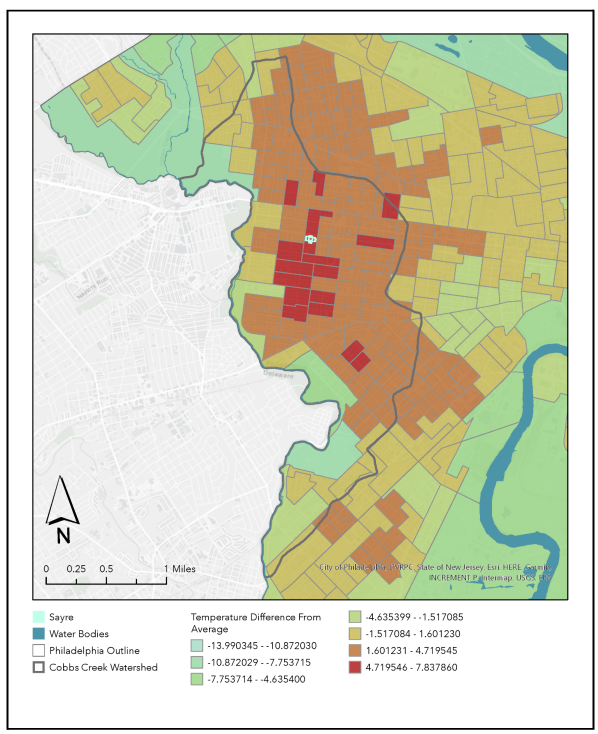

Figure 4. Temperature in Relation to City-wide Average.

(Pennsylvania's Climate Threats, 2016). Out of all the cities in the country, Philadelphia is the 17th fastest-warming city (Climate Central, 2019). Indeed, the number of days per year in which the temperature rises to 90°F or above is predicted to increase from an average of 27 days per year to as many as 68 per year by the end of the century in Philadelphia (Useful climate, 2014).

GSI is able to reduce the intensity of the heat island effect for a few primary reasons. Firstly, the specific heat capacity of flora is higher than for soil, air, and pavement (Climate - Trees vs. Temperature, 2007). The specific heat capacity is the measurement of the amount of heat needed to raise the temperature of one gram of a substance one degree Celsius. The specific heat of each substance in the surrounding environment has a massive impact on the regulation of the ambient temperature in the area (Specific Heat Capacity and Water, n.d.). Dark impervious surfaces can reach up to 190°F when exposed to direct sunlight, while vegetated surfaces usually only reach about 70°F under the same conditions (The science of sustainability, n.d.). Secondly, vegetation releasing moisture during the evapotranspiration process provides ambient cooling, which is able to reduce peak summer temperatures by 1 to 5°C (US EPA, 2014b). Thirdly, plants create shade, which reduces ambient temperature by lessening direct sunlight on the surrounding ground (US EPA, 2014b).

The UHIE is especially relevant to the aims of our design due to the fact that several Sayre teachers and students mentioned that the temperatures in their classrooms range from extreme heat to intense cold; GSI can help to maintain a more consistent and comfortable temperature for students and teachers at the school.

Environmental Benefits of GSI: Air Pollution

Air pollution has a substantial effect on human health and is correlated with stroke, heart disease, pneumonia, and lung cancer (WHO, n.d.). Higher levels of air pollution are directly correlated with distance to major roads. (Shakya et al., 2019) GSI can mitigate air pollution through several methods: by taking up gaseous air pollutants through leaf stomates; lessening smog formation by slowing the reaction rates of both nitrogen oxide and other organic compounds; decreasing photochemical reactions which contribute to the formation of ozone; and by physically intercepting wind-borne particulate matter. (Currie and Bass, 2008; Rowe, 2011; The value of green infrastructure, 2010; Average energy, 2020)

Environmental Benefits of GSI: Habitat Creation and Restoration

Considering GSI is made possible by natural plants, it can also benefit animals and insects whose habitats have reduced from urban development. The native fauna can create corridors between habitat areas through the urban areas (Adams et al., 1989). Such ecological zones and corridors provide spaces for animals to feed and raise young, and will overall help maintain biological diversity in a highly urbanized area (Adams et al., 1989).

Financial Benefits of GSI: Stormwater Fee Reductions and Tax Credits

The Philadelphia Water Department (PWD) levies a stormwater fee for all properties within city limits. Impervious land cover is charged higher than pervious land cover, thereby establishing an incentive to convert impervious surfaces to pervious surfaces (PWD, n.d.). Although GSI can be difficult to finance, the overall cost of the project, including installation and maintenance, may be offset by the reduction of the monthly stormwater fee over the lifespan of the building (Duffield Associates, 2013). For example, Philadelphia will give a property a reduction in fees up to 80%

if the site manages the first inch of rainfall (Natural Resources Defense Council, 2013). If a GSI best management practice (BMP) has a growing medium depth of three inches or more, a landowner is eligible to pay no stormwater fees at all for the surface area. The landowner is entitled to the same total reduction of stormwater fees if up to 30% of the total land does not have GSI, but rather is directed via gravity or other means to the area with GSI (Duffield Associates, 2013).

Financial Benefits of GSI: Green Roofs and Energy Reduction

Green roofs can help to greatly reduce the volume of stormwater runoff and energy use in the building. Green roofs can reduce electricity usage by up to 2% and can reduce natural gas usage by up to 11%. (U.S. Green Building Council, 2008, in Rowe, 2011) In summer months, these energy savings can total up to a 75% reduction in cooling in a one-story building. When taking energy savings from winter months into account, those energy savings total an annual reduction of 25% (Framework energy savings, 2020).

Green roofs can also reduce the flow of heat through a roof, thereby reducing the energy demand for heating and cooling and associated costs of the building beneath the roof. (Liu & Baskaran, 2005) Green roofs accomplish this by storing energy; a green roof can absorb and retain significant amounts of heat, which reduces fluctuations in temperature. They also create this effect when dry by acting as an insulator, which both reduces the cooling energy required by the building during warmer months and reduces the heating energy required by the building during colder months (U.S. EPA, 2008).

As of January 2020, electricity in Philadelphia cost an average of 15.3 cents per kilowatt hour (kWh), and gas was priced at $1.110 per therm (the measurement of heat energy in natural gas). (Average energy, 2020). According to a report prepared for PWD, a green roof can provide "average [electricity] savings of 0.39 kWh/sq ft of green roof. For natural gas savings (from reduced heating), we used an estimate of 123 MM Btu per building" (A triple bottom line, 2009).

Community Benefits of GSI: Crime Reduction

Green spaces can help to prevent crime in several ways. They can reduce aggression and incidents of violence; create public gathering spaces which increase "surveillance" of streets; and signal to potential criminals that nearby occupants are invested in the green space and surrounding properties, which can act as a deterrent (Natural Resources Defense Council, 2013). One study "found that buildings with high levels of vegetation had 48 percent fewer property crimes and 56 percent fewer violent crimes than buildings with low levels of vegetation" (Natural Resources Defense Council, 2013). This is particularly of interest to Sayre High School, whose principal expressed concerns of outdoor safety for students.

Community Benefits of GSI: Scholastic Opportunities & Achievement

GSI can provide an opportunity for students of Sayre to engage in hands-on projects spanning several disciplines, namely: landscape architecture; ecological design; city planning; urban spatial analytics; public health; environmental studies, engineering; biological sciences; urban conservation, and more. According to research from Kuo et al. (2019), multiple studies have shown a link between standardized test performance and greener schools due to a multitude of synergistic effects. A study by Li and Sullivan (2016) demonstrated that students whose classrooms had a view of greenery performed better on concentration tests than students whose classrooms had no view or a building view. Overall, the cognitive benefits of nature can have a positive effect on students' academic performance.

Community Benefits of GSI: Community Pride

Our survey responses showed that most of the staff and students at Sayre High School would like to see their school beautified. This can take place in a variety of ways, such as planting beautiful flowers in the rain gardens, managing overgrown plants, and overall reducing the concrete space in the central courtyards which the classrooms overlook. Furthermore, the redesign of the school's parking lots and recreational centers will make the school a more accessible community gathering space for the greater Cobbs Creek neighborhood. With the addition of benches and a greenery, the parking lot can be converted into an outdoor venue for weekend farmers markets in which the students call showcase their produce from the school gardens, as well as being a space for other community events. This can be achieved because the school already maintains a garden with the students' involvement. Currently, the food grown in the garden is sold to patients at the Sayre Health Center, located in the southwestern corner of the school building.

Social Benefits of GSI: Job Satisfaction

Access to, or even a view of, nature can have a lasting positive impact on employees' job satisfaction levels, well-being, and stress levels (Natural Resources Defense Council, 2013). GSI can provide both access to and, if properly situated, a consistent view of nature. This can be applied to the teachers and staff at Sayre, who desire to work in a school that is less industrial. Staff member Joe Brand pointed out that the Sayre building, due to years of underinvestment, can feel more like an "institution" than a school, with striking visuals of exposed pipes and peeling paint. He asserted that such an environment is not one in which students and teachers can feel emotionally safe; a situation which can lead to disputes, escalated situations, and other manifestations of trauma in the neighborhood. Creating green spaces will lessen the institutional feel of the school, which can lead to higher overall job satisfaction and lower turnover.

Social Benefits of GSI: Health Benefits

According to the EPA, urban green spaces can benefit physical health, including lessening the duration and frequency of hospital stays experienced by surrounding residents (U.S. EPA, 2015). This will be beneficial for the community members who use the health center located in Sayre. Several studies have found that access to green spaces can boost emotional recovery, lessen mental fatigue, improve mood, and lower both anxiety and stress levels (Econsult, 2016). A paper by Kondo et al. (2016) discussed the relationship between nature and human health, stating that there is a positive association between green space and mood, physical activity, and cardiovascular health (Kondo et al. 2016). A study by Li and Sullivan (2016) showed that a view of greenery from a window in a classroom decreases heart rate and stress. Overall, mental and physical well-being is improved by adjacency to greenery, including GSI.

Site Analysis: Impervious Surface Areas

The school sits upon a 358,896 sq ft lot. The footprint is largely impervious; 292,681 sq ft of the lot consists of impervious surfaces. The lot contains a 32,081.62 sq ft 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 estimates an average annual rainfall of 50.18 inches in Philadelphia (US EPA, n.d.). 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 combined sewer overflows. 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 $3,525.47 for their stormwater runoff.

Site Analysis: Usage of Existing Spaces

The school has three separate courtyards in the middle of the building. The middle courtyard has already been converted into a garden which the students use to grow vegetables and fruit in an after-school program. The courtyard on the east side of the school is connected to the cafeteria and is open for students to use during their lunch period. According to Joe Brand, the Netter Center's Site Director at Sayre, the students who do go outside only stand around the steps at the door, and do not use the courtyard itself, as there is nowhere to sit. There was an attempt to turn the courtyard into a communal area, but lack of funding prevented the idea from being finished. Within this courtyard there is one storm drain in the middle, which can be utilized during the creation of the rain garden.

The courtyard on the west side of the school is not physically accessible to the students, as the entrance is in the health center. However, half of the classrooms surrounding this courtyard are used by special needs students, whose current view from their windows is that of a cracked, weedy, concrete slab. Since accessibility into this area is limited, the most ideal use of space is to create a viewing area of nature, with emphasis on colors, patterns, and seasonality. Plants in this courtyard will create an idyllic, meditative effect for those who look at it from the surrounding classrooms which can help to promote positive mental and physical health outcomes.

Lastly, the parking lot in the back of Sayre has the potential to manage a considerable amount of runoff. The parking lot slopes downwards from the school, and the point where the parking lot entrance meets the street frequently forms puddles. There are four drains in a square pattern in the middle of the parking lot. Farther behind the parking lot is a basketball court which is regularly used by young people. This area has the potential to become a green area used for community gatherings.

Site Analysis: Water

As previously discussed, Sayre High School is located within a CSO area. The sewer infrastructure that the school drains into is an old, buried, historic stream that was converted into a sewer during the late 1880s (Puckett, n.d.). During rain events, the sewer overflows into Cobbs Creek, a tributary of the Delaware River. The overflowing water from the CSO has a mixture of sewage, trash, and rainwater, which heavily pollutes the receiving water. The CSO outfall associated with the school is upstream of Eastwick, which is a predominantly Black community (Statistical Atlas, 2018). Eastwick has a history of pollution from both the Folcroft and Clearview Landfills, which are both Superfund sites (US EPA, n.d.). Additionally, the area has a history of flooding, most recently being Tropical Storm Isaias in August 2020 (Eastwick, n.d.). Therefore, any water we can keep out of the CSO system at Sayre will help to mitigate environmental justice problems in the adjacent community.

Site Analysis: Soil

All of Sayre's soils are classified as "urban soils" according to the USDA's Web Soil Survey tool. While we did not have sufficient time to ascertain the exact composition of Sayre's soils, we plan to conduct a site soil analysis this winter with the help of Princeton Hydro, a company which provided a pro bono soil analysis for GSI at the nearby Andrew Hamilton School last year.

Project Goals

We have identified eight primary goals to create the most positive impact in the geographic and demographic context of Sayre High School.

1. Promote environmental justice
2. Reduce combined sewer overflow discharge
3. Enhance positive mental health outcomes
4. Create student and community gathering spaces
5. Instill a sense of school pride
6. Improve STEM education opportunities
7. Foster environmental stewardship
8. Provide access to fresh fruit and vegetables

Survey: Student, Teacher, and Parent Feedback

To fully understand the Sayre community's priorities, we created a survey and conducted site visits to work with the students, staff, and parents of Sayre. A straightforward assessment survey was created with the goal of gathering feedback on what the students and staff would like to see most from this project. The survey lists options that can be included in GSI: edible plants, beautifying the school, a place to study/relax, a place to learn how to garden, and a community gathering area. The survey also includes a few long answer optional questions: what has been their observations on the weather at Sayre (such as flooding or heat); what plants would the respondent like to see included; and what kind of GSI is their ultimate vision for Sayre. The intent of the survey was to create a highly straightforward and accessible questionnaire to receive feedback on what the people who use Sayre would most like to see for the school.

Respondents identified existing challenges:

- "The flooding made it hard for me to get to work. The temperature in my room can be very hot."
- "Very sunny in my classroom all day; it is hot inside the classroom in warm months and cold during the winter months; Little greenery to enjoy."
- "It is, sometimes, too hot or cold in the building. It seems it's hard to get the right balance."

Respondents' visions for the space include:

- "A place where the students can spend their lunch period so they do not have to spend their time in the cafeteria."

- “I would really love to see a place for students and the community to gather and enjoy the outdoors.”
- “A more natural look around and inside the building; edible plants to eat; plants/grass on roof.”
- “Outdoor classroom space and a place for science classes to do outdoor studies.”
- “With the pandemic I think it is most important for students to have a green space outside to relax, and where it is safe. There are articles that talk about the number of trees and green space associated with socioeconomic levels.”
- “The courtyards and grounds are becoming green with lots of pretty plants. A garden area to teach students how to grow edible plants.”

Design Solutions: Permeable Pathways

Permeable pavements are porous surfaces that allow water to penetrate through into the soil while filtering pollutants. The incorporation of permeable pavement in our design will help to create a healthier and pollution-free environment for the Sayre community. In addition, permeable paving has cooling effects that would work to reduce temperatures in the surrounding environment. To this end, at the south of the school, a former service drive will be repurposed as a permeable, shaded, and flexible corridor that prioritizes pedestrian connectivity and stormwater capture while allowing service access and a variety of uses at different times of the day.

The promenade features spaces for community gathering, food distribution, and a market stand. The pathway expands upon the existing food distribution program in the health center by connecting the school with a greenhouse and raised beds; produce from which will be distributed to the community. This pathway also reconnects the school with the active recreation spaces of the Sayre Recreation Center. The two facilities will share the infrastructure at different times of the day. The existing basketball courts will be renovated to include shaded seating spaces, while lighting will be added to ensure this space is safely usable in the evening as well.

Design Solutions: Health Center Farm Stand

An existing program which takes place in the school’s health center sells food grown in the central courtyard to surrounding residents and health center visitors at affordable prices. Our design amplifies and celebrates this connection between the school and the surrounding community by providing a dedicated space along the promenade for a greenhouse, farm stand, seating, and raised garden beds. As a hub for demonstration, education, and connection, the greenhouse showcases stormwater collection from the roof and its reuse for irrigation of the plants in the greenhouse.

Design Solutions: Courtyard Rain Gardens

Courtyards are key interior spaces of the school. Our design will create three distinct gardens for mental health and wellbeing, education and outdoor learning, and fostering social life. Though they serve different functions, the three spaces are unified through the expression of stormwater treatment and conveyance as an engaging experience. Stormwater processes are made visible through a series of connected channels, pavement treatment, and rain gardens, which call attention to the sights, sounds, and flows of water. Seating and tables within the courtyards will provide spaces for students to gather while being immersed in nature.

The plants and soils within the rain gardens have been chosen to balance the desires of the students and staff at Sayre with functional stormwater retention and infiltration. Rain gardens are designed to allow water to infiltrate through the ground before running off into the storm drains. They are a powerful solution to offset stormwater and concurrently have the benefits of reintroducing nature to urban spaces. The benefits for the school would include a beautiful learning environment, an area to relax and unwind, or an area to chat with friends during lunch time. In addition to stormwater, rain gardens are able to alleviate the urban heat island effect which Sayre currently experiences.

Plant species in the rain garden will include Joe Pye Weed, Little Bluestem, Boneset, Swamp Milkweed, Fox Sedge, Pennsylvania Sedge, Goldenrods, Bluebells, Hay Scented Ferns, Ostrich Fern, and Autumn Fern. Shrubs and trees scattered throughout the design will include Allegheny Serviceberry, Gray Birch, Arrowwood Viburnum, Sweet Pepperbush, and Buttonbush. In the pollinator viewing garden, we have chosen Hyssop, Hawthorn, Red-twig Dogwood, Franklin Tree, and several Stonecrop Sedum species. In the existing parking lot spaces, we have identified three types of trees which will be ideal: Swamp White Oak, Red Maple, and Sugar Maple. We also plan to incorporate fruit-producing trees such as Cherry, Apple, Peach, and Pear to enhance equitable access to fresh produce at the school.

Design Solution: Parking Lot

When looking at Sayre High School from an aerial view, one immediately notices the vast parking lot space; it is a concrete desert. For this reason, our second focus area when looking at design solutions is the parking lot. Sayre’s parking lot slopes down with stormwater flowing directly in the direction of the street. The parking lot makes up 35,424 sq ft of the school site, making it a suitable area to incorporate GSI while beautifying the space. Our design focuses on incorporating tree trenches and permeable pavement into the parking lot space with the primary goals of decreasing stormwater runoff, addressing the urban heat island effect, improving walkability, creating a community corridor, and overall campus beautification.

Bioswales are vegetated ditches that collect and filter stormwater. As the stormwater runs through the bioswale, the pollutants are captured in the stems and leaves of the plants. In addition to reducing stormwater and pollutants, bioswales also recharge groundwater (Lynch & Sapin 2017). Finally, and most importantly for the needs of Sayre High School, bioswales combat the urban heat island effect by cooling the surrounding environment. With Sayre being in one of the hottest areas in Philadelphia, the inclusion of bioswales in our design solutions directly addresses this problem. Further addressing this issue is the inclusion of permeable paving in the parking lot space.

Design Solutions: Green Roof

We propose a green roof for Sayre’s building to provide temperature-regulating effects for the occupants of the school while providing habitat for local wildlife, lowering the school’s energy usage and associated costs, managing stormwater, and sequestering carbon. The green roof will be a total of 31,960 square feet, or 29% of the school’s total area; serving to dramatically reduce the amount of impervious surface area onsite.

Design Solutions: Educational Signage and Curriculum Development

To improve students' engagement with GSI, our project will utilize educational signage as well as the development and implementation of both watershed-focused and nutrition-oriented curricula.

Design Performance

With the addition of new trees, rain gardens, raised beds, a green roof, and pervious pavement, our design reduces impervious surfaces by 63% while introducing 70,084 square feet of native plantings and 73 new trees. The introduction of a green roof will shade 29% of the roof, saving energy (Table 2). Trees are able to sequester 13 lbs of carbon each year when they are young and can sequester up to 48 lbs of carbon when they are fully mature, therefore leading to 949 - 3,504 lbs of sequestered carbon annually from trees as seen in Table 1 (Trees Improve Our Air Quality, n.d.). Green roofs, meanwhile, are able to sequester as much as 0.034 lbs of carbon per square foot each year (The Value of Green Infrastructure, 2010). With our design of 31,960 sq. feet, the green roof will sequester 1,099.42 lbs of carbon annually. Rain gardens can also retain 0.52 lbs of sequestered carbon per square foot and thus retain 20,371 annually (Kavehei et al., 2018). Together, our design will lead to up to 24,974.42 lbs of sequestered carbon per year.

Ecosystem Services	Amount
Air pollutant removal by new trees (lbs/yr)	240.90
Air pollutant removal by green roof (lbs/yr)	1,278.40
Carbon dioxide (CO2) sequestered by new trees (lbs/year, maximum)	3,504.00
Carbon dioxide (CO2) sequestered by new green roof (lbs/year, maximum)	1,099.42
Carbon dioxide (CO2) sequestered by rain gardens (lbs/year)	20,370.48

Table 1. Ecosystem services provided by the installation of various plant features including trees, raised garden beds, rain gardens, and a green roof.

Changes After Implementation	Before	After	Change
Change in stormwater peak flow, cubic feet/second/acre, %)	4,400.00	1,867.00	-58%
Reduction in impervious area (sq.	287,778.00	104,640.00	-63%
Reduction in runoff depth (in/year)	35.80	29.00	-19%
Annual groundwater recharge (gallons/year)	157,547.00	969,294.00	84%
Increase in roof area shaded by vegetation (% of roof area)	0.00	31,960.00	29%

Table 2. Percent change in stormwater management and shading produced by the installation of GSI.

Trees and green roofs are also able to remove pollutants from the air with 3.3 lbs per tree and 0.04 lbs per sq. foot of green roof annually, totaling 240.90 lbs/year and 1278.40 lbs/year respectively (Air quality, n.d.; Adams & Marriot, 2008). Therefore, our design can remove a total of 1,519.30 lbs of air pollutants per year.

Finally, with the addition of pervious pavement, rain gardens, trees, and a green roof, the design will reduce peak stormwater flow by 58% from 4,400 cubic feet per second per acre to 1,867 (Table 2). Additionally, the runoff depth was also reduced by 6.8 inches per year; a 19% reduction. Lastly, the annual groundwater recharge prior to our design was 157,547 gallons per year; after implementation of our design, it will increase by 84% to 969,214 gallons per year.

Design Performance Monitoring

Sensors will be deployed on site to measure and analyze environmental health outcomes of our design intervention with the assistance of University of Pennsylvania graduate research assistants and staff from the Netter Center for Community Partnerships. This will include air quality monitoring; measurements of the urban heat island effect through heat index monitoring, thermal imaging for radiant temperature, soil temperature and moisture data logging; measurements of water quality improvement through the percentage reduction of pollutant load in runoff from the site; and measurements of stormwater runoff volume reduction through modeling tools available from the Philadelphia Water Department. Data from monitoring tools will be analyzed to understand the positive effects of GSI, and the data will be incorporated into curricula to educate the students and the community about these effects.

Budget

Financial feasibility is one of the key factors to influence if the project can be successfully implemented or not. The most obvious way to test a project's feasibility is by using the Discounted Cash Flow (DCF) financial model to discount all future estimated cash flow generated by the project, based on its useful life, to present by using a discount factor. Moreover, the project's Net Present Value (NPV) and Internal Rate of Return (IRR) can be calculated further to indicate its feasibility at the same time. Four metrics influence the feasibility in the model, which are initial investment, project's cash flow, maintenance cost, and the discount factor.

Unlike the enterprise valuation, the only cash flow the project can generate is the saving from the stormwater discharge, which is around $42,300 annually. After implementation of our design, our team estimates that the school could save $28,341, or about 67%, from its annual rain stormwater fee. Without considering the time value of the money, the school will save around $1,133,640 in total given the life of the design. For the total investment, only one lump sum investment will be made to finance the project in 2022 (Year 0), about $543,000, which is the total amount of the budget. Our team estimated that the amount of the annual maintenance cost will be around $3,500.69, and the maintenance cost will be subtracted from the annual savings. The last but the most important metric is the discount factor. In this project, the discount factor used Weighted Average Cost of Capital (WACC) to calculate, which has two major components, which is cost of debt and cost of equity. Given the school won't take any debt to finance the project, the cost of debt is zero. The cost of equity is calculated based on the Capital Asset Pricing Model (CAPM), since the school is not publicly traded, it doesn't have any Beta, eventually, the cost of equity is only the 10-year treasury bond rate, which is 1.383% as of December 2021. Thus, the project's discount rate is 1.383% (Quote-US10Y, 2021).

Budget of Rainworks Project at Sayre High School, Philadelphia, PA	
Total Projected Budget (Based on the Budget Table)	$543,000.00

Estimated Annual Saving from Project (Based on School's Historical Expenses)	
Monthly Flat Rate	$3,525.00
Month Per Year	12
Total Estiimated Cost/year	$42,300.00
Maximum Percent of Saving	67%
Annual Saving from the project	$28,341.00
Cost Break Down (Based on the Budget Table)	
Estimated Annual Maintenance Cost	$3,500.69
Estimated Total Cost	$543,000.00
Estimated Life of Use	
Estimated Facility Using Period	40 Years
Exact Period	2022 - 2062
Cost of Equity	
Risk Free Rate	1.38%
Market Risk Premium (According to Statista 2011-2021 MRP)	5.50%
Sayre High School's Beta	N/A (Not public traded)
Propotion of Equity Finance	100%
Cost of Equity: Capital Asset Pricing Model (CAPM = Rf+ B*MRP)	1.38%
Cost of Debt	
Interest Rate	N/A (Doesn't take any debt)
Propotion of Equity Finance	0%
Cost of Debt	0.00%
Cost of Capital (WACC: Weighted Average Cost of Capital)	1.383%

Valuation

**Assuming the project will start in 2022 and will be completed before 2023 rainy season*

Discounted Cash Flow

Project Life	0	1	2	3	4	5	6	...
	2022	2023	2024	2025	2026	2027	2028	...
Annual Saving from the project	$0.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	...
(+) Total Saving (67% of the Total)	$0.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	...
Expenses								
(-) Operation & Maintenance Cost	0	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)	...
(-) Total Investment	$ (543,000.00)	$ -	$ -	$ -	$ -	$ -	$ -	
(=) Total Cash Flow	-$543,000.00	$24,840.31	$ 24,840.31	$ 24,840.31	$ 24,840.31	$ 24,840.31	$ 24,840.31	...
Dicount Factor	1.38%	1.38%	1.38%	1.38%	1.38%	1.38%	1.38%	...
Discount Factor Per Year	98.6%	98.6%	98.6%	98.6%	98.6%	98.6%	98.6%	...
Accmulated Discount Factor	98.6%	97.29%	95.96%	94.65%	93.36%	92.09%	90.83%	...
Value of the Saving from Project @ 2021 Oct	$ (535,592.75)	$ 24,167.22	$ 23,837.55	$ 23,512.37	$ 23,191.63	$ 22,875.27	$ 22,563.22	...
Accumulated Value	$ (535,592.75)	$ (511,425.53)	$ (487,587.98)	$ (464,075.61)	$ (440,883.98)	$ (418,008.71)	$ (395,445.49)	...

Project Life	27	28	29	38	39	40
	2049	2050	2051	2060	2061	2062
Annual Saving from the project	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00
(+) Total Saving (67% of the Total)	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00	$28,341.00
Expenses						
(-) Operation & Maintenance Cost	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)	$ (3,500.69)
(-) Total Investment	$ -	$ -	$ -	$ -	$ -	$ -
(=) Total Cash Flow	$ 24,840.31	$ 24,840.31	$ 24,840.31	$ 24,840.31	$ 24,840.31	$ 24,840.31
Dicount Factor	1.38%	1.38%	1.38%	1.38%	1.38%	1.38%
Discount Factor Per Year	98.6%	98.6%	98.6%	98.6%	98.6%	98.6%
Accmulated Discount Factor	68.07%	67.14%	66.23%	58.53%	57.73%	56.94%
Value of the Saving from Project @ 2021 Oct	$ 16,909.59	$ 16,678.92	$ 16,451.40	$ 14,538.40	$ 14,340.08	$ 14,144.46
Accumulated Value	$ 13,348.85	$ 30,027.77	$ 46,479.17	$ 184,801.65	$ 199,141.73	$ 213,286.19

Net Present Value	$ 213,286.19
Internal Rate of Return	3.35%
Break-Even Year	Year 27

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

Source: https://www.cnbc.com/quotes/US10Y

Figure 5. Valuation of the project, based on the Discounted Cash Flow Financial Model

Our team estimates that the design elements will last for at least 40 years. The model shows that the break-even year is 2049, which is Year 27; the project's NPV is $213,286.19; and the IRR is 3.35%. Since the model shows that the project has passed the break-even point and is able to generate positive NPV and IRR, our team is confident that the project is financially feasible (Figure 5).

Funding

Funding for the project will come from a variety of carefully selected sources, including the University of Pennsylvania's Sustainability Office, state or national grants, regional foundations, private donors, and crowdsourced funding. A part of the funding will come from the University of Pennsylvania itself, which has pledged to donate $100 million to the Philadelphia School District over the span of 10 years. We will be applying to funds such as the Penn Sustainability Office's Green Fund Grant, which can issue grants of up to $30,000. In addition, Projects for Progress from the Office of Social Equity and Community will provide up to $100,000 for projects that fight for equity in issues like achieving educational equity and reducing health disparities; a perfect description of our work in Sayre High School. Penn's Center of Excellence in Environmental Toxicology (CEET) and Penn Environmental Innovations Initiative (EII) are both research grants that can provide $50,000 and $25,000 respectively.

Other than the University of Pennsylvania, we have also identified 15 Philadelphia regional philanthropic foundations. An emphasis will be placed on the William Penn Foundation, which is a Philadelphian family foundation with a mission to improve the city. Its "Watershed Protection: Watershed-Wide or Targeted Sub-Watersheds" grant and the "Investing in Great Public Spaces" grant both have no maximum and can sustain a portion of our budget.

On a larger scale, a significant part of our funding will come from 40 local, state, and federal government grants and programs that target improvements in the Pennsylvania environment. For instance, we have identified PWD's Stormwater Management Incentive Program (SMIP) which funds projects that construct stormwater retrofit projects, and the Growing Greener program that has awarded $34 million to fund 149 projects to clean up waters in Pennsylvania. Environmental education related grants include the EPA's Environmental Education Grants that will provide both mini grants of up to $3,000 or general grants (Level I) up to $20,000.

We estimate that we can attain $105,000 from the University of Pennsylvania and $620,000 from state and national governmental grants, which adds up to $725,000. With the addition of regional foundational funds such as the William Penn Foundation as well as contributions from private donors and crowdsourced funding, we will be able to implement our project at Sayre.

Collaborations for Implementation

In order to successfully implement the design, we will leverage our connections with various entities within both the University of Pennsylvania and the City of Philadelphia. For example, PennPraxis and the Weitzman School of Design at the University of Pennsylvania are launching a "Studio+" initiative. Studio+ is a new and permanent initiative of the Weitzman School of Design focused on community-engaged design, planning, art, and preservation, conceived as a vehicle for action on the part of Penn faculty and students to increase equity and reduce systemic racism embedded in processes, uneven distributions of public resources, under-achieving buildings and spaces, and erasures in the city. This interdisciplinary studio will build from our design proposal, integrate and refine the design, help in fabrication and funding of design components like furniture and educational murals, and will also help conduct workshops with the school and the community. We will also be collaborating with the Philadelphia Orchard Project to plant and maintain food-producing perennial plants in the design. The Water Center at Penn will provide curricular, marketing, and design support to Sayre students and teachers throughout the implementation process. We will also collaborate with TinyWPA, an outdoor classroom design company, to conduct design and fabrication workshops with students at both Penn and Sayre. Additionally, we will collaborate with the School District of Philadelphia and the Philadelphia Water Department to write grant proposals, contract with an engineering firm to create a design schematic, and to build the design. Finally, we will coordinate with Penn Civic House to implement a volunteer network to support education and activities at Sayre, with a particular focus on GSI and environmental justice.

Conclusion

Our GSI design will not only manage stormwater at Sayre, but will provide a multitude of social, environmental, and economic co-benefits for students, staff, and the surrounding community. To increase buy-in to the design and to determine what matters most to the Sayre community, our team has engaged in an equitable and inclusive outreach and design process. To ensure that the design is actually implementable, we have conducted exhaustive analyses of existing conditions, design feasibility, and project performance; identified a wide swath of funding opportunities for which the design is eligible; and have formed partnerships with a diverse range of stakeholders. The GSI design we have collaboratively created with the Sayre community will, once implemented, create a more resilient, equitable, and healthy Sayre High School.

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