United States Environmental Protection Agency

2012 GREEN INFRASTRUCTURE COMMUNITY PARTNERS
3 Rivers Wet Weather
Pittsburgh, Pennsylvania

Conceptual Green Infrastructure Design in the Brookline Neighborhood, City of Pittsburgh

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About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, soil and plants absorb and filter the water. When rain falls on our roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems (storm sewers) and discharged into nearby water bodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, *green infrastructure* refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. Green infrastructure can be a cost-effective approach for improving water quality and helping communities stretch their infrastructure investments further by providing multiple environmental, economic, and community benefits. This multi-benefit approach creates sustainable and resilient water infrastructure that supports and revitalizes urban communities.

The U.S. Environmental Protection Agency (EPA) encourages communities to use green infrastructure to help manage stormwater runoff, reduce sewer overflows, and improve water quality. EPA recognizes the value of working collaboratively with communities to support broader adoption of green infrastructure approaches. Technical assistance is a key component to accelerating the implementation of green infrastructure across the nation and aligns with EPA's commitment to provide community focused outreach and support in the President's *Priority Agenda Enhancing the Climate Resilience of America's Natural Resources*. Creating more resilient systems will become increasingly important in the face of climate change. As more intense weather events or dwindling water supplies stress the performance of the nation's water infrastructure, green infrastructure offers an approach to increase resiliency and adaptability.

For more information about Green Infrastructure, visit http://www.epa.gov/greeninfrastructure.

Acknowledgements

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Executive Summary

The City of Pittsburgh, like many East Coast metropolitan areas, is served by a combined sewer system constructed in the 1800s. This type of system collects stormwater along with wastewater and carries it to a publically owned water treatment works. In 2008, the city entered into a consent decree to address combined sewer overflows (CSOs); part of this agreement required the development of a Long Term Control Plan (LTCP). The LTCP includes a variety of measures, including the use of green infrastructure practices to reduce stormwater runoff, promote infiltration, and provide other benefits.

The organization 3 Rivers Wet Weather (3RWW) was created to help address these issues. Recognizing the opportunity to achieve multiple environmental and livability goals by addressing green infrastructure early in the Wet Weather Plan planning process, 3RWW sought technical assistance from EPA. Using tools to guide site selection, 3RWW identified three sites in the Pittsburgh community for further analysis, including a model conceptual design for green infrastructure practices at each site.

One of these project sites is in a residential neighborhood situated in the hills of Pittsburgh along the southern edge of the city. The conceptual design includes bioretention on Sussex Avenue, near the intersection with Sageman Avenue. Sussex Avenue is an arterial street and green infrastructure installed along this corridor would be highly visible. Based on the project and design goals, an EPA team developed a conceptual stormwater management design that would complement and enhance the Wet Weather Plan to reduce CSOs in the Pittsburgh area.

The conceptual design was intended to achieve the project goals of reducing stormwater volume to the combined sewer system while improving drainage and water quality with bioretention. The design also achieves aesthetic appeal by adding natural vegetative features. The conceptual design includes:

- Bioretention on the northeast quadrant of Sussex Avenue and Sageman Avenue.
- Bioretention on the southeast quadrant of Sussex Avenue and Sageman Avenue.

The other two sites (Frick Museum in Point Breeze and Windermere Drive in Swisshelm Park) are addressed in separate reports.

I. Introduction

The Greater Pittsburgh Area is located on the Allegheny Plateau, where the confluence of the Allegheny River from the northeast and the Monongahela River from the southeast form the Ohio River. The rivers and mountains form the backdrop for the area's economy and livelihood. In addition to being used for swimming, boating, and fishing, the three rivers provide drinking water for the community.

The City of Pittsburgh and surrounding municipalities were built with a combined sewer system serving its older urban core areas. Combined sewers convey sewage and stormwater flows in a single pipe sewer system, allowing combined sewer overflows (CSOs) to Pittsburgh waterways during wet weather. Addressing the sewage overflow problems is a priority for the region, including the Allegheny County Sanitary Authority (ALCOSAN), which provides wastewater treatment services to 83 municipalities in the county.

In January 2008, ALCOSAN entered into a consent decree with the United States Environmental Protection Agency (EPA), Pennsylvania Department of Environmental Protection (DEP), and the Allegheny County Health Department (ACHD). The consent decree is a legal, binding document that requires ALCOSAN to meet a series of requirements for planning, design and construction, operation and permitting with the purpose of improving water quality in receiving waters and protecting designated waterway uses that include drinking water, recreation, aquatic life, and others. The consent decree requires that ALCOSAN reduce CSO discharges into the Ohio, Allegheny, and Monongahela Rivers, and their tributary streams of Chartiers Creek, Saw Mill Run, and Turtle Creek.

This commitment to reduce CSOs and improve water quality and recreation has led the municipalities to consider the use of green infrastructure for stormwater management and CSO reduction.

The 3 Rivers Wet Weather (3RWW) nonprofit was created in 1998 to help Allegheny County municipalities address the region's wet weather overflow problem. As part of their mission, 3RWW created the RainWays® tool to aid residents and engineers in determining the effects of proposed green infrastructure projects on CSO discharges. This tool is available at http://www.3riverswetweather.org/green-infrastructure.

Using RainWays® and EPA's System for Urban Stormwater Treatment and Analysis IntegratioN (SUSTAIN) best management practice siting tool, 3RWW conducted a study assessing the feasibility of using green infrastructure within the City of Pittsburgh, Borough of West View, and Borough of Millvale. These areas are typical of the greater Pittsburgh area with moderate slopes and a constrained urban setting. Three sewersheds in the city (Nine Mile Run, McNeilly Run, and Girty's Run) were evaluated for potential green infrastructure projects on municipal, commercial and residential properties. 3RWW then developed a planning-level methodology to identify potential locations for green infrastructure projects within SUSTAIN, then used the RainWays® tool to analyze flow reduction and costs for implementation. From this study, 12 candidate sites were chosen for further analysis.

After investigating the 12 candidate sites in March of 2013, three of the sites (two in Nine Mile Run and one in McNeilly Run) were selected as green infrastructure conceptual design projects as part of the 2012 EPA Green Infrastructure Community Partners Program. The goal was to determine model sites with the highest likelihood of success in managing stormwater and contributing toward the reduction of CSOs within the ALCOSAN system. The selection process weighed the following long-term as well as near-term considerations:

Long-Term Considerations

- Probability of neighborhood acceptance
- Maintainability
- Visibility
- Contribution toward CSO reductions
- Potential for excessive/debilitating pollutant loads from tributary area (e.g., hot spots and unpaved driveways)
- Frequent flooding

Near-Term Considerations

- Constructability and functionality
- Relative cost compared to other green infrastructure practices
- Existing pavement conditions (pavement needing resurfacing gets priority)

One of the selected project sites was Sussex Avenue within the McNeilly Run Sewershed (City of Pittsburgh, Brookline Neighborhood). Refer to Figure 1-1 for the project location.

This project will enhance the space along Sussex Avenue by providing stormwater treatment facilities, a "green" amenity in a public space, and an educational opportunity for local residents. The project will serve as a model for other existing urban neighborhoods in the greater Pittsburgh area and will demonstrate a range of appropriate green infrastructure tools that can be implemented elsewhere within the region.

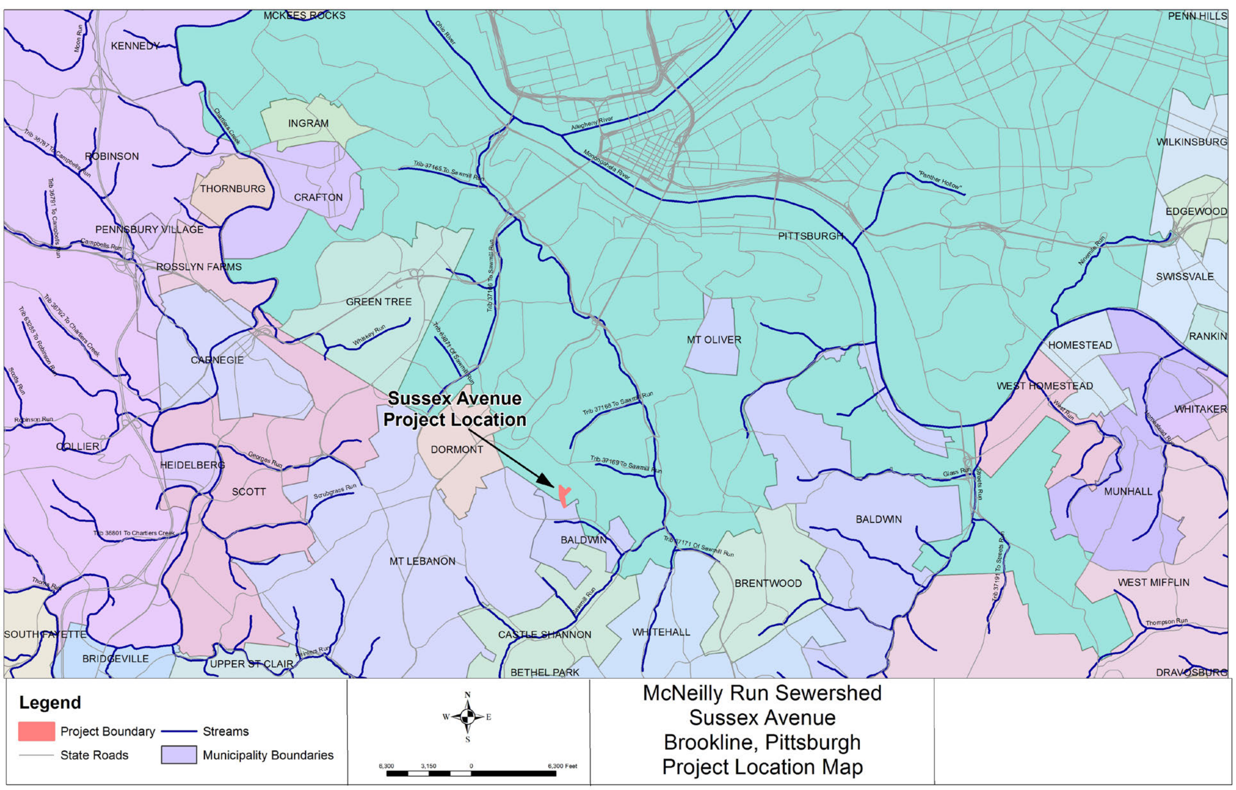

Figure 1-1. Site Location Map

2. McNeilly Run Sewershed: Sussex Avenue Project Site

The project site is located in the Brookline neighborhood within the McNeilly Run Sewershed (see Figure 2-1 and Figure 2-2). This residential neighborhood is Pittsburgh's second largest and is located in the hills along the southern edge of the city, situated south of the Monongahela River. The entire Brookline neighborhood was extensively mined and the location of all historic mines is unknown. The rich Pittsburgh Coal Seam ran directly under the neighborhood; subsidence (i.e., downward shift of the Earth's surface) and the ability of the underlying soils to receive infiltration from stormwater are concerns that will be addressed in the final design stages through geotechnical investigations. Drainage from the project site is captured by the combined sewer system and conveyed to the ALCOSAN interceptor.

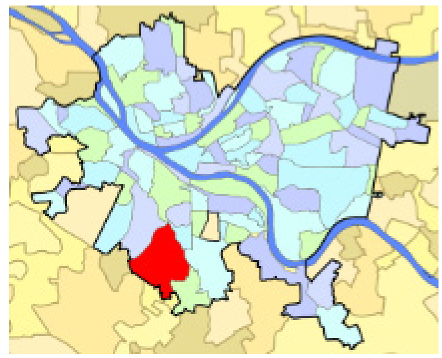

Figure 2-1. Brookline Neighborhood within the City of Pittsburgh

Using green infrastructure concepts at the block scale will help improve water quality, and help decrease CSOs by decreasing the peak flow rate and stormwater volume to the combined sewer system. In addition, the community could experience several other benefits often associated with green infrastructure, including increased property values, enhanced enjoyment of surroundings, a greater sense of well-being, and reduced crime. Information gained from this project will help promote similar projects throughout the greater Pittsburgh area.

Figure 2-2. Sussex Avenue Project Boundary

2.1. Existing Site Conditions

The project site consists of single-family residences (~1/8-acre lots) with a wooded area directly across the street. Houses are arrayed in a medium density configuration with large front yards that separate dwellings from the street. Elevations range from approximately 1,078 to 1,042 feet with several steep roads and topographic depressions. Refer to the Appendix for a copy of the completed site reconnaissance checklist and accompanying map for this area.

Most of the streets have curb and gutter facilities and a few alleys are present. The main arterial street (i.e., Sussex Avenue; see Figure 2-3 and Figure 2-4) has a wide shoulder with no curb and gutter and is owned and maintained by the City of Pittsburgh. Stormwater typically sheet flows off the ground surface into stormwater catch basins that tie directly into the combined sewer system. During small rain events, the stormwater is directed to the ALCOSAN wastewater treatment plant and treated before being released to the Ohio River. During larger rain events, the combined sewer system is overwhelmed and a mixture of sanitary sewage and stormwater is discharged untreated to the local waterways just south of McNeilly Run Road. Pollutants from the area are anticipated to include bacteria, nutrients, and heavy metals, typical of urban areas.

An analysis of the site topography indicates that surface water generally flows north to south on the site. The existing stormwater drainage network currently outfalls to Saw Mill Run, near the intersection of McNeilly Run and Library Road. The predominant soil types suggest poor to fair drainage capabilities overall (see below for a more detailed discussion), yet the soils still have the potential to capture and percolate stormwater, preventing it from entering the combined sewer system. There are no known potential soil contamination issues within the project contributing area. The area is not designated as a groundwater recharge area, and there are no environmentally sensitive areas within the project limits.

Figure 2-3. Sussex Avenue Looking South

Figure 2-4. Sussex Avenue Looking North

2.2. Proposed Site Design

The goals of the field reconnaissance conducted for all three Pittsburgh-area sites on March 4-5, 2013 were to 1) verify the feasibility of implementing the proposed green infrastructure practices from the 3RWW RainWays®, and SUSTAIN study, 2) generate ideas for incorporating practical green infrastructure practices, and 3) further assess the drainage area based on catch basin locations. A variety of green infrastructure practices were feasible throughout the area within the right-of-way.

Many different types of green infrastructure practices were considered for the project site. Based on the project goals and the site constraints, bioretention within the street right-of-way was selected as the preferred practice type. Bioretention is proposed along the east side of Sussex Avenue.

Since the Sussex Avenue right-of-way is situated on an incline of approximately 5 percent (typical of the greater Pittsburgh area), it is important to choose a green infrastructure practice that can demonstrate success on a slope. As this is a demonstration project, the selected practice also needs to translate easily to other locations within the Pittsburgh area, recognizing any lessons learned as well as special design techniques for constructing on moderate slopes (5 to 10 percent). See section 6 for a description of the placement and design of the proposed green infrastructure practice.

3. Goals

3RWW is providing direct assistance to 83 municipalities to coordinate the development of their consent order-required "feasibility studies," which analyze alternatives for the reduction, conveyance, or storage of wet weather flows within the communities. These feasibility studies specify the proposed actions (including both gray and green infrastructure) that municipalities served by ALCOSAN will implement to reduce CSOs. As these studies are integrated into the ALCOSAN Long-Term Control Plan (LTCP), the vision is to ensure that green infrastructure is evaluated and included in the municipal plans where cost-effective and appropriate. There is a sense of urgency in the timing of implementation of green infrastructure; the City's LTCP is already under development and will be the blueprint for the construction of a system that will be required to mitigate sewer overflows in the ALCOSAN service area by 2026. 3RWW will work directly with the municipalities through the existing Feasibility Study Working Group of about 25 municipal engineers who represent more than 70 of the 83 communities. Green infrastructure evaluation projects (such as the conceptual design presented in this report) are one of the mechanisms being used to emphasize the importance of green infrastructure and at the same time bring familiarity to those likely to plan for and design green infrastructure to mitigate sewer overflows.

3.1. Project Goals

Green infrastructure concepts and practices are intended to approximate the hydrologic conditions of the site prior to development through infiltration, evaporation, and detention of stormwater runoff. More specifically, the green infrastructure planned for this project is intended to assist in reducing CSOs while also improving drainage and water quality in the neighborhood. Secondary goals of the project are to improve the aesthetic appeal of the neighborhood while maintaining the historic character of the area. These goals will be accomplished through implementation of bioretention within the project area on Sussex Avenue.

3.2. Design Goals

In accordance with the consent decree, ALCOSAN is working toward a target of no more than four overflows per sewer system regulator per year. Regulator structures direct all the dry weather flow to the ALCOSAN system and control the quantity of flow diverted to the ALCOSAN treatment plant during wet weather conditions. Modeling efforts during a previous study of the ALCOSAN system calculated overflow volumes for each event and ranked them from largest to smallest.

The project site is upstream of regulator S1500POCL01A-OF (POC S-15) and several intermediate CSO outfalls upstream of POC S-15. The model information was analyzed and no overflows were recorded during the simulated time period at the regulator (POC S-15). Rather, overflows occurred at an intermediate CSO outfall (CSO139A001, indicated with the red star in Figure 2-2). The same goal of no more than four overflows per year is desired at CSO139A001. The model information for CSO139A001 was analyzed and it was found that the fifth largest overflow event had a rainfall depth of 0.87 inches. (CSO requirements in Pennsylvania allow for four CSO events per year, so designing to control the fifth largest precipitation event will meet the requirements.) The allowable peak flow rate from this outfall's drainage area to comply with this overflow event is 0.115 cfs per acre of drainage area (i.e. 10,000 cubic feet per day per acre or 74,400 gallons per day per acre). This is essentially the capacity at the regulator, normalized over the drainage area, when the hydraulic grade line is at the crest of the overflow weir. For a green infrastructure practice to assist in meeting the overflow limit, the allowable release rate from the practice should not exceed 0.115 cfs per acre.

For purposes of the conceptual design, the green infrastructure practices are sized to store the runoff resulting from 0.87 inches of rainfall from the tributary drainage area discounting release rates. This is standard design practice and will result in a slightly over-sized system; the sizing of the project would be reviewed as part of the final design.

4. Green Infrastructure Toolbox

Green infrastructure utilizes the natural features of the site in conjunction with the goals of the site development. Multiple controls can be incorporated into the development of the site to complement and enhance the proposed layout while also providing water quality treatment and volume reduction. Green infrastructure practices are those methods that provide control and/or treatment of stormwater runoff on or near locations where the runoff initiates. Typical large-scale practices include approaches such as vegetated infiltration basins and stormwater wetlands. Smaller scale practices include approaches such as permeable pavement and bioretention facilities. The green infrastructure practices identified as appropriate for the project area include vegetated green infrastructure practices (i.e., bioretention). To assist planners and designers in going forward with these conceptual designs, the following discussion addresses constraints and opportunities associated with bioretention practices.

4.1. Vegetated Green Infrastructure Practices

Vegetated green infrastructure practices are vegetated, depressed areas with a fill soil (often engineered soil media) that infiltrate stormwater and remove pollutants through a variety of physical, biological, and chemical treatment processes. Vegetated green infrastructure practices can be large-scale controls treating several acres or small-scale controls placed in parking medians, rights-of-way, and other locations within impervious areas. The following section discusses bioretention as a small-scale control for this project.

Bioretention: Bioretention typically consists of vegetation, a ponding area, mulch layer, and soil media. The depressed area is planted with small- to medium-sized vegetation including trees, shrubs, grasses and perennials and may incorporate a vegetated groundcover or mulch that can withstand urban environments and tolerate periodic inundation and dry periods. Runoff intercepted by the practice is temporarily captured in the depression and then filtered through the soil (often engineered soil) media. Pollutants are removed through a variety of physical, biological, and chemical treatment processes. Pretreatment of stormwater flowing into the bioretention area is recommended to remove large debris, trash, and larger particulates. Pretreatment may include a grass filter strip, sediment forebay, or grass swale. Ponding areas can be designed to increase flow retention and provide flood control.

Bioretention is well suited for removing stormwater pollutants from runoff, particularly for smaller wet weather events. Bioretention can be used to partially or completely meet stormwater management requirements on smaller sites. Bioretention areas are best suited for areas that would typically be dedicated to landscaping and can be designed to capture roof runoff, parking lot runoff, or sidewalk and street runoff (as shown in Figure 4-1 and Figure 4-2). Bioretention is especially useful in this project area to encourage green space within the right-of-way.

Figure 4-1. Bioretention in Median

Source: Aaron Volkening

Figure 4-2. Curb-extension Bioretention

Source: Environmental Services, City of Portland, OR

5. Green Infrastructure Conceptual Design

This section addresses the selection, layout, and design of the green infrastructure practice for the project site. The selection and proposed layout of the controls within the project area are based on the 3RWW RainWays® and SUSTAIN study, determining the effects of green infrastructure on CSO volume reduction, and a field reconnaissance to verify feasibility and identify additional opportunities. The design method is described in section 5.1 and the conceptual layout and sizing practices are discussed in section 5.2. Detailed design information is summarized and presented in section 6 to assist with final design of the green infrastructure practices.

5.1. Analytical Methods

Since a primary goal of this project is to alleviate CSO issues, the design of the green infrastructure practice is intended to retain the runoff volume resulting from 0.87 inches of rainfall from the tributary drainage area, disregarding release rates. The runoff curve number method was used to calculate runoff. Required storage volumes from the tributary drainage areas to the green infrastructure practices are presented in Table 5-1.

The subcatchment areas for the proposed green infrastructure practices were derived from topographic data (provided by 3RWW) and field visits. Note that these data will need to be validated as part of the final design. The soil was represented as medium-infiltrating soil (Hydrologic Soil Group B) to low-infiltrating soil (Hydrologic Soil Group C) per the Natural Resources Conservation Service Soil Survey data provided by 3RWW. Actual soil infiltration rates will need to be determined as part of the final design (see section 6 later in this document).

The final conceptual sizing of the green infrastructure practices was based on available surface area and a projected design cross-section to ensure that the practice, at a minimum, could capture the required storage volume for the regulator capacity. Storage within the practice took into account void space within the soil media and aggregate storage layer but not the required 72-hour dewatering time (to prevent mosquito infestations), infiltration, and evapotranspiration. Therefore, during final design, these parameters should be taken into account which would help decrease the practice sizes. It was also assumed that bioretention systems would include underdrains with a downstream valve at the outlet, which would be regulated to meet dewatering requirements as needed. With Type B soils, an underdrain is not imperative but is useful for future flow monitoring or as a failsafe should underlying soils become clogged. Type C soils should include an underdrain unless in-situ soils are shown to have sufficient infiltration capacity.

Table 5-1. Subcatchment Delineations and Required Storage Volume

Subcatchment	Subcatchment Drainage Area (acres)	Required Storage Volume for Regulator Capacity (cu ft)
Sussex Avenue - North bioretention	0.26	720
Sussex Avenue - South bioretention	0.35	966

5.2. Recommended Sizing and Layout

The conceptual layout and sizing of the green infrastructure practices within the project area are discussed in this section. The cross-section designs used for the sizing of the practices are in section 6.

Within the discussion below, note that the water storage volume is the product of the surface area of the practice and the equivalent storage depth. Equivalent storage depth is the sum of the surface ponding depth and the product of the usable void space and applicable underlying layers, discounting the underlying soil infiltration rate. A 20% usable void space was assumed which is the difference between the porosity and the field capacity of the soil. The cross-section of the final design can vary from the conceptual design cross-section as long as the water storage volume capacity is maintained.

Green infrastructure practices proposed for Sussex Avenue include bioretention areas adjacent to the road, within the right-of way. One bioretention area would be north of Sageman Avenue ("north bioretention") and the second between Sageman Avenue and Cedric Avenue ("south bioretention"). The north bioretention area would collect flow from the front yards and the east side of the road between Norabell Avenue and Sageman Avenue. The south bioretention area would collect flow from the front yards and the east side of the road between Sageman Avenue and Cedric Avenue. The bioretention areas were sized based on available surface area while maintaining a safe distance from roads, and other infrastructure. Once a maximum available surface area was determined, the vertical depth was determined based on the volume of runoff to be stored.

North Bioretention. The north bioretention area is designed to be 870 square feet (6 feet wide by 145 feet long) and will not impede the flow of traffic. The equivalent water storage depth is 0.7 feet resulting in a storage capacity of 609 cubic feet, which meets the required storage volume. The practice cross-section was assumed to include 6 inches of surface storage, and 12 inches of engineered soil. The practice is designed as a terraced system due to the slope of the road and right-of-way.

South Bioretention. Based on the available area of 1,500 square feet (6 feet wide by 250 feet long) for the south bioretention area, and an equivalent water storage depth of 0.7 feet, the available storage volume is 1,050 cubic feet. The equivalent water storage depth assumes 6 inches of surface storage and 12 inches of engineered soil as a terraced system and meets the storage volume requirement.

Table 5-2 and Table 5-3 provide a detailed description of available storage capacity and cross-section depths for each of the green infrastructure practice sites described above. Figure 5-1 shows the placement of the practices.

Table 5-2. Green Infrastructure Practice Sizing and Storage

Green Infrastructure Practice	Location Description	Location	Width (ft)	Length (ft)	Surface Area (sq ft)	Equivalent Water Storage Depth (ft)[1]	Available Water Storage Volume (cu ft)[2]	Runoff Depth Stored (in)[3]
Bioretention	Sussex Ave, north of Sageman Ave.	Right-of-way	6	145	870	0.7	609	0.63
Bioretention	Sussex Ave, south of Sageman Ave.	Right-of-way	6	250	1,500	0.7	1,050	0.81

[1]Equivalent Water Storage Depth: Ponding Depth x void space + Engineered Soil Depth x void space + Aggregate Storage Depth x void space [Example Calculation: (0.5' x 1.0) + (1.0' x 0.2) + (0 x 0.4) = 0.7 feet equivalent depth]
[2]Available Water Storage Volume: Surface Area x Equivalent Water Storage Depth
[3]Runoff Depth Stored: Available Water Storage Volume/Surface Area and converted to inches

Table 5-3. Green Infrastructure Practice Cross-Sections

Green Infrastructure Practice	Location Description	Location	Ponding Depth (inch)	Engineered Soil Depth (inch)	Aggregate Storage Depth (inch)
Bioretention	Sussex Ave, north of Sageman Ave.	Right-of-way	6	12	0
Bioretention	Sussex Ave, south of Sageman Ave.	Right-of-way	6	12	0

Figure 5-1. Proposed Green Infrastructure Practice Placement

6. Green Infrastructure Practice Technical Specifications

This section describes the conceptual design of the green infrastructure practices as proposed in section 5. The Pennsylvania Stormwater Best Management Practices Manual includes design guidance for many green infrastructure practices and should be referenced in any final design steps. The following is additional information, which may be helpful in the design of bioretention applications.

6.1. Design Elements

The green infrastructure siting was based on multiple factors including 1) effectiveness as a demonstration site, 2) multi-use asset for the surrounding neighborhood, 3) potential for volume reduction for CSO issues, and 4) ancillary benefits such as aesthetic improvement. The potential for green infrastructure practice demonstration was evaluated based on the proximity to parks, schools, museums, or other features that would attract the public and acceptability in the neighborhood. The design also considered the potential for applying the green infrastructure design similarly throughout the greater Pittsburgh area.

The conceptual design of the practice takes into account the approximate soil infiltration rate, drainage area, runoff coefficient, and allowable peak flow rates based on the downstream combined sewer regulator. Additional design parameters for bioretention include the surface storage depth, planting soil depth, aggregate storage depth, and void space ratios of the soil and aggregate. As this project moves into final design, other considerations will include buried utilities, connection to the combined sewer system, and topography based on a survey.

6.2. Bioretention

Bioretention areas should have the following design features:

- For unlined systems, maintain a minimum of 5 feet between the green infrastructure practice and any adjacent buildings and at least 10-15 feet between the green infrastructure practice and any adjacent basement.
- The design of the practice should consider the allowable release rate back to the combined sewer. This rate is dicated by the regulator capacity (refer to section 3) and also the recommended maximum facility dewater time of 72 hours. Both flow rates should be calculated and the rate that meets both design criteria will ultimately dictate the design of the practice. Dewatering mechanisms include infiltration through underlying soils as well as flow through an underdrain system. Use of an underdrain system is very effective in areas with low infiltration capacity soils.
- Utilize native and noninvasive plant species tolerant of urban environments, salt, and frequent inundation, and place a maximum of 3 inches of mulch on the surface of the soil.
- For the aggregate storage layer, use clean coarse aggregate AASHTO #4, #5, or equivalent.
- The filter layer placed between the soil media and the storage layer is recommended to be 2 to 4 inches of clean medium sand (ASTM c-33) over 2 to 3 inches of #8 or #78 washed stone.
- Include an overflow structure with a non-erosive overflow channel to safely pass flows that exceed the capacity of the facility; or design the facility as an off-line system where only the design volume enters the bioretention area.
- Inclusion of a pretreatment mechanism such as a grass filter strip, sediment forebay, or grass swale upstream of the practice to enhance the treatment capacity of the unit.

6.2.1. Soil Infiltration Testing and Underdrains

Site evaluation and soil infiltration testing is necessary to determine the suitability of a site for infiltration and gather data for the design of the infiltration practice. The Pennsylvania Stormwater Best Management Practices Manual, Appendix C – Site Evaluation and Soil Testing, should be referenced for evaluation and testing methods.

Expansive soils with a high shrink-swell potential are not prevalent in the Pittsburgh area, but if these soils are found at the site, the green infrastructure practice design should include underdrains and impermeable barriers where the controls are adjacent to infrastructure such as roads and buildings. Drainage should always be directed away from building foundations and road subgrades. If the native soils underneath a green infrastructure practice are low-permeability soils, an underdrain may be required and should meet the following criteria:

- The type of perforated pipe is not critical to the function of the green infrastructure practice as long as the total opening area of the perforations exceeds the expected flow capacity of the underdrain and does not limit infiltration through the soil media. The perforations can be placed closest to the invert of the pipe to achieve maximum potential for draining the facility. If an anaerobic zone is intended, the perforation can be placed at the top of the pipe.
- Place the underdrain within a pocket of drainage stone a minimum of 4 inches thick on all sides.
- The underdrain should drain freely and discharge to the existing sewer infrastructure. Alternatively, the underdrain outlet can be upturned to provide an internal sump (internal water storage) to improve infiltration and water quality. The optimal elevation of the underdrain invert should be no less than 1.5 feet from the surface of the basin to provide an aerobic root zone for plants and to prevent previously-sorbed pollutants from mobilizing.
- Install a valve at the downstream end of the underdrain, where the system connects back to the sewer system. The valve may be used as a passive device to adjust the allowable release rate.

6.2.2. Soil Media

A minimum of 12-18 inches of engineered soil mixture is recommended in most cases for bioretention practices. This may be either an engineered soil mixture to replace the existing soil or a compost amendment to the existing soil. The soil media is typically specified to meet the growth requirements of the selected vegetation while still meeting the hydraulic requirements of the system.

Engineered Soil Mixture: Recognizing that there are many possible variations in soil media, the following is one example:

The engineered soil mixture is a blend of loamy soil, sand, and compost that is 30-40 percent compost (by volume). The expected infiltration rate should range from 1 to 2 inches per hour.

A particle gradation analysis of the blended material, including compost, should be conducted in conformance with ASTM C117/C136 (AASHTO T11/T27). The gradation of the blended material should meet the following gradation criteria:

Sieve Size	Percent Passing
1 inch	100
#4	75-100
#10	40-100
#40	15-50
#100	5-25
#200	5-15

Other design criteria that should be considered:

- Soil media must have an appropriate amount of organic material to support plant growth. Organic matter is considered an additive to help vegetation establish and contributes to sorption of pollutants and should be between 5-10 percent. Additional organic matter can be added to the soil to increase the water holding capacity. Organic materials will oxidize over time, causing an increase in ponding that could adversely affect the performance of the bioretention area. Organic material should consist of aged bark fines, or similar organic material. Organic material should not consist of manure or animal compost. Newspaper mulch has been shown to be an acceptable additive.
- pH should be between 5–8, cation exchange capacity should be greater than 5 milliequivalent/100 g soil.
- High phosphorus concentrations are common in compost and when applied to a bioretention area, can result in leaching of phosphorus. When an overabundance of phosphorus enters waterways, it can cause unhealthy balances of aquatic life. All bioretention media should be analyzed for background levels of nutrients. Total phosphorus should not exceed the industry standard of 15 ppm.

Compost Amendment: It may be possible to restore the surface soils by adding approximately 2.5 inches of compost over the surface of the site (King County 2005) and breaking up the soil with a subsoiler or ripper attached to a tow vehicle (Kees 2008). It may also be beneficial to amend the existing subsurface soil with compost to enhance the infiltration rate. This practice increases infiltration rates and also helps reduce cations and toxicants in the water. The disadvantage is that nutrient leaching occurs for a period of time (Pitt et al. 1999). Establishing native plants with extensive root systems will also help provide channels to promote infiltration in the subsurface soil.

6.2.3. Grading

Bioretention systems function best when the top soil layer is flat. A flat surface allows for even infiltration throughout the system and reduces runoff velocities, thereby minimizing the potential for erosion. Design and construction of long, linear bioretention systems with a flat surface can be problematic when the surrounding terrain is sloped due to the required grading. Terracing the system is one approach to maintaining a flat soil layer while minimizing the required earthwork. Clay check dams and existing driveway approaches are two possible approaches to terracing. The system may be designed with a longitudinal slope similar to a swale, however special attention is required. Storage volume calculations should assume a flat water surface profile if the soil layer is sloped. Care is needed to ensure sufficient infiltration capacity through the engineered soil layer and to guard against surface erosion.

6.2.4. Plant Selection

For the green infrastructure practice to function properly and be attractive, vegetation selection is crucial. Appropriate vegetation will have the following characteristics:

- Plant materials must be tolerant of drought, ponding fluctuations, salt, and saturated soil conditions for 10 to 48 hours.
- Native plant species or hardy cultivars that are not invasive and do not require chemical inputs are recommended to be used to the maximum extent practicable.
- For native plant species, refer to the Pennsylvania Stormwater Best Management Practices Manual; Appendix B (http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-76385/363-0300-002%20Appendix%20B.pdf).
- Turf grass systems may also be used. The advantage of turf grass systems is the reduced maintenance requirements. Figure 6-1 shows an example of a bioretention system planted with turf grass and street trees, while Figure 6-2 shows a typical design for such a system.

Figure 6-1. Bioretention Planted with Turf Grass

Source: Tetra Tech

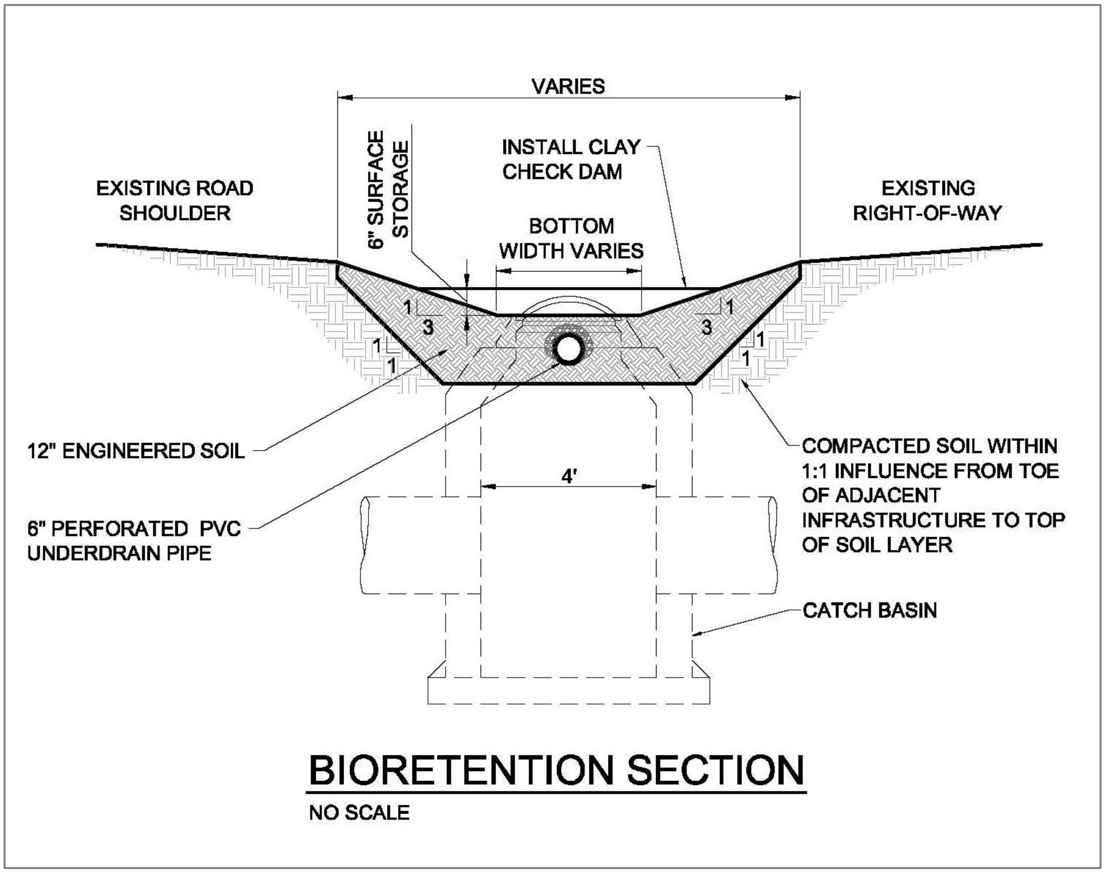

Figure 6-2. Bioretention Cross-Section

7. Operations and Maintenance

Maintenance activities for landscaped practices such as bioretention are generally similar to maintenance activities for any garden. The focus is to remove trash and monitor the health of the plants, replacing or thinning plants as needed. Over time, a natural soil horizon should develop which will assist in plant and root growth. An established plant and soil system will help in improving water quality and keeping the practice drained. The biological and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance.

Table 7-1 outlines the recommended maintenance tasks, their associated frequencies, and other notes.

Table 7-1. Bioretention Operations and Maintenance Considerations.

Task	Frequency	Maintenance notes
Monitor infiltration and drainage	1 time/year	Measure infiltration rate after construction to establish a baseline for future comparison. Inspect drainage time (< 72 hours). Recalculate infiltration rate every 2–3 years. Turning over or replacing the media (top 2–3 inches) might be necessary to improve infiltration (at least 0.5 inch/hour).
Pruning	1–2 times/year	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	As needed	Frequency depends on the location, plant selection, and desired aesthetic appeal.
Mulching	1–2 times/year	Recommend maintaining 1–3 inches uniform mulch layer by replacement or redistributing in plant bed.
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.
Watering	1 time/2–3 days for first 1–2 months; as needed after establishment	If drought conditions exist, watering after the initial year might be required.
Fertilization	1 time initially	One-time spot fertilization for first year vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 30 percent of plants can die. Survival rates increase with time.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the retention area is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated mulch or sediment. May need to clean out the underdrain to remove any accumulated sediment and debris.
Miscellaneous upkeep	12 times/year	Tasks include spot weeding, trash collection, plant health, and removing mulch from the overflow device.

8. Green Infrastructure Practice Cost Estimates

The cost estimates for constructing the green infrastructure practices at each of the sites are found in Table 8-1 and Table 8-2. Cost information was derived from bid tabulation data published by various public agencies and compared against projects constructed in the Pittsburgh area. All cost estimates assume retrofit of the green infrastructure practices and are based on the sizing information from section 5. Retrofit costs take into account pavement removal and subsequent pavement replacement or patching. A 30 percent contingency has been added to all costs. Costs do not include engineering fees, legal fees, soil erosion control, or construction management.

Annual maintenance costs are also included in Table 8-3.

Table 8-1. Sussex Avenue – North Bioretention

Item	Unit	Unit Cost	Quantity	Cost
Earth Excavation	Cu yd	$10.00	75.0	$750
Engineered Soil Mixture	Cu yd	$38.00	48	$1,824
Clay Check Dam	Ea	$75.00	12	$900
6" Perforated Underdrain	LF	$3.25	145	$471
Catch Basin Adjust	Ea	$275.00	1	$275
6" Storm Sewer Tap	Ea	$400.00	2	$800
Shoulder Aggregate, 3" , CIP	Cu yd	$20.00	6	$120
Plantings	Sq ft	$5.00	290	$1,450
Parkway Restoration	Sq yd	$8.00	170	$1,360
Notes:			Sub-Total	$7,950
			30% Contingency	$2,400
			Total	$10,350
				$9/Sq Ft

Table 8-2. Sussex Avenue – South Bioretention

Item	Unit	Unit Cost	Quantity	Cost
Pavement Rem, Modified	Sq yd	$5.00	80.0	$400
Earth Excavation	Cu yd	$10.00	134.0	$1,340
Engineered Soil Mixture	Cu yd	$38.00	86	$3,268
Clay Check Dam	Ea	$75.00	18	$1,350
6" Perforated Underdrain	LF	$3.25	258	$838
6" PVC Perforated Pipe	LF	$7.00	72	$504
Catch Basin Adjust	Ea	$275.00	1	$275
6" Storm Sewer Tap	Ea	$400.00	2	$800
6" Subbase, CIP	Cu yd	$12.00	14	$168
6" Nonreinforced Concrete Driveway	Sq yd	$40.00	80	$3,200
Shoulder Aggregate, 3" , CIP	Cu yd	$20.00	10	$200
Plantings	Sqft	$5.00	500	$2,500
Parkway Restoration	Sq yd	$8.00	285	$2,280
Notes: 6” PVC perforated pipe to be installed under driveways to allow for all bioretention cells to connect to one downstream catch basin.			Sub-Total	$17,123
			30% Contingency	$5,200
			Total	$22,323
				$11/Sq Ft

Annual routine maintenance costs were adapted from Water Environment Research Foundation (WERF) estimates to account for the scale of the green infrastructure practice (WERF 2009). Typical routine maintenance is similar to maintenance for landscaped areas or parks. Maintenance activities for the proposed green infrastructure practices may already be accounted for in existing budgets for current maintenance and upkeep activities.

Table 8-3. Annual Maintenance Cost Estimate

Green Infrastructure Practice	Location Description	Surface Area (square feet)	Average Annual Unit Cost (per Sq Ft/year)	Average Annual Routine Maintenance Cost
Bioretention	Sussex Ave, north	870	$2.28	$2,000
Bioretention	Sussex Ave, south	1,500	$2.28	$3,400

9. Conclusion

Like many older communities with a combined sewer system, Pittsburgh has historically faced problems with CSOs. As part of implementing its LTCP, 3RWW sought model conceptual designs for green infrastructure practices at three typical sites within the community. These site designs would serve multiple purposes; first, as a preliminary design for a site-level project that will help reduce CSOs at the project site and second, as a template or pilot project for integrating green infrastructure practices at other sites throughout the community. The Sussex Avenue site is one of three selected by 3RWW for a model design and the analysis demonstrates that green infrastructure approaches such as bioretention can help reduce combined sewer overflows.

Green infrastructure can be incorporated into stormwater strategies (particularly in retrofits) as municipalities seek to reduce CSOs by reducing stormwater inflow to combined sewer systems. In addition to meeting stormwater management goals, this conceptual design illustrates how green infrastructure can help create a more attractive and livable landscape that weaves functional natural elements into the built environment.

10. References

Kees, Gary. 2008. Using subsoiling to reduce soil compaction. Tech. Rep. 0834–2828–MTDC. Missoula, MT: U.S.

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Pitt, R., Lantrip, J., Harrison, R. 1999. *Infiltration through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity*. EPA/600/X-99/XXX. National Risk Management Research Laboratory, Office of Research and Development, U. S. EPA.

Water Environment Research Foundation (WERF). 2009. *User's Guide to the BMP and LID Whole Life Cost Models*. SW2R08. Version 2.0. Alexandrian, VA.

APPENDIX

Site Reconnaissance Checklist and Map

WATERSHED: McNeilly Run	**SUBWATERSHED:** Sussex Ave	**UNIQUE SITE ID:** MNR-01

DATE: 03-05-13	**ASSESSED BY:** umn/AMT	**CAMERA ID:** —	**PICTURES:** 12 photos
GPS ID:	**LMK ID:**	**LAT:** 40° 23′ 10.52″	**LONG:** 80° 01′ 01.11″

SITE DESCRIPTION

Name: Sussex Avenue, Pittsburgh (Brookline)
Address:

Ownership: ☒ Public ☐ Private ☐ Unknown
If Public, Government Jurisdiction: ☒ Local ☐ State ☐ DOT ☐ Other:

Corresponding USSR/USA Field Sheet? ☐ Yes ☒ No If yes, Unique Site ID:

Proposed Retrofit Location:

Storage nA
☐ Existing Pond ☐ Above Roadway Culvert
☐ Below Outfall ☐ In Conveyance System
☐ In Road ROW ☐ Near Large Parking Lot
☐ Other:

On-Site
☐ Hotspot Operation ☐ Individual Rooftop
☐ Small Parking Lot ☐ Small Impervious Area
☒ Individual Street ☐ Landscape / Hardscape
☐ Underground ☐ Other:

DRAINAGE AREA TO PROPOSED RETROFIT

Drainage Area ≈ 0.5 ac
Imperviousness ≈ 50 %
Impervious Area ≈ 0.25 ac

Notes:

Drainage Area Land Use:
☒ Residential
  ☒ SFH (< 1 ac lots)
  ☐ SFH (> 1 ac lots)
  ☐ Townhouses
  ☐ Multi-Family
☐ Commercial
☐ Institutional
☐ Industrial
☐ Transport-Related
☐ Park
☐ Undeveloped
☐ Other:

EXISTING STORMWATER MANAGEMENT

Existing Stormwater Practice: ☒ Yes ☐ No ☐ Possible
If Yes, Describe:

- Combined sewer in road ROW
- catch basin @ street intersections

Describe Existing Site Conditions, Including Existing Site Drainage and Conveyance:

- no observed sediment sources.
- no mature trees
- wide shoulder & parkway
- houses set back from road
- no existing curb & gutter.

Existing Head Available and Points Where Measured:

not measured.

PROPOSED RETROFIT

Purpose of Retrofit:
☒ Water Quality ☐ Recharge ☒ Channel Protection ☐ Flood Control
☒ Demonstration / Education ☐ Repair ☐ Other:

Retrofit Volume Computations - Target Storage:

0.87 inch rainfall
↳ runoff from this event
$\sim \frac{0.6"}{12} \times \frac{0.5ac}{1/43560} = 1{,}089$ CF.

Retrofit Volume Computations - Available Storage:

6' x 150' = 900 SF
6' x 250' = 1,500 SF
2,400 SF
$\frac{1{,}089 \text{ CF}}{2400 \text{ SF}} = 0.45'$ eq. depth

Proposed Treatment Option:
☐ Extended Detention ☐ Wet Pond ☐ Created Wetland ☒ Bioretention
☐ Filtering Practice ☐ Infiltration ☐ Swale ☐ Other:

Describe Elements of Proposed Retrofit, Including Surface Area, Maximum Depth of Treatment, and Conveyance:

① Bioretention in parkway
tiered system due to slope.

combined sewer to remain in place - may need to move CB's.

SITE CONSTRAINTS

Adjacent Land Use:
☒ Residential ☐ Commercial ☐ Institutional
☐ Industrial ☐ Transport-Related ☐ Park
☐ Undeveloped ☐ Other:
Possible Conflicts Due to Adjacent Land Use? ☐ Yes ☒ No
If Yes, Describe:

Access:
☐ No Constraints
Constrained due to
☒ Slope ☐ Space
☒ Utilities ? ☐ Tree Impacts
☐ Structures ☐ Property Ownership
☐ Other:

Conflicts with Existing Utilities:
☐ None
☒ Unknown

Yes	Possible	
☐	☐	Sewer
☐	☐	Water
☐	☐	Gas
☐	☐	Cable
☐	☐	Electric
☐	☐	Electric to Streetlights
☐		Overhead Wires
☐	☐	Other:

Potential Permitting Factors:

Dam Safety Permits Necessary	☐ Probable	☒ Not Probable
Impacts to Wetlands	☐ Probable	☒ Not Probable
Impacts to a Stream	☐ Probable	☒ Not Probable
Floodplain Fill	☐ Probable	☒ Not Probable
Impacts to Forests	☐ Probable	☒ Not Probable
Impacts to Specimen Trees	☐ Probable	☒ Not Probable

How many?
Approx. DBH

Other factors:

Soils:

Soil auger test holes:	☐ Yes	☒ No
Evidence of poor infiltration (clays, fines):	☒ Yes	☐ No – soil records
Evidence of shallow bedrock:	☐ Yes	☐ No ?
Evidence of high water table (gleying, saturation):	☐ Yes	☐ No ?

Unique Site ID:

SKETCH

see map of site

DESIGN OR DELIVERY NOTES

This site would work well with bioretention in the parkway to collect road runoff. It would capture runoff from the centerline as the road is crowned.

FOLLOW-UP NEEDED TO COMPLETE FIELD CONCEPT

- ☐ Confirm property ownership
- ☒ Confirm drainage area
- ☐ Confirm drainage area impervious cover
- ☒ Confirm volume computations
- ☐ Complete concept sketch
- ☐ Obtain existing stormwater practice as-builts
- ☐ Obtain site as-builts
- ☒ Obtain detailed topography
- ☒ Obtain utility mapping
- ☐ Confirm storm drain invert elevations
- ☐ Confirm soil types
- ☐ Other:____________________

INITIAL FEASIBILITY AND CONSTRUCTION CONSIDERATIONS

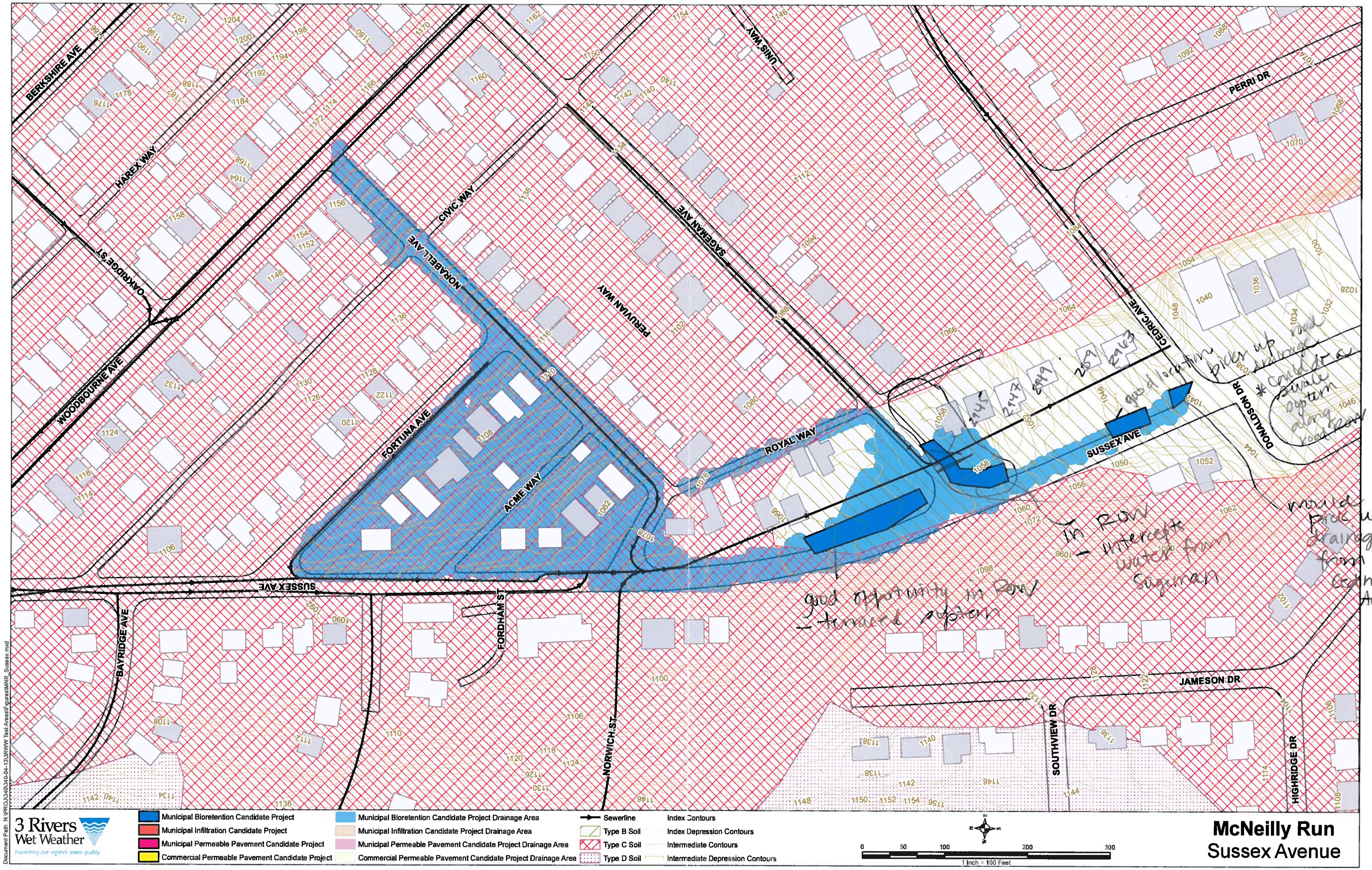
Utility locations

Slope - Terraced system

SITE CANDIDATE FOR FURTHER INVESTIGATION:	☒ YES	☐ NO	☐ MAYBE
IS SITE CANDIDATE FOR EARLY ACTION PROJECT(S):	☐ YES	☐ NO	☐ MAYBE
IF NO, SITE CANDIDATE FOR OTHER RESTORATION PROJECT(S):	☐ YES	☐ NO	☐ MAYBE

IF YES, TYPE(S):____________________

Unique Site ID:______


Document Path: N:\PROJ\340\340-04-13\3RWW Test Areas\Figures\MNR_Sussex.mxd
3 Rivers Wet Weather
Municipal Bioretention Candidate Project
Municipal Infiltration Candidate Project
Municipal Permeable Pavement Candidate Project
Commercial Permeable Pavement Candidate Project
Municipal Bioretention Candidate Project Drainage Area
Municipal Infiltration Candidate Project Drainage Area
Municipal Permeable Pavement Candidate Project Drainage Area
Commercial Permeable Pavement Candidate Project Drainage Area
Sewerline
Type B Soil
Type C Soil
Type D Soil
Index Contours
Index Depression Contours
Intermediate Contours
Intermediate Depression Contours
1 inch = 100 Feet
McNeilly Run
Sussex Avenue
SUSSEX AVE
BAYRIDGE AVE
FORDHAM ST
NORWICH ST
JAMESON DR
SOUTHVIEW DR
HIGHRIDGE DR
ACME WAY
FORTUNA AVE
NORABELL AVE
CIVIC WAY
PERUVIAN WAY
SAGEMAN AVE
ROYAL WAY
UNIS WAY
CEDRIC AVE
DONALDSON DR
PERRI DR
WOODBOURNE AVE
OAKRIDGE ST
HAREX WAY
BERKSHIRE AVE
good opportunity in ROW
- terraced system
In ROW
- intercept water from Sageman
good location
pick up road drainage
* could do swale system along road
would pick up drainage from Cedric Ave
www.PASDA.com - GIS info.