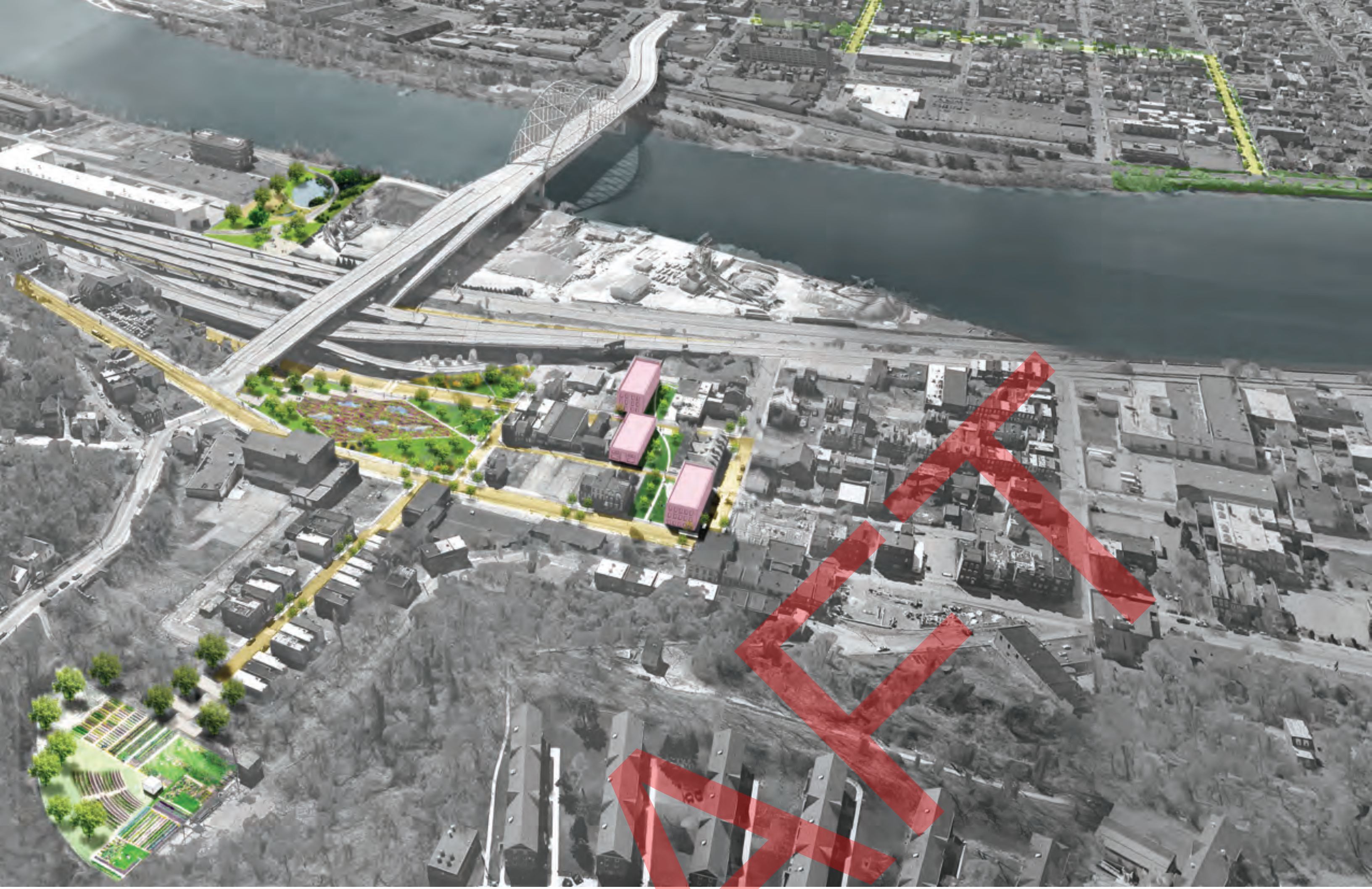

The Green First Plan

A City-Wide Green Infrastructure Assessment

Prepared for
Pittsburgh Water and Sewer Authority

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phro•ne•sis

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Acronyms and Abbreviations

3RWW	3 Rivers Wet Weather, Inc.
Ac	acres
ADF	average daily flow
ALCOSAN	Allegheny County Sanitary Authority
BG	billion gallons
BMP	best management practices
BWWF	base wastewater flow
CB	catch basin
CCTV	closed circuit television
CD	Consent Decree
COA	Consent Order and Agreement
COP	City of Pittsburgh
CSO	combined sewer overflow
CSS	combined sewer system
CWA	Clean Water Act
DCIA	directly connected impervious area
DOJ	U.S. Department of Justice
DSI	direct stream inflow
DWF	dry weather flow
ft	feet or foot
GI	green infrastructure
GIS	geographic information system
GWI	groundwater infiltration
HGL	hydraulic grade line
H&H	hydrologic and hydraulic
I/I	infiltration and inflow
IWM	Integrated Watershed Management
LF	linear feet
LID	low-impact development
LTCP	long-term wet weather control plan
MG	million gallons
MGD	million gallons per day
NMC	Nine Minimum Controls (part of CSO Policy)
NMR	Nine Mile Run
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
OF	overflow
O&M	operations and maintenance
PADEP	Pennsylvania Department of Environmental Protection
PennDOT	Pennsylvania Department of Transportation

POC	point of connection
PS	pump station
PWSA	Pittsburgh Water and Sewer Authority
RDII	rainfall-dependent infiltration and inflow
SF	square feet
SMR	Saw Mill Run
SRT	storage retention tank, or stormwater retention tank
SSO	sanitary sewer overflow
SSS	separate sanitary sewer system
SW	stormwater
SWMM	Stormwater Management Model
TBL	triple bottom line
TMDL	total maximum daily load
Typical Year	Rainfall Record for Typical Year (2003)
URA	Urban Redevelopment Authority
USEPA	U.S. Environmental Protection Agency
WQS	water quality standards
WW	wastewater
WWF	wastewater flow
WWFS	PWSA's Wet Weather Feasibility Study, July 2013
WWP	ALCOSAN's Wet Weather Plan, January 2013
WWTP	wastewater treatment plant

INTRODUCTION

Background

Pittsburgh Water and Sewer Authority (PWSA, or Authority) is committed to Green Infrastructure (GI) and has been developing a "Green First" program, which involves consideration of implementing GI first to capture stormwater at its source to maximize overflow reduction and the myriad of associated local community benefits, often referred to as Triple Bottom Line (TBL) benefits. This "Green First" approach can then inform the necessary implementation of associated gray infrastructure, such that when coupled together into an Integrated Plan, can meet both the City's and potentially the region's similar Consent Orders, and overall short-term and long-term Clean Water Act requirements. In this context, gray infrastructure, often referred to as traditional infrastructure, is composed of man-made, engineered components of a system. In the context of stormwater management, gray infrastructure can include gutters, storm sewers, tunnels, culverts, detention basins, pipes, and mechanical devices used collectively in a system to capture and convey runoff. As land developed and cities grew, gray infrastructure was introduced to move stormwater away from homes, businesses, and streets as quickly as possible during a storm. Pavement, pipes, gutters, and mechanical systems, while necessary, can cause significant stormwater management problems since they prevent natural infiltration processes and speed water movement. Since most gray infrastructure is impervious to water, it can contribute to flooding and pollution, which can add to the cost burden of the local community and government. With factors such as increased development contributing to increased runoff, and increasing intensity and frequency of recent and projected storms, not only in Pittsburgh but across the country, this problem will only increase in the future.

GI is defined as ecologically engineered measures that reduce and treat stormwater at its source while also delivering environmental, social, and economic benefits. GI uses vegetation, soils, and other elements to restore some of the natural processes required to manage water locally and create healthier urban environments. At the city or county scale, GI is a patchwork of natural areas that can provide habitat, flood protection, cleaner air, and cleaner water. At the neighborhood or site scale, GI is comprised of stormwater management systems that mimic nature to soak up, store, and either remove or detain water for slow release to a local waterway or back into the sewer system. The numerous benefits of GI also include adding green space to the city street environment, improving air quality, reducing energy demand, and enhancing wildlife habitat and recreational opportunities.

PWSA's "Green First" program involves exploring and implementing innovative ways to reduce stormwater runoff, reduce combined sewer overflow (CSO) and sanitary sewer overflow (SSO), improve in-stream water quality, reduce localized surface flooding, reduce basement sewage backups, restore habitats, enhance urban settings, and stimulate economic growth.

During 2015, PWSA invested more than $1 million in projects that have the designed capacity to control 3.7 million gallons of stormwater annually. The Authority introduced the Green Infrastructure Grant Program in 2015, and its primary focus is to encourage the development of more GI in Pittsburgh. The Authority seeks to inspire GI projects that will have multiple benefits, such as managing stormwater runoff, increasing infiltration to the ground, reducing peak flows to streets and storm sewers, improving water quality, and helping to protect people and property from flooding. Protecting and enhancing stream corridors and other green spaces can be an important component of an overall strategy for the City, helping create a place that people want to live, work, and play.

In 2015, ten grants were awarded through the Green Infrastructure Mini-Grant Program, and seven grants were awarded through the Green Infrastructure Matching Grant Program, resulting in 17 new GI projects underway in Pittsburgh. In spring 2016, PWSA announced GI Grant Program recipients, composed of three mini construction grants, three mini education grants, and seven matching grants.

In 2015, PWSA was tasked by the Mayor of the City of Pittsburgh with evaluating the benefits of incorporating extensive hydraulically-connected and cost-effective GI implementation throughout the City of Pittsburgh (City) that could be incorporated into a “Green First” Plan of green and gray infrastructure to address regulatory requirements as well as provide triple bottom line (TBL) benefits. This work started with the Shadyside/A-22 Sewershed Flooding Solutions and Green Infrastructure Assessment (Shadyside Flooding Assessment) completed in November 2015. The Shadyside Flooding Assessment evaluated gray, green (source control), and watershed scale (or combinations thereof) infrastructure solutions to reduce reoccurring surface flooding and basement sewage backups in the sewershed during intense rain events in the Maryland/Negley/College Avenue study area, as well as the larger overall A-22 combined sewershed. The Shadyside/A-22 Flooding Assessment determined that existing sewer system improvements, coupled with GI alternatives, could cost-effectively reduce localized surface flooding, basement sewage backups, and CSOs, and could be optimized when coupled with proposed improvements to the existing sewer infrastructure as outlined in PWSA’s wet weather feasibility study. This approach could also have positive effects downstream of these system improvements, in the regional sewer system, by reducing peak flows and combined sewage volume.

With these outcomes from the Shadyside/A-22 Flooding Assessment, the City-Wide GI Assessment was developed to analyze the benefits of GI if implemented in targeted areas across the combined sewer system within the City and the hydraulically connected surrounding municipalities.

There were several drivers for implementing this project, and PWSA and City leaders recognized that implementing a Green First stormwater management program could address multiple issues facing the City and surrounding municipalities, such as:

- Chronic surface flooding and associated hazard areas.
- Direct Stream Inflows (DSI), which are surface streams that flow into the combined sewer system contributing to extraneous flows, lost sewer system capacity, high loads of sediment and debris in the existing deep tunnel interceptors, and increased conveyance and treatment costs.
- Poor water quality and recreational opportunity enhancements.
- Urban planning and the City’s ongoing resilience initiatives.
- Regulatory requirements.
    - The Consent Orders and Agreements (COAs) for wet weather overflows expired on March 30, 2015. The COAs required each municipality in ALCOSAN’s service area to prepare a Feasibility Study to address work required to bring

sewer systems into compliance with the Pennsylvania Clean Streams law, the Clean Water Act, eliminate SSOs, and fulfill the Pennsylvania and U.S. Environmental Protection Agency (USEPA) CSO Policy obligations, with facilities implemented by 2026. PWSA is moving forward with its Adaptive Management approach. PWSA has defined Adaptive Management as an iterative approach to decision-making and project implementation to meet overall regulatory requirements with opportunities to adjust decisions and projects in light of subsequent monitoring and assessment of projects, and learning and knowledge gained of the in-stream water quality and sewer system's performance.

- In fall 2015, the regulatory agencies issued Consent Orders and Agreements (COAs) to 82 municipalities in the ALCOSAN service area, which require evaluation by December 2017 of the effectiveness of source reduction and GI in reducing CSOs and SSOs. The City and PWSA received similar mandates through an USEPA Section 308 Information Requirement letter from the USEPA in January 2016.

Previous Wet Weather Studies

In its 2013 Wet Weather Feasibility Study Report (WWFS), PWSA recommended including a combination of GI and gray infrastructure, to capture and manage a significant amount of stormwater before it reaches the sewer system. PWSA submitted its WWFS to the regulatory agencies in July 2013. The WWFS outlined a five-phase program for reducing CSOs and eliminating SSOs. PWSA's WWFS included the four-year Adaptive Management Plan; improvements to existing infrastructure; increased conveyance capacity in 14 sewersheds for which PWSA's existing collection system could not adequately convey all typical year flows to the ALCOSAN interceptors; diversion structure modifications; and, outfall screen installations. The capital cost estimate was $170 million (2012 dollars) and most of the work (all except the work in the Saw Mill Run Basin) was planned to be implemented through 2026. This represented the increased conveyance needed within the 14 sewersheds. The approach assumed that all combined sewer flows would be conveyed to the ALCOSAN interceptors (generally with most outfalls controlled to a level of four overflows per year), and that the new regional tunnel planned by ALCOSAN (not included in PWSA's cost estimate) would be needed as additional conveyance and storage capacity to convey the combined sewage flows to the wastewater treatment plant.

In 2013, PWSA also prepared Greening the Pittsburgh Wet Weather Plan, which provided an approach to reviewing, recommending, and incorporating a plan for the implementation of GI technologies and policies into PWSA's Wet Weather Feasibility Study.

The PWSA Feasibility Study Draft Report was produced in October 2008, and the results presented were developed from combined sewage alternatives analyses from the CSO Long Term Control Plan project conducted from 2002 to 2008. CSO control alternatives for PWSA's outfalls were composed of gray infrastructure techniques such as a tunnel system, sewer separation, and subsurface storage. The total capital costs developed for the entire PWSA sewer system ranged from $1.43 billion to $1.58 billion, based on 2007 cost data. These capital costs escalated to 2016 dollars would be approximately $1.65 billion to $1.82 billion.

Purpose of This Study

The primary objectives of the City-Wide GI Assessment included:

1. Analyzing 30 combined sewersheds that are currently associated with the planned ALCOSAN plant capacity increase and new tunnel, to determine the site locations within the City, both public and private rights of way, which are most effective at capturing high volumes of stormwater runoff and are the most suitable for GI implementation. These locations are referred to as “high yield drainage areas” and City-Wide GI stormwater overlay maps were developed for these 30 priority sewersheds. The stormwater overlay, discussed in Section 3, is intended as a lens to guide and inform future capital improvement projects and urban planning decisions in the City.

   Analysis of the combined and sanitary sewersheds beyond the initial 30 sewersheds will be conducted, as needed, following completion of this City-Wide project, as part of PWSA’s Source Reduction Study scheduled to be completed by December 2017.

2. Outreach activities, in collaboration with the Mayor’s office, other City departments, municipal representatives, regional organizations, multi-municipal organizations, and others to collaborate and coordinate the GI Assessment work with other ongoing new and redevelopment and resilience initiatives. Numerous watersheds throughout the City are influenced by flows from other adjacent municipalities.

3. Evaluating the feasibility and cost-effectiveness of separating and daylighting streams that currently flow into the combined sewer system.

4. Identifying and quantifying the associated benefits of the identified GI implementation and stream daylighting to include:

   - Combined sewer overflow mitigation,
   - Flooding hazard mitigation at flood prone areas within the sewer system and local streams,
   - Opportunities to align urban planning initiatives with GI implementation, and,
   - Triple bottom line financial, socioeconomic, and environmental analysis.

   The overall objective is to consider “Green First”, that is, to develop a cost-effective use of GI technologies and to highlight the associated benefits compared to the sizing and performance of gray infrastructure options that have been considered.

Related Projects in the “Green First” Program

The City-Wide GI Assessment is a project that parallels the efforts of three other wet weather related projects that PWSA is implementing:

- Shadyside/A-22 Sewershed Flooding Solutions and GI Assessment – A detailed evaluation of the A-22 sewershed, a high priority sewershed because of chronic surface flooding, historical reported basement sewage backups, and the third largest CSO in the sewer system based on annual overflow volume. The analysis included evaluation of high yield stormwater locations to effectively manage or remove stormwater from the combined sewer system to reduce basement sewage backups and surface flooding, while also maximizing CSO reduction. Many of the analysis methodologies employed in the City-Wide project were tested and confirmed during the Shadyside/A-22 project.

- Saw Mill Run Integrated Watershed Management (IWM) project - An integrated approach that is utilizing a combination of “green, gray, and watershed-based” solutions to holistically address water quality issues in the entire Saw Mill Run Watershed, including combined sewer overflows, sanitary sewer overflows, nutrients, sediment, and the other pollutants impairing the watershed. This integrated approach has been demonstrated by other communities across the country to be more cost-effective than a “gray only” approach and can result in numerous additional TBL benefits to PWSA and the City. Pittsburgh is one of 12 municipalities that are part of the Saw Mill Run Watershed, so this approach includes a multi-municipal evaluation and implementation.

- Region Wide Source Reduction/GI Assessment - PWSA is encouraging and leading municipalities to join with them in conducting high yield priority analyses in the region, and implementing source reduction/GI demonstration projects in a select number of high yield locations. This approach was developed in response to Pennsylvania Department of Environmental Protection’s (PADEP) COAs issued to the 82 municipalities, and USEPA’s letter to PWSA, in which they all have obligations to evaluate the effectiveness of source reduction/GI in reducing CSOs and SSOs. Using the replicable processes and methodologies developed in this City-Wide project, the Region Wide approach will be an effective means of achieving the short-term goal of demonstrating the effectiveness of source reduction/GI techniques across municipal borders and in watersheds, and achieving the long-term goal of targeted source reduction/GI implementation to reduce CSOs and SSOs and positively influence water quality in the region.

The City of Pittsburgh is implementing or participating in related projects and initiatives, including Resilient Pittsburgh; 100 Resilient Cities network; Preliminary Resilience Assessment; Climate Action Plan; and, Pittsburgh Climate Initiative.

1. UP-FRONT PLANNING AND SEQUENCING

This section describes the planning and sequencing process followed to identify and select the priority sewersheds and associated areas for the City-Wide Green Infrastructure (GI) Assessment.

1.1 Review Background Information

The project team collected and reviewed numerous local and regional data sets, including:

- GIS information, including the existing sewer system, sewersheds, land uses, populations, topography, and Light Detection and Ranging (LIDAR) elevation survey data, planimetrics, demographics, stream inlet locations, catch basin inlet data, historical stream mapping, and planned and ongoing new and redevelopment sites.
- Historical hazard and public safety information for flooding locations.
- Previous reports including: Pittsburgh Water and Sewer Authority (PWSA)'s Wet Weather Feasibility Study (WWFS) report dated July 2013; Allegheny County Sanitary Authority (ALCOSAN)'s Wet Weather Plan (WWP) dated January 2013; PWSA's Feasibility Study Draft Report dated October 2008; ALCOSAN Starting at the Source Report dated August 2015; and, previous stream inflow studies.
- Urban planning activities across the City and connected municipalities, including planned projects from the Urban Redevelopment Authority (URA), City Planning, Pittsburgh Parks Conservancy, and other local neighborhoods.
- Seven basins' collection system hydrologic and hydraulic (H&H) models provided by ALCOSAN.

The collected information was compiled into geographic information system (GIS) shapefiles, where possible, and all of the data was used to inform the GI evaluation described in this report.

PWSA would like to acknowledge and thank the City Office of Emergency Management (OEMHS), URA, City Planning, PWSA GIS, 3 Rivers Wet Weather (3RWW), and ALCOSAN for their willingness to share information to support this assessment.

1.2 Identification of High Priority Areas for GI and Urban Planning Projects

The team evaluated candidate locations and opportunities for inclusion in the GI Assessment, and considered the following factors:

- One of the key focuses of the GI Assessment was to determine how GI could benefit combined sewer overflow (CSO) reduction. In reviewing the combined sewersheds and combined sewer outfalls that were considered priorities in past projects, a key resource was the ALCOSAN WWP report. This report described the proposed Recommended Plan for regional CSO reduction, and this Plan included a proposed regional tunnel with approximately 30 combined sewer outfalls connected to the proposed tunnel via conveyance conduits and drop shafts. ALCOSAN stated in their WWP (Section 10.4) that these combined sewer outfalls were selected to address the largest overflows by volume and also to provide an enhanced level of control to combined sewer overflows that are directly impacting sensitive areas.

In addition, there are multiple combined sewer regulators and outfalls that are in relative proximity to the combined sewer outfalls to be connected to the proposed tunnel, and they were identified in this study because they may potentially experience some degree of reduction because of the hydraulic improvements associated with the regional tunnel, or because of proposed regulator modifications that may direct more flow into the existing interceptors. There were 62 of these combined sewersheds identified.

Table 1-1 lists the 29 combined sewersheds tributary to the proposed tunnel, and 62 combined sewersheds, all of which were considered for inclusion in this GI Assessment study. For initial consideration, these 91 combined sewersheds were prioritized by annual CSO volume, defined as the annual volume of combined sewer overflow that is discharged in a typical year to the rivers through a combined sewer outfall, and is shown in Table 1-1.

- Top ten hazard and public safety mitigation areas across the City. The City provided a top ten list of the public safety hazard locations. Meetings were held with the City OEMHS to gather details and background information on each location. A detailed description of each location is provided in Section 4 of this report.
- Urban planning/redevelopment sites currently being considered by other stakeholders. Numerous meetings were held with the URA and other city planning stakeholder groups to learn about and identify ongoing or planned new and redevelopment within the City.
- Direct stream inflow locations to the combined sewer system:
  - Woods Run (8 locations)
  - Panther Hollow Stream and Lake
  - Spring Garden
  - Corks Run (2 locations)

  A detailed description of the stream inflow analysis is included in Section 5 of this report.

Figure 1-1 illustrates the locations of the above identified candidate opportunities.

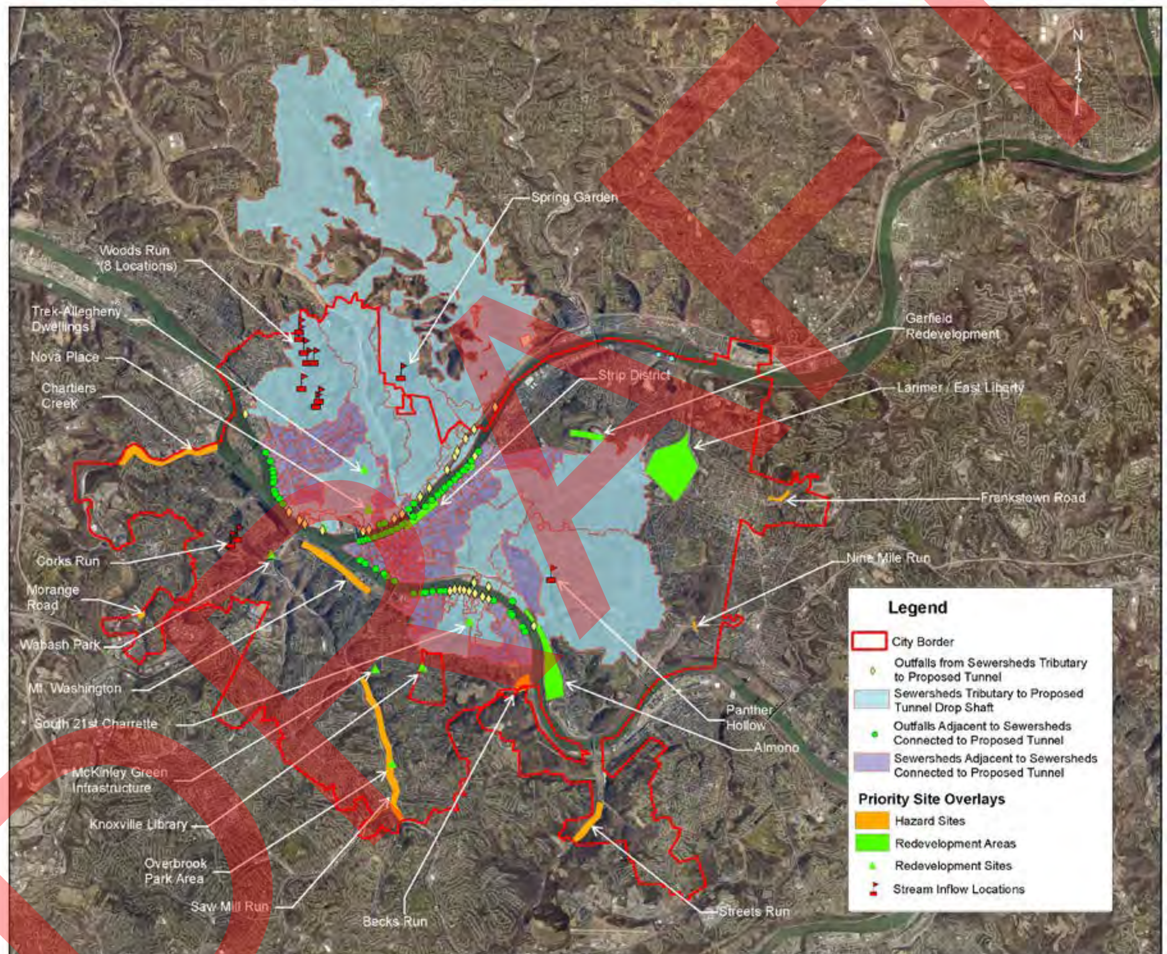

Figure 1-1: Identification of Candidate Areas for GI and Urban Planning Projects

TABLE 1-1
SUMMARY OF 91 COMBINED SEWERSHEDS EVALUATED FOR INCLUSION IN THE GI ASSESSMENT

Count	Outfall	Annual Overflow Volume (MG), Typical Year, from ALCOSAN WWP [1]	Basin
Sewersheds Tributary to Proposed Tunnel Drop Shafts			
1	A-22-OF	593	Main Rivers
2	M-29-OF	400	Main Rivers
3	A-60-OF	198	Main Rivers
4	M-19-OF	150	Main Rivers
5	A-67-OF	128	Lower Ohio/Girty's Run
6	M-16-OF	102	Main Rivers
7	O-27-OF	96.6	Main Rivers
8	A-58-OF	82.0	Main Rivers
9	A-48-OF	47.9	Main Rivers
10	A-66-OF [2]	34.4	Lower Ohio/Girty's Run
11	A-65-OF	19.8	Lower Ohio/Girty's Run
12	M-19B-OF	17.1	Main Rivers
13	O-41-OF	13.6	Main Rivers
14	M-21-OF	10.9	Main Rivers
15	A-62-OF	8.20	Lower Ohio/Girty's Run
16	O-39-OF	6.71	Main Rivers
17	M-22-OF	6.31	Main Rivers
18	A-61-OF	5.32	Main Rivers
19	M-15-OF	4.04	Main Rivers
20	A-64-OF	3.86	Lower Ohio/Girty's Run
21	M-20-OF	1.29	Main Rivers
22	A-56-OF	1.03	Main Rivers
23	A-47-OF	0.74	Main Rivers
24	M-15Z-OF	0.608	Main Rivers
25	M-18-OF	0.598	Main Rivers
26	O-43-OF	0.389	Main Rivers
27	M-17-OF	0.375	Main Rivers
28	A-63-OF [3]	0.158	Lower Ohio/Girty's Run
29	O-40-OF	0.127	Main Rivers
Total Overflow Volume from Sewersheds Tributary to Proposed Tunnel Drop Shafts		**1,933**	

TABLE 1-1
SUMMARY OF 91 COMBINED SEWERSHEDS EVALUATED FOR INCLUSION IN THE GI ASSESSMENT

Count	Outfall	Annual Overflow Volume (MG), Typical Year, from ALCOSAN WWP [1]	Basin
Sewersheds Adjacent to Sewersheds to be Connected to Proposed Tunnel			
1	M-19A-OF	84.5	Main Rivers
2	A-23-OF	56.0	Main Rivers
3	O-34-OF	38.1	Main Rivers
4	M-10-OF	29.2	Main Rivers
5	A-20-OF	23.1	Main Rivers
6	A-18-OF	20.0	Main Rivers
7	O-33-OF	19.3	Main Rivers
8	M-27-OF	19.2	Main Rivers
9	M-05-OF	19.0	Main Rivers
10	A-21-OF	18.5	Main Rivers
11	A-19X-OF	18.2	Main Rivers
12	A-14-OF	18.1	Main Rivers
13	M-26-OF	13.0	Main Rivers
14	A-51-OF	12.8	Main Rivers
15	O-32-OF	10.7	Main Rivers
16	O-38-OF	9.61	Main Rivers
17	M-03-OF	9.45	Main Rivers
18	A-50-OF	8.79	Main Rivers
19	A-12-OF	7.61	Main Rivers
20	A-17-OF	7.18	Main Rivers
21	M-12-OF	7.06	Main Rivers
22	A-19Z-OF	6.26	Main Rivers
23	A-19Y-OF	5.68	Main Rivers
24	A-16-OF	5.16	Main Rivers
25	O-36-OF	4.57	Main Rivers
26	A-59-OF	4.41	Main Rivers
27	A-09-OF	2.61	Main Rivers
28	A-15-OF	2.57	Main Rivers
29	M-14-OF	2.50	Main Rivers
30	A-04-OF	2.39	Main Rivers
31	M-13-OF	2.37	Main Rivers
32	A-01-OF	1.89	Main Rivers
33	A-10-OF	1.57	Main Rivers
34	A-07-OF	1.31	Main Rivers

TABLE 1-1
SUMMARY OF 91 COMBINED SEWERSHEDS EVALUATED FOR INCLUSION IN THE GI ASSESSMENT

Count	Outfall	Annual Overflow Volume (MG), Typical Year, from ALCOSAN WWP [1]	Basin
35	A-18X-OF	1.27	Main Rivers
36	M-11-OF	1.20	Main Rivers
37	A-59Z-OF	0.921	Main Rivers
38	M-01-OF	0.866	Main Rivers
39	O-37-OF	0.641	Main Rivers
40	M-24-OF	0.516	Main Rivers
41	A-49-OF	0.488	Main Rivers
42	A-05-OF	0.455	Main Rivers
43	A-13-OF	0.450	Main Rivers
44	O-35-OF	0.394	Main Rivers
45	A-11-OF	0.370	Main Rivers
46	M-04-OF	0.270	Main Rivers
47	A-18Z-OF	0.222	Main Rivers
48	M-23-OF	0.212	Main Rivers
49	O-31-OF	0.196	Main Rivers
50	M-02-OF	0.187	Main Rivers
51	A-18Y-OF	0.157	Main Rivers
52	M-12Z-OF	0.154	Main Rivers
53	A-08-OF	0.140	Main Rivers
54	A-14Z-OF	0.0762	Main Rivers
55	A-06-OF	0.0517	Main Rivers
56	O-29-OF	0.0455	Main Rivers
57	A-03-OF	0.0257	Main Rivers
58	A-02-OF	0.0224	Main Rivers
59	M-28-OF	0.00361	Main Rivers
60	A-20Z-OF	0	Main Rivers
61	M-04Z-OF	0	Main Rivers
62	O-30-OF	0	Main Rivers
Total Overflow Volume from Sewersheds Adjacent to Sewersheds Tributary to Proposed Tunnel		**502**	

[1] From ALCOSAN WWP, January 2013.
[2] The SWMM Model of Lower Ohio-Girty's Run Basin received from ALCOSAN in 2015 included A-66, so the City-Wide analysis included this sewershed. In 2016, PWSA received ALCOSAN information that the A-66 point of connection (POC) has been closed and the regulator has been sealed. Sanitary flows are directed to adjoining POCs.
[3] The SWMM Model of Lower Ohio-Girty's Run Basin received from ALCOSAN in 2015 included A-63, so the City-Wide analysis included this sewershed. It was found that this sewershed does not require GI to meet 85% combined sewage capture. In June 2016, PWSA received information from ALCOSAN that PennDOT's work on State Route 28 may have resulted in A-63 abandonment. ALCOSAN is working to confirm this with testing.

1.3 Final Selection of High Priority Sewersheds for Analysis

A workshop was held with PWSA staff to review the candidate opportunities for GI and urban planning discussed in Section 1.2. Each sewershed, new development and redevelopment location, flood hazard location, and direct stream inflow location was reviewed and discussed. The outcomes from the workshop identified the following areas of the City to focus on during the City-Wide GI Assessment:

- 30 combined sewersheds, which are listed in Table 1-2. Of the 29 sewersheds that are tributary to the proposed tunnel, shown in Table 1-1, 26 are in the list of selected high priority sewersheds. In addition, A-41, A-42, A-51, and M-19A were included in the selected high priority sewersheds. The 30 high priority sewersheds were selected to align with potential CSO reduction, flood hazards, and direct stream inflow locations across the City. These 30 high priority sewersheds account for just over 3 billion gallons (BG) of CSO discharge in a typical year (representing about one-third of the CSO discharge from the entire ALCOSAN service area).

  Most combined sewage in the 30 high priority sewersheds are generated within the City. Three of the sewersheds (A-42, A-60, and O-27) have contributing flows from other municipalities, but these flows are primarily sanitary flows.

- Of the 30 high priority sewersheds, six were selected for strategic urban planning opportunities. They were primarily selected to align with new and redevelopment initiatives in sewersheds estimated to have larger CSO volumes. These six sewersheds are:
  - M-29 sewershed, including Junction Hollow and Panther Hollow stream and Lake, with connection to the Monongahela River at Almono.
  - M-16 sewershed, including the South 21st Street Corridor and Southside Park and East Carson Street.
  - A-42 sewershed, including Negley Run and the, Washington Boulevard corridor, Larimer, and Homewood.
  - A-41 sewershed, including Heth's Run.
  - M-19 sewershed, including the Hill District & Uptown areas.
  - O-27 sewershed, including Woods Run.

- The top 10 largest direct stream inflows to the combined sewer system. A review of the associated dry and wet weather flows indicated that the locations below were the top 10 stream inflow contributors to the combined sewer system. Of the stream inflows considered, Corks Run has the lowest estimated volume of stream inflow, so it was not selected for this GI Assessment project. The ten stream inflow sites selected are:
  - Eight stream inflow points in the Woods Run watershed (8 locations)
  - Panther Hollow Stream and Lake
  - Spring Garden

- Top 10 City hazard locations, as identified by the City's Office of Emergency Management:
  - Calera Street – Streets Run
  - Morange Road – Chartiers Creek
  - Frankstown Avenue – Homewood
  - Commercial Street - Nine Mile Run
  - Susquehanna Street to East Carson Street - Becks Run
  - Library Road - Saw Mill Run
  - Saw Mill Run Boulevard
  - Route 28 and 31st Street Bridge
  - Mount Washington
  - Rear of Eggers Street

TABLE 1-2
SUMMARY OF 30 SELECTED HIGH PRIORITY COMBINED SEWERSHEDS

Count	Outfall	Wet Weather Combined Sewer Volume (MG)	Annual Overflow Volume (MG), Typical Year, from PWSA System Wide Model Run [1]
1	A-22-OF	1,594.8	580.5
2	A-41-OF	664.5	338.6
3	A-42-OF	2,175.9	783.0
4	A-58-OF	1,007.8	174.2
5	A-60-OF	801.5	209.8
6	A-61-OF	14.1	5.1
7	A-62-OF	8.3	8.4
8	A-65-OF	11.8	20.9
9	M-15-OF	7.9	4.6
10	M-16-OF	249.0	102.9
11	M-19-OF	265.9	146.0
12	M-19A-OF	318.2	83.5
13	M-19B-OF	75.5	17.0
14	M-21-OF	62.6	11.1
15	M-29-OF	1,426.3	402.0
16	O-39-OF	29.3	7.5
17	O-41-OF	33.3	14.5
18	O-40-OF	3.2	0.20
19	A-63-OF [2]	2.9	0.18
20	M-20-OF	13.4	1.7
21	M-18-OF	8.9	0.72
22	A-64-OF	30.3	4.0

TABLE 1-2
SUMMARY OF 30 SELECTED HIGH PRIORITY COMBINED SEWERSHEDS

Count	Outfall	Wet Weather Combined Sewer Volume (MG)	Annual Overflow Volume (MG), Typical Year, from PWSA System Wide Model Run [1]
23	M-17-OF	8.8	0.54
24	M-15Z-OF	10.4	0.61
25	A-47-OF	32.7	0.93
26	M-22-OF	72.0	6.5
27	A-51-OF	119.8	13.1
28	O-43-OF	35.3	0.16
29	A-48-OF	546.0	49.1
30	O-27-OF	696.9	79.6
	Total Volume	**10,327**	**3,067**

[1] Overflow volumes shown are from model runs conducted by PWSA with the system wide model developed from the seven models provided by ALCOSAN (Section 2 provides more discussion). There are slight differences between the overflow volumes for a particular sewershed in Table 1-1 and Table 1-2 due to the different model runs and software versions. These slight differences are acceptable in the modeling industry. Section 2 discusses additional information about modeling software and simulation methods.

[2] The SWMM Model of Lower Ohio-Girty's Run Basin received from ALCOSAN in 2015 included A-63, so the City-Wide analysis and evaluation included this sewershed. It was found that this sewershed does not require GI to meet 85% combined sewage capture. In June 2016, PWSA received information from ALCOSAN that PennDOT's work on State Route 28 may have resulted in A-63 abandonment. ALCOSAN is working to confirm this with testing.

Figure 1-2 displays the selected areas across the City that were evaluated as part of the City-Wide GI Assessment. Figure 1-3 provides greater detail about the locations of the 30 priority sewersheds.

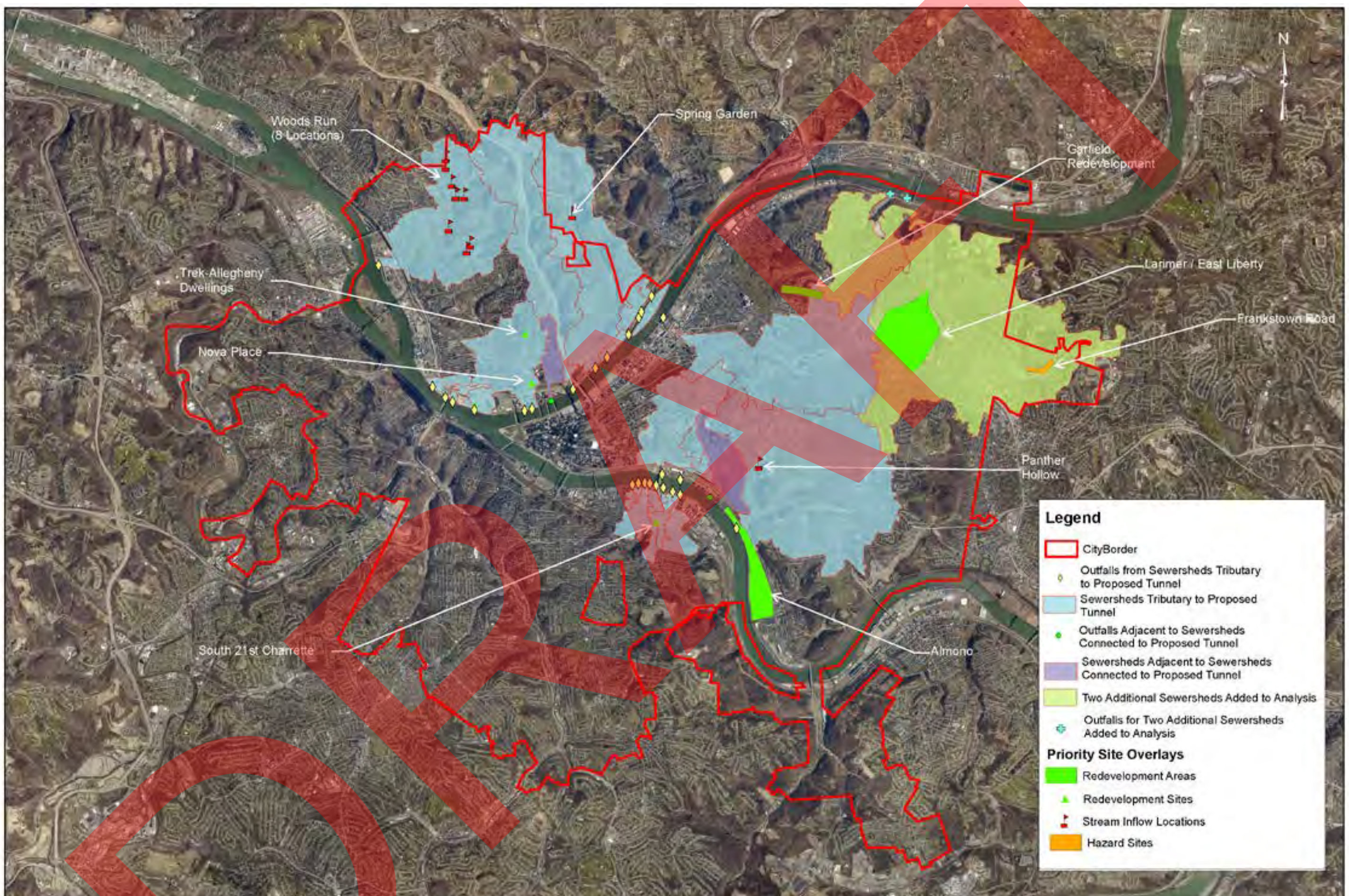

Figure 1-2: 30 Selected High Priority Combined Sewersheds for Analysis

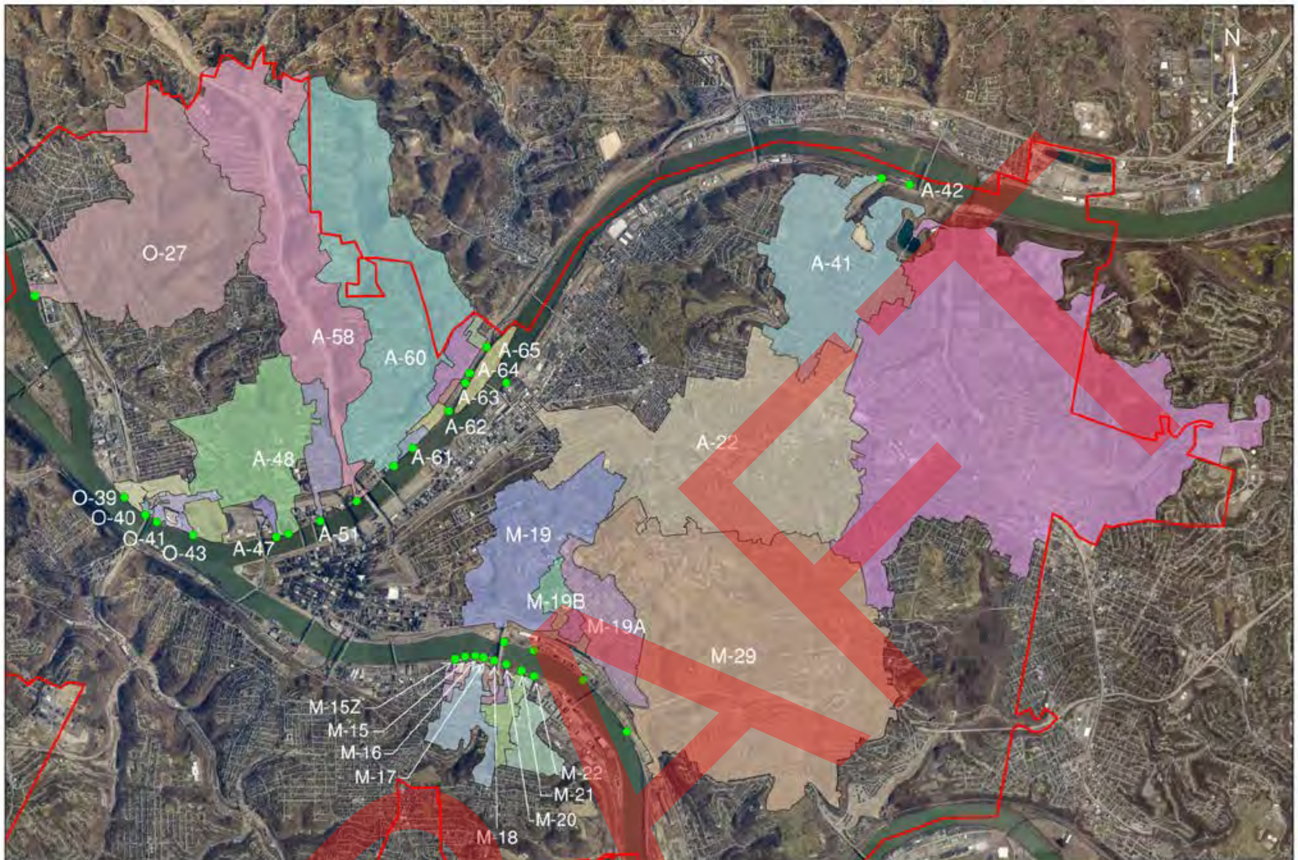

Figure 1-3: 30 Priority Sewersheds

With the high priority sewersheds and other focus areas identified for the GI Assessment, the associated H&H models and target areas for impervious area stormwater management were then reviewed and identified. Section 2 describes the method that was used to develop target GI management goals for the 30 high priority sewersheds. Sections 2 and 3 describe the H&H modeling process that was followed. Sections 4 and 5 of this report describe the detailed investigations and analysis performed for the flood hazard (Section 4) and the direct stream inflow locations (Section 5).

Section 6 introduces the strategic urban planning and GI opportunities as envisioned for six redevelopment initiatives within high priority sewersheds, and Section 7 presents the costing protocols, including the consideration of field investigations, constructability, and operation and maintenance cost development.

Section 8 presents results of the triple bottom line analysis conducted to look to additional environmental, social, and economic benefits.

The report concludes with a summary of the GI Program benefits in Section 9.

2. ESTABLISH TARGET GREEN INFRASTRUCTURE MANAGEMENT LEVEL GOALS

To establish combined sewer overflow (CSO) control targets for the 30 priority combined sewersheds evaluated during the City-Wide project, it was necessary to establish the baseline CSO performance and what influence other system factors, such as ALCOSAN'S Woods Run Wastewater Treatment Plant (WWTP) and ALCOSAN's existing interceptors, have on the potential performance of green infrastructure (GI) and the degree of GI investment needed to meet CSO control goals.

2.1 Review of Hydrologic and Hydraulic Models from ALCOSAN

At the initiation of the City-Wide GI Assessment, PWSA obtained the most up-to-date regional baseline hydrologic and hydraulic (H&H) models from ALCOSAN to use for this project. ALCOSAN uses EPA's SWMM software for H&H system modeling. ALCOSAN provided seven separate Basin-level models that reflected the way the system currently operates. The seven basin models included the following:

- Chartiers Creek
- Lower Ohio/Girty's Run
- Main Rivers
- Saw Mill Run
- Turtle Creek
- Upper Allegheny
- Upper Monongahela

Figure 2-1 shows the locations of the seven ALCOSAN planning basins as described in ALCOSAN's 2013 Wet Weather Plan, Section 3 Existing Conditions.

Rather than run the individual basin models in sequence, the seven basin models were compiled into a single comprehensive system wide model of the ALCOSAN modelled sewers (system model). This model allows seamless system hydraulic response to the applied flow conditions.

Each basin model uses an external inflow file that loads dry weather flow time series into the model at defined loading points. These time series were derived directly from flow monitoring performed by ALCOSAN and 3 Rivers Wet Weather (3RWW) in 2008-2009 as part of a large scale flow monitoring effort across the entire ALCOSAN service area. Since each basin model had an inflow file, the data from each was extracted and then reformatted to create a single inflow file to use with the system model. There were no changes to the time series data, loading point locations or rainfall input files. The conveyance and overflow system outputs from running the system model were similar to the results from the individual basin models.

Another difference between the ALCOSAN basin models and the PWSA-developed system wide model is the version of SWMM used. At the time the original ALCOSAN basin models were developed the then-current SWMM version was 5.0.013. The ALCOSAN basin models were all developed using this version and they have remained in that version to today. For the PWSA-developed system wide model, the current version of SWMM was used (5.1.009). This newer version is the most up-to-date and presumably most reliable version and also has GI modeling capabilities that the older 5.0.013 version does not. The GI modeling capabilities permit assessment of the peak flow rates resultant from stormwater detention and retention within both the combined and separated sewersheds.

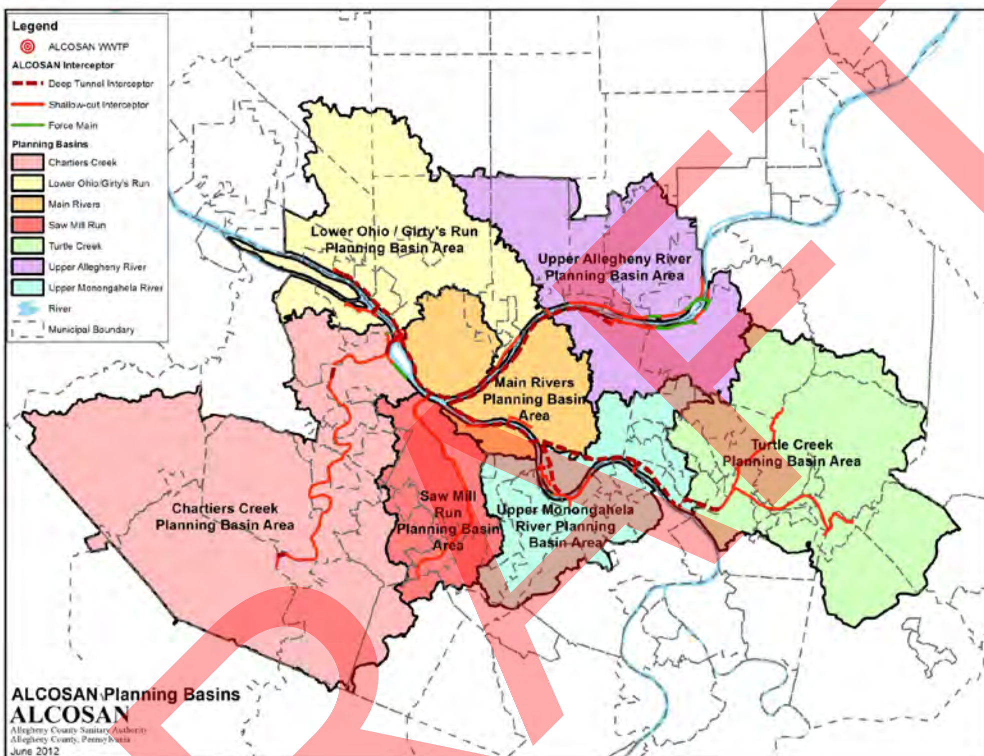

Figure 2-1: Locations of ALCOSAN Planning Basins, WWTP, and Interceptors
(Source: ALCOSAN Wet Weather Plan, 2013)

2.2 Quantify Existing Baseline Conditions and CSO Statistics

After PWSA developed the system wide model, it was used to simulate ALCOSAN's typical year flow conditions to calculate baseline CSO statistics. ALCOSAN uses a modified version of the precipitation measured during calendar year 2003 as their typical year (TY) and this analysis used the same precipitation data. Table 2-1 details the overflow volume results for the City-Wide project's 30 high priority sewersheds using values included in ALCOSAN's Wet Weather Plan (WWP) and updated overflow volumes calculated by the PWSA system wide model for the "typical year". With all of the accumulated software updates between these SWMM versions, some differences in the results were expected. The overflow volume differences are generally minor and the aggregate overflow volume difference between the two models is less than 1.0%. These comparative results are well within the acceptable range for comparable models.

However, it is important to note the differences between the ALCOSAN WWP results and this project's results. The A-41 and A-58 sewersheds each contain multiple outfalls which can discharge combined sewer flow, but the results in Table 2-1 only include the

A-41-OF and A-58-OF outfalls as per ALCOSAN's reporting. However, for subsequent analyses and tables, the total volume for the multiple outfalls is reported, resulting in a higher total volume. The existing conditions, typical year results including wet weather combined sewage flows, CSO volumes, and percent capture results for the system wide model are summarized in Table 2-2.

TABLE 2-1
SWMM VERSION AND MODEL INTEGRATION IMPACTS ON TYPICAL YEAR OVERFLOW VOLUMES

Sewershed	Overflow Volumes (MG)		Model Differences	
	ALCOSAN WWP (SWMM 5.0.013)	PWSA System Wide Model (SWMM 5.1.009)	Volume (MG)	% Difference
A-22-OF	593	580	-12.5	-2.1%
A-41-OF [1]	256	254	-1.7	-0.7%
A-42-OF	777	783	6.0	0.8%
A-47-OF	0.74	0.92	0.2	25.0%
A-48-OF	47.9	49.1	1.2	2.6%
A-51-OF	12.8	13.1	0.3	2.1%
A-58-OF [1]	82	72.8	-9.2	-11.2%
A-60-OF	198	210	11.8	5.9%
A-61-OF	5.32	5.10	-0.2	-4.0%
A-62-OF	8.20	8.41	0.2	2.6%
A-63-OF [2]	0.16	0.18	0.0	12.8%
A-64-OF	3.86	4.05	0.2	4.9%
A-65-OF	19.8	20.9	1.1	5.5%
M-15-OF	4.04	4.65	0.6	15.0%
M-15Z-OF	0.61	0.61	0.0	0.2%
M-16-OF	102	103	0.9	0.9%
M-17-OF	0.38	0.54	0.2	42.0%
M-18-OF	0.60	0.72	0.1	20.1%
M-19A-OF	84.5	83.5	-1.0	-1.2%
M-19B-OF	17.1	17.0	-0.1	-0.8%
M-19-OF	150	146	-4.0	-2.6%
M-20-OF	1.29	1.70	0.4	31.6%
M-21-OF	10.9	11.1	0.2	2.2%
M-22-OF	6.31	6.47	0.2	2.5%

TABLE 2-1 SWMM VERSION AND MODEL INTEGRATION IMPACTS ON TYPICAL YEAR OVERFLOW VOLUMES				
Sewershed	Overflow Volumes (MG)		Model Differences	
	ALCOSAN WWP (SWMM 5.0.013)	PWSA System Wide Model (SWMM 5.1.009)	Volume (MG)	% Difference
M-29-OF	400	402	2.0	0.5%
O-27-OF	96.6	79.6	-17.0	-17.6%
O-39-OF	6.71	7.48	0.8	11.5%
O-40-OF	0.13	0.20	0.1	51.3%
O-41-OF	13.6	14.5	0.9	6.9%
O-43-OF	0.39	0.15	-0.2	-60.3%
Totals	**2,900**	**2,881**	**-18.7**	**-0.6%**

[1] Includes one outfall only.

[2] The SWMM Model of Lower Ohio-Girty's Run Basin received from ALCOSAN in 2015 included A-63, so the City-Wide analysis included this sewershed. It was found that this sewershed does not require GI to meet 85% combined sewage capture. In June 2016, PWSA received information from ALCOSAN that PennDOT's work on State Route 28 may have resulted in A-63 abandonment. ALCOSAN is working to confirm this with testing.

Table 2-2 CSO Statistics for 30 High Priority Sewersheds, Typical Year, Existing Conditions						
Sewershed	Combined Flow Volume (MG)				85% Combined Flow Capture Goal (MG)	
	Inflow to Regulator	Underflow to WWTP	Overflow (CSO)	% WW Capture	CSO Volume Target	Additional CSO Capture Needed
A-22-OF	1,594.8	1,014.3	580.5	63.6%	240.0	340.5
A-41-OF [1]	664.5	325.9	338.6	49.1%	87.0	251.6
A-42-OF	2,175.9	1,392.9	783.0	64.0%	326.4	456.6
A-47-OF	32.7	31.8	0.9	97.2%	4.9	0
A-48-OF	546.0	496.9	49.1	91.0%	81.9	0
A-51-OF	119.8	106.7	13.1	89.1%	18.0	0
A-58-OF [1]	1,007.8	833.6	174.2	82.7%	151.2	23.0
A-60-OF	801.5	591.7	209.8	73.8%	120.2	89.6
A-61-OF	14.1	9.0	5.1	63.8%	2.1	3.0
A-62-OF	8.3	-0.1	8.4	-1.3%	1.2	7.2

Table 2-2
CSO Statistics for 30 High Priority Sewersheds, Typical Year, Existing Conditions

Sewershed	Combined Flow Volume (MG)				85% Combined Flow Capture Goal (MG)	
	Inflow to Regulator	Underflow to WWTP	Overflow (CSO)	% WW Capture	CSO Volume Target	Additional CSO Capture Needed
A-63-OF [2]	2.9	2.7	0.2	93.8%	0.4	0
A-64-OF	30.3	26.3	4.0	86.6%	4.6	0
A-65-OF	11.8	-9.1	20.9	-77.1%	1.8	19.1
M-15-OF	7.9	3.3	4.6	41.2%	1.2	3.4
M-15Z-OF	10.4	9.8	0.6	94.1%	1.6	0
M-16-OF	249.0	146.1	102.9	58.7%	37.4	65.5
M-17-OF	8.8	8.3	0.5	93.9%	1.3	0
M-18-OF	8.9	8.2	0.7	91.9%	1.3	0
M-19A-OF	318.2	234.7	83.5	73.8%	47.7	35.8
M-19B-OF	75.5	58.5	17.0	77.5%	11.3	5.7
M-19-OF	265.9	119.9	146.0	45.1%	39.9	106.1
M-20-OF	13.4	11.7	1.7	87.3%	2.0	0
M-21-OF	62.6	51.5	11.1	82.2%	9.4	1.7
M-22-OF	72.0	65.5	6.5	91.0%	10.8	0
M-29-OF	1,426.3	1,024.3	402.0	71.8%	213.9	188.1
O-27-OF	696.9	617.3	79.6	88.6%	104.5	0
O-39-OF	29.3	21.8	7.5	74.5%	4.4	3.1
O-40-OF	3.2	3.0	0.2	93.9%	0.5	0
O-41-OF	33.3	18.8	14.5	56.3%	5.0	9.5
O-43-OF	35.3	35.1	0.2	99.6%	5.3	0
Totals	**10,327**	**7,260**	**3,067**	**70.3%**	**1,537**	**1,609**

[1] Reflects all outfalls in the sewershed.
[2] The SWMM Model of Lower Ohio-Girty's Run Basin received from ALCOSAN in 2015 included A-63, so the City-Wide analysis included this sewershed. It was found that this sewershed does not require GI to meet 85% combined sewage capture. In June 2016, PWSA received information from ALCOSAN that PennDOT's work on State Route 28 may have resulted in A-63 abandonment. ALCOSAN is working to confirm this with testing.

The columns in Table 2-2 are defined as follows:

- **Inflow to Regulator** represents the total combined sewage flow during the typical year that is influent to the regulator or diversion structure during the "wet weather windows". The "wet weather windows" are portions of where the influent hydrograph to the diversion structure deviates from the expected dry weather flow in response to rainfall. The end of the window is when the influent hydrograph returns back to within 5% of the typical dry weather flow. The starting or ending times of the "wet weather windows" may be adjusted to ensure that all overflow occurs within these windows. The inflow represents the entire flow volume within the starting and stopping times of the "wet weather window" and then summed for the entire typical year.
- **Underflow to WWTP** is the total combined sewage flow within the "wet weather windows" that is conveyed to the interceptors and eventually to the WWTP.
- **Overflow (CSO)** is the total flow within the "wet weather windows" that is diverted at the regulator or diversion structure through an outfall pipe and discharged to receiving waters.
- **% Wastewater Capture** is calculated as the underflow divided by the inflow and it represents the portion of the flow that stays in the sewer system for conveyance to the WWTP.
- **CSO Volume Target** is the CSO discharge reduction needed for a sewershed to achieve 85% combined sewage capture.
- **Additional CSO Capture Needed** is the additional amount that the existing conditions CSO volume needs to be reduced to meet the 85% combined sewage capture target. If this column is blank it means that 85% combined sewage capture is already achieved under existing conditions and no further reduction is needed.

Figure 2-2 graphically depicts the various flow components listed in Table 2-2.

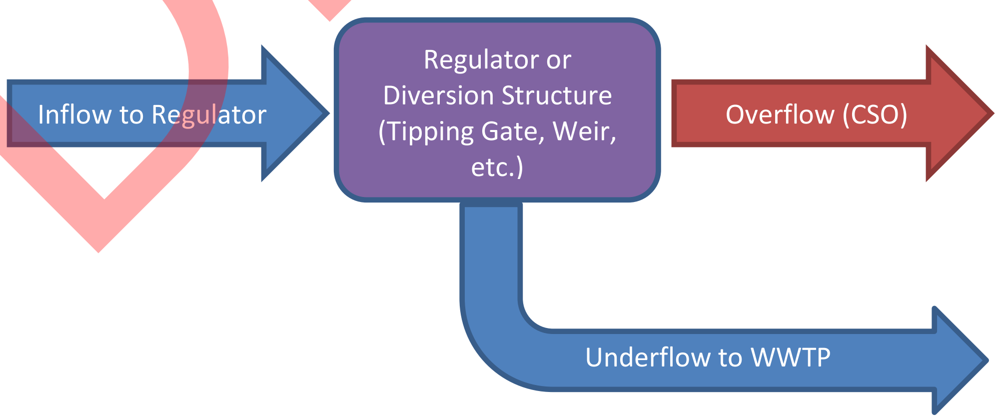

Figure 2-2: Illustration of Combined Sewage Flow Components

The 30 high priority sewersheds account for just over 3 BG of CSO discharge, which represents about one-third of the overflow discharge from the entire collection system tributary to the ALCOSAN conveyance and treatment system. Sewersheds that have negative percent captures indicate situations where CSOs are influenced by either reverse flows or other interconnected CSOs.

2.3 Impervious Surface Reduction Analysis

The GI Assessment approach was to evaluate the potential volume of GI stormwater management needed to meet specific performance and regulatory goals across the 30 high priority sewersheds. The number of GI Best Management Practices (BMPs) to be deployed was based on the necessary impervious area runoff managed by GI within each sewershed, and simply defined as "GI investment". Impervious areas are defined as areas that allow all or a significant portion of the precipitation that falls on them to run off the ground (topographic) surface into entry points in the collection system or to adjacent pervious areas. Impervious areas include rooftops, sidewalks, driveways, parking lots, impervious solids and rock, and streets, unless specifically designed, constructed, and maintained to prevent or control runoff.

The EPA's CSO Control Policy requires at least 85% combined sewage capture be achieved within combined sewer systems as part of a CSO long-term control plan. For this project 85% capture was the target selected for the GI Assessment, as it is consistent with the CSO Control Policy and other approved long term control plans across the United States. The existing ALCOSAN WWP was developed assuming a standard of no more than four overflows per year at each combined sewer outfall. This 85% combined sewage capture target is not meant to presume a final level of control for the region's CSOs, but simply to define a target that has been required as a presumptive compliance goal for other cities like Pittsburgh. This approach allows flexibility to scale the eventually required amount of GI investment, in conjunction with necessary gray infrastructure, to meet whatever CSO target is ultimately agreed upon with regulators.

2.3.1 Development of Scenarios to Define Range of GI that May be Required

To define the range of GI implementation that will need to be implemented in the 30 high priority sewersheds to meet the 85% combined sewage capture goal, it was necessary to conduct an analysis to determine a minimum amount of GI and a maximum amount of GI (to be expressed as acres of impervious area management) to meet the 85% goal. It was anticipated that the capacities of the ALCOSAN interceptors and WWTP will both influence the degree of GI needed to meet the goal, so an understanding of ALCOSAN existing infrastructure and expansion plans was derived from ALCOSAN's 2013 Wet Weather Plan report. As part of their Recommended Plan, ALCOSAN plans to increase the WWTP treatment capacity to 480 million gallons per day (MGD). ALCOSAN considered other alternatives involving a WWTP treatment capacity increase to 600 MGD, but those were not recommended.

ALCOSAN's actions are anticipated to have an impact on overall conveyance system performance and ultimately the amount of GI required to achieve an 85% combined sewage capture goal. On the basis of existing information, four scenarios were developed for H&H modeling simulations to determine the degree to which existing and potential future infrastructure can influence the amount of GI that would need to be implemented to achieve the 85% combined sewage capture goal. The scenarios attempted to estimate the most hydraulically favorable conditions for existing infrastructure, but these scenarios have not been evaluated for feasibility. The scenario with the most hydraulically favorable condition for existing infrastructure essentially represents the minimum level of GI that would need to be implemented to meet the 85% combined sewage capture goal. Conversely, the existing condition scenario represents the maximum level of GI that would need to be implemented to meet the goal. Four system configuration scenarios were identified as described in Table 2-3, and these conditions were simulated with the H&H model.

Table 2-3
Various System Configurations Evaluated to Determine GI Sensitivity

Existing Conditions	This represents the current state of the conveyance system and the WWTP treatment capacity. The WWTP has a 250 MGD treatment capacity and its influent pump station wet well operates at a hydraulic grade line (HGL) level of 670 feet. The existing interceptors have the sediment levels as defined in the current ALCOSAN model.
480 MGD (WWTP Expansion)	This system state is the same as the existing conditions, except the capacity of the WWTP has been expanded to 480 MGD and its operating wet well HGL level reduced to 660 feet.
600 MGD (WWTP Expansion & System Improvements)	This system state is the same as the existing conditions, except the capacity of the WWTP has been expanded to 600 MGD and its operating wet well HGL level reduced to 660 feet. Also, the existing interceptors are modeled with their sediment removed to maximize wastewater conveyance to the WWTP and regulator structures for 19 of the 30 high priority sewersheds have modified tipping gate settings to allow more flow to enter the interceptors.
Lowered HGL Operation During Wet Weather Conditions	This system state represents an attempt to maximize the performance of the existing infrastructure. This alternative is not currently planned to be implemented by ALCOSAN. In this scenario, the WWTP is modeled as a free outfall to represent lowering the water level at the existing pump station during wet weather conditions such that it is below the crown of the connecting deep tunnel. This provides for the existing conveyance capacity to be maximized. This scenario also assumes that the necessary high rate treatment infrastructure is constructed at the WWTP to process any flows above 600 MGD (modeling results indicate peak flows at or above 600 MGD occur 29 hours in a typical year). The necessary infrastructure to accomplish this scenario is discussed in Section 3.3. The technical feasibility of all potential treatment plant wet weather capacity scenarios is currently under discussion between PWSA and ALCOSAN. The existing interceptors are modeled with their sediment removed and regulator structures for 19 of the 30 high priority sewersheds have modified tipping gate settings to allow more flow to enter the interceptors.

Table 2-4 lists the annual CSO and SSO discharges from the entire ALCOSAN service area (including municipal CSO and SSO discharges) for these four system configurations. The model allows calculation of overflow reductions and assessment of differing and required levels of GI implementation only within the 30 sewersheds based upon the system-wide calculation of flows.

TABLE 2-4
SYSTEM CONFIGURATION SUMMARY OF TYPICAL YEAR DISCHARGES

System Configuration	System-Wide Annual CSO and SSO Discharge Volume
Existing Conditions	10.2 Billion Gallons (BG) [1]
480 MGD (WWTP Expansion) [2]	7.3 BG
600 MGD (WWTP Expansion & System Improvements) [2]	6.0 BG
Lowered HGL Operation During Wet Weather Conditions [2]	5.5 BG

[2] The technical feasibility of all potential treatment plant wet weather capacity scenarios is currently under discussion between PWSA and ALCOSAN.

2.3.2 Impervious Surface Overflow Reduction Results

After simulating the system model to evaluate the different configurations listed in Table 2-4, it became apparent that the WWTP and interceptor conveyance system exert a significant impact on the GI investment necessary to meet the 85% wet weather capture goal across the 30 high priority sewersheds. Table 2-5 compares the required directly connected impervious area (DCIA) whose runoff must be removed from the system vs. the DCIA whose runoff must be managed by GI to reach the 85% wet weather control goal. The results for the 480 MGD and Lowered HGL Operation During Wet Weather Conditions scenarios are presented to show the range of resulting impervious area to be managed. All zero entries in Table 2-5 indicate a sewershed already achieves the 85% wet weather control goal and no GI is needed. Table 2-5 is further explained below:

- **Total DCIA** represents the impervious area that directly connects to the collection system. Examples of DCIA would include paved roadways where runoff is directed to storm grates where the flow enters the collection system. In the SWMM model, DCIA represents the impervious surfaces that contribute flow to the sewer system. Some impervious surface such as paved driveways that drain to the backyard of a house do not directly contribute flow to the collection

[1] The ALCOSAN WWP indicates a current system-wide overflow volume (CSO and SSO) of 9.67 BG. The difference between the 10.2 BG and 9.67 BG is that ALCOSAN subtracts the separated stormwater overflows (which are regulated differently by regulators) from CSO volumes to derive the reported combined sewer overflow volume. The numbers have also been adjusted to SWMM 5.0.013 for consistency with numbers previously reported by ALCOSAN.

system and although they are impervious surfaces they are not part of the model's runoff calculations.

- **DCIA Removed** represents the DCIA acres whose runoff needs to be completely removed from the collection system for a sewershed to reach the 85% wet weather capture target. This analysis was done to provide an estimate of the DCIA managed by GI acres that would be needed to reach the same goal.
- **DCIA Managed by GI** represents the DCIA acres that must be managed by GI elements in the SWMM model to achieve the 85% wet weather capture goal. The GI elements collect and slowly release runoff rather than removing it, so more DCIA acres must be managed than if the flow was completely removed from the collection system.

Table 2-6 is similar to Table 2-5, but it compares the minimum DCIA that must be managed by GI to the level of GI that is used for all of the City-Wide alternatives. If the GI managed acres are greater than the minimum required for 85% wet weather capture, it is for one of the following reasons:

- The sewershed is being targeted for potential urban planning improvements and GI managed acres were added to evaluate the level of untreated overflow reduction that may be possible.
- The sewershed had high influent flow volumes (wet weather inflow) to the diversion structure and it was determined that some GI investment was warranted to reduce the high wet weather inflows.
- GI was added to certain sewersheds to help reduce potential localized surface flooding and basement sewage backups during wet weather events. These potential areas were revealed by examining the HGLs of the primary interceptor sewers in the sewershed. The GI was added with the understanding that this would also contribute to CSO reduction.
- For the A-22 sewershed, the percentage of DCIA managed by GI was set to 30%. This level of GI investment was previously determined during an earlier study focused on reducing localized surface flooding and basement sewage backups in the A-22 sewershed.

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TABLE 2-5
DCIA REMOVED VS. DCIA MANAGED BY GI 85% WW CAPTURE (EACH SEWERSHED)

Sewershed	Total DCIA (acres)	480 MGD (WWTP Expansion)				Lowered HGL Operation During Wet Weather Conditions			
		DCIA Removed		DCIA GI Managed		DCIA Removed		DCIA GI Managed	
		%	Acres	%	Acres	%	Acres	%	Acres
A-22-OF	898.0	42.5%	382.0	43.0%	386.1	7.0%	62.9	7.0%	62.9
A-41-OF	234.7	75.0%	176.0	85.0%	199.5	57.0%	133.8	60.0%	140.8
A-42-OF	839.7	72.6%	609.3	73.0%	613.0	47.0%	394.7	58.0%	487.0
A-47-OF	9.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-48-OF	167.1	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-51-OF	34.6	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-58-OF	151.7	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-60-OF	175.2	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-61-OF	10.7	37.6%	4.0	37.0%	4.0	0.0%	0.0	0.0%	0.0
A-62-OF	5.7	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-63-OF [1]	1.0	0.0%	0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-64-OF	18.4	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-65-OF	4.6	14.0%	0.6	15.0%	0.7	0.0%	0.0	0.0%	0.0
M-15-OF	3.7	65.3%	2.4	65.0%	2.4	0.0%	0.0	0.0%	0.0
M-15Z-OF	3.1	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-16-OF	100.0	75.0%	75.0	85.0%	85.0	0.0%	0.0	0.0%	0.0
M-17-OF	6.2	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-18-OF	5.1	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-19A-OF	142.6	40.2%	57.3	41.0%	58.5	35.0%	49.9	35.0%	49.9
M-19B-OF	32.1	27.6%	8.9	28.0%	9.0	33.0%	10.6	33.0%	10.6

TABLE 2-5
DCIA REMOVED VS. DCIA MANAGED BY GI 85% WW CAPTURE (EACH SEWERSHED)

Sewershed	Total DCIA (acres)	480 MGD (WWTP Expansion)				Lowered HGL Operation During Wet Weather Conditions			
		DCIA Removed		DCIA GI Managed		DCIA Removed		DCIA GI Managed	
		%	Acres	%	Acres	%	Acres	%	Acres
M-19-OF	119.1	55.2%	65.7	55.0%	65.5	0.0%	0.0	0.0%	0.0
M-20-OF	6.2	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-21-OF	29.2	8.0%	2.3	8.0%	2.3	0.0%	0.0	0.0%	0.0
M-22-OF	16.4	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-29-OF	362.3	60.1%	217.7	60.0%	217.4	0.0%	0.0	0.0%	0.0
O-27-OF	195.6	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
O-39-OF	23.8	21.0%	5.0	21.0%	5.0	0.0%	0.0	0.0%	0.0
O-40-OF	2.8	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
O-41-OF	27.9	55.8%	15.6	56.0%	15.6	47.0%	13.1	56.0%	15.6
O-43-OF	9.8	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
Totals	**3,636**	**44.6%**	**1,622**	**45.8%**	**1,664**	**18.3%**	**665**	**21.1%**	**767**

[1] The SWMM Model of Lower Ohio-Girty's Run Basin received from ALCOSAN in 2015 included A-63, so the City-Wide analysis included this sewershed. It was found that this sewershed does not require GI to meet 85% combined sewage capture. In June 2016, PWSA received information from ALCOSAN that PennDOT's work on State Route 28 may have resulted in A-63 abandonment. ALCOSAN is working to confirm this with testing.

Table 2-6: DCIA Managed by GI (85% WW Capture each sewershed vs. City-Wide Alternatives)									
Sewershed	Total DCIA (acres)	480 MGD (WWTP Expansion)				Lowered HGL Operation During Wet Weather Conditions			
		85% WW Capture		CityWide Alternatives		85% WW Capture		CityWide Alternatives	
		%	Acres	%	Acres	%	Acres	%	Acres
A-22-OF	898.0	43.0%	386.1	43.0%	387.7	7.0%	62.9	30.0%	271.0
A-41-OF	234.7	85.0%	199.5	85.0%	199.5	60.0%	140.8	60.0%	140.8
A-42-OF	839.7	73.0%	613.0	73.0%	614.10	58.0%	487.0	58.0%	485.1
A-47-OF	9.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-48-OF	167.1	0.0%	0.0	25.0%	41.8	0.0%	0.0	25.0%	41.8
A-51-OF	34.6	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-58-OF	151.7	0.0%	0.0	25.0%	37.9	0.0%	0.0	25.0%	37.9
A-60-OF	175.2	0.0%	0.0	25.0%	43.8	0.0%	0.0	25.0%	43.8
A-61-OF	10.7	37.0%	4.0	37.0%	4.0	0.0%	0.0	0.0%	0.0
A-62-OF	5.7	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-63-OF [1]	1.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-64-OF	18.4	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-65-OF	4.6	15.0%	0.7	15.0%	0.7	0.0%	0.0	0.0%	0.0
M-15-OF	3.7	65.0%	2.4	65.0%	2.4	0.0%	0.0	0.0%	0.0
M-15Z-OF	3.1	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-16-OF	100.0	85.0%	85.0	85.0%	85.0	0.0%	0.0	25.0%	25.2
M-17-OF	6.2	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-18-OF	5.1	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-19A-OF	142.6	41.0%	58.5	41.0%	58.4	35.0%	49.9	35.0%	49.9
M-19B-OF	32.1	28.0%	9.0	28.0%	9.0	33.0%	10.6	33.0%	10.6

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Table 2-6: DCIA Managed by GI (85% WW Capture each sewershed vs. City-Wide Alternatives)									
Sewershed	Total DCIA (acres)	480 MGD (WWTP Expansion)				Lowered HGL Operation During Wet Weather Conditions			
		85% WW Capture		CityWide Alternatives		85% WW Capture		CityWide Alternatives	
		%	Acres	%	Acres	%	Acres	%	Acres
M-19-OF	119.1	55.0%	65.5	55.0%	65.7	0.0%	0.0	25.0%	29.8
M-20-OF	6.2	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-21-OF	29.2	8.0%	2.3	8.0%	2.3	0.0%	0.0	0.0%	0.0
M-22-OF	16.4	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-29-OF	362.3	60.0%	217.4	60.0%	217.7	0.0%	0.0	25.0%	90.5
O-27-OF	195.6	0.0%	0.0	22.0%	43.7	0.0%	0.0	22.0%	43.7
O-39-OF	23.8	21.0%	5.0	21.0%	5.1	0.0%	0.0	0.0%	0.0
O-40-OF	2.8	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
O-41-OF	27.9	56.0%	15.6	56.0%	15.6	56.0%	15.6	56.0%	15.6
O-43-OF	9.8	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
Totals	**3,636**	**45.8%**	**1,664**	**50.3%**	**1,835**	**21.1%**	**767**	**35.3%**	**1,286**

[1] The SWMM Model of Lower Ohio-Girty's Run Basin received from ALCOSAN in 2015 included A-63, so the City-Wide analysis included this sewershed. It was found that this sewershed does not require GI to meet 85% combined sewage capture. In June 2016, PWSA received information from ALCOSAN that PennDOT's work on State Route 28 may have resulted in A-63 abandonment. ALCOSAN is working to confirm this with testing.

Examining the results in Table 2-5 and Table 2-6 reveal several important insights:

- As expected, the DCIA whose runoff is managed by GI is somewhat greater (3% to 15% increase) than the DCIA whose runoff must be removed from the system to meet the 85% wet weather capture goal. This relatively small difference is partly explained because approximately 50% of the runoff in the GI management scenario infiltrates and is removed from the system while it is being detained before it is discharged back to the system. So, even the GI managed scenario removes a significant portion of the DCIA runoff.
- Under the 480 MGD (WWTP expansion) scenario, it was determined that approximately 46% of the existing impervious surface area (1,664 acres) would need to managed by GI within the 30 high priority sewersheds for each sewershed to meet the 85% wet weather capture target. For the reasons described previously in this section, a total of 1,835 impervious acres was selected to carry forward for further analysis.
- Under the Lowered HGL Operation During Wet Weather Conditions scenario, approximately 770 impervious acres would need to be managed by GI for each sewershed to meet the 85% wet weather capture target. This represents just over 21% of the total impervious area within the 30 priority sewersheds. For the reasons described previously in this section, a total of 1,286 impervious acres was selected to carry forward for further analysis.

The 600 MGD scenario (WWTP Expansion & System Improvements) is not included in Tables 2-5 and 2-6 because it is considered to be an incremental improvement beyond the 480 MGD alternative. It is included in the GI modeling results described in Section 3.

2.3.3 Project Benefits

Applying the above described approach results in the following benefits to achieving the goals of the City-Wide project:

- Enables informed discussion of the relative merits of conveyance and WWTP investments vs. GI investments and how the performance of those investments mutually interact.
- Defines a potential range of expected GI investment, rather than a single cost associated with a particular overflow reduction volume assumption.
- Allows for an understanding of offsetting costs (higher GI costs with lower conveyance and WWTP capacities costs vs. lower GI costs with higher conveyance and WWTP capacities costs) when developing integrated green-gray plans.

The results of this analysis were used to inform the detailed GI modeling simulations as described in Section 3 and subsequent overflow reduction results and cost estimates as described in Section 9 of this report.

3. GREEN INFRASTRUCTURE MODELING APPROACH USING GIS AND SWMM

This section describes the process used for modeling the performance of green infrastructure (GI) for stormwater management, and resultant combined sewer overflow (CSO) reductions within the 30 high priority sewersheds. Section 3.1 details the process for selecting the highest yield stormwater capture locations for GI placement using ArcGIS software. Section 3.2 outlines how the selected high yield stormwater capture locations were then integrated into SWMM hydrologic and hydraulic (H&H) modeling software (v5.1.009) and modeled for GI performance using the SWMM low impact development (LID) Tool. Specific GI sizing criteria, subsurface infiltration, and underdrain model representation are also discussed in Section 3.2. A summary of the CSO benefits are then presented in Section 3.3. The results presented within this section demonstrate the performance of GI using a conservative infiltration rate assumption and a capture and slow release back into the combined sewer system (CSS) methodology that would most likely be implemented in most areas throughout the CSS.

3.1 Identification of Target Green Infrastructure Locations Using GIS

The first step in determining the high yield GI locations was to identify the areas where the greatest volume of stormwater runoff enters the CSS through mapped PWSA drainage inlet locations. These areas were considered to be the "highest yield" target opportunities for GI, and were determined using the following tools and procedures. Stormwater runoff drainage areas to each PWSA inlet were determined by creating a surface level hydrologic model to represent the 30 high priority sewersheds. The surface level hydrologic model was created using the ESRI based Arc Hydro Data Model and existing GIS data from PWSA, ALCOSAN, and publicly available data from the Pennsylvania Spatial Data Access. The existing GIS data used to create the surface level hydrologic model is summarized in Table 3-1.

TABLE 3-1
ARC HYDRO DATA OVERVIEW

Data	Description	Source	Year
Digital Elevation Model	LiDAR-derived rasters with one meter cell size	Pennsylvania Spatial Data Access	2006
Breaklines	Polyline defining boundaries for roads, bridges, parcels, and water bodies	Pennsylvania Spatial Data Access	2006
Building Footprints	Polygons of footprints of buildings, houses, and other structures	Pennsylvania Spatial Data Access	2013
Allegheny County Parking Areas	Polygons of parking lot areas in Allegheny County	Allegheny County Division of Computer Services	2000
City of Pittsburgh Drainage Inlets	Point file of grate drainage inlets within the City of Pittsburgh boundary	Pittsburgh Water and Sewer Authority	2008
SWMM Sewershed Boundaries	Polygons of sewershed boundaries based on CSO outfalls	Allegheny County Sanitary Authority	N/A

Using the surface level hydrologic model, the contributing drainage area of each PWSA known stormwater drainage inlet location within the 30 high priority sewersheds was delineated based on the surface topography. As an example, the delineated drainage areas for the PWSA inlets within the A-22 sewershed are shown in Figure 3-1. This figure illustrates the delineated PWSA inlet drainage areas (blue areas) overlain on the 2006 Digital Elevation Model (in shades of grey); the lighter the grey shade shown equals a higher elevation in the digital elevation model. It should also be noted that the black area in the middle of the figure clearly delineates the location of the historic stream valley before being filled in (current location of existing trunk combined sewer and Busway).

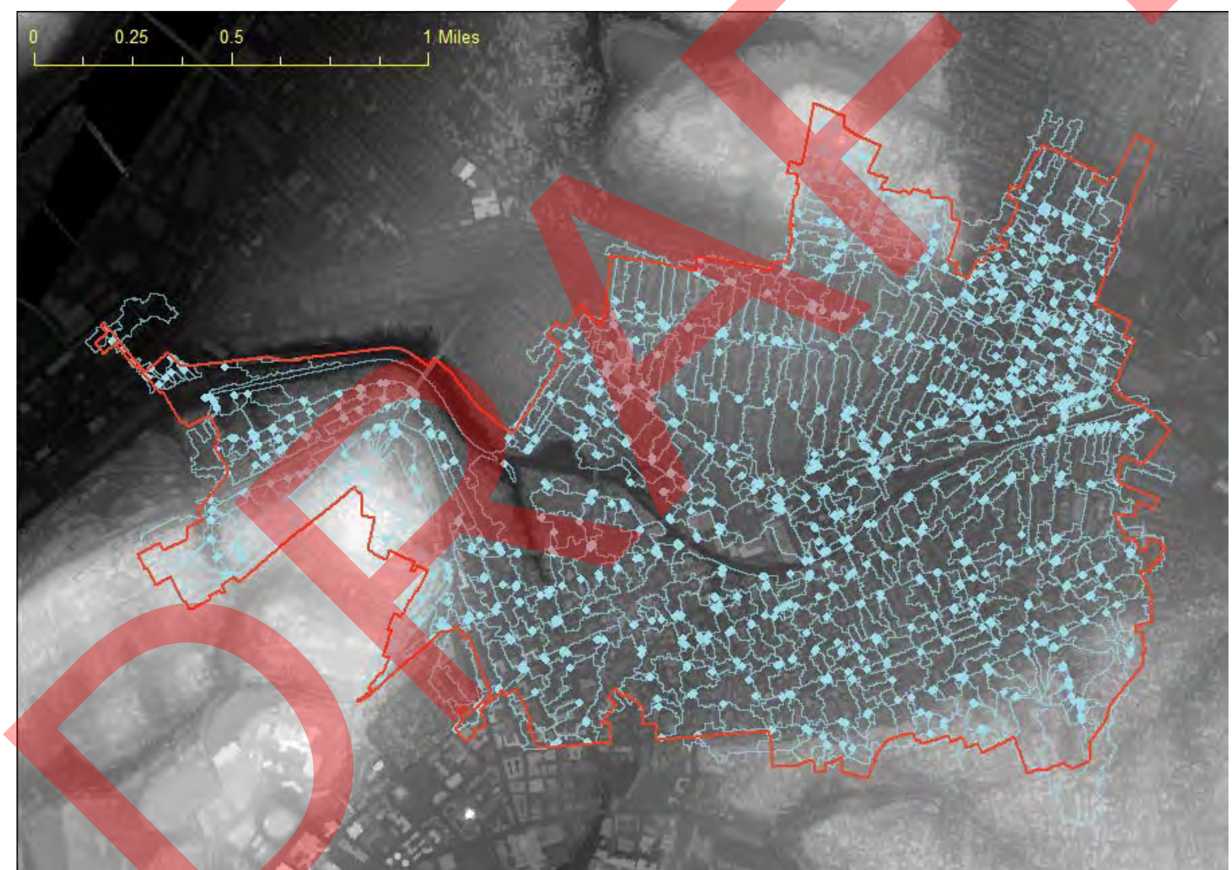

Figure 3-1: Arc Hydro Surface Level Hydrologic Output Results for the A-22 Sewershed

For each individual drainage area in the 30 high priority sewersheds (example shown in blue in Figure 3-1), the contributing impervious area was calculated using the road, roof, and parking lot shapefiles from the Pennsylvania Spatial Data Access database. The stormwater drainage inlets were then ranked highest to lowest based on the total contributing impervious area to the inlet. The highest ranking inlets were used to determine the most effective locations for "high yield" stormwater management utilizing GI best management practices (BMPs). Figure 3-2 provides an example map showing the stormwater inlets ranked by highest contributing impervious area for the A-22 sewershed.

The process of developing a surface level hydrologic model, creating drainage areas for the PWSA stormwater drainage inlets, and ranking the inlets based upon the contributing impervious surface was then repeated for each of the 30 high priority CSO sewersheds. Among these 30 sewersheds, the contributing impervious area per stormwater drainage inlet ranged from less than 0.5 acre to 27.5 acres. The ranking results were instrumental in identifying "high yield" target areas of focus for subsequent GI analysis and evaluations.

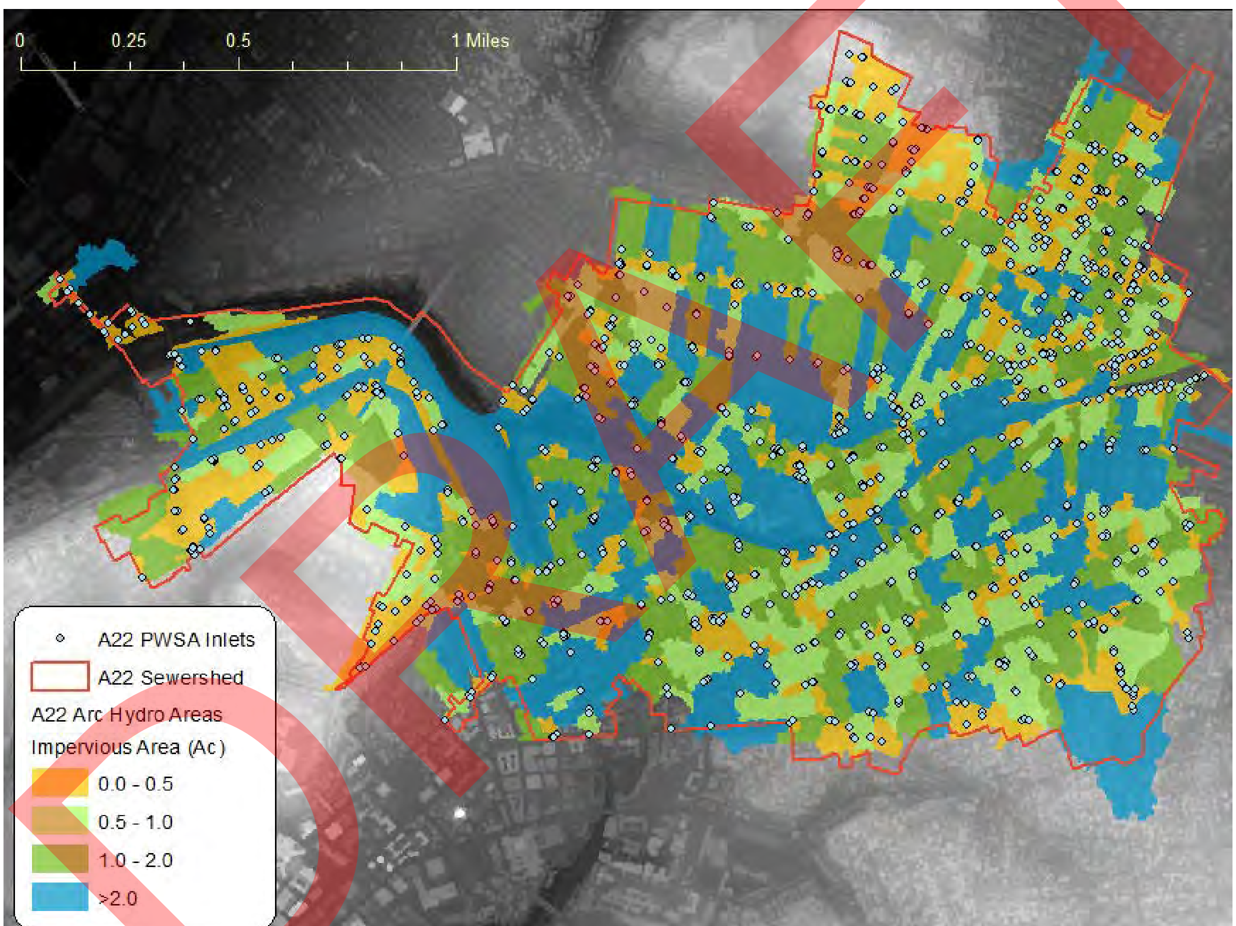

Figure 3-2: Highest Ranking PWSA Stormwater Inlet Areas in the A-22 Sewershed Based on Tributary Impervious Area

3.2 Incorporate High Yield GI Locations into SWMM

This section outlines the process for incorporating the high yield GI locations within the 30 high priority sewersheds (as described in Section 3.1) into the regional SWMM H&H sewer system model to determine the resultant stormwater and CSO reduction benefits. This process consisted of the following four steps:

Figure 3-3: Process for Incorporating High Yield GI Locations into SWMM

Figure 3-3 illustrates the four step process results for the A-22 sewershed. It was determined that management of 30% of the impervious surface stormwater runoff area is needed to achieve the goal of 85% combined sewage capture, along with surface flooding and basement sewage backup mitigation for a specific storm condition, in the A-22 sewershed. For A-22, 30% of the impervious surface is approximately 271 acres. The highest yield PWSA stormwater drainage inlets and associated drainage areas were then selected to meet the 30% target impervious surface management value. The 30% target areas were then overlain on the existing combined sewer subcatchments represented in the regional SWMM sewer system model.

Appendix A provides maps for each of the 30 high priority sewersheds, showing the target high yield drainage areas and the sewer subcatchment areas for impervious surface area management.

As shown in Figure 3-3, many of the high yield drainage areas encompass multiple combined sewer modeled subcatchment boundaries and are rarely an exact 1:1 match. To address this conflict, a simple process flow diagram was developed for incorporating the SWMM LID Tool into the overlapping sewer subcatchments in the SWMM model. The process flow diagram for incorporating the high yield drainage areas into the SWMM LID Tool is shown in Figure 3-4. This process is further illustrated in Figure 3-5 using an example high yield drainage area within the A-22 sewershed. The high yield drainage area GI location presented in Figure 3-5 is presented for example purposes only and should not be considered a definitive GI implementation area as of the authoring of this study.

Using the process outlined in Figure 3-4 and further illustrated in Figure 3-5, each combined sewer modeled subcatchment that overlapped with a high yield drainage area was modified for the SWMM LID Tool.

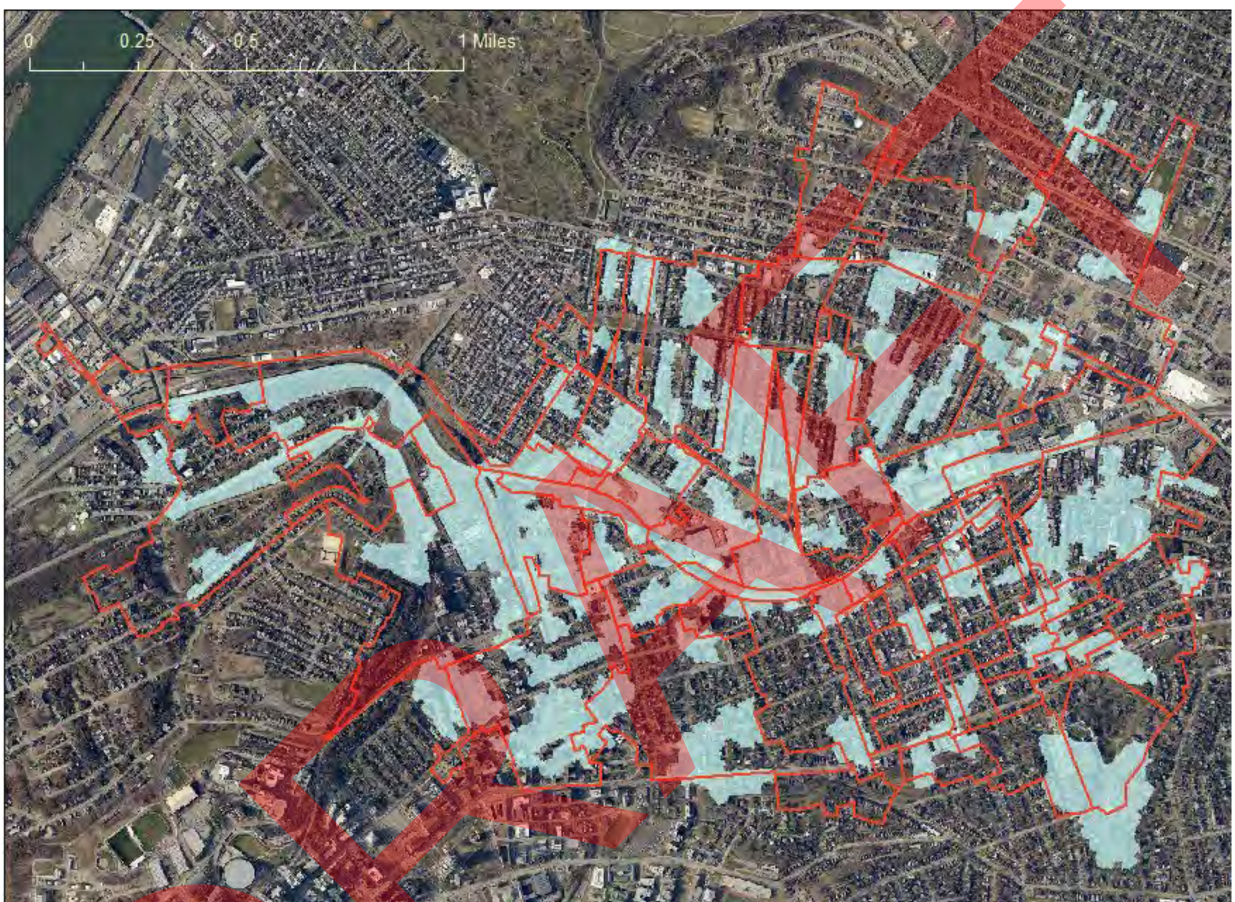

Figure 3-4: Target High Yield Drainage Areas (Blue Areas) and SWMM Subcatchment Areas (Red Outlines) for A-22 Sewershed for 30% Impervious Surface Area Management

Incorporate LID Into SWMM Subcatchment Based On Impervious Area Process

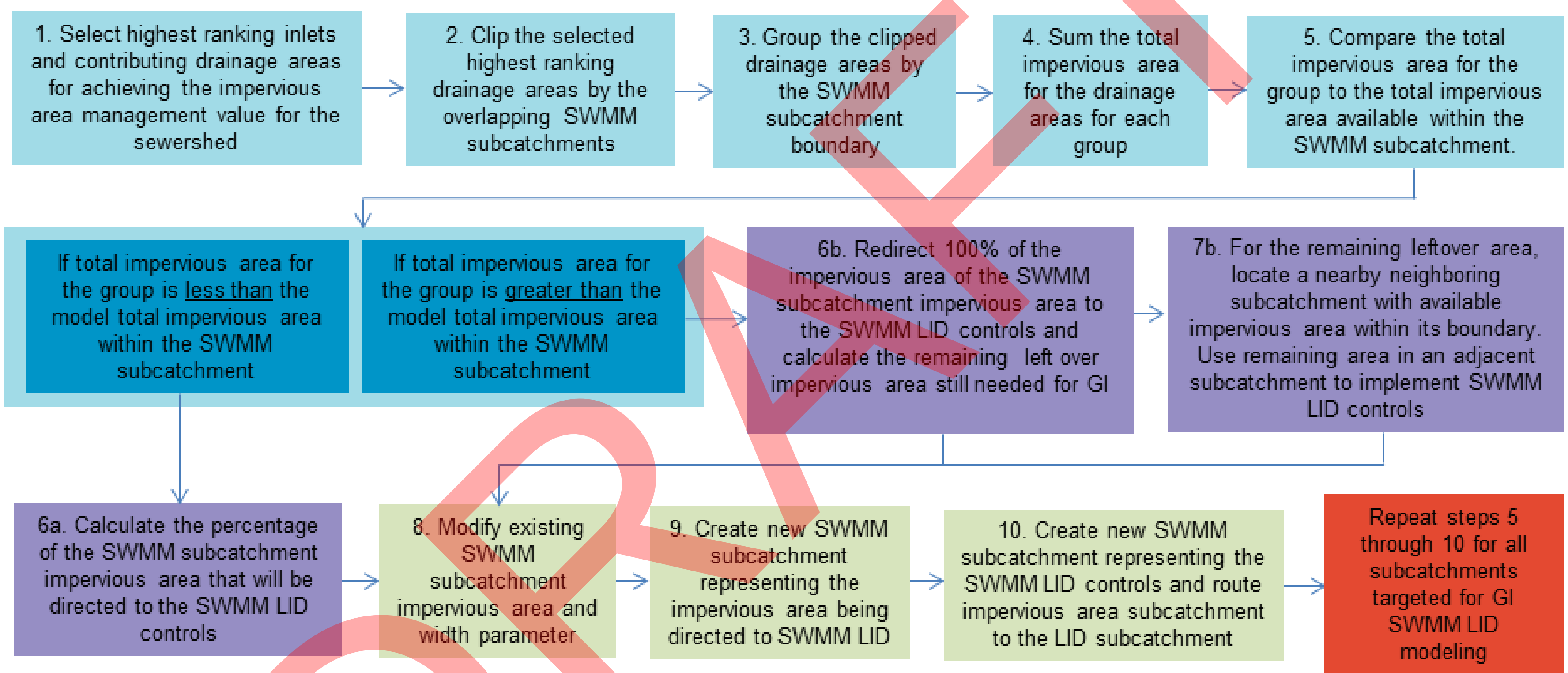

Figure 3-5: Process Used for Incorporating Arc Hydro Results into the SWMM LID Tool for Combined Sewer Subcatchments in the 30 High Priority Sewersheds

Figure 3-6: Example Illustration for Incorporating Arc Hydro Results into the SWMM LID Tool for Combined Sewer Subcatchments in the 30 High Priority Sewersheds

Once all of the target high yield drainage areas were successfully incorporated into the regional SWMM model, the specific parameters within the LID Tool were standardized across all of the 30 high priority sewersheds. Table 3-2 shows the SWMM LID Tool parameters used for each of the 30 high priority sewersheds. The SWMM LID Tool parameters were selected based upon a sensitivity analysis conducted as part of a previous GI study conducted within the A-22 sewershed. A brief summary, including the results of this sensitivity analysis, are presented in Appendix B.

TABLE 3-2
SUMMARY OF SWMM LID TOOL MODELING PARAMETERS AND ASSUMPTIONS (PERFORMANCE CRITERIA)

SWMM LID Tool Parameter	Model Assumption
SWMM LID GI Type	Infiltration Trench
GI Rainfall Depth Sizing	1.5 inches over contributing impervious drainage area
Assumed Infiltration Rate	0.1 inches per hour
Assumed Depth of GI	4 feet
Assumed Width of GI	4 feet
Assumed Length per GI Unit	200 feet
Underdrain Height Offset	6 inches
Underdrain Coefficient – Optimized for 72 Hour Emptying Time to the CSS from BMP Full	0.082

The basic functioning principal of GI is to serve as a storage facility to temporarily store runoff with a portion of the runoff being infiltrated or evaporated and the remainder returned to the existing CSS via an under drain. ALCOSAN's Starting at the Source report (2015), which also evaluated the CSO reduction effectiveness of GI within the region, assumes the same basic principles. However, there are slight differences between PWSA's and ALCOSAN's GI modeling approach. ALCOSAN primarily relied upon a 1.0-inch rainfall depth GI sizing requirement for the basis of their investigation, but they did perform a "limited number of model simulations" under 1.5-inch rainfall depth size. Likewise, ALCOSAN also utilized a 24-hour return period for the GI emptying time for the bulk of their analysis and also performed a limited number of model simulations under a 72-hour return period. Generally, the approaches between PWSA and ALCOSAN are very similar in terms capturing and storing runoff in a distributed manner and slowly releasing it back into the CSS, however there are slight differences in GI sizing and optimized underdrain slow release return time as part of the model simulations. For the infiltration parameters, it is unclear from the Starting at the Source report exactly what infiltration approach and parameters were used to model the GI infiltration losses.

As previously stated, the underdrain coefficient for the SWMM LID tool modeling analysis was optimized to the 72-hour return time. This is based upon typical year modeling of the hydraulics of the existing ALCOSAN interceptor system. Typical year modeling results indicate that generally the interceptors return to dry weather flow after a large rain event after 72-hours of operation. Using these findings, the 72-hour return time was found to be optimal as a target drain down time to slowly empty the detained stormwater back into the existing CSS. The infiltration rate of 0.1 inches per hour was selected to be conservative and corresponds to fine and very fine clay type soil particles according to the United States Department of Agriculture[1]. There is concern from regulatory agencies, municipalities and municipal engineers that infiltrated stormwater may potentially return back into the sewer system as inflow and/or infiltration (I/I) from groundwater. To account for this potential effect, a conservative and relatively low infiltration rate of 0.1 inches per hour based on clay type soils was assumed, with the rest of the captured stormwater being returned back to the existing CSS through an underdrain system. In the field and practice, larger infiltration rates will likely be experienced with potentially some of the infiltrated water reentering the CSS as I/I. The demonstration projects currently being designed and implemented are being monitored to understand the effects of infiltration and the resultant flow balances.

The SWMM LID Tool allows for the simulation of various GI technologies including rain gardens, infiltration trenches, bioinfiltration, bioswales, and rain barrels/cisterns directly within the SWMM model. Each GI technology within the SWMM LID Tool has varying functional components based on the technology simulated. For this study, all GI locations were simulated using subsurface infiltration trenches. Infiltration trenches were selected as the GI modeled technology for the 30 high priority sewersheds because it was assumed that the stormwater would be captured in the GI BMP and slowly released over a 72-hour time period back into the CSS. Infiltration trenches within the SWMM LID Tool during rain events allow for transfer of captured stormwater runoff to an underground detention facility with a slow release underdrain. While the infiltration trench was modeled within SWMM, any BMP that can capture the stormwater runoff, transfer the water to an underground detention reservoir (rock trench or modular storage) and utilize an underdrain to slowly release the captured stormwater back into the CSS can be constructed in the field. This includes bioretention, rain gardens and the variations thereof, green roofs, and porous pavement.

The 30 high priority sewersheds with LID Tool parameters were then integrated into the system wide model, which was created by stitching together the eight ALCOSAN planning basin models. The creation of the system wide model allowed for wastewater treatment plant (WWTP) capacity scenarios and GI to be modeled together to observe the changes in GI performance with WWTP capacity changes and hydraulic modification

[1] http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr10/tr/?cid=nrcs144p2_074846

to the existing interceptor system. Section 2 of this report provides a detailed discussion of the system wide model and the capacity scenarios selected. In order to simulate GI flow reduction benefits using the SWMM LID Tool, SWMM Version 5.1.009 was used for all 30 high priority sewersheds. The GI was also modeled in tandem with direct stream removal (see Section 5). The CSO reduction benefits of GI and direct stream removal within the 30 high priority sewersheds are presented in Section 3.3.

3.3 Summary of Green Infrastructure Modeling Results

The following provides a discussion of the GI modeling results using the SWMM LID Tool within the 30 high priority sewersheds. All results presented in Section 3.3 include direct stream removal locations in addition to GI using SWMM LID. The direct stream removal locations are presented in Section 5.

The GI modeling analysis examined the impervious area management to achieve 85% combined sewage capture at each individual CSO, as well as the area required to achieve aggregate 85% capture for all 30 high priority sewersheds. See Section 2 for a detailed discussion of the 85% combined sewage capture target value. The required impervious area GI management is influenced by the ALCOSAN WWTP wet weather capacity, the hydraulic capacity of the combined sewer regulators, and the conveyance capacity of the existing ALCOSAN interceptor system. Two potential WWTP capacity and conveyance system configurations were selected to evaluate the GI management that may be required for those scenarios:

- The 480 million gallons per day (MGD) (WWTP Expansion) configuration (as described in Section 2 of this report) consists of 480 MGD WWTP capacity combined with GI. This scenario resulted in the need to manage approximately 1,835 acres of directly connected impervious area (DCIA) within the 30 high priority sewersheds to meet at least 85% combined sewage capture at each individual CSO.
- The Lowered Hydraulic Grade Line (HGL) Operation During Wet Weather Conditions configuration (as described in Section 2 of this report) represents the Lowered HGL Operation During Wet Weather Conditions combined with GI. This scenario resulted in the need to manage approximately 1,286 acres of directly connected impervious area within the 30 high priority sewersheds to meet at least 85% combined sewage capture at each individual CSO.

The Lowered HGL Operation During Wet Weather Conditions scenario was selected to understand the maximum available conveyance capacity of the existing ALCOSAN interceptors. In order to match the wet weather treatment capacity of the WWTP to this potentially available conveyance capacity, the Lowered HGL Operation During Wet Weather scenario would need further investigation in coordination with ALCOSAN. The Lowered HGL Operation During Wet Weather Conditions scenario would likely require a new influent pump station installed deeper than the current PS to pump additional wet weather flow, additional access shafts along the existing deep tunnel interceptors to facilitate maintenance and cleaning of the existing tunnels, and potential mitigation of surge/transient pressures would be required. A new influent pumping station is proposed as part of ALCOSAN's Recommended Plan to dewater the proposed regional wet weather tunnels. The technical feasibility of all potential treatment plant wet weather capacity scenarios is currently under discussion between PWSA and ALCOSAN. This GI Assessment includes evaluating removal or detaining the existing streams entering the CSS, including adding grit/sediment traps, which are reported to be a large source of the sediment entering the existing tunnels contributing to the need to remove the accumulated sediment.

The GI management results for the 480 MGD (WWTP Expansion) configuration and the Lowered HGL Operation During Wet Weather Conditions configuration compared with existing conditions are shown in Table 3-3. The results in Table 3-3 provide the directly connected impervious area that would need to be managed in each of the 30 high priority sewersheds to achieve the target 85% combined sewage capture at each CSO.

The two GI management scenarios of 1,286 and 1,835 directly connected impervious acres were then modified for SWMM LID using the approach as outlined in Section 3.2. Each GI management scenario was then simulated in the system wide model under four ALCOSAN WWTP and interceptor hydraulic capacity scenarios as shown in Table 3-4 and previously summarized in Section 2.

The aggregate 30 high priority sewershed typical year results of the SWMM LID Tool model simulations are presented in Table 3-5. The results from Table 3-5 are also presented graphically as "performance curves" in Figure 3-6. The performance curves in Figure 3-6 are a visual representation of the typical year CSO results for the SWMM LID GI modeling analysis.

Modeling results on an individual sewershed basis are provided in Appendix C.

TABLE 3-3
GI MODELING MANAGEMENT ACREAGES FOR THE 30 HIGH PRIORITY SEWERSHEDS FOR TWO SYSTEM CONFIGURATIONS: 480 MGD (WWTP EXPANSION) AND LOWERED HGL OPERATION DURING WET WEATHER CONDITIONS

		480 MGD (WWTP Expansion)		Lowered HGL Operation During Wet Weather Conditions, Sediment Removed, and 19 CSO Regulators Modified	
High Priority Sewershed	Existing Conditions Directly Connected Impervious Acres (DCIA) (Ac)	% Impervious Acres Modeled Using SWMM LID	Total DCIA Modeled Using SWMM LID (Ac)	% Impervious Acres Modeled Using SWMM LID	Total DCIA Modeled Using SWMM LID (Ac)
A-22-OF	898.0	43%	387.7	30%	271
A-41-OF	234.7	85%	199.5	60%	140.8
A-42-OF	839.7	73%	614.1	58%	485.1
A-47-OF	9.0	0%	0	0%	0
A-48-OF	167.1	25%	41.8	25%	41.8
A-51-OF	34.6	0%	0	0%	0
A-58-OF	151.7	25%	37.9	25%	37.9
A-60-OF	175.2	25%	43.8	25%	43.8
A-61-OF	10.7	37%	4.0	0%	0
A-62-OF	5.7	0%	0	0%	0
A-63-OF	1.0	0%	0	0%	0
A-64-OF	18.4	0%	0	0%	0
A-65-OF	4.6	15%	0.7	0%	0
M-15-OF	3.7	65%	2.4	0%	0
M-15Z-OF	3.1	0%	0	0%	0
M-16-OF	100.0	85%	85.0	25%	25.2
M-17-OF	6.2	0%	0	0%	0
M-18-OF	5.1	0%	0	0%	0
M-19A-OF	142.6	41%	58.4	35%	49.9
M-19B-OF	32.1	28%	9.0	33%	10.6
M-19-OF	119.1	55%	65.7	25%	29.8
M-20-OF	6.2	0%	0	0%	0
M-21-OF	29.2	8%	2.3	0%	0
M-22-OF	16.4	0%	0	0%	0
M-29-OF	362.3	60%	217.7	25%	90.5

TABLE 3-3
GI MODELING MANAGEMENT ACREAGES FOR THE 30 HIGH PRIORITY SEWERSHEDS FOR TWO SYSTEM CONFIGURATIONS: 480 MGD (WWTP EXPANSION) AND LOWERED HGL OPERATION DURING WET WEATHER CONDITIONS

		480 MGD (WWTP Expansion)		Lowered HGL Operation During Wet Weather Conditions, Sediment Removed, and 19 CSO Regulators Modified	
High Priority Sewershed	Existing Conditions Directly Connected Impervious Acres (DCIA) (Ac)	% Impervious Acres Modeled Using SWMM LID	Total DCIA Modeled Using SWMM LID (Ac)	% Impervious Acres Modeled Using SWMM LID	Total DCIA Modeled Using SWMM LID (Ac)
O-27-OF	195.6	22%	43.7	22%	43.7
O-39-OF	23.8	21%	5.1	0%	0
O-40-OF	2.8	0%	0	0%	0
O-41-OF	27.9	56%	15.6	56%	15.6
O-43-OF	9.8	0%	0	0%	0
Totals =	3,636.2	50.45%	1,834.5	35.35%	1,285.7

TABLE 3-4
VARIOUS SYSTEM CONFIGURATIONS EVALUATED TO DETERMINE GI SENSITIVITY

Existing Conditions	This represents the current state of the collection system and the WWTP treatment capacity. The WWTP has a 250 MGD treatment capacity and its influent pump station wet well operates at an HGL level of 670 feet. The existing interceptors have the sediment levels as defined in the current ALCOSAN model.
480 MGD (WWTP Expansion) [1]	This system state is the same as the existing conditions, except the capacity of the WWTP has been expanded to 480 MGD and its operating wet well HGL level reduced to 660 feet.
600 MGD (WWTP Expansion & System Improvements) [1]	This system state is the same as the existing conditions, except the capacity of the WWTP has been expanded to 600 MGD and its operating wet well HGL level reduced to 660 feet. Also, the existing interceptors are modeled with their sediment removed to maximize wastewater conveyance to the WWTP and regulator structures for 19 of the 30 high priority sewersheds have modified tipping gate settings to allow more flow to enter the interceptors. Based on typical year modeling analysis under this scenario, it is anticipated that the full 600 MGD capacity would be utilized approximately 24 to 48 hours annually.
Lowered HGL Operation During Wet Weather Conditions [1]	This system state represents an attempt to maximize the performance of the existing infrastructure. This system state is not currently planned to be implemented by ALCOSAN. In this scenario, the WWTP is modeled as a free outfall to represent lowering the water level at the existing pump station during wet weather conditions such that it is below the crown of the connecting deep tunnel. This provides for the existing conveyance capacity to be maximized. This scenario also assumes that the necessary high rate treatment infrastructure is constructed at the WWTP to process any flows above 600 MGD (modeling results indicate peak flows at or above 600 MGD occur 29 hours in a typical year). The necessary infrastructure to accomplish this scenario is discussed in Section 3.3. The technical feasibility of all potential treatment plant wet weather capacity scenarios is currently under discussion between PWSA and ALCOSAN. The existing interceptors are modeled with their sediment removed and regulator structures for 19 of the 30 high priority sewersheds have modified tipping gate settings to allow more flow to enter the interceptors.

[1] The technical feasibility of all potential treatment plant wet weather capacity scenarios is currently under discussion between PWSA and ALCOSAN.

TABLE 3-5
AGGREGATE TYPICAL YEAR CSO GI AND STREAM REMOVAL MODELING RESULTS FOR THE 30 HIGH PRIORITY SEWERSHEDS

	Existing Conditions (250 MGD Capacity)			480 MGD (WWTP Expansion)		
	CSO Remaining (MG)	CSO Reduced (MG)	Percent Combined Sewage Capture (%)	CSO Remaining (MG)	CSO Reduced (MG)	Percent Combined Sewage Capture (%)
Plant Capacity Alone	3,067	0	70%	2,480	587	76%
With GI Management 1,286 impervious acres	2,400	667	77%	1,795	685	83%
With GI Management 1,835 impervious acres	2,083	984	80%	1,534	946	**85%**

	600 MGD WWTP Expansion with Interceptor Hydraulic Improvements and Open Tipping Gates at 19 CSO Regulator Structures (Feasibility would need to be evaluated)			Lowered HGL Operation During Wet Weather with Interceptor Hydraulic Improvements and Open Tipping Gates at 19 Regulator Structures (Feasibility would need to be evaluated)		
	CSO Remaining (MG)	CSO Reduced (MG)	Percent Combined Sewage Capture (%)	CSO Remaining (MG)	CSO Reduced (MG)	Percent Combined Sewage Capture (%)
Plant Expansion Alone	1,701	1,366	84%	1,542	1,525	**85%**
With GI Management 1,286 impervious acres	1,124	576	**89%**	970	572	**91%**
With GI Management 1,835 impervious acres	910	790	**91%**	766	775	**93%**

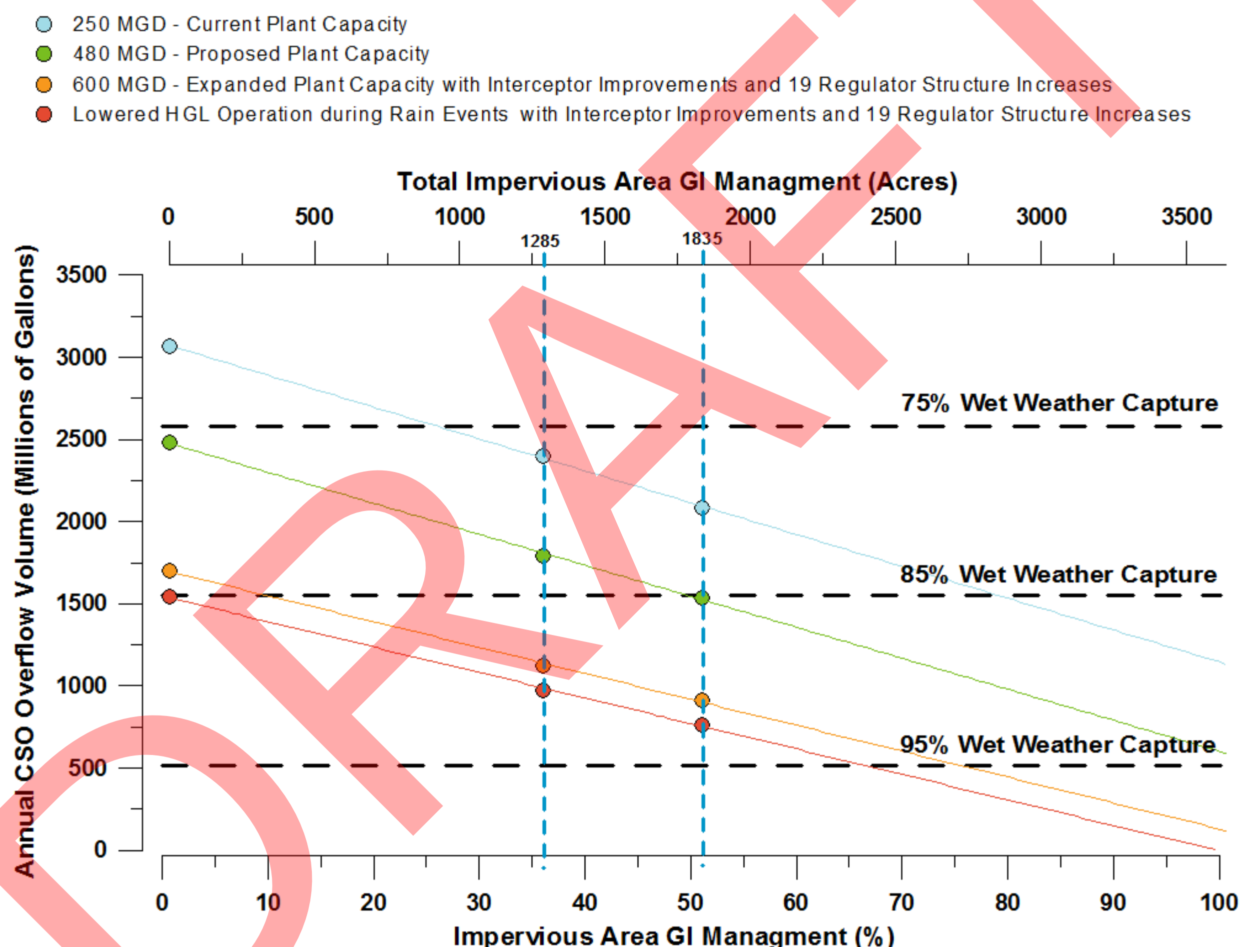

Figure 3-7: Aggregate Typical Year CSO GI and Stream Removal Modeling Performance Curves for the 30 High Priority Sewersheds

In addition to analyzing the overflow volume reductions at the individual 30 high priority sewersheds as presented in Table 3-5 and Figure 3-6, the total ALCOSAN service area systemwide overflow reduction results were also analyzed. This was done to observe any potential overflow reductions within neighboring sewersheds that were not part of the 30 high priority sewersheds. The total ALCOSAN systemwide overflow was determined by calculating the net overflow reduction change within the SWMM outfall loadings report with and without GI implemented. The total ALCOSAN service area systemwide overflow reductions were calculated using three of the four system configuration scenarios:

- 480 MGD conditions with 1,835 impervious acres managed by GI within the City of Pittsburgh and direct stream removal,
- 600 MGD conditions with 1,835 impervious acres managed by GI within the City of Pittsburgh and direct stream removal, and
- Lowered HGL Operation During Wet Weather Conditions with 1,286 impervious acres of GI managed by GI in the City of Pittsburgh and direct stream removal.

The results from the systemwide overflow reduction analysis are shown in Table 3-6.

TABLE 3-6
OVERFLOW REDUCTION RESULTS FOR THREE SYSTEM CONFIGURATIONS WITH GREEN INFRASTRUCTURE IN PRIORITY SEWERSHEDS AND STREAM INFLOW REMOVAL, TYPICAL YEAR, SYSTEMWIDE [1]

Stormwater Management Scenario	480 MGD (WWTP Expansion)	600 MGD WWTP Expansion & System Improvements, Sediment Removed, and 19 Regulator Modifications	Lowered HGL Operation During Wet Weather Conditions, Sediment Removed, and 19 Regulator Modifications
Impervious Acres Managed with GI	1,835	1,835	1,286
Overflow Volume Reduction Attributable to GI (BG)	0.97	0.97	0.69
Aggregate Combined Sewage Capture (30 Sewersheds)	85%	91%	91%
Total ALCOSAN Systemwide Overflow Volume Reduction (BG)[2]	4.09	5.00	5.20
Total ALCOSAN Systemwide Overflow Volume Remaining (BG)[2]	5.89	4.98	4.78

[1] Systemwide model results include overflow reduction that may occur in neighboring sewersheds as a result of the improvements in the priority sewersheds.

[2] SWMM Model Version 5.1.009 Results (as described in Section 2 of this report).

3.4 Discussion of Green Infrastructure Modeling Results

The following are some observations based upon the modeling results presented in Section 3.3:

- An increase in the ALCOSAN wet weather treatment capacity from 250 MGD to 480 MGD will:
  - Reduce annual CSO volume in the 30 high priority sewersheds from 3,070 MG to 2,480 MG exclusive of GI investment, and representing approximately 76% aggregate capture of combined sewage for the sewersheds.
  - With a GI impervious area management of 1,286 acres, CSO volume can be further reduced to about 1,790 MG, representing approximately 83% aggregate capture for the 30 high priority sewersheds.
  - With a GI impervious area management of 1,835 acres, CSO volume can be further reduced to 1,530 MG, representing 85% aggregate capture for the 30 high priority sewersheds.
  - Reduce CSO volume for two of the 30 CSOs, A-47 and O-43, representing 99.8% capture.

- An increase in the ALCOSAN wet weather treatment capacity to 600 MGD with additional interceptor hydraulic increase from sediment removal, and opening the existing tipping gates at 19 CSO regulator structures will:
  - Reduce the annual CSO to 1,700 MG; yielding approximately an 84% capture exclusive of GI investment for the 30 high priority sewersheds.
  - With a GI impervious area management of 1,286 acres, CSO volume can be further reduced to 1,120 MG, yielding an aggregate 89% capture for the 30 high priority sewersheds.
  - With a GI impervious area management of 1,835 acres, CSO volume can be further reduced to 910 MG, yielding an aggregate 91% capture for the 30 high priority sewersheds with at least 85% capture at each individual CSO, except A-41 and M-19B with 80.1%, and 82.7% captures, respectively.
  - Reduce CSO volume for four CSOs, O-43, M-15, A-47, and A-48, each representing 99% or greater capture.
  - Reduce CSO volume for three other CSOs, O-27, O-39, and A-51, each representing at least 98% capture.

- An increase in the ALCOSAN wet weather conveyance and treatment capacity in the Lowered HGL Operation During Wet Weather Conditions scenario with additional interceptor hydraulic increase from sediment removal, and opening the existing tipping gates at 19 CSO regulator structures will:
  - Reduce the annual CSO volume to 1,540 MG; yielding an aggregate 85% combined sewage capture exclusive of GI investment for the 30 high priority sewersheds.
  - With a GI impervious area management level of 1,286 acres, CSO volume could be further reduced to 970 MG; yielding an aggregate 91% combined sewage capture for the 30 high priority sewersheds.
  - With a GI impervious area management of 1,835 acres, CSO volume can be further reduced to 770 MG; yielding an aggregate 93% capture for the 30 high priority sewersheds with at least 85% capture at each individual CSO, except M-19B with 83.1% capture.
  - Reduce CSO volume for six CSOs, O-43, M-15, A-47, A-48, A-60, and A-65, representing 99% or greater capture.
  - Reduce CSO volume for four CSOs, O-27, O-39, M-19, and A-51, representing at least 98% capture.

In summary, the results of the GI modeling analysis for the 30 high priority sewersheds indicate:

- GI integrated with wet weather WWTP capacity increases can achieve at least an aggregate 85% combined sewage capture in the 30 high priority sewersheds along with at least 85% capture at each individual CSO.
  - 480 MGD treatment plant wet weather capacity: With a GI impervious area management of 1,835 acres, CSO volume can be reduced from 3,067 MG to 1,500 MG, representing an 85% aggregate capture for the 30 high priority sewersheds.
  - 600 MGD treatment plant wet weather capacity with interceptor hydraulic increase from sediment removal, and opening the existing tipping gates at 19 CSO regulator structures (not currently planned and needs further evaluation): With a GI impervious area management of 1,835 acres, CSO volume can be reduced from 3,067 MG to 910 MG remaining, yielding an aggregate 91% capture for the 30 high priority sewersheds with at least 85% capture at each individual CSO, except A-41 and M-19B with 80.1% and 82.7% captures, respectively. Regulator modifications or slight increases in the amount of GI within each shed could increase the capture for each of these 2 CSOs to 85% capture.
  - Lowered HGL Operation During Wet Weather Conditions scenario with interceptor hydraulic increase from sediment removal, and opening the existing tipping gates at 19 CSO regulator structures (not currently planned and needs further evaluation): With a GI impervious area management of 1,835 acres, CSO volume can be reduced from 3,067

MG to 766 MG remaining, yielding an aggregate 93% capture for the 30 high priority sewersheds with at least 85% capture at each individual CSO, except M-19B with 83.1% capture. Regulator modifications or slight increases in the amount of GI within this shed could increase this CSO to 85% capture.

- The two selected levels of impervious area management with GI (1,286 acres and 1,835 acres) across the 30 high priority sewersheds represent feasible amounts of area that could be controlled with GI – representing just 9% and 13% of the total area, respectively.
- The listed WWTP capacity scenarios are currently under discussion between PWSA and ALCOSAN and need further coordination.

The cost analysis results using the CSO reduction benefits results outlined in this section are presented in Section 9.

4. FLOOD HAZARD MITIGATION ANALYSIS

PWSA coordinated with the City of Pittsburgh (City) Office of Emergency Management and Homeland Security (OEMHS) to obtain the Hazard Vulnerability Assessment report dated September 2013, which formed the basis for identification of the "top 10", or the ten most hazardous, hazard locations. These locations are listed in Table 4-1. Field investigations were conducted to better understand each hazard and helped to establish the root cause(s) of the hazard situation in these locations. The root causes are also included in the table. Of the ten hazard locations, the hazard conditions for three, Route 28 and 31st St. Bridge (#4), Mount Washington (#9), and Rear of Eggers Street (#10), appear to be the result of landslides and slope instability, and hence they could not be addressed as part of this study. Locations along Library Road (#2) and Saw Mill Run Road (#3) experience recurring flooding, which can benefit from upstream stormwater reduction measures. Because these two hazard areas are located in the Saw Mill Run (SMR) watershed, they will be addressed during the completion of Integrated Watershed Management (IWM) project being completed by PWSA, and hence were not included in this study. The remaining five locations are flooding related hazard locations elsewhere in the City of Pittsburgh. However, for one of the five, (Becks Run area (#5)), an existing in-stream hydraulic model of the watershed has not been developed and development of a model was beyond the scope of this study; Becks Run flooding will need to be analyzed as part of a future separate study. Therefore, the remaining four hazard locations were analyzed in greater detail and are described herein; they include:

1. Morange Road - located in the Chartiers Creek Basin in the C-25 sewershed
2. Frankstown Avenue - located in the Upper Allegheny Basin in the A-42 sewershed
3. Streets Run - located in the Monongahela Basin in the M-42 sewershed
4. Nine Mile Run - located in the Monongahela Basin in the M-47 sewershed

The flooding at Morange Road and Frankstown Road were found to result from the sewer capacity issues and these areas were analyzed using the existing hydrologic and hydraulic (H&H) collection system model. The flooding at Streets Run and Nine Mile Run were found to result from the stream overtopping a culvert or the stream banks, and these areas were analyzed using available open channel stream models obtained from ALCOSAN.

TABLE 4-1
TOP 10 HAZARD LOCATIONS IN THE CITY OF PITTSBURGH

Priority	Location	Description (Provided by PWSA & City)	Focus	Suspected Root Cause of Hazard Location	General Sewer Condition (CCTV)	Suggested Next Actions
1	Streets Run	Recurring flooding	Stream	Stream floods due to large rain events	Unknown - No CCTV	Impervious area stormwater runoff reduction or upstream stormwater detention necessary to address root cause. Use stream model for further analysis.
2	Library Road	Recurring flooding	Stream	Stream floods due to large rain events	Good overall condition	Impervious area reduction or upstream stormwater detention necessary to address root cause. To be analyzed as part of SMR IWM project. No further actions as part of this study.
3	Saw Mill Road	Recurring flooding	Stream	Stream floods due to large rain events	Sediment and minor joint displacement in pipe (vitrified clay) observed	Impervious area reduction or upstream stormwater detention necessary to address root cause. To be analyzed as part of SMR IWM project. No further actions as part of this study.
4	Route 28 and 31st St. Bridge	Landslides and slope instability	Slope Instability	Steep slope; winter icing issues require road closure by City Public Works	Good overall condition	Impervious area reduction will not address root cause. No further actions as part of this study.
5	Becks Run Area	Recurring basement and first floor flooding	Stream	Stream floods due to large rain events	Areas of infiltration observed and deposits; fair condition overall	Impervious area reduction or upstream stormwater detention necessary to address root cause. Stream model needs to be created for further analysis. No further actions as part of this study.

TABLE 4-1
TOP 10 HAZARD LOCATIONS IN THE CITY OF PITTSBURGH

Priority	Location	Description (Provided by PWSA & City)	Focus	Suspected Root Cause of Hazard Location	General Sewer Condition (CCTV)	Suggested Next Actions
6	Morange Road	Recurring flooding	Level of Service	Sewer surcharges during storm events cause street flooding	Videos are zoom-only; no capacity-related defects evident; entire length of pipe not available	Utilize H&H model to check wet weather sewer capacity. PWSA to perform CCTV inspection.
7	Frankstown Avenue	Recurring flooding and slope instability	Level of Service and Slope Instability	Sewer surcharges during storm events cause street flooding; steep slopes	Partial CCTV video available; PWSA's follow-up inspections did not indicate any sewer structural problems that could be causing the flooding	Utilize H&H model to check wet weather sewer capacity. PWSA to perform CCTV inspection.
8	Nine Mile Run	Recurring flooding along Commercial Road near culvert	Level of Service and Culvert Size	Insufficient culvert capacity under Commercial Road	No CCTV of culvert; Visual inspection performed. No structural issues observed that could cause the flooding	Increased culvert size, impervious area reduction, or upstream stormwater detention necessary to address root cause. Use stream model for further analysis.
9	Mount Washington	Landslides and slope instability	Slope Instability	Steep slope; landslide prone	No sewers run downslope; two sections of sewer parallel at top of slope; sewer system not a contributor	Impervious area reduction will not address root cause. No further actions as part of this study.
10	Rear of Eggers Street	Landslides and slope instability	Slope Instability	Steep slope; landslide prone	Good overall condition	Impervious area reduction will not address root cause. No further actions as part of this study.

4.1 Current Level of Service

4.1.1 Morange Road Flooding Hazard Location

This hazard location is at the intersection of Morange Road and West Busway in the C-25 sewershed that drains to Chartiers Creek, is located near the Oakwood and East Carnegie neighborhoods of the City of Pittsburgh. There are two trunk sewers at this location: a 24-inch diameter combined sewer conveying flows from the Borough of Crafton, and a PWSA combined sewer, with a size varying between 30 and 36 inches in diameter. The PWSA combined sewer conveys flows from the City of Pittsburgh, and also conveys sanitary flows from upstream areas in Green Tree Borough. Figure 4-1 shows the general area around the Morange Road flooding location, and Figure 4-2 shows a photograph of the reported flooding area just upstream of the busway culvert along Morange Road. Although hard to see in the photograph, there are several catch basins connected to the PWSA storm sewer. The storm sewer flow is routed to the PWSA combined sewer about 500 feet downstream of the flooding location. During wet weather events, the capacity of this sewer is exceeded, causing flooding at this location as well as multiple upstream manholes along the combined sewer.

Figure 4-1: Morange Road Flooding Area

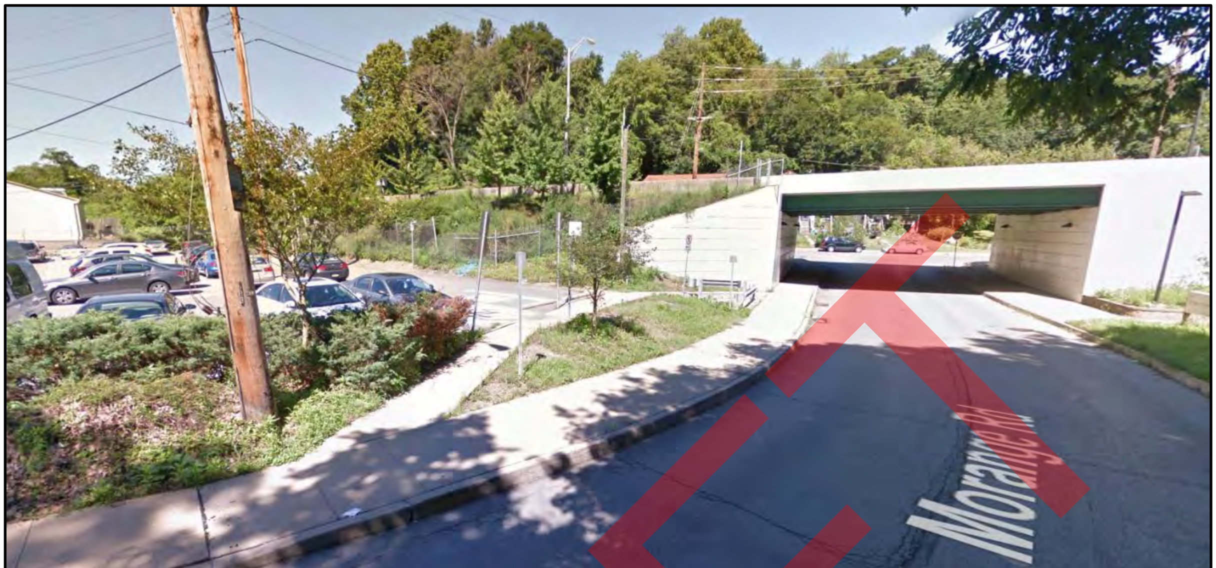

Figure 4-2: Culvert at the Morange Road Flooding Location (Multiple Inlets Near Underpass)

To establish the current level of protection of the sewer system against flooding (level of service), the existing conditions SWMM hydrologic and hydraulic (H&H) systemwide model was simulated for the typical year wet weather conditions using the EPA SWMM5 engine Version 5.0.013. The flooding at this location results from a combination of limited capacity in the combined sewer and large peak flows conveyed from the upstream areas, which results in backflow from the combined sewer into the storm sewer, and then flow exiting the inlets in Morange Road. It appears that multiple inlets have been constructed in the flooding location area, which actually exacerbates the flooding because the inlets allow more flow to escape from the sewer system.

The model simulation results were analyzed to identify the wet weather events in the typical year for which the depth of flow (for the manholes in which flooding was indicated in the model), does not rise high enough to cause street flooding. For the manholes in the Morange Road area, the largest event in the typical year that does not result in flooding was the storm that occurred on July 22, 2003. This event had a maximum intensity of 0.96 inches per hour and rainfall volume of 1.158 inches over 19 hours. Both the maximum intensity and rainfall volume for this event have a return period less than one year; therefore, the current level of service to protect against surface flooding from the existing sewer system is less than a one year storm event, meaning the model results indicate that annual flooding likely occurs at this location.

4.1.2 Frankstown Avenue Hazard Flooding Location

This location is along Frankstown Avenue in the A-42 sewershed, eventually draining to Allegheny River, in the 13th Ward near the Homewood area of the City of Pittsburgh. In the existing conditions H&H model, the sewers along Frankstown Avenue were not included. To simulate the flooding for this Assessment, the model was modified by adding the 15-inch diameter sewer along Frankstown Avenue between Standard Avenue and Angora Way, and adjusting the model subcatchments used to represent the hydrologic characteristics of the area. Figure 4-3 shows the general area around the Frankstown Avenue flooding location, along with the 15-inch diameter trunk sewer that was added to the model, and Figure 4-4 shows a photograph of the stretch of Frankstown Avenue that experiences flooding.

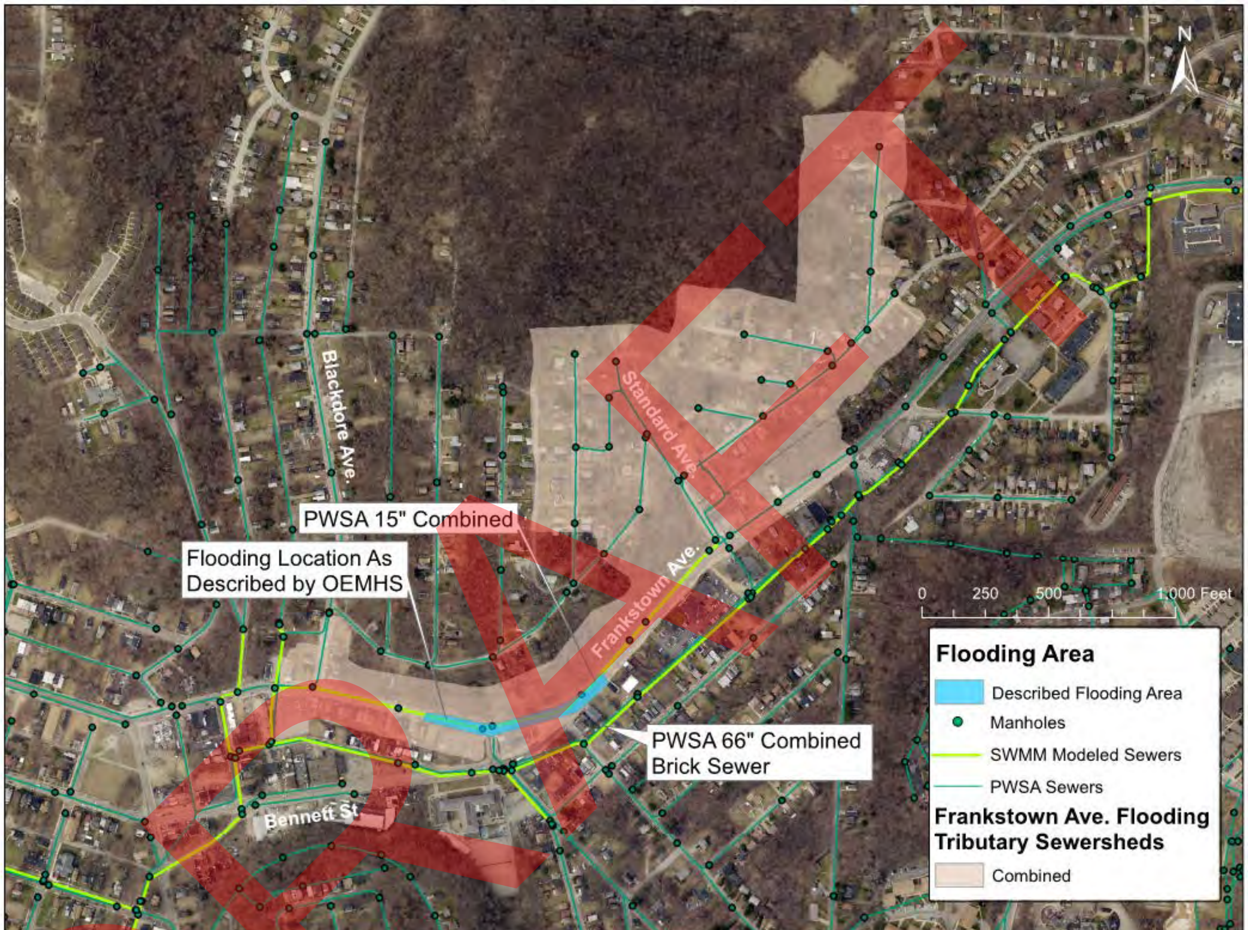

Figure 4-3: General Area around the Frankstown Avenue Flooding Location

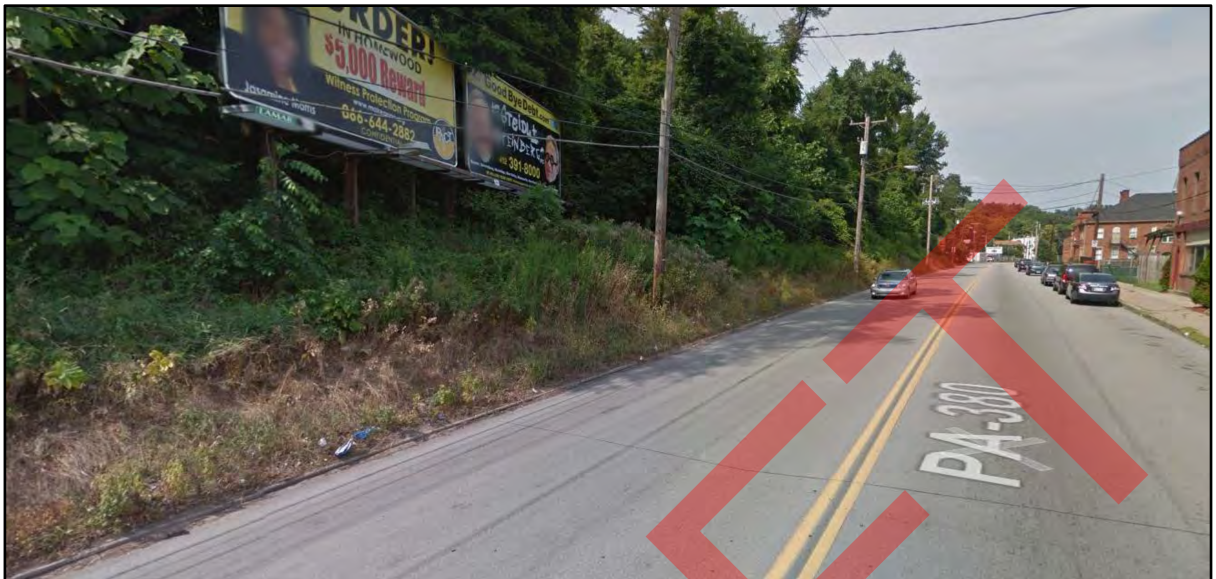

Figure 4-4: Frankstown Avenue Flooding Area

To establish the current level of service within the existing combined sewer, the modified existing conditions systemwide H&H model was used to simulate wet weather conditions for the typical year using the EPA SWMM5 engine version 5.0.013. The flooding at this location results from the introduction of significant peak flows from areas upstream of a stretch of flat-sloped pipes. The model simulation results were analyzed to identify the wet weather events in the typical year for which the depth of flow (for the manholes in which flooding was indicated in the model), does not rise high enough to cause street flooding. For the manholes in the Frankstown Avenue area, the largest event in the typical year that does not result in flooding occurred on December 10, 2003. This event has a maximum intensity of 0.58 inches per hour and rainfall volume of 1.353 inches over 19.5 hours. Both the maximum intensity and rainfall volume for this event have a return period less than one year; therefore, the current level of service provided by the existing collection system to prevent flooding is less than a one year storm event, meaning the model results indicate that annual flooding likely occurs at this location.

4.1.3 Streets Run Hazard Flooding Location

Streets Run is a 5.2-mile-long tributary to the Monongahela River; the downstream portion of the stream is in the Hays neighborhood of the City of Pittsburgh. The tributary area of this urban stream includes portions of Pittsburgh and the boroughs of Baldwin, Brentwood, West Mifflin, and Whitehall. Streets Run is located in the M-42 sewershed.

There are two locations along Streets Run that were evaluated for flooding concerns. One of the flooding locations is at the GalvTech Building along Baldwin Road, upstream of the point where the Streets Run stream enters a culvert. The streamflow in the culvert eventually discharges to the Monongahela River. Figure 4-5 illustrates the locations of the sanitary sewers, the open stream, and the stream culvert near the GalvTech Building, and Figure 4-6 shows Streets Run just upstream of the GalvTech Building along Baldwin Road.

The second Streets Run flooding location, upstream of the GalvTech flooding location, is at Calera Street where the stream makes two 90 degree bends while crossing under a small bridge. Figure 4-7 shows the general area of the Calera Street flooding location, and Figure 4-8 shows the bridge over Streets Run at Calera Street.

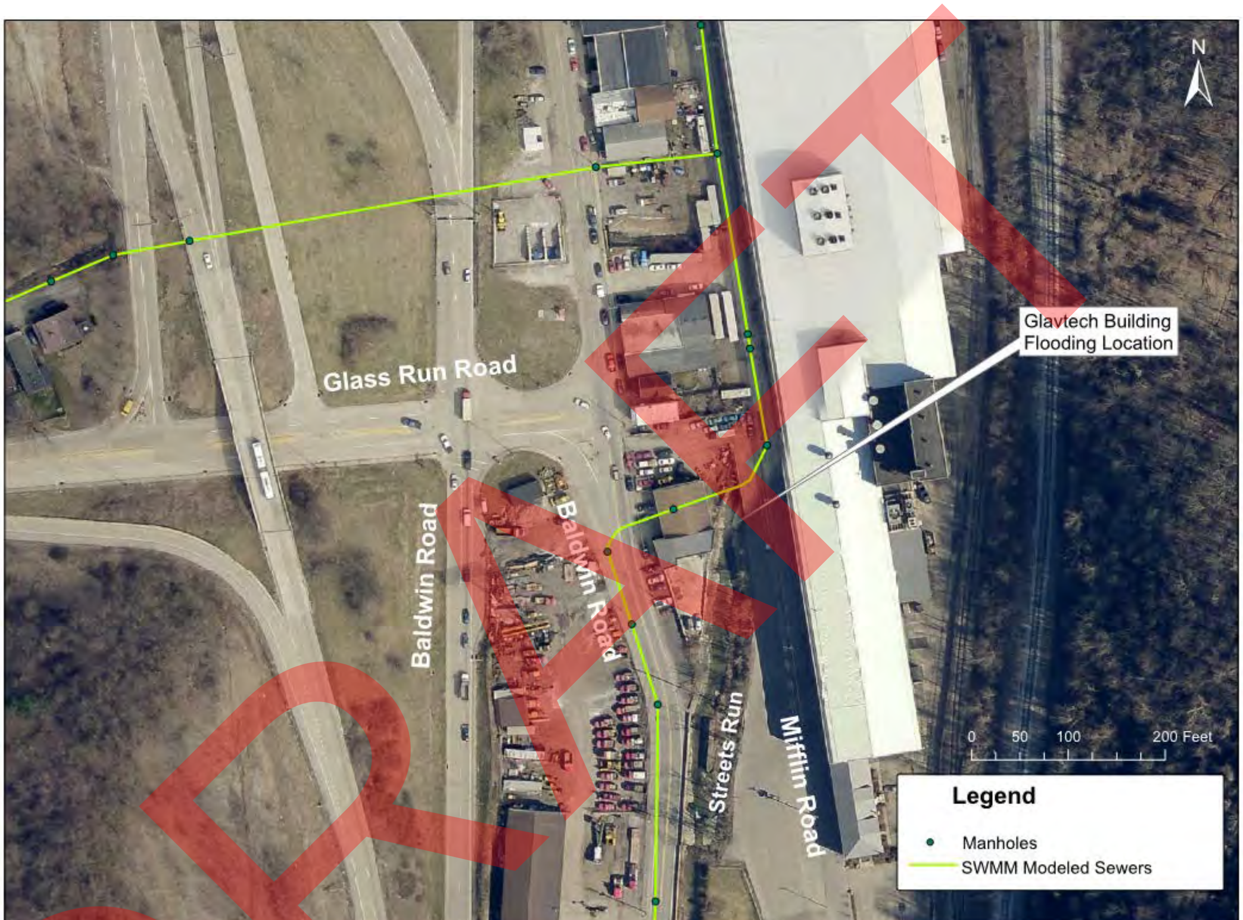

Figure 4-5: The GalvTech Building Flooding Location Area

Figure 4-6: Streets Run Just Upstream of the GalvTech Building

To establish the current level of service for this hazard location, the Streets Run stream water quality model was obtained from ALCOSAN and was simulated for the typical year wet weather conditions using the EPA SWMM5 version 5.0.013. The flood level elevation at the GalvTech Building was established using the information included in the model, and for the Calera Street location the flood elevation was determined through field investigations. The flood level at the GalvTech Building was determined to be 11.5 feet, and for Calera Street it was determined to be 5.5 feet above the bottom of the stream. For the channel nodes included in the model to represent these stream locations, the model simulation results were analyzed to identify the largest wet weather event in the typical year for which the depth of flow at any of these nodes does not exceed the flood level. For both of these flooding locations along Streets Run, it was determined that the largest event in the typical year that does not exceed the flood levels occurred on June 20, 2003. This event has a maximum intensity of approximately 1.06 inches per hour and rainfall volume of 1.7 inches over 18.25 hours. Both the maximum intensity and rainfall volume for this event have a return period less than one year; therefore, the current level of service to prevent flooding is less than a one year storm event, meaning the model results indicate that annual flooding likely occurs at this location.

Figure 4-7: Calera Street Flooding Area

Figure 4-8: Calera Street Bridge Over Streets Run

4.1.4 Nine Mile Run

The Nine Mile Run watershed is an urban watershed located in Pittsburgh's East End, and the stream is a tributary to the Monongahela River. Nine Mile Run is in the M-47 sewershed and flows to the Monongahela River. The stream receives overflows from seven combined sewer diversion structures located in Pittsburgh, and three sanitary sewer diversion structures located in Edgewood Borough.

The flood prone location along Nine Mile Run that was evaluated in this study is the culvert crossing at Commercial Street, near the southern end of Frick Park in the City of Pittsburgh. The water quality model for Nine Mile Run as received from ALCOSAN did not include the culvert at the flooding location. The culvert dimensions were measured in the field and the culvert was added to the model. Figure 4-9 illustrates the general area around the Commercial Street flooding location, and Figure 4-10 shows the upstream side of the culvert that floods during significant wet weather events.

Figure 4-9: General Area of the Commercial Street Flooding Location along Nine Mile Run

Figure 4-10: Flooding Location at Commercial Street Culvert along Nine Mile Run

To establish the current level of service at this flooding location, the stream water quality model for Nine Mile Run was simulated for the typical year wet weather conditions using the EPA SWMM5 engine Version 5.0.013. The flood level at the Commercial Street culvert was measured in the field as 8.42 feet. For the channel node in the model representing this location, the model simulation results were analyzed to identify the largest wet weather event in the typical year for which the depth of flow at this node did not exceed the flood level. For this location along Nine Mile Run, the largest event in the typical year that did not exceed the flood levels was found to occur on July 4, 2003. This event has a maximum intensity of approximately 1.77 inches per hour and rainfall volume of 0.69 inch over 1.75 hours. Both the maximum intensity and rainfall volume for this event have a return period less than one year; therefore, the current level of service to prevent flooding is less than a one year storm event, meaning that model results indicate that annual flooding likely occurs at this location.

4.2 Analysis of Increased Levels of Service

Increased levels of service were analyzed for each of the four flooding hazard areas discussed above. Model simulations were conducted with varied wet weather conditions, along with estimated area reductions in upstream tributary areas to simulate reduced stormwater runoff, to determine various levels of service that could potentially be achieved with GI and best management practice (BMP) applications for stormwater management. The wet weather conditions evaluated were:

- Wet weather events in the typical year
- 2-Year frequency, 24-hour duration design storm
- 5-year frequency, 24-hour duration design storm

- 10-year frequency, 24-hour design storm;
- 25-year frequency, 24-hour design storm;
- August 31, 2014 storm - In PWSA's A-22 sewershed study to address flooding issues in the Shadyside area of Pittsburgh, the August 31, 2014 storm was assumed as a flooding level of protection in the analysis. This was the most recent wet weather event that resulted in flooding in the Shadyside area. This storm had a rainfall intensity of 1.05 inches in 15 minutes, and a rainfall volume of 2.25 inches in 10 hours. This rainfall intensity has occurred in 4 of the last 6 years (through 2015).

The results for evaluating increases in level of service for each flooding area are described as follows.

4.2.1 Morange Road

The flooding at the intersection of Morange Road and the West Busway is mostly attributed to large amounts of stormwater entering the combined sewer system such that the conveyance capacity of the combined sewer system is exceeded, resulting in flow backing up through the connected storm sewers and localized flooding occurring along Morange Road. But the location of this flooding is such that it impacts the sewers from two municipalities, Crafton Borough and the City of Pittsburgh. The sewer surcharge conditions exist for some distance upstream of this location, causing multiple manholes to flood along the 24-inch diameter Crafton sewer and the 30-inch and 36-inch diameter segments of the PWSA sewer. Figure 4-11 shows the existing conditions hydraulic grade line (HGL) profile along the PWSA sewer during a wet weather event on August 29, 2003. The August 29, 2003 event was found to be the most severe storm in this sewershed in the typical year. In Figure 4-11, flooding is indicated where the wastewater flow level (in blue) reaches the tops of the manholes; this occurs at four manholes for this wet weather event. Since most of the flooding results from significant peak flows entering the collection system during wet weather, a reduction in the peak flow is the desired solution. This may be achieved by reducing the surface runoff from the combined areas upstream of the flooded manholes.

As previously mentioned, the current level of service provided by the existing collection system is less than a 1-year recurrence storm event. Increased level of service was evaluated for various wet weather conditions: the typical year, the 2-year, 5-year, 10-year, and 25-year frequency 24-hour duration design storms, and the August 31, 2014 event. The systemwide model was used to simulate the system response to these rainfall events, and to vary levels of impervious area reductions (to simulate reductions in stormwater runoff with GI, best management practices (BMPs), or similar) to estimate the amount of impervious area reduction that would reduce the flooding at the manholes in this area. The impervious area reduction was implemented in the model simulations by removing areas from the model so that no wet weather contribution was generated in these areas. This represents the impervious area to be managed by GI and BMPs to reduce stormwater runoff in these impervious areas.

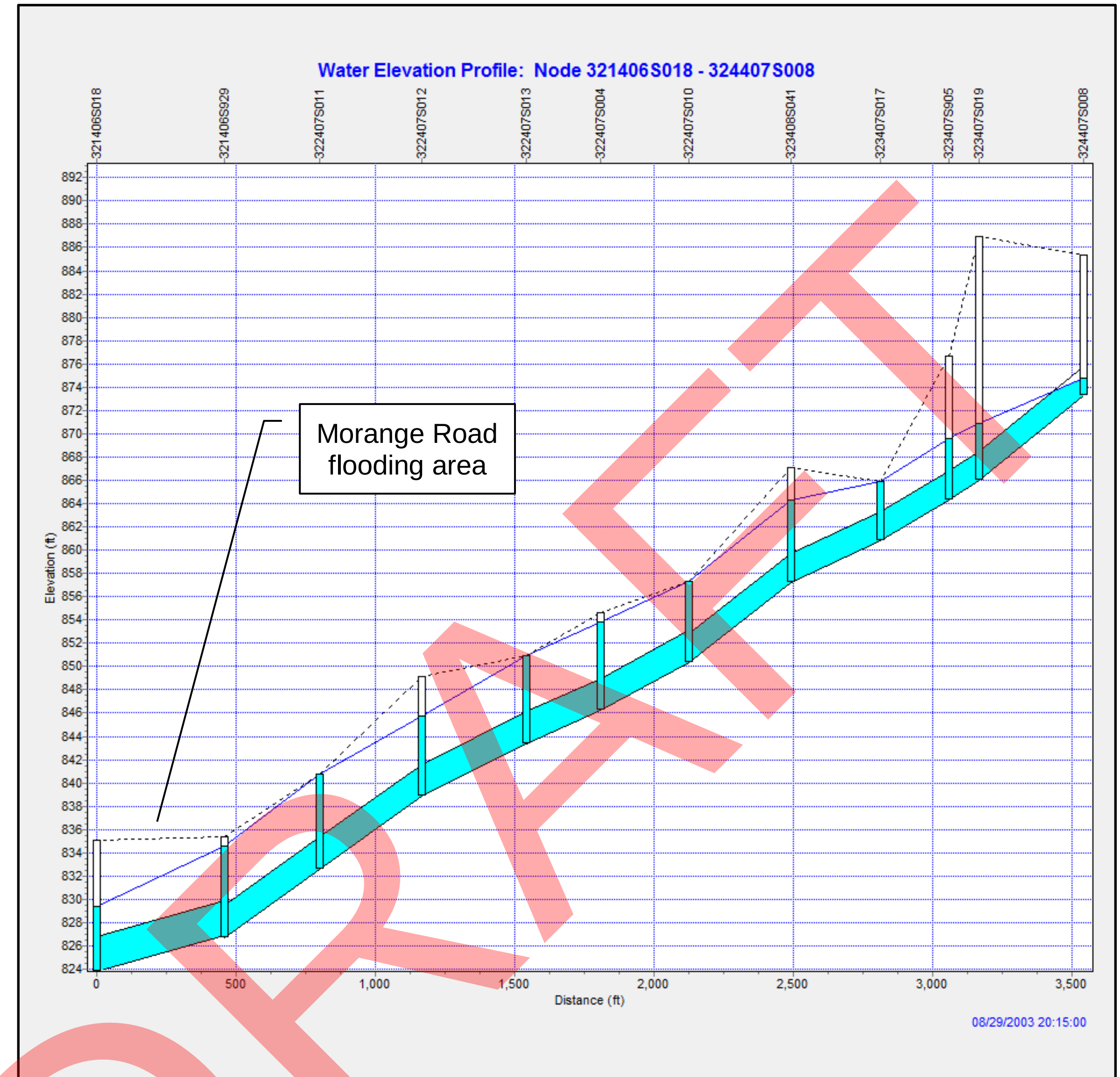

Figure 4-11: Existing Conditions HGL Profile along the Morange Road PWSA Sewer for the Wet Weather Event on 8/29/2003

The Crafton trunk sewer receives runoff from combined sewersheds within C-24. The C-24 subcatchment area upstream of the flooding location is composed of 8.65 acres of impervious area and 32.13 acres of pervious area, for a total of 40.78 acres. Table 4-2 shows the percentage of impervious area that would need to be managed with GI BMPs to mitigate the flooding at the manholes along the Crafton trunk sewer.

The August 31, 2014 storm was analyzed because it was found to be severe and caused flooding in several areas of the City.

TABLE 4-2 IMPERVIOUS AREA MANAGEMENT PERCENTAGES IN THE CRAFTON AREAS OF MORANGE ROAD		
Level of Service (Wet Weather Condition)	**Impervious Area Management (%) Tributary to the Crafton Trunk Sewer (C-24)**	**% of Total Area**
Typical Year	30	6.4%
2 Year	10	2.1%
5 Year	40	8.5%
10 Year	50	10.6%
25 Year	70	14.8%
Aug. 31, 2014 Storm	50	10.6%

Most of the area contributing runoff to the flooding at Morange Road is in sewershed C-25 within the City of Pittsburgh, and also includes wastewater flows from Green Tree Borough. Figure 4-12 shows the tributary area in the C-25 sewershed. Table 4-3 lists the distribution of tributary combined area for the C-25 sewershed.

TABLE 4-3 TRIBUTARY COMBINED AREA IN C-25 SEWERSHED			
Area (acres)	**Impervious**	**Pervious**	**Total**
C-25 Area Upstream of Morange Rd	80.25	236.79	317.04
C-25 Area Downstream of Morange Rd	19.32	93.65	112.97
C-25 Total Sewershed Area	99.57	330.44	430.01

Figure 4-12: Tributary Area in the C-25 Sewershed

To analyze how to mitigate the flooding at manholes along the PWSA sewer, simulations were conducted to represent impervious area reduction in the areas upstream of the Morange Road flooding location. This did not result in elimination of flooding for the higher magnitude storms. Then, a simulation was conducted in which the impervious area was reduced for the entire C-25 sewershed, incorporating an additional 19.3 acres of impervious area downstream of the Morange Road flooding location. This did not eliminate the flooding for the higher magnitude storms. In an attempt to increase the amount of runoff control, subsequent simulations included area reductions for both impervious and pervious areas for the entire C-25 sewershed. Figure 4-13 shows the HGL profile along the PWSA combined sewer for the August 29, 2003 event in the typical year, with a simulation incorporating a 30 percent area reduction.

Table 4-4 shows the percentage of area that would need to be removed in the City of Pittsburgh areas of C-25 to mitigate the flooding at the manholes along the PWSA trunk sewer.

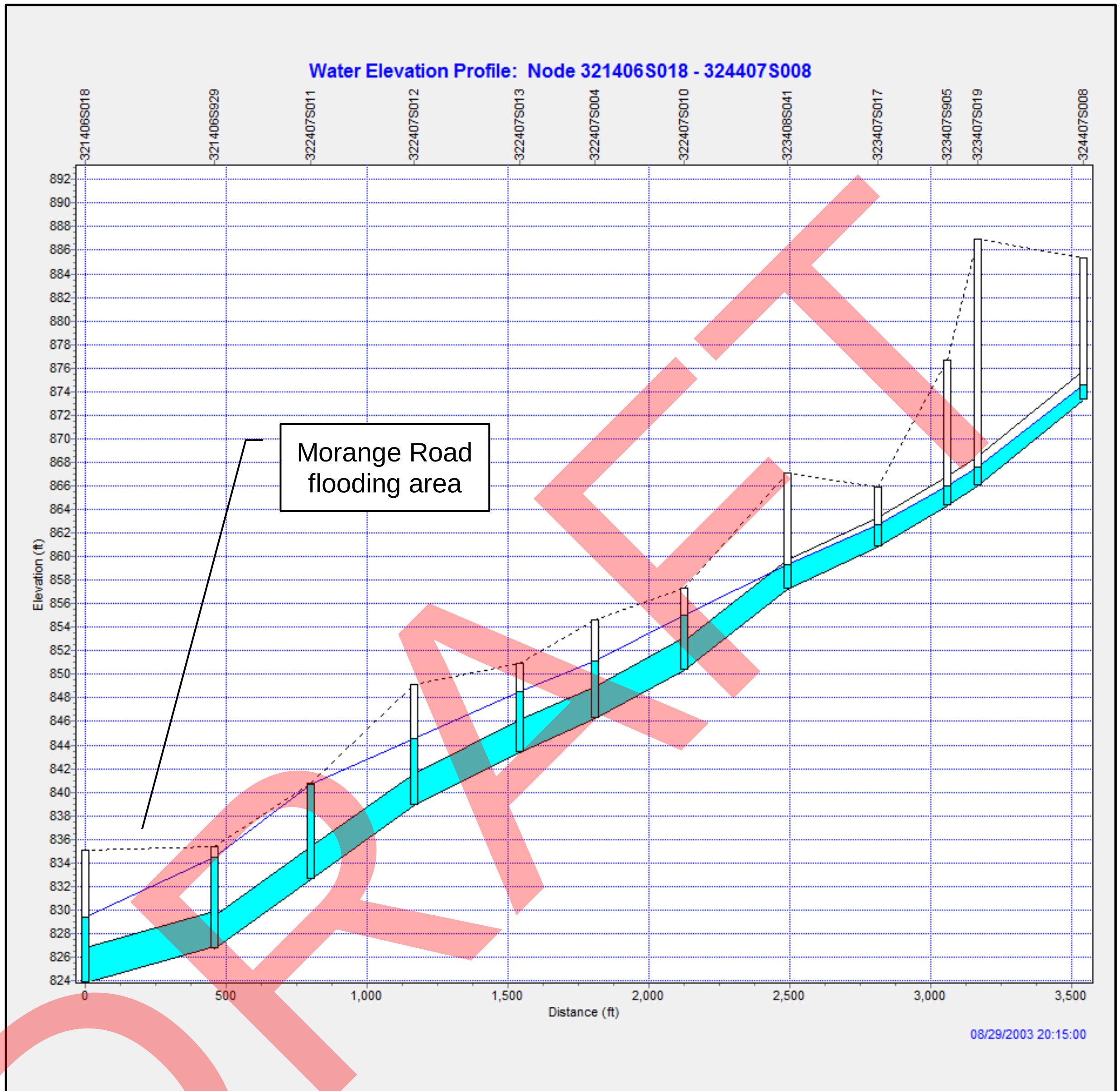

Figure 4-13: HGL Profile Along PWSA Sewer in the Morange Road area with 30% Area Reduction

Table 4-4 shows that a significant reduction of stormwater runoff entering the Pittsburgh combined sewer from both impervious and pervious areas would be needed to achieve a level of service to reduce the flood frequency under more severe storm conditions than the typical year events. For example, a 50% reduction in stormwater runoff would be needed for a 2-year frequency level of control, and a 60% reduction in stormwater runoff would be needed for a 5-year frequency storm and the August 31, 2014 event level of control.

For an urbanized area, these levels of reduction may be too great to achieve the desired level of service with GI facilities alone. It may be more feasible to investigate a blend of green and gray facilities, such as more regionalized detention coupled with local GI BMPs, including downspout disconnections, to achieve the desired level of service. In addition, it is recommended that the City continues coordination of impervious area reductions in the C-25 sewershed with Green Tree Borough.

TABLE 4-4
AREA MANAGEMENT PERCENTAGES USING GI AND BMPs IN THE CITY OF PITTSBURGH AREAS OF MORANGE ROAD TO MITIGATE FLOODING

Level of Control (Wet Weather Condition)	Area Management (%) in C-25
Typical Year	30
2 Year	50
5 Year	60
10 Year	70
25 Year	80
August 31, 2014 Storm	60

4.2.2 Frankstown Avenue

As previously mentioned, in the existing conditions model the sewers along Frankstown Avenue were not included in the model obtained from ALCOSAN. To simulate the hydraulic conditions for this area, the 15-inch diameter combined sewer along Frankstown Avenue between Standard Avenue and Angora Way was added to the H&H model, and the area contributing flows to this sewer was delineated. This area is derived from two adjacent sub-catchments in the A-42 sewershed, as shown in Figure 4-14. Figure 4-14 also shows the area delineated for the Frankstown Avenue flooding location. This area is composed of 2.55 acres in the smaller subcatchment, plus 42.60 acres in the larger subcatchment, for a total of 45.15 acres. This area comprises 10.22 acres of impervious area and 34.93 acres of pervious area.

Figure 4-14: Areas Contributing Flows along Frankstown Avenue

The flooding along Frankstown Avenue is mostly attributed to peak flows entering the combined sewer system just upstream of a stretch of flat pipe, causing the conveyance capacity of the combined sewer system to be exceeded. These existing conditions result in localized flooding. Figure 4-15 shows the existing conditions HGL profile in the 15-inch diameter sewer along Frankstown Avenue during a wet weather event (August 29, 2003) in the typical year. The results show that flooding at one manhole would occur for this storm condition.

Figure 4-15: Existing Conditions HGL Profile in the 15-inch Diameter Sewer Along Frankstown Avenue

To simulate various ways to mitigate the flooding at this location, the entire impervious area of 10.22 acres was removed to simulate stormwater runoff management with GI. This was not effective for eliminating flooding for the design storm conditions. Furthermore, simulating removal of both the impervious and pervious areas indicated that this was not effective in eliminating the flooding. After determining that reduction of the stormwater runoff alone cannot mitigate the flooding, it was deemed necessary to consider improvements to the existing conveyance system. Improving the conveyance of the existing system was simulated by increasing the diameter of the trunk sewer along Frankstown Avenue from 15 inches to 30 inches, while maintaining the existing slope of the pipes. In the upsized pipe scenario simulations, the impervious area was reduced to the degree needed to mitigate flooding. Thus, the model results indicate that both green and gray solutions are likely necessary to mitigate flooding at this hazard location.

Figure 4-16 shows the HGL profile of the upsized 30-inch diameter sewer during the August 29, 2003 event in the typical year. This illustrates that there is no flooding expected for this event, with an upsized pipe diameter of 30 inches and with zero impervious areas removed. Table 4-5 shows the percentage of impervious area that would need to be removed to mitigate the flooding at the manholes of the upsized trunk sewer along the Frankstown Avenue for various wet weather scenarios.

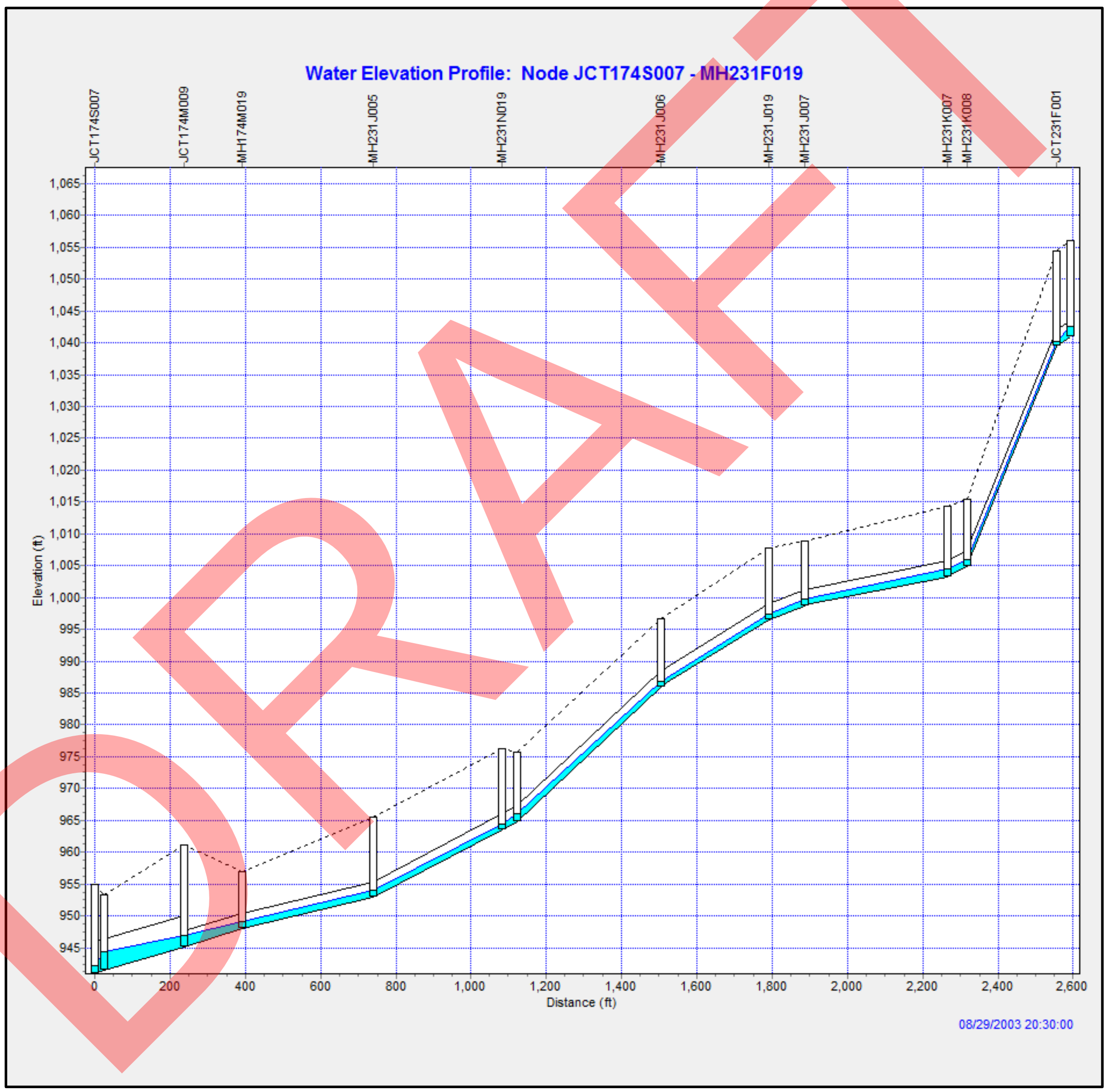

Figure 4-16: HGL Profile for the Upsized 30-inch Diameter Sewer (Gray) Scenario Along Frankstown Avenue

Table 4-5 shows that with an upsized pipe and no reduction in impervious area, flooding is mitigated in the typical year and for the 2-year frequency storm. However, for more severe storms, even with the combined sewer pipe upsized to 30 inches in diameter, a significant amount of impervious area management would be needed to achieve greater levels of service to mitigate flooding. For storms analyzed that are more severe than a 2-year frequency storm, management of at least 80% impervious area would need to be employed to mitigate flooding for these storm conditions. For an urbanized area, management of 80% impervious area may be too great to achieve the desired level of service with GI facilities alone. It may be more feasible to investigate an increase in pipe size beyond 30 inches in diameter, a different pipe slope configuration, or a combination thereof, with a lower percentage of impervious area management, to achieve the desired level of service.

TABLE 4-5
IMPERVIOUS AREA MANAGEMENT PERCENTAGES FOR THE UPSIZED SEWER SCENARIO TO MITIGATE FLOODING ALONG FRANKSTOWN AVENUE

Level of Service (Wet Weather Condition)	Impervious Area Reduction (%)
Typical Year	0
2 Year	0
5 Year	80 (after allowing for backwater)
10 Year	100 (after allowing for backwater)
25 Year	>100
August 31, 2014 Storm	80 (after allowing for backwater)

4.2.3 Streets Run

There are two locations along the Streets Run stream that were evaluated for flooding concerns, the upstream location at Calera Street and the downstream location at the GalvTech Building.

Flooding has been reported at the Calera Street location, and to determine the degree that GI may improve existing conditions, stream model simulations were conducted using area reduction analysis for the areas upstream of this location. There are 4,299 acres upstream of the Calera Street flooding location, of which 409 acres are impervious and 3,890 acres are pervious. Figure 4-17 shows the area tributary to the Calera Street flooding location. The impervious area is less than 10 percent of the total area upstream of the flooding location, which, managed alone, does not substantially reduce flooding. Thus, the model simulation included removal of both impervious and pervious areas to simulate reductions in stormwater runoff through GI BMPs to various levels to mitigate flooding for the typical year wet weather conditions, selected design storms, and the August 31, 2014 event.

The stream baseflow is generated in the Streets Run stream model, and to analyze higher depths of flow, the rainfall intensities for the various rainfall events were simulated with the peak baseflow condition that occurred during the typical year.

Using the Streets Run stream model for wet weather events in the typical year, the results showed that the maximum depth at the Calera Street Bridge is projected to be 6.3 feet. This exceeds the flood threshold of 5.5 feet, and the model confirmed that this location experiences flooding during the typical year conditions. Figure 4-18 illustrates the flooding extent for the 8/31/14 storm event, as determined from the modeling simulations.

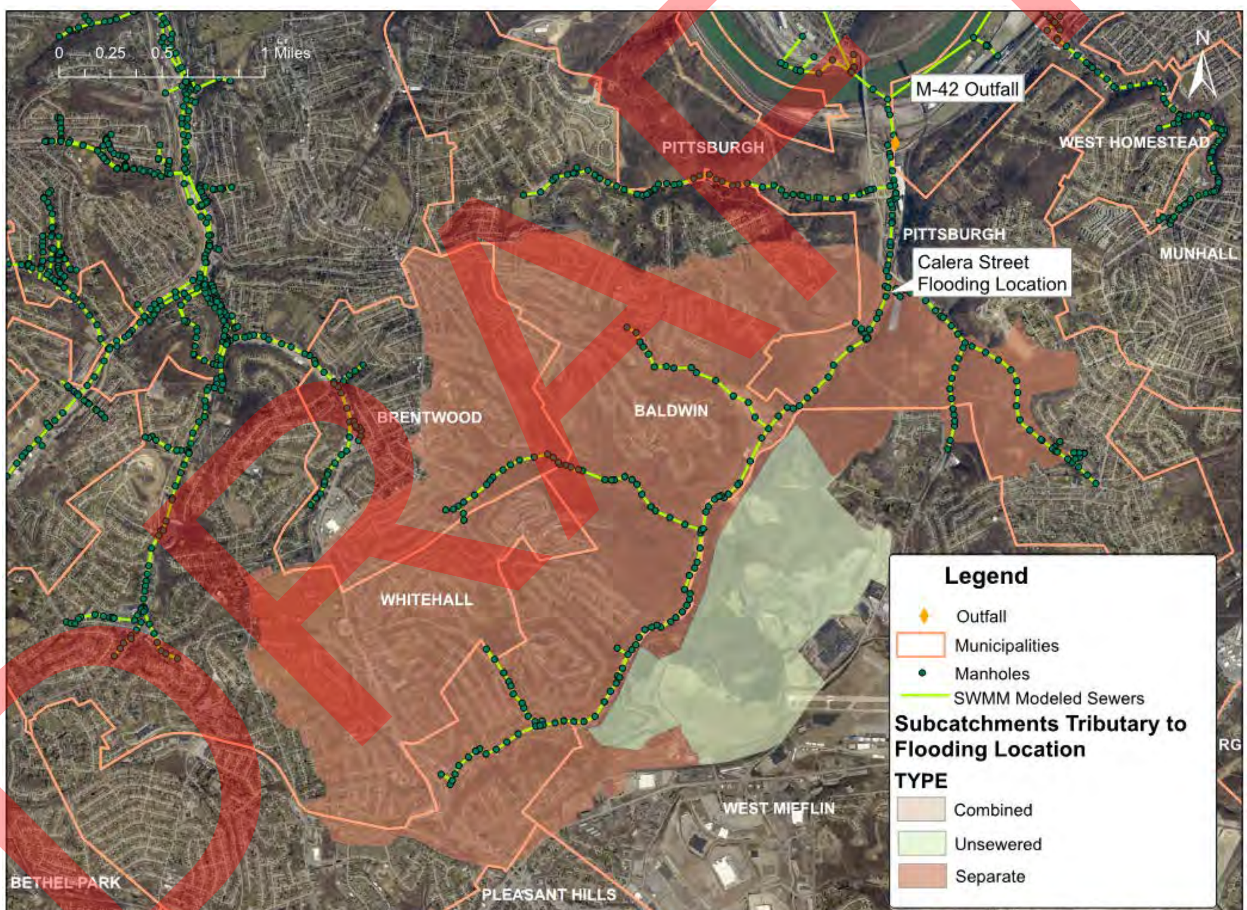

Figure 4-17: Areas Contributing Flows to the Calera Street Flooding Location

Figure 4-18: Calera Street Area Flooding for August 31, 2014 Event, Modeled Results

Table 4-6 shows the percentage of tributary area that would need to be managed to mitigate the flooding at Calera Street and the GalvTech Building. The table shows that a significant amount of area would need to be managed to mitigate flooding. For example, for the typical year events, 50 percent of the area (impervious and pervious) would need to be managed upstream of the Calera Street location to reduce the maximum depth at the Calera Street Bridge to a depth less than the flood threshold of 5.5 feet. For the more severe design storms, a significant amount of both impervious and pervious area management would be needed to achieve a level of service to mitigate flooding. For storms analyzed that are more severe than a 2-year frequency storm, at least 70% of the area would need to be managed to mitigate flooding for these storm conditions.

Model simulations of the storm event on August 31, 2014 (rainfall intensity of 1.05 inches of rain in 15 minutes) show that managing stormwater runoff from 30% of the area upstream of Calera Street would mitigate the flooding. The reason the impervious area runoff management is 70% at the GalvTech Building is the existing stream is narrowed as it enters the culvert pipe along the building. This culvert pipe is severely undersized for these large events, resulting in flooding. For a highly developed area, 70% area management may be too great to achieve the desired level of service with GI facilities alone, and it is likely that a blend of gray and green facilities would be more feasible to achieve the desired level of service. However, for the Calera Street location, achieving 30% reduction of stormwater runoff from the upstream areas is more manageable, and a combination of regional detention, local GI BMPs, and targeted downspout disconnection could be feasible. Future analysis of the Streets Run flooding should focus on the Calera Street location, because it is the most upstream location, and managing stormwater upstream will also reduce flooding at the GalvTech Building. Future projects to reduce flooding at the GalvTech Building could then be considered after the stormwater management work upstream of Calera Street is completed.

TABLE 4-6
AREA MANAGEMENT PERCENTAGES REQUIRED TO CONTROL STREETS RUN FLOODING

Level of Service (Wet Weather Conditions)	Impervious and Pervious Area Management (%)	
	GalvTech Building	Calera Street
Typical Year	50	50
2-year, 24-Hour	40	0
5-year, 24-Hour	80	50
10-year, 24-Hour	>100	60
25-year, 24-Hour	>100	70
August 31, 2014 Storm	70	30

As shown in Figure 4-17, several municipalities contribute stormwater runoff and storm flows to storm sewers in this area. In addition to Pittsburgh, other municipalities contributing flows are Baldwin Borough, Brentwood Borough, Whitehall Borough, and West Mifflin. It is recommended that a solution should be coordinated together among these municipalities.

4.2.4 Nine Mile Run

The flood-prone location along Nine Mile Run that was evaluated in this study is the culvert crossing at Commercial Street. In the Nine Mile Run stream model there are 2,589 acres upstream of the culvert, of which 388 acres are impervious and 2,201 acres are pervious. Figure 4-19 shows the areas within the M-47 sewershed that are tributary to the Commercial Street flooding location. The impervious area is less than 15 percent of the total area upstream of the flooding location, which is not enough area of potential management to mitigate the flooding. In the model simulations, both impervious and pervious areas were removed to simulate reductions in stormwater runoff to various levels to mitigate flooding for the typical year wet weather events, design storms, and the

August 31, 2014 event. Figure 4-20 illustrates the flooding area for the 8/31/14 storm event, as determined from the modeling simulations.

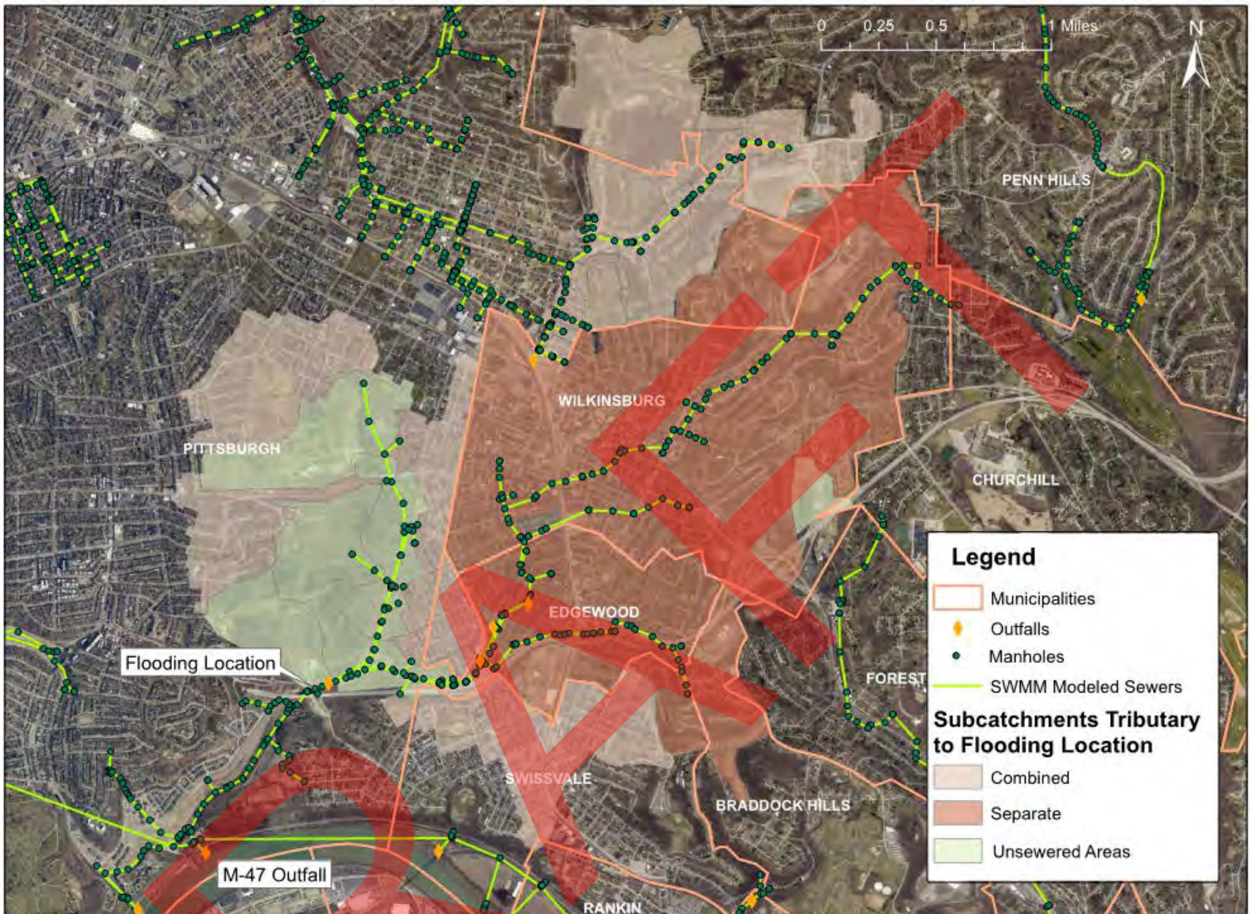

Figure 4-19: Areas Contributing Flows to the Commercial Street Culvert Flooding Location

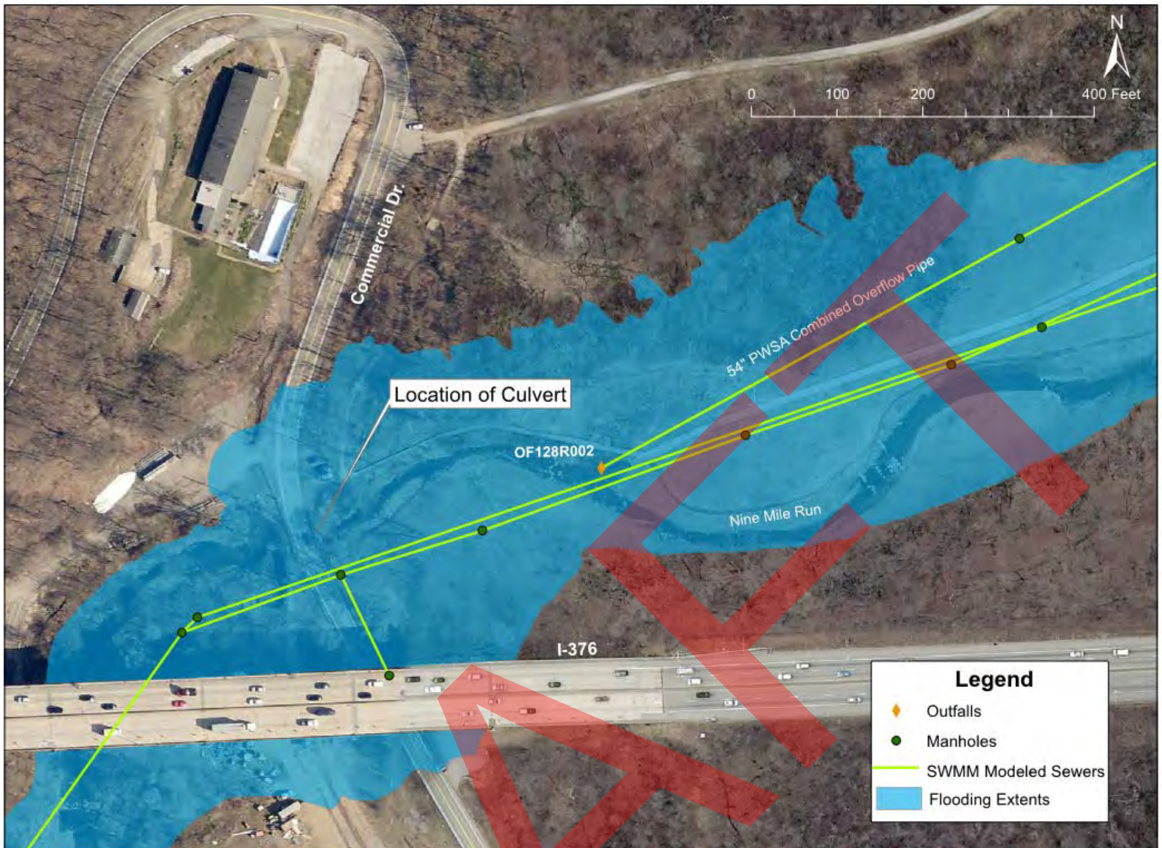

Figure 4-20: Commercial Street Area Flooding for August 31, 2014 Event, Modeled Results

The Nine Mile Run stream baseflow is generated in the stream model, and to analyze higher depths of flow, the rainfall intensities for the various rainfall events were simulated with the peak baseflow condition that occurred for the typical year.

Table 4-7 shows the percentage of area, both impervious and pervious, that would need to be managed to mitigate the flooding at the Commercial Street culvert. The model results show that to reduce the stream level to at or below the flood threshold level of 8.42 feet for more severe conditions than the typical year events and the 2-year frequency event, a significant amount of area management, 70% or greater, would need to be employed. This degree of area management may not be feasible in a highly developed urban area, and perhaps a blend of green and gray facilities should be investigated to achieve the desired level of service. As shown in Figure 4-19, several municipalities contribute flows to the combined and storm sewers in this area. In addition to Pittsburgh, other municipalities contributing flows are Wilkinsburg, Edgewood, Swissvale, Braddock Hills, and Penn Hills. It is recommended that a solution is coordinated together among these municipalities.

TABLE 4-7
AREA MANAGEMENT PERCENTAGES REQUIRED TO CONTROL FLOODING AT THE COMMERCIAL STREET CULVERT

Level of Service (Wet Weather Conditions)	Impervious and Pervious Area Management (%)
Typical Year	0
2-year, 24-Hour	30
5-year, 24-Hour	70
10-year, 24-Hour	80
25-year, 24-Hour	90
August 31, 2014 Storm	70

4.3 Establish Target GI Implementation Level

To evaluate the degree of GI and BMP facilities that could be established to mitigate flooding in the four flooding hazard areas, model simulations were conducted for a specific wet weather event to develop a target area for stormwater runoff management with GI BMPs. The wet weather condition evaluated was the August 31, 2014 storm. For PWSA's A-22 Sewershed study to address flooding issues in the Shadyside area of Pittsburgh, the August 31, 2014 storm was selected for the level of service because it was a recent extreme rain event that resulted in flooding in the Shadyside area. This event had a peak intensity of 1.05 inches in 15 minutes and a rainfall volume of 2.26 inches over 10 hours. For the four flood hazard locations evaluated in this GI Assessment study, it was assumed that this same level of service was also considered appropriate. The A-22 Sewershed study and this GI Assessment study determined for the August 31, 2014 event condition that detaining and slowly releasing the first 1.5 inches of runoff entering the sewer system could mitigate surface flooding and basement sewage backups while also reducing combined sewer overflows. This design criteria was selected for the four flood hazard areas.

The results of the target GI implementation analysis for the four flooding areas are described as follows.

4.3.1 Morange Road

For this area, manhole flooding in the Pittsburgh trunk sewer that results in flooding along Morange Road was observed in the model results for the 30 and 36-inch diameter portions of the PWSA trunk sewer. The 30-inch and 36-inch diameter PWSA sewer experiences significant surcharge and manhole flooding, and to mitigate the flooding for the August 31, 2014 event conditions, the amount of runoff that needs to be managed cannot be achieved from only the Pittsburgh area upstream of Morange Road. Stormwater runoff from both impervious and pervious areas needs to be managed in the entire C-25 sewershed. As indicated in Table 4-4, to mitigate the flooding for the August 31, 2014 event, 60 percent of the area in the C-25 sewershed would require stormwater runoff management. The C-25 sewershed includes 99.6 acres of impervious area and 330.5 acres of pervious area for a total of 430.0 acres. *To mitigate the flooding for the August 31, 2014 event condition, stormwater runoff from 59.7 acres of impervious area and 198.3 acres of pervious area (total 258 acres) would need to be managed, to detain and slowly release the first 1.5 inches of runoff to the combined sewer.* Figure 4-21 shows the HGL profile along the PWSA trunk sewer with the stormwater runoff in upstream areas managed.

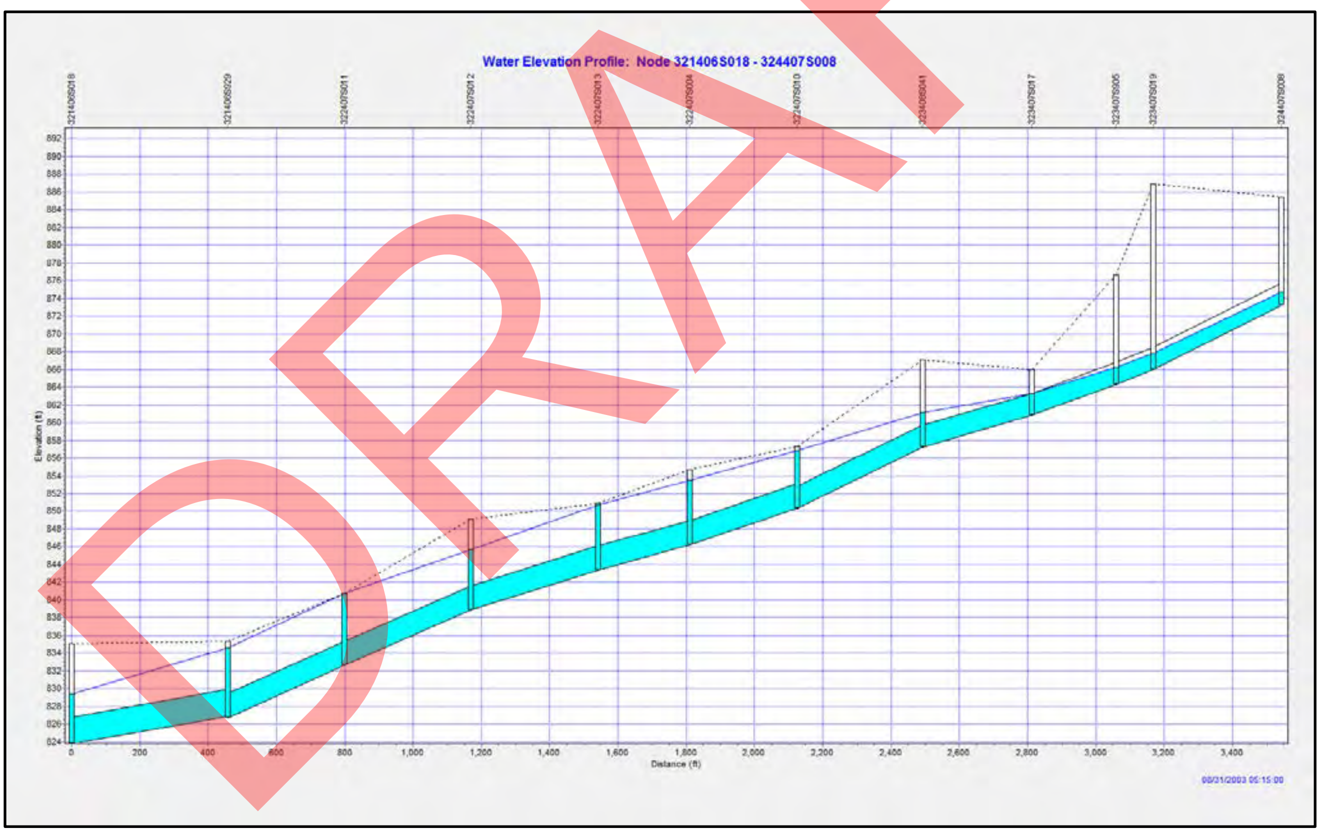

Figure 4-21: HGL Profile for the PWSA Trunk Sewer along Morange Road, with Stormwater Runoff Managed from 60% Area in the C-25 Sewershed, 8/31/2014 Event

4.3.2 Frankstown Avenue

For this area, upsizing the sewer along Frankstown Avenue from 15 inches to 30 inches in diameter was sufficient to control the flooding during the typical year wet weather events. As indicated in Table 4-5, to mitigate the flooding for the August 31, 2014 event, 80 percent of the impervious area would need to be removed. In Figure 4-16, which shows the HGL profile for the upsized 30-inch diameter sewer along Frankstown Avenue, the upstream manhole floods, but this flooding results from the backwater in the downstream trunk sewer, and not from the runoff generated in the Frankstown Avenue contributing areas. The PWSA subcatchments upstream of the flooding location include 10.2 acres of impervious area and 34.9 acres of pervious area, for a total of 45.1 acres. *To mitigate flooding for the August 31, 2014 event condition along the upsized 30-inch diameter trunk sewer, stormwater runoff from 8.17 acres of impervious area would need to be managed to detain and slowly release the first 1.5 inches of runoff to the combined sewer.* Figure 4-22 shows the HGL profile along the upsized 30-inch diameter PWSA trunk sewer along Frankstown Avenue with this impervious area managed. It should be noted that the flooding along the upstream reaches of the profile would be addressed with this scenario, but for this larger event, manholes in the downstream reaches of the profile become flooded due to downstream conveyance limitations.

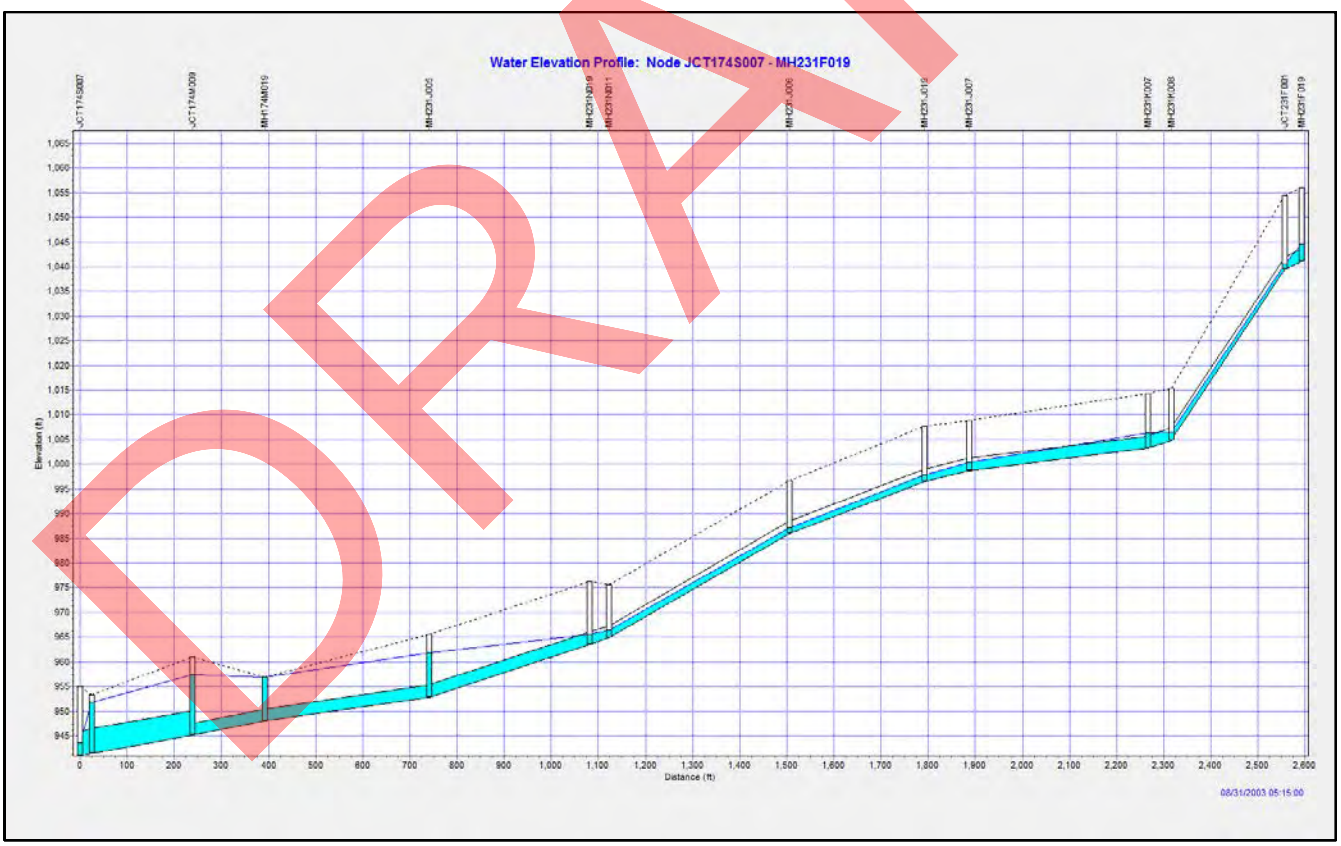

Figure 4-22: HGL Profile for the Upsized 30-inch Diameter PWSA Trunk Sewer along Frankstown Avenue, with Stormwater Runoff from 80% Impervious Area Managed, 8/31/2014 Event

4.3.3 Streets Run

For this location, the primary flooding concern is at the Calera Street Bridge. As indicated in Table 4-6, to mitigate the flooding for the August 31, 2014 event, 30 percent of the area upstream of this location will require stormwater runoff management. The subcatchments upstream of this flooding location include 409 acres of impervious area and 3,890 acres of pervious area, for a total of 4,299 acres. *To mitigate flooding at the Calera Street Bridge for the August 31, 2014 event condition, stormwater runoff from123 acres of impervious area and 1,167 acres of pervious area (total of 1,290 acres) would need to be managed, to detain and slowly release the first 1.5 inches of runoff to the stream.* Model simulations show that with stormwater runoff managed in this total area, the stream depth at the Calera Street Bridge would be reduced to 5.4 feet, less than the flood threshold of 5.5 feet, to address flooding for the August 31, 2014 event condition.

4.3.4 Nine Mile Run

For this location, the flooding concern is at the culvert along Commercial Street. As indicated in Table 4-7, to mitigate the flooding for the August 31, 2014 event, stormwater runoff from 70 percent of the upstream area would need to be managed. The subcatchments upstream of the flooding location include 388 acres of impervious area and 2,201 acres of pervious area, for a total of 2,589 acres. *To mitigate flooding at the Commercial Street culvert for the August 31, 2014 event condition, stormwater runoff from 272 acres of impervious area and 1,541 acres of pervious area (total of 1,813 acres) would need to be managed, to detain and slowly release the first 1.5 inches of runoff to the stream.* The model simulations show that the stream depth at the culvert would be reduced to 7.48 feet, less than the flood threshold of 8.42 feet, to mitigate flooding for the August 31, 2014 event condition.

4.4 Flood Hazard Results Summary

4.4.1 Target GI Implementation Level

Using the results in Section 4.3, Table 4-8 provides a summary of the amount of area requiring stormwater management to mitigate the flooding for the August 31, 2014 event condition at the four hazard locations within Pittsburgh that were part of this evaluation.

TABLE 4-8
TARGET AREA STORMWATER MANAGEMENT TO MITIGATE FLOODING AT PITTSBURGH HAZARD LOCATIONS, 8/31/2014 WET WEATHER CONDITIONS

Location	Stormwater Area Management (acres)		
	Impervious	Pervious	Total
Morange Road (City of Pittsburgh)	59.7	198.3	258.0
Frankstown Avenue[1] (City of Pittsburgh)	8.2	0	8.2
Calera Street Bridge (Streets Run)	123.0	1,167.0	1,290
Commercial Street Culvert (Nine Mile Run)	272.0	1,541.0	1,813.0

[1] Also requires upsizing a portion of the Frankstown Avenue sewer along the flat section from 15 inches to 30 inches in diameter.

4.4.2 Collection System Benefits

The primary objective of this evaluation was to identify measures to address flooding during large rain events at the hazard locations within Pittsburgh, primarily through stormwater management using GI BMPs. By managing the stormwater, additional benefits in terms of reducing flows entering the collection system and reduction of untreated overflow volume were also observed in the modeling. To quantify the overflow reductions at the outfalls impacted by the stormwater runoff managed areas, the collection system for these areas was simulated with the system wide model, and the reduction in overflow volumes for the typical year were quantified.

4.4.2.1 Morange Road

To quantify the overflow reduction benefits, system wide model simulations were conducted for the typical year, reflecting implementation of 60 percent area reduction in all combined subcatchments of the C-25 sewershed only. In addition to the main diversion chamber at the bottom of the sewershed where it ties into the Chartiers Creek interceptor, there are several municipal diversion structures. Table 4-9 presents the typical year overflow volume for these diversion structures and compares the existing conditions with the scenario of 60 percent combined sewer area stormwater runoff managed with GI BMPs for the C-25 sewershed. At the C-25 diversion structure, the typical year overflow volume was reduced from 60.5 million gallons (MG) to 26.7 MG, for a 56 percent reduction. The percent capture (as defined in the EPA CSO Policy, and described in Section 2 of this report) of combined sewage would increase from 59% under existing conditions to 82%, if the target GI level was implemented. For the entire C-25 sewershed, which includes all the upstream overflow and diversion structures, the typical year overflow volume was reduced from 84.1 MG to 34.2 MG, representing a 59 percent reduction.

TABLE 4-9 TYPICAL YEAR CSO VOLUME FOR C-25 DIVERSION STRUCTURES, WITH 60% AREA STORMWATER RUNOFF MANAGEMENT WITH GI IN COMBINED SEWER SUBCATCHMENTS OF C-25 SEWERSHED (MORANGE ROAD AREA)		
CSO Volume (MG)		
Diversion Structure	**Existing Conditions**	**Target GI Scenario: 60% Combined Area Reduction in C-25**
DC039L001 [1]	0.20	0
DC039M001 [1]	17.10	6.21
DC039M002 [1]	2.39	0.48
DC040R001 [1]	0.06	0.01
DC040R002 [1]	0.01	0
CSO-039K001	18.09	5.97
DC068H001	0.41	0.10
DC068H002	4.92	1.45
DC039E001	0.05	0
DC039J001	0.12	0.03
C-25-Weir	60.48	26.68
Total for C-25	84.06	34.23

[1] These diversion structures, listed above CSO-039K001, share the same outfall, CSO-039K001.

4.4.2.2 Frankstown Avenue

The Frankstown Avenue area is part of a broader green infrastructure and urban planning evaluation for the Negley Run (A-42) sewershed, therefore, the proposed target area stormwater management with GI would be addressed as part of this work. See Sections 3 and 6.5 of this report for further details. In addition, a portion of wet weather flow from this area is diverted through the Rosedale diversion chamber to an overflow that discharges into Nine Mile Run. Green infrastructure work within the Frankstown Avenue area of A-42 will provide additional benefit to the Nine Mile Run stream.

4.4.2.3 Streets Run and Nine Mile Run

Both Streets Run and Nine Mile Run experience flooding from excessive amounts of stormwater runoff, primarily coming from the separate sewer systems. The majority of the acreage requiring stormwater management is located in the separate sewer systems. If excessive amounts of stormwater are entering the storm sewers and then the streams during rain events, it is likely that portions of the stormwater are also entering the separate sanitary sewers.

Stormwater can enter sanitary sewers through multiple locations in the public sewers as well as the private property lateral (sewer from a building to the main public sewer). Stormwater can enter through structural defects and leaks in the public sanitary sewers, cross-connections between the sanitary sewers and storm sewers, defects or leaks in the public storm sewers, as well as downspouts or other storm drain connections from private property improperly connected to the sanitary sewer lateral. Separate sanitary sewers were not designed to carry stormwater; only sewage. In both Streets Run and Nine Mile Run, the separate sewer systems ultimately enter the downstream combined sewer systems. Therefore, stormwater is not only causing flooding in the streams, but also likely contributing to both downstream sanitary sewer and combined sewer overflows. Projects to address the flooding in both Streets Run and Nine Mile Run should be developed to holistically address the stormwater problems at their sources and manage the stormwater entering both the storm sewers and the sanitary sewers. Holistic projects addressing both issues may be more cost-effective and provide more local community benefits by addressing the root causes of the flooding and overflows – excessive amounts of stormwater entering the respective sewer systems. These projects will also allow investment into the existing sanitary and storm systems to address the defects in the systems already constructed rather than building new systems and then having to come back and spend more to address the failing existing systems.

To understand how much stormwater enters the sanitary sewers, the R-values were reviewed in the separate sewer areas within the collection system model. An “R-value” is the amount of rainfall that enters sanitary sewers during and after a wet weather event, usually expressed as a percent of rainfall. Reduction of R-values can be accomplished by removal of rainfall-dependent infiltration and inflow (RDII) entering the sanitary sewer system. These RDII removal projects can then be coordinated and constructed with stormwater management projects designed to address the flooding so the stormwater ultimately is connected to the right detention and conveyance systems and properly managed to address both overflows and flooding. Figures 4-27 and 4-29 provide the sanitary sewer system R-values in the Streets Run and Nine Mile Run watersheds as represented in the ALCOSAN SWMM models, and based on 2008-2009 flow monitoring conducted by ALCOSAN and 3RWW. An R-value of greater than 5 is considered to be excessive indicating that too much stormwater is entering the sanitary sewer system. As can be seen in both figures, the majority of the area within each watershed is characterized by excessive amounts of stormwater entering the sanitary sewer system.

The areas with high R-values therefore present an opportunity to prioritize the management of the stormwater both within the storm sewer system (to address the flooding) and within the sanitary sewer system (to address the SSOs and CSOs). The next steps in the analysis therefore focused on the areas with the highest R-values by acreage to target the impervious and pervious areas (2,150 acres for Streets Run area; 1,813 acres for Nine Mile Run area) for stormwater management to address both flooding and overflow volume reductions.

Streets Run and Nine Mile Run are both located in the Upper Monongahela Basin. To quantify the overflow reduction benefits that could be addressed with projects that also reduce the flooding, the Upper Monongahela Basin system model was simulated for the typical year wet weather conditions using EPA SWMM 5.0.013 engine. Two scenarios were evaluated, with R-values compared between the scenarios. The first scenario included managing the stormwater in 50% of the combined sewer area with GI BMPs and the R values in the separate sewer area reduced by 25 percent to simulate RDII reduction. The second scenario was the same as the first scenario for the combined sewer area but included a 50% reduction in the R values in the separate sewer area to simulate RDII reduction.

Figure 4-27 shows the existing condition maximum R-value distribution by model subcatchment in the separate sewer areas of the Streets Run sewershed (M-42). R-values range from 3% to 29% in the sanitary sewersheds. These R values are the maximum computed among the wet weather events monitored by ALCOSAN and 3RWW in 2008-2009. The red and dark orange areas in Figure 4-27 indicate the areas that should be targeted first for R-value reduction because these are the subcatchments with the highest R-values, ranging from 16% to 29%. These would also be the target areas for stormwater management for flooding reduction as shown in Figure 4-28 (1,290 acres). These target subcatchments are located primarily in Brentwood, Baldwin, and Whitehall Boroughs, with a relatively small area in Pittsburgh, which indicates that PWSA would need to coordinate closely with these boroughs to obtain any recent flow monitoring data and information about any recent RDII reduction measures, and to collaborate in developing flooding reduction solutions. Table 4-10 provides the estimated overflow reductions for the Streets Run sewershed for the two evaluated scenarios.

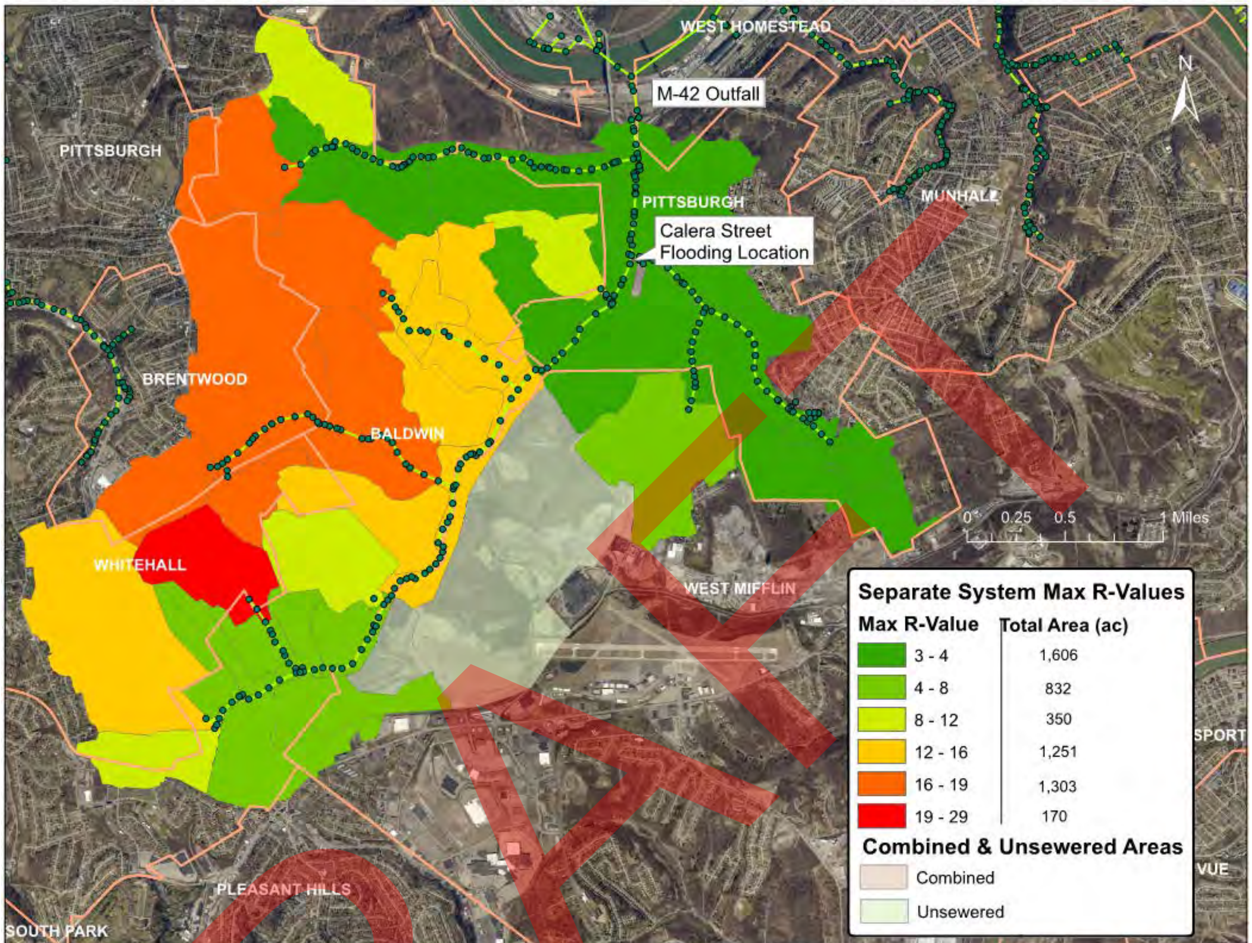

Figure 4-23: Maximum R-Values for the Sanitary Sewer Subcatchment Areas of Streets Run (M-42) Sewershed, Existing Conditions

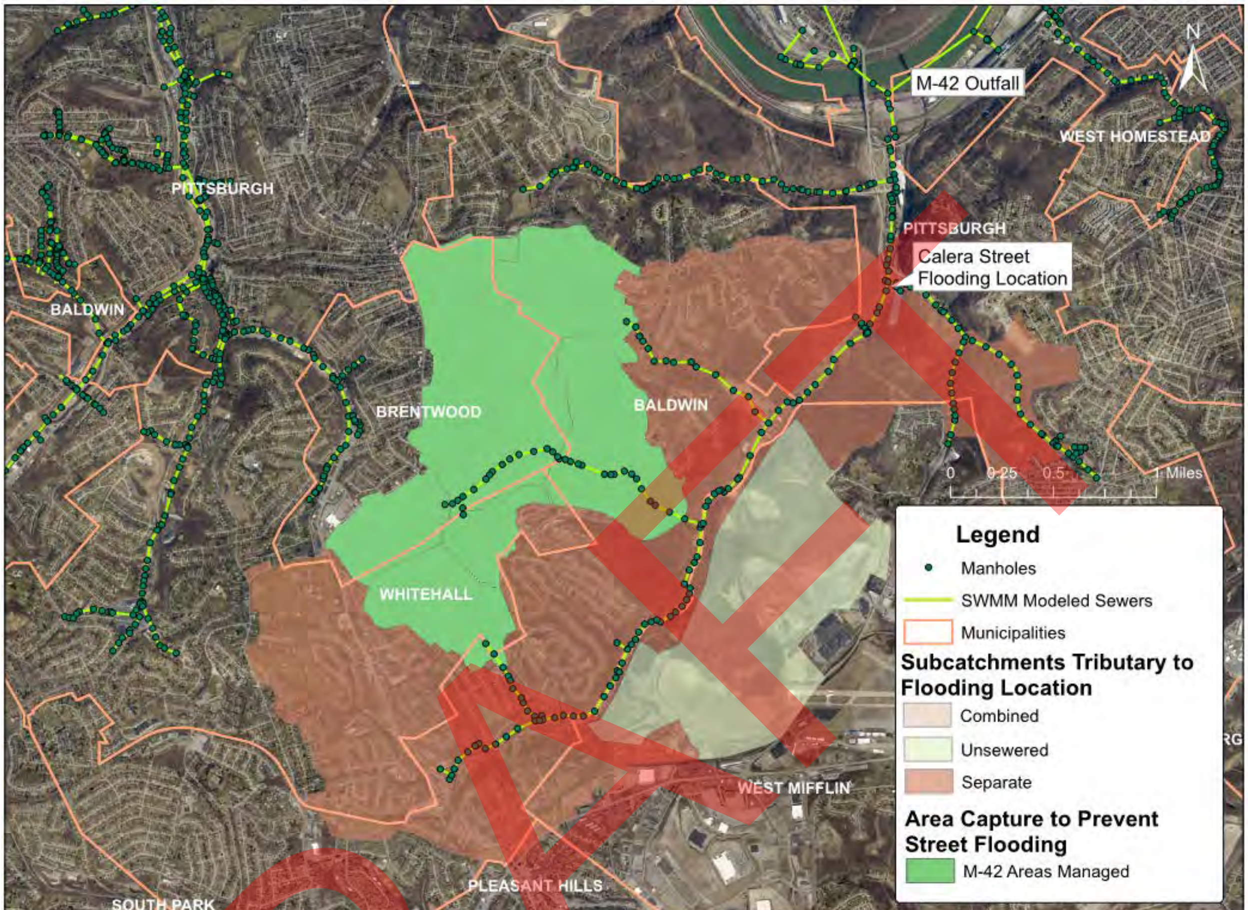

Figure 4-24: Target R-Value Reduction Areas in Streets Run Sewershed to Estimate Overflow Reduction Benefits

Figure 4-29 shows the maximum R-value distribution by model subcatchment in the separate sewer areas of Nine Mile Run (M-47). R-values range from 3% to 32% in the sanitary sewersheds. These R values are the maximum computed among the wet weather events monitored by ALCOSAN and 3RWW in 2008-2009. The red and dark orange areas in Figure 4-29 indicate the areas that should be targeted for R-value reduction because these are the subcatchments with the highest R-values, ranging from 16% to 32%. These would also be the target areas for stormwater management for flooding reduction as shown in Figure 4-30 (1,408 acres). These target subcatchments are located primarily in Wilkinsburg, Edgewood, and Swissvale Boroughs, with a relatively small area in Pittsburgh, which indicates that PWSA would need to collaborate and coordinate closely with these boroughs to implement RDII reduction measures.

Table 4-10 provides the estimated overflow reductions for the Nine Mile Run sewershed for the two evaluated scenarios.

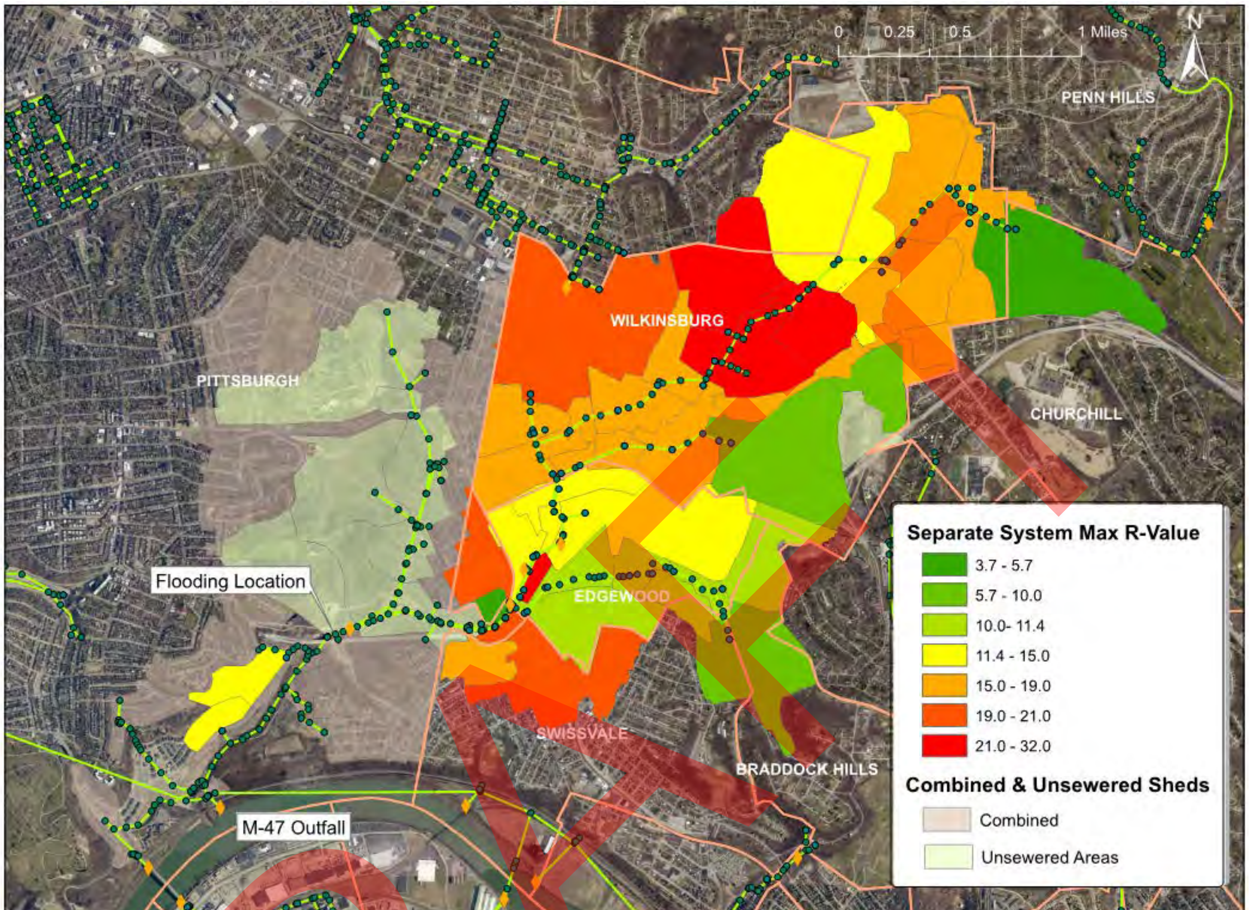

Figure 4-25: Maximum R-Values for the Sanitary Sewer Subcatchment Areas of Nine Mile Run (M-47) Sewershed, Existing Conditions

Table 4-10 also compares the typical year overflow volumes for the two evaluated scenarios for the outfalls within the M-42 (Streets Run) and M-47 (Nine Mile Run) sewersheds. For the M-47 sewershed, in which Nine Mile Run is present, in the first scenario, the typical year overflow would be reduced by 77 MG (32 percent reduction), and in the second scenario the overflow would be reduced by 89 MG (37 percent reduction). Under existing conditions, the CSO percent capture for M-47 is 71.5%, which is expected to increase to 76.7% for the first scenario and increase to 78.2% for the second scenario. The typical year SSO volume would be reduced by 75%.

For the M-42 sewershed in which Streets Run is present, in the first scenario the typical year overflow would be reduced by 13 MG (8 percent reduction), and in the second scenario the overflow would be reduced by 27 MG (17 percent reduction). The existing conditions CSO percent capture for M-42 is 85.5%, which is expected to increase to 86.8% for the first scenario and increase to 88.1% for the second scenario. The typical year SSO volume would be reduced by 100%.

In addition, these scenarios result in approximately 7 MG reduction in overflow volume during the typical year at the M-59 interceptor relief overflow, which is upstream of M-47.

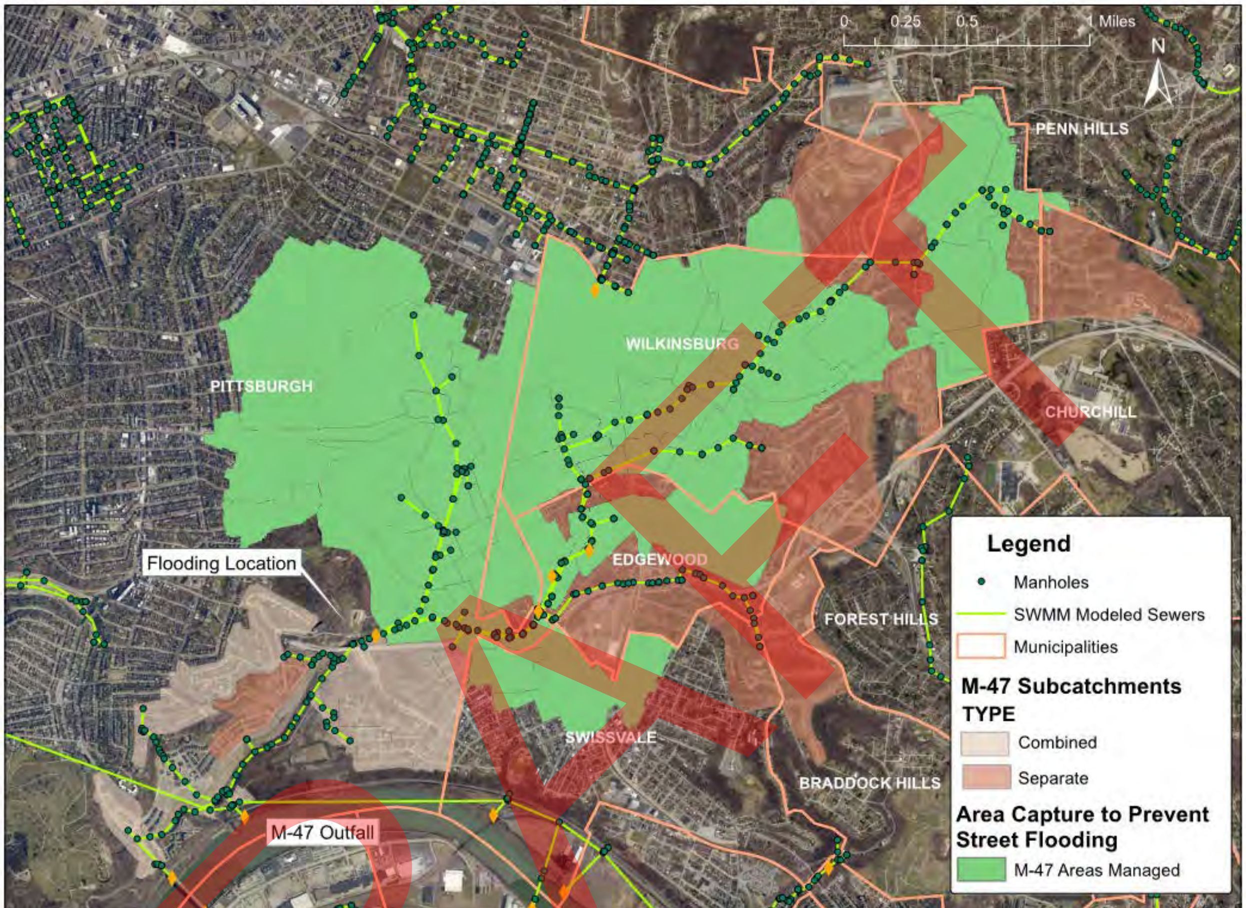

Figure 4-26: Target R-Value Reduction Areas and Target Capture Areas in Nine Mile Run Sewershed to Estimate Overflow Reduction Benefits

TABLE 4-10
TYPICAL YEAR OVERFLOW VOLUME FOR THE STREETS RUN AND NINE MILE RUN SEWERSHEDS WITH TARGET R-VALUE REDUCTION AND TARGET AREA CAPTURE

Diversion Structure	Type	Existing Conditions (MG)	Overflow Volume With 50% CSS Area Managed and 25% RDII Reduction in SSS (MG)	Overflow Volume With 50% CSS Area Managed and 50% RDII Reduction in SSS (MG)
Nine Mile Run Subcatchments				
M-47-OF	CSO	217.00	156.53	146.51
LBs_1111646	CSO	1.27	1.28	1.28
CSO128R002	CSO	17.65	4.81	4.81
Edgewood-MH20_SSO	SSO	2.21	1.87	1.49
Edgewood-Allenby_SSO	SSO	0.04	0.00	0
KoenigField_SSO	SSO	5.67	2.45	0.48
Subtotals				
M-47	CSO	235.92	162.62	152.60
M-47	SSO	7.92	4.33	1.97
M-47-Total		243.83	166.95	154.56

TABLE 4-10 TYPICAL YEAR OVERFLOW VOLUME FOR THE STREETS RUN AND NINE MILE RUN SEWERSHEDS WITH TARGET R-VALUE REDUCTION AND TARGET AREA CAPTURE				
Diversion Structure	**Type**	**Existing Conditions (MG)**	**Overflow Volume With 50% CSS Area Managed and 25% RDII Reduction in SSS (MG)**	**Overflow Volume With 50% CSS Area Managed and 50% RDII Reduction in SSS (MG)**
Streets Run Subcatchments				
Baldwin_SSO	SSO	0.19	0.04	0
CSO_184E001	CSO	0	1.45	1.45
CSO_185H001	CSO	2.17	2.03	2.03
CSO_134A001	CSO	0.60	0.60	0.60
M-42-OFWEIR	CSO	152.16	137.93	124.21
Subtotals				
M-42	CSO	154.93	142.00	128.29
M-42	SSO	0.19	0.04	0
M-42-Total		155.12	142.05	128.29

4.5 Capital Costs

Planning level capital costs were developed for all four flood hazard locations and are presented below, except for the Frankstown Road location. Because the stormwater management for the Frankstown Road flood hazard area aligned with high yield drainage areas for GI BMP installations, the cost was included in the high yield drainage area GI BMP costs for the A-42 sewershed and is discussed in Sections 6 and 9 of this report. The cost to upsize the flat section of pipe from 15-inch to 30-inch diameter was considered minor and should be addressed as part of PWSA's ongoing sewer asset management program.

The capital costs were developed to mitigate flooding up to the August 31, 2014 event condition, with a peak rainfall intensity of 1.05 inches of rain in 15 minutes, and a rainfall volume of 2.26 inches in 10 hours. Rain events that exceed this particular event could still create flooding at these locations. However, the August 31, 2014 event was considered to be an extreme event and a reasonable level of protection from flooding.

In preparing the estimates of capital costs, the cost criteria, such as GI costs per impervious acre, are described in Section 7. With GI and BMP applications, it was assumed that the first 1.5 inches of stormwater runoff would be detained and slowly released to the combined or storm sewer system.

4.5.1 Morange Road

As discussed in Section 4.1.1, Morange Road floods because of a combination of limited capacity in the combined sewer and large peak flows conveyed from the upstream areas, which results in backflow from the combined sewer into the storm sewer, and then flow exiting at the stormwater inlets. To reduce flooding, the stormwater runoff from a total of 258 acres would need to be managed with GI BMPs (detain and slowly release the first 1.5 inches of runoff). The 258 total acres were reviewed and converted to an equivalent number of impervious acres based on the amount of runoff from the previous surfaces as quantified by the collection system model. The estimated capital cost to manage the stormwater and mitigate flooding for the August 31, 2014 event conditions is estimated to be $33,010,000, as shown in Table 4-11. In addition to mitigating flooding for events up to the August 31, 2014 event condition, this strategy also results in reduction of 50 million gallons of overflow volume.

TABLE 4-11 PLANNING LEVEL COST ESTIMATE FOR FLOOD HAZARD MITIGATION (UP TO THE AUGUST 31, 2014 EVENT CONDITION)	
Commercial Street - Nine Mile Run (M-47)	
Capital Cost to Address Flooding[1] (Commercial Street)	$243,000,000
Sewer Asset Management and RDII Reduction Cost	$85,700,000
RDII Private Source Reduction Cost	$39,600,000
Calera Street - Streets Run (M-42)	
Capital Cost to Address Flooding[1] (Calera Street)	$29,800,000
Sewer Asset Management and RDII Reduction Cost	$43,500,000
RDII Private Source Reduction Cost	$20,800,000
Morange Road - Chartiers Creek (C-25)	
Capital Cost to Address Flooding	$33,010,000

[1] Average of regional detention and distributed BMP costs. If regional detention can be performed, costs could be lower. Additional evaluation, including storm sewer system surveying, is beyond the scope of this project, and is required to develop a complete opinion of probable construction cost.

4.5.2 Streets Run and Nine Mile Run

Stormwater runoff management across a total of 1,813 acres is required to mitigate flooding at Commercial Street in the Nine Mile Run sewershed up to the August 31, 2014 event conditions. This equates to 1,408 acres (490 impervious acres) in the separate sewer system and 405 acres in the combined sewer system. A total of 1,291 acres (123 impervious acres) of stormwater runoff management, all in the separate sewer system, is required to mitigate flooding at Calera Street in the Streets Run sewershed for the August 31, 2014 event conditions.

To develop a planning level cost estimate to manage the stormwater in the separate sewer system in both Nine Mile Run and Streets Run sewersheds, the existing storm sewer mapping available in GIS was reviewed and opportunities for regional detention were examined. The available storm sewer data is limited in GIS and no invert elevation information is currently available. There may be opportunities available for regional detention based on the current locations of the storm sewers, although without accurate invert elevations of the existing storm sewer network, it was not possible to develop accurate costs for regional detention. To develop an overall order of magnitude cost for stormwater management to address flooding, a regional detention cost was developed assuming a maximum depth of the detention structure of 8 feet. A second cost assuming the use of distributed GI BMPs across the 1,408 acres in the Nine Mile Run sewershed (490 impervious acres) and the 1,291 acres in the Streets Run sewershed (123 impervious acres) was also determined. The two costs were then averaged to determine an order of magnitude cost to manage the stormwater runoff in the separate sewer areas. The estimate for the Nine Mile Run sewershed also included 405 acres of impervious area runoff in the combined sewer system managed with GI BMPs. For the GI BMPs in the combined sewer area, the cost per impervious acre was developed and described in Section 7. The capital costs to address flooding in the Nine Mile Run and Streets Run locations are shown in Table 4-11. If regional detention can be performed in lieu of distributed GI BMPs, costs may be lower. Additional evaluation, including storm sewer system surveying, is beyond the scope of this project and is required to develop a complete opinion of probable construction cost for both Nine Mile Run and Streets Run flooding locations.

The stormwater management to address the flooding is optimized when addressed in the same areas that have the highest RDII entering the sanitary sewer system. Also, given the very high levels of RDII observed from the flow monitoring and modeling, there is a high need for asset management to renew the condition of the existing sewer system in the tributary areas to the flooding locations in Nine Mile Run and Streets Run. With careful attention to the performance of the needed asset management, the sewer system could be renewed to address not only the structural and maintenance condition of the existing sewers, but to also reduce RDII. To develop capital costs for the asset management and RDII reduction, a cost estimate was developed, with components to renew the existing sanitary sewers primarily with cured-in-place pipe (CIPP) lining, and grouting of 75% of the manholes. A total unit cost of $239 per linear feet (LF) of mainline sewer was estimated. Point repairs were assumed every 50 feet of sewer, in addition to the CIPP lining. Based on GIS maps, a total of 359,000 LF of local 8-inch to 12-inch diameter sanitary sewers were estimated to be located within the target separate sewer areas of the Nine Mile Run (M-47) sewershed, and 182,000 LF of sanitary sewers were estimated within the target separate sewer areas of the Streets Run (M-42) sewershed.

To develop costs for private source disconnections, including downspouts, sump pumps, and targeted area drains removal, a planning level cost estimate was developed. The cost estimate also included lining the first 10 feet of the private sewer lateral from the mainline. Details of how the cost estimate was derived are described in Section 7 of this report. A total cost per property of $9,900 for private source disconnections was estimated, and it was assumed that 50% of the properties would require private source disconnections. It is important to note that the public and private source RDII removal costs assume a target of 50% of the RDII would be removed. The costs do not include addressing foundation drains, because these improvements are typically not cost-effective. The costs for the public and private source asset management and RDII removal are provided in Table 4-11.

In addition to addressing flooding for events up to the August 31, 2014 event condition, this strategy also results in reduction of 123 million gallons of overflow volume from the M-42 and M-47 sewersheds.

As provided in Table 4-10, in addition to addressing flooding up to the August 31, 2014 event, the M-47 sewershed (Nine Mile Run) combined sewage percent capture is predicted by the model to increase from 71.5% to 78.2% with this work. The typical year SSO volume in this sewershed would be reduced by 75%. For the M-42 sewershed (Streets Run), the combined sewage percent capture is predicted by the model to increase from 85.5% to 88.1% with this work. The typical year SSO volume in this sewershed would be reduced by 100%, essentially eliminating SSOs for the typical year.

It is highly recommended that RDII removal and source reduction be included in cost estimates for alternatives analysis. The Water Environment Federation (WEF) addressed the issue of cost effectiveness in the 2013 Guide for Municipal Wet Weather Strategies Publication (pages 67 - 70). The WEF Guide recommends that all costs be included when comparing conveyance and treatment versus RDII removal with reduced conveyance and treatment solutions, including the ongoing asset management costs for the existing sanitary and storm sewer systems, including flooding reduction. These costs can be substantial, as illustrated in the cases of Nine Mile Run and Streets Run. The majority of the costs provided in Table 4-11 would still be required to be added to any regional conveyance and treatment solution focused only on CSO and SSO control. It could be argued that the private source RDII removal costs would not be required under a conveyance and treatment solution, and that the costs for asset renewal could be less because pipes and manholes would only be fixed to address structural and maintenance defects and not for RDII removal. To illustrate this comparison, Table 4-12 was developed to compare conveyance and treatment and RDII removal on a relative cost per gallon basis for the areas tributary to the Commercial Street and Calera Street flooding locations. Because the RDII removal may provide both asset renewal and overflow volume reduction for the same investment, the relative cost per gallon of overflow reduced is lower with the RDII removal solution ($3.76 versus $5.82, or a 35% lower cost). This cost may be offset with a reduction in ongoing treatment costs that the RDII solution offers (not calculated for this comparison). Given that the regulatory agencies have requested that municipalities in the region evaluate source reduction, the results of this analysis provide compelling support for stormwater management and RDII removal demonstration projects to be conducted to confirm the modeled results.

Recommendations for solutions for the Morange Road and Frankstown Road flooding hazard areas were carried forward to the GI Assessment recommendations. For the Streets Run and Nine Mile Run flooding areas, regardless of the type of overflow reduction solution selected in these areas, additional costs to address flooding and asset management of the existing sewer system are required, and demonstration projects to holistically address the stormwater are recommended.

Section 9 of this report provides the cost for a Green First solution and its total cost and cost per gallon of overflow reduced.

TABLE 4-12
CONVEY AND TREAT VERSUS RDII REMOVAL RELATIVE COST COMPARISON

	RDII Removal Solution	Conveyance and Treatment Based Solution
Commercial Street - Nine Mile Run (M-47)		
Capital Cost to Address Flooding[1] (Commercial Street)	$243,000,000	$243,000,000
Sewer Asset Management Cost	$85,700,000	$55,700,000[2]
RDII Private Source Reduction Cost	$39,600,000	Convey & Treat. No RDII removal.
Calera Street - Streets Run (M-42)		
Capital Cost to Address Flooding[1] (Calera Street)	$29,800,000	$29,800,000
Sewer Asset Management Cost	$43,500,000	$32,600,000
RDII Private Source Reduction Cost	$20,800,000	Convey & Treat. No RDII removal.
Total Cost	$462,400,000	$361,100,000[2]
Overflow Volume Reduction (MG)	123	62[3]
Cost Per Gallon of Overflow Reduced	**$3.76**	**$5.82**

[1] Average of regional detention and distributed GI/BMP costs. If regional detention can be performed, costs may be lower. Additional evaluation, including storm sewer system surveying, is beyond the scope of this project and is required to develop a complete opinion of probable construction cost.
[2] 65% applied to asset management cost for convey and treat to account for lower cost due to only addressing structural and maintenance defects over time and not I/I related defects.
[3] Only about a 50% reduction in overflow volume may be achieved because RDII removal is not performed.

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5. STREAM INFLOW IMPROVEMENTS ANALYSIS

Direct Stream Inflow (DSI) is defined as a surface stream that connects into the combined sewer system. There are several known (and potentially other unknown) DSIs within the PWSA service area. Depending upon the nature of the stream, DSI can take up valuable conveyance capacity in the collection system as well as a portion of the available treatment plant capacity. A perennial stream can contribute flow throughout the year, adding to the base wastewater flow in the collection system. An understanding of the significant amounts of stormwater runoff, including the perennial stream baseflow and other seasonal stream influences, is extremely important for an already capacity deficient collection system. Removing DSI from the collection system can thus restore significant amounts of wastewater conveyance and treatment capacity in dry and wet weather within the system, resulting in reduced combined sewer overflows (CSOs). Stream removal and daylighting projects can also potentially provide significant opportunities for catalyzing new development and redevelopment of surrounding land areas.

As discussed in Section 1 of this report, the current top 10 largest DSI locations were reviewed and identified as listed below. This Section of the report discusses the evaluations performed for each location, options for detaining and/or removing the DSI (stream base flow and stormwater runoff during wet weather conditions) from the sewer system, and opinions of estimated capital cost for the identified stream inflow solutions.

- Spring Garden
- Woods Run (8 locations)
- Panther Hollow Stream and Lake

5.1 Spring Garden Stream Inflow

5.1.1 Site Information and Review of Past Stream Removal Reports

The Spring Garden DSI is located along Spring Garden Avenue just north of Wilson Road in Reserve Township. This DSI location has been evaluated in previous studies as listed below. Each study was reviewed to gather background information on the location for this analysis.

- ALCOSAN Wet Weather Plan Report (2013)
- PWSA Wet Weather Feasibility Study (WWFS) Report (2013)
- 3 Rivers 2nd Nature – Stream Restoration & Daylighting Report (2001)

Data analysis was also conducted, utilizing the following resources:

- PASDA Digital Elevation Models
- Existing PWSA GIS data for storm sewers, combined sewers, and inlets

- 3 Rivers Wet Weather (3RWW) Regional Sewer Mapping Tool
- USGS StreamStats Version 3 Beta
- Historic Mapping: http://peoplemaps.esri.com/pittsburgh/
- Previous PWSA Flow Monitoring data in the Spring Garden area (2003-2004 data)
- Field visits

5.1.2 Site Overview

The 3 River's 2nd Nature Report notes that the Spring Garden total watershed area is 2,302 acres, making it the 7th largest watershed in Allegheny County. The upstream half of the Spring Garden sewershed is located in Reserve Township, and the downstream half of the sewershed is located in the City of Pittsburgh's Troy Hill neighborhood. The contributing drainage area for the Spring Garden inflow point covers 334 acres, mostly within Reserve Township.

The stream carries a base flow throughout the year, and also contributes flow from stormwater runoff. The entire stream enters a 72-inch diameter combined sewer system upstream of the City of Pittsburgh, near the intersection of Spring Garden Avenue and Wilson Road in Reserve Township. Ideally, the stream inflow can be captured at this location and "daylighted" or detained. Figure 5-1 highlights the stream inflow point and contributing drainage area. There are 2 SSOs owned by Reserve Township located upstream of the Spring Garden DSI location.

At this inflow point, the stream flows constantly into a 72-inch diameter PWSA-owned combined sewer and contributes to combined sewer overflows (CSOs) through the A-60 outfall at the Allegheny River. During a site visit on a dry weather day, an active, flowing stream base flow was observed. The collection system model indicates the base stream flow entering the sewer system to be approximately 97 million gallons annually. Figure 5-2 shows the entire A-60 combined sewershed, with the stream inflow location identified.

Table 5-1 lists the characteristics of the Spring Garden watershed provided by the USGS StreamStats tool. This tool provides useful information related to land use and the amount of impervious and pervious areas.

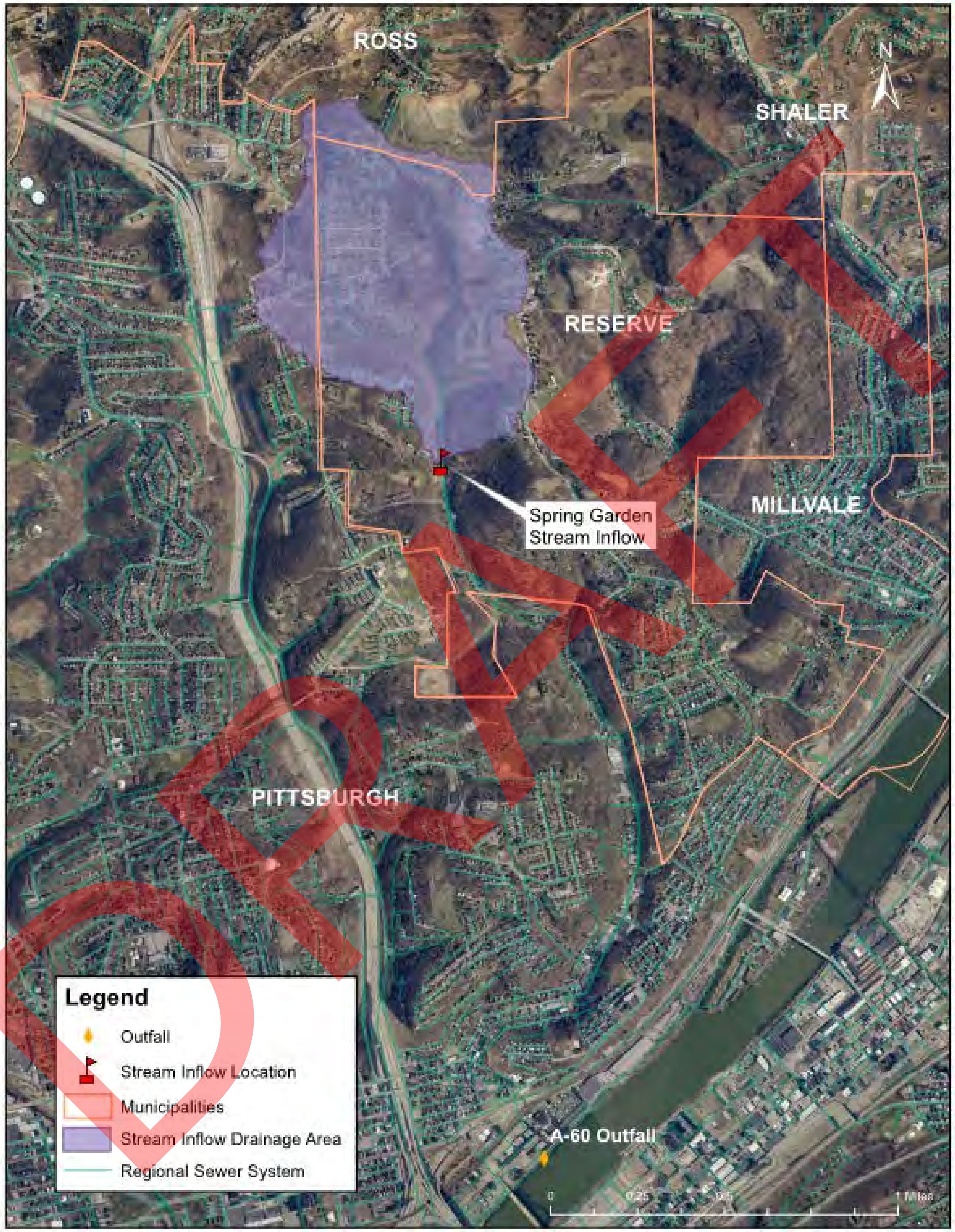


Figure 5-1: Spring Garden Watershed Area and Stream Inflow Point

Figure 5-2: Spring Garden Combined Sewershed A-60

TABLE 5-1
SPRING GARDEN BASIN CHARACTERISTICS USED FOR THE USGS STREAMSTATS TOOL

Label	Value	Units	Definition
DRNAREA	1.78	square miles	Area that drains to a point on a stream
BSLOPD	11.9	degrees	Mean basin slope measured in degrees
BSLOPDRAW	12.15	degrees	Mean basin slope, in degrees, raw value unadjusted for bias
FOREST	4	percent	Percentage of area covered by forest
PRECIP	37	inches	Mean Annual Precipitation
URBAN	90	percent	Percentage of basin with urban development
ELEV	1060.6	feet	Mean Basin Elevation
DRN	3.6	dimensionless	Drainage quality (1=well drained to 7=poorly drained) from dataset at http://water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml
IMPNLCD01	22	percent	Percentage of impervious area determined from NLCD 2001 impervious dataset
LC01DEV	68	percent	Percentage of land-use from NLCD 2001 classes 21-24
LC11IMP	22.7	percent	Percentage of impervious area determined from NLCD 2011 impervious dataset
LC11DEV	68.4	percent	Percentage of land-use from NLCD 2011 classes 21-24

5.1.3 Stream and Collection System Modeling Approach

The ALCOSAN Main Rivers Basin hydrologic and hydraulic (H&H) model was used to model the inflow point, as well as run simulations to quantify the resulting effects on the existing combined sewer system and combined sewer overflow at the A-60 outfall. The existing ALCOSAN model contains sewer trunk lines throughout the A-60 sewershed, up to and including the stream inflow point.

To update the Main Rivers model to represent the daylighting and detention options covered in section 5.1.4, the existing SWMM model subcatchments currently contributing wet weather flow to the stream inflow point were redirected to a new node. Combined with the stream base flow, this new node represented the flows that would need to be managed in any detention or daylighting solution. A total of 334 acres of the 1,282 acres in the A-60 sewershed was determined to connect to the stream inflow point.

The two SSO outfalls located upstream of the stream inflow point show no activations during the typical year. The SSO outfalls were left as shown, and not directed into modeled detention and daylighting features. The SSOs will need to be closed prior to any work to manage the flows from the Spring Garden Stream. The 2013 Reserve Township long term control plan outlines a plan to capture flow from, and close the outfalls with a larger diameter sanitary sewer line.

5.1.4 Conceptual Daylighting and Storage Options

5.1.4.1 Daylighting Option

Stream daylighting could take two forms. One option would be to remove the stream from the existing combined sewer and restore the natural stream channel down to the Allegheny River. The second option would be to divert the stream flow out of the combined sewer system to a new storm sewer and route the new storm sewer to the Allegheny River. From the Spring Garden stream inflow point located in Reserve Township, the combined sewer runs along Spring Garden Avenue towards the City. The existing street is narrow along the proposed conveyance pathway and homes are situated close to the right-of-way. The inflow point is approximately two miles from the Allegheny River. For these reasons, the first option of restoring the natural stream channel was ruled out. However, the second option of routing the stream to the river using a new storm sewer was evaluated as a potential option.

For the daylighting option, the watershed was modeled with all of the contributing area entering the stream inflow point and being routed downstream to the Allegheny River via a new storm sewer. This includes all base stream flows and wet weather flows. Base stream flows for the Spring Garden watershed include approximately 97 million gallons annually. With no stream flow entering the combined sewer system from Spring Garden, the combined sewer overflow volume at the A-60 outfall would be reduced by approximately 54 million gallons under typical year wet weather conditions.

Full daylighting provides the most overflow reduction. However, due largely to the distance from the inflow point to the Allegheny River, the constraints of the Spring Garden area, and the large wet weather flows, the costs of full daylighting are significantly greater than the costs of the other options. This daylighting cost was previously estimated as part of PWSA's 2013 WWFS to be over $31 million.

5.1.4.2 Detention & Slow Release Option

Another scenario for managing the stream volume from the Spring Garden watershed is to temporarily detain the peak wet weather stream volumes within a larger best management practice (BMP) facility near the inflow location. Multiple options were evaluated including subsurface storage and surface storage. Subsurface storage options include modular storage, larger concrete cell storage or aggregate storage. Surface storage includes options such as subsurface gravel wetlands, and dry basins. All surface and subsurface options would route the stream base flow through the BMPs, while maintaining the storage volume capacity needed to temporarily detain the peak flows during typical year rain events.

In all subsurface and surface storage BMP options, the peak wet weather flows detained within the BMPs were modeled as a slow release over approximately 72 hours back into the combined sewer system to maximize overflow reduction at the A-60 outfall. The 72 hours was selected based on previous analysis on the time it takes for the deep tunnel interceptors to regain capacity after typical year storm events. This scenario involves routing both the base stream flow and the wet weather flow through the storage structure.

Site visit observations indicate that there appears to be limited area for surface storage near the Spring Garden stream inflow location. There may be opportunities to capture and manage flows on parcels adjacent to the steam inflow point. For the conceptual stage of evaluating this storage option, the assumption was made to evaluate the storage options at adjacent parcels, which serve as the most feasible location for managing flows from a technical standpoint.

An analysis was conducted using a combination surface and subsurface storage option with all stream flows detained and slowly released back to the combined sewer system. The storage BMP was sized to detain all of the base stream flow and wet weather flow for the typical year wet weather events. To manage that volume, the surface and subsurface storage layers would require an equivalent of a 1 acre (43,560 square feet (SF)) footprint assuming a 7-foot depth. This would achieve the required volume to detain an estimated 2,244,000 gallons, as determined to be required by the hydraulic model. To optimize release to the combined sewer system over 72 hours, small diameter underdrain piping was modeled as 6 inches in diameter.

In this scenario, all of the existing 169 million gallons of annual stream volume (baseflow volume and wet weather volume) will still enter the combined sewer system. However, the detention storage helps to significantly reduce the peak flows in the combined sewer system, reducing A-60 CSO volume by approximately 44 million gallons in the typical year.

Facilities associated with this scenario involve the surface and subsurface storage, connections back to the existing combined sewer, and any necessary property purchases to store the water. The approximate cost for this scenario is $1.8 million.

5.1.4.3 Blend of Detention & Separation Option

A third scenario to manage the Spring Garden inflow was evaluated to include a blend of detention and separation. This would involve detaining the base stream flow and the wet weather flow with surface detention structure and slowly releasing the detained flow into a small diameter storm sewer routed to the Allegheny River. The smaller diameter storm sewer results in a significantly lower cost as compared to the $31 million full daylighting scenario as indicated in the PWSA WWFS.

For this scenario, the watershed was modeled with the Spring Garden inflow contributing drainage area being routed into surface and subsurface storage before being released into an 8-inch and 12-inch diameter pipe that would drain all the way to the Allegheny River and exit via a new storm sewer outfall.

This option provides the removal of all Spring Garden stream dry and wet weather volume during the typical year from the combined sewer system resulting in an A-60 CSO reduction of approximately 53 million gallons. Rain events larger than the typical year design detention capacity would be diverted into the combined sewer system. This alternative provides nearly the same amount of CSO reduction during the typical year compared with full daylighting, and it removes the stream inflow from the system. The cost of this scenario is approximately $10.7 million.

5.1.5 CSO Reduction Benefits

The costs and overflow reduction benefits for the above alternatives are summarized in in Table 5-2. The CSO removal quantities are based on managing the stream base flow, and wet weather flow. The model indicates that the stream base flow is approximately 96,884,000 gallons per typical year. The wet weather generated flows entering the stream were shown to be approximately 71,939,000 gallons per typical year.

Table 5-2 shows the overflow volume (MG) at the A-60 CSO outfall for existing conditions and the three alternatives considered. Under current conditions, the typical year A-60 CSO volume is approximately 210 MG. The detain and slow release options reduce the outfall volume to 166 MG or 157 MG remaining in the typical year, respectively, depending if the connection is back into the combined system or small diameter daylighting pipe to the river. The full daylighting option with no storage results in a remaining overflow volume of 156 MG in the typical year.

The combination detention and daylighting alternative provides the greatest cost-benefit for CSO reduction, and may also provide reduced wastewater flows conveyed to treatment and reduction of the grit and sediment entering the existing combined sewer and downstream deep tunnel interceptor system.

TABLE 5-2
SPRING GARDEN STREAM INFLOW IMPROVEMENT SCENARIOS, TYPICAL YEAR

Scenario	Modeled Scenario	Outfall Overflow Volume (MG) A-60 OF -Typical Year	Annual Stream Flow Volume Entering System (MG)	Overflow Volume Reduced (MG)	Planning Level Capital Cost Estimate	System Improvement Description
1	Existing Conditions- MR Basin Model Run	210.2	168.8	-	-	Main Rivers basin model run
2	Detain 2.2 MG & Slow Release into CSS (Routing all Base & Wet Weather Flows Through Storage)	166.5	168.8	44	$1,831,000	All flows (base stream flow and wet weather) area routed through the storage, and connected back to the CSS through a 6" orifice.
3	Detain 2.2 MG & Daylight through smaller diameter Storm Sewer (Base Stream Flow Routed Through Storage)	157.3	0	53	$10,723,000	All flows (base stream flow and wet weather) area routed through the storage, and daylighted to the river through a small diameter storm sewer.
4	Full Daylighting to River	156.1	0	54	$31,491,000 [1]	All base stream flows, and wet weather flows are fully removed from the CSS inflow point and daylighted to the river.

[1] From 2013 WWFS. Sized for 5-year Design Storm.

5.1.5.1 Cost Estimates

The planning level capital cost estimate for the detention and slow release alternative is summarized in Table 5-3. The cost is based on an assumption that a surface detention feature is used and constructed on parcels neighboring the stream inflow point. Unit costs for grading, excavation, and small diameter daylighting pipe were developed from the ALCOSAN costing tool and local bid tabulations. A conservative assumption of 15 feet of depth was made in the excavation quantities. Additional discussion for the development of the costs is included in Section 7 of this report.

TABLE 5-3
SPRING GARDEN STREAM INFLOW IMPROVEMENT SCENARIO, PLANNING LEVEL CAPITAL COST ESTIMATE; SPRING GARDEN SOLUTION: DETENTION POND & SMALL DIAMETER SEPARATION PIPE TO RIVER; CONTROL LEVEL: 2.2 MG STORAGE

Items of Work	Approximate Quantity	Unit of Measure	Unit Bid Price	Total
Land Acquisition	1	EA	$312,500	$313,000
Mobilization, Demobilization, and Field Office	1	LS	$268,700	$269,000
Field Survey and Engineering	1	LS	$11,240	$12,000
Erosion and Sediment Control	1	LS	$11,240	$12,000
Grading	5,856	SY	$5	$27,000
Engineered Soil Media and Gravel	3,550	CY	$60	$213,000
8" PVC SDR-26 Sewer Pipe, Less than 15' Deep	500	LF	$125	$63,000
Excavation 0-15' Deep	16,000	CY	$9	$144,000
Vegetation	30,000	SF	$3	$90,000
Rock and Obstruction Excavation – All Depths	500	CY	$25	$13,000
Outlet Structure	1	EA	$3,000	$3,000
Overflow Structure	1	EA	$9,000	$9,000
Small Diameter Storm Daylight Pipe 8" – 12"	10,970	LF	$347	$3,807,000
Pipe Tunnel Boring Under Rt. 28	300	LF	$3,211	$964,000
Maintenance & Protection of Traffic	1	LS	$17,000	$17,000
			Subtotal	$5,956,000
Planning Level Construction Contingency			40%	$2,383,000
Engineering (Planning, Design, & CA Services)			20%	$1,192,000
Project Contingency			20%	$1,192,000
			Total	$10,723,000

5.2 Woods Run Stream Inflow

5.2.1 Site Information and Review of Past Stream Removal Reports

The Woods Run DSIs are actually 8 separate locations that route primarily surface drainage from hillsides and nearby roads into the combined sewer system. This DSI location has been evaluated in previous studies as listed below. Each study was reviewed to gather background information for this analysis.

- ALCOSAN Wet Weather Plan Report (2013)
- PWSA Wet Weather Feasibility Study report (2013)
- 3 Rivers 2nd Nature – Stream Restoration & Daylighting Report (2001)

Data analysis was also conducted, utilizing the following resources:

- PASDA Digital Elevation Models
- Existing PWSA GIS data for storm sewers, combined sewers, and inlets
- 3 Rivers Wet Weather (3RWW) Regional Sewer Mapping Tool
- USGS StreamStats Version 3 Beta
- Previous PWSA Flow Monitoring data in the Woods Run area (2003-2004 data)
- Historic Mapping: http://peoplemaps.esri.com/pittsburgh/
- Field measured data at site visits in 2015

5.2.2 Site Overview and Field Visit Observations

The Woods Run watershed and sewershed are located in the City's Brighton Heights and Marshall-Shadeland neighborhoods. The 3RWW's 2nd Nature Report notes that the Woods Run Watershed area is 1,280 acres, making it the 14th largest watershed in Allegheny County.

The United States Geological Survey's "StreamStats" tool was used to compare the Woods Run watershed boundary against other gathered information. Figure 5-3 shows the watershed area, which is tributary to the O-27 combined sewershed. Table 5-4 presents the basin characteristics that were obtained from the USGS StreamStats tool.

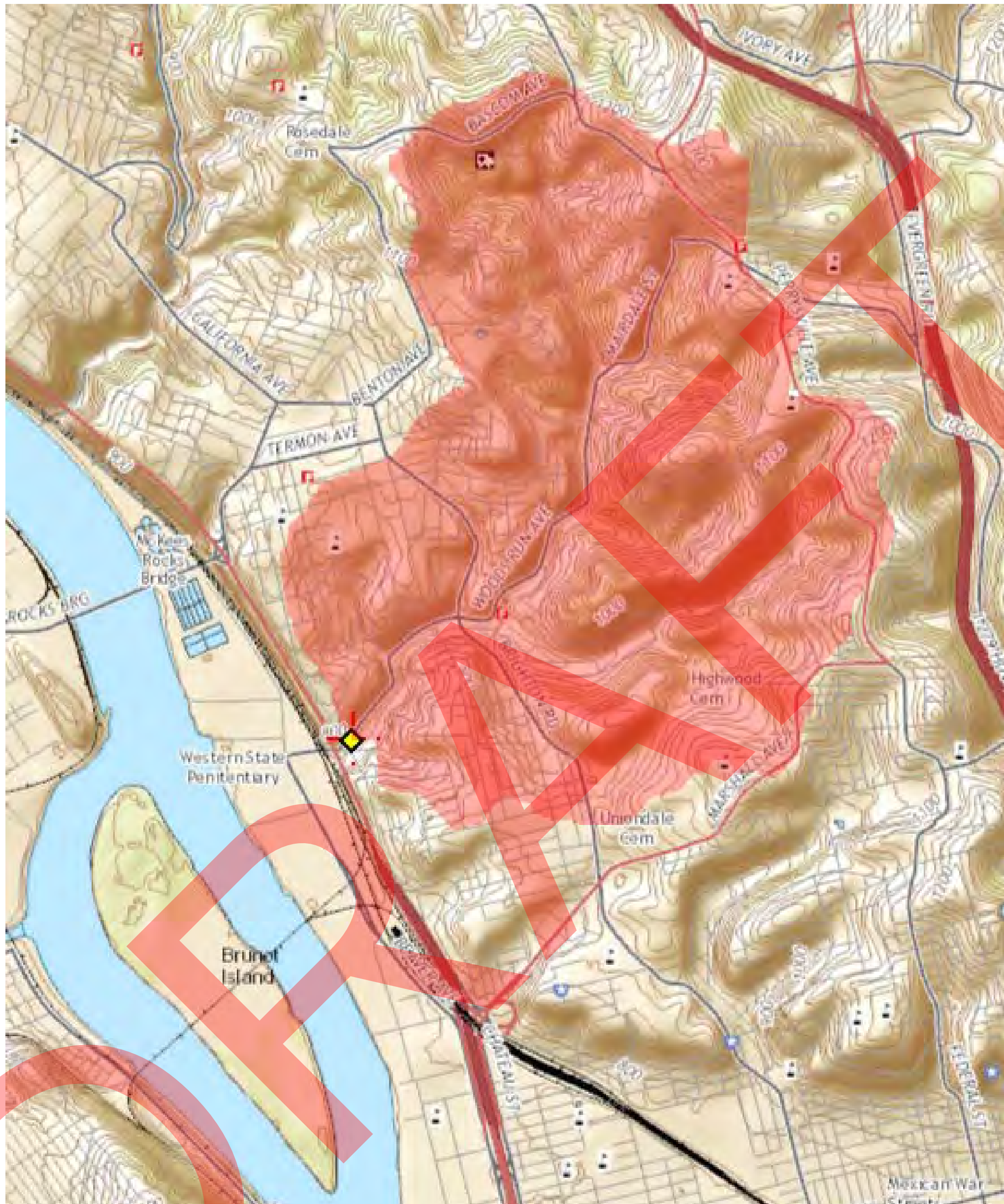


Figure 5-3: Woods Run Watershed

TABLE 5-4
WOODS RUN BASIN CHARACTERISTICS USED FOR THE STREAMSTATS TOOL

Label	Value	Units	Definition
DRNAREA	1.94	square miles	Area that drains to a point on a stream
BSLOPD	10.9	degrees	Mean basin slope measured in degrees
BSLOPDRAW	11.14	degrees	Mean basin slope, in degrees, raw value unadjusted for bias
FOREST	35	percent	Percentage of area covered by forest
PRECIP	37	inches	Mean Annual Precipitation
URBAN	62	percent	Percentage of basin with urban development
ELEV	1004.6	feet	Mean Basin Elevation
DRN	3.6	dimensionless	Drainage quality (1=well drained to 7=poorly drained) from dataset at http://water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml
IMPNLCD01	26	percent	Percentage of impervious area determined from NLCD 2001 impervious dataset
LC01DEV	75	percent	Percentage of land-use from NLCD 2001 classes 21-24
LC11IMP	26.9	percent	Percentage of impervious area determined from NLCD 2011 impervious dataset
LC11DEV	75.3	percent	Percentage of land-use from NLCD 2011 classes 21-24

Based on a review of the information available, there are 8 documented stream inflow locations with the potential to be captured in a daylighting or detention solution. Given the close proximity of the inflow points and drainage areas, all 8 locations in Woods Run, were evaluated together. Figure 5-4 highlights these inflow points and contributing drainage areas.

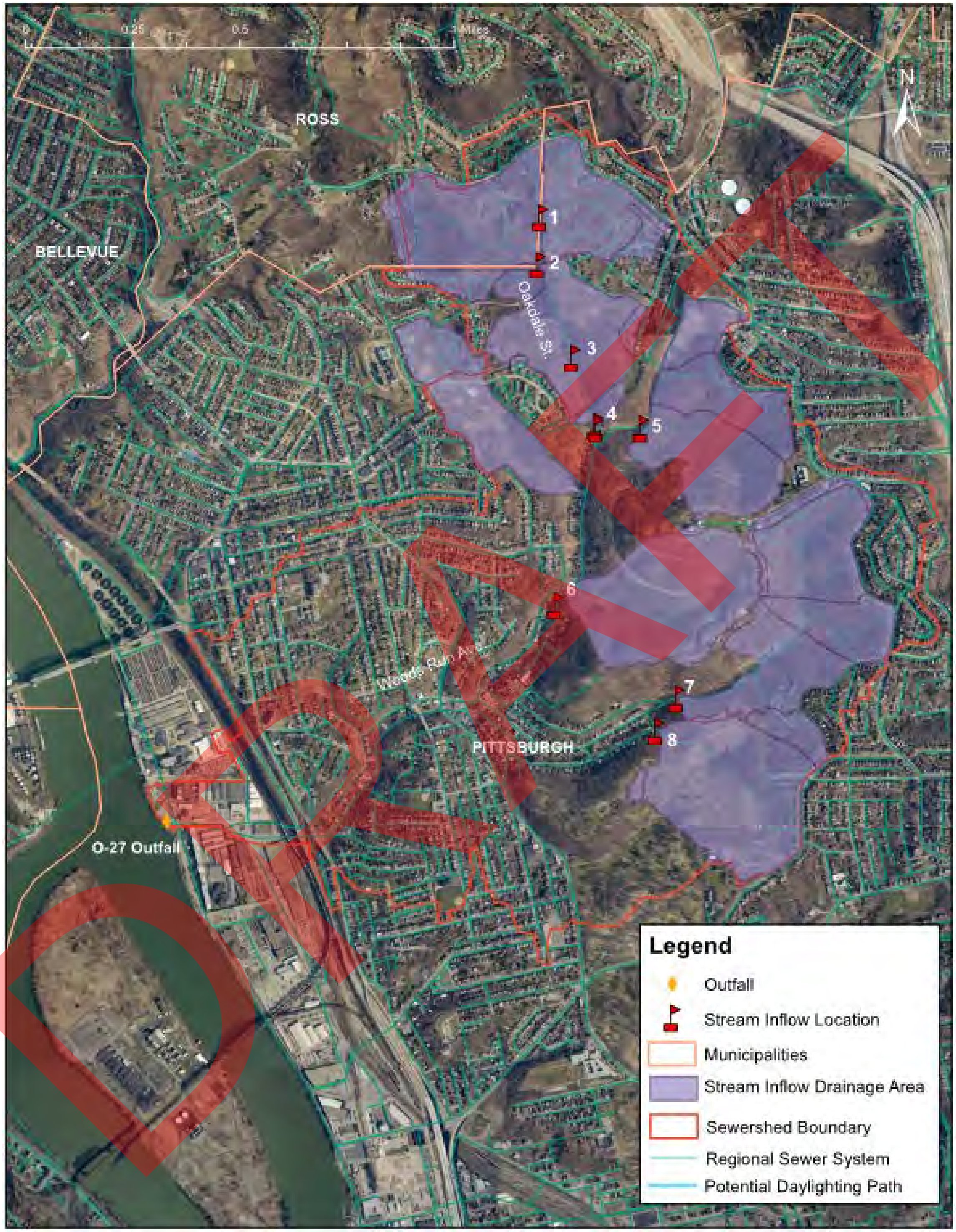


Figure 5-4: Documented Stream Inflow Points in the Woods Run O-27 Sewershed

5.2.2.1 Stream Base Flow

Only 1 of the 8 stream inflow points was observed during 2015 field visits to have stream dry weather base flow. Inflow Point 5 in Figure 5-4 shows the location of the stream inflow point where dry weather base flow was observed. The contributing drainage area for this location is approximately 71.9 acres and the inflow point enters into a 36-inch diameter PWSA brick combined sewer. There are two active tributary branches of the stream, meeting directly upstream of the inflow point.

During a site visit on a dry weather day (September 9, 2015), an active flowing stream base flow was observed and measured. At this site visit, both contributing stream branch flows were measured separately using a Marsh-McBirney Model 2000 Flo-Mate portable flowmeter. The measured flow was 5.4 gallons per minute (GPM) from the main stem, and 2.7 GPM from the west tributary. Figure 5-5 shows the two tributaries, along with the direct inflow point to the combined sewer system. Given the fluctuating nature of stream base flows, additional long term flow monitoring is recommended to inform the design of any stream removal improvements. For the purpose of this study, the measured stream base flow was carried forward and used in this analysis.

Figure 5-5: Stream Inflow from Two Woods Run Tributaries

5.2.3 Stream and Collection System Modeling Approach

The ALCOSAN Main Rivers Basin hydrologic and hydraulic (H&H) model was used to model the inflow points, as well as run simulations to quantify the resulting effects on the existing combined sewer system and CSO O-27. The existing ALCOSAN model contains sewer trunk lines throughout the O-27 sewershed, up to and including all of the 8 inflow points. The model subcatchments as received were not set up to specifically separate and quantify runoff from the 8 stream inflow points tributary areas. The model represented these stream inflow points grouped together with other combined sewer flows in the sewershed.

To update the Main Rivers model to represent the wet weather flows entering the 8 inflow points, the existing model subcatchments were divided to represent the tributary areas draining to each inflow point. ArcMAP GIS 3D Analyst tool was used to perform contour tracing to identify the areas naturally draining to the inflow points. These areas were compared against the existing SWMM model subcatchments, and overlaid with the PWSA sewer system GIS data to check, confirm, and refine the areas draining to each inflow point. The resulting subcatchments were then included in the SWMM model to represent both the areas continuing to drain to the combined system, and those that would be diverted into a daylighted stream or other detention option. A total of 492 acres of the 1,227 acres in the O-27 sewershed was determined to connect to one of the 8 inflow points.

This analysis considered several stream daylighting alternatives, including partial and full daylighting, and surface detention as described below. Overland runoff, inflow and infiltration (I&I), and base stream flow were quantified in the model and diverted from the combined sewer system in these alternatives.

5.2.4 Conceptual Daylighting Option Location and Conveyance Pathways

With the stream inflows isolated from other sewage flows in the model within the sewershed, a daylighting option was modeled to simulate the multiple stream flow components being diverted into a separate channel. Stream daylighting would restore the natural stream channel, and divert flow out of the combined sewer system. The daylighting would remove from the combined sewer system both the stream base flow during dry weather periods, and the wet weather runoff from the 8 contributing drainage areas upstream of the inflow points.

Currently, the Woods Run inflow points capture stormwater runoff from steeply sloped, undeveloped and wooded terrain. At the 8 stream inflow locations, the stormwater runs off the hillsides and into a ravine where it is captured by an inlet structure and directed into the combined sewer system. Before development of this area, these hillside regions historically drained into a common stream channel. The stream path flowed through the valley along what is now Woods Run Road, and discharged into the Ohio River.

The primary daylighting path investigated was the historic stream channel path running along Woods Run Road taking into account elevation and topography as it follows the natural valleys within the watershed. This alternative presents the challenges of establishing a stream along densely developed roadways with limited width along the ravine. Figure 5-6 shows the preferred daylighting path along Woods Run Avenue and Oakdale Street.

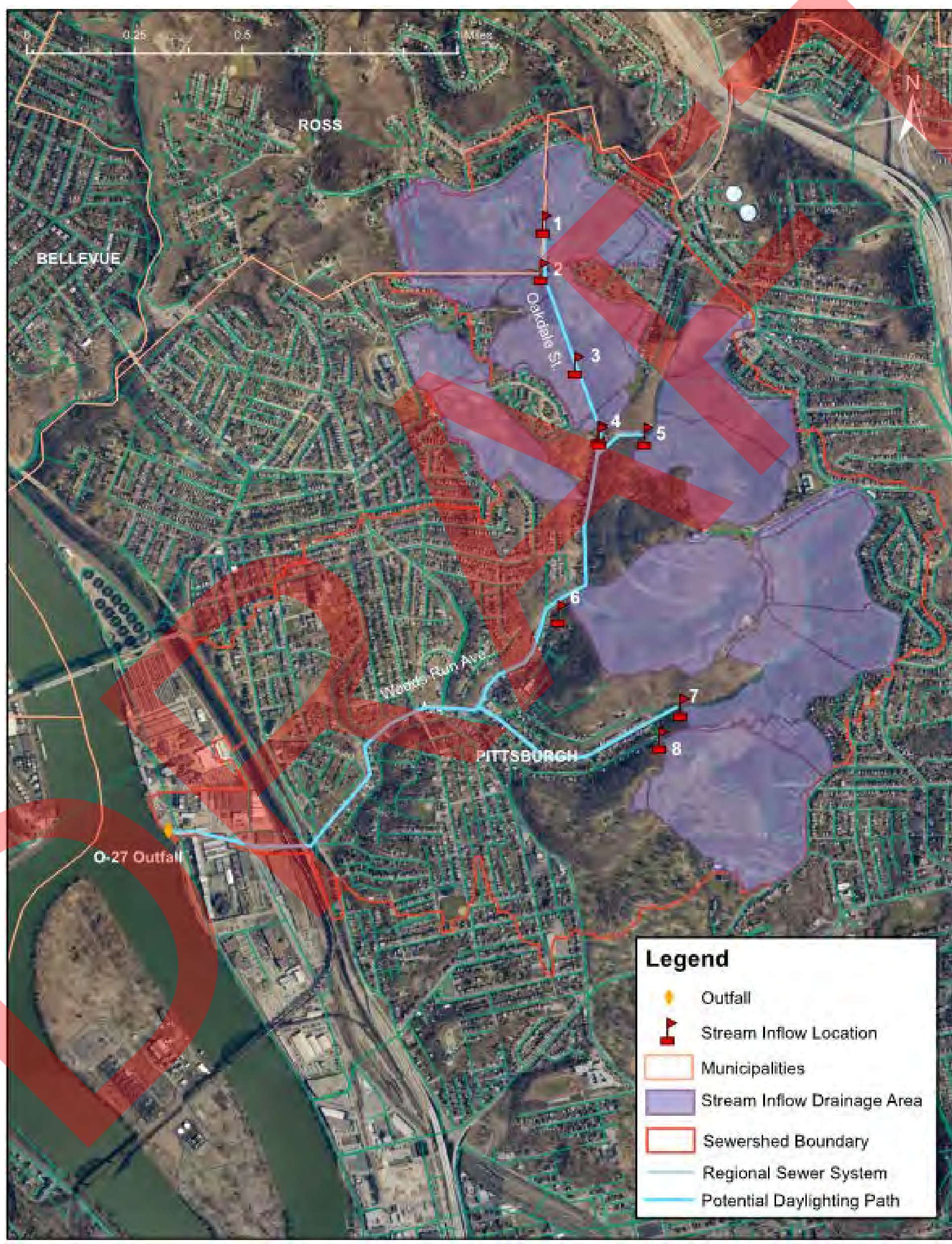


Figure 5-6: Preferred Pathway for Woods Run Stream Daylighting

Figure 5-7 provides an aerial view of a portion of the potential daylighting path, showing the typical level of development and topography within the O-27 sewershed. For a new conveyance pipe, approximately 15,000 feet of storm sewer would be required to capture the 8 inflow points and convey the flow to the Ohio River. This concept as evaluated in PWSA's WWFS required pipe sizes to range from 42 inches in diameter to over 108 inches in diameter to effectively convey both the stream base flow and wet weather peak flows from the 5-year design storm event. With the density and type of development along the potential pathway, construction of a large new storm sewer would be very challenging.

Figure 5-7: Aerial View of a Portion of the Potential Woods Run Stream Daylighting Pathway

5.2.5 Detention Option

With the difficult pathway needed for full stream daylighting, an upstream distributed detention option was evaluated to capture and temporarily detain the stream and wet weather runoff flows. By diverting the base and wet weather flows at the inflow points to detention prior to entering the combined sewer system (CSS), the flows can be managed closer to the source. Each unique inflow location was evaluated for the possible use of constructed surface storage, subsurface storage, or distributed right-of-way BMPs that would help reduce and slow the peak flows into the combined sewer system during rain events. The BMPs would be designed to slowly return the detained wet weather volume over 72 hours back into the combined sewer system to maximize overflow reduction at the O-27 outfall.

The stream inflow modeling was performed by routing all the associated stream inflows through a modeled storage node with a small diameter underdrain. All flows from modeled detention features were connected back into the combined sewer system, and fully drained within 72 hours.

The modeling results, with the Typical Year wet weather events simulated, were used to estimate the storage capacity needed for each inflow location. The detention volumes were optimized to be able to handle all wet weather events in the Typical Year without overflowing. Table 5-5 summarizes the volumes needed for each detention location, and associated stream inflow point to meet the target wet weather control (Typical Year) for this for option.

TABLE 5-5
REQUIRED STORAGE VOLUME NEEDED FOR THE WOODS RUN DETENTION OPTION, TYPICAL YEAR

Detention Location	Stream Inflow Points Managed	Storage Volume (MG)
A	1, 2	0.16
B	3, 4	0.50
C	5	0.35
D	Separate Storm Sewer Area	0.10
E	6	0.22
F	7	0.48
G	8	0.28
	Total	2.10

These required storage volumes were used as a basis for selecting the type of detention, as well as the storage detention size required. Each of the 7 locations was evaluated independently to select the best solution for each location. Available space, topography, detention sizing, ability to capture sediment and debris, and the characteristics of the existing sewer systems, such as depth, were taken into account. The 7 detention locations, selected type of detention, and planning level cost estimates are summarized in Appendix D.

Figure 5.8 below illustrates the locations, and stream inflow points captured by each detention location. Detention BMPs are not to scale, and are shown enlarged in this figure for visual purposes.

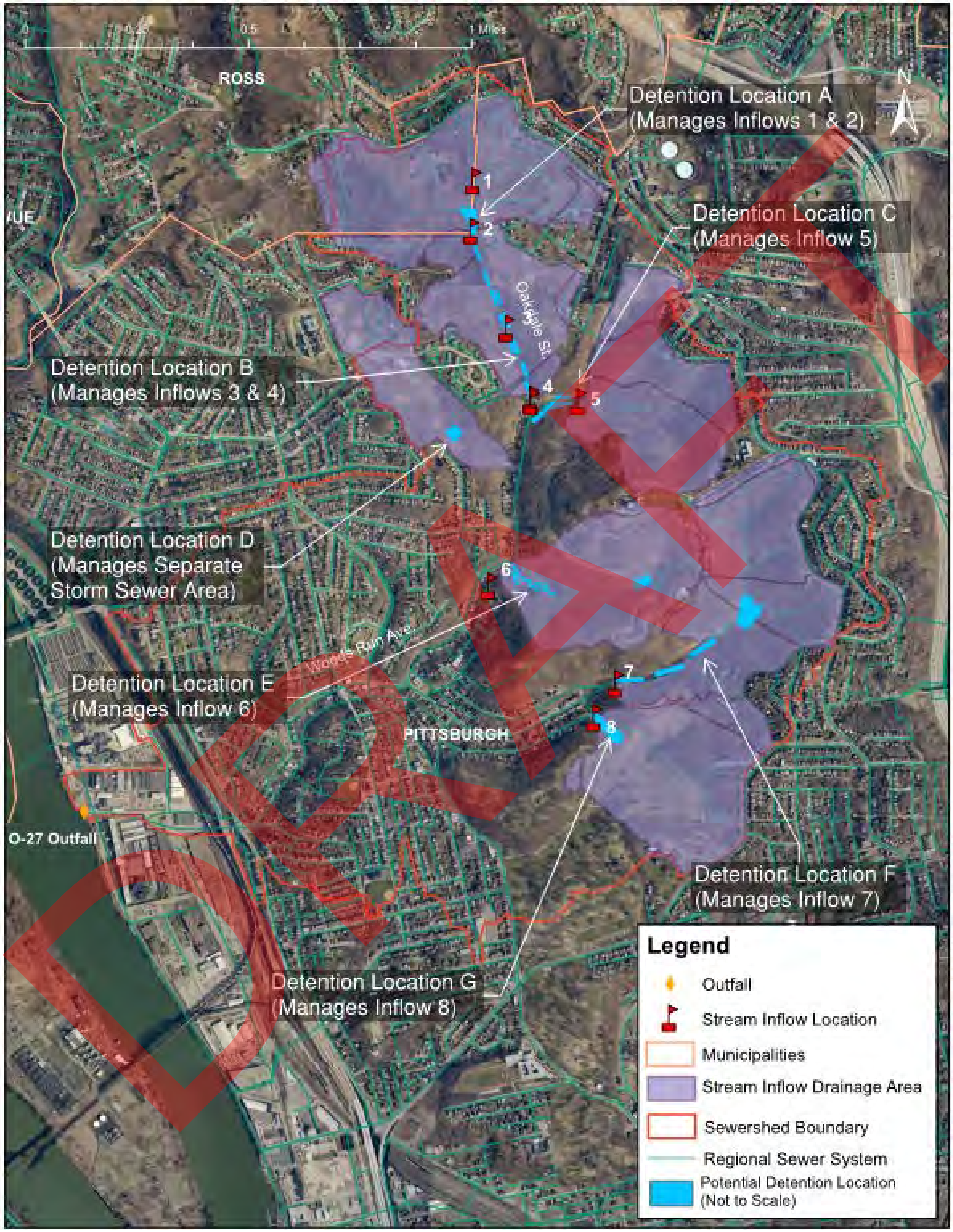


Figure 5-8: Stream Inflow Points Captured by Each Detention Location

A rendering of the potential detention location 3 surface / subsurface is shown in Figure 5-9 for illustrative purposes. The large diameter pipe beneath the street surface represents the existing PWSA 36" combined sewer. The stream base and wet weather flows would be diverted from the 36" sewer and routed to detention location 3, shown on the left side of the image. A pretreatment system would screen grit and other debris prior to entering the subsurface storage facility. All diverted stream flow in this example, and all other Woods Run inflow locations, will connect back into the combined sewer system. In this example, the subsurface detention would have an underdrain connecting to the 36" combined sewer further downstream on Mairdale Ave. This detention feature offers the benefit of pretreating, and managing peak flows from larger storm events prior to entering the sewer system.

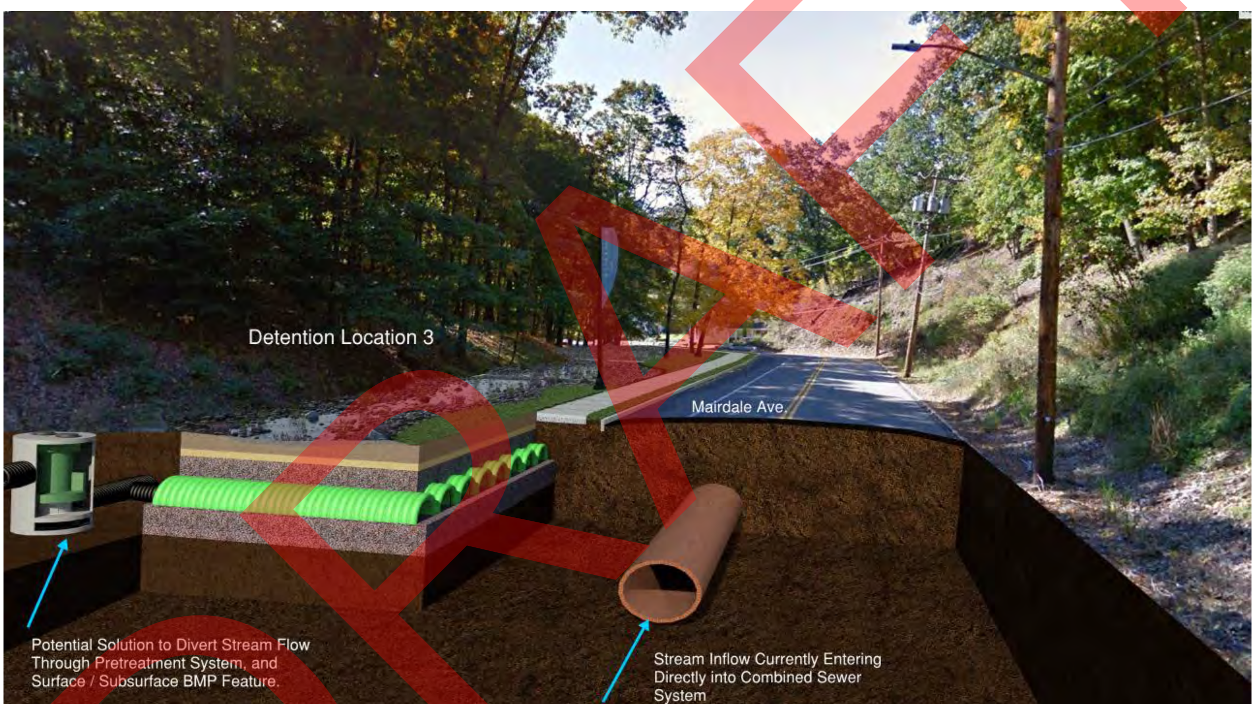


Figure 5-9: Rendering for Detention Location 3

5.2.6 CSO Reduction Benefits at the O-27 Outfall

The collection system model was used to simulate the Typical Year and estimate CSO overflow reduction volumes for both the daylighting option and the detention option.

The stream daylighting option resulted in a 22% reduction in CSO volume at outfall O-27 during the typical year. Annual CSO volume was reduced by 16 MG from 73 MG to 57 MG in the Typical Year.

The option managing flow near the inflow points with 7 detention features resulted in a 20% reduction in CSO volume at outfall O-27. Overflow volume was reduced by 15 MG from 73 MG to 58 MG in the Typical Year.

5.2.7 Planning Level Capital Costs

Estimated costs of the inflow detention option for the seven inflow points are listed in Table 5-6. The combination of these improvements result in the removal of approximately 2,832,000 gallons of base stream flow, and an additional 16,900,000 gallons of wet weather flow. The total cost of the seven distributed detention facilities within the Woods Run sewershed is $10.5 million.

TABLE 5-6
ESTIMATED COSTS OF THE WOODS RUN STREAM IMPROVEMENTS ALTERNATIVES

System Number	Location	Description	Estimated Capital Cost
1	Northern end of Oakdale Street	Subsurface Storage	$752,000
2	Near Oakdale St. and Mairdale Avenue	Distributed BMPs	$3,869,000
3	Mairdale Avenue and River View Drive	Surface and Subsurface Storage	$1,057,000
4	Benton Field	Surface and Subsurface Storage	$319,000
5	Behind 915 Woods Run Ave Houses	Distributed BMPs and Subsurface storage	$1,245,000
6	Kilbuck Road	Distributed BMPs and Subsurface storage	$2,343,000
7	Smithton Avenue and Henley Street	Subsurface Storage	$890,000
			$10,475,000

5.3 Panther Hollow Stream Inflow Locations

5.3.1 Site Information and Review Past Stream Removal Reports

Reports reviewed for the Panther Hollow stream inflow locations include:

- ALCOSAN Wet Weather Plan Report (2013)
- PWSA Wet Weather Feasibility Study (2013)
- 3 Rivers 2nd Nature – Stream Restoration & Daylighting Report (2001)
- Panther Hollow Conceptual Design Memo by EDC (2009)

Data analysis was conducted, utilizing the following resources:

- PASDA Digital Elevation Models
- Existing PWSA GIS data for storm sewers, combined sewers, and inlets
- 3RWW Regional Sewer Mapping Tool
- USGS StreamStats Version 3 Beta
- Additional Flow Monitoring data provided by ALCOSAN (data from 2013-2015)

5.3.1.1 Background Information

With significant work and study previously completed for the Panther Hollow Lake, this information was reviewed and expanded on throughout this analysis. The Pittsburgh Parks Conservancy has conducted in-depth data gathering and planning on the Panther Hollow Stream and Lake. Conceptual daylighting routes have been investigated by EDC in the "Panther Hollow Conceptual Design Memo".

This analysis will build off of previous work, while providing further insight into the downstream impacts on CSO that discharges into the Monongahela River at the M-29 point of connection, as a result of detaining or daylighting the Panther Hollow stream base flow and wet weather flows.

5.3.2 Site Overview and Field Visit Observations

The Panther Hollow watershed was first reviewed to determine the boundaries of the wet weather flow contribution to the Panther Hollow Lake. The existing ALCOSAN Main Rivers Basin SWMM model has delineated the boundaries generating wet weather flow, and separated out the upstream residential areas currently serviced by the combined sewer system. The remaining 176-acre area was used in modeling as the area generating wet weather flow to the lake. The Panther Hollow watershed upstream of the lake is illustrated in Figure 5-10.

Figure 5-10: Panther Hollow Watershed Upstream of Panther Hollow Lake

The portion of Schenley Park in the sewershed directly south of the Panther Hollow shed was included in the analysis as an area for potential stormwater runoff capture by a stream daylighting project. This 94-acre area is shaded in Figure 5-11. Together, these two sheds make up the land area contributing stormwater runoff that was evaluated for a potential stream daylighting project. Model simulations were based on managing these two watersheds.

Figure 5-11: Panther Hollow Watershed and Schenley Park Potential Stormwater Capture Area

To better understand the Panther Hollow Lake and base inflow, a site visit was carried out in September 2015 to observe the lake inflow and overflow points. A photo of the lake is provided in Figure 5-12.

Figure 5-12: Panther Hollow Lake

Figure 5-13 shows the diversion structure located at the eastern side of the lake. Base stream flow from the Panther Hollow Stream is either diverted 90 degrees into the lake, or continues through the weir structure into a concrete overflow channel running alongside the lake, and eventually discharges to a PWSA combined sewer.

Figure 5-13: Stream Inflow Diversion Structure at Panther Hollow Lake

Figure 5-14: Overflow Channel Downstream of the Stream Inflow Diversion at Panther Hollow Lake

The concrete overflow channel, shown in Figure 5-14, is one of the two means for both the wet weather flow and the stream base flow to enter the PWSA combined sewer system. The channel flows are not currently measured by a flow meter, nor have they been measured in the past. The currently active ALCOSAN flow monitor is placed on the lake overflow pipe. This pipe conveys overflow discharge from the two overflow weirs shown in Figure 5-15. Lake overflow discharge is conveyed through the overflow pipe to a PWSA combined sewer.

Figure 5-15: Panther Hollow Lake Overflow Weirs Diverting Water to the Lake Overflow Pipe

This layout is summarized in Figure 5-16, showing the two overflow lines, the location of the ALCOSAN flow meter, and the connection to PWSA's 72-inch diameter combined sewer. As described in the sections below on base stream flow and wet weather flow, the overflow channel diversion causes uncertainties in the monitored flow data because flow that is diverted through the overflow channel is not measured by the meter. A combination of flow meter data and hydrologic and hydraulic (H&H) modeling was used to develop a reliable estimate of flows based on available data.

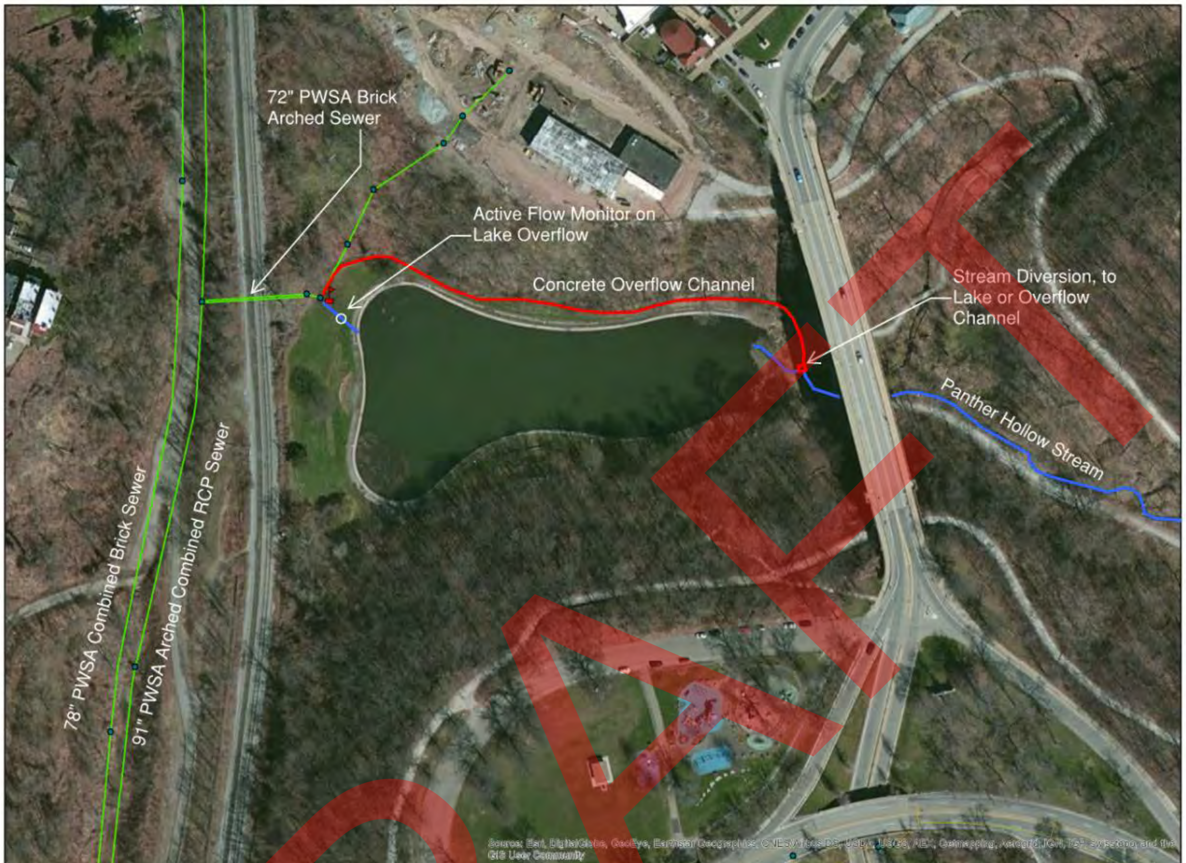


Figure 5-16: Panther Hollow Stream and Lake Flow Configurations

5.3.2.1 Estimating Base Stream Flow

In order to estimate the base stream flow, an average of monthly 2015 ALCOSAN flow metering data was compared with the stream base flows generated with the SWMM models. The SWMM model indicates a base flow of approximately 14 MG per year from the Panther Hollow Lake sewershed. A review of recent flow monitoring shows a much higher stream base flow. After subtracting out wet weather events from the 2015 flow monitoring data, the average base flow from Panther Hollow Lake throughout the year was approximately 68 MG per year. As shown in Figure 5-16, this data is limited to flows entering the combined system through the overflow weirs in the lake, and does not include base stream flow conveyed through the concrete overflow channel. During a 2015 field site visit, there was a stream base flow observed in the concrete channel. Actual stream base flow may be higher than 68 MG per year, if the concrete channel flows were measured and included in the total.

5.3.3 Stream and Collection System Modeling Approach

5.3.3.1 SWMM Model Updates

The ALCOSAN Main Rivers Basin H&H SWMM model was used to model the two inflow points, as well as run simulations to quantify the resulting effects on the existing combined sewer system and combined sewer overflow at M-29. The existing ALCOSAN model contains sewer trunk lines throughout M-29, up to and including the two inflow points. The model as received was not set up to specifically separate and quantify runoff from the two stream inflow point tributary areas. The model combined these stream inflow points with other combined sewer flows in the sewershed.

To update the Main Rivers model to represent the wet weather flows entering the two inflow points, the existing model subcatchments were divided up as needed to represent the areas draining to each inflow point. The ArcMAP GIS 3D Analyst tool was used to perform contour tracing to identify the areas naturally draining to the inflow points. These areas were compared against the existing SWMM model subcatchments, and overlaid with the PWSA sewer system GIS data to check and refine the areas draining to each inflow point. The resulting subcatchments were then included in the SWMM model to represent both the areas continuing to drain to the combined system, and those that would be diverted into a daylighted stream or other detention option. An area of 270 acres of the 2,378-acre total M-29 area was determined to connect to the two inflow points or the separate storm sewer shed.

5.3.4 Conceptual Daylighting Option Location and Conveyance Pathways

To daylight Panther Hollow Stream, conveyance options were investigated taking into account the existing features between the Lake and the Allegheny River. This includes the recreational aspects of the park including Junction Hollow Trail, and the soccer field. Obstacles within the last 2,200 feet from the river outlet location include railroad tracks, bridges, highways, buildings, parking lots, and the existing topography.

M-29 and Panther Hollow were identified as a key opportunity for the city, that also required more in depth planning given the challenges and multiple stakeholders involved. Section 6 expands on strategic urban planning aspects of the Panther Hollow daylighting location, along with a broader strategic plan for the watershed as a whole.

Potential daylighting solutions and cost estimates are provided in the M-29 portion of Section 6. Figure 5-17 shows an overview of the potential conveyance pathway discussed in Section 6.

Figure 5-17: Panther Hollow Stream Conveyance Pathway

5.3.5 CSO Reduction Benefits

The daylighting options would remove base flow from Panther Hollow Lake, along with wet weather contributions from 270 acres. Typical year modeling results with the daylighting option show a CSO volume reduction of 31,900,000 gallons per year reduction at the M-29 outfall. The existing conditions overflow volume of 423,800,000 gallons per year would be reduced 7.5% to 391,900,000 gallons per year. As noted above, these reductions will likely increase as the SWMM model is updated with more detailed flow monitoring specific to the Panther Hollow Lake area.

In addition to the CSO reduction benefits, approximately 68,000,000 gallons of base stream flow would be removed from the conveyance and treatment system throughout the year. Removal of the stream base flow would also provide a reduction in sediment and grit entering the conveyance system.

5.3.5.1 Costs

Costs associated with the capture and daylighting of the two inflows are estimated to be approximately $25,000,000 to $40,000,000. Additional costs for urban planning work in the M-29 sewershed are outlined in detail in Section 6.

6. Urban Planning and Green Infrastructure Plan

6.1 Green First Approach and Process

During dry weather, the ALCOSAN Wastewater Treatment Plant (WWTP) receives 197 MG per day from its 83 customer municipalities. Of this total dry weather flow, it is estimated (based on percentage of the total population) that the City of Pittsburgh (City) contributes roughly 72 MG daily to the ALCOSAN WWTP, or about 36.5% of their total gallons processed, with the remainder coming from the 82 other municipalities. However, during a rain event of as little as 0.1 inches, ALCOSAN's capacity is exceeded and the stormwater overwhelms the system capacity, causing overflows of rainwater and sewage into the rivers. In a typical year approximately 9 BG of sewage overflows during rainfall events into our rivers, causing the US Environmental Protection Agency to require action from ALCOSAN, PWSA and the City, and the 82 other municipalities.

Green infrastructure, or rainwater installations that use vegetation and natural hydrologic processes to manage and treat rainwater, needs to be a key part of our combined sewer overflow solution. This report is part of the ongoing work to find the best ways to implement green infrastructure projects that both manage stormwater and support communities and follows Mayor Peduto's leadership around the P4 initiative: People, Planet, Place, and Performance.

Green infrastructure enhances communities by creating beautiful and high performing landscapes that weave our open space assets into a thriving ecological network. In the process, there will be opportunities for workforce development that will empower Pittsburgh residents and drive neighborhood revitalization. Where once we saw open space as the leftover areas in and between our neighborhoods, Pittsburgh is now consciously shaping our green-space to be ecologically high performing streetscapes, parks, and other amenities that are an economically viable complement to traditional gray infrastructure.

In addition, this report is framed to support the City's resiliency pursuits. Climate change creates a dynamic environment and projections for increased rainfall and number of extreme weather events need to be accounted for in our infrastructure planning. Combined with smart cities technology, surface-based green stormwater infrastructure has the potential to be quickly mobilized and more easily adjusted to allow for adaptive management.

This report focuses on the range of technical solutions that could be installed to reduce our CSO problem. In many cases, these solutions cannot be implemented without significant reexamination of how our stormwater resources are regulated. We need to integrate water-first planning into existing planning efforts, enable multiagency and multi-partner action, and develop economic incentives and long term workforce opportunities to achieve the required performance levels and the desired community benefit. Pittsburgh will not be the first city to implement green infrastructure, but we can strive to be the most innovative in its design, implementation, and integration with our communities.

Previous sections have focused on critical performance goals that ensure a successful city-wide green infrastructure plan. This section defines the process used for strategic urban planning on a sewershed scale. This process is focused on developing a holistic "green infrastructure-first" approach. This approach emphasizes the identification of opportunities that support both resilient infrastructure strategies and are catalytic redevelopment opportunities within each Pittsburgh sewershed.

6.1.1 A Prioritized Approach to CSO

The purpose of the City-Wide GI Assessment is to create a stormwater overlay to inform responsible development and redevelopment through the stormwater lens. The City-Wide project intends to:

- Identify high-yield stormwater runoff areas as CSO reduction opportunity sites for green infrastructure interventions
- Coordinate with City departments and agencies to ensure a comprehensive evaluation is conducted
- Strategize urban planning based on stormwater management
- Explore and assess potential stream separation and daylighting opportunities

The process is part of PWSA's larger strategy to meet EPA compliance and includes an Investigation Phase that assesses surface issues and contributions to the combined sewer system. Sewershed surface issues are then overlaid onto the urban context to find opportunities for high performing projects. PWSA will develop an implementation program that will be monitored and evaluated to ensure long term performance.

The Urban Planning portion of the GI Assessment focused on the sheds that generate the most combined sewer overflow volume and consist of six highly urbanized sewersheds. The sheds vary in size and configuration and do not have contributions from separated upstream sewer systems.

The sheds were selected with an "80/20 approach" that recognizes that the 80% of stormwater is coming from 20% of the sheds, thus the focus on 6 sheds out of a total of the roughly 200 sheds in the City boundaries. The six sheds represent approximately 13,800 acres and over 10,000 stormwater inlets. 40% of all stormwater inlets in Pittsburgh are within these six sewer sheds and together they contribute over 3.0 billion gallons of CSO each year.

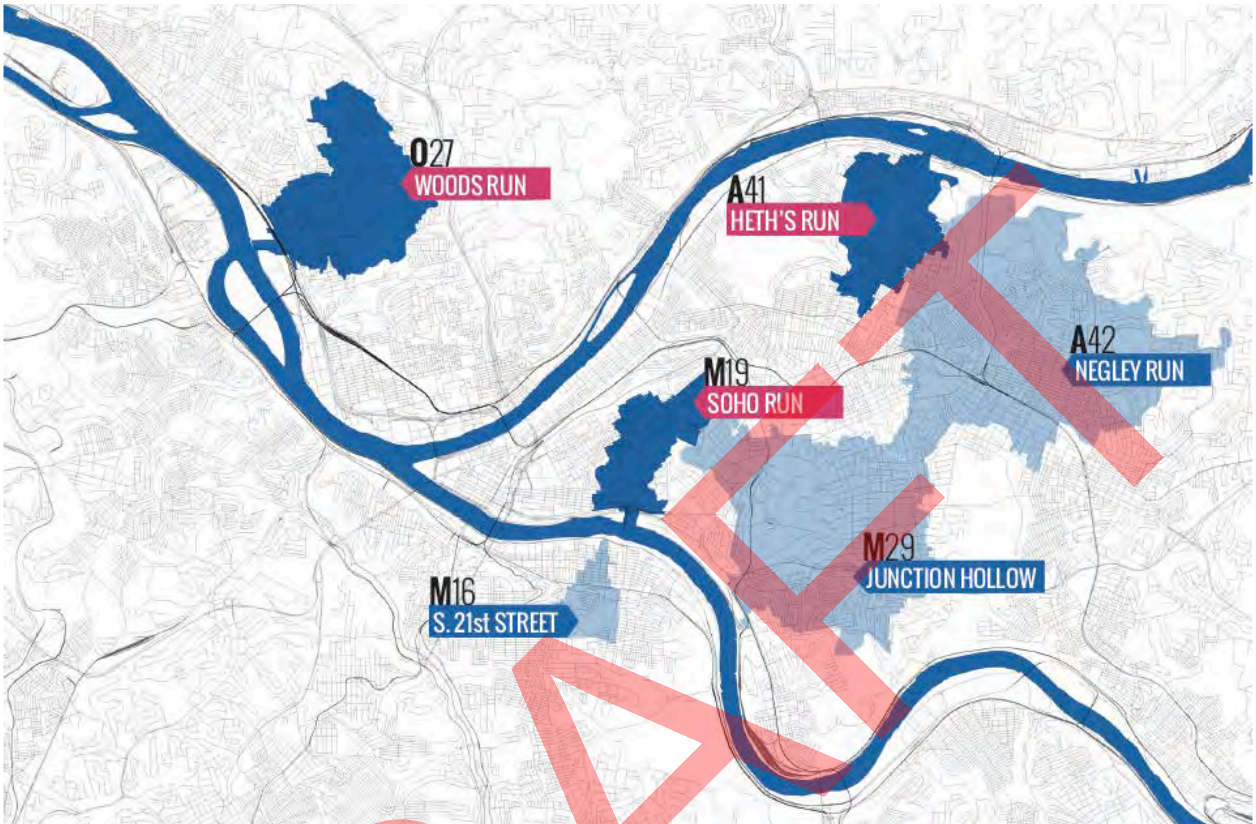


Figure 6-1

The six selected areas are shown in Table 6-1.

TABLE 6-1 GI AND URBAN PLANNING ANALYSIS LOCATIONS		
City Area/Neighborhood	**Sewershed Point of Connection (POC)**	**River Basin**
Four Mile Run	M-29	Monongahela River
Washington Blvd & Negley Run	A-42	Allegheny River
South Side	M-16	Monongahela River
Woods Run	O-27	Ohio River
Heth's Run	A-41	Allegheny River
Hill District/Uptown	M-19	Monongahela River

The largest contributing sewersheds included Woods Run (O-27), South 21st Street in the South Side (M-16), the Hill District or Soho Run (M-19), Junction Hollow (M-29), Heth's Run (A-41), and Negley Run (A-42). Each of these sewershed spans multiple neighborhoods and the character of the upstream urban fabric determines the quantity, quality, frequency, and speed of stormwater into the system. The study looked for opportunities to implement upstream green infrastructure to delay or prevent water from entering the system while improving our streetscape and green-spaces.

6.1.2 Beyond the Technical: Guiding Principles for an Integrated GI Approach

The team established a set of Guiding Principles to further assist in the selection of the GI locations with the sewersheds that combined the data driven, technical metrics used to measure the effectiveness of CSO reduction within the priority sewersheds discussed in the previous section. These Guiding Principles emerged from discussions with the Mayor's office and his staff, multiple City departments, and key community stakeholders.

Many of these guiding principles support the quantitative outcomes for CSO reduction discussed in the previous sections; others, however, serve to broaden the lens and establish qualitative outcomes to improve the communities where these investments are being made, further complementing the redevelopment efforts proposed in these areas. The Guiding Principles offer an additional benefit: they better leverage the limited resources of each City department into a shared effort.

The seven Guiding Principles are outlined below along with a brief description for each:

1. **Cost-Effective Public Realm Investment:** By investing in City-owned property within the public realm the cost of acquired private property for GI is avoided. Furthermore, improvements can be more efficiently shared across City departments when other planned improvements are coordinated.
2. **Create Workforce Development Opportunities:** Investment in GI should be viewed as an opportunity to provide jobs, especially within communities that would best benefit from access to new or better employment opportunities. Ideally, workforce development will encompass all segments of the populations to develop lifelong careers, from the PhD's researching and monitoring the effectiveness of GI, to the "Ph-Do" working to implement the construction of proposed GI in addition to maintaining it.
3. **Re-Establish Riverfront Connections:** As Pittsburgh further redevelops and enhances its numerous riverfront areas, opportunities to improve and create new riverfront connections should be explored in conjunction with proposed GI, providing pathways linking people and runoff to the City's three rivers.
4. **Complete Streets Approach:** Pittsburgh is looking to develop a network of key City corridors into Complete Streets, which are streets that focus multiple modes of transportation, placing emphasis on public transit, bicyclists, and pedestrians. GI should be incorporated within these Complete Streets as many of the corridors also have the highest potential to reduce CSO.

5. **Focus on Healthy, Walkable Communities:** Emphasis should be placed on enhancing corridors to improve access to recreation and healthy food, and encourage walking beyond the Complete Street corridors. GI can be leveraged to further enhance the effectiveness of improving the overall health and safety of a community.

6. **Resilient Infrastructure:** GI can be used to support the efforts of the City in becoming more resilient by reducing flooding, decentralizing runoff capture, and upgrading the aging infrastructure. Creating a smart system that more effectively and efficiently handles stormwater today and in the future.

7. **Align with People, Planet, Place and Performance (P4) Metrics:** Pittsburgh's P4 initiative looks to forge a new model for urban growth and development that is innovative, inclusive and sustainable. GI addresses all four of the components of this framework.

These principles were used to develop plans for each of the six sewersheds that show how stormwater could be managed in a way that generates long-term benefits for each neighborhood.

6.1.3 Managing Water at Three Scales

To establish a city-wide stormwater plan, we need a system that is structured for managing constantly changing resources and flows. Adaptive management is a structured, iterative, and emergent process of decision-making and action that may inform the management system. Adaptive management describes management systems that are well suited for dynamic systems where conditions are constantly in flux and where there is a high degree of uncertainty. Adaptive management is best known for its application to the management of natural resources, such as species populations, but can be applied to any organization that is in an uncertain and emerging context.

Through the evaluation of the first six sheds, a replicable method of analysis has been established that can yield consistent data to inform city-wide modeling. This process creates a Shed Management Plan, which can then be referenced and implemented by agencies, collaborators and stakeholders. The management of the Shed Management Plan needs to be iterative and will cross political, neighborhood, and agency boundaries.

Currently, our city's stormwater management does not enable easy implementation of the plans identified in the City-Wide process. The existing organizational structures, policy, and responsibilities do not enable collaborative decisions and streamlined action. An Adaptive Management model should be considered when structuring the policy, processes, and administrative structure for the control of rainwater as a resource.

Green infrastructure challenges the way we manage our cities. For the City-Wide GI Assessment recommendations to be successful, institutions, policies, and processes need to be structured around an adaptive management model that addresses issues at the appropriate temporal and spatial scale, creates a constant feedback loop of information and action, and has organizations that are structured for collaborative action.

The process includes work at the...

City-Wide SCALE

System wide modeling. Understand the full functioning of the system and the City's contributions.

Select priority sheds. Identify which sheds should be addressed based on potential benefit to the overall system and other criteria.

Create or revise shed-scale masterplanning.

Policy and administrative changes. Make changes to policies, programs, and/or organizational repsonsibility to allow for consisten application across all sheds. Establish integrated funding strategy.

Review shed progress and adjust City-Wide modeling.

ONGOING 2016

SHED SCALE

Model the shed's baseline performance, target reduction level, and esablish the Dashboard (1.0) that distills key indicators in an easy-to-read format.

Identify preliminary target areas within sheds where the model shows contributions to be high. Target areas may indicate high inflow resulting from impervious surface or may result from localized sewer configuration and so need to be investigated further.

Analyze the urban context. Urban analyses should include physical, ecological, and cultural assets, as well as economic activity.

Develop system schematic(s). Each shed will have a hydrological logic based on physical configuration and available resources. The schematic needs to indicate how each component works within the system.

Identify locations and types of green infrastructure. Develop areas of focus where green infrastructure functions as a system or independently.

Assess performance with hydrologic and economic modeling. Model proposed green infrastructure alternatives for hydrological effectiveness, costs, and triple bottom line benefits. Revise the Dashboard (2.0).

Share the preliminary assessment with the community. Reach out to all levels of the community for feedback, from elected officials, community organizations, and the general public. Anticipate the need for general education on CSO issues. Discuss project prioritization criteria and possible administration mechanisms.

Identify projects for implementation.

Develop a shed-wide plan of action and funding strategy for infrastructure. Prioritize short, mid, and long term implementation. Apply consistent criteria for assessing projects, including areas of risk, areas where projects are easy to implement, areas of development activity, and areas where synergies efforts can multiply benefits.

ONGOING, SIX SHEDS, JUNE 2016

PROJECT SCALE

RISK
projects that will lower risk

OPPORTUNITY
projects that are easy to implement

DEVELOPMENT
projects in areas of high activity

SYNERGIES
projects with multiple benefits

Design, engineer, and construct projects according to shed-wide plan of action. Assign responsibilty for projects and coordinate ongoing implementation.

Monitor operations and maintenance. Make adjustments when needed. Update computer models and shed dashboard to communicate progress

ONGOING, PROJECTS FUNDED AS OF JUNE 2016

And is informed by:

The **City-Wide ADVISORY TEAM** is a community based review team to advise on system-

The **SHED-WIDE ADVISORY TEAM** is a community based review team to advise on sewershed-specific projects and priorities and is a conduit for communication with the community.

Figure 6-2

6.1.4 A Green-First Planning Approach

Each of the sheds went through a rigorous analysis that synthesized stormwater performance criteria with urban design and community development.

Early in the process, PWSA initiated and conducted multiple meetings with the Urban Redevelopment Authority (URA), the Department of City Planning, and associated City agencies to obtain the relevant development plans for the City. Examples include existing community-driven redevelopment plans, engaged stakeholder development plans, and city department progress reports on current initiatives being pursued. Where these plans were not yet incorporated into GIS, PWSA collected and developed the information using GIS to display the data for use in overlaying with the identified GI locations.

Once the digital database was established and organized, plans were studied in conjunction with characteristics of sewershed areas. These characteristics focused on existing conditions both natural and built. Natural conditions included soils, vegetation, historic streambeds, and slopes. Built conditions included corridors, undermined areas, parks, open space, and the existing sewer system. The next step synthesized this information (planned redevelopment + existing conditions) with high yield areas. From the synthesis of factors (planned redevelopment, existing conditions, and high yield) the six priority sewersheds were selected. The first six sheds were established where proposed GI would best complement the strategic urban development plans, existing characteristics, and high yield areas to most effectively achieve a “green first” approach.

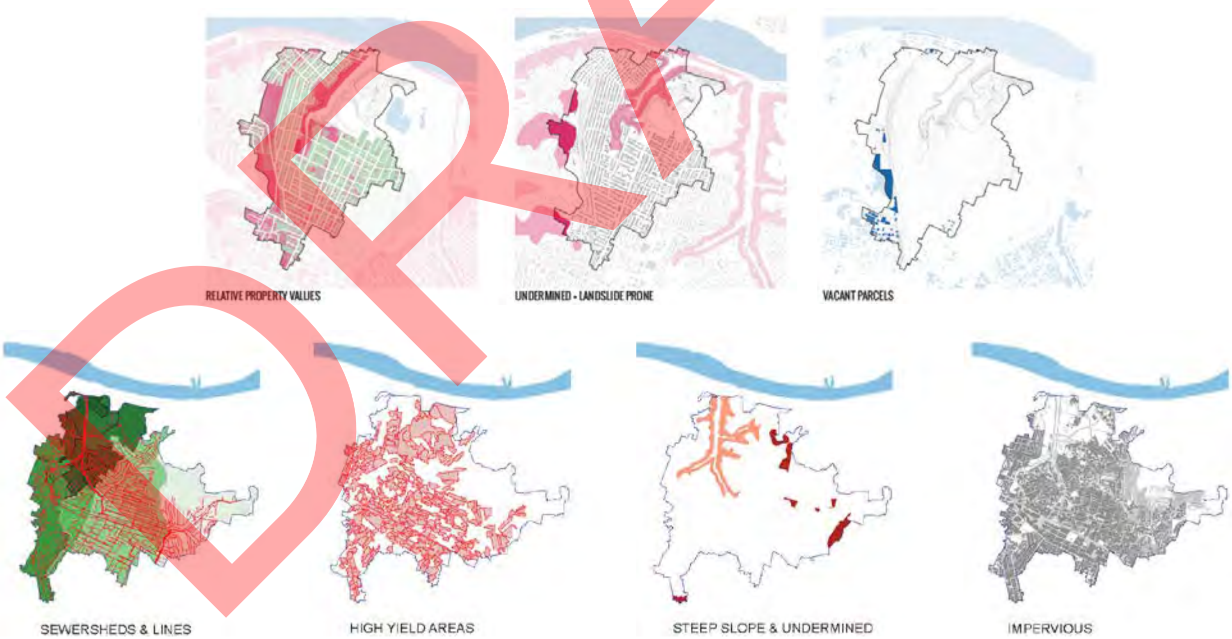


Figure 6-3

The next step for integrating GI into the City-Wide GI Assessment was establishing the metrics to measure capture potential for GI within the priority sewersheds. PWSA overlaid the redevelopment plans and proposed GI locations with the digital terrain model, ArcHydro analyses, and with identified stream removal locations. To the greatest extent possible, these known development plans were utilized to inform the ArcHydro results. However, because of the expedited timing of this project, the ArcHydro analyses were conducted in parallel with the synthesizing of development plans. The overlays were used to understand how known development plans align with the identified GI and stream removal locations, and to highlight coordination opportunities. PWSA produced maps and GIS shapefiles to display the overlays and coordination opportunities, and met to discuss the findings with regard to coordinating with urban planning.

Figure 6-4: Example Community Development Plan with Coordination Opportunities for Green Infrastructure: 2015 Community Consensus Vision Homewood Cluster Planning, Operation Better Block, Inc.

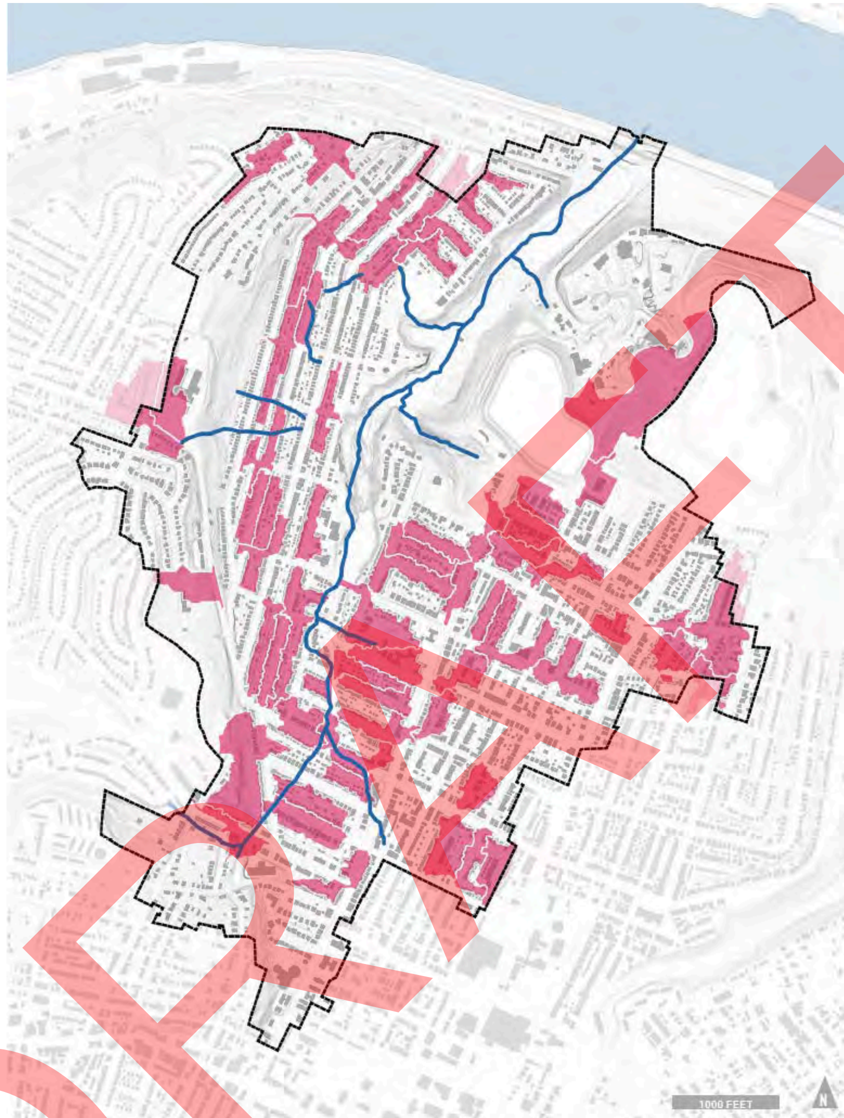


Figure 6-5

Based on the findings of identified GI locations and the known development plans, work was conducted to align the various locations, using GIS tools and assessments performed using ArcHydro software and hydrologic and hydraulic (H&H) SWMM model runs, performed to update the stormwater runoff and CSO reduction benefits previously determined and discussed in Section 3. On the basis of aligned GI locations and development plans, modified ArcHydro results and SWMM runoff files were generated. Then, the SWMM modified runoff files were used to run the SWMM models for the typical year of precipitation, and thus, updates were derived for the stormwater runoff and CSO reduction benefits.

The identification of high yield GI locations and stream removal locations led to indications of additional new and redevelopment opportunities, and also opportunities to reimagine areas of the City. PWSA identified the likely locations and general concepts for the development areas and features that could be merged with the management of storm and surface waters. These general concepts will be used by others as part of the urban planning and market studies to be conducted in parallel with this work (separate from the City Wide GI Assessment). In short, the GI concepts, strategic urban planning approach, and CSO reduction were tested and refinements made to ensure the most effective combination.

The team applied a process of overlay analysis to the six priority sewersheds to create an Urban Design Framework. The Urban Design Framework served as a synthesis of the redevelopment plans, key corridors, and important nodes within the community. Nodes could be important intersections of corridors or key areas within the community like business districts, institutions, or open space well positioned to capture high yield areas. Furthermore, emphasis was placed on Complete Streets, connectivity to rivers, high risk areas, and areas within each community where redevelopment had been proposed.

This initial framework was shared with multiple City departments, the Mayor's office, and key community stakeholders. When commentary necessitated changes to the Urban Design Framework, refinements were made. These refinements served to inform the next steps and to identify specific opportunities for GI within the six sewersheds.

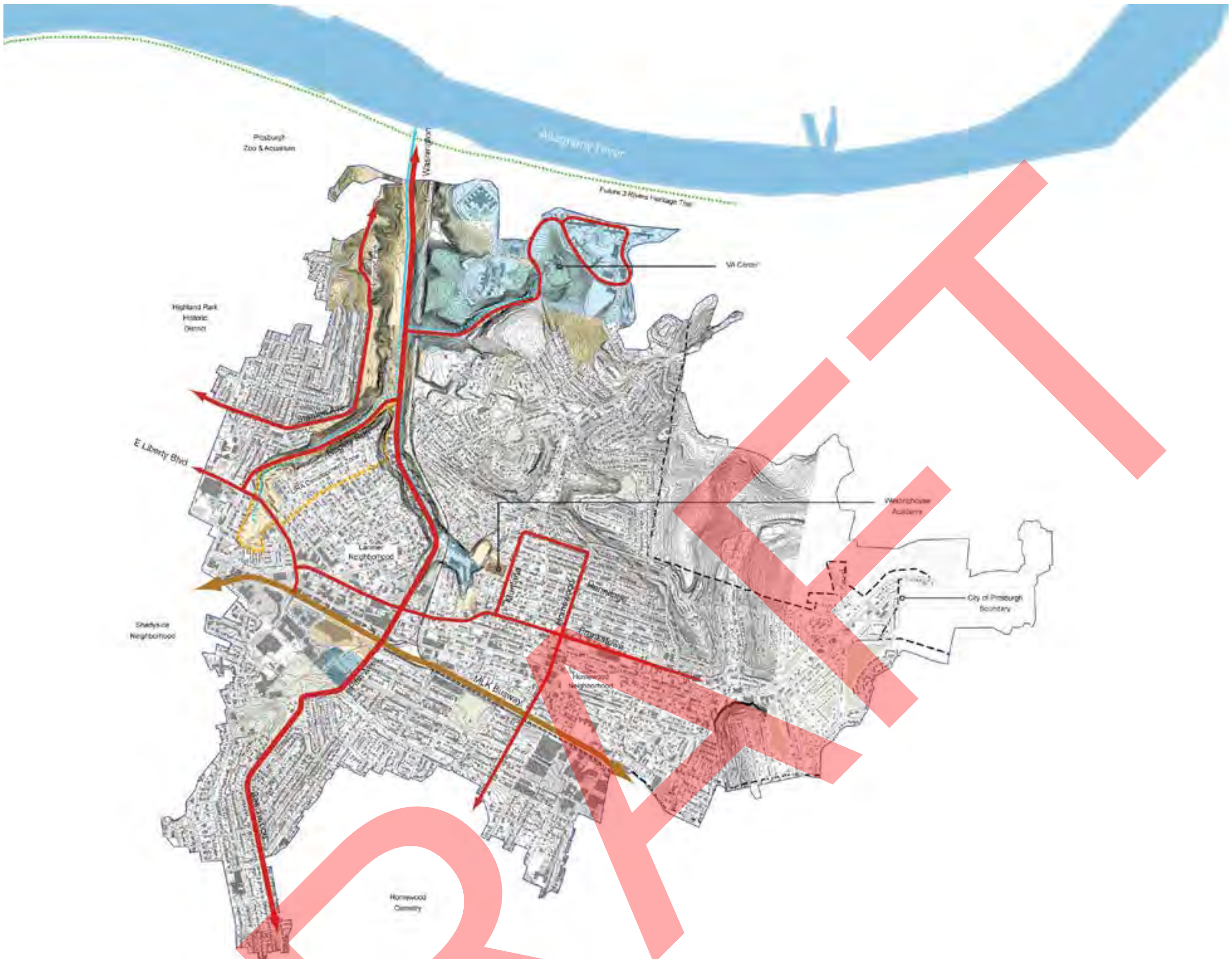


Figure 6-6: Example Urban Design Framework Synthesis for A-42 Sewershed

6.1.5 Finding: Sewershed Morphology

Historically each shed was the location of a stream or run that connected upstream areas to the primary river waterway, through a series of secondary creeks and runs, and tertiary channels and seasonal waterways. Though this pattern can sometimes be difficult to read in the current topography, the historic topography can still be read in maps of the subgrade sewer networks that were originally constructed in the valley floors.

Today this primary-secondary-tertiary conveyance remains the dominant morphological structure for all of the sheds. This allows for a common set of strategies to establish a hierarchy of green infrastructure, including:

- direct river reconnection
- valley surface storage and conveyance on distributed sites
- upstream surface conveyance and capture in the public right of way
- net zero or offline sites
- green infrastructure to improve the performance of private properties with pay-for-success or other models

To reach the required overflow reduction levels for each sewershed, the strategies have to be evaluated as a networked system with two goals. First, the infrastructure improvements should detain 1.5" of water during a storm event, releasing the water slowly back into the system after a 72 hour period, likely after the storm event has passed and without triggering an overflow event. Second, and more ambitiously, the infrastructure should prevent the water from reentering the sewer system, thus preventing the need for treatment at the ALCOSAN plant. Both of these are significant changes and require extensive analysis, including modeling for future climate change projections.

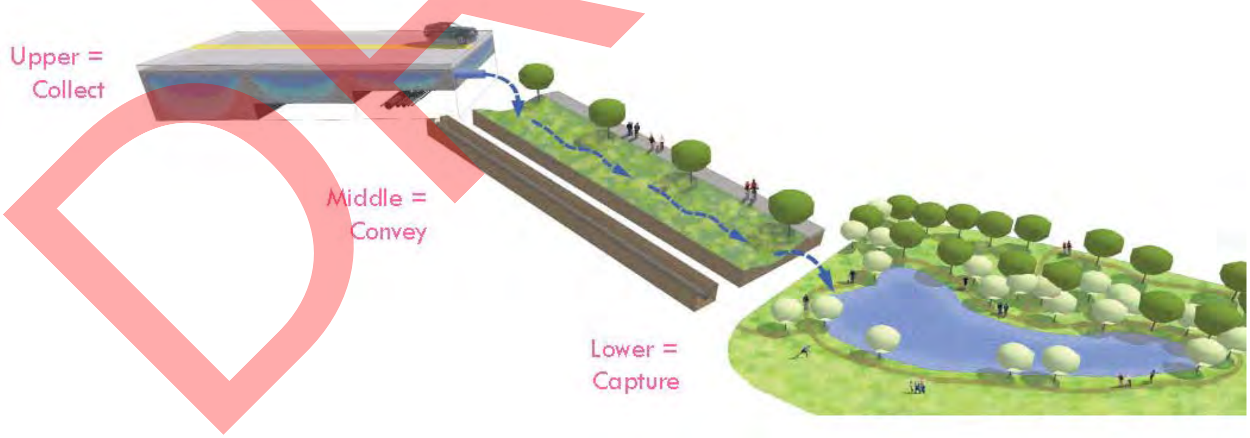


Figure 6-7

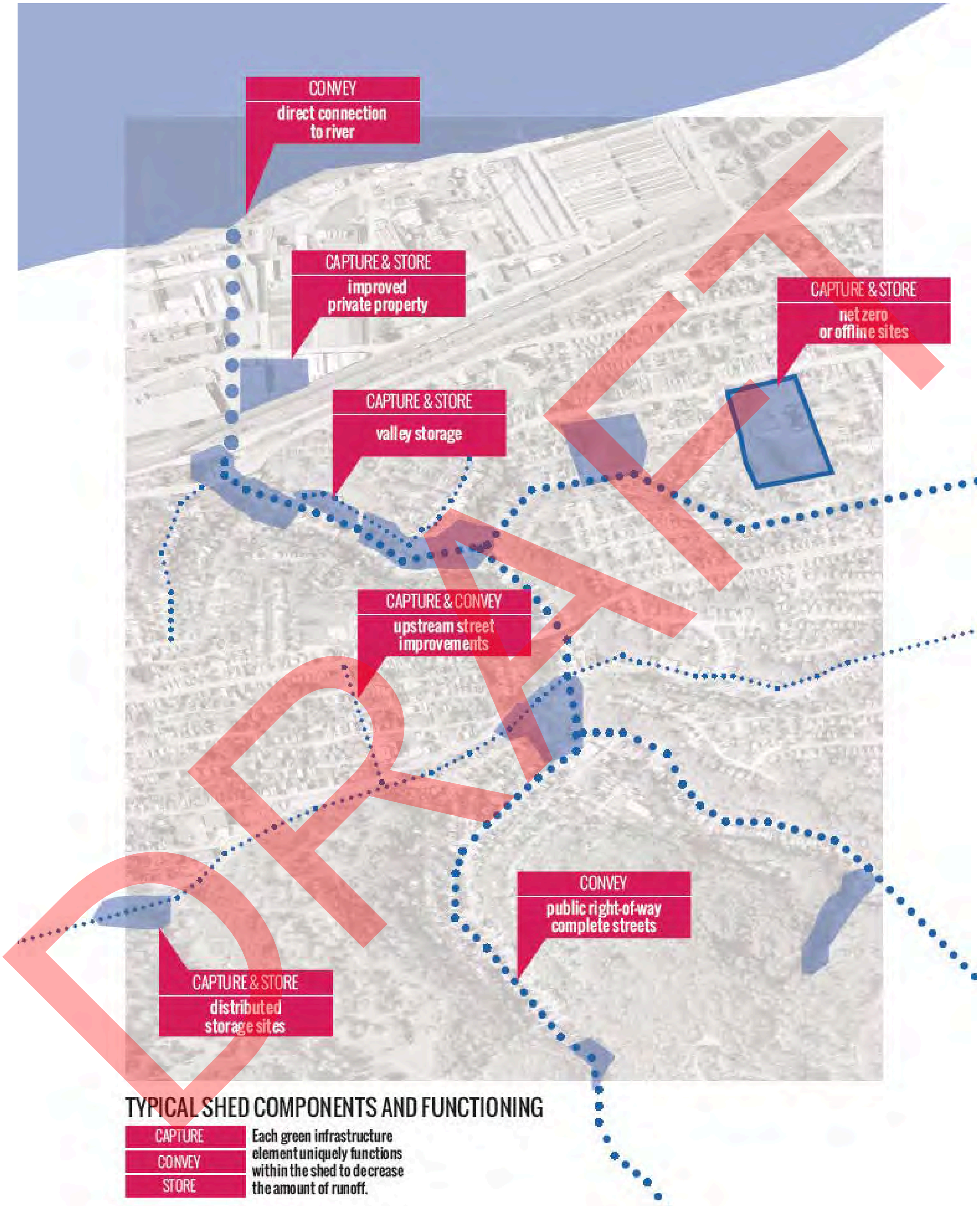

CONVEY
direct connection to river
CAPTURE & STORE
improved private property
CAPTURE & STORE
net zero or offline sites
CAPTURE & STORE
valley storage
CAPTURE & CONVEY
upstream street improvements
CONVEY
public right-of-way complete streets
CAPTURE & STORE
distributed storage sites
TYPICAL SHED COMPONENTS AND FUNCTIONING
CAPTURE
CONVEY
STORE
Each green infrastructure element uniquely functions within the shed to decrease the amount of runoff.
DRAFT

Figure 6-8

6.1.6 Finding: Centralized, Decentralized, or Hybrid System Design

While each shed is unique in its balance of large scale or small scale installations, there are some principles common to all sheds.

The degree of centralization or distribution of the system components affects the type, costs, and operations of each shed's system. Each shed needs to work as a system with a focus on the interrelatedness of upstream and downstream systems. For example, some sheds may be focused around a central valley or primary gathering point for the water with an extensive capture and conveyance system. Other sheds may have more opportunity for distributed locations that can be taken offline, thus eliminating the need to connect the sites. Different types of infrastructure will be needed to dynamically regulate flows.

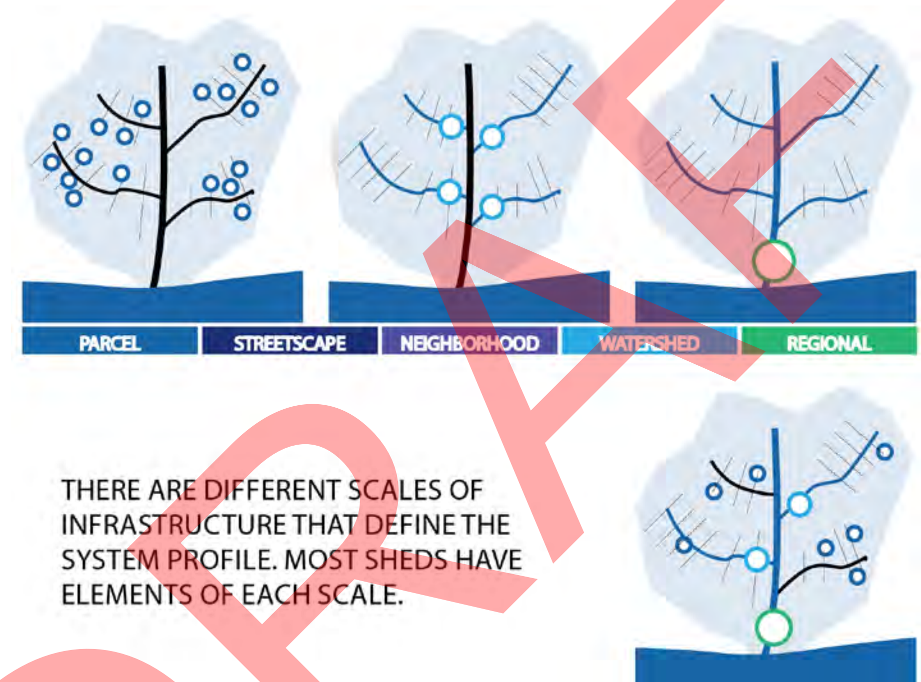


Figure 6-9

Redundancy needs to be integrated into each system design. Redundancy can allow for a factor of safety, providing excess capacity in case of an overload in any one element. Redundancy can also account for long term system stressors such as increased precipitation due to climate change. Lastly, redundancy creates the flexibility required for long term system implementation. Since there are multiple ways that the system can be implemented, redundancy allows for short term and long term changes without compromising performance.

Green infrastructure components are interdependent and some are more important in determining the performance of the system. To use an ecological analogy, the functioning of an "old growth forest" is driven by the 200 year old trees that allow for the presence and behavior of other species. Some sheds have significantly large elements that will enable or drive the capacity of other elements. Centralized valley storage, such as a naturalized wetland, allows for upstream storage infrastructure to be minimized, reducing the infrastructure's footprint in a dense urban environment. Valley infrastructure is dependent on upstream capture and conveyance—if the valley infrastructure is not in place, the nature of the upstream systems changes dramatically. Conversely, the valley cannot function as a wetland without the upstream infrastructure to deliver the water.

6.1.7 Finding: Managing Broader Benefit and Scales of Time

Green infrastructure challenges the way we manage our cities because it assigns economic, ecological, and social value to natural services, it needs to be designed and managed as dynamic flows over time, and it emphasizes opportunities for shared value instead of segregated systems. The City-Wide GI Assessment presents a new paradigm for how the City designs and manages infrastructure and is distinguished by a few key principles.

First, the City-Wide Analysis assigns economic, ecological, and social value to the natural services that can be provided in the landscape, such as water capture and storage. The functioning of green infrastructure such as wetlands or bioswales can be monetized and compared to the performance and cost of more traditional engineered systems. In addition, the improved ecological systems improve other areas of performance. At the largest scale, cleaner water quality allows for compliance with regulations, but also greater biodiversity. At the scale of the neighborhood, the increased tree coverage from tree wells in sidewalk plantings can have a very real effect on localized urban heat island effects and decrease property owners' costs to cool their buildings. Studies also show that green infrastructure improvements also have measurable effects on property values and improve resident perception of safety and satisfaction; and furthermore, emerging research shows that the presence of plants in our everyday experiences boosts personal health and wellbeing. The City-Wide GI Assessment makes the case for improved hydrological performance with green infrastructure and also takes into account the collateral benefits of "triple bottom line" thinking.

Second, the systems need to be designed and managed as a network of flows over time, not just as a series of physical facilities. This requires thinking in different timescales and will be facilitated through technology that allows us to model, simulate, and make midcourse adjustments as needed.

At the smallest timescale, the day, green stormwater installations can have controls that dynamically respond to weather or storm events. Sensors can predict direction and severity of storms, triggering smart infrastructure to anticipate impact, such as lowering the level of an existing reservoir in anticipation of a storm event. Seasonal performance can be directed with similar technology.

At the next timescale, the systems need to be designed and phased in over decades of time, with modeling and flow analysis constantly revised to allow for networked components. For example, an upstream development that changes the runoff profile of a shed needs to be modeled to understand the performance of other parts of the system and to be able to consistently record benefits from continued improvements.

Lastly, the systems need to be designed for generation-scale evolution. Both green and gray systems age over time and have profiles of growth and decay. Understanding the performance relative to maintenance and replacement milestones is key to maintaining biotic systems. The maintenance regimen, both in time and in tasks, evolves through the life cycle of the infrastructure, and the net present value of infrastructure needs to be considered accordingly.

Third, the City-Wide GI Assessment emphasizes opportunities to create shared value instead of isolating or segregating systems. Green infrastructure projects should rarely be considered in isolation but should be integrated into other infrastructure investments. For example, the city's commitment to Complete Streets means that stormwater conveyance can more easily be advanced at these locations. Scheduled improvement in the city's parks should be reviewed for opportunities to incorporate green infrastructure, giving character and functionality while achieving multiple benefits for the same dollar spent. In areas of rapid development, instituting incentives and controls would encourage green infrastructure that helps meet the City's goals while creating higher performing, beautiful places.

6.1.8 Finding: Managing Risk and Resiliency in Climate Change

The City of Pittsburgh is addressing resiliency and climate change through the Office of Sustainability's initiatives like the Rand Corporation's Study on Resilient Stormwater Management in Allegheny County. While the goal of the study is to support improved stormwater management and resiliency in the entire county, the early findings have raised questions about the targets set for city-wide planning. According to the Rand Corporation's preliminary presentations, stormwater models based on an average year may not be reflective of emerging data on climate change statistics. Their research suggests that precipitation models may need to be adjusted to account for a greater frequency of more severe events and that the "average year" may have already been exceeded in the majority of the past 10 years.

While the frequency of rain events may be increasing, there is evidence that the intensity of some of those events is also increasing, releasing large amounts of water in very brief events. Sometimes referred to as "extreme rainfall," the events make it very difficult to design systems that can handle both the small and frequent events as well as the intense but less frequent events. In many cases we can find old newspaper headlines about previous flooding events on flood prone sites. These sites may have seemed to be free of problems in recent decades, but with the confluence of failing infrastructure and shifting climate patterns, we are seeing issues at these sites arise again.

Many other cities, such as those along coastlines or in arid climates, are addressing water issues with a greater sense of urgency. For example, Copenhagen has developed a Cloudburst Plan (2012) as part of the Danish capital's Climate Action Plan. The Cloudburst Plan addresses frequency and intensity of events with shedwide planning and a commitment to major infrastructure replacement. New York City has pledged millions of dollars to major design and engineering initiatives that will change the way their waterfronts function.

Places like New York and Copenhagen are using a similar set of criteria for ranking initiatives including:

- Risk: Measures that will lower risk
- Opportunity: Measures that are easy to implement
- Development: Measures in areas of high activity
- Synergies: Measures with multiple benefits

These cities also face similar administrative and funding challenges that limit system-wide adoption. Other cities that do not have the same risk profile, such as Chattanooga, Tennessee, may not need the same existential level of investment, but do need to reinvent their administrative systems to account for the risk of failure by inaction. Chattanooga has adopted a full range of policies and programs to support distributed strategies for green infrastructure.

Although flooding and water quality are two of the major reasons for green infrastructure, the City should also consider long term risk and resiliency around an adequate supply of safe drinking water. All of the City's drinking water supply comes from the rivers and, while the rivers are much cleaner than before, there is a growing risk of upstream pollution contamination related to extractive industries. Currently the City-Wide approach to stormwater is to use green infrastructure to retain or slow it for use on site with infiltration or biotic systems. However, future studies could also examine the potential of stormwater conveyance and storage for reuse as a potable water source with integrated microfiltration and distribution, instead of just delayed release back into the rivers. Decentralized water treatment and supply is already a reality in many places and is something that PWSA could evaluate in relation to its core service model.

Figure 6-10

6.1.9 Finding: The Evolution of Policy and Administrative Structures

The biggest challenge to successful green infrastructure networks is not necessarily with the technologies themselves, but with the regulations, responsibility, and financing of the systems. Though this report was focused on the technical implementation and not on administrative structure, it has become apparent that the full range of solutions can only be enabled with changes to governance of the system.

Over the course of this project through internal and external meetings a number of concerns have consistently risen to the top as major issues that could inhibit a strong and effective green infrastructure network. Many focus on the distributed control of system components, making it difficult to act in an integrated way. There is both vertical zoning of the systems as they pass from the surface through pipes administered by various agencies while horizontally moving across municipal boundaries in a way that requires coordinated action. Because this report focused on sheds within a single municipality, the City of Pittsburgh, the focus will be on the vertical zoning and the associated interagency jurisdictional issues.

Today, stormwater's journey begins at the surface where the Department of Public Works and private property owners control its flow, each under different legal requirements. Once the water enters the combined sewer system it becomes the responsibility of PWSA until it enters ALCOSAN's conveyance and treatment system. Green infrastructure challenges the clear boundary between the agencies who control flows on the surface and the agencies who control flows in below grade systems.

Green infrastructure extends the responsibility for water quality and quantity into a realm in which responsible agencies traditionally do not have control. It is not necessarily a lack of will but a lack of administrative infrastructure for coordinated action that inhibits full implementation. Many of these issues are challenges for other cities as well.

Issues to be resolved include:

- There are no rainwater management plans and it is unclear who would administer them and how they would be legally binding.
- Planning and projects are loosely coordinated between siloed agencies, including Public Works, City Planning, PWSA and others.
- Perceived gaps in planning or coordination capacity of these organizations are filled with nonprofits who advocate for coordinated efforts but do not control the process or the assets.
- Existing planning and administrative practices across the country are not often suited to address dynamic or adaptive resource flows. Current controls are better suited to regulating placemaking, not monitoring and adjusting to the dynamic flows or performance of these places (this is a challenge for other resource flows such as energy or parking).
- In addition, the City is a part of ALCOSAN's larger cohort of municipalities and may need different administrative structure than others in this cohort.

Effective and innovative green infrastructure and rainwater control will be limited unless these issues can be drawn into the design problem. There are a few possible responses and it is likely that some combination would be necessary:

- Reshape the agencies to create a structure that allows for coordinated action and adaptive management.
- Change the jurisdictional boundaries to allow for existing agencies to have increased authority.
- Create market or regulatory mechanisms to incent or require action.

6.1.10 Process + Approach: Green Infrastructure Concept Plans, Beyond the Framework and Analysis

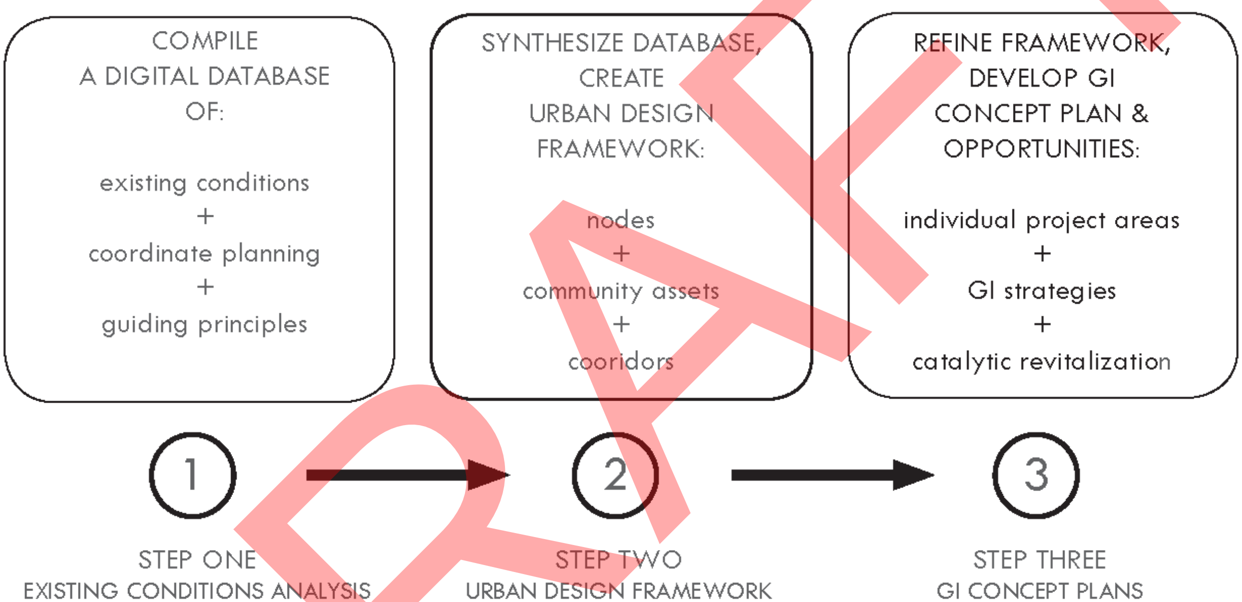


Figure 6-11

From the outset, a holistic approach grounded in sewershed-based design principles (established in the Framework plan) sets the stage for successful selection of individual projects and concept plans to emerge. The identification of individual projects and concepts was the third step in a complex, systems-based design approach that was preceded by the following:

- **STEP ONE: Digital Database of Existing Conditions** - Reviewed and analyzed existing plans and studies completed to date for proposed GI solutions throughout the six defined watersheds:
- **STEP TWO: Urban Design Framework Plan** - Facilitated a series of initial strategic stakeholder workshops and participated in bi-weekly stakeholder and/or community meetings. This provided technical support from early schematic design development through final stages of the GI Concept Plans

Ways to leverage these opportunities were woven into a larger vision that creates neighborhood nodes, corridors, and links community assets with interconnected GI strategies. This sewershed-based, systems approach uses urban planning and community revitalization to shape the Green Infrastructure Concept Plan. It serves as a catalyst for a broader vision that can be strategically implemented. These concept plans were refined with community and stakeholder input.

- **STEP THREE: Green Infrastructure Concept Plans** - to be integrated into the Preliminary Design Report and will lay the foundation for further development of a holistic sewershed-based design approach for Green Infrastructure concepts within the six watersheds.

A true collaboration will require City leadership, community, and stakeholder members to be an integral part of the process moving forward towards implementation opportunities. The process and approach with the proposed design outcomes are summarized in the following sections for each of the six areas:

- Four Mile Run (M-29)
- Washington Blvd + Negley Run (A-42)
- South Side (M-16)
- Woods Run (O-27)
- Heth's Run (A-41)
- Hill District/Uptown (M-19)

6.1.10.1 Sewershed Approaches for Green Infrastructure Concepts: Upper, Middle, and Lower

The position of a potential green infrastructure site within the sewershed played an important role as the team identified opportunities and concepts for GI in the priority sewersheds. In general, sites and corridors located in upper portions of the sewershed are candidates for green infrastructure solutions that primarily collect runoff, sites and corridors in middle portions primarily convey runoff, and sites and corridors in lower portions of the sewershed capture runoff.

The **upper portions** of the sewershed, "Upland Neighborhoods," are often more developed with more impervious areas, making them suited for pervious pavement opportunities that can also convey runoff down the system. Upper portions are most effective at **collecting** runoff since they often contain numerous high yield areas and high amounts of impervious surface. When these areas are not in the public realm, public-private partnerships could be developed to expand opportunities.

In the **middle portions** of the sewershed, or "Tributary Gateways," **conveyance** becomes more of a priority. Runoff collected in the upper sewershed as well as high yield areas within the middle zone provide the stormwater flow carried by the conveyance system. Ideally this conveyance is accomplished with bioswales where street widths can be narrowed or within existing valleys through more natural settings like parks. Where steeper slopes exist, check dams are provided to slow the velocity and erosive power of water and provide storage volume as well. Many of the existing valleys would benefit from ecological restoration that reduce the amount of sediment washing into the system in addition to offering more resilient and diverse habitats. Where bioswales are not possible, pervious pavements can be utilized to convey runoff through highly porous gravels and supplemental underdrain pipes.

The **lower portions** “Greenway Boulevards” provide great opportunities to provide larger **capture** basins for the runoff that is collected and conveyed from the upper and middle portions. Many of these areas offer large, more gradually sloped areas in publicly owned parks or open space. These are ideal locations for storage. When practical, this should enhance the connection to the riverfront.

Within the three categories of **collect, convey, and capture,** a number of GI approaches collectively offer a **“kit of parts approach”.** The definition of these is provided in the Appendices F and G.

Figure 6-12

"Kit of Parts approach" to system-wide Green Infrastructure design solutions

Figure 6-13

6.2 M29 Four Mile Run

Figure 6-14

6.2.1 Sewershed Existing Conditions

Four Mile Run has several stormwater-related opportunities and constraints which include approximately 2,400 acres of diverse physical and social landscapes, including highly urbanized activity centers, multi-family and single-family neighborhoods, and large natural park areas. Flood Mitigation is an important public health and safety issue for the residents residing within the lower watershed neighborhoods. Two major combined sewer lines converge at the lower watershed zone, which regularly results in surface flooding and basement sewage backups during wet weather. In addition, steep slopes and high percentages of invasive vegetation are directly increasing sediment loads and erosive conditions along drainage corridors.

Schenley Park is well positioned to absorb stormwater and provide new amenities that park users have been requesting through an existing community dialogue process. Schenley Park makes up roughly 20% of the M-29 sewershed that mostly drains to Panther Hollow Lake and Junction Hollow. Panther Hollow Lake lies in the heart of Schenley Park and is a control point for stormwater runoff as well as a confluence of two spring fed streams that deposit approximately 68 million gallons of water, annually, into the combined sewer system. The lake however suffers from poor water quality and aging infrastructure. The Park is positioned well within the watershed to accept stormwater before it enters the combined sewer system via upland flows from the Squirrel Hill neighborhood. One benefit of diverting stormwater at this point in the system is that it reduces the bottleneck that occurs downstream in “The Run” where surcharging and flooding occurs.

Four Mile Run is well-suited to be an inaugural implementation and monitoring focus for green infrastructure in the City. The University of Pittsburgh and Carnegie Mellon University together represent 10% of the total sewershed and the densest, highly urbanized area of the sewershed. The majority of the remaining 70% of the sewershed is made up of urban neighborhoods, including Oakland, Greenfield, Squirrel Hill, and Hazelwood. The surrounding stakeholder community has well-organized, active groups that have provided support and interest in sustainability, green infrastructure solutions, and community development in the areas surrounding Four Mile Run.

Figure 6-15

6.2.2 M29 Four Mile Run: Urban Design Framework Plan

Schenley Park offers a number of opportunities for green infrastructure in the Four Mile Run sewershed. The Park is well positioned within the sewershed to be an ecologically sensitive conveyance system of stormwater from the combined system in Squirrel Hill and Oakland. Corridors through and nearby the park are already being targeted as future Complete Streets. Junction Hollow could provide a high volume of capture and could accommodate a connection to the river.

Flagstaff Hill Institutions are well-suited to serve as partners for education and demonstration of green infrastructure at this highly-visible community node. The Phipps Conservatory and its Center for Sustainable Landscapes, Carnegie Mellon, University of Pittsburgh, and Pittsburgh Parks Conservancy each could find opportunities to participate in the development of green infrastructure strategies along Schenley Drive and Panther Hollow.

Forbes Avenue and Schenley Drive are important corridors and offer opportunities for highly visible Complete Streets projects. Together the two streets would be an excellent park-to-park corridor between Schenley and Frick Parks.

The vibrant business district in **Squirrel Hill** neighborhood along Forbes Avenue provides a great midpoint for the above mentioned park-to-park connection and the high volume of impervious area coincide with numerous high yield areas identified through modeling. Within the Squirrel Hill neighborhood, Murray Ave., Wightman St., and Bartlett St. are well suited to accommodate GI based on high yield areas and their generous right-of-way widths.

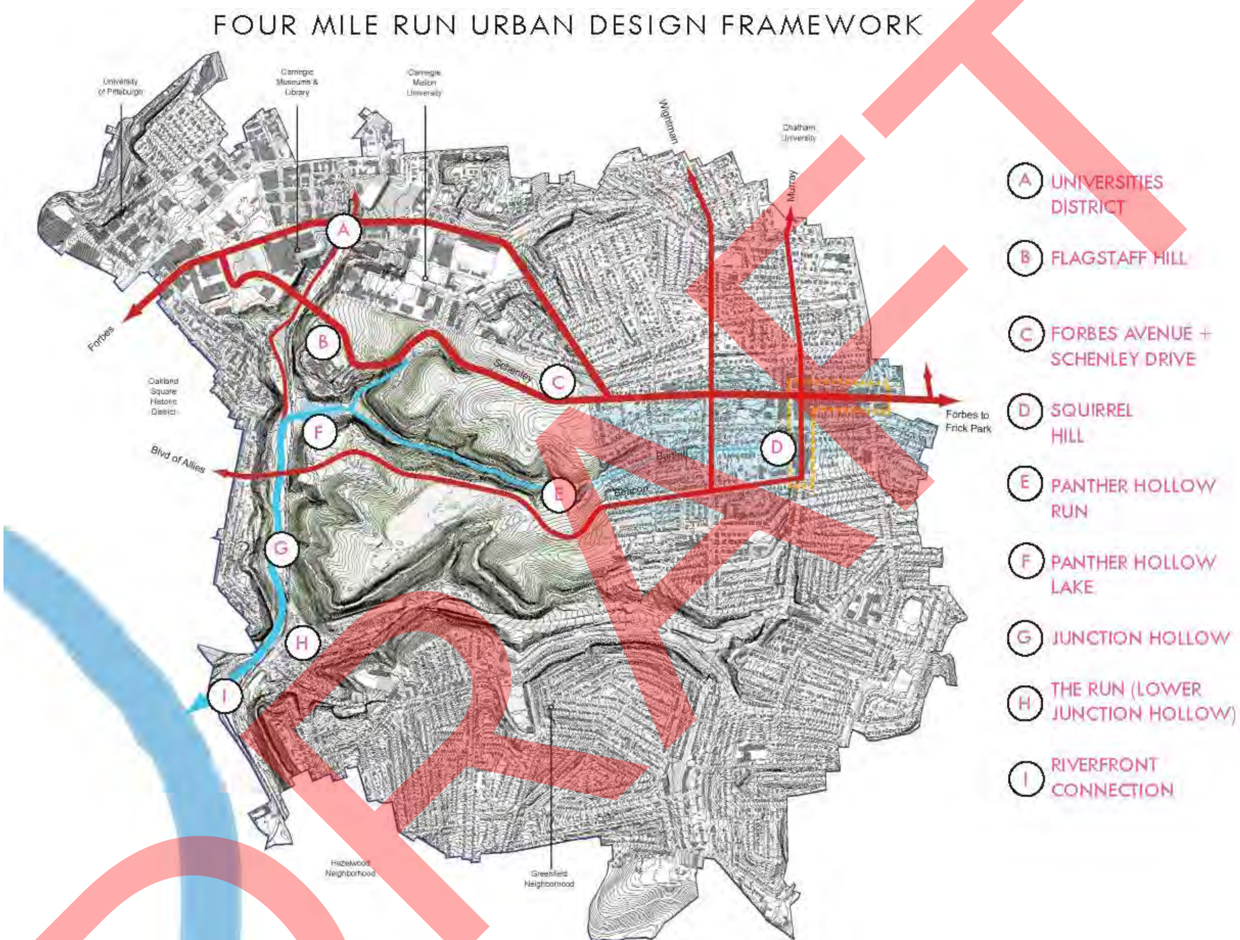


Figure 6-16

Within Schenley Park, **Panther Hollow Run** is the natural streambed that once accepted runoff from the Squirrel Hill neighborhood. Planned ecological restoration should be coordinated with green infrastructure stormwater management. The stream terminates into an existing poor-quality lowland wet forest at **Panther Hollow Lake**. Restoration would allow this area to serve as an effective wetland for filtering runoff to improve water quality as it reaches the lake. The community desires that the lake be restored as a usable recreational amenity; proper restoration of the Hollow above is paramount to achieving this goal.

Junction Hollow runs north-south connecting the Universities District, Schenley Park, and neighborhoods south of the park. Its relative low slopes, large area, and position at the lower end of the watershed combine to make it an effective location to capture runoff. In addition, it could serve to daylight the spring overflow from Panther Hollow Lake to remove stormwater from combined sewers and accommodate additional Park programmed space.

The above mentioned framework for the areas in Four Mile Run should reduce flooding in **"The Run"** at the south end of Junction Hollow. Between this area and the river is the area where the 3 Rivers Heritage Trail is located. These parcels are partially City-owned and provide opportunities to link the Park and Universities District to proposed riverfront redevelopment at Almono, and provide a new **riverfront connection** access point for citizens.

The Framework of corridors, key assets, and nodes for Four Mile Run provide clearly defined risks and opportunities for the most realistic green infrastructure solutions in this sewershed. Taken as a whole system, they also provide a substantial opportunity to connect multiple neighborhoods to the Monongahela River, Three Rivers Heritage Trail, Schenley Park, and Frick Park through a system of green infrastructure-focused Complete Streets corridors.

6.2.3 M29 Four Mile Run: Green Infrastructure Concept Plan

Figure 6-17

This concept looks to redirect stormwater runoff from the Squirrel Hill neighborhood into Schenley Park while also making improvements to the public realm of the neighborhood: specifically, the business district at Squirrel Hill and the wide gateway boulevards leading to the park. Schenley Drive and the parking area around Phipps Conservatory can become a highly-visible green demonstration site and a Complete Street. Junction Hollow has a potential to capture large volumes of stormwater. In addition, daylighting this stream provides a great amenity connecting neighborhoods to parks and to the riverfront.

Figure 6-18

The **Universities District** in the upper portion of the sewershed is a dense urban area with high percentage of impervious area. Forbes Avenue offers a great opportunity for a Complete Street with GI. The Universities and Cultural Institutions offer partnerships for additional GI opportunities. More specifically, the recreation fields at Forbes Ave. and Beeler St. could provide capture potential. The research and monitoring opportunities offered by these institutions should be nurtured further. The runoff of these upland areas should be collected and conveyed to the upper end of Junction Hollow. Within this valley Boundary/Neville Street provides opportunity for capture and conveyance. Large surface parking lots in this area offer further opportunities for pervious pavement and subsurface capture. Public-private partnerships should be explored where lots are located on privately-owned land.

Figure 6-19

Schenley Drive at **Flagstaff Hill** has the opportunity to provide an expanded, highly visible demonstration and education project for GI that would provide opportunities to partner with adjacent institutions: Pittsburgh Parks Conservancy, Phipps Conservatory & the Center for Sustainable Landscapes, Carnegie Mellon University, and University of Pittsburgh. Pervious pavement and reduced pavement in Schenley Drive would enhance the entry and parking experience for visitors.

Figure 6-20

East of Flagstaff Hill on **Schenley Drive**, the addition of pervious pavement and reduction of pavement can be continued, increasing the capture and storage potential and continuing the work of the Schenley Drive Green Street Plan design effort. Paralleling this street, Phipps Run would benefit from ecological restoration and additional check dams and small wetland capture areas could be provided.

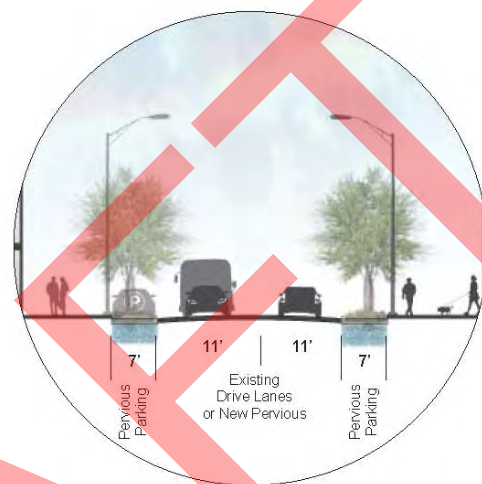


Figure 6-21

As Schenley Drive transitions into **Forbes Avenue**, a more urban approach can be taken with pervious pavement collecting and conveying runoff from the vibrant Squirrel Hill business district. In addition, the reduced CSO improvements to this streetscape would improve the pedestrian and biking experience, along with providing an enhanced park-to-park green street between Schenley and Frick Parks. The intersection of Murray and Forbes Avenues can be the nucleus of these improvements.

High-yield capture areas within the **Squirrel Hill** neighborhood are concentrated near the business-focused corridors of Forbes and Murray Ave. Runoff captured is conveyed from the business district through the neighborhood to Schenley Park's Panther Hollow Run. The pavement of Wightman Street could be reduced to accommodate a bioswale with adjacent bike lanes. Pervious streets like Murdoch St., with its existing stone cobbles, could further collect and convey runoff to Bartlett St. Bartlett St. is the low point of the existing valley and runoff from Squirrel Hill flows towards Panther Hollow Run.

Figure 6-22: Existing Wightman Street

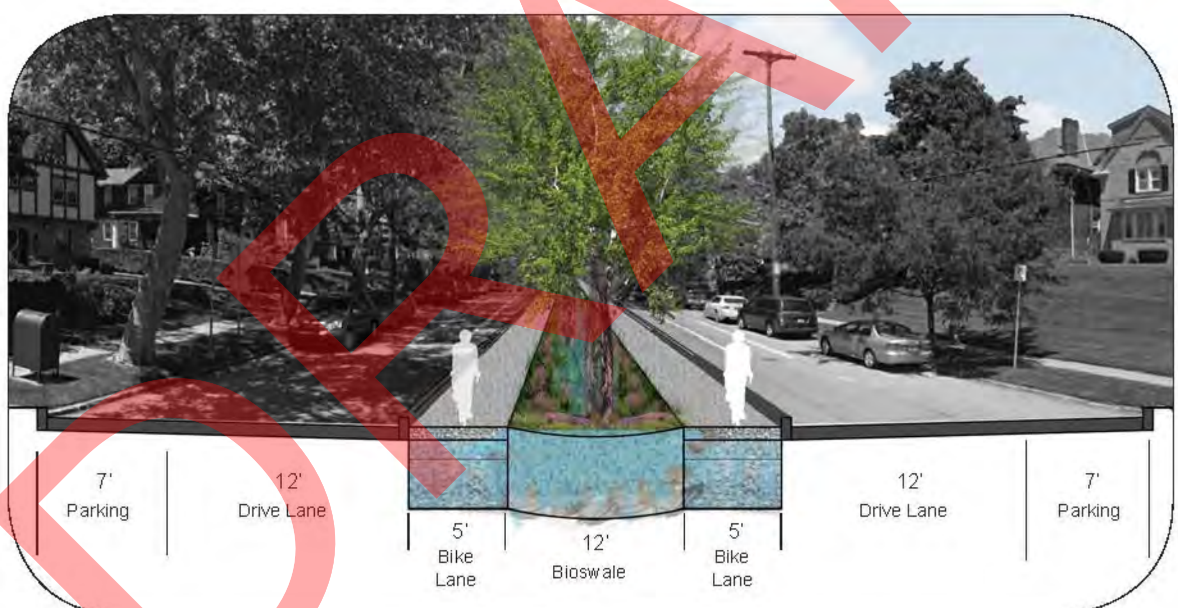


Figure 6-23: Proposed Wightman Street with Bioswale

Figure 6-24

This runoff from Squirrel Hill would be reintroduced to **Panther Hollow** at Bartlett St., along the west edge of the park. Panther Hollow would benefit from ecological restoration and reintroducing runoff back into the system would be done carefully, overtime, as the valley is restored. Additional opportunities could include capturing and storing runoff for irrigation at the adjacent golf course. At the lower end of the Hollow an existing low slope area would make an ideal wetland for capture and cleaning runoff from both Phipps Run and Panther Hollow Run prior to entering Panther Hollow Lake.

Figure 6-25

Dredging **Panther Hollow Lake** would increase its storage potential and begin to restore the natural systems and diversity of the lake. Additional capture storage could be provided as "freeboard" above the normal lake level. Combined with efforts upstream, the goal would be to restore the lake as a usable amenity for park users. The estimated 68 million gallons of annual flow coming from Panther Hollow Lake can be diverted from the combined sewer system and brought to the surface to serve as baseflow for a daylit stream in an ecologically engineered channel.

Figure 6-26

This daylighted stream would run through **Junction Hollow**. Junction Hollow's gentler slopes and broad profile offer large volumes of capture potential. North of Panther Hollow Lake there are large parking areas and streets that can store water beneath pervious pavement. South of Panther Hollow Lake capture is accomplished with storage sites and constructed wetlands. The character of storage can be defined from additional input from the community, providing opportunity for additional park programming. The recreation field at the lower end of Junction Hollow also offers capture potential.

In an effort to address an important City-Wide guiding principle seeking direct **riverfront connectivity**, a partnership with the Almono Development team would help overcome challenges to providing a daylit stream corridor from Junction Hollow Run to the Monongahela River. There is further opportunity to use the existing parcel and surface parking lots bounded by 2nd Street, Saline Street, and Interstate 376 in this effort.

The collective whole of the corridors, public open space, and Junction Hollow improve the connectivity between institutions, neighborhoods, and other assets surrounding the park. They also offer an enhanced connection to the riverfront.

6.3 A42 Washington Boulevard and Negley Run

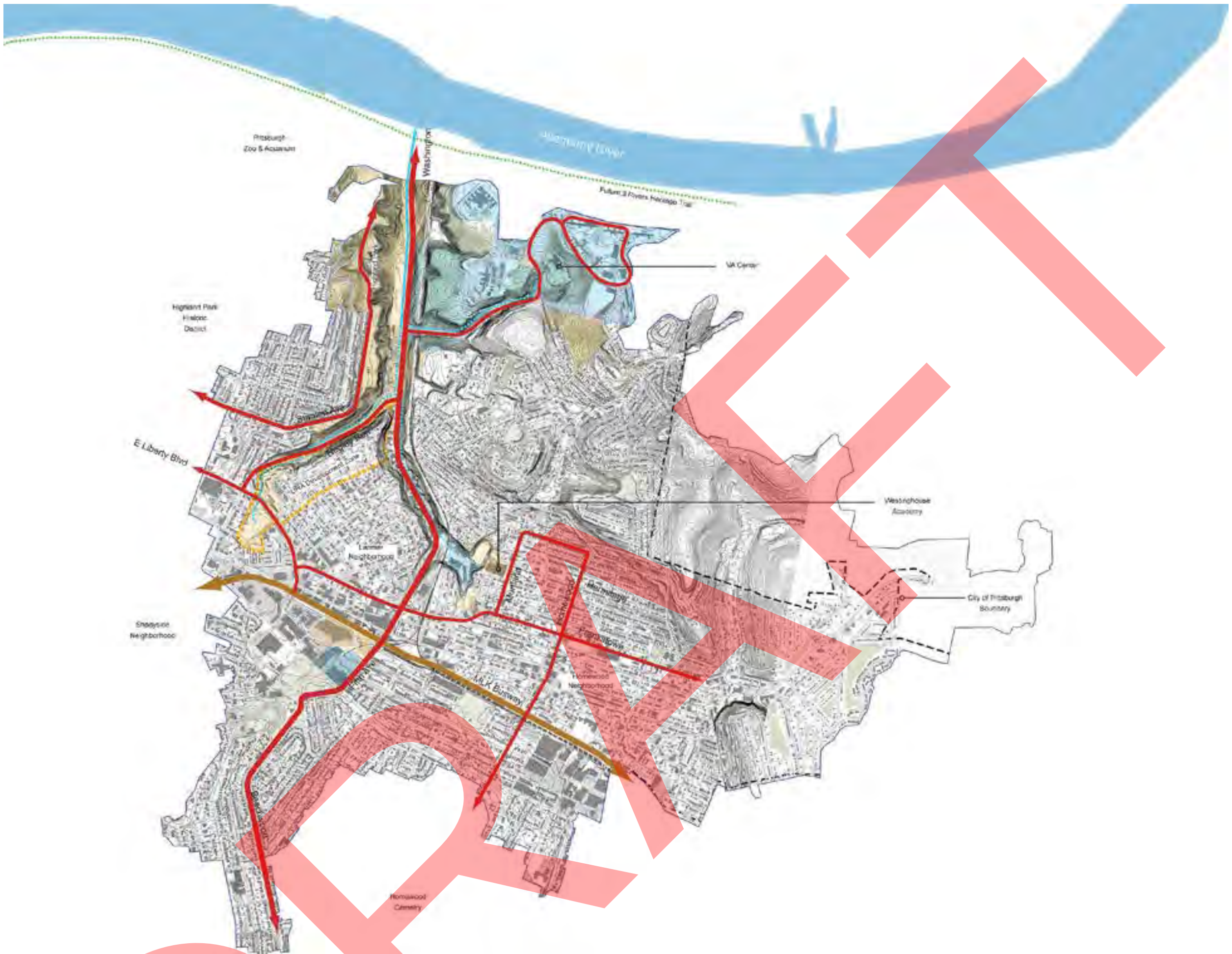


Figure 6-27

6.3.1 Sewershed Existing Conditions

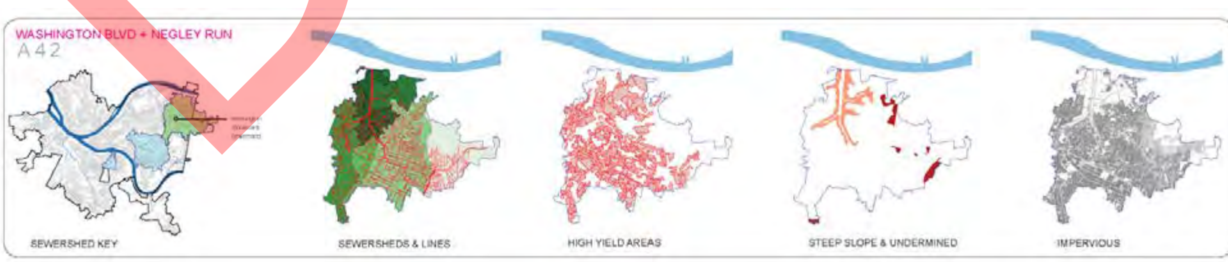


Figure 6-28

The A-42 Sewershed is 3,300 acres of dense, urban neighborhood development with only 10% of its land area covered by Park or park-like forested conditions. Washington Blvd and Negley Run Blvd. are the primary drainage corridors for the sewershed, capturing the largest volume of water of any sewershed in the City. The upper and middle reaches of the sewershed are dominated by dense single-family residential development, with multi-family, commercial and light industrial mixed in. Although the neighborhoods are dense, a patchwork of vacant lots and buildings are spread throughout the sewershed, providing some opportunities for distributed storage within neighborhoods. The lower reach of the sewershed includes portions of Highland Park, a broadly forested institutional campus of potential partners including Pittsburgh Job Corps Center, Shuman Juvenile Detention Center, US Army Reserve, Southwestern Veterans Center, and former VA Hospital site, and a stretch of light industrial and commercial development down Washington Blvd. drainage corridor. On the upstream third of the sewershed the MLK Busway intersects with important corridors extending to the south like Fifth Avenue, Beechwood Blvd. and Homewood Avenue. Also in this southern portion, Mellon and Westinghouse Parks are well situated to capture runoff.

Figure 6-29

6.3.2 A42 Washington Blvd. + Negley Run: Urban Design Framework Plan

The Washington Boulevard and Negley Run sewershed has a number of areas where stormwater can be captured and stored at a large scale. Corridors and site specific projects above potential sites are positioned in neighborhoods that would benefit from revitalization. One prime example is the Westinghouse Academy in the Homewood neighborhood, which could see public-realm improvements to street corridors extending away from the school and could leverage dollars into campus improvements.

In the Lincoln Lemington neighborhood east of Washington Boulevard and immediately south of the Allegheny River, there is a strong potential for workforce development partnerships like the **VA Center**, Job Corps and the Juvenile Detention Center. This area has a number of high yield sites as well as existing open spaces and a corridor well suited for GI.

Washington Boulevard provides an outstanding gateway and undeveloped areas with low slopes to accommodate large capture areas along with opportunities for pervious parking in large surface lots.

Washington Boulevard runs within Negley Run until it hits **Negley Run Boulevard** and runs up into the Larimer neighborhood above. Adjacent redevelopment plans in the Larimer neighborhood offer additional opportunity for GI. Above Negley Run Blvd in the **Highland Park** neighborhood are a number of streets, including Stanton Ave., East Liberty Blvd., and Highland Ave., that offer potential for GI.

The **MLK Busway and large adjacent surface lots near Fifth Avenue** offer opportunities for reducing impervious area. Streets surrounding **Westinghouse Park** could convey stormwater to this park that contains existing landforms that could be used to capture stormwater. **Mellon Park** could serve a similar role with **Beechwood Blvd**. conveying stormwater north into the park. This potential Complete Street connects neighborhoods to the south like Squirrel Hill.

The Homewood neighborhood and its **Westinghouse Academy** provide one of the best opportunities to demonstrate how GI investment into a community can be a catalyst for redevelopment: improving walkability, public health, and access to public transportation. Downstream from Westinghouse Academy, an athletic field and the former Silver Lake site offer large areas for capture potential as well as amenities to improve the well-being of this community. These efforts are identified and supported in previous planning efforts. In short, GI reinvestment would serve as catalyst, or what can be referred to as Urban Acupuncture, to accelerate the revitalization of Homewood.

In combination, the corridors of Washington Blvd., Negley Run Blvd., Stanton Ave., Beechwood Blvd., and a number of other streets serve to better link the various neighborhoods, and their shared assets, into a strategic framework, an Urban Design Framework that improves the quality of life in the A42 sewershed while addressing the goals for CSO reduction. Collectively, the network of green infrastructure corridors would provide system redundancy and an excellent grid of connectivity for Complete Streets efforts.

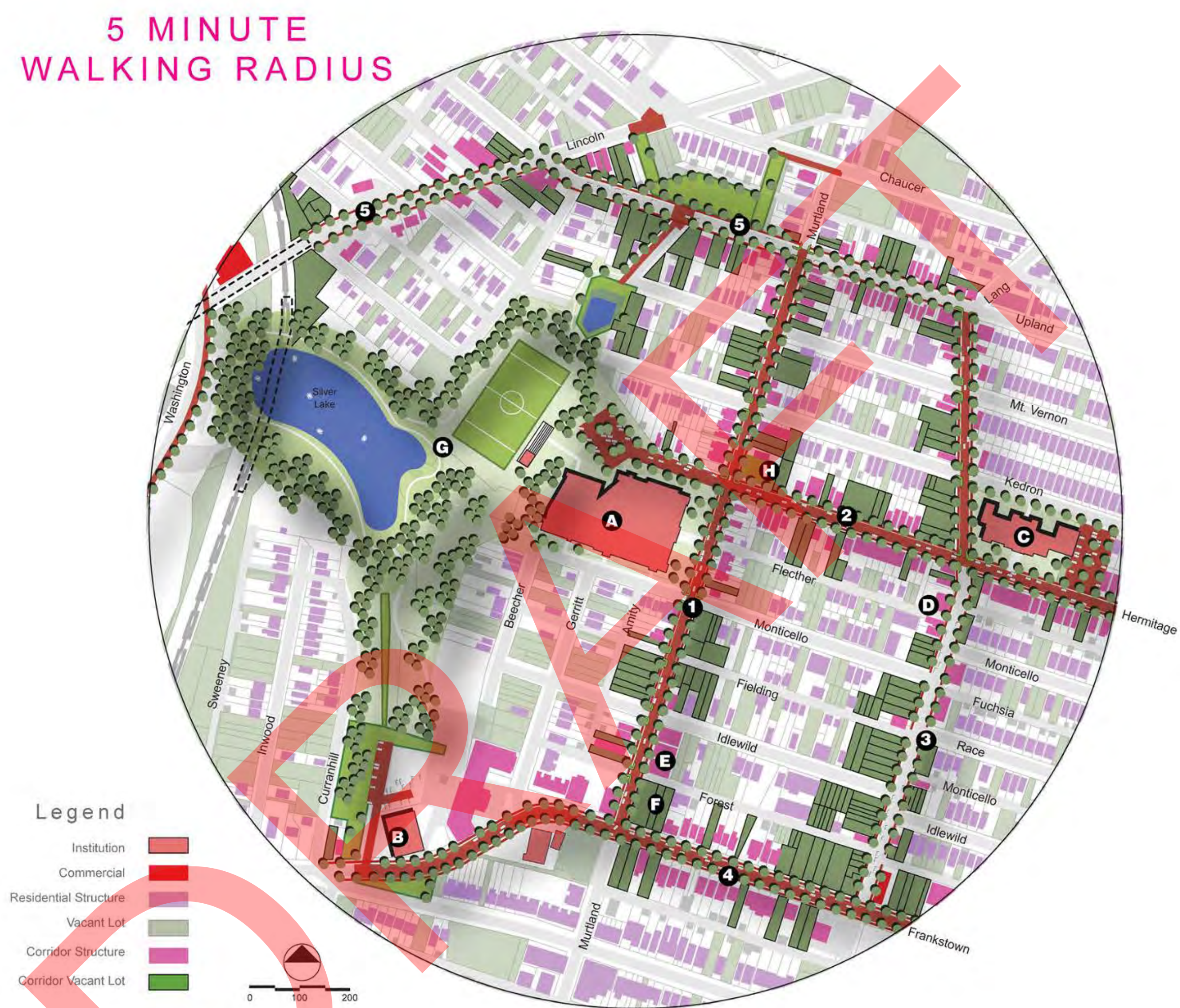


Figure 6-30: Homewood Urban Acupuncture Focus Around Westinghouse Academy

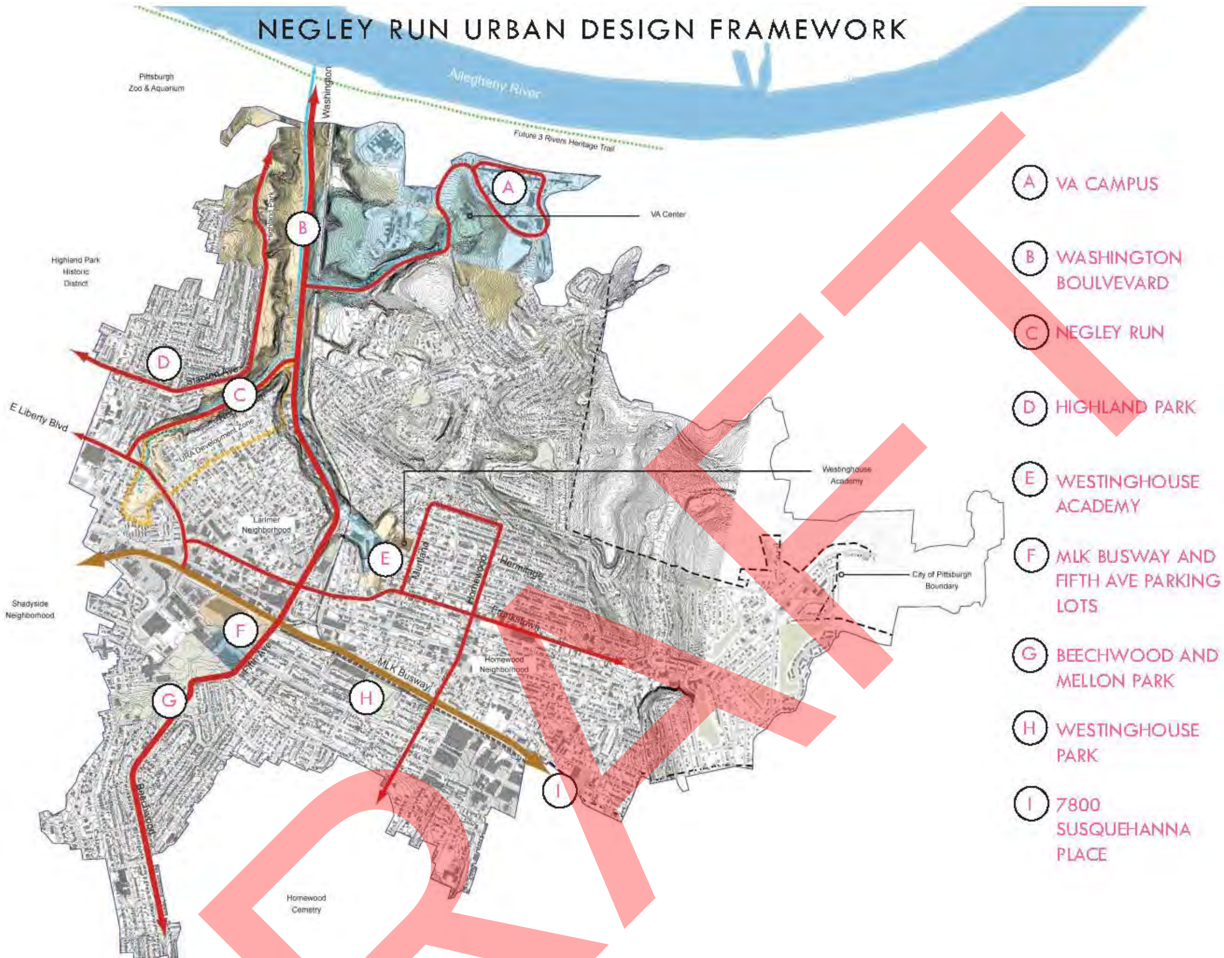

NEGLEY RUN URBAN DESIGN FRAMEWORK
Allegheny River
Pittsburgh Zoo & Aquarium
Washington
Future 3 Rivers Heritage Trail
VA Center
Highland Park Historic District
E Liberty Blvd
Larimer Neighborhood
Westinghouse Academy
City of Pittsburgh Boundary
Shadyside Neighborhood
MLK Busway
Homewood Neighborhood
Homewood Cemetery
A VA CAMPUS
B WASHINGTON BOULVEVARD
C NEGLEY RUN
D HIGHLAND PARK
E WESTINGHOUSE ACADEMY
F MLK BUSWAY AND FIFTH AVE PARKING LOTS
G BEECHWOOD AND MELLON PARK
H WESTINGHOUSE PARK
I 7800 SUSQUEHANNA PLACE

Figure 6-31

1 COMMUNITY ASSETS

- A WESTINGHOUSE IS A NUCLEUS FOR NEIGHBORHOOD
- B YWCA NEARBY ON FRANKSTOWN
- C HERMITAGE SCHOOL COULD BE REDEVELOPED
- D COMMERCIAL BUILDINGS ON LANG
- E +/- 700 STRUCTURES WITHIN 5 MINUTES OF SCHOOL
- F +/- 450 VACANT LOTS WITHIN 5 MINUTES OF SCHOOL
- G MANY STREETS DRAIN TO ATHLETIC FIELD AND BELOW
- H EXISTING COMMUNITY GARDEN

2 HEALTHY CORRIDORS

- PUBLIC REALM REINVESTMENT A CATALYST FOR GROWTH
- GREEN INFRASTRUCTURE AND COMPLETE STREETS
- HEALTHIER WALKABLE COMMUNITY
- ACCESS TO TRAILS AND OUTDOOR AMENITIES
- OPPORTUNITIES TO INTERACT WITH NATURE
- IMPROVED SAFETY FOR PEDESTRIANS AND CYCLISTS
- BETTER ACCESS TO HEALTHY FOOD

3 HOUSING INFILL + RENOVATE

- 1 PHASE 1 (MURTLAND) 41 VACANT LOTS + 33 STRUCTURES
- 2 PHASE 2 (HERMITAGE) 23 VACANT LOTS + 31 STRUCTURES
- 3 PHASE 3 (LANG) 63 VACANT LOTS + 25 STRUCTURES
- 4 PHASE 4 (FRANKSTOWN) 8 VACANT LOTS + 34 STRUCTURES
- 5 PHASE 5 (UPLAND/LINCOLN) 38 VACANT LOTS + 45 STRUCTURES
- COMBINED - 175 VACANT LOTS & 170 STRUCTURES
- WORKFORCE DEVELOPMENT AND TRAINING

4 TRANSIT LINES

- IMPROVED CONNECTION TO TRANSIT ON FRANKSTOWN
- TRANSIT ORIENTED DEVELOPMENT (TOD)
- EXPAND POSSIBLE FUNDING STREAMS
- BUSWAY AND TERMINAL WITHIN 10 MINUTE
- IMPROVED ACCESS TO JOBS AND HIGHER EDUCATION
- NEW CONNECTION TO TRANSIT ON WASHINGTON

Figure 6-32

6.3.3 A42 Washington Blvd. and Negley Run: Green Infrastructure Concept Plan

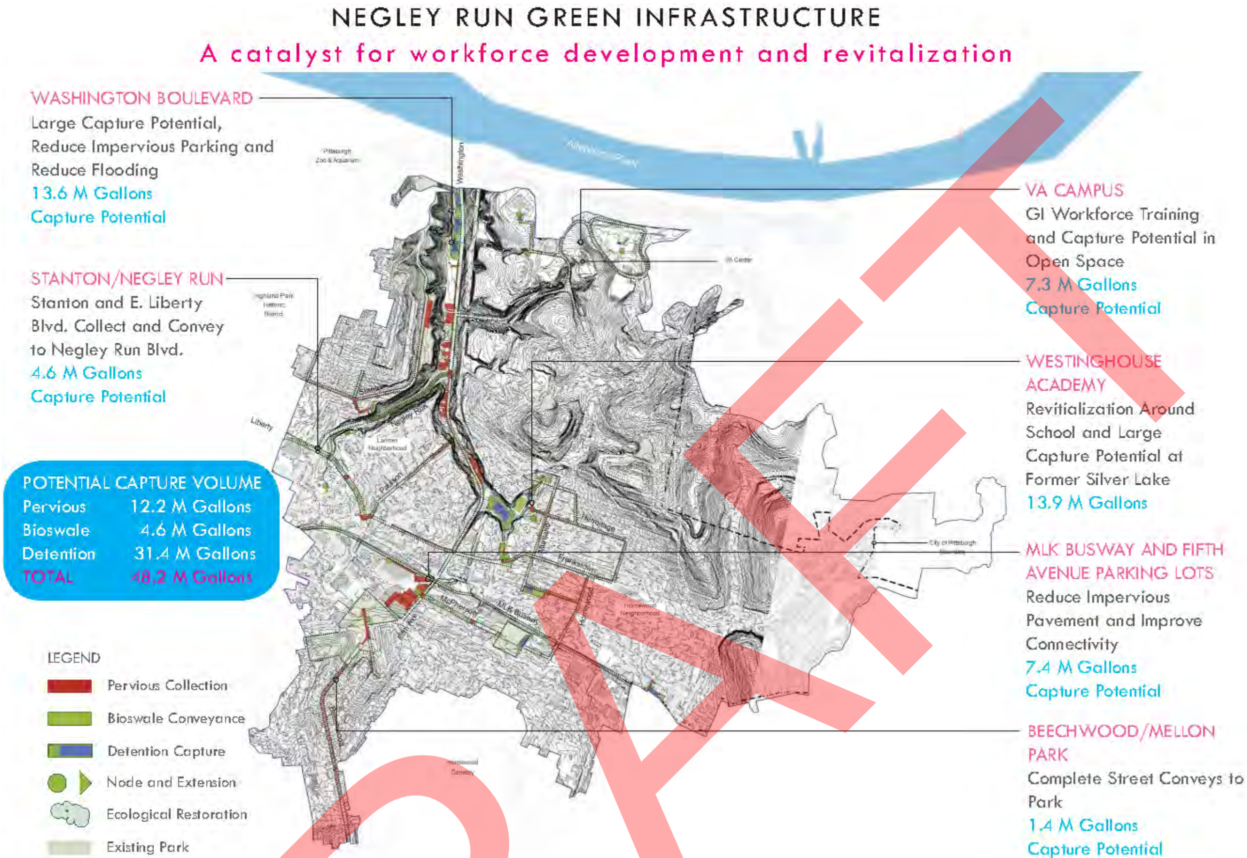


Figure 6-33

Washington Boulevard has potential pervious pavement and storage sites closer to the River. At the west side of this sewershed in the Highland Park neighborhood, Stanton Avenue and other streets around the Dilworth Academy can capture stormwater. Below and adjacent at Negley Run, East Liberty Boulevard's existing medians could be converted for capture and conveyance. In the Lincoln-Lemington neighborhood, adjacent to the Allegheny River bluffs, there is significant opportunity to team with one of several institutions on workforce development programming. Streets radiating from Westinghouse Academy can convey rainwater and serve as catalyst for revitalization. Large-scale pervious pavement opportunities exist around the bus terminal and busway. Beechwood Blvd. can capture and convey to storage in Mellon Park.

Figure 6-34

The **Highland Park** neighborhood has a number of high yield areas, and streets like Stanton Ave., Highland Ave., and Heberton St. can be used to collect and convey runoff to **Negley Run Boulevard**. Negley Run Blvd. is a good candidate for a Complete Street and construction is already underway for some GI improvements. Adjacent Negley Run Boulevard, a natural drainage channel can convey runoff from East Liberty Avenue. Proposed redevelopment in the Larimer neighborhood includes stormwater improvements that support this approach with community and stakeholder input.

Figure 6-35

Beechwood Boulevard provides an important connection to the south and offers opportunity as a Complete Street and to collect and convey runoff to **Mellon Park**. Westinghouse Park shares similar capture potential from surrounding streets like McPherson St.

Figure 6-36

Pervious pavement and reduced impervious area would serve to collect runoff along the **MLK Busway**, bus terminal, and **additional large surface parking** lots at Chatham University - East Side Campus. Improvement to the Busway should also look to improve surrounding residents' access to public transportation.

Figure 6-37

The **Westinghouse Academy** and surrounding Homewood neighborhood provide a great opportunity to reinvest in the public realm and serve as catalyst for redevelopment: an approach that is supported by previous planning and community engagement efforts. Streets radiating out from the school like Hermitage St. and Murtland Ave. work to collect and convey stormwater downstream. Hermitage St. is also the location of a former school at Lang Avenue that could serve as a nucleus for redevelopment. The athletic field east of the school offers capture potential, along with the former **Silver Lake** site, now an industrial site. This large flat site provides a high volume of potential capture for storage sites, which could make a great amenity for the neighborhood

Figure 6-38: 5 Minute Walking Radius

Westinghouse Academy is the central focus of a green infrastructure-based Urban Acupuncture planning initiative.

Figure 6-39

The area surrounding the **VA Center**, Juvenile Detention Center, and Job Corps west of Washington Boulevard offers a different approach for GI solutions thanks to larger areas of open space and undeveloped areas. Runoff from building and surface lots can be collected and conveyed to basins along **Highland Drive** where runoff is ultimately taken to Washington Boulevard (see section views below). Beyond the potential volumes of capture surrounding these institutions, they offer a tremendous opportunity for workforce training and development focused on GI and sustainable development.

Figure 6-40

Washington Boulevard lies in the valley that serves as a convergence for the various sub-basins draining to it. The street itself has the potential to be a Complete Street. Large surface lots adjacent the City Police and Fire facilities, along with a bike track, offer pervious pavement and subsurface capture potential. Towards the northern edge of the valley, lower slopes and a broad profile offer high volumes for storage to the west of the Boulevard and can provide sedimentation capture areas to reduce the need for cleaning often clogged catch basins. A goal beyond the CSO reduction should be to reduce flooding in this low lying area. Proposed GI upstream from this may also improve this condition.

Figure 6-41: Existing Highland Drive (east of Washington Blvd.)

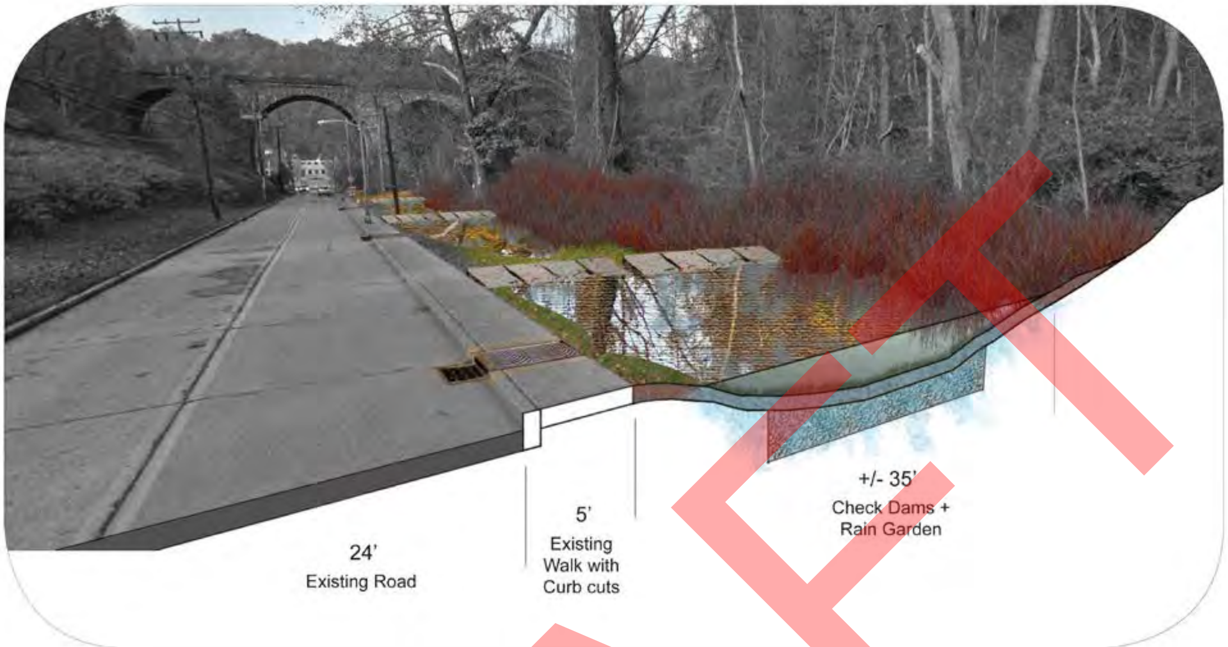


Figure 6-42: Proposed Bioswale adjacent Highland Drive (east of Washington Blvd.)

6.4 M16 South Side/ South 21st Street

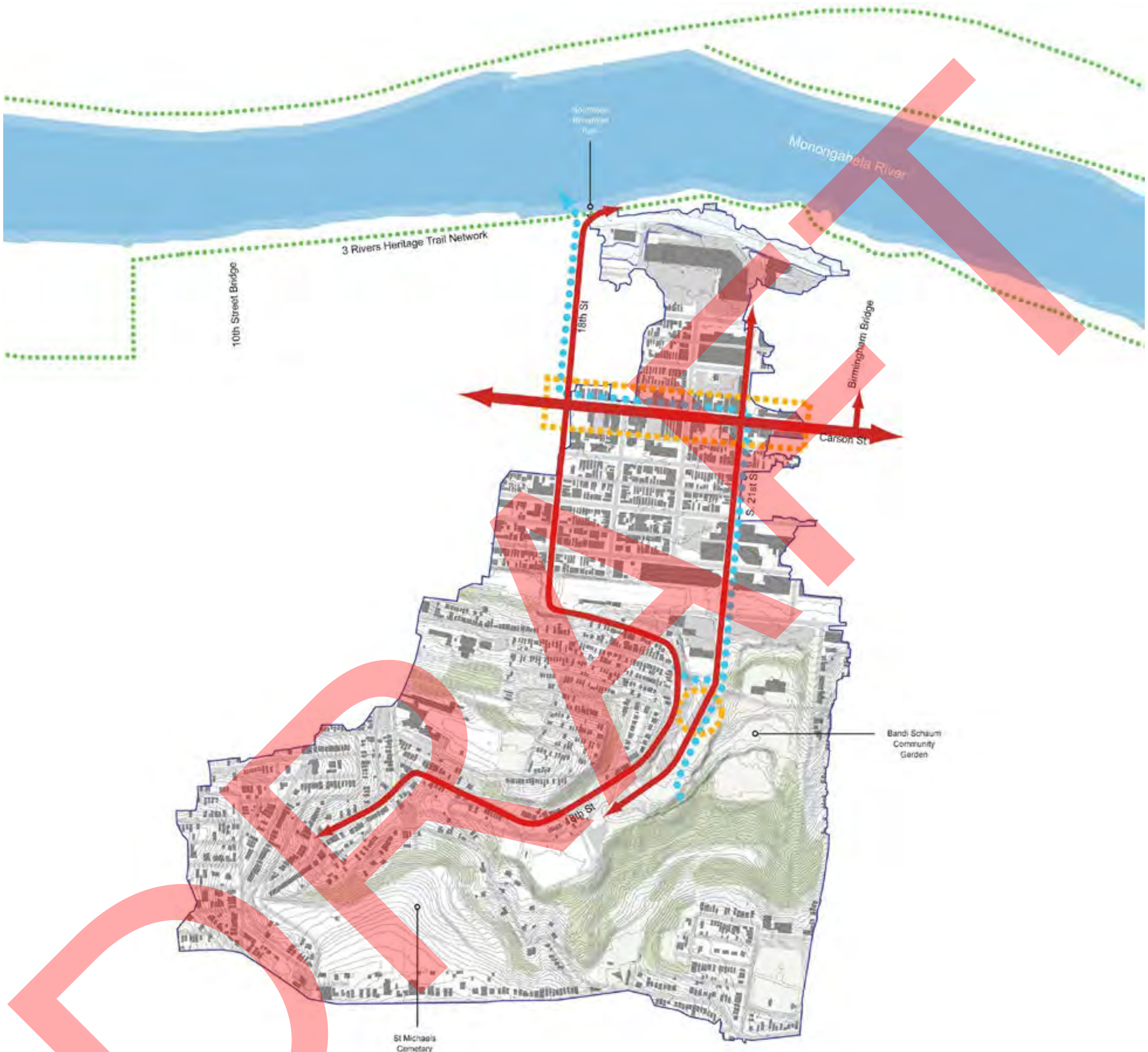


Figure 6-43

6.4.1 Sewershed Existing Conditions

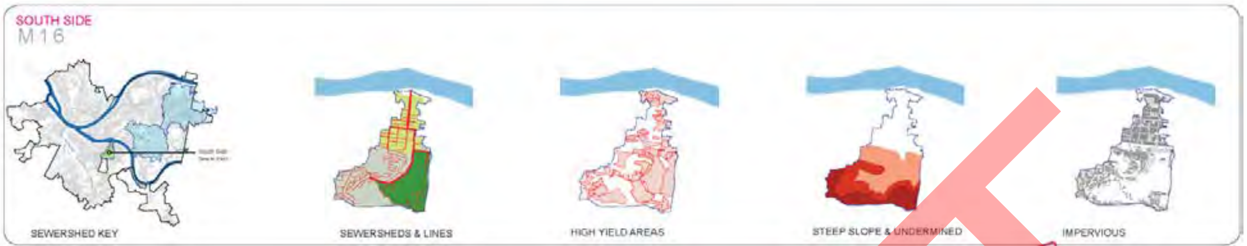


Figure 6-44

Figure 6-45

The M16 South Side watershed is the smallest of the six focus sewersheds. South Side Park comprises a good portion of the south half of the sewershed, and this park has a number of opportunities for capture. The park also contains a majority of the steep slopes of this sewershed which contribute to sediment loads into the system. Within the park itself are a mix of programmed spaces like the football field, where existing springs seep from the adjacent hillside. Throughout the park are a number of non-programmed uses like community gardens and informal gathering spaces. The South Side Slopes Neighborhood Association is active and interested in improving the park and is currently seeking funds to complete a master plan. South 21st Street extends north from the Park, intersecting with a neighborhood mixed-use retail district on East Carson Street, which is an active corridor with reinvestment capital earmarked for implementation in the coming years. Continuing east on Carson, South 18th Street intersects and connects to the river as it extends north to the Monongahela River.

6.4.2 M16 South Side/ South 21st Street: Urban Design Framework Plan

Existing access to the river is a unique characteristic of this sewershed. **Riverfront Park** access via an existing at-grade railroad crossing at the north end of South 18th Street provides a great opportunity for an enhanced riverfront connection or potential daylighting of spring fed flows from South Side Park.

South 18th Street extends south from the River and intersects with Carson Street, where the mixed-use retail district is centered. South 18th Street continues south, eventually defining the west border of South Side Park, along the base of the slopes of the Southside Slopes neighborhood, affording it the ability to capture and convey runoff.

Carson Street is a PennDOT highway as well as being the vibrant business district for the neighborhood. It can link South 18th Street (with its riverfront connection) to South 21st Street. PennDOT plans on improving this corridor in 2017 and proposed GI should be coordinated with these efforts.

South 21st Street intersects with Carson and extends up into the existing valley of South Side Park where it terminates, making it an effective street for GI. This street has already been identified for GI in proposed plans generated with community input.

The **South Side Park** valley has gentler slopes and broad section. There are a number of surface parking lots in this area at the base of the valley. Continuing up the valley, **Quarry Field** is a football field used for various recreational activities. Spring water seeps from the slopes at the field's edge and could create a baseflow for a daylighted stream.

The M16 sewershed provides a number of opportunities for GI in critical corridors that would link South Side Park with the mixed-used retail district and the riverfront. The Urban Design Framework emphasizes the opportunity for green infrastructure-focused stormwater conveyance system from the highest elevations of the watershed to the River; providing significant urban connectivity between neighborhoods and the City's natural resources.

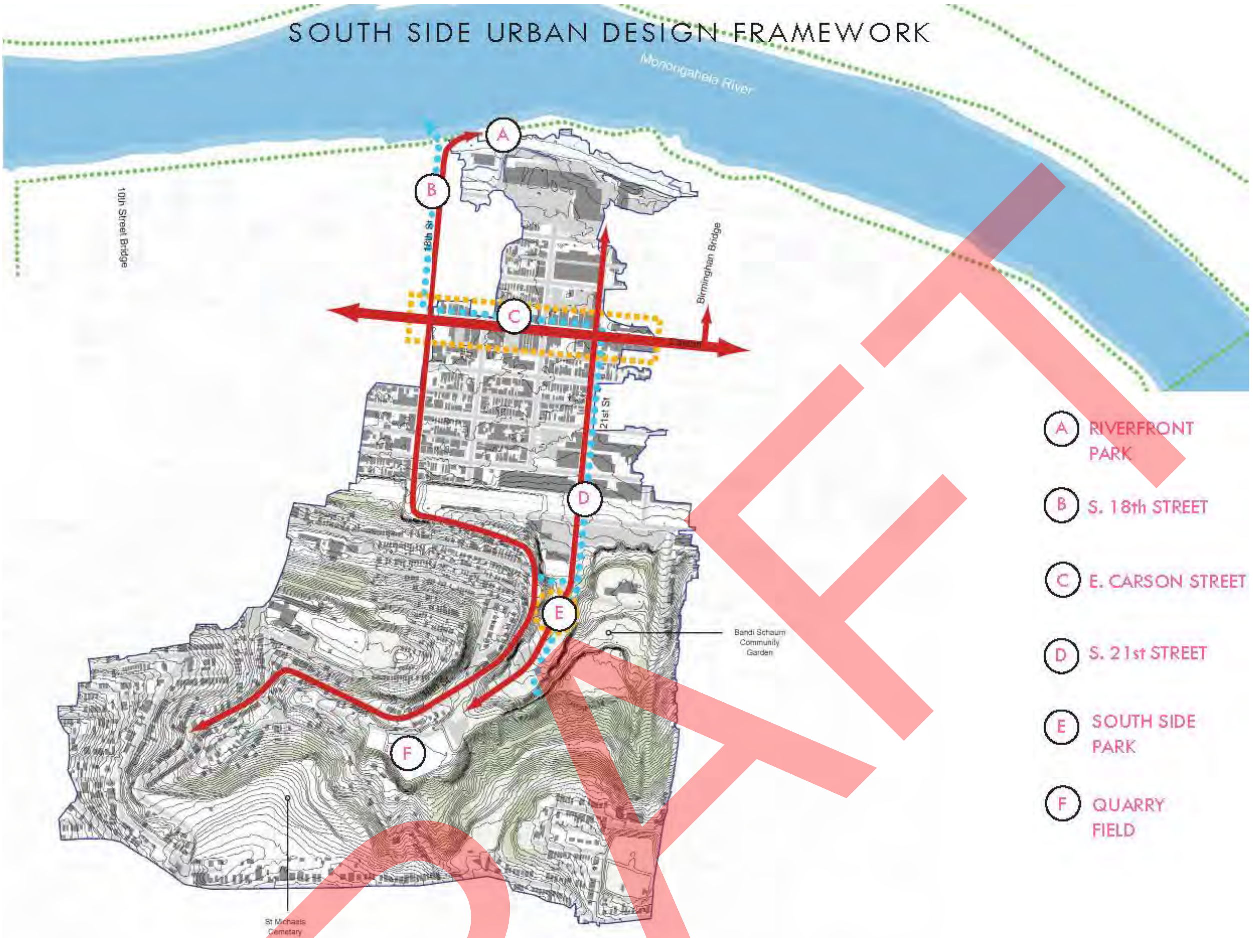

SOUTH SIDE URBAN DESIGN FRAMEWORK
Monongahela River
10th Street Bridge
18th St
Birmingham Bridge
21st St
A
B
C
D
E
F
Bandi Schaum Community Garden
St Michaels Cemetery
A RIVERFRONT PARK
B S. 18th STREET
C E. CARSON STREET
D S. 21st STREET
E SOUTH SIDE PARK
F QUARRY FIELD

Figure 6-46

6.4.3 M16 South Site Slopes/ South 21st Street: Green Infrastructure Concept Plan

South Side Park has the potential to capture large volumes of stormwater along its western edge, including Quarry Field. Here groundwater seeps could be daylighted through the park. From the park, South 21st Street can convey water north utilizing pervious pavement and green street improvements. At East Carson Street, bioswales and pervious pavement convey the stormwater west to South 18th Street. Along the vibrant mixed-use street, East Carson improvements should be coordinated with future PennDOT projects to improve the pedestrian experience and safety. South 18th Street provides the final connection to the existing riverfront via an at-grade railroad crossing.

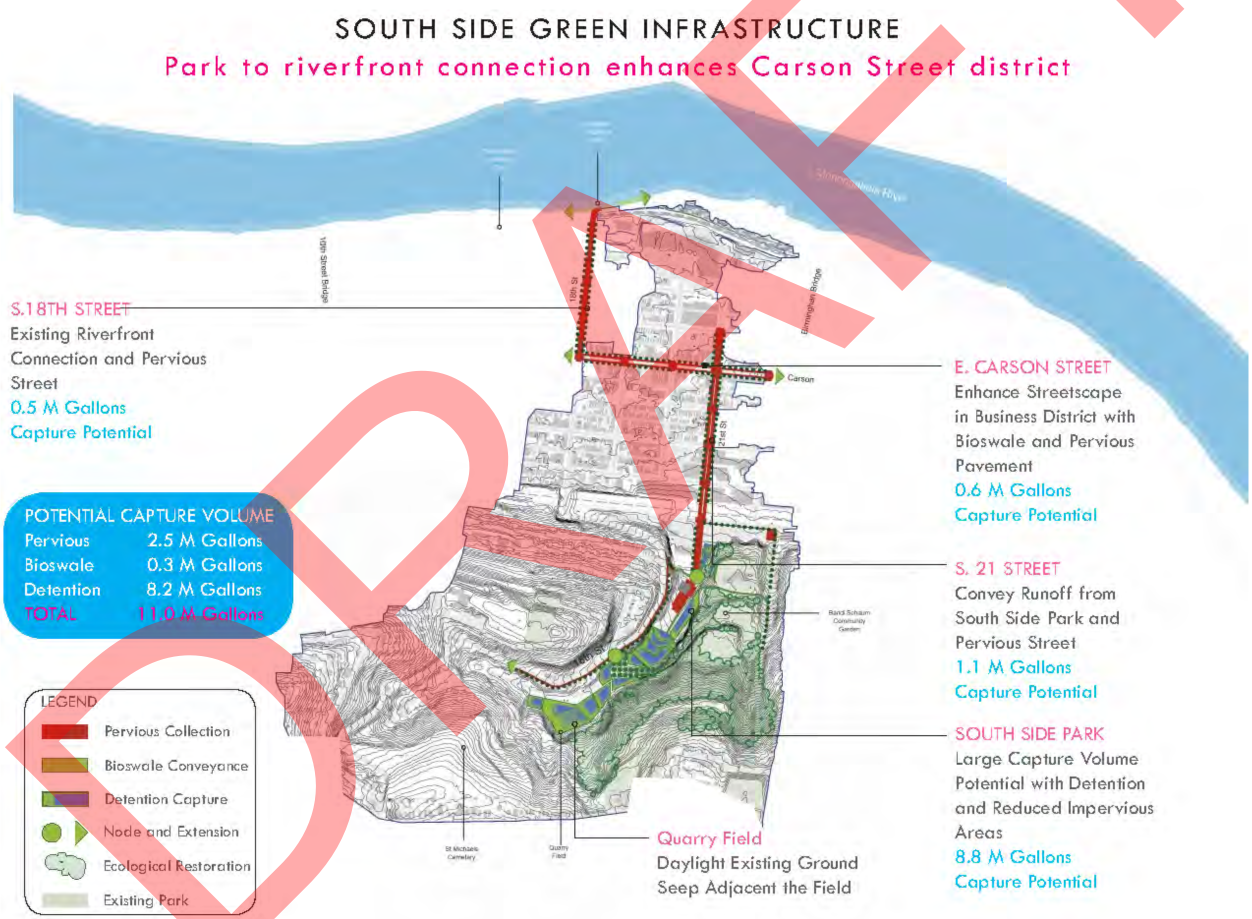


Figure 6-47

Figure 6-48

The existing **riverfront connection** at **South 18th Street** is unique in comparison to the other priority sewersheds; enhancing this connection will further strengthen awareness of the Riverfront Park, highlight connectivity for people throughout the sewershed, and allow the completion of a green infrastructure conveyance system or a daylighted stream flow that begins in South Side Park.

Figure 6-49

East Carson Street serves as the nucleus for retail in the South Side neighborhood. This vibrant street would be improved by making it more pedestrian and bike friendly. As PennDOT looks to make improvements on this state highway, GI should be incorporated. The existing street width and sidewalks accommodate the introduction of a center bioswale and pervious pavement would further reduce runoff and collection and capture opportunities (see section views as follows). East Carson Street connects with South 21st Street, four blocks to the west of South 18th Street.

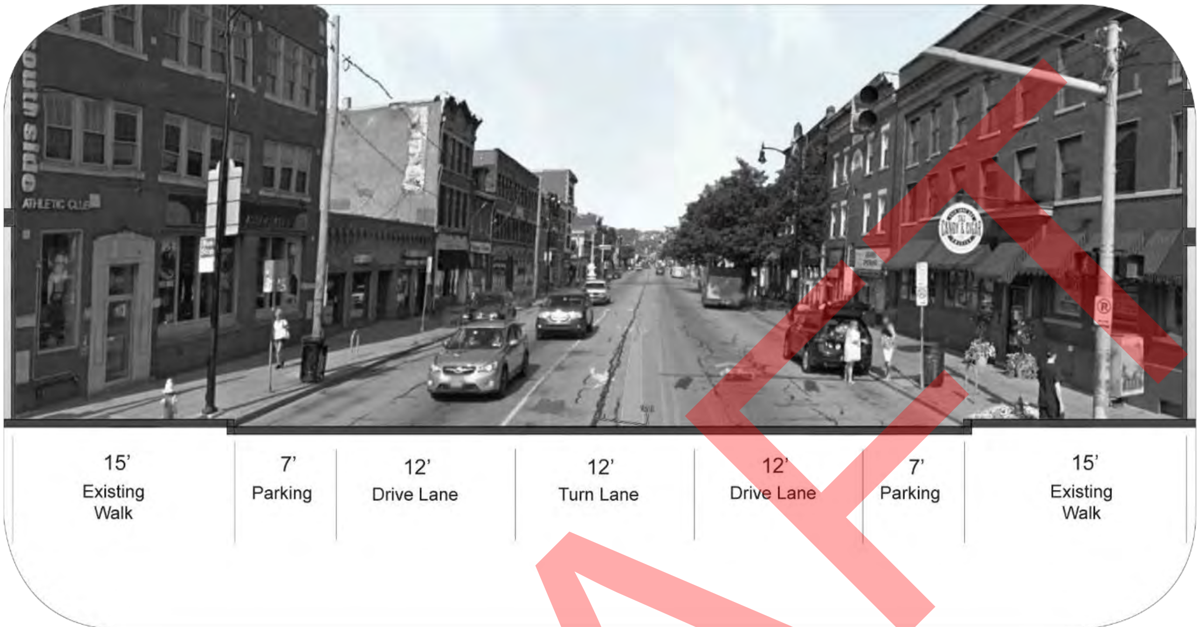


Figure 6-50: Existing East Carson Street

Figure 6-51: Proposed Bioswale, Pervious Parking, and Street Trees in East Carson Street


Figure 6-52

GI has been proposed in **South 21st Street** in redevelopment plans and is supported by the community. The gentle slope of the street lends itself to the introduction of pervious pavement and additional GI in the street. South 21st Street connects Carson to South Side Park and should be considered as a green boulevard and gateway to an underutilized portion of the park.


Figure 6-53

South Side Park is a critical area for CSO reduction in the sewershed. It contains large areas of high yield in addition to providing areas for large storage volumes. These storage sites are placed within the existing valley on the western edge of park. The lower slopes and broad cross-section of this valley accommodate a series of stepped ponds.

Quarry Field is at the upper reaches of the valley and the adjacent hillside groundwater seep could serve as baseflow for a daylighted stream that continues down the valley. At the base of the valley where South 21st Street terminates, existing unused parking lots could be depaved or transformed to pervious pavement. This area at the base of the valley has also been discussed as a potential site for a PWSA Operations Center that would be integrated into the environmental education programming in the park, complementing GI concepts in this sewershed.

6.5 A41 Heth's Run

6.5.1 Existing Sewershed Conditions

The A41 Sewershed is located in some of Pittsburgh's most stable residential neighborhoods. This sewershed is configured similar to the watershed and the sewer follows the path of the now underground Heth's Run, which once was tributary to the Allegheny River. At the highest points in the shed, Stanton Heights, Garfield, and East Liberty contribute some stormwater but the majority of runoff comes from the Morningside and Highland Park neighborhoods. The neighborhoods are mostly comprised of single family detached homes and there is little vacancy. The Heth's Run valley is currently used as a parking lot for the Pittsburgh Zoo and is contiguous with Highland Park, one of the largest municipal parks in the city. Highland Park is also home to both a covered and uncovered drinking water reservoir.

Today's sewer mains follow hydrologic flow lines very closely. Heth's Avenue and Heth's Way were built on top of the main branches of Heth's Run. The majority of A41's stormwater follows here today.

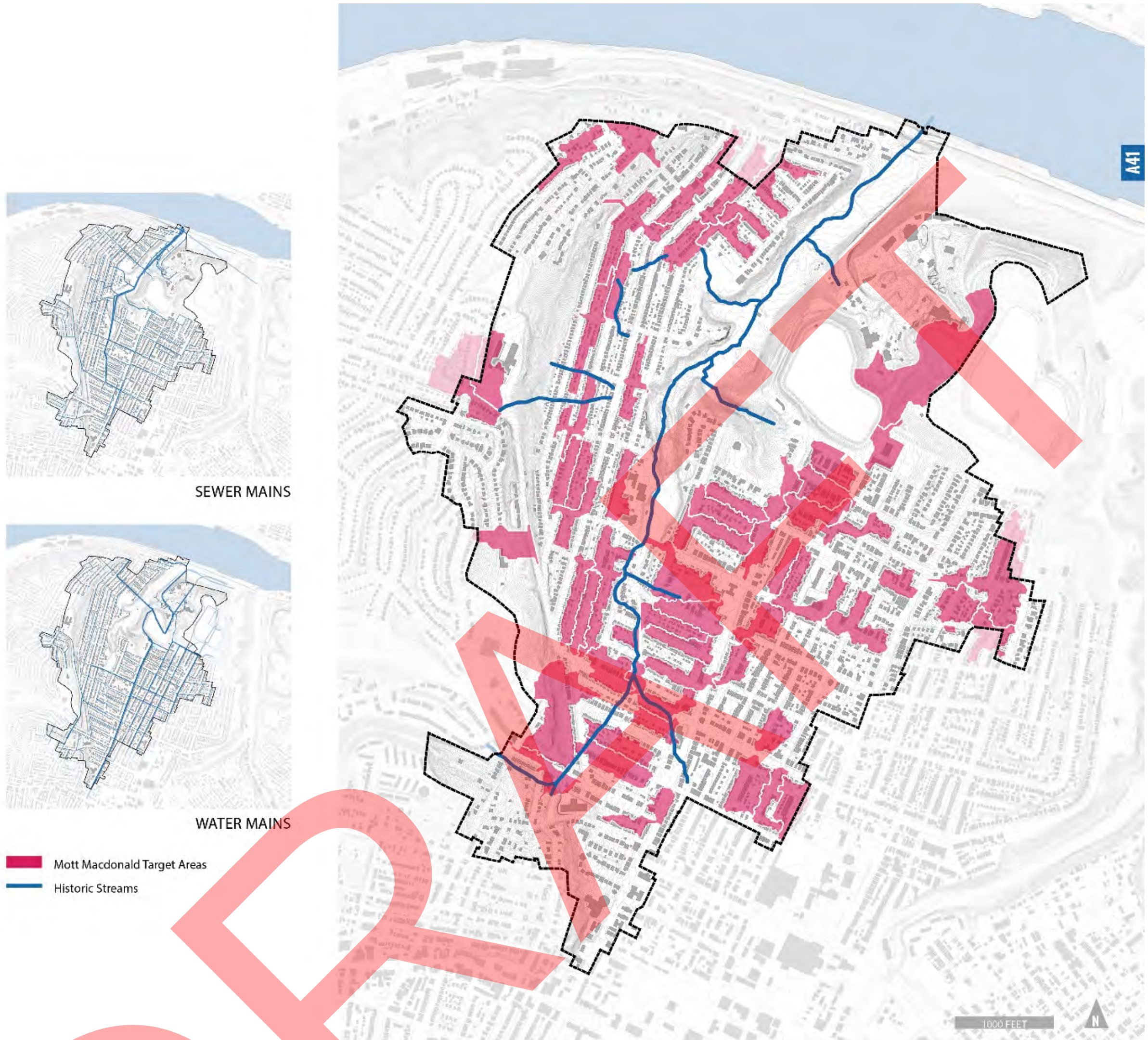


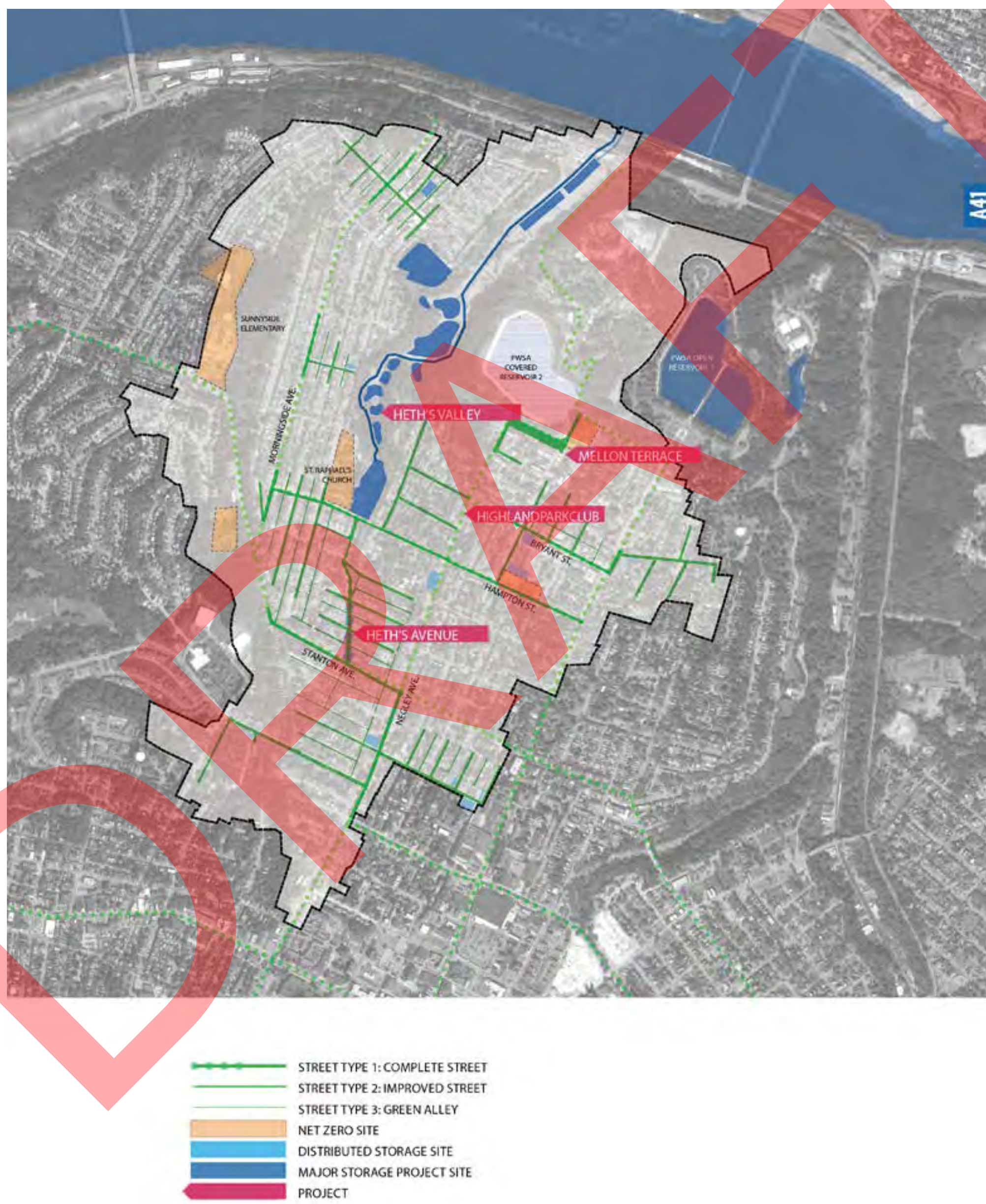
Figure 6-54

Stormwater from rainfall is the major driving force behind the geology of Pittsburgh. Recognizing where and how stormwater historically flowed can give us clues to where those flows want to occur today.

Today's sewer mains follow hydrologic flow lines very closely. Heth's Avenue and Heth's Way were built on top of the main branches of Heth's Run. The majority of A41's stormwater follows here today.

6.5.2 Urban Design Framework Plan

The A41 Sewershed is distinguished by its absence of vacant parcels and a largely open valley floor. Neighborhoods comprised of single family detached homes surround the valley of the former Heth's Run. To the east lies Pittsburgh's Highland Park, home to two large drinking water reservoirs and the Pittsburgh Zoo. The valley floor, which has been filled and graded in most places, is largely consumed by parking.



. **Figure 6-55**

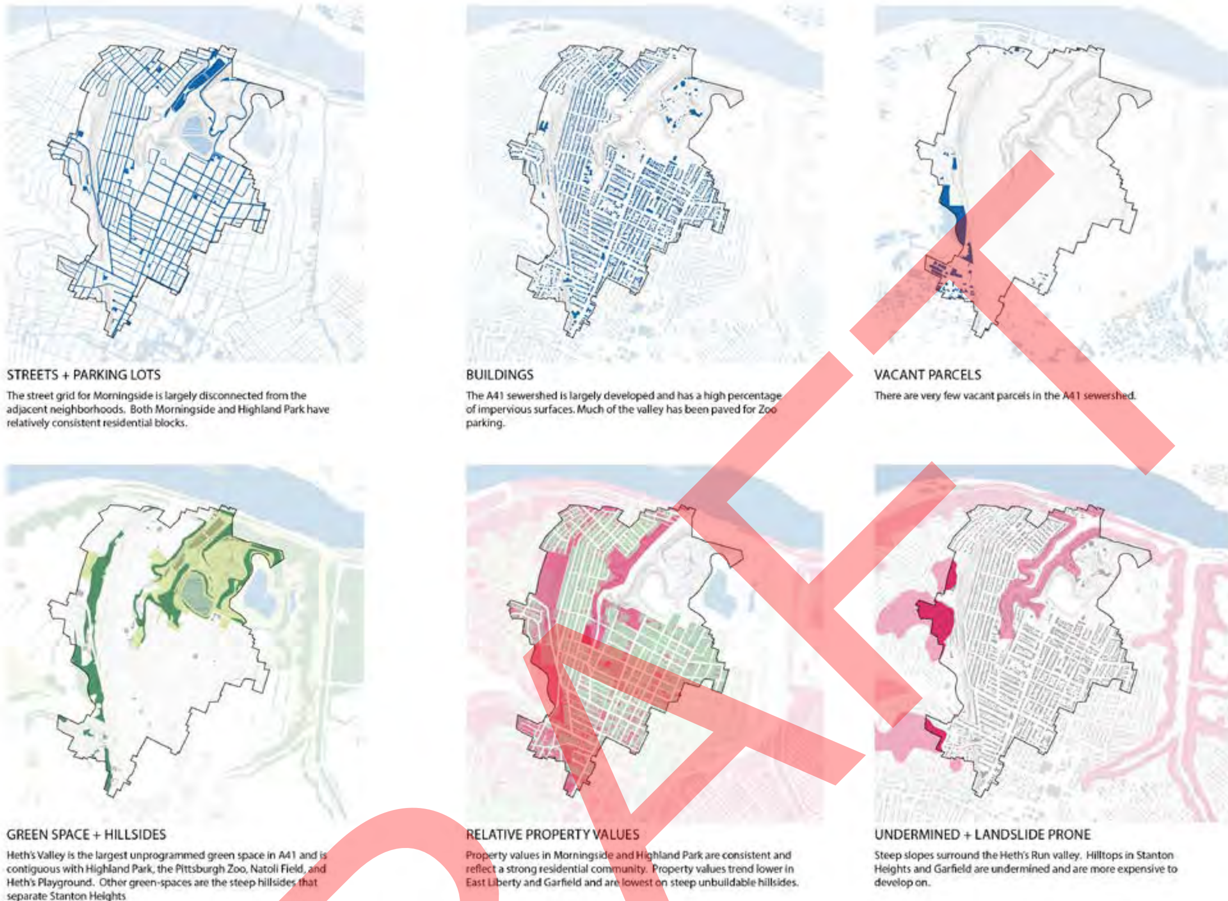


Figure 6-56

Understanding the unique urban fabric of a sewershed allows PWSA to identify potential synergies between infrastructure and communities. Better streets, better parks, better green-spaces, better hillsides, better homes, and better developments can all have positive ripple effects for people, planet, place, and performance.

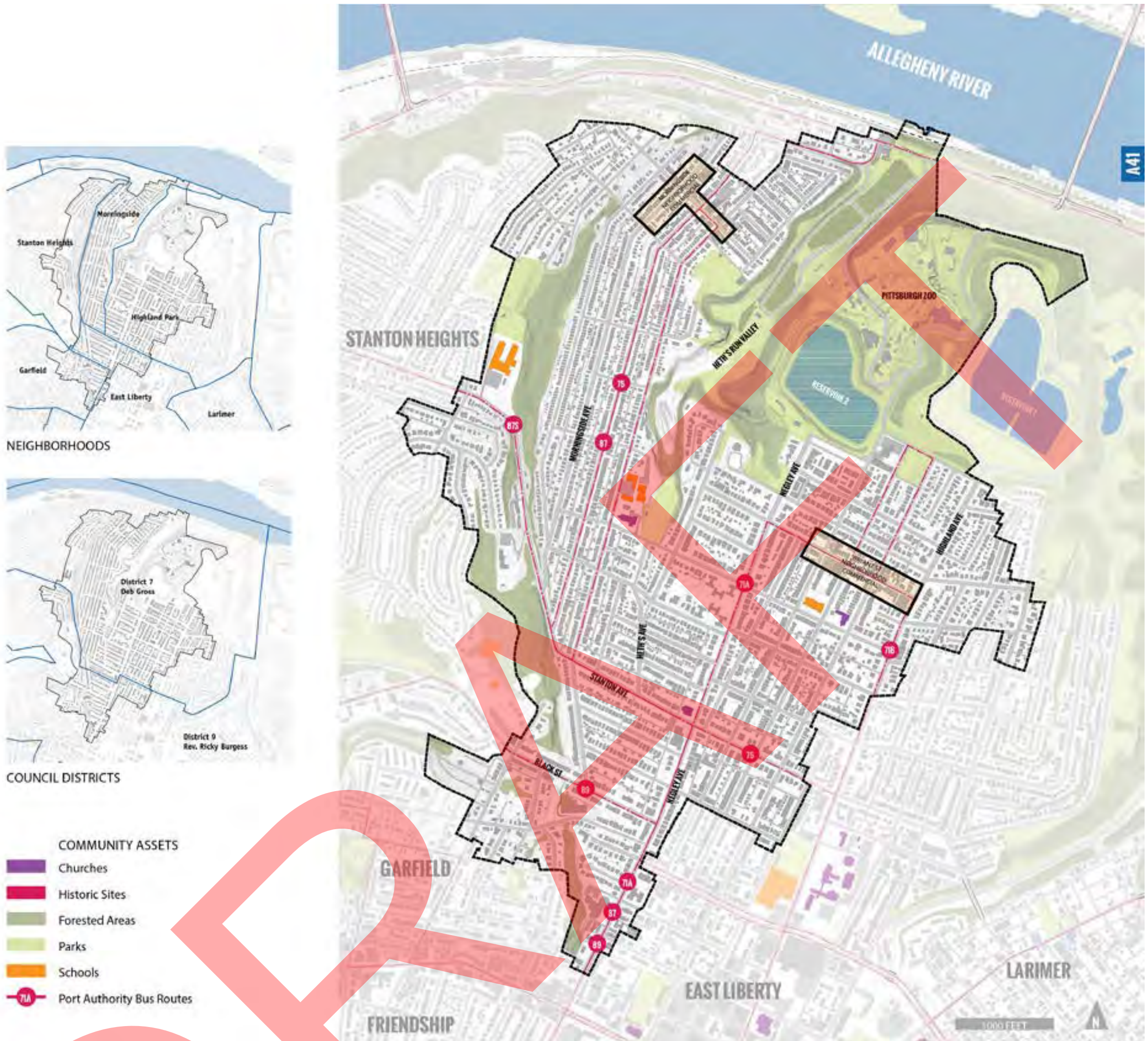

ALLEGHENY RIVER
A41
STANTON HEIGHTS
PITTSBURGH ZOO
GARFIELD
EAST LIBERTY
LARIMER
FRIENDSHIP
STANTON AVE
NEIGHBORHOODS
Morningside
Stanton Heights
Highland Park
Garfield
East Liberty
Larimer
COUNCIL DISTRICTS
District 7 Deb Gross
District 9 Rev. Ricky Burgess
COMMUNITY ASSETS
Churches
Historic Sites
Forested Areas
Parks
Schools
Port Authority Bus Routes

Figure 6-57

Figure 6-58

Highland Park is a quiet residential neighborhood with a vibrant neighborhood commercial district at Bryant St. It is home to Gilded Age landmarks like the King Estate and the grand entry to Highland Park. Local schools and churches remain civic landmarks, even when they are converted to other uses, as evidenced by the recently renovated Union Project community center.

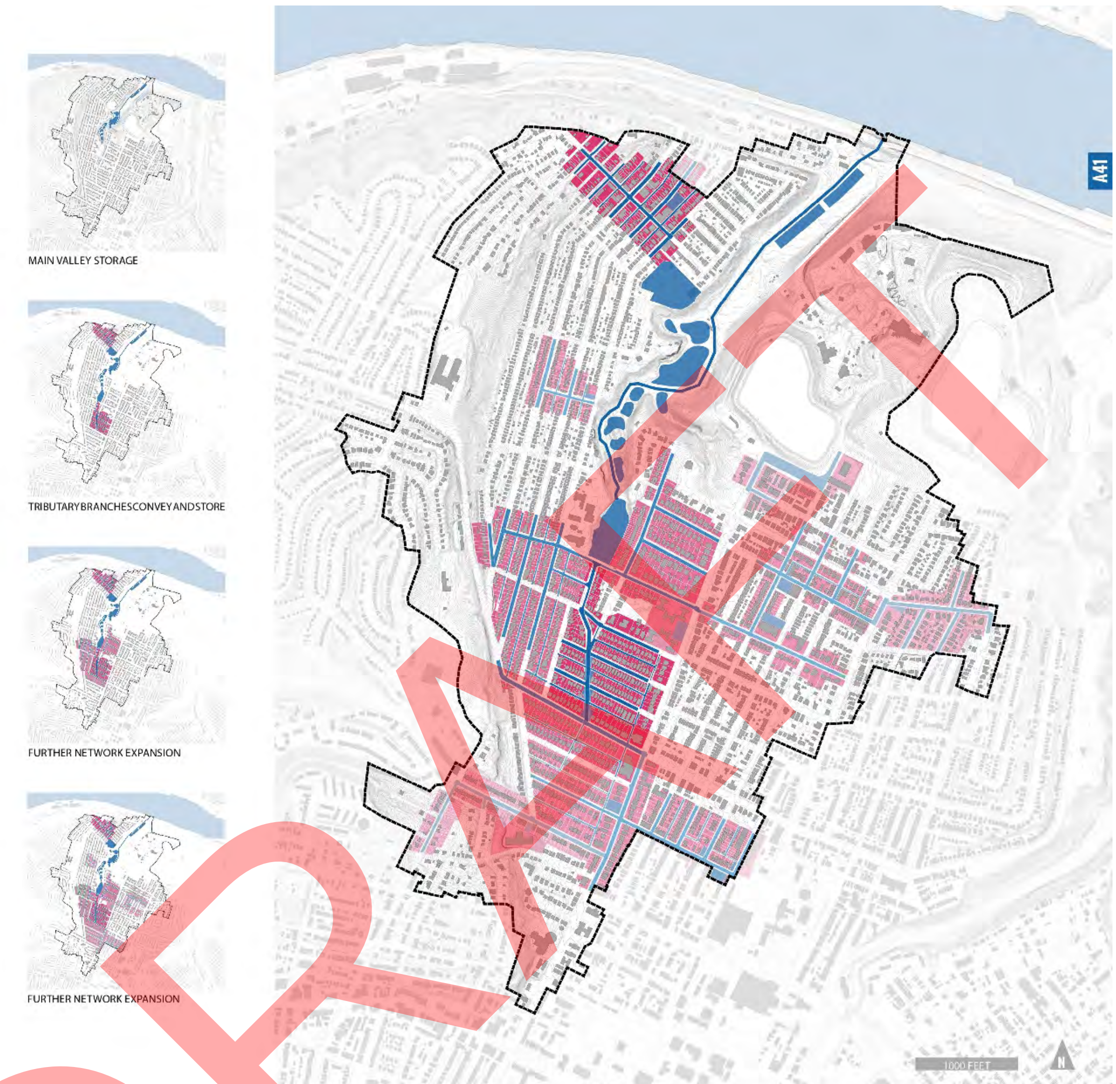


Figure 6-59

Green infrastructure works by restoring, mimicking, and supercharging natural hydrologic processes. It needs to be deployed as a network and can reconcile historical flows with modern land use. We studied the historical development of the city of Pittsburgh, and the impact of development on the city's topography.

Hydrologic networks rely on a hierarchy of parts and differentiated functioning. Often there are critical pieces of green infrastructure that need to be installed and scaled to anticipate further expansion of the green infrastructure network.

We identified "opportunity sites" throughout each priority sewershed that could both fulfill local stormwater infrastructure needs and support healthy communities and neighborhoods. The result is a hybridization between natural and man-made resource flows.

In A41 Heth's Run, storage infrastructure at Natoli Field and Heth's Playground could allow for street improvements throughout the shed. As street improvements and detention sites come online, the network can be further expanded until the targeted areas are served by green infrastructure.

6.5.3 Heth's Run Concept Plan

6.5.3.1 Heth's Ave Green Boulevard & Blue Valley

The A41 shed strategy reestablishes the importance of Heth's Valley as storage and Heth's Avenue as a collector, gathering water from adjacent streets, storing it in "stop-and-drop" subsurface detention under Heth's Field, and then continuing to the restored wetlands and stream in the valley.

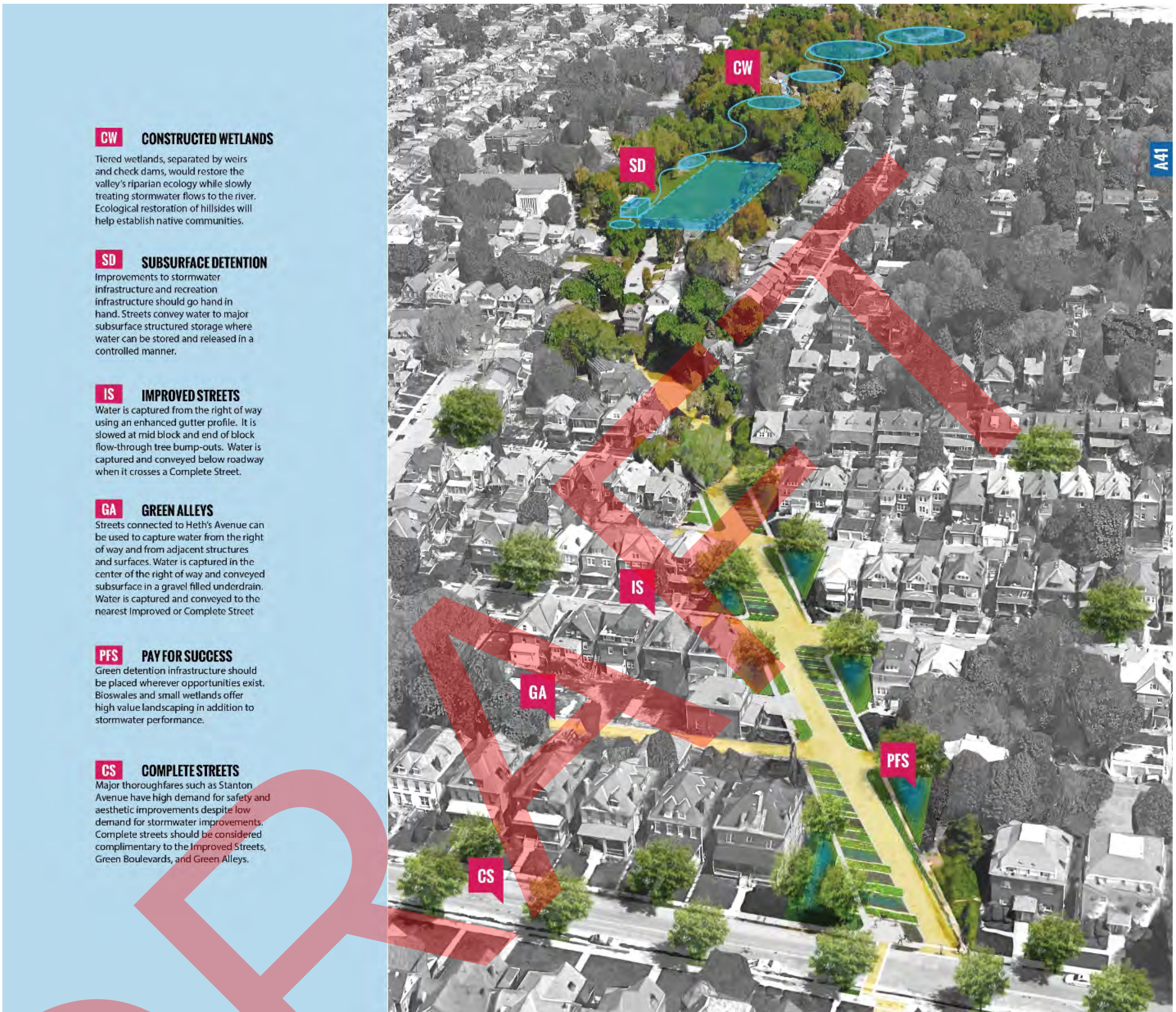


Figure 6-60

Historically Heth's Valley (Haight's Valley) was a wetlands area that captured and contained water from the shed. The Pittsburgh Parks Conservancy and the Pittsburgh Zoo are embarking on a transformation of the asphalt parking lot to an extension of Highland Park. The functioning of the valley would likely include wetlands, pass through conveyance, energy dissipation, and structured storage. Ecological restoration is needed to prevent sedimentation and to improve water quality. Ultimately, water should be released to the Allegheny without reentering the storm-sewer system.

Most of A41's sewage and stormwater flow through pipes buried below Heth's Avenue. As PWSA moves toward segregating sanitary and stormwater sewers, Heth's Ave should be considered as a priority site.

Heth's Ave is an underutilized concrete slab street on average 36 feet wide. There is low traffic count and low demand for parking on this street so an aggressive road diet is possible. Decreasing the width of the road would allow for generous rain gardens on either side and would establish the corridor as a pedestrian and cyclist friendly access to Heth's Playground and extend Highland Park into the neighborhood. Networked tree pits, improved gutter profiles, and green alleys would allow surface flows from Jackson St, Avondale Pl, and Wellesley Ave to travel to Heth's Playground without entering subsurface infrastructure.

Water could be captured and conveyed within the right of way using an enhanced gutter profile and slowed at mid-block and end of block flow-through tree bump-outs. Streets sloped toward Heth's Avenue can be used to capture water from the right of way and from adjacent structures and surfaces.

6.5.3.2 Natoli Field

Morningside's neighborhood business district is located at Greenwood Street and Morningside Avenue and connects the surrounding neighborhood to green-space, public transit, and other amenities. The district could be given a unique identity with well-designed stormwater infrastructure.

Figure 6-61

Natoli Field offers 165,000 square feet of recreational fields and is at the bottom of the Greenwood St sewershed. It is an ideal site for subsurface detention before stormwater drops into the Heth's Run Valley. A former playground at the unoccupied Morningside Elementary School could incorporate either surface or subsurface detention on a smaller scale, at 16,000 square feet.

City steps on Greenwood St descending from El Paso to Duffield could be an exciting opportunity for tiered detention and conveyance structures along a new fully accessible route, giving the public an up close look at natural resource flows within the neighborhood.

6.5.3.3 Highland Park Club Apartments

The Highland Park Club Apartments is one of the few large developed parcels in A41 and is a classic "towers in the park" community of low-rise apartments. Already endowed with generous green spaces, this site could make the most of them by incorporating green stormwater strategies including green roofs, rain gardens, and bioswales.

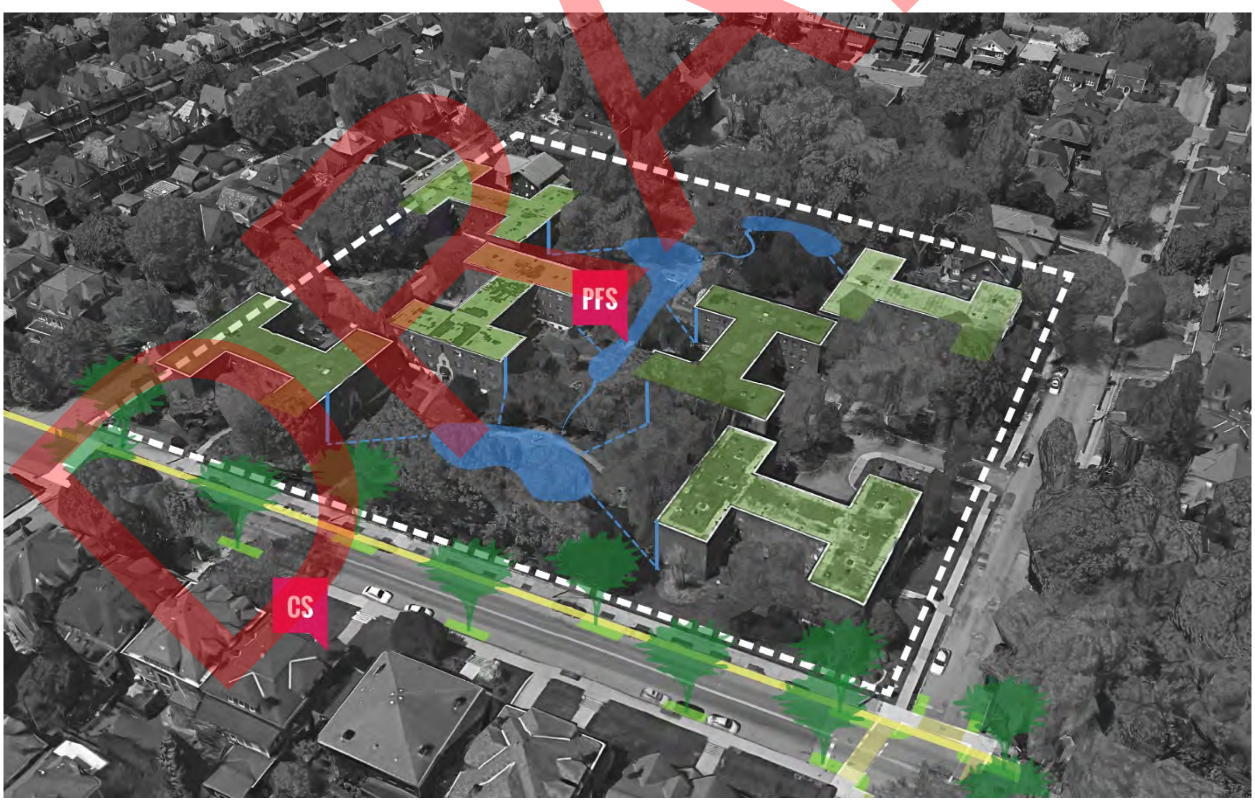


Figure 6-62

Maximizing the detention potential of this site could enable surface flows from the right of way to be managed on private property. This could be accomplished through a public-private partnership model called "pay-for-success" whereby the public stormwater management entity pays a private property owner for management of a certain volume of water.

6.6 M19 Soho Run

6.6.1 Existing Sewershed Conditions

The M19 Sewershed is nestled in the core of the East End between some of Pittsburgh's largest economic centers. The M19 Sewershed is closely aligned with the watershed for the now underground Soho Run which was tributary to the Monongahela until the combined sewer network was constructed. Starting at the top of the Herron Hill, Soho Run flowed through the Upper Hill District, the Middle Hill District, Terrace Village, and Uptown (Bluff) before reaching the Monongahela River near today's Birmingham Bridge. Once a vibrant community that was home to Pittsburgh's Jazz scene, the Hill District today is marked by vacancy and blight. Surrounded on all sides by neighborhoods with rapid development, it is expected that M19 will soon see major land use changes. Ways to anticipate development in M19 and its impact on stormwater management were considered.

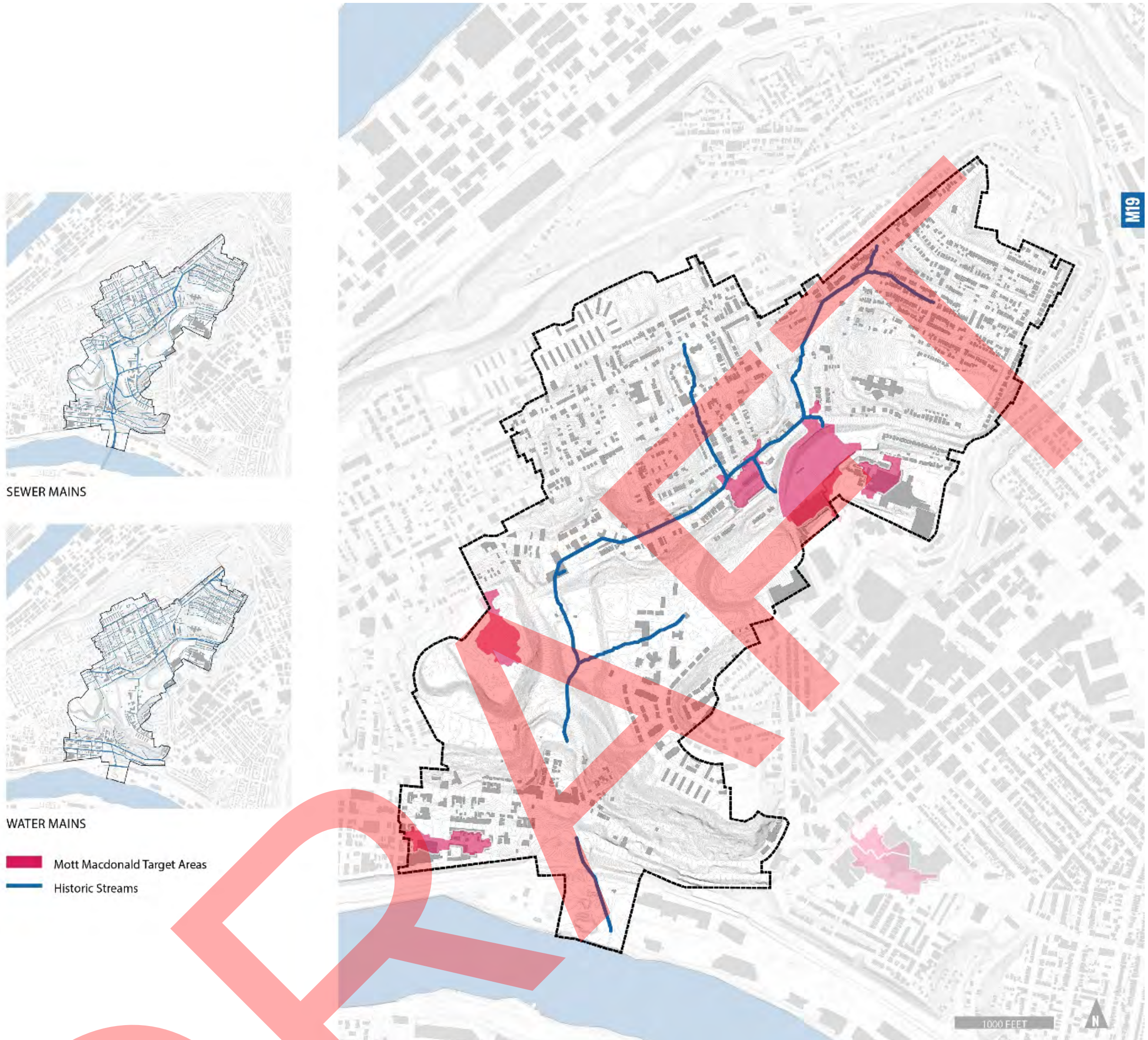


Figure 6-63

Stormwater from rainfall is the major driving force behind the geology of Pittsburgh. Recognizing where and how stormwater historically flowed can give us clues to where those flows want to occur today.

Today's sewer mains follow hydrologic flow lines very closely. What was Soho Run now flows more than 60 feet below the surface of today's Kennard Playground in a hand built brick sewer main. This approach to stormwater management lacks the riparian ecology needed to absorb, detain, and slow stormwater.

6.6.2 Urban Design Framework Plan

Located at the heart of Pittsburgh's East End, M19 is surrounded on all sides by culturally and economically diverse neighborhoods. Downtown is to the west. Oakland with its hospitals and universities is to the east. Polish Hill, the Strip District, Lawrenceville, and Bloomfield are to the north. South Side is just over the Birmingham Bridge to the south.

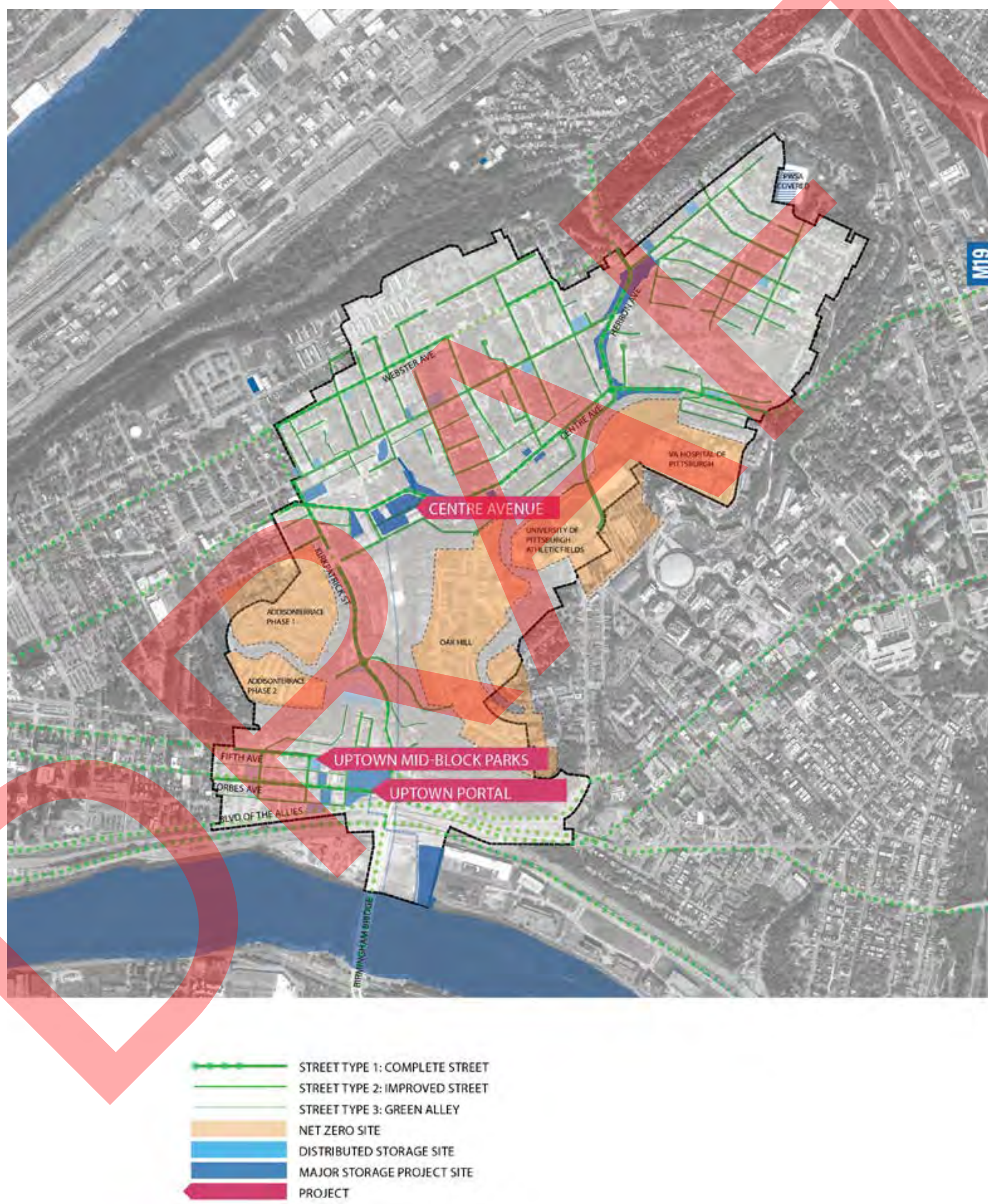


Figure 6-64

Centre Avenue forms the civic spine of the Hill District and even after decades of disinvestment it remains home to the churches, schools, and neighborhood businesses that are helping the community to rebuild. The Hill District is distinctly separated from Uptown by Housing Authority developments in Terrace Village. Uptown is home to the city's most highly traveled thoroughfares that connect the East End to Downtown and beyond.

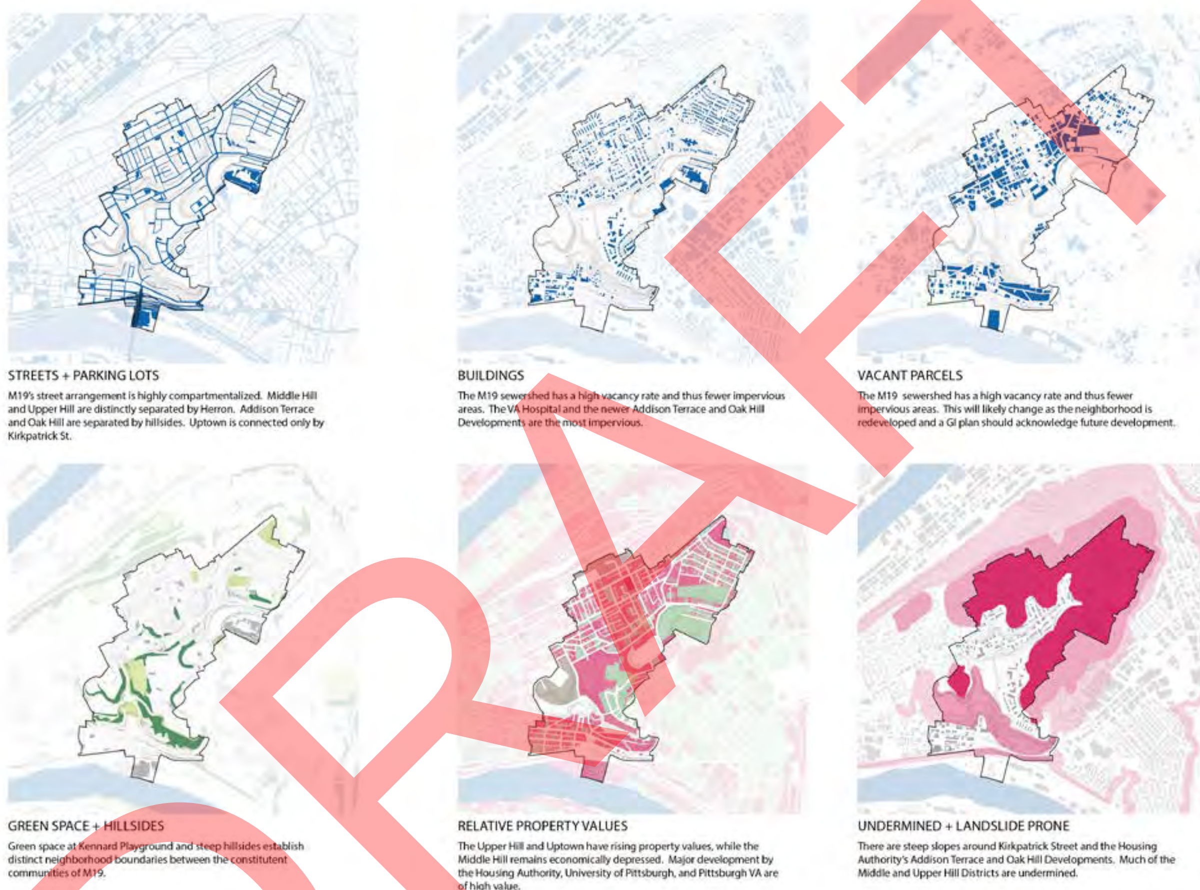


Figure 6-65

Understanding the unique urban fabric of a sewershed allows PWSA to identify potential synergies between infrastructure and communities. Better streets, better parks, better green-spaces, better hillsides, better homes, and better developments can all have positive ripple effects for people, planet, place, and performance.

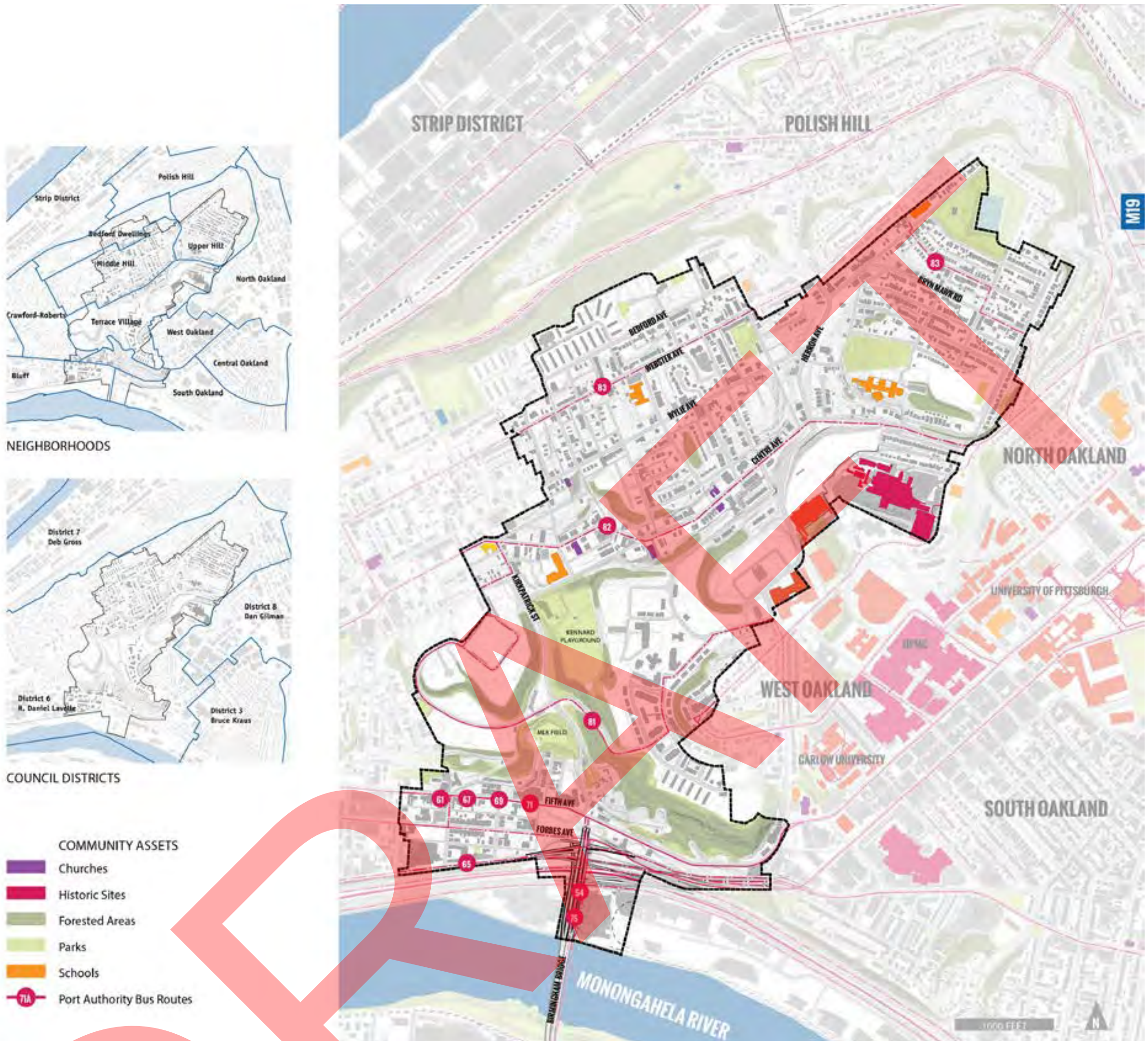

Polish Hill
Strip District
Bedford Dwellings
Upper Hill
Middle Hill
North Oakland
Crawford-Roberts
Terrace Village
West Oakland
Central Oakland
Bluff
South Oakland
NEIGHBORHOODS
District 7 Deb Gross
District 8 Dan Gilman
District 6 R. Daniel Lavelle
District 3 Bruce Kraus
COUNCIL DISTRICTS
COMMUNITY ASSETS
Churches
Historic Sites
Forested Areas
Parks
Schools
Port Authority Bus Routes
STRIP DISTRICT
POLISH HILL
M19
BEDFORD AVE
WEBSTER AVE
WYLIE AVE
CENTRE AVE
HERRON AVE
BRYN MAWR RD
NORTH OAKLAND
KIRKPATRICK ST
KENNARD PLAYGROUND
UNIVERSITY OF PITTSBURGH
UPMC
WEST OAKLAND
CARLOW UNIVERSITY
SOUTH OAKLAND
FIFTH AVE
FORBES AVE
MONONGAHELA RIVER

Figure 6-66

Figure 6-67

The Middle Hill has seen a steady decline following its effective disconnection from downtown by the construction of the Civic Arena in the early 1960s. This led to blight and the current high vacancy rates.

With leadership from local community groups, the neighborhood is rebuilding. While it is not currently identified as a stormwater target area, more impervious surfaces will soon be introduced by redevelopment. A green infrastructure network could be established now in anticipation of the community's future stormwater management needs.

Large scale redevelopment of former Housing Authority sites are built with separated sewer systems that feed back into the combined system, essentially losing the benefit of a separated system. These systems should be examined to be taken offline where possible.

Figure 6-68

Uptown is home to the city's most highly traveled thoroughfares that connect the East End to Downtown and beyond. Fifth and Forbes Avenues carry heavy traffic through Uptown and for decades this traffic has discouraged residential growth. Today these corridors are valuable for the transit access they provide, an economic force that will be leveraged by the new Uptown Eco Innovation District. Vacant parcels are quickly being acquired by developers and the neighborhood is preparing itself for growth.

The Uptown Eco Innovation District establishes Uptown as a zone for targeted environmental improvements and environmentally sensitive redevelopment. Projects designed and built in this district could set a precedent for the rest of the city to follow.

While connections to Downtown and Oakland are good for automobiles and transit, they are very poor for pedestrians and cyclists. Improvements to the streetscape for green infrastructure could be leveraged to improve walkability and bikeability throughout Uptown and its neighboring communities.

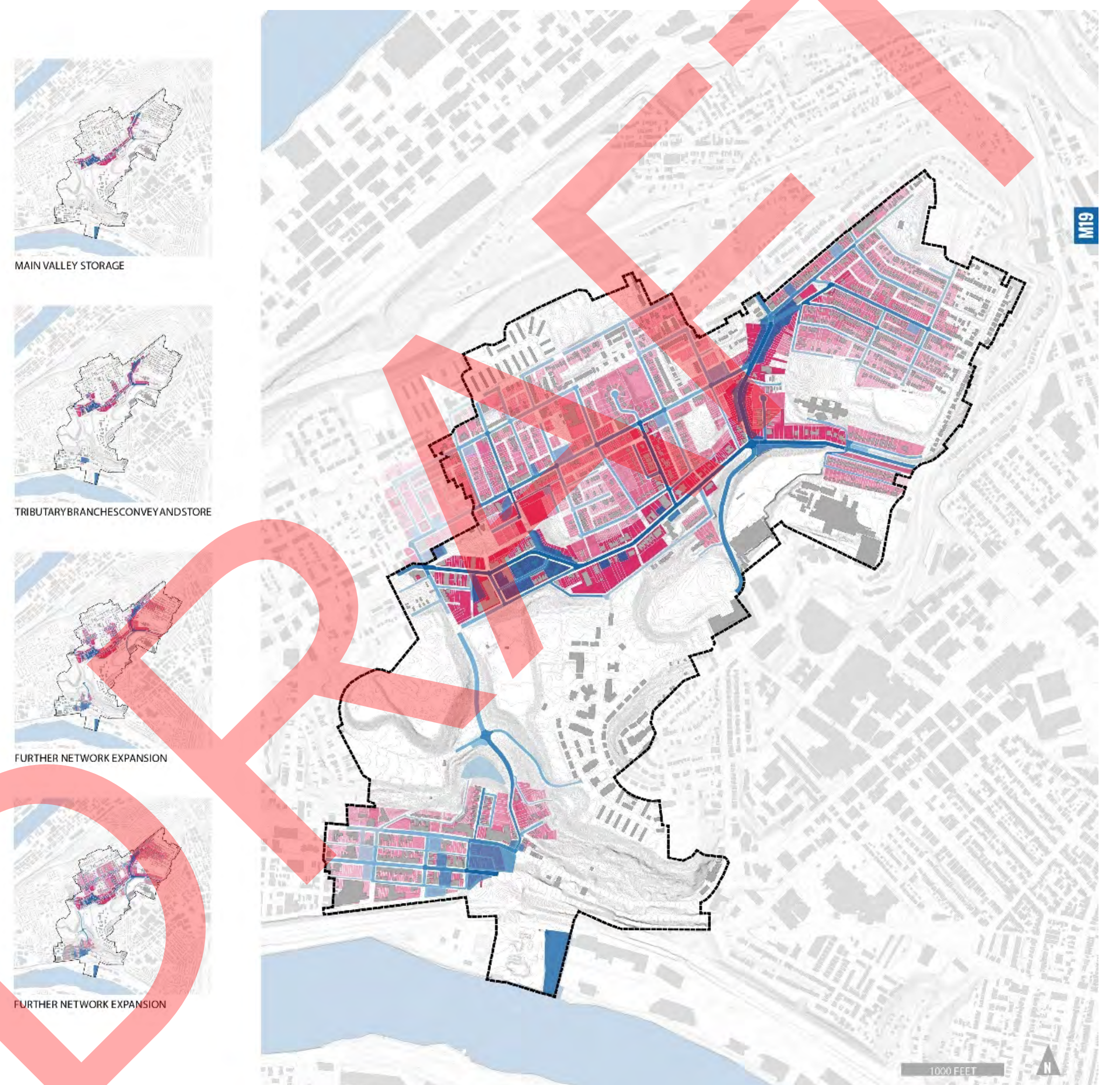


Figure 6-69

Green infrastructure works by restoring, mimicking, and supercharging natural hydrologic processes. It needs to be deployed as a network and can reconcile historical flows with modern land use. We studied the historical development of the city of Pittsburgh, and the impact of development on the city's topography.

Hydrologic networks rely on a hierarchy of parts and differentiated functioning. Often there are critical pieces of green infrastructure that need to be installed and scaled to anticipate further expansion of the green infrastructure network.

We identified "opportunity sites" throughout each priority sewershed that could both fulfill local stormwater infrastructure needs and support healthy communities and neighborhoods. The result is a hybridization between natural and man-made resource flows

In M19 Soho Run, the storage infrastructure at the Centre Ave low-point and at the Uptown Portal site could allow for street improvements throughout the shed. As street improvements and detention sites come online, the network can be further expanded to connect to remaining target parcels.

6.6.3 Soho Run Concept Plan

6.6.3.1 Centre Avenue Basin

When affordable housing was planned for the last remaining undeveloped hilltops, the projects filled Soho Valley to create the Kennard Playground. This effectively created an earthen dam, trapping a 42 foot deep potential reservoir on Centre Avenue that is kept dry by the combined sewer pipe running south. Because of this obstacle, surface conveyance to the Monongahela is not an option for the majority of rainfall within the M19 sewershed. The brick sewer pipe is buried up to 60 feet deep, following the former Soho Street.

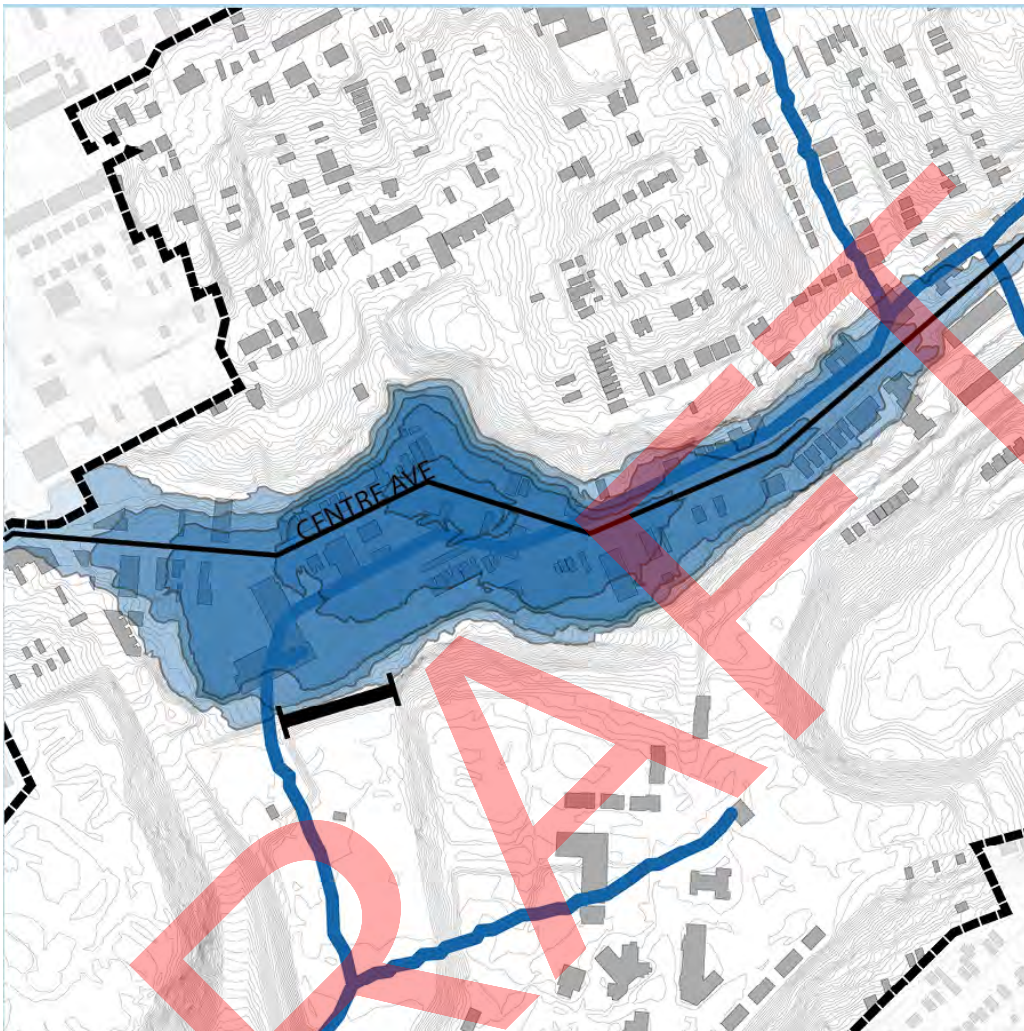


Figure 6-70

Treating this area as a high volume stormwater reservoir is not an option as there are local landmarks and highly trafficked roads. A gas station has occupied the lowest point of this virtual lake for several decades and the sewers that drain the tub are clearly visible. The case for maintaining our existing infrastructure is clear when you consider that if "Lake Soho" were to exist, it would be 28 acres in area, the largest body of water in Pittsburgh, and second largest body of water in Allegheny County.

This topographic feature has significant impact on stormwater management strategy. At present, there is only one way out for stormwater and sanitary sewage from the majority of the M19 Sewershed. Separation of these flows would require tunneling for a new sanitary main, tunneling for a new stormwater main, or insertion of a dedicated sanitary pipe inside the existing combined pipe. Until then, as much stormwater as possible needs to be captured, detained, and slow released.

Figure 6-71

The low-point of Centre Avenue, at the deepest part of the virtual "Lake Soho", could become the major detention area serving much of M19. A gas station and surrounding vacant parcels could be networked together as a public stormwater green space at the heart of the Hill District, forming a new civic center that acts as an anchor to redevelopment further down Centre Avenue.

6.6.3.2 Soho Run Valley

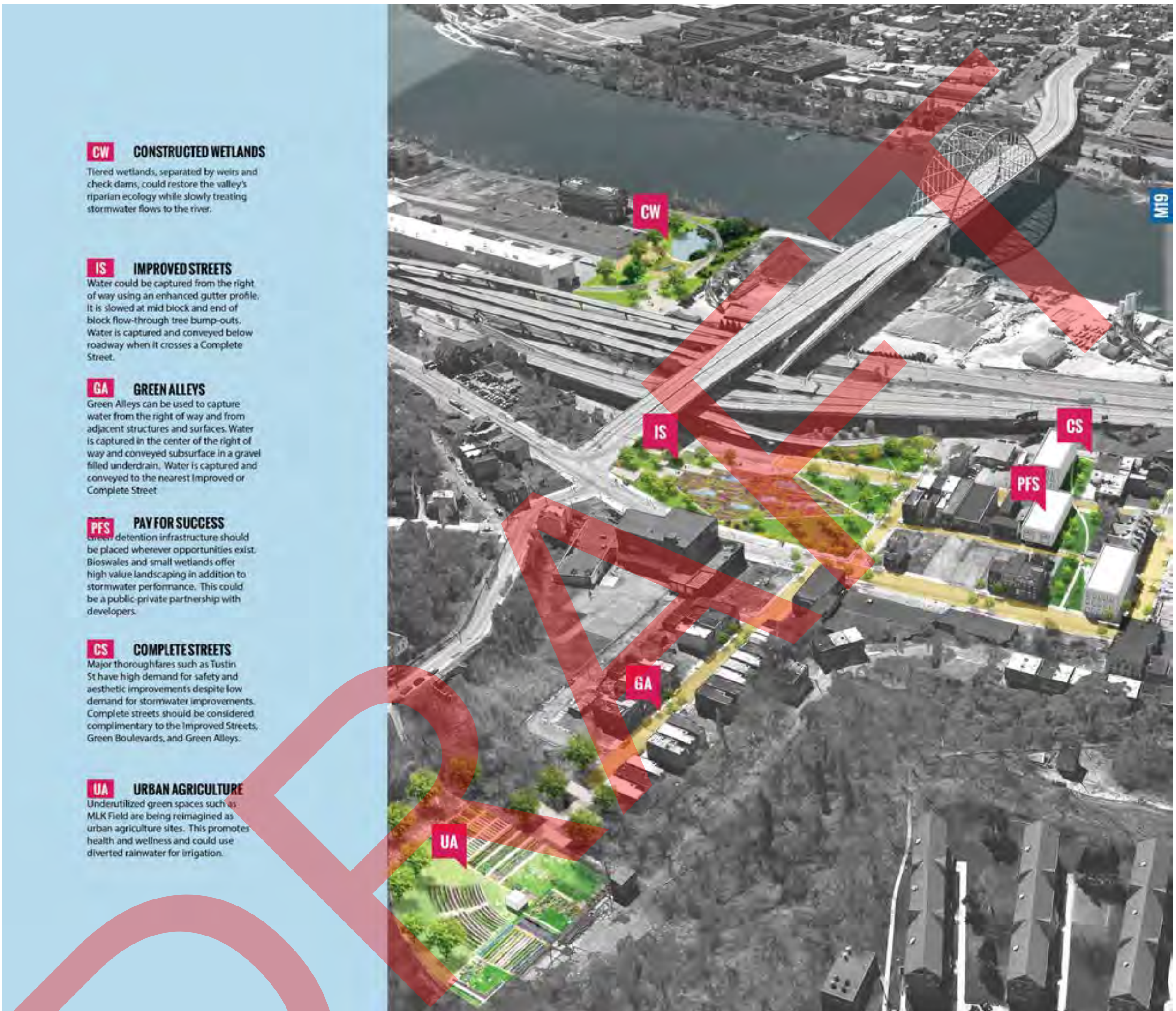


Figure 6-72

Today's Soho Run valley is very different from what was there 150 years ago. Rainwater has not flowed over the surface of the valley since diversion of the Run into the Soho Street sewer main in the early 1900s. Following hilltop leveling in the 1950s, the valley was filled and regraded, erasing all evidence of natural stormwater flows. A series of green infrastructure projects could reclaim some of the stormwater management potential inherent in today's man-made topography.

MLK Park, a former ball-field and now urban agriculture site, could detain stormwater from the slopes immediately surrounding it and the road right-of-way for mid-slope storage. Capacity should be modeled for slope stability.

Key to any and all Green Infrastructure improvements in the Soho Run Valley is the Uptown Portal Park. This site, between Fifth, Forbes, and the Birmingham Bridge aggregates stormwater flows from all sides and reconciles challenging changes in grade for both cyclists and pedestrians.

In Uptown, bands of mid-block green-spaces could provide tiered detention basins through the neighborhood while providing improved mid-block connectivity. In addition to acting as a distributed detention network for stormwater, distributed parklets make the neighborhood more walkable and offer a unique type of development for Uptown's Eco Innovation District.

Green alleys could provide stormwater conveyance to the stormwater detention parks and could serve as an off-street route for cyclists and pedestrians.

Conversion of Brady Street to a stormwater conveyance park could allow stormwater to slowly make its way down to the Monongahela River through a series of interconnected tree-pits and detention basins and solve pedestrian and bike connectivity issues. A project that connects people and water to the river would benefit both Uptown and the Hill. The solution needs to navigate under the nine bridges and on ramps carrying thirteen E-W lanes and six N-S lanes of traffic and will not be an easy solution, but could be a dramatic public space providing access to the E-W Jail Trail Bike-way, Pittsburgh Technology Center, Almono Hazelwood, and ultimately, Washington, DC.

Restoration of riparian ecology at the base of the Run could provide the final treatment for both water volume and water quality before a naturalized day-lit outflow to the Monongahela River.

6.6.3.3 MLK Park

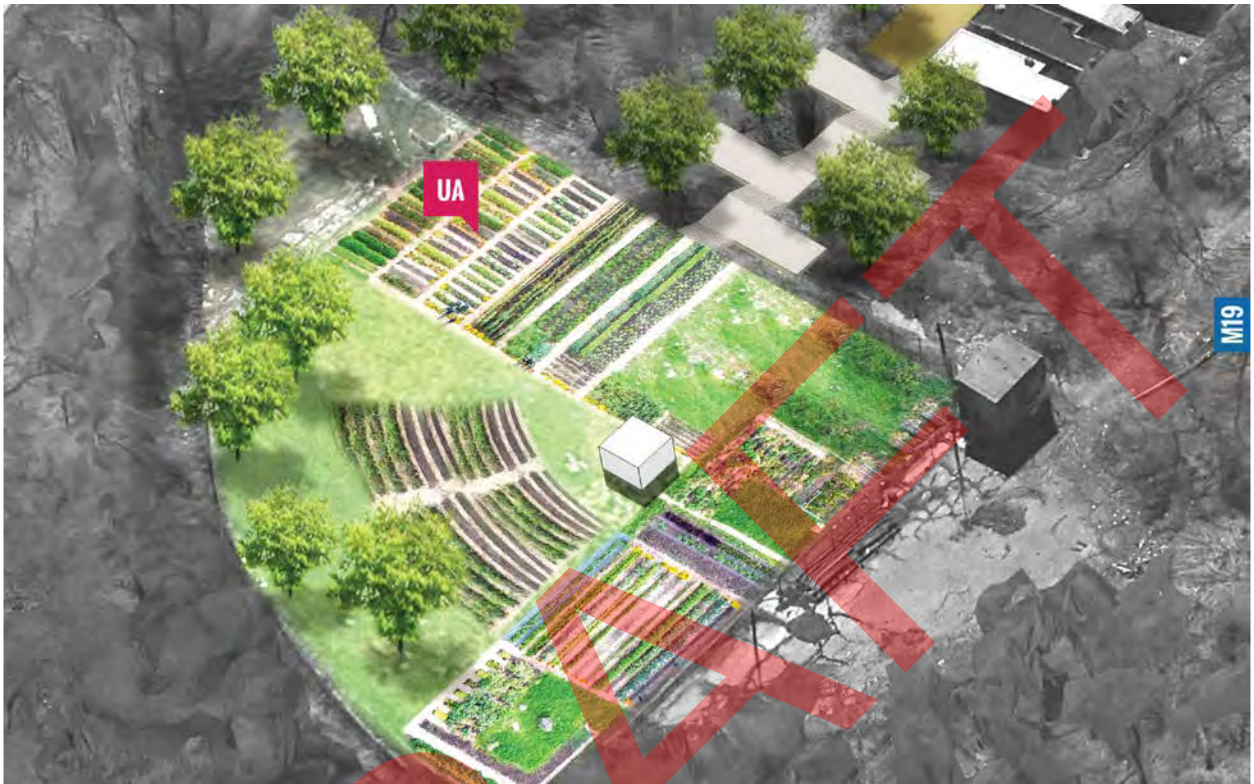


Figure 6-73

MLK Park, a former ball-field and now urban agriculture site, could detain stormwater from the slopes immediately surrounding it while providing the potential for natural irrigation. Urban agriculture promotes health and wellness. Diverted rainwater could be used for irrigation.

6.6.3.4 Uptown Midblock Parklets

Figure 6-74

Bands of mid-block green-spaces could provide tiered detention basins through the neighborhood while providing improved mid-block connectivity. Using the pay-for-success model, PWSA could work with developers to incent creative solutions that manage stormwater and improve the public realm.

In addition to acting as a distributed detention network for stormwater, distributed parkland makes the neighborhood more walkable in support of higher density development in Uptown. Green alleys could provide stormwater conveyance to the stormwater detention parks. In addition, they could serve as an off-street route for cyclists and pedestrians.

6.6.3.5 Uptown Portal Park

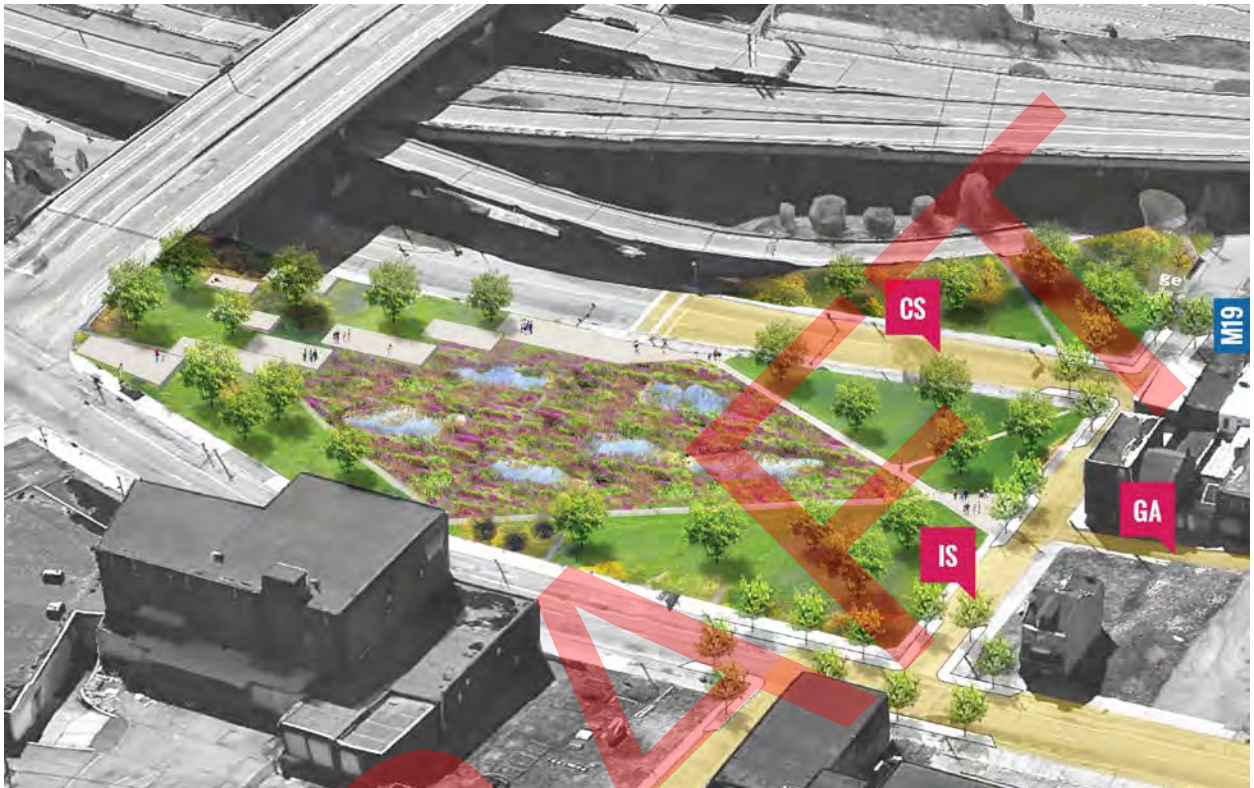


Figure 6-75

Nestled between Fifth Avenue, Forbes Avenue, and the Birmingham Bridge are a series of parcels that could become the Uptown Portal Park. At this point, stormwater from Uptown, Kirkpatrick Street, MLK Park, and Fifth Avenue converge and could be detained. Cyclists and pedestrians lack an accessible route across the site and improving the site is key to establishing Uptown as a walkable, bikeable neighborhood. Visible from the most highly trafficked automobile and transit corridor in the city, the site is an opportunity to redefine a key portal between Uptown, the Hill District, Oakland, Downtown, South Side, Pittsburgh Technology Center, and the in-progress ALMONO development.

6.6.3.6 Soho Run at the Monongahela River

Figure 6-76

Restoration of riparian ecology at the base of the Run could provide the final treatment for both water volume and water quality before a naturalized day-lit outflow to the Monongahela. Reclamation of this underutilized site on the Mon could add value to current development of the Pittsburgh Technology Center and the future development of the ALMONO site. It could provide crucial riverfront access to the Uptown community and connects the Jail Trail Bike-way to a potential future trail along the riverfront.

6.7 O27 Woods Run

6.7.1 Existing Sewershed Conditions

The O27 Sewershed is located in the North Western corner of the city. The sewershed is closely aligned to the watershed for the now underground Woods Run which was tributary to the Ohio River until the construction of the combined sewer network. The highest points in the shed are in Ross Township, Perry North, and Perry South and the many branches of Woods Run flow through Riverview Park and along Woods Run Avenue before combining with flows from Brighton Heights and Marshall-Shadeland. Woods Run then flows through a highly industrialized area and its former outfall to the Ohio was just upstream of today's ALCOSAN WWTP. Developed as a Streetcar Suburb, the neighborhoods have seen a slow decline since the discontinuation of Pittsburgh's streetcar network. While no major development is expected, new residents are taking advantage of the area's proximity to Riverview Park.

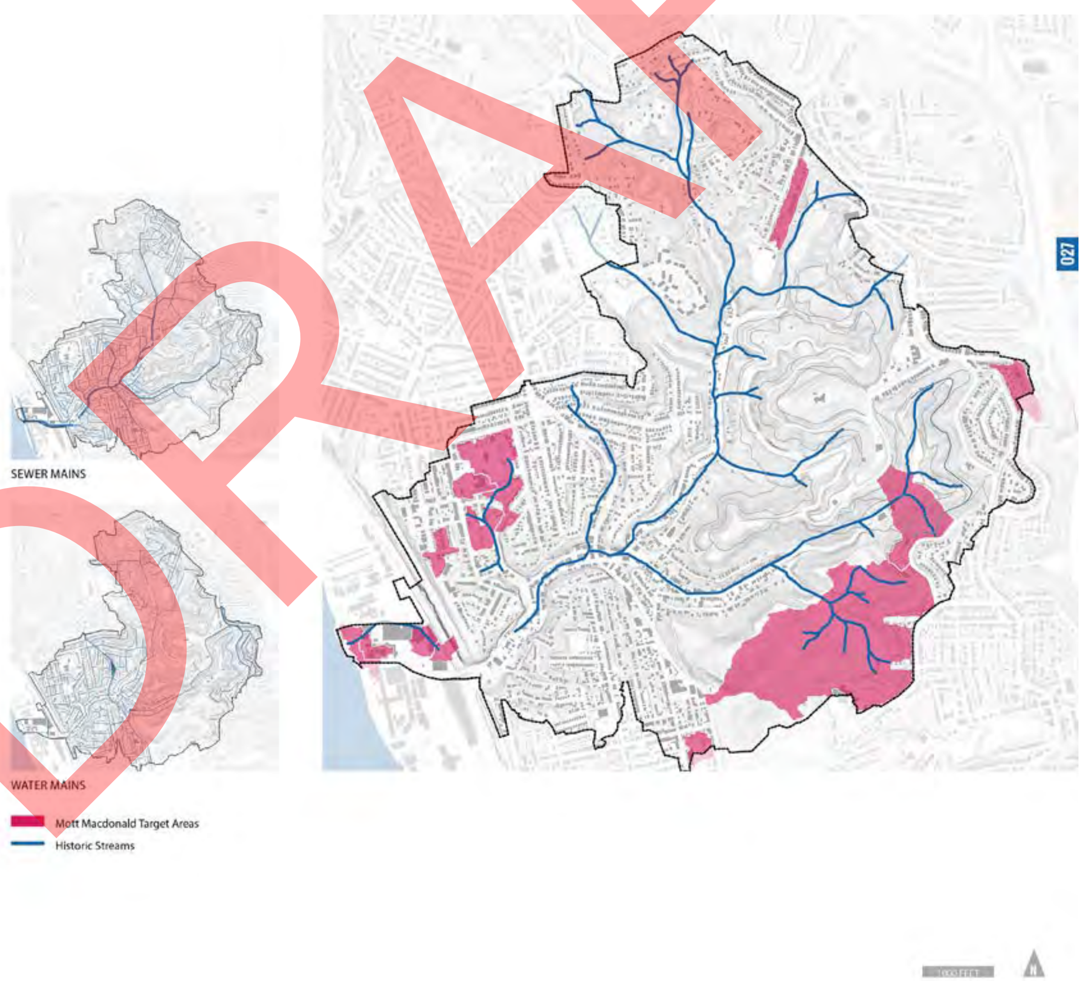


Figure 6-77

Stormwater from rainfall is the major driving force behind the geology of Pittsburgh. Recognizing where and how stormwater historically flowed can give us clues to where those flows want to occur today.

Today's sewer mains follow hydrologic flow lines very closely. Woods Run was once one of the largest streams in the City of Pittsburgh and had many tributary branches. Today's stormwater continues to flow in the sewer mains built along these original branches.

6.7.2 Urban Design Framework

The O27 sewershed is distinguished by the amount of green-space in the upper parts of the shed. Dramatically steep wooded slopes have constrained where development has been able to occur. Riverview Park, one of the largest public parks in the city and one of the oldest, has protected an additional 251 acres from development. Adjacent to the Park are several large cemeteries forming an ecologically contiguous green space.

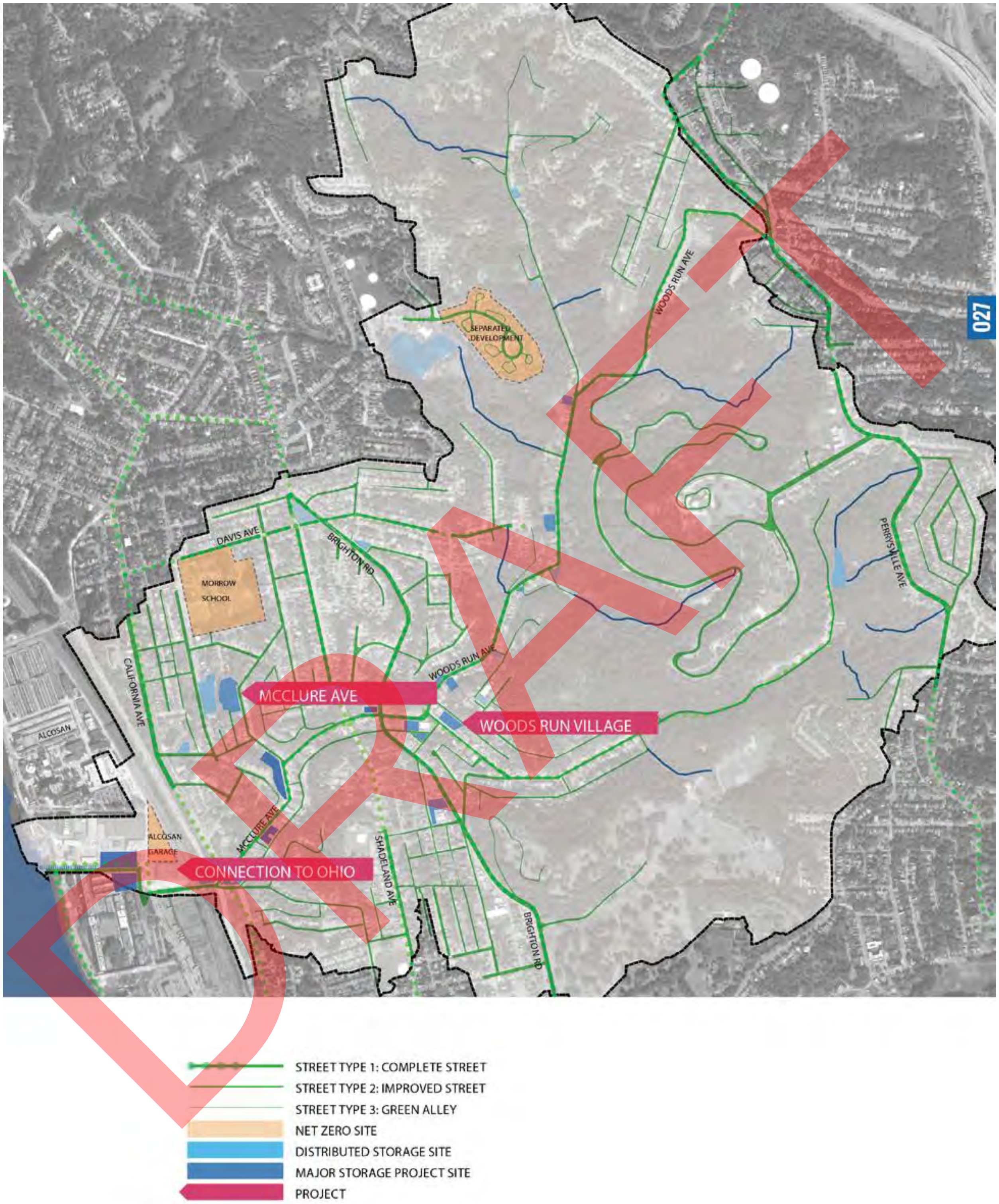

DAVIS AVE
MORROW SCHOOL
BRIGHTON RD
WOODS RUN AVE
SEPARATED DEVELOPMENT
PERRYSVILLE AVE
CALIFORNIA AVE
ALCOSAN
MCCLURE AVE
WOODS RUN VILLAGE
ALCOSAN GARAGE
CONNECTION TO OHIO
SHADELAND AVE
027
STREET TYPE 1: COMPLETE STREET
STREET TYPE 2: IMPROVED STREET
STREET TYPE 3: GREEN ALLEY
NET ZERO SITE
DISTRIBUTED STORAGE SITE
MAJOR STORAGE PROJECT SITE
PROJECT
DRAFT

Figure 6-78

The comparatively level hilltops to the west of the Park supported streetcar suburbs at Brighton Heights and Marshall-Shadeland. Major thoroughfares from downtown Pittsburgh to the Southeast reflect these original streetcar lines.

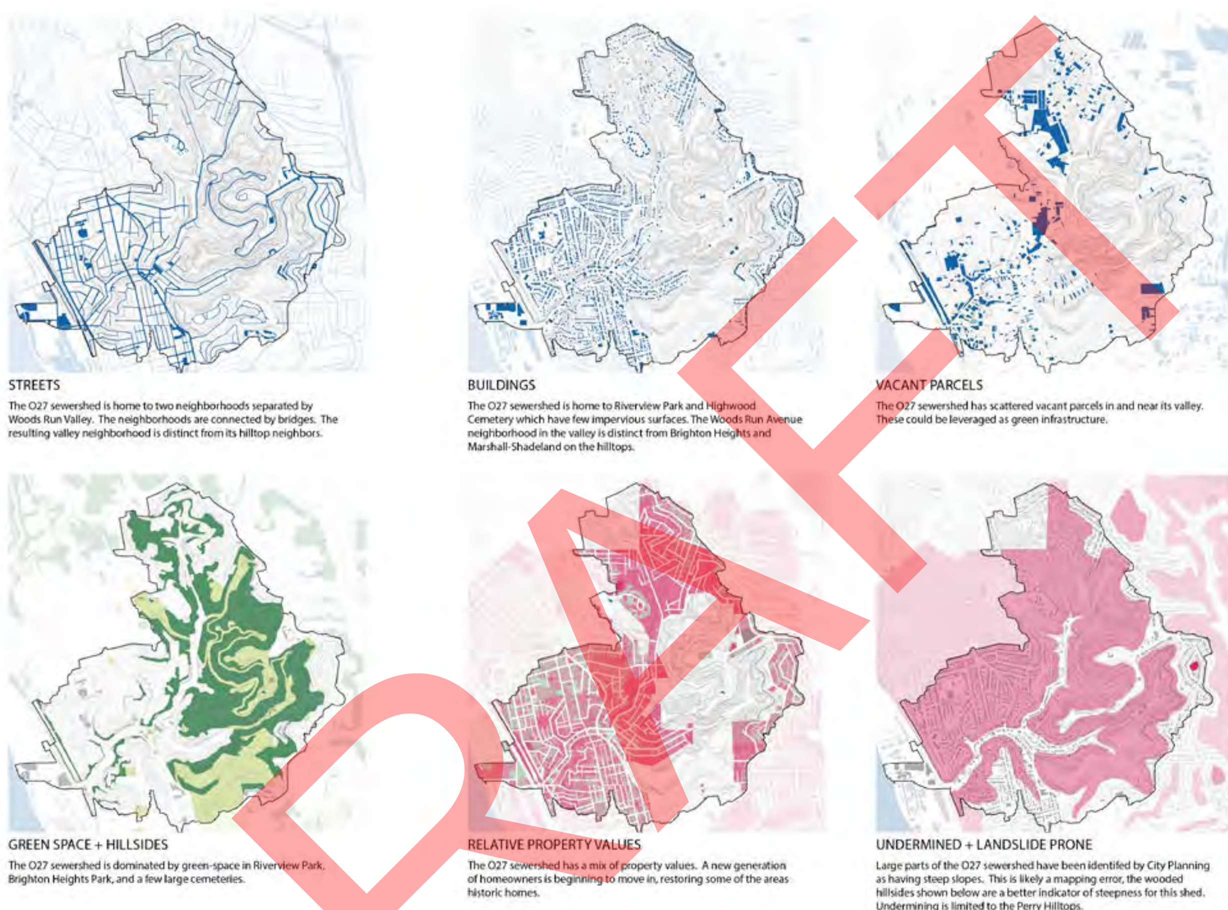


Figure 6-79

Understanding the unique urban fabric of a sewershed allows PWSA to identify potential synergies between infrastructure and communities. Better streets, better parks, better green-spaces, better hillsides, better homes, and better developments can all have positive ripple effects for people, planet, place, and performance.

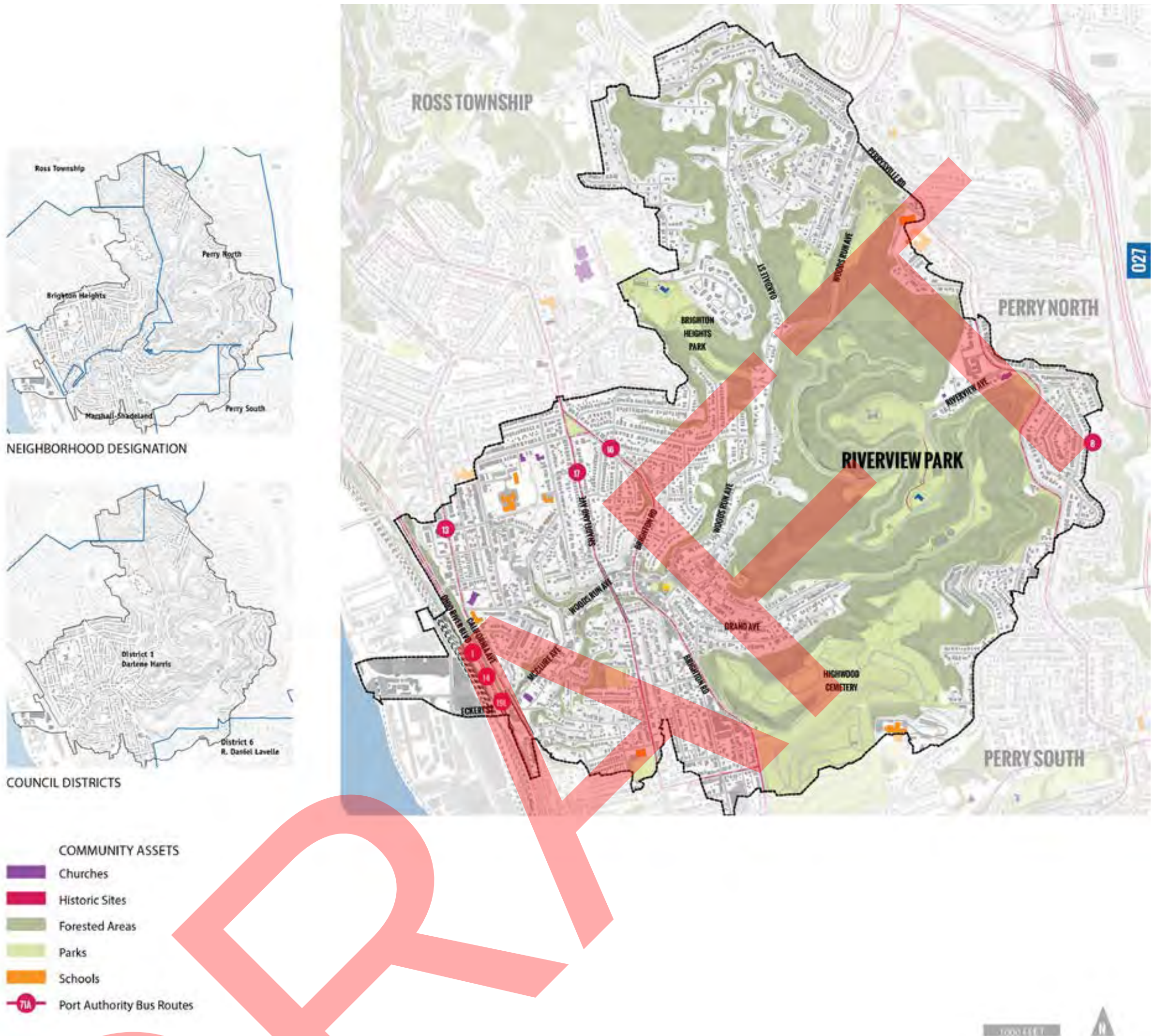

ROSS TOWNSHIP
PERRY NORTH
RIVERVIEW PARK
PERRY SOUTH
BRIGHTON HEIGHTS PARK
HIGHWOOD CEMETERY
NEIGHBORHOOD DESIGNATION
COUNCIL DISTRICTS
COMMUNITY ASSETS
Churches
Historic Sites
Forested Areas
Parks
Schools
Port Authority Bus Routes

Figure 6-80

CARNEGIE LIBRARY @ WOODS RUN
Source: Soracco Photography

CALIFORNIA AVE + OHIO RIVER BLVD BRIDGES OVER WOODS RUN VALLEY
Source: Microsoft Here Maps

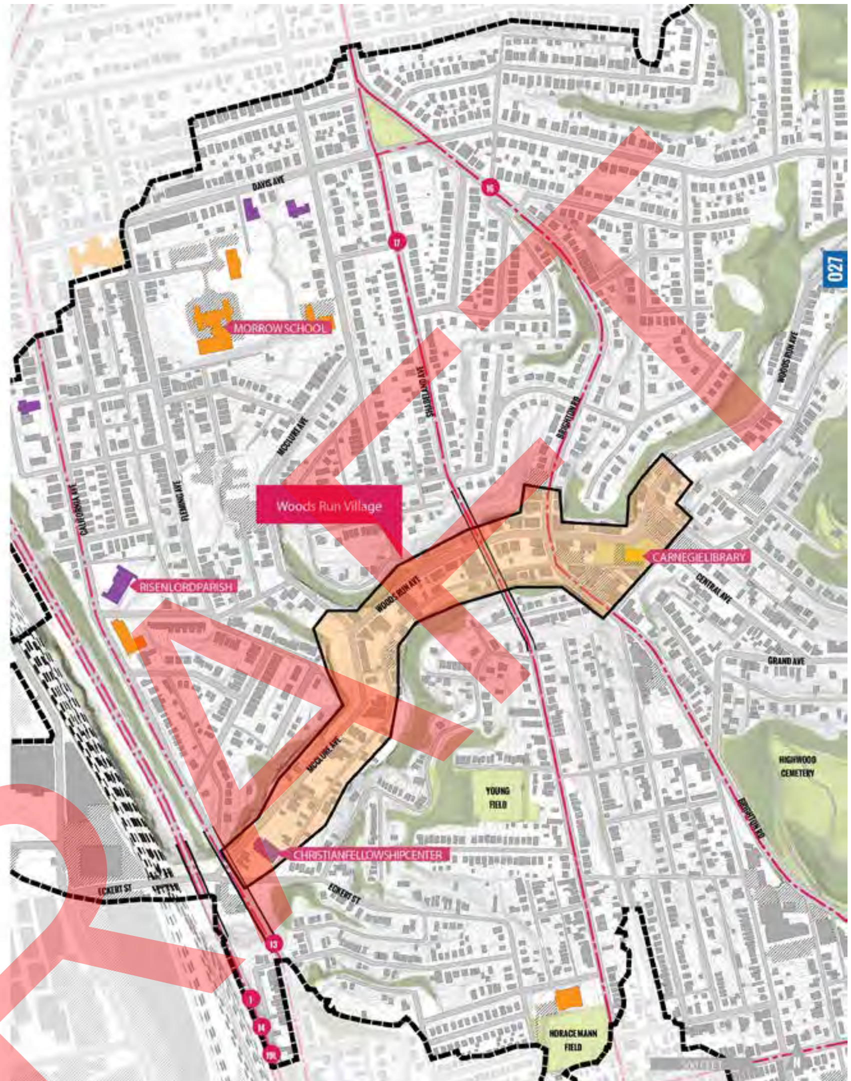


Figure 6-81

Connectivity between valley and hilltop is limited to McClure Avenue and Brighton Road. Three of the major thoroughfares from south to the north bridge over the valley at Shadeland Avenue, California Avenue, and Ohio River Boulevard. As a result, the valley of Woods Run is characteristically distinct from the hilltops of Brighton Heights and Marshall-Shadeland.

Though it does not have its own neighborhood designation, the Woods Run valley is a distinct community. The village center near the intersection of Brighton Road and Woods Run Avenue includes civic assets that could support an engaged and active community. A few storefronts form a neighborhood commercial center and the newly renovated Carnegie Library serves as the community focal point.

A series of vacant lots and green spaces could be integrated with green infrastructure to provide improved walkability between the library, playground, fire station, commercial storefronts, and the surrounding residential neighborhoods.

Lecky Avenue, parallel to Woods Run Avenue, could be converted to a green alley. Improvements to this alley, which carries the primary sewer main for O27, would enable a bikeable corridor from the Three Rivers Heritage Bike Trail to Riverview Park.

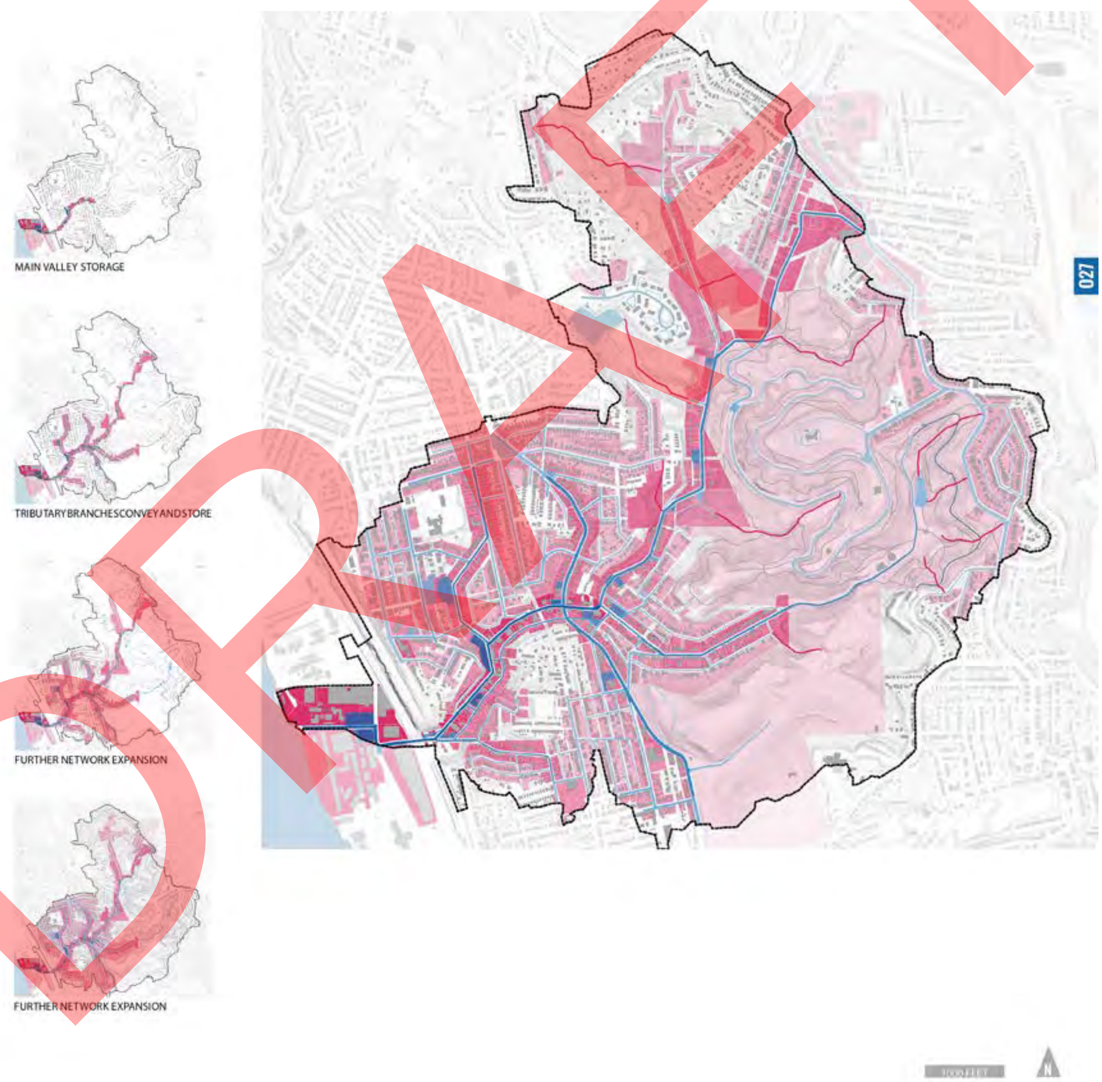


Figure 6-82

Green infrastructure works by restoring, mimicking, and supercharging natural hydrologic processes. Its deployment as a network needs to reconcile historical flows with modern land use. We studied the historical development of the city of Pittsburgh, and the impact of development on the city's topography.

An effective hydrologic network relies on an established hierarchy. The most critical pieces of green infrastructure need to be installed first and need to be scaled to anticipate further expansion of the green infrastructure network.

We identified "opportunity sites" throughout each priority sewershed that could both fulfill local stormwater infrastructure needs and support healthy communities and neighborhoods. The result is a hybridization between natural and man-made resource flows.

In O27, the storage infrastructure in the main valley and along tributary branches could allow for street improvements throughout the shed. As street improvements and detention sites come online, the network can be further expanded until every parcel is served by green infrastructure.

6.7.3 Woods Run Concept Plan

6.7.3.1 Woods Run Village

Four tributary branches of Woods Run converge at the core of the Woods Run Valley. Each branch carries with it a major road and the convergence of both rainwater and economic activity demands that investment in green stormwater infrastructure should reinforce the area as a civic center. Key elements such as a library, playground, and fire station are already in place.

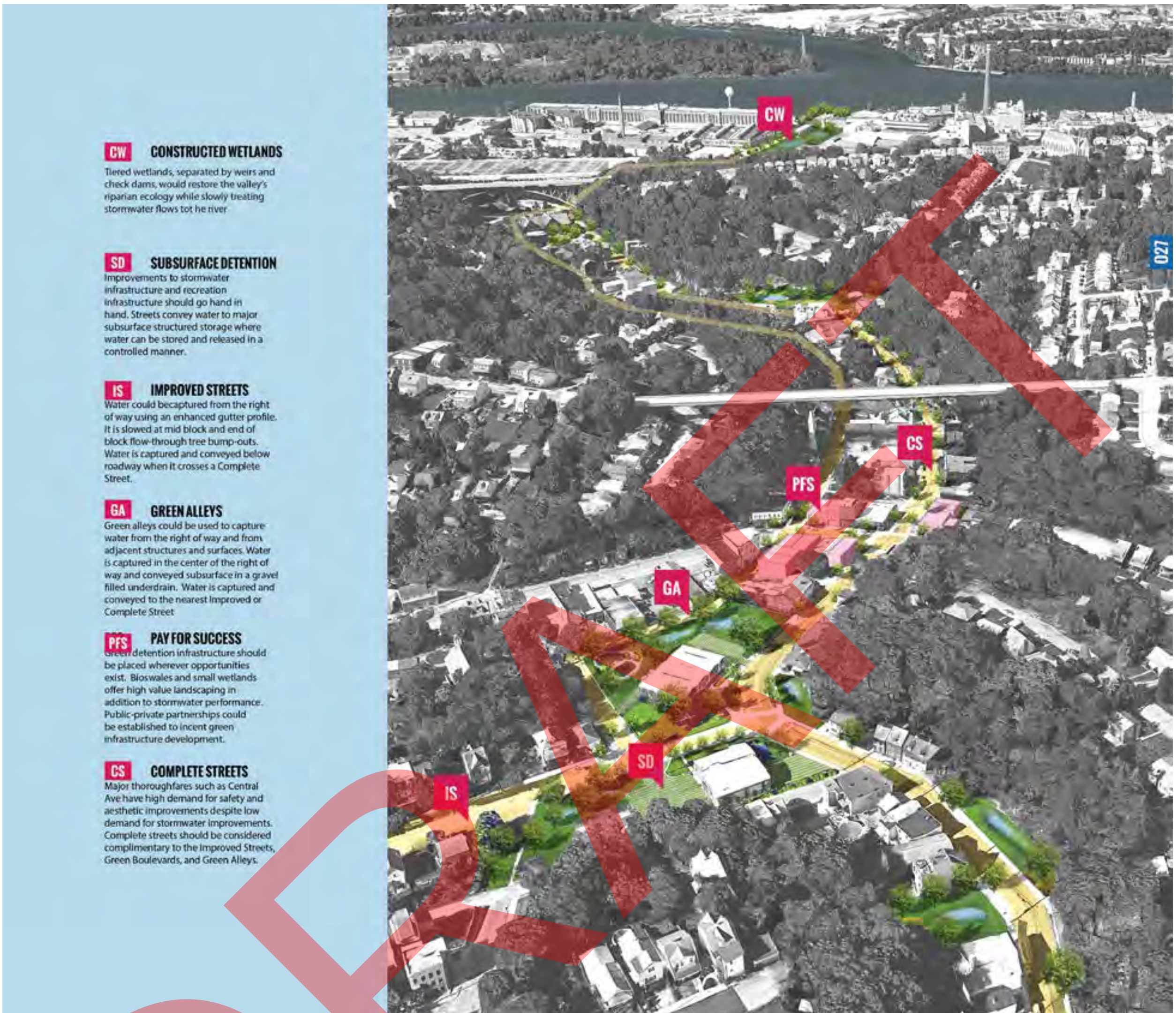


Figure 6-83

Pay for Success development opportunities could exist at the intersection of Brighton Road and Woods Run Avenue, reinforcing the intersection as a community focal point and taking advantage of access to transit.

Pedestrian and Bicycle routes through the area could establish a connection from the riverfront bicycle trail to Riverview Park.

Renovation of an existing playground and Library grounds could reinvigorate an already green village center. Vacation of a portion of Lecky Ave adjacent to the library could activate an inaccessible vacant parcel.

6.7.3.2 McClure Avenue Wilds

Figure 6-84

URA owned parcels at a key low point on McClure Avenue could detain stormwater flows from the surrounding Brighton Heights neighborhood as well as from the nearby Morrow School. The site, which is bisected by a 60" sewer main, could provide both stormwater performance and naturalized passive recreation areas.

6.7.3.3 Woods Run at the Ohio River

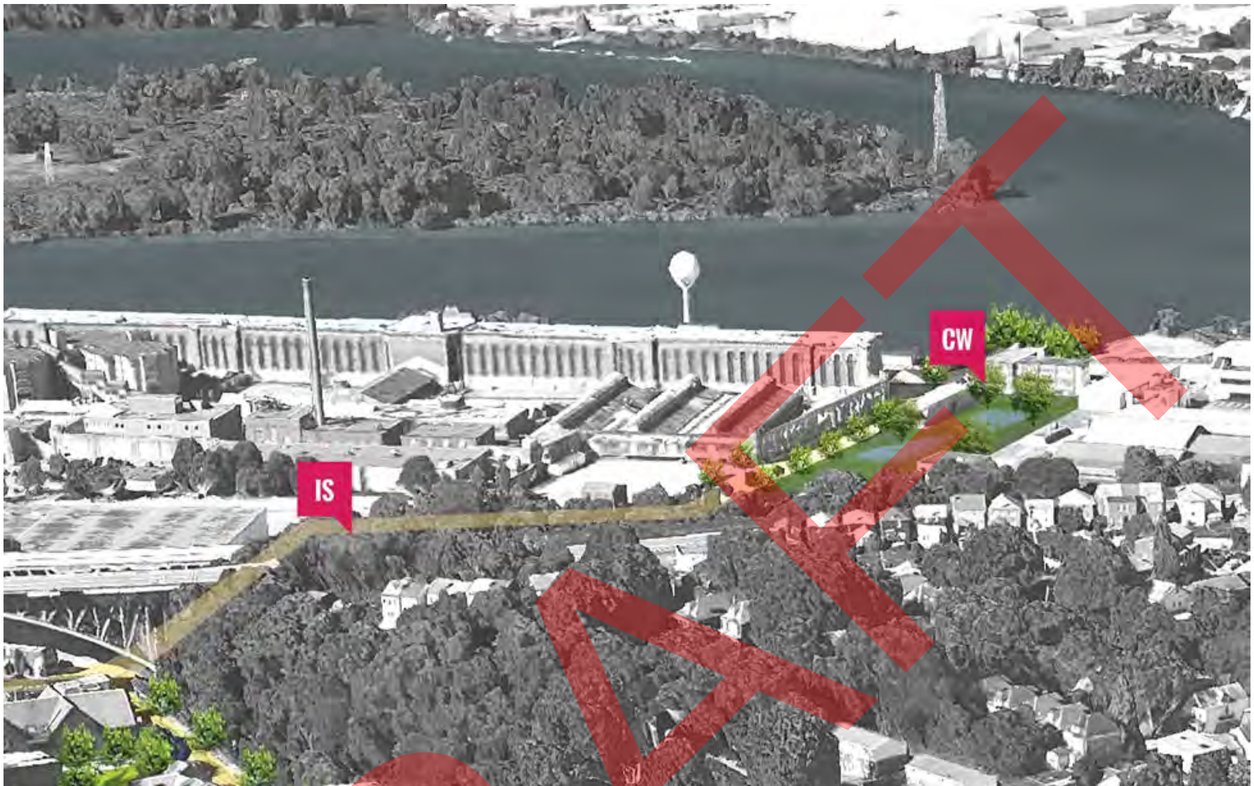


Figure 6-85

Highly industrialized since the steel town days, the Ohio Riverfront at Woods Run is almost entirely paved over or otherwise developed. Home to the Western State Penitentiary and ALCOSAN, this area is the uninspired industrial terminus to the Three Rivers Heritage Trail. Green Infrastructure could be used to soften the area's hard-scape while continuing the Three Rivers Heritage Trail upslope to Riverview Park.

6.8 Review: Integrated GI Approach and Meeting the Guiding Principles

The GI concepts and opportunities for each sewershed have unique nuances, however, the systems proposed achieve elements of the seven guiding principles defined at the beginning of the GI Assessment. Each system addresses:

- Cost Effective Public Realm Investments
- Create Workforce Development Opportunities
- Re-Establish Riverfront Connections
- Support Complete Streets Infrastructure Investment
- Focus on Healthy, Walkable Communities
- Implement Resilient Infrastructure
- People, Planet, Place, and Performance

They all offer investment in the public realm that is catalyst for redevelopment or enhances the existing vibrancy of each neighborhood. They improve the connectivity of community assets and encourage healthy, walkable places to live and work, and support Complete Streets infrastructure investment. Strategies are woven throughout that provide opportunity for workforce development. Riverfront connections are extended or enhanced in each system. Each meet guiding principles and creating a more resilient and sustainable Pittsburgh for People, Planet, Place, and Performance.

7. COST ESTIMATES DEVELOPMENT

This section describes the design, constructability, and costing protocols followed to develop capital costs and where applicable, operation and maintenance costs, for the green infrastructure (GI) best management practices (BMPs) and other associated gray infrastructure within the 30 high priority sewersheds and associated areas for the City-Wide GI Assessment.

7.1 Field Investigations, Constructability, and Costing Protocols

7.1.1 Green Infrastructure Cost Development

Green infrastructure BMP costs were developed using a detailed and itemized costing spreadsheet tracking the quantities and unit costs for each primary component of the BMPs. Costs were developed and compared to the equivalent cost per 1 acre of impervious surface managed for a reasonableness check. Construction costs without contingency were calculated to be $150,000 to $200,000 per acre of impervious area managed. Using the high end of this range, the base construction cost was selected to be $200,000 per impervious acre managed. These costs were compared to costs from other Mott MacDonald GI projects, costs from other communities implementing GI programs, as well as ALCOSAN's Starting at the Source (August 2015) and the GI and source control report, and found to be in-line with those reported costs. Additional contingencies were added to these construction costs to establish overall capital costs as shown in Table 7-1. Applying these contingencies, the low range cost was set at $324,000 per acre and the high range cost was set at $432,000 per acre.

TABLE 7-1
CONTINGENCIES FACTORS

Planning Level Cost Contingencies	Percentage
Construction	25%
Engineering (Planning, Design & CA services)	20%
Overall Project	20%
Class 4 Cost Estimate Range	+20% to -10%

To provide greater confidence in the installation costs and constructability for the GI BMPs, as part of the Shadyside/A-22 Sewershed Flooding Solutions & Green Infrastructure Assessment Project, the project team worked with PWSA and MM to perform field investigations of several of the high yield catch basin drainage areas. The field investigations identified local site scale BMPs that could be implemented to potentially achieve the required capture volumes. These BMPs were determined based on the available area, amount of stormwater tributary to the location, and type most suitable for the specific locations. Planning level costs were then developed for the site scale BMPs. The site scale BMP costs were then averaged to develop an overall average cost of GI per impervious acre managed. This approach provided further confirmation for using overall costs of $324,000 - $432,000 on average per impervious acre managed.

These assumptions are conservative based on the planning level assumptions for the cost estimates. In addition, because of the planning level nature of the cost estimates, a cost range was developed and provided for the GI alternatives based on the estimated overall capital costs.

It should also be noted that the costs for GI included in this report assume 100% is paid by the ratepayers and not offset by the likely benefits of cost-sharing with new development and redevelopment. As the appropriate ordinances are developed and enacted for managing stormwater runoff from new development and redevelopment within the City, the public costs for GI may be reduced. These anticipated mechanisms will ensure that new development and redevelopment will share in a portion of the costs of GI in the City, which may reduce the costs to the ratepayers, while also allowing the new development and redevelopment to realize the triple bottom line benefits associated with GI (discussed in Section 8 of this report) beyond CSO reduction and basement sewage backups.

For example, ALCOSAN's Starting at the Source Report (August 2015) states the following:

> *Redevelopment is assumed to affect 0.3% of impervious cover per year over the course of the WWP implementation (through 2046). At this redevelopment rate, runoff from approximately 10% of the impervious cover in the combined sewered area would be managed through stormwater ordinance driven GSI* [Green Stormwater Infrastructure] *at a rough order-of-magnitude value to the rate payers of $370 million."* (Page 3-32)

Using this analysis, private development GI could account for 1,110 impervious acres of privately provided GI through 2046, representing a potential cost reduction of $420 million for the ratepayers (based on an average capital cost per impervious acre of $378,000). Over 10 years, the potential cost reduction could be approximately $140 million for the ratepayers assuming a linear redevelopment rate of 0.3% per year.

7.1.2 Private Infiltration/Inflow Removal Disconnection Program

As discussed in Section 3 of this report, the GI analysis included identifying high yield drainage areas tributary to mapped catch basin inlets. These high yield drainage areas include both public and private sources of stormwater. To provide the significant benefits of managing stormwater to reduce CSO, surface flooding, and basement sewage backups, strategic cost-effective disconnection of private property drainage is recommended. The GI cost-basis described in Section 7.1.1 includes a factor for stormwater runoff from private impervious surfaces. While the overall capital cost range for GI of $324,000 - $432,000 per impervious acre managed was conservatively estimated to also include strategic cost-effective disconnection of private drainage in the locations of BMPs, it was decided to explicitly include a separate line item cost for downspout disconnections in the combined sewersheds to add additional conservatism to the GI costs.

To estimate the downspout disconnections cost, several sources were evaluated, including:

- A literature review was performed of the various utilities currently conducting downspout disconnection programs, including the Water Environment Federation (WEF) Private Property Library
- Mott MacDonald's experience with private source projects in other communities
- The 3RWW/ALCOSAN Alternatives Costing Tool (ACT) extension for private property infiltration/inflow (I/I) disconnections

Figure 7-1 provides an excerpt from 3RWW / ALCOSAN ACT extension, which includes four technologies for private source removal, based on 2010 costs.

Based on this information, an average cost estimate of $3,000 per property was used for downspout (exterior roof leader) disconnections where the downspouts are either routed to a right-of-way BMP or disconnected on the property where an adequate discharge location exists. It is anticipated that only cost-effective downspout disconnections falling within this average cost range would be performed. If areas with more expensive downspout disconnections on average were encountered then those locations would be re-examined and other more cost-effective areas for impervious surface runoff capture would be identified.

C3 Private Inflow and Infiltration Removal

Table C-4 – Private I/I Removal Unit Costs

Technology	Default Unit Cost	Units	User Defined Unit Cost Option?	O&M Cost Estimate
Sump Pump Discharge Rerouting	$4700	Per sump pump rerouting	Yes	User to input a lump sum value for all Private I/I reduction alternatives where applicable
Footing Drain Disconnection	$8000	Per disconnection	Yes	
Exterior Roof Leader Disconnection	$20	Per homeowner disconnection	Yes	
	$70	Per municipality disconnection		
Private Drain Disconnection	$600	Per drain disconnection	Yes	

ACT User Reference Manual

Exterior Roof Leader Disconnect

For buildings where roof leaders are tied into the footing drains and make their way to the sanitary lateral, this work includes disconnecting (cutting) the down pipe and providing a discharge to the ground for homes or other establishments with an adequate discharge location and where local codes permit. Basin planners will need to specify the estimated number of roof leaders to be disconnected, and whether the work will be performed by the homeowner or municipality. The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Private Drain Disconnection

This work includes sealing the connection from a driveway drain or other private storm drain to a sanitary sewer. It also includes re-routing the drain line to an existing storm outlet or constructing a new drain outlet. The basin planners will need to specify the estimated number of drains to remove and the total length of new storm sewer required. Based on these assumptions, a default unit cost is applied ($600 per disconnection). The user has the ability to change this unit cost, but must provide acceptable documentation of the basis of cost.

Figure 7-1: Excerpt from 3RWW / ALCOSAN Costing Tool: Private Source Removal

7.1.3 Gray Infrastructure Component Cost Development

The team conducted field investigations to evaluate and develop costs for each of the flooding hazard locations, direct stream inflow locations, and urban planning areas identified in this study. The cost development included, in some cases, the use of storm sewer piping, underground detention coupled with surface level GI, junction boxes, manholes, etc. to manage the associated stormwater and base flows.

The ALCOSAN ACT tool was used to develop costs for these elements. The ACT tool is a widely used planning level cost estimating template based on local and regional data.

The tool was reviewed, found to provide detailed and comprehensive project costs, and the cost assumptions are reasonable as compared with other similar project cost estimates. The ACT tool has the ability to estimate a wide range of gray infrastructure cost elements. Assumptions were made where applicable for number of utility crossings, spacing of manholes, depth of installations, and number of service laterals encountered with the proposed construction. In cases where the ACT tool did not include the needed cost elements, local costs were obtained. Appendix E provides more detail, including the cost estimate tables. The contingencies added to develop overall capital costs are listed in Table 7-1. Where more uncertainty existed with the planning level cost estimates for the stream daylighting locations, a larger construction cost contingency of 40% was used.

An example cost estimate for the Spring Garden detention and stream daylighting that used a combination of ALCOSAN ACT tool data and local cost data is provided in Figure 7-2. The example estimate contains the quantities and unit costs for the primary project component line items. The unit bid prices for each item of work were obtained from a range of sources, including the Allegheny County Assessment, ACT Tool, RS Means, and recent bid tabulations from PWSA projects. Planning level contingencies were added, as appropriate, to account for project unknowns.

7.2 Green Infrastructure Operation & Maintenance Cost Development

As with all assets, routine maintenance is necessary to operate at the designed level of service, and prevent or limit excessive repairs. GI BMPs are no different. In fact, the industry often speaks about the lack of sufficient asset management of the aging sewer and water lines within our communities and the deferred maintenance and lack of funding. GI maintenance may look and feel different than what most sewer and water utilities area accustomed to doing. GI should be considered no different than a sewer or water line in terms of the need for funding and performance of maintenance.

As the Philadelphia Water Department and other cities with GI programs have demonstrated, partnerships with other city departments, local neighbors, and competitive bidding of maintenance contracts may offset and lower costs for GI maintenance. In addition, the creation of a local labor force from the currently unemployed for GI maintenance is being demonstrated in Philadelphia, Pennsylvania; Washington, DC; and Columbus, Ohio, among other cities. The maintenance work is similar to landscaping work, which can be easily taught and trained, also opening the opportunities for new business development within Pittsburgh and Allegheny County.

Sring Garden Solution: Detention Pond & Small Diameter Daylighting Pipe To River						
Control Level: 2.2 MG Storage						
Items of Work	**Approx. Quantity**	**UOM**	**Unit Bid Price**		**Total**	**Assumptions / Costs**
Land Acquisition	1	EA	$	312,500	$ 313,000	Costs from Allegheny County Assessment 2016 full market value cost figures with a 25% markup.
Mobilization, Demobilization, and Field Office	1	LS	$	268,700	$ 269,000	5% of the total construction cost.
Field Survey and Engineering	1	LS	$	11,240	$ 12,000	2% of the total construction cost.
Erosion and Sediment Control	1	LS	$	11,240	$ 12,000	2% of the total construction cost.
Grading	5,856	SY	$	5	$ 27,000	1.1 Acre grading with 10% additional added. Costing figure from RS Means estimating data.
Engineered Soil Media & Gravel	3,550	CY	$	60	$ 213,000	1.1 Acre detention area sub base at 2' depth . Cost figure from recent GI projects.
8" PVC SDR-26 Sewer Pipe, Less than 15' Deep	500	LF	$	125	$ 63,000	Installed pipe costs from recent bid tabs.
Excavation 0-15' Deep	16,000	CY	$	9	$ 144,000	From RS Means Item 312316130500 "excavation with no sheeting or dewatering." Costs range from $3.09 per CY to $8.66 per CY depending on the excavator size with a 2-1/2 CY excavator as the lowest cost and 0.75 CY excavator as the high cost. Excavation based on the storage footprint, taking into account 15' excavation depth.
Vegetation	30,000	SF	$	3	$ 90,000	Costs from recent, similar projects.
Rock and Obstruction Excavation - All Depths	500	CY	$	25	$ 13,000	Costs from recent PWSA bid tabs.
Outlet Structure	1	EA	$	3,000	$ 3,000	Estimate based on comparable structure costs.
Overflow Structure	1	EA	$	8,500	$ 9,000	Estimate based on comparable structure costs.
Small diameter storm daylight pipe 8"-12"	10,970	LF	$	347	$ 3,807,000	$3,809,162 current year probable construction cost from ACT tool. Sizing from modeling detention & release (5511' in 8", 4540' in 12"). Assumes utility crossing every 50', manholes every 300', 75% of length in street/25% in sidewalk.
Pipe Tunnel Boring Under Rt. 28	300	LF	$	3,211	$ 964,000	$963,158 current year probable construction cost from ACT tool.
Maintenance Traffic Protection	1	LS	$	16,860	$ 17,000	3% of the total construction cost.
			Subtotal		$ 5,956,000.00	
Planning Level Construction Contingency			40%		$2,383,000	
Engineering (Planning, Design, & CA Services)			20%		$1,192,000	
Project Contingency			20%		$1,192,000	
			Total:		$10,723,000	

Figure 7-2: Example Cost Estimate for Gray Infrastructure Components of Spring Garden Detention and Stream Daylighting

To develop operation and maintenance costs for the GI identified as part of the City-Wide GI Assessment, the following primary sources were reviewed:

- *Water Environment Research Foundation's User's Guide to the BMP and LID Whole Life Cost Models* (Lampe et al., 2005). Spreadsheet tools to help users identify and combine capital costs and ongoing maintenance expenditures to estimate whole life costs for stormwater management. The models provide a framework for calculating capital and long-term maintenance costs of individual best management practices and low-impact development techniques.

- *Green Infrastructure Implementation*, WEF Special Publication, 2014. This source summarizes staff hours and typical annual O&M costs as a percent of construction, obtained from multiple programs, including EPA research, across the country.
- *Philadelphia Water Department Long Term Control Plan Update, Basis of Cost Opinions,* 2009 – GI O&M costs development. This source provides bottom-up cost estimates and equivalent percentages of construction cost for the necessary maintenance activities for various types of GI.
- *The Importance of Operation and Maintenance for the Long-Term Success of Green Infrastructure – USEPA,* 2013. The report examines the O&M practices of 22 green infrastructure projects funded by the American Recovery and Reinvestment Act Clean Water State Revolving Fund, and highlights both the opportunities and challenges associated with green infrastructure O&M.
- *Green Infrastructure Cost-Benefit Resources – USEPA website.* This resource provides links to findings from other communities demonstrating realized cost savings through their green infrastructure programs, as well as available tools to inform cost-benefit analysis.

Based on these resources, Mott MacDonald's experience on other projects, and the local knowledge from 3RWW and PWSA, the primary maintenance tasks, frequencies, and the estimated hours are in Table 7-2. Associated O&M costs were also developed. Table 7-3 gives an annualized O&M cost estimate per impervious acre managed for three types of GI BMPs.

TABLE 7-2
PRIMARY GI BMPs MAINTENANCE TASKS, FREQUENCY, AND ESTIMATED ANNUAL HOURS

Primary GI BMPs Maintenance Tasks	Frequency	Total Hours Per Year per Impervious Acre
▪ For the first 6 months following construction, the BMP should be inspected at least twice after storm events that exceed 1/2 inch of rainfall to confirm draining and no excessive erosion. Conduct any needed repairs or stabilization. ▪ Bare or eroding areas in the BMP area should be stabilized with appropriate cover. ▪ One-time, spot fertilization may be needed for initial plantings. ▪ Watering is needed once a week during the first 2 months, and then as needed during first growing season (April-October), depending on rainfall. ▪ Remove and replace dead plants. Up to 10% of the plant stock may die off in the first year, so construction contracts should include a Care and Replacement Warranty to ensure that vegetation is properly established and survives during the first growing season following construction.	Upon establishment	6
▪ Check curb cuts and inlets and remove accumulated grit, leaves, and debris that may block inflow.	At least 4 times a year	8
▪ Spot weeding, trash removal, and mulch raking.	Twice during growing season	4
▪ Add reinforcement planting to maintain desired vegetation density. ▪ Remove invasive plants using recommended control methods. ▪ Remove any dead or diseased plants.	As needed	4
▪ Inspect underdrain at Year 1. ▪ Verify drain-out time at Year 1. ▪ Supplement mulch in devoid areas to maintain a 2 inch layer. ▪ Prune trees and shrubs. ▪ Remove sediment in pre-treatment cells and inflow points. ▪ For permeable pavement, vacuum porous asphalt or concrete surface with commercial cleaning unit.	Annual	4
▪ Remove and replace the mulch layer ▪ Inspect underdrain. Clean if required.	Once every 2-3 years	4
▪ Remove and replace soil media.	Once every 8-10 years depending on loading	8
Estimated Total per Year		38

TABLE 7-3 ANNUALIZED O&M COSTS FOR GI BMPs	
Type of GI BMP	**Annualized O&M Costs ($ per Impervious Acre Managed per Year)**
Porous Pavement	$3,000
Stormwater Tree Trenches	$3,600
Bioretention	$4,000

These annualized O&M costs are between 2% to 3% of the developed GI construction cost of $150,000 - $200,000 per impervious acre managed. These costs were carried forward to develop Net Present Value O&M costs for the 480 MGD WWTP Expansion scenario (with GI implementation of 1,835 impervious acres managed in 18 sewersheds) and the Lowered HGL Operation During Wet Weather Conditions scenario (with GI implementation of 1,286 impervious acres managed in 13 sewersheds). An overhaul of the GI BMPs was assumed to be needed on average every 25 years, so a replacement cost at year 25 was included in the Net Present Value O&M Cost analysis.

Long term replacement costs assume significant work is required to restore the functionality of the GI BMPs. At approximately the 25 year mark, excess sedimentation buildup may require replacement of the infiltration soil layers, and geotextile fabric around the storage layer. For example, for bioretention with subsurface storage, this would include excavating the top mulch layer, along with the engineered soil. Excavation around the sides of the storage layer would be required as well to allow for the replacement of geotextile fabric around the sides and top of the storage layer. Rebuilding the BMP includes work items related to aggregate and engineered soil backfill, mulch replacement, plantings, shrubs, and the replacement of rip rap aprons and check dams / berms if used. Table 7-4 provides an example summary of the unit cost items and associated costs for replacement work for a typical bioretention installation. For a typical set of GI BMP installations managing one impervious acre from a residential neighborhood, the 25-year cost estimate to replace the functional layers of each BMP was estimated to be $36,400 in 2016 year dollars. This cost includes a 10% contingency as a factor for unknowns.

TABLE 7-4
ESTIMATED REPLACEMENT COSTS AT YEAR 25 FOR TYPICAL GI BMPs, 1 ACRE OF MANAGED IMPERVIOUS SURFACE, FOR NET PRESENT VALUE COST ESTIMATING

Task	Quantity of Work	Unit	Unit Cost	Cost
Remove & set aside rip rap aprons / check dam / berms	16	HR	$34.00	$544
Excavate/Remove Plantings and Mulch	16	CY	$40.00	$640
Excavate Engineered Soil Layer, and aggregate backfill on sides of Modular storage	166	CY	$40.00	$6,640
Replace geotextile around sides and top of storage layer	470	SY	$6.00	$2,820
Replace aggregate on side of modular storage	56	CY	$45.00	$2,520
Amend Soil & Replace engineered soil in Trench	166	CY	$45.00	$7,470
Install 2" thick layer of mulch	16	CY	$45.00	$720
Install New Plantings / Shrubs	400	EA	$28.00	$11,200
Re-install rip rap apron / check dam/ berms	16	HR	$34.00	$544
			Subtotal	$33,100
			Total Including 10% Contingency	$36,400

Using the developed operation and maintenance costs, Net Present Value O&M costs were projected over periods of both 25 and 50 years, based on routine maintenance as well as significant replacement work at year 25. An inflation rate of 3.5% and a discount rate of 6% per year were assumed, consistent with Engineering News-Record (ENR) indices. Total construction costs for retrofitting for the Free Outfall scenario with GI in 13 sewersheds (1,286 impervious acres managed) and the 480 MGD (WWTP capacity) scenario with GI in 18 sewersheds (1,835 impervious acres managed) retrofitted scenarios were distributed evenly over the first 10 years, assuming complete build-out of the GI BMPs by year 10. Results are provided in Table 7-5.

TABLE 7-5 25 AND 50 YEAR NET PRESENT VALUE GI O&M COSTS FOR TWO CITY-WIDE GI SCENARIOS (NET PRESENT VALUE)		
Year	**Lowered HGL Operation During Wet Weather Conditions Scenario** **GI in 13 sewersheds** **1,286 Impervious Acres Managed**	**480 MGD WWTP Expansion Scenario** **GI in 18 sewersheds** **1,835 Impervious Acres Managed**
25	$106,900,000	$153,000,000
50	$202,000,000	$288,000,000

Table 7-6 provides the annual O&M costs required during the first 10 years as the GI BMPs are being constructed for either the Free Outfall scenario for GI in 13 sewersheds (1,286 impervious acres managed) or the 480 MGD (WWTP capacity) scenario for GI in 18 sewersheds (1,835 impervious acres managed). An even build-out over 10 years was assumed. The "Net Present Value" column lists the projected costs throughout the first 10 years in present value 2016 dollars. The "Future Cost" column, shows the future year estimated O&M cost required in that year.

Anticipated staffing requirements to complete the O&M tasks outlined in Table 7-2 for each retrofit scenario were also estimated. Table 7-7 outlines the projected staffing requirements during years 1 through 10. The costs assume an average of 38 hours of O&M per impervious acre of GI per year as listed in Table 7-2. To account for vacation, sick time and training, 1,920 hours of labor per year was assumed per staff person.

Table 7-7 indicates that at Year 1 the GI BMPs could be operated and maintained with a staff of 2 to 3 people at an approximate annual cost of $700,000 - $1 million depending on the selected GI scenario. A GI program built out over 10 years would create 17 to 25 new O&M jobs depending on the selected GI scenario. These O&M jobs do not include the associated potential new jobs from material supply and construction.

TABLE 7-6
O&M COSTS NET PRESENT VALUE OVER 10-YEAR GI BUILD-OUT PERIOD FOR TWO CITY-WIDE GI SCENARIOS

Year	Lowered HGL Operation During Wet Weather Conditions Scenario GI in13 sewersheds 1,286 Impervious Acres Managed		480 MGD WWTP Expansion Scenario 18 sewersheds 1,835 Impervious Acres Managed	
	Future Cost	Net Present Value (2016 Dollars)	Future Cost	Net Present Value (2016 Dollars)
1	----	$703,000	----	$1,000,000
2	$1,400,000	$1,400,000	$2,100,000	$2,000,000
3	$2,300,000	$2,000,000	$3,200,000	$2,900,000
4	$3,100,000	$2,600,000	$4,500,000	$3,700,000
5	$4,000,000	$3,200,000	$5,800,000	$4,600,000
6	$5,000,000	$3,700,000	$7,200,000	$5,300,000
7	$6,100,000	$4,300,000	$8,600,000	$6,000,000
8	$7,200,000	$4,800,000	$10,200,000	$6,800,000
9	$8,300,000	$5,200,000	$11,900,000	$7,500,000
10	$9,600,000	$5,700,000	$13,700,000	$8,100,000

TABLE 7-7 GI O&M STAFF REQUIREMENTS OVER 10-YEAR GI BUILD-OUT PERIOD			
Year	**Lowered HGL Operation During Wet Weather Conditions Scenario:** **GI in 13 sewersheds** **1,286 Impervious Acres Managed (Cumulative Acres per Year)**	**480 MGD (WWTP Expansion)Scenario:** **GI in 18 sewersheds** **1,835 Impervious Acres Managed (Cumulative Acres per Year)**	**Range of Required Employees**
1	129	184	2 to 3
2	257	367	4 to 5
3	386	551	6 to 8
4	514	734	7 to 10
5	643	918	9 to 13
6	772	1,101	11 to 15
7	900	1,285	12 to 18
8	1,029	1,468	14 to 20
9	1,157	1,652	16 to 23
10	1,286	1,835	17 to 25

7.3 Green Infrastructure Learning Curve and Effects on Costs

Throughout the implementation of the region's wet weather plans, Stormwater Act 167 requirements, and overall Clean Water Act requirements, the cost of GI BMPs is expected to decline for a number of reasons. The projected cost reductions are credited to improvements in site layouts, reduction in design costs, a reduction in the cost for materials, and reductions in perceived construction risk as incorporating GI into our streets, parking lots, buildings, and homes become the "standard" method of doing business. Communities have spent the last century learning how to remove "nature" – plants, grass, trees, porous soils – from our cities and urban landscapes, and instead have now learned that "nature" is needed in order to prosper, be healthy, and create livable, resilient, and sustainable communities. Therefore, it is not surprising that it will take some time to learn how to re-incorporate nature back into our urban City. As our learning curve improves on building "nature" back into our communities, the associated costs of GI will decrease.

Better Site Design: Site designers currently have limited requirements to manage stormwater within the City and these stormwater requirements are often added as an afterthought to the traditional site design. As stormwater regulations are updated in the City to address CSO reduction, surface flooding reduction, and basement sewage backups reduction, site designers will adopt improved site design techniques. These techniques on average can reduce impervious area on each site by 20% or more compared to the current site designs. Several cities across the country have already implemented similar impervious area reduction requirements for new development and redevelopment to reduce costs.

Reductions in Design and Construction Administration Costs: Because GI BMP designs are just starting to be understood by many local engineers and PWSA has not yet developed standard BMP details that can be used as "plug & play" for retrofit designs, design and construction administration and inspection costs are currently high relative to total construction cost. These design and construction-related costs are estimated to be reduced by 5% - 10% compared to current costs, as GI design and construction standards are developed, adopted, and become familiar to users in this region.

Reductions in Material Cost: As GI technologies, such as porous pavement, bioretention, and tree trenches, are incorporated into street reconstruction and renewal projects more frequently, materials needed to build them will no longer be considered specialty materials. For example, porous pavement is currently estimated at $12 per square foot in the Pittsburgh region. In Kansas City and New Orleans where porous pavement has been used on several projects and local suppliers have been trained, costs are about $7.50 per square foot. In the future, as these materials become standard in our region, unit costs may be reduced.

Reductions in Perceived Construction Risk: As GI is incorporated into street reconstruction and renewal projects and new development and redevelopment projects across the City, GI will become the standard method of doing business. Local contractors will learn the techniques to efficiently install the various BMPs, and, construction costs may be reduced. Current GI cost estimates include both a 25% construction contingency and a 20% overall project contingency to account for these perceived risks. These cost contingencies may be reduced by 50% or more over time due to the lowered risk and lower contractor costs.

Reductions in O&M Costs: As GI is incorporated into the urban landscape, the associated O&M costs are expected to become more predictable and efficiencies in maintenance and BMP designs will result in lower overall O&M costs. In addition, if O&M work will be done by a contractor, competitively bid contracts will drive down O&M costs. O&M cost reductions of 10% - 30% may occur, depending on the type of BMPs and associated frequency of O&M required, influenced by stormwater and pollutant loads.

To remain conservative in the overall GI costs developed for the City-Wide GI Assessment, these potential cost reduction efficiencies in materials, construction costs, design costs, O&M costs, and contingencies are not included in the cost estimates for the GI scenarios.

In addition to learning curves that may reduce GI costs, GI also can provide numerous social, economic, and environmental benefits. Section 8 of this report identifies and discusses these associated "Triple Bottom Line" benefits for the analyzed GI scenarios.

8. TRIPLE BOTTOM LINE ANALYSIS

The word "sustainability" is commonly described with the term "3P", which means Planet, People, and Prosperity. Instead of focusing solely on the direct financial impacts of a project, applying a triple bottom line (TBL) analysis adds considerations for environmental and social equity factors to the overall decision-making. Quantifying the environmental and social benefits of a project can be complex, and there is no "one-size-fits-all" approach to apply in all cases. However, applying a TBL approach can result in more holistic, and presumably better, decisions. Figure 8-1 shows the overlapping aspects of the broad categories of environmental, economic, and social benefits and how they converge on sustainability.

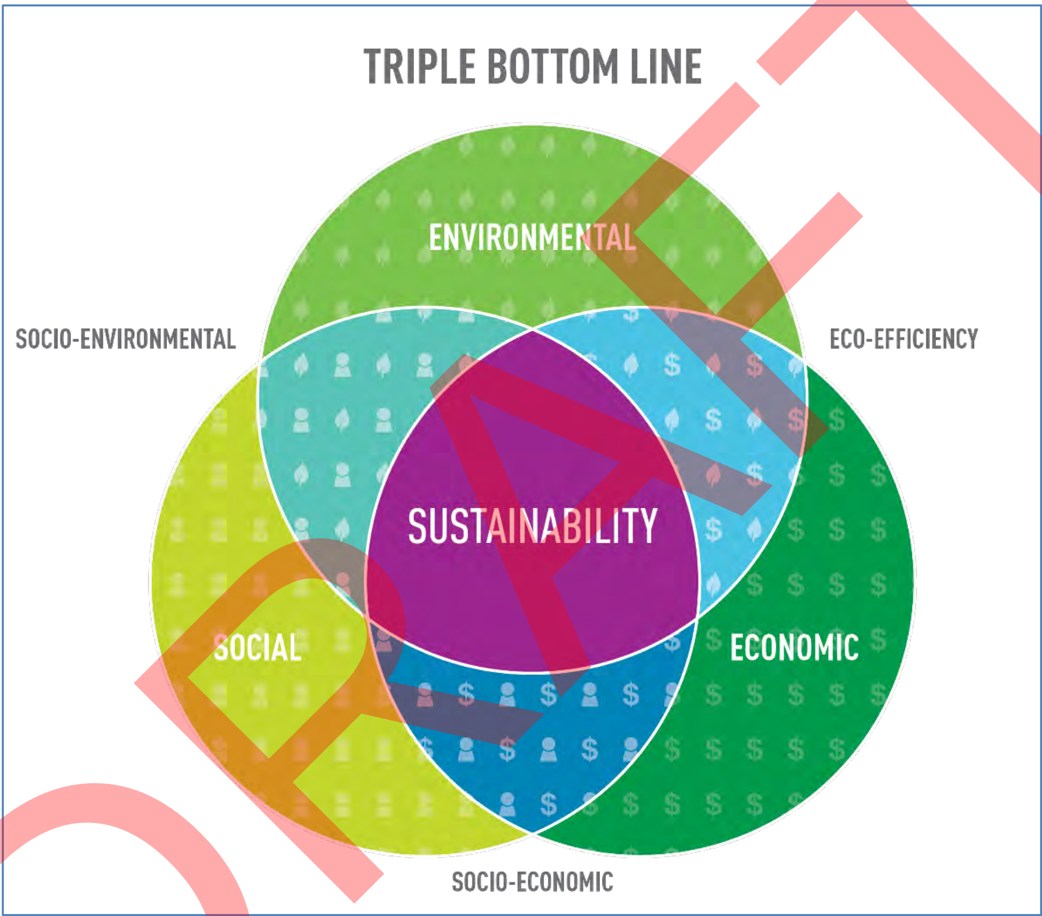


Figure 8-1: Triple Bottom Line Analysis Categories

8.1 Triple Bottom Line Approach

There are several benefit calculation methods, as well as different calculation software, to help quantify TBL benefits. The Envision™ framework is an increasingly used and industry-wide approach to evaluating TBL benefits. Utilizing this defined rating system allows users to evaluate a project according to a common sustainability framework; then TBL software may be used to quantify the potential benefits. For this study, the TBL benefits were quantified using a combination of AutoCASE web-based software and some custom calculations. AutoCASE was chosen as the primary TBL computation software because it is an easy to use and popular TBL software that allows projects to be quickly defined and calculated. Custom calculations were used in cases where an alternative calculation approach was deemed more appropriate than the calculation method applied by AutoCASE. When a custom calculation was used, a description of the approach and a rationale for its use is provided.

8.1.1 Envision Framework

The Envision™ framework is the product of a joint collaboration between the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design and the Institute for Sustainable Infrastructure (ISI). Envision™ provides a holistic framework for evaluating and rating the social, environmental, and economic business case of infrastructure projects. It evaluates, grades, and recognizes infrastructure projects that use transformational, collaborative approaches to assess the sustainability indicators over the course of the project's life cycle.

Envision has a variety of assessment tools that can be used by infrastructure owners, design teams, community groups, environmental organizations, constructors, regulators, and policy makers to:

- Assess costs and benefits over the project lifecycle
- Evaluate environmental benefits
- Use outcome-based objectives.
- Reach higher levels of sustainability achievement

AutoCASE was developed in conjunction with the ISI's Economics Committee to enhance the Envision rating system by adding the ability to provide value-based and risk-adjusted TBL analyses of stormwater infrastructure projects. The methodologies and data have been adapted from recent literature quantifying each cost and benefit and can be adjusted for specific locations. AutoCASE uses a Monte Carlo simulation to account for the uncertainty around the tool's inputs and methodologies. This provides users with a probability distribution of potential outcomes, rather than only a single expected value, which can imply a misleading degree of certainty in the results. A summary of the benefit calculations is included below.

8.2 Initial Project Setup

AutoCASE allows a user to manage multiple analyses and projects according to a hierarchical relationship. Numerous projects and design alternatives can be managed under the same analysis folder. Figure 8-2 shows the concept of this analysis management. Within each project, specific design alternatives are filled in with their user defined inputs or the default values included in AutoCASE. After the necessary inputs are provided, an analysis report is provided that compares the alternatives with either the "do nothing" existing condition option or benefits provided by a specific alternative.

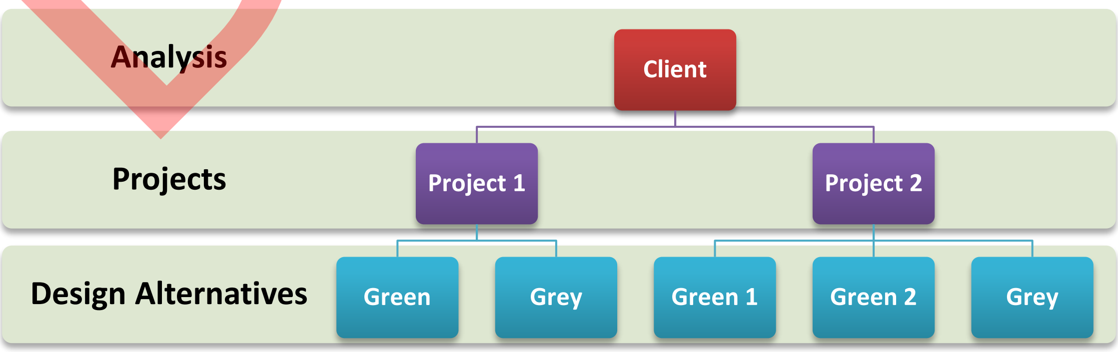


Figure 8-2: AutoCASE Analysis Management

For each design alternative, there are options to select the specific benefits that the user wishes to calculate from a mix of environmental, economic, and social categories. These benefits do not form definite groups, but rather intersect just like the sustainability concept diagram in Figure 8-1.

The benefits categories in the AutoCASE tool are identified in Figure 8-3. For this study, the Air Pollution, Carbon Emission, Heat Island, and Recreational Use benefits were calculated using the AutoCASE tool. Due to the site specific nature and the detailed available information, the flood risk and property uplift benefits are highlighted in red in Figure 8-3 because they were calculated outside of AutoCASE. The wetland benefit is also highlighted because AutoCASE can calculate this benefit, but it was deemed to be not applicable to this investigation. Although economic water quality was analyzed manually using the AutoCASE methodology. Detailed descriptions of AutoCASE's benefit calculations can be found in

Appendix H.

Figure 8-3: Benefits Categories in the AutoCASE Tool

8.3 Project Inputs

Because of the diverse benefits that can be calculated by AutoCASE, there are over 400 potential inputs that can be defined. Having this large number of inputs allows the analyses to be tailored to closely match specific project conditions. Each input impacts at least one of the benefit calculations, and many inputs are used across multiple benefit calculations. Because many of the inputs are only approximately known, AutoCASE also allows the user to input a range of values and relevant probability distributions. These ranges provide the basis for the risk assessment in the model, allowing the user to indicate uncertainty around values. Many of the inputs have default values that are calculated automatically by AutoCASE based on published research or from other input values, but a user can overwrite any of these defaults.

AutoCASE requires three types of inputs to perform its TBL calculations which are classified as design components, common components and additional components. These are further detailed in the following sections.

8.3.1 Design Components

AutoCASE allows evaluation of a wide spectrum of GI feature types that can be evaluated individually or collectively as part of an overall project. As a user selects the design feature(s) that are applicable for their project they input relevant data and answer input questionnaires for the selected design features.

These designs can include both grey and green infrastructure features, and each project can be set up with a combination of these design features, or just have a single feature. These features can also be compared to each other in the results in relative analysis. For the GI evaluation in this project, bioretention was selected as the GI feature for analysis.

8.3.2 Common Components

Within AutoCASE there are nine common component input categories and each category leads to other hierarchy selections or questions for inputs that influence the project's benefits and values. These common inputs must be completed to calculate project benefits. Table 8-1 provides a description of the common inputs required for the benefits analysis.

Table 8-1
Description of Common Inputs for AutoCASE Benefits Analysis

Category	Description
Locations and Dates	This section includes inputs such as the project location, starting date, and operation duration of the project. This section also includes construction and planning inputs that can have significant impacts on benefit calculations.
General Site Questions	This section includes inputs such as infiltration and the 24-hour design storm selected for the site. Currently in AutoCASE, the 24-hour design storm input is not used for calculating flood risk mitigation, but it affects the design of the selected alternatives to be able to handle the runoff volume generated by the design storm.
Jobs, Revenues, and Decommissioning	These inputs are used for capital expenditure's shadow wage allocation. Revenues and decommissioning are not analyzed in this study.
Government Impact	Includes possible restrictions from government entities such as taxes and penalties. These impacts were not included in this study.
Water Quality and Usage	Water Quality and Usage section controls the project's water quality benefit by applying Vaughan's Water Quality Ladder and quantifying its social and environmental value. For this project, the economic aspects of the water quality benefit are manually analyzed using a methodology provided by AutoCASE. The social and environmental water quality benefits were not included in this study.
Other Costs and Benefits	Other Costs and Benefits section is used to calculate site specific benefits outside of AutoCASE that the user would like to directly enter. For this project, the flood risk reduction and property uplift benefits were externally calculated.
Wetland Characteristics	Wetland Characteristics section has several questionnaires to quantify the social and recreational benefits, and to identify potential storm and flood protection additions to the site.
Energy Usage	The Energy Usage component has inputs related to the amount of energy saved or additionally consumed by the design feature choice and the change in use of various energy sectors. This also affects the Carbon Emission reduction and Air Pollution sequestration benefits.
Recreational Use	The Recreational Use section includes questionnaires to help quantify the social benefits due to increased recreational opportunities.

8.3.3 Additional Inputs

There are 6 additional input categories, with multiple questions for each category. Even though this component is stated as "additional", it has critical impact on the benefits calculations. Table 8-2 provides a description of the additional inputs for the benefits analysis.

Table 8-2:
Description of the Additional Inputs for AutoCASE Benefits Analysis

Category	Description
General Value Used	This section includes inputs such as population, city/town area, and median house values of the city. For this project, individual City-Wide sewershed projects were created with site specific entries. These inputs have the most impacts in property uplifts benefit analysis. The current AutoCASE method for calculating property uplift has an input of percentage of GI design area within the entire area, rather than the percent of area that would be managed by the design. As a result, the property uplift benefit was calculated outside of AutoCASE using percent of low impact development (LID) retrofitted area, rather the actual ratio of design over the total city area.
Financial Assumptions	The Financial Assumption section includes values such as the discount rate, inflation rate, and taxes that need to be accounted for the duration of the project. For this project the discount rate is set to 4.88% and inflation is set to 4%.
Air Pollution Costs	This section includes the air pollution factors of CO, SO_2, NO_2, $PM_{2.5}$, and O_3 in current year dollars per ton. The default values for this section are calculated with ranges of the increase in vegetated area or the number of trees and shrubs planted. The default values were used for this project.
Carbon Emissions	The Carbon Emissions section includes the discount for the carbon emission, social values, and carbon footprint associated with the project's construction and operation. For this project default values were used for the analysis.
Flood Risk	Variables such as the existing storage volume and additional inputs defining additional drainage areas outside of the project area are included in this section. For this project, the flood risk benefits are calculated outside of AutoCASE and are detailed section 8.4.4.
Green Roof Characteristics and Heat Risk	This section includes values required to compare the difference between traditional grey and green roof impacts to the heat island risk analysis. Since green roofs were not a GI type investigated in this project, this section was not used.

8.4 Triple Bottom Line Benefits and Calculations

AutoCASE has the ability to provide detailed breakdowns of the various costs and benefits computed based on the user-defined inputs and default input values. Not all categories of costs and benefits that are calculable by AutoCASE were implemented for this GI assessment, and some values were computed independently of AutoCASE. Only a subset of the potential calculable benefits were evaluated for this project, the overall TBL benefits calculated later in this section are likely under-estimated. The various result types are detailed below and followed by the computed ranges of costs and benefits of implementing GI solutions across the priority sewersheds.

8.4.1 Air Quality and Carbon Emission

Improvements in air quality are quantified according to the changes in reduction of energy usages from GI project construction and implementation, change in material usages, and increases in vegetated area. The bioretention feature type includes the number of trees and shrubs planted as part of this calculation. Air quality change was computed using the estimated number of trees and shrubs planted and surface area of the increased vegetative cover. Characteristics that could be defined but were not incorporated for this project include electricity generation, green roofs and concrete material usage. The added green space is estimated to be 50% of LID-managed impervious area. The air pollutants reduced in this benefits calculation include carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and fine particulate matter with diameters 2.5 micrometers or less ($PM_{2.5}$).

8.4.2 Heat Island Mortality Reduction Benefit

AutoCASE uses an enhanced version of the EPA's Value of a Statistical Life (VSL) method to assign value to lives saved from heat mortality as a result of the GI implementation. The temperature reduction or increase of a design alternative is based on changes in surface cover type and were estimated according to the Figure 8-4. Then this information was used to identify avoided death over the life of the project. This number of estimated lives saved was multiplied by the VSL to quantify the financial benefit of the temperature reduction. The limitations of this method include: (1) it does not take into account the non-mortality cases; (2) it does not incorporate additional benefits of having plants over the designed area.

For this study 50% of the GI managed impervious areas are assumed to be additional vegetated areas. The calculation assumes additional green spaces from the new GI, and some areas remain as existing conditions. The benefit calculation does not include reduction in numbers of non-mortality heat-related cases that could be considered benefits as well. The value of temperature reduced throughout the sewersheds was set as 5.35 degrees F, which is the standard value for the bioretention GI method.

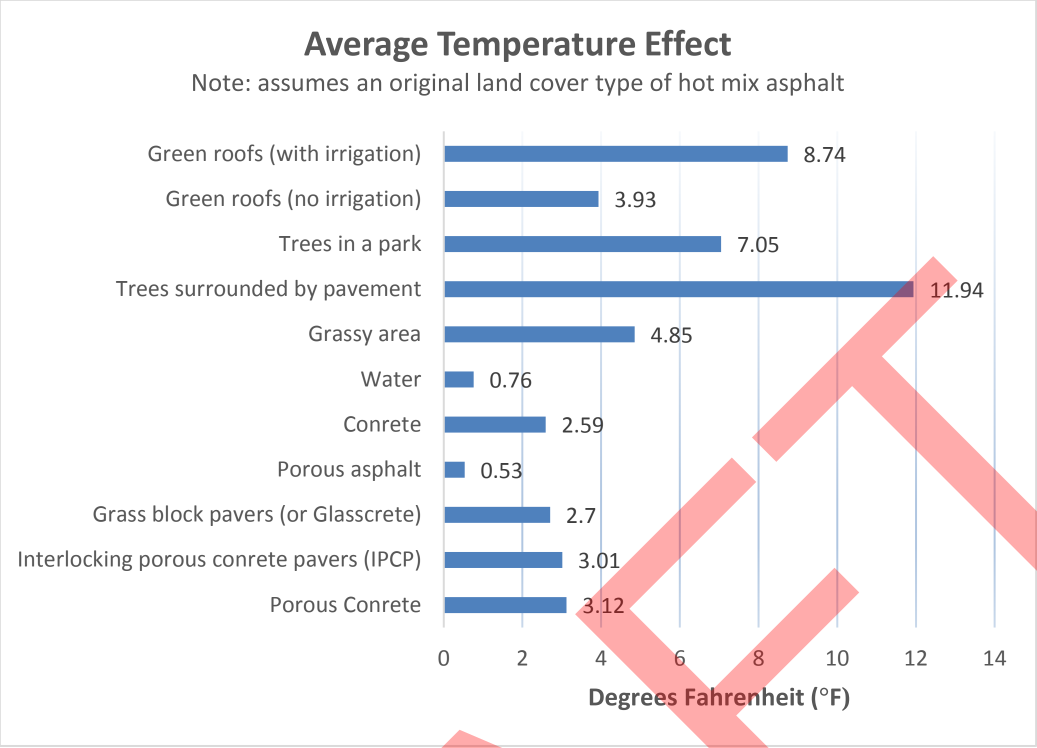


Figure 8-4: Average Temperature Effect of Various GI Types

8.4.3 Recreational Use Benefit

This benefit was calculated by estimating the increased total user days expected after the project is constructed, then multiplying this value by the estimated WTP of users. In this study, the increase in new recreational area within additional vegetated area is estimated to be 75% of retrofitted impervious area. This value can be improved with actual park survey data or site specific increase in recreational usage data if they are available. This benefit could have an increased positive impact if a greater percentage of additional green space is utilized as recreational area, and this varies significantly for every sewershed. For example, if the additional vegetation is created as parking area curves, this area cannot be used for recreation. On the other hand, if the additional green space were for parks, residential developments, or schools to expand their green space, then these would be mostly recreational use, and the recreational benefit can be increased.

8.4.4 Flood Risk Reduction Benefit

The flood risk reduction benefit was calculated separately from AutoCASE. The principal reason for this was to utilize local knowledge of the collection system and of the frequency and number of properties that experience flooding (basement sewage backups during rain events) from more severe storms and limitations of the collection system infrastructure. The key factor in this calculation is determining the number of houses subject to basement sewage backups and the severity of storm event needed to induce backup conditions. The final calculation was based on a combination of historical rainfall analysis, model simulation results, and questionnaires to property owners in the Shadyside neighborhood in the A-22 sewershed to get direct feedback about experiences with basement sewage backup conditions. After a historical review of storm events that have occurred in 50 years, the frequency of storms that are expected to result in basement sewage backup conditions was calculated. Analysis of the A-22 sewershed indicated basement sewage backup conditions under approximately a 4 inches/hour rainfall intensity over a period of 15 minutes. Using this estimate for the starting point of basement backup occurrence, the likelihood of basement backups across the 30 priority sewersheds was estimated. However, it is recognized that predicting the occurrences of basement sewage backups is difficult, even with local knowledge and that many factors can influence when these conditions occur that cannot be predicted. However, this approach for this calculation was deemed to be the most defensible methodology with the data that was readily available.

8.4.5 Property Value Uplift Benefit

The property value uplift benefit is calculated based on the population, number of houses, and the property values that can benefit from the GI project. In this report, percent of LID according to the LID modeling is incorporated as property value uplift due to percentage of LID managed and retrofitted area rather than actual design to city ratio. The property uplift rate of 3.5% was selected based on Philadelphia Water Department (PWD)'s experience (*A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds, Stratus Consulting, Inc., 2009*), and to avoid double counting, a 50% multiplier is included in this calculation. This benefit is especially site specific, and a sum of the smaller area calculations are more beneficial rather than one large area. Up-to-date census information is useful for more realistic results. The limitation is that even though one area is divided into smaller regions, it is still difficult to incorporate the demographic gap within the region. If the region has a significant gap of maximum and minimum property value, the uplift calculation might not reflect the entire region.

This benefit was calculated manually as a one-time benefit manually to involve the appropriate percent GI-managed area, rather than computing a ratio of design area to study area. In this way, the GI area is not limited to one location; rather, the GI could be distributed throughout the impervious area. The difference in the Property Value Uplift benefits in the two scenarios was because of the difference in managed LID area. This result also varied with land usage of the sewersheds. Densely populated residential areas had higher benefits than commercial areas or low population areas. One of the most influential factors that could be added in future work to refine the Property Value Uplift benefit calculation is to incorporate the demographic and economic difference within the area. For example, a single sewershed can have residents with widely varying socioeconomic status. The current property uplift calculation has a single average house price, but in the future the equation could be modified if it is identified that the amount of impact by GI could be different in subareas of the sewershed. In addition, additional local survey data can be beneficial to enhance the calculation because uplift rates are different throughout the nation. In this study, the range of uplift rate used was 2.12% to 4.37%, with 3.14% as the expected rate. Areas with a lower median house price could experience a larger impact with GI and other expected social development along with green construction. On the other hand, a high cost of living area might experience less impact compared to other areas.

In this study, population was used to calculate number of households in the area, and multiplied by the median house price. So, higher house prices and greater population in an area results in larger benefit values compared to an area with relatively lower house prices and lower population. It was also found that commercial and industrial areas such as O-41 had the lowest percentage of benefit from property uplift.

8.4.6 Economic Water Quality Benefit

AutoCASE calculates the water quality environmental and social benefit by estimating the change in water quality. In this study, only the economic water quality benefit was calculated because there were no water quality impact results available to identify the change in water quality. AutoCASE provided economic water quality benefit calculations to utilize the possible impact benefit by the design feature with the design storm volume. This method estimated source loadings according to the AutoCASE selections, then estimated changes in runoff and pollutant loadings from the GI elements.

This benefit analysis was computed to target just the economic water quality impact by calculating pollutant amounts that are removed from GI implementation, and monetizing by amount of pollutant. Each design feature has different amounts of pollutant removal levels and in this study, the benefit was estimated in accordance with applying bioretention as the GI method. If water quality improvement data is available, AutoCASE has a feature to calculate the social and environmental benefits of water quality.

Average rainfall data over a 60 year period was used to conduct this analysis to calculate amounts of runoff volume that are managed by the GI. The pollutants that are monetized are total suspended solids, total phosphorus, total Kjeldahl nitrogen, total zinc, total lead, and total copper. During construction, a 10% gain of benefit was assumed every year. The GI operation period was assumed to have full benefit every year.

8.5 TBL Quantified Results

The TBL benefits were calculated across the 30 priority sewersheds for two different levels of GI implementation representing the expected range of GI implementation needed to meet the 85% combined sewage capture goal in each of the sewersheds. Because the TBL benefits are only derived from GI investments, any changes in WWTP capacity or deep interceptor conveyance are not relevant in computing TBL benefits. These two levels of GI investment are:

- 1,286 acres of impervious area managed by GI in 13 sewersheds.
- 1,835 acres of impervious area managed by GI in 18 sewersheds.

The TBL analysis considered the variety of sizes, demographic conditions, and land usages of the sewersheds targeted for impervious area management. Table 8-3 shows the seven TBL benefit categories and the individual and total TBL benefits, represented as net present value (NPV), for managing 1,286 acres of impervious area with GI in 13 sewersheds. Individual sewershed results are listed in Appendix H.

Table 8-3:
50-Year TBL Benefits (Net Present Value) for 1,286 Acres of Directly Connected Impervious Area Managed by GI

Category	90% Confidence Interval NPV	
	Low Range	High Range
Air Pollution Reduced by Vegetation	$5,070,000	$9,180,000
Carbon Reduced by Vegetation	$710,000	$2,960,000
Flood Risk Reduction	$333,130,000	$666,260,000
Heat Island Effect Reduction	$3,020,000	$6,750,000
Property Value Increase	$33,120,000	$68,270,000
Recreational Value Addition	$9,880,000	$15,550,000
Economic Water Quality Benefit	$7,280,000	$9,780,000
Total TBL Benefit	**$392,210,000**	**$778,750,000**
Total TBL Benefit without Flood Risk Reduction	**$59,080,000**	**$112,490,000**

Table 8-4 shows the seven TBL benefit categories values and the individual and total TBL benefits for managing 1,835 impervious acres with GI in 18 sewersheds. Individual sewershed results are listed in Appendix H.

Table 8-4: 50-Year TBL Benefits (Net Present Value) for 1,835 Acres of Directly Connected Impervious Area Managed by GI

Category	90% Confidence Interval NPV	
	Low Range	High Range
Air Pollution Reduced by Vegetation	$7,260,000	$13,090,000
Carbon Reduced by Vegetation	$1,010,000	$4,220,000
Flood Risk Reduction	$335,750,000	$671,500,000
Heat Island Effect Reduction	$4,280,000	$9,610,000
Property Value Increase	$54,770,000	$112,900,000
Recreational Value Addition	$14,120,000	$22,210,000
Economic Water Quality Benefit	$10,390,000	$13,950,000
Total TBL Benefit	**$427,580,000**	**$847,480,000**
Total TBL Benefit without Flood Risk Reduction	**$91,830,000**	**$175,980,000**

Table 8-5 summarizes the estimated pollutant reduction for the six pollutants for the two scenarios.

Table 8-5 Pollutant Reductions for Different Impervious Acres Managed by GI (Bioretention)

Pollutant	Pollutant Removal (lbs) – Directly Connected Impervious Area (DCIA) Managed by GI	
	1,286 DCIA Acres	1,835 DCIA Acres
Total Suspended Solids	782,899	1,117,010
Total Phosphorus	13,327	19,014
Total Kjeldahl Nitrogen	32,417	46,251
Total Zinc	720	1,028
Total Lead	77	110
Total Copper	257	367

8.6 Conclusions

Both levels of GI implementation provide significant TBL benefits across the seven benefits categories. The computed TBL benefits are expected to range between $390M and $850M with a majority of the benefit value from the flood reduction benefit. However, even without including this benefit the TBL benefits would still range between $60M and $175M for the two GI implementation levels.

9. CITY-WIDE GI ASSESSMENT SUMMARY

The goal of this City-Wide Green Infrastructure (GI) Assessment, hereafter referred to as the Green First Plan, was developed based on a GI-based integrated planning approach to reduce CSO and SSO overflows, remove or detain stream inflows, reduce specific flood hazards, and reduce the occurrence of basement sewage backups. This effort has also allowed us to develop a stormwater overlay lens for use as a comprehensive planning tool for future new and redevelopment. The findings of our assessment include both common metrics such as untreated overflow volumes reduced, but also ancillary benefits derived from GI implementations such as Triple Bottom Line (TBL) benefits and reduced flows being conveyed to the wastewater treatment plant (WWTP). The 30 sewersheds included in this assessment are each located within the City of Pittsburgh (City). The volume of untreated overflow and stormwater flow from these sewersheds represent approximately one third of the total untreated overflow discharged from the entire collection system tributary to the ALCOSAN Woods Run WWTP.

Earlier sections of this report describe each of the detailed investigations undertaken during this GI Assessment. This section integrates these various results, place them in context and present a summary of key findings and recommendations. It is important to understand the following points when reading this section.

- **Different GI applications provide different types of benefits.** No one metric is sufficient to decide if a particular GI project proceeds to design and then on to construction. Some GI benefits directly overlap with the benefits provided by traditional gray infrastructure, such as reducing untreated overflows to meet regulatory goals. However, since GI also provides multiple benefits and helps address multiple water quality and public health regulatory issues, the GI evaluation process is often more complex than the often more straightforward evaluative process typically applied to a gray infrastructure.
- **The Green First Plan has a green focus, but is also dependent on key gray infrastructure improvements.** All collection systems are interactive networks whose adequacy is based on inputs (entering flows), conveyance (flow traveling throughout the network) and outputs (discharges from the WWTP, CSOs, SSOs, etc.). Changes to any of these elements have impacts on the other elements. The development of an effective plan which includes GI depends on all of the elements working effectively together. GI investments primarily address the input component of the system by slowing and reducing the flows entering the system that then need to be conveyed and discharged through an output location. Although GI elements can be very effective at addressing the system's flow inputs, the conveyance and treatment components of the entire system must also function optimally to maximize the overall results. As demonstrated in the GI Assessment's results, key gray infrastructure investments must still be made for the GI elements to be maximally effective.

- **It is important to understand not simply the cost of an alternative, but its value.** Just because an alternative is cheaper than others does not automatically mean it is the best alternative (although it may be). Because a sizable portion of the value of a GI project may derive from factors other than volume of untreated overflow reduced, GI projects need to be evaluated with the overall value that they provide. However, these ancillary benefits are often weighed differently by different stakeholders and further discussions would be needed to determine how the results provided in this report should be used to influence any future decision-making.
- **This Assessment only focused on 30 priority sewersheds within the PWSA system, not the entire collection system tributary to ALCOSAN's Woods Run Wastewater Treatment Plant (WWTP).** The results provided in this report are important for understanding the effectiveness of applying large scale GI within the City at high yield and high benefit locations. Although the results of this Assessment provide insight on the benefits of applying GI across the larger region tributary to the ALCOSAN conveyance and treatment system, those regional results would need to be investigated further with the inclusion of additional information.
- **The benefits from this Assessment extend to the municipalities beyond PWSA and the City.** Having PWSA and City adopt the Green First plan which includes GI to meet target regulatory goals may also provide multiple regional benefits to tributary municipalities. The sewer collection system is inextricably and hydraulically linked. Theoretically, taking a gallon of stormwater out at one location frees up pipeline capacity for another stormwater gallon to enter elsewhere. By capturing and slowing the entry of stormwater into the collection system within the City and surrounding areas, capacity is freed up in the existing interceptors to accept more flow and be conveyed to the WWTP, thereby reducing regional overflows. The results show that the system-wide overflow volume reduction is competitive with the 2013 ALCOSAN Recommended Wet Weather Plan (Recommended Plan) at potentially a lower overall cost per gallon, which would benefit all of the region's ratepayers.
- **The methodologies and "blueprints" from this Assessment can be applied Region-wide.** High yield stormwater capture locations within the combined sewer systems (CSS), the separate sewer systems (SSS) in which the stormwater flows are conveyed to a downstream CSS, and the sanitary sewers with excessive infiltration and inflow (I/I) in which the flows are conveyed to a downstream CSS exist across the regional ALCOSAN service area. In addition there may be stormwater capture locations in the SSS that may reduce flooding hazards that stem from excess stormwater. This study revealed that the region has a stormwater management problem with excessive stormwater entering the CSS that highly influences CSO frequency and magnitude in many locations across the service area. Addressing the root cause of this problem by intercepting and managing this stormwater locally provides multiple benefits for far reaches downstream. The results support and re-affirm a regional approach for targeted stormwater management at high-yield locations that maximize stormwater management, overflow reduction, and community benefits.

9.1 High Yield GI Locations

A principal focus of this GI Assessment has been investigating the expected performance of distributed GI applied across the 30 priority sewersheds. The magnitude of GI Best Management Practices (BMPs) evaluated was based on the calculated impervious area stormwater runoff to be managed by GI within each sewershed, and defined as "GI investment". Impervious areas are defined as areas that allow all or a significant portion of the precipitation that falls on them to run off the ground (topographic) surface. Impervious areas include rooftops, sidewalks, driveways, parking lots, impervious solids and rock, and streets, unless specifically designed, constructed, and maintained to prevent or control runoff.

The EPA's CSO Control Policy (1994) requires at least 85% combined sewage capture be achieved within combined sewer systems as part of a CSO long-term control plan. For this Assessment 85% combined sewage capture was the target selected as it is consistent with the CSO Control Policy and other approved long term control plans across the United States. The current Recommended Plan was developed assuming a standard of no more than four overflows per year at each combined sewer outfall. The 85% combined sewage capture target is not meant to presume a final level of control for the region's CSOs, but simply to define a target that has been required as a presumptive compliance goal for other cities like Pittsburgh. This approach also allows flexibility to scale the eventually required amount of GI investment, in conjunction with necessary gray infrastructure, to meet whatever CSO target is ultimately agreed upon with regulators.

Analyses completed for this Assessment, described in Section 2, revealed that the level of GI investment needed to achieve the goal of 85% combined sewage capture would be highly influenced by the capacity and operation of ALCOSAN's Woods Run WWTP and the conveyance capacity of ALCOSAN's existing interceptors. These critical infrastructure components are planned to be expanded or supplemented as part of the Recommended Plan. However, the ultimate build out capacity of these conveyance and treatment components and the timing of their expansions is subject to regulatory and other items. With this understanding the high yield GI analysis was evaluated with four different potential scenarios of this existing gray infrastructure as listed in Table 9-1. As the capacity of the existing gray infrastructure increases, the level of GI investment needed to reach the 85% combined sewage capture target decreases. Under existing conditions, 13 of the sewersheds already meet the 85% combined sewage capture goal and therefore would not need any GI implementation. As the capacities of the WWTP and tunnels are expanded, an increasing number of sewersheds would meet the 85% combined sewage capture goal. Under the Lowered Hydraulic Grade Line (HGL) Operation During Wet Weather Conditions (Lowered HGL Operation) option, which represents an attempt to maximize the performance of the existing conveyance and treatment infrastructure, 17 of the 30 high priority sewersheds would achieve 85% combined sewage control and would not require any GI implementation.

TABLE 9-1
SYSTEM CONFIGURATIONS EVALUATED TO DETERMINE GI SENSITIVITY

Existing Conditions	This represents the current state of the collection system and the WWTP treatment capacity. The WWTP has a 250 million gallons per day (MGD) treatment capacity and its influent pump station wet well operates at an HGL level of 670 feet. The existing interceptors have the sediment levels as defined in the current ALCOSAN model.
480 MGD (WWTP Expansion) [1]	This system state is the same as the existing conditions, except the capacity of the WWTP has been expanded to 480 MGD and its operating wet well HGL level reduced to 660 feet.
600 MGD (WWTP Expansion & System Improvements) [1]	This system state is the same as the existing conditions, except the capacity of the WWTP has been expanded to 600 MGD and its operating wet well HGL level reduced to 660 feet. Also, the existing interceptors are modeled with their sediment removed to maximize wastewater conveyance to the interceptor, and regulator structures for 19 of the 30 high priority sewersheds have modified tipping gate settings to allow more flow to enter the interceptors.
Lowered HGL Operation During Wet Weather Conditions [1]	This system state represents an attempt to maximize the performance of the existing gray infrastructure. This alternative is not currently planned to be implemented by ALCOSAN. In this scenario, the WWTP is modeled as a free outfall to represent lowering the water level at the existing pump station during wet weather conditions such that it is below the crown of the connecting deep tunnel. This provides for the existing conveyance capacity to be maximized. This scenario also assumes that the necessary high rate treatment infrastructure is constructed at the WWTP to process any flows above 600 MGD (modeling results indicate peak flows at or above 600 MGD occur 29 hours in a typical year). The necessary infrastructure to accomplish this scenario is discussed in Section 3.3. The existing interceptors are modeled with their sediment removed and regulator structures for 19 of the 30 high priority sewersheds have modified tipping gate settings to allow more flow to enter the interceptors. A more detailed explanation of this configuration is included in Section 2 of this report.

[1] The technical feasibility of all potential treatment plant wet weather capacity scenarios is currently under discussion between PWSA and ALCOSAN.

Table 9-2 details the directly connected impervious area (DCIA) generated stormwater runoff that must be managed by GI for each of the 30 priority sewersheds to achieve the 85% combined sewage capture goal under the four configuration scenarios. Under existing conditions, 63% of the DCIA stormwater runoff would need to be managed. However, only 35% of the DCIA stormwater runoff would need to be managed under the Lower HGL Operation condition. Entries with a green highlight indicate that the sewershed achieves the 85% combined sewage capture goal and no additional GI investment is needed.

Table 9-3 includes planning level capital cost estimates for each of the sewersheds based on the amount of impervious acres in high yield drainage areas that need to be managed by GI to achieve at least the 85% combined sewage capture goal. Entries with a green highlight indicate that the sewershed achieves the 85% combined sewage capture goal and no additional GI investment is needed. GI BMP costs were developed using a detailed and itemized costing spreadsheet estimating the quantities and unit costs for each primary component of the BMPs. Costs were developed and compared to the equivalent cost per acre of impervious surface managed for a reasonableness check. Construction costs without contingency were calculated to be $150,000 to $200,000 per impervious acre managed. Using the high end of this range, the base construction cost was selected to be $200,000 per impervious acre. These costs were compared to costs from other Mott MacDonald GI projects, costs from other communities implementing GI programs, as well as the ALCOSAN Starting at the Source report (August 2015) and found to be in-line with the reported costs. The contingencies added to these construction costs to develop overall capital costs are listed in Table 9-4. Applying these contingencies, the low range cost was estimated at $324,000 per acre and the high range cost was estimated at $432,000 per acre.

TABLE 9-2
CONTINGENCIES FACTORS

Planning Level Cost Contingencies	Percentage
Construction	25%
Engineering (Planning, Design and Construction Administration Services)	20%
Overall Project	20%
Class 4 Cost Estimate Range	+20% to -10%

Operation and maintenance (O&M) costs over both a 25-year and 50-year life cycle were developed for the GI under both the 1,835 and 1,286 impervious acres scenarios. Section 7 details the development of these O&M costs. Table 9-12 summarizes the O&M costs for both scenarios.

TABLE 9-3
GI IMPERVIOUS AREA STORMWATER RUNOFF MANAGED TO ACHIEVE 85% COMBINED SEWAGE CAPTURE GOAL IN 30 PRIORITY SEWERSHEDS

Sewershed	Impervious Area (Ac)	Existing Conditions (250 MGD WWTP)		480 MGD (WWTP Expansion)		Lowered HGL Operation	
		Percentage	Acres	Percentage	Acres	Percentage	Acres
A-22-OF	898.0	56.7%	509.1	43.2%	387.7	30.2%	271.0
A-41-OF	234.7	85.0%	199.5	85.0%	199.5	60.0%	140.8
A-42-OF	839.7	85.0%	713.8	73.1%	614.1	57.8%	485.1
A-47-OF	9.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-48-OF	167.1	25.0%	41.8	25.0%	41.8	25.0%	41.8
A-51-OF	34.6	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-58-OF	151.7	25.0%	37.9	25.0%	37.9	25.0%	37.9
A-60-OF	175.2	85.0%	148.9	25.0%	43.8	25.0%	43.8
A-61-OF	10.7	53.9%	5.8	37.3%	4.0	0.0%	0.0
A-62-OF	5.7	86.0%	4.9	0.0%	0.0	0.0%	0.0
A-63-OF	1.0	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-64-OF	18.4	0.0%	0.0	0.0%	0.0	0.0%	0.0
A-65-OF	4.6	85.0%	3.9	15.1%	0.7	0.0%	0.0
M-15-OF	3.7	85.0%	3.1	65.3%	2.4	0.0%	0.0
M-15Z-OF	3.1	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-16-OF	100.0	85.0%	85.0	85.0%	85.0	25.2%	25.2
M-17-OF	6.2	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-18-OF	5.1	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-19A-OF	142.6	40.0%	57.1	41.0%	58.4	35.0%	49.9

TABLE 9-3
GI IMPERVIOUS AREA STORMWATER RUNOFF MANAGED TO ACHIEVE 85% COMBINED SEWAGE CAPTURE GOAL IN 30 PRIORITY SEWERSHEDS

Sewershed	Impervious Area (Ac)	Existing Conditions (250 MGD WWTP)		480 MGD (WWTP Expansion)		Lowered HGL Operation	
		Percentage	Acres	Percentage	Acres	Percentage	Acres
M-19B-OF	32.1	27.1%	8.7	28.0%	9.0	33.0%	10.6
M-19-OF	119.1	85.0%	101.2	55.2%	65.7	25.0%	29.8
M-20-OF	6.2	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-21-OF	29.2	11.6%	3.4	7.9%	2.3	0.0%	0.0
M-22-OF	16.4	0.0%	0.0	0.0%	0.0	0.0%	0.0
M-29-OF	362.3	85.0%	307.9	60.1%	217.7	25.0%	90.5
O-27-OF	195.6	25.0%	48.9	22.3%	43.7	22.3%	43.7
O-39-OF	23.8	31.6%	7.5	21.4%	5.1	0.0%	0.0
O-40-OF	2.8	0.0%	0.0	0.0%	0.0	0.0%	0.0
O-41-OF	27.9	56.3%	15.7	56.0%	15.6	56.0%	15.6
O-43-OF	9.8	0.0%	0.0	0.0%	0.0	0.0%	0.0
Totals	**3,636**	**63%**	**2,304**	**50%**	**1,835**	**35%**	**1,286**

TABLE 9-4
GI CAPITAL COSTS TO ACHIEVE 85% COMBINED SEWAGE CAPTURE GOAL IN 30 PRIORITY SEWERSHEDS

Sewershed	Existing Conditions		480 MGD (WWTP Expansion)		Lowered HGL Operation	
	$324,000/ac	**$432,000/ac**	**$324,000/ac**	**$432,000/ac**	**$324,000/ac**	**$432,000/ac**
A-22-OF	$164,953,931	$219,938,575	$125,626,939	$167,502,585	$87,816,098	$117,088,131
A-41-OF	$64,641,888	$86,189,184	$64,641,888	$86,189,184	$45,629,568	$60,839,424
A-42-OF	$231,256,960	$308,342,614	$198,980,500	$265,307,333	$157,172,400	$209,563,200
A-47-OF	$0	$0	$0	$0	$0	$0
A-48-OF	$13,537,357	$18,049,810	$13,536,720	$18,048,960	$13,536,720	$18,048,960
A-51-OF	$0	$0	$0	$0	$0	$0
A-58-OF	$12,285,476	$16,380,635	$12,286,080	$16,381,440	$12,286,080	$16,381,440
A-60-OF	$48,246,743	$64,328,991	$14,190,004	$18,920,006	$14,190,004	$18,920,006
A-61-OF	$1,872,535	$2,496,713	$1,296,000	$1,728,000	$0	$0
A-62-OF	$1,595,381	$2,127,175	$0	$0	$0	$0
A-63-OF	$0	$0	$0	$0	$0	$0
A-64-OF	$0	$0	$0	$0	$0	$0
A-65-OF	$1,265,959	$1,687,945	$224,532	$299,376	$0	$0
M-15-OF	$1,013,472	$1,351,296	$778,352	$1,037,802	$0	$0
M-15Z-OF	$0	$0	$0	$0	$0	$0
M-16-OF	$27,553,324	$36,737,765	$27,548,317	$36,731,089	$8,160,336	$10,880,447
M-17-OF	$0	$0	$0	$0	$0	$0
M-18-OF	$0	$0	$0	$0	$0	$0
M-19A-OF	$18,489,622	$24,652,830	$18,924,565	$25,232,753	$16,170,565	$21,560,753

TABLE 9-4
GI CAPITAL COSTS TO ACHIEVE 85% COMBINED SEWAGE CAPTURE GOAL IN 30 PRIORITY SEWERSHEDS

Sewershed	Existing Conditions		480 MGD (WWTP Expansion)		Lowered HGL Operation	
	$324,000/ac	$432,000/ac	$324,000/ac	$432,000/ac	$324,000/ac	$432,000/ac
M-19B-OF	$2,822,056	$3,762,741	$2,916,000	$3,888,000	$3,434,400	$4,579,200
M-19-OF	$32,800,140	$43,733,520	$21,286,323	$28,381,765	$9,645,208	$12,860,277
M-20-OF	$0	$0	$0	$0	$0	$0
M-21-OF	$1,098,600	$1,464,800	$748,203	$997,604	$0	$0
M-22-OF	$0	$0	$0	$0	$0	$0
M-29-OF	$99,764,571	$133,019,427	$70,531,447	$94,041,930	$29,322,000	$39,096,000
O-27-OF	$15,840,701	$21,120,935	$14,148,979	$18,865,305	$14,148,979	$18,865,305
O-39-OF	$2,428,887	$3,238,515	$1,643,494	$2,191,325	$0	$0
O-40-OF	$0	$0	$0	$0	$0	$0
O-41-OF	$5,082,994	$6,777,325	$5,054,400	$6,739,200	$5,054,400	$6,739,200
O-43-OF	$0	$0	$0	$0	$0	$0
Totals	**$746,550,598**	**$995,400,797**	**$594,362,743**	**$792,483,657**	**$416,566,757**	**$555,422,343**

9.1.1 Downspout Disconnection Program

The GI analysis included identifying high yield drainage areas tributary to mapped catch basin inlets. These high yield drainage areas include both public and private sources of stormwater. To provide the maximum benefits of managing stormwater to reduce CSO, localized surface flooding, and basement sewage backups, strategic cost-effective disconnection of private property downspouts is recommended to be performed. The GI cost-basis described above includes the necessary sizing of BMPs to include stormwater runoff from private impervious surfaces. While the overall capital cost range for GI of $324,000 - $432,000 per impervious acre managed was conservatively estimated to also include strategic cost-effective disconnection of downspouts in the locations of BMPs, it was decided to explicitly include a separate line item cost for downspout disconnections in the CSS to add additional conservatism to the GI costs.

To estimate the downspout disconnections cost, several sources were evaluated, including:

- a literature review was performed of the various utilities currently performing downspout disconnection programs, including the Water Environment Federation (WEF) Private Property Library;
- MM's experience with private source projects in other communities; and
- the 3RWW / ALCOSAN ACT tool extension for private property I/I disconnections

Based on this information, an average cost estimate of $3,000 per property was utilized for downspout disconnections where either the downspouts are directed to a right-of-way BMP or disconnected on the property where an adequate discharge location exists. This cost also realizes that only cost-effective downspout disconnections falling within this average cost range would be performed. If more expensive downspout disconnections on average were encountered then those locations would be re-examined and other more cost-effective areas for impervious surface runoff capture would be identified. To determine an overall cost for the 1,835 impervious acres managed and 1,286 impervious acres managed scenarios, the number of buildings in each of the sewersheds within the targeted high yield drainage areas was determined. A total of 24,000 buildings and 16,900 buildings, for the scenarios, respectively, were calculated. A total cost of $72 million for the 1,835 acre scenario and $50.7 million for the 1,286 acre scenario was calculated for the targeted downspout disconnections. A Class 4 cost range of +20% to -10% was also applied to (and already included within) these costs.

9.2 Stream Inflow Removal

An integral part of PWSA's GI program includes the removal of direct stream inflow (DSI) into the combined sewer system. DSI is defined as a surface stream that connects into the combined sewer system. There are several known (and potentially other unknown) DSIs within the PWSA service area. Depending upon the nature of the stream, DSI can take up valuable conveyance capacity in the collection system and also uses a portion of the available treatment plant capacity. A perennial stream can contribute flow throughout the year, adding to the base wastewater flow in the collection system. An understanding of the significant amounts of stormwater runoff, including the perennial stream baseflow and other seasonal streams' influences, is extremely important for a capacity deficient collection system. Removing stream inflows into the sewer system provides several benefits, including:

- Removing a major source of sediment being transported into the existing interceptors thereby reducing the conveyance capacity of the existing interceptors and requiring potentially costly cleaning
- Removing a continuous source of (stream and stormwater) flow that needs to be treated at the WWTP. This has the benefit of reducing flows being transported to the WWTP unless greater infiltration occurs to make up for this reduction.
- Restoring significant amounts of wastewater conveyance and treatment capacity in dry and wet weather conditions within the system resulting in reduced CSOs.
- Potentially provide opportunities for catalyzing new development and redevelopment of surrounding land areas.

As discussed in Section 1 of this report, the 10 largest DSI locations were reviewed and identified as listed below. Section 5 of the report discusses the evaluations performed for each location, options for detaining and/or removing the DSI (stream base flow and stormwater runoff during wet weather conditions) from the sewer system, and opinions of estimated capital cost for the following stream inflow solutions:

- Woods Run (8 locations)
- Spring Garden
- Panther Hollow Stream and Lake

Section 5 of this report describes the following solutions that were recommended for each location:

1. **Woods Run** – Detention with slow release of flows into the CSS utilizing GI best management practices (BMPs) to address the 8 inflow locations. A summary of the types of BMPs and capital cost per location is provided in Table 9-5.
2. **Spring Garden** – Detention with slow release into a shallow storm sewer that ultimately discharges to the Allegheny River.
3. **Panther Hollow** – Detention with daylighted surface channel and discharge into the Monongahela River. Modeling estimates of base flow are varied: the current SWMM model provided from ALCOSAN shows 14.0 MG/year of stream base (dry weather) flow, although estimates based on 2015 ALCOSAN flow monitoring data indicate a base stream flow of 68.0 MG/year. Additional flow monitoring and model calibration should be performed to confirm the CSO reduction indicated in Table 9-6.

Table 9-6 also includes the results for the three stream removal/detention solutions. A range of capital costs for the Panther Hollow stream removal solution is provided. Further study and coordination with other projects in the areas adjacent to these DSI opportunities are needed to confirm estimated costs.

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TABLE 9-5
ESTIMATED COSTS OF THE WOODS RUN STREAM IMPROVEMENTS ALTERNATIVES

Distributed Detention			
System #	**Location**	**Description**	**Capital Cost**
1	Northern end of Oakdale Street	Subsurface Storage	$752,000
2	Near Oakdale Street and Mairdale Avenue	Distributed BMPs	$3,869,000
3	Mairdale Avenue and River View Drive	Surface and Subsurface Storage	$1,057,000
4	Benton Field	Surface and Subsurface Storage	$319,000
5	Behind 915 Woods Run Avenue Houses	Distributed BMPs and Subsurface storage	$1,245,000
6	Kilbuck Road	Distributed BMPs and Subsurface storage	$2,343,000
7	Smithton Avenue and Henley Street	Subsurface Storage	$890,000
		Total:	**$10,475,000**

TABLE 9-6 STREAM INFLOW REMOVAL/DETENTION RESULTS				
Category	**Spring Garden**	**Woods Run**	**PANTHER HOLLOW**	**Total**
Capital Cost	$10.7M	$10.5M	$25M - $40M	$46.2M - $62.0M
Overflow Volume Reduced (MG)	52.9	15.0	31.9[1]	99.8
Capital Cost per Overflow Gallon Reduced ($/gallon)	$0.20	$0.70	$0.78 - $1.25	$0.46 - $0.61
Typical Year Stream Volume Removed (MG)	168.8	19.7	98.7[2]	267.5
Capital Cost per Stream Volume Removed ($/gallon)	$0.06	$0.53	$0.25 - $0.41	$0.16 - $0.21

[1]Current SWMM model shows 14.0 MG/year stream base flow, while a base stream flow of 68 MG/year was estimated based on 2015 ALCOSAN flow monitoring. Additional flow monitoring and model calibration should be performed to confirm the CSO reduction.

[2] Based on field measured flow from 2015 ALCOSAN flow monitoring. A base dry weather stream flow of 68 MG/year was estimated. It appears from field investigation that the majority of the wet weather flow is diverted around the existing lake.

The results indicate that stream removal can be cost-effective and competitive with other gray and GI improvements while also providing additional benefits.

9.3 High Yield GI and Stream Inflow Removal Overflow Reduction Results

Table 9-7 provides the overflow reduction results as a result of the implementation of high yield GI and direct stream inflow removal as described in this report and as summarized in Sections 9.1 and 9.2. The results of the evaluation completed as part of this report indicate that 970 MG of overflow (CSO and SSO) would be reduced by the implementation of GI to manage 1,835 impervious acres and direct stream inflow removal/detention for the 480 MGD and 600 MGD WWTP expansion scenarios. Under the Lowered HGL Operation scenario, 690 MG of overflow would be reduced by implementing GI to manage 1,286 impervious acres and direct stream inflow removal/detention. The incorporation of GI and strategic stream removal/detention alternatives, coupled with the three scenarios involving potential WWTP expansion and existing conveyance system configurations (Section 9.1), provide a system-wide overflow (CSO and SSO) volume reduction range of 4.09 BG to 5.20 BG for typical year conditions.

TABLE 9-7
OVERFLOW REDUCTION RESULTS FOR THREE SYSTEM CONFIGURATIONS WITH GREEN INFRASTRUCTURE AND STREAM INFLOW, TYPICAL YEAR, SYSTEMWIDE [1]

Stormwater Management Scenario	480 MGD WWTP WWTP Expansion	600 MGD WWTP Expansion, Sediment Removed, and 19 Regulator Modifications	Lowered HGL Operation During Wet Weather, Sediment Removed, and 19 Regulator Modifications
Number of Priority Sheds Retrofitted with GI	18	18	13
Impervious Acres Managed	1,835	1,835	1,286
Overflow Volume Reduction Attributable to GI (BG)	0.97	0.97	0.69
Aggregate Combined Sewage Capture (30 Sewersheds)	85%	91%	91%
Total ALCOSAN Systemwide Overflow Volume Reduction (BG)[2]	4.09	5.00	5.20

[1] Including overflow reduction that may occur in neighboring sewersheds.

[2] SWMM Model Version 5.1.009 Results (as described in Section 2 of this report).

9.4 Flood Hazard Mitigation

The flood hazard mitigation investigation focused on known highly prone flood hazard areas within the City. PWSA coordinated with the City's Office of Emergency Management and Homeland Security (OEMHS) to obtain background information on the flood hazard sites. Four locations were evaluated as part of this study as listed in Table 9-8.

TABLE 9-8
FLOOD HAZARD MITIGATION EVALUATION SITES

Priority	Location	Description (Provided by PWSA and City)	Focus	Suspected Root Cause
1	13th Ward - Frankstown Ave.	Recurrent flooding along roadway	Level of Service (sewer system)	Sewer surcharges during storm events cause street flooding slopes
2	Chartiers Creek / Morange Rd.	Recurrent flooding at roadway	Level of Service (sewer system)	Sewer surcharges during storm events cause street flooding
3	Streets Run Stream at Calera St.	Recurrent flooding from stream overtopping roadway	Stream	Stream floods due to large rain events; stream flooding interacting with sewer system
4	Nine Mile Run Stream at Commercial Rd.	Recurrent flooding from stream overtopping roadway and culvert	Stream / Culvert Size	Insufficient culvert capacity under Commercial Road

The evaluation revealed that the root causes of the flooding, overflows from the sewer system, and identified poor water quality in the streams were common and were either due to excessive amounts of stormwater entering the sewer system during rain events, poor condition of the existing storm or sanitary sewer assets, or a combination of both. An approach for reducing the flood hazard locations was then determined to be a combination of stormwater management through source control GI BMPs and renewing or improving the existing storm or sanitary assets. This approach allows reduction of the multiple root causes of flooding, overflows, and poor in-stream water quality. Multiple storm events of varying sizes and intensities were analyzed for each location to determine the extents of flooding and levels of protection. Estimates were developed, assuming GI and other improvements would be designed for a flooding level of protection up to the August 31, 2014 storm event condition, with a peak rainfall intensity of 1.05 inches in 15 minutes, and a rainfall volume of 2.25 inches in 10 hours..

1. **13th Ward - Frankstown Avenue Flooding:** This area is located in the combined sewer system and the collection system model indicates that the combined sewer system surcharges in this area from excessive amounts of stormwater runoff leading to flooding at least once in a typical year. To increase the level of protection against flooding from the sewer system in this area to the August 31, 2014 event (1.05 inches of rain in 15 minutes), the stormwater runoff from 23 acres of tributary area would need to be managed with GI. The evaluation also found a flat slope section of 15-inch sewer that needs to be upsized in conjunction with the stormwater runoff management. The pipe upsizing will be performed as part of PWSA's ongoing asset management capital improvement program. The cost for the 23 acres of stormwater management is included as part of the A-42 sewershed high yield GI locations identified for reduction of CSOs.
2. **Chartiers Creek / Morange Road Flooding:** This area is located in the combined sewer system and the collection system model indicates that the sewer system surcharges in this area from excessive amounts of stormwater runoff leading to flooding at least once in a typical year. To increase the level of protection of flooding from the sewer system in this area to the August 31, 2014 event (1.05 inches of rain in 15 minutes), the stormwater runoff from 262 acres of tributary area would need to be managed with GI. By addressing the stormwater runoff from the 262 acres, not only would flooding be reduced, but a CSO reduction of 50 million gallons, representing a 59% reduction, would also be achieved. The capital cost for this work was determined to be $33 million.
3. **Nine Mile Run and Streets Run Stream Flooding:** Both areas experience stream flooding that leads to extensive road and surface flooding from excessive amounts of stormwater runoff. The stormwater runoff appears to primarily originate from the upstream separate sewer systems. The in-stream hydraulic models indicate that flooding occurs in rain events of 0.8 inches or more in 15 minutes. To increase the level of protection against flooding from the sewer system in these areas to the August 31, 2014 event (1.05 inches of rain in 15 minutes), extensive stormwater management is necessary.

   The separate sewer areas tributary to the flooding locations were observed to have excessive amounts of stormwater entering the sanitary sewer system (called rainfall derived inflow and infiltration – RDII) in most locations. In order to manage the stormwater to reduce flooding it is also necessary to manage the stormwater entering the sanitary sewer system as this water leads to SSOs and CSOs into the same streams during both small and large rain events. To optimize both the stormwater management locations for flooding and reductions in the RDII, the stormwater high yield drainage areas were selected in the areas with the highest amounts of RDII. Stormwater can enter sanitary sewers through multiple locations in the public sewers as well as the private property lateral (sewer from a building to the main public sewer). Stormwater can enter through structural defects and leaks in the public sanitary sewers, cross-connections between the sanitary sewers and storm sewers, defects or leaks in the public storm sewers, as well as downspouts or other storm drain connections from private property improperly connected to the sanitary sewer lateral. Separate sanitary sewers were not designed to carry stormwater; only sewage. In both Streets Run and Nine Mile Run sewersheds, the separate sewer systems ultimately enter the downstream combined sewer systems. Therefore, stormwater is not only causing flooding in the streams, but also likely contributing to both downstream sanitary sewer and combined sewer overflows due to RDII influences within the separate sanitary sewers.

Acknowledging these issues, approaches to holistically address the stormwater problems at their sources and manage the stormwater entering both the storm sewers (leading to the flooding) and the sanitary sewers (leading to SSOs and CSOs) were developed. Holistic approaches addressing both issues may be more cost-effective and provide more local community benefits by reducing the root causes of the flooding and overflows. These approaches also allow investment back into the existing sanitary and storm systems (asset management) to address the defects in the systems already constructed rather than building new conveyance and treatment based systems and then having to come back in the future to spend more on asset management of the still failing existing systems.

The evaluation determined for Nine Mile Run that stormwater would holistically need to be managed as described above within 466 acres (29%) of the combined sewer area, and 1,408 acres (59%) of the separate sewer area. For Streets Run, 1,291 acres of the separate sewer area requires holistic stormwater management. The associated capital costs to reduce the flooding, reduce RDII, and manage the sanitary and storm sewer assets within both areas are provided in Table 9-9.

Table 9-9 presents the costs to reduce flooding under two CSO and SSO reduction scenarios. The first includes an RDII removal based solution and the second a conveyance and treatment based solution. Both scenarios were examined to illustrate that regardless of the type of CSO and SSO reduction solution selected, the costs to reduce flooding and asset management must be added to both overflow reduction approaches.

TABLE 9-9 FLOOD HAZARD REDUCTION (COMPARED TO EXISTING CONDITIONS)		
	RDII Removal Based Overflow Reduction	**Conveyance and Treatment Based Overflow Reduction**
Commercial St - Nine Mile Run (M47)		
Capital Cost to Reduce Flooding[1]	$243M	$243M
Sewer Asset Management Cost	$85.7M	$55.7M[2]
RDII Private Source Reduction Cost	$39.6M	Convey and Treat. No RDII removal
Calera St - Streets Run (M42)		
Capital Cost to Reduce Flooding[1]	$29.8M	$29.8M
Sewer Asset Management Cost	$43.5M	$32.6M
RDII Private Source Reduction Cost	$20.8M	Convey and Treat. No RDII removal
Total Cost	$462.4M	$361.1M[2]
Overflow Volume Reduction (MG)	123	62[3]
TY Volume Removed from RDII reduction (MG)	110	0

[1] Average of regional detention and distributed GI BMP costs. If regional detention can be performed, costs could be lower. Additional evaluation, including storm sewer system surveying, beyond the scope of this Assessment is required to develop final capital costs.

[2] 65% applied to asset management cost for convey and treat to account for lower cost due to only addressing structural and maintenance defects over time and not I/I related defects.

[3] Only about a 50% reduction in overflow volume may be achieved because RDII removal is not performed.

The following observations are noted regarding Table 9-9:

- The costs to reduce flooding are substantial, $243 million for Nine Mile Run and $29.8 million for Streets Run. The capital costs are considered order of magnitude estimate and include the average of regional detention and distributed GI BMP costs. If regional detention can be performed, costs could be lower. Additional evaluation, including storm sewer system surveying, beyond the scope of this Assessment, is required to develop final capital costs. See Section 4 of this report for further details.
- Regardless of the type of overflow reduction solution selected, additional costs to reduce flooding and manage the existing sanitary and storm sewer assets are required. On a relative cost per gallon of overflow reduced, the RDII removal based solution provides a better value. Demonstration projects to holistically address the stormwater in both the storm and sanitary systems should be performed to better quantify the costs and associated benefits. For this reason, the capital costs for this work in Nine Mile Run and Streets Run are not included in the alternatives presented later in this section.
- The results indicate that the stormwater runoff leading to the flooding primarily originates from municipalities outside of the City's borders. It is recommended that PWSA work with the upstream municipalities, primarily Wilkinsburg and Edgewood in Nine Mile Run, and Brentwood, Baldwin and Whitehall in Streets Run, to perform the recommended demonstration projects. This type of collaboration and the types of demonstration projects encouraged are consistent with the flow targets and source reduction approach being required by the regulators and would provide good example demonstrations to show the multiple benefits of flooding reduction, RDII reduction, and asset renewal that can be achieved.

9.5 Urban Planning

PWSA undertook a strategic urban planning process focused on developing a holistic "Green First" approach. This approach emphasizes the identification of opportunities that support both resilient infrastructure strategies and are catalytic redevelopment opportunities within individual Pittsburgh sewersheds. The City and many engaged collaborative partners continue active planning pursuits that focus on the same streets, neighborhoods, and parks; these are common areas with the high-yield drainage areas where GI was being targeted as part of this Assessment. Through a highly collaborative planning process, PWSA worked with various stakeholders to understand each community's assets, current planning processes, and community goals, and secured community and stakeholder input. Section 6 of this report more fully describes this process and approach.

From the synthesis of three primary factors (planned redevelopment, existing conditions, and high yield stormwater runoff areas targeted for GI), six priority sewersheds were selected where proposed GI would best complement strategic urban development plans, existing characteristics, and high yield areas to most effectively illustrate what a Green First approach could look like for the six selected priority sewersheds in the City. The six selected areas are shown in Table 9-10.

TABLE 9-10 GI AND URBAN PLANNING ANALYSIS LOCATIONS		
City Area/Neighborhood	**Sewershed Point of Connection (POC)**	**River Basin**
Four Mile Run	M-29	Monongahela River
Washington Blvd and Negley Run	A-42	Allegheny River
South Side	M-16	Monongahela River
Woods Run	O-27	Ohio River
Heth's Run	A-41	Allegheny River
Hill District/Uptown	M-19	Monongahela River

PWSA worked with the stakeholders to establish a set of Guiding Principles to further assist in the selection of the GI locations with the sewersheds that combined the data driven, technical metrics used to measure the effectiveness of CSO reduction within the priority sewersheds. These Guiding Principles emerged from discussions with the Mayor and his staff, multiple City departments, and key community stakeholders.

Many of these Guiding Principles support the quantitative outcomes for CSO reduction; others, however serve to broaden the lens and establish qualitative outcomes to improve the communities where these investments are being made, further complementing the redevelopment efforts proposed in these areas. The Guiding Principles offer an additional benefit: they better leverage the limited resources of City departments into a shared effort.

The seven Guiding Principles that framed the urban planning processes included in this effort are outlined below along with a brief description of each:

1. **Cost-Effective Public Realm Investment:** By investing in City-owned property within the public realm the cost of acquired private property for GI is avoided. Furthermore, improvements can be more efficiently shared across City departments when other planned improvements are coordinated
2. **Create Workforce Development Opportunities:** Investment in GI should be viewed as an opportunity to provide jobs, especially within communities that would best benefit from access to new or better employment opportunities. Ideally, workforce development will encompass all segments of the populations to develop lifelong careers, from the PhD's researching and monitoring the effectiveness of GI, to the "Ph-Do" working to implement the construction of proposed GI in addition to maintaining it.
3. **Re-Establish Riverfront Connections:** As Pittsburgh further redevelops and enhances its numerous riverfront areas, opportunities to improve and create new

riverfront connections should be explored in conjunction with proposed GI, providing pathways linking people and runoff to the City's three rivers.

4. **Complete Streets Approach:** Pittsburgh is looking to develop a network of key City corridors into complete streets, which are streets that focus multiple modes of transportation, placing emphasis on public transit, bicyclists, and pedestrians. GI should be incorporated within these complete streets as many of the corridors also have the highest potential to reduce CSO.
5. **Focus on Healthy, Walkable Communities:** Emphasis should be placed on enhancing corridors to improve access to recreation and healthy food, and encourage walking beyond the Complete Street corridors. GI can leveraged to further enhance the effectiveness of improving the overall health and safety of a community.
6. **Resilient Infrastructure:** GI can be used to support the efforts of the City in becoming more resilient by reducing flooding, decentralizing runoff capture, and upgrading the aging infrastructure through asset management. Creating a smart system utilizing and optimizing the existing infrastructure that more effectively and efficiently handles stormwater today and in the future.
7. **Align with People, Planet, Place and Performance (P4) Metrics:** Pittsburgh's P4 looks to forge a new model for urban growth and development that is innovative, inclusive and sustainable. GI certainly addresses all four of the components of this framework.

From these Guiding Principles, GI concept plans were developed within each of the 6 urban planning sewersheds focused around the high yield stormwater runoff areas while also weaving these opportunities into a larger vision that creates neighborhood nodes, corridors, and links community assets with interconnected GI strategies. The sewershed-based systems approach used urban planning and community revitalization to shape the GI concept plans, serving as a catalyst for a broader vision that can be implemented and embraced by the local communities.

9.5.1 Urban Plan Capital Costs

The capital costs for the GI proposed as part of the six sewersheds urban plans assume that the identified high yield stormwater runoff areas are captured within each sewershed and stormwater runoff is detained and slowly returned back to the CSS. The same assumptions for GI sizing and cost estimating as described in Sections 7 and 9.1 of this report were applied to the GI included in the urban plans. The following items are not included in the urban plan GI capital costs:

- Daylighting of captured stormwater flows to the rivers in each of the 6 sewersheds, except for Panther Hollow Lake in M-29 (which was included in the costs as a stream removal location). Further study and stakeholder coordination is required to evaluate the costs and added benefits of additional stream daylighting of captured stormwater flows to the rivers.
- Property acquisition costs outside of the right-of-way were not included. Some urban plan concepts have been developed that could be located on currently abandoned private properties or properties not currently owned by the City, for

example, the re-creation of Silver Lake in A-42. Because of the unknowns of property acquisition, the costs and associated benefits of siting GI at these private property locations requires further study. However, the associated stormwater in the high yield stormwater runoff areas surrounding these locations is still included in the developed capital costs with the designation of GI being located in the right of way to capture high yield stormwater runoff should the private property acquisition costs prove to not be feasible or cost-effective.

The GI costs for the urban plans, not including the above described exceptions, are included in the Green First Plan costs presented in Section 9.6 below.

9.6 Green First Plan Results

The purpose of the City-Wide GI Assessment was to determine the opportunities for implementing large scale GI across the City to address a variety of issues, including combined sewer and sanitary sewer overflows, stream inflow removal/detention, localized flood hazard reduction, basement sewage backup reduction during rain events, and developing a stormwater overlay lens for use as a comprehensive planning tool for future new and redevelopment. The results of the developed Green First alternatives are summarized in Tables 9-11 and 9-12. The results indicate that maximizing the treatment plant capacity and optimizing the existing tunnel assets have great value. The GI that is needed for additional overflow reduction to meet the 85% combined sewage capture goal can also reduce basement sewage backups and localized surface flooding.

TABLE 9-11
CAPITAL COSTS AND OVERFLOW REDUCTION FOR THE 30 PRIORITY SEWERSHED GREEN FIRST APPROACH

System	Plant Capacity (MGD)	480 MGD WWTP Expansion	600 MGD WWTP Expansion & System Improvements	Lowered HGL Operation During Wet Weather Conditions
	Sediment Removed From Existing Tunnel?	No	Yes	Yes
	19 of 30 CSO Underflows Modified to Allow More Flow to Tunnel?	No	Yes	Yes
City-Wide	GI Impervious Area Managed (acres)	1,835	1,835	1,286
	Flood Hazard Reduction and Overflow Reduction Costs included?	Only Frankstown Road and Morange Road Included		
	Stream Removal/Detention Costs included?	Panther Hollow, Woods Run, and Spring Garden Included		
	Surface Flooding and Basement Sewage Backup Reduction Costs Included?	In sewersheds where GI is located, it was assumed that GI would be designed for a flooding level of protection up to a rainfall intensity of 1.05 inches in 15 minutes.		
System Improvements	WWTP Upgrade Capital Cost ($M) [1]	$334	$378	$378
	Existing Tunnel Cleaning and Modernization Allowance ($M) [2]	$0	$200	$200
	New Wet Weather Pump Station Cost to Allow Lower HGL Operation ($M) [3]	$0	$0	$150
	High Rate Treatment at WWTP to treat flows above 600 MGD ($M) [2]	$0	$0	$70-$100

TABLE 9-11
CAPITAL COSTS AND OVERFLOW REDUCTION FOR THE 30 PRIORITY SEWERSHED GREEN FIRST APPROACH

GI + Stream Removal	Green Infrastructure ($M) [4]	$690 – 920	$690 – 920	$490 – 660
	Stream Removal/Detention ($M)	$46 – 62	$46 – 62	$46 – 62
	Total Capital Cost ($M)	**$1,070 – 1,310**	**$1,310 – 1,560**	**$1,340 – 1,550**
	Total System Wide Overflow Reduction (BG)	**4.09**	**5.00**	**5.20**

[1] From ALCOSAN Wet Weather Plan Report (2013).

[2] Allowance.

[3] From ALCOSAN Wet Weather Plan report (2013). Used cost for new tunnel dewatering pump station.

[4] Includes costs for GI, downspout disconnections, Frankstown Road (part of the A-42 estimated cost), and Morange Road flooding reduction ($33 M).

TABLE 9-12
TOTAL COSTS (INCLUDING O&M) FOR THE 30 PRIORITY SEWERSHED GREEN FIRST APPROACH

	480 MGD WWTP Expansion	600 MGD WWTP Expansion & System Improvements	Lowered HGL Operation During Wet Weather Conditions
GI Impervious Area Managed (acres)	1,835	1,835	1,286
Total Capital Cost ($ Million)	**$1,070 – 1,310**	**$1,310 – 1,560**	**$1,340 – 1,550**
Total System Wide Overflow Reduction (billion gallons)[1]	**4.09**	**5.00**	**5.20**
Total Capital Cost Per Overflow Gallon Reduced	**$0.26 – 0.32**	**$0.26 – 0.31**	**$0.26 – 0.30**
Annual O&M Cost for GI (at buildout) ($ Million)	$8.1	$8.1	$5.7
50-Year Net Present Value (Annual O&M + GI Replacement at Year 25) ($ Million)	$288	$288	$202
Total Net Present Value Cost ($ Million)	**$1,358 – 1,598**	**$1,598 – 1,848**	**$1,542 – 1,752**

[1] SWMM 5.1.009 Results.

9.6.1 Key Points for Interpreting Comparisons with ALCOSAN's Recommended Plan

Some of the components from the City-Wide GI Assessment described in this report have many similarities to, but also many important differences from, ALCOSAN's Recommended Plan. Both plans are composed of a combination of projects to help mitigate ALCOSAN's and the region's CSOs and SSOs. When the analyses were being conducted for this Assessment, the Recommended Plan report (2013) and Starting at the Source report (2015) were the most recent ALCOSAN public documents available. It is important to note that ALCOSAN is still in negotiations with the US EPA regarding the details of the plan to be implemented. If the plan agreed to between ALCOSAN and the regulators differs from the Recommended Plan, some of these points may change or no longer apply. Listed below are some of the most important differences between the Green First Plan and the Recommended Plan.

- **The Recommended Plan was developed with sufficient detail to be directly implementable while the Green First Plan was intended to determine what could be possible if a large scale GI approach were implemented.** ALCOSAN's Recommended Plan was developed over several years and by numerous consultant teams specifically to provide a detailed and implementable plan to address specific collection system issues and comply with the terms of their Consent Decree. The Green First Plan, as it has been developed to date, provides valuable insight into how effective a GI focused plan could be, but it has not been developed to the same level of detail as the Recommended Plan.
- **The Recommended Plan focuses on the entire tributary collection system to the WWTP while the Green First Plan focusses on the 30 priority sewersheds.** The Recommended Plan was specifically developed to provide particular outcomes for SSO reduction, CSO reduction, and prioritization of sensitive receiving water areas. The various components of the Recommended Plan were developed to meet specific regulatory requirements. The Green First Plan focused on the 30 priority sewersheds and what benefits could be realized in those areas from a large scale GI approach. Although both approaches provide some similar benefits (i.e., untreated overflow reduction) they do not provide benefits necessarily in the same locations or to the same benefit level.
- **The Recommended Plan was specifically developed to achieve outcomes related to ALCOSAN's responsibilities in the functioning of the overall collection system.** ALCOSAN is responsible for both larger sized conveyance features (shallow-cut and deep interceptors) that convey wastewater from tributary systems and for treating the conveyed wastewater before discharging it to receiving waters. As would be expected, the Recommended Plan focuses on mitigating negative aspects that are relevant to its responsibilities (principally reducing untreated CSO and SSO discharges). However, upstream tributary systems (such as PWSA) have other outcomes they are trying to achieve beyond just mitigating untreated overflows. Much of the Green First Plan is focused on these other outcomes such as reducing localized surface flooding, reducing basement sewage backups, disconnecting streams from entering the collection system, and evaluating the potential benefits of urban planning opportunities, in

addition to the reduction of untreated overflows. Because the focus of these two plans are very different, the results that each provides needs to be understood in the context of what they were each trying to achieve.

- **Although the goals and outcomes of ALCOSAN's Recommended Plan and the Green First Plan are different, some types of comparisons can be performed.** Reducing overflow volumes is one of the most common regulatory requirements for any long term control plan. Although the Recommended Plan and the Green First Plan have different goals and types of benefits, they both provide overflow reduction as a key benefit. As a result, comparing the overflow reduction benefits can provide meaningful insight on the benefits of the two plans. However, it is important to reemphasize that the relative portion of the CSO vs. SSO reductions of the two plans will be different and the locations of where the overflow reductions occur will not be the same.
- **The Green First Plan scenarios incorporate some common gray components and some different gray components compared to the Recommended Plan.** The Recommended Plan includes the construction of new tunnels and increasing the capacity of the Woods Run WWTP as core components of the plan. The scenarios investigated for this Assessment also include increasing the capacity of the WWTP, but also include improvements not currently in the Recommended Plan. One such element is the removal of the sediment in the existing interceptor tunnels that is assumed as part of the 600 MGD (WWTP Expansion) and the Lowered HGL Operation scenarios. Removing the sediment allows greater flows to be conveyed to the WWTP. ALCOSAN does not assume the removal of the sediment in the interceptor tunnel as part of the Recommended Plan. Also, the Lowered HGL Operation scenario assumes that an HGL level in the Main Pump Station wet well at a level that is also not incorporated into the Recommended Plan. These operational conditions would need to be studied in coordination with ALCOSAN to determine their viability.

9.7 Triple Bottom Line Benefits

TBL benefits represent a unique value addition of GI implementation. Section 8 detailed the various TBL benefits calculated for this Assessment and a summary of those results is included in Table 9-13 for both the 1,286 and 1,835 impervious acres managed scenarios. These benefits are calculated assuming a 10-year construction period and a 50-year in service period for the GI. The total TBL benefits range between $390 million and $850 million net present value (NPV). It is important to note that this flood reduction benefit is the flood reduction provided by the distributed GI and not from the specific flood hazard investigations detailed in Section 4 of this report. These TBL benefits from implementing the recommended City-Wide GI Assessment offer significant benefits to the City and associated ratepayers; benefits not currently available with a solely gray infrastructure approach to overflow and localized flooding reduction.

TABLE 9-13
50-YEAR TBL NET PRESENT VALUE (NPV) BENEFITS

Category	GI TBL Benefits (90% Confidence Interval NPV)			
	1,286 GI Managed Acres		1,835 GI Managed Acres	
	Low	High	Low	High
Air Pollution Reduced by Vegetation	$5,070,000	$9,180,000	$7,260,000	$13,090,000
Carbon Reduced by Vegetation	$710,000	$2,960,000	$1,010,000	$4,220,000
Flood Risk Reduction	$333,130,000	$666,260,000	$335,750,000	$671,500,000
Heat Island Effect Reduction	$3,020,000	$6,750,000	$4,280,000	$9,610,000
Property Value Increase	$33,120,000	$68,270,000	$54,770,000	$112,900,000
Recreational Value Addition	$9,880,000	$15,550,000	$14,120,000	$22,210,000
Economic Water Quality Benefit	$7,280,000	$9,780,000	$10,390,000	$13,950,000
Total TBL Benefit	**$392,212,000**	**$778,750,000**	**$427,580,000**	**$847,480,000**
Total Benefit / GI managed impervious acre	**$305,000**	**$606,000**	**$233,000**	**$462,000**

It is also likely that the true TBL benefits are higher than those listed in Table 9-13. The numbers are likely conservative for the following reasons:

- **Not all TBL benefit types were included in the calculations.** An example is the Shadow Wage benefit which results from jobs created by the GI projects for operations and maintenance, material supply and construction. Insufficient local data was available to perform these calculations. However, the GI O&M costs development determined that 17 to 25 new jobs, 1,286 managed acres and 1,835 managed acres scenarios respectively, for GI O&M would be created. It is recommended that further analysis is performed to confirm the Shadow Wage benefits associated with the City-Wide GI program.
- **Conservative assumptions have been made for the Flood Risk Reduction benefit.** Although the Flood Risk reduction benefit is by far the largest TBL value it is still likely conservative – meaning that the actual calculated value is less than the likely real benefit. For example, the property devaluation from having a flood prone house or property has not been included in the calculation. Having a history of basement or property flooding will almost certainly reduce a home's value when trying to sell it or it could potentially make the home unsellable. Based on the number of properties projected to be affected by localized surface flooding and basement sewage backups, the cumulative property devaluation and the associated increase in resultant property values from the localized flood reduction by GI is likely significant and if included would further increase the Flood Risk Reduction benefit.

9.8 Key Findings and Recommendations

The data and results generated from this Assessment lead to the following key findings and recommendations:

9.8.1 Key Findings:

1. **Acknowledge additional clean water regulatory requirements for the City.** Large-scale GI investment is attractive because it provides multiple benefits and can address multiple regulatory requirements, including overflow reduction and water quality, localized surface flooding reduction, and basement sewage backup reduction during rain events, and can provide asset management..
2. **May achieve nearly equal overflow volume reduction and potentially reduce costs compared to the Recommended Plan.** Large scale GI investment across a subset of the selected 30 priority sewersheds combined with key gray infrastructure investments can result in a feasible and cost-effective solution. The results from Tables 9-11 to 9-13 indicate that a reduction of between 4.1 BG and 5.2 BG of untreated CSO and SSO volume in the ALCOSAN conveyance and treatment system could possibly be achieved by investing in the existing WWTP, the existing interceptors and GI in a subset of the 30 priority sewersheds evaluated in this Assessment. These scenarios also provide other TBL and flow reduction benefits that makes these compelling alternatives that appear deserving of further detailed study and demonstration.

3. **Provides significant TBL benefits.** The calculated TBL benefits range from $390M to $850M from the distributed GI implementation. The calculated TBL benefits included in this report do not include all potential TBL benefits that could be realized. It is expected that other TBL benefits, such as the creation of green jobs to construct, operate and maintain the GI could also be significant.

4. **Addresses reduction in overflows, localized surface flooding, and basement sewage backups, and increases the resiliency of the existing sewer infrastructure.** By designing GI to provide distributed storage and source control, the root causes of overflows, flooding, and poor water quality – excessive amounts of stormwater runoff – can be reduced.

5. **Removes or detains streamflows from the ALCOSAN system.** The GI program recommends that the 10 largest sources of direct stream inflow be removed and/or detained to reduce overflows and reduce sediment from entering the ALCOSAN interceptors. This approach may also allow for targeted investment to modernize the existing deep tunnel interceptors by adding additional access shafts to enable more effective cleaning and future maintenance.

6. **Supports the development of local community urban plans.** PWSA undertook a strategic urban planning process focused on developing a holistic "Green First" approach. This approach emphasized the identification of GI opportunities that can support resilient infrastructure strategies and can be catalytic redevelopment opportunities. PWSA, through a highly collaborative planning process, worked with the various stakeholders to understand each community's assets, current planning processes, community goals, and input.

7. **Demonstrates the value of source control to the entire region. The benefits from this Assessment extend to the municipalities beyond the City.** The Green First alternatives provide multiple regional benefits to the tributary municipalities. The sewer collection system is inextricably and hydraulically linked. Taking a stormwater gallon out at one location frees up capacity for another stormwater gallon to enter elsewhere. By capturing and slowing the stormwater down within the City and surrounding areas, this effectively frees up capacity in the existing interceptors to allow portions of the municipalities' flows to make it to the WWTP, thereby also reducing regional overflows. The results show that overflow volume systemwide is reduced and may provide similar overflow volume reduction to ALCOSAN's Recommended Plan.

8. **The methodologies and "blueprints" from this Assessment can be applied Region-wide.** High yield stormwater runoff capture locations both within the combined sewer systems (CSS) and separate sewer systems (SSS) exist across the ALCOSAN service area. This study revealed that the region has a stormwater management problem that leads to having a CSO and SSO problem and excessive stormwater entering the CSS and SSS in many locations across the service area. Intercepting and managing this stormwater locally provides multiple benefits for far reaches downstream. The results support and re-affirm a regional approach to stormwater management at the locations that maximize stormwater management, overflow reduction, and local community benefits.

9. **Implementing GI does not limit any future gray or green infrastructure investment.** The nature of GI projects allows them to be implemented incrementally while evaluating their effectiveness on the system conveyance. Most gray infrastructure does not lend itself to an incremental investment. For example, a storage tank must be built to a defined volume that is expected to meet a performance requirement. If it is later determined that additional storage is needed, it is typically not possible to "scale up" the existing tank and a completely new tank would need to be built. Because its performance can be continuously evaluated, the risk of overbuilding or underbuilding GI is greatly reduced versus traditional gray infrastructure. GI can be complementary to any future infrastructure investment.

10. **Employs GI technologies that shave off peak flows during and after wet weather events.** The high yield GI elements in this Assessment were structured to apply a "delay and slow return" approach rather than being intended to physically remove the flows from the collection system. Even when applying a conservative 0.1 in/hr infiltration rate for the periods when the flow was resident in the GI elements, significant volumes are predicted to be offloaded from the collection system. Over the typical year roughly 40 percent of the flow that enters the modeled GI BMPs is removed due to evaporation and infiltration. These findings will be confirmed with the planned demonstration projects.

9.8.2 Key Recommendations:

1. **Work with ALCOSAN and support efforts to maximize the ultimate capacity of the Woods Run WWTP.** The system improvement modeling simulations during this Assessment determined that the most foundational improvement for reducing untreated overflows in the ALCOSAN tributary collection system is upgrading the Woods Run WWTP wet weather treatment capacity.

2. **Work with ALCOSAN and support efforts to maximize the conveyance capacity and develop effective asset management options for ALCOSAN's existing deep interceptors.** After the Woods Run WWTP, improving the conveyance and asset management condition of the existing deep interceptors is the next best investment to reduce untreated overflows and increase the viability of GI alternatives. The construction of new access shafts to the existing deep interceptors would improve accessibility, address issues with entrained air, enable proper cleaning and maintenance, and with improved access for inspection and maintenance, reduce the risk of a failure. PWSA can proactively assist by supporting removal of influent streams and building grit traps to keep sediment from being carried by streamflows into the interceptors. This can significantly reduce the sediment load being conveyed to the interceptors and reduce future cleaning needs.

3. **Advocate, support and investigate the application of real time controls to PWSA diversion chambers as a potential additional cost effective effort to increase performance of the existing collection system infrastructure.** The flow control devices in most existing diversion structures consist of tipping gates that are configured to allow reduced flows to enter the interceptors during wet weather conditions to prevent overloading. Adding real time control to these

existing flow control devices at the interceptors could allow optimized control of flows and could provide even greater overflow reduction.

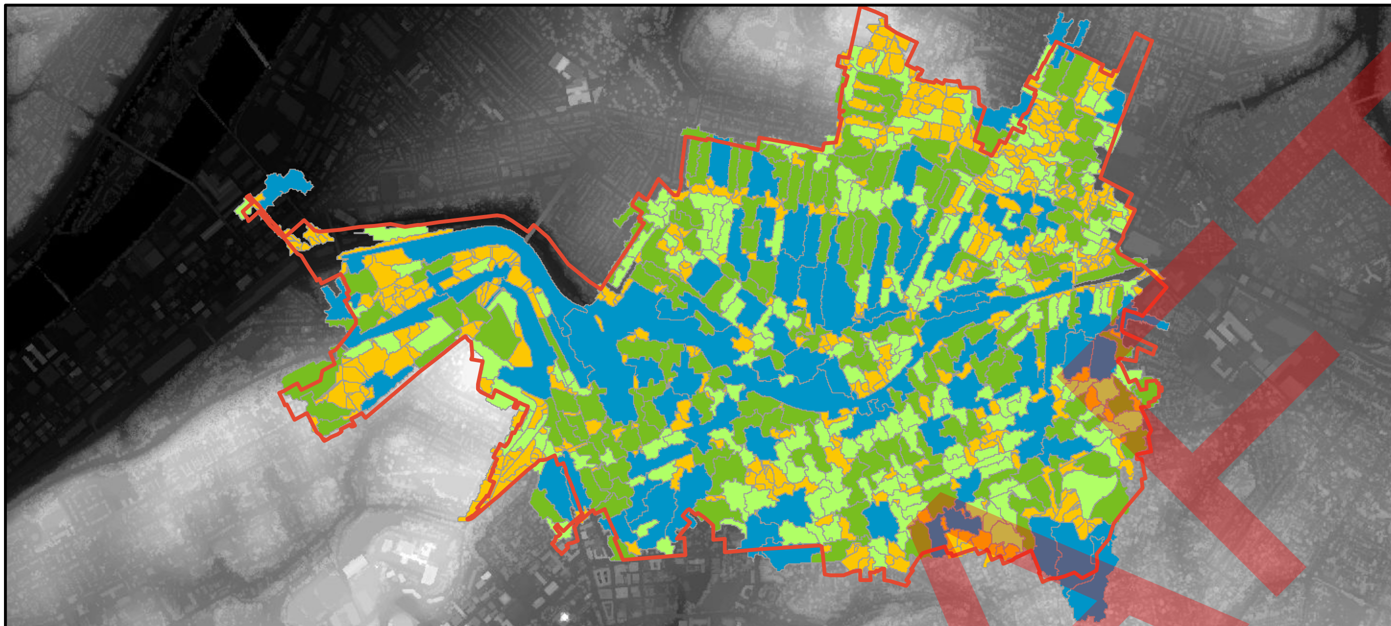
4. **Implement several demonstration projects and evaluate their performance.** The GI demonstration projects will provide local data on how well the various GI BMPs perform and confirm the modeling assumptions used. Evaluation of these initial results will serve as a checkpoint to determine if the GI BMPs are performing as expected or if course correction is needed.

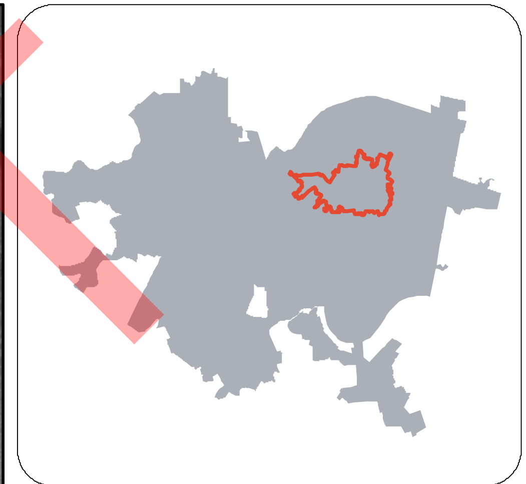
5. **Based on the intelligence from the GI demonstration projects, implement large-scale targeted GI installations.** Assuming the demonstration projects provide positive results, it is recommended that the highest yield stormwater locations identified in the 30 priority sewersheds be targeted first in a broader GI implementation. This implementation would provide the first large-scale results and another important check of GI performance, to evaluate if it continues to represent the most cost effective investment to meet PWSA's and the region's regulatory requirements.

6. **Use the collected data to improve the ALCOSAN SWMM model to enable it to be effectively used for PWSA, the City, and the region.** The SWMM model provided by ALCOSAN for this Assessment was originally built to evaluate larger scale gray infrastructure for the specific purpose of evaluating existing CSO and SSO volumes and the corresponding CSO and SSO reduction benefits of various gray alternatives. PWSA's goals include addressing issues such as designing specific GI implementations, evaluating upstream impacts such as basement sewage backups and direct stream inflows, as well as reducing localized surface flooding hazards. Each of these priorities require more model detail than the current SWMM model provides to allow for more accurate quantification of these geographically disparate problems and solutions. As the model detail is improved, potential GI investments can be more accurately evaluated, sized, and targeted to address specific problems.

7. **Work with neighboring municipalities to implement demonstration projects in both the CSS and SSS to confirm the value of source control.** High yield stormwater capture locations, both within the CSS and SSS, exist across the entire regional ALCOSAN service area. The region's stormwater management problem knows no political boundaries. Siting and implementing projects that can demonstrate the different types and effectiveness of source control that benefit the local municipality, and also PWSA and ALCOSAN, is an important next step.

A22 Sewershed Stormwater Overlay





A22 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

A22 Sewershed Target Areas

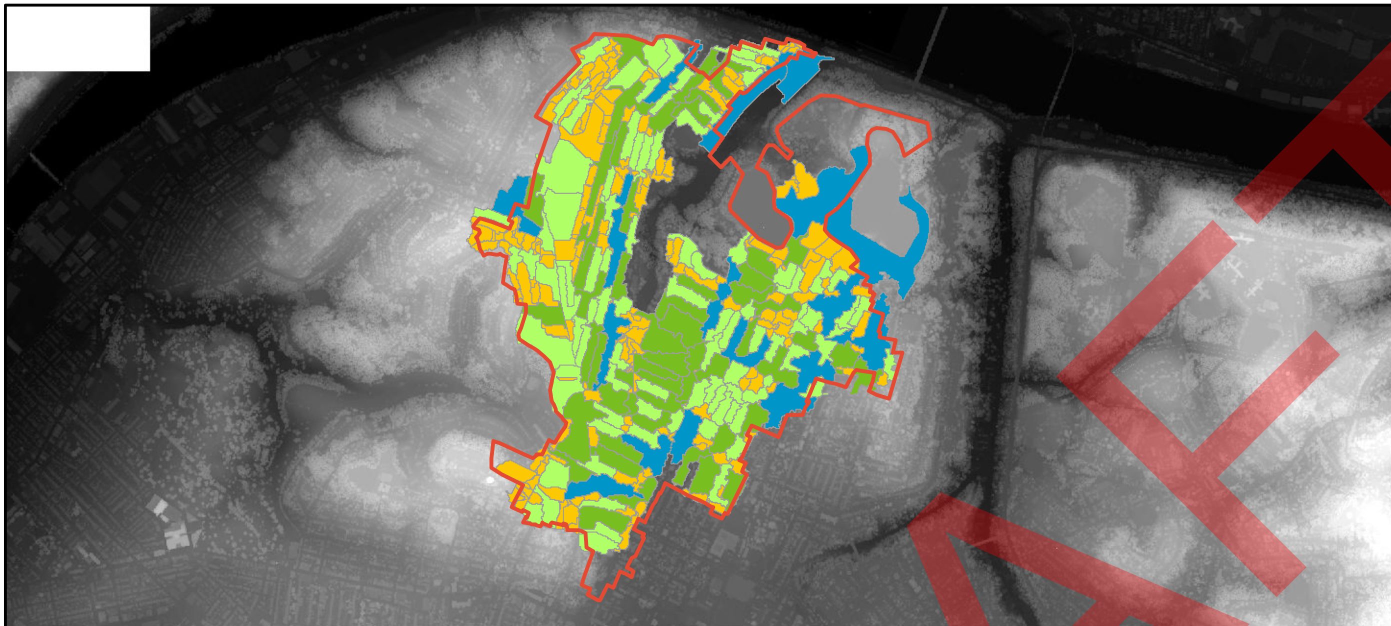
- 30% Target Areas - Lowered HGL During Wet Weather Conditions
- 43% Target Areas - 480 MGD

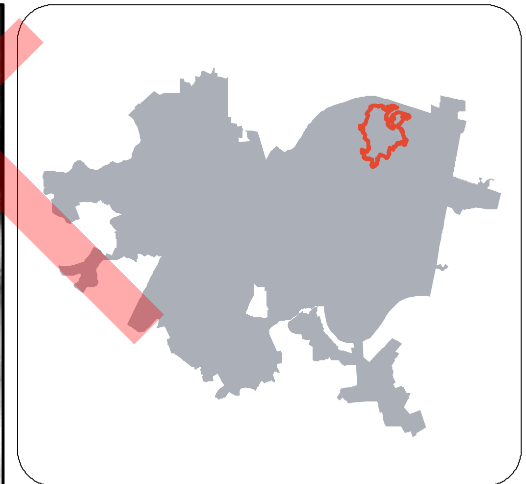
0 0.25 0.5 1 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A41 Sewershed Stormwater Overlay





A41 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

A41 Sewershed Target Areas

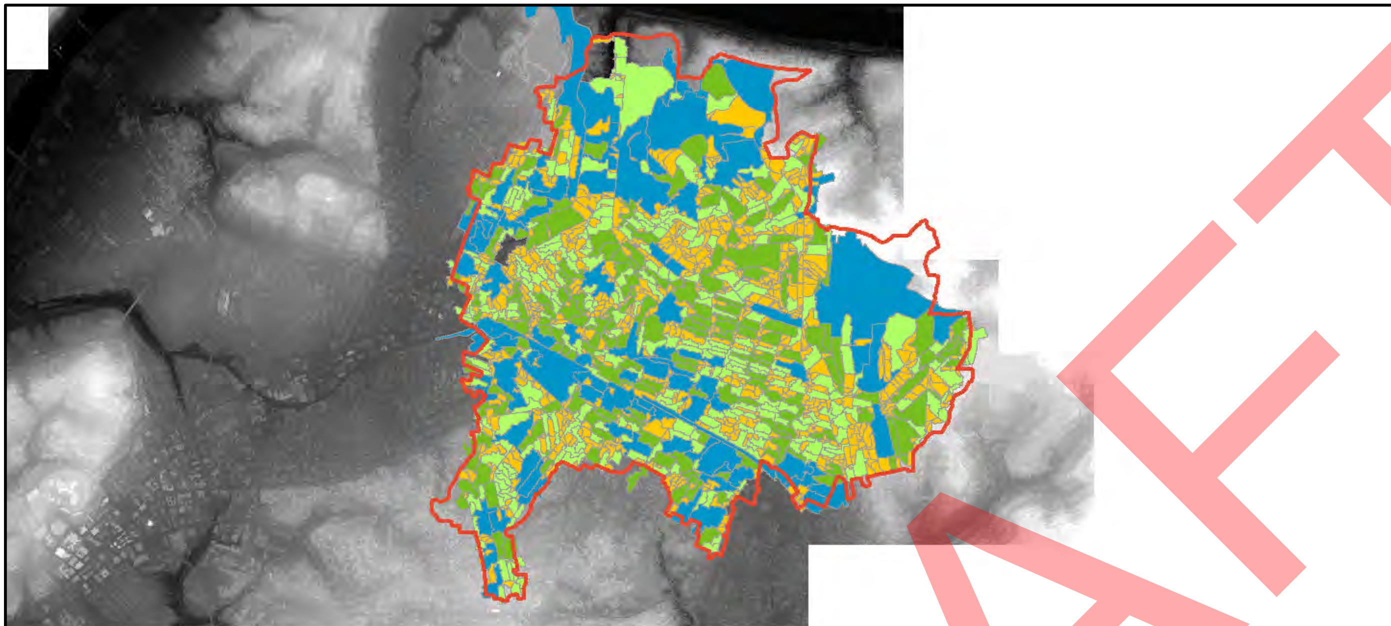
- 60% Target Areas - Lowered HGL During Wet Weather Conditions
- 85% Target Areas - 480 MGD

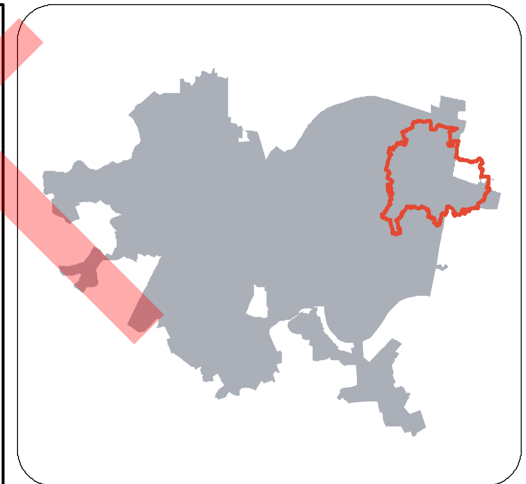
0 0.25 0.5 1 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A42 Sewershed Stormwater Overlay



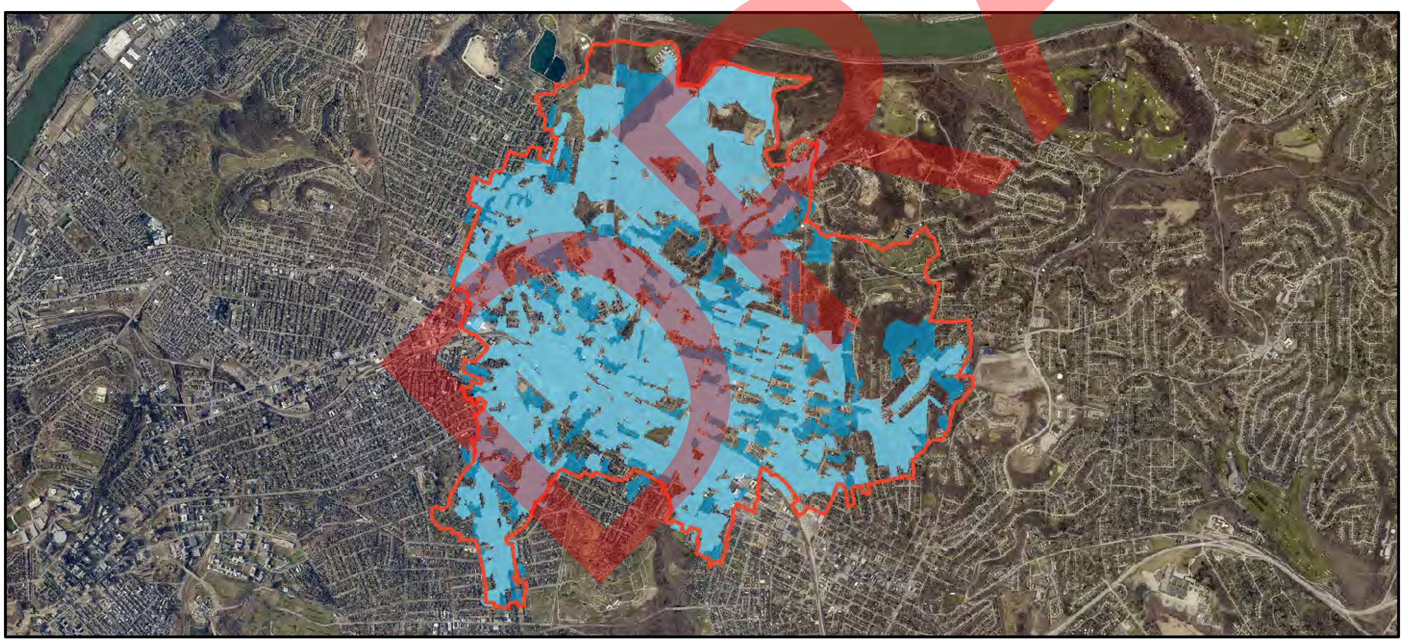


A42 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

A42 Sewershed Target Areas

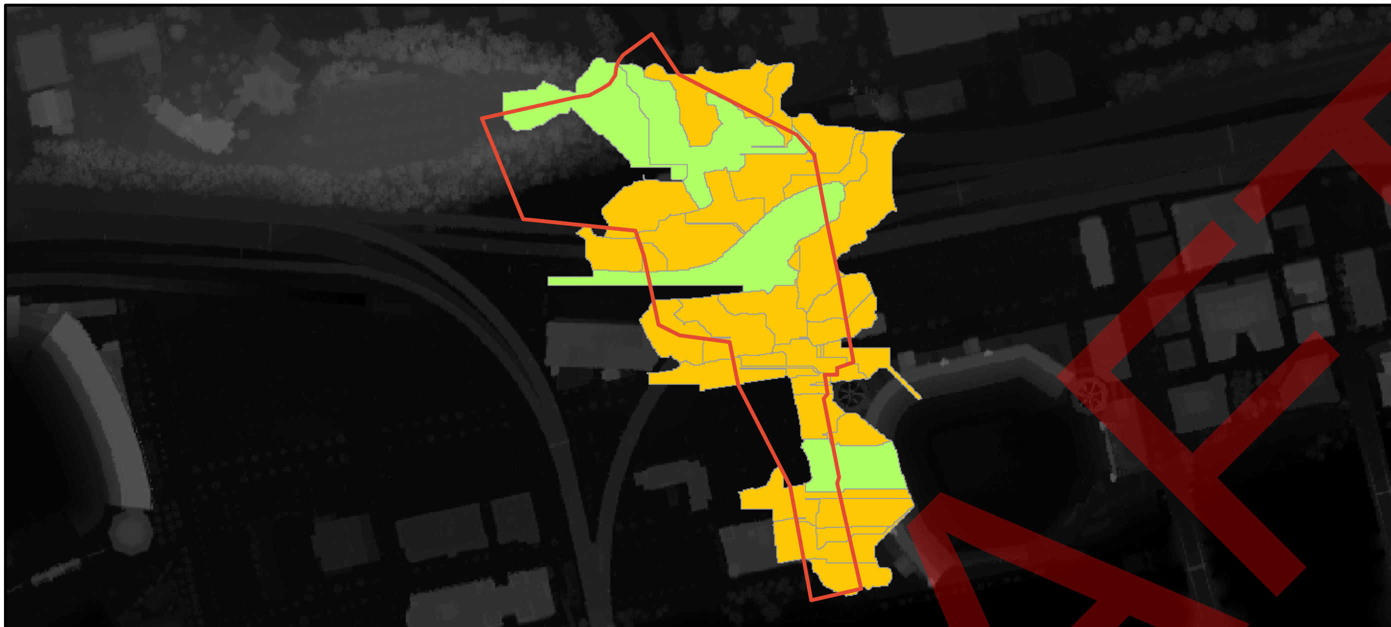


- 57% Target Areas - Lowered HGL During Wet Weather Conditions
- 73% Target Areas - 480 MGD

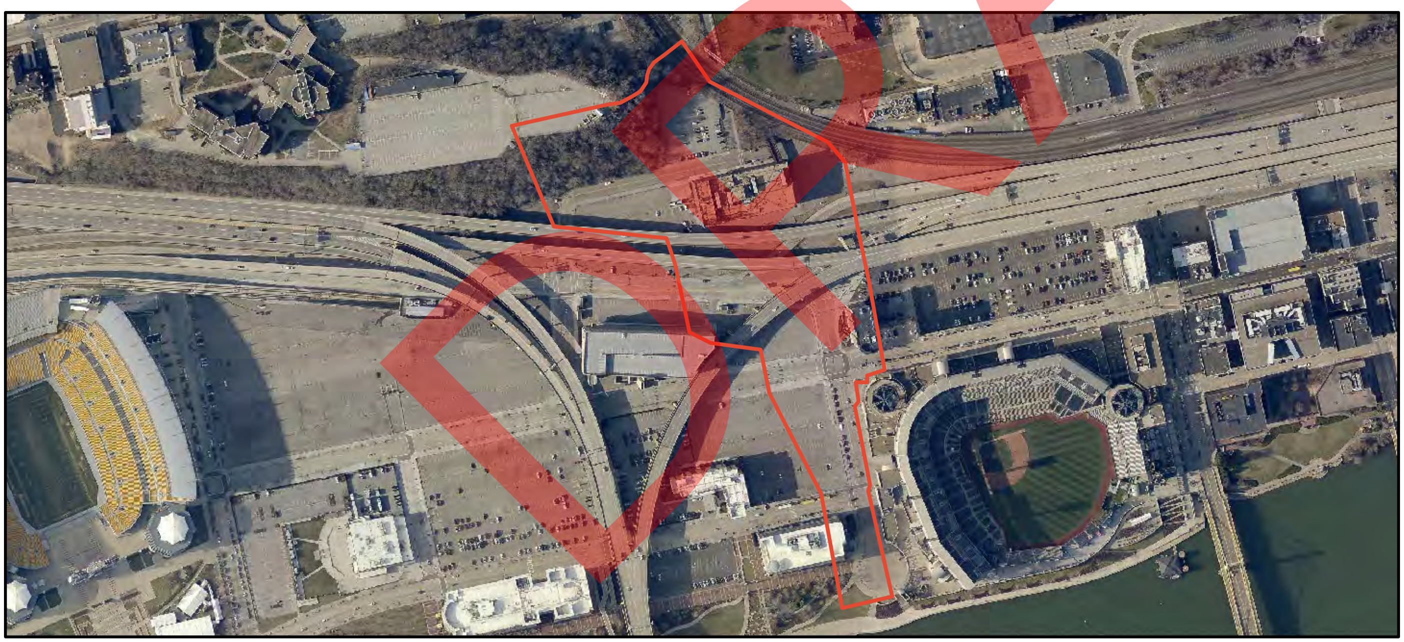
0 0.5 1 2 Miles

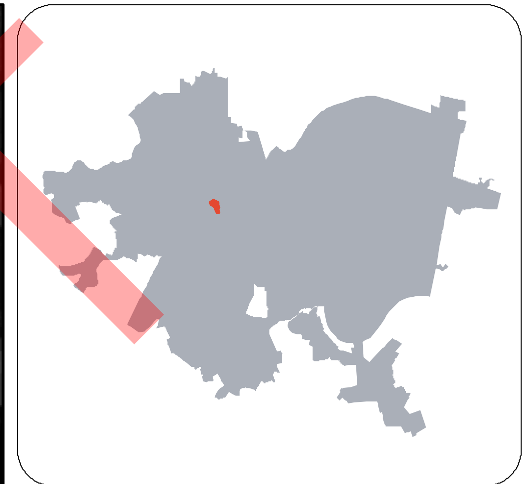
Appendix A: Sewershed Stormwater and Target Area Maps

A47 Sewershed Stormwater Overlay



A47 Sewershed Target Areas





A47 Arc Hydro Areas
Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

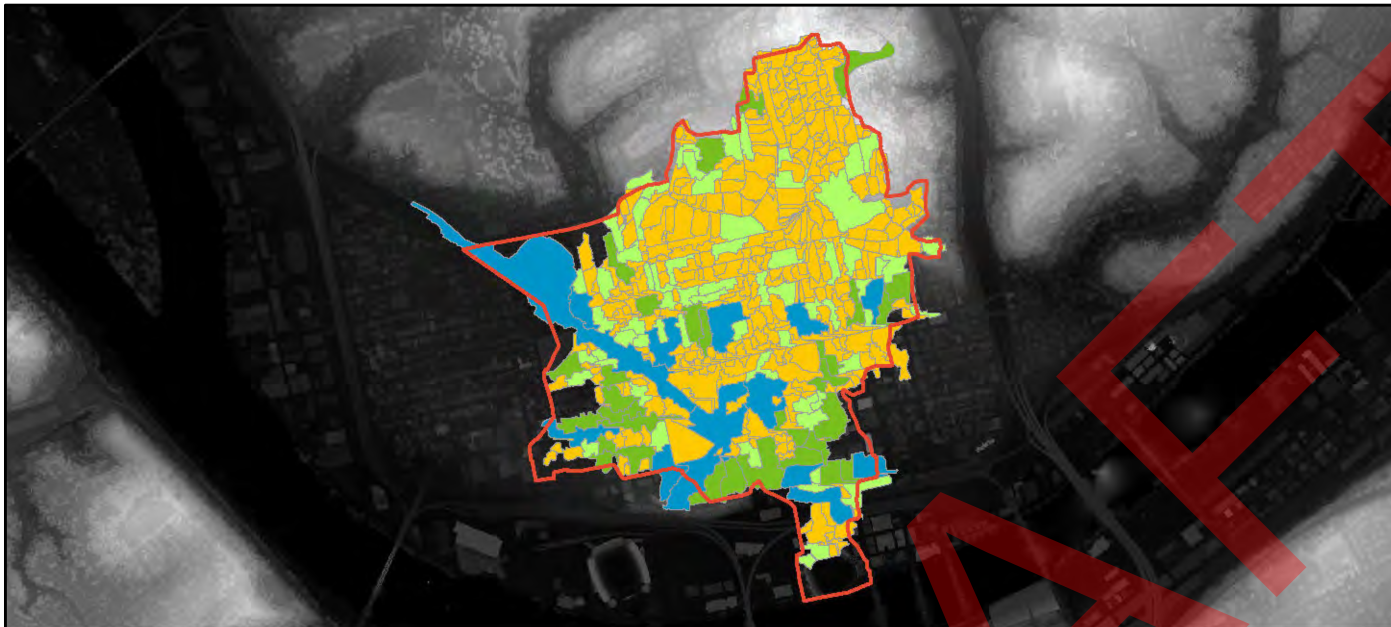
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

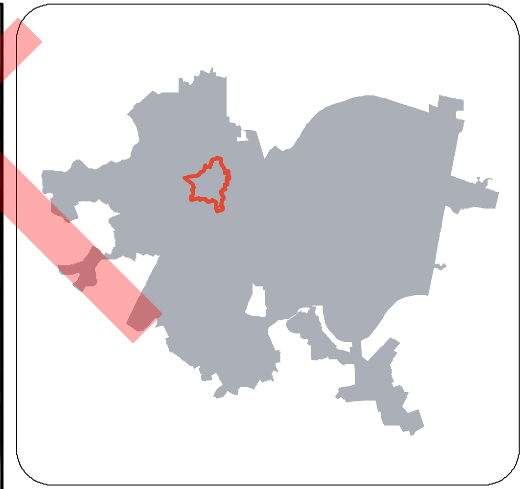
0 0.05 0.1 0.2 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A48 Sewershed Stormwater Overlay





A48 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

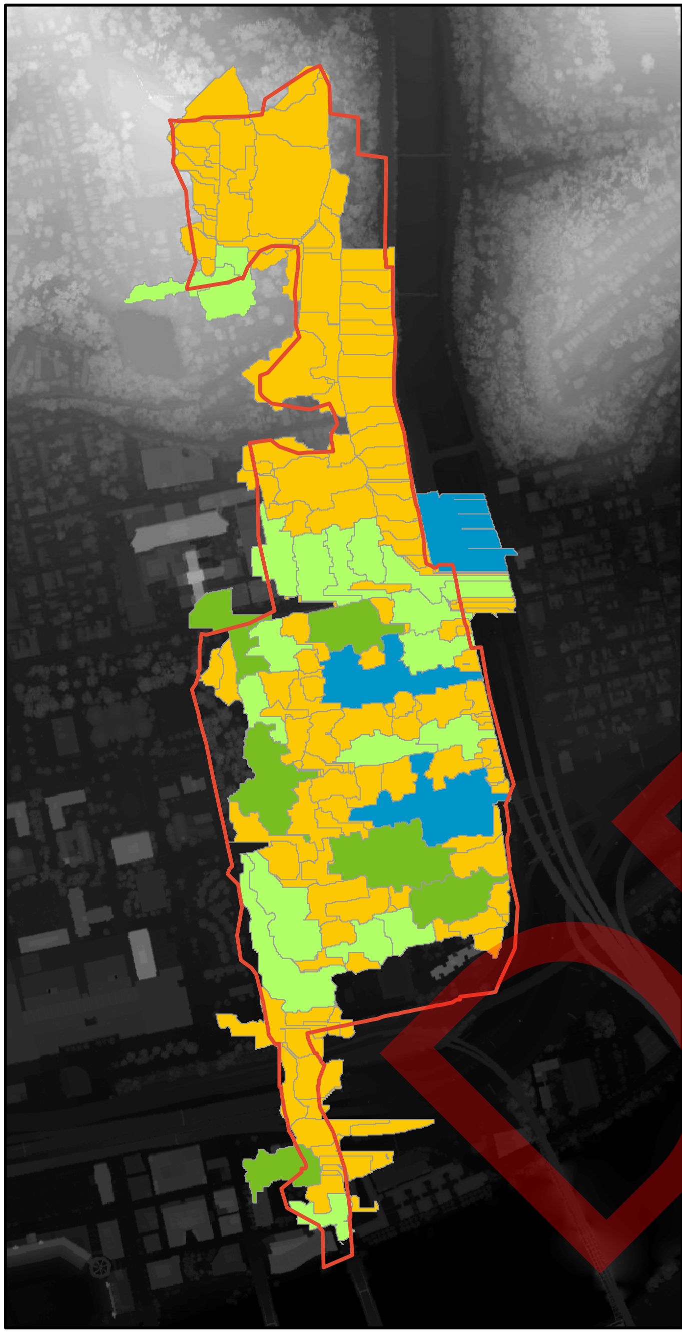
A48 Sewershed Target Areas

- 25% Target Areas - Lowered HGL During Wet Weather Conditions
- 25% Target Areas - 480 MGD

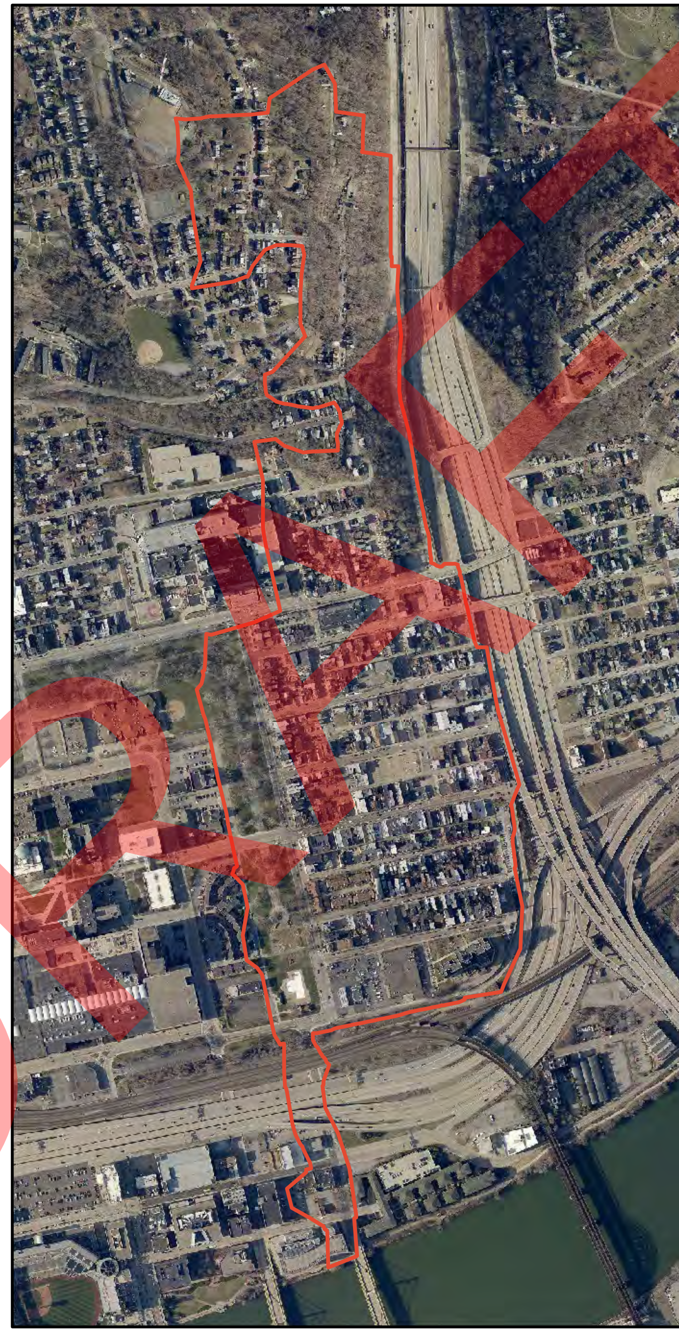
0 0.25 0.5 1 Miles

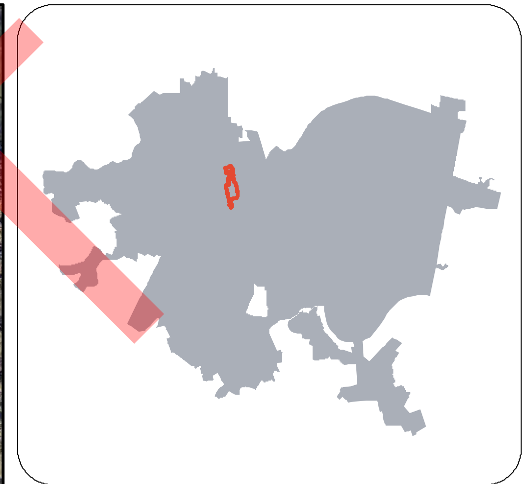
Appendix A: Sewershed Stormwater and Target Area Maps

A51 Sewershed Stormwater Overlay



A51 Sewershed Target Areas





A51 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

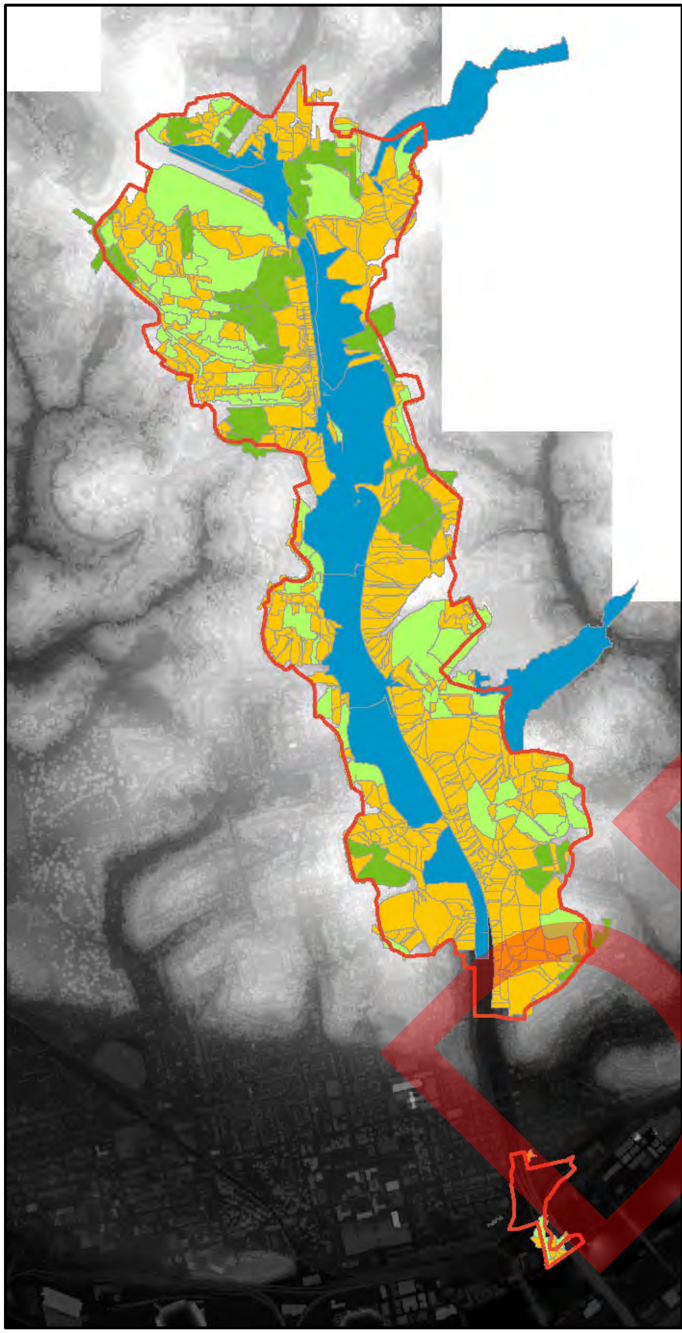
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

0 0.1 0.2 0.4 Miles

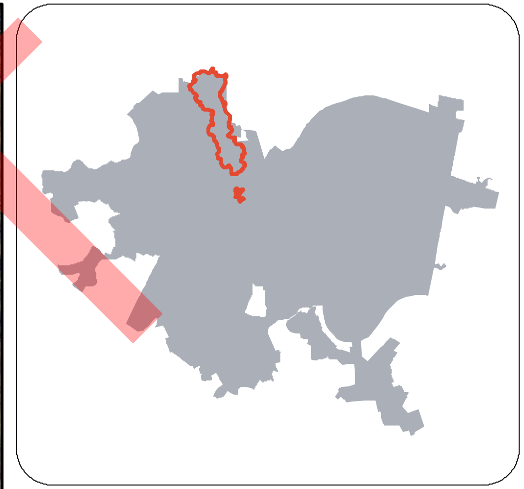
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A58 Sewershed Stormwater Overlay



A58 Sewershed Target Areas



A58 Arc Hydro Areas

Impervious Area (Ac)

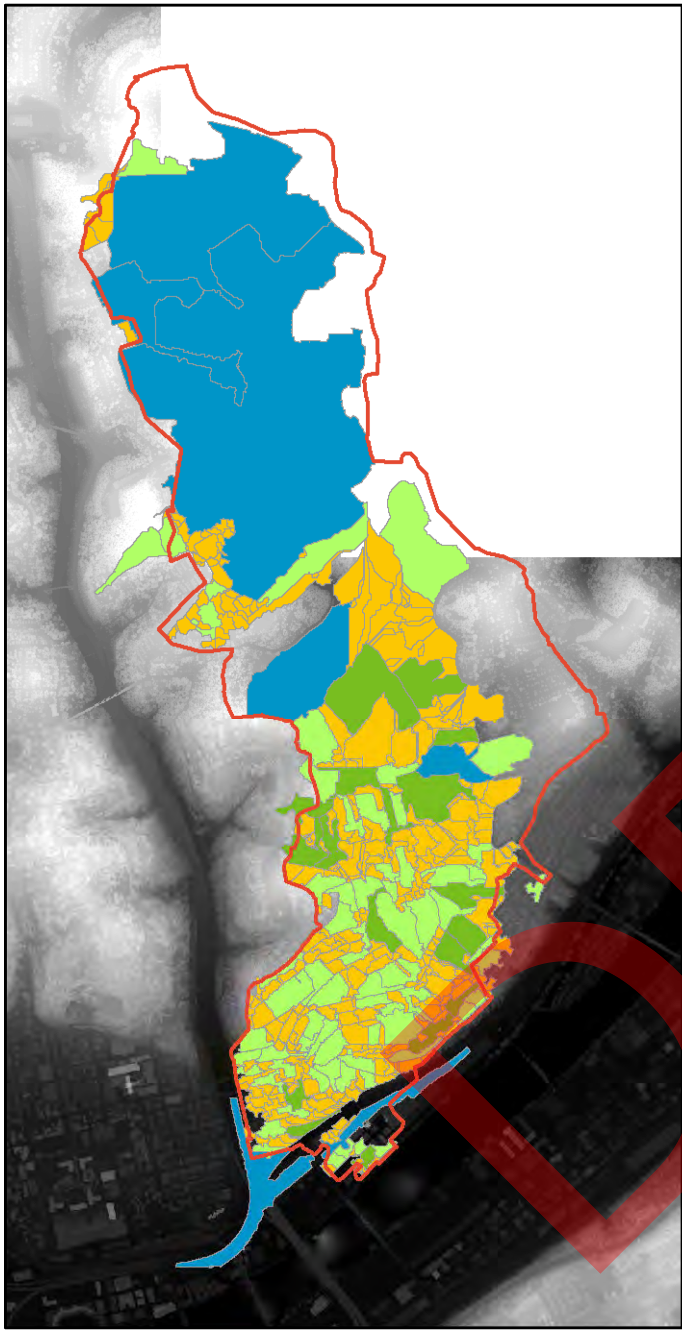
- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 25% Target Areas - Lowered HGL During Wet Weather Conditions
- 25% Target Areas - 480 MGD

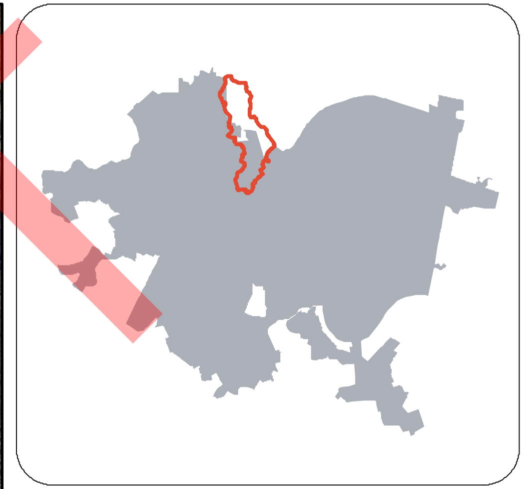
0 0.25 0.5 1 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

A60 Sewershed Stormwater Overlay



A60 Sewershed Target Areas



A60 Arc Hydro Areas Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 25% Target Areas - Lowered HGL During Wet Weather Conditions
- 25% Target Areas - 480 MGD

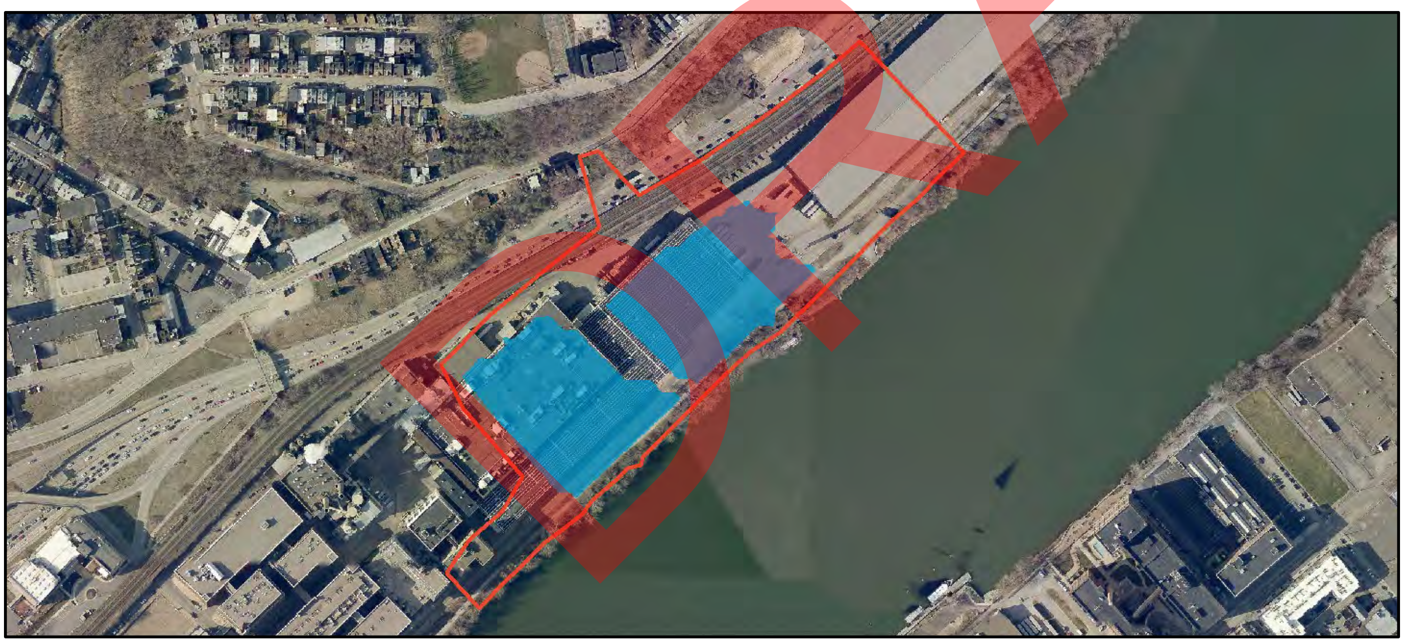
0 0.25 0.5 1 Miles

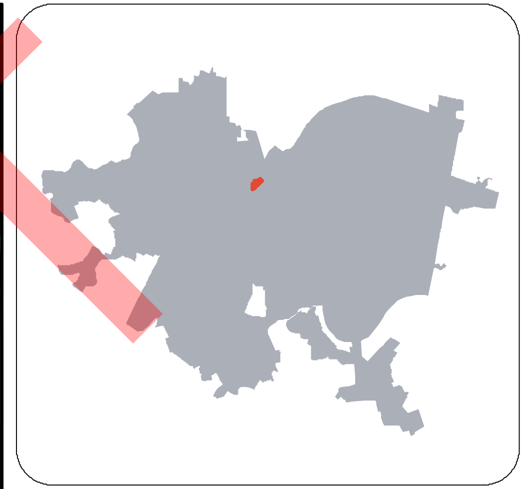
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A61 Sewershed Stormwater Overlay

A61 Sewershed Target Areas





A61 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

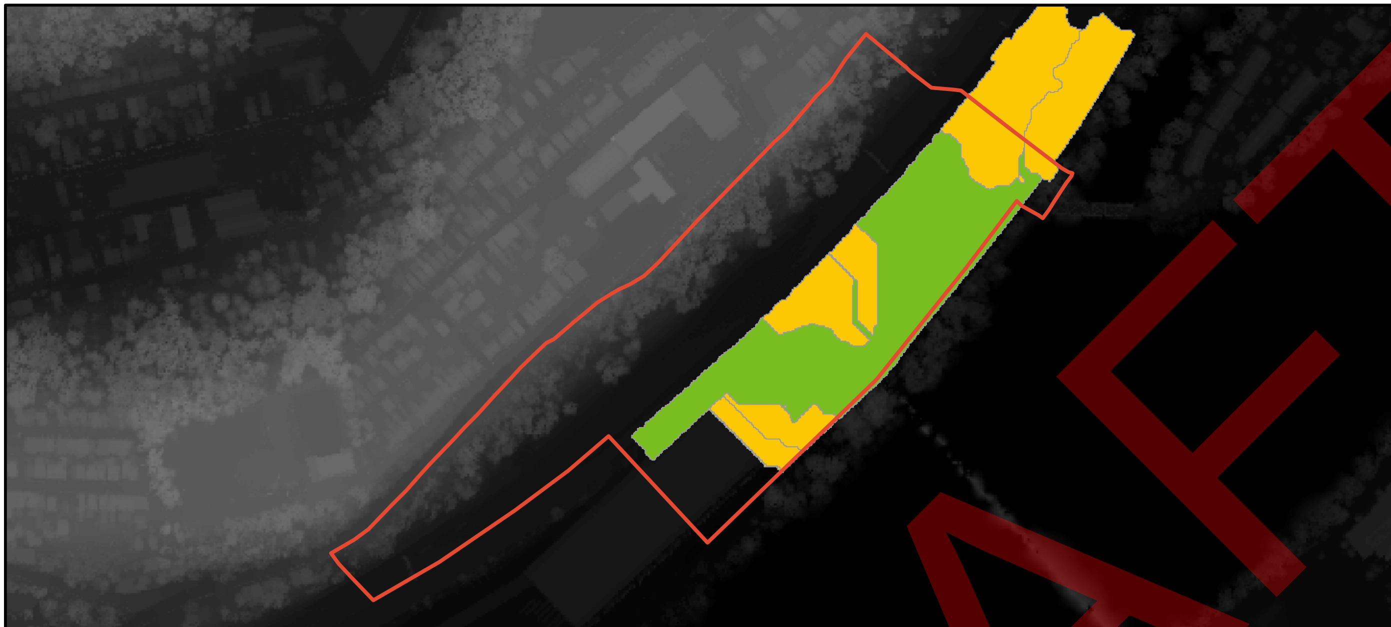
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 38% Target Areas - 480 MGD

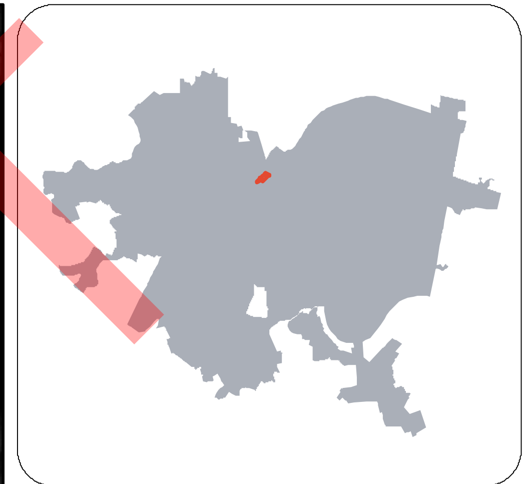
0 0.05 0.1 0.2 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A62 Sewershed Stormwater Overlay





A62 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

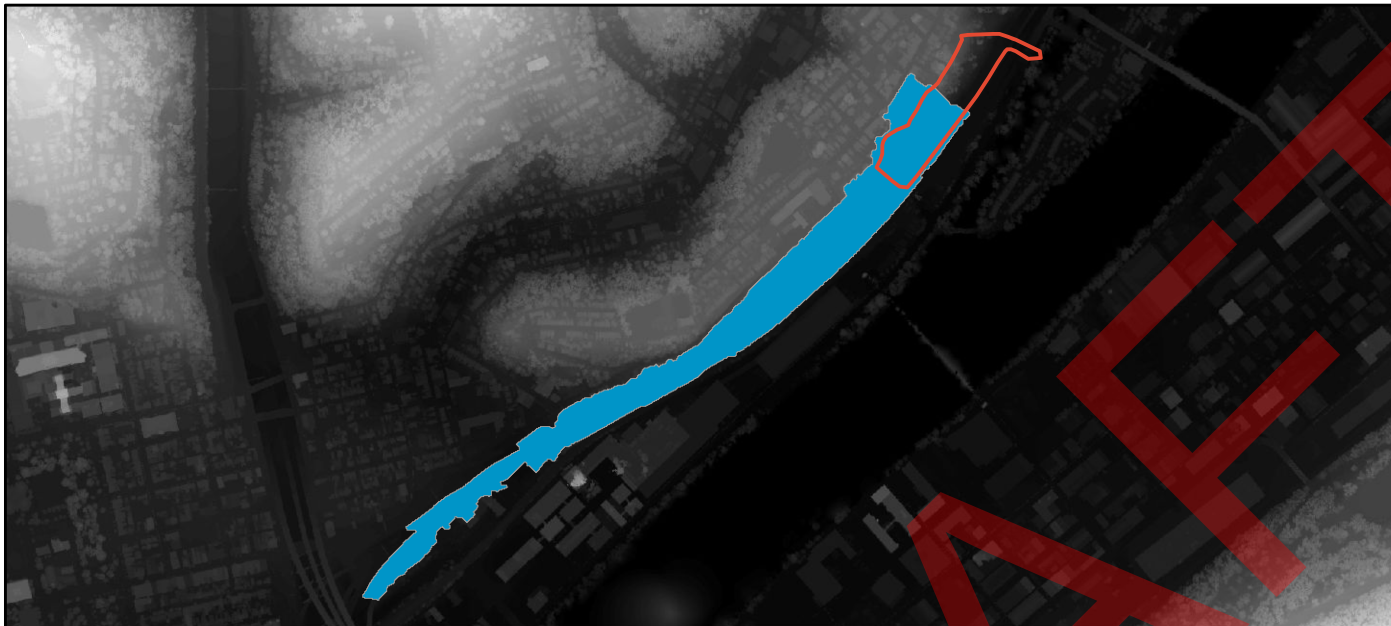
A62 Sewershed Target Areas

- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

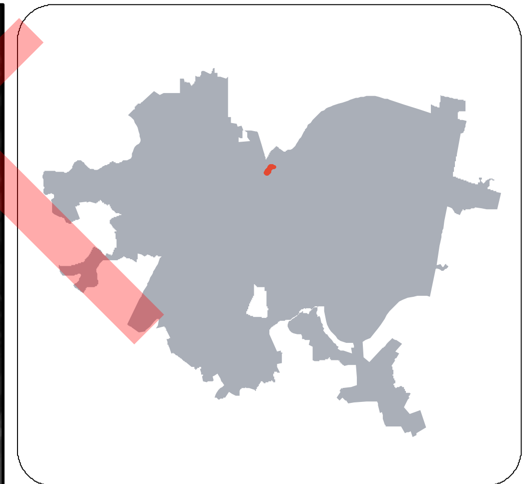
0 0.05 0.1 0.2 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

A63 Sewershed Stormwater Overlay



A63 Sewershed Target Areas



A63 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

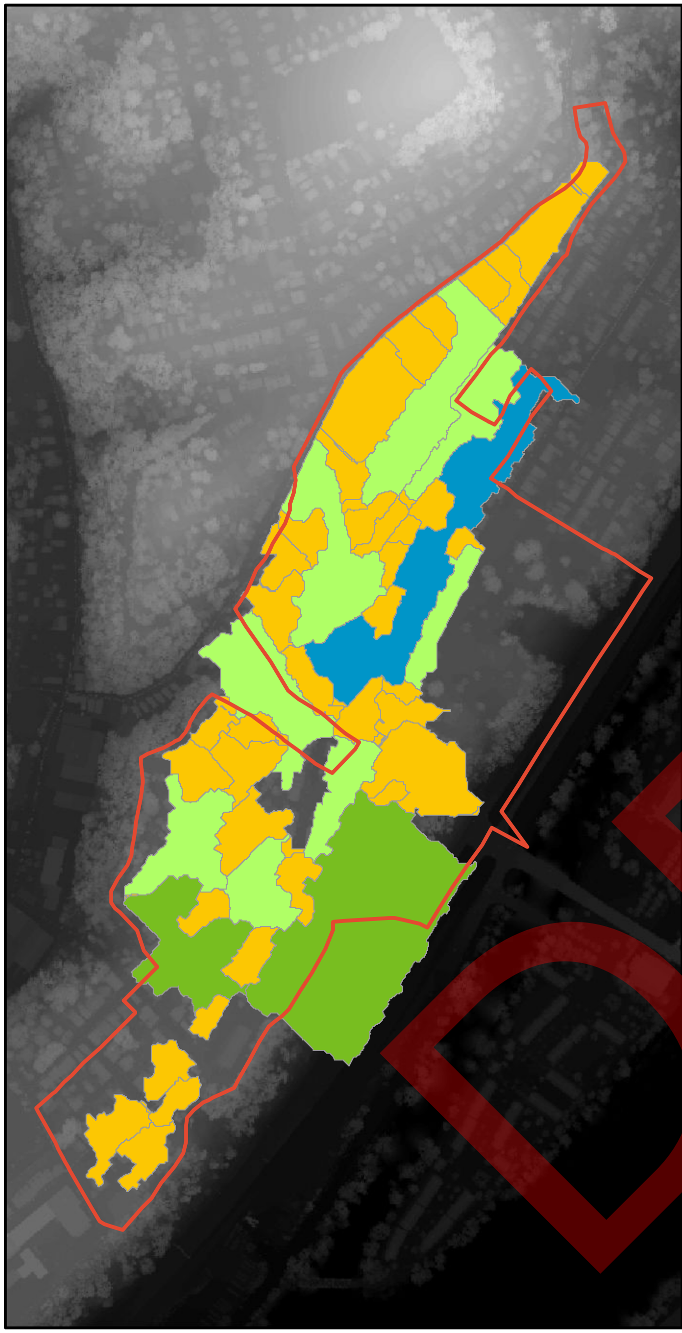
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

0 0.125 0.25 0.5 Miles

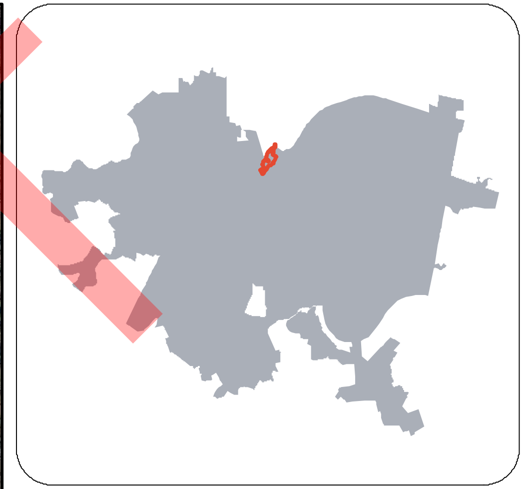
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A64 Sewershed Stormwater Overlay



A64 Sewershed Target Areas



A64 Arc Hydro Areas
Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

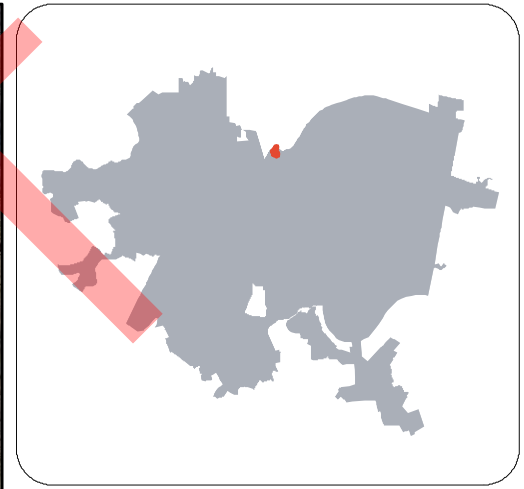
0 0.05 0.1 0.2 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

A65 Sewershed Stormwater Overlay

A65 Sewershed Target Areas



A65 Arc Hydro Areas
Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

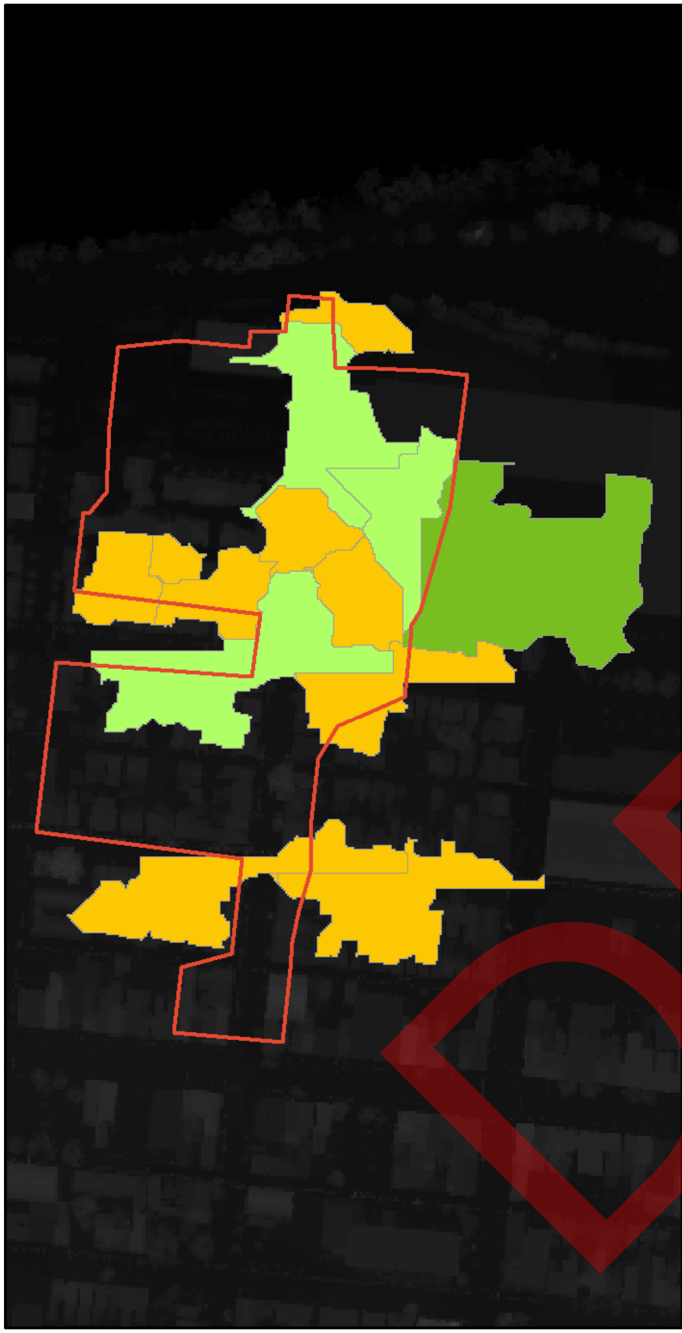
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

0 0.03 0.06 0.12 Miles

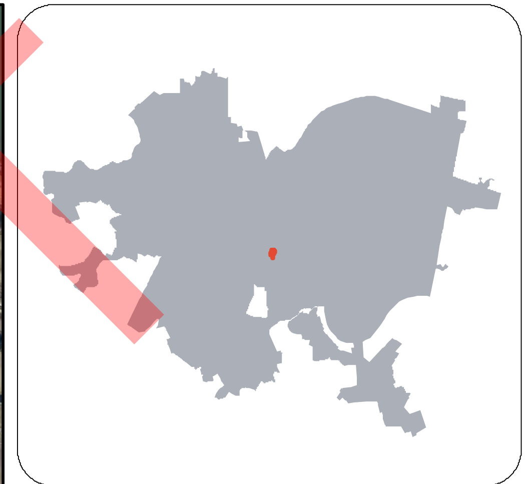
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

M15 Sewershed Stormwater Overlay



M15 Sewershed Target Areas



M15 Arc Hydro Areas
Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

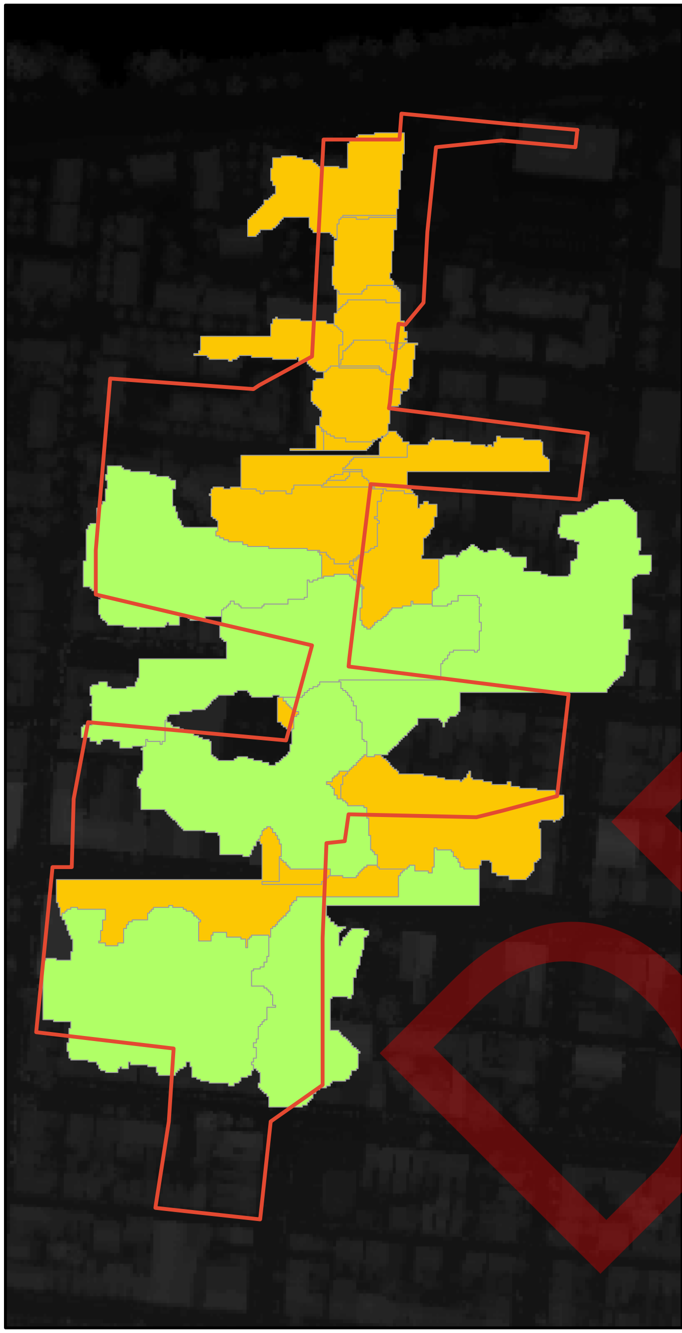
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 65% Target Areas - 480 MGD

0 0.03 0.06 0.12 Miles

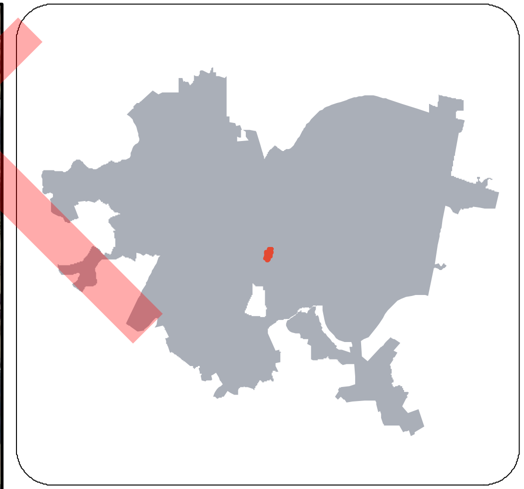
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

M15Z Sewershed Stormwater Overlay



M15Z Sewershed Target Areas



M15Z Arc Hydro Areas

Impervious Area (Ac)

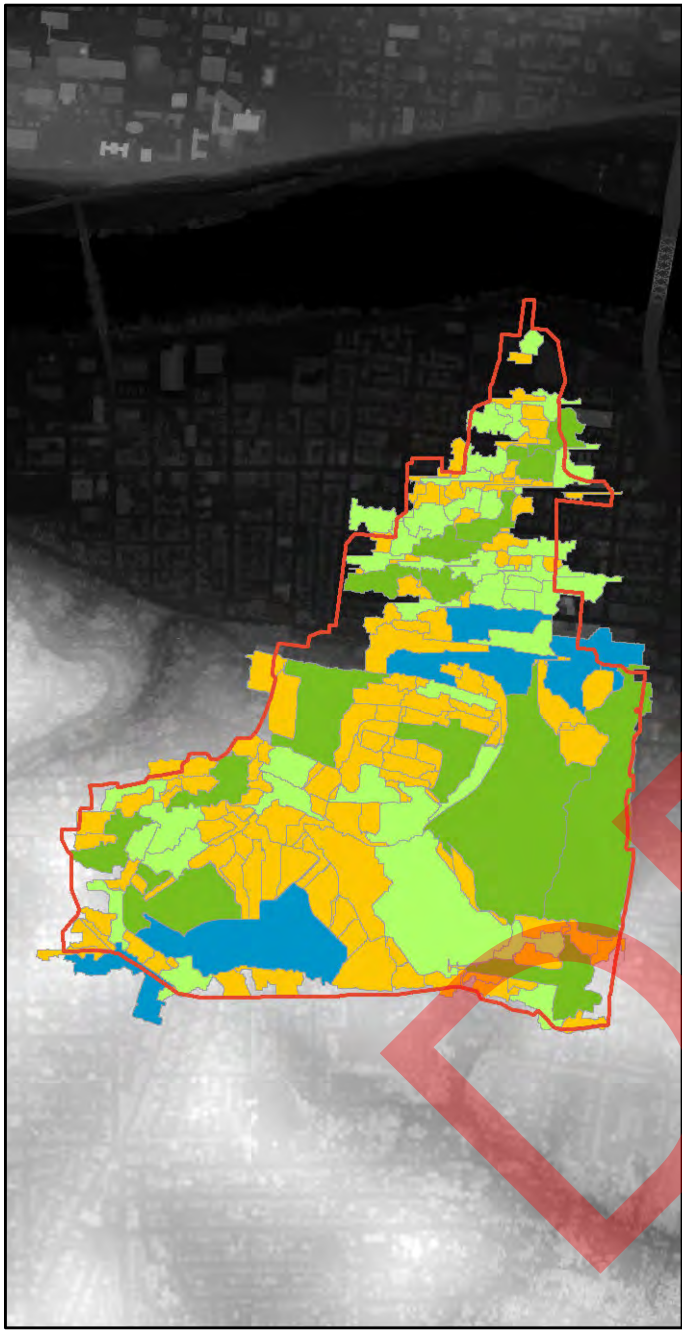
- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

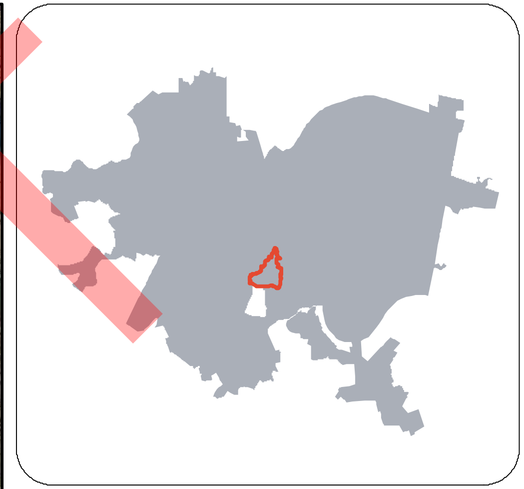
0 0.0275 0.055 0.11 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

M16 Sewershed Stormwater Overlay



M16 Sewershed Target Areas



M16 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

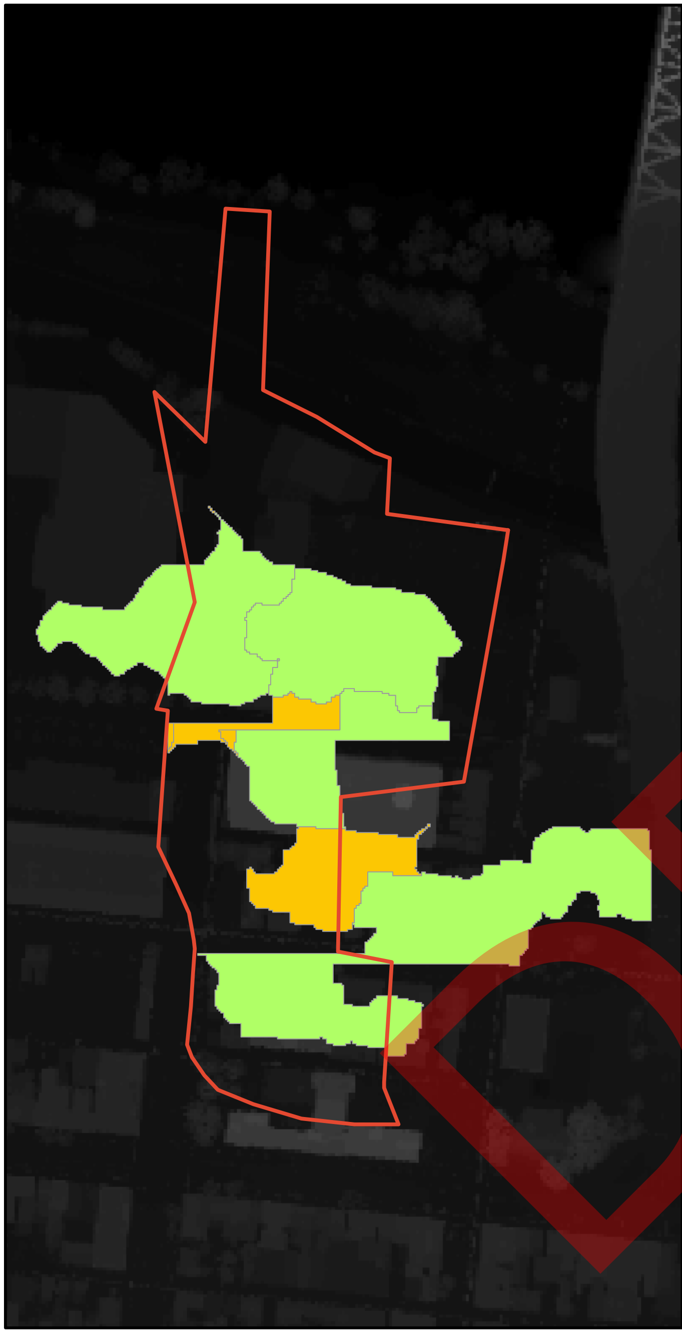
- 25% Target Areas - Lowered HGL During Wet Weather Conditions
- 85% Target Areas - 480 MGD

0 0.125 0.25 0.5 Miles

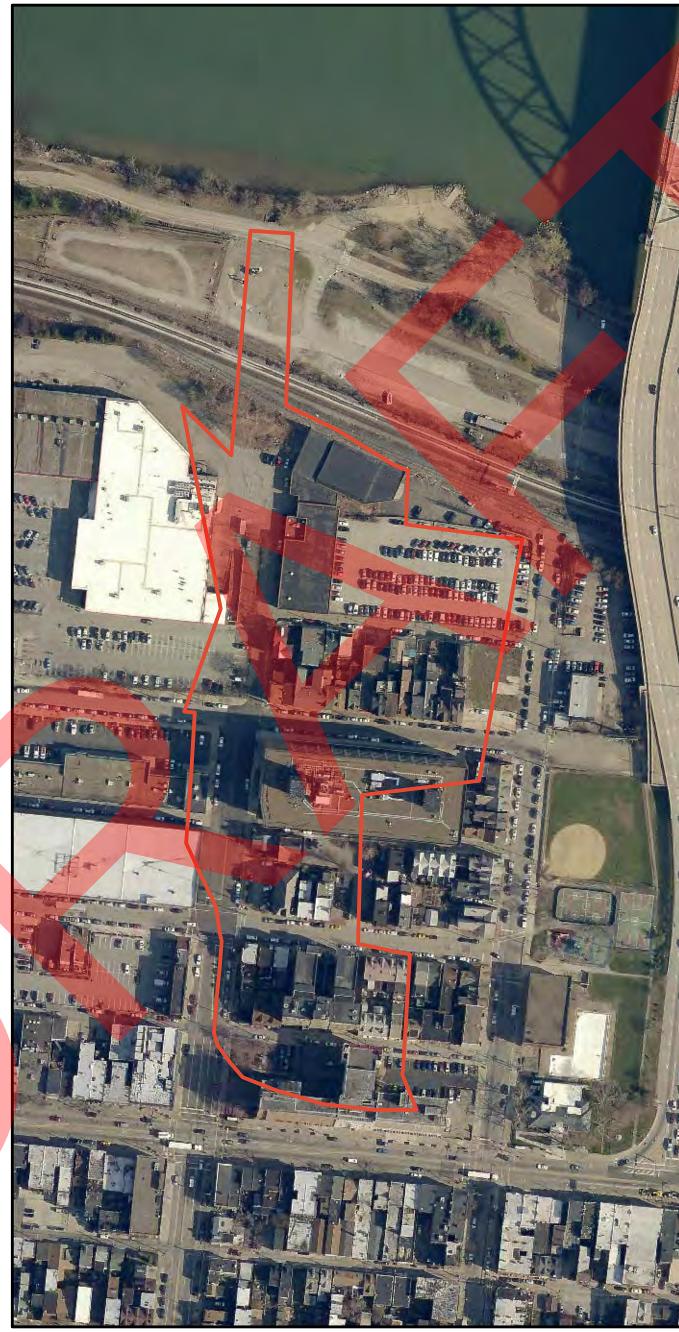
Appendix A: Sewershed Stormwater and Target Area Maps

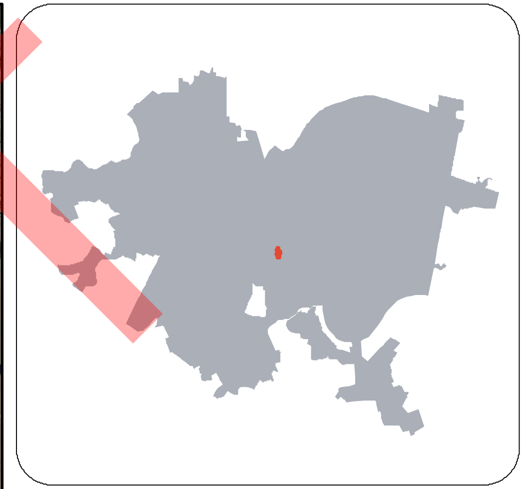
PGH2O

M17 Sewershed Stormwater Overlay



M17 Sewershed Target Areas





M17 Arc Hydro Areas Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

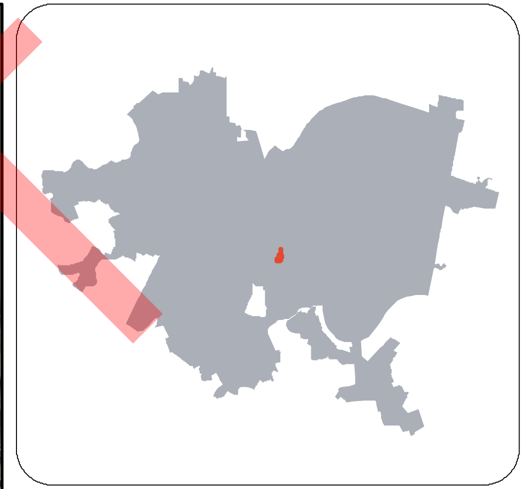
0 0.025 0.05 0.1 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

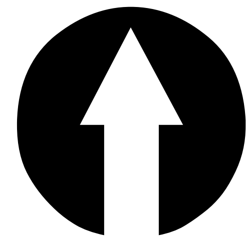
M18 Sewershed Stormwater Overlay

M18 Sewershed Target Areas



M18 Arc Hydro Areas Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0



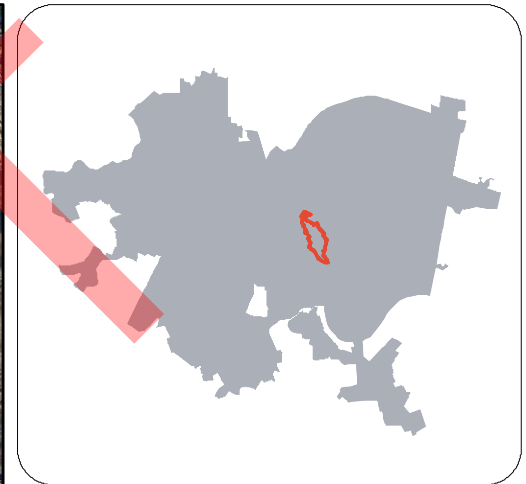
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

0 0.05 0.1 0.2 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

M19A Sewershed Stormwater Overlay

M19A Sewershed Target Areas



M19A Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

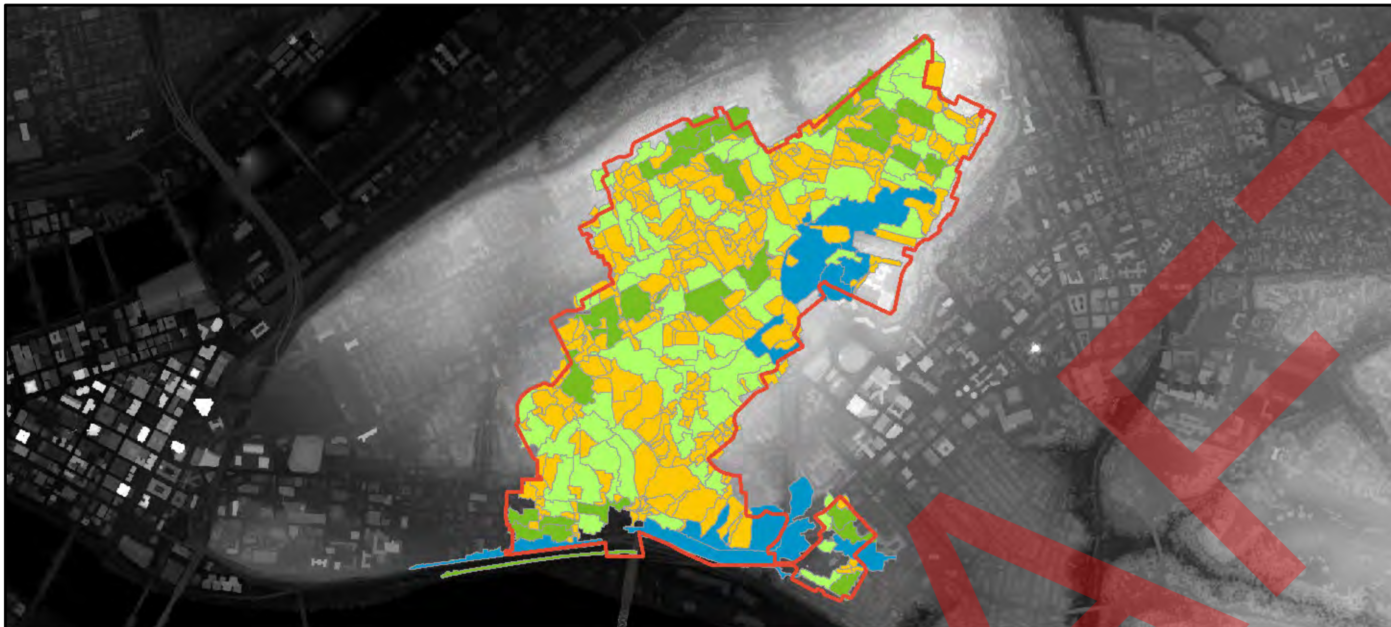
- 35% Target Areas - Lowered HGL During Wet Weather Conditions
- 41% Target Areas - 480 MGD

0 0.125 0.25 0.5 Miles

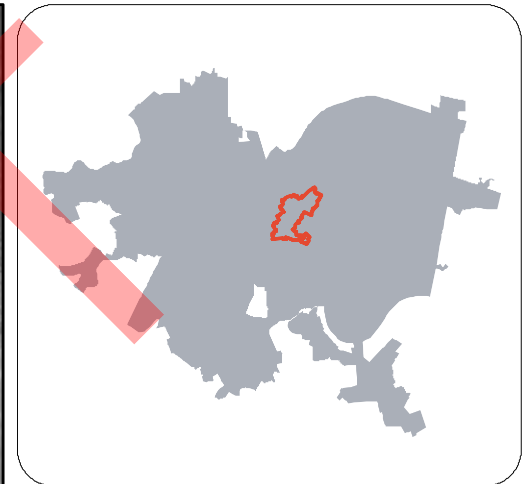
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

M19 Sewershed Stormwater Overlay



M19 Sewershed Target Areas



M19 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

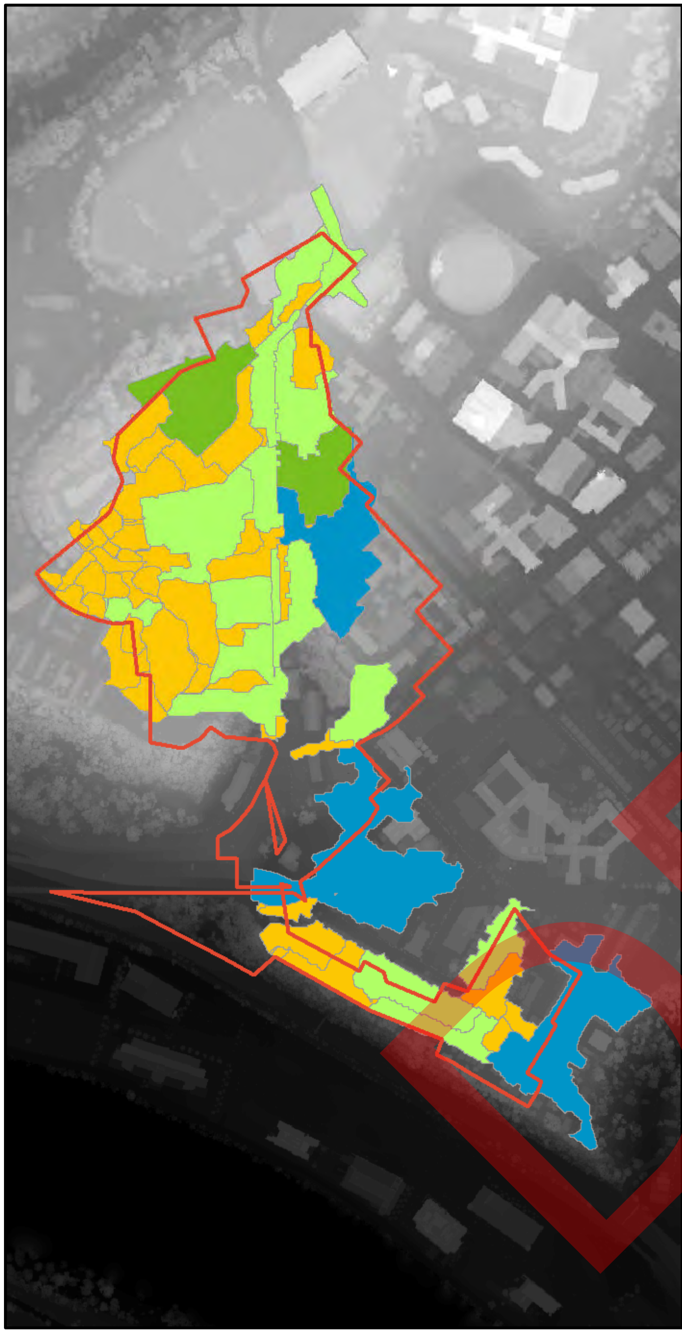
- 25% Target Areas - Lowered HGL During Wet Weather Conditions
- 55% Target Areas - 480 MGD

0 0.275 0.55 1.1 Miles

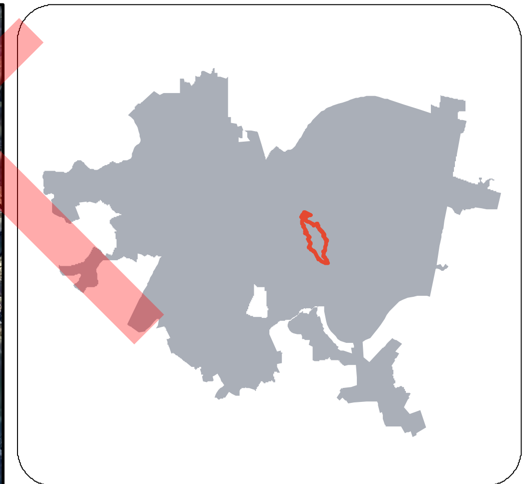
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

M19B Sewershed Stormwater Overlay



M19B Sewershed Target Areas



M19B Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

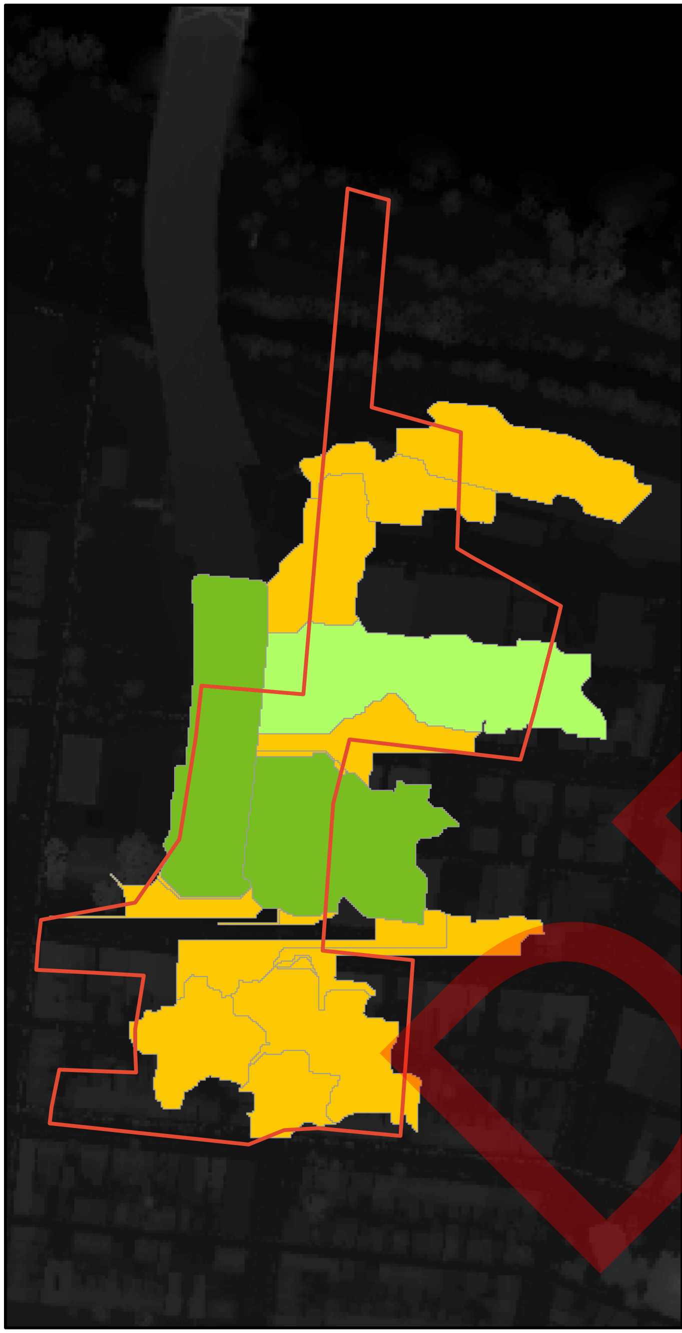
- 33% Target Areas - Lowered HGL During Wet Weather Conditions
- 28% Target Areas - 480 MGD

0 0.1 0.2 0.4 Miles

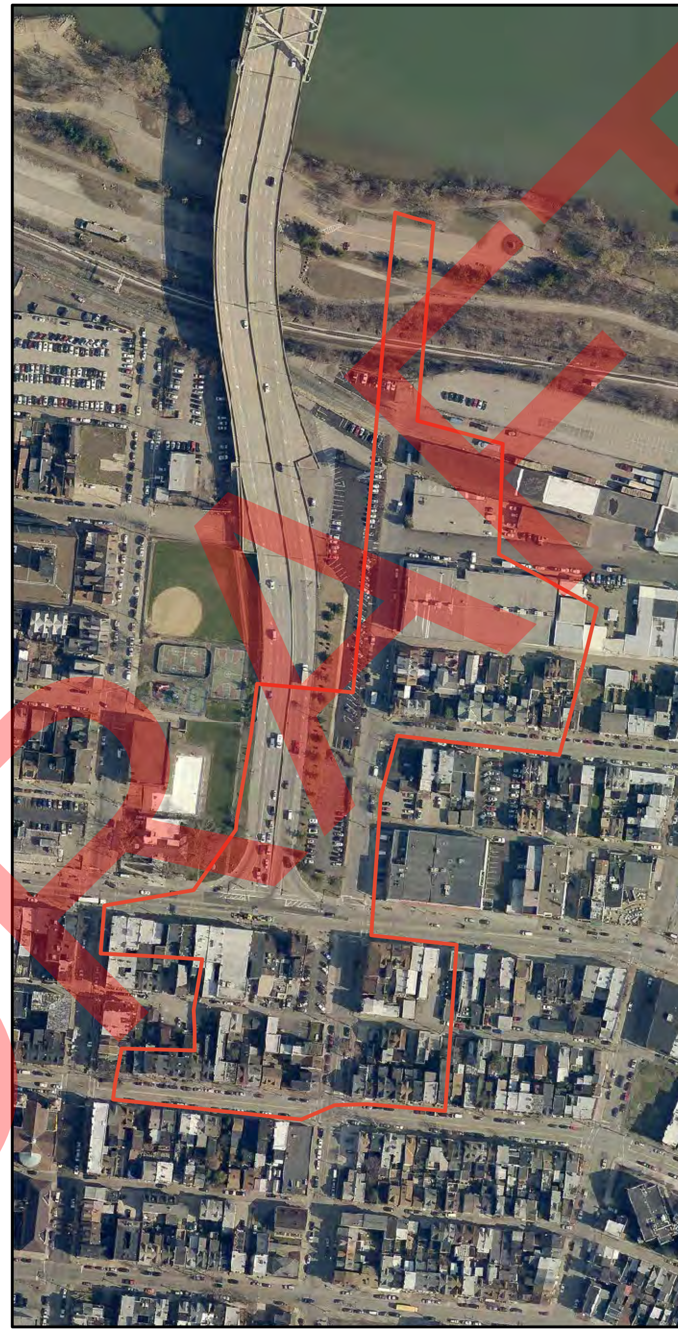
Appendix A: Sewershed Stormwater and Target Area Maps

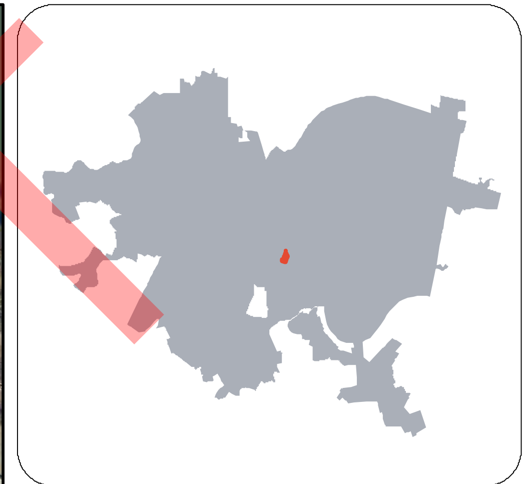
PGH2O

M20 Sewershed Stormwater Overlay



M20 Sewershed Target Areas





M20 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

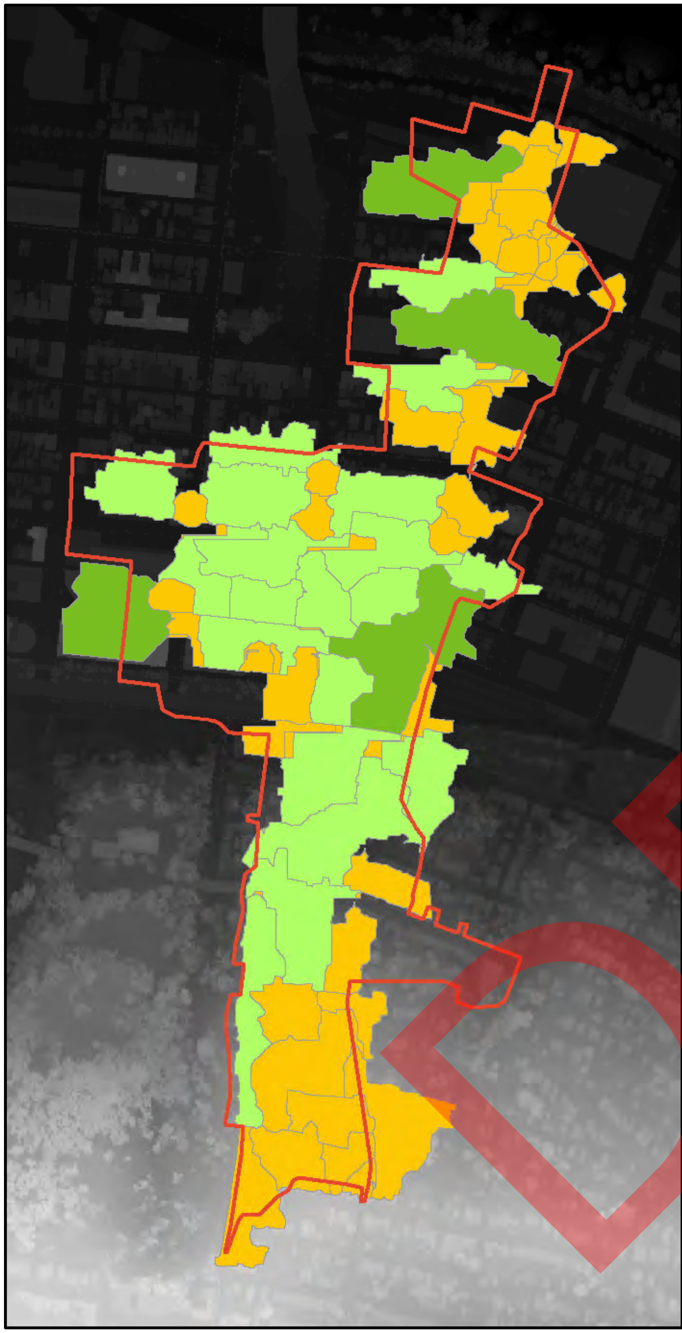
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

0 0.035 0.07 0.14 Miles

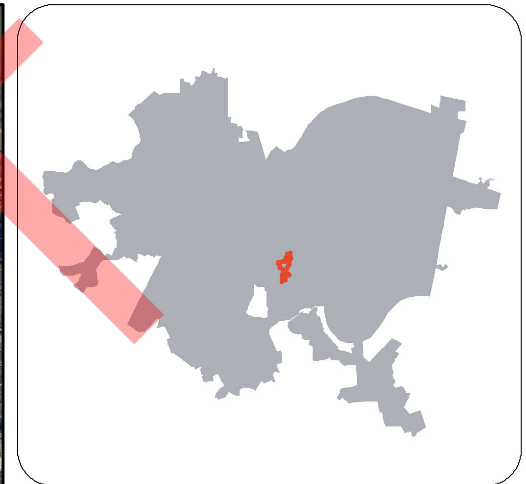
Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

M21 Sewershed Stormwater Overlay



M21 Sewershed Target Areas



M21 Arc Hydro Areas
Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

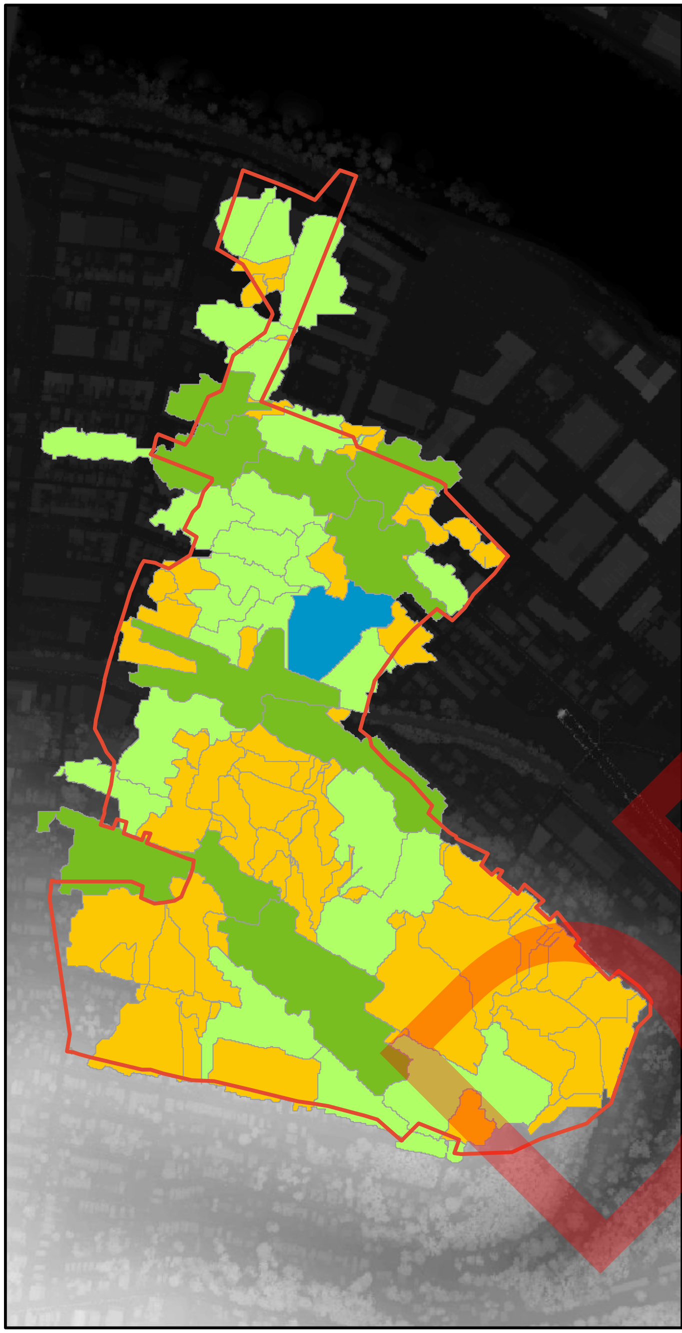
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 8% Target Areas - 480 MGD

0 0.05 0.1 0.2 Miles

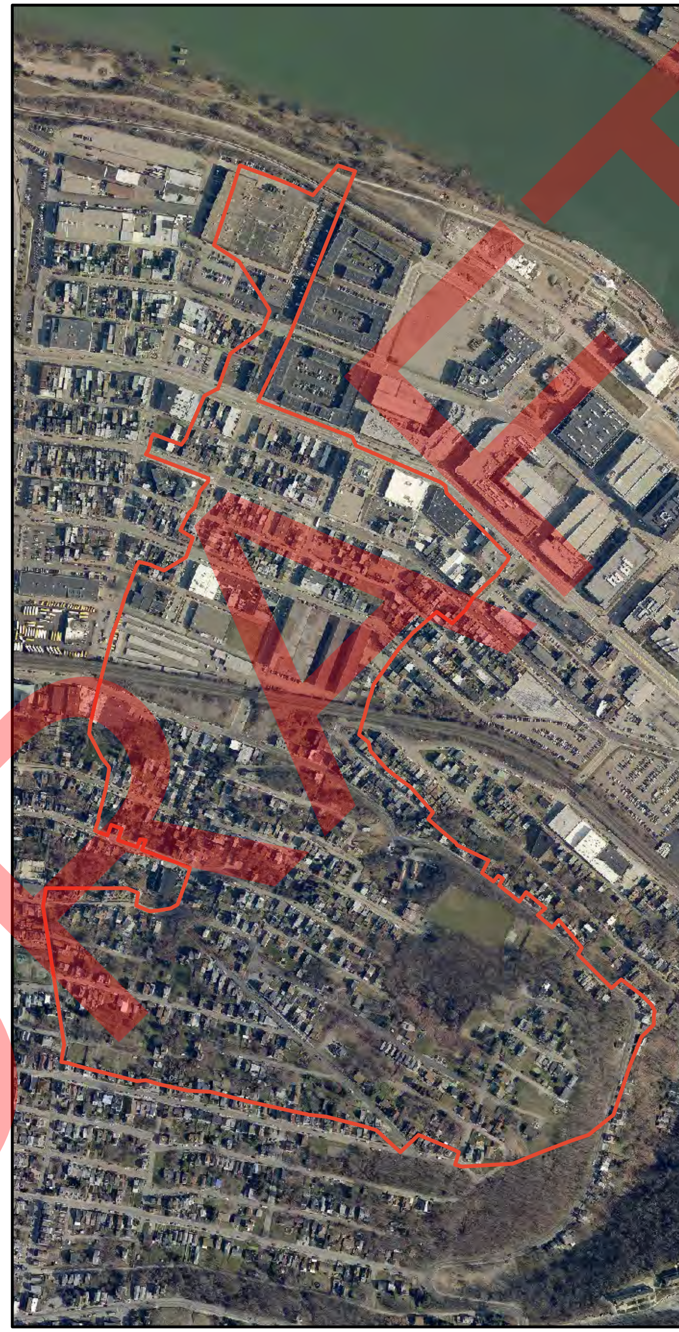
Appendix A: Sewershed Stormwater and Target Area Maps

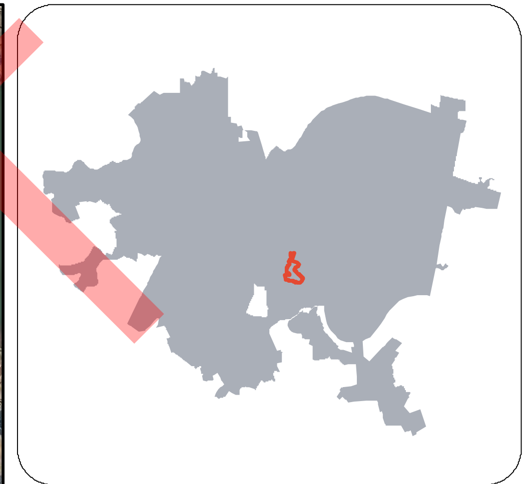
PGH2O

M22 Sewershed Stormwater Overlay



M22 Sewershed Target Areas





M22 Arc Hydro Areas Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

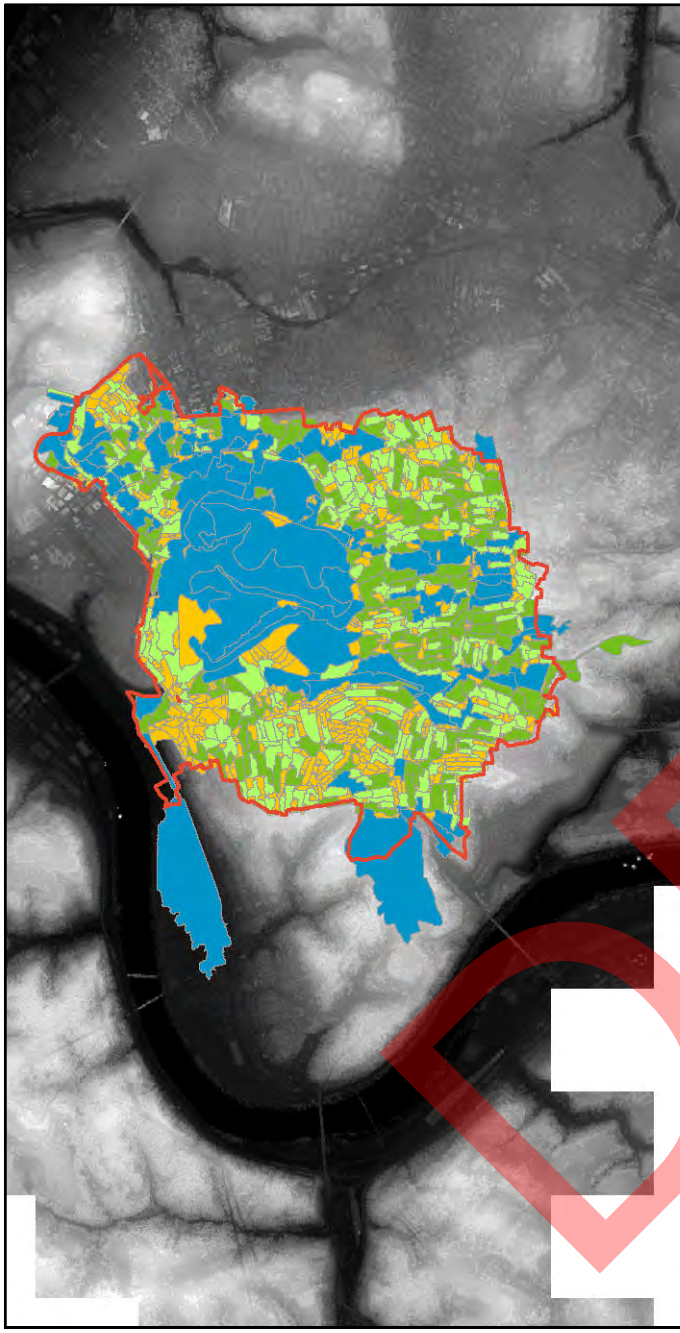
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 8% Target Areas - 480 MGD

0 0.075 0.15 0.3 Miles

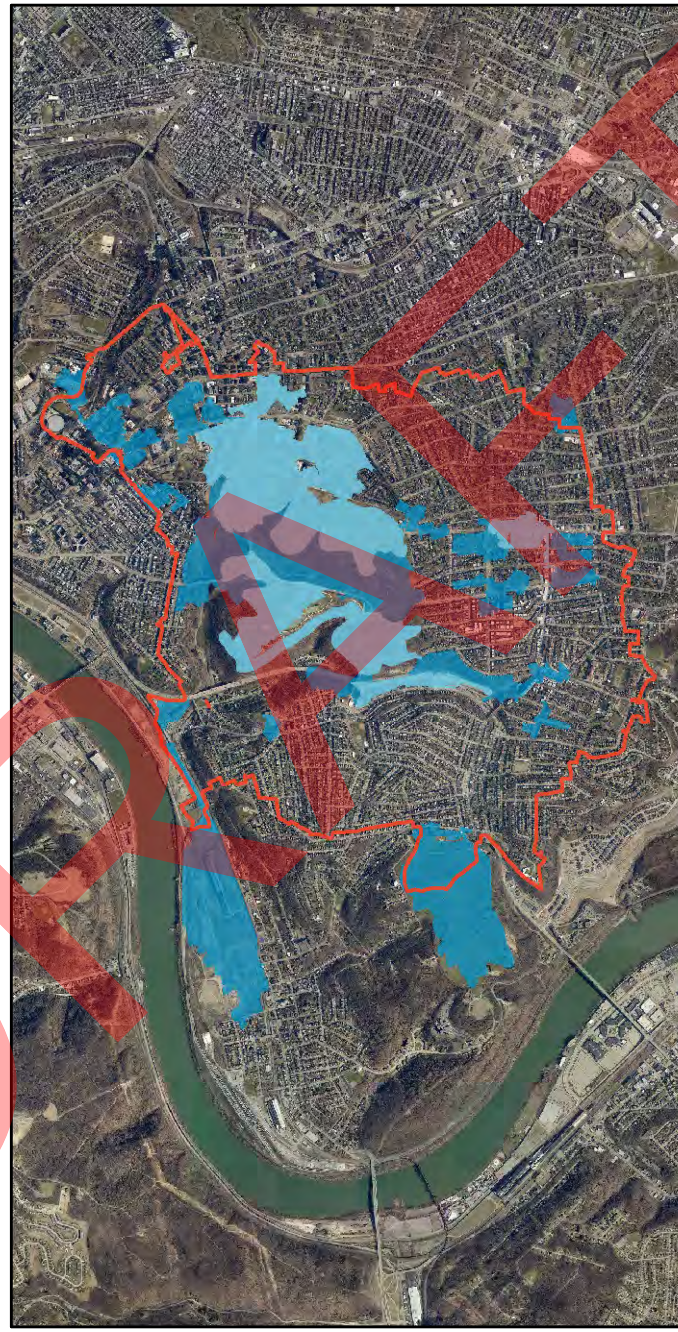
Appendix A: Sewershed Stormwater and Target Area Maps

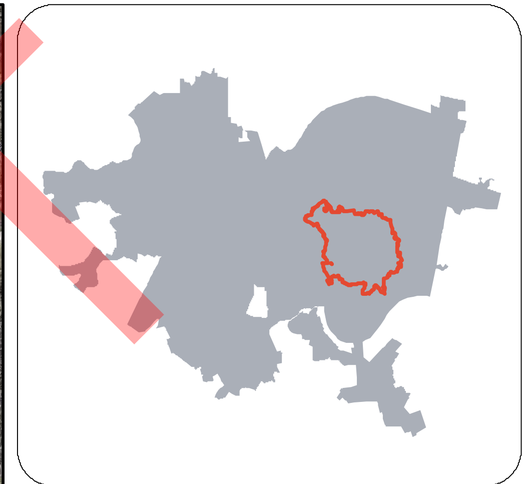
PGH2O

M29 Sewershed Stormwater Overlay



M29 Sewershed Target Areas





M29 Arc Hydro Areas

Impervious Area (Ac)

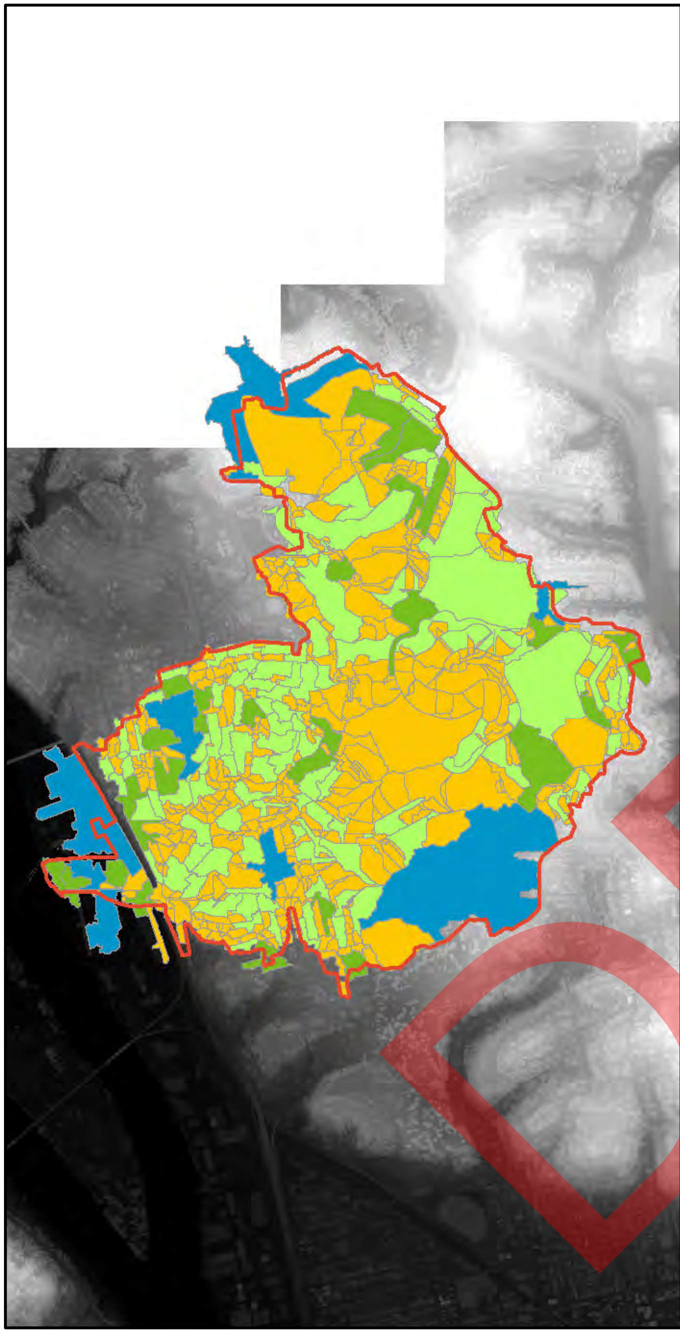
- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 25% Target Areas - Lowered HGL During Wet Weather Conditions
- 60% Target Areas - 480 MGD

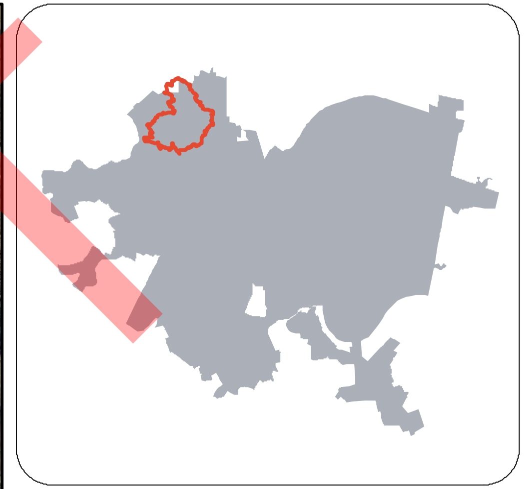
0 0.5 1 2 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

O27 Sewershed Stormwater Overlay



O27 Sewershed Target Areas



O27 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 25% Target Areas - Lowered HGL During Wet Weather Conditions
- 25% Target Areas - 480 MGD

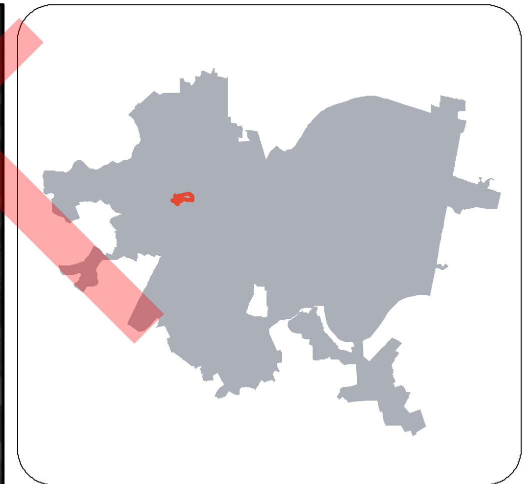
0 0.325 0.65 1.3 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

O39 Sewershed Stormwater Overlay

O39 Sewershed Target Areas



O39 Arc Hydro Areas

Impervious Area (Ac)

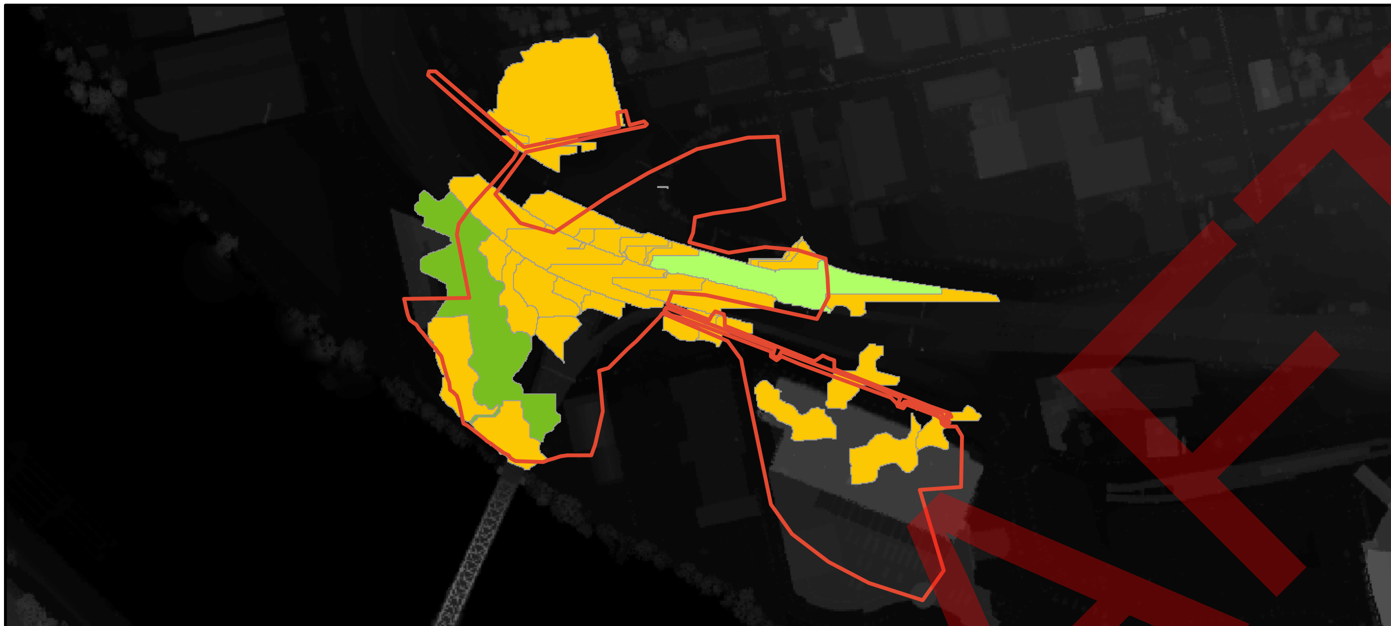
- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

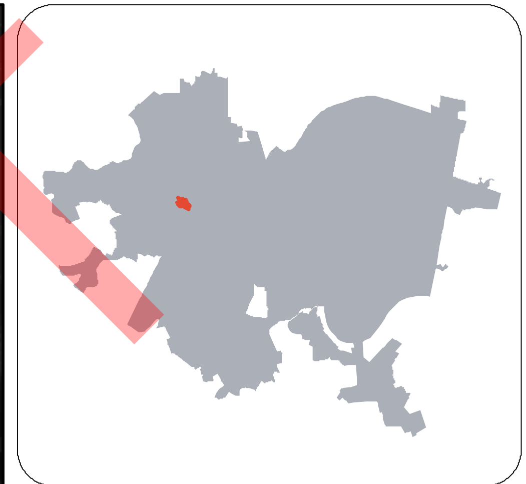
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 21% Target Areas - 480 MGD

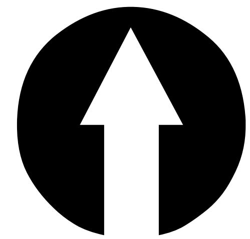
0 0.075 0.15 0.3 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

O40 Sewershed Stormwater Overlay







O40 Arc Hydro Areas
Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

O40 Sewershed Target Areas

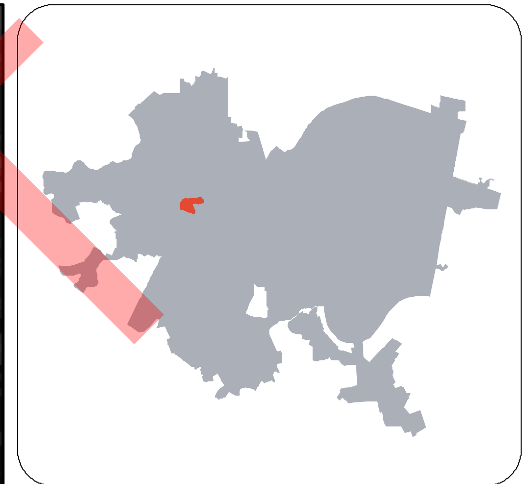
- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

0 0.05 0.1 0.2 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

O41 Sewershed Stormwater Overlay

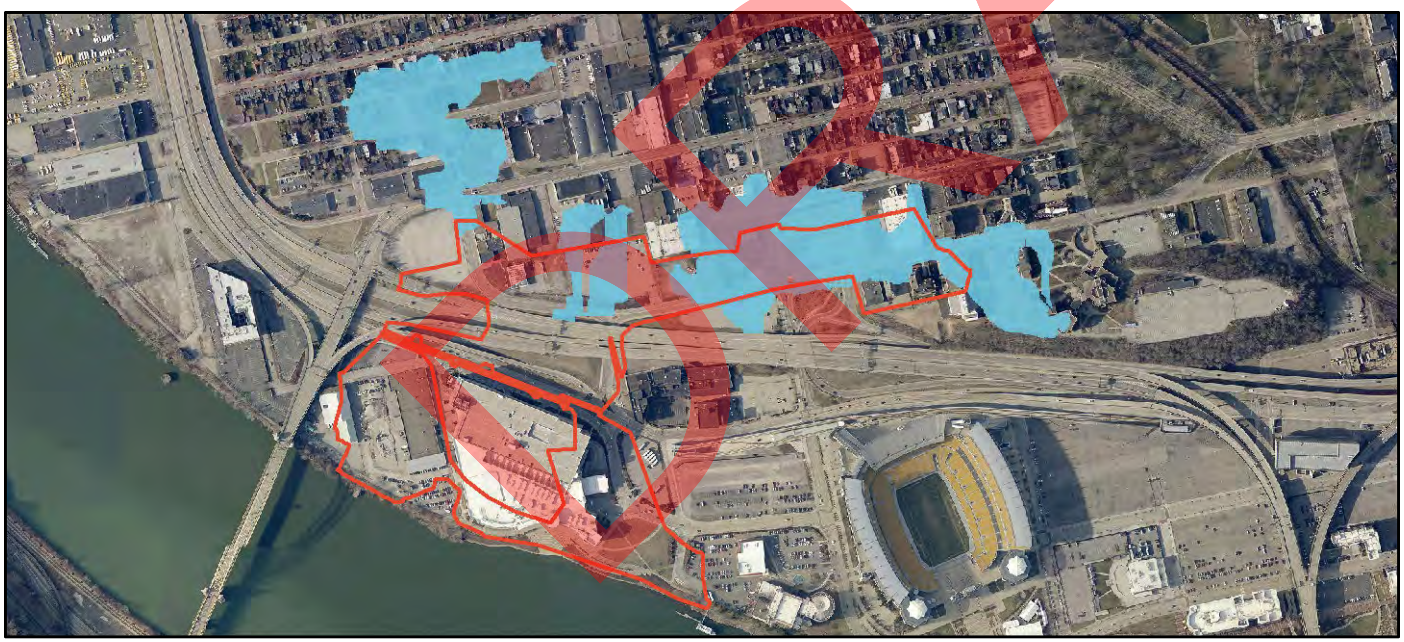


O41 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

O41 Sewershed Target Areas

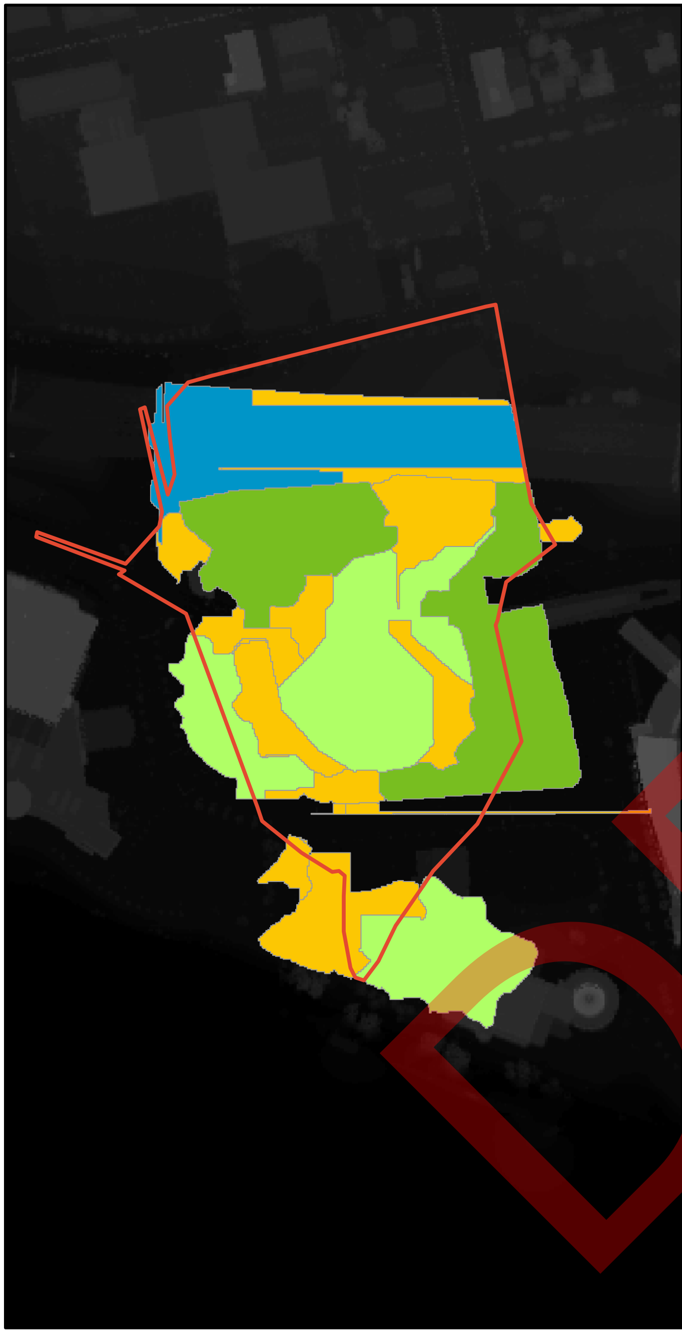


- 56% Target Areas - Lowered HGL During Wet Weather Conditions
- 56% Target Areas - 480 MGD

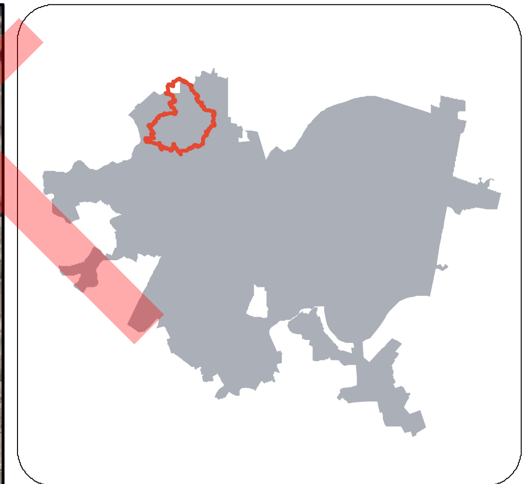
0 0.1 0.2 0.4 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

O43 Sewershed Stormwater Overlay



O43 Sewershed Target Areas



O43 Arc Hydro Areas

Impervious Area (Ac)

- 0.0 - 0.5
- 0.5 - 1.0
- 1.0 - 2.0
- >2.0

- 0% Target Areas - Lowered HGL During Wet Weather Conditions
- 0% Target Areas - 480 MGD

0 0.0425 0.085 0.17 Miles

Appendix A: Sewershed Stormwater and Target Area Maps

PGH2O

APPENDIX B
SWMM LID SENSITIVITY ANALYSIS

Prior to the PWSA City-Wide Green Infrastructure Assessment, a modeling sensitivity analysis using the SWMM Low Impact Development (LID) tool was conducted within the A-22 Sewershed. The following sensitivity analysis was originally part of previous study called the Shadyside/A-22 Flooding Assessment. The Shadyside/A-22 Flooding Assessment served as modeling "test bed" for many of the approaches carried forward as part of the larger City-Wide GI Assessment including the Arc Hydro Analysis and the SWMM LID approaches. The SWMM LID tool sensitivity analysis was performed using a subset of SWMM subcatchments in the A22 sewershed. The findings herein are expected to be consistent and scalable when modelled as part of full City-Wide Green Infrastructure Assessment within other sewersheds throughout the City.

The subcatchments selected for the sensitivity analysis were located within the Shadyside neighborhood of the City of Pittsburgh. The primary reason these subcatchments were selected was due to their proximity to a historical basement and street flooding complaint area. Figure 1 shows the subcatchments in the Shadyside area used for the SWMM LID Tool sensitivity analysis.

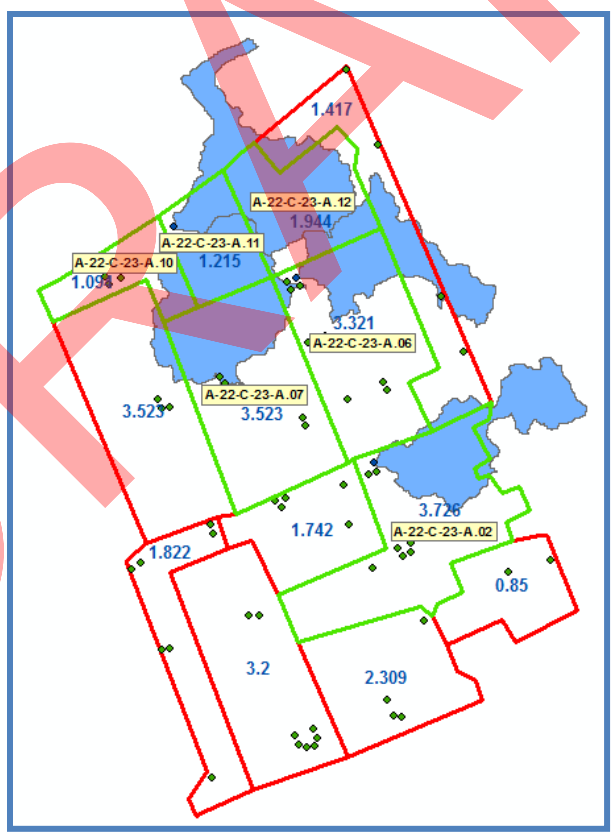


Figure 1: Subcatchments Selected for the SWMM LID Tool Sensitivity Analysis (Subcatchments shown in green – SWMM LID BMP areas shown in blue)

The SWMM LID Tool allows for the simulation of various GI technologies including rain gardens, infiltration trenches, bioinfiltration, bioswales, and rain barrels/cisterns directly within the hydraulic model. Each GI technology within the LID Tool has varying functional components based on the technology simulated. For this study all GI was simulated using rock filled infiltration trenches. Infiltration trenches were selected since this GI type allows for the high rate transfer of runoff to a subsurface storage facility. Infiltration trenches within the SWMM LID Tool provide the ability to quickly transfer high rate runoff to a subsurface storage layer allowing for the necessary detention of the peak flows, whereas the other GI technologies within SWMM LID Tool do not offer this capability.

Using the infiltration trench as the standard GI technology within the SWMM LID Tool, the following modeling parameters were evaluated as part of the sensitivity analysis:

- GI Size (0.75, 1.0, 1.5, 2.0 inches) of runoff captured
- Infiltration Rate (0.05, 0.10, 0.25, 0.50 in/hour)
- GI Return Time (24, 36, 60, 72 hours)
- Underdrain Height Offset (0, 6, 8, 12 inches)

The parameters listed above were then run in singular independent simulations for the observed August 31, 2014 flooding rainfall event to observe the relative change in peak flow and runoff in comparison to the baseline scenario (existing conditions with no LID). This equated to a total of 32 independent SWMM LID Tool simulations within the sensitivity subcatchments. The results from this analysis are shown in Table 1. A key observation from each parameter is included in the Table.

From the results presented in Table 1, it was determined that the following parameters would be carried forward for the full SWMM LID tool within the entire A22 sewershed:

- GI Size (0.75, 1.0, 1.5, 2.0 inches) of runoff captured
- Infiltration Rate (set constant at 0.10 in/hour)
- GI Return Time (24 and 72 hours)
- Underdrain Height Offset (set constant at 6 inches)
- All GI in the full A22 simulations would be modeled using infiltration trenches in the SWMM LID Tool to provide for the needed storage, detention and slow release functionality.

TABLE 1
SENSITIVITY ANALYSIS RESULTS USING THE SWMM LID TOOL FOR AUGUST 31, 2014 OBSERVED RAINFALL EVENT

Model Simulation	Model Parameter Values	Total Runoff Volume (Gal)	Delta Total Runoff Volume (Gal)	Total Infiltration Volume (Gal)	Delta Total Infiltration Volume (Gal)	Peak Runoff Volume (MGD)	Delta Peak Runoff Volume (MGD)	Runoff Volume Delayed (Gal)	Delta Runoff Volume Delayed (Gal)	Key Observation From Analysis of Parameter
Existing Conditions		69,846		0		3.320		88		
GI Size (inches)	0.75	67,544	-2,302	2,302	+2,302	3.097	-0.222	17,490	+17,402	GI Size has influence on Runoff Volume, Infiltration, Peak Flow, and Delay
	1.00	66,798	-3,048	3,048	+3,048	2.150	-1.169	23,046	+22,958	
	1.25	66,074	-3,773	3,773	+3,773	0.998	-2.321	28,482	+28,394	
	2.00	64,046	-5,800	5,800	+5,800	0.084	-3.236	42,979	+42,891	
Infiltration Rate (in/hr) - Assuming GI Size of 0.75	0.05	67,544	-2,302	2,302	+2,302	3.097	-0.222	17,490	+17,402	Infiltration has influence on Runoff Volume and Infiltration. But not on Peak Runoff or Delay
	0.10	65,275	-4,571	4,571	+4,571	3.096	-0.224	18,282	+18,193	
	0.25	60,656	-9,190	9,190	+9,190	3.085	-0.235	19,873	+19,784	
	0.50	55,089	-14,757	14,757	+14,757	3.066	-0.254	22,473	+22,385	
GI Return Rate (hrs) - Assuming GI Size of 0.75	24	67,544	-2,302	2,302	+2,302	3.097	-0.222	17,490	+17,402	Return Rate does not have an influence on any of the results for the August 31 Design Storm
	36	66,607	-3,239	3,239	+3,239	3.103	-0.217	18,096	+18,008	
	60	66,607	-3,239	3,239	+3,239	3.103	-0.217	18,096	+18,008	
	72	64,027	-5,819	5,819	+5,819	3.108	-0.212	18,467	+18,379	
Underdrain Height (inches) - Assuming GI Size of 0.75	0	67,544	-2,302	2,302	+2,302	3.097	-0.222	17,490	+17,402	Underdrain Height has an influence on Total Runoff and Infiltration. But not on Peak Runoff or Delay
	6	65,463	-4,383	4,383	+4,383	3.104	-0.216	17,601	+17,513	
	8	53,963	-15,884	15,884	+15,884	3.072	-0.248	22,347	+22,259	
	12	53,041	-16,805	16,805	+16,805	3.074	-0.246	22,443	+22,354	

The full A22 sewershed with the impervious area of 270 acres retrofitted for SWMM LID was then simulated with various incremental GI design rainfall depths (in inches of rainfall over the contributing impervious drainage area) and detention times (in hours stored after a single rain event). The results were then used to determine the optimal GI design to maximize typical year CSO volume reduction. The results of the model simulations are shown in Table 2.

TABLE 2
A22 TYPICAL YEAR CSO REDUCTION FOR VARYING GI DESIGN DEPTH AND RETURN TIME USING 270 AC OF IMPERVIOUS AREA RETROFITTED FOR SWMM LID

GI Size (inches)	A22 Sewershed Typical Year CSO (MG) Existing Typical Year CSO Volume at A22 = 586.1 MG			
	24 Hour Return Time		72 Hour Return Time	
	CSO Discharge (MG)	CSO Reduction (MG)	CSO Discharge (MG)	CSO Reduction (MG)
0.75	476.4	109.7	462.7	123.4
1.00	469.8	116.3	452.8	133.3
1.50	452.2	133.9	429.8	156.3
2.00	428.1	158.0	416.1	170.0

Based on the results in Table 2, it was determined that 1.5-inch capture design detained for 72 hours was the optimum GI design size and was recommended to carry forward for future sewershed modeling analysis.

Analysis of the typical year rainfall and CSO activations at A-22 further confirm the 1.5-inch GI design. Figure 2, shows the 91 rainfall events during the typical year versus the modeled CSO volume activation at A-22. Capturing and detaining up to the 1.5-inch rainfall event would represent approximately 95.6% of the rainfall events in the typical year. Similar rainfall to CSO activations have also been observed in other sewersheds.

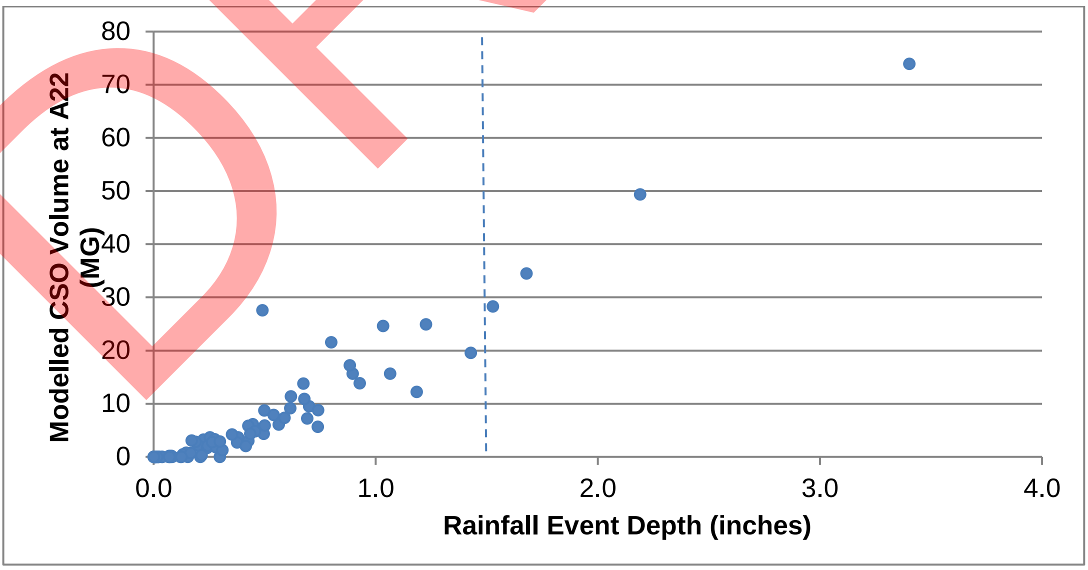


Figure 2: Relationship of Rainfall Event Size and CSO Volume at A22 (Existing Conditions)

Appendix C: Existing Conditions - 250 MGD Treatment Plant - Individual Sewershed Typical Year Overflow Results											
	Existing Conditions		No GI Implemented			1285 Impervious Acres of GI Management			1835 Impervious Acres of GI Management		
Sewershed	Annual Wet Weather Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume Reduced (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)
A-22-OF	1594.8	580.5	580.5	0	63.6%	425.9	154.6	73.3%	356.4	224.1	77.7%
A-41-OF	664.5	338.6	338.6	0	49.0%	300.6	37.9	54.8%	278.2	60.3	58.1%
A-42-OF	2175.9	783.0	783.0	0	64.0%	576.3	206.7	73.5%	520.1	262.9	76.1%
A-47-OF	32.7	0.9	0.9	0	97.2%	0.9	0.0	97.2%	0.8	0.1	97.6%
A-48-OF	546.0	49.1	49.1	0	91.0%	36.4	12.7	93.3%	28.3	20.8	94.8%
A-51-OF	119.8	13.1	13.1	0	89.1%	12.9	0.2	89.2%	12.5	0.6	89.6%
A-58-OF	1007.8	174.2	174.2	0	82.7%	152.1	22.1	84.9%	149.4	24.8	85.2%
A-60-OF	801.5	209.8	209.8	0	73.8%	157.7	52.0	80.3%	153.6	56.1	80.8%
A-61-OF	14.1	5.1	5.1	0	63.9%	5.0	0.1	64.3%	3.2	2.0	77.7%
A-62-OF	8.3	8.4	8.4	0	-1.1%	8.0	0.4	3.6%	7.9	0.5	5.5%
A-63-OF	2.9	0.2	0.2	0	93.7%	0.2	0.0	93.7%	0.2	0.0	93.7%
A-64-OF	30.3	4.0	4.0	0	86.6%	3.9	0.1	87.0%	3.7	0.3	87.7%
A-65-OF	11.8	20.9	20.9	0	-77.8%	20.7	0.2	-76.5%	20.3	0.6	-73.1%
M-15-OF	7.9	4.6	4.6	0	40.9%	4.6	0.1	41.7%	3.2	1.5	59.5%
M-15Z-OF	10.4	0.6	0.6	0	94.1%	0.6	0.0	94.2%	0.6	0.0	94.3%
M-16-OF	249.0	102.9	102.9	0	58.7%	86.0	16.9	65.5%	46.4	56.4	81.4%
M-17-OF	8.8	0.5	0.5	0	93.9%	0.5	0.0	93.9%	0.5	0.0	94.0%
M-18-OF	8.9	0.7	0.7	0	91.9%	0.7	0.0	91.9%	0.7	0.0	92.0%
M-19A-OF	318.2	83.5	83.5	0	73.8%	55.0	28.4	82.7%	50.1	33.3	84.2%
M-19B-OF	75.5	17.0	17.0	0	77.5%	10.7	6.2	85.8%	11.6	5.4	84.7%
M-19-OF	265.9	146.0	146.0	0	45.1%	126.0	20.0	52.6%	92.5	53.6	65.2%
M-20-OF	13.4	1.7	1.7	0	87.3%	1.6	0.1	87.8%	1.5	0.2	88.7%
M-21-OF	62.6	11.1	11.1	0	82.2%	11.0	0.1	82.4%	9.9	1.2	84.2%
M-22-OF	72.0	6.5	6.5	0	91.0%	6.4	0.1	91.1%	6.2	0.3	91.4%
M-29-OF	1426.3	402.0	402.0	0	71.8%	337.6	64.4	76.3%	271.0	131.0	81.0%
O-27-OF	696.9	79.6	79.6	0	88.6%	45.0	34.5	93.5%	43.2	36.3	93.8%
O-39-OF	29.3	7.5	7.5	0	74.5%	7.5	0.0	74.5%	5.3	2.2	81.8%
O-40-OF	3.2	0.2	0.2	0	93.9%	0.2	0.0	94.3%	0.2	0.0	94.3%
O-41-OF	33.3	14.5	14.5	0	56.3%	5.5	9.1	83.6%	5.4	9.1	83.8%
O-43-OF	35.3	0.2	0.2	0	99.6%	0.1	0.0	99.6%	0.1	0.0	99.6%
Aggregate =	10327.21	3066.84	3066.84	0	70%	2400.04	666.81	77%	2083.15	983.69	80%

Notes:

CSO Sewersheds >99.5% Capture Highlighted in Green

The results presented above represent the localized overflow reduction benefits and do not include systemwide overflow reductions at other neighboring sewersheds. Refer to Table 3-6 in Section 3 to view the full systemwide overflow reductions.

Appendix C: 480 MGD Treatment Plant - Individual Sewershed Typical Year Overflow Results											
	Existing Conditions		No GI Implemented			1285 Impervious Acres of GI Management			1835 Impervious Acres of GI Management		
Sewershed	Annual Wet Weather Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume Reduced (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)
A-22-OF	1594.8	580.5	486.4	94.1	69.5%	330.7	155.7	79.3%	266.3	220.1	83.3%
A-41-OF	664.5	338.6	292.6	45.9	56.0%	243.6	49.0	63.3%	224.9	67.7	66.2%
A-42-OF	2175.9	783.0	716.4	66.6	67.1%	472.9	243.5	78.3%	435.5	280.9	80.0%
A-47-OF	32.7	0.9	0.1	0.9	99.8%	0.0	0.1	100.0%	0.1	0.0	99.8%
A-48-OF	546.0	49.1	27.4	21.7	95.0%	15.2	12.2	97.2%	14.2	13.2	97.4%
A-51-OF	119.8	13.1	8.1	5.0	93.2%	8.1	0.0	93.2%	8.1	0.0	93.2%
A-58-OF	1007.8	174.2	111.2	63.0	89.0%	90.1	21.1	91.1%	90.6	20.6	91.0%
A-60-OF	801.5	209.8	79.8	129.9	90.0%	47.7	32.1	94.0%	47.8	32.0	94.0%
A-61-OF	14.1	5.1	3.8	1.3	73.1%	3.8	0.0	72.8%	1.9	1.9	86.4%
A-62-OF	8.3	8.4	0.8	7.6	90.3%	0.8	0.1	90.9%	0.7	0.1	91.4%
A-63-OF	2.9	0.2	0.2	0.0	93.7%	0.2	0.0	93.7%	0.2	0.0	93.7%
A-64-OF	30.3	4.0	2.9	1.2	90.5%	2.9	0.0	90.5%	2.9	0.0	90.5%
A-65-OF	11.8	20.9	2.5	18.4	79.1%	2.3	0.1	80.2%	2.1	0.3	82.0%
M-15-OF	7.9	4.6	3.7	0.9	52.9%	3.7	0.0	52.9%	1.9	1.8	75.7%
M-15Z-OF	10.4	0.6	0.6	0.0	94.1%	0.6	0.0	94.1%	0.6	0.0	94.2%
M-16-OF	249.0	102.9	101.3	1.6	59.3%	84.8	16.5	66.0%	45.9	55.4	81.6%
M-17-OF	8.8	0.5	0.4	0.1	95.3%	0.4	0.0	95.3%	0.4	0.0	95.2%
M-18-OF	8.9	0.7	0.7	0.0	91.9%	0.7	0.0	91.9%	0.7	0.0	91.9%
M-19A-OF	318.2	83.5	83.5	0.0	73.8%	55.1	28.3	82.7%	50.6	32.8	84.1%
M-19B-OF	75.5	17.0	16.9	0.0	77.6%	10.7	6.2	85.8%	11.8	5.2	84.4%
M-19-OF	265.9	146.0	91.4	54.6	65.6%	74.4	17.0	72.0%	48.5	42.9	81.8%
M-20-OF	13.4	1.7	0.4	1.3	96.7%	0.4	0.0	96.7%	0.4	0.0	96.7%
M-21-OF	62.6	11.1	10.8	0.4	82.8%	10.8	0.0	82.8%	9.6	1.2	84.7%
M-22-OF	72.0	6.5	5.5	1.0	92.3%	5.5	0.0	92.3%	5.5	0.0	92.4%
M-29-OF	1426.3	402.0	338.0	64.0	76.3%	276.8	61.2	80.6%	212.6	125.4	85.1%
O-27-OF	696.9	79.6	73.5	6.1	89.5%	40.2	33.3	94.2%	40.0	33.5	94.3%
O-39-OF	29.3	7.5	6.5	0.9	77.7%	6.5	0.0	77.7%	4.7	1.8	84.0%
O-40-OF	3.2	0.2	0.2	0.0	94.0%	0.2	0.0	94.3%	0.2	0.0	94.4%
O-41-OF	33.3	14.5	14.5	0.0	56.4%	5.5	9.0	83.6%	5.4	9.1	83.6%
O-43-OF	35.3	0.2	0.1	0.1	99.8%	0.1	0.0	99.8%	0.1	0.0	99.8%
Aggregate =	10327.21	3066.84	2480.20	586.64	76%	1794.86	685.34	83%	1534.13	946.08	85%

Notes:

CSO Sewersheds >99.5% Capture Highlighted in Green

The results presented above represent the localized overflow reduction benefits and do not include systemwide overflow reductions at other neighboring sewersheds. Refer to Table 3-6 in Section 3 to view the full systemwide overflow reductions.

Appendix C: 600 MGD Treatment Plant - No Sediment - Open 19 CSOs - Individual Sewershed Typical Year Overflow Results											
	Existing Conditions		No GI Implemented			1285 Impervious Acres of GI Management			1835 Impervious Acres of GI Management		
Sewershed	Annual Wet Weather Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume Reduced (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)
A-22-OF	1594.8	580.5	310.6	269.9	80.5%	209.4	101.2	86.9%	161.6	149.0	89.9%
A-41-OF	664.5	338.6	240.6	97.9	63.8%	160.8	79.8	75.8%	132.6	108.1	80.1%
A-42-OF	2175.9	783.0	586.4	196.6	73.0%	359.3	227.1	83.5%	309.0	277.4	85.8%
A-47-OF	32.7	0.9	0.0	0.9	99.9%	0.0	0.0	100.0%	0.0	0.0	100.0%
A-48-OF	546.0	49.1	13.8	35.3	97.5%	5.3	8.6	99.0%	5.4	8.4	99.0%
A-51-OF	119.8	13.1	2.0	11.0	98.3%	2.1	-0.1	98.2%	2.1	-0.1	98.2%
A-58-OF	1007.8	174.2	101.2	73.0	90.0%	82.6	18.6	91.8%	82.6	18.6	91.8%
A-60-OF	801.5	209.8	34.9	174.8	95.6%	17.2	17.7	97.9%	16.9	18.0	97.9%
A-61-OF	14.1	5.1	1.4	3.7	89.9%	1.4	0.0	90.2%	0.6	0.8	95.8%
A-62-OF	8.3	8.4	0.4	8.0	95.2%	0.4	0.0	95.1%	0.4	0.0	95.1%
A-63-OF	2.9	0.2	0.2	0.0	94.0%	0.2	0.0	93.7%	0.2	0.0	93.7%
A-64-OF	30.3	4.0	2.8	1.2	90.7%	2.9	-0.1	90.5%	2.9	-0.1	90.6%
A-65-OF	11.8	20.9	1.1	19.8	90.6%	1.1	0.0	90.6%	0.9	0.2	92.2%
M-15-OF	7.9	4.6	0.0	4.6	99.5%	0.0	0.0	99.6%	0.0	0.0	99.6%
M-15Z-OF	10.4	0.6	0.6	0.0	93.9%	0.6	0.0	94.2%	0.6	0.0	94.2%
M-16-OF	249.0	102.9	36.3	66.5	85.4%	25.7	10.6	89.7%	5.6	30.7	97.7%
M-17-OF	8.8	0.5	0.4	0.2	96.0%	0.4	-0.1	95.3%	0.4	-0.1	95.3%
M-18-OF	8.9	0.7	0.7	0.0	92.1%	0.7	0.0	91.9%	0.7	0.0	91.9%
M-19A-OF	318.2	83.5	78.8	4.7	75.2%	50.0	28.8	84.3%	45.4	33.4	85.7%
M-19B-OF	75.5	17.0	18.5	-1.5	75.5%	11.9	6.6	84.3%	13.0	5.4	82.7%
M-19-OF	265.9	146.0	26.5	119.5	90.0%	24.3	2.3	90.9%	10.3	16.2	96.1%
M-20-OF	13.4	1.7	0.4	1.3	96.9%	0.4	0.0	96.7%	0.4	0.0	96.7%
M-21-OF	62.6	11.1	2.8	8.3	95.5%	3.2	-0.4	94.9%	2.8	0.1	95.6%
M-22-OF	72.0	6.5	5.5	1.0	92.4%	5.5	0.0	92.3%	5.5	0.0	92.3%
M-29-OF	1426.3	402.0	194.2	207.8	86.4%	145.2	49.0	89.8%	96.6	97.7	93.2%
O-27-OF	696.9	79.6	27.9	51.7	96.0%	8.0	19.9	98.8%	8.0	19.9	98.9%
O-39-OF	29.3	7.5	0.7	6.8	97.6%	0.9	-0.2	96.8%	0.6	0.1	98.0%
O-40-OF	3.2	0.2	0.3	-0.1	90.1%	0.2	0.1	92.8%	0.2	0.1	92.8%
O-41-OF	33.3	14.5	11.4	3.1	65.6%	4.5	7.0	86.6%	4.5	7.0	86.6%
O-43-OF	35.3	0.2	0.0	0.1	99.9%	0.1	0.0	99.9%	0.1	0.0	99.9%
Aggregate =	10327.21	3066.84	1700.79	1366.05	84%	1124.42	576.37	89%	909.88	790.91	91%

Notes:

CSO Sewersheds >99.5% Capture Highlighted in Green

The results presented above represent the localized overflow reduction benefits and do not include systemwide overflow reductions at other neighboring sewersheds. Refer to Table 3-6 in Section 3 to view the full systemwide overflow reductions.

	Appendix C: Lowered HGL Operation during Rain Events - No Sediment - Open 19 CSOs - Individual Sewershed Typical Year Overflow Results										
	Existing Conditions		No GI Implemented			1285 Impervious Acres of GI Management			1835 Impervious Acres of GI Management		
Sewershed	Annual Wet Weather Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume (MG)	Annual CSO Volume Reduced (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)	Annual CSO Volume (MG)	Annual CSO Volume Reduced by GI (MG)	Percent Wet Weather Capture (%)
A-22-OF	1594.8	580.5	273.8	306.7	82.8%	167.5	106.3	89.5%	124.5	149.4	92.2%
A-41-OF	664.5	338.6	192.9	145.7	71.0%	116.6	76.3	82.5%	91.0	101.9	86.3%
A-42-OF	2175.9	783.0	537.7	245.3	75.3%	322.6	215.1	85.2%	271.8	265.8	87.5%
A-47-OF	32.7	0.9	0.1	0.9	99.8%	0.0	0.1	100.0%	0.0	0.1	100.0%
A-48-OF	546.0	49.1	17.7	31.5	96.8%	4.5	13.2	99.2%	4.4	13.3	99.2%
A-51-OF	119.8	13.1	2.2	10.9	98.2%	2.1	0.1	98.3%	2.1	0.1	98.2%
A-58-OF	1007.8	174.2	101.4	72.8	89.9%	82.3	19.1	91.8%	80.9	20.5	92.0%
A-60-OF	801.5	209.8	23.9	185.8	97.0%	8.4	15.6	99.0%	8.4	15.6	99.0%
A-61-OF	14.1	5.1	1.3	3.8	90.5%	1.4	0.0	90.3%	0.6	0.7	95.7%
A-62-OF	8.3	8.4	0.3	8.1	96.5%	0.3	0.0	96.5%	0.3	0.0	96.5%
A-63-OF	2.9	0.2	0.2	0.0	93.7%	0.2	0.0	93.7%	0.2	0.0	93.7%
A-64-OF	30.3	4.0	2.9	1.2	90.5%	2.9	0.0	90.5%	2.9	0.0	90.5%
A-65-OF	11.8	20.9	0.1	20.8	99.1%	0.1	0.0	99.1%	0.1	0.0	99.4%
M-15-OF	7.9	4.6	0.0	4.6	99.6%	0.0	0.0	99.6%	0.0	0.0	99.6%
M-15Z-OF	10.4	0.6	0.6	0.0	94.2%	0.6	0.0	94.2%	0.6	0.0	94.3%
M-16-OF	249.0	102.9	36.8	66.1	85.2%	25.7	11.0	89.7%	5.6	31.2	97.8%
M-17-OF	8.8	0.5	0.4	0.1	95.3%	0.4	0.0	95.3%	0.4	0.0	95.4%
M-18-OF	8.9	0.7	0.7	0.0	91.9%	0.7	0.0	91.9%	0.7	0.0	92.0%
M-19A-OF	318.2	83.5	78.6	4.9	75.3%	50.0	28.6	84.3%	44.8	33.7	85.9%
M-19B-OF	75.5	17.0	18.3	-1.3	75.8%	11.8	6.4	84.4%	12.7	5.5	83.1%
M-19-OF	265.9	146.0	21.4	124.6	91.9%	13.7	7.7	94.9%	5.3	16.1	98.0%
M-20-OF	13.4	1.7	0.4	1.3	96.7%	0.4	0.0	96.7%	0.4	0.0	96.7%
M-21-OF	62.6	11.1	3.2	7.9	94.9%	3.2	0.0	94.9%	2.8	0.5	95.6%
M-22-OF	72.0	6.5	5.5	1.0	92.3%	5.5	0.0	92.3%	5.3	0.2	92.6%
M-29-OF	1426.3	402.0	180.6	221.4	87.3%	135.1	45.4	90.5%	87.2	93.4	93.9%
O-27-OF	696.9	79.6	27.7	51.8	96.0%	8.0	19.7	98.9%	8.0	19.8	98.9%
O-39-OF	29.3	7.5	0.9	6.6	96.8%	0.9	0.0	96.8%	0.6	0.3	98.0%
O-40-OF	3.2	0.2	0.4	-0.2	88.2%	0.2	0.1	92.8%	0.2	0.1	92.8%
O-41-OF	33.3	14.5	11.6	2.9	65.0%	4.5	7.2	86.6%	4.3	7.3	87.0%
O-43-OF	35.3	0.2	0.1	0.1	99.9%	0.1	0.0	99.9%	0.1	0.0	99.9%
Aggregate =	10327.21	3066.84	1541.67	1525.17	85%	969.81	571.87	91%	766.28	775.40	93%

Notes:

CSO Sewersheds >99.5% Capture Highlighted in Green

The results presented above represent the localized overflow reduction benefits and do not include systemwide overflow reductions at other neighboring sewersheds. Refer to Table 3-6 in Section 3 to view the full systemwide overflow reductions.

APPENDIX D
WOODS RUN STREAM INFLOW EVALUATION, DETENTION LOCATION A

Modeling showed that a 0.16 MG detention facility is required to handle flows from the 92-acre tributary runoff area from both inflow points shown in Figure D-1. These two inflow locations were grouped together based on close proximity, and have adjacent drainage areas.

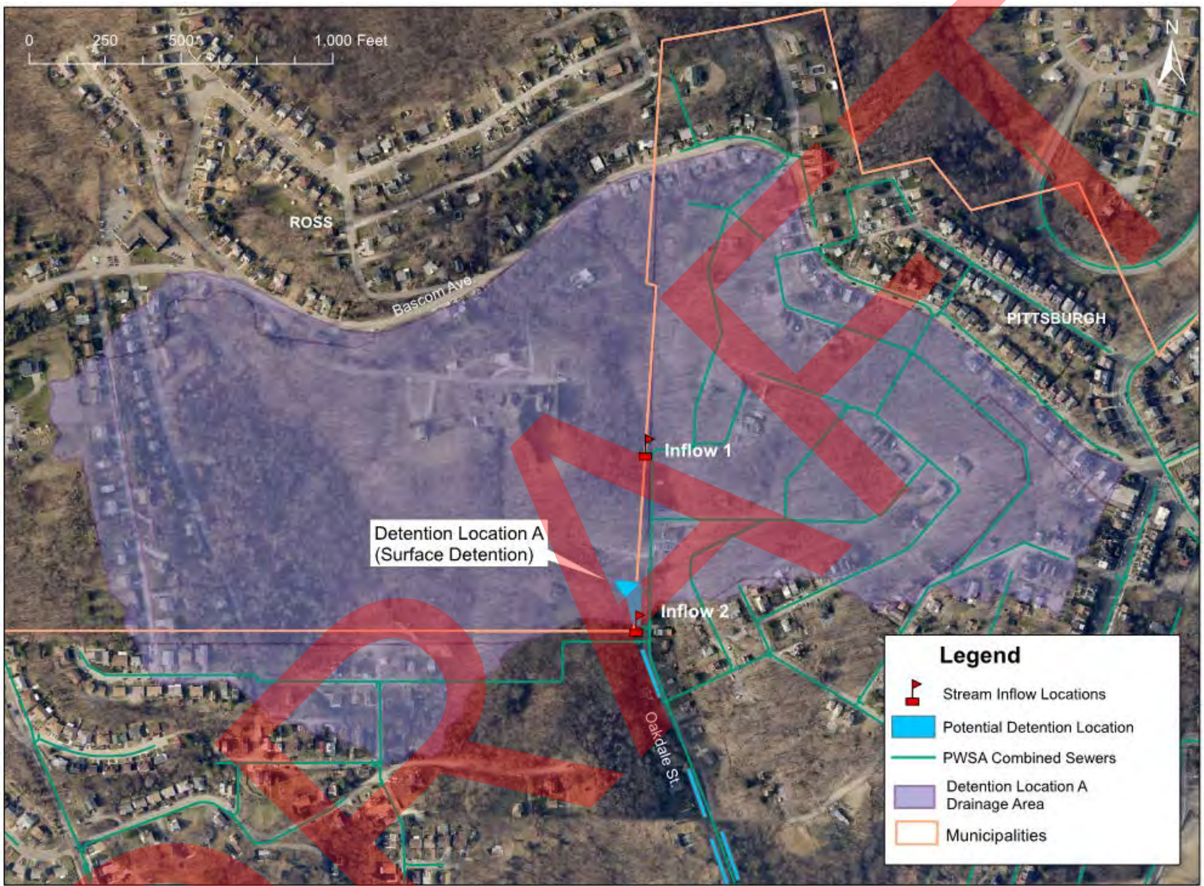


Figure D-1: Woods Run Potential Inflow Detention Location A

ASSUMPTIONS AND PROJECT DETAILS

Project Siting Considerations: The land areas shown in Figure D-1 were selected due to their flat terrain and close proximity to the two direct stream inflow locations. It was assumed that the flat, non-developed parcel could be obtained and used for stormwater detention features.

Detention Overview: It was assumed that the parcel shaded in Figure D-1 could be used as a subsurface gravel wetland storage facility, due to the grading and depth needed to divert the stream into the storage. For cost estimating, approximate excavation depth was assumed to be a conservative 15-footdepth. The calculated storage depth, given the footprint area as shown, would be approximately 2.6 feet deep. This could be handled both through surface ponding and detention within the subsurface gravel storage layer.

The grading at this location appears to allow for both surface and subsurface storage.

Cost Estimate: An estimate is provided in Table D-1 outlining the typical project costs associated with the size and type of detention facility described above. A 40% planning contingency has been added to account for unknown factors not quantified in these preliminary planning level assumptions.

TABLE D-1
PLANNING LEVEL COST ESTIMATE FOR WOODS RUN DETENTION LOCATION A

Storage Location A Solution: Detention & Slow release into CSS				
Control Level: 0.16 MG Storage				
Items of Work	**Approx. Quantity**	**Unit of Measure**	**Unit Bid Price**	**Total**
Land Acquisition	1	EA	$ 100,000.00	$ 100,000.00
Mobilization, Demobilization, and Field Office	1	LS	$ 15,050.00	$ 16,000.00
Field Survey and Engineering	1	LS	$ 5,600.00	$ 6,000.00
Erosion and Sediment Control	1	LS	$ 5,600.00	$ 6,000.00
Storm Trap Subsurface Storage	21,390	CF	$ 5.50	$ 118,000.00
Compacted Aggregate Base	460	CY	$ 60.00	$ 28,000.00
Engineered Soil Media & Gravel	674	CY	$ 60.00	$ 41,000.00
Excavation 0-15' Deep	5,058	CY	$ 9.00	$ 46,000.00
Vegetation	8,276	SF	$ 1.00	$ 9,000.00
Rock and Obstruction Excavation - All Depths	20	CY	$ 25.00	$ 1,000.00
Outlet Structure	1	EA	$ 3,000.00	$ 3,000.00
Maintenance Traffic Protection	1	LS	$ 8,400.00	$ 9,000.00
			Subtotal	$ 417,000.00
Planning Level Construction Contingency			40%	$167,000
Engineering (Planning, Design, & Construction Administration Services)			20%	$84,000
Project Contingency			20%	$84,000
			Total:	$752,000

DETENTION LOCATION B

This detention location would capture stormwater runoff from a 56-acre area. Runoff from both sides of the shed enters into the combined sewer system along Oakdale Street and conveyed south along the center of the sewershed. This location was best suited to capture flow in bioswale type BMPs within the right of way on either side of Oakdale Street.

Assumptions and Project Details

Project Siting Considerations: With no large flat areas to capture stormwater regionally at this location, distributed BMPs were laid out alongside Oakdale Street as shown in Figure D-2 below.

BMP Overview: Modeling showed that 0.5 MG of storage was required for this location to capture the largest storm event in the Typical Year. 20 BMPs were envisioned for this area, with each capturing 3,350 cubic feet (cf), or 25,000 gallons, of runoff at each BMP location. A total of 500,000 gallons of storage would be needed. For sizing and cost estimating, approximate dimensions of the required BMPs were assumed to be approximately 6 feet x 6 feet x 100 feet length. This sizing conservatively does not take into account any infiltration.

Cost Estimate

An estimate is provided in Table D-2 outlining the typical project costs associated with the size and type BMPs described above. A standard high and low unit price per gallon of storage was applied to the total 500,000 gallon BMP volume to develop a cost range for this work. A 40% planning contingency has been added to account for the unknown factors not quantified in these preliminary planning level assumptions.

Figure D-2: Woods Run Potential Inflow Detention Location B

TABLE D-2
PLANNING LEVEL COST ESTIMATE FOR WOODS RUN DETENTION LOCATION B

Storage Location B Solution: distributed BMPs					
Control Level: 0.5 MG Storage					
Items of Work	**Approx. Quantity**	**Unit of Measure**	**Unit Bid Price**	**Total**	
Bioswale Type BMP using Low Unit Price	500000	gal	$3.68	$	1,842,000.00
Bioswale Type BMP using High Unit Price	500,000	gal	$4.91	$	2,456,000.00
			Subtotal (average)	$	2,149,000.00
Planning Level Construction Contingency			40%		$860,000
Engineering (Planning, Design, & Construction Administration Services)			20%		$430,000
Project Contingency			20%		$430,000
			Total:		$3,869,000

DETENTION LOCATION C

The detention projects envisioned at inflow location C would be planned to handle the stream base flow from the Mairdale stream inflow point, as well as the wet weather peak flows for the Typical Year

Assumptions and Project Details

Project Siting Considerations: As shown in Figure D-3, the stream inflow point enters a 36-inch diameter combined sewer on the northern side of Mairdale Street, and crosses perpendicular to Mairdale as it continues towards Woods Run Ave. A large, flat parcel of land, shown in Figure D-4, was identified across the street from the inflow point as a possible stormwater management location for this inflow point.

BMP Overview: The flat parcel of land identified above, along with two other locations for BMPs along the right-of-way, make up the 0.31 acres of footprint required to manage the stream base flow and 72-acre tributary area. Modeling showed that 0.35 MG of storage was required for this location to capture the largest storm event in the Typical Year.

It is anticipated that this location could function as tiered stormwater ponding and subsurface storage similar to the bioswale project installed in 2013 by others at Mt. Alvernia along Hawthorne Road in Millvale. Figure D-5 shows a possible layout for this location.

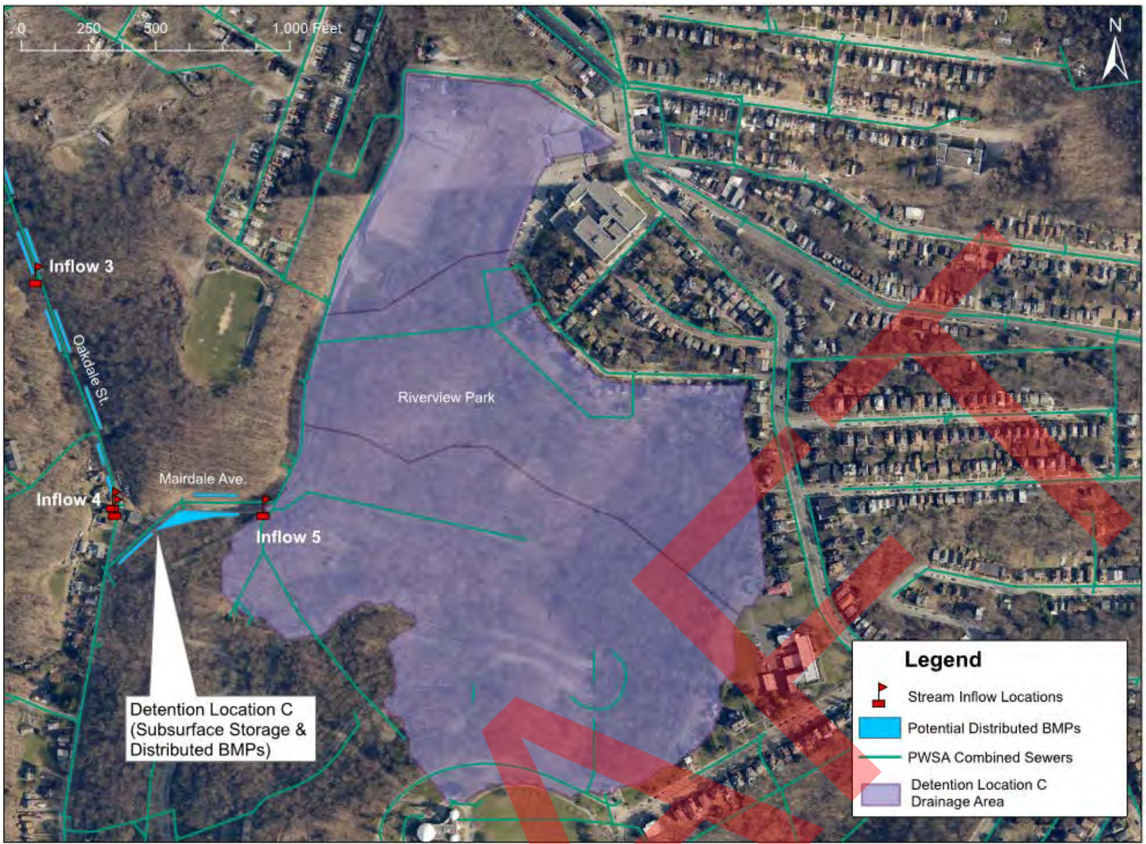


Figure D-3: Woods Run Inflow Detention Location C

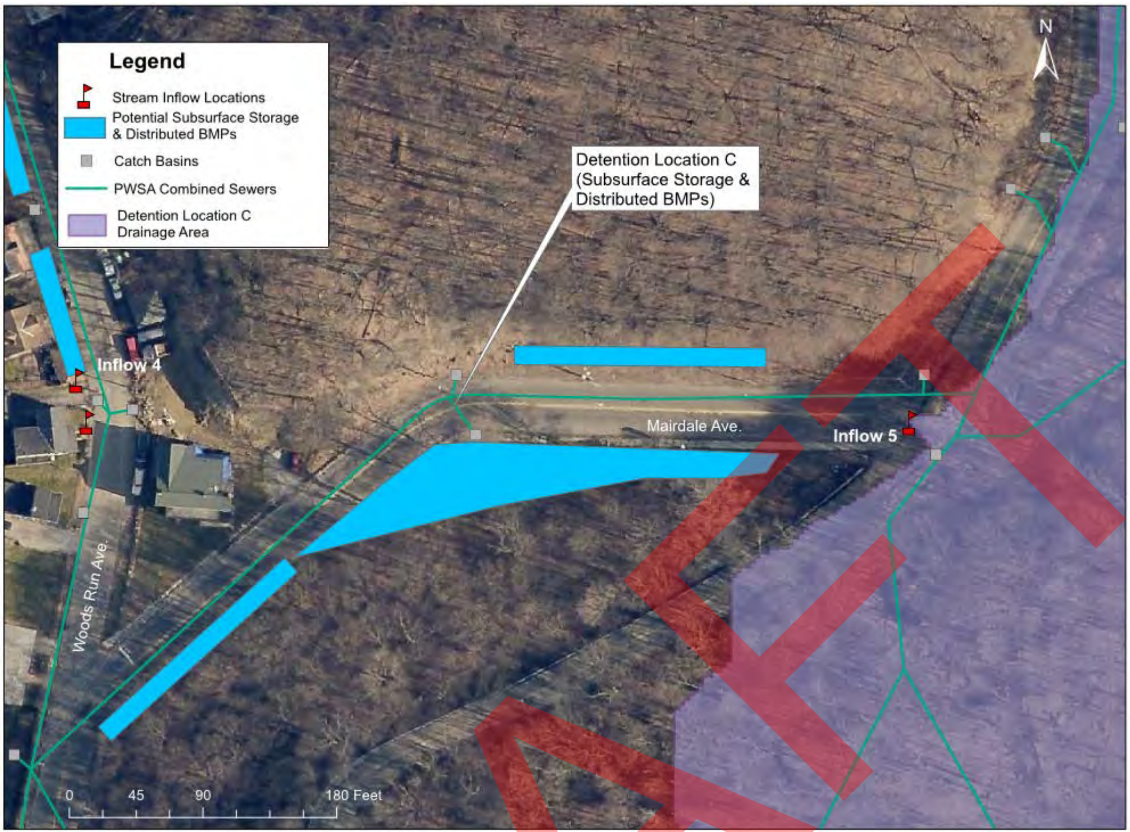


Figure D-4: Close-Up of Woods Run Inflow Detention Location C

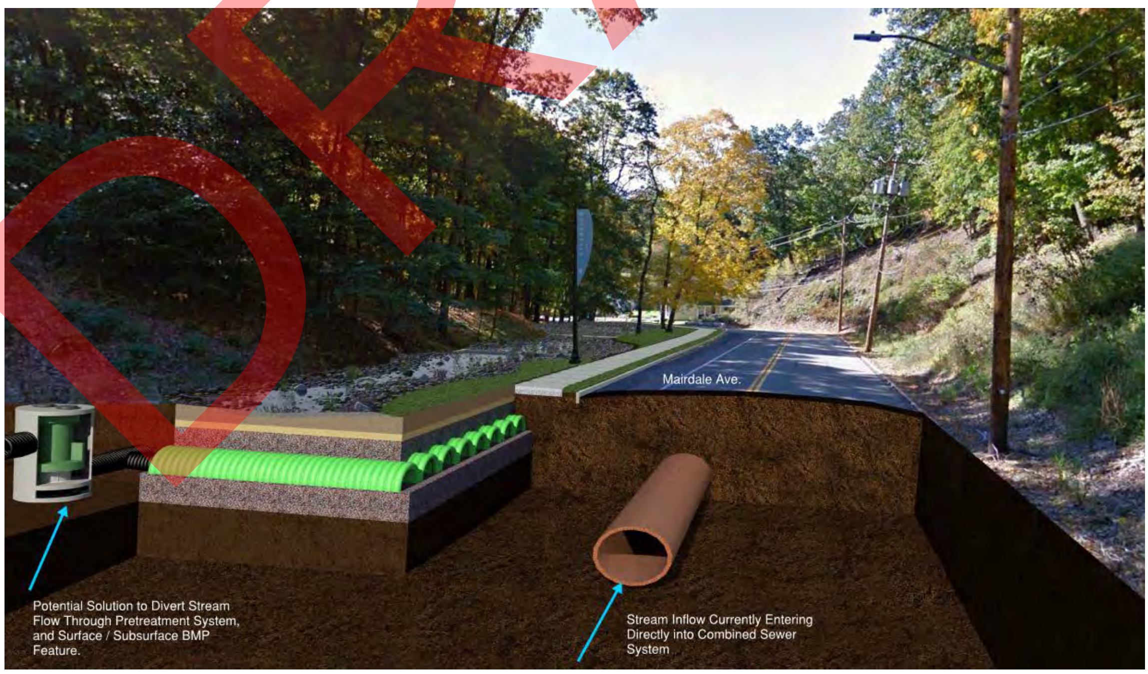


Figure D-5: Envisioned Layout for Potential Bioswale at Detention Location C

Cost Estimate

An estimate is provided in Table D-3 outlining the typical project costs associated with the size and type of surface and subsurface storage described above. A 40% planning contingency has been added to account for the unknown factors not quantified in these preliminary planning level assumptions.

TABLE D-3
PLANNING LEVEL COST ESTIMATE FOR THE WOODS RUN DETENTION LOCATION C

Storage Location C Solution: Surface and Surface Detention & Slow release into CSS					
Control Level: 0.35 MG Storage					
Items of Work	**Approx. Quantity**	**Unit of Measure**	**Unit Bid Price**		**Total**
Mobilization, Demobilization, and Field Office	1	LS	$ 27,900.00	$	28,000.00
Field Survey and Engineering	1	LS	$ 10,400.00	$	11,000.00
Erosion and Sediment Control	1	LS	$ 10,400.00	$	11,000.00
Storm Trap Subsurface Storage	46,791	CF	$ 4.50	$	211,000.00
Compacted Aggregate Base	750	CY	$ 60.00	$	46,000.00
Engineered Soil Media & Gravel	1,100	CY	$ 60.00	$	67,000.00
8" PVC SDR-26 Sewer Pipe, Less than 15' Deep	750	LF	$ 125.00	$	94,000.00
Excavation 0-15' Deep	8,252	CY	$ 9.00	$	75,000.00
Vegetation	13,504	SF	$ 1.00	$	14,000.00
Rock and Obstruction Excavation - All Depths	25	CY	$ 25.00	$	1,000.00
Outlet Structure	1	EA	$ 3,000.00	$	3,000.00
Overflow Structure	1	EA	$ 8,500.00	$	9,000.00
Maintenance Traffic Protection	1	LS	$ 15,600.00	$	16,000.00
			Subtotal	$	586,000.00
Planning Level Construction Contingency			40%		$235,000
Engineering (Planning, Design, & Construction Administration Services)			20%		$118,000
Project Contingency			20%		$118,000
			Total:		$1,057,000

DETENTION LOCATION D

BMP location D is located in the one drainage area evaluated in this section that is not considered a stream inflow location. Rainfall runoff from the Benton Field Park is captured in a separate storm sewer system and routed to the combined sewer system along Woods Run Avenue. This sewershed was identified as a good location to intercept and manage the stormwater upstream of the discharge location into the combined sewer system.

Assumptions and Project Details

Project Siting Considerations: As shown in Figure D-6, the Benton Field sewershed covers a 40-acre area consisting of parks, some residential housing, and a wooded area. Downstream of the residential and park areas, an open and relatively flat area, shown in Figure D-7 was identified as a possible stormwater management location to intercept the storm sewer flow. Alternatively, there is an unpaved road connecting the park to Woods Run Avenue in which the alignment could be used to site distributed BMPs along the roadside.

BMP Overview: A flat section of land near the junction location of the storm sewer pipes was selected as a possible location for surface detention. Because the storm sewer depths and surface have not been surveyed, assumptions for slope and grading were made in selecting this storage type.

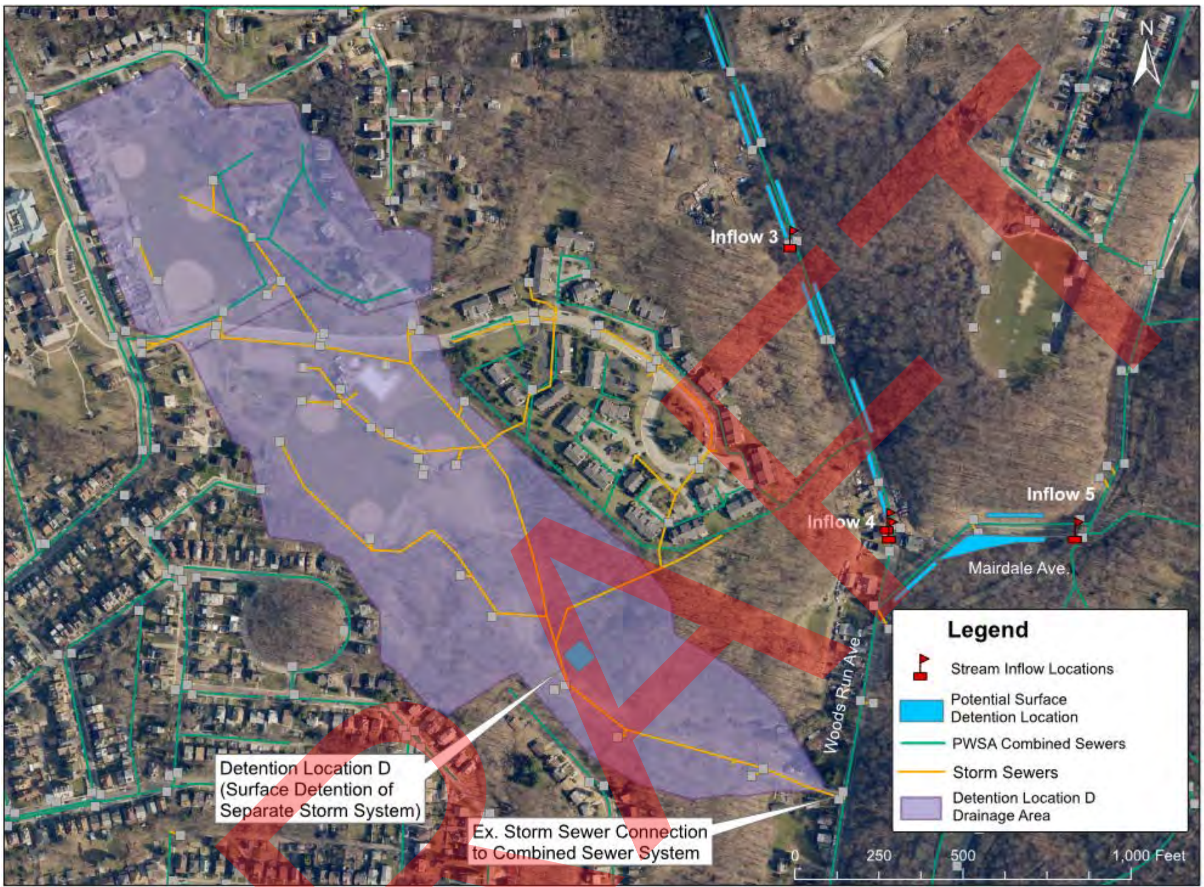


Figure D-6: Woods Run Stormwater Runoff Detention Location D

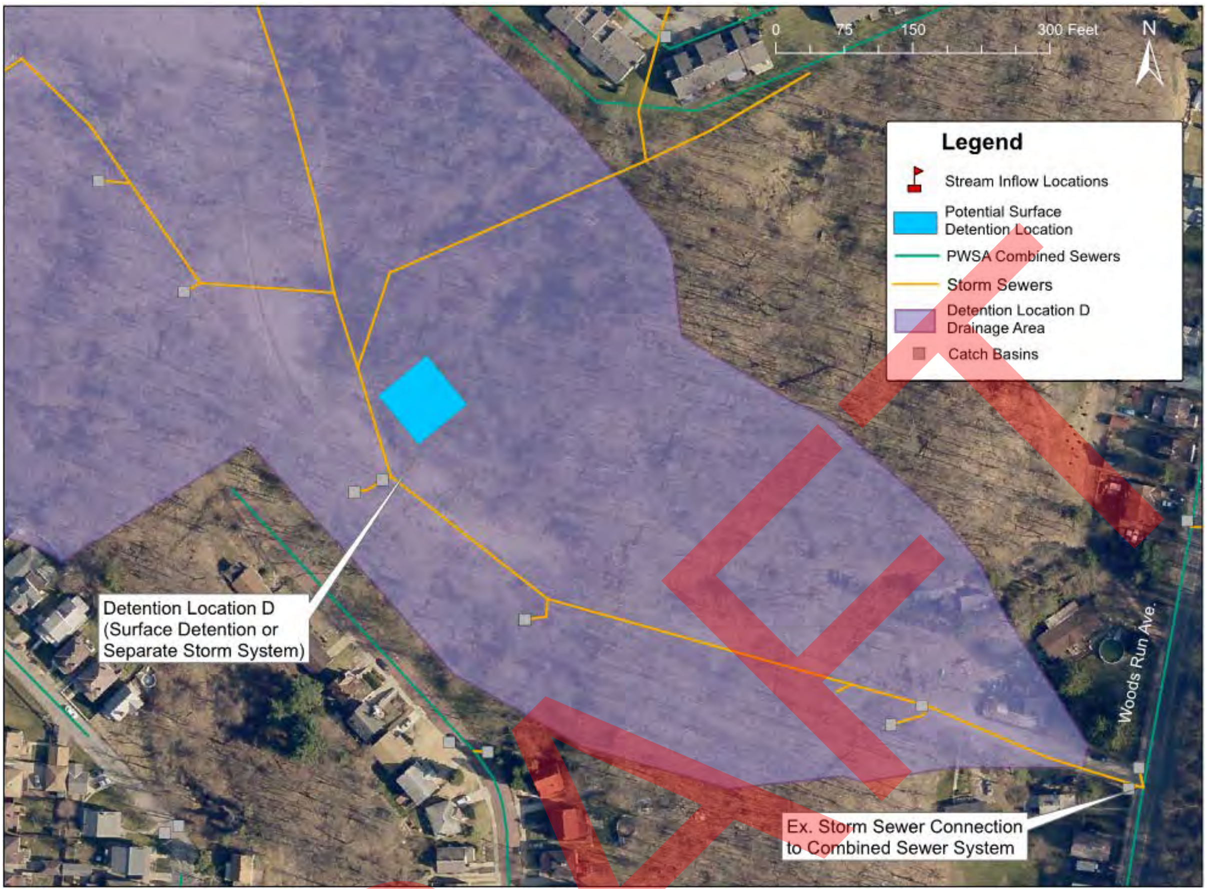


Figure D-7: Close-Up of Woods Run Stormwater Runoff Detention Location D

Cost Estimate

An estimate is provided in Table D-4 outlining the typical project costs associated with the size and type of surface detention described above. A 40% planning contingency has been added to account for the unknown factors not quantified in these preliminary planning level assumptions.

TABLE D-4
PLANNING LEVEL COST ESTIMATE FOR THE WOODS RUN DETENTION LOCATION D

Storage Location D Solution: Surface Detention & Slow release into CSS				
Control Level: 0.1 MG Storage				
Items of Work	**Approx. Quantity**	**Unit of Measure**	**Unit Bid Price**	**Total**
Mobilization, Demobilization, and Field Office	1	LS	$ 8,350.00	$ 9,000.00
Field Survey and Engineering	1	LS	$ 3,080.00	$ 4,000.00
Erosion and Sediment Control	1	LS	$ 3,080.00	$ 4,000.00
Grading	586	SY	$ 12.00	$ 8,000.00
Engineered Soil Media & Gravel	390	CY	$ 60.00	$ 24,000.00
8" PVC SDR-26 Sewer Pipe, Less than 15' Deep	400	LF	$ 125.00	$ 50,000.00
Excavation 0-15' Deep	2,928	CY	$ 15.00	$ 44,000.00
Vegetation	4,792	SF	$ 3.00	$ 15,000.00
Rock and Obstruction Excavation - All Depths	20	CY	$ 25.00	$ 1,000.00
Outlet Structure	1	EA	$ 3,000.00	$ 3,000.00
Overflow Structure	1	EA	$ 8,500.00	$ 9,000.00
Maintenance Traffic Protection	1	LS	$ 4,620.00	$ 5,000.00
			Subtotal	$ 176,000.00
Planning Level Construction Contingency			40%	$71,000
Engineering (Planning, Design, & Construction Administration Services)			20%	$36,000
Project Contingency			20%	$36,000
			Total:	$319,000

DETENTION LOCATION E

BMP Location E is planned to intercept wet weather runoff from a 66-acre area covering parts of Riverview Park. The runoff follows a shallow ravine and enters an inflow point to the combined sewer system behind the houses near 915 Woods Run Avenue. During field visits in 2015, base stream flow was not observed at this location.

Assumptions and Project Details

Project Siting Considerations: The contributing park areas consist primarily of wooded area, along with runoff contributed from the Riverview Avenue road through the park. This drainage area is made up largely of steeply sloped hillsides, however, a few locations were identified for BMPs. Towards the middle of the drainage area, there is a flat section of land near where Riverview Avenue makes a sharp bend. This large, flat, and undeveloped parcel has the potential to be used to manage wet weather flows from the upper sections of the park. Additionally, there is a private drive near the downstream end of the shed where BMPs may be able to be sited. These physical features and the potential detention location are shown in Figure D-8.

BMP Overview: For this analysis, it was assumed that 50% of the required 0.22 MG of storage would be captured by the regional subsurface detention, with the other half of the flow being captured by the distributed BMPs sited at the downstream section of the shed.

Figure D-8: Woods Run Inflow Detention Location E

Cost Estimate

Tables D-5 and D-6 provide cost estimates for both the subsurface detention as well as the distributed BMPs. A 40% planning contingency has been added to account for the unknown factors not quantified in these preliminary planning level assumptions.

TABLE D-5
PLANNING LEVEL COST ESTIMATE FOR THE WOODS RUN DISTRIBUTED BMPS FOR LOCATION E

Storage Location E Solution: distributed BMPs				
Control Level: 0.11 MG Storage				
Items of Work	**Approx. Quantity**	**Unit of Measure**	**Unit Bid Price**	**Total**
Bioswale Type BMP using Low Unit Price	110000	gal	$3.68	$ 406,000.00
Bioswale Type BMP using High Unit Price	110,000	gal	$4.91	$ 541,000.00
			Subtotal (average	$ 474,000.00
Planning Level Construction Contingency			40%	$190,000
Engineering (Planning, Design, & Construction Administration Services)			20%	$95,000
Project Contingency			20%	$95,000
			Total:	$854,000

TABLE D-6
PLANNING LEVEL COST ESTIMATE FOR THE WOODS RUN DETENTION LOCATION E

Storage Location E Solution: Subsurface Detention & Slow release into CSS				
Control Level: 0.11 MG Storage				
Items of Work	**Approx. Quantity**	**Unit of Measure**	**Unit Bid Price**	**Total**
Mobilization, Demobilization, and Field Office	1	LS	$ 10,250.00	$ 11,000.00
Field Survey and Engineering	1	LS	$ 3,820.00	$ 4,000.00
Erosion and Sediment Control	1	LS	$ 3,820.00	$ 4,000.00
Storm Trap Subsurface Storage	14,706	CF	$ 5.50	$ 81,000.00
Compacted Aggregate Base	266	CY	$ 60.00	$ 16,000.00
Engineered Soil Media & Gravel	390	CY	$ 60.00	$ 24,000.00
8" PVC SDR-26 Sewer Pipe, Less than 15' Deep	200	LF	$ 125.00	$ 25,000.00
Excavation 0-15' Deep	2,928	CY	$ 9.00	$ 27,000.00
Vegetation	4,792	SF	$ 1.00	$ 5,000.00
Rock and Obstruction Excavation - All Depths	20	CY	$ 25.00	$ 1,000.00
Outlet Structure	1	EA	$ 3,000.00	$ 3,000.00
Overflow Structure	1	EA	$ 8,500.00	$ 9,000.00
Maintenance Traffic Protection	1	LS	$ 5,730.00	$ 6,000.00
			Subtotal	$ 216,000.00
Planning Level Construction Contingency			40%	$87,000
Engineering (Planning, Design, & Construction Administration Services)			20%	$44,000
Project Contingency			20%	$44,000
			Total:	$391,000

DETENTION LOCATION F

Detention location F is planned to capture stormwater runoff from the 90-acre area of land containing part of Riverview Park and Kilbuck Road.

Assumptions and Project Details

Project Siting Considerations: The contributing park areas consist primarily of wooded area, along with runoff contributed from Kilbuck Road, which runs through the park. This drainage area is made up largely of steeply sloped hillsides with runoff flowing down Kilbuck Road, which bisects the shed. Towards the middle of the drainage area, there is a flat section of land located within the park area. This large, flat, and undeveloped parcel has the potential to be used to manage wet weather flows from the upper sections of the park. Additionally, distributed BMPs along Kilbuck Road were envisioned to capture a portion of the flow. These physical features and the potential detention location are shown in Figure D-9.

BMP Overview: For this analysis, it was assumed that 66% of the required 0.48 MG of storage would be captured by regional subsurface detention located within the park. The remaining 33% of storage volume could be met with the use of distributed BMPs along Kilbuck Road prior to the inflow point near the intersection of Rothpletz Street and Kilbuck Road.

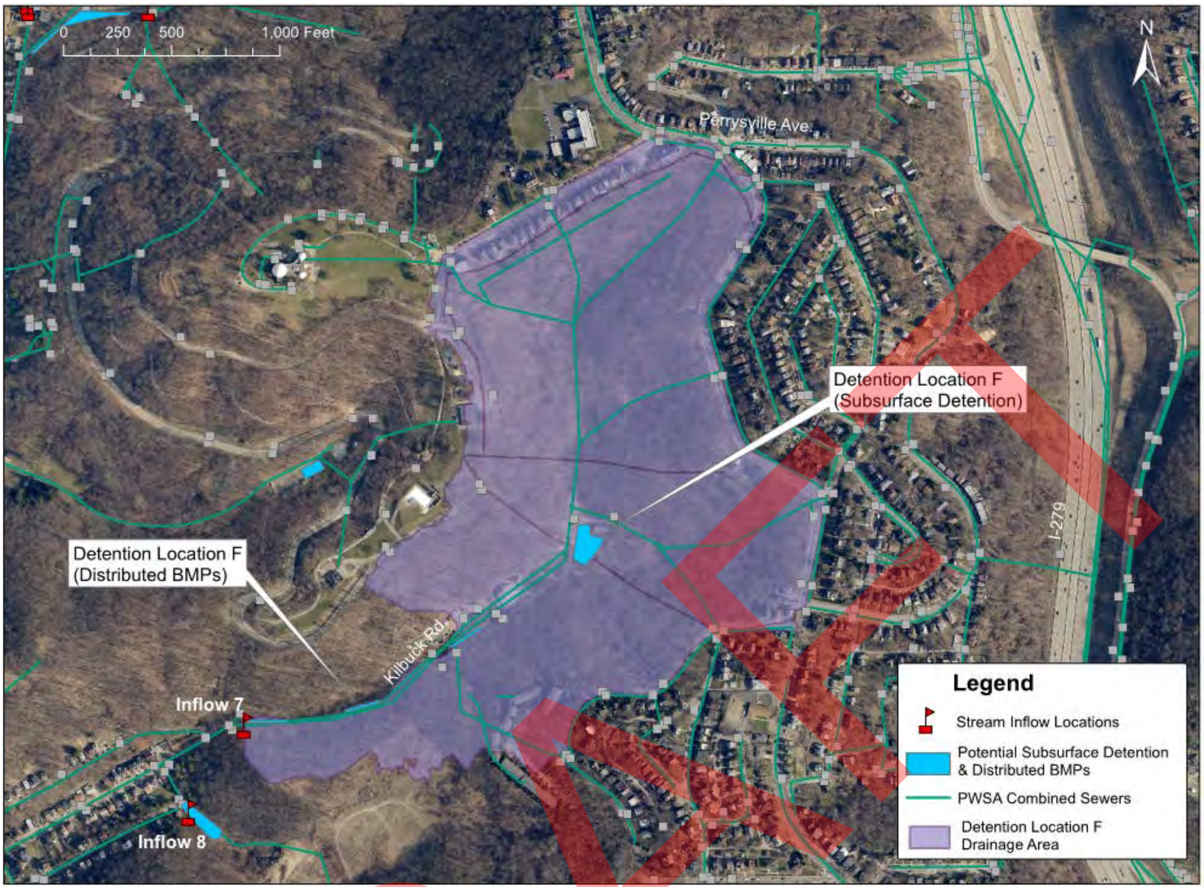


Figure D-9: Woods Run Inflow Detention Location F

Cost Estimate

Tables D-7 and D-8 provide cost estimates for both the subsurface detention as well as the distributed BMPs. A 40% planning contingency has been added to account for the unknown factors not quantified in these preliminary planning level assumptions.

TABLE D-7
PLANNING LEVEL COST ESTIMATE FOR THE WOODS RUN DISTRIBUTED BMPS FOR LOCATION F

Storage Location F Solution: distributed BMPs					
Control Level: 0.16 MG Storage					
Items of Work	Approx. Quantity	Unit of Measure	Unit Bid Price		Total
Bioswale Type BMP using Low Unit Price	160000	gal	$3.68	$	590,000.00
Bioswale Type BMP using High Unit Price	160,000	gal	$4.91	$	786,000.00
			Subtotal (average)	$	688,000.00
Planning Level Construction Contingency			40%		$276,000
Engineering (Planning, Design, & Construction Administration Services)			20%		$138,000
Project Contingency			20%		$138,000
			Total:		$1,240,000

TABLE D-8

PLANNING LEVEL COST ESTIMATE FOR THE WOODS RUN DETENTION LOCATION F

Storage Location F Solution: Subsurface Detention & Slow release into CSS					
Control Level: 0.32 MG Storage					
Items of Work	Approx. Quantity	Unit of Measure	Unit Bid Price		Total
Mobilization, Demobilization, and Field Office	1	LS	$ 29,100.00	$	30,000.00
Field Survey and Engineering	1	LS	$ 10,860.00	$	11,000.00
Erosion and Sediment Control	1	LS	$ 10,860.00	$	11,000.00
Storm Trap Subsurface Storage	42,781	CF	$ 5.50	$	236,000.00
Compacted Aggregate Base	910	CY	$ 60.00	$	55,000.00
Engineered Soil Media & Gravel	1,335	CY	$ 60.00	$	81,000.00
8" PVC SDR-26 Sewer Pipe, Less than 15' Deep	400	LF	$ 125.00	$	50,000.00
Excavation 0-15' Deep	10,009	CY	$ 9.00	$	91,000.00
Vegetation	16,379	SF	$ 1.00	$	17,000.00
Rock and Obstruction Excavation - All Depths	40	CY	$ 25.00	$	1,000.00
Outlet Structure	1	EA	$ 3,000.00	$	3,000.00
Overflow Structure	1	EA	$ 8,500.00	$	9,000.00
Maintenance Traffic Protection	1	LS	$ 16,290.00	$	17,000.00
			Subtotal	$	612,000.00
Planning Level Construction Contingency			40%		$245,000
Engineering (Planning, Design, & Construction Administration Services)			20%		$123,000
Project Contingency			20%		$123,000
			Total:		$1,103,000

DETENTION LOCATION G

Detention location G captures flow adjacent to the BMP location F sewershed. This location largely captures stormwater runoff from the Highwood Cemetery, neighboring wooded areas, and a few residential streets.

Assumptions and Project Details

Project Siting Considerations: Runoff from the cemetery and wooded areas travels through the undeveloped terrain in a shallow ravine to the location of a PWSA catch basin located near the intersection of Smithton Avenue and Henley Street. At present no open space is available for detention downstream of the inflow point. An opportunity was identified to site subsurface stormwater management features in the shallow ravine directly upstream of the inflow point between the cemetery and the existing PWSA catch basin.

BMP Overview: Modeling indicated that a 0.28 MG subsurface storage feature could effectively manage runoff from the 76-acre contributing area for the Typical Year wet weather conditions. This storage feature, as highlighted in Figure D-10, assumes 11,300 SF footprint, with an average depth of 3.3 feet for storage. The required storage depth could be met through a combination of surface ponding and subsurface storage.

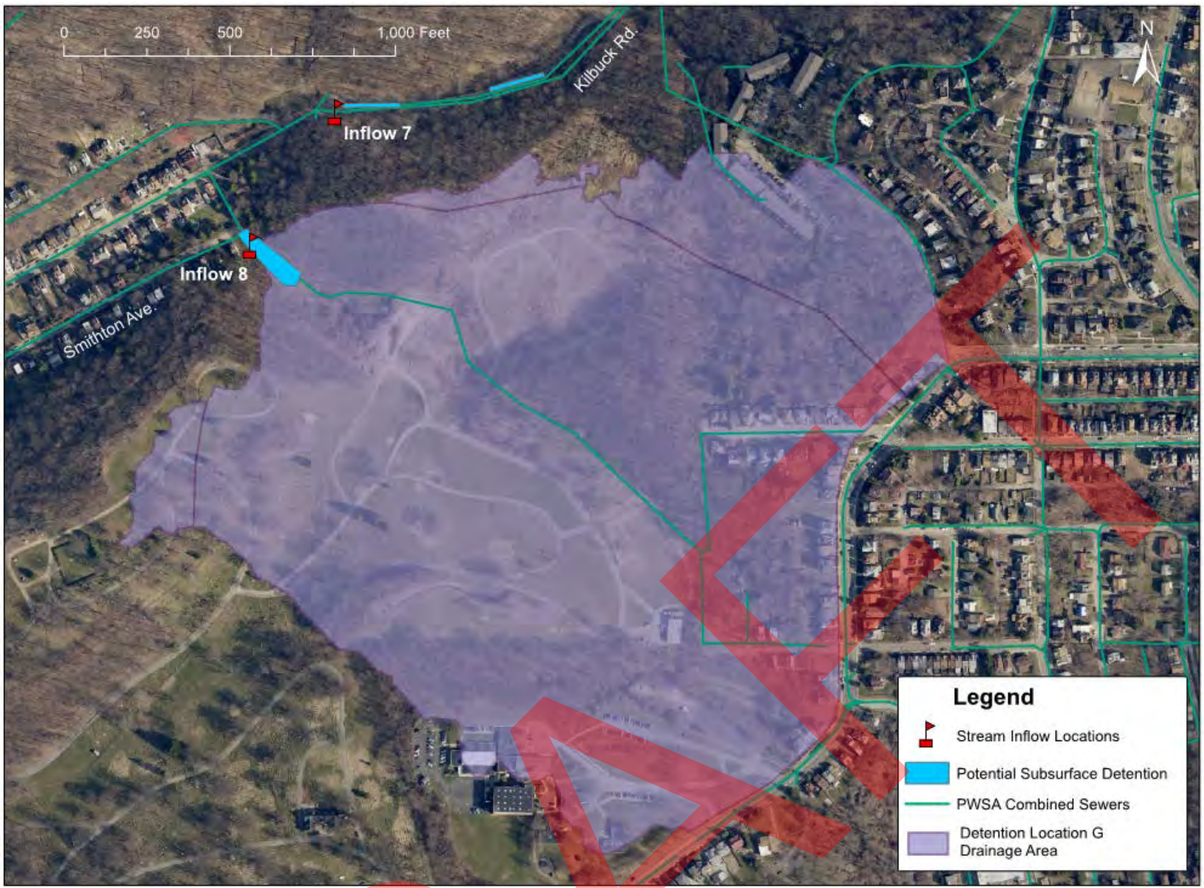


Figure D-10 Woods Run Inflow Detention Location G

Cost Estimate

An estimate is provided in Table D-9 outlining the typical project costs associated with the size and type of subsurface storage described above. A 40% planning contingency has been added to account for the unknown factors not quantified in these preliminary planning level assumptions.

TABLE D-9
PLANNING LEVEL COST ESTIMATE FOR THE WOODS RUN DETENTION LOCATION G

Storage Location G Solution: Subsurface Detention & Slow release into CSS				
Control Level: 0.28 MG Storage				
Items of Work	**Approx. Quantity**	**Unit of Measure**	**Unit Bid Price**	**Total**
Mobilization, Demobilization, and Field Office	1	LS	$ 23,500.00	$ 24,000.00
Field Survey and Engineering	1	LS	$ 8,760.00	$ 9,000.00
Erosion and Sediment Control	1	LS	$ 8,760.00	$ 9,000.00
Storm Trap Subsurface Storage	37,433	CF	$ 5.50	$ 206,000.00
Compacted Aggregate Base	629	CY	$ 60.00	$ 38,000.00
Engineered Soil Media & Gravel	923	CY	$ 60.00	$ 56,000.00
8" PVC SDR-26 Sewer Pipe, Less than 15' Deep	400	LF	$ 125.00	$ 50,000.00
Excavation 0-15' Deep	6,921	CY	$ 9.00	$ 63,000.00
Vegetation	11,326	SF	$ 1.00	$ 12,000.00
Rock and Obstruction Excavation - All Depths	40	CY	$ 25.00	$ 1,000.00
Outlet Structure with Underdrain and Overflow Structure	1	EA	$ 3,000.00	$ 3,000.00
Overflow Structure	1	EA	$ 8,500.00	$ 9,000.00
Maintenance Traffic Protection	1	LS	$ 13,140.00	$ 14,000.00
			Subtotal	$ 494,000.00
Planning Level Construction Contingency			40%	$198,000
Engineering (Planning, Design, & Construction Administration Services)			20%	$99,000
Project Contingency			20%	$99,000
			Total:	$890,000

APPENDIX E – TABLE OF CONTENTS

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Subject A-22 and City Wide BMP “Design Criteria and Costing Guidance Memorandum

Date July 30, 2015 (Updated March 2016)

Technical notes

Purpose:

The purpose of this technical memo is to provide design criteria and general sizing guidance for green infrastructure (GI) BMPs for the field investigations being performed. A cost estimating template spreadsheet has also been developed to provide unit price costs for the common elements of GI BMPs likely to be used in the Shadyside/A22 and City-Wide GI Assessment areas.

Site Investigation:

Site field investigations will be performed to evaluate BMP siting locations as determined by the high yield drainage area locations. While the analysis determined the priority locations for GI based on drainage area to capture the highest amount of flow, the site investigation will provide more information about the feasibility of construction at each site, the site specific configurations of BMPs to be used, and potential conflicts or issues with each site.

The required volume reduction to address both overflow reduction during typical year storm events and address surface and basement sewage flooding during the selected design storm event was input into the SWMM model and priority area drainage tools. These tools then generated a prioritized method of capturing this required volume. Output data includes the high yield drainage area inlet locations and the necessary capture volume for the BMP(s). The site visits will serve as a check into the feasibility of constructing the recommended size BMPs at each location.

BMP Concepts:

At this point, specific BMP design details remain open and will be guided by the findings from the site visits. However, the primary design functionality will be to capture runoff from the impervious surfaces, treat, store, infiltrate (where possible), and slowly return the captured stormwater via an underdrain back into the combined sewer system. One possible example of this setup is shown in Figure 1.

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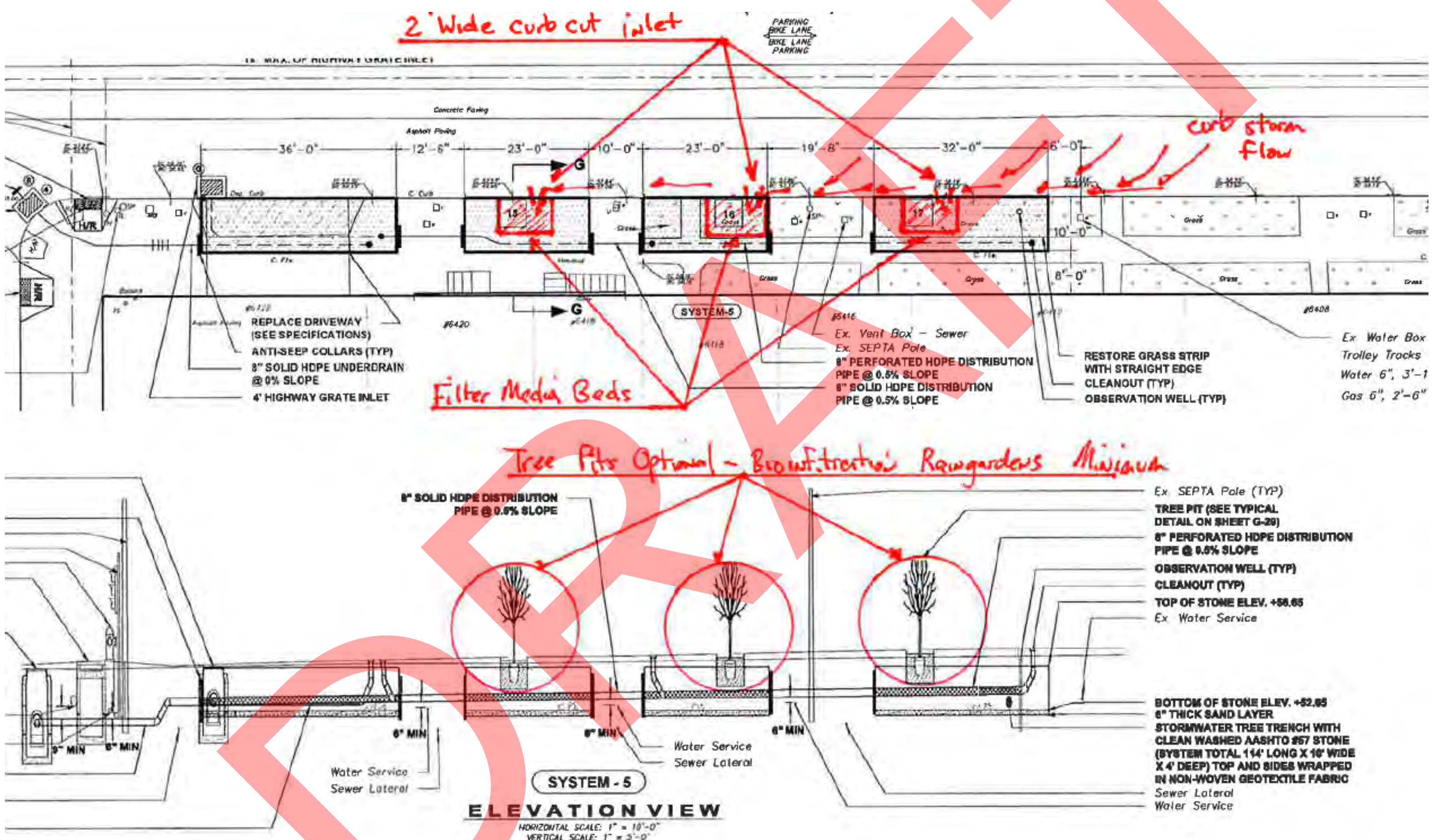

Figure 1: Example BMP – Capture, Treat, Store & Release

In this example, stormwater runoff is captured at the existing catch basin location (new inlet can also be installed) and the new curb cuts to the tree pits and routed to multiple BMPs sited and linked by distribution piping in order to meet the desired capture volume and be installed around existing utilities and site constraints. Distribution piping connecting the BMPs uses slotted piping elevated above the base of each storage cell to allow for storage volume prior to infiltration (where soil conditions allow) or discharging into the underdrain pipe. The underdrain pipe is then connected to the new (or existing) inlet to allow a slow and controlled discharge back into the existing combined sewer or a new shallow storm sewer (where available). The underdrain pipe can have a cap installed with a small orifice hole installed in the cap, a vortex valve, or utilize an automated valve tied to downstream sewer level to control the rate of flow back into the combined sewer system. If a new inlet is installed, a weir is installed in the inlet to separate the inlet to the distribution piping and outlet from the underdrain piping. See stormwater tree trench functionality illustration in Figure 2 for a detailed explanation. BMPs may need to be divided and linked similar to this example due to space limitations and utility conflicts.

Design may utilize underground storage crates, underground arch concrete structures, or similar storage options. The storage method used will largely be determined by field information collected as outlined below. Tree pits or plantings with appropriate soil media are installed within each storage cell to aid in treating the captured stormwater runoff before it is infiltrated or slowly released back into the combined sewer system.

Design will be site specific and does not necessarily need to be within the sidewalk area. A new catch basin or multiple basins, dependent on site conditions, may need to be installed to capture the associated runoff along with the curb cuts. BMPs installed within the available footprint at each site are acceptable, i.e., in the roadway, curb bump-outs, available grass or open-space, etc,. as long as the BMPs provide equivalent functionality and required storage volume.

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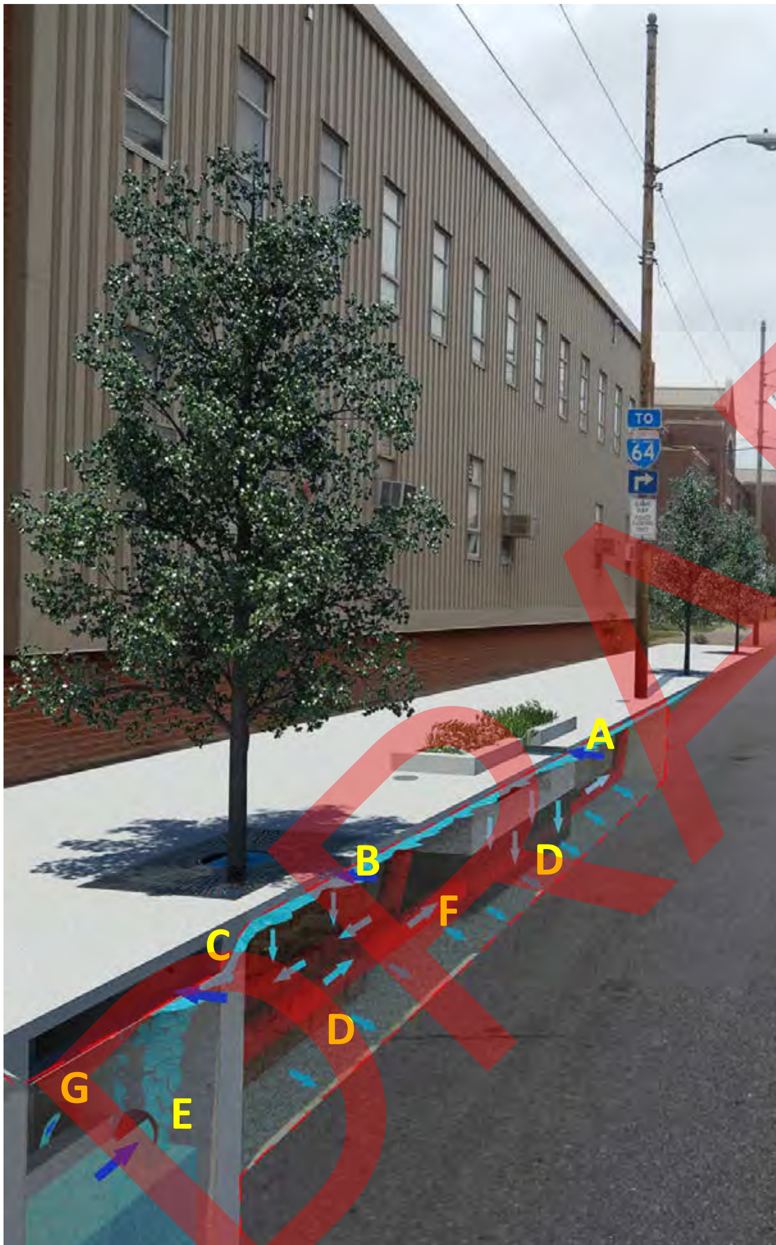

Subsurface Stormwater Treatment Trench

Below grade stormwater treatment trenches have been successfully utilized on many projects in urban settings where space is limited and maximum water quality benefits are necessary. BMPs do not need to be tree trenches, as described, as long as the BMPs provide equivalent functionality. The treatment process is as follows:

1. Stormwater runoff from the drainage area is collected along the gutter in the traditional manner.

2. Runoff along the curb is intercepted and diverted into entry points **A** (depicted as a bioinfiltration curb box) and **B** (depicted as tree pit filter box) but are tailored to the individual site location. Runoff that enters through these entry points will receive additional biological treatment and pollutant uptake from the plantings above. If the flow capacity of the bioinfiltration and tree pit are exceeded, the runoff travels to entry point **C** (engineered split box catch basin).

3. Stormwater runoff entering the bioinfiltration areas receives treatment via the engineered soil media and is then able to slowly infiltrate into the underlying gravel trench and native soil. **D**

4. The split box catch basin diverts the runoff to the detention area via a horizontal perforated distribution pipe **E**. Prior to entering the distribution pipe a screen-type filter is typically installed in the catch basin to keep debris out of the distribution pipe (not shown in rendering).

5. Runoff enters the perforated distribution pipe and distributes within the detention trench which serves to detain the runoff during and after the storm event. In some cases, volume reduction can be realized in cases where infiltration into the native soils is achievable. **F**

6. Treated stormwater that cannot be infiltrated or utilized by the plantings is slowly returned back to the existing combined sewer or to a storm sewer system via an underdrain and flow control orifice. **G**

Calculations and Costing:

The attached BMP Costing Reference spreadsheet can be used to perform calculations for each BMP site. The "Design Criteria_BMP_1" tab can be used for each potential BMP site and replicated for additional sites. The boxes highlighted in yellow in the spreadsheet are the parameters that should be updated as appropriate for each site. The calculation sheet is intended to estimate the footprint needed to manage the contributing area drainage. Field investigations will determine the feasibility of the footprint at the site. The length, width, and depth can be modified in the spreadsheet as needed to fit the BMP at specific sites. Please assume a 1 ½-inch Depth of Runoff Goal in the calculations. The "BMP Cost Summary" tab is intended to track and summarize the various BMP sites onto one sheet, provide reference unit costs and provide the ability to calculate the total construction cost for each BMP location utilizing this type of storage concept.

Field Investigation:

The site investigation should take note of the following for the BMPs at the high yield drainage areas:

<u>Existing Site and Utilities:</u>

- Photograph closeup and zoomed out overview of each BMP site location/inlet.
- Parking Lane Conflicts – Would the BMP impact or reduce on street parking?
- Street Parking Signs – Identify "No Parking" areas where bump out or on street BMPs could be sited.
- Fire Hydrant Locations – Possible on street BMP location not impacting parking.
- Valves and Manholes – Photograph visible valve and manhole covers.
- Large Trees and Utility Posts – Possible interferences with BMPs.
- Catch Basin Condition – Photographed and note the type and condition of the catch basins as visible from the surface without removing grates.
- Sidewalk Condition – Photograph and note sidewalk condition and measure width from curbing to private property.
- Photograph Condition of Existing Street Pavement – Document condition of street surface for possible utility coordination with City repaving efforts.
- Existing Greenspace – Photograph and note existing tree pits and green areas with potential for retrofit to handle stormwater.
- Check Flow Path – Note if depicted drainage area appears incorrect. This could be due to curb bump outs or other features that divert flow that was not apparent with the drainage area modeling.
- Private Property – Determine options for routing of stormwater runoff from properties. Can downspouts be disconnected on private property or will the water need to be routed and connected to the right-of-way BMP(s). Are there driveway drains, options for disconnection?

Design Criteria:

- Calculate BMP footprint required to meet required storage volume based on:
  - Depth of storage should be limited to 4 feet from final surface
  - Width of storage areas is largely limited by available space.
  - Length of storage depends on available space but may need to be divided into multiple storage cells on sloped streets, and utility conflict areas.
  - Divided storage cells should be located within 30 feet of one another if possible. This should allow storage to be linked across the street from one another if needed.
  - BMP loading ratio should generally be 15:1 to 20:1 where possible. Exceptions can be made. (Ratio is area of captured impervious surface to available surface infiltration area of BMP.)
  - May utilize underground storage crates, underground arch concrete structures, or similar detention/storage options. The detention/storage method used will largely be determined by field information.
  - Tree pits or plantings should be installed within each storage cell to allow a portion of the diverted runoff to be filtered through soil media.
  - A new catch basin inlet with weir or equal may need to be installed to divert flow to the underground detention/storage. Curb cuts can also be used to direct flow where conditions allow.
  - Location will be site specific and does not necessarily need to be within the sidewalk area. BMPs installed within the available footprint at each site are acceptable, i.e., in the roadway, curb bump-outs, available grass or open-space, etc., as long as the BMPs provide equivalent functionality and required storage volume.
  - Consider cost-effective private property stormwater disconnections to the BMPs based on local conditions. Discuss site specific conditions with project manager to determine best technologies to use for downspout disconnections.

BMP Costing Reference Spreadsheet
(Electronic copy provided)

PWSA 2016 City-Wide BMP Unit Cost References

No.	Cost Item	Unit	Unit Cost	Description
1	Excavation	CY	$75.00	
2	Asphalt Roadway Reconstruction	SY	$134.00	Concrete paving base + $24/SY for bituminous surface repaving
3	Concrete Roadway Reconstruction	SY	$110.00	Referencing Concrete paving base bid item, which includes concrete subbase
4	AASHTO #57	CY	$40.00	Aggregate used for subsurface storage layer, sidewalk base, and pipe bedding
5	AASHTO 2A	CY	$30.00	Aggreate used for road concrete sub base
6	Asphalt Binder Course	SY	$29.54	Installed cost assuming up to 2.5" layer
7	Asphalt Wearing Course	SY	$27.16	Installed cost assuming up to 1.5" layer
8	Concrete Paving Base	SY	$110.00	8" in depth minimum, or match existing slab depth
9	Porous Pavement	SF	$12.00	based on recent Philadelphia costs for porous pavement in street areas
10	Porous Pavement Clean Outs	EA	$250.00	Based off of bid prices from Philadelphia ajusted to Pittsburgh. Assuming 5' depth
11	Curbing	LF	$40.00	Concrete Deep Curb
12	Conc. Sidewalk	SY	$95.00	4" depth concrete sidewalk
13	8" Perf. Dist. Pipe	LF	$47.13	8" perforated PVC pipe
14	8" Perf. Underdrain	LF	$47.13	8" perforated PVC pipe
15	12" Storm Sewer	LF	$70.00	12" solid wall PVC pipe
16	15" Storm Sewer	LF	$75.00	15" solid wall PVC pipe
17	18" Storm Sewer	LF	$85.00	18" Solid wall PVC pipe
18	New Inlets	EA	$5,000.00	New type II inlet installed
19	48" Diameter Manholes (0-10 Feet Depth)	EA	$6,500.00	48" MH at 0-10 feet depth
20	48" Diameter Manholes (> 10 Feet Depth)	FT	$250.00	Price per vertical foot over 10' depth
21	Curb Cut	EA	$200.00	Curb cut into existing curbing to direct stormwater into BMP.
22	Underdrain Connection to Catch Basin	EA	$400.00	Underdrain connecting into catch basin with small diameter slow release orifice.
23	Storage (AASHTO #57 wrapped in geotextile/impermeable layer)	CY	$93.00	#57 aggregate used as a subsurface storage layer.
24	Storage (R-Tanks)	CF	$7.00	Modular stormwater storage. Multiple products available.
26	Plantings	SF	$25.00	Average cost per SF for plantings and grasses based on PWD and PWSA bid tabs
27	Tree Pit, Tree, and Media (5' x 5' x 3')	EA	$1,300.00	Average cost for tree based on PWD and PWSA bid tabs
28	Topsoil and Sodding	SY	$15.00	Based on PWSA and Philadelphia bid tabs
29	6" Sand Filter	CY	$65.00	Sand layer used as a choker course between engineered soil and storage layer.
30	Observation Well	EA	$1,469.00	Vertical observation well or cleanout used to access subsurface storage
32	Rain Barrels (50 gal barrel per downspout)	EA	$250.00	Assume $130 for 50 gal barrel with built in overflow to be directed to yard area. Assume one 50 gallon barrel per downspout. Assume $250 for installed cost per house.
33	Downspout Disconnect with Pop Up	EA	$750.00	Based on typical labor and material unit costs. Assumes tight construction area
35	Backflow Valve	EA	$10,875.00	Backflow prevention valve on house lateral

	BMP Dimensions															Connections from Existing Inlets to BMPs (Pipe, Trench)						
BMP Location	Width	Depth	Length	Plantings	Storage (R-Tanks)	Storage (AASHTO #57 wrapped in geotextile/impermeable layer)	Tree Pit, Tree, and Media (5' x 5' x 3')	8" Perf. Dist. Pipe	8" Perf. Underdrain	New Inlets	Excavation	6" Sand Filter	Conc. Sidewalk	Curbing	Obs. Wells	12" HDPE Pipe	Excavation	AASHTO #57	AASHTO 2A	Concrete Paving Base	Asphalt Binder Course	Asphalt Wearing Course
	FT	FT	FT	SF	CF	CY	EA	FT	FT	EA	CY	CY	SY	LF	EA	LF	CY	CY	CY	SY	SY	SY
1	8	4.5	245	0	7,604	0	3	245	50	2	326.7	36	136.1	245	3	120	40	36.5	0.0	53.3	53.3	
2																						
3																						
4																						
5																						
6																						
7																						
8																						
9																						
10																						
11																						
12																						
			Totals	0	7,604	0	3	245	50	2	327	36.3	136	245	3	120	40	36.5	0.0	53.3	53	0
			Unit Cost	$25.00	$7.00	$93.00	$1,300	$47.13	$47.13	$5,000.00	$75.00	$65.00	$95.00	$40.00	$1,469.00	$70.00	$75.00	$40.00	$30.00	$110.00	$29.54	$27.16
			Cost Factor	1.000	1.000	1.000	1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
			Total Cost	$0	$53,229	$0	$3,900	$11,547	$2,357	$10,000	$24,500	$2,359	$12,931	$9,800	$4,407	$8,400	$3,000	$1,460	$0	$5,867	$1,575	$0

Total BMP Cost:	$155,332

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	BMP Dimensions										
BMP Location	Width	Depth	Length	Plantings	Storage (R-Tanks)	Storage (AASHTO #57 wrapped in geotextile/impermeable layer)	Tree Pit, Tree, and Media (5' x 5' x 3')	8" Perf. Dist. Pipe	8" Perf. Underdrain	New Inlets	Excavation
	FT	FT	FT	SF	CF	CY	EA	FT	FT	EA	CY
2	8	4.5	475	0	0	559	3	475	50	2	633.3
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
			Totals	0	0	559	3	475	50	2	633
			Unit Cost	$25.00	$7.00	$93.00	$1,300	$47.13	$47.13	$5,000.00	$75.00
			Cost Factor	1.000	1.000	1.000	1	1.000	1.000	1.000	1.000
			Total Cost	$0	$0	$51,970	$3,900	$22,387	$2,357	$10,000	$47,500

						Connections from Existing Inlets to BMPs (Pipe, Trench)						
BMP Location		6" Sand Filter	Conc. Sidewalk	Curbing	Obs. Wells	12" HDPE Pipe	Excavation	AASHTO #57	AASHTO 2A	Concrete Paving Base	Asphalt Binder Course	Asphalt Wearing Course
		CY	SY	LF	EA	LF	CY	CY	CY	SY	SY	SY
2		70.4	263.9	475	3	120	40	36.5	0.0	53.3	53.3	
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
	Totals	70.4	264	475	3	120	40	36.5	0.0	53.3	53	0
	Unit Cost	$65.00	$95.00	$40.00	$1,469.00	$70.00	$75.00	$40.00	$30.00	$110.00	$29.54	$27.16
	Cost Factor	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Total Cost	$4,574	$25,069	$19,000	$4,407	$8,400	$3,000	$1,460	$0	$5,867	$1,575	$0

Total BMP Cost:	$211,466

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Example Project
BMP Locations Evaluation
Design Criteria Summary

Author:	
Date:	/ / 2015
Design Consultant:	
BMP Location:	

General Project Data

BMP Name:	1-acre Capture w/ R-Tank Storage
Model Subcatchment Name(s):	
Total Impervious Area Managed (sf):	43,560
Total Storage Volume (cf):	6,636
Total Trees in Systems:	3

User Input Fields

Example Project
BMP Locations Evaluation
Design Criteria Calculation Sheet

System Name:	Tree Pit Box
System Function:	Detention/Slow Release

Contributing Pervious Area (sf):	0	**Orifice Diameter (in):**	6/8
Contributing Impervious Area (sf):	43,560	**Slow Release Hydraulic Head (ft):**	3.67
Disconnected Impervious Area (sf):	0	**Volume Below Orifice or Center of Underdrain (cf):**	1552
Storage Footprint (sf):	1,960	**Infiltration Footprint (sf):**	1,960
Storage Volume (cf):	6,636	**Infiltration Depth Head (ft):**	4.5
Model Top Area (cf):	1,475		

Calculated Fields:

Total Contributing Drainage Area (sf):	43,560	**Peak Release Rate from Orifice (cfs):**	0.032467532
Loading Ratio for Total Contributing Drainage Area (cfs):	22	**Storm Size Managed (in):**	1.828006428
Loading Ratio for Connected Impervious Area (cfs):	22		

System Description and Calculations:

Approximate Storage Volume with Voids (cf):	8,379	Available storage (Storage footprint x depth x void ratio)
Depth of Runoff Goal (in):	1.5	
1.5" Storage Volume (cf):	5,445	Required volume based on impervious area managed x runoff depth
Pipe Length:	120	
Pipe Void Ratio:	92	Taking into account the wall thickness of the pipe subtracting from the overall available storage capacity
Pipe Volume with Voids (cf):	22	Based on the pipe void ration in cell L38, this is the volume taken up in the trench from the underdrain pipe material
Number of Trees in Trench:	3	
Tree Pit Volume Removed (cf):	213.75	This is the potential storage volume taken up by the tree pit assuming a 5x5x3 tree pit
Average Infiltration Test Results (in/hr):	0.00	
R Tank / #57 Storage Volume	7,604	The volume required for R Tank or #57 backfill (storage footprint - tree pit volume - pipe volume)
Potential Infiltration (cfs):	0.00	
Length of Trench (ft):	245	
Width in Footway (ft):	8	
Depth in Footway (ft):	4.5	
Footprint in Footway (sf):	1,960	
Storage Fill Type:	R-Tanks	
Void Ratio (%):	95	Void ratio of storage system or backfill material in bmp. Assuming 0.40 for #57 aggregate and 0.95 for R-Tanks

MOTT MACDONALD

PGH2O Pittsburgh Water & Sewer Authority

Example Project
BMP Locations Evaluation
Design Criteria Summary

Author:	
Date:	/ / 2015
Design Consultant:	
BMP Location:	

General Project Data

BMP Name:	1-acre Capture with Gravel Storage
Model Subcatchment Name(s):	
Total Impervious Area Managed (sf):	43,560
Total Storage Volume (cf):	5,505
Total Trees in Systems:	3

User Input Fields

Example Project
BMP Locations Evaluation
Design Criteria Calculation Sheet

System Name:	Tree Pit Box
System Function:	Detention/Slow Release

Contributing Pervious Area (sf):	0	Orifice Diameter (in):	6/8
Contributing Impervious Area (sf):	43,560	Slow Release Hydraulic Head (ft):	3.67
Disconnected Impervious Area (sf):	0	Volume Below Orifice or Center of Underdrain (cf):	1267
Storage Footprint (sf):	3,800	Infiltration Footprint (sf):	3,800
Storage Volume (cf):	5,505	Infiltration Depth Head (ft):	4.5
Model Top Area (cf):	1,223		

Calculated Fields:

Total Contributing Drainage Area (sf):	43,560	Peak Release Rate from Orifice (cfs):	0.032467532
Loading Ratio for Total Contributing Drainage Area (cfs):	11	Storm Size Managed (in):	1.516642792
Loading Ratio for Connected Impervious Area (cfs):	11		

System Description and Calculations:

Approximate Storage Volume with Voids (cf):	6,840	Available storage (Storage footprint x depth x void ratio)
Depth of Runoff Goal (in):	1.5	
1.5" Storage Volume (cf):	5,445	Required volume based on impervious area managed x runoff depth
Pipe Length:	120	
Pipe Void Ratio:	92	Taking into account the wall thickness of the pipe subtracting from the overall available storage capacity
Pipe Volume with Voids (cf):	22	Based on the pipe void ration in cell L38, this is the volume taken up in the trench from the underdrain pipe material
Number of Trees in Trench:	3	
Tree Pit Volume Removed (cf):	90	This is the potential storage volume taken up by the tree pit assuming a 5x5x3 tree pit
Average Infiltration Test Results (in/hr):	0.00	
R Tank / #57 Storage Volume	15,088	The volume required for R Tank or #57 backfill (storage footprint - tree pit volume - pipe volume)
Potential Infiltration (cfs):	0.00	
Length of Trench (ft):	475	
Width in Footway (ft):	8	
Depth in Footway (ft):	4.5	
Footprint in Footway (sf):	3,800	
Storage Fill Type:	AASHTO #57	
Void Ratio (%):	40	Void ratio of storage system or backfill material in bmp. Assuming 0.40 for #57 aggregate and 0.95 for R-Tanks

Urban Design Sewershed Evaluation for Pittsburgh Water and Sewer Authority

Completed for the City-Wide Sewer Shed Evaluation 2016

evolve
environment :: architecture

ARCADIS Design & Consultancy for natural and built assets

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katherine camp

2016

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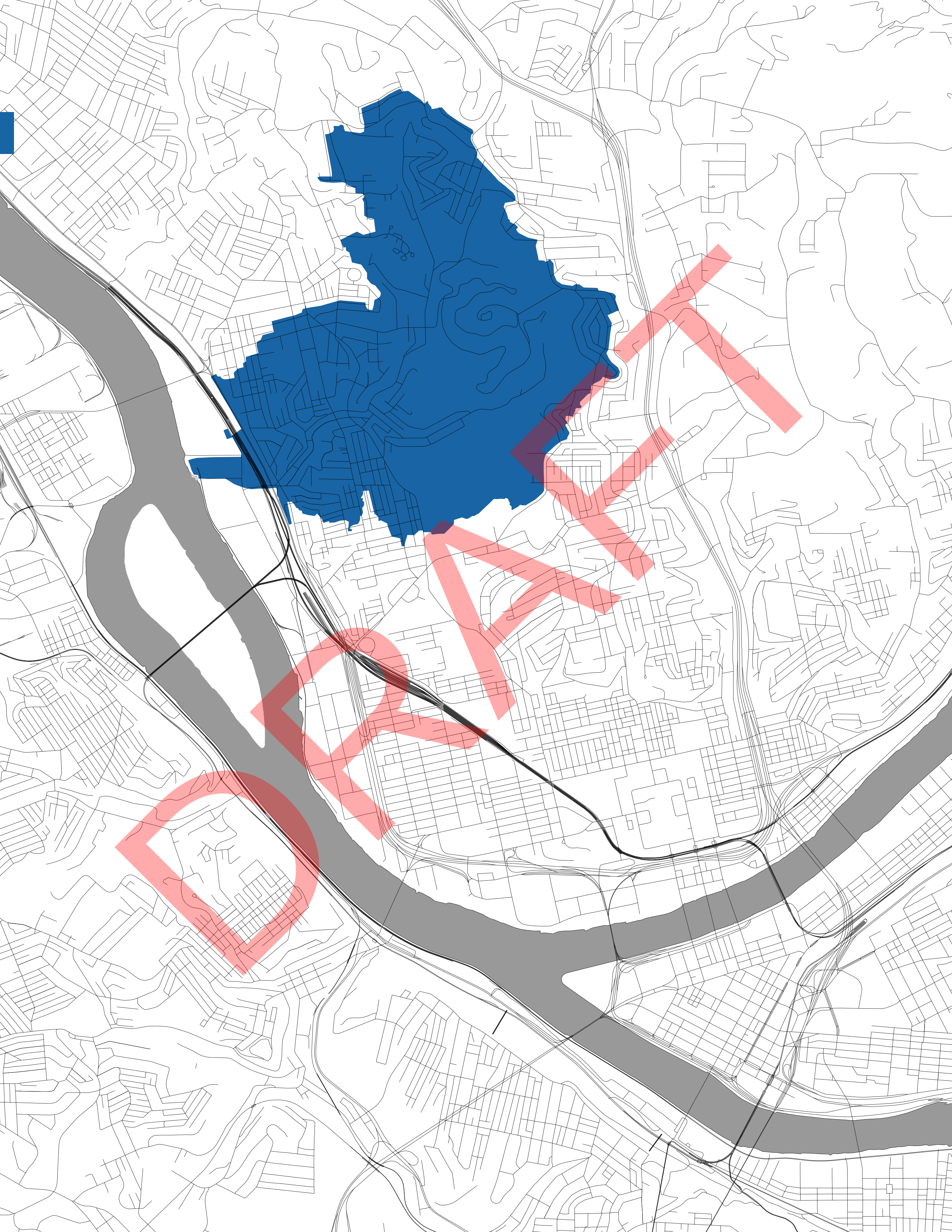
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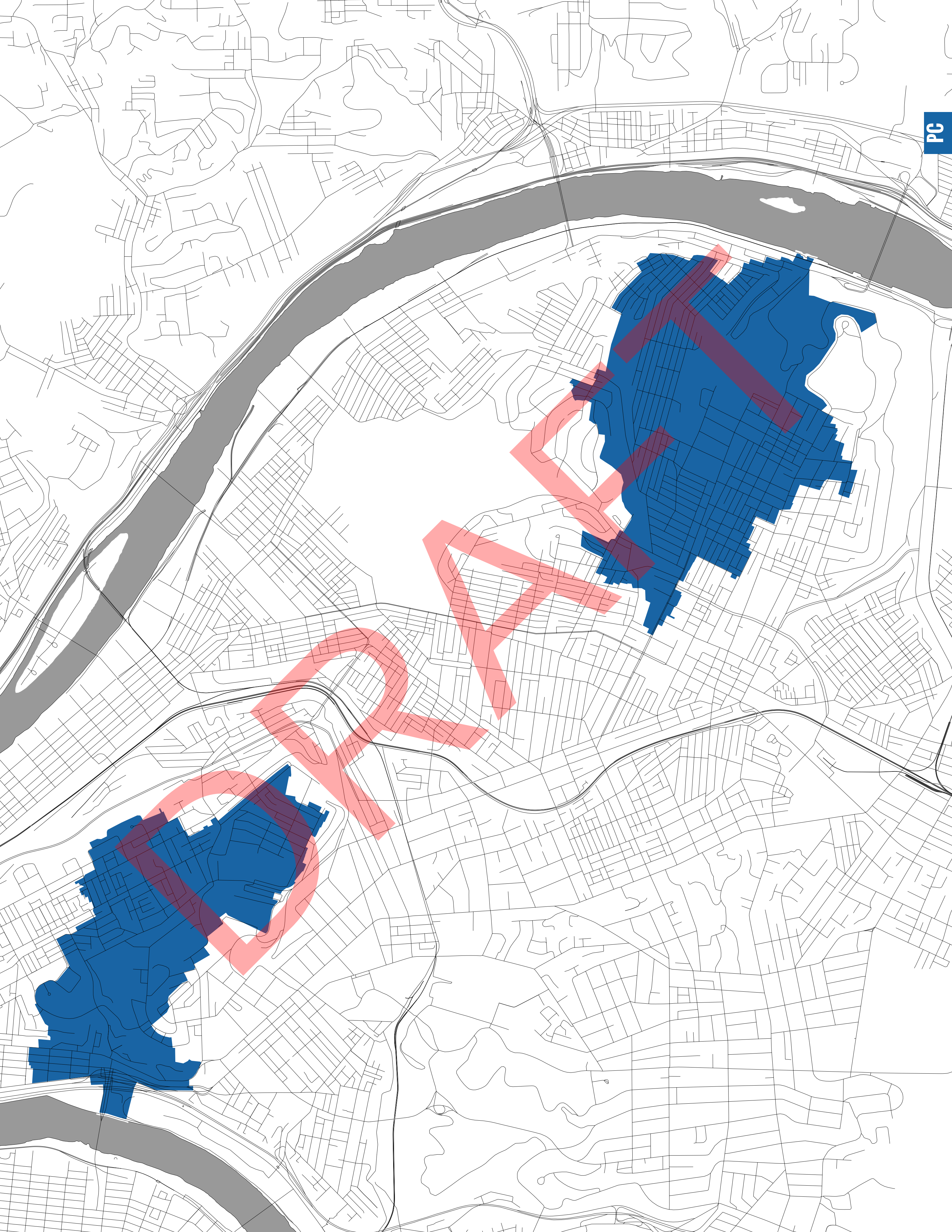


PLAN CONTEXT

Pittsburgh owes it existence to the meanders and confluence of three great American rivers. The Allegheny, Monongahela, and the Ohio Rivers are a point of pride and are integral to the City's identity. As the city continues its historic transition from a riverfront industrial superpower to an education and research mecca, the quality of our rivers and riverfronts is of paramount importance. This study looks at ways to keep our rivers clean while creating great community focused infrastructure for a maturing city.

Green Infrastructure, or rainwater installations that use vegetation and natural hydrologic processes to manage and treat rainwater, needs to be a key part of our combined sewer overflow (CSO) solution. This report is part of the on-going work to find the best ways to implement Green Infrastructure projects that both manage stormwater and support communities and follows Mayor Peduto's leadership around P4: People, Planet, Place, and Performance.

Green Infrastructure enhances communities by creating beautiful and high performing landscapes that weave our open space assets into a thriving ecological network. In the process, there will be opportunities for workforce development that will empower Pittsburgh residents and drive neighborhood revitalization. Where once we saw open space as the leftover areas in and between our neighborhoods, Pittsburgh is now consciously shaping our greenspace to be ecologically high performing streetscapes, parks, and other amenities that are an economically viable compliment to traditional grey infrastructure.

In addition, this report is framed to support the City's resiliency pursuits. Climate change creates a dynamic environment and projections for increased rainfall and number of extreme weather events need to be accounted for in our infrastructure planning. Combined with smart cities technology, surface-based green stormwater infrastructure has the potential to be quickly mobilized and more easily adjusted to allow for adaptive management.

This report focuses on the range of technical solutions that could be installed to solve our CSO problem. In many cases, these solutions cannot be implemented without significant reexamination of how our stormwater resources are regulated. We need to integrate water-first planning into existing planning efforts, enable multi-agency and multi-partner action, and develop economic incentivizeives and long-term workforce opportunities to achieve the required performance levels and the desired community benefit. Pittsburgh will not be the first city to implement Green Infrastructure, but we can strive to be the most innovative in its design, implementation, and integration with our communities.

PROJECTS IN MOTION ACROSS THE CITY

A22

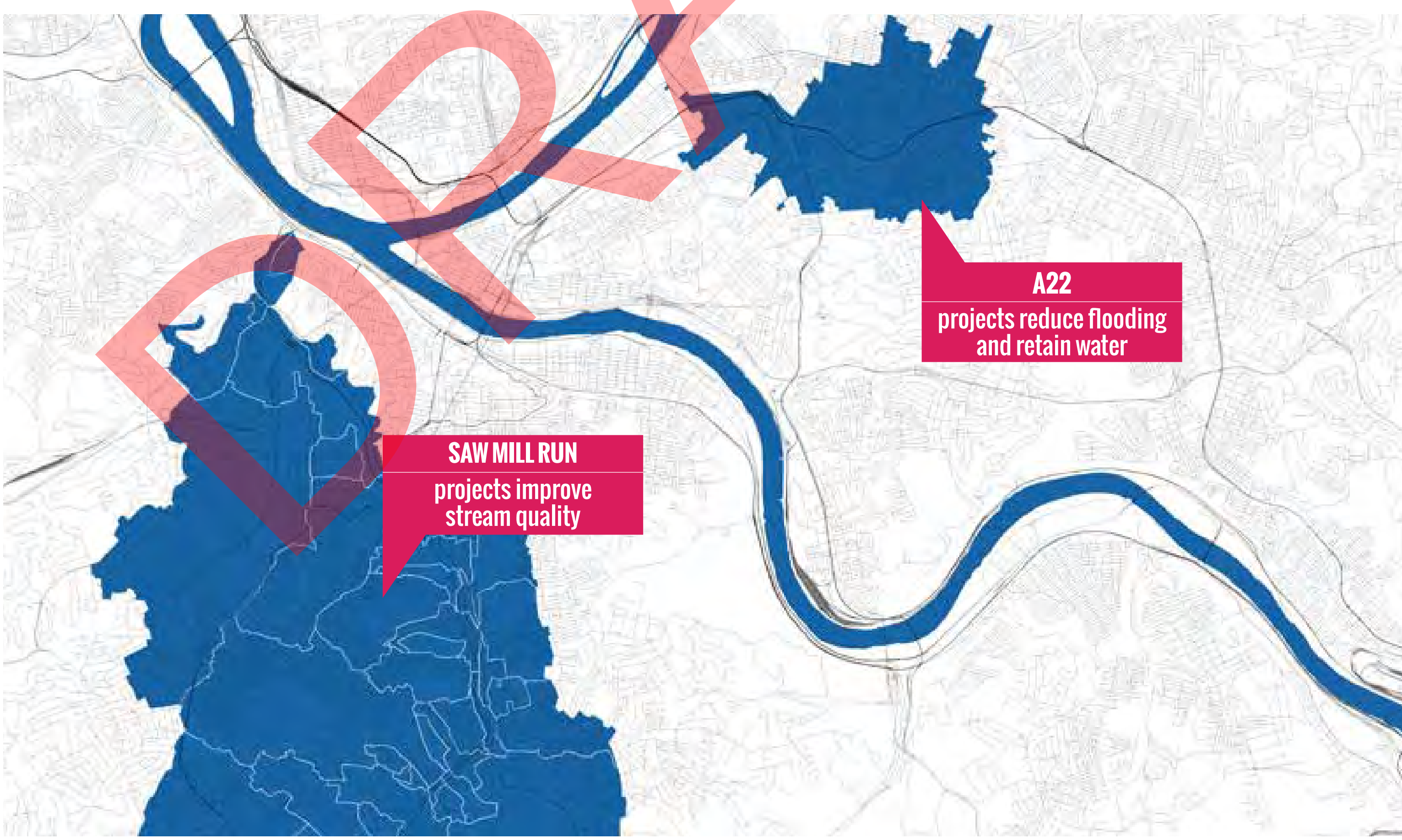
Green Infrastructure EVALUATION

Pittsburgh Water and Sewer Authority examined one of the largest sewersheds in the city, A-22 (Allegheny River, structure 22). The sewershed was modeled, reduction levels determined, and projects identified. Projects will address street flooding and basement sewerage flooding through installing distributed Green Infrastructure in the landscape to delay or prevent water from entering the combined sewer system. It was estimated that Green Infrastructure deployed in this shed could increase the resiliency of the sewer system by 60% and reduce flooding from 4 events in 5 years to 1 event in 25 years.

SAW MILL RUN

INTEGRATED WATERSHED PLANNING

PWSA also has a large shed-wide effort at stormwater reduction in the Saw Mill Run watershed. Unlike A-22, which has no surface stream, Saw Mill Run is a surface channel that collects water from combined and separated sewer systems from 12 municipalities. PWSA has funded work on a comprehensive watershed management plan, focusing on water quality using the EPA's regulatory framework. PWSA works with a watershed coordinator housed at a multi-municipal community development organization, Economic Development South, and with the Army Corps of Engineers to make short-term and long-term improvements to the watershed.

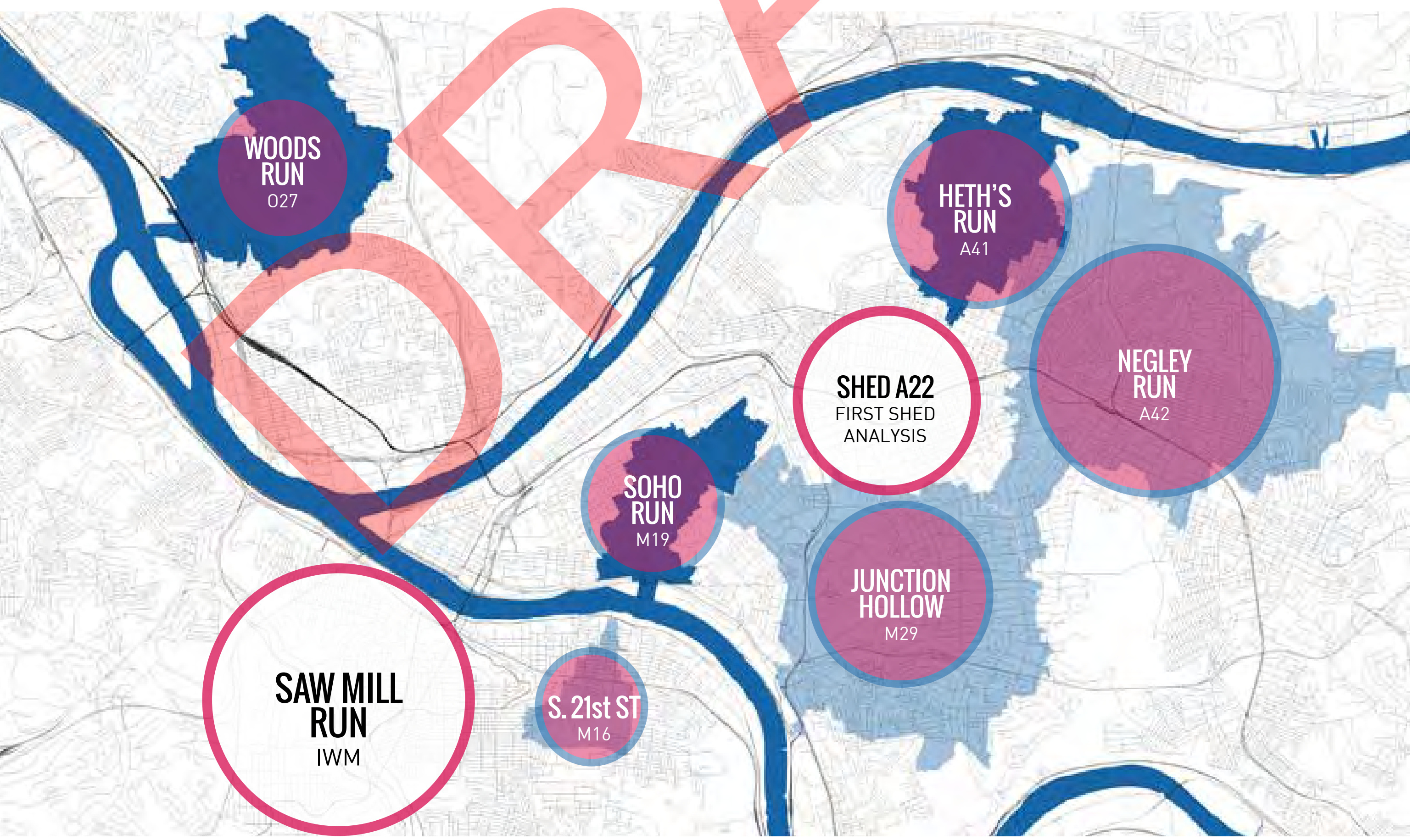


A PRIORITIZED APPROACH TO CSO REDUCTION

During dry weather, the Allegheny County Sanitary Authority (ALCOSAN) Wastewater Treatment Plant receives 197 MG of waste waterper day from its 83 customer municipalities. Of this total dry weather flow, it is estimated (based on percentage of the total population) that the City of Pittsburgh contributes roughly 72 MG annually to the ALCOSAN Waste Treatment Plant, or about 36.5% of their total gallons processed annually, with the remainder coming from the 82 other municipalities. However, during a rain event of as little as 0.1 inches, ALCOSAN's capacity is exceeded and the stormwater overwhelms the system to cause rainwater and sewage to overflow into the rivers. In a typical year approximately 9 BG of sewage overflows during rainfall events into our rivers, causing the US Environmental Protection Agency (EPA) to require action from ALCOSAN through a Consent Decree and the Commonwealth of Pennsylvania Department of Environmental Protection (DEP) to require action from PWSA through a Consent Order.

It is possible to trace the frequency and severity of events to specific combined sewer outfalls and upstream sewersheds. PWSA has targeted the biggest contributing sheds as the first sheds to be addressed through a City-Wide Sewershed Assessment.

City-Wide identified six of PWSA's thirty priority sewersheds for further conceptual planning including, Woods Run (O-27), South 21st Street in the South Side (M-16), the Hill District or Soho Run (M-19), Junction Hollow (M-29), Heth's Run (A-41), and Negley Run (A-42). Each of these sewershed spans multiple neighborhoods and the character of the upstream urban fabric determines the quantity, quality, frequency, and speed stormwater enters into the system. The study looked for opportunities to implement upstream Green Infrastructure to delay or prevent water from entering the system while improving our streetscape and greenspaces.



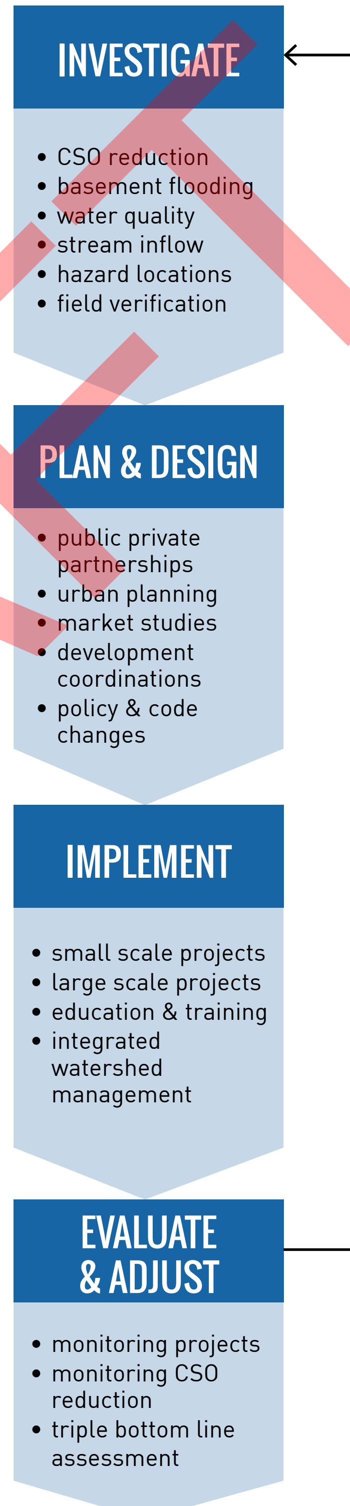
CITY-WIDE G.I. ASSESSMENT PROCESS

The purpose of the City-Wide G.I. Assessment is to create a stormwater overlay to inform responsible development and redevelopment through the stormwater lens. The Sewershed Analysis part of the Assessment intends to:

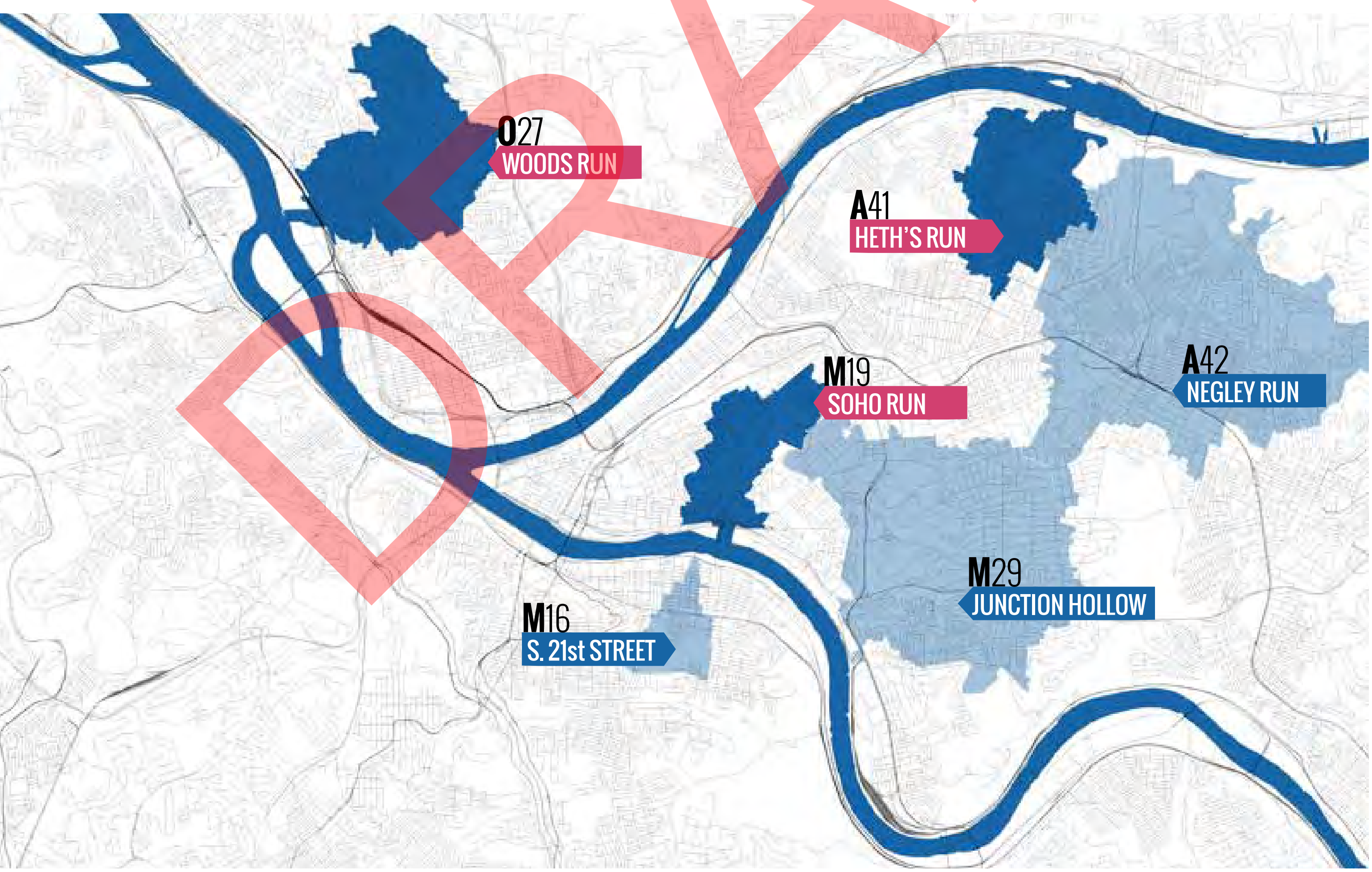
- Identify high-yield CSO reduction opportunity sites for Green Infrastructure interventions
- Coordinate with City departments and agencies to ensure a comprehensive evaluation is conducted
- Strategize urban planning based on stormwater management
- Explore and assess potential stream separation and daylighting opportunities

The process is part of PWSA's larger strategy to meet EPA compliance and includes an Investigation Phase that assesses surface issues and contributions to the combined sewer system. Sewershed surface issues are then overlaid onto the urban context to find opportunities for high performing projects. PWSA will develop an implementation program that will be monitored and evaluated to ensure long-term performance.

PWSA's priority sewersheds were selected with an "80/20 approach" indicating that the majority of CSO is coming from just a few major sheds. Within the thirty largest sewersheds, six were selected for further investeigation. The six sheds represent approximately 13,800 acres and over 10,000 stormwater inlets. Forty percent of all the sewer inlets in Pittsburgh are within these six sewersheds and together they contribute over 3.0 billion gallons of CSO each year. The sheds vary in size and configuration and do not have surface flows that meet the river or have contributions from separated upstream sewer systems, such as Nine Mile Run, Saw Mill Run, or Girty's Run.



Green Infrastructure solutions can be appropriate at many scales of implementation.



Sewersheds included in Round One of PWSA's City-Wide Sewershed Analysis. A41, M19, and O27 were studied by Arcadis and evolveEA. A42, M16, and M29 were studied by Mott MacDonald and Phronesis.

SEWERSHED MORPHOLOGY

Historically each shed was the location of a stream or run that connected upstream areas to the primary river waterway, through a series of secondary creeks and runs, tertiary channels, and seasonal waterways. Though this pattern may be difficult to read in the current topography, the historic topography can still be read in maps of the sub-grade sewer networks that were originally constructed in the valley floors.

Today this primary-secondary-tertiary conveyance remains the dominant morphological structure for all of the sheds. This allows for a common set of strategies to establish a hierarchy of green infrastructure, including:

- direct river reconnection
- valley surface storage and conveyance on distributed sites
- upstream surface conveyance and capture in the public right of way
- net zero or offline sites
- green infrastructure to improve the performance of private properties with pay-for-success or other models

To reach the required CSO reduction levels for each sewershed, the strategies have to be evaluated as a networked system with two goals. First the infrastructure improvements should detain 1.5" of water during a storm event, releasing the water slowly back into the system over a 72 hour period when there is capacity within the system to convey it to ALCOSAN. Second, and more ambitiously, the infrastructure should prevent the water from reentering the sewer system, thus preventing the need for treatment at the ALCOSAN plant where possible. Both of these are significant changes and require extensive analysis, including modeling for future climate change projections.

CAPTURE

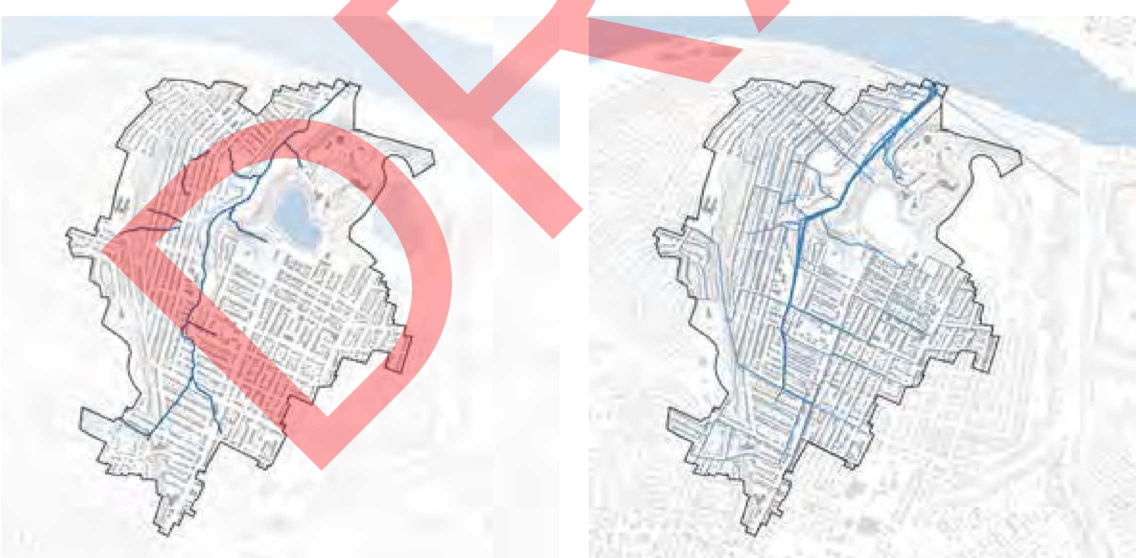
collection of water close to where it falls

CONVEY

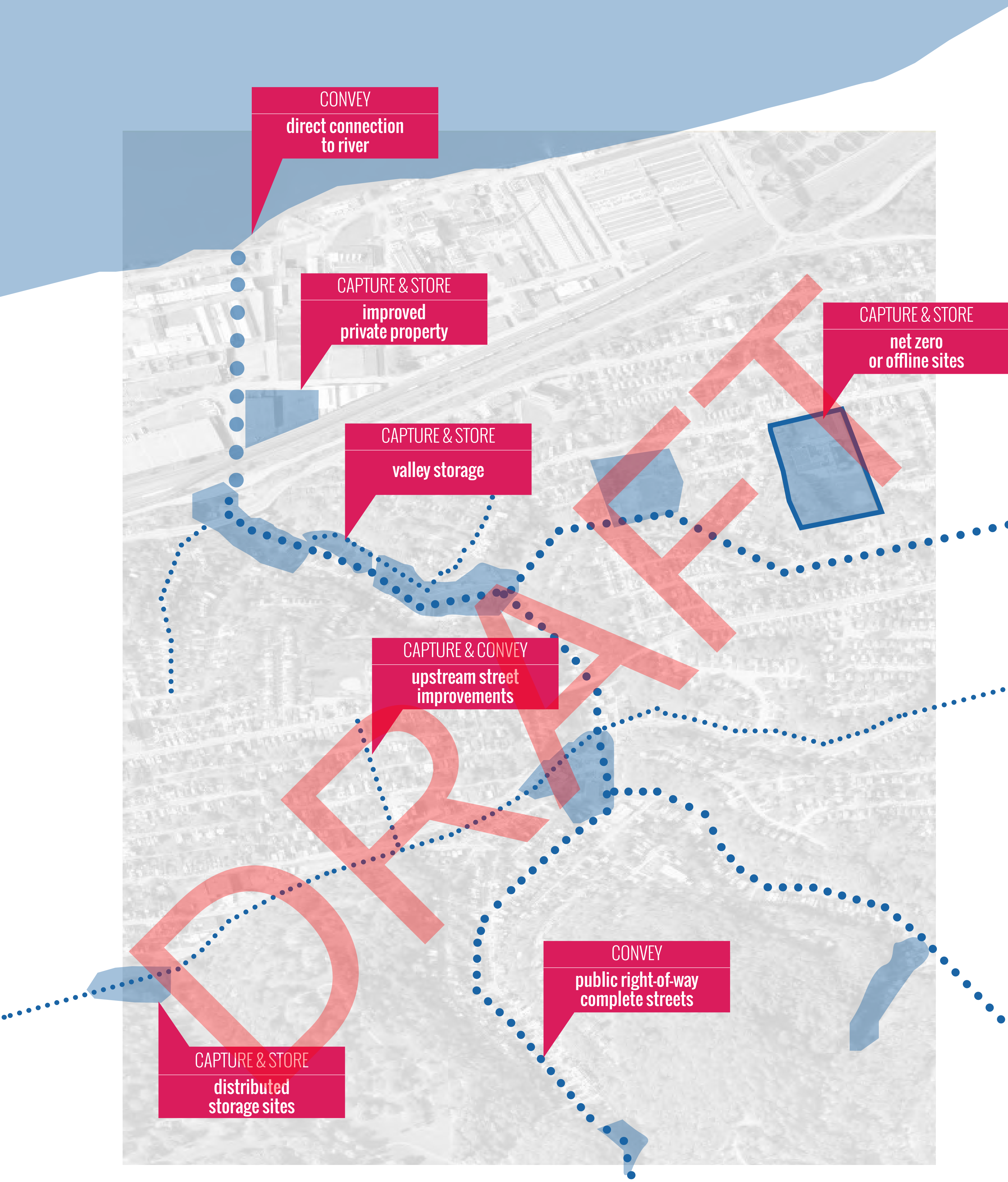
directing flow to appropriate locations for detention, infiltration, or outfall to a natural body of water

STORE

holding water from peak rainfall events to allow the water to slowly re-enter the system when capacity is available



Historic location of Heth's Run and location of combined sewers.



TYPICAL SHED COMPONENTS AND FUNCTIONING

CAPTURE
CONVEY
STORE

Each Green Infrastructure element uniquely functions within the shed to decrease the amount of runoff.

SYSTEM DESIGN PRINCIPLES

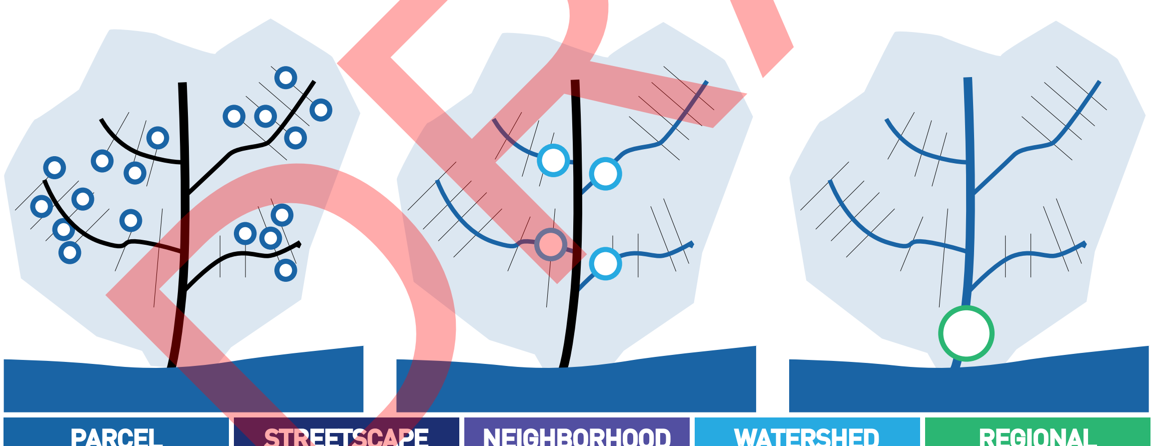
While each shed is unique in its balance of large-scale or small-scale installations, there are some common principles for all sheds.

The degree of centralization or distribution of the system components affects the type, costs, and operations of each shed's system. Each shed should work as an integrated system connecting upstream and downstream flows. For example, some sheds may be focused around a central valley or primary gathering point for the water with an extensive capture and conveyance system. Other sheds may have more opportunity for distributed locations that can be removed entirely from the system, thus eliminating the need to connect the sites. Different types of infrastructure will be needed to regulate flows but the same principals will be consistent.

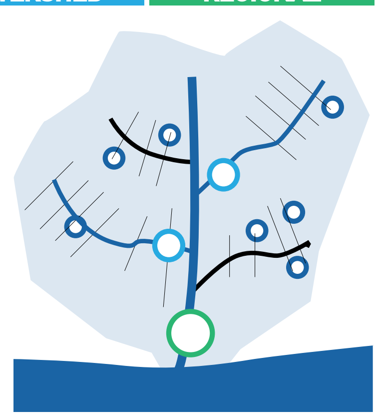
Redundancy needs to be integrated into each system design. Systemwide, redundancy of stormwater management infrastructure can allow for a factor of safety, strategically providing excess capacity to better respond to extreme events. Redundancy can also account for long-term system stressors such as increased precipitation due to climate change. Lastly, redundancy creates the flexibility required for long-term system implementation.

Since there are multiple ways that the system can be implemented, redundancy allows for short-term and long-term changes without compromising performance.

Green Infrastructure components are interdependent and some can serve as indicators the overall system's performance. To use an ecological analogy, the functioning of an "old growth forest" is driven by the 200 year old trees that allow for the presence and behavior of other species. Some sheds may have significantly larger elements that will enable or drive the capacity of other elements. Centralized valley storage, such as a naturalized wetland, allows for upstream storage infrastructure to be minimized, reducing the infrastructure's footprint in a dense urban environment. Valley infrastructure is dependent on upstream capture and conveyance—if the valley infrastructure is not in place, the nature of the upstream systems changes dramatically. Conversely, the valley cannot function as a wetland without the upstream infrastructure to deliver the water.



THERE ARE DIFFERENT SCALES OF INFRASTRUCTURE THAT DEFINE THE SYSTEM PROFILE. MOST SHEDS HAVE ELEMENTS OF EACH SCALE.



GREEN INFRASTRUCTURE IMPLICATIONS

The City-Wide Sewershed Analysis presents a new paradigm for how the City designs and manages stormwater management infrastructure and is distinguished by a few key principles.

First, the City-Wide Analysis assigns economic, ecological, and social value to the natural services that can be provided in the landscape, such as water capture and storage. Green Infrastructure such as wetlands or bioswales can be monetized and compared to the performance and cost of more traditional engineered systems. In addition, the improved ecological systems can enhance other areas of performance. At the largest scale, cleaner water quality allows for compliance with regulations, but also supports greater flora and fauna biodiversity. At the neighborhood scale, increased tree canopy from tree pits in sidewalk plantings can have a very real effect on localized urban heat island effects and decrease property owners' costs to cool their buildings. Studies also show that Green Infrastructure improvements have measurable effects on property values and improve resident perception of safety and satisfaction. The City-Wide Analysis indicates that improved hydrological performance with Green Infrastructure has collateral "triple bottom line" benefits.

Second, the systems need to be designed and managed as a network of flows over time, not just as a series of physical facilities. This requires thinking in different timescales and will be facilitated through technology that allows us to model, simulate, and make mid-course adjustments as needed.

On the day to day timescale, green stormwater installations can have controls that dynamically respond to weather or storm events. Sensors can predict direction and severity of storms, triggering smart infrastructure to anticipate impact, such as lowering the level of an existing reservoir in anticipation of a storm event. Seasonal performance can be directed with similar technology.

As GI projects are designed and implemented over the year to year and decade to decade timescale, constant modeling and flow analysis is necessary to understand performance and broader network impact. For example, an upstream development may change the runoff profile of a shed. By establishing an adaptive approach to record and manage Green Infrastructure within a shed, systemwide performance can be tracked and used to inform future development. Continuous measurement and reassessment can help to magnify benefits provided by on-going improvements.

Lastly, the systems need to be designed for generation-scale evolution. Both green and grey systems age over time and have life cycles. Understanding the performance relative to maintenance and replacement milestones is key to maintaining biotic systems. The maintenance regimen, both in time and in tasks, evolves through the life cycle of the infrastructure, and the net present value of infrastructure needs to be considered accordingly.

Third, the City-Wide Analysis emphasizes opportunities to create shared value instead of isolating or segregating systems. Green Infrastructure projects should rarely be considered in isolation but should be integrated with other infrastructure investments. For example, the city's commitment to complete streets means that stormwater conveyance can more easily be advanced at these locations. Scheduled improvement in the city's parks should be reviewed for opportunities to incorporate Green Infrastructure, giving character and functionality while achieving multiple benefits for the same dollar spent. In areas of rapid development, instituting incentivizeives and controls would encourage Green Infrastructure that helps meet the City's goals while creating higher performing, beautiful places.

GREEN INFRASTRUCTURE CHALLENGES THE WAY WE MANAGE OUR CITIES BECAUSE IT:

...ASSIGNS ECONOMIC, ECOLOGICAL, AND SOCIAL VALUE TO NATURAL SERVICES

...NEEDS TO BE DESIGNED AND MANAGED AS DYNAMIC FLOWS OVER TIME

...EMPHASIZES OPPORTUNITIES FOR SHARED VALUE INSTEAD OF SEGREGATED SYSTEMS

FUTURE RESILIENCY CONCERNS

The City of Pittsburgh is addressing resiliency and climate change through the Office of Sustainability's initiatives like the Rand Corporation's Study on Resilient Stormwater Management in Allegheny County. While the goal of the study is to support improved stormwater management and resiliency in the entire county, the early findings have raised questions about the targets set for City-Wide planning. According to the Rand Corporation's preliminary presentations, stormwater models based on an average year may not be reflective of emerging data on climate change statistics. Their research suggests that precipitation models may need to be adjusted to account for a greater frequency of more severe events and that the "average year" may have already been exceeded in the majority of the past 10 years.

While the frequency of rain events may be increasing, there is evidence that the intensity of storm events is also increasing. Sometimes referred to "extreme rainfall," these events make it very difficult to design systems that can handle both the small and frequent event as well as the intense but less frequent event. In many cases we can find old newspaper headlines about previous flooding events on flood prone sites. These sites may have seemed to be free of problems in recent decades, but with the confluence of failing infrastructure and shifting climate patterns, we are seeing issues at these sites arise again.

Many other cities, such as those along coastlines or in arid climates, are addressing water issues with a greater sense of urgency. For example, Copenhagen has developed a Cloudburst Plan (2012) as part of the Danish capitol's Climate Action Plan. The Cloudburst plan addresses frequency and intensity of events with shed-wide planning and a commitment to major infrastructure replacement. New York City has pledged millions of dollars to major design and engineering initiatives that will change the way their waterfronts function.

Places like New York and Copenhagen are using a similar set of criteria for ranking initiatives including:

RISK

measures that proactively improve the city's resilience

OPPORTUNITY

measures that are easy to implement

DEVELOPMENT

measures in areas of high activity

SYNERGIES

measures with multiple benefits

These cities also face similar administrative and funding challenges that limit system-wide adoption. Other cities that do not have the same risk profile, such as Chattanooga, Tennessee, may not need the same existential level of investment, but do need to reinvent their administrative systems to account for the risk of failure by inaction. Chattanooga has adopted a full range of policies and programs to support distributed Green Infrastructure strategies.

Although flooding and water quality are two of the major reasons for Green Infrastructure, the City should also consider long-term risk and resiliency around an adequate supply of safe drinking water. All of the City's drinking water supply comes from the rivers and, while the rivers are much cleaner than before, there is a growing risk of upstream pollution contamination related to extractive industries. Currently, the City-Wide approach to stormwater management is to use Green Infrastructure to infiltrate flows onsite with biotic systems where possible, or detain flows for slow release. However, future studies could also examine the potential of stormwater conveyance and storage for reuse as a potable water source with integrated micro-filtration and distribution, instead of just delayed release back into the rivers. Decentralized water treatment and supply is already a reality in many places and is something that PWSA could evaluate in relation to its core service model.

IMPLICATIONS FOR POLICY AND ADMINISTRATIVE STRUCTURE

The biggest challenge to successful Green Infrastructure networks is not necessarily with the technologies themselves, but with the regulations, responsibility, and financing of the systems. Though this report was focused on the technical implementation and not on the administrative structure, it has become apparent that the full range of solutions can only be enabled with changes to governance.

Over the course of this project through internal and external meetings, a number of concerns have consistently risen to the top as major issues that could inhibit a strong and effective Green Infrastructure network. Many focus on the distributed control of system components, making it difficult to act in an integrated way. Ownership and stewardship of stormwater infrastructure requires coordinated action as the system crosses agency boundaries along the vertical axis and municipal boundaries in the horizontal axes. Because this report focused on sheds within a single municipality, the City of Pittsburgh, we will focus on the vertical axis and its associated inter-agency jurisdictional issues.

Today, stormwater's journey begins at the surface where the Department of Public Works and private property owners control its flow, each under different legal requirements. Once the water enters the combined sewer system it becomes the responsibility of PWSA until it enters ALCOSAN's interceptors and pipe structures. Green Infrastructure challenges the clear boundary between the agencies who control surface flows and the agencies who control flows in below grade systems.

Green Infrastructure extends the responsibility for water quality and quantity into a realm in which responsible agencies traditionally do not have control. It is not necessarily a lack of will but a lack of administrative infrastructure for coordinated action that inhibits full implementation. Many of these issues are challenges for other cities as well.

Issues to be resolved include:

It is unclear who would administer existing stormwater management plans and how they would be legally binding.

Planning and projects are loosely coordinated between siloed agencies, including Public Works, City Planning, PWSA and others.

Perceived gaps in planning or coordination capacity of these organizations are filled with nonprofits who advocate for coordinated efforts but do not control the process, the assets, or the regulatory responsibility for compliance.

Existing planning and administrative practices across the country are not often suited to address dynamic or adaptive resource flows. Current controls are better suited to regulating placemaking, not monitoring and adjusting to the dynamic flows or performance of these places (this is a challenge for other resource flows such as energy or parking).

In addition, the City is a part of ALCOSAN's larger cohort of municipalities and may need a different administrative structure than others in this cohort.

Effective and innovative Green Infrastructure and rainwater control will be limited unless these issues can be drawn into the design prcess. There are a few possible responses and it is likely that some combination would be necessary:

Reshape the agencies to create a structure that allows for coordinated action and adaptive management.

Change the jurisdictional boundaries to allow for existing agencies to have increased authority.

Create market or regulatory mechanisms to incentivize or require action.

MANAGING WATER AT THREE SCALES

To establish a City-Wide water plan, we need a system that is structured for managing constantly changing resources and flows. Adaptive management is a structured, iterative, and emergent process of decision-making and action that may inform the management system. Adaptive management describes management systems that are well suited for dynamic systems where conditions are constantly in flux and where there is a high degree of uncertainty. Adaptive management is best known for its application to the management of natural resources, such as species populations, but can be applied to any organization that is in an uncertain and emerging context.

Through the evaluation of the first six sheds, a replicable method of analysis has been established that can yield consistent data to inform City-Wide modeling. This process creates a Shed Management Plan, which can then be referenced and implemented by agencies, collaborators and stakeholders. The management of the Shed Management Plan needs to be iterative and will cross political, neighborhood, and agency boundaries.

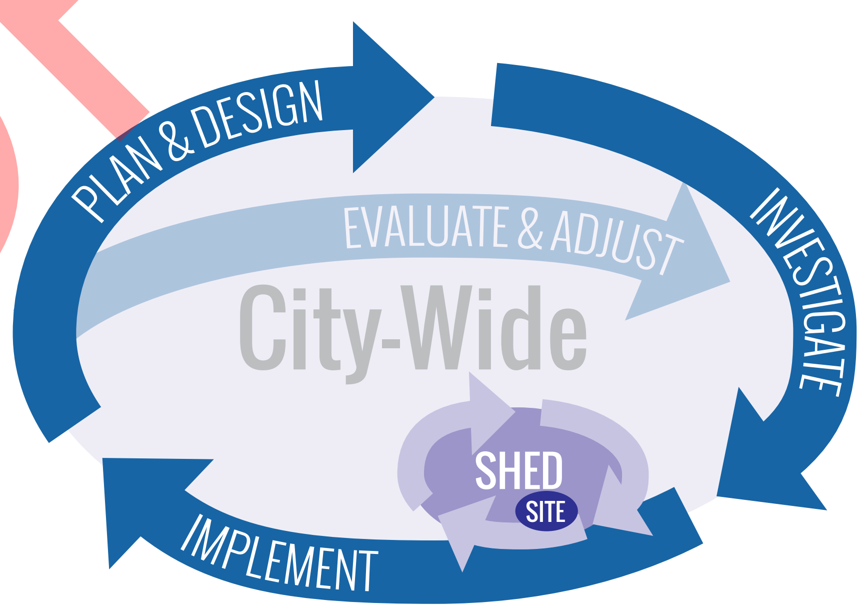
Currently, our city's stormwater management does not enable easy implementation of the plans identified in the City-Wide process. The existing organizational structures, policy, and responsibilities do not enable collaborative decisions and streamlined action. An Adaptive Management model should be considered when structuring the policy, processes, and administrative structure for the control of rainwater as a resource.

FOR THE CITY-WIDE RECOMMENDATIONS TO BE SUCCESSFULLY IMPLEMENTED, IT IS IMPORTANT TO ALLOW INSTITUTIONS, POLICIES AND PROCESSES TO DRAW UPON AN ADAPTIVE MANAGEMENT MODEL THAT:

...ADDRESSES ISSUES AT THE APPROPRIATE TEMPORAL AND SPATIAL SCALE

...CREATES A CONSTANT FEEDBACK LOOP OF INFORMATION AND ACTION

...CREATES ORGANIZATIONS CAPABLE OF COLLABORATIVE ACTION



The process includes work at the...

CITY-WIDE SCALE

Understand the full functioning of the system and the City's contributions through systemwide modeling.

Select priority sheds. Identify which sheds should be addressed based on potential benefit to the overall system and other criteria.

Create or revise shed-scale masterplanning.

Policy and administrative changes. Make changes to policies, programs, and/or organizational responsibility to allow for consistent application across all sheds. Establish integrated funding strategy.

Review shed progress and adjust City-Wide modeling.

ON-GOING 2016

SHED SCALE

Model the shed's baseline performance, establish target reduction level, and create the Dashboard (1.0) that distills key indicators in an easy-to-read format.

Identify preliminary high capture stormwater locations within sheds based upon modeling. Target areas may indicate high inflow resulting from impervious surface or may result from localized sewer configuration and so need to be investigated further.

Analyze the urban context. Urban analyses should include physical, ecological, and cultural assets, as well as economic activity.

Develop system schematic(s). Each shed's hydrologic strategy is based on physical configuration and available resources. The schematic needs to indicate how each component works within the system.

Identify locations for Green Infrastructure implementation. Develop areas of focus where Green Infrastructure functions as a system or independently depending on shed characteristics.

Assess performance with hydrologic and economic modeling. Model proposed Green Infrastructure alternatives for hydrological effectiveness, costs, and triple bottom line benefits. Revise the Dashboard (2.0).

Share the preliminary assessment with the community. Reach out to all levels of the community for feedback, from elected officials, community organizations, and the general public. Anticipate the need for general education on CSO issues. Discuss project prioritization criteria and possible administration mechanisms.

Identify projects for implementation.

Develop a shed-wide plan of action and funding strategy for infrastructure. Prioritize short, mid, and long-term implementation. Apply consistent criteria for assessing projects, including areas of risk, areas where projects are easy to implement, areas of development activity, and areas where synergies efforts can multiply benefits.

ON-GOING, SIX SHEDS, JUNE 2016

PROJECT SCALE

RISK
projects that proactively improve the city's resilience

OPPORTUNITY
projects that are easy to implement

DEVELOPMENT
projects in areas of high activity

SYNERGIES
projects with multiple benefits

Design, engineer, and construct projects according to shed-wide plan of action. Assign responsibility for projects and coordinate on-going implementation.

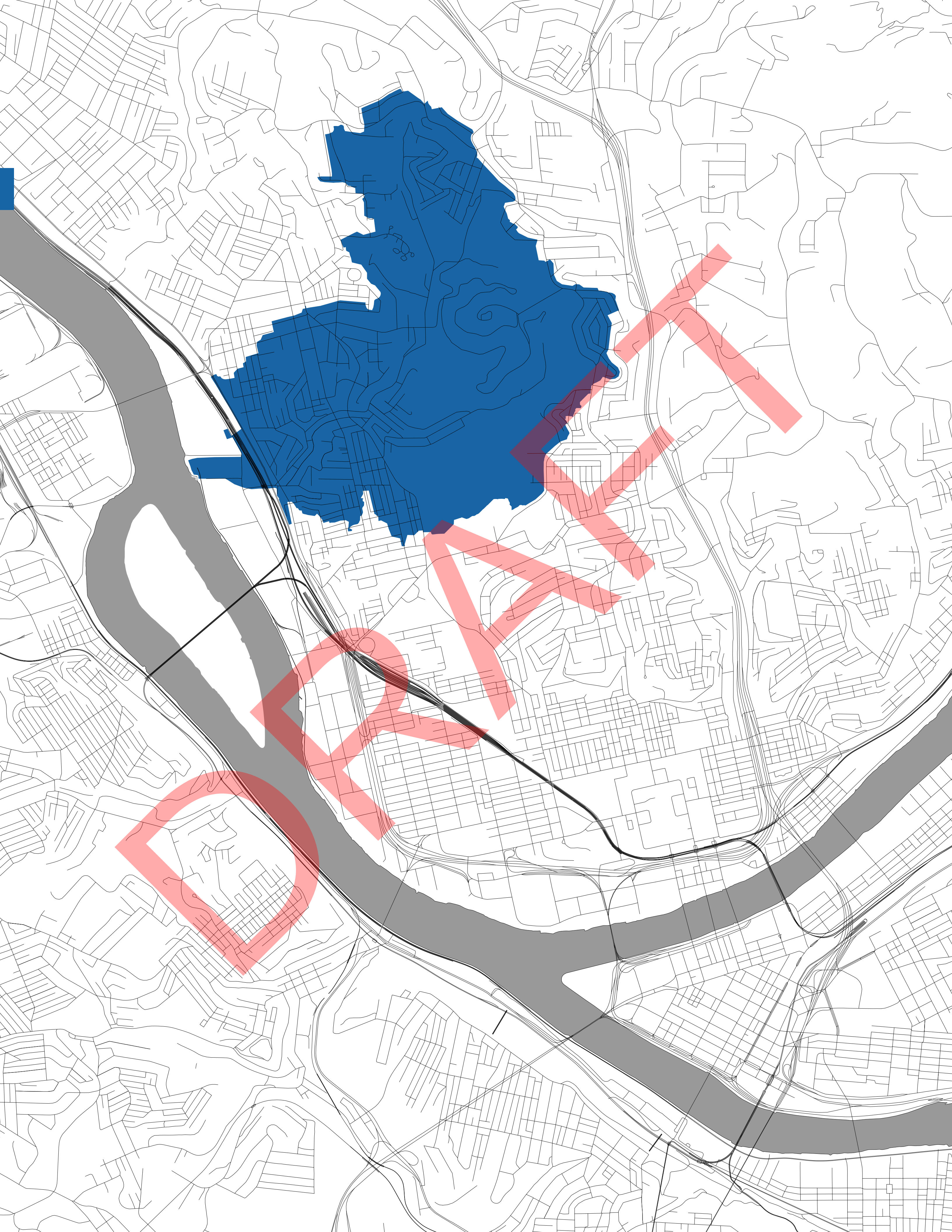
Monitor operations and maintenance. Make adjustments when needed. Update computer models and shed dashboard to communicate progress and make mid-course corrections.

ON-GOING, PROJECTS FUNDED AS OF JUNE 2016

And is informed by:

The **CITY-WIDE ADVISORY TEAM** is a community based review team to advise on system-wide roles and policy.

The **SHED-WIDE ADVISORY TEAM** is a community based review team to advise on sewershed specific projects and priorities as well as a communication conduit for residents.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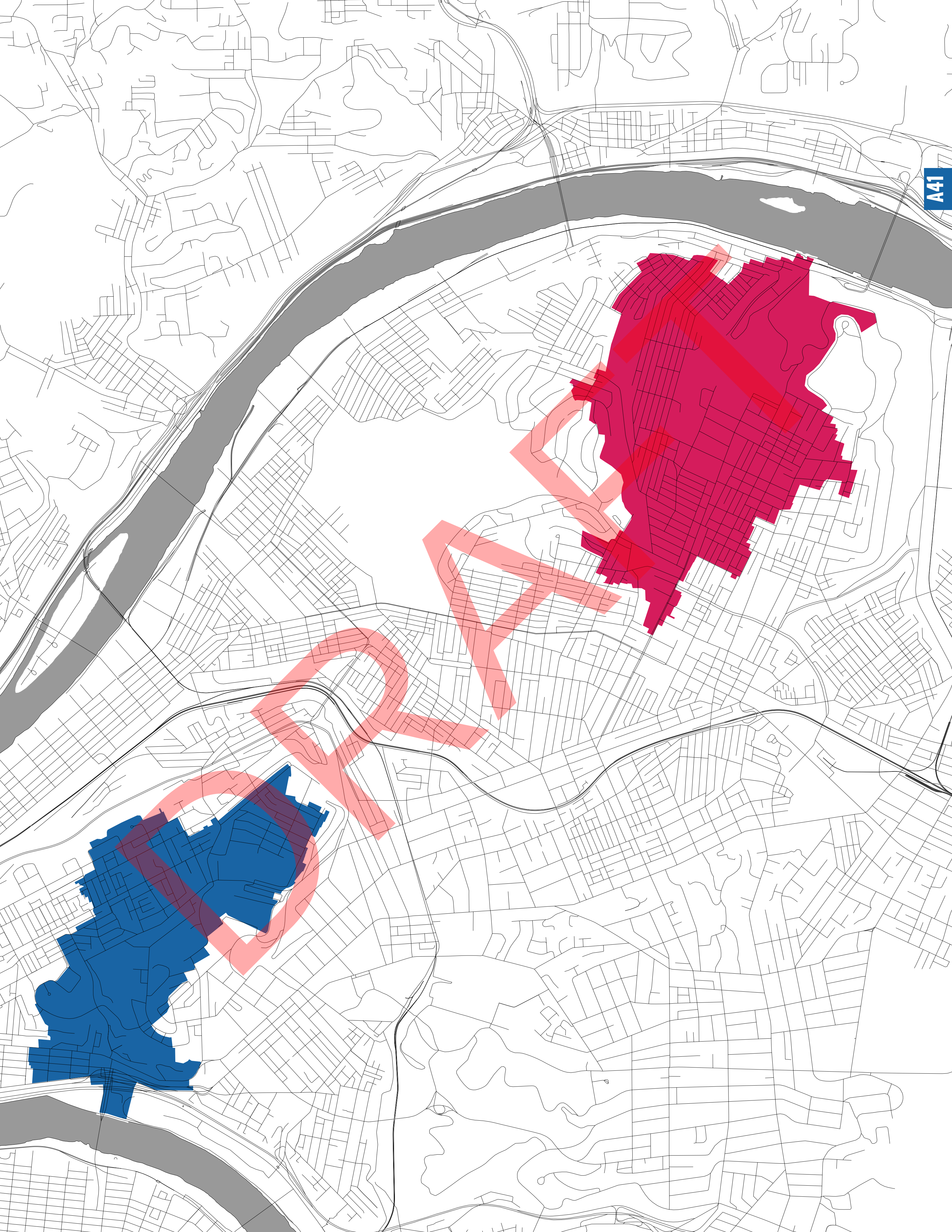
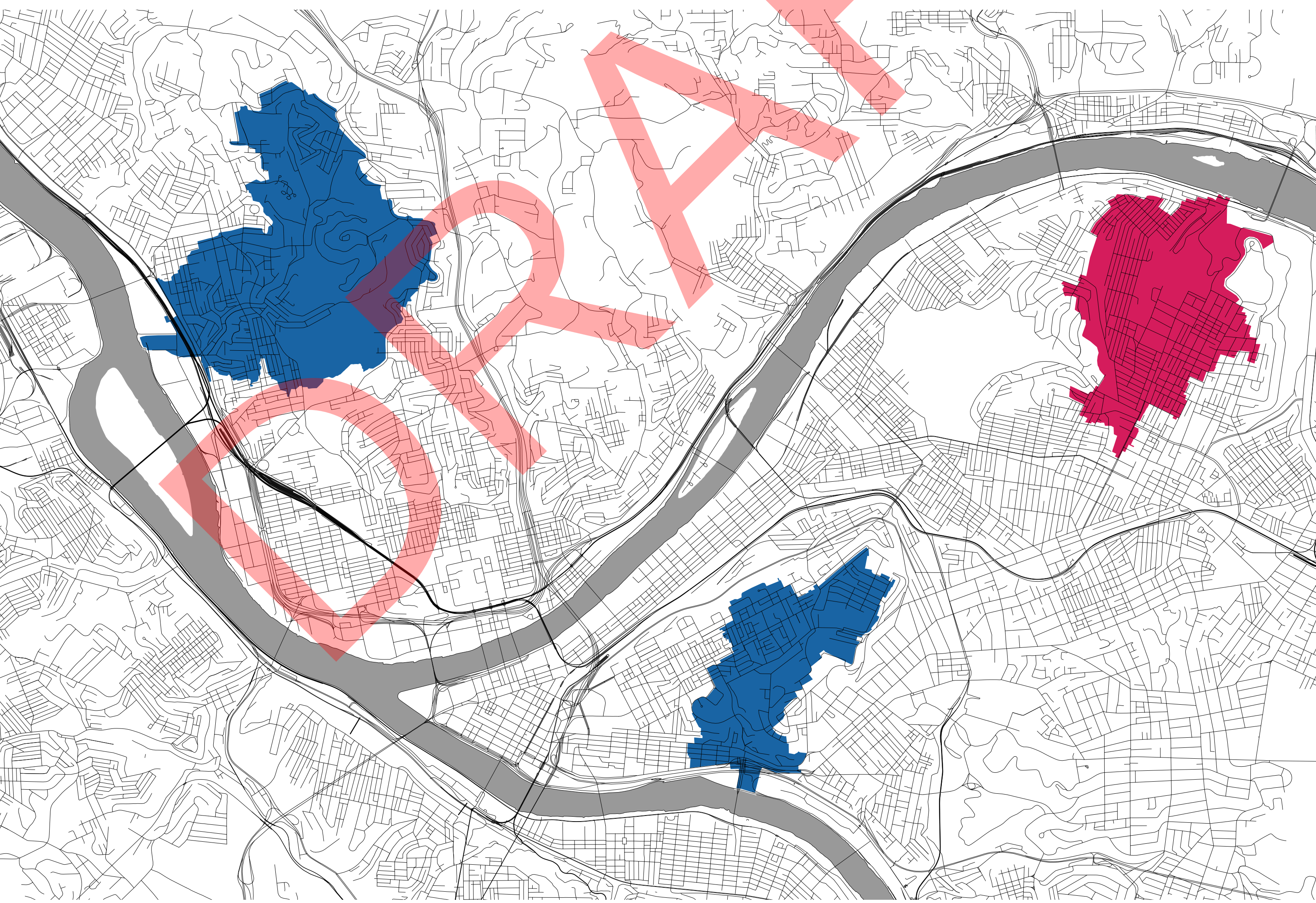

A41
DRAFT

A41 HETH'S RUN

The A41 Sewershed is located in some of Pittsburgh's most stable residential neighborhoods. This sewershed is configured similar to the watershed and the sewer follows the path of the now underground Heth's Run, which once was tributary to the Allegheny River. The highest points in the shed, Stanton Heights, Garfield, and East Liberty contribute some stormwater but the majority of runoff comes from the Morningside and Highland Park neighborhoods. The neighborhoods are mostly comprised of single family detached homes and there is little vacancy. The Heth's Run valley is currently used as a parking lot for the Pittsburgh Zoo and is contiguous with Highland Park, one of the largest municipal parks in the city. Highland Park is also home to both a covered and uncovered drinking water reservoir.



OPPOSITE PAGE. A view of a woman collecting water at the Morningside Playground near Chislett Street., c. 1916.

A41 SHED SUMMARY

HETH'S AVENUE

Heth's Avenue forms the boundary between two neighborhoods with Morningside to the west and Highland Park to the east. It closely follows the historic Heth's Run stream channel and is a low-spot for the surrounding neighborhoods.

Heth's Avenue could become the prototype for a new streetscape typology. Stepped detention basins, networked tree pits and rain gardens, and a narrowed right-of-way could bring the greenery of Heth's Run deep into the neighborhood.

HETH'S VALLEY

Water from the surrounding neighborhoods could flow to an underground detention facilities to "stop and drop" locations prior to entering a restored Heth's Valley with a naturalized series of wetlands and surface flow. Other areas will share functions with Pittsburgh Zoo parking and entry.

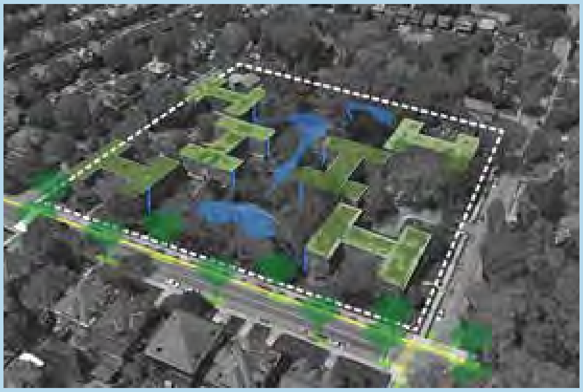
MELLON TERRACE

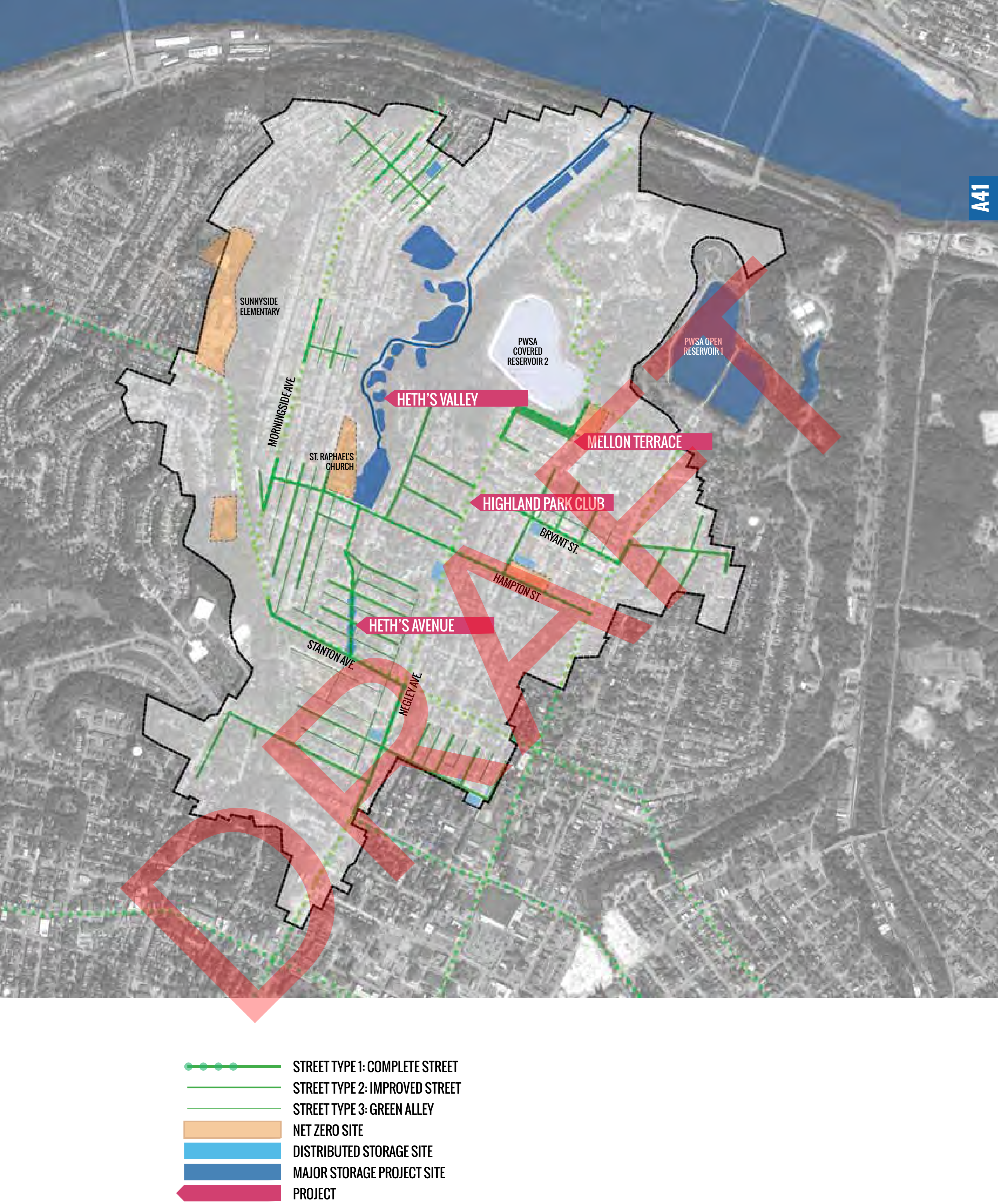
Mellon Terrace offers up to 37,700 square feet of potential rain garden for surface runoff from Mellon St, Callowhill St, and the northern terminus of Negley Ave. It is also adjacent to the Parklane, a 30 story residential tower whose parcel is covered with impermeable surfaces.

HIGHLAND PARK CLUB

Highland Park Club is one of the few large developed parcels that could retain its own site water or even accept water from adjacent sites. Endowed with generous greenspaces, this site could incorporate strategies including green roofs, rain gardens, and bioswales. This could be accomplished through public-private partnership.

Other Net Zero areas in A41 include St. Raphael's campus and Sunnyside Elementary.




SUNNYSIDE ELEMENTARY
MORNINGSIDE AVE.
ST. RAPHAEL'S CHURCH
HETH'S VALLEY
PWSA COVERED RESERVOIR 2
PWSA OPEN RESERVOIR 1
MELLON TERRACE
HIGHLAND PARK CLUB
BRYANT ST.
HAMPTON ST.
HETH'S AVENUE
STANTON AVE.
NEGLEY AVE.
DRAFT
A41
STREET TYPE 1: COMPLETE STREET
STREET TYPE 2: IMPROVED STREET
STREET TYPE 3: GREEN ALLEY
NET ZERO SITE
DISTRIBUTED STORAGE SITE
MAJOR STORAGE PROJECT SITE
PROJECT

STORMWATER DISTRICT

HETH'S AVE GREEN BOULEVARD & BLUE VALLEY

The A41 shed strategy reestablishes the importance of Heth's Valley as storage and Heth's Avenue as a collector, gathering water from adjacent streets, storing it in "stop-and-drop" subsurface detention under Heth's Field, and then continuing to the restored wetlands and stream in the valley.

Historically Heth's Valley (Haight's Valley) was a wetlands area that captured and contained water from the shed. The Pittsburgh Parks Conservancy and the Pittsburgh Zoo are embarking on a transformation of the asphalt parking lot to an extension of Highland Park. The functioning of the valley would likely include wetlands, pass through conveyance, energy dissipation, and structured storage. Ecological restoration is needed to prevent sedimentation and to improve water quality. Ultimately, water should be released to the Allegheny without reentering the combined sewer system.

Most of A41's sewage and stormwater flow through pipes buried below Heth's Avenue. As PWSA moves toward a green approach to stormwater management, Heth's Avenue should be considered a priority site.

Heth's Ave is an underutilized concrete slab street on average 36 feet wide. There is low traffic count and low demand for parking on this street so an aggressive road diet is possible. Decreasing the width of the road would allow for generous rain gardens on either side and would establish the corridor as a pedestrian and cyclist friendly access to Heth's Playground and extend Highland Park into the neighborhood. Networked tree pits, improved gutter profiles, and green alleys would allow surface flows from Jackson St, Avondale Pl, and Wellesley Ave to travel to Heth's Playground without entering subsurface infrastructure.

Water could be captured and conveyed within the right-of-way using an enhanced gutter profile and slowed at mid block and end of block flow-through tree bumpouts. Streets sloped toward Heth's Avenue can be used to capture water from the right-of-way and from adjacent structures and surfaces.

CW CONSTRUCTED WETLANDS

Tiered wetlands, separated by weirs and check dams, would restore the valley's riparian ecology while slowly treating stormwater flows before they enter the river. Ecological restoration of hillsides will help establish native communities.

SD SUBSURFACE DETENTION

Improvements to stormwater infrastructure and recreation infrastructure should go hand in hand. Streets convey water to major subsurface structured storage where water can be stored and released in a controlled manner.

IS IMPROVED STREETS

Water is captured from the right-of-way using an enhanced gutter profile. It is slowed at mid block and end of block flow-through tree bumpouts. Water is captured and conveyed below the roadway when it crosses a Complete Street.

GA GREEN ALLEYS

Side streets connected to Heth's Avenue can be used to capture water from the right-of-way and adjacent structures. Water is captured in the center of the right-of-way and conveyed subsurface in a gravel filled under-drain.

PFS PAY-FOR-SUCCESS

Green Infrastructure should be placed wherever opportunities exist. Bioswales and small wetlands offer high value landscaping in addition to stormwater performance. Creative financing models can support additional private investments.

CS COMPLETE STREETS

Major thoroughfares such as Stanton Avenue have high demand for safety and aesthetic improvements despite low demand for stormwater improvements. Complete streets should be considered complimentary to the Improved Streets, Green Boulevards, and Green Alleys.


CW
SD
IS
GA
PFS
CS

PRIORITY PROJECT: RECREATIONAL PARK

NATOLI FIELD

Morningside's neighborhood business district is located at Greenwood Street and Morningside Avenue and connects the surrounding neighborhood to greenspace, public transit, and other amenities. The district could be given a unique identity with well designed stormwater infrastructure.

Natoli Field offers 165,000 square feet of recreational fields and is at the bottom of Greenwood Street. It is an ideal site for subsurface detention before stormwater drops into the Heth's Run Valley. A former playground at the unoccupied Morningside Elementary School could incorporate either surface or subsurface detention on a smaller scale, at 16,000 square feet.

City steps on Greenwood St descending from El Paso Street to Duffield Street could be an exciting opportunity for tiered detention and conveyance structures along a new fully accessible route, giving the public an up close look at the water that flows within the neighborhood.

MAYNARD STREET, SEATTLE, WA
Source: SvR Design

PRIVATE DEVELOPMENT

HIGHLAND PARK CLUB

The Highland Park Club Apartments is one of the few large developed parcels in A41 is a classic "towers in the park" community of low-rise apartments. Already endowed with generous greenspaces, this site could make the most of them by incorporating green stormwater strategies including green roofs, rain gardens, and bioswales.

Maximizing the detention potential of this site could enable surface flows from the right-of-way to be managed on private property. This could be accomplished through a public-private partnership model called "pay-for-success" whereby the public stormwater management entity pays a private property owner for management of a certain volume of water.

LIVING WALL, CHELSEA, NY, NY
Source: Claire Lui

CW	CONSTRUCTED WETLANDS
SD	SUBSURFACE DETENTION
IS	IMPROVED STREETS
GA	GREEN ALLEYS
PFS	PAY-FOR-SUCCESS
CS	COMPLETE STREETS


BLUE STAIRS
IS
GA
CS
PFS
SD
CW
A41


PFS
CS

A41 INVENTORY

OFFLINE SITES

On a case by case basis, there could be opportunities throughout Pittsburgh for stormwater contributions to be completely removed from the stormwater conveyance network. Strategically targeted improvements within the parcel boundaries of some sites could make it possible for most if not all stormwater to be managed on site.

East Liberty Presbyterian Church (shed A-22) sets a strong precedent for the offline site strategy. Since installing rain gardens and permeable paving as well as overflow monitors, the site has not contributed any stormwater to the combined sewer system, even in a 3.7" event.

Large sites such as the Sunnyside Elementary School in Stanton Heights would have the most opportunities for an ambitious on site management solution. In this case, the building has a large impervious roof, a large impervious parking lot, and a large amount of underutilized green open space. Due to the amount of open space, high volume detention and infiltration infrastructure could be used to store and infiltrate on site. The roof of Sunnyside Elementary School is large enough to serve multiple functions including potential photo-voltaic paneling to generate power, white TPO membrane to reflect heat, and roof gardens to absorb moisture.

Medium sites such as St. Raphael's parish could also be taken offline. By building detention infrastructure under parking lots and converting flat rooftops to greenroofs, the site can dramatically reduce its stormwater contributions.

SUNNYSIDE ELEMENTARY SCHOOL
Source: Stanton Heights Neighborhood Association

ST RAPHAEL'S PARISH AND SCHOOL
Source: St Raphael's Parish

CW	CONSTRUCTED WETLANDS
SD	SUBSURFACE DETENTION
IS	IMPROVED STREETS
GA	GREEN ALLEYS
PFS	PAY-FOR-SUCCESS
CS	COMPLETE STREETS


SD
GR
SD
SD
CW


GR
GA
SD
CS

A41 BY THE NUMBERS

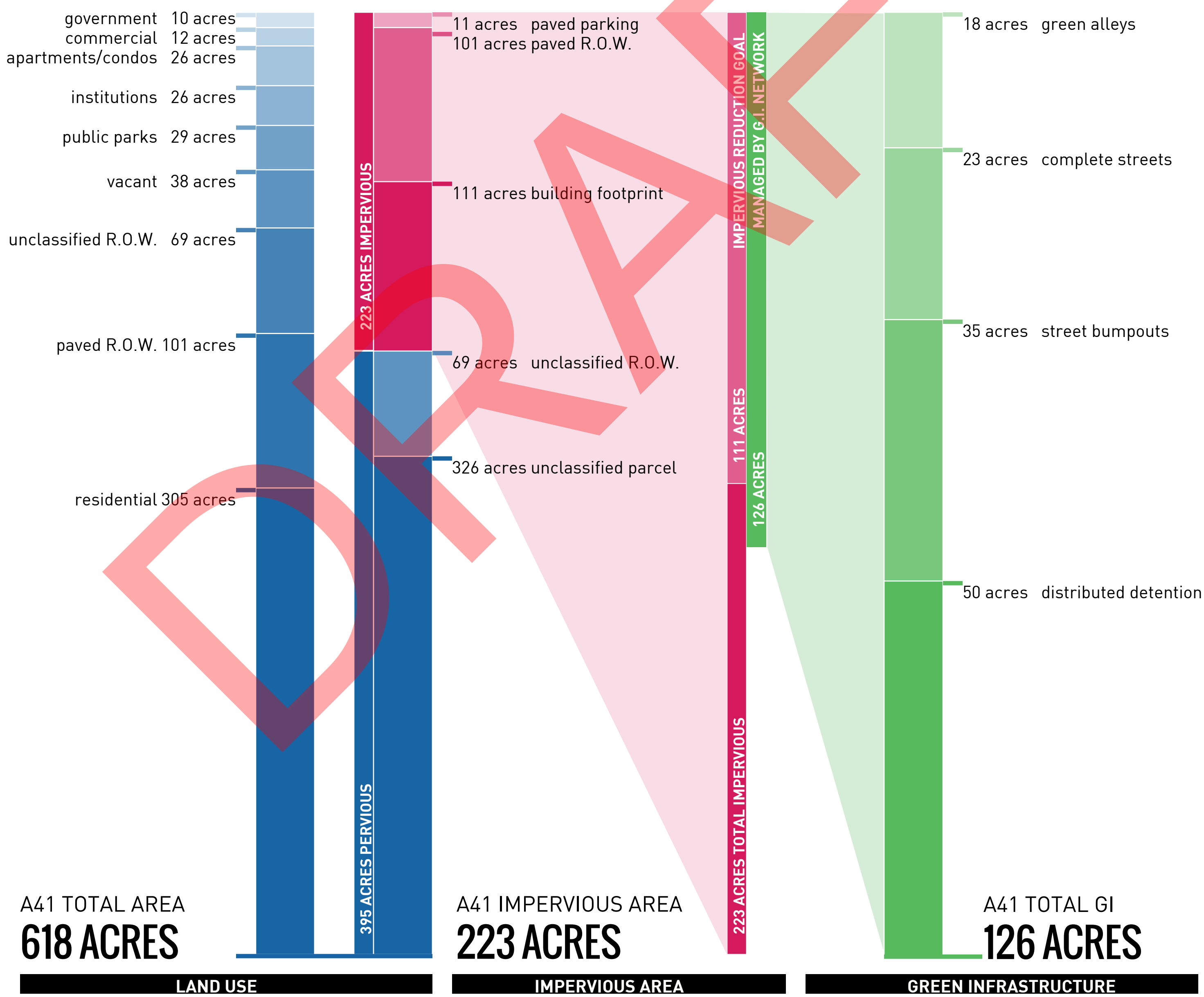
The A41 sewershed has distinct opportunities for urban streetscape improvements and valley parkland improvements. Both would better connect the neighborhood to the park and ultimately to the river.

17.3% OF THE SHED IS VACANT OR UNCLASSIFIED

36.1% OF THE SHED IS IMPERVIOUS

RESIDENTIAL IS THE MOST COMMON LAND USE (PUBLIC & PRIVATE)

5.8% OF THE LAND IS OWNED BY GOVERNMENT OR INSTITUTIONS



COMMUNITY STAKEHOLDERS

Many of the projects are at a significant scale or require cross-agency coordination. The following is a list of stakeholders identified in the preliminary process.

City-Wide

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

ALCOSAN	Tim Prevost
City Planning	Michael Smith
Council District 7	Deborah Gross
Council District 9	Rev. Ricky Burgess
Public Works (DPW)	Mike Gable
PWSA	staff
URA	staff

SHED SCALE

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

Allegheny Railroad	
Army Corps. of Engineers	
Pittsburgh Zoo	Parks Conservancy, WRT
East Liberty	ELDI, ELCC
Garfield	Bloomfield Garfield
Corporation	
Highland Park [park]	Parks Conservancy, DPW
Highland Park [n hood]	HPCC
Morningside	MACC
Stanton Heights	SHNA

PROJECTS

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

Heth's Playground	MACC, Parks Conservancy
Natoli Field	MACC, Parks Conservancy
St. Raphael's	Parish
Union Project	Jeffrey Dorsey, ED
Sunnyside Elementary	Principal
Borland Green	Borland Green Association
Highland Park Club Apts.	
Homeowners	
Developers	Morningside School

A41 SOLUTIONS

NETWORK SCENARIO

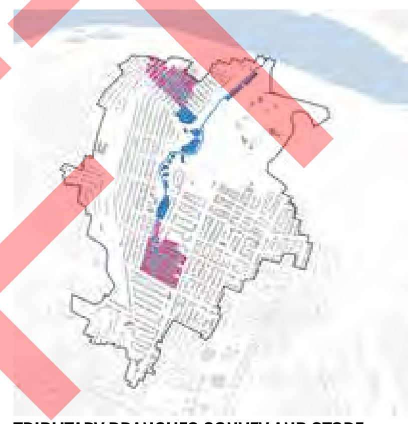
Green Infrastructure works by restoring, mimicking, and supercharging natural hydrologic processes. It needs to be deployed as a network and can reconcile historical flows with modern land use. We studied the historical development of the City of Pittsburgh, and the impact of development on the city's topography.

Hydrologic networks rely on a hierarchy of parts with differentiated functioning. Often there are critical pieces of Green Infrastructure that need to be installed and scaled to anticipate further expansion of the Green Infrastructure network.

We identified "opportunity sites" throughout each priority sewershed that could both fulfill local stormwater infrastructure needs and support healthy communities and neighborhoods. The result is a hybridization between natural and manmade resource flow controls.

In A41 Heth's Run, storage infrastructure at Natoli Field and Heth's Playground could allow for street improvements throughout the shed. As street improvements and detention sites come online, the network can be further expanded until the targeted areas are served by Green Infrastructure.

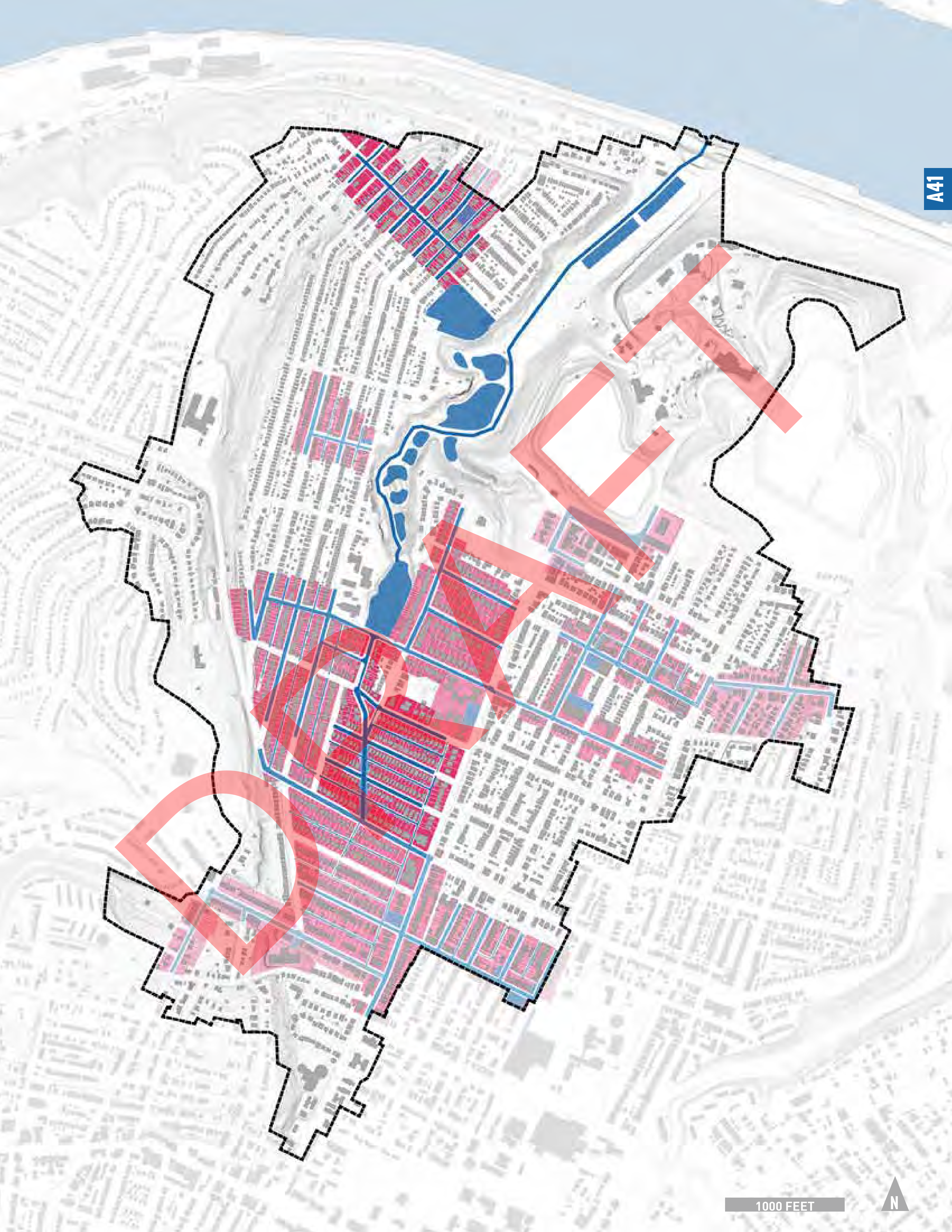
MAIN VALLEY STORAGE



TRIBUTARY BRANCHES CONVEY AND STORE

FURTHER NETWORK EXPANSION

FURTHER NETWORK EXPANSION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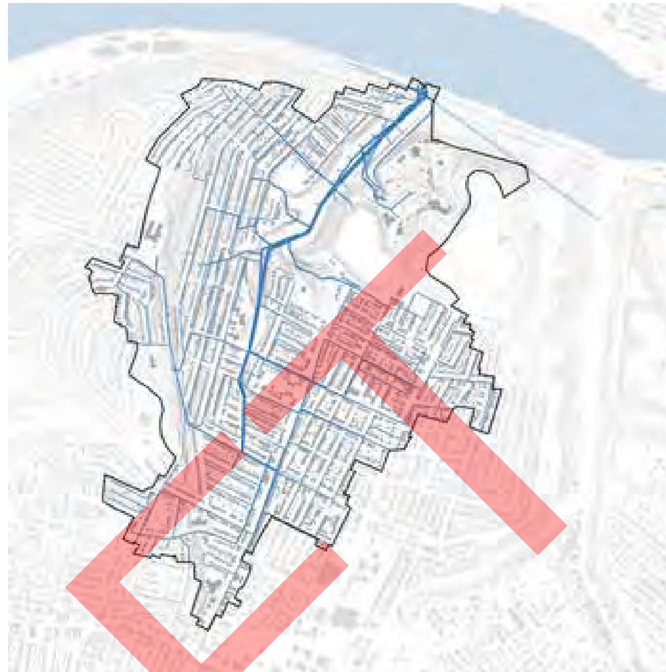
A41 INVENTORY

HYDROLOGIC ANALYSES

Stormwater from rainfall is the major driving force behind the geology of Pittsburgh. Recognizing where and how stormwater historically flowed can give us clues as to where those flows want to occur today.

Today's sewer mains follow hydrologic flow lines very closely. Heth's Avenue and Heth's Way were built on top of the main branches of Heth's Run. The majority of A41's stormwater flows here today.

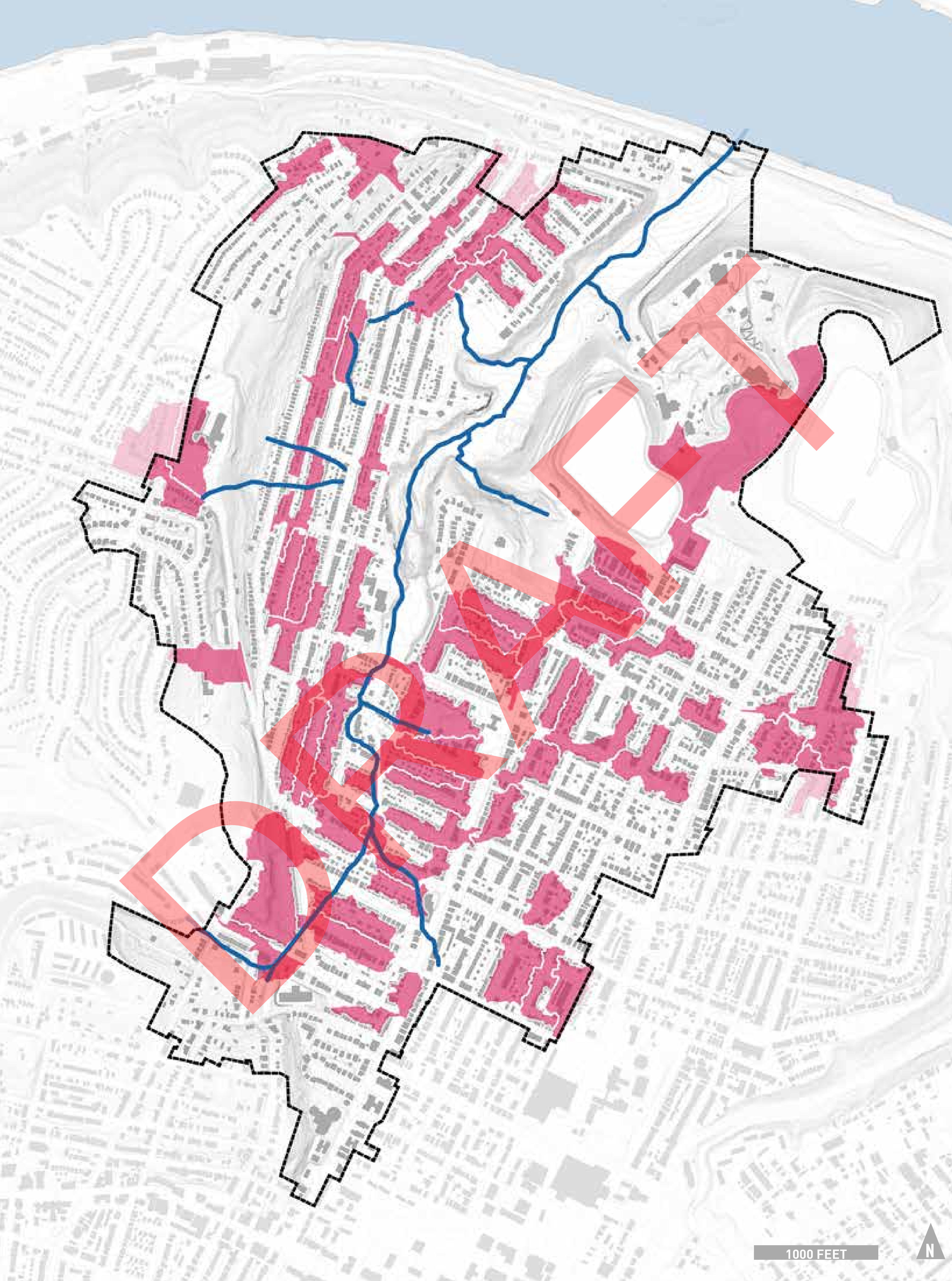


SEWER MAINS

WATER MAINS

MOTT MACDONALD TARGET AREAS

HISTORIC STREAMS



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A41 INVENTORY

SHED OVERVIEW

Understanding the unique urban fabric of a sewershed allows PWSA to identify potential synergies between infrastructure and communities. Better streets, better parks, better greenspaces, better hillsides, better homes, and better developments can all have positive ripple effects for people, planet, place, and performance.

STREETS + PARKING LOTS

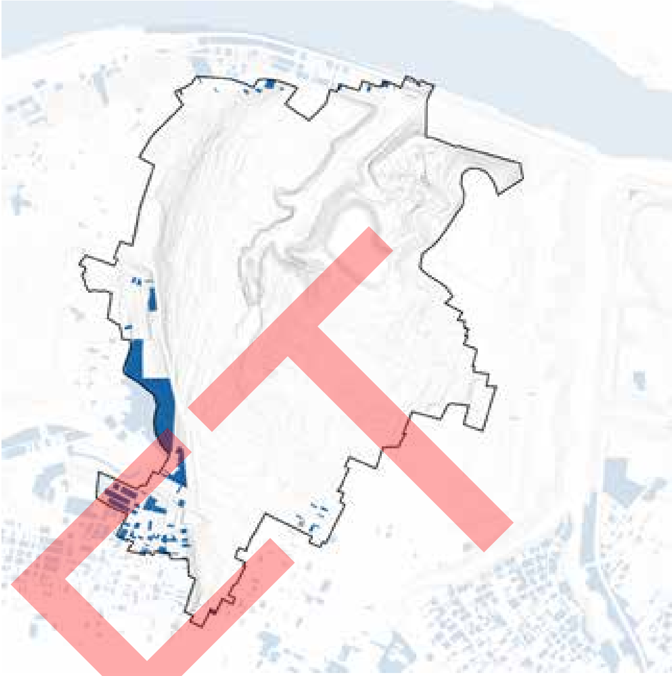
The street grid for Morningside is largely disconnected from the adjacent neighborhoods. Both Morningside and Highland Park have relatively consistent residential blocks of similar lot and building sizes..

GREENSPACE + HILLSIDES

Heth's Valley is the largest unprogrammed greenspace in A41 and is contiguous with Highland Park, the Pittsburgh Zoo, Natoli Field, and Heth's Playground. Other greenspaces are the steep hillsides that separate Stanton Heights from Morninside.

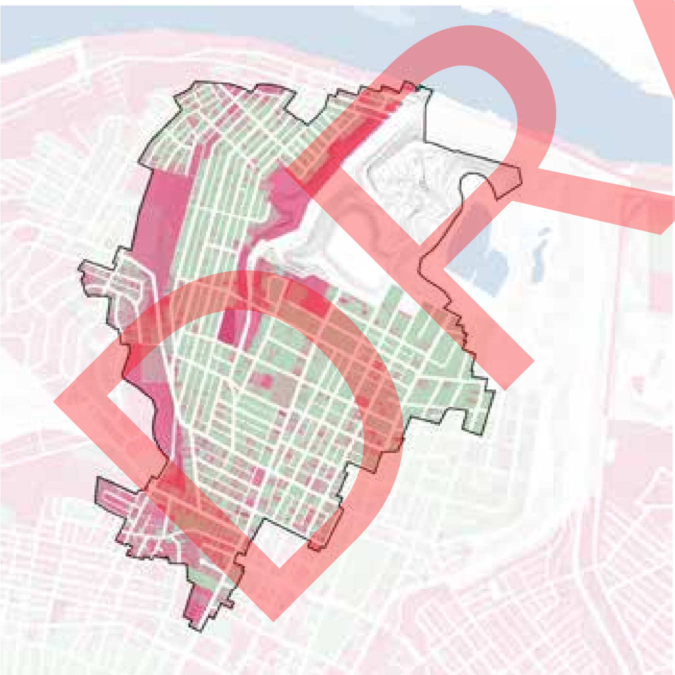
BUILDINGS

The A41 sewershed is largely developed and has a high percentage of impervious surfaces. Much of the valley is currently paved for Zoo parking.



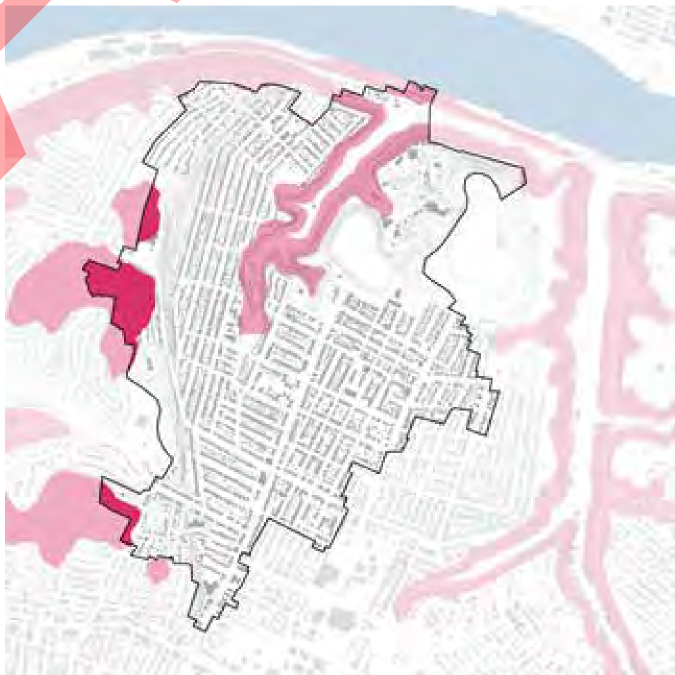
VACANT PARCELS

There are very few vacant parcels in the A41 sewershed.



RELATIVE PROPERTY VALUES

Property values in Morningside and Highland Park are consistent and reflect a strong residential community. Property values trend lower in East Liberty and Garfield and are lowest on steep unbuildable hillsides.



UNDERMINED + LANDSLIDE PRONE

Steep slopes surround the Heth's Run valley. Hilltops in Stanton Heights and Garfield are undermined and are more expensive to develop on.

URBAN CONTEXT

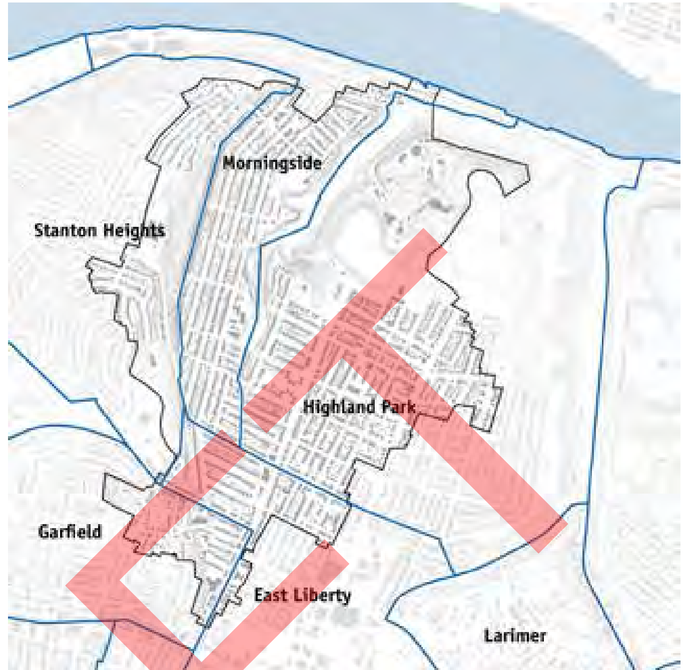
The A41 Sewershed is distinguished by its absence of vacant parcels and a largely open valley floor. Neighborhoods comprised of single family detached homes surround the valley of the former Heth's Run. To the east lies Pittsburgh's Highland Park, home to two large drinking water reservoirs and the Pittsburgh Zoo. The valley floor, which has been filled and graded in most places, is largely consumed by parking.

Neighborhoods
East Liberty
Garfield
Highland Park
Morningside
Stanton Heights

Council District 7
Deb Gross

Council District 9
Rev. Ricky Burgess

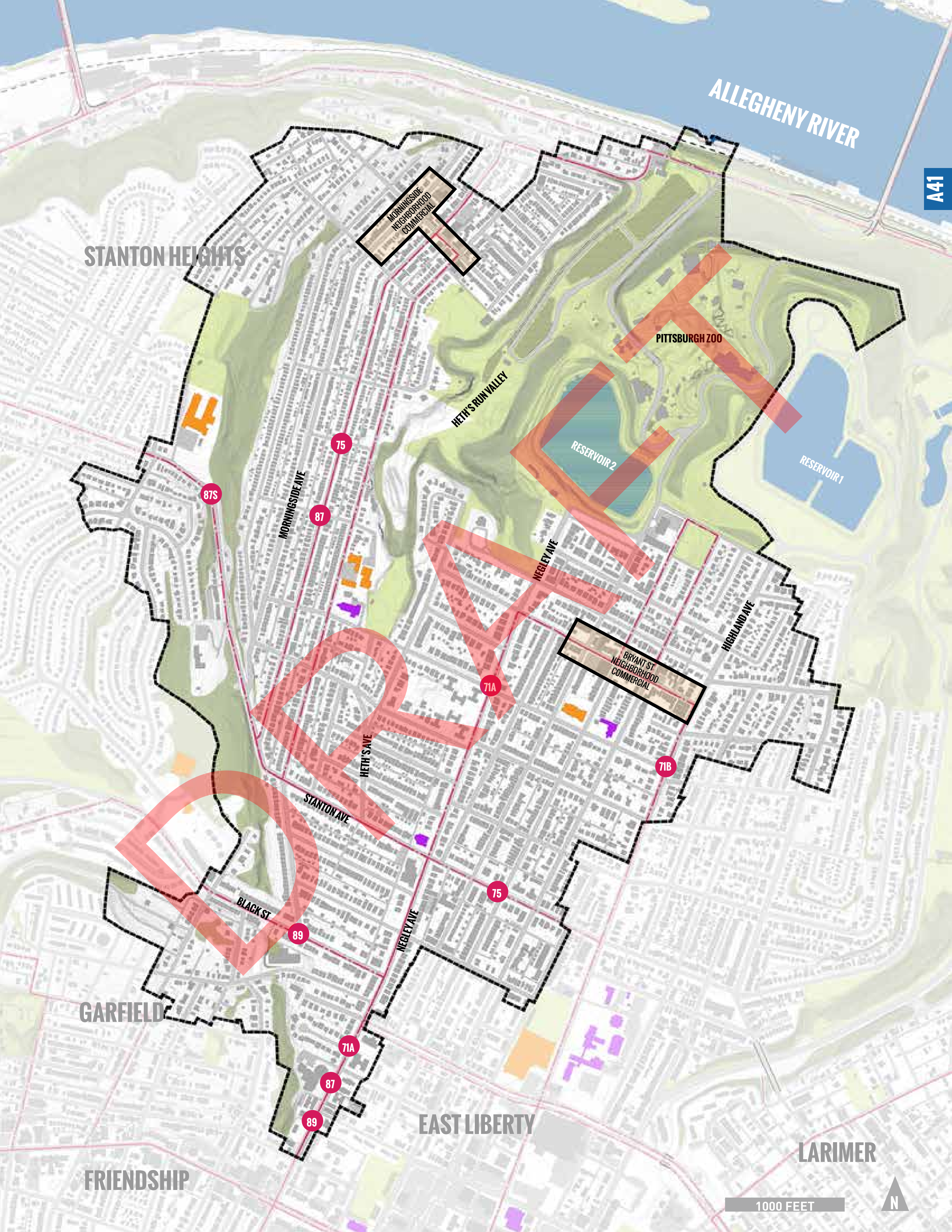
Community Groups
Bloomfield Garfield Corporation
East Liberty Chamber of Commerce
East Liberty Development Inc
Highland Park Community Council
Morningside Area Community Council
Stanton Heights Neighborhood Association



NEIGHBORHOODS

COUNCIL DISTRICTS

- Churches
- Historic Sites
- Forested Areas
- Parks
- Schools
- 71A Port Authority Bus Routes


ALLEGHENY RIVER
A41
STANTON HEIGHTS
MORNINGSIDE NEIGHBORHOOD COMMERCIAL
PITTSBURGH ZOO
HETH'S RUN VALLEY
RESERVOIR 2
RESERVOIR 1
75
87S
87
MORNINGSIDE AVE
NEGLEY AVE
BRYANT ST NEIGHBORHOOD COMMERCIAL
HIGHLAND AVE
71A
71B
HETH'S AVE
STANTON AVE
DRAFT
75
BLACK ST
89
NEGLEY AVE
GARFIELD
71A
87
89
EAST LIBERTY
LARIMER
FRIENDSHIP
1000 FEET
N

A41 INVENTORY

BRYANT ST + HIGHLAND PARK

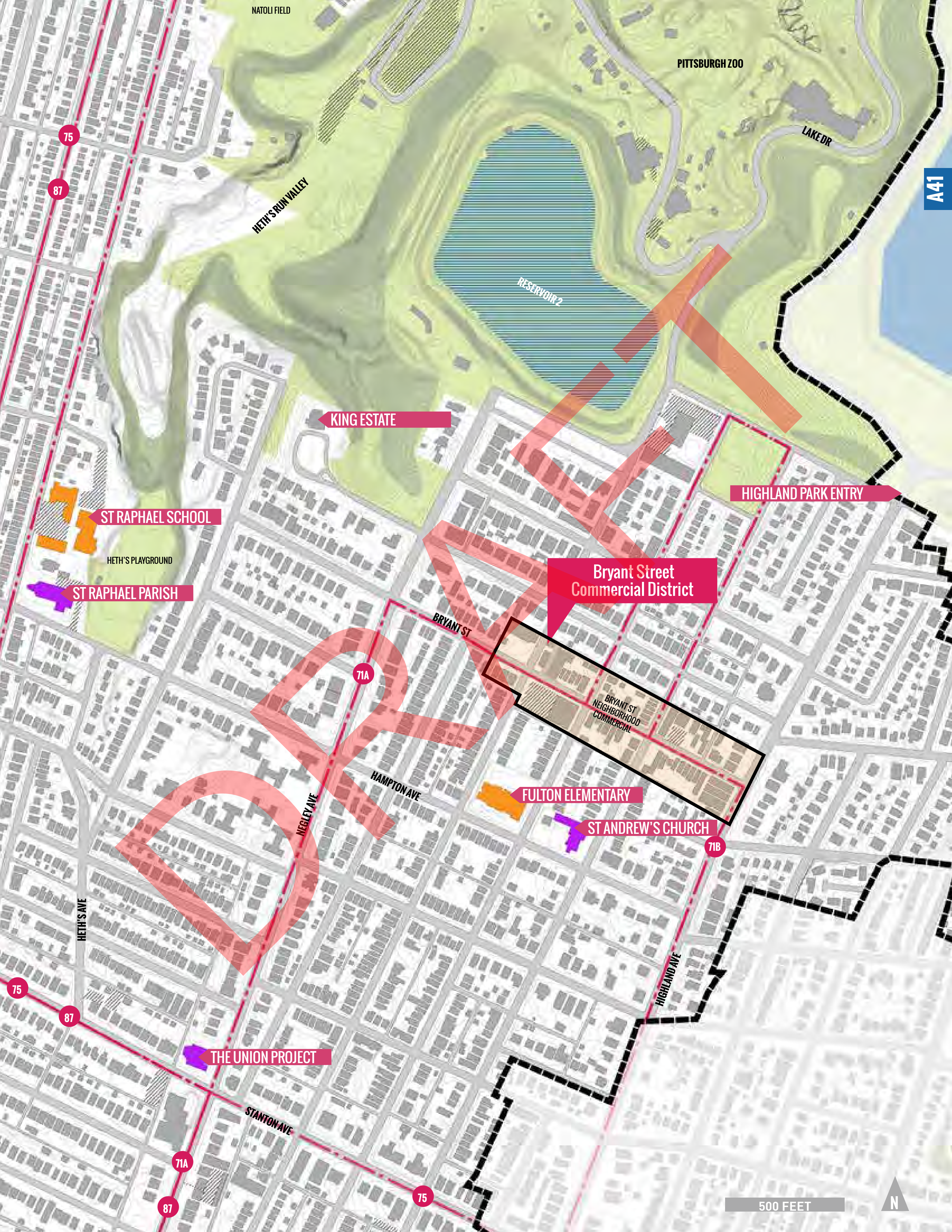
Highland Park is a quiet residential neighborhood with a vibrant neighborhood commercial district at Bryant St. It is home to Gilded Age landmarks like the King Estate and the grand entry to Highland Park. Local schools and churches remain civic landmarks, even when they are converted to other uses, as evidenced by the recently renovated Union Project community center.

BRYANT STREET CLOSED FOR FESTIVAL
Source: Highland Park Community Council

HOMES IN HIGHLAND PARK
Source: Highland Park Club Apartments

HIGHLAND PARK ENTRY, 1900
Source: Pittsburgh Parks Conservancy

- Churches
- Historic Sites
- Forested Areas
- Parks
- Schools
- 71A Port Authority Bus Routes


NATOLI FIELD
PITTSBURGH ZOO
LAKE DR
A41
HETH'S RUN VALLEY
RESERVOIR 2
KING ESTATE
HIGHLAND PARK ENTRY
ST RAPHAEL SCHOOL
HETH'S PLAYGROUND
ST RAPHAEL PARISH
Bryant Street Commercial District
BRYANT ST
BRYANT ST NEIGHBORHOOD COMMERCIAL
71A
HAMPTON AVE
NEGLEY AVE
FULTON ELEMENTARY
ST ANDREW'S CHURCH
71B
HETH'S AVE
HIGHLAND AVE
75
87
THE UNION PROJECT
STANTON AVE
500 FEET
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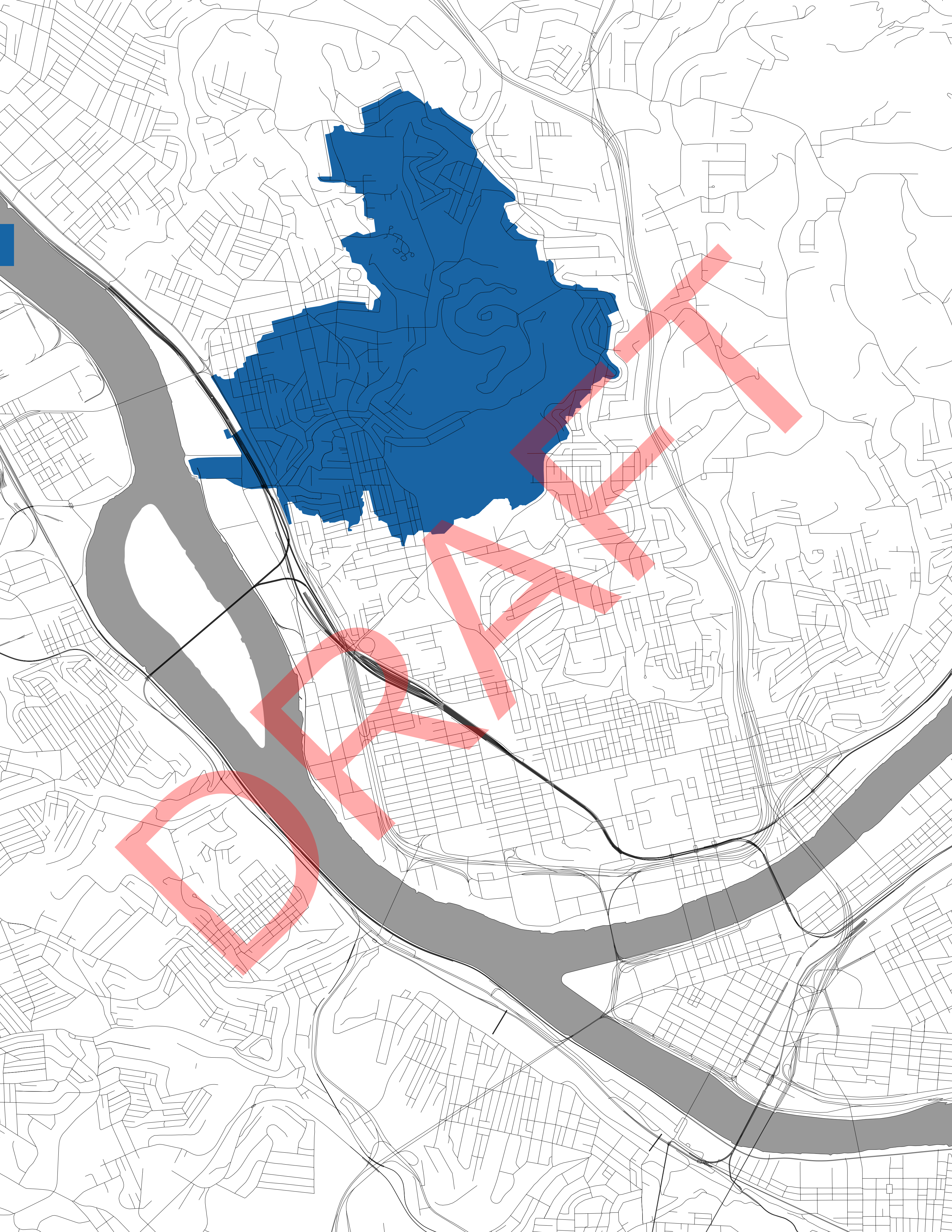
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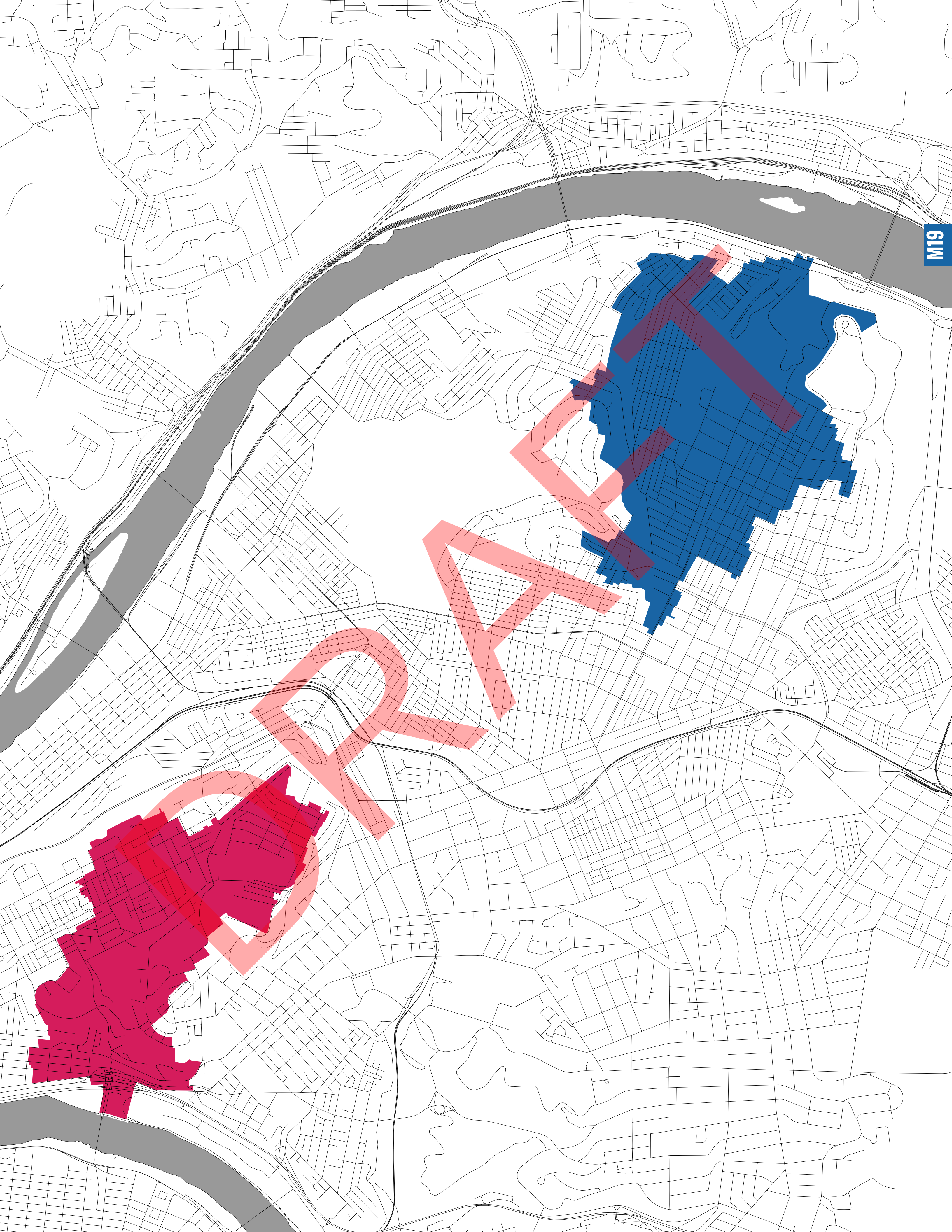
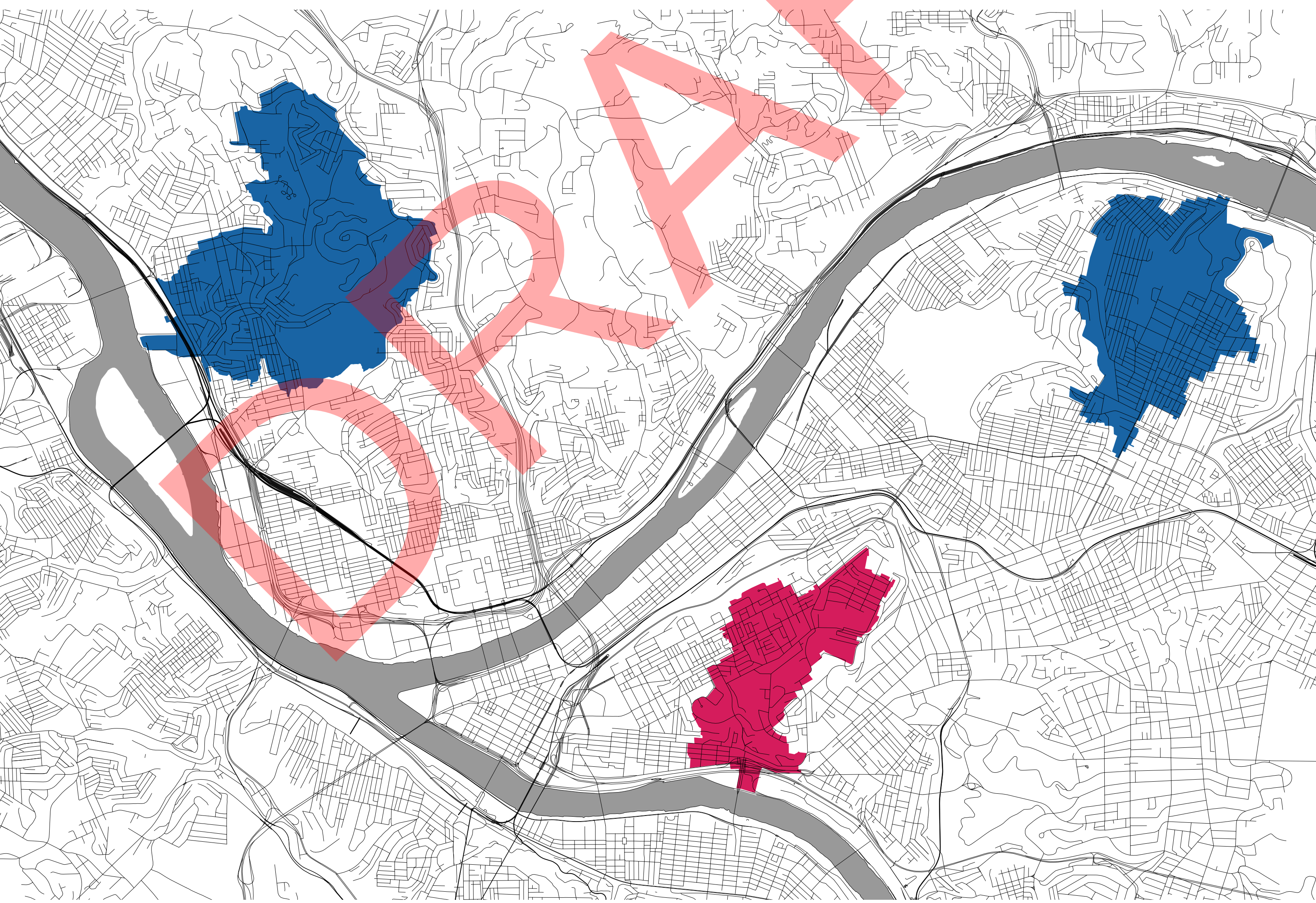

M19

M19 SOHO RUN

The M19 Sewershed is nestled in the core of the East End between some of Pittsburgh's largest economic centers. The M19 Sewershed is closely aligned with the watershed for the now underground Soho Run which was tributary to the Monongahela until the combined sewer network was constructed. Starting at the top of the Herron Hill, Soho Run flowed through the Upper Hill District, the Middle Hill District, Terrace Village, and Uptown (Bluff) before reaching the Monongahela near today's Birmingham Bridge. Once a vibrant community that was home to Pittsburgh's Jazz scene, the Hill District today is marked by vacancy and blight. Surrounded on all sides by neighborhoods with rapid development, it is expected that M19 will soon see major land use changes. We look at ways to anticipate development in M19 and its impact on stormwater management.



OPPOSITE PAGE. Sewer being constructed for M19 in the Hill or Soho. c. 1910.

M19 SHED SUMMARY

UPTOWN PORTAL

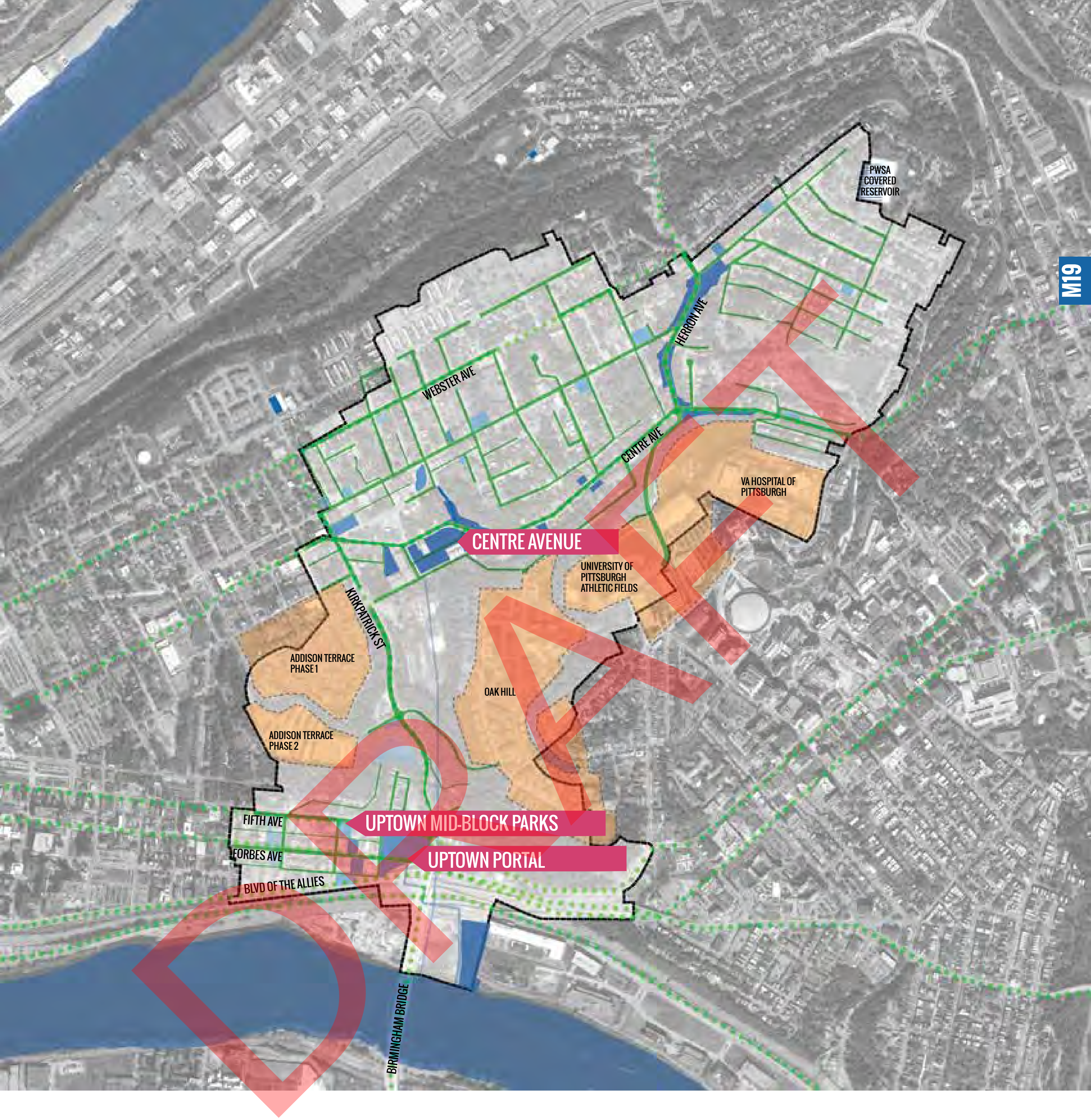
This site, between Fifth, Forbes, and the Birmingham Bridge aggregates stormwater flows from all sides and could reconcile challenging changes in grade for both cyclists and pedestrians.

UPTOWN MID-BLOCK PARKS

Bands of mid-block greenspaces could provide tiered detention basins through the neighborhood while providing improved mid-block connectivity. Using the pay-for-success model, PWSA could work with developers to incentivizeivize creative solutions that manage stormwater and improve the public realm.

CENTRE AVENUE

The lowest point of Centre Avenue in the Middle Hill District is a key collection point for stormwater flows as well as the eastern anchor for the Hill's Centre Avenue business district. Establishing the site of an existing gas station as a community parklet with Green Infrastructure could catalyze development and growth.



STREET TYPE 1: COMPLETE STREET
STREET TYPE 2: IMPROVED STREET
STREET TYPE 3: GREEN ALLEY
NET ZERO SITE
DISTRIBUTED STORAGE SITE
MAJOR STORAGE PROJECT SITE
PROJECT

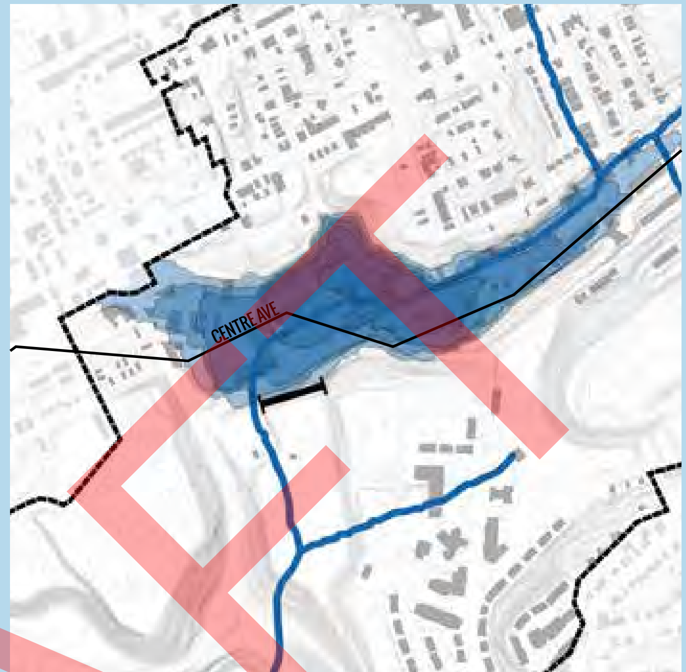
PRIORITY PROJECT
CENTRE AVENUE BASIN

During the 1950s, many of Pittsburgh's undeveloped hilltops were leveled to make way for affordable housing. The hilltop leveling process for the construction of Addison Terrace and Terrace village filled Soho Valley to create the Kennard Playground. This effectively created an earthen dam, trapping a 42 foot deep potential reservoir on Centre Avenue that is kept dry by the combined sewer pipe running south. Because of this obstacle, surface conveyance to the Monongahela is not an option for the majority of rainfall within the M19 sewershed. The brick sewer pipe is buried up to 60 feet deep, following the former Soho Street.

Treating this area as a high volume stormwater reservoir is not an option as there are local landmarks and highly trafficked roads. A gas station occupies the lowest point of this virtual lake for several decades and the sewer inlets that keep the basin dry are clearly visible. The case for maintaining our existing infrastructure is clear when you consider that if "Lake Soho" were to exist, it would be 28 acres in size, the largest body of water in Pittsburgh, and second largest body of water in Allegheny County.

This topographic feature has significant impact on the M19 stormwater management strategy. At present, there is only way out for stormwater and sanitary sewage from the majority of the M19 Sewershed. Separation of these flows would require tunneling for a new sanitary main, tunneling for a new stormwater main, or insertion of a dedicated sanitary pipe inside the existing combined pipe. Until then, as much stormwater as possible needs to be captured, detained, and slow released.

The low point of Centre Avenue, at the deepest part of the virtual "Lake Soho", could become the major detention area serving much of M19. A gas station and surrounding vacant parcels could be networked together as a public stormwater greenspace at the heart of the hill district, forming a new civic center that acts as an anchor to redevelopment further down Centre Avenue.



VIRTUAL "LAKE SOHO" ON CENTRE AVE

QUNLI STORMWATER PARK, HAERBIN CITY, CHINA
Source: Turenscape


DIY STORE
DIY

PRIORITY SITES

SOHO RUN VALLEY

Today's Soho Run valley is very different from what was there 150 years ago. Rainwater has not flowed over the surface of the valley since diversion of the Run into the Soho Street sewer main in the early 1900s. Following hilltop leveling in the 1950s, the valley was filled and regraded, erasing all evidence of natural stormwater flows. A series of Green Infrastructure projects could reclaim some of the stormwater management potential inherent in today's manmade topography.

MLK Park, a former ballfield and now urban agriculture site, could detain stormwater from the slopes immediately surrounding it and the road right-of-way for mid-slope storage. Capacity should be modeled for slope stability.

Key to any and all Green Infrastructure improvements in the Soho Run Valley is the Uptown Portal Park. This site, between Fifth, Forbes, and the Birmingham Bridge aggregates stormwater flows from all sides and reconciles challenging changes in grade for both cyclists and pedestrians.

In Uptown, bands of mid-block greenspaces could provide tiered detention basins through the neighborhood while providing improved mid-block connectivity. In addition to acting as a distributed detention network for stormwater, distributed parklets make the neighborhood more walkable and offer a unique type of development for Uptown's EcoInnovation District.

Green alleys could provide stormwater conveyance to the stormwater detention parks and could serve as an off street route for cyclists and pedestrians.

Conversion of Brady Street to a stormwater conveyance park could allow stormwater to slowly make its way down to the Monongahela through a series of interconnected tree pits and detention basins and solve pedestrian and bike connectivity issues. A project that connects people and water to the river would benefit both Uptown and the Hill. The solution needs to navigate under the nine bridges and on ramps carrying thirteen E-W lanes and six N-S lanes of traffic and will not be an easy solution but could be a dramatic public space that providing access to the E-W Jail Trail Bike-way, Pittsburgh Technology Center, Almono in Hazelwood, and ultimately, Washington, DC via the Great Allegheny Passage Trail.

Restoration of riparian ecology at the base of Soho Run could provide treatment to improve water quality before a naturalized day-lit outflow to the Monongahela.

CW CONSTRUCTED WETLANDS

Tiered wetlands, separated by weirs and check dams, would restore the valley's riparian ecology while slowly treating stormwater flows before they enter the river. Ecological restoration of hillsides will help establish native communities.

IS IMPROVED STREETS

Water could be captured from the right-of-way using an enhanced gutter profile. It is slowed at mid block and end of block flow-through tree bumpouts. Water is captured and conveyed below the roadway when it crosses a Complete Street.

GA GREEN ALLEYS

Green Alleys can be used to capture water from the right-of-way and from adjacent structures and surfaces. Water is captured in the center of the right-of-way and conveyed subsurface in a gravel filled under-drain. Water is captured and conveyed to the nearest Improved or Complete Street

PFS PAY-FOR-SUCCESS

Green Infrastructure should be placed wherever opportunities exist. Bioswales and small wetlands offer high value landscaping in addition to stormwater performance. Creative financing models can support additional private investments.

CS COMPLETE STREETS

Major thoroughfares such as Tustin St have high demand for safety and aesthetic improvements despite low demand for stormwater improvements. Complete streets should be considered complimentary to the Improved Streets, Green Boulevards, and Green Alleys.

UA URBAN AGRICULTURE

Underutilized greenspaces such as MLK Field are being reimagined as urban agriculture sites. This promotes health and wellness and could use diverted rainwater for irrigation.


CW
IS
CS
PFS
GA
UA

PRIORITY PROJECT: URBAN AGRICULTURE

MLK PARK

MLK Park, a former ballfield and now urban agriculture site, could detain stormwater from the adjacent slopes while providing the potential for passive water harvesting. Urban agriculture promotes health and wellness for residents in the surrounding communities.

SUNFLOWERS IN MLK PARK
Source: Grow Pittsburgh

PRIVATE DEVELOPMENT

UPTOWN MIDBLOCK PARKLETS

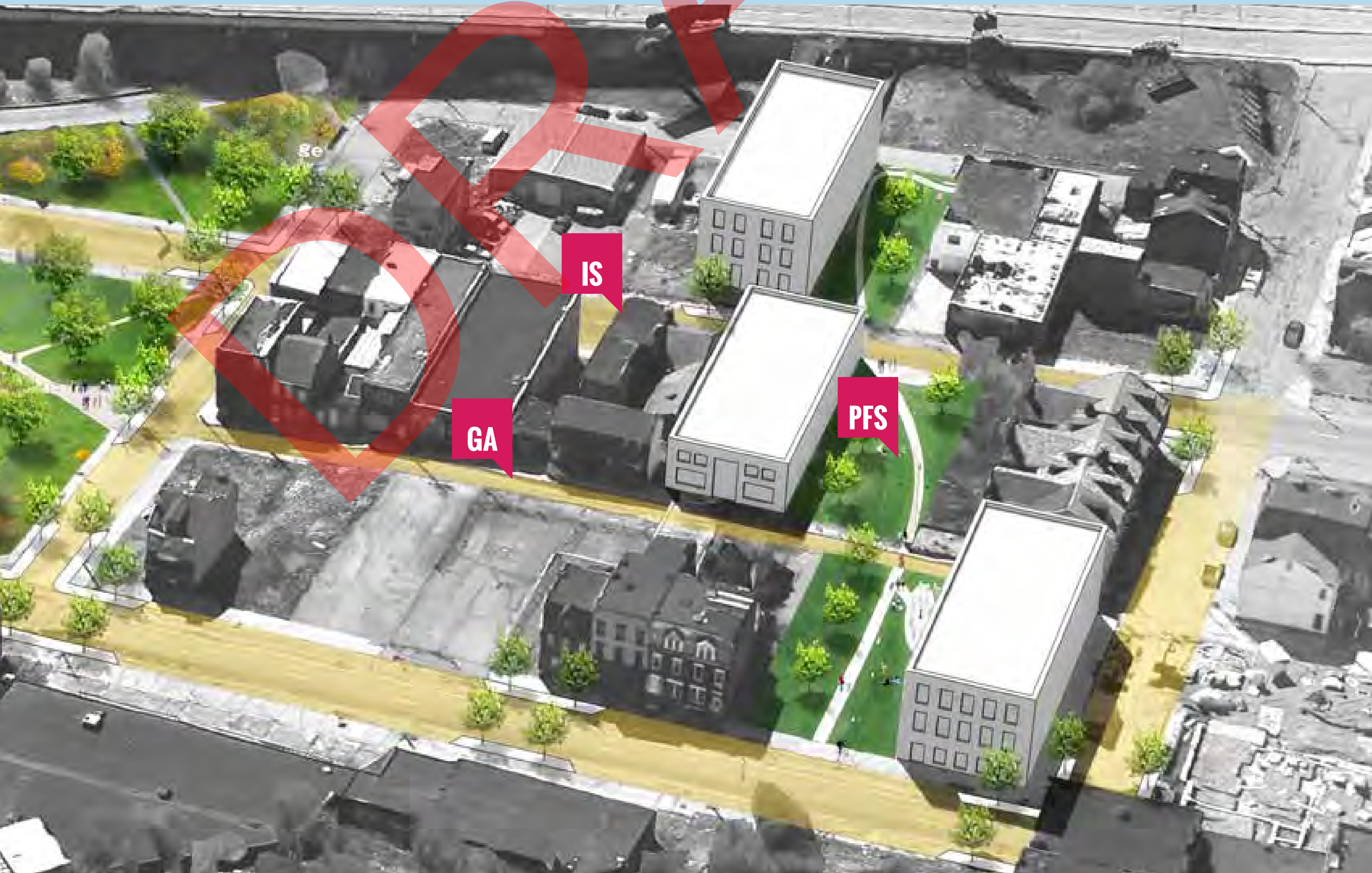
Bands of mid-block greenspaces could provide tiered detention basins through the neighborhood while providing improved mid-block connectivity. Using the pay-for-success model, PWSA could work with developers to incentivize creative solutions that manage stormwater and improve the public realm.

In addition to acting as a distributed stormwater detention network, distributed parkland makes the neighborhood more walkable in support of higher density development in Uptown. Green alleys could provide stormwater conveyance to proposed stormwater detention parks. In addition they could serve as an off street route for cyclists and pedestrians.

WESTERN HARBOR, MALMO, SWEDEN
Source: nerdyplanner.blogspot.com

CW	CONSTRUCTED WETLANDS
UA	URBAN AGRICULTURE
IS	IMPROVED STREETS
GA	GREEN ALLEYS
PFS	PAY-FOR-SUCCESS
CS	COMPLETE STREETS


UA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PRIORITY PROJECT: OPEN SPACE & PARK
UPTOWN PORTAL PARK

Nestled between Fifth Avenue, Forbes Avenue, and the Birmingham Bridge are a series of parcels that could become the Uptown Portal Park. At this point, stormwater from Uptown, Kirkpatrick Street, MLK Park, and Fifth Avenue converge and could be detained. Cyclists and Pedestrians lack an accessible route across the site and improving the site is key to establishing Uptown as a walkable, bikeable neighborhood. Visible from the most highly trafficked automobile and transit corridor in the city, the site is an opportunity to redefine a key portal between Uptown, the Hill District, Oakland, Downtown, South Side, Pittsburgh Technology Center, and the in progress ALMONO development.

HILGARD GARDEN, BERKELEY, CA
Source: Joe Fletcher Photography, Mary Barensfeld Architecture

PRIORITY PROJECT: OPEN SPACE & PARK
SOHO RUN @ THE MON RIVER

Restoration of riparian ecology at the base of Soho Run could provide the final treatment for stormwater, improving water quality before entering a naturalized day-lit outflow to the Monongahela. Reclamation of this underutilized site along the Mon could add value to current development at the Pittsburgh Technology Center and the future development of the ALMONO site. It could provide crucial riverfront access to the Uptown community and connects the Jail Trail Bikeway to a potential future trail along the riverfront.

CUMBERLAND PARK, NASHVILLE, TN
Source: Hargreaves Associates

CW	CONSTRUCTED WETLANDS
UA	URBAN AGRICULTURE
IS	IMPROVED STREETS
GA	GREEN ALLEYS
PFS	PAY-FOR-SUCCESS
CS	COMPLETE STREETS


CS
GA
IS


CW

M19 INVENTORY

SEPARATED SITES

Newly reconstructed developments on the Terrace Village hilltops between the Middle Hill District and Uptown, partnerships between developers and the Housing Authority, feature a separated sewer system. Stormwater is captured and conveyed from the developments in pipes that run parallel to the sanitary sewer pipes. The developments also likely include stormwater detention infrastructure designed to meet the requirements of Pittsburgh's Municipal Code.

A separated sewer system is a step in the right direction in a city that is almost entirely combined. However, once the separated sewer system leaves the development, it combines back into a combined sewer pipe. To truly reap the benefits from existing separated sewer investments upslope, investments could be made to find a green conveyance strategy that uses rain gardens, bioswales, and detention infrastructure.

ADDISON TERRACE PHASE ONE
Source: KBK Enterprises

OAK HILL APARTMENTS
Source: Graves Design Group

ADDISON TERRACE PHASE ONE
ADDISON TERRACE PHASE TWO
OAK HILL APARTMENTS
DRAFT

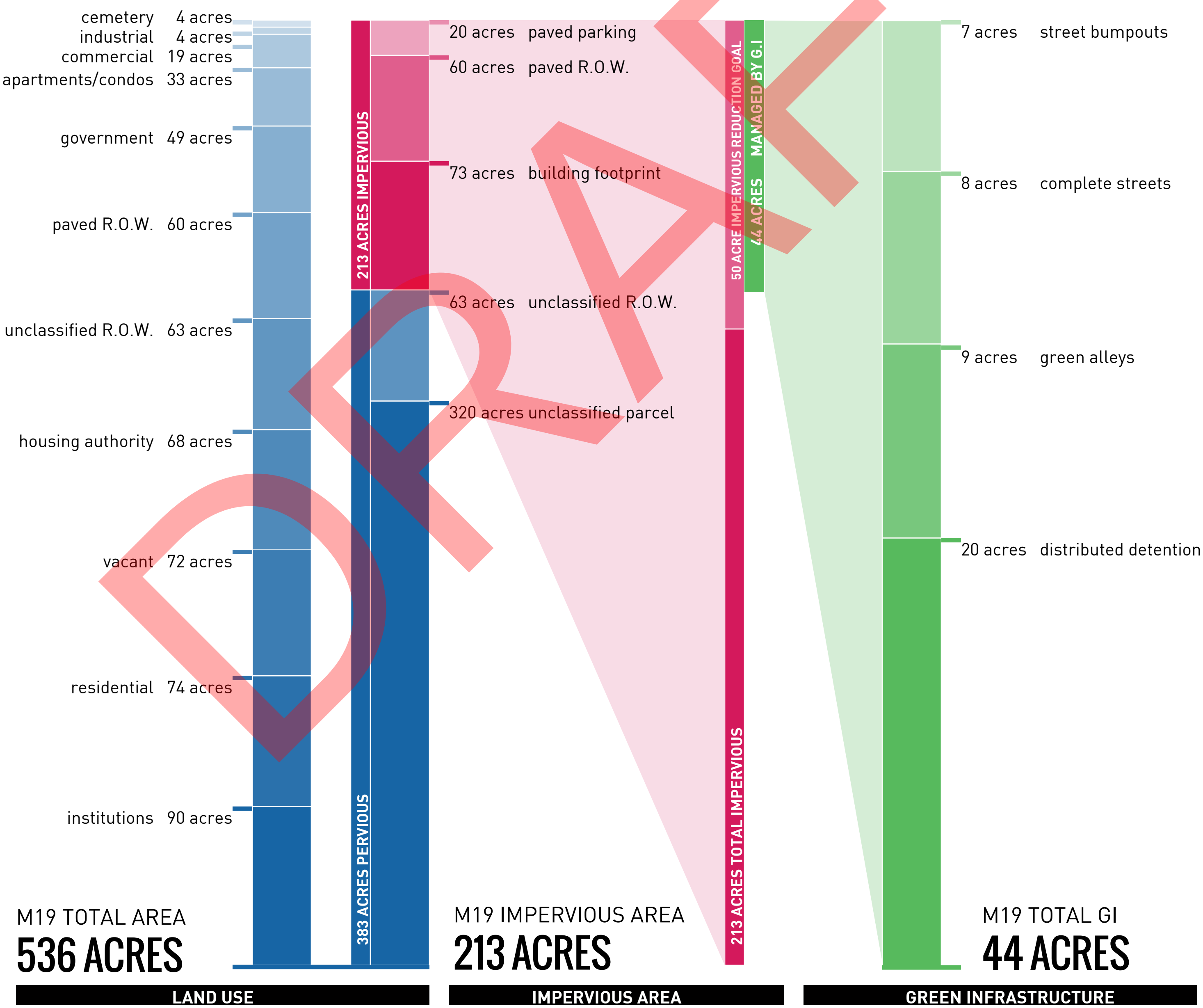
M19 BY THE NUMBERS

25.2% OF THE SHED IS VACANT OR UNCLASSIFIED

28.5% OF THE SHED IS IMPERVIOUS

INSTITUTIONS IS THE MOST COMMON LAND USE (PUBLIC & PRIVATE)

38.6% OF THE LAND IS OWNED BY GOVERNMENT OR INSTITUTIONS



COMMUNITY STAKEHOLDERS

Many of the projects are at a significant scale or require cross-agency coordination. The following is a list of stakeholders identified in the preliminary process.

City-Wide

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

ALCOSAN	Tim Prevost
City Planning	Justin Miller
Council District 6	R. Daniel Lavelle
Public Works	Mike Gable
PWSA	staff
URA	staff

SHED SCALE

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

Hill CDC	Marimba Milliones
Hill District Consensus Group	
Hill House	Cheryl Hall-Russell
Milliones University Prep	principal
PGH Green Innovators	Tom Bartnik
One Soho	
Uptown Ecoinnovation District	Justin Miller, City Planning
Uptown Partners	Jeanne McNutt
Start Uptown	Dale McNutt

PROJECTS

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

Kennard Playground	
MLK Park and Garden	TreePGH, GrowPGH, Landslide Farm
Churches	
Carnegie Library Centre Ave	CLP
Action Housing	
Developers	KBK, MBS
Addison Terrace	Housing Authority
Bedford Dwellings	Housing Authority
Oak Hill	Housing Authority
University of Pittsburgh	
Uptown to River Conveyance	PennDOT, Public Works
VA Hospital	

M19 SOLUTIONS

NETWORK SCENARIO

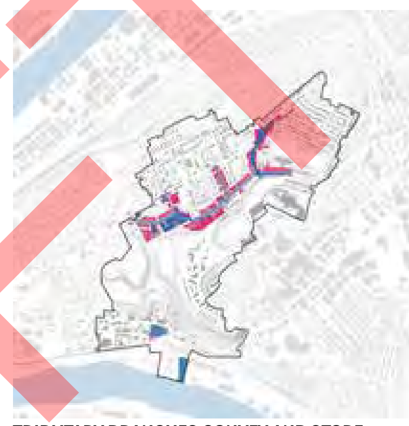
Green Infrastructure works by restoring, mimicking, and supercharging natural hydrologic processes. It needs to be deployed as a network and can reconcile historical flows with modern land use. We studied the historical development of the City of Pittsburgh, and the impact of development on the city's topography.

Hydrologic networks rely on a hierarchy of parts with differentiated functioning. Often there are critical pieces of Green Infrastructure that need to be installed and scaled to anticipate further expansion of the Green Infrastructure network.

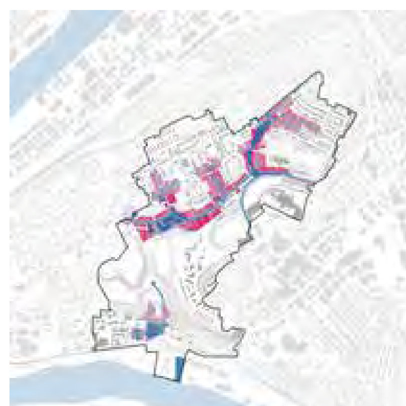
We identified "opportunity sites" throughout each priority sewershed that could both fulfill local stormwater infrastructure needs and support healthy communities and neighborhoods. The result is a hybridization between natural and manmade resource flow controls.

In M19 Soho Run, the storage infrastructure at the Centre Ave low point and at the Uptown Portal site could allow for street improvements throughout the shed. As street improvements and detention sites come online, the network can be further expanded to connect to remaining target parcels.

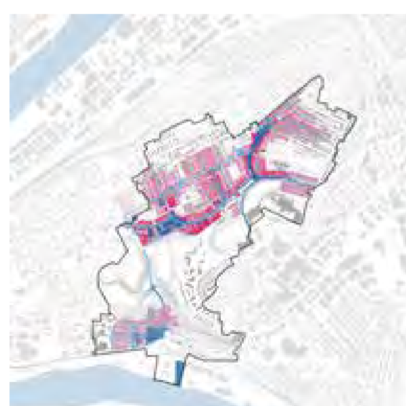
MAIN VALLEY STORAGE



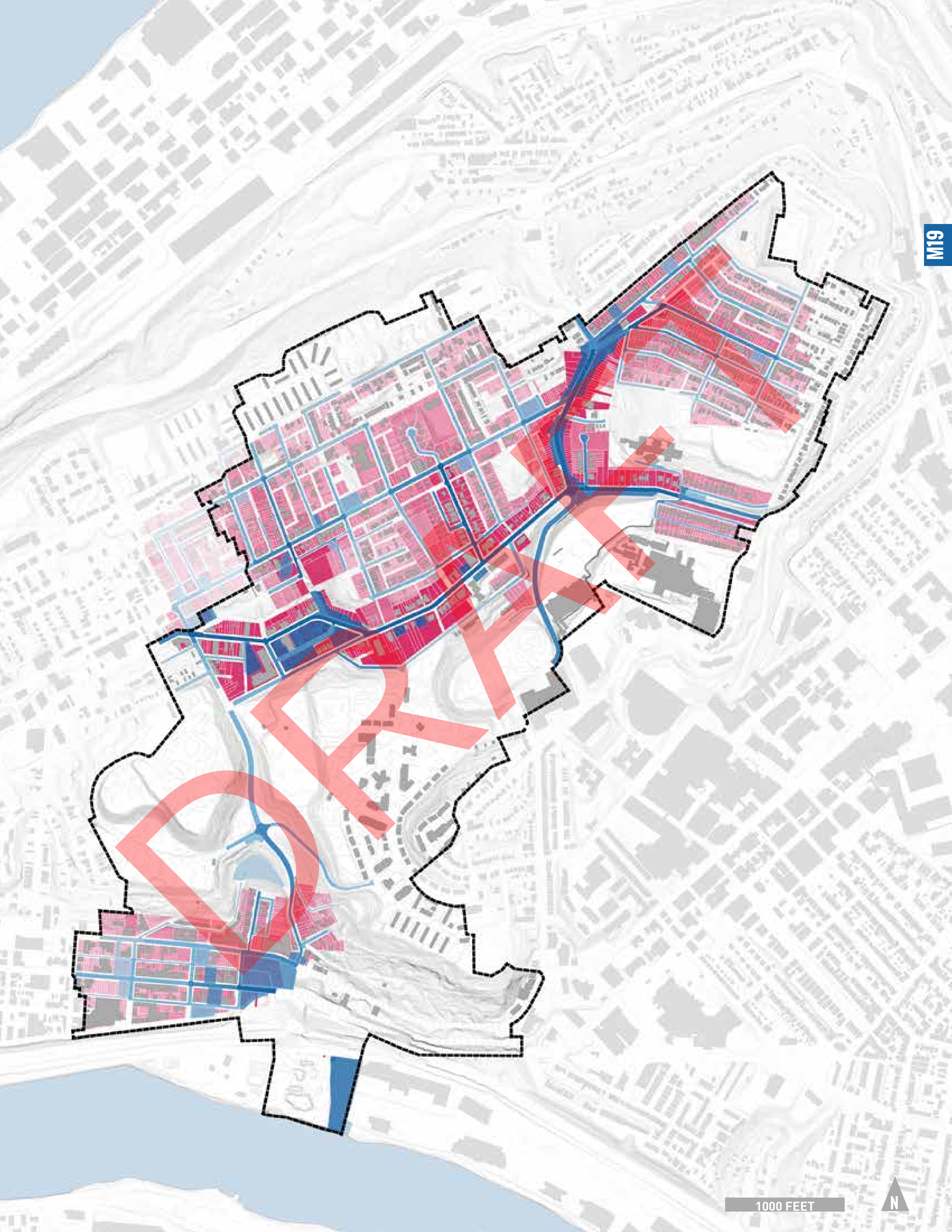
TRIBUTARY BRANCHES CONVEY AND STORE



FURTHER NETWORK EXPANSION



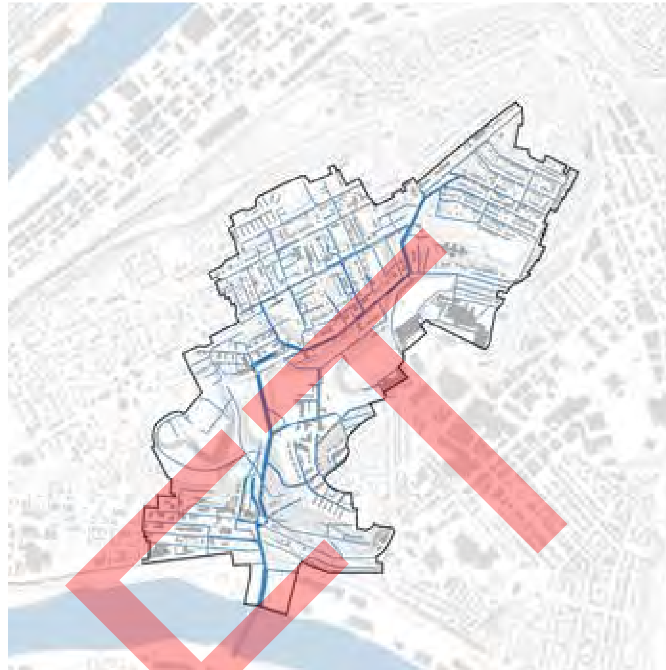
FURTHER NETWORK EXPANSION


M19
DRAFT
1000 FEET
N

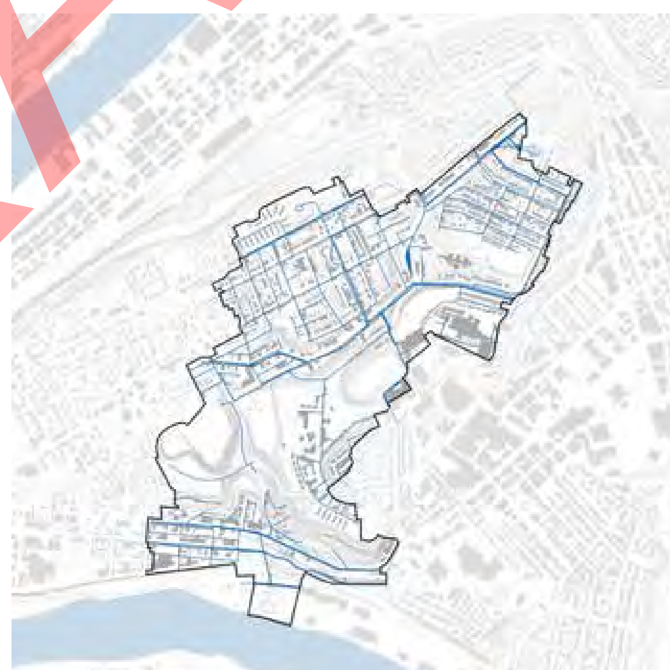
HYDROLOGIC ANALYSES

Hill leveling efforts for the creation of Addison Terrace and Terrace Village lead to the creation of a “Virtual Lake”, functionally dividing the Soho Run sewershed into two distinct subsheds: the Middle-Upper Hill District and Uptown.

Today’s sewer mains follow hydrologic flow lines very closely. What was Soho Run now flows more than 60 feet below the surface of today’s Kennard Playground in a hand built brick sewer main. This approach to stormwater management lacks the riparian ecology needed to absorb, detain, and slow stormwater.



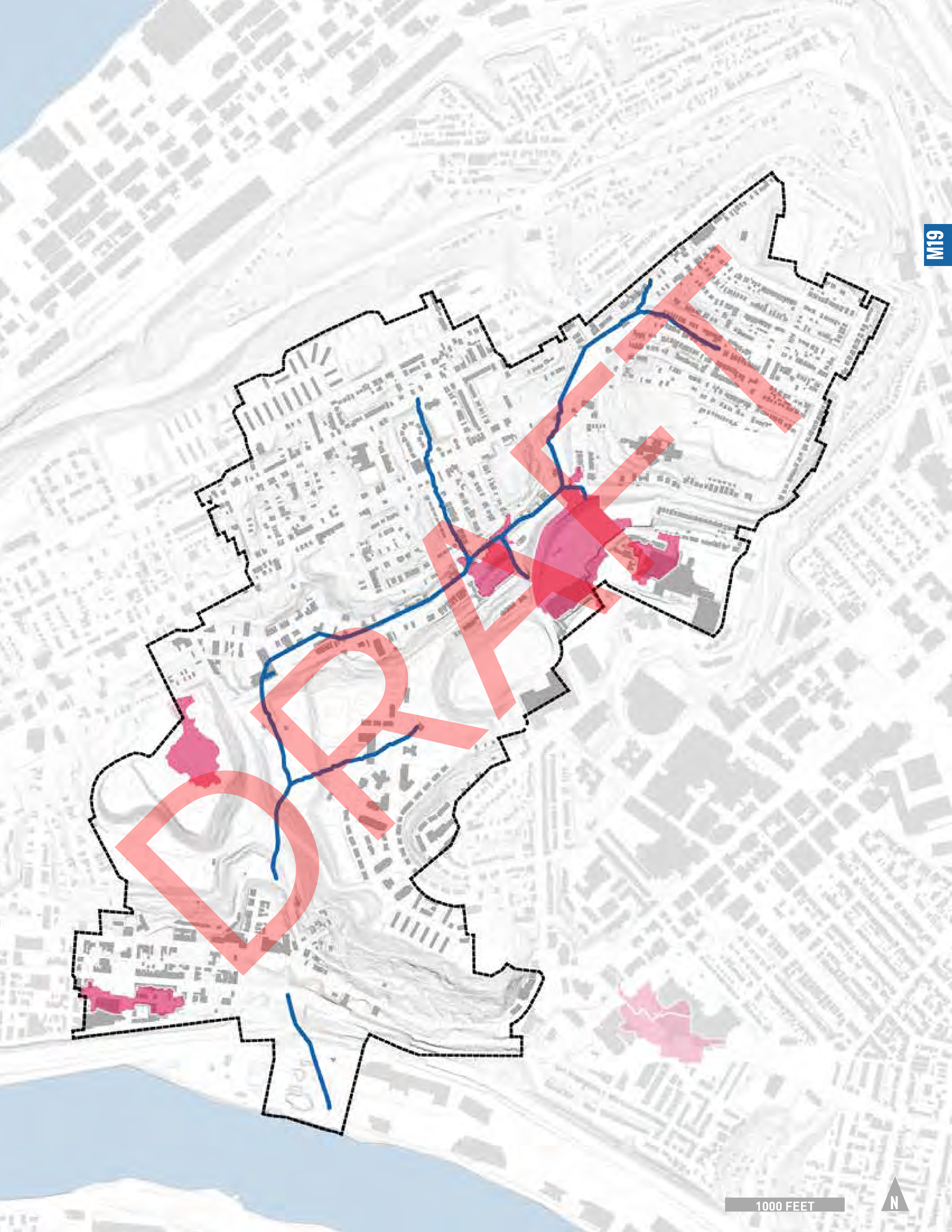
SEWER MAINS



WATER MAINS

Mott Macdonald Target Areas

Historic Streams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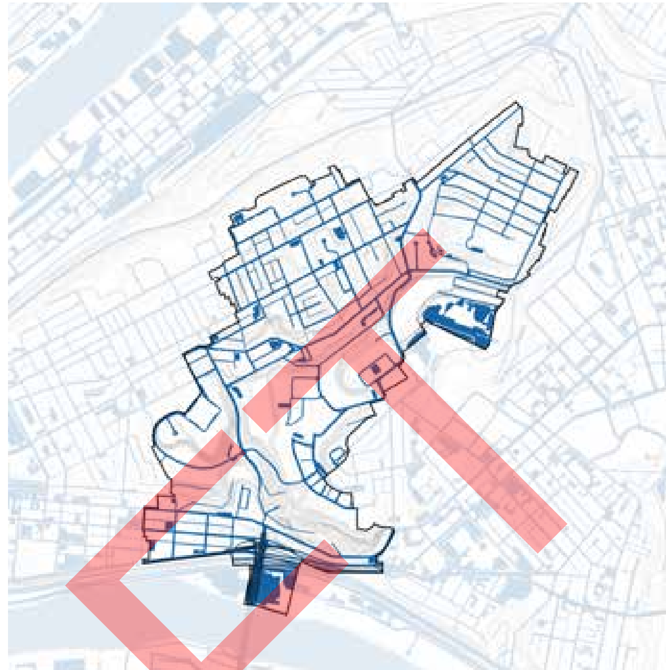
SHED OVERVIEW

Understanding the unique urban fabric of a sewershed allows PWSA to identify potential synergies between infrastructure and communities. Better streets, better parks, better greenspaces, better hillsides, better homes, and better developments can all have positive ripple effects for people, planet, place, and performance.

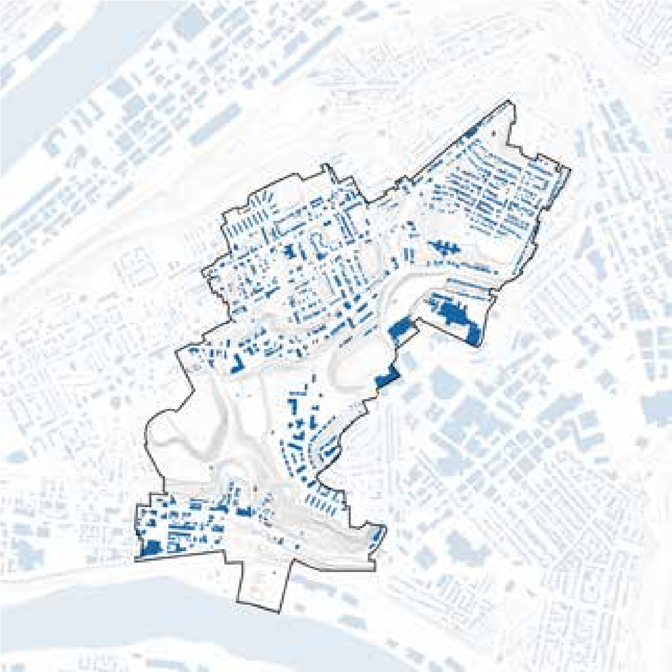


STREETS + PARKING LOTS

M19's street arrangement is highly compartmentalized. Middle Hill and Upper Hill are distinctly separated by Herron Avenue. Addison Terrace and Oak Hill Developments are separated by hillsides. Uptown is connected only by Kirkpatrick St.

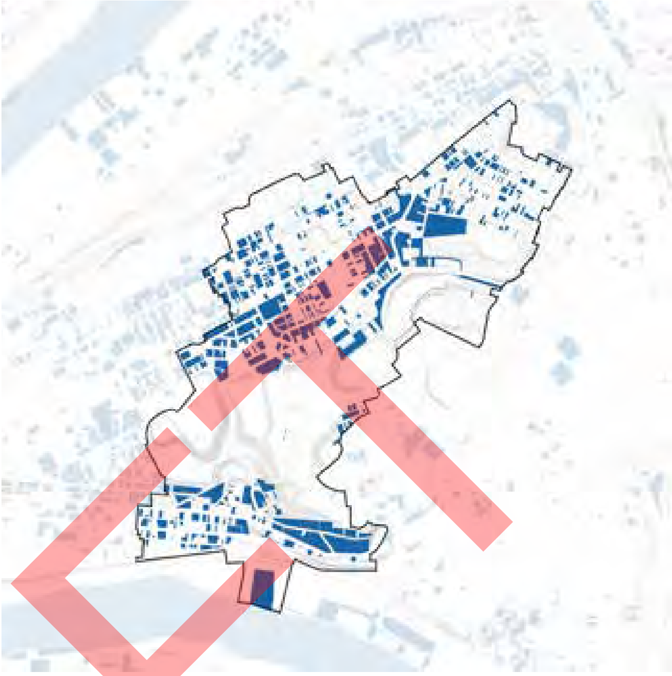
GREENSPACE + HILLSIDES

Greenspace at Kennard Playground and steep hillsides establish distinct neighborhood boundaries between the constituent communities of M19.



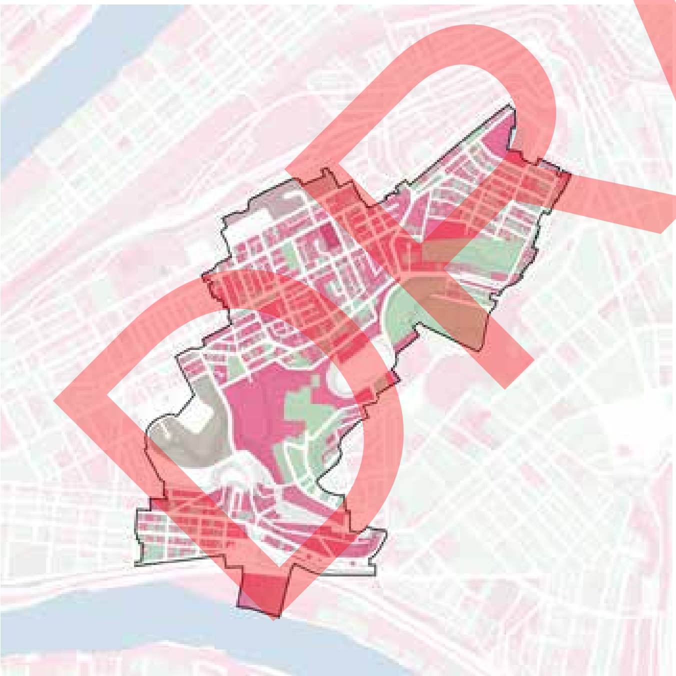
BUILDINGS

The M19 sewershed has a high vacancy rate and thus fewer impervious areas. The VA Hospital and the newer Addison Terrace and Oak Hill Developments are the most impervious areas in the shed.



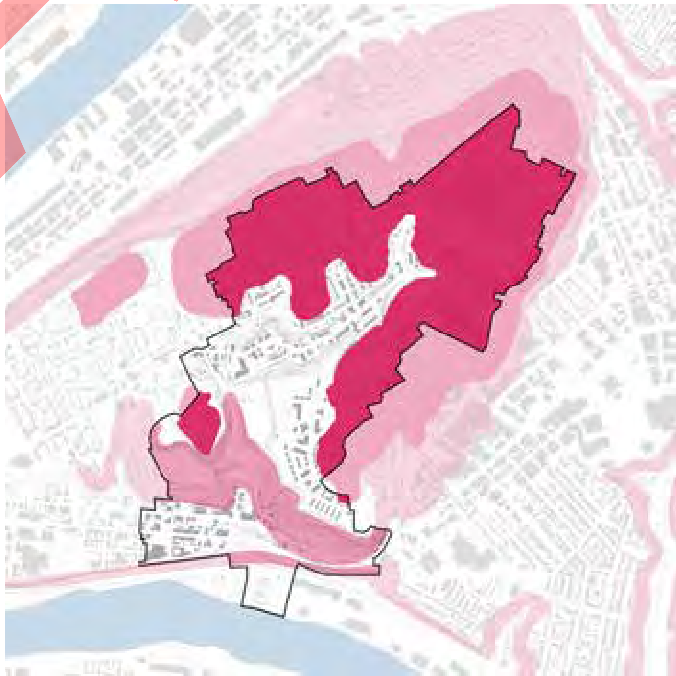
VACANT PARCELS

Dramatic population decline and mid-century urban renewal have lead to an abundance of vacant parcels throughout the M19 sewershed. This will likely change as the neighborhood is redeveloped and a GI plan should acknowledge the stormwater implications of future development.



RELATIVE PROPERTY VALUES

The Upper Hill and Uptown have rising property values, while the Middle Hill remains economically depressed. Major development by the Housing Authority, University of Pittsburgh, and Pittsburgh VA are of high value.



UNDERMINED + LANDSLIDE PRONE

There are steep slopes around Kirkpatrick Street and the Housing Authority's Addison Terrace and Oak Hill Developments. Much of the Middle and Upper Hill Districts are undermined, making these sites more challenging to develop.

M19 INVENTORY

URBAN CONTEXT

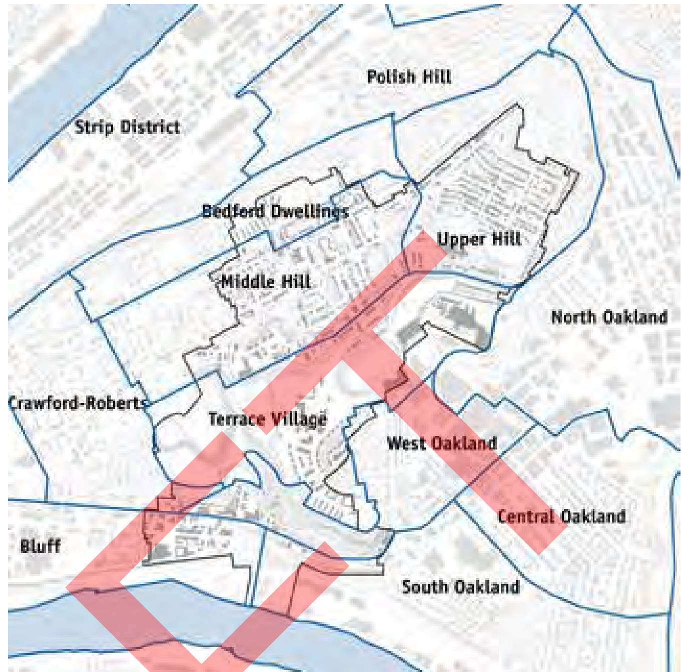
Located at the heart of Pittsburgh's East End, M19 is surrounded on all sides by culturally and economically diverse neighborhoods. Downtown is to the west. Oakland with its hospitals and universities is to the east. Polish Hill, the Strip District, Lawrenceville, and Bloomfield are to the north. South Side is just over the Birmingham Bridge to the south.

Centre Avenue forms the civic spine of the Hill District and even after decades of disinvestment it remains home to the churches, schools, and neighborhood businesses that are helping the community to rebuild. The Hill District is distinctly separated from Uptown by Housing Authority developments in Terrace Village. Uptown is home to the city's most highly traveled thoroughfares that connect the East End to Downtown and beyond.

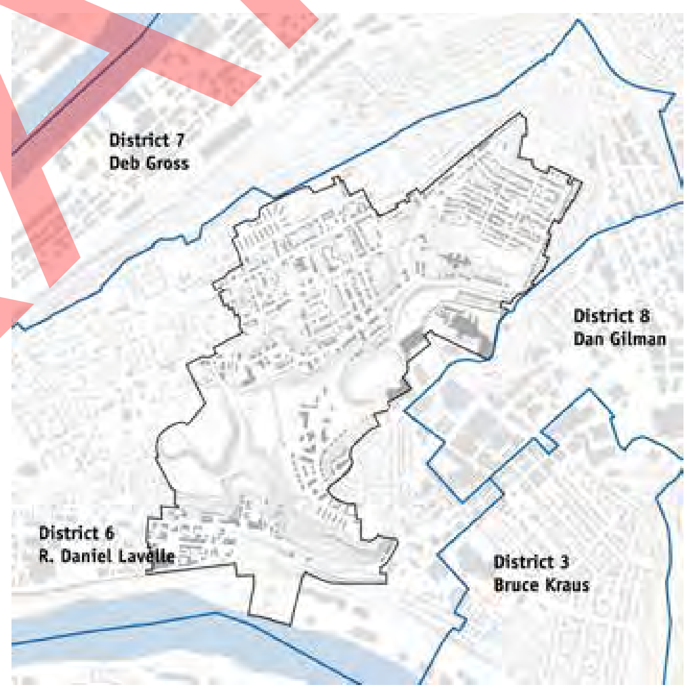
Neighborhoods
Bedford Dwellings
Bluff [Uptown Ecoinnovation District]
Middle Hill District
South Oakland [Pittsburgh Technology Center]
Terrace Village [Addison Terrace, Oak Hill]
Upper Hill District

Council District 6
R. Daniel Lavelle

Community Groups
Hill Community Development Corporation
Hill District Consensus Group
Hill House Association
One Soho
Uptown EcoInnovation District
Uptown Partners



NEIGHBORHOODS



COUNCIL DISTRICTS

Churches

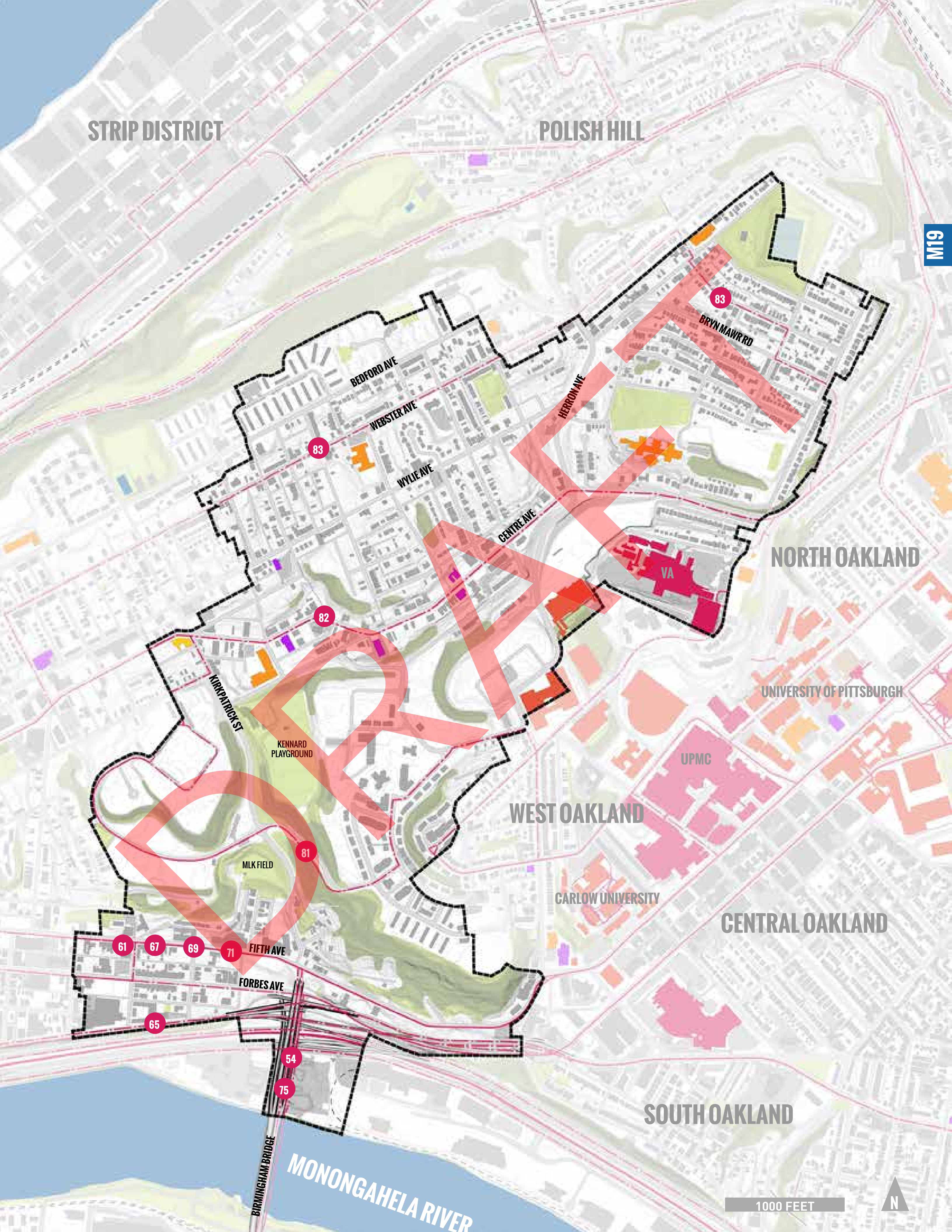
Historic Sites

Forested Areas

Parks

Schools

71A Port Authority Bus Routes


STRIP DISTRICT
POLISH HILL
M19
BEDFORD AVE
WEBSTER AVE
WYLIE AVE
HERRON AVE
BRYN MAWR RD
CENTRE AVE
VA
NORTH OAKLAND
UNIVERSITY OF PITTSBURGH
KIRKPATRICK ST
KENNARD PLAYGROUND
UPMC
WEST OAKLAND
MLK FIELD
CARLOW UNIVERSITY
CENTRAL OAKLAND
FIFTH AVE
FORBES AVE
SOUTH OAKLAND
BIRMINGHAM BRIDGE
MONONGAHELA RIVER
1000 FEET
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83
83
82
81
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DRAFT

URBAN CONTEXT THE MIDDLE HILL

Centre Avenue forms the civic spine of the Hill District and even after decades of disinvestment it remains home to the churches, schools, and neighborhood businesses that are helping the community to rebuild. The Middle Hill has seen a steady decline following its effective disconnection from downtown by the construction of the Civic Arena in the early 1960s. This lead to blight and the current high vacancy rates.

With leadership from local community groups, the neighborhood is rebuilding. While it is not currently identified as a stormwater target area, more impervious surfaces will soon be introduced by redevelopment. A Green Infrastructure network could be established now in anticipation of the community's future stormwater management needs.

Large scale redevelopment of former Housing Authority sites are built with separated sewer systems that feed back into the combined system, essentially losing the benefit of a separated system. These systems should be examined to be taken offline where possible.

CARNEGIE LIBRARY @ HILL DISTRICT
Source: Soracco Photography

CENTRE AVE + KIRKPATRICK STREET
Source: Microsoft Here Maps

Churches

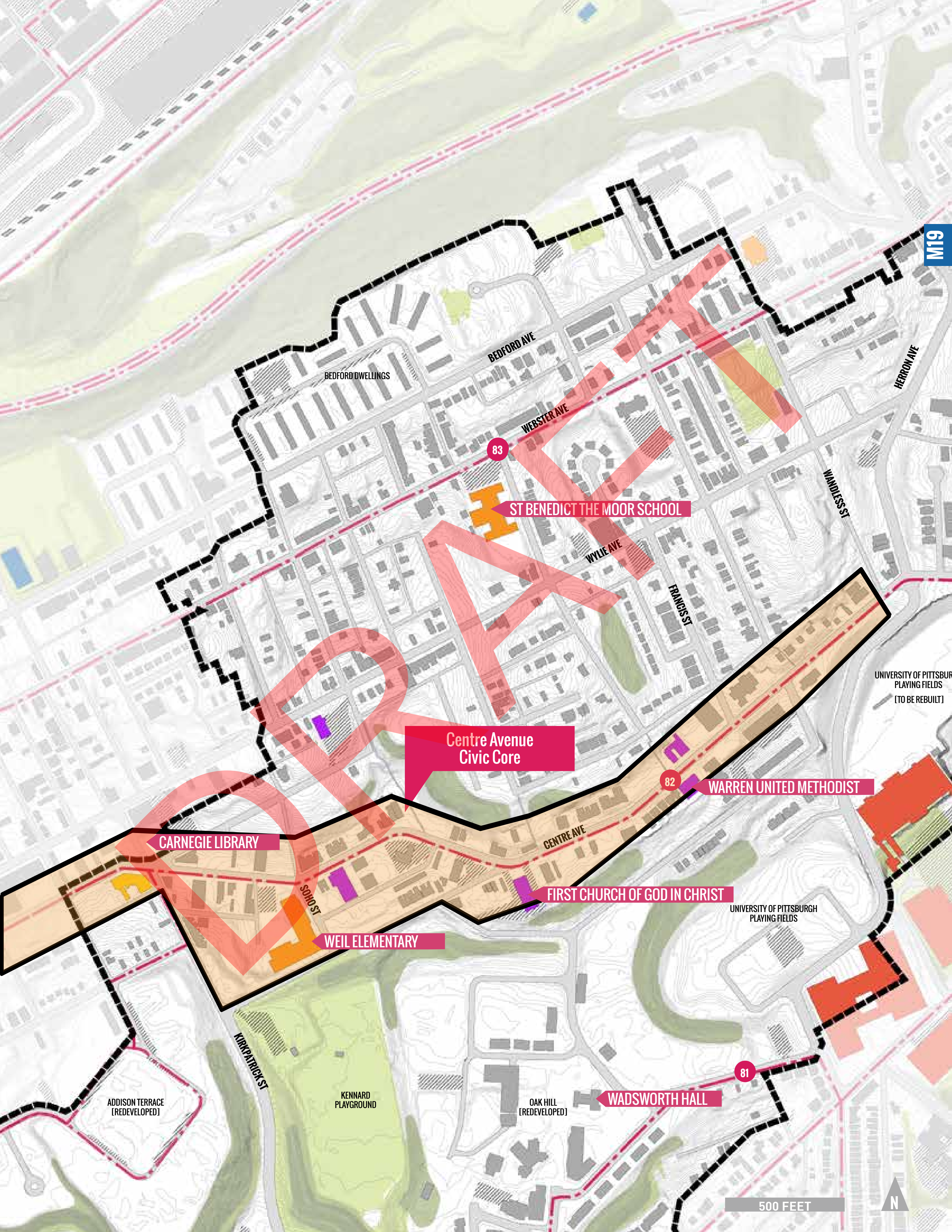
Historic Sites

Forested Areas

Parks

Schools

71A Port Authority Bus Routes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M19
BEDFORD DWELLINGS
BEDFORD AVE
WEBSTER AVE
HERRON AVE
83
ST BENEDICT THE MOOR SCHOOL
WYLIE AVE
WANDLESS ST
FRANCIS ST
UNIVERSITY OF PITTSBUR
PLAYING FIELDS
[TO BE REBUILT]
Centre Avenue
Civic Core
82
WARREN UNITED METHODIST
CARNEGIE LIBRARY
CENTRE AVE
SOHO ST
FIRST CHURCH OF GOD IN CHRIST
UNIVERSITY OF PITTSBURGH
PLAYING FIELDS
WEIL ELEMENTARY
KIRKPATRICK ST
81
ADDISON TERRACE
[REDEVELOPED]
KENNARD
PLAYGROUND
OAK HILL
[REDEVELOPED]
WADSWORTH HALL
500 FEET
N

M19 INVENTORY

URBAN CONTEXT SOHO VALLEY

Uptown is home to the city's most highly traveled thoroughfares that connect the East End to Downtown and beyond. Fifth and Forbes Avenues carry heavy traffic through Uptown and for decades this traffic has discouraged residential growth. Today these corridors are valuable for the transit access they provide, an economic force that will be leveraged by the new Uptown EcoInnovation District. Vacant parcels are quickly being acquired by developers and the neighborhood is preparing itself for growth.

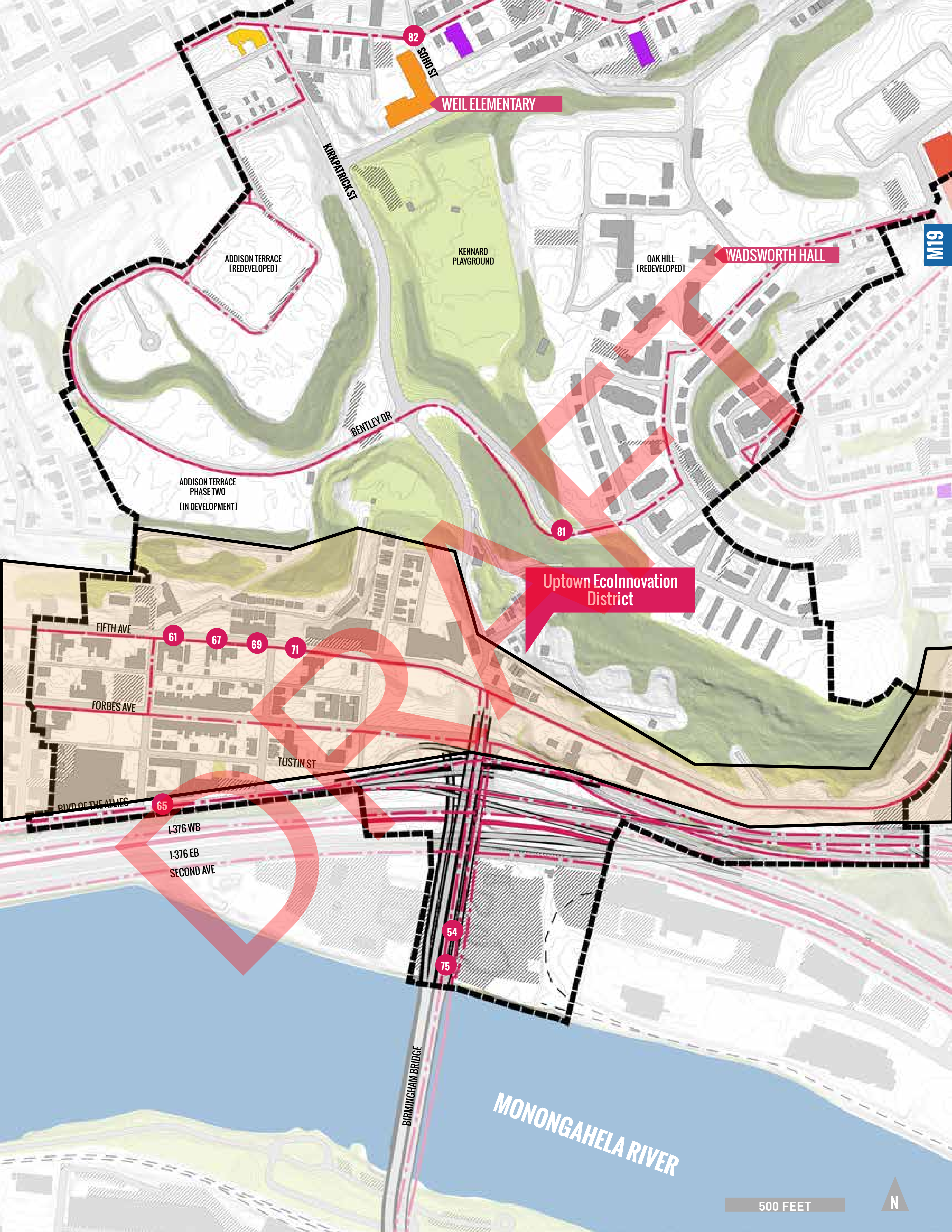
The Uptown EcoInnovation District establishes Uptown as a zone for targeted improvements to the urban fabric and environmentally sensitive redevelopment. Projects designed and built in this district could set a precedent for the rest of the city to follow.

While connections to Downtown and Oakland are good for automobiles and transit, they are very poor for pedestrians and cyclists. Street improvements that incorporate Green Infrastructure should be leveraged to improve walkability and bikeability throughout Uptown and its neighboring communities.

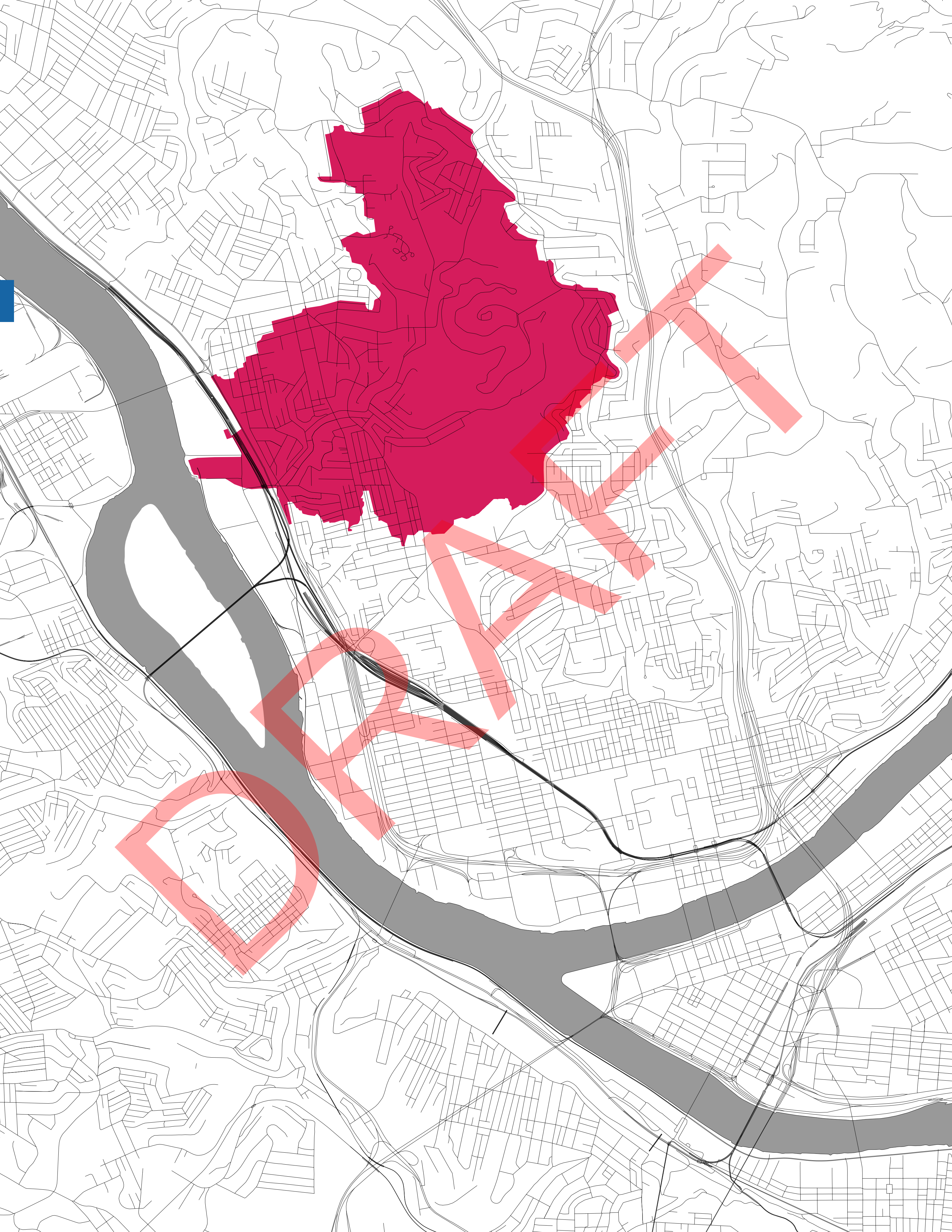
FORBES AVENUE ROWHOUSES
Source: Joseph Wingenfeld

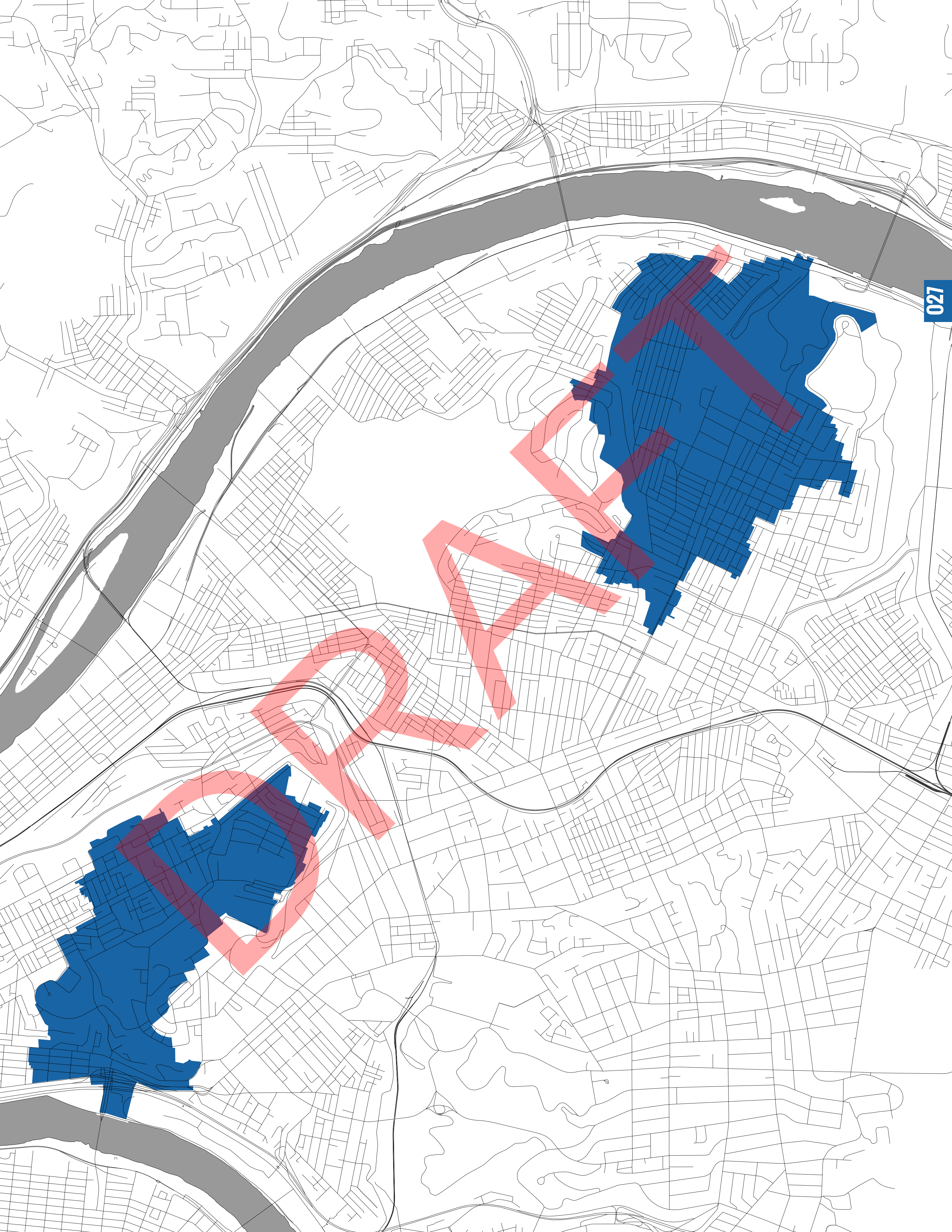
"WELCOME TO UPTOWN"
Source: Simon Sculpture

- Churches
- Historic Sites
- Forested Areas
- Parks
- Schools
- 71A Port Authority Bus Routes



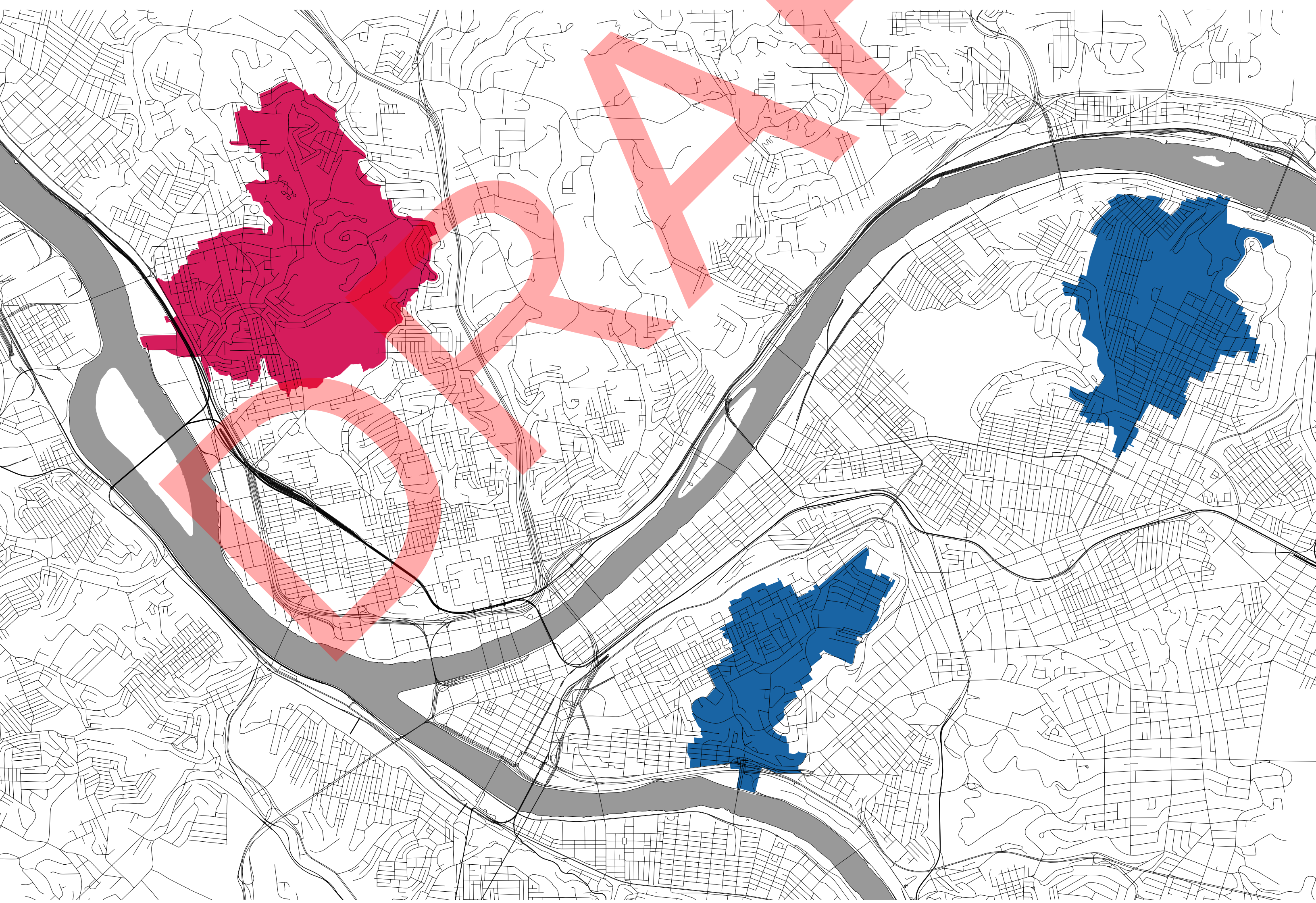
82
SOHO ST
WEIL ELEMENTARY
KIRKPATRICK ST
KENNARD PLAYGROUND
ADDISON TERRACE [REDEVELOPED]
OAK HILL [REDEVELOPED]
WADSWORTH HALL
M19
BENTLEY DR
ADDISON TERRACE PHASE TWO [IN DEVELOPMENT]
81
Uptown EcoInnovation District
FIFTH AVE
61
67
69
71
FORBES AVE
TUSTIN ST
BLVD OF THE ALLIES
65
I-376 WB
I-376 EB
SECOND AVE
54
75
BIRMINGHAM BRIDGE
MONONGAHELA RIVER
500 FEET
N
DRAFT





027 WOODS RUN

The 027 Sewershed is located in the North Western corner of the city. The sewershed is closely aligned to the watershed for the now underground Woods Run which was tributary to the Ohio River until the construction of the combined sewer network. The highest points in the shed are in Ross Township, Perry North, and Perry South and the many branches of Woods Run flow through Riverview Park and along Woods Run Avenue before combining with flows from Brighton Heights and Marshall-Shadeland. Woods Run then flows through a highly industrialized area and its former outfall to the Ohio was just upstream of today's ALCOSAN Treatment Plant. Developed as a Streetcar Suburb, the Northside neighborhoods have seen a slow decline since the discontinuation of Pittsburgh's streetcar network. While no major development is expected, new residents are taking advantage of the area's proximity to Riverview Park.



OPPOSITE PAGE. A view of Woods Run Avenue below Davis Avenue Bridge, looking north.. c.1908

SHED SUMMARY

WOODS RUN VILLAGE

The confluence of four major tributary branches to Woods Run and the crossroads of Brighton Road and Woods Run Avenue form the civic center to one of Pittsburgh's most authentic valley communities.

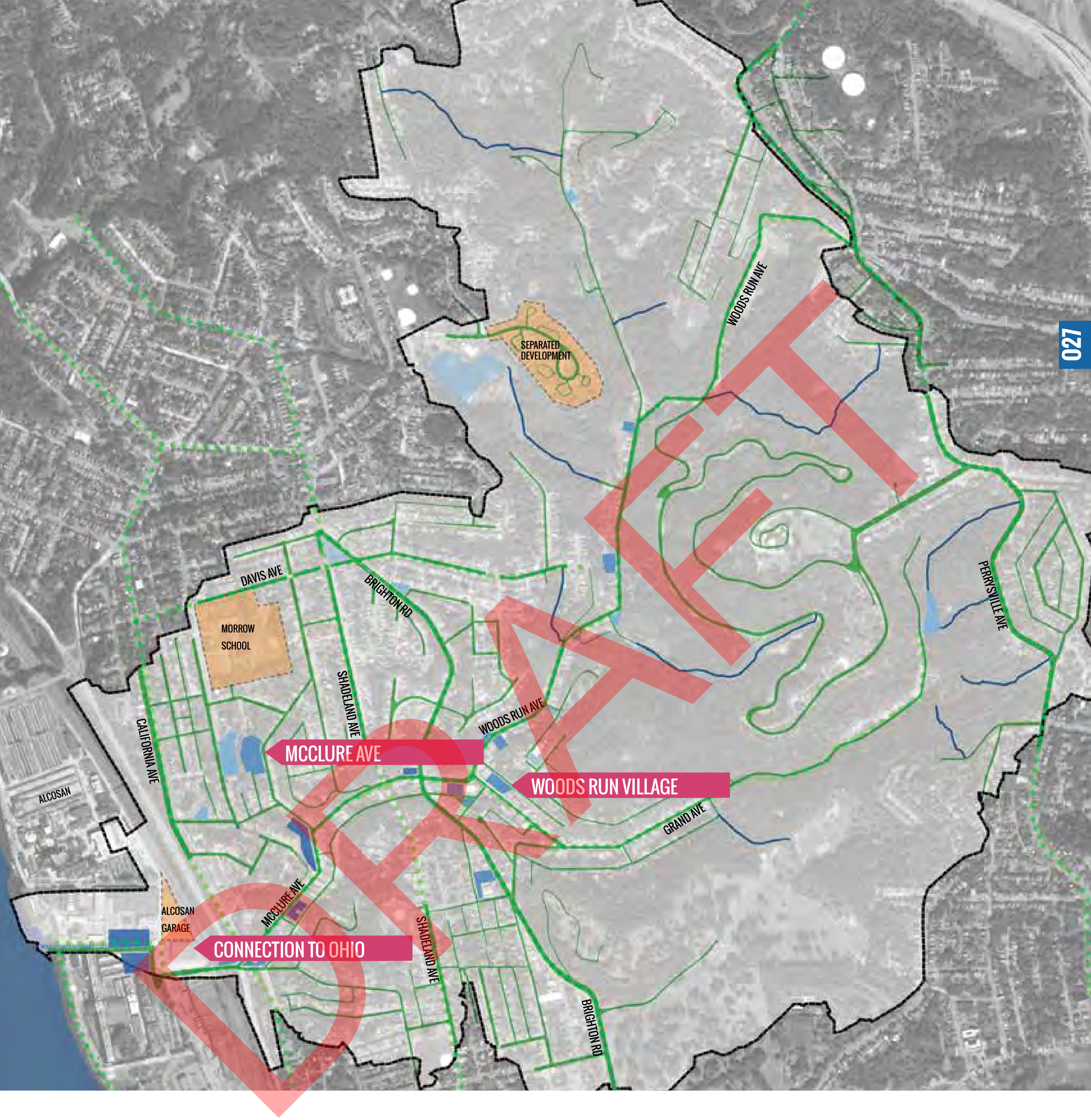
A recently renovated branch of the Carnegie Library, a firehouse, and a playground are complimented by a small neighborhood commercial district. Improvements to the streetscape, alleys, and greenspaces could catalyze civic engagement and add value to the nearby residential areas.

MCCLURE AVE

URA owned parcels at a key low point on McClure Avenue could detain stormwater flows from the surrounding Brighton Heights neighborhood as well as from the nearby Morrow School. The site, which is bisected by a 15" sewer main and is the former site of St. John's General Hospital, could provide both stormwater performance and naturalized passive recreation areas.

CONNECTION TO OHIO

Highly industrialized since the steel town days, the Ohio Riverfront at Woods Run is almost entirely paved over or otherwise developed. Home to the Western State Penitentiary and ALCOSAN, this area is the uninspired industrial terminus to the Three Rivers Heritage Trail. Green Infrastructure could be used to soften the area's hard-scape while continuing the Three Rivers Heritage Trail inland to Riverview Park.



STREET TYPE 1: COMPLETE STREET
STREET TYPE 2: IMPROVED STREET
STREET TYPE 3: GREEN ALLEY
NET ZERO SITE
DISTRIBUTED STORAGE SITE
MAJOR STORAGE PROJECT SITE
PROJECT

STORMWATER DISTRICT

WOODS RUN VILLAGE

Four tributary branches of Woods Run converge at the core of the Woods Run Valley. Each branch carries with it a major road and the convergence of both rainwater and economic activity demands that investment in green stormwater infrastructure should reinforce the area as a civic center. Key elements such as a library, playground, and fire station are already in place.

Pay-for-Success development opportunities could exist at the intersection of Brighton Road and Woods Run Avenue, reinforcing the intersection as a community focal point and taking advantage of access to transit.

Pedestrian and Bicycle routes through the area could establish a connection from the riverfront bicycle trail to Riverview Park.

Renovation of an existing playground and Library grounds could reinvigorate an already green village center. Vacation of a portion of Lecky Ave adjacent to the library could activate an inaccessible vacant parcel.

CW CONSTRUCTED WETLANDS

Tiered wetlands, separated by weirs and check dams, would restore the valley's riparian ecology while slowly treating stormwater flows before they enter the river. Ecological restoration of hillsides will help establish native communities.

SD SUBSURFACE DETENTION

Improvements to stormwater infrastructure and recreation infrastructure should go hand in hand. Streets convey water to major subsurface structured storage where water can be stored and released in a controlled manner.

IS IMPROVED STREETS

Water could be captured from the right-of-way using an enhanced gutter profile. It is slowed at mid block and end of block flow-through tree bumpouts. Water is captured and conveyed below the roadway when it crosses a Complete Street.

GA GREEN ALLEYS

Green Alleys can be used to capture water from the right-of-way and from adjacent structures and surfaces. Water is captured in the center of the right-of-way and conveyed subsurface in a gravel filled under-drain. Water is captured and conveyed to the nearest Improved or Complete Street

PFS PAY-FOR-SUCCESS

Green Infrastructure should be placed wherever opportunities exist. Bioswales and small wetlands offer high value landscaping in addition to stormwater performance. Creative financing models can support additional private investments.

CS COMPLETE STREETS

Major thoroughfares such as Tustin St have high demand for safety and aesthetic improvements despite low demand for stormwater improvements. Complete streets should be considered complimentary to the Improved Streets, Green Boulevards, and Green Alleys.


CW
CS
PFS
GA
SD
IS

PRIORITY PROJECT: OPEN SPACE & PARK

McCLURE AVENUE WILDS

URA owned parcels at a key low point on McClure Avenue could detain stormwater flows from the surrounding Brighton Heights neighborhood as well as from the nearby Morrow School. The site, which is bisected by a 15" sewer main, could provide both stormwater performance and naturalized passive recreation areas.

LOWER CODORNICES CREEK RESTORATION, ALBANY, NY
Source: Restoration Design Group

PRIVATE DEVELOPMENT & TRAIL

WOODS RUN @ THE OHIO RIVER

Highly industrialized since the steel town days, the Ohio Riverfront at Woods Run is almost entirely paved over or otherwise developed. Home to the Western State Penitentiary and ALCOSAN, this area is the uninspired industrial terminus to the Three Rivers Heritage Trail. Green Infrastructure could be used to soften the area's hard-scape while continuing the Three Rivers Heritage Trail inland to Riverview Park.

INDIANAPOLIS CULTURAL TRAIL WITH BIOSWALES AND PERMEABLE PAVING
Source: Circle City Bicycles

- **CW** CONSTRUCTED WETLANDS
- **SD** SUBSURFACE DETENTION
- **IS** IMPROVED STREETS
- **GA** GREEN ALLEYS
- **PFS** PAY-FOR-SUCCESS
- **CS** COMPLETE STREETS


SD
IMPROVE FIELDS
GA
CS
HIGH VOLUME DETENTION


CW
IS

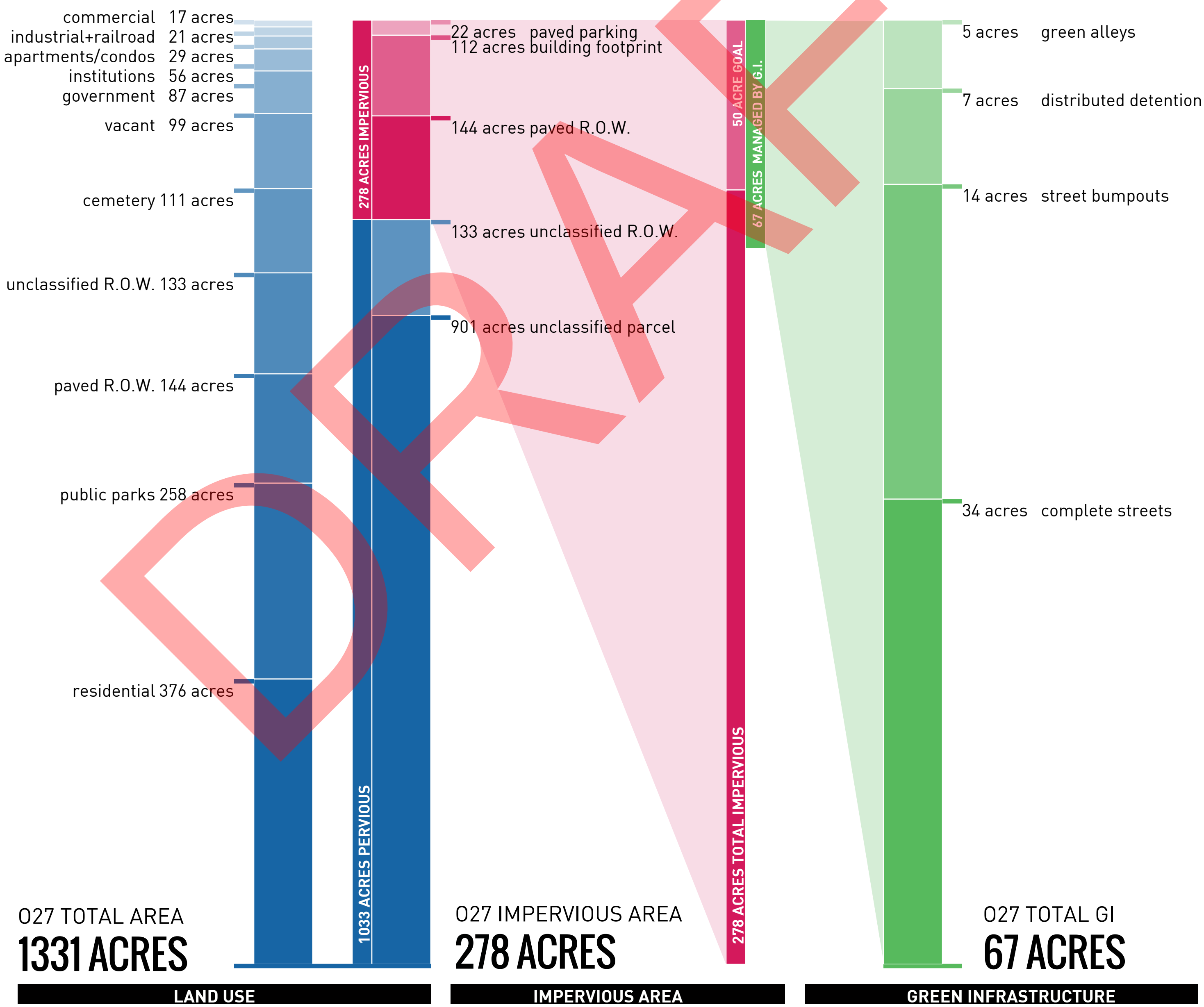
027 BY THE NUMBERS

22.5% OF THE SHED IS VACANT OR UNCLASSIFIED

26.9% OF THE SHED IS IMPERVIOUS

RESIDENTIAL IS THE MOST COMMON LAND USE (PUBLIC & PRIVATE)

13.8% OF THE LAND IS OWNED BY GOVERNMENT OR INSTITUTIONS



COMMUNITY STAKEHOLDERS

Many of the projects are at a significant scale or require cross-agency coordination.
The following is a list of stakeholders identified in the preliminary process.

City-Wide

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

ALCOSAN	Tim Prevost
City Planning	Stephanie Joy Everett
Council District 1	Darlene Harris
Public Works	Mike Gable
URA	

SHED SCALE

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

Brighton Heights	BHCF, Jess Mooney
Brightwood Civic Group	
Observatory Hill Inc.	
One Northside	
Perry North + South	PHCC
Riverview Park	Parks Conservancy

PROJECTS

INDIVIDUALS, AGENCIES, AND ORGANIZATIONS

ALCOSAN @ Preble Avenue	Tim Prevost
Carnegie Library	
Cemeteries	
Engineered Polymer Solutions	
Fire Department	
Homeowners	
Morrow School	PPS
The Pittsburgh Project	
URA @ McClure Ave	URA, GTECH
Western State Penitentiary	Commonwealth of PA, PennDOT

NETWORK SCENARIO

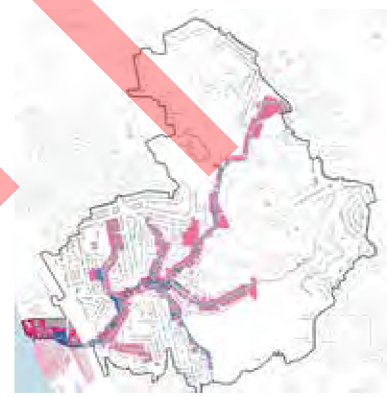
Green Infrastructure works by restoring, mimicking, and supercharging natural hydrologic processes. It needs to be deployed as a network and can reconcile historical flows with modern land use. We studied the historical development of the City of Pittsburgh, and the impact of development on the city's topography.

Hydrologic networks rely on a hierarchy of parts with differentiated functioning. Often there are critical pieces of Green Infrastructure that need to be installed and scaled to anticipate further expansion of the Green Infrastructure network.

We identified "opportunity sites" throughout each priority sewershed that could both fulfill local stormwater infrastructure needs and support healthy communities and neighborhoods. The result is a hybridization between natural and manmade resource flow controls.

In 027 Woods Run, the storage infrastructure in the main valley and along tributary branches could allow for street improvements throughout the shed. As street improvements and detention sites come online, the network can be further expanded until every and parcel are served by Green Infrastructure. The 027 sewershed also includes several natural valleys with small streams that are being evaluated for their potential for stormwater management as part fo the City-Wide study.

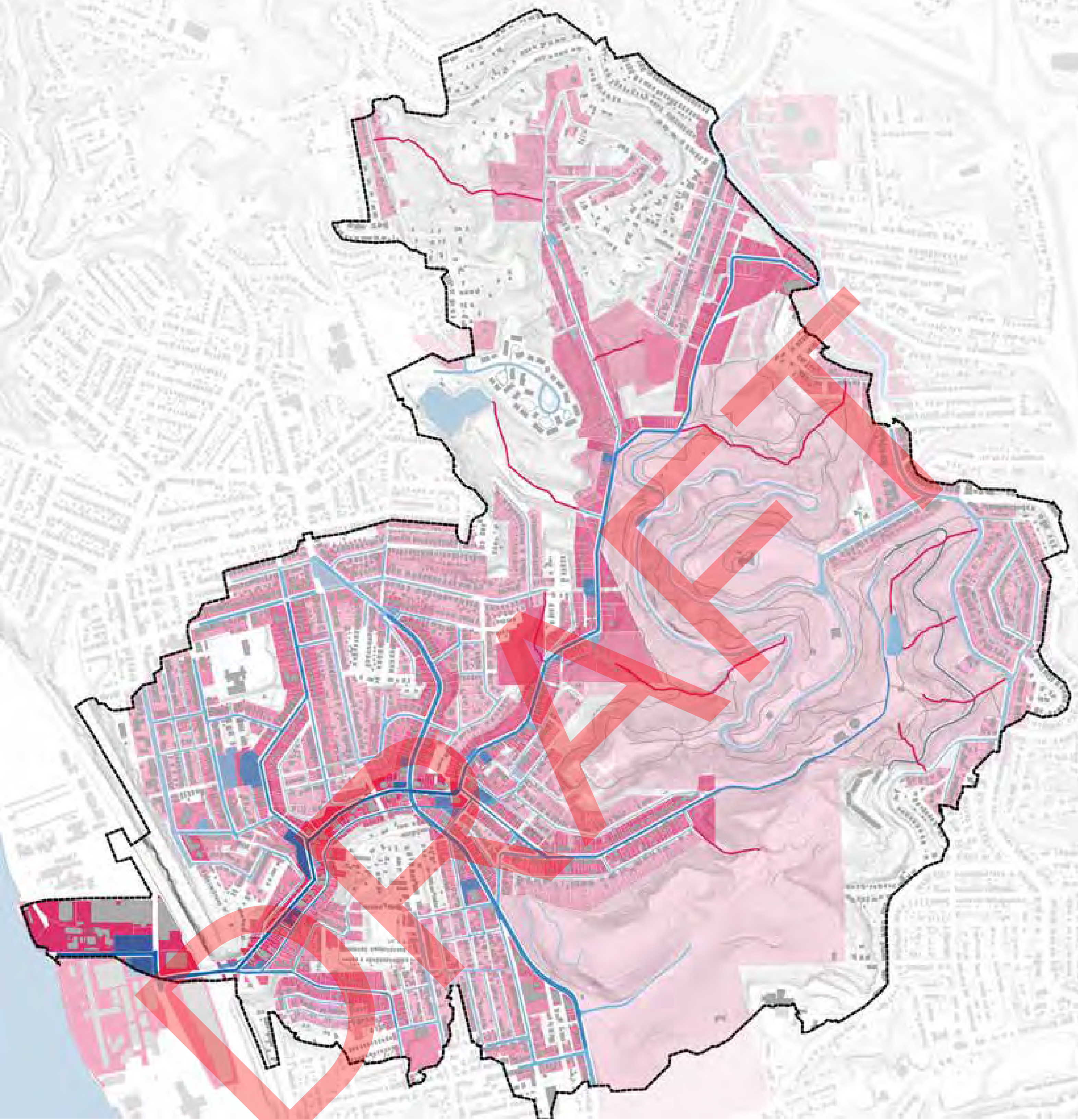
MAIN VALLEY STORAGE



TRIBUTARY BRANCHES CONVEY AND STORE

FURTHER NETWORK EXPANSION

FURTHER NETWORK EXPANSION



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HYDROLOGIC ANALYSES

Stormwater from rainfall is the major driving force behind the geology of Pittsburgh. Recognizing where and how stormwater historically flowed can give us clues to where those flows want to occur today.

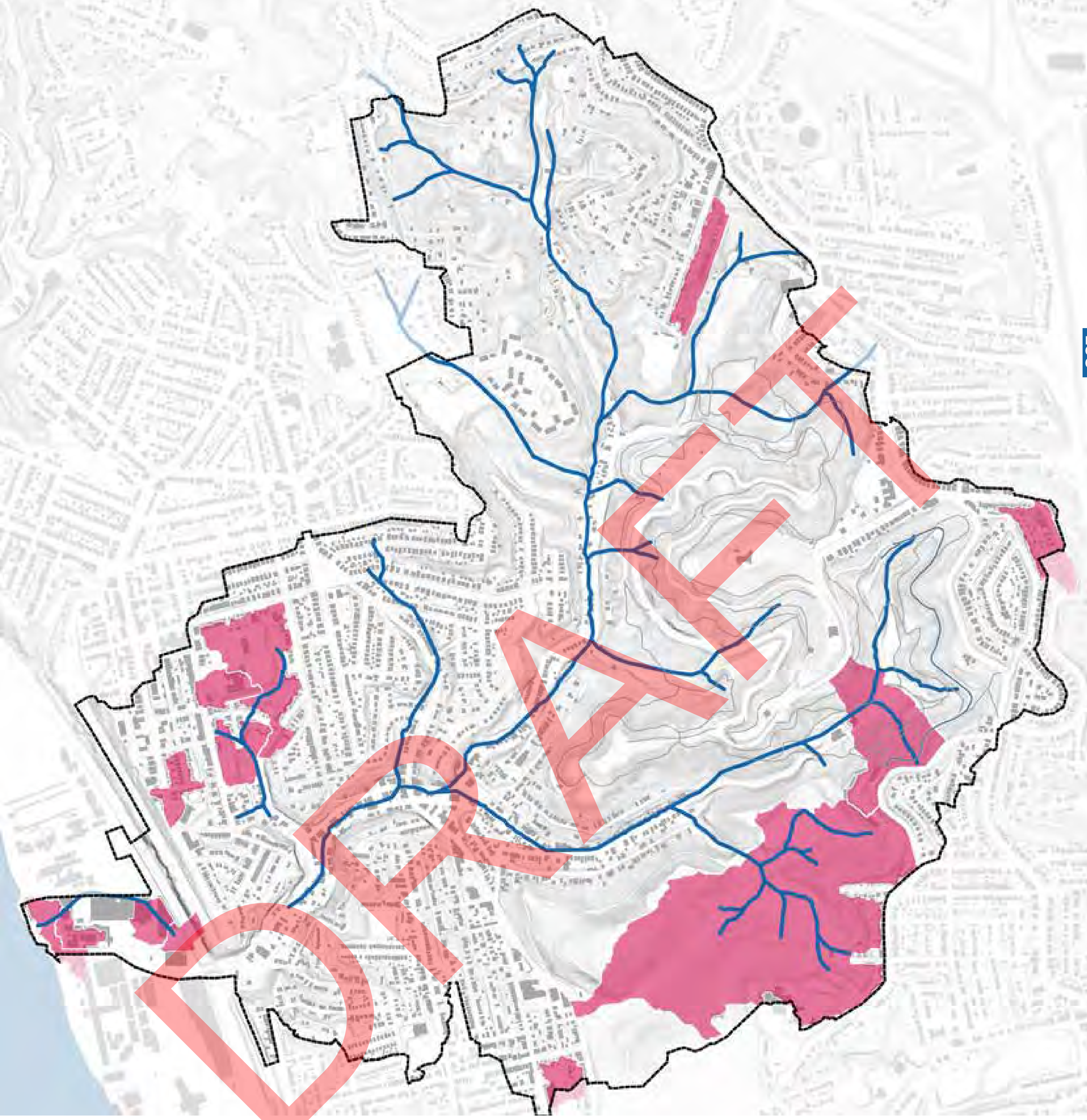
Today's sewer mains follow hydrologic flow lines very closely. Woods Run was once one of the largest streams in the City of Pittsburgh and had many tributary branches. Today's stormwater continues to flow in the sewer mains built along these original branches.

SEWER MAINS

WATER MAINS

Mott Macdonald Target Areas

Historic Streams



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027 INVENTORY

SHED OVERVIEW

Understanding the unique urban fabric of a sewershed allows PWSA to identify potential synergies between infrastructure and communities. Better streets, better parks, better greenspaces, better hillsides, better homes, and better developments can all have positive ripple effects for people, planet, place, and performance.

STREETS

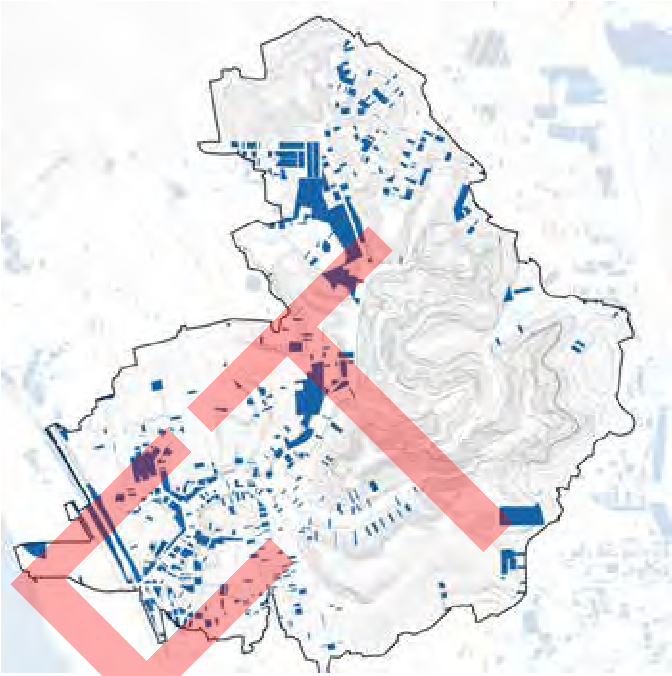
Brighton Heights and Marshall-Shadeland are separated by Woods Run Valley and are connected by bridges. The neighborhood in the valley between them is distinct from its hilltop neighbors.

GREENSPACE + HILLSIDES

The 027 sewershed is dominated by green-space in Riverview Park, Brighton Heights Park, and a few large cemeteries.

BUILDINGS

The 027 sewershed is home to Riverview Park and Highwood Cemetery which have few impervious surfaces. The community along Woods Run Avenue in the valley is distinct from the hill top Brighton Heights and Marshall-Shadeland neighborhoods to which it belongs.

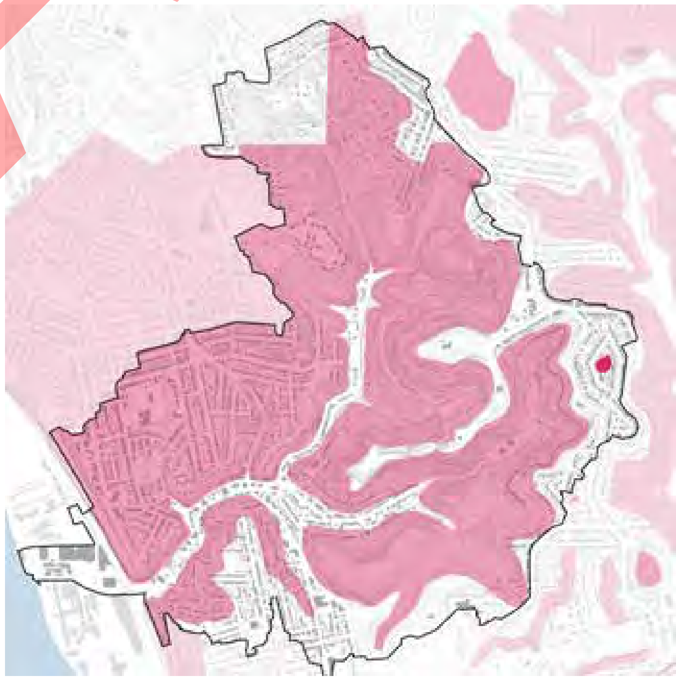


VACANT PARCELS

The 027 sewershed has scattered vacant parcels in and near its valley. These could be leveraged as Green Infrastructure.

RELATIVE PROPERTY VALUES

The 027 sewershed has a mix of property values. A new generation of homeowners is beginning to move in, restoring some of the areas historic homes.



UNDERMINED + LANDSLIDE PRONE

Large parts of the 027 sewershed have been identified by City Planning as having steep slopes. This is likely a mapping error, the wooded hillsides shown below are a better indicator of steepness for this shed. Undermining is limited to the Perry Hilltops.

027 INVENTORY

URBAN CONTEXT

The 027 sewershed is distinguished by the amount of green-space in the upper parts of the shed. Dramatically steep wooded slopes have constrained where development has been able to occur. Riverview Park, one of the largest public parks in the city and one of the oldest, has protected an additional 251 acres from development. Adjacent to the Park are several large cemeteries forming an ecologically contiguous greenspace.

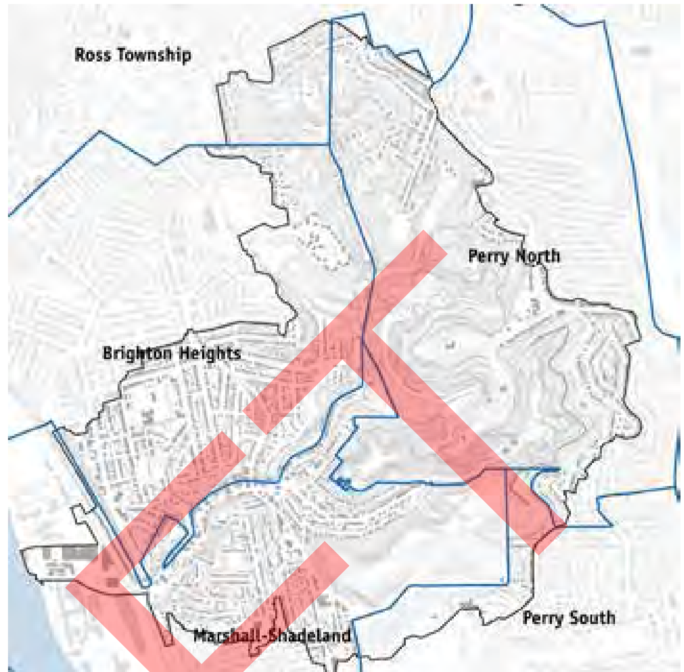
The comparatively level hilltops to the west of the Park supported streetcar suburbs at Brighton Heights and Marshall-Shadeland. Major thoroughfares from downtown Pittsburgh to the Southeast reflect these original streetcar lines.

Neighborhoods
Brighton Heights
Marshall-Shadeland [Brightwood, Woods Run Avenue]
Perry North [Observatory Hill]
Perry South

Council District 1
Darlene Harris

Community Groups
Brighton Heights Citizens Federation
Brightwood Civic Group
Observatory Hill Inc.
One Northside
Perry Hilltop Community Council

Adjacent Municipality
Ross Township



NEIGHBORHOOD DESIGNATION

COUNCIL DISTRICTS

COMMUNITY ASSETS

- Churches
- Historic Sites
- Forested Areas
- Parks
- Schools
- 71A Port Authority Bus Routes


ROSS TOWNSHIP
OBSERVATORY HILL
PERRY NORTH
PERRY SOUTH
RIVERVIEW PARK
BRIGHTON HEIGHTS PARK
HIGHWOOD CEMETERY
PERRYSVILLE RD
WOODS RUN AVE
OAKDALE ST
RIVERVIEW AVE
SHADELAND AVE
BRIGHTON RD
GRAND AVE
MCCLURE AVE
CALIFORNIA AVE
OHIO RIVER BLVD
ECKERT ST
16
17
13
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DRAFT
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027 INVENTORY

URBAN CONTEXT WOODS RUN

Connectivity between valley and hilltop is limited to McClure Avenue and Brighton Road. Three of the major thoroughfares from south the north bridge over the valley at Shadeland Avenue, California Avenue, and Ohio River Boulevard. As a result, the valley of Woods Run is characteristically distinct from the hilltops of Brighton Heights and Marshall-Shadeland.

Though it does not have its own neighborhood designation, the Woods Run valley is a distinct community. The village center near the intersection of Brighton Road and Woods Run Avenue includes civic assets that could support an engaged and active community. A few storefronts form a neighborhood commercial center and the newly renovated Carnegie Library serves as the community focal point.

A series of vacant lots and greenspaces could be integrated with Green Infrastructure to provide improved walkability between the library, playground, fire station, commercial storefronts, and the surrounding residential neighborhoods.

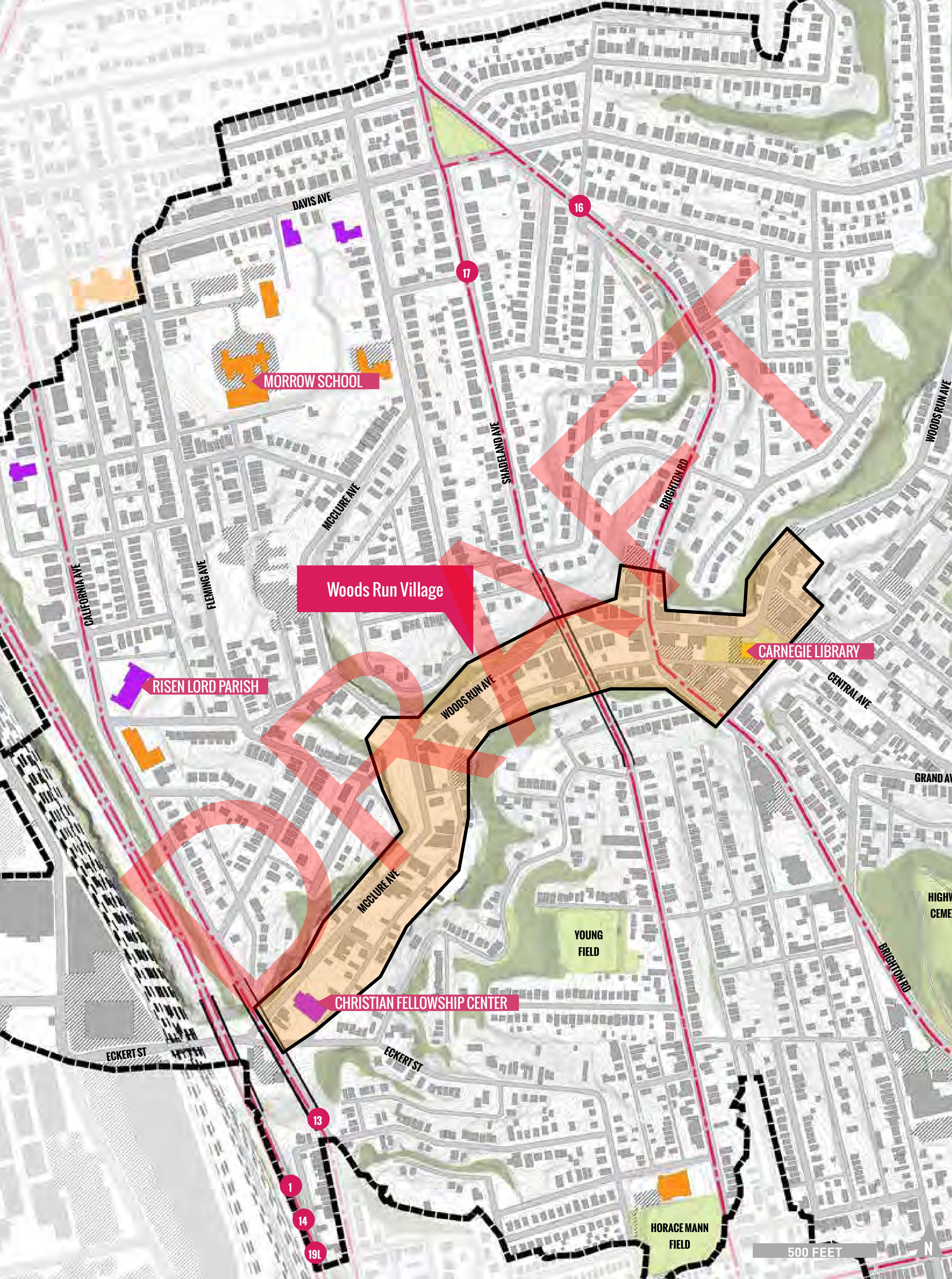
Lecky Avenue, parallel to Woods Run Avenue, could be converted to a green alley. Improvements to this alley, which carries the primary sewer main for 027, would enable a bikeable corridor from the Three Rivers Heritage Bike Trail to Riverview Park.

CARNEGIE LIBRARY @ WOODS RUN
Source: Soracco Photography

CALIFORNIA AVE + OHIO RIVER BLVD
BRIDGES OVER WOODS RUN VALLEY
Source: Microsoft Here Maps

COMMUNITY ASSETS

- Churches
- Historic Sites
- Forested Areas
- Parks
- Schools
- 71A Port Authority Bus Routes



Woods Run Village
DAVIS AVE
MORROW SCHOOL
RISEN LORD PARISH
CHRISTIAN FELLOWSHIP CENTER
CARNEGIE LIBRARY
CALIFORNIA AVE
FLEMING AVE
MCCLURE AVE
SHADELAND AVE
BRIGHTON RD
WOODS RUN AVE
CENTRAL AVE
GRAND AVE
HIGHWOOD CEMETERY
YOUNG FIELD
HORACE MANN FIELD
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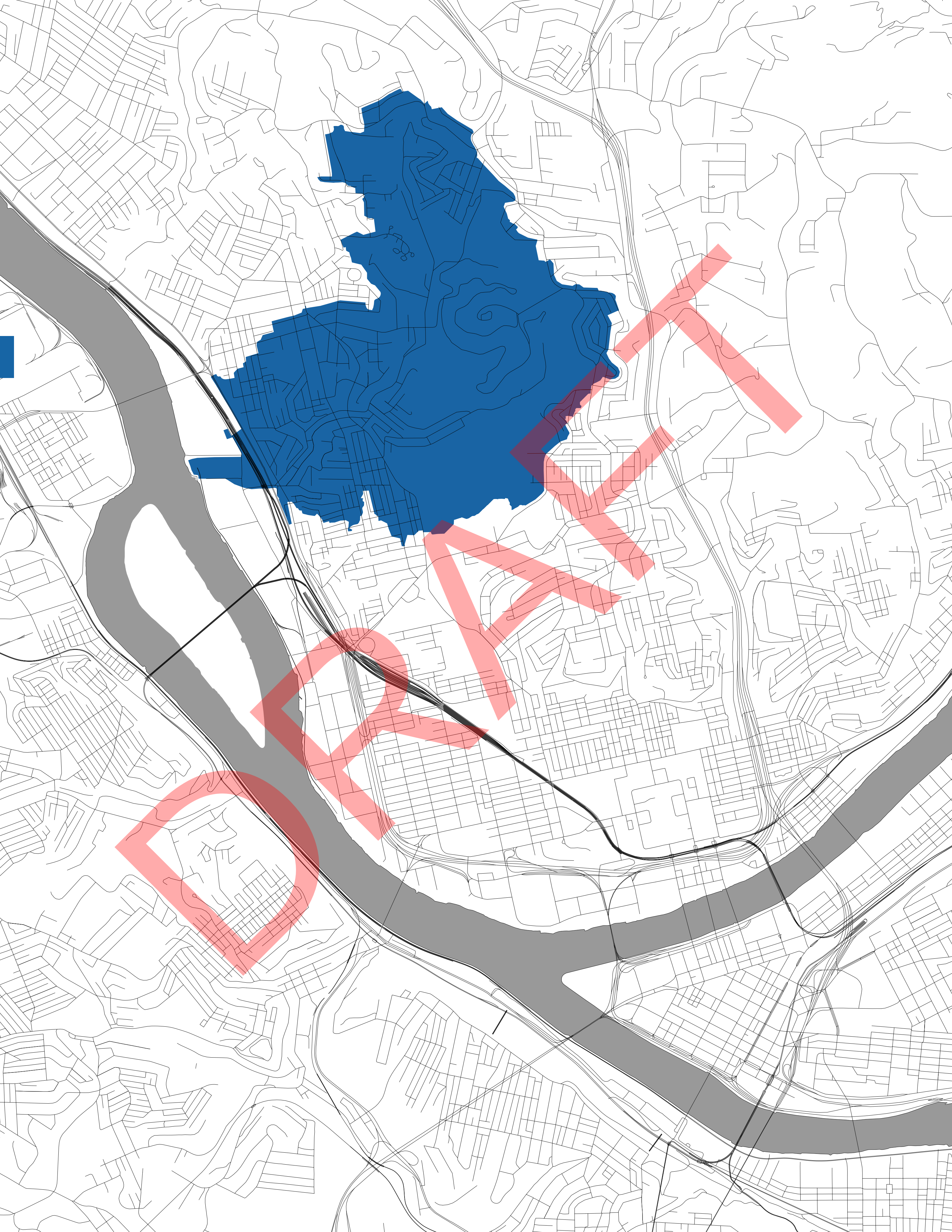
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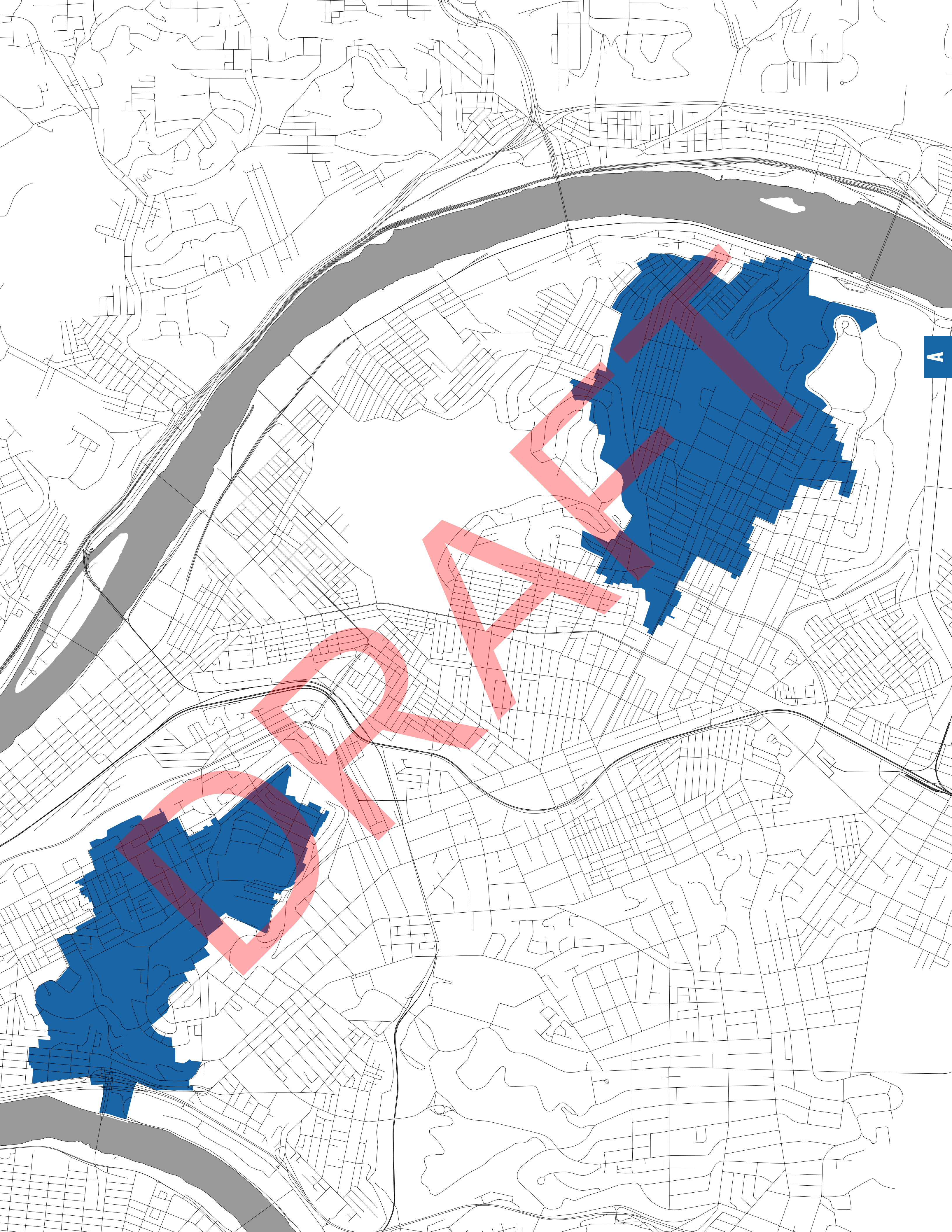
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APPENDICES

The following appendices provide cost summaries prepared by Arcadis and a map of the Green Infrastructure network used as the basis for calculations. In our technical analysis, we focused on only the highest priority Green Infrastructure opportunities for the calculation of cost and performance.

In our urban analysis of the three sheds, we looked at each shed comprehensively to identify every possible opportunity for Green Infrastructure. As PWSA plans their Green Infrastructure implementation strategy, it will be helpful for them to have the comprehensive opportunity maps in the preceding sections so that they can consider all available alternatives.

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APPENDIX

A41 COST SUMMARY

A41
Capital Cost Summary

A 41 - All focus areas	A 41 - Controlled Area and Volume				A 41 - BMP Unit Cost Template	
GI Strategy	Tributary Impervious Area Detain and Slow Release [acres]	Tributary Impervious Area Detained and Daylighted [acres]	Total BMP Footprint [acres]	Total Runoff Storage Volume [MG]	Cost per Imp Acre Removed [$M]	Total cost estimate [$M]
"Green the Valley" Water Quality Detention			9.0			$ 8.09
Valley Detention Costs			9.0	2.9		$ 3.19
Valley Conveyance Costs						$ 4.90
"Stop and Drop" Detention		50.0	1.5	2.0	$ 0.10	$ 4.78
Heth's Playground		*42.3*	*0.9*	*1.7*	*$ 0.08*	*$ 3.30*
Mellon Terrace		*2.8*	*0.3*	*0.1*	*$ 0.26*	*$ 0.71*
Natoli Field		*3.4*	*0.1*	*0.1*	*$ 0.15*	*$ 0.51*
Vetter and Chislett		*1.5*	*0.1*	*0.1*	*$ 0.17*	*$ 0.25*
"Establish / Expand Network" GI Volume	32.4	44.5	6.8	3.1	$ 0.20	$ 15.39
Flow through Rain Garden	*14.8*		*0.8*	*0.6*	*$ 0.18*	*$ 2.60*
Road diet Swale		*9.6*	*0.6*	*0.4*	*$ 0.17*	*$ 1.59*
Stormwater Intersection Bumpout		*20.0*	*1.1*	*0.8*	*$ 0.25*	*$ 5.03*
Distributed Storage Tree Trench		*14.9*	*0.6*	*0.6*	*$ 0.16*	*$ 2.44*
Green Alley [add-on]	*17.7*		*3.7*	*0.7*	*$ 0.21*	*$ 3.74*
Conveyance						$ 8.69
Building Disconnect Cost						$ 4.75
Enhanced Curb & Gutter Conveyance Costs						$ 2.39
Pipe Network Conveyance Costs						$ 1.56
Total Controlled	32	94	17.3	5.2	$ 0.29	$ 37.0
Total Controlled - without Valley Development					$ 0.23	$ 28.9

Notes

1. Cost reflects capital cost estimate and does not reflect engineering and construction services
2. GI Sizing volume based on providing void storage for 1.5" of runoff depth for contributing areas
3. Contributing roadway and building footprint areas were considered to contribute 100% of their runoff volume
4. Other contributing area within the right of way is considered to contribute 50% of the runoff volume
5. Private parcel area outside of right of way and outside of building footprints is considered to contribute 10% of the runoff volume, if within 25 feet of curb.
6. Disconnect cost based on assumption of $4 per sq ft controlled, or assuming $1000 per downspout that intercepts 250 sq ft
7. New Road Inlet structures included in GI Cost Estimates
8. Capital costs per Stop and Drop Location exclude cost estimate of the Valley Detention space. The Valley Detention space is not accounted for in providing additional controlled acres. It does facilitate the daylighting of stormwater volume and the contributing flows would receive water quality improvements. Since it does not facilitate the capture of controlled acres, it is not included in the cost per impevious acre controlled.
9. Valley Detention Cost based on Envision AUTOCASE "high cost" for constructed wetlands. Valley Conveyance, which would be in the form of a natural stream conveyance is based on literature review to provide conservative capital cost estimate.
10. Other Project costs are estimated based on unit costs provided by MM and are detailed in BMP Cost Estimate excel workbook.

A41 GI NETWORK USED FOR CALCULATION

LEGEND

Distributed Detention Sites

Stormwater Feature

Complete Street

Green Alley

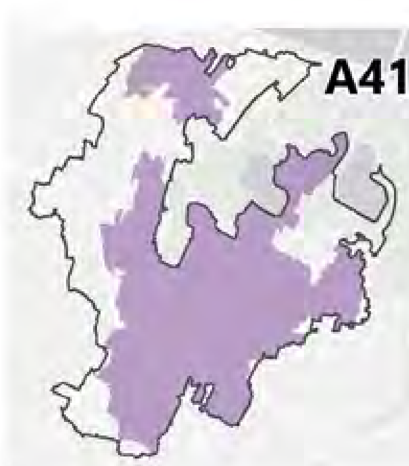
Improved Street

Conveyance

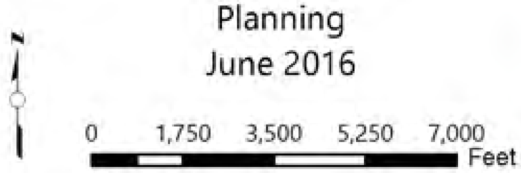
Storm Sewer Conveyance

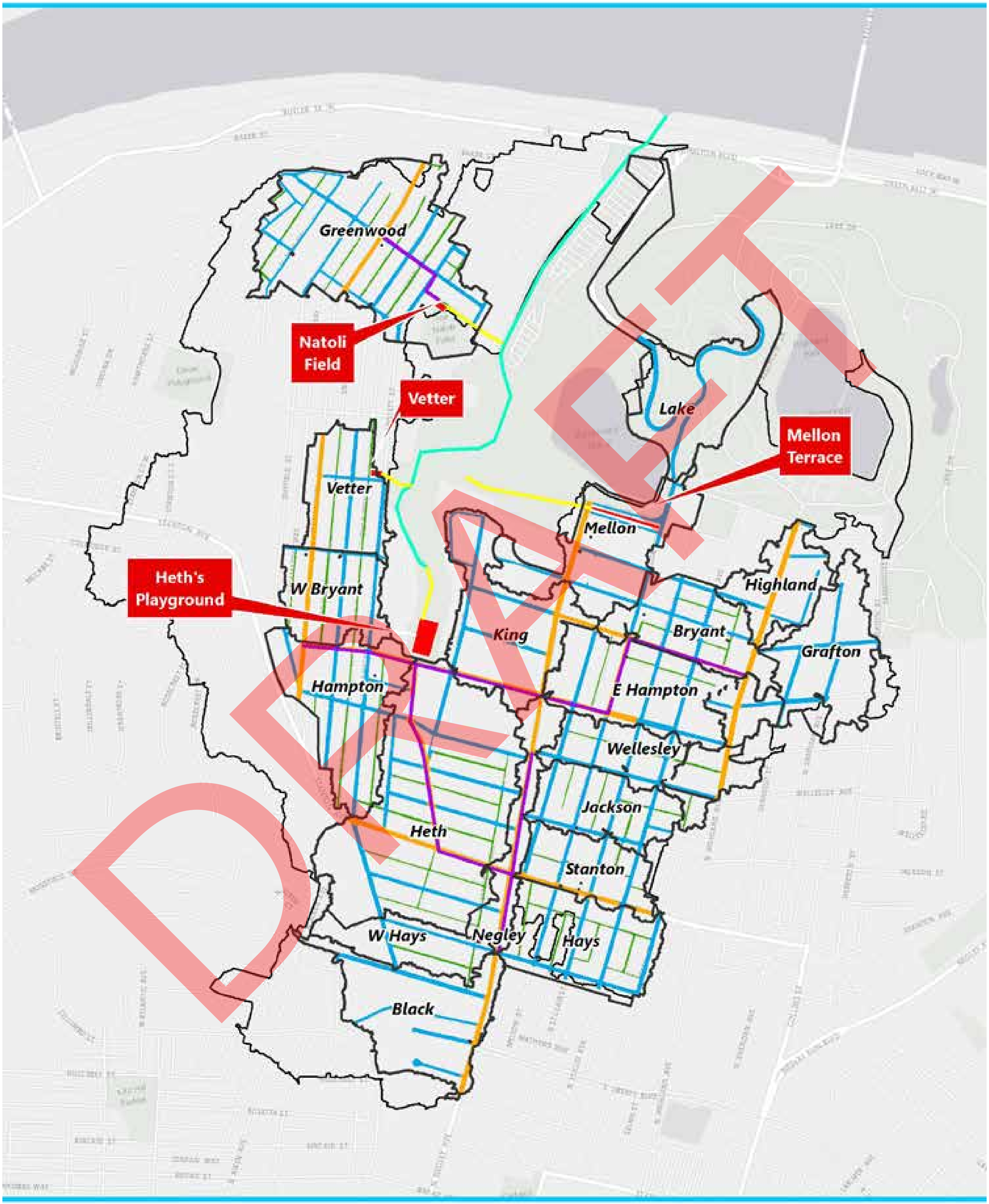
Distributed Detention Conveyance

Daylighted Conveyance



Citywide GI Planning
June 2016




Greenwood
Natoli Field
Vetter
Lake
Mellon Terrace
Vetter
Mellon
Heth's Playground
W Bryant
Highland
King
Bryant
Grafton
Hampton
E Hampton
Wellesley
Jackson
Heth
Stanton
W Hays
Negley
Hays
Black
DRAFT

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M19 COST SUMMARY

M19
Capital Cost Summary

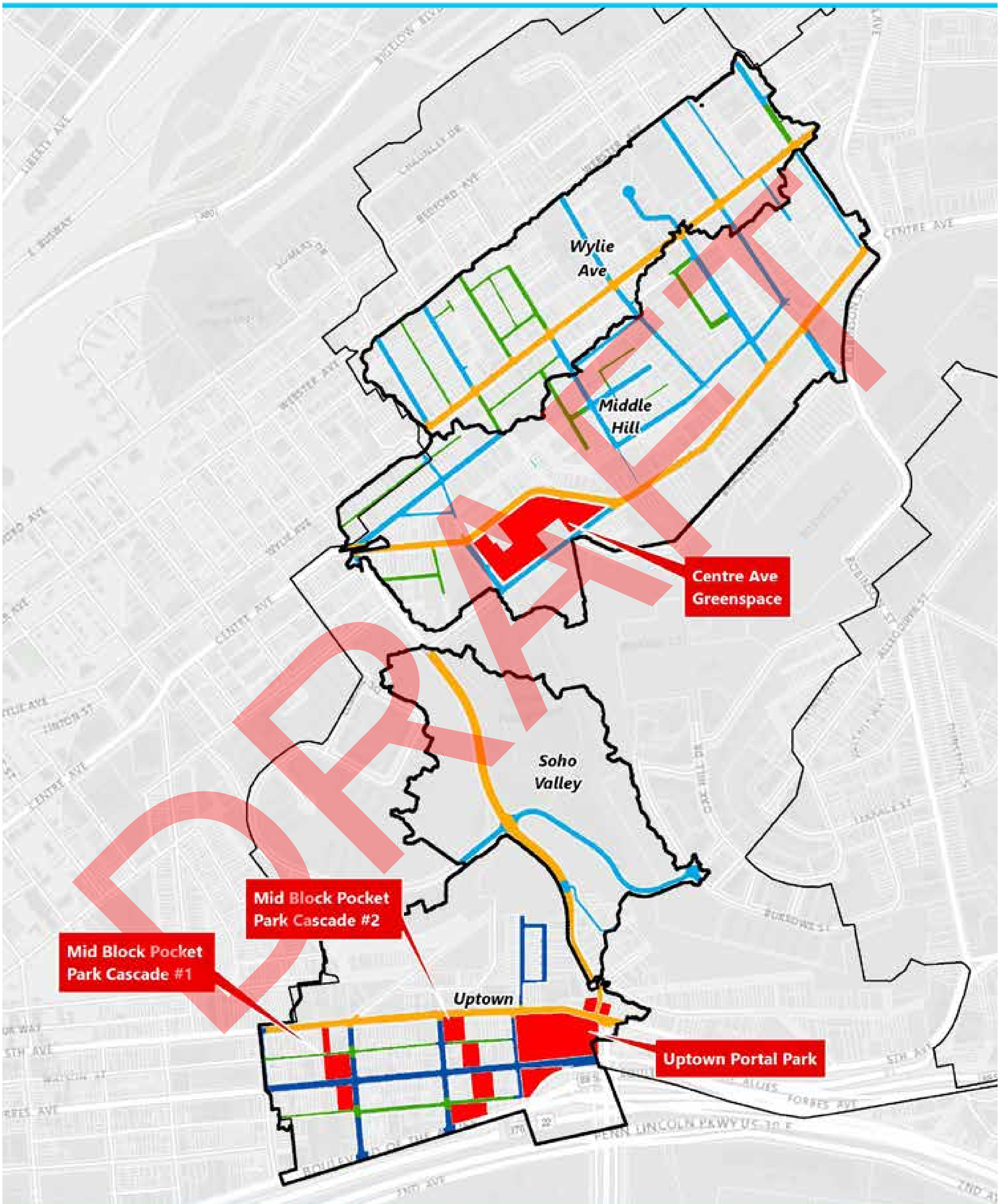
M19 - All focus areas	M 19 - Controlled Area and Volume				M 19 - BMP Unit Cost Template	
GI Strategy	Tributary Impervious Area Detain and Slow Release [acres]	Tributary Impervious Area Detained and Daylighted [acres]	Total BMP Footprint [acres]	Total Runoff Storage Volume [MG]	Cost per Imp Acre Controlled [$M]	Total cost estimate [$M]
Distributed Detention Sites	19.0	0.0	1.2	0.8	$ 0.13	$ 2.53
Mid Block Pocket Park #1	*1.0*		*0.1*	*0.0*	*$ 0.20*	*$ 0.20*
Mid Block Pocket Park #2	*1.5*		*0.2*	*0.1*	*$ 0.17*	*$ 0.25*
Uptown Portal Park	*8.5*		*0.6*	*0.3*	*$ 0.12*	*$ 1.06*
Centre Ave Greenspace	*8.0*		*0.3*	*0.3*	*$ 0.13*	*$ 1.02*
"Establish / Expand Network" GI Volume	20.8	0.0	1.9	0.8	$ 0.19	$ 4.04
Flow through Rain Garden	*0.9*		*0.0*	*0.0*	*$ 0.18*	*$ 0.15*
Stormwater Intersection Bumpout	*3.9*		*0.2*	*0.2*	*$ 0.25*	*$ 0.98*
Distributed Storage Tree Trench	*10.4*		*0.4*	*0.4*	*$ 0.16*	*$ 1.71*
Green Alley [add-on]	*5.7*		*1.2*	*0.2*	*$ 0.21*	*$ 1.20*
Conveyance						$ 1.36
Building Disconnect Cost						$ 0.37
Enhanced Curb & Gutter Conveyance Costs						$ 0.99
Total Controlled	40	0.0	3.1	1.6	$ 0.20	$ 7.9

Notes

1. Cost reflects capital cost estimate and does not reflect engineering and construction services.
2. GI Sizing volume based on providing void storage for 1.5" of runoff depth for contributing areas.
3. Contributing roadway and building footprint areas were considered to contribute 100% of their runoff volume.
4. Other contributing area within the right of way is considered to contribute 50% of the runoff volume.
5. Private parcel area outside of right of way and outside of building footprints is considered to contribute 10% of the runoff volume, if within 25 feet of curb.
6. Disconnect cost based on assumption of $4 per sq ft controlled, or assuming $1000 per downspout that intercepts 250 sq ft.
7. New Road Inlet structures included in GI Cost Estimates.
8. Project costs are estimated based on unit costs provided by MM and are detailed in BMP Cost Estimate excel workbook.

APPENDIX

M19 GI NETWORK USED FOR CALCULATION



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027 COST SUMMARY

O27
Capital Cost Summary

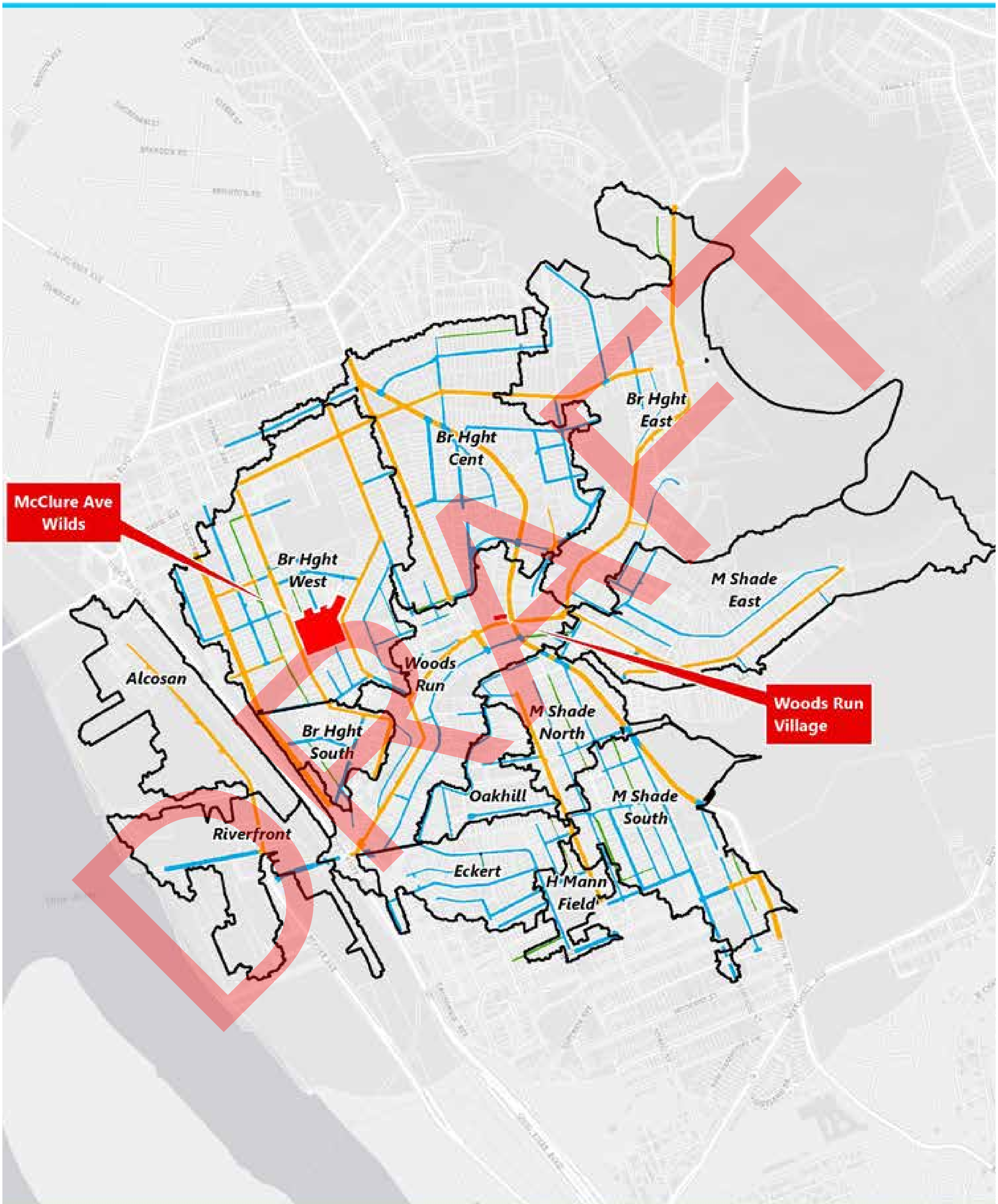
O 27 - All focus areas	O 27 - Controlled Area and Volume				O 27 - BMP Unit Cost Template	
GI Strategy	Tributary Impervious Area Detain and Slow Release [acres]	Tributary Impervious Area Detained and Daylighted [acres]	Total BMP Footprint [acres]	Total Runoff Storage Volume [MG]	Cost per Imp Acre Removed [$M]	Total cost estimate [$M]
Distributed Detention Sites	6.5	0.0	0.8	0.3	$ 0.15	$ 1.01
Woods Run Village	*2.0*		*0.2*	*0.1*	*$ 0.13*	*$ 0.26*
McClure Wilds	*4.5*		*0.6*	*0.2*	*$ 0.17*	*$ 0.75*
"Establish / Expand Network" GI Volume	61.0	0.0	3.7	2.5	$ 0.19	$ 11.57
Flow through Rain Garden	*8.3*		*0.5*	*0.3*	*$ 0.18*	*$ 1.46*
Stormwater Intersection Bumpout	*14.3*		*0.8*	*0.6*	*$ 0.25*	*$ 3.58*
Distributed Storage Tree Trench	*33.7*		*1.4*	*1.4*	*$ 0.16*	*$ 5.53*
Green Alley [add-on]	*4.7*		*1.0*	*0.2*	*$ 0.21*	*$ 1.00*
Conveyance						$ 3.25
Building Disconnect Cost						$ 1.19
Enhanced Curb & Gutter Conveyance Costs						$ 2.06
Total Controlled	67	0.0	4.5	2.7	$ 0.23	$ 15.8

Notes

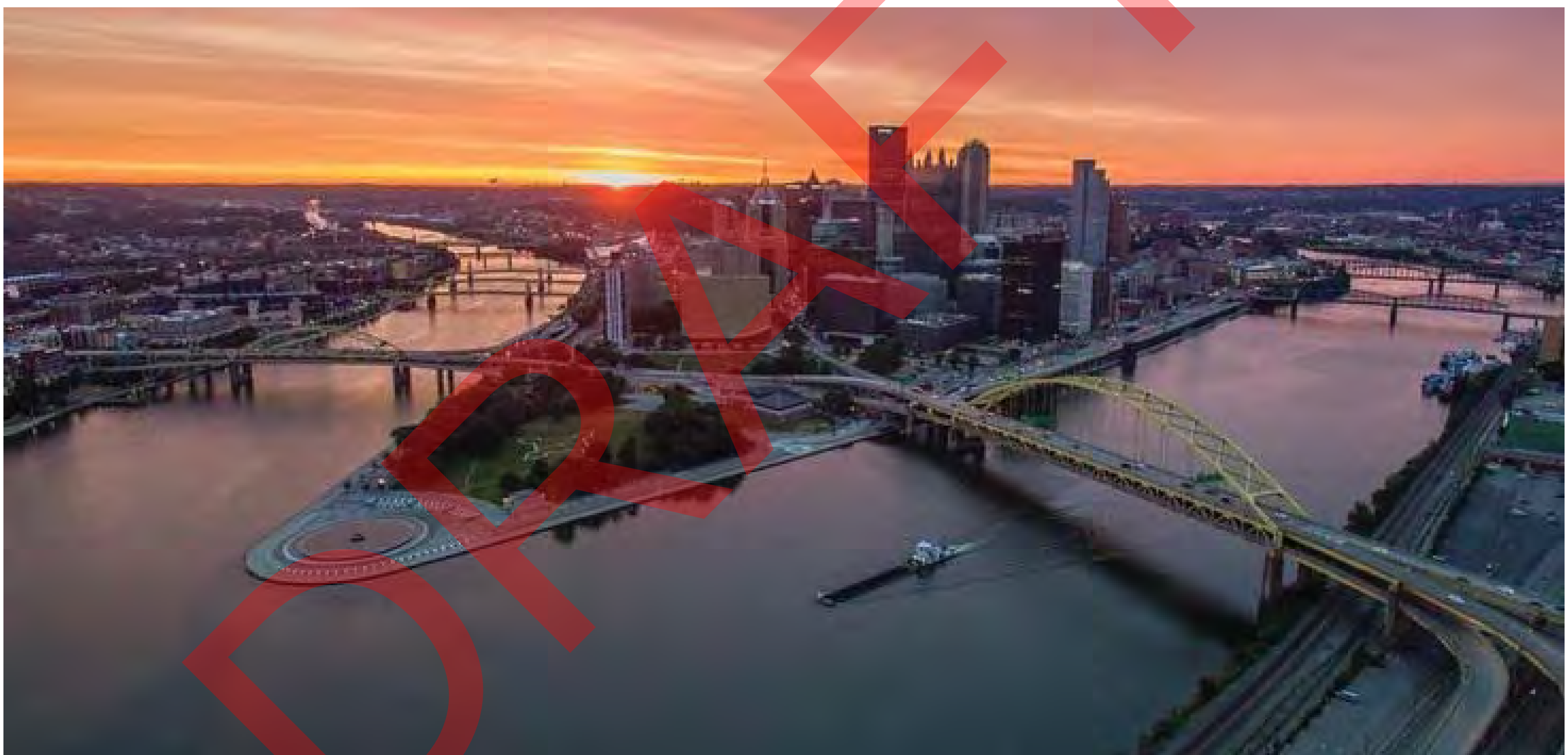
1. Cost reflects capital cost estimate and does not reflect engineering and construction services.
2. GI Sizing volume based on providing void storage for 1.5" of runoff depth for contributing areas.
3. Contributing roadway and building footprint areas were considered to contribute 100% of their runoff volume.
4. Other contributing area within the right of way is considered to contribute 50% of the runoff volume.
5. Private parcel area outside of right of way and outside of building footprints is considered to
6. Disconnect cost based on assumption of $4 per sq ft controlled, or assuming $1000 per downspout that intercepts 250 sq ft.
7. New Road Inlet structures included in GI Cost Estimates.
8. Project costs are estimated based on unit costs provided by MM and are detailed in BMP Cost Estimate excel workbook.

APPENDIX

027 GI NETWORK USED FOR CALCULATION


McClure Ave Wilds
Woods Run Village
Br Hght East
Br Hght Cent
Br Hght West
M Shade East
Woods Run
Alcosan
M Shade North
Br Hght South
Oakhill
M Shade South
Riverfront
Eckert
H Mann Field
DRAFT

URBAN PLANNING AND
GREEN INFRASTRUCTURE ASSESSEMENT



phro•ne•sis

HOLISTIC GREEN INFRASTRUCTURE INTEGRATION INTO PITTSBURGH'S URBAN FABRIC

TABLE OF CONTENTS

HOLISTIC GREEN INFRASTRUCTURE

To ensure a successful city-wide green infrastructure plan the team used a process they defined as “strategic” urban planning. A process that is focused on developing a holistic “green infrastructure-first” approach. This approach emphasizes the identification of opportunities that support both resilient infrastructure strategies and are catalytic redevelopment opportunities within each Pittsburgh sewershed.

...opportunities that support both resilient infrastructure strategies and are catalytic redevelopment opportunities...

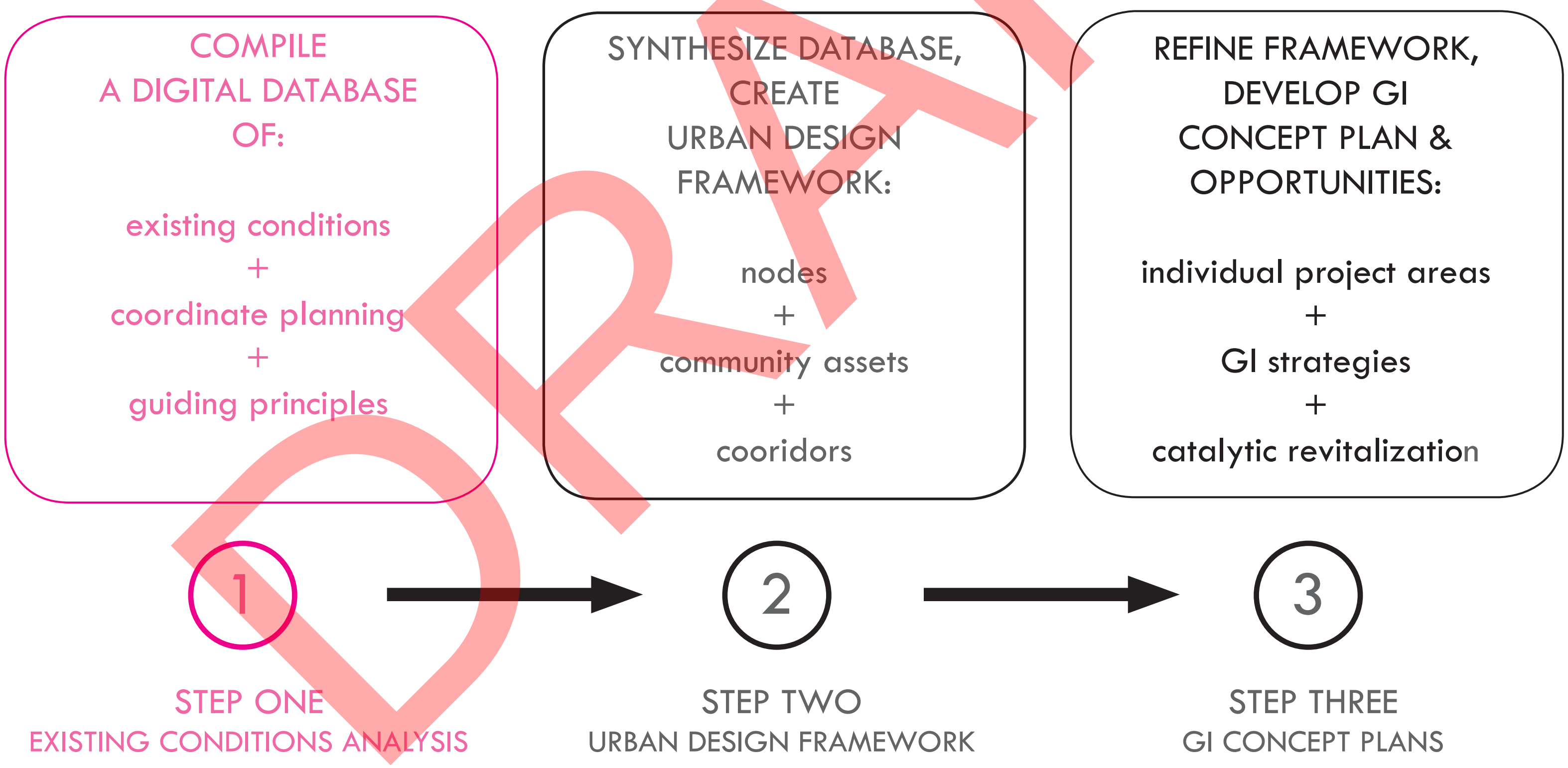
AN INTEGRATED AND SYSTEM-BASED APPROACH

To achieve the vision of holistic green infrastructure the team used an iterative and integral process. outlined below:

> STEP ONE: Digital Database of Existing Conditions - Review and analyze existing conditions along with a collaborative planning process with multiple City Departments, coordinating existing plans and studies completed to date for study area

> STEP TWO: Urban Design Framework Plan - Synthesized digital database into key nodes and community assets connected by corridors

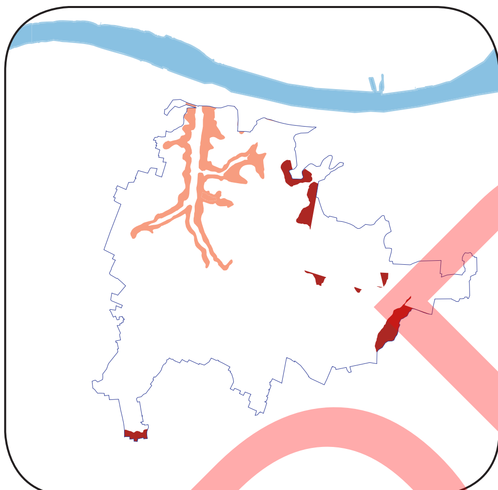
> STEP THREE: Green Infrastructure Concept Plans - Refine the Framework plans with community input and technical analysis to develop GI concept plans and opportunities in each sewershed for a connected GI system.



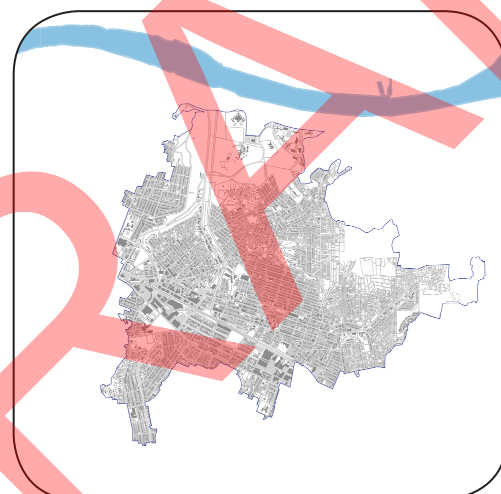
A FOUNDATION GROUNDED ON EXISTING CONDITIONS

The initial step in the process was gathering data and developing mapping related to the conditions that existed within the sewersheds. The understanding of these conditions grounded the opportunities and constraints for each area. This data extended beyond sewershed related infrastructure like sewershed boundaries and pipes, to other conditions, that play and integral role in urban planning like topography, land use, corridors, and nodes. Hazard areas of steep slopes, landslide prone, and undermined areas were clearly defined and avoided where practical. Field observation was completely to supplement the mapping and enrich the teams understanding.

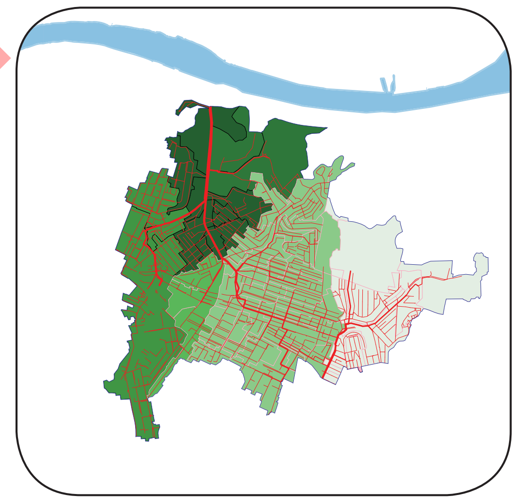
...understanding of these conditions grounded the opportunities and constraints...



Existing Steep Slopes and Undermined Areas



Existing Impervious Surfaces



Existing Sewersheds and Sewer Lines

COLLABORATIVE PLANNING APPROACH

The City of Pittsburgh has many active planning pursuits that focus on the same streets, neighborhoods, and parks where green infrastructure is being targeted. By understanding the community assets, current planning processes, community goals, and engaging in stakeholder input, the integration of green infrastructure can be “leveraged” into multiple smart infrastructure systems through a highly collaborative planning process. To achieve this goal multiple meetings with the Urban Redevelopment Authority (URA), City Planning, and associated City agencies were conducted to obtain the relevant development plans for the City.

...the integration of green infrastructure can be “leveraged” into multiple smart infrastructure systems..

Homewood Cluster Planning | Cluster 2 Vision Plan at Westinghouse Academy.
Prepared by Operation Better Block and studio for spatial practice.

COMMUNITY OUTREACH REFINES THE VISION

The initial framework was shared with multiple City departments along with the Mayor's office. Community outreach meetings were conducted at multiple levels, including small groups of key stakeholders like Universities as well as larger sessions with many participants. When commentary necessitated changes, refinements were made. These refinements served to inform the next steps; developing the concepts identifying specific opportunities for GI within the sewersheds.

...when commentary necessitated changes, refinements were made.

Community engagement meeting for one of the priority sewersheds.

GUIDING PRINCIPLES FOR REGENERATIVE SYSTEM

The team established a set of Guiding Principles to further assist in the selection of the GI locations with the sewersheds that combined the data driven, technical metrics used to measure the effectiveness of CSO reduction within the priority sewersheds discussed in the previous section. These Guiding Principles emerged from discussions with the Mayor's office and his staff, multiple City departments, and key community stakeholders.

Many of these guiding principles support the quantitative outcomes for CSO reduction discussed in the previous sections; others, however serve to broaden the lens and establish qualitative outcomes to improve the communities where these investments are being made, further complementing the redevelopment efforts proposed in these areas. The Guiding Principles offer an additional benefit: **they better leverage the limited resources of each City department into a shared effort.**
The seven Guiding Principles are outlined below along with a brief description for each:

1) Public Realm Investment = Cost Effective:

By investing in City-owned property within the public realm the cost of acquired private property for GI is avoided. Furthermore, improvements can be more efficiently shared across City departments when other planned improvements are coordinated.

2) Create Workforce Development Opportunities:

Investment in GI should be viewed as an opportunity to provide jobs, especially within communities that would best benefit from access to new or better employment opportunities. Workforce development will encompass all segments of the population to develop lifelong careers, research and monitoring to construction and maintenance.

3) Re-Establish Riverfront Connections:

As Pittsburgh further redevelops and enhances its numerous riverfront areas, opportunities to improve and create new riverfront connections should be explored in conjunction with proposed GI, providing pathways linking people and runoff to the City's three rivers.

4) Complete Streets

Pittsburgh is looking to develop a network of key City corridors into Complete Streets, which are streets that focus multiple modes of transportation, placing emphasis on public transit, bicyclists, and pedestrians. GI should be incorporated within these Complete Streets as many of the corridors also have the highest potential to reduce CSO.

5) Focus on Healthy, Walkable Communities

Emphasis should be placed on enhancing corridors to improve access to recreation and healthy food, and encourage walking beyond the Complete Street corridors. GI can be leveraged to further enhance the effectiveness of improving the overall health and safety of a community.

6) Resilient Infrastructure

GI can be used to support the efforts of the City in becoming more resilient by reducing flooding, decentralizing runoff capture, and upgrading the aging infrastructure. Creating a smart system that more effectively and efficiently handles stormwater today and in the future.

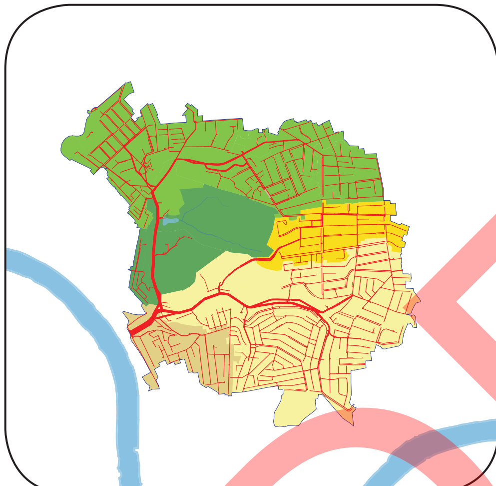
7) People, Planet, Place and Performance

Pittsburgh's P4 initiative looks to forge a new model for urban growth and development that is innovative, inclusive and sustainable. GI addresses all four of the components of this framework.

URBAN DESIGN FRAMEWORK

After the sewersheds were selected, and Guiding Principles established, an important early step in this process identified the nodes, corridors, and connectivity that should be focused on when looking at opportunities for GI. This early planning process was referred to as the Urban Design Framework. The Urban Design Framework served as a synthesis of the redevelopment plans, key corridors, and important nodes within the community. Nodes could be important intersections of corridors or key areas within the community like business districts, institutions, or open space well positioned to capture high yield areas. Furthermore, emphasis was placed on Complete Streets, connectivity to rivers, and areas within in community where redevelopment had been proposed.

...the Framework served as a synthesis of the redevelopment plans, key corridors, and important nodes...



SYNTHESIZE DATABASE,
CREATE
URBAN DESIGN
FRAMEWORK:

nodes
+
community assets
+
cooridors

REFINE FRAMEWORK,
DEVELOP GI
CONCEPT PLAN &
OPPORTUNITIES:

individual project areas
+
GI strategies
+
catalytic revitalization

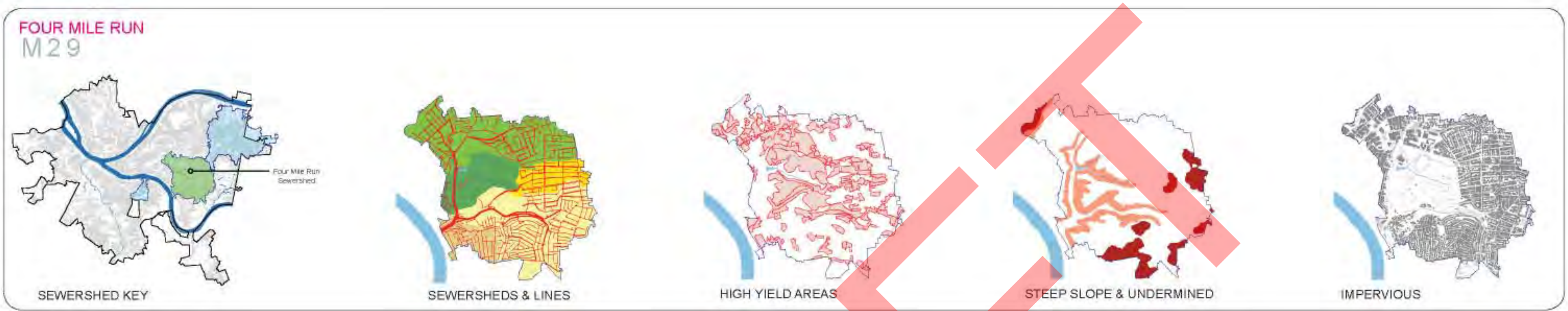
1 → 2 → 3

STEP ONE
EXISTING CONDITIONS ANALYSIS

STEP TWO
URBAN DESIGN FRAMEWORK

STEP THREE
GI CONCEPT PLANS

FOUR MILE RUN OPPORTUNITIES AND CONSTRAINTS

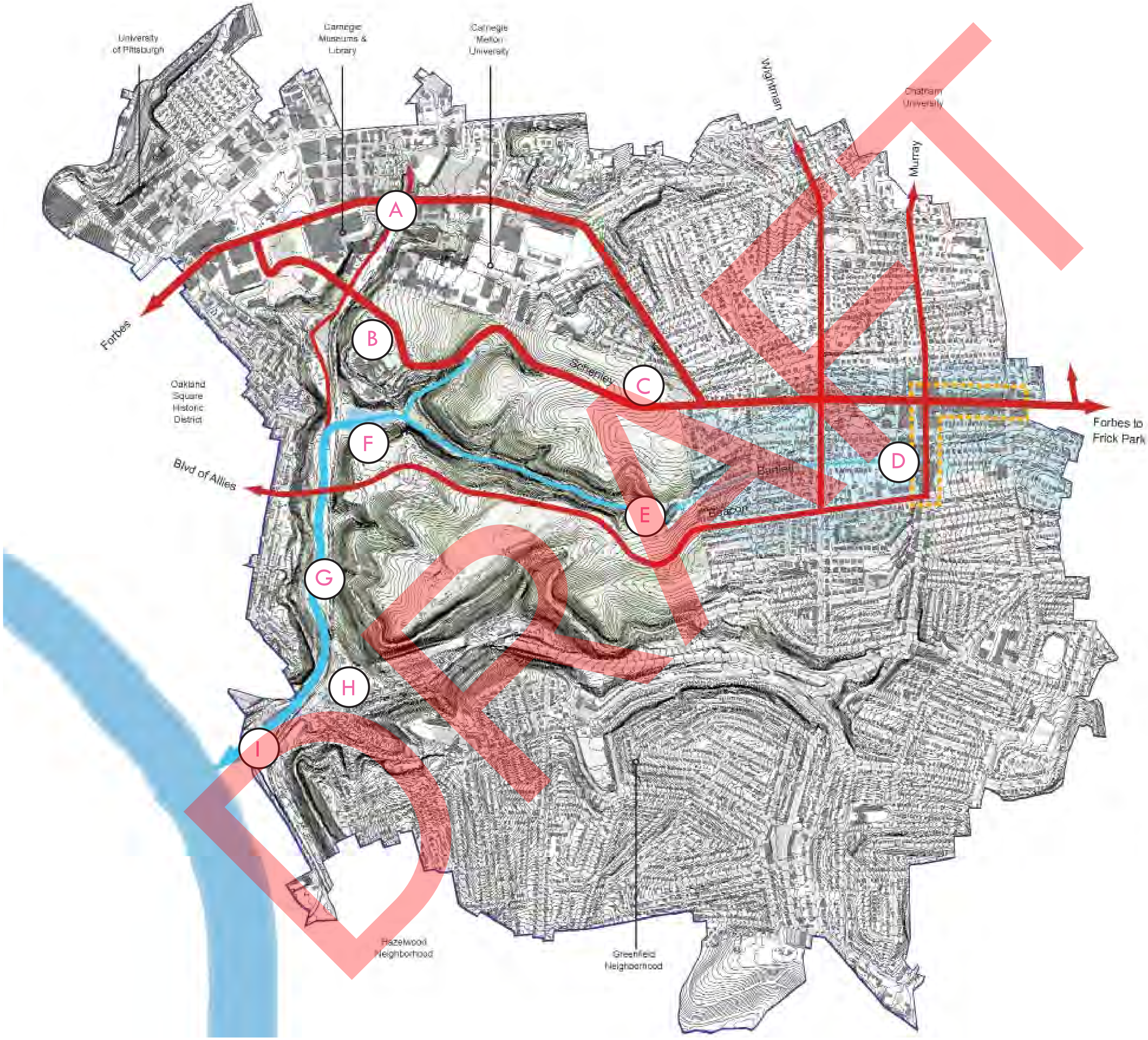


The Four Mile Run sewershed surrounds its greatest asset for green infrastructure: Schenley Park. The Park is well positioned within the sewershed to accept stormwater from the combined system in Squirrel Hill. Corridors through and nearby the park are already being targeted as future Complete Streets. Junction Hollow provides high volume capture potential and could accommodate a connection to the river.

- Flood Control At The Run (Lower Junction Hollow)
- Restore Squirrel Hill Runoff Into Schenley Park
- Schenley Park Ecological Restoration Opportunities
- Institutions Offer Partnership and Research Opportunities
- Junction Hollow Has Large Capture Potential
- Flagstaff Hill GI Education and Demostration
- Schenley Drive + Forbes as Park to Park Green Street
- Restore Panther Hollow Lake
- Riverfront Connection and Daylighted Stream

Runoff from green area restored to Panther Hollow Run.

FOUR MILE RUN URBAN DESIGN FRAMEWORK



A UNIVERSITIES DISTRICT

B FLAGSTAFF HILL

C FORBES AVENUE + SCHENLEY DRIVE

D SQUIRREL HILL

E PANTHER HOLLOW RUN

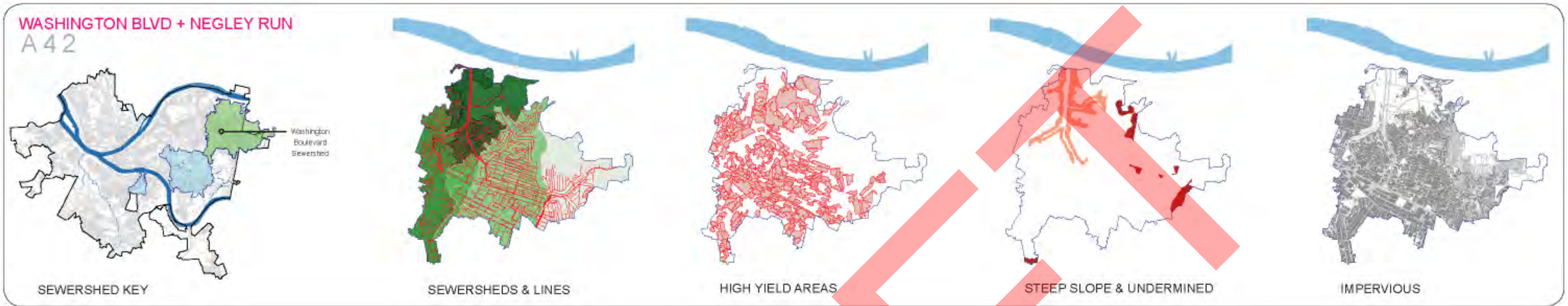
F PANTHER HOLLOW LAKE

G JUNCTION HOLLOW

H THE RUN (LOWER JUNCTION HOLLOW)

I RIVERFRONT CONNECTION

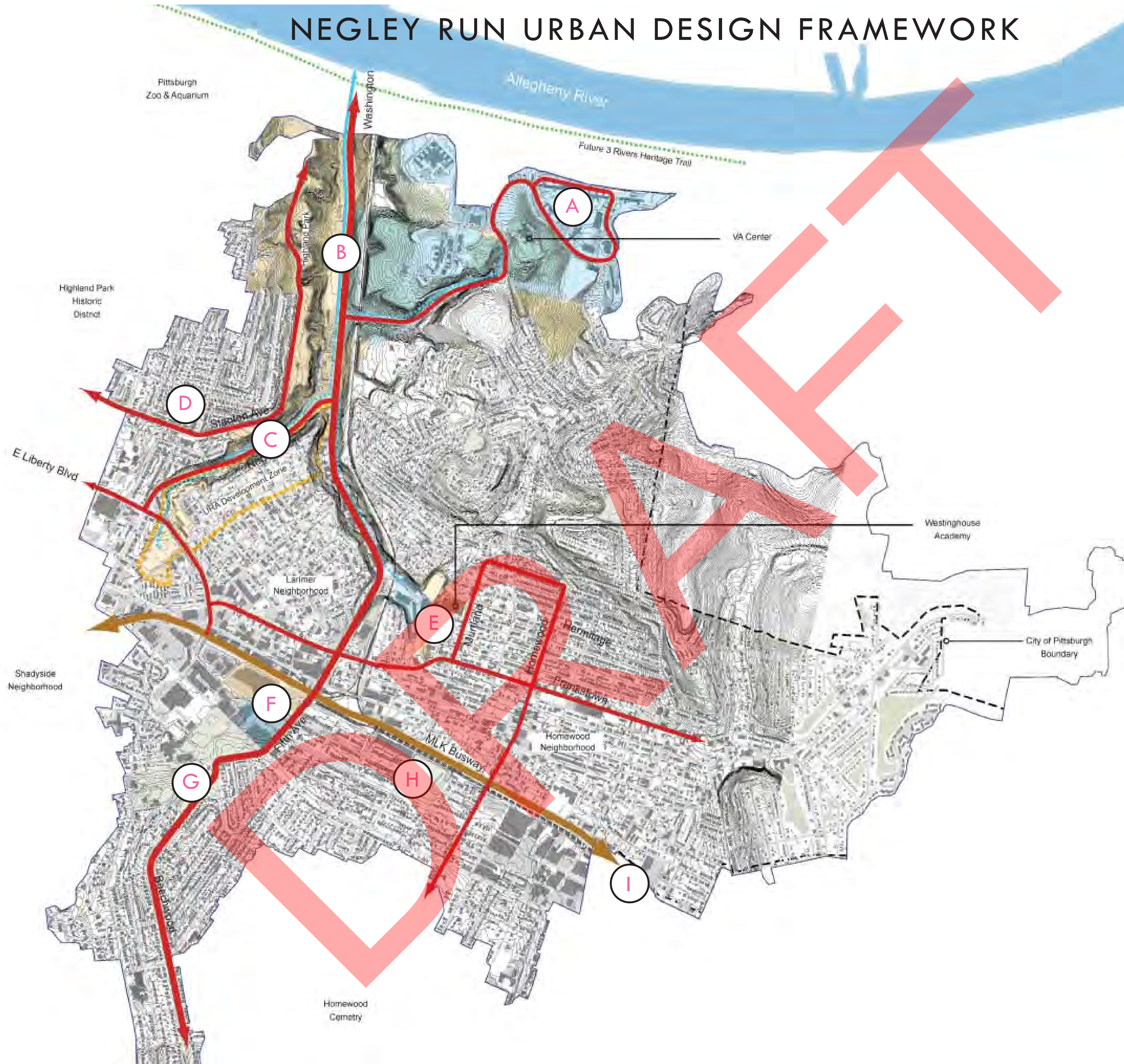
NEGLEY RUN OPPORTUNITIES AND CONSTRAINTS



The Washington Boulevard and Negley Run Sewershed has large-scale stormwater capture areas. Key development corridors and site specific projects like Westinghouse Academy can revitalize portions of Homewood. Strong potential partnerships for workforce development exist at the former VA Hospital, the VA Center, Job Corps, and the Shuman Juvenile Detention Center.

- Workforce Training at VA Campus
- Reduce Flooding at Washington Boulevard
- Washington Boulevard Large Capture Potential
- Highland Collects and Negley Run Conveys
- Westinghouse Academy | Silver Lake Neighborhood Revitalization
- Reduce Impervious Area on MLK Busway and Fifth Avenue Parking Lots
- Beechwood Conveys to Mellon Park
- Westinghouse Park Capture Potential
- 7800 Susquhanna Training and Demostration

NEGLEY RUN URBAN DESIGN FRAMEWORK



Ⓐ VA CAMPUS

Ⓑ WASHINGTON BOULVEVARD

Ⓒ NEGLEY RUN

Ⓓ HIGHLAND PARK

Ⓔ WESTINGHOUSE ACADEMY

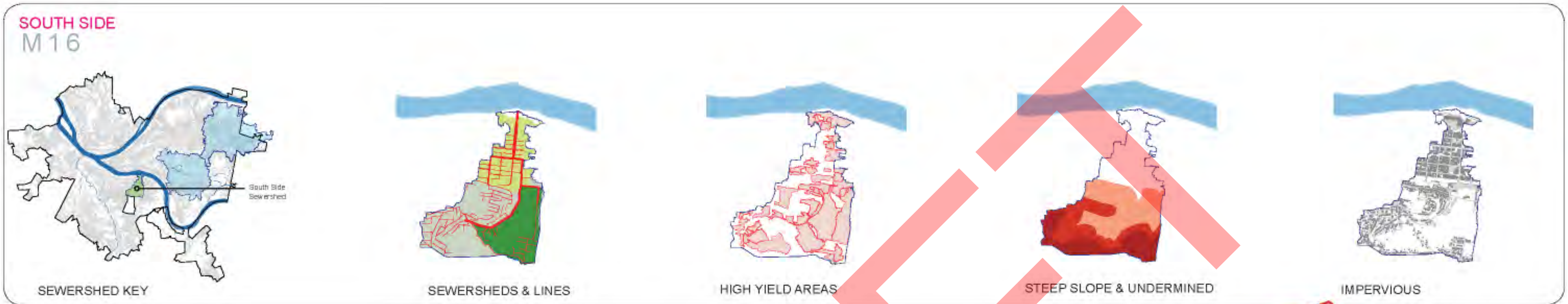
Ⓕ MLK BUSWAY AND FIFTH AVE PARKING LOTS

Ⓖ BEECHWOOD AND MELLON PARK

Ⓗ WESTINGHOUSE PARK

Ⓘ 7800 SUSQUEHANNA

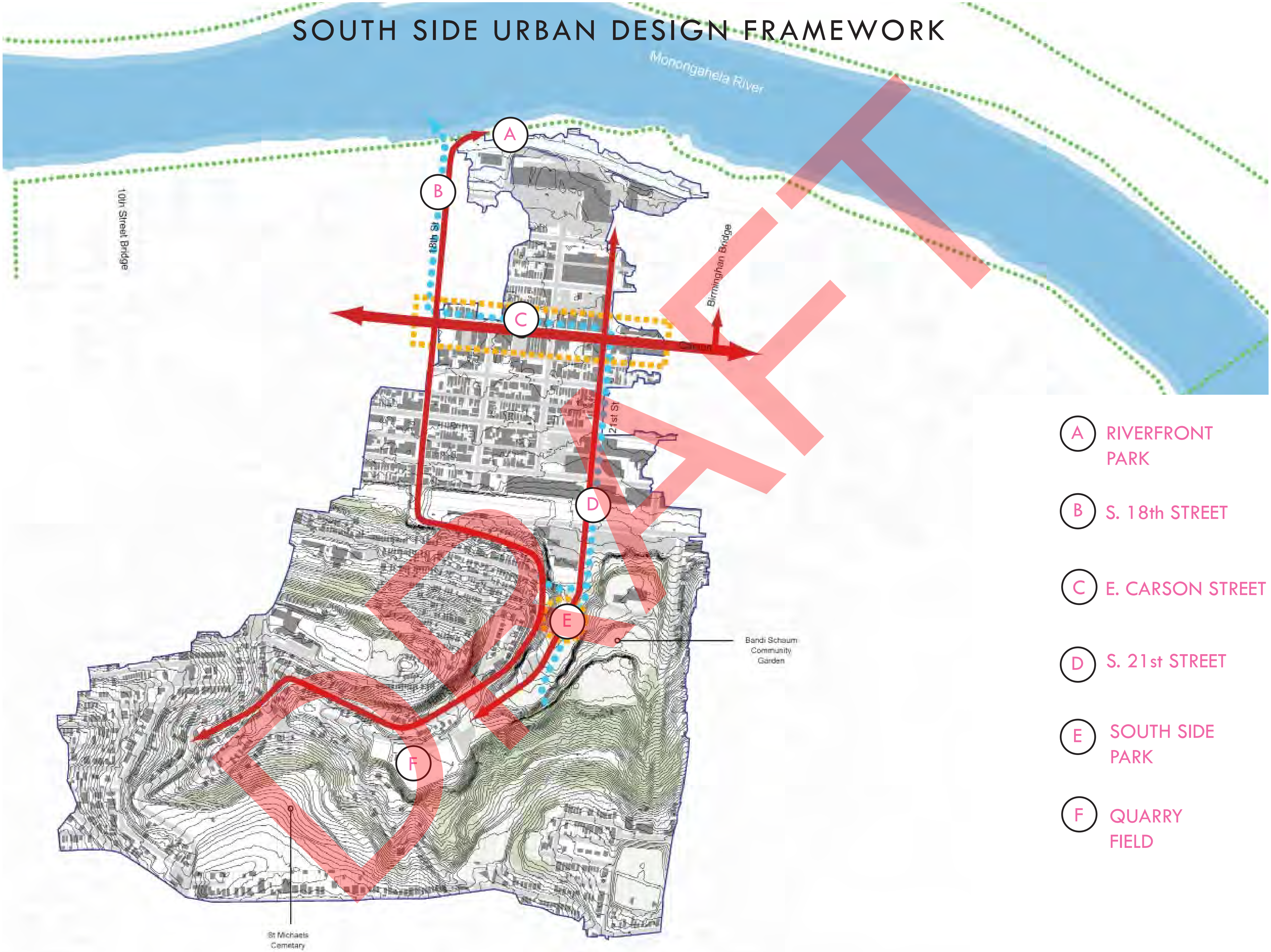
SOUTH SIDE OPPORTUNITIES AND CONSTRAINTS



South Side Park has the potential to capture a large quantity of stormwater. South 21st Street can convey this stored water as the first of three major corridors, including Carson Street (a major mixed use pedestrian oriented retail corridor), and South 18th Street, which already has an existing railroad crossing and connection to the Riverfront. Existing access to the river is unique among the priority sewersheds and it provides a great opportunity for an enhanced riverfront connection or potential daylighting of spring fed flow from South Side Park.

- Existing Riverfront Connection at South 18th Street
- Carson Street As a Greener/Pedestrian Friendly Retail Corridor
- Leverage Proposed Investment by PennDOT in Carson
- South 21st Street Extends from Existing Valley of South Side Park
- South Side Park Has Large Capture Areas
- Reduce Paving in South Side Park

SOUTH SIDE URBAN DESIGN FRAMEWORK



A RIVERFRONT PARK

B S. 18th STREET

C E. CARSON STREET

D S. 21st STREET

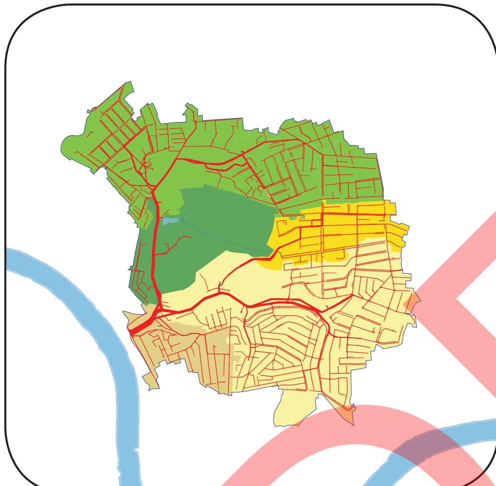
E SOUTH SIDE PARK

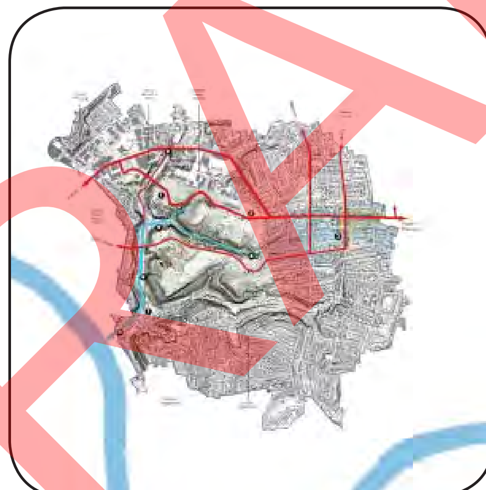
F QUARRY FIELD

GREEN INFRASTRUCTURE CONCEPT PLANS

Design principles established in the Framework plan, and opportunities and constraints identified in the existing conditions analysis, sets the stage for successful selection of individual projects and for concept plans to emerge. Ways to leverage the opportunities identified in Framework were woven into a larger vision that creates neighborhood nodes and corridors, and links community assets with interconnected GI strategies. This sewershed-based, systems approach uses urban planning and community revitalization to shape the Green Infrastructure Concept Plans; serving as a catalyst for a broader vision that can be implemented. A true collaboration will require City leadership, community, and stakeholder members to be an integral part of the process moving forward towards implementation opportunities.

...link community assets with interconnected GI strategies, serving as a catalyst for a broader vision...





REFINE FRAMEWORK, DEVELOP GI CONCEPT PLAN & OPPORTUNITIES:

individual project areas
+
GI strategies
+
catalytic revitalization

1 → 2 → 3

STEP ONE
EXISTING CONDITIONS ANALYSIS

STEP TWO
URBAN DESIGN FRAMEWORK

STEP THREE
GI CONCEPT PLANS

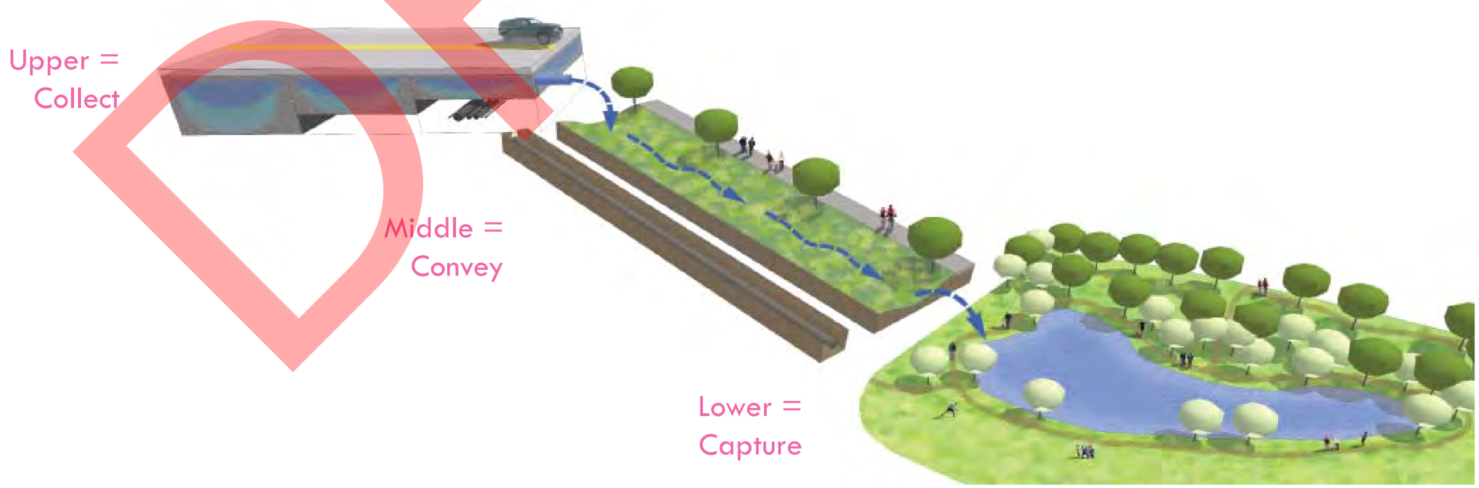
POSITION IN SEWERSHED INFORMS GI APPROACH

The upper portions of the sewershed, “Upland Neighborhoods,” are often more developed with more impervious areas, making them suited for pervious pavement opportunities that can also convey runoff down the system. Upper portions are most effective at collecting runoff since they often contain numerous high yield areas and high amounts of impervious surface. When these areas are not in the public realm, public-private partnerships could be developed to expand opportunities.

In the middle portions of the sewershed, or “Tributary Gateways,” conveyance becomes more of a priority. Runoff collected in the upper sewershed as well as high yield areas within the middle zone provide the stormwater flow carried by the conveyance system. Ideally this conveyance is accomplished with bioswales where street widths can be narrowed or within existing valleys through more natural settings like parks. Where steeper slopes exist, check dams are provided to slow the velocity and erosive power of water and provide storage volume as well. Many of the existing valleys would benefit from ecological restoration that reduce the amount of sediment washing into the system in addition to offering more resilient and diverse habitats. Where bioswales are not possible, pervious pavements can be utilized to convey runoff through highly porous gravels and supplemental underdrain pipes.

The lower portions, “Greenway Boulevards” provide great opportunities to provide larger capture basins for the runoff that is collected and conveyed from the upper and middle portions. Many of these areas offer large, more gradually sloped areas in publicly owned parks or open space. These are ideal locations for storage. When practical, this should enhance the connection to the riverfront.

...As the team identified opportunities and concepts for GI in the priority sewersheds the position of the study area within the sewershed played an important role.



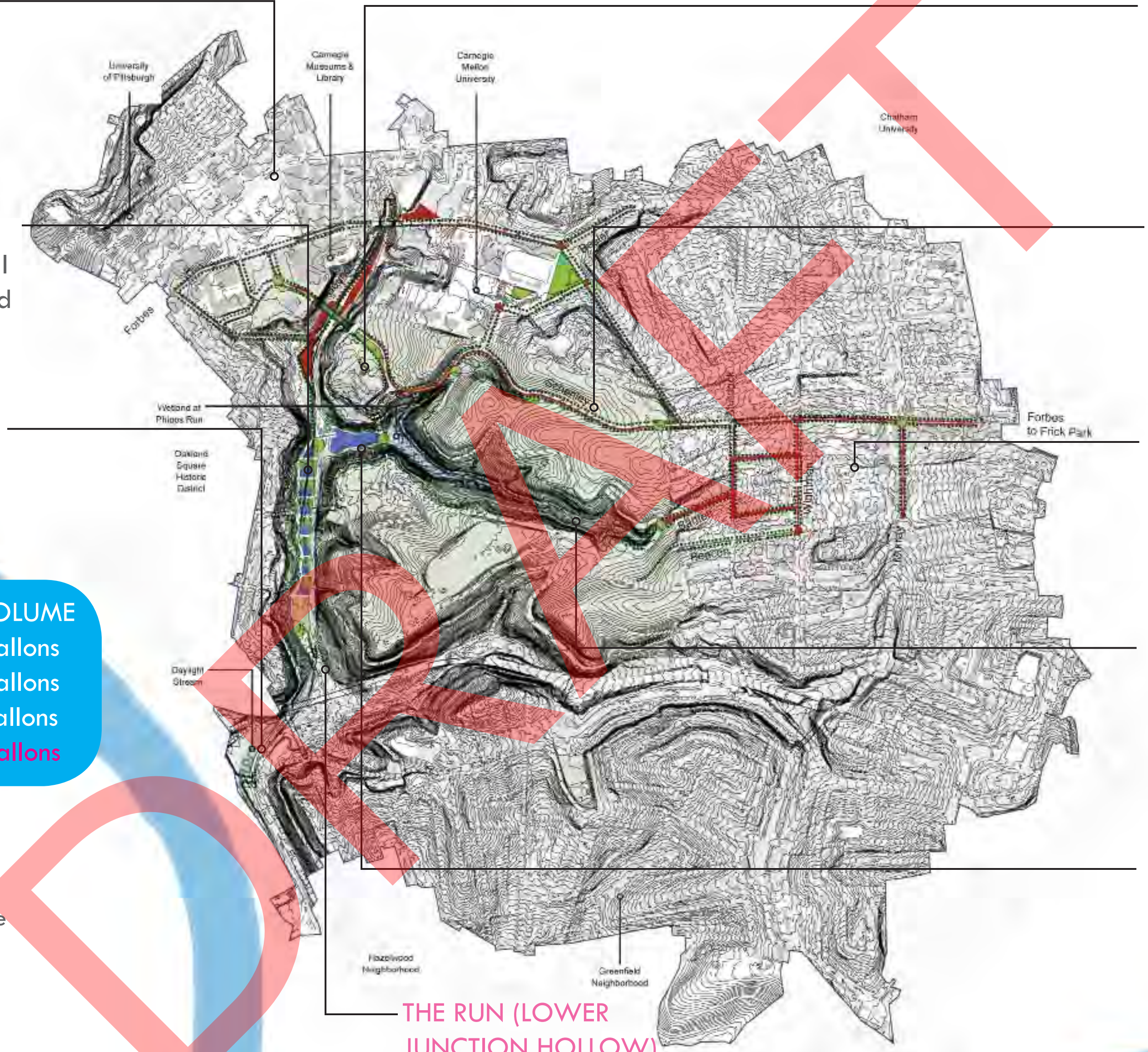
FOUR MILE RUN CONCEPTS AND OPPORTUNITIES

This concept looks to redirect stormwater runoff from the Squirrel Hill neighborhood into Schenley Park while also making improvements to the public realm of the neighborhood: specifically, the business district at Squirrel Hill and the wide gateway boulevards leading to the park. Schenley Drive and the parking area around Phipps Conservatory can become a highly-visible green demonstration site and a Complete Street. Junction Hollow has a potential to capture large volumes of stormwater. In addition, daylighting this stream provides a great amenity connecting neighborhoods to parks and to the riverfront.

Bird's eye of the Four Mile Run sewershed overlaid with proposed green infrastructure.

FOUR MILE RUN GREEN INFRASTRUCTURE

Connects park,institutions, people & riverfront



UNIVERSITIES DISTRICT
Public/Private Partnerships and Monitoring
6.7 M Gallons Capture Potential

JUNCTION HOLLOW
Large Capture Potential and Park Expansion and
12.1 M Gallons Capture Potential

Riverfront Connection/ Stream Daylighiting

FLAGSTAFF HILL
Highly Visible, GI Demonstration and Education
2.1 M Gallons Capture Potential

SCHENLEY DRIVE + FORBES AVENUE
Park to Park Complete Street
0.3 M Gallons Capture Potential

SQUIRREL HILL
Enhance Public Realm at Business District and Reconnect Runoff to Park
2.3 M Gallons Capture Potential

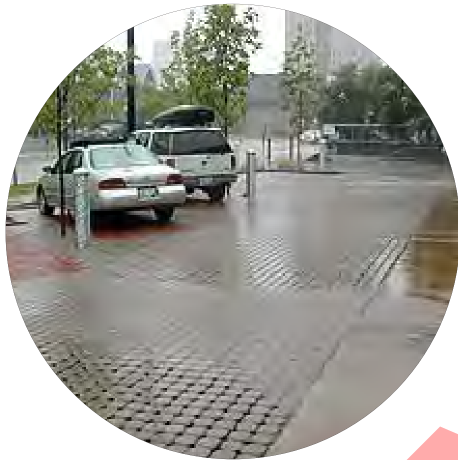
PANTHER HOLLOW RUN
Ecological Restoration and Watershed Reconnection
1.0 M Gallons Capture Potential

PANTHER HOLLOW LAKE
Restoring an Amenity for Park and Community
1.3 M Gallons Capture Potential

THE RUN (LOWER JUNCTION HOLLOW)
Reduce Flooding in Residential Areas

POTENTIAL CAPTURE VOLUME	
Pervious	6.8 M Gallons
Bioswale	4.3 M Gallons
Detention	14.7 M Gallons
TOTAL	25.8 M Gallons

LEGEND
- Pervious Collection
- Bioswale Conveyance
- Detention Capture
- Node and Extension
- Ecological Restoration
- Existing Park



UNIVERSITIES DISTRICT

The Universities District in the upper portion of the sewershed is a dense urban area with high percentage of impervious area. Forbes Avenue offers a great opportunity for a Complete Street with GI. The Universities and Cultural Institutions offers partnerships for additional GI opportunities. More specifically, the recreation fields at Forbes Ave. and Beeler St. could provide capture potential. The research and monitoring opportunities offered by these institutions should be nurtured further. The runoff of these upland areas should be collected and conveyed to the upper end of Junction Hollow. Within this valley Boundary/Neville Street provides opportunity for capture and conveyance. Large surface parking lots in this area offer further opportunities for pervious pavement and subsurface capture. Public-private partnerships should be explored where lots are located on privately-owned land.

FLAGSTAFF HILL AND SCHENLEY DRIVE

Schenley Drive at Flagstaff Hill has the opportunity to provide an expanded, highly visible demonstration and education project for GI that would provide opportunities to partner with adjacent institutions: Pittsburgh Parks Conservancy, Phipps Conservatory & the Center for Sustainable Landscapes, Carnegie Mellon University, and University of Pittsburgh. Pervious pavement and reduced pavement in Schenley Drive would enhance the entry and parking experience for visitors.

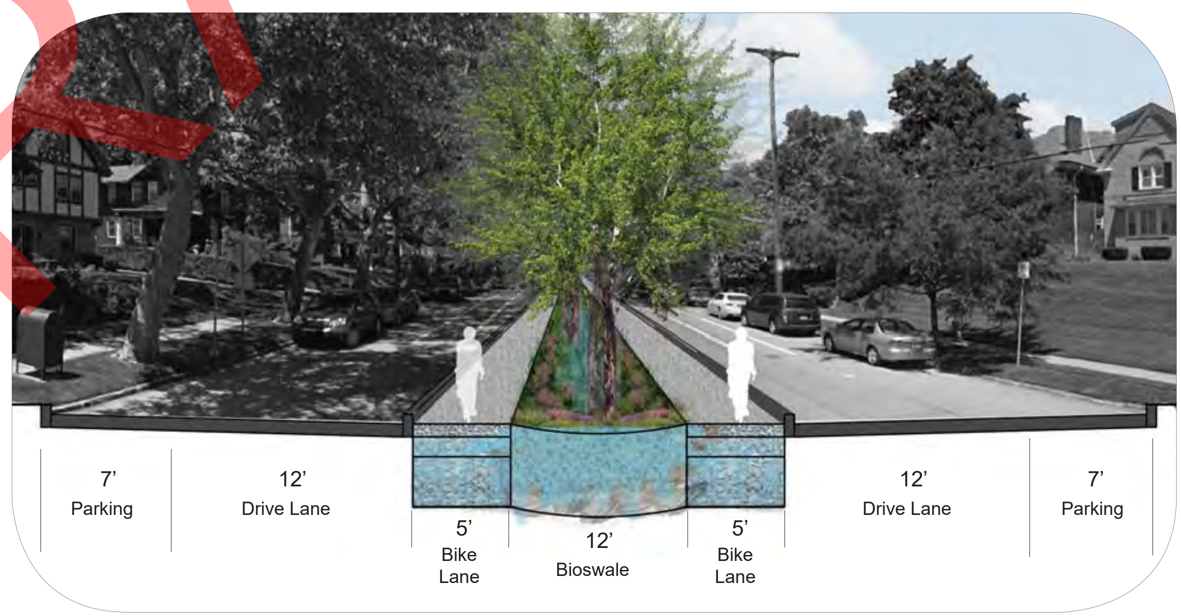
East of Flagstaff Hill on Schenley Drive, the addition of pervious pavement and reduction of pavement can be continued, increasing the capture and storage potential and continuing the work of the Schenley Drive Green Street Plan design effort. Paralleling this street, Phipps Run would benefit from ecological restoration and additional check dams and small wetland capture areas could be provided.

SQUIRREL HILL

As Schenley Drive transitions into Forbes Avenue, a more urban approach can be taken with pervious pavement collecting and conveying runoff from the vibrant Squirrel Hill business district. In addition, the reduced CSO improvements to this streetscape would improve the pedestrian and biking experience, along with providing an enhanced park-to-park green street between Schenley and Frick Parks. The intersection of Murray and Forbes Avenues can be the nucleus of these improvements.

High-yield capture areas within the Squirrel Hill neighborhood are concentrated near the business-focused corridors of Forbes and Murray Ave. Runoff captured is conveyed from the business district through the neighborhood to Schenley Park's Panther Hollow Run. The pavement of Wightman Street could be reduced to accommodate a bioswale with adjacent bike lanes. Pervious streets like Murdoch St., with its existing stone cobbles, could further collect and convey runoff to Bartlett St. Bartlett St. is the low point of the existing valley and runoff from Squirrel Hill flows towards Panther Hollow Run.

WIGHTMAN - BEFORE



WIGHTMAN - AFTER




PANTHER HOLLOW RUN

Runoff from Squirrel Hill would be reintroduced to Panther Hollow Run at Bartlett St., along the west edge of the park. Panther Hollow would benefit from ecological restoration and reintroducing runoff back into the system would be done carefully, overtime, as the valley is restored. Additional opportunities could include capturing and storing runoff for irrigation at the adjacent golf course. At the lower end of the Hollow an existing low slope area would make an ideal wetland for capture and cleaning runoff from both Phipps Run and Panther Hollow Run prior to entering Panther Hollow Lake.

PANTHER HOLLOW LAKE

Dredging Panther Hollow Lake would increase its storage potential and begin to restore the natural systems and diversity of the lake. Additional capture storage could be provided as "freeboard" above the normal lake level. Combined with efforts upstream, the goal would be to restore the lake as a usable amenity for park users. The estimated 68 million gallons of annual flow coming from Panther Hollow Lake can be diverted from the combined sewer system and brought to the surface to serve as baseflow for a daylighted stream in an ecologically engineered channel.

FOUR MILE RUN GREEN INFRASTRUCTURE VISUALIZATION

JUNCTION HOLLOW

This daylighted stream would run through Junction Hollow. Junction Hollow's gentler slopes and broad profile offer large volumes of capture potential. North of Panther Hollow Lake there are large parking areas and streets that can store water beneath pervious pavement. South of Panther Hollow Lake capture is accomplished with storage sites and constructed wetlands. The character of storage can be defined from additional input from the community, providing opportunity for additional park programming. The recreation field at the lower end of Junction Hollow also offers capture potential.

RIVERFRONT CONNECTIVITY

In an effort to address an important City-wide guiding principle seeking direct riverfront connectivity, a partnership with the Almono Development team would help overcome challenges to providing a daylit stream corridor from Junction Hollow Run to the Monogahela River. There is further opportunity to use the existing parcel and surface parking lots bounded by 2nd Street, Saline Street, and Interstate 376 in this effort.

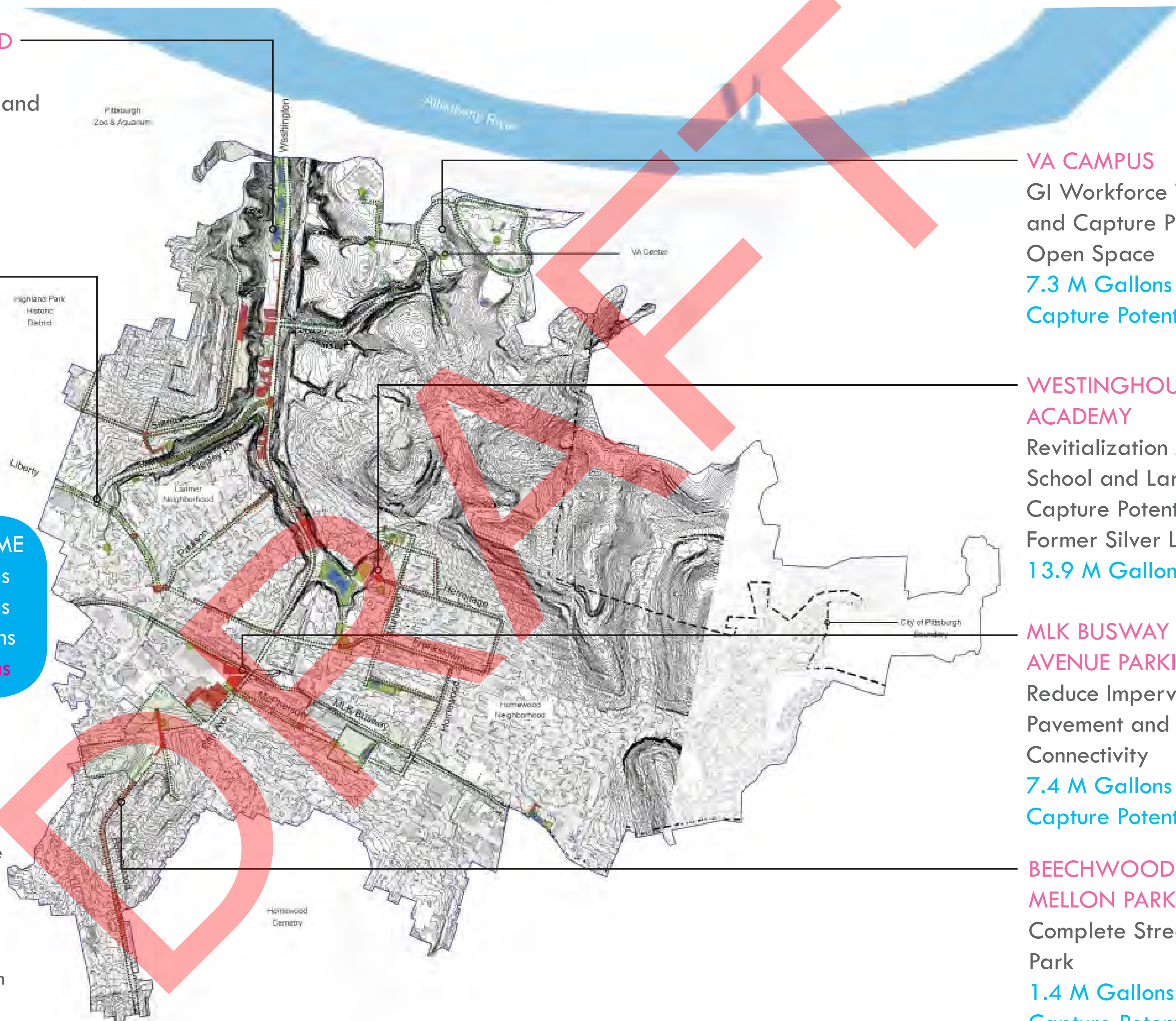
The collective whole of the corridors, public open space, and runs improve the connectivity between institutions, neighborhoods, and other assets surrounding the park. They also offer an enhanced connection to the riverfront.

Washington Boulevard has potential pervious pavement and storage sites closer to the River. At the west side of this sewershed in the Highland Park neighborhood, Stanton Avenue and other streets around the Dilworth Academy can capture stormwater. Below and adjacent at Negley Run, East Liberty Boulevard's existing medians could be converted for capture and conveyance. In the Lincoln-Lemington neighborhood, adjacent to the Allegheny River bluffs, there is significant opportunity to team with one of several institutions on workforce development programming. Streets radiating from Westinghouse Academy can convey rainwater and serve as catalyst for revitalization. Large-scale pervious pavement opportunities exist around the bus terminal and busway. Beechwood Blvd. can capture and convey to storage in Mellon Park.

Bird's eye of the Negley Run sewershed overlaid with proposed green infrastructure.

NEGLEY RUN GREEN INFRASTRUCTURE

A catalyst for workforce development and revitalization



WASHINGTON BOULEVARD
Large Capture Potential, Reduce Impervious Parking and Reduce Flooding
13.6 M Gallons Capture Potential

STANTON/NEGLEY RUN
Stanton and E. Liberty Blvd. Collect and Convey to Negley Run Blvd.
4.6 M Gallons Capture Potential

POTENTIAL CAPTURE VOLUME	
Pervious	12.2 M Gallons
Bioswale	4.6 M Gallons
Detention	31.4 M Gallons
TOTAL	48.2 M Gallons

LEGEND

- Pervious Collection
- Bioswale Conveyance
- Detention Capture
- Node and Extension
- Ecological Restoration
- Existing Park

VA CAMPUS
GI Workforce Training and Capture Potential in Open Space
7.3 M Gallons Capture Potential

WESTINGHOUSE ACADEMY
Revitalization Around School and Large Capture Potential at Former Silver Lake
13.9 M Gallons

MLK BUSWAY AND FIFTH AVENUE PARKING LOTS
Reduce Impervious Pavement and Improve Connectivity
7.4 M Gallons Capture Potential

BEECHWOOD BLVD/ MELLON PARK
Complete Street Conveys to Park
1.4 M Gallons Capture Potential

NEGLEY RUN GREEN INFRASTRUCTURE VISUALIZATION




HIGHLAND PARK / STANTON AVE

The Highland Park neighborhood has a number of high yield areas, and streets like Stanton Ave., Highland Ave., and Heberton St. can be used to collect and convey runoff to Negley Run Boulevard. Negley Run Blvd. is a good candidate for a Complete Street and construction is already underway for some GI improvements. Adjacent Negley Run Boulevard, a natural drainage channel can convey runoff from East Liberty Avenue. Proposed redevelopment in the Larimer neighborhood includes stormwater improvements that support this approach with community and stakeholder input

BEECHWOOD BLVD / MELLON PARK

Beechwood Boulevard provides an important connection to the south and offers opportunity as a Complete Street and to collect and convey runoff to Mellon Park. Westinghouse Park shares similar capture potential from surrounding streets like McPherson St.

MLK BUSWAY & ADJACENT PARKING LOTS

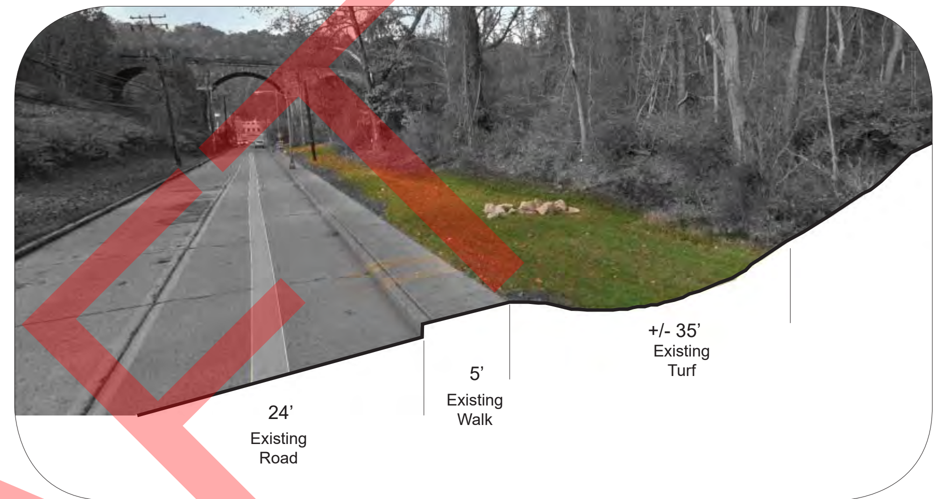
Pervious pavement and reduced impervious area would serve to collect runoff along the MLK Busway, bus terminal, and additional large surface parking lots at Chatham University - East Side Campus. Improvement to the Busway should also look to improve surrounding residents' access to public transportation.

WASHINGTON BOULEVARD

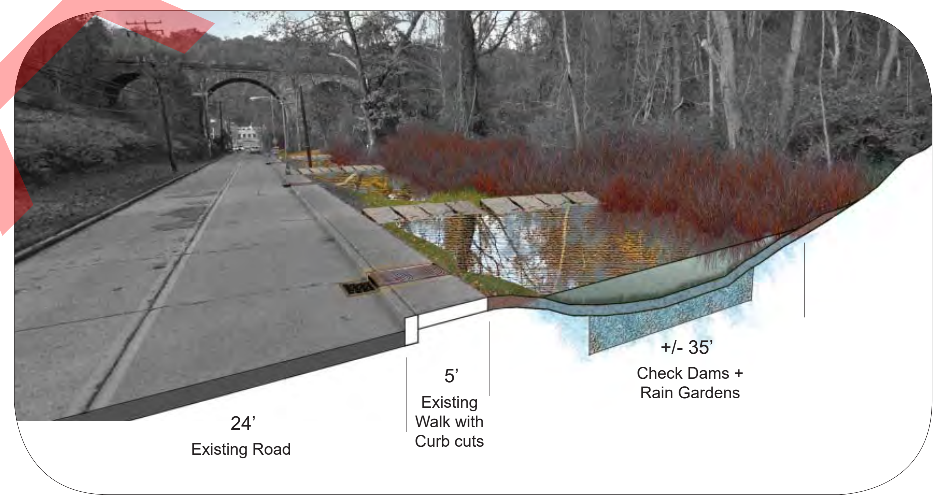
Washington Boulevard lies in the valley that serves as a convergence for the various sub-basins draining to it. The street itself has the potential to be a Complete Street. Large surface lots adjacent the City Police and Fire facilities, along with a bike track, offer pervious pavement and subsurface capture potential. Towards the northern edge of the valley, lower slopes and a broad profile offer high volumes for storage to the west of the Boulevard and can provide sedimentation capture areas to reduce the need for cleaning often clogged catch basins. A goal beyond the CSO reduction should be to reduce flooding in this low lying area. Proposed GI upstream from this will also improve this condition.

VA CAMPUS / HIGHLAND DRIVE

The area surrounding the VA Center, Juvenile Detention Center, and Job Corps west of Washington Boulevard offers a different approach for GI solutions thanks to larger areas of open space and undeveloped areas. Runoff from building and surface lots can be collected and conveyed to basins along Highland Drive where runoff is ultimately taken to Washington Boulevard (see section views below). Beyond the potential volumes of capture surrounding these institutions, they offer a tremendous opportunity for workforce training and development focused on GI and sustainable development.



Existing Cross Section: Highland Drive



Proposed Cross Section: Highland Drive with adjacent storage

HOMEWOOD / WESTINGHOUSE ACADEMY

The Westinghouse Academy and surrounding Homewood neighborhood provide a great opportunity to reinvest in the public realm and serve as catalyst for redevelopment: an approach that is supported by previous planning and community engagement efforts. Streets radiating out from the school like Hermitage St. and Murtland Ave. work to collect and convey stormwater downstream. Hermitage St. is also the location of a former school at Lang Avenue that could serve as a nucleus for redevelopment. The athletic field east of the school offers capture potential, along with the former Silver Lake site, now an industrial site. This large flat site provides a high volume of potential capture for storage sites, which could make a great amenity for the neighborhood. In short, GI reinvestment would serve as catalyst, or what can be referred to as Urban Acupuncture, to begin to revitalize Homewood.

- Westinghouse Academy A Nucleus for Public Realm Improvement
- Transit Oriented Development Within 5 Minute Walk
- Over 400 Vacant Lots within 5 Minute Radius = Infill Opportunity
- Large Number of Vacant Lots Offer Infill Opportunity
- Healthy, Walkable Corridors Connected to Transit
- Former Silver Lake Could Be Restored As Amenity and GI
- Hermitage School Could Take Advantage of Ssurrounding Public-Realm Improvements

URBAN ACUPUNCTURE FOR HOMEWOOD + WESTINGHOUSE ACADEMY

1 COMMUNITY ASSETS

- **A** WESTINGHOUSE IS A NUCLEUS FOR NEIGHBORHOOD
- **B** YMCA NEARBY ON FRANKSTOWN
- **C** HERMITAGE SCHOOL COULD BE REDEVELOPED
- **D** COMMERCIAL BUILDINGS ON LANG
- **E** +/- 700 STRUCTURES WITHIN 5 MINUTES OF SCHOOL
- **F** +/- 450 VACANT LOTS WITHIN 5 MINUTES OF SCHOOL
- **G** MANY STREETS DRAIN TO ATHLETIC FIELD AND BELOW
- **H** EXISTING COMMUNITY GARDEN

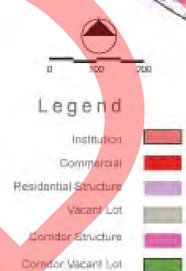
3 HOUSING INFILL + RENOVATE

- **1** PHASE 1 (MURTLAND) 41 VACANT LOTS + 33 STRUCTURES
- **2** PHASE 2 (HERMITAGE) 23 VACANT LOTS + 31 STRUCTURES
- **3** PHASE 3 (LANG) 63 VACANT LOTS + 25 STRUCTURES
- **4** PHASE 4 (FRANKSTOWN) 8 VACANT LOTS + 34 STRUCTURES
- **5** PHASE 5 (UPLAND/LINCOLN) 38 VACANT LOTS + 45 STRUCTURES

COMBINED - 175 VACANT LOTS & 170 STRUCTURES

WORKFORCE DEVELOPMENT AND TRAINING

5 MINUTE WALKING RADIUS



2015 COMMUNITY CONSENSUS VISION
Homewood Cluster Planning
Operation Better Block, Inc.

- Create Neighborhood Park on Lang Avenue
- Vacant Land for Stormwater If Flood Prone
- Infill Housing and Renovate Existing Stock
- Provide Small Parks and Community Gardens
- Renovate Hermitage School
- Provide Mixed-Use on Lang Avenue

DRAFT

2 HEALTHY CORRIDORS

PUBLIC REALM REINVESTMENT A CATALYST FOR GROWTH
GREEN INFRASTRUCTURE AND COMPLETE STREETS
HEALTHIER WALKABLE COMMUNITY
ACCESS TO TRAILS AND OUTDOOR AMENITIES
OPPORTUNITIES TO INTERACT WITH NATURE
IMPROVED SAFETY FOR PEDESTRIANS AND CYCLISTS
BETTER ACCESS TO HEALTHY FOOD

4 TRANSIT LINES

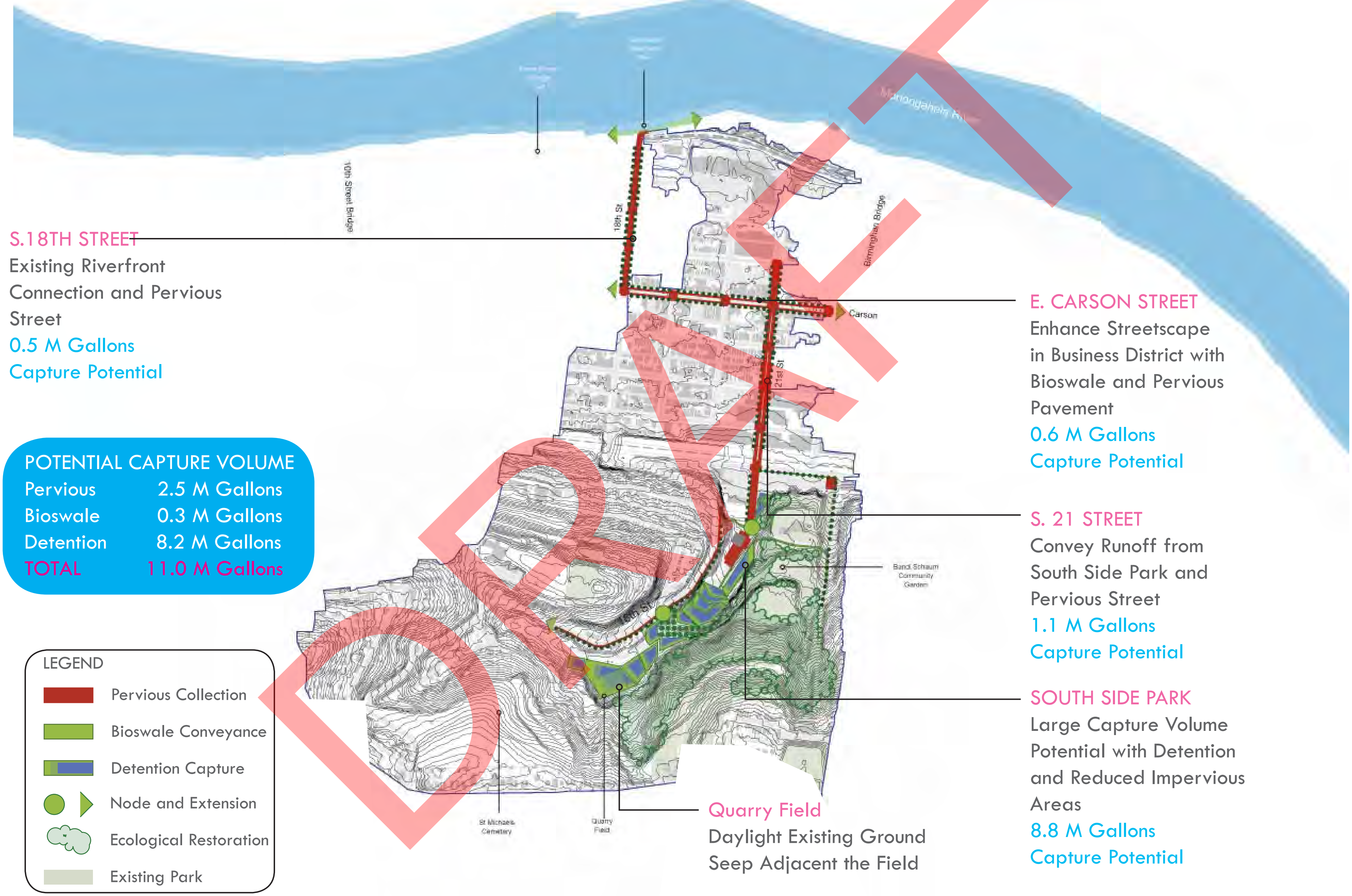
IMPROVED CONNECTION TO TRANSIT ON FRANKSTOWN
TRANSIT ORIENTED DEVELOPMENT (TOD)
EXPAND POSSIBLE FUNDING STREAMS
BUSWAY AND TERMINAL WITHIN 10 MINUTE
IMPROVED ACCESS TO JOBS AND HIGHER EDUCATION
NEW CONNECTION TO TRANSIT ON WASHINGTON

SOUTH SIDE CONCEPTS AND OPPORTUNITIES

South Side Park has the potential to capture large volumes of stormwater along its western edge, including Quarry Field. Here groundwater seeps could be daylighted through the park. From the park, South 21st Street can convey water north utilizing pervious pavement and green street improvements. At E Carson Street, bioswales and pervious pavement convey the stormwater west to South 18th Street. Along the vibrant mixed-use street, Carson improvements should be coordinated with future PennDOT projects to improve the pedestrian experience and safety. South 18th Street provides the final connection to the existing riverfront via an at-grade railroad crossing.

SOUTH SIDE GREEN INFRASTRUCTURE

Park to riverfront connection enhances Carson Street district



S.18TH STREET
Existing Riverfront Connection and Pervious Street
0.5 M Gallons Capture Potential

E. CARSON STREET
Enhance Streetscape in Business District with Bioswale and Pervious Pavement
0.6 M Gallons Capture Potential

S. 21 STREET
Convey Runoff from South Side Park and Pervious Street
1.1 M Gallons Capture Potential

SOUTH SIDE PARK
Large Capture Volume Potential with Detention and Reduced Impervious Areas
8.8 M Gallons Capture Potential

Quarry Field
Daylight Existing Ground Seep Adjacent the Field

POTENTIAL CAPTURE VOLUME	
Pervious	2.5 M Gallons
Bioswale	0.3 M Gallons
Detention	8.2 M Gallons
TOTAL	11.0 M Gallons

LEGEND
- Pervious Collection
- Bioswale Conveyance
- Detention Capture
- Node and Extension
- Ecological Restoration
- Existing Park

SOUTH SIDE GREEN INFRASTRUCTURE VISUALIZATION

SOUTH 18TH STREET

The existing riverfront connection at South 18th Street is unique in comparison to the other priority sewersheds; enhancing this connection will further strengthen awareness of the Riverfront Park, highlight connectivity for people throughout the sewershed, and allow the completion of a green infrastructure conveyance system or a daylighted stream flow that begins in South Side Park.

SOUTH 21ST STREET

GI has been proposed in South 21st Street in redevelopment plans and is supported by the community. The gentle slope of the street lends itself to the introduction of pervious pavement and additional GI in the street. South 21st Street connects Carson to South Side Park and should be considered as a green boulevard and gateway to an underutilized portion of the park.

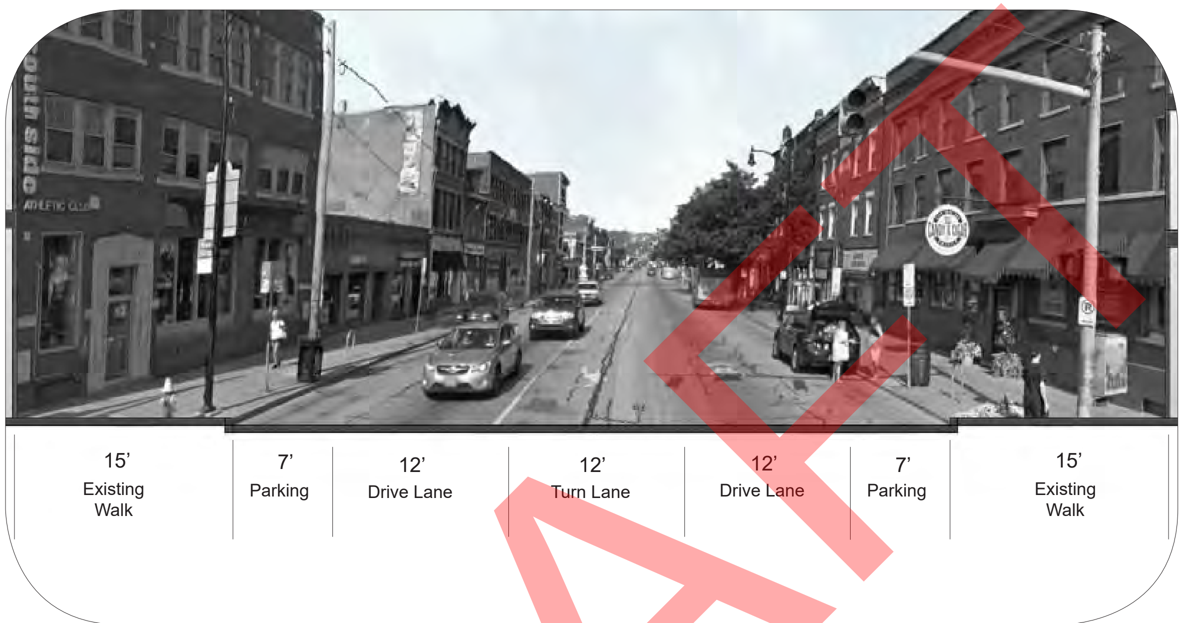
SOUTH SIDE GREEN INFRASTRUCTURE VISUALIZATION

MLK BUSWAY & ADJACENT PARKING LOTS

South Side Park is a critical area for CSO reduction in the sewershed. It contains large areas of high yield in addition to providing areas for large storage volumes. These storage sites are placed within the existing valley on the western edge of park. The lower slopes and broad cross-section of this valley accommodate a series of stepped ponds. Quarry Field is at the upper reaches of the valley and the adjacent hillside groundwater seep could serve as baseflow for a daylighted stream that continues down the valley. At the base of the valley where South 21st Street terminates, existing unused parking lots could be depaved or transformed to pervious pavement. This area at the base of the valley has also been discussed as a potential site for a PWSA Operations Center that would be integrated into the environmental education programming in the park, complementing GI concepts in this sewershed.

EAST CARSON STREET

E Carson Street serves as the nucleus for retail in the South Side neighborhood. This vibrant street would be improved by making it more pedestrian and bike friendly. As PennDOT looks to make improvements on this state highway, GI should be incorporated. The existing street width and sidewalks accommodate the introduction of a center bioswale and pervious pavement would further reduce runoff and collection and capture opportunities (see section views on following page). E Carson Street connects with South 21st Street, four blocks to the west of South 18th Street.



Existing Cross Section: East Carson Street

Proposed Cross Section: East Carson Street with integrated green infrastructure

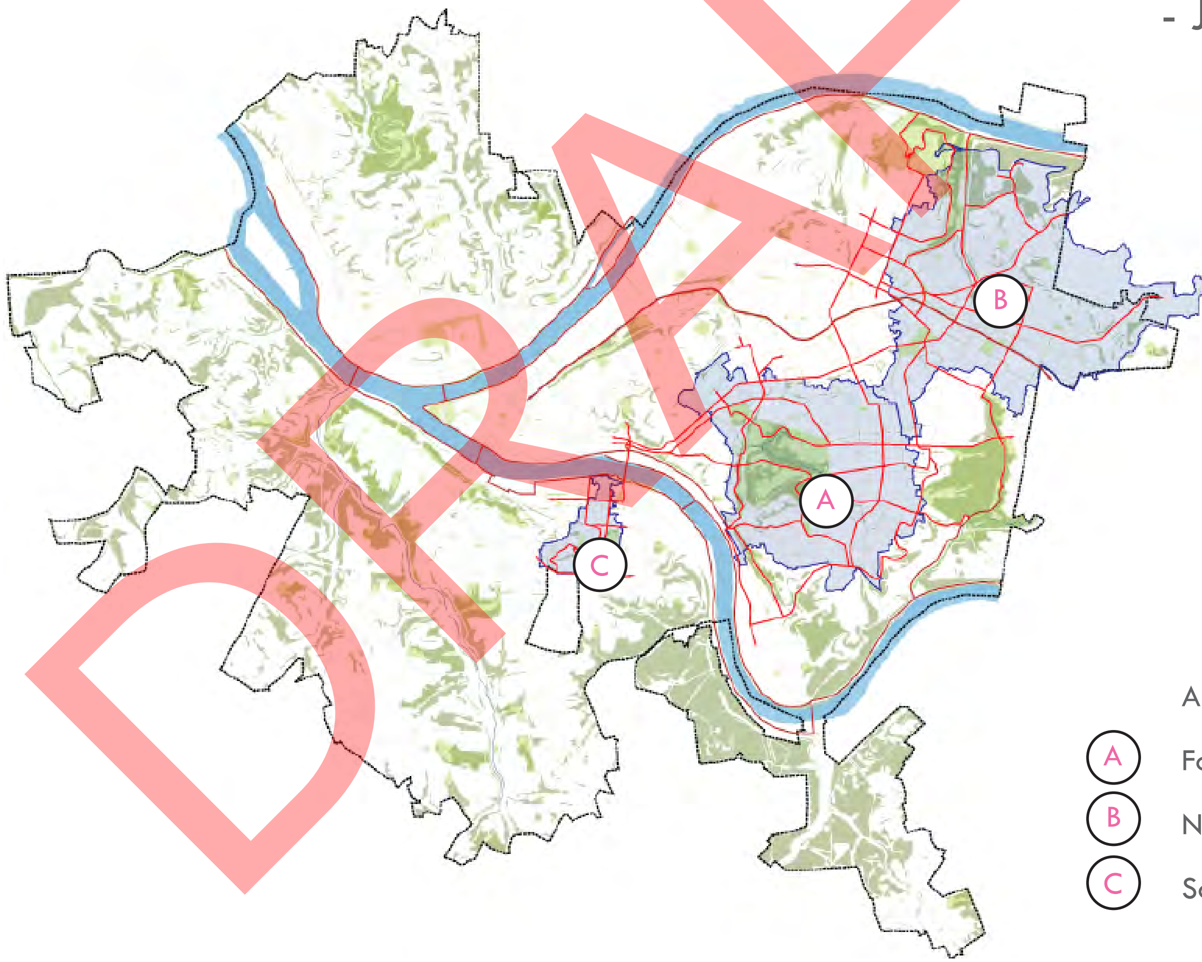
KIT OF PARTS ENHANCES ADAPTABILITY OF CONCEPTS

GI concepts will be refined in the next stage using a "kit of parts approach" with this approach multiple opportunities exist that best suit the needs of each area. Within the upper portion of the sewershed the kit of parts would focus on collection. Here pervious pavement shifts the constraint of traditional concrete and asphalt roadways (impervious surfaces) that shed stormwater as runoff and provides opportunities where pervious solutions help to reduce runoff from these surfaces by allowing stormwater to be absorbed into the ground and subsurface capture areas. Examples include pervious concrete, the use of non-rigid pavers, and open-celled pavers. Bioswales are constructed, linear depressions intended to convey stormwater towards a drainage feature, or intercept flow along the length of a parking lot or green field. Bioswales encourage infiltration into the groundwater aquifer, and help to filter containments out of stormwater prior to overflow in the larger capture areas Detention areas are basins used for capture, often vegetated with native plants, they are not designed to permit permanent impoundment of water, instead the are designed to detain the volume for up to 48 hours. The basin is designed with aggregate below the topsoil to hold stormwater and not drown plant material. These basins serve watersheds larger than two acres.

REPLICATION IN OTHER SEWERSHEDS

As the City looks to expand opportunities for "regenerative green infrastructure" into other sewersheds around Pittsburgh, the approach outlined in the document can be easily replicated. A process that first identifies opportunities and constraints based on existing conditions and other collaborative planning efforts, then synthesizes this information into priority nodes and community assets that are connected with GI corridors, and finally, identifies individual projects and GI strategies that make the City more resilient while also revitalizing communities.

"Designing a dream city is easy,
rebuilding a living one takes imagination."
- Jane Jacobs



	AREA/SEWERSHED	OUTFALL
A	Four Mile Run	M-29
B	Negley Run	A-42
C	South Side	M-16

DRAFT

END OF DOCUMENT

APPENDIX H
DETAILED TBL BENEFIT CALCULATIONS AND RESULTS

This appendix details the various TBL calculations to calculate the various TBL benefit values and also includes sewershed by sewershed TBL benefit calculation results. Much of the calculation detail in this appendix was provided directly from AutoCASE.

<u>Carbon Emission by Vegetation:</u>
<u>Air Pollution by Vegetation:</u>

To quantifying the value of changes in Air Pollution and Carbon Emissions involves the quantification of changing emissions due to energy usage, materials usage, and a change in vegetation.

1. Energy usage, avoided electricity, natural gas, propane, and diesel are used to estimate reductions in carbon dioxide and other air pollution. Location-specific data is drawn upon so that the appropriate electricity grid emissions factors are used in estimating these changes (e.g., a grid that is highly reliant on coal plants would have much higher emissions factors than a grid that uses a high proportion of renewable energy).
2. New vegetation can remove both carbon dioxide and air pollution from the atmosphere. If trees are being planted, the # of new trees is input into a model that incorporates tree growth, light exposure, size, health, and lifespan to calculate sequestration rates for each year of the analysis. That value is summed with any sequestration taking place by any green roofs, herbaceous plants, shrubs, and grassy areas planted as part of the project.
3. Carbon emissions, the use of concrete can lead to a large amount of emissions during the construction phase. Similarly, while a green roof can sequester carbon through the life of the roof, the materials required to build a green roof lead to an increase in carbon emissions over that of a traditional roof.
4. Furthermore, the soil the newly planted vegetation is growing in has the ability to store large amounts of carbon over the lifetime of the project. These factors, along with the negative impact of maintenance activities, are all taken into account when modeling changes in carbon emissions and air pollution in AutoCASE.

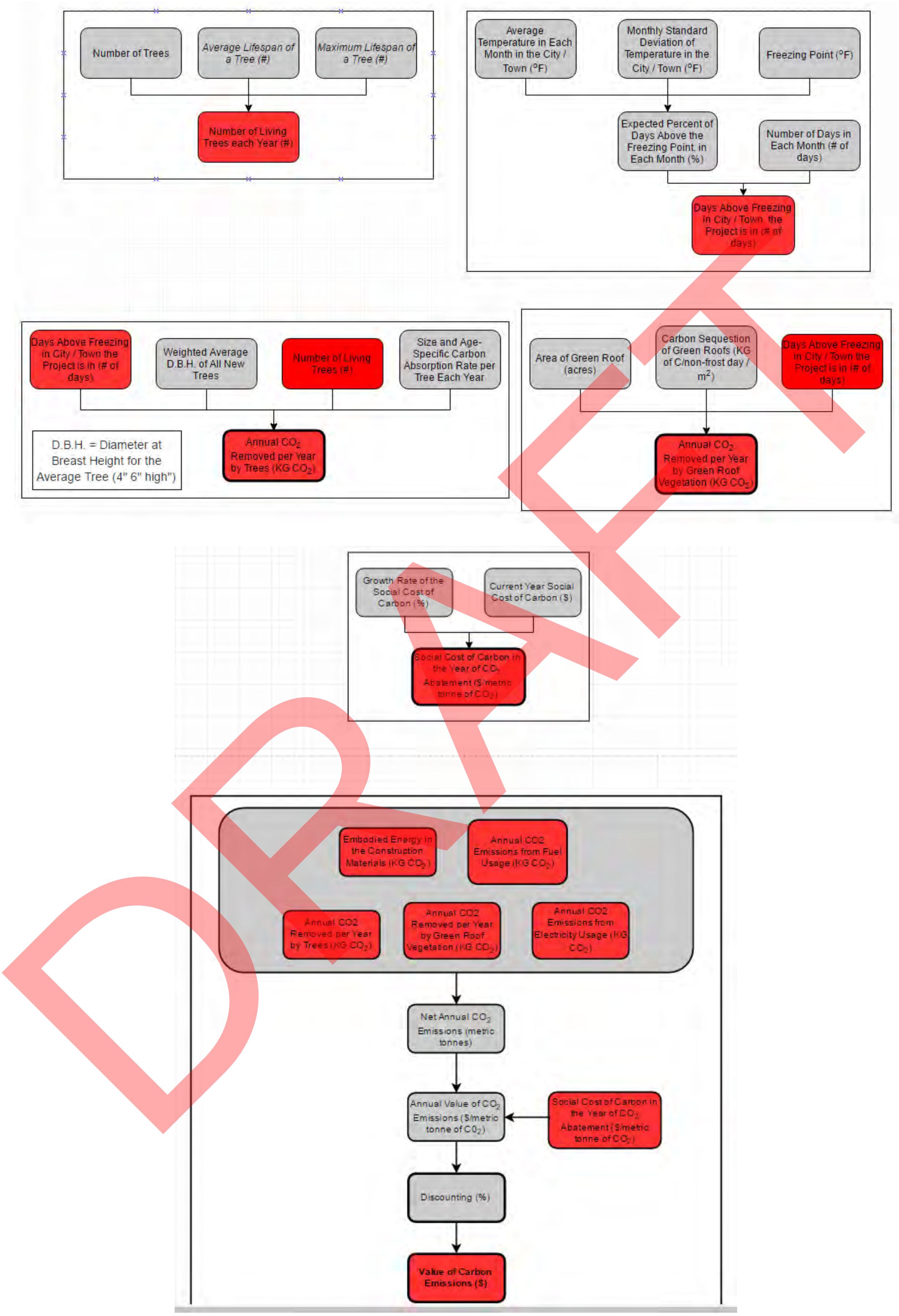
Carbon and Air Pollutant Emissions Analysis additional factors:

1. Calculation methodology

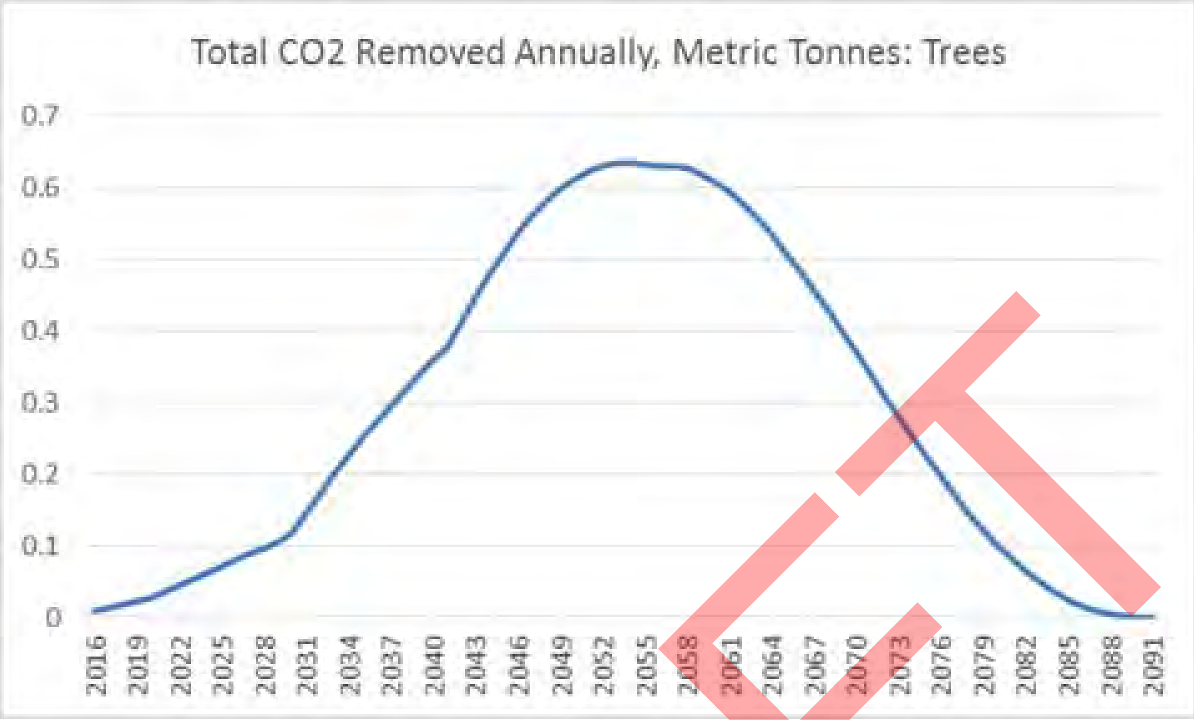
   For trees: It's not an equation, refer below structure chart for an understanding of how it works. Additionally iTree which uses a similar methodology can be referred. There are a number of factors that affect carbon sequestration and air pollution:

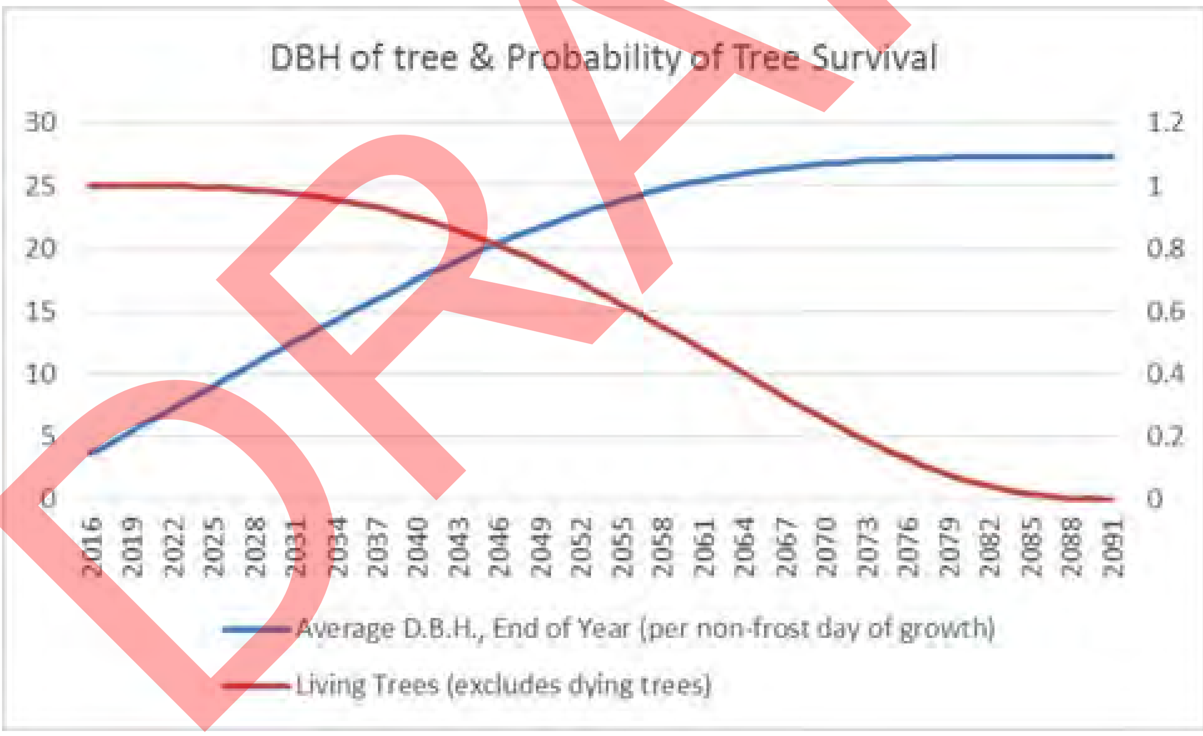
   - Tree size
   - Average Age
   - Max Age
   - Weather Patterns

   What is not shown in the structure charts above is that sequestration occurs over time, and is determined by probabilities of the state of trees planted over time. For other vegetation – static rates for carbon and air pollution per non-frost day.



Number of Trees
Average Lifespan of a Tree (#)
Maximum Lifespan of a Tree (#)
Number of Living Trees each Year (#)
Average Temperature in Each Month in the City / Town (°F)
Monthly Standard Deviation of Temperature in the City / Town (°F)
Freezing Point (°F)
Expected Percent of Days Above the Freezing Point in Each Month (%)
Number of Days in Each Month (# of days)
Days Above Freezing in City / Town the Project is in (# of days)
Days Above Freezing in City / Town the Project is in (# of days)
Weighted Average D.B.H. of All New Trees
Number of Living Trees (#)
Size and Age-Specific Carbon Absorption Rate per Tree Each Year
D.B.H. = Diameter at Breast Height for the Average Tree (4" 6" high")
Annual CO_2 Removed per Year by Trees (KG CO_2)
Area of Green Roof (acres)
Carbon Sequestion of Green Roofs (KG of C/non-frost day / m^2)
Days Above Freezing in City / Town the Project is in (# of days)
Annual CO_2 Removed per Year by Green Roof Vegetation (KG CO_2)
Growth Rate of the Social Cost of Carbon (%)
Current Year Social Cost of Carbon ($)
Social Cost of Carbon in the Year of CO_2 Abatement ($/metric tonne of CO_2)
Embodied Energy in the Construction Materials (KG CO_2)
Annual CO2 Emissions from Fuel Usage (KG CO_2)
Annual CO2 Removed per Year by Trees (KG CO_2)
Annual CO2 Removed per Year by Green Roof Vegetation (KG CO_2)
Annual CO2 Emissions from Electricity Usage (KG CO_2)
Net Annual CO_2 Emissions (metric tonnes)
Annual Value of CO_2 Emissions ($/metric tonne of CO_2)
Social Cost of Carbon in the Year of CO_2 Abatement ($/metric tonne of CO_2)
Discounting (%)
Value of Carbon Emissions ($)


Total CO2 Removed Annually, Metric Tonnes: Trees
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2016 2019 2022 2025 2028 2031 2034 2037 2040 2043 2046 2049 2052 2055 2058 2061 2064 2067 2070 2073 2076 2079 2082 2085 2088 2091


DBH of tree & Probability of Tree Survival
30
25
20
15
10
5
0
1.2
1
0.8
0.6
0.4
0.2
0
2016 2019 2022 2025 2028 2031 2034 2037 2040 2043 2046 2049 2052 2055 2058 2061 2064 2067 2070 2073 2076 2079 2082 2085 2088 2091
Average D.B.H., End of Year (per non-frost day of growth)
Living Trees (excludes dying trees)

Property Value:

The value is derived from variations in housing prices, which in some part reflect the value of local environmental attributes

1. The numbers of houses affected by the GI/LID/BMP area are city population and city area.
2. The city population divided by persons per household to get households.
3. Then take the ratio of GI/LID/BMP feature to city area as a scaling factor and apply that to the property uplift factor and also account for possible double counting.

   Example Calculation - a City of 100,000 people and 2.6 person per household = 40,000 households. Let's assume an average property value of $100,000. If there is 10 acres of green infrastructure in the 100 acre city area this would give a scaling factor of 10%. For a property uplift factor of 2.5% and a 50% possible double counting the uplift is 1.25%. So we would calculate the benefit as 40,000 * $100,000 * 10% * 1.25% = $5,000,000

A summary of the impacts on property prices as a result of LID projects			
Author(s) and Year	**Value from 100% Low Impact Design**		
-	**Low**	**Expected**	**High**
Ward et. al. (2008)	3.5%	4.3%	5.0%
Shultz and Schmitz (2008)	0.7%	1.1%	2.7%
Wachter and Wong (2006)		2.0%	
Anderson and Cordell (1988)	3.5%	4.0%	4.5%
Braden and Johnston (2003)	0.0%	2.5%	5.0%

Heat Island Effect:

Estimates of how much people are willing to pay for small reductions in their risks of dying from adverse health conditions that may be caused by the heat island effect instead of placing a dollar value on individual lives (II LLC 2014). EPA's Value Statistical Life (VSP) is commonly used and AutoCASE has modified version.

1. Determining reduced temperatures in the area as a result of the project
   i. The total of change in land cover, by land cover type, due to the project is divided by the total acres in the town/city that the project is being built in to calculate an overall percentage increase of each land cover type
2. Reduction in temperature is then used to determine avoided death over the life of the project (Minimum Mortality Temperature, or MMT)
3. The Value of Statistical Life (estimates of willingness to pay for small reductions in mortality risks) is used to quantify the benefit of reduced heat mortality rates
   i. Value of Statistical Life: Suppose each person in a sample of 100,000 people were asked how much he or she would be willing to pay for a reduction in their individual risk of dying of 1 in 100,000, or 0.001%, over the next year. Since this reduction in risk would mean that we would expect one fewer death among the sample of

100,000 people over the next year on average, this is sometimes described as "one statistical life saved." Now suppose that the average response to this hypothetical question was $100. Then the total dollar amount that the group would be willing to pay to save one statistical life in a year would be $100 per person × 100,000 people, or $10 million. (EPA 2016)

ii. $9.1 million (2012) is expected VSL with a range of $5.2 million to 12.9 Million

MM Heat Island Effect Analysis additional factor:

1. The initial land cover types for the project location determined by followings:

In an absolute analysis it is based on non-vegetated surface types, in the relative analysis it is based on the explicitly defined alternative surface type.

2. MMT calculation methodology (referred from provided information by AutoCASE

Heat mortality is based on the numbers from this study:

Curriero, F. C., Heiner, K. S., Samet, J. M., Zeger, S. L., Strug, L., & Patz, J. A. (2002). Temperature and mortality in 11 cities of the eastern United States

http://aje.oxfordjournals.org/content/155/1/80.full.pdf

The authors summarized the relative risk curves for mortality in relation to temperature with three variables: the temperature at which the estimated relative risk curves from the GAM achieved their minimum or minimum mortality temperature (MMT), the average slope of the estimated relative risk curves at temperatures lower than the MMT (cold slope), and the average slope of the curves at temperatures higher than the MMT (hot slope).

Here is the associated temperature mortality graph from said article showing the MMT (p83):

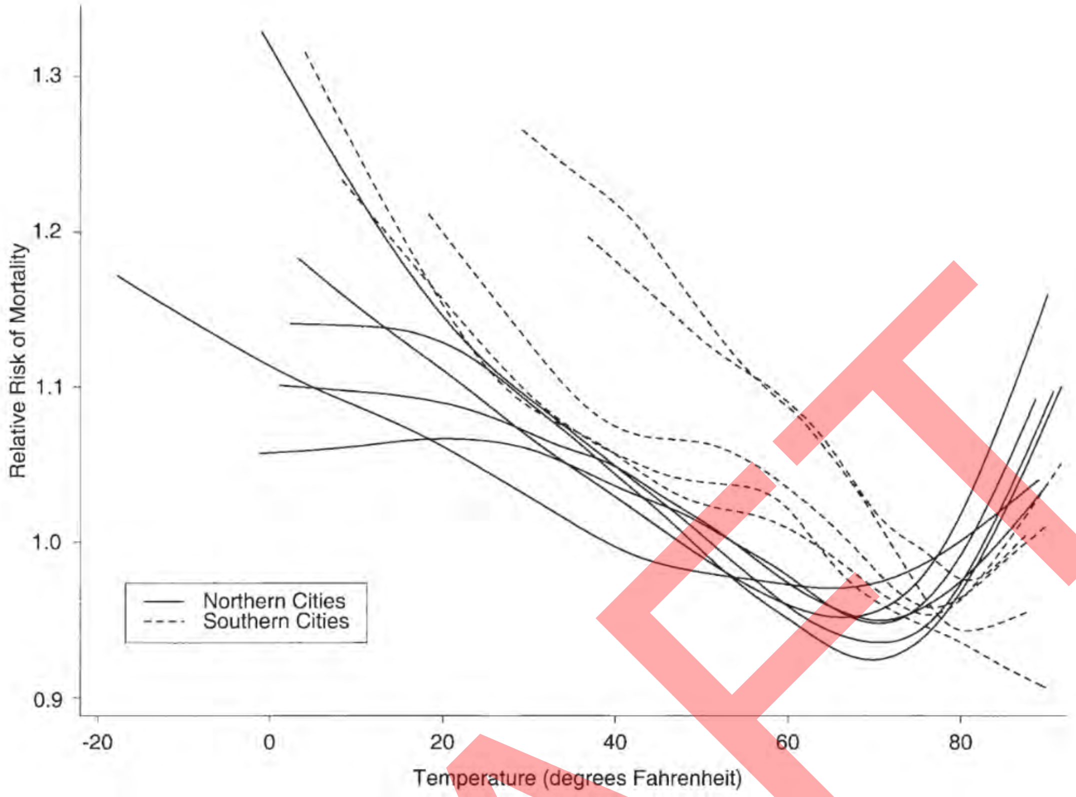
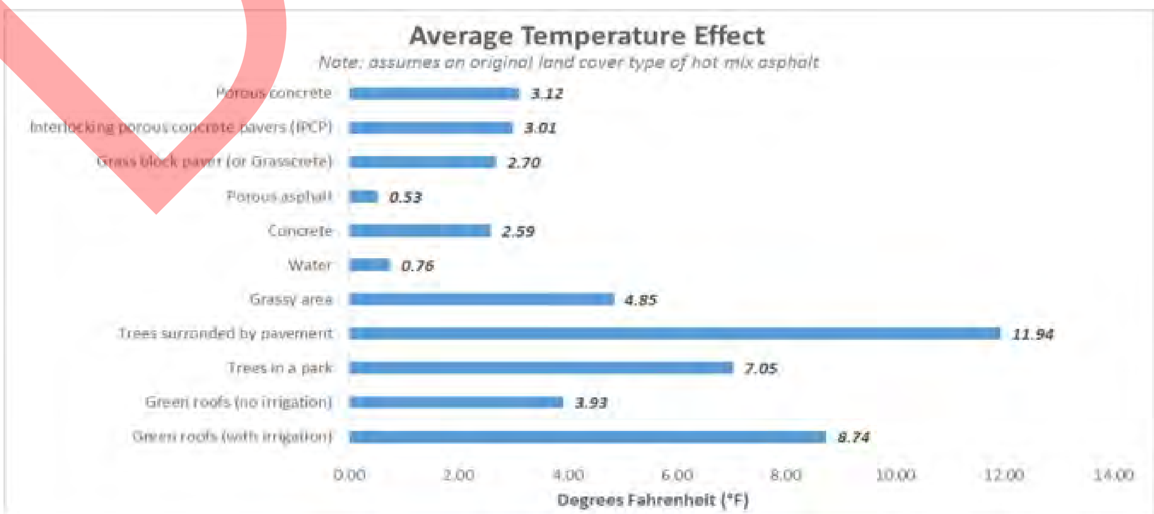


FIGURE 1. Temperature-mortality relative risk functions for 11 US cities, 1973–1994. Northern cities: Boston, Massachusetts; Chicago, Illinois; New York, New York; Philadelphia, Pennsylvania; Baltimore, Maryland; and Washington, DC. Southern cities: Charlotte, North Carolina; Atlanta, Georgia; Jacksonville, Florida; Tampa, Florida; and Miami, Florida. °C = 5/9 × (°F – 32).

Then AutoCASE conducted statistical analysis to determine the effect of latitude on heat mortality. They regressed the results from this study on the latitude because more southerly cities have a higher tolerance for hot weather. The relationship is linear but it is truncated to maintain reasonable values. For instance, it doesn't extrapolate to Alaska's latitude.

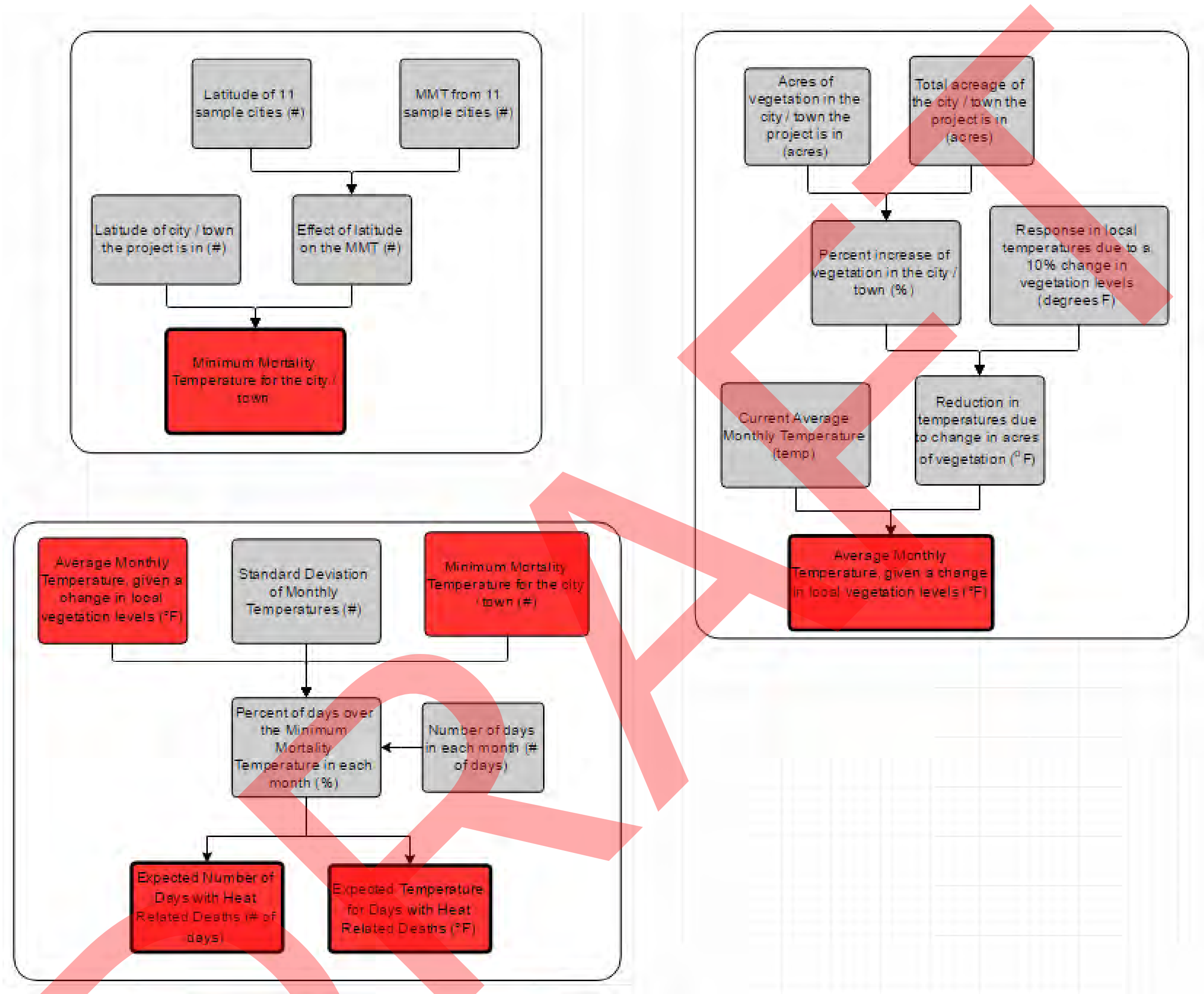
3. Types of land cover and their temperature reduction

All land cover types except for grey, impervious, and enclosed storage features count as green, so they all help. Calculations change based on land cover type; please see attached horizontal bar chart:



4. Heat Island Reduction systematic benefits
   Local temperatures and heat island reductions affect the MMT, which can change the probability of mortality, and this is valued by the statistical value of a life.

   This structure chart provides an overview:



Recreational Value:

Estimating the increased total user days expected after the project is constructed, then multiplying this value by the estimated WTP of users.

1. *Increased total user days per year, is based off of two inputs: the new users per year per acre and the number of days each new user will use the facility*

   i. # of new users per year per acre = Average population density of the city or town where the project is being constructed

   ii. # of days each user will use:
      Low value: 52 times per year
      Middle value (by PWD): 75.58 days per year
      High value: 104 times per year

iii. These three values shape a probability distribution from which a value is randomly taken for each iteration of the Monte Carlo simulation.

(# of days per user) *(# of new users per acre per year) = New user days/acre/year

iv. (WTP value) * (New user days per acre year) = Total Recreational Use value from the project

The WTP value is calculated using the US Army Corps of Engineers methodology, which evaluates qualitative responses into points, then translates points into dollars.

MM Recreational Value Analysis Additional Factor:

1. WTP (Willing to Pay)

It is based off of a study by the Army Corp of Engineers – it changes based on the answer to the questions in AutoCASE. Population density determines how many people will use recreational space, but WTP does not vary by project location.

There is a structure chart attached and you can look at http://planning.usace.army.mil/toolbox/library/EGMs/EGM15-03.pdf (The unit day value (UDV) method for estimating recreation benefits relies on expert or informed opinion and judgment to approximate the average willingness to pay of users of Federal or federally assisted recreation resources.) They have more detailed documentation from the USACE if needed.

Economic Water Quality:

AutoCASE has following methodology to generate economic benefit of Water Quality:

Runoff [Pollutant Loadings] (mg/L) = Source Runoff [Pollutant Loadings] (mg/L) * BMP [Pollutant Reduction Ratios]

Pollutant Loadings	Concentration	Concentration (Phosphorus Equivalents)	Abatement Costs (per lb)
Total Suspended Solids (mg/L)	292.13	N/A	0.19
Total Phosphorus (mg/L)	0.56	N/A	1.32
Total Nitrogen (mg/L)	3.25	N/A	-
Total Kjeldahl Nitrogen (mg/L)	2.52	N/A	1.17
Total Zinc (mg/L)	0.24	217.20	1.32
Dissolved Zinc (mg/L)	0.12	N/A	-
Total Lead (mg/L)	0.08	0.72	1.32
Dissolved Lead (mg/L	0.02	N/A	-
Total Copper (mg/L)	0.04	50.88	1.32
Dissolved Copper (mg/L)	0.02	N/A	-
Fecal Cloriform (#/L)	59,184.29	N/A	-

BMP	Total Suspended Solids (mg/L)	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Zinc (mg/L)	Dissolved Zinc (mg/L)	Total Lead (mg/L)	Dissolved Lead (mg/L	Total Copper (mg/L)	Dissolved Copper (mg/L)	Fecal Cloriform (#/L)
Porous Asphalt	0.23	0.51	1.46	0.47	0.26	0.27	0.18	1.00	0.60	0.97	1.00
Interlocking Porous Concrete Paver	0.23	0.51	1.46	0.47	0.26	0.27	0.18	1.00	0.60	0.97	1.00
Grass Block Paver	0.23	0.51	1.46	0.47	0.26	0.27	0.18	1.00	0.60	0.97	1.00
Porous Concrete	0.23	0.51	1.46	0.47	0.26	0.27	0.18	1.00	0.60	0.97	1.00
Road	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Driveways	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Sidewalk	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Parking Lot	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Other Asphalt	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Other Concrete	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rain Barrel	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cistern	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bioretention/Rain Garden	0.25	2.22	1.21	1.20	0.28	0.52	0.09	0.74	0.60	1.25	1.00
Constructed Wetland	0.35	0.83	0.60	0.88	0.40	0.40	0.51	1.09	0.49	0.69	0.21
Retention Pond	0.26	0.55	0.60	0.80	0.43	0.60	0.33	0.92	0.47	0.69	0.20
Dry Detention Pond	0.35	0.78	0.76	1.02	0.40	0.64	0.42	0.83	0.54	0.71	0.50
Vegetated Swales	0.71	1.36	0.86	0.99	0.62	0.53	0.68	0.66	0.75	0.77	0.98
Piping	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Green Roof	0.41	1.31	0.70	0.89	0.27	0.41	0.21	0.44	0.28	0.46	1.00
Grey Roof	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Infiltration Trench	0.35	0.83	0.60	0.88	0.40	0.40	0.51	1.09	0.49	0.69	0.21
Infiltration Basin	0.35	0.83	0.60	0.88	0.40	0.40	0.51	1.09	0.49	0.69	0.21
Vegetated Buffer Strip	0.41	1.31	0.70	0.89	0.27	0.41	0.21	0.44	0.28	0.46	1.00
Additional Trees	0.25	2.22	1.21	1.20	0.28	0.52	0.09	0.74	0.60	1.25	1.00
Additional Shrubs	0.25	2.22	1.21	1.20	0.28	0.52	0.09	0.74	0.60	1.25	1.00
Planter Boxes	0.25	2.22	1.21	1.20	0.28	0.52	0.09	0.74	0.60	1.25	1.00
Managed Turf	0.41	1.31	0.70	0.89	0.27	0.41	0.21	0.44	0.28	0.46	1.00
Unmanaged Turf	0.41	1.31	0.70	0.89	0.27	0.41	0.21	0.44	0.28	0.46	1.00
Undisturbed Land	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Impervious Surface	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Then,

Economic Benefit [Water Quality] ($) = Runoff [Pollutant Loadings] (mg per Liter) *Runoff [Volume] (Liter) *Monetization Factors [WWTP Abatement Costs] ($ per lb.) *2.2046e-6 (lb./mg)

Finally, the benefit was adjusted for construction phase which expected to show the progression of increase in water quality benefits. Refer excel calculator for this methodology for further detail.

Individual Sewershed Benefit Results:

The following section includes TBL benefit calculations broken down on a sewershed by sewershed basis. The results are listed separately for the two different scenarios.

Scenario 1: Lowered HGL Operation during Wet Weather Conditions including GI elements placed in 13 sewersheds with a total DCIA area managed of 1,286 acres.

A22:

A22	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$1,456,066	$1,093,991	$1,916,929
Carbon Reduction by Vegetation	$335,024	$145,138	$607,988
Flood Risk	$273,802,667	$156,458,667	$391,146,667
Heat Island Effect	$993,399	$600,750	$1,407,728
Property Value	$15,741,679	$10,621,375	$21,894,060
Recreational Value	$2,629,823	$2,073,214	$3,261,114
Economic Water Quality	$1,797,753	$1,534,369	$2,061,137
Total	***$296,756,411***	***$172,527,504***	***$422,295,623***

A41:

A41	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$762,194	$550,450	$1,007,262
Carbon Reduction by Vegetation	$178,859	$77,881	$326,273
Flood Risk	$94,758,067	$54,147,467	$135,368,667
Heat Island Effect	$509,386	$336,885	$741,641
Property Value	$4,915,900	$3,316,903	$6,837,201
Recreational Value	$1,373,767	$1,083,819	$1,704,820
Economic Water Quality	$934,035	$797,193	$1,070,878
Total	***$103,432,208***	***$60,310,597***	***$147,056,742***

A42:

A42	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$2,626,524	$1,896,856	$3,471,031
Carbon Reduction by Vegetation	$616,312	$268,363	$1,124,274
Flood Risk	$219,139,667	$125,222,667	$313,056,667
Heat Island Effect	$1,749,695	$1,158,765	$2,545,829
Property Value	$9,929,887	$6,699,987	$13,810,823
Recreational Value	$4,732,732	$3,733,838	$5,873,233
Economic Water Quality	$3,218,044	$2,746,577	$3,689,511
Total	***$242,012,861***	***$141,727,054***	***$343,571,367***

A48:

A48	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$226,226	$163,380	$298,966
Carbon Reduction by Vegetation	$52,949	$23,056	$96,589
Flood Risk	$46,080,067	$26,331,467	$65,828,667
Heat Island Effect	$151,364	$100,066	$220,420
Property Value	$986,156	$665,388	$1,371,579
Recreational Value	$408,488	$322,272	$506,926
Economic Water Quality	$277,292	$236,667	$317,917
Total	***$48,182,541***	***$27,842,296***	***$68,641,064***

A58:

A58	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$205,722	$148,570	$271,867
Carbon Reduction by Vegetation	$48,320	$21,040	$88,146
Flood Risk	$54,379,267	$31,073,867	$77,684,667
Heat Island Effect	$137,609	$90,971	$200,390
Property Value	$764,090	$515,554	$1,062,722
Recreational Value	$369,460	$291,482	$458,493
Economic Water Quality	$251,420	$214,585	$288,255
Total	***$56,155,887***	***$32,356,069***	***$80,054,539***

A60:

A60	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$237,130	$171,253	$313,374
Carbon Reduction by Vegetation	$55,721	$24,263	$101,647
Flood Risk	$62,527,733	$35,730,133	$89,325,333
Heat Island Effect	$158,604	$104,853	$230,961
Property Value	$676,509	$456,461	$940,912
Recreational Value	$426,700	$336,641	$529,527
Economic Water Quality	$290,559	$247,990	$333,128
Total	***$64,372,957***	***$37,071,594***	***$91,774,883***

M16:

M16	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$136,440	$98,536	$180,309
Carbon Reduction by Vegetation	$32,087	$13,972	$58,532
Flood Risk	$32,762,333	$18,721,333	$46,803,333
Heat Island Effect	$91,267	$60,332	$132,910
Property Value	$636,321	$429,345	$885,017
Recreational Value	$244,572	$192,953	$303,510
Economic Water Quality	$167,171	$142,679	$191,663
Total	***$34,070,192***	***$19,659,150***	***$48,555,274***

M19:

M19	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$161,287	$116,481	$213,146
Carbon Reduction by Vegetation	$37,766	$16,445	$68,893
Flood Risk	$53,652,200	$30,658,400	$76,646,000
Heat Island Effect	$107,923	$71,343	$157,163
Property Value	$673,566	$454,475	$936,818
Recreational Value	$291,405	$229,901	$361,628
Economic Water Quality	$197,686	$168,724	$226,649
Total	***$55,121,833***	***$31,715,769***	***$78,610,297***

M19A:

M19A	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$270,661	$195,470	$357,687
Carbon Reduction by Vegetation	$63,503	$27,651	$115,841
Flood Risk	$47,161,800	$26,949,600	$67,374,000
Heat Island Effect	$181,044	$119,691	$263,636
Property Value	$1,013,240	$683,663	$1,409,248
Recreational Value	$486,543	$383,853	$603,790
Economic Water Quality	$331,025	$282,528	$379,523
Total	***$49,507,816***	***$28,642,456***	***$70,503,725***

M19B:

M19B	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$57,365	$41,429	$75,810
Carbon Reduction by Vegetation	$13,416	$5,842	$24,474
Flood Risk	$7,244,067	$4,139,467	$10,348,667
Heat Island Effect	$38,395	$25,380	$55,916
Property Value	$101,083	$68,204	$140,589
Recreational Value	$104,073	$82,107	$129,153
Economic Water Quality	$70,318	$60,016	$80,620
Total	***$7,628,716***	***$4,422,444***	***$10,855,229***

M29:

M29	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$490,423	$354,180	$648,109
Carbon Reduction by Vegetation	$115,021	$50,084	$209,820
Flood Risk	$320,326,067	$183,043,467	$457,608,667
Heat Island Effect	$327,927	$216,832	$477,490
Property Value	$12,871,811	$8,684,990	$17,902,550
Recreational Value	$882,021	$695,861	$1,094,572
Economic Water Quality	$600,357	$512,400	$688,313
Total	***$335,613,626***	***$193,557,814***	***$478,629,521***

O27:

O27	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$236,071	$177,375	$310,792
Carbon Reduction by Vegetation	$55,431	$24,136	$101,117
Flood Risk	$73,779,533	$42,159,733	$105,399,333
Heat Island Effect	$161,505	$97,597	$228,929
Property Value	$766,716	$517,326	$1,066,375
Recreational Value	$427,021	$336,641	$529,527
Economic Water Quality	$289,896	$247,424	$332,368
Total	***$75,716,173***	***$43,560,232***	***$107,968,440***

O41:

O41	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$84,431	$60,976	$111,578
Carbon Reduction by Vegetation	$19,766	$8,607	$36,058
Flood Risk	$195,067	$111,467	$278,667
Heat Island Effect	$56,504	$37,350	$82,286
Property Value	$11,450	$7,726	$15,925
Recreational Value	$153,508	$121,109	$190,501
Economic Water Quality	$103,487	$88,325	$118,648
Total	***$624,213***	***$435,560***	***$833,664***

Scenario 2: 480 MGD (WWTP Expansion) including GI elements placed in 18 sewersheds with a total DCIA area managed of 1,835 acres.

A22:

A22	***Value***	***Low CI***	***High CI***
Air Pollution Reduced by Vegetation	$2,090,751	$1,570,882	$2,752,503
Carbon Reduction by Vegetation	$479,545	$207,747	$870,260
Flood Risk	$273,802,667	$156,458,667	$391,146,667
Heat Island Effect	$1,425,186	$862,202	$2,019,319
Property Value	$22,563,073	$15,223,970	$31,381,486
Recreational Value	$3,785,904	$2,984,608	$4,694,712
Economic Water Quality	$2,572,163	$2,195,110	$2,948,718
Total	***$306,719,289***	***$179,503,187***	***$435,813,665***

A41:

A41	***Value***	***Low CI***	***High CI***
Air Pollution Reduced by Vegetation	$1,080,425	$780,276	$1,427,817
Carbon Reduction by Vegetation	$253,340	$110,313	$462,142
Flood Risk	$94,758,067	$54,147,467	$135,368,667
Heat Island Effect	$721,715	$477,422	$1,050,666
Property Value	$6,964,192	$4,698,946	$9,686,034
Recreational Value	$1,946,170	$1,535,410	$2,415,161
Economic Water Quality	$1,323,518	$1,129,545	$1,517,331
Total	***$107,047,426***	***$62,879,379***	***$151,927,818***

A42:

A42	***Value***	***Low CI***	***High CI***
Air Pollution Reduced by Vegetation	$3,324,791	$2,401,140	$4,393,813
Carbon Reduction by Vegetation	$780,033	$339,653	$1,422,932
Flood Risk	$219,139,667	$125,222,667	$313,056,667
Heat Island Effect	$2,212,205	$1,465,828	$3,218,009
Property Value	$12,497,961	$8,432,742	$17,382,587
Recreational Value	$5,992,018	$4,727,339	$7,435,985
Economic Water Quality	$4,074,049	$3,476,960	$4,670,642
Total	***$248,020,724***	***$146,066,329***	***$351,580,635***

A48:

A48	***Value***	***Low CI***	***High CI***
Air Pollution Reduced by Vegetation	$226,226	$163,380	$298,966
Carbon Reduction by Vegetation	$52,949	$23,056	$96,589
Flood Risk	$46,080,067	$26,331,467	$65,828,667
Heat Island Effect	$151,364	$100,066	$220,420
Property Value	$986,156	$665,388	$1,371,579
Recreational Value	$408,488	$322,272	$506,926
Economic Water Quality	$277,159	$236,667	$317,917
Total	***$48,182,409***	***$27,842,296***	***$68,641,064***

A58:

A58	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$205,722	$148,570	$271,867
Carbon Reduction by Vegetation	$48,320	$21,040	$88,146
Flood Risk	$54,379,267	$31,073,867	$77,684,667
Heat Island Effect	$137,609	$90,971	$200,390
Property Value	$764,090	$515,554	$1,062,722
Recreational Value	$369,460	$291,482	$458,493
Economic Water Quality	$251,553	$214,585	$288,255
Total	***$56,156,020***	***$32,356,069***	***$80,054,539***

A60:

A60	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$237,130	$171,253	$313,374
Carbon Reduction by Vegetation	$55,721	$24,263	$101,647
Flood Risk	$62,527,733	$35,730,133	$89,325,333
Heat Island Effect	$158,604	$104,853	$230,961
Property Value	$676,509	$456,461	$940,912
Recreational Value	$426,700	$336,641	$529,527
Economic Water Quality	$290,535	$247,990	$333,128
Total	***$64,372,932***	***$37,071,594***	***$91,774,883***

A61:

A61	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$21,614	$15,610	$28,565
Carbon Reduction by Vegetation	$4,964	$2,161	$9,055
Flood Risk	$744,800	$425,600	$1,064,000
Heat Island Effect	$14,490	$9,578	$21,102
Property Value	$10,058	$6,787	$13,989
Recreational Value	$39,027	$30,790	$48,432
Economic Water Quality	$26,535	$22,648	$30,423
Total	***$861,488***	***$513,173***	***$1,215,566***

A65:

A65	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$3,741	$2,701	$4,942
Carbon Reduction by Vegetation	$738	$321	$1,346
Flood Risk	$673,867	$385,067	$962,667
Heat Island Effect	$2,536	$1,676	$3,693
Property Value	$3,575	$2,412	$4,972
Recreational Value	$6,765	$5,337	$8,395
Economic Water Quality	$4,597	$3,963	$5,324
Total	***$695,819***	***$401,477***	***$991,338***

M15:

M15	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$13,027	$9,407	$17,214
Carbon Reduction by Vegetation	$3,153	$1,373	$5,751
Flood Risk	$425,600	$243,200	$608,000
Heat Island Effect	$8,694	$5,747	$12,661
Property Value	$44,643	$30,122	$62,091
Recreational Value	$23,416	$18,474	$29,059
Economic Water Quality	$15,936	$13,589	$18,254
Total	***$534,469***	***$321,911***	***$753,030***

M16:

M16	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$460,124	$332,298	$608,068
Carbon Reduction by Vegetation	$107,955	$47,007	$196,930
Flood Risk	$32,762,333	$18,721,333	$46,803,333
Heat Island Effect	$307,674	$203,436	$448,005
Property Value	$2,163,492	$1,459,772	$3,009,059
Recreational Value	$829,984	$654,807	$1,029,995
Economic Water Quality	$564,041	$481,260	$646,482
Total	***$37,195,604***	***$21,899,913***	***$52,741,872***

M19:

M19	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$355,189	$256,513	$469,391
Carbon Reduction by Vegetation	$83,560	$36,385	$152,429
Flood Risk	$53,652,200	$30,658,400	$76,646,000
Heat Island Effect	$237,495	$157,021	$345,830
Property Value	$1,481,845	$999,844	$2,061,000
Recreational Value	$640,051	$504,961	$794,291
Economic Water Quality	$435,829	$371,985	$499,693
Total	***$56,886,169***	***$32,985,110***	***$80,968,633***

M19A:

M19A	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$316,109	$228,292	$417,748
Carbon Reduction by Vegetation	$74,102	$32,266	$135,176
Flood Risk	$47,161,800	$26,949,600	$67,374,000
Heat Island Effect	$211,443	$139,793	$307,898
Property Value	$1,186,938	$800,862	$1,650,834
Recreational Value	$569,801	$449,539	$707,113
Economic Water Quality	$387,473	$330,654	$444,171
Total	***$49,907,666***	***$28,931,006***	***$71,036,940***

M19B:

M19B	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$48,680	$35,157	$64,333
Carbon Reduction by Vegetation	$11,314	$4,927	$20,639
Flood Risk	$7,244,067	$4,139,467	$10,348,667
Heat Island Effect	$32,600	$21,549	$47,476
Property Value	$85,767	$57,870	$119,288
Recreational Value	$88,462	$69,791	$109,780
Economic Water Quality	$59,704	$50,957	$68,451
Total	***$7,570,594***	***$4,379,717***	***$10,778,634***

M21:

M21	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$12,930	$9,339	$17,089
Carbon Reduction by Vegetation	$2,862	$1,246	$5,221
Flood Risk	$5,142,667	$2,938,667	$7,346,667
Heat Island Effect	$8,694	$5,747	$12,661
Property Value	$40,741	$27,489	$56,664
Recreational Value	$23,416	$18,474	$29,059
Economic Water Quality	$15,319	$13,022	$17,493
Total	***$5,246,629***	***$3,013,984***	***$7,484,853***

M29:

M29	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$1,173,219	$881,492	$1,544,559
Carbon Reduction by Vegetation	$276,550	$120,419	$504,481
Flood Risk	$320,326,067	$183,043,467	$457,608,667
Heat Island Effect	$801,012	$484,323	$1,135,173
Property Value	$30,892,346	$20,843,976	$42,966,121
Recreational Value	$2,124,689	$1,674,993	$2,634,721
Economic Water Quality	$1,444,104	$1,232,591	$1,655,754
Total	***$357,037,987***	***$208,281,261***	***$508,049,476***

O27:

O27	*Value*	*Low CI*	*High CI*
Air Pollution Reduced by Vegetation	$236,071	$177,375	$310,792
Carbon Reduction by Vegetation	$55,431	$24,136	$101,117
Flood Risk	$73,779,533	$42,159,733	$105,399,333
Heat Island Effect	$161,505	$97,597	$228,929
Property Value	$766,716	$517,326	$1,066,375
Recreational Value	$427,021	$336,641	$529,527
Economic Water Quality	$289,896	$247,424	$332,368
Total	***$75,716,173***	***$43,560,232***	***$107,968,440***

O39:

O39	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$27,573	$19,913	$36,439
Carbon Reduction by Vegetation	$6,373	$2,775	$11,625
Flood Risk	$2,181,200	$1,246,400	$3,116,000
Heat Island Effect	$18,474	$12,211	$26,904
Property Value	$33,470	$22,583	$46,551
Recreational Value	$49,435	$39,001	$61,348
Economic Water Quality	$33,650	$28,876	$38,789
Total	***$2,350,174***	***$1,371,758***	***$3,337,655***

O41:

O41	Value	Low CI	High CI
Air Pollution Reduced by Vegetation	$84,431	$60,976	$111,578
Carbon Reduction by Vegetation	$19,766	$8,607	$36,058
Flood Risk	$195,067	$111,467	$278,667
Heat Island Effect	$56,504	$37,350	$82,286
Property Value	$11,450	$7,726	$15,925
Recreational Value	$153,508	$121,109	$190,501
Economic Water Quality	$103,487	$88,325	$118,648
Total	***$624,213***	***$435,560***	***$833,664***