Delaware River Bacteria Study

An Evaluation of the Occurrence and Sources of Fecal Indicator Bacteria in the Camden-Chester-Philadelphia Region and Opportunities for Remediation

The Water Center
UNIVERSITY *of* PENNSYLVANIA

Acknowledgements

Acronyms

BEACH: Beaches Environmental Assessment and Coastal Health Act

CCMUA: Camden County Municipal Utilities Authority

CDC: Centers for Disease Control and Prevention

CIP: Capital Improvement Program

CSO: Combined Sewer Overflow

CSS: Combined Sewer System

CWA: Clean Water Act

CZMA: Coastal Zone Management Act

DCIA: Directly Connected Impervious Area

DO: Dissolved Oxygen

DRBC: Delaware River Basin Commission

DRWC: Delaware River Waterfront Corporation

DVRPC: Delaware Valley Regional Planning Commission

EMA: Ethidium Monoazide

ESA: Eastern Service Area Tunnel

FCB: Fecal Coliform Bacteria

FIB: Fecal Indicator Bacteria

FRNA: Male-specific (F+) Coliphages

GM: Geometric Mean

I/I: Infiltration and Inflow Management

LTCP: Long Term Control Plans

MGD: Millions of Gallons per Day

MST: Microbial Source Tracking

MS4: Municipal Separate Storm Sewer System

NJDEP: New Jersey Department of Environmental Protection

NMC: Nine Minimum Control Program

NOAA: National Oceanographic and Atmospheric Administration

NPDES: National Pollutant Discharge Elimination System

PADEP: Pennsylvania Department of Environmental Protection

PCBs: Polychlorinated Biphenyls

PCR: Polymerase Chain Reaction

PWD: Philadelphia Water Department

qPCR: quantitative Polymerase Chain Reaction

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RADC: Riverfront Alliance of Delaware County

SDFs: Screening and disinfection facilities

SMART: Stormwater Management and Resource Training

SSO: Sanitary Sewer Overflow

STP: Sewage Treatment Plant

SRF: State Revolving Fund

STV: Statistical Threshold Value

SWMP: Stormwater Management Program

SWWPCP: Southwest Water Pollution Control Plant

WDC: The Water Data Collaborative

WPCF: Water Pollution Control Facility

WPCP: Water Pollution Control Plants

WRTP: Western Region Treatment Plant

Executive Summary

The Delaware River Bacteria Study is an independent, science-based water quality and water policy study. It evaluates the occurrence and sources of fecal indicator bacteria (FIB) in the Camden-Chester-Philadelphia region of the Delaware River and opportunities for remediation. These bacteria are used as an indicator of recreational water quality by state and federal regulatory agencies. The Delaware River Basin is a source of water for drinking, agricultural and industrial use for over 15 million people, making it an important watershed to the region. The Study Area for this project is the 27-mile stretch of the Delaware River from mile 108 to mile 81 and the tidal reaches of the tributaries to the main stem. Over the last few decades, this stretch of the river has developed a history of recreation due to improved water quality and expanded waterfront access. At the same time, the water quality standards for this stretch of the river have been set to meet FIB levels appropriate for boating recreation. This report reviews existing and new data in the context of meeting FIB levels appropriate for swimming recreation. It focuses on combined sewer overflow (CSO) policy and long-term control plans (LTCPs), which describe the planning, design, construction, and monitoring of CSO controls to result in compliance with the water quality-based requirements of the Clean Water Act (CWA), while also reviewing other relevant CWA programs and policies.

Objectives

The report aims to identify some of the major challenges to achieving swimmable waters within this Study Area and opportunities to accelerate improvements. Because water quality criteria for swimming are based on FIB, the focus is their occurrence and remediation. The analysis and report are structured around three objectives:

1. Understanding existing FIB water quality conditions and identifying knowledge gaps.

2. Understanding the timing and extent of future FIB water quality improvements from committed investments.

3. Identifying additional opportunities for improved FIB water quality.

Based on these objectives, this report does not attempt to address public health and safety issues that might be relevant in the Study Area with respect to water recreation. It also is not designed to fully assess equitable access to water recreation in the Camden-Chester-Philadelphia region. These important topics are being addressed through other research, projects and initiatives.

Audience

The audience for this report is stakeholders in the region, including but not limited to funders, utilities along the Delaware River such as Philadelphia Water Department (PWD), Camden County Municipal Utilities Authority (CCMUA), and Delaware County Regional Water Quality Control Authority (DELCORA) as well as upstream utilities, regulatory entities, municipal wastewater and stormwater managers, the recreating public, ratepayers, dischargers, academics, environmental advocates, business owners, waterfront land owners, city and regional planners, and policymakers.

Methods and Findings

The study engaged a multi-disciplinary team to conduct a comprehensive analysis of water quality data for FIB, existing water quality programs and investments, water quality regulation and policy, opportunities and constraints inherent in the current regulatory framework, and opportunities and constraints inherent in the socioeconomic landscape of the Study Area. It involved desk top research, stakeholder engagement through meetings as well as group and individual interviews, data collection and analysis, and regulatory and policy review. A brief overview of the methods and findings for each objective is described below and in more detail in Section 3.

To explore the water recreation and monitoring data, visit the interactive Delaware River Bacteria Data Viewer created by the Water Center at Penn.[1]

Objective 1: Understanding existing FIB water quality conditions and identifying knowledge gaps

Methods

There were two prongs to the methodology of Objective 1- analyzing existing bacteria monitoring data and implementing a supplemental bacteria monitoring effort. To evaluate existing water quality data, statistical analysis was conducted on available FIB data, including center channel and nearshore data resulting from monitoring efforts led by the Delaware River Basin Commission (DRBC) and PWD. To fill in gaps, the project team conducted a supplemental monitoring effort at fifteen sites on the Delaware River in the summer of 2021. This effort aimed to expand upon the existing monitoring data by:

(1) collecting pre- and post-wet weather water samples to understand how FIB signals decay after a rain event,

(2) sampling at tributary sites, mainstem sites, and CSO outfalls to help understand the relative magnitude of FIB concentrations across sites, and

(3) piloting the use of microbial source tracking DNA markers such as Human Bacteroides (HF183), avian marker, and the gull marker. These markers were used to explore the benefits of microbial source tracking approaches and whether these markers could be useful in identifying hotspots of raw sewage contamination and prioritizing remediation measures in the Study Area.

Findings

The analysis of existing data resulted in seven main findings:

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[1] Water Center at Penn (2023). Delaware River Bacteria Data Viewer. Retrieved from https://experience.arcgis.com/experience/caa71fcc2dfb45feb031e7b6d7d878f1/

1. At the regional scale, center channel water quality conditions are closer to meeting EPA's Recommendation 1 (REC-1) criteria for primary contact recreation than nearshore water quality conditions.
2. Nearshore water quality is highly localized and dynamic. Bacteria levels vary widely across short distances (e.g., Penn's Landing Lagoon and Independence Seaport Museum). They also vary considerably from month to month and year to year.
3. At nearshore sampling sites, dry weather water quality conditions are generally closer to meeting EPA's REC-1 criteria than wet weather water quality conditions.
4. During dry weather conditions, some nearshore sampling sites are notable for their consistently poor water quality. These sites include Pyne Poynt Park, Independence Seaport Museum, Schuylkill Banks, Bartram's Garden, and John Heinz Wildlife Refuge. Other sites are notable for their consistently favorable water quality. These include Linden Avenue Boat Launch, Riverton Yacht Club, and Ft. Mifflin.
5. Overall, the nearshore sampling sites with the highest bacteria levels were those within 2,500 feet of a combined sewer outfall.
6. For some nearshore locations, wet weather pollution may not be a primary driver of bacteria levels.
7. There is significant room for improvement in the design and coordination of nearshore FIB monitoring programs in the Study Area.

The supplemental bacteria monitoring effort resulted in nine general findings:
1. Qualitative differences in E. coli levels were noted between sites. Two sampling sites appeared to have consistently high E. coli levels: Pyne Poynt and Frankford/Tacony at Castor Ave. Four sampling sites appeared to have relatively lower E. coli levels: Penns Landing, Washington Avenue Green, National Park, and Bartram's Garden.
2. Wet weather days appear to correspond to higher *E. coli* levels, and dry weather days appear to correspond to lower *E. coli* levels. This suggests that there are wet weather sources for FIB, such as degraded or impaired infrastructure, illicit discharges/illicit connections, stormwater, or CSOs.
3. E. coli levels were highest for the samples taken near CSO outfalls compared to levels measured at other nearshore sites.
4. Average concentrations of HF183 measured from the main stem and tidal tributaries were typically one to two and a half orders of magnitude lower than average concentrations measured from CSO sites. From the data, CSOs have the highest levels of HF183 and are a significant source of human fecal pollution at the sampled sites.
5. HF183 concentrations show a wet weather effect.
6. There is a weak but significant positive association between HF183 and *E. coli* concentrations. This confirms that FIB is generally from a human source and is therefore a meaningful indicator of human health risk in the Study Area.

7. Most sites appear chronically impaired with HF183 levels well above the risk-based threshold, but some sites had relatively low levels of HF183 impairment.
8. Avian marker concentrations showed that avian fecal matter contributes to measured FIB. The Avian marker was detected frequently in samples collected across all sites, suggesting that avian marker in this region is ubiquitous.
9. Gull markers were not found at any of the sites, which is consistent with visual observations that gulls are not prevalent within the Study Area.

Objective 2: Understanding the timing and extent of future FIB water quality improvements from committed investments

Methods

To better understand the timing and extent of future water quality improvements from committed investments, the project team reviewed the LTCPs for water utilities on the Delaware River including PWD, CCMUA and DELCORA. The team also conducted interviews and reviewed relevant state and federal policies governing CSO management. This report focuses on LTCPs because they provide the most scope for adaptive management. While stormwater management and other Clean Water Act programs can drive future improvements and were also reviewed, these programs are not currently focused on reducing bacteria levels in the waterways directly impacting the Study Area so they are not currently driving significant investments.

Findings

All three utilities have LTCPs to reduce CSOs and have committed to substantial investments over the coming years. Investments targeted to CSO remediation currently total $667 million, and planned investments over the next five-year period total more than $1 billion.

PWD, which contributes the largest annual volume of CSO, is currently working on short- and long-term plans to increase the capacity of its collection system and wastewater treatment plants. By LTCP completion in 2036, PWD anticipates further reducing the average annual overflow volume to about a fifty percent reduction in bacteria loading from 2021 through both traditional gray infrastructure and green stormwater infrastructure projects. The long-term vision for Philadelphia integrates CSO and water resources management into the socioeconomic fabric of the City by creating amenities for those who live and work there.

CCMUA's LTCP, which is expected to be run through 2035, consists of six program elements that will have phased and overlapping implementation schedules. The six program elements are:
    (1) completion of current projects,
    (2) iterative efficacy evaluation,
    (3) a formalized green stormwater infrastructure program,
    (4) a street flooding mitigation program,
    (5) a Cooper River water quality optimization program, and

(6) additional structural controls.

CCMUA will focus initially on projects that will provide significant near-term overflow and street flooding benefits such as the expansion of the Water Pollution Control Facility (WPCF) # 1 and the restoration of the hydraulic capacity of the Camden collection system. Construction of a 30 million gallon per day (MGD) sewage pump will increase capacity to accept more flow from City of Camden's CSO systems during wet weather.

Between 1999 and 2018, DELCORA invested over $100 million in system improvements including partially separating flow to a CSO regulator, replacing older CSO regulator models, and replacing leaking pipes that resulted in decreased volumes of overflows, reduced debris in overflows, and improved routine maintenance. The LTCP, which runs through 2040, has a major element called the Eastern Service Area (ESA) Tunnel, which will capture combined sewer overflows and is planned to be completed by 2028.

Objective 3: Identifying additional opportunities for improved FIB water quality
Methods
The project team used three approaches to identify additional opportunities for improved FIB water quality in the Study Area. First, the project team engaged stakeholders through group meetings and interviews to understand their concerns and how those concerns might constrain or support opportunities for remediation. Second, the project team conducted a desktop review of LTCPs beyond the Study Area to identify best practices that might translate to the Study Area. Third, the project team used a suitability analysis of existing recreation access sites to identify potential focus areas for further investment.

Findings
Stakeholder groups raised both support for and concerns about investments to improve recreational water quality in the Study Area. While the intent of this study is not to analyze stakeholder preferences, their perspectives highlighted the importance of including affected stakeholders in the decision-making process to ensure the most equitable and just distribution of benefits from water quality investments. They also highlighted the benefit of an integrated, "one water" approach that considers the sustainability and resiliency of our cities and their water systems as well as the issues of equity and fairness.

A limited review of the literature and selected CSO LTCPs showed that there are two primary approaches to managing CSOs: (1) inactivating the pathogens before discharge and (2) eliminating CSO discharges from impacted waterways. LTCP strategies include green infrastructure, increased storage capacity in the collection system, sewage treatment plant (STP) expansion and/or storage at the plant, Inflow/Infiltration reduction, sewer separation, and CSO discharge treatment. While the existing LTCPs outline one approach to compliance and financing under EPA's current CSO policy, there may be other ways to accelerate and target water quality improvements to enhance benefits to communities and aquatic systems in the Study Area. For example, compliance could also be achieved by developing plans for each tributary as opposed to the whole

CSO system. In addition, there is a knowledge gap in understanding the magnitude, location and timing of bacteria loading from municipal separate storm sewer systems (MS4) in the Study Area. While not at the scale of the CSOs, MS4s could be an important cause of FIB impacts at specific sites and should drive remediation to address those impacts.

To identify potential focus areas for further investment, the project team conducted a comprehensive suitability analysis of existing recreation access sites, which used publicly available GIS data to score 37 recreation access sites on the Delaware mainstem across fourteen attributes. A scoring system was designed to give higher scores to sites where a confluence of water quality conditions, physical factors, and equity considerations indicate targeted investments are best directed, and the ten recreation access sites that scored the highest were selected for further discussion with stakeholders. Based on these discussions, one focus area was selected in each city: Pyne Poynt Park in Camden, Chester City Boat Ramp in Chester, and Frankford Arsenal in Philadelphia. Three additional sites were added based on existing public boating programs at or near the sites: River Fields on the Delaware River mainstem just north of the Study Area, Bartram's Garden on the Schuylkill River, and John Heinz National Wildlife Refuge on Darby Creek.

Recommendations
The findings were used to develop a series of recommended actions to reduce bacteria levels and improve recreational opportunities in the Study Area. The recommendations include both general actions to advance the goal of swimmable waters in the Study Area as well as specific actions that could be targeted to the six identified focus areas. Investments that can be planned and executed relatively quickly should be the priority. Any near-term projects must have demonstrable benefits for rate payers if rates will be used and the projects reviewed by the Water Board. Ideally, any near-term projects implemented to reduce bacteria levels will have multiple benefits to improve the return on investment to the Camden-Chester-Philadelphia region. For these reasons, the recommendations are meant to be actionable within a five-year time span and cost-effective. Finally, while this study does not address public health or equitable water recreation access specifically, the recommended actions are meant to result in reductions in bacteria in the river, benefit the surrounding community overall, and take affordability and environmental justice issues into account.

With this context in mind, the following recommendations were identified and reviewed with stakeholders:

1. Ensure that cities in the Study Area develop and document clear community priorities for river-based water recreation to direct and drive LTCP/MS4 implementation.
2. Advocate for non-debt financing at the federal and state level for water quality upgrades in CSO watersheds to accelerate LTCP timelines.
3. Develop a community science monitoring network and use the data to better inform the public about bacteria levels.
4. Accelerate investments in green stormwater infrastructure in all communities bordering the Study Area.

5. Continually improve implementation of the nine minimum controls (NMC) outlined in each of the LTCPs and communicate with the public about these activities.
6. Incorporate climate change risks into CSO remediation strategies.

The analysis of focus areas resulted in the identification of recommended actions to meet site-specific conditions as outlined below.

Recommended Actions to Meet Site-Specific Conditions

- Implement Green Stormwater Infrastructure (GSI) projects in targeted CSO sewersheds impacting the focus area
- Pilot different inlet filters near the focus area
- Pilot outfall netting near the focus area
- Prioritize planned pipe lining in targeted CSO sewersheds impacting the focus area
- Prioritize planned infiltration and inflow management (I/I) activities in targeted CSO sewersheds impacting the focus area
- Map MS4 outfalls and implement GSI and other best management practices to address identified challenges
- Initiate/expand bacteria monitoring and share data on public platforms

The six identified focus areas – Pyne Poynt Park, Chester Riverfront, Bartram's Garden, John Heinz National Wildlife Refuge, River Fields, and Frankford Arsenal Boat Ramp – are good candidates for piloting approaches to better understand the nature and cause of bacteria impairments and to design pollution reduction strategies to assist in achieving swimmable waters in the Delaware River. What is learned from these pilots would then be used to inform future investments.

Conclusion

As set out in the findings, the data reviewed and monitoring done for this project showed that FIB levels are highly variable and localized. They also showed that remediating CSOs remains central to attaining swimmable water quality in the Study Area. Mapping of MS4 outfalls and additional monitoring would help fill knowledge gaps and direct additional investments. Remediating MS4 impacts at specific sites are likely to be less expensive than system-wide CSO remediation strategies. To identify the best near term investments, we need to understand the conditions at specific sites better and fit actions to those conditions. Because debt financing is dependent on repayments from ratepayers, new non-debt funding should be targeted for new investments to limit the additional burden on the already financially and environmentally burdened communities in the Study Area.

Community residents, business owners, elected officials, water system managers, clean water advocates, recreationers, and funders are all essential to advancing water quality in the Study Area. All stakeholders have a role in accelerating the pace to a cleaner Delaware River and tidal tributaries in the Study Area. It is important to identify common goals and funding priorities because more important than any specific action is a strong partnership across all stakeholder groups, embracing a shared vision for sustained, meaningful progress.

1 Introduction

The Delaware River Bacteria Study is an independent, science-based water quality and water policy study. It evaluates the occurrence and sources of fecal indicator bacteria in the Camden-Chester-Philadelphia region of the Delaware River and opportunities for remediation. The Study Area is the 27-mile stretch of the Delaware River from mile 108 to mile 81 and the tidal reaches of the tributaries to the main stem (*Figure 1: Study Area*). This area is defined as Zone 3 and Upper Zone 4 by the Delaware River Basin Commission (DRBC) – the agency that regulates water quality in the Delaware River.

Figure 1: Study Area
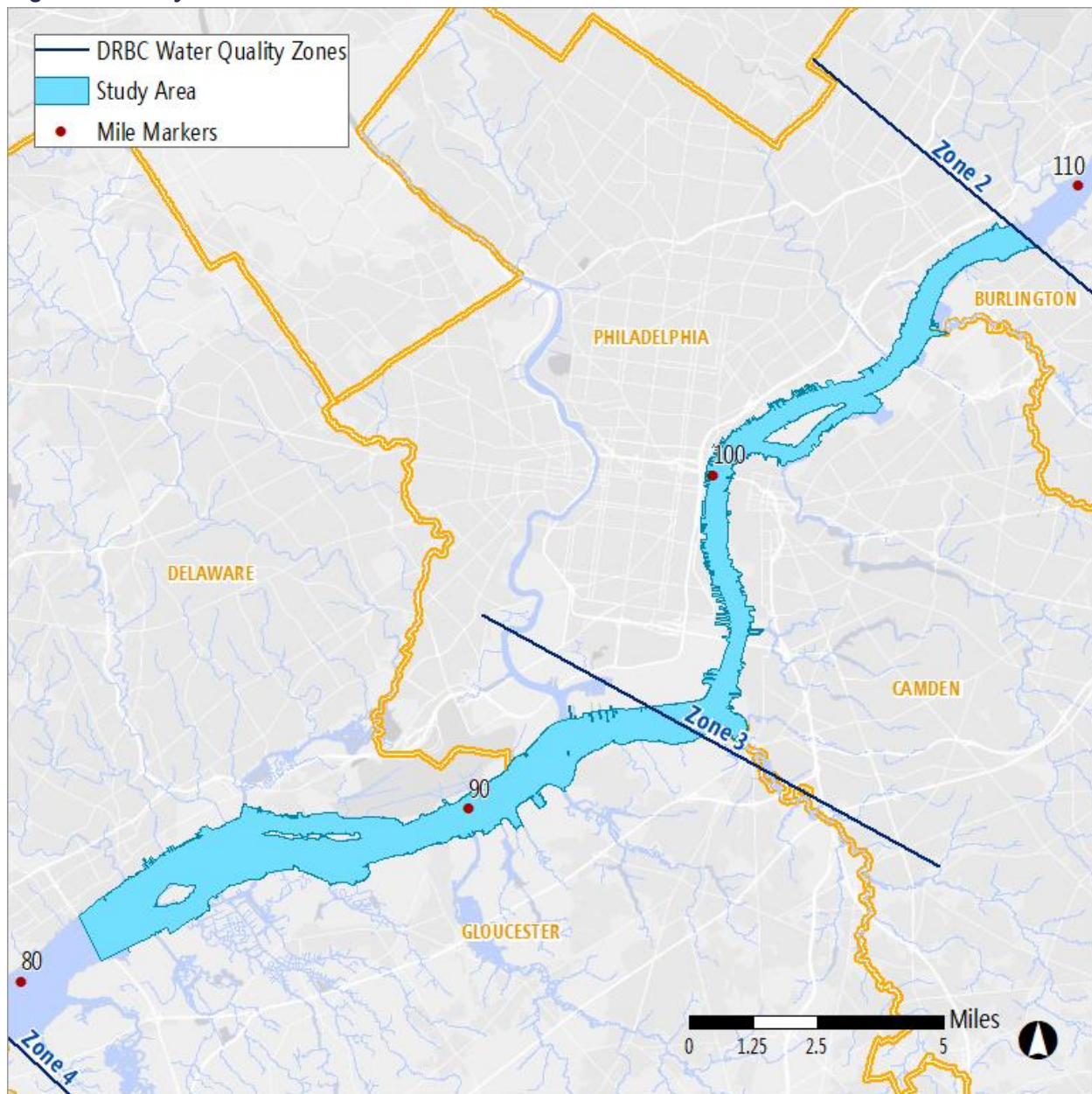
Objectives of the Study

This study aims to inform stakeholders about the factors impacting water quality for swimming for the waters within the Study Area. Because water quality criteria for safe swimming are based on fecal indicator bacteria, the study focuses on the occurrence and remediation of fecal indicator bacteria.

The project was designed around three primary objectives:

1. Understanding existing FIB water quality conditions and identifying knowledge gaps.

2. Understanding the timing and extent of future FIB water quality improvements from committed investments.

3. Identifying additional opportunities for improved FIB water quality.

Role of the Study in Environmental Decision-Making

The Delaware River Bacteria Study is designed to inform a complex environmental decision-making process. Decisions about recreational water quality in the Study Area involve tradeoffs between many different environmental, social, and economic factors. They also involve diverse stakeholder groups, including the recreating public, ratepayers, dischargers, utilities, regulators, academics, environmental advocates, and policymakers. Each group has its own set of preferences regarding whether, where, and how to improve recreational water quality in the Study Area.

Primarily, the study is a fact-finding analysis. Ideally, the study findings will help stakeholders to align priorities and chart a shared path forward. By coordinating with respect to water quality studies, capital investments, operational improvements, and the use of state and regional funds, stakeholders can realize water quality improvements that provide targeted community benefits. In addition, by including community members in the decision-making process, stakeholders can reflect community values in water quality investments.

While the intent of this study is not to analyze stakeholder preferences, the study objectives did require some understanding of stakeholder perspectives. The project team engaged with stakeholders throughout the study. Stakeholders included the American Littoral Society, Delaware River Basin Commission (DRBC), Philadelphia Water Department (PWD), PennFuture, Pennsylvania Environmental Council, and others. This engagement was preliminary in nature as it was not the primary purpose of the Study. The Methods and Findings section describes the scope of the stakeholder engagement and summarizes key concerns. It is important to clarify that this report does not address equitable access to the Delaware River, public health, or safety. Instead, it addresses water quality under the Clean Water Act (CWA) with particular focus on the CSO program.

2   Background

Recreational Activity in the Study Area

In the last several decades, improved water quality and expanded waterfront access have supported increasing recreational activity in the Study Area. A detailed review of water-based recreation in the Study Area is provided in Appendix 1. This section summarizes key trends and findings. It provides context for the analysis of existing water quality conditions (Objective 1).

Before colonization, the Lenape people lived along this stretch of the Delaware River and its tributaries. They traveled by water using dugout canoes and fished throughout the Delaware River watershed, while also hunting and growing food. Most of the Lenape people had been forced to leave or chose to leave the area by the beginning of the 19th century. There is no record of the Lenape differentiating their use of the river between transportation, food, and recreation.[2]

After colonization, the region was impacted by the Industrial Revolution. Since then, growing populations have used the Delaware River for varying and often competing purposes, including deep water navigation, industrial development, water supply, waste disposal, fisheries, and recreation.[3] By the 1920s, industrialization and overfishing had devastated fish populations and aquatic life, especially between Philadelphia and the Borough of Marcus Hook. By the 1940s, pollution of the Delaware River was widely recognized after more than a century of uncontrolled discharges of municipal and industrial waste.[4]

In the early 1960s, the City of Philadelphia began constructing Penn's Landing, a site initially envisioned as a public waterfront attraction. Beginning in the 1980s, investment in public access increased with the establishment of Pennsylvania's Coastal Zone Management Program and associated grant funding. By 1997, Philadelphia had 11 publicly owned access sites along the Delaware River.

The Delaware River Waterfront Corporation (DRWC) plans to develop the waterfront into a destination for residents and tourists. DRWC was formed in 2009 to direct development along Philadelphia's Delaware River

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[2] Lenape Nation of Pennsylvania, https://www.lenape-nation.org; Lenape Indian Tribe Delaware, Kent County, http://www.lenapeindiantribeofdelaware.com; Nanticoke Lenni, https://nanticoke-lenape.info; West Philadelphia Collaborative History, The Original People and Their Land: The Lenape, Pre-History to the 18th Century, https://collaborativehistory.gse.upenn.edu/stories/original-people-and-their-land-lenape-pre-history-18th-century

[3] Hardy, Charles III (2017). Fish or Foul: A History of the Delaware River Basin Through the Perspective of the American Shad, 1682 to the Present. West Chester University. Retrieved from https://www.drsfa.org/sites/default/files/attached_files/FishorFoul.pdf

[4] Delaware River Basin Commission (DRBC) (2019). Delaware River Water Quality: A Brief Recap. Retrieved from https://www.nj.gov/drbc/programs/quality/history.html

waterfront from Oregon to Allegheny Avenues, including Penn's Landing. Central to its mission is the design, development, and programming of public amenities and spaces.[5]

The region continues to show support for a recreational river. A 2012 study by researchers at Drexel University investigated recreational activities at three separate sites along the Delaware River in Philadelphia: Pleasant Hill Park, Pennypack Park, and Frankford Arsenal. Observed activities included jet-skiing, kayaking, boating, fishing, wading in the water, and even swimming.[6]

Today, the Study Area supports water-based recreation at more than 40 official recreation access sites. Appendix 1 provides an inventory of these sites and describes how the inventory was developed. It includes 17 recreation access sites in New Jersey and 25 sites in Pennsylvania. *Figure 2: Map of Recreation Access Sites in the Study Area* maps the recreation sites and shows the recreation category for each one. To explore this water recreation data more, visit the interactive Delaware River Bacteria Data Viewer created by the Water Center at Penn.[7] The recreation category is based on the most immersive recreational activity at each site. The three categories are as follows, from most immersive to least immersive:

- Most Immersive: Swimming, Wading, Jet Skiing, Paddle Boarding, Kayaking
- Moderately Immersive: Paddle Boating, Motor Boating, Sail Boating
- Least Immersive: Fishing

The inventory of recreation sites shows that recreational access has expanded dramatically in recent years. Ten sites became available for recreation in the last 25 years, and six became available in the last fifteen. Note that this inventory was not intended to show every location where people swim, boat, or fish on the Delaware River.

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[5] Delaware River Waterfront Corporation (DRWC) (2020). The Delaware River Waterfront Corporation. Retrieved from https://www.delawareriverwaterfront.com/

[6] Sunger, Neha et al., (2012) Recreational Use Assessment of Water-Based Activities, Using Time-Lapse Construction Cameras. Retrieved from https://www.nature.com/articles/jes20124; WHYY; Auciello, Justin. Annual N.J. Beach Water Quality Monitoring Program Gets Underway. (2020). WHYY. Retrieved from https://whyy.org/articles/annual-n-j-beach-water-quality-monitoring-program-gets-underway

[7] Water Center at Penn (2023). Delaware River Bacteria Data Viewer. Retrieved from https://experience.arcgis.com/experience/caa71fcc2dfb45feb031e7b6d7d878f1/

Figure 2: Map of Recreation Access Sites in the Study Area

Source: Water Center at Penn (2023). Delaware River Bacteria Data Viewer. Retrieved from https://experience.arcgis.com/experience/caa71fcc2dfb45feb031e7b6d7d878f1/
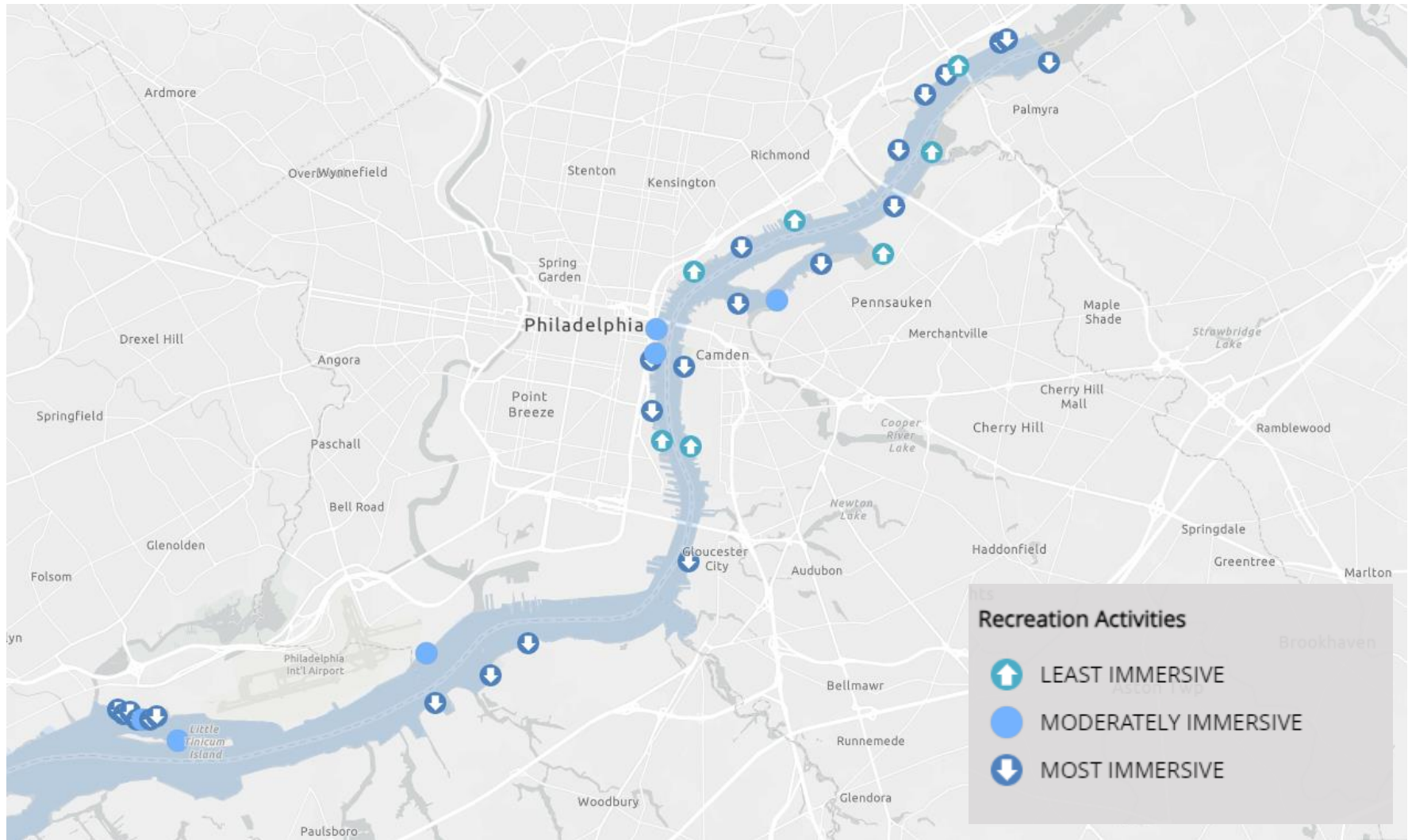
Water Quality Criteria for Recreational Waters

Throughout this report, water quality conditions in the Study Area are evaluated against the EPA's Recommendation 1 criteria for primary contact recreation (*Table 1*). These criteria use fecal indicator bacteria (FIB) to estimate the potential for human infectious disease.

The most common health risk to water recreators is coming into contact with disease-causing microorganisms from fecal pollution.[8] Since it would be impractical to test for every disease-causing microorganism, beaches and other water recreation sites are typically tested for fecal indicator bacteria species that indicate the presence of fecal pollution.

The EPA released its current recommended water quality criteria for recreational waters in 2012.[9] They are based on extensive epidemiological studies at U.S. beaches and provide a sound basis for risk management. As shown in *Table 1,* criteria values are provided for FIB at two illness rates, 32 and 36 illnesses per 1,000 swimmers. Criteria values are also provided for two indicators, Enterococci and *E. coli*. This report evaluated water quality conditions against the Recommendation 1 (REC-1) criteria for *E. coli*, which the EPA recommends as the best indicator for freshwater recreation sites.

Table 1*: EPA's Recommended Water Quality Criteria for Recreational Waters*

Criteria Elements	Recommendation 1 Estimated illness rate = 36/1,000		Recommendation 2 Estimated illness rate = 32/1,000	
Indicator	GM (cfu/100mL)	STV (cfu/100mL)	GM (cfu/100mL)	STV (cfu/100mL)
Enterococci (marine & fresh)	35	130	30	110
E.coli (fresh)	126	410	100	320

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[8] Environmental Protection Agency (2012). Recreational Water Quality Criteria. Retrieved from https://www.epa.gov/sites/default/files/2015-10/documents/rwqc2012.pdf

[9] Environmental Protection Agency (2023). Report on the 2nd Five-Year Review of EPA's Recreational Water Quality Criteria. Retrieved from https://www.epa.gov/system/files/documents/2023-05/2023-5year-review-rwqc-report.pdf

A freshwater recreation site meets the EPA's REC-1 criteria for primary contact recreation when:

- The average *E. coli* level in a 30-day period does not exceed 126 CFU/100mL (where the average is calculated as the geometric mean or GM), and
- There is no more than a 10% excursion frequency of the Statistical Threshold Value (STV) of 410 CFU/100mL in the same 30-day period.
- The EPA recommends at least five samples within a 30-day period to accurately characterize the average and 90th percentile *E. coli* levels.

The EPA suggests using both the GM and STV in evaluating recreational water quality. Water quality samples at a particular site will be characterized by a distribution of different values. The GM provides insight into the central tendency of the distribution, while the STV provides insight into the frequency and magnitude of high values. Appendix 2 provides more background on the water quality standards and public bathing regulations applicable in the Study Area.

Understanding the EPA Criteria for Recreational Waters

Before applying the EPA criteria for recreational waters to the Study Area, it is important to review what they can and cannot tell us about public health risk and ways to improve public health outcomes.

Detecting high levels of indicator bacteria that exceed the EPA criteria for recreational waters does tell us that:

- The water is likely contaminated by fecal pollution.

- Coming into contact with the water may expose recreators to disease-causing microorganisms (pathogens).

- Coming into contact with the water may lead to illnesses of the gastrointestinal system or upper respiratory tract, or skin, eye, ear, nose, or throat infections.

Detecting high levels of indicator bacteria that exceed the EPA criteria for recreational waters does not tell us about:

- Public health risk at a particular location. Public health risk is a function of both water quality and exposure.

- Pollution sources impacting a particular location. Fecal indicator bacteria can come from humans or animals, and some can also come from plants or soil.

Wastewater and Stormwater Discharges in the Study Area

A major pathway for fecal indicator bacteria to enter urban waterways is the discharge of wastewater and stormwater through runoff and sewer systems. Discharges from combined sewer systems, sanitary sewer systems, and municipal separate storm sewer systems can all be significant sources of FIB in a watershed, particularly during wet weather events. This section focuses on wastewater and stormwater discharges from systems operated by the cities of Camden, Chester, and Philadelphia. It provides context for the analysis of existing water quality conditions (Objective 1) and the evaluation of additional opportunities for remediation (Objective 3).

The cities of Camden, Chester, and Philadelphia all have regional sewer systems that serve both the city and neighboring townships and boroughs. These are often referred to as satellite systems. Each city also has both combined sewer systems and separate sewer systems.

Combined Sewer Systems

In areas with combined sewers, a single pipe carries stormwater from streets, houses, and businesses as well as wastewater from homes and businesses to a wastewater treatment plant. Some of the older sections of Camden, Chester, and Philadelphia are served by a combined sewer system (CSS).

Separate Sewer Systems

In areas with separate sewers, one pipe carries stormwater to the city's streams while another carries wastewater to a wastewater treatment plant.

The cities of Chester, Camden, and Philadelphia are not the only sources of stormwater and wastewater discharges to the Study Area. As discussed in the PWD report documenting the development of the Tidal Waters Bacteria and Dissolved Oxygen Models, water quality in the upper portions of the tidal Delaware River may be impacted by discharges from the head of tidal influence at River Mile 134.4 to Delaware City, Delaware at River Mile 61.8.[10] This includes discharges to the streams that are tributary to the main stem of the Delaware River and discharges to the Schuylkill River.

Table 2 lists the permitted municipal wastewater treatment plants discharging to this region, but it was out of the scope of this study to identify all direct stormwater outfalls to the Study Area.

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[10] Philadelphia Water Department (2015). Retrieved from
https://water.phila.gov/pool/WQ_Model_Complete_Report_FinalDigital_WITHAPPENDICES_WithAddendumpage_2016_09_19.pdf

Table 2: Municipal WWTPs Discharging to the Upper Portion of the Tidal Delaware River

Municipal wastewater treatment plants	River Mile
Ewing Lawrence Sewerage Authority	133.8
Morrisville Boro Mun. Auth-STP	133.0
Trenton DPW Sewerage Authority	131.8
Hamilton Twp WPCF	128.5
Bordentown Sewerage Authority	128.3
Lower Bucks County Joint MA	122.0
Florence Twp STP	121.3
Bristol Boro WSA	119.3
Burlington Twp DPW	118.5
Burlington City STP	117.3
Bristol Twp WWTP	116.8
Willingboro Twp MUA	111.3
Delran Sewerage Authority	111.0
Cinnaminson Sewerage Authority	108.8
Moorestown WWTP	105.5
Maple Shade POTW	105.5
Philadelphia - Northeast WPCP	104.0
Camden County MUA	98.0
Philadelphia - Southeast WPCP	96.8
Philadelphia - Southwest WPCP	90.8
Gloucester County Utility Authority	89.5
Tinicum Twp WWTP	85.5
Little Washington STP	84.0
DELCORA	80.5
Southwest Delaware County MUA	80.5
Logan Twp MUA	79.5
Wilmington WWTP	72.0
Carneys Point WWTP	71.3
Pennsville Twp Sewerage Authority	65.0

Source: Philadelphia Water Department (PWD) (2015). Green City, Clean Waters - Tidal Waters Water Quality Model – Bacteria and Dissolved Oxygen.

Philadelphia and the Regional Service Area

With the first sewers being built around 1740, the existing system is the result of more than 280 years of urban development and wastewater management.[11] It includes both combined sewers and separate sewers and serves both Philadelphia and surrounding communities. The system is owned and operated by the City of Philadelphia and managed by The Philadelphia Water Department (PWD). The department budget is managed separately through an enterprise fund, meaning that rates paid for these services can only be used to provide these services and cannot be committed or leveraged for other city initiatives.

The eleven Pennsylvania municipalities served by Philadelphia's wastewater treatment plants each own and operate sanitary collection systems. The sanitary pipes discharge wastewater directly into Philadelphia's combined collection system for conveyance to its treatment facilities. During wet weather events, the sanitary flows from these municipalities contribute to the overflow conditions experienced by Philadelphia's system.

Stormwater

PWD's separate storm sewer system is primarily located in the 'newer,' post-1950 sections of the city (e.g., Northeast and Northwest Philadelphia). While the sanitary system conveys its wastewater to a treatment facility where the water is cleaned and disinfected before it is discharged into a waterway, the separate stormwater pipes discharge runoff directly to nearby streams and creeks, as well as directly discharging to the Delaware River (*Figure 3: PWD Stormwater Outfalls*). According to its 2023 annual report, PWD manages 18 MS4 outfalls on the Delaware River and reports 122 MS4 outfalls to the Delaware mainstem that it does not manage.[12]

The eleven Pennsylvania municipalities served by Philadelphia's wastewater treatment plants each own and operate stormwater collection systems. The stormwater pipes typically discharge directly to a creek, stream or river in the municipality.

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[11] For history of Philadelphia's Water Department and its management of drainage, see https://waterhistoryphl.org/

[12] Stormwater Management Program Annual Report. National Pollutant Discharge Elimination System (NPDES) Permit No. PA 0054712 Reporting Period July 1, 2022 to June 30, 2023 at Table F.1-1 at 3. Retrieved from https://water.phila.gov/pool/files/fy22-npdes-annual-report.pdf
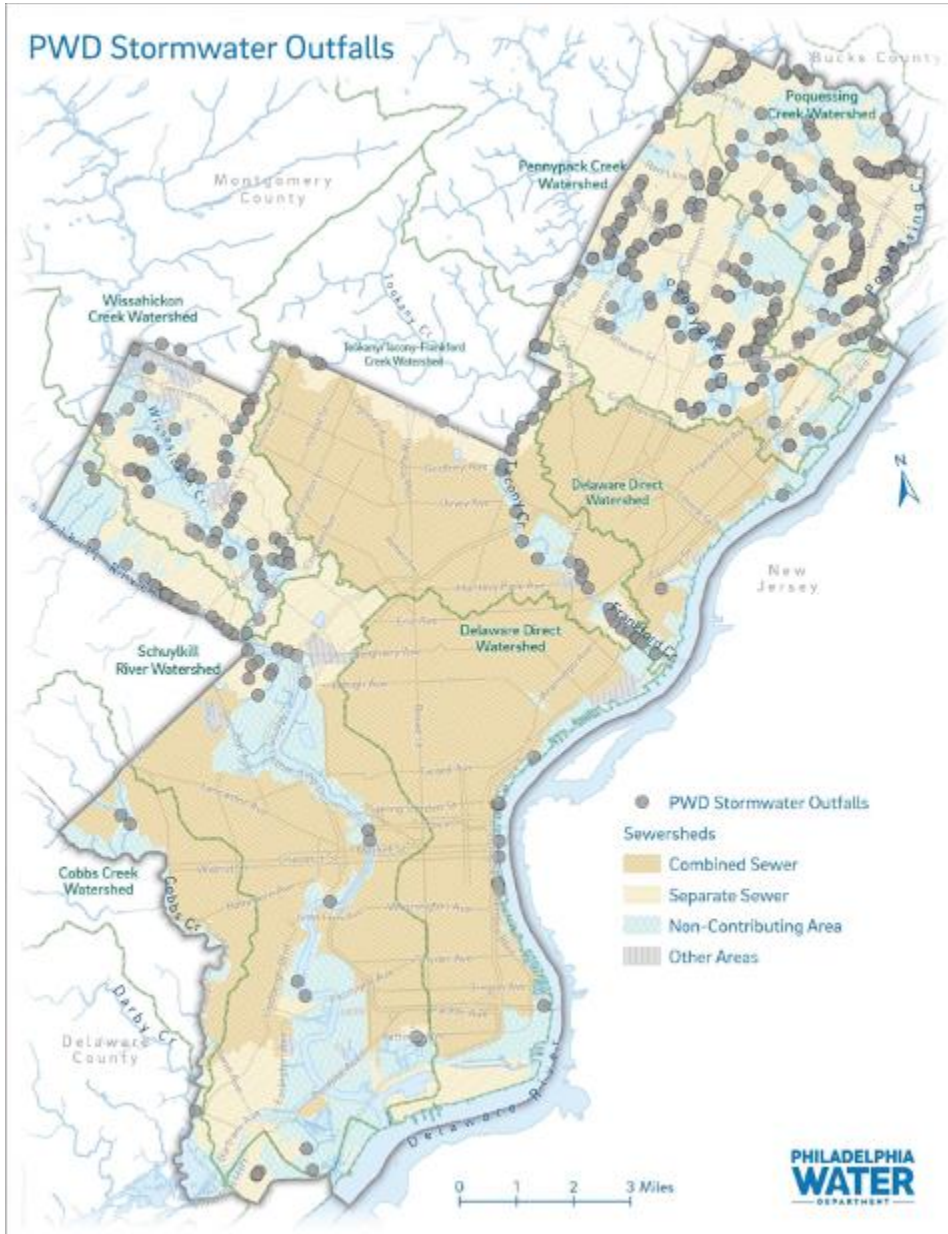
Source: Philadelphia Water Department (PWD) (2015). Green City, Clean Waters - Tidal Waters Water Quality Model – Bacteria and Dissolved Oxygen.

Wastewater

The Philadelphia wastewater system serves the entire city as well as parts of Bucks, Delaware, and Montgomery counties. The service area covers more than 364 square miles and includes a population of more than 2.3 million people (*Figure 3: PWD Stormwater Outfalls*). Approximately 36% of the service area and 33% of the population served are located outside of the city limits. The system includes 19 pump stations, 94,116

manholes, 26 storm relief structures, and 71,962 inlets. Along with these structures, the 3,716-mile collection system includes 762 miles of sanitary sewer, 737 miles of storm sewer, 1,855 miles of combined sewers, 13 miles of forced mains, and 349 miles of appurtenant piping.

The system includes three water pollution control plants (WPCPs). The Northeast Plant was built in 1923 to manage 60 million gallons per day (MGD). The Southeast Plant and the Southwest Plant were built in 1946. All three plants were upgraded by the 1980s and a biosolids processing facility was built in 1989. Through a partnership, this facility was augmented to add drying capabilities and began producing biosolid pellets in 2012.

The Philadelphia Water Department also manages the drinking water system for the city. The 2023 operating budget across all three water sectors (drinking water, stormwater, and wastewater) is approximately $424 million.[13]

New Jersey Municipalities Bordering the Study Area

Stormwater

Every municipality in New Jersey that borders the Study Area is subject to the MS4 permit program. As shown in *Figure 1: Study Area*, there are three New Jersey counties that border the Study Area – Burlington, Camden, and Gloucester. Within these counties, there are more than ten municipalities that border the Study Area. Each one is responsible for the stormwater pollution that they discharge into the river. Camden and Gloucester City have both combined and separate sewer systems (*Figure 4: Camden and Gloucester Sewer Systems*).

Wastewater

The Camden County Municipal Utilities Authority (CCMUA) operates the regional wastewater treatment system for Camden County, New Jersey. Serving a population of 510,000, approximately 77,000 of whom live in the City of Camden, CCMUA treats 80 million gallons of sewage daily. This sewage flows through 135 miles of pipes and 27 pump stations to the utility's Water Pollution Control Facility. The facility is the third largest in the state, servicing areas that combine denser urban and suburban communities and rural countryside. CCMUA reports operating revenue of approximately $93 million annually, with total assets (including capital

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[13] Philadelphia Water Department (2022). Fiscal Year 2023 Operating Budget, Received from https://phlcouncil.com/wp-content/uploads/2022/04/Philadelphia-Water-Department-FY2023-Budget-Detail.pdf

assets) valued at approximately $590 million and total liabilities (current and long-term) of approximately $300 million.[14]

The Camden County Municipal Utilities Authority is a founding member of the Camden Stormwater Management and Resource Training Initiative (or Camden SMART), a cross-sector collaboration with the community to address both combined sewage flooding and water quality. The initiative is focused on developing stormwater management policy, installing neighborhood-scale green and gray infrastructure projects, and developing green infrastructure training programs.

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[14]Camden County Municipal Utilities Authority (2021). Retrieved from http://www.ccmua.org/wp-content/uploads/2023/05/2021-CCMUA-Audit.pdf

Figure 4: Camden and Gloucester Sewer Systems
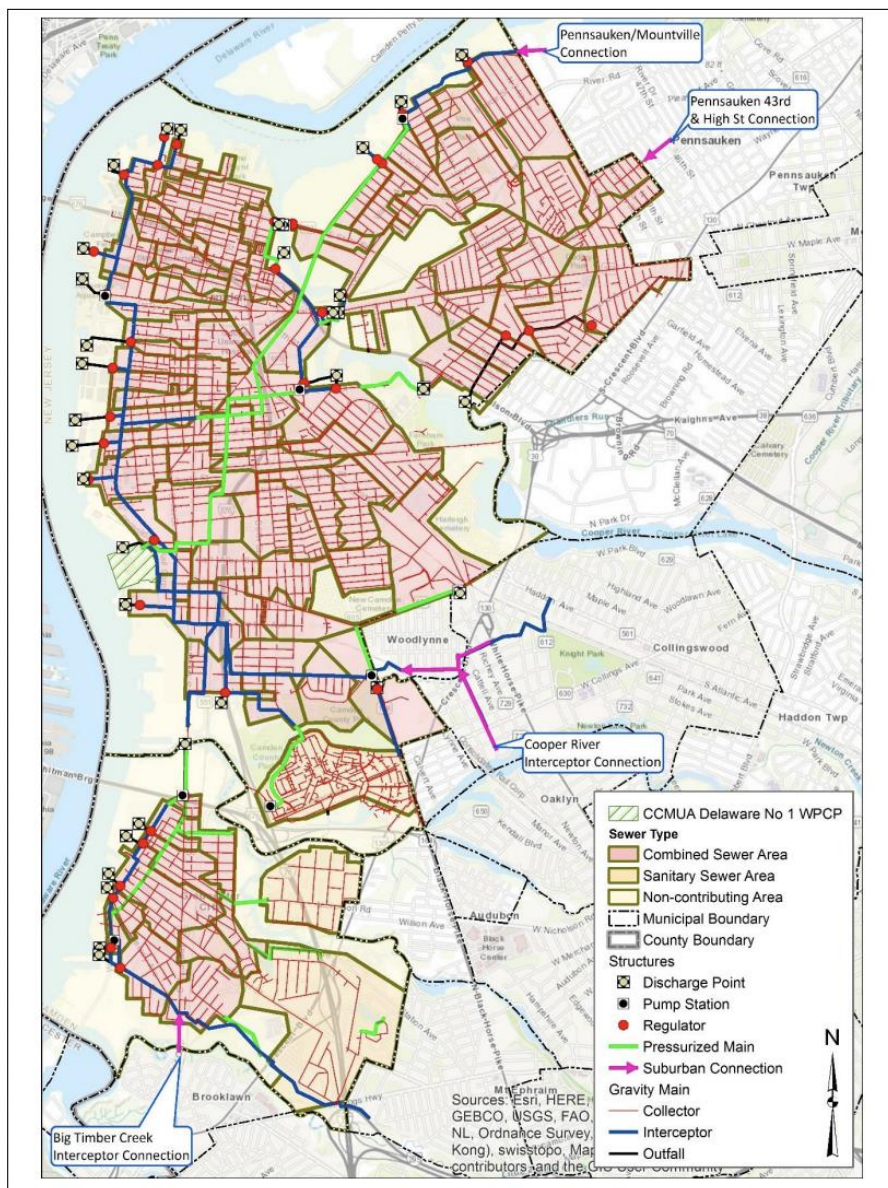
Source: Camden County Municipal Utilities Authority Systems Characterization Report (2018).

Delaware County Municipalities and The City of Chester

Stormwater

There are four municipalities immediately south of Philadelphia at the southern end of the Study Area. They include Tinicum Township, Ridley Township, Eddystone Borough, and the City of Chester. The two townships and the borough have MS4 permits covering the pollution from their separate storm sewer systems. The City of Chester has both combined and separate sewer systems (_Figure 5: Chester City Service Area_).

In Chester, stormwater is managed by the Stormwater Authority of the City of Chester, which has implemented a stormwater utility fee that brought in $3.5 million in 2021. The authority's assets are $25.9 million, and liabilities are $22.6 million.[15] The city developed a green stormwater infrastructure plan in partnership with the Delaware Valley Regional Planning Commission in June 2017, providing the framing for the stormwater authority's work.

Figure 5: Chester City Service Area
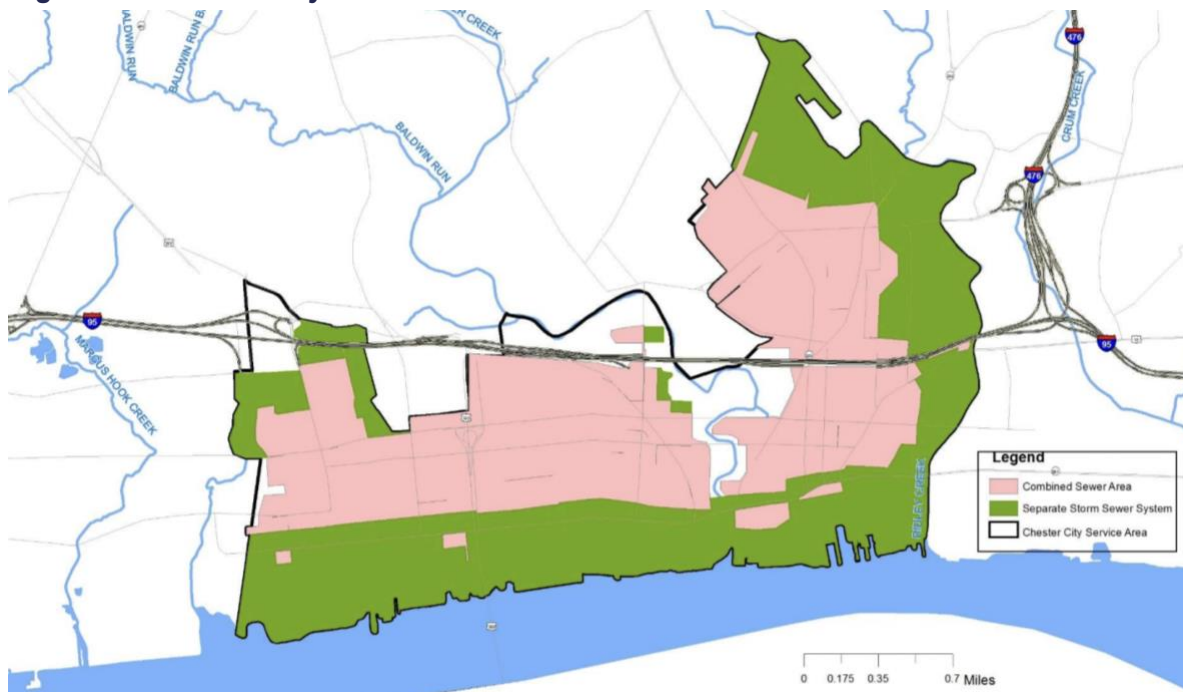
Source: DELCORA Combined Sewer Overflow-Long Term Control Plan Update (2020).

Wastewater

Serving as a municipal authority, DELCORA, the Delaware County Regional Water Quality Control Authority, owns, operates, and maintains wastewater facilities serving approximately half a million people in 46 municipalities in Delaware and Chester counties *(Figure 5: Chester City Service Area)*. DELCORA collects and conveys an average daily wastewater flow of approximately 60 million gallons per day (MGD) with an instantaneous peak flow of approximately 200 MGD.

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[15] Stormwater Authority of the City of Chester Financial Statement (2021).
https://www.chesterstormwaterauthority.com/_files/ugd/fcf170_30a1b30777ae4272847d5d11b58de5c0.pdf

DELCORA entered into agreements with the City of Philadelphia in 1974 and 2013 to convey wastewater to the City's Southwest Water Pollution Control Plant (SWWPCP) to serve its eastern service area (*Figure 6: DELCORA Service Area*). The three thresholds are instantaneous flow at 100 MGD, maximum daily flow at 75 MGD, and annual average daily flow at 50 MGD. DELCORA owns and operates three major pump stations that transport wastewater to the City's SWWPCP. The pump stations are the Central Delaware Pump Station (CDPS) with a design capacity of 40 million gallons per day (MGD); Muckinipates Pump Station (MPS) with a design capacity of 24 MGD; and Darby Creek Pump Station (DCPS) with a design capacity of 60 MGD. In 2020, DELCORA sent an average of approximately 23 MGD to the SWWPCP.

Local townships and boroughs own their own collection systems and convey wastewater to three conveyance authorities: the Central Delaware County Authority, the Muckinipates Authority, and the Darby Creek Joint Authority. All the wastewater authorities in DELCORA's eastern service area have entered into agreements with DELCORA for treatment, and the Radnor-Haverford-Marple (RHM) Sewer Authority has entered into an Agreement with the Darby Creek Joint Authority. In the Eastern Service Area, DELCORA owns and operates three major pump stations that transport wastewater to the City of Philadelphia SWWPCP and the WRTP. DELCORA also owns and operates three small pump stations tributary to the CDPS. The Central Delaware Pump Station (CDPS) flow is pumped to DELCORA's Western Regional Treatment Plant in Chester. Wet weather flows that are in excess of 20 MGD are diverted to SWWPCP.

In its western region, DELCORA operates its Western Region Treatment Plant (WRTP) located in Chester and the collection and conveyance systems in the City of Chester, the Boroughs of Upland, Parkside, Trainer, Rose Valley, and Marcus Hook and a portion of Chester Township. The system includes eight pump stations and their respective force mains. Additionally, there are ten small lift stations and approximately 129 miles of separate and combined sewers. The 129 miles of sewers are 11.7 miles of an interceptor system, 3,209 maintenance holes, 25 CSO regulators controlling storm overflows, and two outfalls with no regulators. Chester Pump Station CSO (Outfall #027) and the Jeffrey Street CSO (Outfall #006) were eliminated and removed from the NPDES permit effective January 1, 2014.

The WRTP also processes wastewaters from the Boroughs of Eddystone, Brookhaven, the Townships of Lower Chichester, Nether Providence, Upper Providence, and Southern Delaware County Authority, Bethel Township Sewer Authority, Southwest Delaware County Municipal Authority, and Middletown Township Sewer Authority. Additionally, typical dry weather flow (up to 20 MGD of wet-weather flow) from the Central Delaware Pump Station is diverted for treatment at the WRTP.

The WRTP is a permitted 50 MGD activated sludge treatment plant including a proposed outfall upgrade. The WRTP is about 45 years old, and major components have been upgraded. The 2020 Annual Average from the WRTP was 39.28 MGD. DELCORA reported $77.6 million in revenues in 2021 and $66 million in expenses, with the excess revenues being dedicated to a capital improvement fund.

Figure 6: DELCORA Service Area
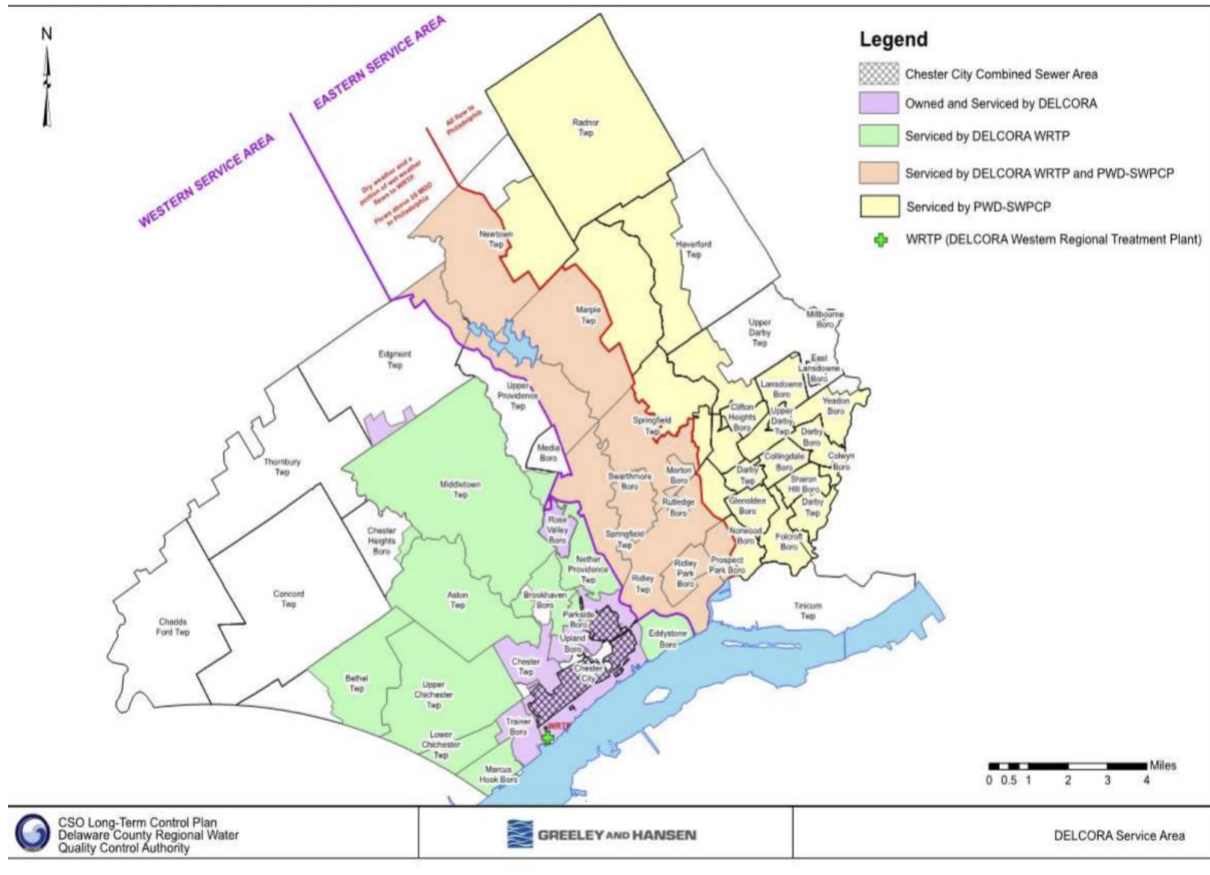
Source: DELCORA

CSOs Across the Study Area

During wet weather events, CSOs are likely the most significant source of FIB to the Study Area. Unlike WPCP and MS4 discharges, CSOs release untreated sewage into receiving waters by design. *Figure 7: Combined Sewer Systems Impacting the Study Area* shows the geographic extent of the combined sewer systems impacting the Study Area.

Figure 7: Combined Sewer Systems Impacting the Study Area
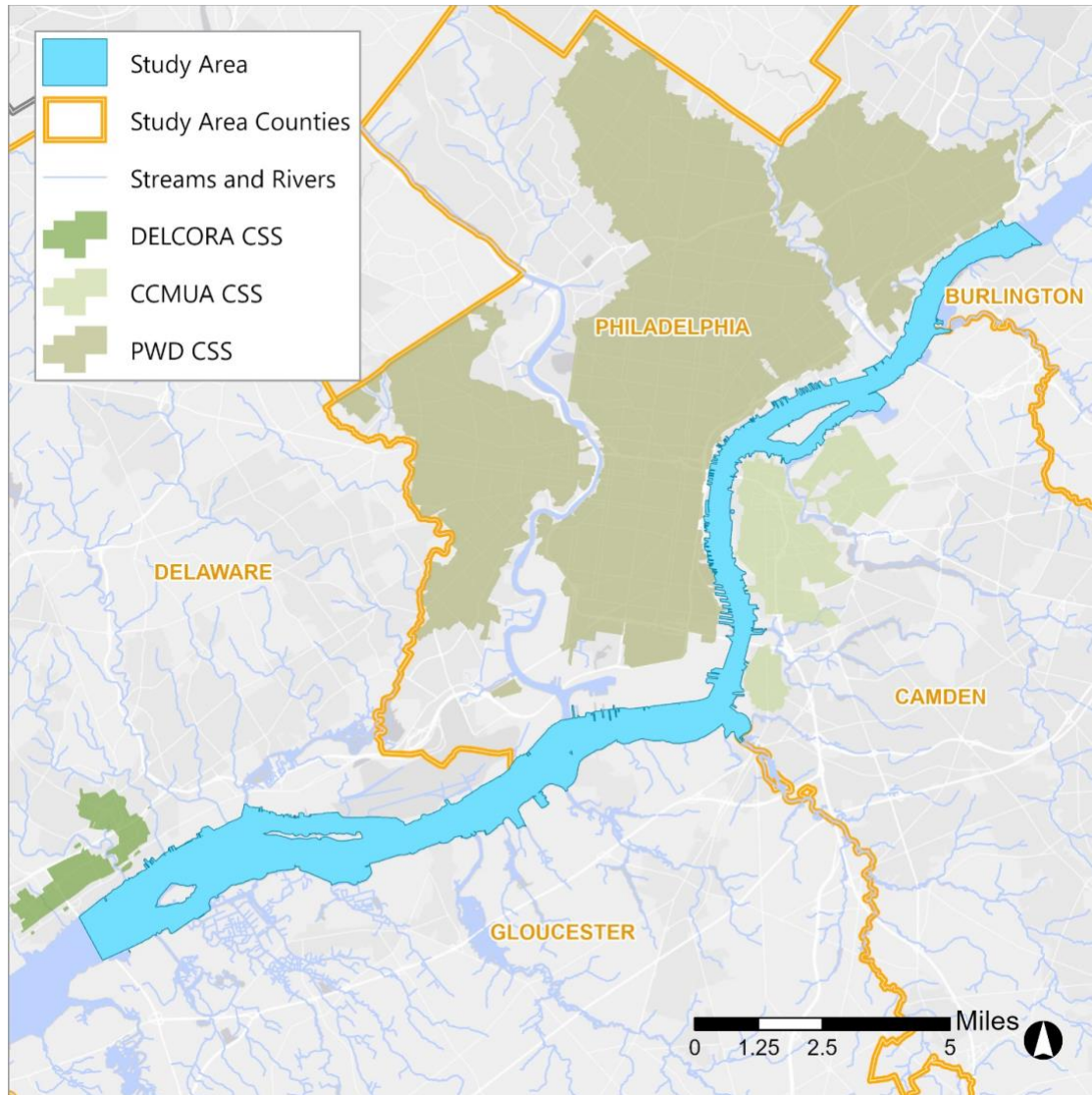
The PWD, CCMUA, and DELCORA have each performed monitoring and modeling to estimate baseline CSO discharges for the "typical hydrologic year." *Figure 8: Distribution of Annual Combined Sewer Overflow Volume (Million Gallons)* shows estimated overflow volumes across the three combined sewer systems, while *Figure 9: Distribution of Annual Combined Sewer Overflow Frequency (# of Occurrences)* shows estimated overflow frequencies. The outfalls discharging the highest CSO volumes are located in Philadelphia. However, the outfalls with the most frequent overflows are distributed throughout Philadelphia, Camden, Gloucester, and Chester. Recreation access sites are also shown for reference.

Figure 8: Distribution of Annual Combined Sewer Overflow Volume (Million Gallons)
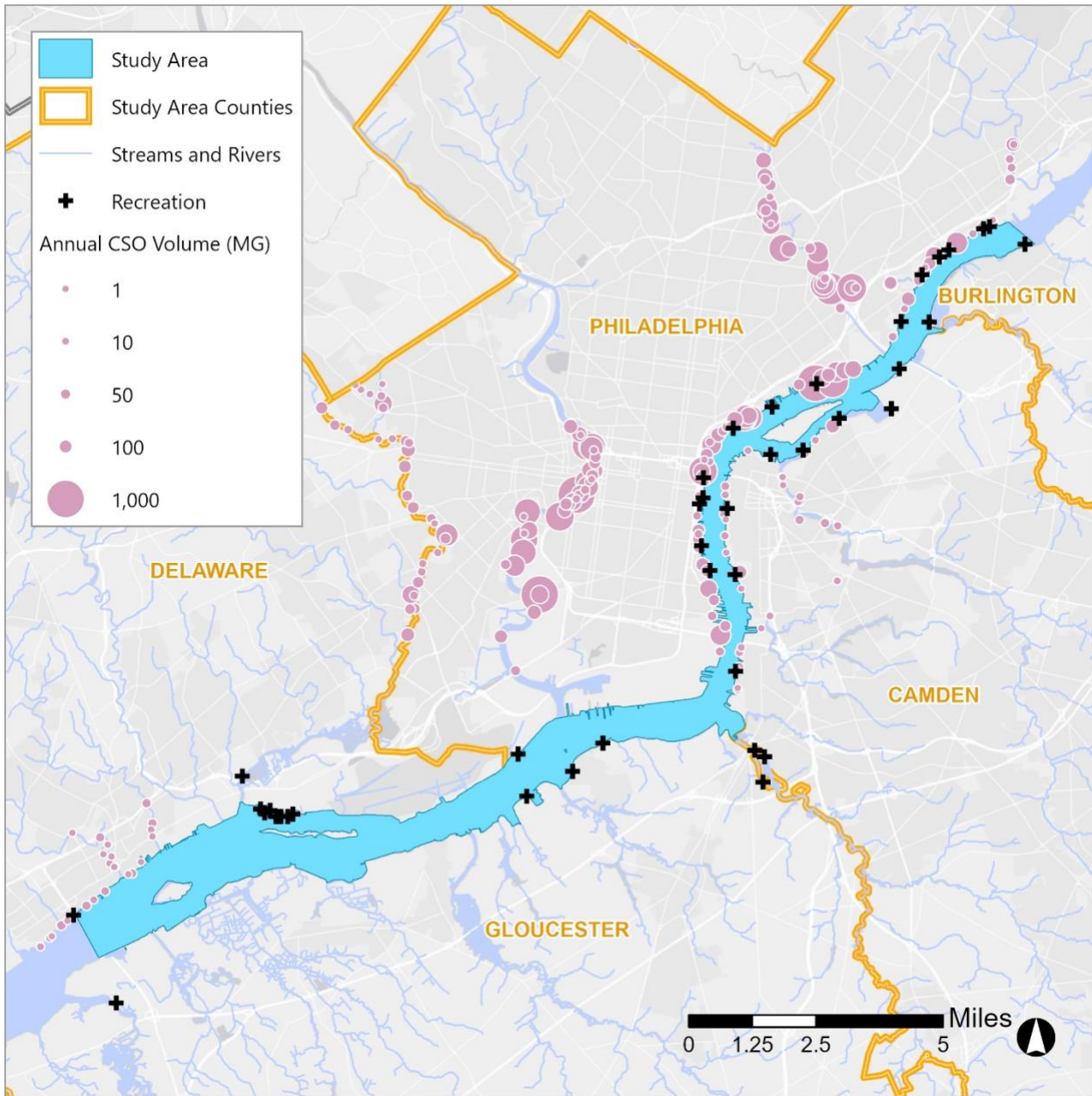
Figure 9: Distribution of Annual Combined Sewer Overflow Frequency (# of Occurrences)
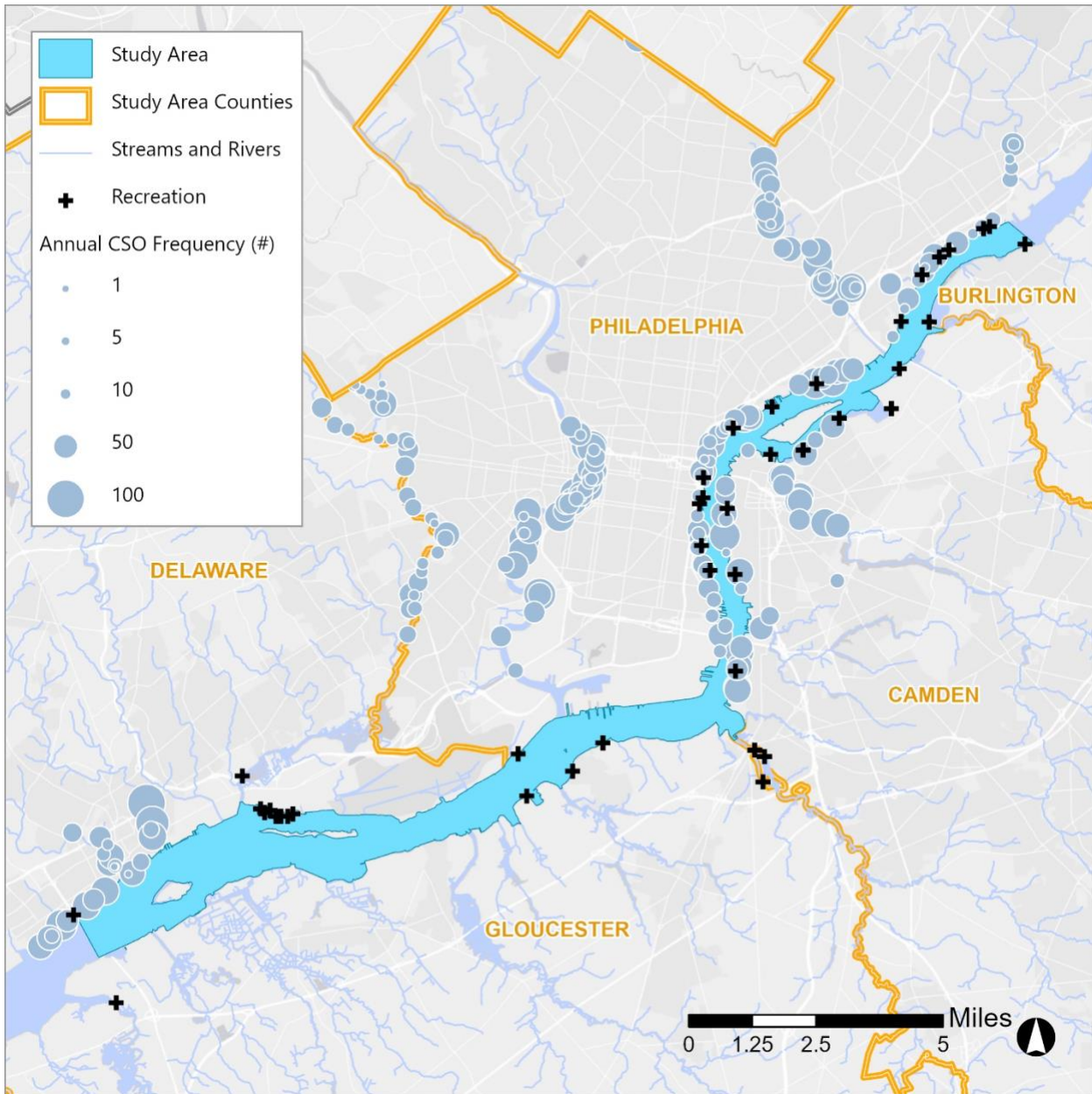
Some of the CSO modeling results for the "typical hydrologic year" are shown in *Table 3* (for all outfalls) and *Table 4* (for outfalls discharging directly to the Delaware River). The total annual CSO volume discharged by PWD is more than twenty times the total annual CSO volume discharged by CCMUA and DELCORA combined. This difference is somewhat less for the outfalls discharging directly to the Delaware River. For these outfalls, the annual CSO volume discharged by PWD is about 10.6 times the annual CSO volume discharged by CCMUA and DELCORA combined.

Table 3: CSO Modeling Results for the "Typical Hydrologic Year"

Overflow Characteristics	PWD	CCMUA	DELCORA
Total Volume (MG/year)	20,598	627	300
Maximum Volume from a Single Outfall (MG/year)	530	115	42
Maximum Frequency from a Single Outfall (#/ year)	83	70	91
CSO Outfalls (#)	164	30	24

Table 4: Estimated CSO Discharges for Outfalls on the Delaware River

Overflow Characteristics	PWD	CCMUA	DELCORA
Total Volume (MG/year)	6,354	433	165
Maximum Volume from a Single Outfall (MG/year)	512	115	42
Maximum Frequency from a Single Outfall (#/ year)	71	70	71
CSO Outfalls (#)	54	18	11

Clean Water Act Requirements for Wastewater and Stormwater Discharges

The Clean Water Act (CWA) uses two methods to protect the quality of water: monitoring water quality standards and controlling discharges from point sources.[16] Under CWA §301, discharge of a pollutant from a point source into waters of the United States is illegal without a National Pollution Discharge Elimination System (NPDES) Permit. There are three types of point source discharges that are relevant to this study:

- Discharges from wastewater treatment plants (commonly called water pollution control plants or WPCPs),
- Discharges from municipal separate storm sewer systems (MS4), and
- Discharges from combined sewer systems (CSOs).

Wastewater Treatment Plant Discharges

NPDES permits for WPCPs include effluent limitations that control the parameters of the plant's discharge as measured at specific outfalls where the treated water leaves the plant and enters the waterway. These permits cover multiple parameters and can include technology-based water quality effluent limitations (requiring a minimum level of treatment based on available technologies) and water quality effluent limitations (limiting the amount of specific pollutant in the discharge). Three entities manage WPCPs in the Study Area as outlined above, and each one of their facilities has an NPDES permit. These permits limit the level of fecal indicator bacteria in the discharge. For this report, we assume that all the plants are operating as designed and in compliance with their individual NPDES permit.

Stormwater Discharges

NPDES permits for MS4s require permittees to develop and implement a comprehensive Stormwater Management Program (SWMP) that includes six minimum control measures. These measures include: 1) public education and outreach, 2) public involvement and participation, 3) illicit discharge detection and elimination, 4) construction site runoff control, 5) post-construction stormwater management in new development and redevelopment, and 6) pollution prevention and good housekeeping for municipal operations and maintenance. The Pennsylvania DEP introduced a requirement for MS4 permittees to prepare Pollutant Reduction Plans to reduce their existing sediment and nutrient loads in stormwater draining from Urbanized

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[16] Cornell Law School (2023). Clean Water Act. Retrieved from https://www.law.cornell.edu/wex/clean_water_act_(cwa)#:~:text=The%20Environmental%20Protection%20Agency%2C%20authorized,EPA%20and%20by%20the%20states

Areas.[17] In 2018, a target was established of a 10% reduction in sediment loads. Neither the PA DEP nor the NJ DEP currently require reductions to bacteria loading through their MS4 programs.

The Study Area receives MS4 discharges from municipalities along the Delaware River and its tributaries. For example, the Wissahickon Creek watershed has 13 MS4 permittees. Discharges from these MS4s flow from the Wissahickon Creek which flows into the Schuylkill River and then into the Delaware River. With nine tributaries to the Study Area on the Pennsylvania side, there are more than 50 MS4 permittees whose stormwater discharges flow to the Study Area. On the New Jersey side, there are more than 30 MS4 permittees in Camden County within the Delaware River watershed. While it was beyond the scope of this report to document all the MS4 permittees and MS4 outfalls impacting the Study Area, the efficacy of MS4 implementation throughout all the watersheds that drain into the Study Area impacts the water quality.

Combined Sewer Overflow Discharges

Through a policy adopted by the EPA in 1994, cities with combined sewer systems are required to control CSOs by implementing nine minimum controls (NMCs) and developing long-term control plans (LTCPs). An LTCP describes the planning, design, construction, and monitoring of CSO controls to ultimately result in compliance with the requirements of the CWA. The CSO Policy provided two alternative approaches to evaluate CSO controls: the presumption approach and the demonstration approach. The presumption approach is the one selected by the CSO managers in the Study Area. Under the presumption approach, "planned CSO controls are presumed to provide an adequate level of control to meet the water quality-based requirements of the Clean Water Act if they meet one of three performance criteria and the permitting authority determines that the presumption is reasonable."[18] The three performance criteria are:

- No more than an average four overflow events per year (although the permitting authority may allow up to two additional overflow events per year); or
- Elimination or the capture for treatment of no less than 85 percent by volume of the combined sewage collected in the combined sewer system during precipitation events on a system-wide annual average basis (*Figure 10: Schematic of 85 percent capture performance criterion*); or
- Elimination or removal of no less than the mass of pollutants, identified as causing water quality impairment, for the volume that would be eliminated or captured for treatment under the second criterion.

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[17] Pennsylvania Department of Environmental Protection (2022). Retrieved from https://www.legis.state.pa.us/WU01/LI/TR/Transcripts/2022_0071H.pdf

[18] United States Government Accountability Office (2023). Retrieved from https://www.gao.gov/assets/gao-23-105285.pdf

Figure 10: Schematic of 85 percent capture performance criterion
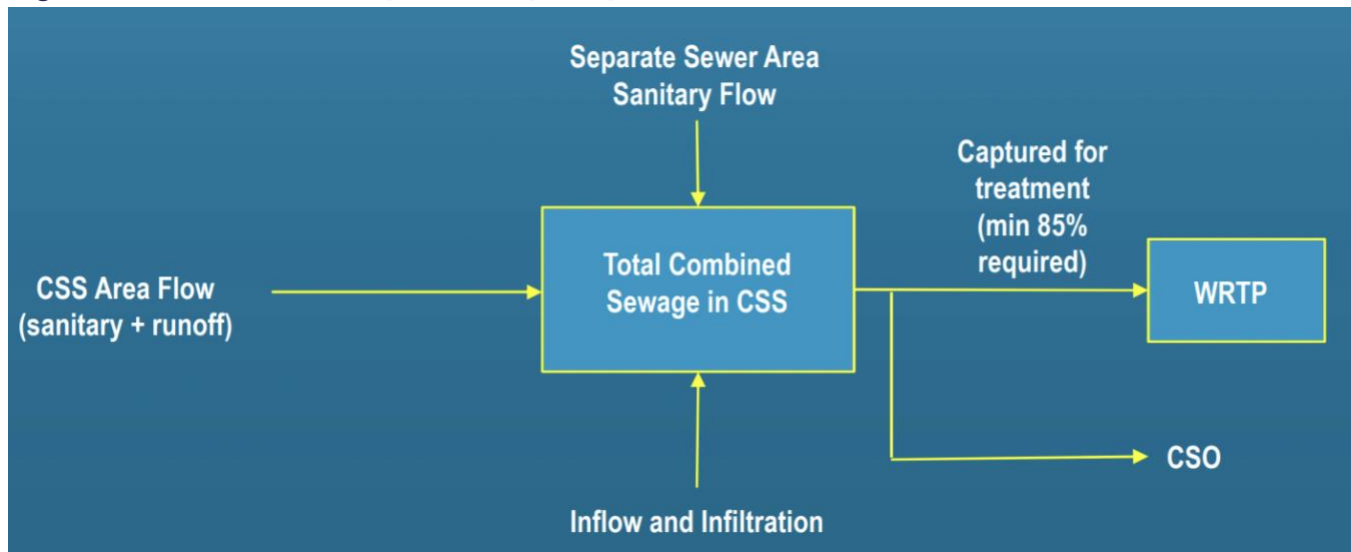
Source: DELCORA Combined Sewer Overflow-Long Term Control Plan Update (2020).

In 2000, Congress amended the Clean Water Act to require compliance with the policy and incorporation of LTCPs into enforceable mechanisms - a permit, administrative order, or court order.[19] The LTCPs developed by the cities of Chester, Camden, and Philadelphia are described further in a subsequent section on Committed Investments in the Study Area.

Under the CSO policy, the nine minimum control program is implemented as the first phase of investment in a city's watershed and people. It includes a series of affordable measures to reduce CSO discharges without requiring major engineering projects or construction efforts. Requirements of the policy provide enhanced public notifications of CSO locations, health concerns, and discharge events. It involves the implementation of system improvements that aim to eliminate dry weather overflows, monitor system operations, and calibrate hydraulic models.

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[19] 33 USC Section 1342(q). Retrieved from https://www.law.cornell.edu/uscode/text/33/1342

The main focus areas of the NMCs are:

1. Review and improvement of on-going operation and maintenance programs

2. Measures to maximize the use of the collection system for storage

3. Review and modification of the industrial pretreatment program

4. Measures to maximize flow to the wastewater treatment facilities

5. Measures to detect and eliminate dry weather overflows

6. Control of the discharge of solid and floatable materials

7. Implementation of programs to prevent generation and discharge of pollutants at the source

8. Public notification of CSO impacts

9. Comprehensive inspection and monitoring programs to characterize and report overflows and other conditions in the combined sewer system[20]

The second phase of the CSO policy focuses on implementation of selected CSO control measures set out in the LTCP. Once LTCP implementation is completed, water system managers are required to continue to implement the NMCs and conduct post-construction monitoring to collect sufficient information to track the effectiveness of the selected controls.

In 2012, recognizing that it would be beneficial to assist cities in navigating the compliance process over multiple permits, EPA issued a memo that outlined a voluntary approach to integrated planning for stormwater and wastewater. It outlines a six-step process for identifying water quality improvement requirements, engaging with community members, and then prioritizing those activities that would have the most significant impact as early as possible. In 2019, this voluntary approach was codified in the Clean Water Act through the Water Infrastructure and Improvement Act. This process is aligned with what has become known in the water sector as the "One Water" approach, which integrates planning across drinking water, stormwater and wastewater. There are elements of this "One Water" approach in the Clean Water Act compliance strategies for Chester, Camden, and Philadelphia.

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[20] New Jersey Department of Environmental Protection (2013). https://www.nj.gov/dep/dwq/pdf/camden_cso_faqs.pdf

A January 2023 General Accounting Office report on EPA's CSO Policy included a detailed assessment of 11 municipalities with CSOs. The report found that the average time for these CSO systems to reach the post-construction period was 35 years and that all 11 systems faced financial challenges in implementing their LTCPs.[21]   The report notes that the CSO policy allows states flexibility in their water quality standards to reflect site-specific conditions. For example, Indiana revised its water quality standards for certain waters in Indianapolis during wet weather such that new water quality requirements apply for up to 4 days after CSO discharges. The federal and state regulators decided that requiring the city to invest in additional CSO controls would not be cost-effective. The new standards were approved in July 2020.[22] It is important to note that he CSO program is the primary focus of the study going forward – the information provided on MS4 and WPCP permits was to provide context on forms of discharge and existing water quality conditions of the Study Area overall.

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[21] Government Accountability Office (2023). GAO report at 24-5. The report notes that low-income household water assistance programs can help address the affordability challenge and enable a community to achieve compliance as quickly as possible. Id. at 29. Retrieved from https://www.gao.gov/assets/gao-23-105285.pdf

[22] Government Accountability Office (2023). GAO report at 31-32. https://www.gao.gov/assets/gao-23-105285.pdf

Implementation Challenges and Approaches

As permittees seek to achieve compliance with Clean Water Act requirements, they face significant challenges and uncertainties. Among them are challenges related to water infrastructure financing and uncertainties related to climate change. An adaptive management approach is one way to sustain progress towards compliance in the face of these challenges.

Water Infrastructure Finance

When the Clean Water Act was first passed, it included a construction grants program that allowed wastewater treatment facilities access to funding to improve their treatment processes or build new facilities with better treatment. These construction grants were catalytic in realizing the substantial water quality improvements in the first decades of implementing Clean Water Act requirements. More than $60 billion was invested in improving wastewater treatment across the country.

In 1987, fifteen years after the act was passed, Congress revised the financial mechanism to create state revolving fund (SRF) programs that would finance projects through low-interest loans. The construction grant program was ended as of 1990 (with the exception of grants that are still available to the District of Columbia). Each SRF program is capitalized annually with a federal grant based on a formula that reflects a needs assessment for each state. The state must provide 20% of the federal amount as matching funds to receive the full federal grant, and it must operate the SRF program according to certain requirements. Over the 35 years since its inception, the Clean Water SRF program has provided $163 billion to help fund over 44,000 low-interest loans for clean water projects.[23] However, because these programs act as banks, accessing these funds can be challenging if a community can't meet the eligibility requirements or has other priorities to which their debt-financing capacity must be directed.

As cities began to grapple with the costs of addressing their CSO challenges, it became clear that the financial burdens could be overwhelming for some communities. To assist with the implementation of the 1994 CSO Policy and to help communities develop long-term control plans that were financially manageable, the EPA developed the Guidance for Financial Capability Assessment and Schedule Development.[24] This guidance outlined metrics EPA could use to determine financial capability and indicated that LTCP permit terms could be extended to reduce the annual fiscal burden on a city from its CSO compliance costs. Implementation of this policy resulted in LTCPs with planning horizons of 30 years or more. While it reduced annual fiscal

[23] Environmental Protection Agency (2023). Retrieved from https://www.epa.gov/cwsrf

[24] Environmental Protection Agency FCA guidance (1997). Retrieved from https://www3.epa.gov/npdes/pubs/csofc.pdf

burdens, it extended the environmental burden on the community from continued poor water quality. In 2023, this guidance was replaced by the Financial Capability Assessment Guidance.[25]

In the case of Philadelphia, because of the size of its wastewater and combined sewer systems, the scale of its needs can overwhelm the annual resources available through Pennsylvania's SRF program, known as PENNVEST. Nonetheless, the City has accessed SRF funding for various projects, including more than $50 million for green stormwater infrastructure projects and several large drinking water and wastewater projects. CCMUA has used SRF funding to keep user rates level while still making significant capital improvements. DELCORA has received two PENNVEST loans since its inception for a total of $15 million.[26]

Climate Change

In addition to CWA compliance, climate change is significantly impacting the management of water systems in the Northeast in the near and long term. In January 2022, the Philadelphia Water Department adopted required guidance entitled "Climate-Resilient Planning and Design Guidance" that includes climate projections, tools and risk management strategies that should help build long-term resilience.[27] In the Study Area, less frequent but larger storm events, longer summer dry periods, increased air and water temperatures, sea level rise, and changes in the salt line all factor into future management planning.

The scientific literature does not provide a clear picture as to how climate change will impact pathogen levels in the Study Area. Changes in precipitation, flow regimes, salinity, CSO volume and frequency, and air and water temperatures could all affect infrastructure performance and pathogen levels. As water managers proceed with capital improvements, climate change will play into how specific projects are designed and implemented through the adaptive management process. Climate change will also likely impact how water managers consider future CSO control efforts.[28]

Some water advocates caution against building larger and larger storage to mitigate the impacts of climate change. They argue that cities need to develop more integrated and resilient water infrastructure.[29] Recent

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[25] Environmental Protection Agency (2023). Retrieved from https://www.epa.gov/waterfinancecenter/clean-water-act-financial-capability-assessment-guidance

[26] A list of projects approved for Delaware County, Pennsylvania can be found at https://www.pennvest.pa.gov/Information/Pages/Approved-Projects.aspx

[27] Philadelphia Water Department, (2022). Climate-Resilient Planning and Design Guidance at 1-4. Retrieved from https://water.phila.gov/pool/files/climate-resilient-guidance.pdf

[28] Government Accountability Office (2023). GAO report at 33. https://www.gao.gov/assets/gao-23-105285.pdf

[29] Kruzman, D. (2022). "Cities are investing billions in new sewage systems. They're already obsolete.", Grist. Retrieved from https://grist.org/cities/cities-are-investing-billions-in-new-sewage-systems-theyre-already-obsolete/

studies have investigated the use of green stormwater infrastructure to reduce CSOs and sanitary sewer overflows. A comprehensive review of 66 of these studies noted that several found gray-green hybrid strategies were likely to be the most cost-effective.[30]

Adaptive Management

Water resource managers within the Study Area are all committed to meeting the Clean Water Act's fishable and swimmable goals. In addition, water resource managers are all invested in moving forward with progressive programs involving stormwater utilities, CSO minimization, green infrastructure, operational efficiencies, and net-zero energy and greenhouse gas emissions. Realizing these visions requires significant capital improvements in communities with minimal financial capacity.

An adaptive management approach is key to addressing bacteria in the Study Area in the face of financing challenges and climate change uncertainties. Adaptive management is defined by the Congressional Research Service as:

> …the process of incorporating new scientific and programmatic information into the implementation of a project or plan to ensure that the goals of the activity are being reached efficiently. It promotes flexible decision-making to modify existing activities or create new activities if new circumstances arise (e.g., new scientific information) or if projects are not meeting their goals. The complex and dynamic nature of ecosystems makes their restoration and management amenable to an adaptive management approach, and the concept is being implemented at scales that include entire regions or river basins.[31]

Adaptive management is integrated into the CSO Long-term Control Plan agreements for PWD, CCMUA, and DELCORA. This flexibility allows all stakeholders to adjust the approaches used to achieve water quality improvements as science, innovation, costs and benefits, impacts of climate change, and changing regional economics shift over time.

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[30] Muttil et al., (2023). Impacts of Extreme Rainfalls on Sewer Overflows and WSUD-Based Mitigation Strategies: A Review. *Water*. Retrieved from https://doi.org/10.3390/w15030429

[31] Congressional Research Service Reports R41671. (2011). Retrieved from https://crsreports.congress.gov/product/pdf/R/R41671

3   Methods and Findings

Objective 1: Understanding Existing FIB Water Quality Conditions and Identifying Knowledge Gaps

METHODS

To understand existing water quality conditions in the Study Area and identify knowledge gaps, the project team identified existing monitoring programs that sampled for FIB, then aggregated and analyzed the bacteria monitoring data. Bacteria monitoring programs in the Study Area include center channel and nearshore monitoring efforts led by the Delaware River Basin Commission (DRBC) and the Philadelphia Water Department (PWD). Separate analyses were conducted for center channel data and nearshore data. These environments are characterized by different water quality conditions and environmental processes. To explore this data further, visit the interactive Delaware River Bacteria Data Viewer created by the Water Center at Penn.[32]

Existing Bacteria Monitoring Data

Center Channel Data

The longest-running monitoring program in the Study Area is the DRBC's Delaware Estuary Water Quality Monitoring Program. This program has been collecting bacterial data from 22 stations on the river's center channel since 1967. Samples are collected once monthly from April to October and the program analyzes fecal coliform and enterococcus levels to determine compliance with the commission's water quality standards for recreational use.

For this study, bacteria sampling data were downloaded from the National Water Quality Monitoring Council Water Quality Portal. Data were downloaded for the five stations within the Study Area, three stations upstream of the Study Area, and three stations downstream of the Study Area. The three stations upstream of the Study Area are: Florence Bend (RM 122.4), Burlington Bristol Bridge (RM 117.8), and Torresdale (RM 110.7). The three stations downstream of the Study Area are: Marcus Hook (RM 78.1), Oldmans Point (RM 74.9), and Cherry Island (RM 71.0). Because the portal archives data collected before 2005, the period of record for the downloaded data was 2005-2019.

Although recreation activities tend to take place in the nearshore environment, the extensive center channel data collected by DRBC can provide insights into regional water quality conditions. Analyses were conducted

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[32] Water Center at Penn (2023). Delaware River Bacteria Data Viewer. Retrieved from
https://experience.arcgis.com/experience/caa71fcc2dfb45feb031e7b6d7d878f1/

to explore the difference in bacteria levels between different stations, as well as the distribution of bacteria levels at each station. These analyses used the EPA's REC-1 criteria for primary contact recreation as a basis for comparison.

Nearshore Data

In 2019, both DRBC and PWD initiated nearshore monitoring programs to address the gaps identified in the center channel monitoring program. The intent of the programs was to better understand bacteria levels where people recreate. Both programs conducted more frequent summer sampling at public recreation sites, and both programs tested for fecal coliform, *E. coli*, and Enterococci.

The DRBC program began with eight nearshore monitoring sites in 2019 and expanded to nine in 2020 (*Figure 11: Nearshore monitoring sites sampled by DRBC and PWD*). Five sites are located in New Jersey, and three to four in Pennsylvania (Penn Treaty Park was added in 2020). The program was designed to collect samples five times per month during the recreation season, from May to September (with the exception of 2020, when the COVID-19 crisis delayed the start of sampling to July). DRBC Enterococci and *E. coli* values had an upper detection limit of 24,196. This is important to note when comparing geometric means across sampling programs.

The PWD program was conducted in 2019, but not in 2020. The program included ten nearshore monitoring sites in Philadelphia, six of which are in the Study Area (*Figure 11: Nearshore monitoring sites sampled by DRBC and PWD*). Each site was sampled five times per month between June and September. Sample dates were preselected approximately two months in advance, and samples were collected between Monday and Thursday. The majority of *E. coli* and Enterococci samples had no upper detection limit and reached maximum values of up to 33,480. However, several samples did have an upper detection limit of 24,196. Again, this is important to note when comparing geometric means across sampling programs.

Together, the DRBC and PWD monitoring programs collected samples from 16 monitoring sites within the Study Area - 11 in Pennsylvania and five in New Jersey. Note that three sites were sampled by both programs: Frankford Arsenal, Penn Treaty Park, and Washington Avenue Green. Also note that the adjacent sites of Penn's Landing Lagoon and Independence Seaport Museum are shown as separate sites. While DRBC sampled the water within the enclosed lagoon, PWD sampled the water in the open river.

Table 5 provides a summary of the DRBC and PWD nearshore monitoring programs.

For the nearshore data, analyses were conducted to compare nearshore water quality conditions to center channel water quality conditions, and to compare water quality conditions at different nearshore monitoring sites. The data was also analyzed to explore how bacteria levels varied with the season, with wet weather, and with proximity to CSOs. These analyses used the EPA's REC-1 criteria for primary contact recreation as a basis for comparison.

Table 5: Summary of DRBC and PWD nearshore monitoring programs

Monitoring Program	Total Sites	PA Sites	NJ Sites	Sample Period	Samples Per Month	Total Samples
DRBC 2019	8	3	5	May-Sept	5	165
DRBC 2020	9	4	5	July-Sept	5	167
PWD 2019	10	10	0	June-Sept	5	180

Figure 11: Nearshore monitoring sites sampled by DRBC and PWD

Key
1. Linden Avenue Boat Launch
2. Riverton Yacht Club
3. Palmyra Cove
4. Frankford Arsenal/Frankford Boat Launch
5. Pennsauken Access (Delair Boat Launch)
6. Penn Treaty Park
7. Pyne Poynt Park
8. Independence Seaport Museum
9. Penn's Landing Lagoon
10. Washington Avenue Green
11. Pier 68
12. National Park (Red Bank Battlefield Park)
13. Ft. Mifflin
14. Schuylkill Banks
15. Bartram's Garden
16. John Heinz Wildlife Refuge Canoe Launch

Supplemental Bacteria Monitoring Effort

For existing water quality data, statistical analysis was conducted on available fecal indicator bacteria data. To fill in data gaps, the project team conducted a supplemental monitoring effort in the summer of 2021. This effort aimed to expand upon the existing monitoring data in three important ways:

1. The monitoring effort aimed to collect water samples on five sequential dates, pre- and post-wet weather. This approach was intended to help understand how FIB signals decay after a rain event.
2. The monitoring effort conducted concurrent sampling at tributary sites, mainstem sites, and CSO outfalls. This approach was intended to help understand the relative magnitude of FIB concentrations across sites.
3. The monitoring effort piloted the use of microbial source tracking DNA markers. Samples were analyzed for Human Bacteroides, avian marker, and the gull marker. This approach was intended to explore the benefits of microbial source tracking approaches in the Study Area. To view this data, visit the interactive Delaware River Bacteria Data Viewer created by the Water Center at Penn.

Sample Locations

Samples were collected at nine sites on the Delaware River, four sites on the tidal tributaries, and two CSO outfalls (*Table 6*). Nine of the fifteen sites were in Pennsylvania and six were in New Jersey.

Table 6: Supplemental Sampling Locations

Site Type	Site Name
Delaware River	Palmyra Cove Nature Park (NJ)
	Frankford Arsenal (PA)
	Pennsauken Access/Delair Boat Launch (NJ)
	Penn Treaty Park (PA)
	Pyne Poynt (NJ)
	Penns Landing (PA)
	Washington Avenue Green (PA)
	National Park/Redbank Battlefield Park (NJ)
	Chester Waterfront (PA)
Tidal Tributaries	Frankford/Tacony at Castor Ave (PA)
	Cooper River at Kaighns Ave (NJ)
	Schuylkill River at Schuylkill Banks (PA)
	Schuylkill River at Bartram's Garden (PA)
CSO Outfalls	Frankford/Tacony at Castor Ave (PA)
	Cooper River at 32nd and Farragut (NJ)

Samples were collected in late August 2021, as the remnants of Tropical Storm Fred brought rainfall to the region. The first day of sampling, on August 18th, was intended to represent dry-weather conditions. The second day of sampling, on August 19th, was intended to represent wet-weather conditions. The third, fourth, and fifth days of sampling, on August 20th, August 22nd, and August 24th, were intended to represent the return to dry-weather conditions.

Once the sampling effort began, observed rainfall patterns diverged from the forecast. Rainfall depths were relatively small and highly variable from one sampling site to another. The project team used rainfall data from the nearest rain gauge to interpret monitoring results. For sites with no nearby rain gauges, the project team used local precipitation estimates from Weather Underground.

Sample Analysis

Samples were analyzed at the Sales Laboratory at Drexel University operated by Dr. Christopher Sales. Samples were analyzed for fecal coliform, *E. coli*, enterococci, human-associated HF183 Bacteroides marker (HF183), and avian-associated fecal markers. Five field parameters were also recorded: pH, temperature, dissolved oxygen (DO), conductivity, and turbidity.

Generally, recreational water quality monitoring requires measuring fecal indicator bacteria using culture-based enumeration methods. Fecal indicator bacteria (FIB) are used as a proxy for sewage contamination, and increased incidence of swimming-related illness has been observed to coincide with elevated FIB concentrations. However, FIB can originate from a range of sources including human and non-human contamination. Molecular-based water quality monitoring methods for detection and quantification of host-associated fecal bacterial DNA can provide critical information regarding the source of microbial contamination and associated risk to recreators. Microbial Source Tracking (MST) uses host-associated genomic sequences that are specific to a pollution source and can assist watershed managers in identifying and eliminating sources of fecal contamination to a water body. Analysis of host-associated markers focused on differences in HF183 and avian marker concentrations across sites, and the relationships between FIB, HF183 and avian markers.

For HF183, the method used was modified from EPA Method 1696. The target gene sequences were the Bacteroides human-associated gene sequences commonly found in the feces of humans.

FINDINGS

Existing Bacteria Monitoring Data

Generally, the existing data and data collected for this project show exceedances of water quality standards for primary contact recreation during both wet and dry weather conditions. They also show exceedances from samples taken in the center channel and near shore areas. Under certain conditions, the water quality at

certain locations in the Study Area meets the water quality standards for primary contact recreation. This section elaborates on the following key findings:

1. At the regional scale, center channel water quality conditions are closer to meeting EPA's REC-1 criteria than nearshore water quality conditions.

2. Nearshore water quality is highly localized and dynamic. Bacteria levels vary widely across short distances (e.g., Penn's Landing Lagoon and Independence Seaport Museum). They also vary considerably from month to month and year to year.

3. At nearshore sampling sites, dry weather water quality conditions are generally closer to meeting EPA's REC-1 criteria than wet weather water quality conditions.

4. During dry weather conditions, some nearshore sampling sites are notable for their consistently poor water quality. These sites include Pyne Poynt Park, Independence Seaport Museum, Schuylkill Banks, Bartram's Garden, and John Heinz Wildlife Refuge. Other sites are notable for their consistently favorable water quality. These include Linden Avenue Boat Launch, Riverton Yacht Club, and Ft. Mifflin.

5. Overall, the nearshore sampling sites with the highest bacteria levels were those within 2,500 feet of a combined sewer outfall.

6. For some nearshore locations, wet weather pollution may not be a primary driver of bacteria levels.

7. There is significant room for improvement in the design and coordination of nearshore FIB monitoring programs in the Study Area.

> **1.** **At the regional scale, center channel water quality conditions are closer to EPA's REC-1 criteria than nearshore water quality conditions.**

From 2005 to 2019, most monthly samples collected at stations within the Study Area had *E. coli* levels below EPA's REC-1 criterion of 126 CFU/100 mL (*Table 7).* Stations within the Study Area are outlined in red.

Table 7: Percent of Center Channel E. Coli Concentrations Below 126 CFU/100 mL

Center Channel Station	Location Relative to Study Area	% of Monthly Samples Below Reference Value
Florence Bend	Upstream	88.1%
Burlington Bristol Bridge	Upstream	88.1%
Torresdale	Upstream	86.0%
Betsy Ross Bridge	Study Area	72.9%
Benjamin Franklin Bridge	Study Area	67.9%
Navy Yard	Study Area	74.4%
Paulsboro	Study Area	90.4%
Eddystone	Study Area	92.1%
Marcus Hook	Downstream	90.4%
Oldmans Point	Downstream	96.8%
Cherry Island	Downstream	96.0%

In addition, geometric mean *E. coli* levels for all stations within the Study Area were below the REC-1 criterion (*Figure 12: Distribution of Center Channel E. Coli Concentrations, 2005-2019*). Stations within the Study Area are outlined in red. Note that stations upstream and downstream of the Study Area tended to have lower bacteria levels and less variability in bacteria levels.

Figure 12: Distribution of Center Channel E. Coli Concentrations, 2005-2019
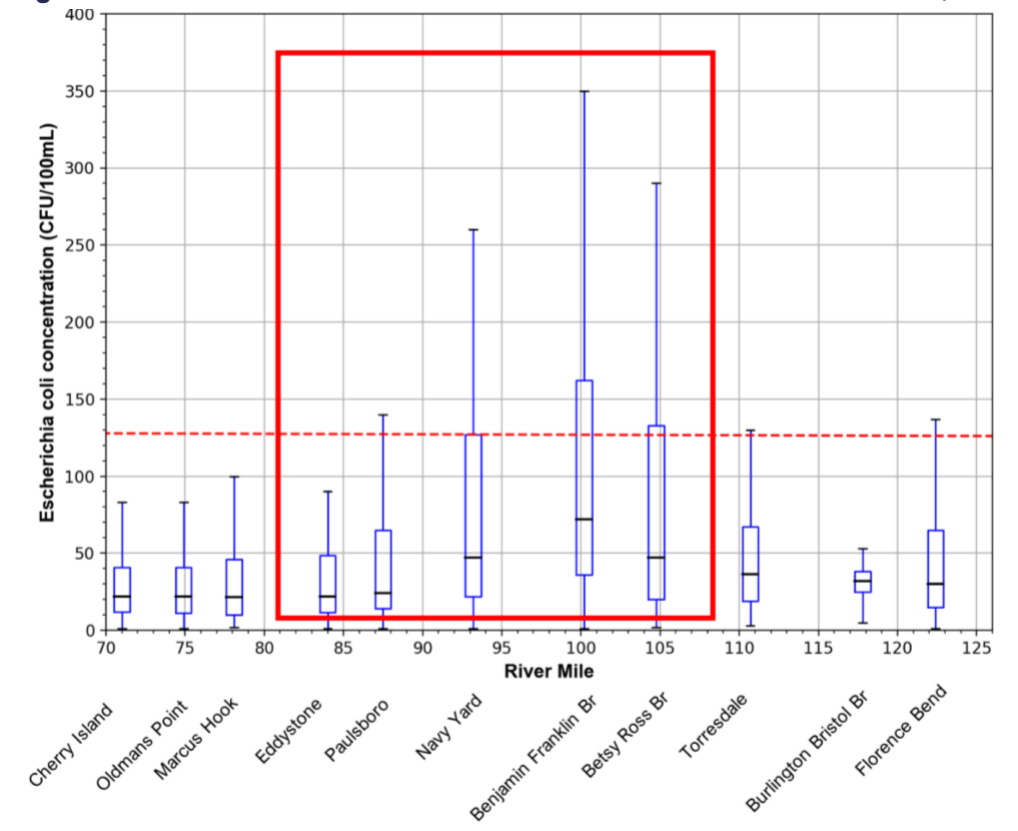
In contrast, a much lower share of nearshore samples collected in 2019 and 2020 had monthly geometric mean *E. coli* levels below the recommended EPA REC-1 criterion (*Table 8*).

Table 8: Percent of Nearshore E. Coli Concentrations Below 126 CFU/100 mL

Monitoring Program	Total % Below Reference Value	Wet Weather % Below Reference Value	Dry Weather % Below Reference Value
DRBC 2019	30%	22%	35%
DRBC 2020	46%	22%	51%
PWD 2019	20%	11%	33%

> **2.** **Nearshore water quality is highly localized and dynamic. Bacteria levels vary widely across short distances (e.g., Penn's Landing Lagoon and Independence Seaport Museum). They also vary considerably from month to month and year to year.**

Table 9: Monthly Geometric Mean of Nearshore E. Coli Concentrations (CFU/100 mL)

	Site (River Mile)	May	Jun	Jul	Aug	Sep
DRBC 2019	Riverton Yacht Club, NJ (108.50)	169	225	85	135	
	Palmyra Cove, NJ (106.71)	298	350	400	74	
	Frankford Arsenal, PA (106.11)	1,697	281	284	290	
	Pennsauken Access, NJ (104.30)	301	209	130	137	
	Pyne Poynt Park, NJ (101.62)	733	731	713	1,994	
	Penn Treaty Park, PA (100.99)					
	Penn's Landing Lagoon, PA (99.51)	198	222	234	388	
	Washington Avenue Green, PA (98.66)	141	713	182	171	
	National Park, NJ (92.03)	140	322	182	389	

	Site (River Mile)	May	Jun	Jul	Aug	Sep
DRBC 2020	Riverton Yacht Club, NJ (108.50)			194	201	55
	Palmyra Cove, NJ (106.71)			315	191	70
	Frankford Arsenal, PA (106.11)			198	362	78
	Pennsauken Access, NJ (104.30)			178	218	58
	Pyne Poynt Park, NJ (101.62)			1,478	995	306
	Penn Treaty Park, PA (100.99)			186	220	64
	Penn's Landing Lagoon, PA (99.51)			35	155	49
	Washington Avenue Green, PA (98.66)			62	182	50
	National Park, NJ (92.03)			146	122	96

	Site (River Mile)	May	Jun	July	Aug	Sep
PWD 2019	Linden Avenue Boat Launch, PA (110.32)		722	188	131	49
	Frankford Arsenal, PA (106.11)		2,984	522	1,009	39
	Penn Treaty Park, PA (100.99)		1,435	338	1,292	213
	Independence Seaport Museum, PA (99.57)		1,519	323	1,021	439
	Washington Avenue Green, PA (98.66)			276	677	330
	Pier 68, PA (98.22)		1,684			
	Ft. Mifflin, PA (91.54)		795	148	105	41
	Schuylkill Banks, PA (99.98)		1,112	369	1,247	1,123
	Bartram's Garden, PA (92.4)		1,207	651	759	503
	John Heinz Wildlife Refuge, PA (90.73)		5,906	3,231	2,259	477

> **3. At nearshore sampling sites, dry weather water quality conditions are generally closer to meeting EPA's REC-1 criteria than wet weather water quality conditions.**

Wet weather is often a primary driver of fecal pollution in urban watersheds. For the purposes of this analysis, weather conditions were categorized based on the amount of rainfall recorded at Philadelphia International Airport over the two days preceding a sample date. Samples were considered to represent wet weather conditions when at least 0.1 inches of cumulative rainfall was recorded over the preceding two days.

Figure 13: Percent of Nearshore E. Coli Concentrations Below 126 CFU/100 mL, Wet-Weather versus Dry-Weather Conditions

Combined sewer overflows (CSOs) are one of the ways that human sewage can be released into urban rivers. Based on the large areas served by combined sewer systems in Philadelphia, Camden, and Chester, CSOs are assumed to be one of the largest contributors to wet weather bacteria pollution within the Study Area.

Figure 14: Geometric mean E. coli concentrations vs. distance to the nearest CSO plots the geometric mean *E. coli* concentration at each monitoring site against the distance from the monitoring site to the nearest combined sewer outfall. The highest geometric mean concentrations are observed for monitoring sites within 2,500 feet of a combined sewer outfall, although one high value was recorded within 9,000 feet of a CSO. Lower geometric mean concentrations are observed for monitoring sites greater than 2,500 feet from a combined sewer outfall. Note that there may be other environmental parameters that influence bacterial concentration and persistence that are correlated with proximity to CSOs (such as tidal range and sediment resuspension).

Figure 14: Geometric mean E. coli concentrations vs. distance to the nearest CSO
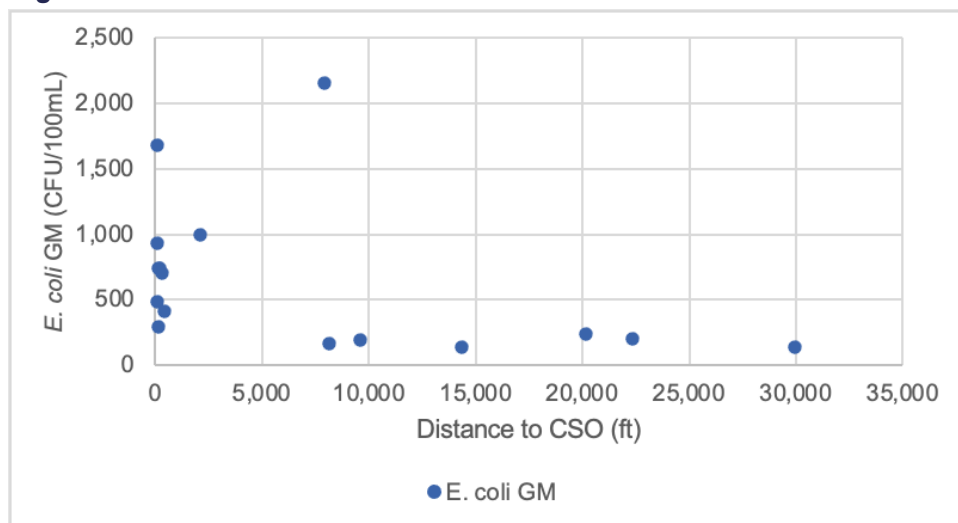
> **6. For some nearshore locations, wet weather pollution may not be a primary driver of bacteria levels.**

For each nearshore sampling site, the project team used Student's t-test, which is used to compare the means between two groups, to assess the statistical significance of the difference between wet-weather and dry-weather bacteria levels. *Table 11* shows the P values for rejecting the null hypothesis. P values greater than 0.05 (highlighted in yellow) mean there is no statistically significant difference between dry versus wet weather conditions. At the eight sites with P values greater than 0.05, wet weather may not be a primary driver of bacteria levels.

Table 11 also shows the overlap between sites where wet weather may not be a primary driver of bacteria levels, and sites with consistently poor (red) or consistently favorable (blue) *E. coli* levels. Interestingly, most of the sites showing consistently poor or favorable *E. coli* levels are also sites with no statistically significant difference between dry versus wet weather conditions.

Table 11: Statistical significance of difference in wet-weather and dry-weather E. coli levels

Site (Program, River Mile)	P values
Linden Avenue Boat Launch, PA (PWD, 110.3)	0.163
Riverton Yacht Club, NJ (DRBC, 108.1)	0.219
Palmyra Cove, NJ (DRBC, 106.7)	0.008
Frankford Arsenal, PA (PWD, 106.1)	0.060
Frankford Boat Launch, PA (DRBC, 106.1)	0.001
Pennsauken Access, NJ (DRBC, 104.3)	0.243
Pyne Poynt Park, NJ (DRBC, 101.3)	0.934
Penn Treaty Park, PA (PWD, 101)	0.043
Penn Treaty Park, PA (DRBC, 101)	0.022
Independence Seaport Museum, PA (PWD, 99.5)	0.041
Penn's Landing Lagoon, PA (DRBC, 99.5)	0.040
Washington Avenue Green, PA (PWD, 98.7)	0.022
Washington Avenue Green, PA (DRBC, 98.7)	0.036
Pier 68, PA (PWD, 98.22)	0.742
National Park, NJ (DRBC, 92.03)	0.032
Ft. Mifflin, PA (PWD, 91.54)	0.136
Schuylkill Banks, PA (PWD, 92.4)	0.105
Bartram's Garden, PA (PWD, 92.4)	0.007

> **7. There is significant room for improvement in the design and coordination of nearshore fecal indicator bacteria (FIB) monitoring programs in the Study Area.**

In reviewing the available monitoring data, several limitations were identified. For the nearshore data, sampling was largely conducted independent of weather conditions, and was not coordinated among DRBC, PWD, and DELCORA. Although sampling did occur during dry and wet weather conditions, the timing of sampling events in relation to wet weather events was not predetermined, limiting the ability to observe the water quality response to wet weather events. In addition to the small sample size and lack of wet weather samples, the lack of consistency among agency sampling methodologies limits the ability to characterize near shore water quality conditions. In addition, there are no monitoring sites in the City of Chester. While some bacterial monitoring data is available from DELCORA, the sampling locations and frequency were not designed to assess recreational water quality conditions.

Data collection needs to be designed to clarify the sources of bacterial pollution and opportunities for remediation, particularly in locations that are relatively closer to meeting the EPA criteria for safe swimming. One location that needs to be evaluated is Fort Mifflin, south of where the Schuylkill River meets the Delaware River. This site had consistently favorable conditions during dry weather.

Another important knowledge gap is the role that MS4 stormwater discharges and resuspension of bacteria from sediments play in the Study Area. Because combined systems may treat most stormwater during small storm events at certain locations, MS4 discharges may be a larger problem during small storms at specific locations. Likewise, certain sites may be more prone to resuspension of bacteria from sediments because of their physical characteristics. Water managers and regulatory agencies need to better understand the potential scale of these sources as well as the locations and conditions under which they are more problematic.

One final knowledge gap that surfaced while reviewing the existing data is understanding how reducing bacteria levels in tributary flows might impact bacteria levels in the Study Area. It might be an effective strategy, for example, to reduce bacteria levels in the tributaries that feed into the Study Area. Reducing bacteria levels in the tributaries would have the added benefit of helping those rivers - already designated for primary contact recreation - to attain that use. It would also relieve the persistent environmental burden for communities adjacent to those tributary waters.

Supplemental Bacteria Monitoring Effort

The supplemental bacteria monitoring effort conducted in the summer of 2021 collected water quality samples from 13 locations on the Delaware River and its tributaries and two CSO outfalls (*Table 12, Figure 15: Supplemental Sampling Locations*). As discussed in the Methods section, the monitoring effort was intended to help understand:

1. How FIB signals decay after a rain event.
2. The relative magnitude of FIB levels across mainstem sites, tributary sites, and CSO outfalls.
3. The potential benefits of microbial source tracking approaches in the Study Area.

To explore the supplemental bacteria monitoring data more, visit the interactive Delaware River Bacteria Data Viewer created by the Water Center at Penn.[33]

Table 12: Supplemental Sampling Locations

Site Type	Site Name
Delaware River	Palmyra Cove Nature Park (NJ)
	Frankford Arsenal (PA)
	Pennsauken Access/Delair Boat Launch (NJ)
	Penn Treaty Park (PA)
	Pyne Poynt (NJ)
	Penns Landing (PA)
	Washington Avenue Green (PA)
	National Park/Redbank Battlefield Park (NJ)
	Chester Waterfront (PA)
Tidal Tributaries	Frankford/Tacony at Castor Ave (PA)
	Cooper River at Kaighns Ave (NJ)
	Schuylkill River at Schuylkill Banks (PA)
	Schuylkill River at Bartram's Garden (PA)
CSO Outfalls	Frankford/Tacony at Castor Ave (PA)
	Cooper River at 32nd and Farragut (NJ)

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[33] Water Center at Penn (2023). Delaware River Bacteria Data Viewer. Retrieved from https://experience.arcgis.com/experience/caa71fcc2dfb45feb031e7b6d7d878f1/

Figure 15: Supplemental Sampling Locations
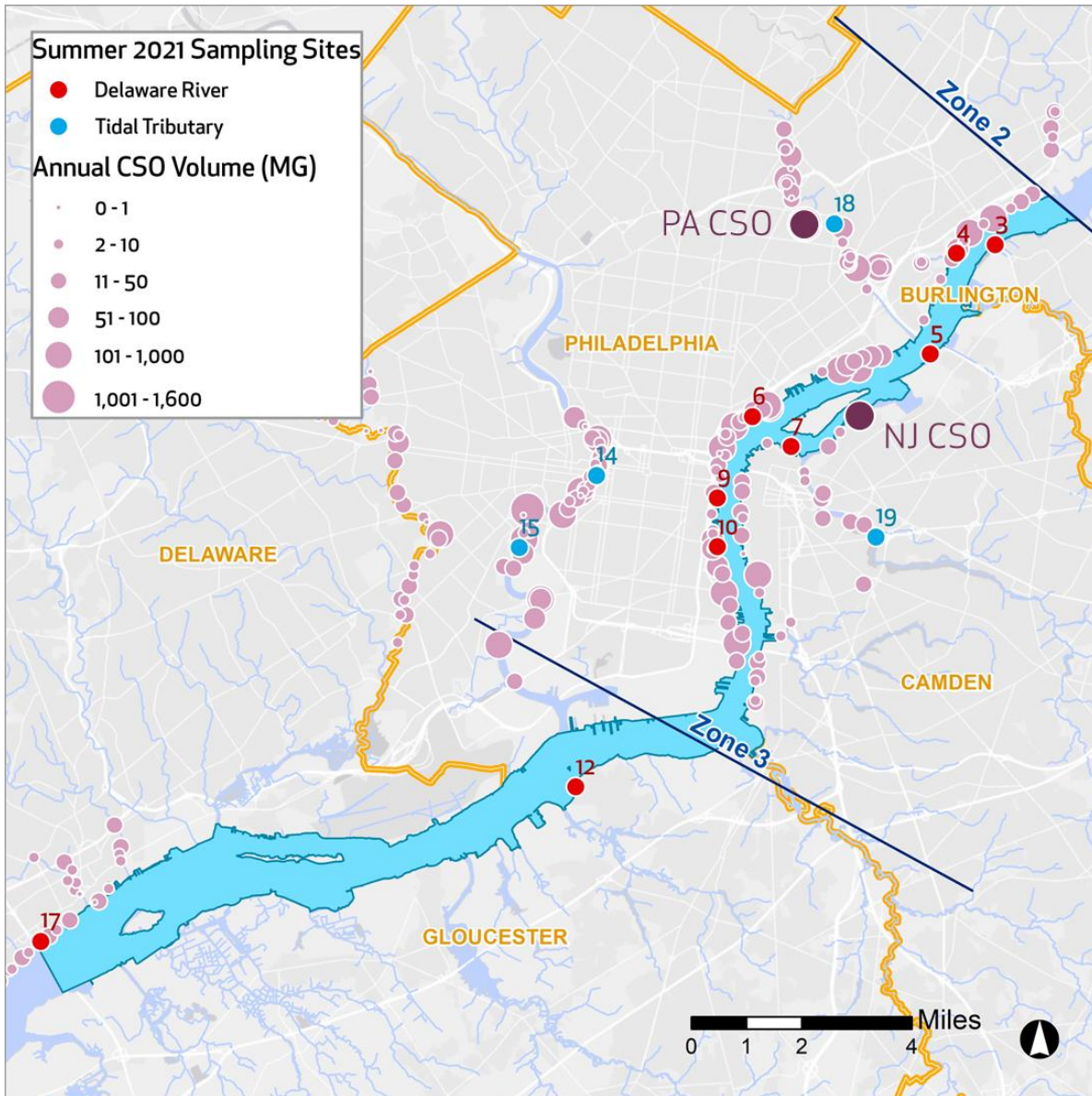
*In the Map above, the numbers correspond to the sampling site location numbers identified.
Key

3-Palmyra Cove

4-Frankford Arsenal/Frankford Boat Launch

5-Pennsauken Access (Delair Boat Launch)

6-Penn Treaty Park

7-Pyne Poynt Park

9-Penn's Landing Lagoon

10-Washington Avenue Green

12-National Park (Red Bank Battlefield Park)

14-Schuylkill Banks

15-Bartram's Garden

17-Chester Waterfront

18- Frankford/Tacony at Castor Ave

19- Cooper River at Kaighns Ave

Decay in FIB Signals

Once the sampling effort began, observed rainfall patterns diverged from the forecast. The goal was to capture one pre-wet weather day, one wet weather day, and three post-wet weather days. Instead, the project team captured one pre-wet weather day (Day 1), three wet weather days (Day 2, Day 3, and Day 4), and one post-wet weather day (Day 5). Days with less than 0.1 inch of precipitation were tagged as dry, and days with greater than 0.1 inch of precipitation were tagged as wet. Rainfall depths were relatively small and highly variable from one sampling site to another (*Table 13Table 13: Observed Rainfall (in inches) during Supplemental Bacteria Monitoring Effort*).

Table 13: Observed Rainfall (in inches) during Supplemental Bacteria Monitoring Effort

Site Type	Site Name	8/17/2021	8/18/2021 Day 1	8/19/2021 Day 2	8/20/2021 Day 3	8/21/2021	8/22/2021 Day 4	8/23/2021	8/24/2021 Day 5
Delaware River	Palmyra Cove Nature Park	0.05	0.05	1.11	0.11	0.16	1.07	0.39	0.00
	Frankford Arsenal	0.05	0.05	1.11	0.11	0.16	1.07	0.39	0.00
	Pennsauken Access	0.08	0.02	0.03	0.10	0.07	1.13	0.79	0.00
	Pyne Poynt	0.07	0.02	0.44	0.13	0.12	1.12	0.61	0.00
	Penn Treaty Park	0.07	0.02	0.44	0.13	0.12	1.12	0.61	0.00
	Penns Landing	0.02	0.02	0.44	0.20	0.35	1.17	0.36	0.00
	Washington Avenue Green	0.02	0.02	0.44	0.20	0.35	1.17	0.36	0.00
	National Park	0.06	0.00	0.44	0.30	0.04	0.93	0.33	0.00
	Chester Waterfront	0.06	0.00	0.44	0.30	0.04	0.93	0.33	0.00
Tidal Tributaries	Frankford/Tacony at Castor Ave	0.08	0.02	0.98	0.11	0.13	1.11	0.46	0.00
	Cooper River at Kaighns Ave	0.08	0.02	0.03	0.10	0.07	1.13	0.79	0.00
	Schuylkill Banks	0.08	0.01	0.49	0.17	0.19	1.12	0.45	0.00
	Bartram's Garden	0.11	0.00	0.01	0.12	0.08	0.99	0.48	0.00
CSO Outfalls	Frankford/Tacony at Castor Ave		0.02	0.98		0.13	1.11		
	Cooper River at 32nd and Farragut		0.02	0.03		0.07	1.13		

The observed rainfall patterns and the limited sample size did not allow for robust analysis of how FIB signals at different sites decay after a rain event. Overall, wet weather days appear to correspond to higher *E. coli* levels, and dry weather days appear to correspond to lower *E. coli* levels (*Table 14*). Statistical analysis (a Student's t-test) confirmed that the difference between mean dry weather levels and mean wet weather levels was statistically significant. This suggests that there are wet weather sources for FIB, such as degraded or impaired infrastructure, illicit discharges/illicit connections, stormwater, or CSOs.

Qualitative differences in *E. coli* levels were also noted between sites. Two sampling sites appeared to have consistently high *E. coli* levels: Pyne Poynt and Frankford/Tacony at Castor Ave. These sites are shown in red in the table below. The Pyne Poynt finding is consistent with the DRBC and PWD sampling efforts. Four

sampling sites appeared to have relatively lower *E. coli* levels: Penns Landing, Washington Avenue Green, National Park, and Bartram's Garden. These sites are shown in blue in the table below.

Table 14: E. Coli Levels from Supplemental Bacteria Monitoring Effort (CFU/100 mL)

Site Type	Site Name	Day 1 Pre-Wet	Day 2 Wet	Day 3 Wet	Day 4 Wet	Day 5 Post-Wet
Delaware River	Palmyra Cove Nature Park	20	0	400	500	0
	Frankford Arsenal	100	0	180	300	0
	Pennsauken Access	20	0	200	1,100	200
	Pyne Poynt	640	300	2,200	10,300	1,000
	Penn Treaty Park	10	1,600	0	400	0
	Penns Landing	20	700	0	100	0
	Washington Avenue Green	120	100	300	100	0
	National Park	30	100	500	100	0
	Chester Waterfront	1,610	0	1,600	400	0
Tidal Tributaries	**Frankford/Tacony at Castor Ave**	710	6,200	1,300	4,800	8,100
	Cooper River at Kaighns Ave	110	0	100	1,000	800
	Schuylkill Banks	50	2,300	400	0	300
	Bartram's Garden	110	1,600	0	100	0
CSO Outfalls	Frankford/Tacony at Castor Ave		9,400		4,000	
	Cooper River at 32nd and Farragut		2,700		176,800	

Relative magnitude of FIB levels across mainstem sites, tributary sites, and CSO outfalls

As expected*, E. coli* levels were highest for the samples taken near CSO outfalls. The levels measured near the outfalls on wet weather days were generally an order of magnitude greater than the levels measured at other nearshore sites. The exceptions were Frankford/Tacony at Castor Avenue, and Pyne Poynt. *E. coli* levels at these two sites were as high as or higher than levels at the outfalls. Also, E. coli levels at these two locations did not show the same decline on Day 5 as levels at the other sites. These observations demonstrate the importance of site-specific monitoring to identify and remediate the source of water quality impairments. In general, CSOs are a significant source of FIB to the Study Area. However, at particular locations, CSOs may not be the only or even the primary cause of impairment.

Benefits of microbial source tracking approaches in the Study Area

FIB can originate from a range of sources including human and non-human contamination. The supplemental sampling effort piloted the use of microbial source tracking (MST) DNA markers in the Study Area to explore whether these markers could be useful in identifying hotspots of raw sewage contamination and prioritizing remediation measures. Samples were analyzed for human-associated HF183 Bacteroides marker (HF183), an avian-associated fecal marker, and a gull-associated fecal marker. Results for HF183 and avian marker were

informative and are discussed below. All concentrations are in copy numbers [CN] / 100 milliliters. The gull marker was not detected at any of the sites monitored and is not discussed further. The absence of this marker is consistent with visual observations that gulls are not prevalent within the Study Area.

Table 15: HF183 Levels from Supplemental Bacteria Monitoring Effort (CN/100 mL)

Site Type	Site Name	Day 1 Pre-Wet	Day 2 Wet	Day 3 Wet	Day 4 Wet	Day 5 Post-Wet
Delaware River	Palmyra Cove Nature Park	-	5,293	5,714	-	4,096
	Frankford Arsenal	6,917	24,848	2,773	132,733	49,553
	Pennsauken Access	-	-	2,843	-	-
	Pyne Poynt	10,717	41,815	10,336	105,088	20,732
	Penn Treaty Park	14,027	69,815	17,610	265,015	34,245
	Penns Landing	59,188	56,162	17,512	350,240	15,294
	Washington Avenue Green	26,727	13,131	14,166	74,620	39,674
	National Park	5,903	11,619	23,074	3,778	26,894
	Chester Waterfront	7,740	7,609	-	32,364	14,891
Tidal Tributaries	**Frankford/Tacony at Castor Ave**	11,820	209,510	133,778	751,429	433,608
	Cooper River at Kaighns Ave	-	-	-	886	1,741
	Schuylkill Banks	1,511	42,251	-	871,689	7,444
	Bartram's Garden	5,723	54,348	3,656	77,429	24,239
CSO Outfalls	Frankford/Tacony at Castor Ave	NA	190,289	NA	363,370	NA
	Cooper River at 32nd and Farragut	NA	67,653	NA	3,048,076	NA

HF183 concentrations showed some patterns that mirrored the findings from *E. coli* concentrations and others that were distinct from the findings from *E. coli* concentrations. Results that reinforced the *E. coli* findings include:

1. Average concentrations of HF183 measured from the main stem and tidal tributaries were typically one to two and a half orders of magnitude lower than average concentrations measured from CSO sites. From the data, CSOs have the highest levels of HF183 and are a significant source of human fecal pollution at the sampled sites.
2. HF183 concentrations show a wet weather effect, with the highest levels on Day 4.
3. At the site scale, HF183 levels are exceptionally high at the Frankford/Tacony nearshore sampling site, with no decline on Day 5. This finding shows how HF183 can be used to prioritize areas that need immediate remediation.
4. Finally, across all samples there is a weak but significant positive association between HF183 and *E. coli* concentrations. This confirms that FIB is generally from a human source and is therefore a meaningful indicator of human health risk in the Study Area.

Results that were distinct the *E. coli* findings include:

1. Most sites appear chronically impaired, with HF183 levels well above the risk-based threshold of 525 CN/100mL reported by Boehm et al. (2020) for recreational waters without gull contamination.[34] However, the sites monitored receive treated wastewater effluent during dry and wet weather conditions. Treated wastewater is known to contain high levels of HF183. Therefore, the risk associated with measuring HF183 at these sites is not well understood.

   Use of a viability-based test could assist in determining if fresh sewage is responsible for the elevated HF183 measurements in the Study Area, as opposed to treated sewage. Understanding the extent to which fresh sewage is impacting a site could help prioritize remediation measures. For example, propidium monoazide (PMA) pretreatment and subsequent HF183 detection using ddPCR or qPCR could determine the fraction of viable human marker measured. This and other monitoring tools to better understand sources of fecal pollution in the Study Area are discussed further in Appendix 3.

2. The HF183 human marker showed different sites with relatively low levels of impairment. HF183 was not detected in most of the samples from Pennsauken Access/Delair Boat Launch and Cooper River at Kaighns Ave. Interestingly, these two sites are relatively far from combined sewer outfalls. The Pennsauken Access site is upstream of all the Camden outfalls, and the Cooper River site is upstream of most of the combined sewer outfalls along the tributary.

3. In contrast to the *E. coli* findings, the HF183 marker showed chronic impairment at the two Schuylkill River sites.

Avian marker concentrations showed that avian fecal matter contributes to measured FIB. The Avian marker was detected frequently (60% or more of the time) in samples collected across all sites. This suggests that avian marker in this region is ubiquitous. Concentrations measured from the main stem and tidal tributaries were similar in magnitude to the Avian concentrations measured from CSO sites (Table 16). Increases in avian marker concentrations on Day 4 suggest a wash effect with wet weather events. Runoff may transport accumulated avian fecal matter into waterways and contribute to higher levels observed in wet weather compared with dry weather.

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[34] Boehm et al., (2020). Refined ambient water quality thresholds for human-associated fecal indicator HF183 for recreational waters with and without co-occurring gull fecal contamination. Microbial Risk Analysis, Volume 16. Retrieved from https://doi.org/10.1016/j.mran.2020.100139

Table 16: Avian Marker Levels from Supplemental Bacteria Monitoring Effort (CN/100 mL)

Site Type	Site Name	Day 1 Pre-Wet	Day 2 Wet	Day 3 Wet	Day 4 Wet	Day 5 Post-Wet
Delaware River	Palmyra Cove Nature Park	-	48	58	49	66
	Frankford Arsenal	22	26	-	53	20
	Pennsauken Access	20	23	50	47	36
	Pyne Poynt	-	19	-	48	34
	Penn Treaty Park	18	30	-	54	49
	Penns Landing	19	29	46	142	46
	Washington Avenue Green	-	26	54	58	44
	National Park	20	17	-	-	31
	Chester Waterfront	-	27	-	48	47
Tidal Tributaries	Frankford/Tacony at Castor Ave	-	78	55	71	22
	Cooper River at Kaighns Ave	-	19	49	-	34
	Schuylkill Banks	17	82	-	108	77
	Bartram's Garden	17	72	-	55	26
CSO Outfalls	Frankford/Tacony at Castor Ave	NA	26	NA	56	NA
	Cooper River at 32nd and Farragut	NA	21	NA	103	NA

In addition to the information described above, piloting the use of MST markers provided information on relative cost and effort compared to FIB. While FIB can be analyzed by many different labs quickly and at low cost, it was difficult to identify a lab that could analyze MST DNA markers. The cost of the analysis was much higher than the cost of analysis for FIB, and the turnaround time was in the order of months instead of days or weeks. Further use of MST DNA markers should be carefully targeted in the future, with a focus on areas that are not impacted by wastewater treatment plant discharges.

Objective 2: Understanding the Timing and Extent of Future FIB Water Quality Improvements from Committed Investments

METHODS

Through the Clean Water Act requirements described in the Background section, stormwater and wastewater utilities in the Study Area have committed to extensive water infrastructure investments. These investments have already led to significant reductions in FIB loads. For example, discharges from the region's WPCPs to the upper portion of the Delaware Estuary now have much lower concentrations of fecal coliform bacteria (FCB), as reported in the monthly Discharge Monitoring Reports required under the NPDES program.

To better understand the timing and extent of future water quality improvements from committed investments, the project team reviewed the LTCPs for the Philadelphia Water Department, the Camden County Municipal Utility Authority and the Delaware County Regional Water Quality Control Authority.

This study focuses on LTCPs because they provide the most scope for adaptive management. Given their long-term planning horizons and their use of the presumption approach, the LTCPs in the Study Area are relatively more flexible than the NPDES permits for WPCPs and MS4s. In addition, the MS4 programs in Pennsylvania and New Jersey are not currently requiring bacteria load reductions. As discussed in the Background section, the use of LTCPs to drive water quality improvements presents challenges as well as opportunities. In the Study Area, these challenges include: 1) the absolute costs and affordability of the LTCP for low-income customers, 2) the availability of capital and the time it takes to plan, design, construct and operate these systems, and 3) the complex nature of modeling the impacts of the LTCP components on water quality conditions in the receiving waters.

FINDINGS

This section summarizes the project team's findings from the review of LTCPs for PWD, DELCORA, and CCMUA. As shown in *Figure 16: Timeline for LTCP Implementation*, the LTCPs for the three CSO systems are scheduled to be completed in 2036, 2040, and 2035, respectively. While this may seem like an extended timeline, it reflects the financial capacity of each community to fund plan implementation as documented when the LTCPs were completed. At a high level, the additional reduction in bacteria loading as a result of LTCP implementation can be estimated as roughly 50%.[35] Of the three CSO systems in the Study Area, PWD contributes by far the largest annual volume of CSOs. By 2021, PWD had reduced the annual average CSO volume to roughly 10 billion gallons. By LTCP completion, PWD anticipates further reducing the average annual overflow volume to roughly five billion gallons.[36] Assuming relatively uniform bacteria concentrations, this translates to a fifty percent reduction in bacteria loading from 2021.

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[35] Environmental Protection Agency (2023). NPDES Combined Sewer Overflow Program Progress. Retrieved from https://www.epa.gov/npdes/combined-sewer-overflow-program-progress

[36] Philadelphia Water Department (2023). PWD Response to Penn Environment Sewage Statement. Retrieved from https://water.phila.gov/drops/pwd-response-to-penn-environment-sewage-statement/#:~:text=PWD%20is%20committed%20to%20implementing,in%20the%20next%20three%20years

Figure 16: Timeline for LTCP Implementation
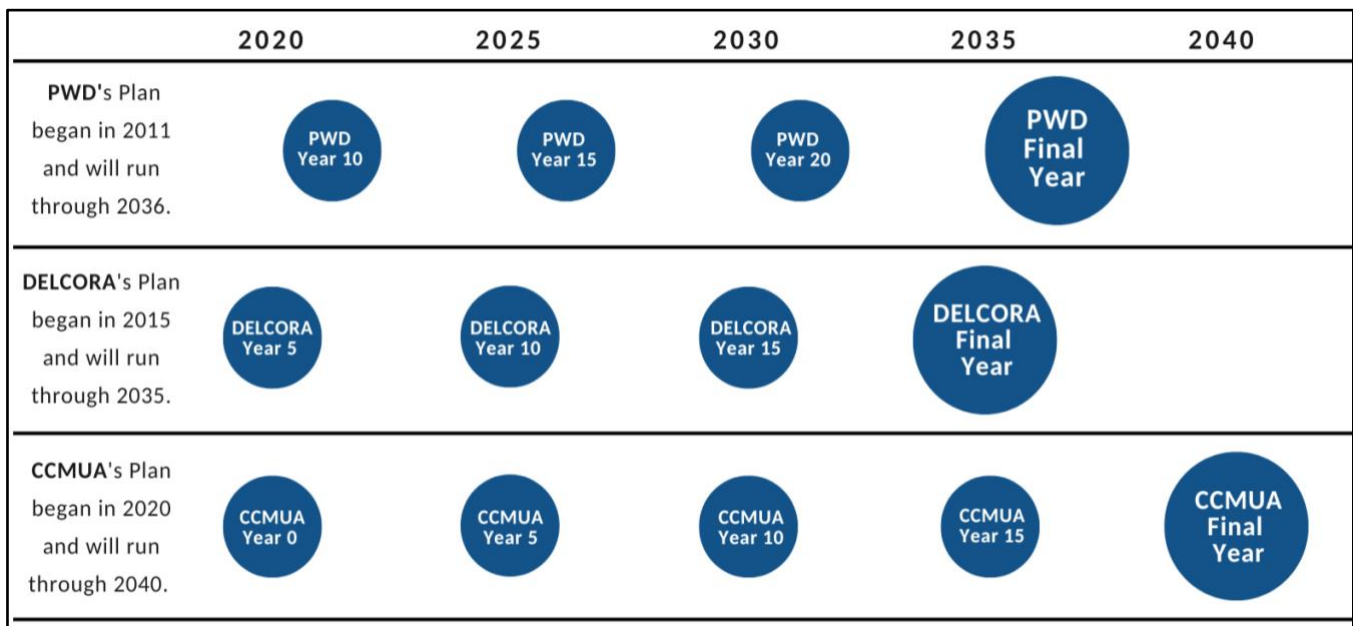
Overall, the three water utilities have committed to significant investments over the coming years. Public-facing documents show the commitments summarized in *Table 17*. Note that all three utilities are limited in the scope of their investments by their ability to use rates to leverage financing options and to access non-rate revenue such as grants. Also, many of the project estimates are limited to project implementation and do not include the full lifecycle costs of the infrastructure. Finally, while each LTCP includes estimated costs of implementation, these figures do not reflect current rates of inflation. With that in mind, investments targeted to CSO remediation currently total $667 million, and planned investments over the next five-year period total more than $1 billion.

Table 17: Near-Term Commitments for LTCP Implementation

Utility	Current Projects	5-Year Capital Improvements	Capital Reserve	Source
PWD	$155 M	$804 M	-	PWD Fiscal Year 2023 Budget
DELCORA	$472 M (tunnel project)	-	$19.4 M	DELCORA Budget 2023
CCMUA	$40 M	$31 M	$27 M	CCMUA Approved Budget 2023

Philadelphia Water Department (PWD)

PWD's FY 2022-2027 Capital Improvement Program (CIP) includes $3.975 billion, with LTCP expenditures representing over 20% ($804 Million) of the total. This doubles the City's CIP from just several years earlier and represents a significant reinvestment by the City in its drinking water, wastewater, and stormwater systems. Since 2020, PWD has submitted applications for federal assistance totaling $936 million, with $398 million awarded as low-cost loans to maintain the lowest costs to the consumer. The funding PWD is working to obtain from the Bipartisan Infrastructure Law (BIL) can help address the need for $3.975 billion in planned capital improvement projects over the next six years.

Capital projects implemented in the Philadelphia area included:

- Developing Real Time Control (RTC) & Flow Optimization programs

- Outfall Elimination

- Collection System Improvements

- Other Capital Programs and Projects (e.g., targeted infiltration/inflow reduction, CSO capture, and wet weather treatment maximation programs)[37]

Gray Stormwater Infrastructure

PWD is currently working on short- and long-term plans to increase the capacity of its collection system and wastewater treatment plants, which collect and treat 350 million gallons of sewage per day on average, with a design capacity of 522 million gallons per day, and the ability to reach/peak over 1.1 billion gallons per day during wet weather. Every additional gallon treated during wet weather is one less gallon of untreated wastewater entering the Delaware River.

PWD has more than 15 traditional gray infrastructure projects in the pipeline to reduce CSO volume and frequency that will be implemented in the coming 5-7 years. The estimated cost for these 15 projects is over a quarter billion dollars. Examples include:

1. Replacement of the 42nd St. Pumping Station and the CSO S-50 Outfall
   - Location: Tidal Schuylkill River ½ mile upstream of Bartram's Garden

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[37]See Section 10 of PWD's LTCP at https://water.phila.gov/reporting/ltcp/

- Description: Increase the capacity of the existing 8 MGD pump station to a wet-weather pumping station with 100 MGD capacity.
- Improvements: Estimated 200-300 MG/year CSO reduction to the tidal Schuylkill River, primarily from one of the biggest CSO outfalls in the City (Mill Creek).

2. Addition of a Pretreatment Facility at Northeast (NE) WPCP
   - Location: Tacony-Frankford Creek, Delaware River, south of the Betsy Ross Bridge
   - Description: Construction of an additional pretreatment building and conveyance system to take more flow into the NEWPCP. This will allow for a 215 MGD, or 50% increase in wet weather plant capacity and conveyance, significantly reducing the frequency of Combined Sewer Overflow (CSO) discharges into the Delaware River.
   - Improvements: Potential reduction of 300 MG/yr in CSO to the Delaware River

3. Additional Primary and Final Sedimentation Tanks at Southwest (SW) WPCP
   - Location: Delaware River south of the Schuylkill River confluence
   - Description: Construction of additional primary and final sedimentation tanks at the Southwest Water Pollution Control Plant to increase wet weather capacity and operational flexibility. Expanding the final sedimentation system can allow additional dry weather treatment capacity.
   - Improvements: Allows SWWPCP to treat wet weather flows to 540 MGD.

4. Additional significant improvements not directly related to FIB reductions
   - Sidestream treatment for ammonia reduction to the Delaware River $50M
   - Effluent pumping at the NE WPCP $80 million.

Green Stormwater Infrastructure

1. Progress
   - As of Dec 31, 2021, PWD has completed 2,196 Greened Acres across 835 stormwater management projects.

2. Year 10 Evaluation and Adaptation Plan Report
   - In May 2022, PWD submitted its Year 10 Evaluation and Adaptation Plan Report to the PA DEP.
   - The report is a comprehensive assessment of PWD's Green City, Clean Waters program at the Year 10 milestone, including an assessment of compliance with Water Quality Based Effluent Limits (WQBEL) Performance Standards and an updated assessment of receiving water conditions.

3. Key Stormwater Related Program Updates
   - Rebuild of Hydrologic and Hydraulic model informed by a decade of data collection.
   - Update to Greened Acre calculation method that better accounts for infiltration and slow release.
   - Evaluation of Green Stormwater Infrastructure (GSI) monitoring dataset showcasing better than anticipated performance.

4,430 acres in the two municipalities served by combined sewers.[38] In 2021, CCMUA invested $77 million in construction for a raw sewage pump that allows a 30 MGD increase in capacity to accept more flow from City of Camden's CSO systems during wet weather.

The LTCP developed by CCMUA consists of six program elements that will have phased and overlapping implementation schedules. Due to the extremely limited affordability and financial capabilities of the Cities of Camden and Gloucester these controls will require significant external funding and will likely need to be implemented over an extended period as resources permit.[39] The six program elements are:

1. **Completion of Current Projects**: Timely completion of ongoing control projects including the capacity expansion of CCMUA's Delaware Water Pollution Control Facility # 1 to 185 MGD, the restoration of the hydraulic capacity of Camden's combined collection sewer system through a comprehensive sewer cleaning and rehabilitation program and related capital improvements such as the upgrading of Camden's Arch Street pump station capacity.

2. **Iterative Efficacy Evaluation**: The evaluation of the efficacy of these current improvements through comprehensive flow monitoring which will inform the refinement and recalibration of the existing hydrologic / hydraulic model to the current conditions. This will establish a new baseline of overflow statistics informed by the wet weather operating history with these capacity improvements in place. Similar evaluations may occur after the implementation of the formalized green stormwater infrastructure and the street flooding mitigation program elements.

3. **Formalized Green Stormwater Infrastructure Program**: Accelerating green stormwater infrastructure through a coordinated, formalized and expanded GSI Implementation Program with the goal of achieving a ten percent reduction in the directly connected impervious areas contributing stormwater runoff to the combined sewer system.

4. **Street Flooding Mitigation Program**: The development and rapid implementation of a comprehensive Street Flooding Mitigation Program will be developed within the City of Camden to provide an empirical understanding of the frequency, location and extent of street flooding remaining after the Camden sewer

[38] Philadelphia Water Department (2015). Tidal Waters Water Quality Model – Bacteria and Dissolved Oxygen - Consent Order & Agreement - Deliverable IX and X, City of Philadelphia Combined Sewer Overflow Long Term Control Plan. Retrieved from https://water.phila.gov/pool/WQ_Model_Complete_Report_FinalDigital_WITHAPPENDICES_WithAddendumpage_2016_09_19.pdf

[39] Id. at Executive Summary.

system is cleaned. This will serve as the basis for short and long-term operational and capital improvements.

5. **Cooper River Water Quality Optimization Program**: The Cooper River is an important environmental, recreational and economic asset for the City of Camden's economic redevelopment. Eliminating Camden's CSOs from the Cooper River is not financially feasible. CCMUA and the City of Camden are committing to work with the other Cooper River municipalities, stakeholders and NJDEP to develop a Cooper River Water Quality Optimization Strategy during the next NJPDES permit cycle.

6. **Additional Structural Controls**: Within the limitations imposed by affordability constraints, structural controls in each of the five sub-systems that will raise the level of CSO capture in each sub-system and system-wide to no less than 85% of wet weather flows during the Typical Year. These additional controls include satellite control facilities and the potential build out of the Water Pollution Control Facility (WPCF) #1 capacity to 220 MGD.[40]

CCMUA's Selection & Implementation Alternatives Report (SIAR) focuses on near term community benefits through:

- Sustainable community redevelopment using green stormwater infrastructure (GSI);

- Reducing street and basement flooding of combined sewage during storms; and

- The optimization of and reinvestment in existing community assets such as the restoration of the Camden sewer system through comprehensive cleaning.

CCMUA and the cities will focus initially on projects that will provide significant near-term overflow and street flooding benefits such as the expansion of the WPCF # 1 and the restoration of the hydraulic capacity of the Camden collection system.

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[40] Id. at Appendix 1: E-17 to E-18.

Table 18 shows the implementation schedule for the CCMUA LTCP. It is based on the five-year NJPDES permit cycle.

Table 18: CCMUA LTCP Implementation Schedule

Time Frame	Activities
2020	• Continued cleaning of Camden CSO outfalls • Completion of Camden regulator mechanism rehabilitation • Completion of Arch Street PS capacity expansion • NJPDES renewal discussions with NJDEP. The NJPDES permit will include the implementation schedule for the implementation of the long term CSO plan as defined in the SIAR

2021-2025:
First Five Year
NJPDES Permit Cycle
	• Completion of initial Camden collection system and outfall cleaning - Program Element 1 (system optimization)
	• Completion of the expansion of CCMUA's WPCF # 1 to 185 MGD - Program Element 1
	• Ongoing collection system maintenance, inspection & cleaning
	• Submission of a Construction and Financing Schedule as required by paragraph G-8(a) of the NJPDES permits
	• Development and implementation of GSI Program Plan - target reduction of 2% (30 acres) - Program Element 3 (green first)
	• Development and implementation of Camden Street Flooding Mitigation Program - Program Element 4
	• Develop the Cooper River Regional Water Quality Optimization Strategy - Program Element 5
	• (2025) Permit Cycle 1 Progress Evaluation:
	  o Evaluate the impacts of the expansion of the WPCF # 1 to 185 MGD over a range of wet weather including the potential to increase wet weather flows from CCMUA's Gloucester City pump station, thereby potentially reducing overall flows in Gloucester City
	  o GSI implementation status (acres of DCIA reduction)
	  o Street flooding mitigation status to ascertain the efficacy of cleaning the Camden pipes and outfalls and of the expansion of the WPCF # 1 wet weather treatment capacity to 185 MGD
	  o Updated Financial Capacity Assessment and Construction & Financing Schedule for inclusion in next NJPDES Permit. *Program Element 2 (iterative evaluation)*

2026 - 2030: Second Five Year NJPDES Permit Cycle	• Continued Implementation of GSI Program and the Street Flooding Mitigation Program - (Program Elements 3 and 4)

Time Frame	Activities
	o *(2030) Revise GSI Program based as needed on lessons learned during previous five years* o *Target reduction of directly connected impervious area (DCIA) by 2.0% (30 acres)* o *(2030) Revised Street Flooding Mitigation Program as needed based on lessons learned during previous five-year cycle* ● Reduction of wet weather flow from Pennsauken into the Camden combined sewer system in sewershed C-32 - Program Element 6 ● Efficacy Evaluation - Program Element 2 ● Feasibility study for further expansion of WPCF # 1 up to 220 MGD as necessary - Program Element 6 ● Updated Financial Capacity Assessment and Construction & Financing Schedule for inclusion in next NJPDES Permit - Program Element 2

Delaware County Regional Water Quality Control Authority (DELCORA)

Between 1999 and 2018, DELCORA invested over $100 million in system improvements including partially separating flow to a CSO regulator, replacing older CSO regulator models, and replacing leaking pipes that resulted in decreased volumes of overflows, reduced debris in overflows, and improved routine maintenance. The LTCP was updated in March 2022.

A major element of the DELCORA plan is the Eastern Service Area (ESA) Tunnel, which will capture combined sewer overflows. The tunnel project is planned to be completed by 2028 with an estimated cost of over $400 million. However, because the project is diverting flows that would have gone to a PWD facility, DELCORA will be saving approximately $400 million in avoided payments to PWD for wastewater treatment services.

As stated in the DELCORA CSO Long Term Control Plan Update (LTCPU), DELCORA proposes the Selected CSO Control Plan, adding CSO control technologies to control unauthorized releases, further reduce I/I, and improve CSO capture. With these additional control technologies, modeling indicates that 85% wet weather capture will be achieved for each of the three receiving streams. The Selected CSO Control Plan addresses feedback obtained through communications with USEPA and PADEP, updates to the model, and updates to costs for the most recent dollar values through an adaptive management review. The technologies included in the Selected CSO Control Plan are discussed below. *Table 19* shows the estimated costs of the selected CSO Control Plan projects.

- Expanding the proposed ESA tunnel diameter to detain and convey excessive combined sewer overflows to the WRTP through the construction of two new tunnel drop shafts and connecting conveyance piping.

- Regulator improvements at 10 locations in the existing collection system and modifying CSO regulators to increase utilization of the Eastern Service Area tunnel.
- Viable locations for green infrastructure throughout the combined sewer system.
- Partial sewer separation of the neighborhood downstream of Veterans Memorial Park.
- Increasing flow to the DELCORA WRTP for treatment along the Delaware River by adding to, extending, and rehabilitating the existing conveyance system to alleviate sewer hydraulic bottleneck.
- Providing additional secondary clarification and disinfection for the increased flow to the WRTP.
- Storage at CSO Regulator 19 to reduce the volume and frequency of untreated effluent.
- Installation of a relief sewer line in Upland to mitigate unauthorized releases.
- I/I control implementation to prevent wet weather flow from Rose Valley Pump Station.
- Connecting a relief diversion pipe to the West End Interceptor from Tilghman Street.
- Diversion Structures and Pipeline from Tilghman Street to the West End Interceptor to reduce surcharging of the West End Interceptor.

Table 19: Estimated Capital and Lifecycle Costs of DELCORA LTCP Projects

	Capital Costs ($)	LCC ($M)
Upland Relief Sewer Line	$0.9	$1.1
Regulator Modifications and New Wet Weathe Weirs	$5.8	$10.6
Rose Valley I/I Controls	$3.5	$3.5
Tilghman St Diversion	$0.8	$0.8
ESA Tunnel Expansion	$52.0	$62.5
Conveyance Piping to Drop Shafts and Tunnels	$32.8	$33.9
Additional WRTP Secondary Clarification	$22.0	$30.0
RCI Arboretum Modifications	$8.3	$9.2
Partial Sewer Separation with Green/Grey Infrastructure	$18.9	$21.1
CSO Storage	$15.3	$16.1
Comprehensive Separate Sewer System Infiltration and Inflow Control Program	$6.7	$6.7
Project Management, Public Outreach and Flow/Hydraulic Monitoring and Modeling	$14.9	$14.9
TOTAL	$181.9	$210.4

DELCORA's proposed performance criteria are:

- 94 percent capture on a systemwide annual average basis for the typical year, and
- No more than four activations in the typical year from CSOs 2, 7, and 8

DELCORA's recommended plan uses a phased approach. The first element consists of improvements DELCORA is already implementing and smaller CSO control technologies increasing capture without overloading the existing sewer system. The second element of this program consists of a connection to the expanded ESA Tunnel to capture CSOs. The model shows that the proposed projects will reduce the systemwide average annual activation rate from 36 to 6 events systemwide with no outfalls activating more than 12 times a year. However, these frequencies of activation are not performance measures. These proposed projects are predicated on the assumption that the ESA Wastewater Tunnel is constructed as planned.[41]

Objective 3: Identifying Additional Opportunities for Improved FIB Water Quality

METHODS

The project team used three approaches to identify additional opportunities for improved water quality in the Study Area. First, the project team used stakeholder engagement to understand stakeholder concerns and how they might constrain opportunities for remediation. Second, the project team used a review of LTCPs beyond the Study Area to identify best practices that might translate to the Study Area. Third, the project team used a suitability analysis of existing recreation access sites to identify potential focus areas for further investment. Each approach is described in more detail below.

Stakeholder Engagement

As discussed in the Introduction, the Delaware River Bacteria Study is meant to inform a complex environmental decision-making process. Decisions about recreational water quality in the Study Area involve tradeoffs between many different environmental, social, and economic factors. They also involve diverse stakeholder groups, including the recreating public, ratepayers, dischargers, utilities, regulators, academics, environmental advocates, and policymakers. Each group has its own set of preferences regarding whether, where, and how to improve recreational water quality in the Study Area.

To understand the range of stakeholder perspectives and concerns, the project team sought feedback on the study approach, methodology, and findings throughout its development. Beginning in April 2020, the project team held meetings with two advisory groups. The first was known as the Water Quality Advisory Team and consisted of advisors from the Academy of Natural Sciences at Drexel University, Mayfly Communications, Moonshot Missions, the Stroud Water Research Center, and West Chester University. The second was initially

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[41] DELCORA (2015). CSO Long Term Control Plan. https://www.delcora.org/combined-sewer-systems/delcora-cso-ltcp/

known as the Return to the River Advisory Team and consisted of representatives from the American Littoral Society, Upstream Alliance, and Verna Harrison Associates. The project team also held meetings and shared draft documents with representatives from the Delaware River Basin Commission, the Philadelphia Water Department, Delaware Riverkeeper Network, PennFuture, River Network, Bartram's Gardens, and the Pennsylvania Environmental Council.

Review of LTCPs Beyond the Study Area

The project team conducted an extensive review of LTCPs beyond the Study Area to identify best practices. Among other documents, this review included the US EPA's 2004 Report to Congress on Impacts and Control of CSOs and SSOs. Section 8-1 of this report describes technologies used to reduce the impacts of CSOs (Combined Sewer Overflows) and Sanitary Sewer Overflows (SSOs). The review also included a 2012 report from the Alliance for the Great Lakes that outlines investments made or planned in seven Great Lakes communities with combined sewer systems and helps demonstrate this blended strategy for CSO remediation, and a 2023 report by the US Government Accountability Office (GAO) on the status and progress of LTCPs to control CSOs. GAO analyzed law, policies, and guidance related to CSOs, reviewed EPA reports, and interviewed EPA officials. GAO also conducted in-depth reviews of 11 municipalities at different points in completing their LTCPs. Finally, the team reviewed a 2012 report from the Alliance for the Great Lakes that outlines investments made or planned in seven Great Lakes communities with combined sewer systems.

Focus Areas

To identify potential focus areas for further investment, the project team conducted a comprehensive suitability analysis of existing recreation access sites. The suitability analysis used publicly available GIS data to score 37 recreation access sites on the Delaware mainstem across fourteen attributes. These attributes were related to five themes: use, equity, water quality, safety hazards, and co-benefits. A scoring system was designed to give higher scores to sites where a confluence of water quality conditions, physical factors, and equity considerations indicate targeted investments are best directed. *Table 20* summarizes the attributes and how they were scored.

Table 20: Suitability Analysis Attributes

Theme	Attribute	Scoring Methodology
Use	Recreational Activity	Sites with more immersive activities (e.g., kayaking, wading) were given higher scores.
	Public Access	Sites with public access were given higher scores.
Equity	Social Vulnerability	Sites in census tracts with a higher CDC Social Vulnerability Index were given higher scores
	Public Transit Accessibility	Sites closer to a transit stop were given higher scores.

Water Quality	Data Availability	Sites with nearshore sampling data were given higher scores.
	Proximity to CSOs	Sites located farther from CSOs were given higher scores.
Safety Factors	Industrial Waste Outfalls	Sites with fewer nearby industrial waste outfalls were given higher scores.
	Industrial Sites	Sites with fewer nearby power plants, petroleum terminals, and oil refineries were given higher scores.
	Superfund Sites	Sites farther from Superfund sites were given higher scores.
	Ports	Sites farther from ports were given higher scores.
Co-Benefits	Population	Sites with more people living within a half-mile were given higher scores.
	Pedestrian Wayfinding	Sites with more pedestrian wayfinding features (signs and sidewalks) and fewer barriers (highways and train tracks) were given higher scores.
	Park and Trail Facilities	Sites that are more connected to the existing open space network were given higher scores.

FINDINGS

The project team used three approaches to identify additional opportunities for improved water quality in the Study Area. First, the project team used stakeholder engagement to understand stakeholder concerns and how they might constrain opportunities for remediation. Second, the project team used a review of LTCPs beyond the Study Area to identify best practices that might translate to the Study Area. Third, the project team used a suitability analysis of existing recreation access sites to identify potential focus areas for further investment. The findings from each approach are described below.

Stakeholder Engagement

Stakeholder groups voiced support for and raised several concerns about investments to improve recreational water quality in the Study Area. While the intent of this study is not to analyze stakeholder preferences, identifying the range of stakeholder comments can help inform the decision-making process.

The concerns highlight the importance of including affected stakeholders in the decision-making process – including the cities' water ratepayers, waterfront organizations, landowners, developers, politicians, regulators, and water-recreation advocates. Including the voices of affected stakeholders will ensure the most equitable and just distribution of benefits from water quality investments.

The concerns also highlight the benefit of an integrated, "one water" approach. This approach considers the sustainability and resiliency of our cities and their water systems, as well as the issues of equity and fairness. An integrated approach should include federal, regional, state, and local regulatory entities and municipal wastewater and stormwater managers, all working in partnership with local watershed stakeholders and community members.

Changing these large combined systems takes substantial new resources to remediate the legacy of pollutants, the tens of thousands of acres of impervious cover, and water infrastructure disinvestment that has impacted our nation's cities and towns. It requires a significant change in the direction of public investments, multi-party agreements, and additional sources of non-debt funding. These changes can include large-scale construction projects that disrupt people's lives and neighborhoods for years at a time. Making sure we are making the right investments in the right places is essential. Moving forward with these systemic changes will mean balancing across community-identified priorities.

Studies focusing on the equitable distribution of green infrastructure in Philadelphia provide an example of this kind of holistic analysis. Recent studies have signaled to the Philadelphia Water Department (PWD) that investments in green stormwater infrastructure should be shifted toward neighborhoods in the city that generally are not in sewersheds that outfall to the Delaware River mainstem.

One study looked at the sustainability of financing for the *Green City Clean Waters* plan in Philadelphia. A set of academic and conservation partners recommended to PWD that racial equity needed to play a larger role in decisions about green stormwater infrastructure project implementation through its incentives program. The study found that:

> Most co-benefits of [green stormwater infrastructure] GSI projects are spatially constrained. In other words, the co-benefits of GSI diminish quickly as distance from the project increases. If no spatial co-benefit criteria are taken into consideration when making investment decisions, communities meant to benefit may not actually receive the co-benefits of the project. By strategically targeting investments to neighborhoods that lack GSI and have other socioeconomic vulnerabilities, PWD can make sure that GSI co-benefits are being distributed in an equitable way while also addressing historic environmental injustices. In addition, because GSI associated with redevelopment projects only happens in certain neighborhoods and is driven primarily by market forces, not equity objectives, the incentives program should be more focused equity on outcomes as these can be achieved without depending on private development to determine GSI project locations. While projects need to happen across the entire CSO

area, PWD should prioritize certain neighborhoods and/or project types sooner in order to deliver co-benefits to neighborhoods that have suffered from sustained lack of investment.[42]

Another study, *Green Stormwater Infrastructure Focus Area Project*, included a priority map developed between 2019 and 2021 by the Academy of Natural Science, in collaboration with Drexel University College of Engineering, The Nature Conservancy, and the Tyler School of Art and Architecture at Temple University.[43] The project aimed to highlight regions in Philadelphia where targeted private investment in green stormwater infrastructure (GSI) could support the City's efforts to reduce CSOs while also providing substantive community benefits to neighborhoods suffering from chronic disinvestment and facing cumulative environmental burdens.

The aggregated mapping of the land cover, rainfall sensitivity, socio-economic, demographic, and cumulative environmental hazard layers identified the following neighborhoods as recommended for GSI: Frankford, Harrowgate, Port Richmond, Upper Kensington, Glenwood, East Poplar, Tioga, Franklinville, Fairhill, Stanton, Cobbs Creek, Greenwich, Southwest Schuylkill, Grays Ferry, and Point Breeze. All or part of Tioga, Franklinville, Harrowgate, Upper Kensington, and Port Richmond drain to two of the city's most problematic CSOs, known as D25 and D22, which outfall to the Delaware River mainstem. Of the neighborhoods identified by the aggregated mapping for GSI investment, Port Richmond and Harrowgate are closest to the Study Area. Others are close to tidal tributaries, including Cobbs Creek and Grays Ferry.

Review of LTCPs Beyond the Study Area

A limited review of the literature and selected CSO LTCPs shows that there are two primary approaches to managing CSOs: inactivating the pathogens in the discharges or disconnecting CSO discharges from impacted waterways. Both approaches are focused on structural solutions that manage CSO flows in bulk and not on reaching a specific pathogen loading rate, likely reflecting the challenge of managing the site-specific conditions that affect pathogen loading.

Inactivating pathogens requires installation of technologies at treatment locations. Inactivation technologies generally include chemical treatment, oxidation or ultraviolet treatment. An inactivation strategy depends on

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[42] Environmental Finance Center, University of Maryland. (2022). Sustainable Funding for Philadelphia's Green City, Clean Water Plan: Advancing Implementation on Private and Non-City Public Lands (pp. 22–23). Retrieved from https://arch.umd.edu/sites/default/files/docs/publications/PA_Green%20City%20Clean%20Waters_FINAL.pdf

[43] Alexis Shulman, Academy of Natural Sciences, email communication, September 9, 2022.

sending CSO flows to treatment facilities, which means retrofitting existing infrastructure to develop sufficient capacity throughout the system to capture and treat CSO flows.

A strategy focused on disconnecting CSO discharges from impacted waterways is based on the goal of eliminating the sanitary sewer flows in CSO discharges from reaching the waterway. Disconnection can be structural, such as physically redirecting or eliminating discharges, or functional, such as GSI implementation that reduces the amount of stormwater flow and adds capacity to manage more sanitary flows without discharging. In practice, implementation includes sewer separation projects which result in sanitary flows being separated and directed to treatment facilities while stormwater flows discharge to waterways. It can also include adding storage capacity to the system and building overflow retention facilities that hold flows during storm events, delaying treatment until the treatment facility has sufficient available capacity to accept additional flows for treatment.

Most CSO communities have adopted blended strategies that reduce the amount of stormwater flows into their CSO systems, maximize and augment the amount of storage of CSO flows within the system, and maximize and augment CSO treatment capacity.[44] Green stormwater infrastructure programs reduce peak flows in the overall system by decreasing the stormwater volume. Smart infrastructure allows system operators to maximize storage within the existing infrastructure. Augmenting storage - often through storage tunnels - expands the capacity of the CSO system to treat combined flows to remove pathogens while also decreasing the number of CSO events. Separating combined sewers expands the capacity of treatment facilities to remove pathogens from sanitary flows. Inactivation technologies are generally implemented at existing treatment facilities, though stormwater inlet filters that reduce pathogen loading can be deployed throughout the combined system.

The Alliance for the Great Lakes 2012 report helps demonstrate this blended strategy for CSO remediation. The capital projects proposed in the utilities' LTPCs include increased pump capacity, real-time control system improvement, first flush capture basins, in-pipe disinfection systems, outfall disinfection and de-chlorination,

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[44] EPA CSO SSO report at 8-1. Retrieved from https://www.epa.gov/sites/default/files/2015-10/documents/csossortc2004_full.pdf. GAO Jan 2023 report at 12. Retrieved from https://www.gao.gov/assets/gao-23-105285.pdf

storage tunnels and reservoirs, increased treatment capacity, relief sewers, sewer separation, and tunnel disinfection system. Most of the LTCPs included significant investments in GSI to reduce volumes.[45]

LTCP strategies include:

- Green infrastructure

- Increased storage capacity in the collection system

- STP expansion and/or storage at the plant

- Inflow/Infiltration reduction in the entire collection system that conveys flows to the treatment works to free up storage capacity or conveyance in the sewer system and/or treatment capacity at the STP.

- Sewer separation; and,

- CSO discharge treatment.

- The National Policy also encourages municipalities to consider the use of a bypass of secondary treatment in the evaluation of alternatives. [46]

Consideration of new strategies adopted by other CSO managers across the country should continually be revisited for their usefulness for systems in the Study Area. The Great Lakes Water Authority, manager of the largest CSO system in the country, has implemented several screening and disinfection facilities (SDFs) that provide treatment of CSO flows before they are discharged to waterways. These facilities require significant investment and currently use chlorination for disinfection. The design for these facilities could quickly evolve to have a smaller footprint than other CSO management strategies and use a preferable treatment technology (like UV treatment) to become a more viable alternative. It is also possible that, given the accentuated spikes in wet weather and drought caused by climate change, water managers will soon turn to water reuse strategies as a means to meet water supply needs during droughts with the added benefit of reducing greywater sanitary flows (which can be as much of 75% of flows) in combined systems.

[45] O. Lyandres and L. Welch, (2012). Reducing Combined Sewer Overflows in the Great Lakes: Why Investing in Infrastructure is Critical to Improving Water Quality. Alliance for the Great Lakes. Retrieved from https://greatlakes.org/wp-content/uploads/2016/08/AGL_Reducing_CSO__14_FINAL-1.pdf For more detail regarding specific investments, see at Great Lakes Water Authority Wastewater Master Plan, June 2020 at 1-23 to 1-26, 8 -1 to 9 - 23

[46] Combined Sewer Outfall Individual NJPDES Discharge Permits. (2013). Retrieved from https://www.nj.gov/dep/dwq/pdf/camden_cso_faqs.pdf. Philadelphia Combined Sewer Overflow Long Term Control Plan Update. (2009) Retrieved from https://water.phila.gov/pool/files/LTCPU_Section01_Introduction.pdf

Focus Areas

To identify potential focus areas for further investment, the project team conducted a comprehensive suitability analysis of existing recreation access sites. The suitability analysis used publicly available GIS data to score 37 recreation access sites on the Delaware mainstem across fourteen attributes. A scoring system was designed to give higher scores to sites where a confluence of water quality conditions, physical factors, and equity considerations indicate targeted investments are best directed. The ten recreation access sites that scored the highest were selected for further discussion with stakeholders.

Table 21 lists the top ten sites and summarizes selected site attributes.

Table 21: Top Ten Sites for Potential Investment from Suitability Analysis

Site	Population within half mile	Social Vulnerability Index	Distance to nearest transit stop (ft)	Distance to nearest CSO (ft)	Industrial Waste Outfalls within 3,000 (#)	Distance to nearest port (ft)
Pyne Poynt Park	900	1.00	1,971	2,364	0	7,561
Governor Printz Park	400	0.66	2,459	12,266	0	5,163
Penn's Landing	1,600	0.26	653	817	0	2,728
Red Bank Battlefield Park	1,150	0.55	8,378	12,026	0	5,264
Wiggin's Waterfront Park	700	0.92	939	660	0	1,161
Rivergate Boat Ramp	800	0.49	4,486	11,793	1	1,551
Washington Avenue Green	1,610	0.26	846	413	0	931
Frankford Arsenal	1,200	0.79	1,918	400	0	10,097
Independence Seaport Museum	1,100	0.26	499	483	0	3,292
Chester City Boat Ramp	800	0.99	801	849	8	6,888

Based on stakeholder discussions, one focus area was selected in each city: Pyne Poynt Park in Camden, Chester City Boat Ramp in Chester, and Frankford Arsenal in Philadelphia. Three additional sites were added based on existing public boating programs at or near the sites: River Fields on the Delaware River mainstem

just north of the Study Area, Bartram's Garden on the Schuylkill River, and John Heinz National Wildlife Refuge on Darby Creek.

4   Recommendations

This section discusses potential actions to reduce bacteria levels and improve recreational opportunities in the Study Area. The potential actions focus on CSOs because: 1) they release untreated sewage into receiving waters by design, and 2) the regulatory framework for LTCPs provides significant scope for adaptive management. Given their long-term planning horizons and their use of the presumption approach, the LTCPs in the Study Area are relatively more flexible than the NPDES permits for WPCPs and MS4s.

While the existing LTCPs outline one approach to compliance and financing under the current CSO policy, there may be ways to accelerate and target water quality improvements to enhance benefits to communities and aquatic systems in the Study Area. These improvements could be realized in specific locations under specific conditions. Expanding primary contact recreation does not require elimination of all bacteria exceedances or all combined sewer overflows in the Study Area.

This section outlines both general actions to advance the goal of swimmable waters in the Study Area, and specific actions that could be targeted to the six identified focus areas. The priority should be on investments that have multiple benefits and can be planned and executed relatively quickly. At the same time, collecting more bacteria data in the Study Area will further our understanding of bacteria persistence and the conditions under which bacteria levels are likely to meet the water quality standards for primary contact recreation. Additional data collection could support more localized modeling approaches that could help with site-specific CSO remediation design.

Note that these actions center around water recreation in the Study Area: the main stem Delaware River and tidal areas adjacent to Camden, Chester and Philadelphia. The other non-tidal tributary waterways upstream of the Study Area around which these communities were built – waterways that are already designated for primary contact recreation – are currently impaired for this use. In many instances, these waterways may be more readily accessible to lower income, vulnerable communities for water recreation. Developing a strategy to remediate CSO impacts on these tributary waters outside of the Study Area, while not within the scope of this study, holds significant promise for broader benefits.

Also outside of the scope of this study, but worth future consideration, is the development of a multi-jurisdictional integrated wastewater and stormwater plan across communities in the Study Area. Such a plan would help prioritize projects across municipalities to direct available federal resources more efficiently and achieve water quality improvements faster. While inherently complex, this kind of process could be enormously beneficial to all stakeholders and achieve significant efficiencies. For many reasons, the conditions might be ideal for initiation of this kind of a multiple-party approach to our region's water resource issues that includes full consideration of the sustainability and resiliency of our cities and their water systems in the context of equity and fairness.

All three systems currently use a system-wide approach to compliance with the CSO policy. Because both CCMUA and DELCORA are much smaller systems and because they do not also have MS4 compliance obligations, a system-wide approach may truly be their best and only option. The complexity of the system managed by PWD, however, also means there could be multiple approaches to CSO policy compliance. PWD could, for example, adopt a tributary approach that integrates CSO and MS4 compliance based on the specific challenges in a specific tributary. It could also adopt an approach that includes new smaller facilities for CSO storage and/or treatment that could accelerate remediation in parts of the city that have long experienced multiple environmental burdens. However, there is nothing in the CSO policy or NPDES compliance that would require pivoting away from the current systemic approach. The potential actions below are framed with this reality in mind.

General

The project team identified six recommendations that could help stakeholders achieve swimmable waters within the Study Area. These actions could also advance water equity in communities that have historically experienced underinvestment in terms of access to clean rivers and streams. The actions focus on Camden, Chester and Philadelphia. The actions do not include new large gray infrastructure projects - the required planning and procurement processes would prohibit implementation at an accelerated pace. In addition, it is beyond the scope of this project to provide substantive review of large, engineered capital projects outlined in the LTCPs and the development of feasible alternatives.

These potential actions are directed at several audiences, including community residents, business owners, elected officials, water system managers, clean water advocates, and funders. Each potential action is assigned to a proposed lead. However, all stakeholders have a role in accelerating the pace to a cleaner Delaware River and tidal tributaries in the Study Area. More important than any specific action, the stronger the partnership across all stakeholder groups, the more likely meaningful progress will be made and sustained.

1) **Ensure that cities in the Study Area develop and document clear community priorities for river-based water recreation to direct and drive LTCP/MS4 implementation.**

Stormwater and wastewater managers' role in this water recreation challenge is primarily provision of clean water. None of them oppose having water clean enough for swimming in the mainstem of the Delaware River, in the tidal tributary waters, and in other waterways in their cities. However, it is beyond their authority to prioritize specific recreational water access sites or develop water recreation at public parks. In addition, Clean Water Act policies as implemented to date will not be sufficient to drive accelerated action at specific sites.

It must be the broader city governments - not the water utilities - that set and document the priorities for equitable water recreational opportunities. Those priorities can then be used to drive adaptation of the LTCPs to meet each community's goals.

Investments in clean water can serve as a significant economic driver for Philadelphia, Camden and Chester. Some cities have adopted a vision centered on their water resources such as Milwaukee's Water City Agenda. Other cities are investing in specific water recreation opportunities. Oklahoma City has a $45.2 million whitewater rafting and kayaking center in the heart of the city. The Argo Cascades in Ann Arbor, Michigan, provides canoeing, kayaking, tubing and paddle boarding in a man-made river paralleling the Huron River. POOL+ is a non-profit initiative in New York City to locate a water-filtering pool structure directly in the river.[47] These examples outline the kind of water-centric vision Camden, Chester and Philadelphia could develop with the input of residents and driven by city officials. Developing river-centric visions would help further refine water quality investment priorities for stormwater and wastewater managers in the region.

Identifying priorities for water recreation is expected to become more pressing over time. With the higher temperatures resulting from climate change, all the communities in the Study Area will see an increased need for cooling strategies like wading, splashing and swimming. While building new off-river facilities may be part of the overall solution, investments in existing infrastructure - particularly existing natural infrastructure like our rivers and streams - should be a key strategy in achieving cost-effective

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[47] Milwaukee Water Commons Water City Agenda. (2016) Retrieved from https://www.milwaukeewatercommons.org/water-city-agenda; https://www.riversportokc.org/adventures/whitewater-rafting/
Ann Arbor Department of Recreation Canoe, Kayak and Tube. Retrieved from https://www.a2gov.org/departments/Parks-Recreation/play/Pages/Canoeing.aspx
+POOL. Retrieved from https://pluspool.org/

solutions that meet community needs. The examples above all center their natural water resources in their vision as can be the case for the communities in the Study Area.

Stakeholders should help initiate and support community-led processes in each community to identify water recreation priorities on natural waterways. The process must include underrepresented communities to assess the adequacy of existing opportunities and help identify new opportunities. The documented outcomes of these processes can then become the basis for reprioritization of large capital investments to accelerate water quality improvements at specific locations along the rivers. As ratepayers are going to be the ones financing most of the investments, they must be part of the decision-making process.

In Philadelphia, the process needs to include existing and potential sites in the Study Area as well as sites on the non-tidal parts of the tributaries upstream of the Study Area in the city. Integrating natural water recreation prioritization with a six-tributary approach to CSO and MS4 compliance in Philadelphia could be catalytic to moving toward a more robust "One Water" frame.

Cost estimate: Public engagement processes will vary depending on community size and possibility of leveraging existing opportunities; potentially most needed in Philadelphia, where the Philadelphia Water Department has existing public engagement processes that could be leveraged.

Leads: City governments, community organizations.

2)   Advocate for non-debt financing at the federal and state level for water quality upgrades in CSO watersheds to accelerate LTCP timelines.

Water advocates, water utility managers and other stakeholders in the Study Area should partner to understand the full clean water compliance obligations, the available financing options, water affordability challenges and the communities' interest in water recreation in the Study Area. With this knowledge in hand and this partnership formed, they will be well-positioned to deliver a strong and consistent message to decision makers and state and federal funders about the need to accelerate implementation of the LTCPs generally so that the public health and environmental benefits can be realized sooner, without adversely impacting ratepayers facing affordability challenges. The importance of federal funding support that does not negatively impact low-income communities is of national interest.[48]

Over the next five years, substantial investments are planned to reduce the volume of CSOs in the Study Area as set out in the three LTCPs. All three wastewater systems need additional resources to speed up the timelines for implementation of their plans. It is essential, though, that additional financial resources not come only in the form of additional debt-financing. The communities served by these wastewater systems have suffered from decades of disinvestment and new investments to alleviate long-standing environmental burdens should not require additional wealth extraction from the community.[49]

While there are both state and federal programs that provide non-debt financing to support water infrastructure investments, none of them provide the scale of resources necessary to address the CSO remediation challenge. When the Clean Water Act was first passed, it included grant financing to help upgrade treatment facilities. The same kind of large-scale grant program is needed now to remediate the impacts of CSOs. Existing grant programs, such as the Sewer Overflow and Stormwater Reuse Municipal Grant program, could be repurposed to deliver substantial federal funding directly to CSO communities across the country, including those along the Delaware River where the cost of the CSO

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[48] Kruzman, D. (2022). "Cities are investing billions in new sewage systems. They're already obsolete.", Grist. Retrieved from https://grist.org/cities/cities-are-investing-billions-in-new-sewage-systems-theyre-already-obsolete/

[49] PENNVEST's current policies for distributing principal forgiveness and grants according to affordability through the Clean Water State Revolving Fund generally disqualify Philadelphia. While a different policy for defining affordability which would allow Philadelphia to qualify would advance water equity, the resources available through the Clean Water State Revolving Fund have never been and will not be sufficient even with the Infrastructure Investment and Jobs Act funding to fund the needed CSO remediation in Philadelphia, let alone the many other communities in Pennsylvania that need to remediate their combined sewer systems.

remediation is estimated at almost $2 billion.[50] Water system managers, local elected officials, residents and other stakeholders should deliver a unified message to state and federal representatives that these grant funds are essential to remediate CSO challenges.

Cost estimate: Relatively low for partnership development and joint advocacy.

Leads: City governments, community organizations, elected officials (local, state, federal level), water advocates.

3) **Develop a community science monitoring network and use the data to better inform the public about bacteria levels.**

More consistent and regular bacteria monitoring efforts on the Delaware River will allow for better targeting of investments, better communication of health risks and more support for the efforts of water managers and numerous organizations that interact with the Delaware River in their daily operations and have a shared goal for a cleaner, healthier river.

The monitoring network should include regulators, water utilities, watershed organizations and academic institutions. Its purposes should include better characterization of bacteria in the overall system and understanding conditions at specific sites. It should encompass multiple locations, including existing monitoring locations, existing water access sites, and new sites close to environmental justice communities as well as sites that will help develop a more complete understanding of bacteria persistence in the river. Monitoring also should include MS4 outfalls and sediment sampling. The monitoring network must be sufficiently resourced to allow for coordination and implementation of quality assurance protocols.

The program could be used to pilot new rapid field approaches and investigate more effective methods to assess all recreational water risks, including methods that assess the level of live bacteria in recreational waters. It could help meet some of the data collection priorities outlined in the co-regulators process. The monitoring network in the Study Area could be paired with more robust bacteria monitoring on the upstream tributaries that drain to the Study Area, particularly above the CSO systems in each community, to better characterize the impact of CSOs in those areas. More detailed information is provided in Appendix 3.

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[50]US EPA Region 3 Press Office. (2021). Chester received a $2.4 million grant through this program for green stormwater infrastructure. Retrieved from https://www.epa.gov/newsreleases/epa-awards-24-million-grant-city-chester-green-infrastructure-project-address

The data collected through this monitoring network can better inform the public about water quality conditions. Public health officials and community members can partner to develop a communications strategy based on sufficient data about sources, near-shore conditions, and risk that could include enhancing and expanding PWD's CSOCast/RiverCast systems to include CCMUA and DELCORA. Many cities across the globe are moving toward CSS overflow public notification systems. Programs and tools used on the Charles River and the Potomac River for publicly sharing the data might be instructive.[51]

Cost estimate: A minimum of $20,000 per monitoring season and location; augmented public information and communications strategy reasonably modest additional investment.

Leads: City governments, DRBC, community organizations, regional water science organizations/academic institutions.

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[51] Environmental Protection Agency (2023). Live Water Quality Data for the Lower Charles River. https://www.epa.gov/charlesriver/live-water-quality-data-lower-charles-river; Department of Energy & Environment. Anacostia and Potomac River Monitoring Program. https://doee.dc.gov/service/anacostia-and-potomac-river-monitoring-program

4) **Accelerate investments in green stormwater infrastructure in all communities bordering the Study Area.**

Green stormwater infrastructure (GSI) that involves filtration of stormwater runoff through vegetation often provides multiple benefits to a community beyond improving water quality and reducing flows in combined sewer systems. The practices can help provide shade to reduce heat island, calm traffic, help attenuate flooding, and provide green space that improves public health, for example. GSI projects are lower risk investments that can benefit all communities. They are the most accessible strategy in MS4 communities to reduce the impacts of pollution in stormwater runoff. All stakeholders should advocate for and support much larger and more equitable GSI investments in all MS4 parts of the Study Area.

Not all GSI projects are worthy projects. Careful planning along with community engagement will help ensure long-term success. And communities that have been burdened by pollution and disinvestment should be prioritized not only to address inequities but also because the impact of these projects has the greatest potential in these communities.

Camden, Chester, and Philadelphia

GSI programs are in place in the three cities in the Study Area. Chester has a stormwater utility and implements GSI projects. CCMUA supports GSI projects to help reduce flows into its combined system. Recent focus on PWD's program has resulted in recommendations about where GSI should be prioritized. The aggregated mapping of the work led by the Academy of Natural Sciences identified the following neighborhoods as recommended for prioritizing GSI investment: Frankford, Harrowgate, Port Richmond, Upper Kensington, Glenwood, East Poplar, Tioga, Franklinville, Fairhill, Stanton, Cobbs Creek, Greenwich, Southwest Schuylkill, Grays Ferry, and Point Breeze. Of these neighborhoods, Port Richmond and Harrowgate are close to the mainstem of the Delaware River in the Study Area. Southwest Schuylkill, Grays Ferry, Frankford and Cobbs Creek neighborhoods are near tidal tributary areas in the Study Area.

Cost estimate: $200,000 per greened acre.

Leads: City governments, PWD, CCMUA, DELCORA, community organizations.

Other communities adjacent to the Study Area

While not the largest source of bacteria overall in the Study Area, MS4 systems can be significant contributors, particularly at specific locations and during smaller storm events when most of the stormwater in combined sewer areas should be directed to water treatment facilities. At the moment, the MS4 programs in New Jersey and Pennsylvania MS4 programs do not include specific pollution reduction requirements for bacteria in their existing permits. Nonetheless, GSI practices installed to meet other water pollution challenges can still be impactful in reducing bacteria loading.

All MS4 outfalls should be identified in the Study Area. Regulators, municipal officials, and water advocates should partner to identify GSI projects to reduce and treat stormwater flows to the Study Area.

Cost estimate: $200,000 or less per greened acre.

Leads: Municipal governments with MS4 outfalls to the Study Area, state environmental agencies, community organizations, water advocates.

Financing GSI

Communities throughout the Study Area will need to identify funding and financing to support increased investments in GSI. Accounting rules allow for public entities to use capital funds for distributed infrastructure like GSI on private land, which opens more opportunities for implementation. These rules may also soon allow for capital funds to be used for some operations and maintenance expenses during the vegetation establishment period. For communities that don't have a stormwater fee in place, this revenue stream could be essential to achieving equitable GSI funding and implementation.

With this in mind, stakeholders should advocate for communities that manage separated storm system outfalls to the Study Area to conduct preliminary feasibility studies for stormwater fees. The New Jersey Department of Environmental Protection has funding available to support these feasibility studies. A recent court decision in Pennsylvania regarding the West Chester Borough stream protection fee has impacted progress regarding municipal stormwater fee adoption in the short term; the results of the appeal of the decision to the Pennsylvania Supreme Court will provide more clarity.

Costs: Variable depending on the size of the community; several organizations in New Jersey and Pennsylvania are already well-positioned to educate communities about stormwater fees, reducing the potential costs for initiative.

Leads: Communities with MS4 outfalls in the Study Area, state environmental agencies, community organizations, water advocates.

5) **Continually improve implementation of the nine minimum controls outlined in each of the LTCPs and communicate with the public about these activities.**

Continued improvement on adherence to the nine minimum control measures (NMCs) that are part of the CSO program should be a priority for water system managers and, perhaps more importantly, regularly communicated to the public in a clear and understandable manner. These activities include cleaning and maintenance of sewers, outfalls, and tide gates. All CSO systems are required to report on their progress in meeting the requirements of the NMCs on an annual basis. While there is a continuous review by the utilities and the regulators on the status of the NMCs, community organizations and water advocates should understand and track NMC compliance to ensure maximum protection of water quality.

Involve the public in NMC review

Although the three CSO system managers have been regularly meeting the NMCs, it is important that these activities and their benefits are regularly communicated to the public in a clear and understandable way. Water advocates should partner with the CSO system managers to participate in the review process.

Develop communication tools and methods that will bridge the gap in understanding about NMC compliance

Most ratepayers and residents in the Study Area do not know what happens to their stormwater or wastewater. While the water system managers have communications materials available in various formats, partnering with community organizations and water advocates to have a broader reach is essential to developing a more representative group of engaged stakeholders.

Costs: Minimal addition to current public education activities and engagement.

Leads: PWD, CCMUA, DELCORA, water advocates.

Determine the reason for dry weather bacteria loading challenges in tributaries and prioritize resolution.

The data reviewed indicated that, while dry weather water quality was significantly better than wet weather water quality, there were places and times where bacteria levels during dry weather are high. One specific example identified in this report is upstream of Adams Avenue in the Frankford Creek watershed, outside of the CSO area in Philadelphia. Priority should be given to undertaking trackback studies for any sources of dry weather discharges into the Delaware River mainstem and its tributaries as well as the corresponding corrective actions.

Cost estimate: To be determined; dependent on scale of problem.

Leads: PWD, CCMUA, DELCORA

6) Incorporate climate change risks into CSO remediation strategies

The LTCPs were developed without the benefit of the current understanding of climate change impacts in the region. The biggest risks to water systems are likely more severe wet weather events and river level rise. Each CSO sewer system manager is responsible for evaluating new capital investments in light of the current state of climate science as opposed to investing in new projects that will be overwhelmed by climate impacts. As noted earlier, PWD has adopted mandatory climate resilience guidance. However, the process of how individual projects are reviewed before implementation begins is not transparent to the public. CSO sewer system managers should address the need for transparency by either updating the LTCP or engaging the public through other processes that outline climate challenges to the water systems and clearly communicate how CSO management decisions being made today are incorporating current climate science.

All three CSO LTCPs mention the use of GSI to reduce stormwater flows into their CSO systems, with Philadelphia's Green City Clean Water Plan being the most extensive. Depending on how GSI practices are designed and maintained, they may not deliver the systemic stormwater flow reductions initially anticipated given the more frequent large storm events our region is experiencing because of climate change. GSI strategies will need to be continually reviewed in the context of adaptive management along with the other CSO remediation strategies.

Cost estimate: Uncertain.

Leads: PWD, CCMUA, DELCORA, stormwater managers, DRBC, state and federal environmental agencies, regional water science organizations/academic institutions.

Accelerating Action at Six Focus Areas

The project team also identified a set of site-specific actions that could help achieve swimmable waters at identified focus areas. As discussed in the Methods and Findings section, the focus areas are sites where a confluence of water quality conditions, physical factors, and equity considerations suggest targeted investments are best directed. They were selected through a GIS-based site suitability analysis, complemented by extensive stakeholder discussions.

The six focus areas identified by the project team include Pyne Poynt Park, Chester Riverfront, Bartram's Garden, John Heinz National Wildlife Refuge, River Fields, and Frankford Arsenal Boat Ramp. These locations could be good candidates for piloting approaches to better understand the nature and cause of bacteria impairments and design pollution reduction strategies. Any of these sites could be used to develop multi-scenario modeling that builds on the sewershed mapping from the Green Stormwater Infrastructure Focus Area Project. Multi-scenario modeling also could be used to develop a site-specific CSO remediation approach. The recommendations for each site build on the following relatively fast and lower cost strategies.

Generalized Focus Area Site Recommendations:

- Implement GSI projects in targeted sewersheds impacting the focus area

- Pilot different inlet filters near the focus area

- Pilot outfall nettingnear the focus area

- Prioritize planned pipe lining in targeted CSO sewersheds impacting the focus area

- Prioritize planned I/I activities in targeted CSO sewersheds impacting the focus area

- Map MS4 outfalls and implement GSI and other best management practices to address identified challenges

- Initiate/expand bacteria monitoring and share data on public platforms

Pyne Poynt Park

Pyne Poynt Park in Camden is a county-owned park with great potential for direct and easy access to the Delaware River. Because of limited options in Camden, providing river-based water recreation should include sites on the Delaware River. However, the site is approximately 1,500 feet downstream of the Cooper River and approximately 8,500 feet downstream, from Camden's largest CSO at 32nd and Farragut Streets. This is the only CSO owned by the CCMUA (the others are owned by the City of Camden) and is the largest in Camden, with a potential daily discharge of up to 300 MGD during wet weather (about one third of all system-wide overflows). Reducing the volume and/or frequency of combined sewage overflows from the CSO at 32nd

and Farragut would address one cause of bacteria impairments at Pyne Poynt Park. As discussed in the Methods and Findings section, however, Pyne Poynt Park was observed to have consistently high *E. coli* levels and no statistically significant difference between dry versus wet weather conditions. Additional investigation is needed to understand the cause of dry weather bacteria impairments at the site.

Ongoing investments are planned or underway that are estimated to total between $30 to $40 million. The significance of these improvements on water quality at Pyne Poynt Park will require further investigation, including an engineering analysis of how the Delaware Back-Bay and Cooper River impact the Pyne Point water quality. Projects include:

- Elimination of Pennsauken's two historic but unapproved interconnections of stormwater sewers into Camden's combined sewer system and the construction of a Pennsauken stormwater pumping station will significantly reduce flooding in Pennsauken, the Cramer Hill section of Camden, and overflows from the CSO at 32nd and Farragut. Project cost estimates range from $15 to $20 million, and the work is ongoing.
- Construction of additional green infrastructure projects in the Cramer Hill section of Camden to reduce stormwater inputs into the upstream combined sewer system. Depending on the availability of suitable public space, this project could cost up to $10 million.
- Clean out of sewer system to maximize conveyance capacity away from the CSO at 32nd Street and Farragut and toward CCMUA treatment plant downstream.
- Gray infrastructure interventions such as sewer separation, underground storage construction, and end of pipe treatment/disinfection.

Additional site-specific actions that could help improve recreational water quality at Pyne Poynt Park include:

a) Supporting federal, state, and local investments to reduce CSO overflows and realizing more water-based recreation at Pyne Point. Funding approaches should focus on grant funding and other non-debt financing strategies so as not to increase the financial burden on local ratepayers.

b) Initiating a summer bacteria monitoring program in partnership with the existing program run through Urban Promise. Identifying all outfalls - CSO and MS4 - near the site and consider them in the development of the monitoring plan. Sediment testing should be included as well. MS4 outfall and sediment sampling are essential here because of the high dry weather FIB levels. The monitoring program should also help identify the role of the Back Bay and Cooper River and inform remediation of those sources and could also include Microbial Source Tracking DNA markers such as HF183. Use of a viability-based test could assist in determining the extent and timing of fresh sewage contamination. For example, propidium monoazide (PMA) pretreatment and subsequent HF183 detection using ddPCR or qPCR could determine the fraction of viable human marker measured. This and other

monitoring tools to better understand sources of fecal pollution in the Study Area are discussed further in Appendix 3.

c) Implementing buffers to intercept any overland flow, particularly between the river and areas where Canada geese congregate.

d) Developing a publicly facing platform to share and communicate the information gathered from the monitoring program.

e) Supporting GSI implementation to reduce combined sewer flow and also improve water quality generally in both CSO and MS4 areas that could impact water quality.

Costs: Minimum of $20,000 per monitoring season and location; modest additional resources for public-facing data platform and advocacy activities; resolving dry weather exceedances could have a wide cost range.

Leads: City of Camden, CCMUA, community organizations, water advocates.

Chester Riverfront

Chester Riverfront boasts 100-acres of land and has, in recent years, been the focus of enhanced community engagement and access to the riverfront. Chester has potential for key infrastructure improvements that combine both sustainability and resiliency. A key aspect of Chester's redevelopment plan is to mitigate the impacts of climate change and rising sea levels through stormwater management and the development of natural landscapes.

In addition, the Riverfront Alliance of Delaware County (RADC) has developed the Chester Waterfront Master Plan. The RADC is a consortium of private sector corporations and non-profit organizations seeking to catalyze physical, economic and social development along the river. The plan envisions public open spaces for passive recreation to improve the community's connection to the river and offers the opportunity for public access to the river. The plan envisions a marina, a fishing pier, and trails, representing an important expansion of water and fishing recreation in the area. While this plan does not currently include public access specifically for swimming, it could become part of a future iteration of the plan. This plan provides the basis needed to help prioritize public investment. Potential funding sources include grants from Pennsylvania's Department of Community and Economic Development as well as support from the Philadelphia Union, M&T Charitable Foundation, the Chester Economic Development Authority, and the Chester Redevelopment Authority.

Ongoing initiatives and investments are making significant progress in reducing CSOs in the city of Chester and providing public access to water recreation. The city plans to reduce average annual CSO volumes by as much as 94% by building a tunnel. The tunnel is estimated to cost $410 million and be completed by 2028.

Additional site-specific actions that could help improve recreational water quality at the Chester Riverfront include:

Community organizations and residents lead a process in Chester to learn about their views on the DELCORA Tunnel and the RADC Waterfront Master Plan if this has not been done.

a) Ensuring that any concerns raised by local stakeholders about these plans are heard by local, regional, state and federal decision-makers.

b) Subject to identified concerns, supporting federal, state, and local investments to reduce CSO overflows and realizing more water-based recreation at the Chester Riverfront. Funding approaches should focus on grant funding and other non-debt financing strategies so as not to increase the financial burden on local ratepayers.

c) Initiating a summer bacteria monitoring program at the waterfront through a partnership of the City of Chester, DELCORA, community members, research entities, and watershed organizations among others. Identifying all outfalls - CSO and MS4 - near site and include them in the monitoring plan. Sediment testing should be included in the monitoring plan if feasible.

d) Developing a publicly facing platform to share and communicate the information gathered from the bacteria monitoring program.

e) Supporting expenditures to ensure maintenance of all wastewater and stormwater infrastructure according to asset management plans to ensure water quality that supports primary contact water recreation.

Costs: Minimum of $20,000 per season and per site for bacteria monitoring program. Modest additional resources for public-facing data platforms and advocacy activities.

Leads: City of Chester, RADC, DELCORA, community organizations, water advocates.

Bartram's Garden

Bartram's Garden is located in South Philadelphia on the tidal portion of the Schuylkill River. While owned by the Philadelphia Department of Parks and Recreation, it is operated by the John Bartram Association, a non-profit organization and supports a public boating program. To ensure good water quality for this program, Bartram's Garden conducts bacteria monitoring. From conversations with staff, it appears that monitoring results reflect what has been found at other locations - while some dry weather testing has shown low pathogen levels, other dry weather sampling has shown exceedances so that monitoring to date has not provided sufficient information to predict water quality conditions that would support primary contact recreation. Upstream of this location, PWD has instituted its RiverCast system to help predict water quality conditions, but

it does not extend to Bartram's Gardens. There is a good correlation between this site and the results of the aggregated mapping developed to focus GSI investments in Philadelphia to address equity.

Additional site-specific actions that could help improve recreational water quality at Bartram's Garden include:

a) Developing a site-specific strategy to reduce bacteria loading at Bartram's Garden. This strategy would consider which infrastructure projects included in the LTCP are most likely to impact this site and ensure appropriate prioritization in PWD's capital improvement planning. It would also consider additional strategies such as:

- Targeting GSI implementation on both public and private land in this area;
- Piloting different inlet filters and pipe netting systems within associated sewersheds and monitoring effectiveness;
- Identifying needed pipe relining projects in associated sewersheds and ensuring appropriate prioritization in PWD's operations and maintenance schedule; and
- Prioritizing remediation of any illicit discharges and other possible dry weather sources of bacteria at the site.

b) Supporting federal, state, and local investments for CSO remediation projects at this site. Funding approaches should focus on grant funding and other non-debt financing strategies so as not to increase the financial burden on local ratepayers.

c) Augmenting the existing bacteria monitoring program. Identifying all outfalls - CSO and MS4 - near the site and include them in the monitoring plan. Sediment testing should be included in the monitoring plan if feasible. The monitoring program could pilot the use Microbial Source Tracking DNA markers such as HF183 to better understand the cause of bacteria impairments. Use of a viability-based test could assist in determining the extent and timing of fresh sewage contamination.

d) Develop a publicly facing platform to share and communicate the information gathered from this monitoring program.

Costs: $200,000 per greened acre; variable costs of inlet filters and netting systems depending on number, size, materials; reprioritizing relining projects should not require significant resources; resolving dry weather exceedances could have a wide cost range; minimum of $20,000 per monitoring season and location; modest additional resources for public-facing data platform.

Leads: Bartram's Gardens, PWD.

John Heinz National Wildlife Refuge

John Heinz National Wildlife Refuge is a federally managed site located in South Philadelphia on the tidal portion of Darby-Cobbs Creek watershed. The refuge supports a public boating program but there is not currently a bacteria monitoring program. This refuge is in a neighborhood that has been impacted by multiple environmental burdens, including air pollution from the Philadelphia Airport and Interstate 95, a remediated Superfund site at a landfill, and a continually impaired watershed. While the refuge is located in the MS4 area of the city, the upstream area of the Cobbs Creek which flows into the refuge is served by the City's combined system. There is a good correlation between areas upstream of the refuge and the results of the aggregated mapping developed to focus GSI investments in Philadelphia to address equity. This location presents a specific opportunity to leverage additional federal investments potentially available through the US Fish and Wildlife Service and through transportation investments.[52]

Additional site-specific actions that could help improve recreational water quality at John Heinz National Wildlife Refuge include:

a) Developing a site-specific strategy to reduce bacteria loading at the refuge. This strategy would consider which infrastructure projects included in the LTCP are most likely to impact this site as well as projects designed to address MS4 water quality impacts and ensure appropriate prioritization in PWD's capital improvement planning. I should consider additional strategies such as:

   - Targeting GSI implementation on both public and private land in this area;
   - Piloting different inlet filters and netting systems within associated sewersheds and monitoring effectiveness;
   - Identifying needed relining projects in associated sewersheds and ensuring appropriate prioritization in PWD's operations and maintenance schedule; and
   - Prioritizing remediation of any illicit discharges and other possible dry weather sources of bacteria at the site.

b) Supporting federal, state, and local investments for CSO remediation projects at this site. Funding approaches should focus on grant funding and other non-debt financing strategies so as not to increase the financial burden on local ratepayers.

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[52] University of Pennsylvania School of Engineering General Robotics, Automation, Sensing and Perception Lab is conducting bathemetry research in the Schuylkill River near Bartram's Garden to better understand underwater weather. This research will help explore site-specific conditions. https://www.grasp.upenn.edu/projects/underwater-weather/

c) Initiating a summer bacteria monitoring program at the refuge. Identifying all outfalls - CSO and MS4 - that impact the refuge and include them in the development of the monitoring plan. Sediment testing should be included in the monitoring plan as this may be an important source at this location given the topography of the refuge. The monitoring program could include the use of microbial source tracking DNA markers to help identify the impacts of wildlife on bacteria loading.

d) Developing a publicly facing platform to share and communicate the information gathered from this monitoring program.

Costs: $200,000 per greened acre; variable costs of inlet filters and netting systems depending on number, size, materials; reprioritizing relining projects should not require significant resources; resolving dry weather exceedances could have a wide cost range; minimum of $20,000 per monitoring season and location; modest additional resources for public-facing data platforms.

Leads: John Heinz Wildlife Refuge, Friends of John Heinz Wildlife Refuge, PWD.

River Fields

While this site is just north of the Study Area, it is being included because it may be an excellent opportunity in Philadelphia for developing water recreation both on Pennypack Creek and on the main stem of the Delaware River. At the mouth of Pennypack Creek, the site is just south of the Baxter Water Treatment Plant, presenting an existing opportunity for joint prioritization between the Philadelphia Water Department and the Philadelphia Department of Parks and Recreation for water recreation; PWD would benefit from high water quality near its intakes and the neighborhood would benefit from additional amenities at the park. Because there are only four CSOs upstream on Pennypack Creek, addressing water quality challenges in the tidal reaches at this location could be less complicated than at other locations. The site is also just downstream of the Linden Avenue data collection site where the data reviewed for this report showed bacteria levels more often below the EPA criteria. The neighborhood immediately adjacent to this site is lower income and demographically diverse. The park has baseball and soccer fields that support local leagues, so it is already valued for recreation. However, there are few trees and there are opportunities for significant investment at the park.

Additional site-specific actions that could help improve recreational water quality at River Fields include:

a) Developing a site-specific strategy to reduce pathogen loading at River Fields. This strategy would consider which infrastructure projects included in the LTCP are most likely to impact this site and ensure appropriate prioritization in PWD's capital improvement planning. It should consider additional strategies such as:

- Targeting GSI implementation on both public and private land in this area;

- Piloting different inlet filters and netting systems within associated sewersheds and monitoring effectiveness;

- Identifying needed relining projects in associated sewersheds and ensuring appropriate prioritization in PWD's operations and maintenance schedule; and

- Prioritizing remediation of any illicit discharges and other possible dry weather sources of bacteria at the site.

b) Supporting federal, state, and local investments for CSO remediation projects at this site. Funding approaches should focus on grant funding and other non-debt financing strategies so as not to increase the financial burden on local ratepayers.

c) Augmenting existing bacteria monitoring. Identify all outfalls - CSO and MS4 - near the site and include them in the monitoring plan. Sediment testing should be included in the monitoring plan if feasible. The monitoring program could pilot the use of Microbial Source Tracking DNA markers such as HF183 to better understand the cause of bacteria impairments. Use of a viability-based test could assist in determining the extent and timing of fresh sewage contamination.

d) Developing a publicly facing platform to share and communicate the information gathered from this monitoring program.

Costs: $200,000 per greened acre; variable costs of inlet filters and netting systems depending on number, size, materials; reprioritizing relining projects should not require significant resources; resolving dry weather exceedances could have a wide cost range; minimum of $20,000 per monitoring season and location; modest additional resources for public-facing data platform.

Leads: PWD, Pennypack Ecological Restoration Trust.

Frankford Arsenal Boat Ramp

The Frankford Arsenal Boat Launch is a 20-acre former ammunition plant located in Northeast Philadelphia. It is one of Philadelphia's three public boat launches and borders Frankford Inlet, near the outlet of Frankford Creek and the Delaware River. The boat launch serves as a popular picnic and fishing spot. The Frankford Arsenal Boat Ramp is a Pennsylvania Fish and Boat Commission (PFBC) site, creating a specific opportunity for partnering with this state entity. As many as five CSO outfalls are near the site and more within 1 mile of the site. In addition, it is close to where Frankford Creek meets the mainstem of the Delaware River. There is a good correlation between this access point and the results of the aggregated mapping developed to focus GSI investments in Philadelphia to address equity. In addition, some of the geometric mean nearshore data reviewed for this report showed the site sometimes meets EPA criteria.

Additional site-specific actions that could help improve recreational water quality at Frankford Arsenal Boat Ramp include:

a) Developing a site-specific strategy to reduce bacteria loading at the boat ramp. This strategy would consider which infrastructure projects included in the LTCP are most likely to impact this site and ensure appropriate prioritization in PWD's capital improvement planning. It should consider additional strategies such as:

- Targeting GSI implementation on both public and private land in this area;

- Piloting different inlet filters and netting systems within the sewershed and monitoring effectiveness;

- Identifying needed relining projects in the sewershed and ensuring appropriate prioritization in PWD's operations and maintenance schedule; and

- Prioritizing remediation of any illicit discharges and other possible dry weather sources of bacteria at the site.

b) Supporting federal, state, and local investments for CSO remediation projects at this site. Funding approaches should focus on grant funding and other non-debt financing strategies so as not to increase the financial burden on local ratepayers.

c) Initiating a summer bacteria monitoring program at the ramp. Identifying all outfalls - CSO and MS4 - near the site and include them in developing the monitoring plan. Sediment testing should be included in the monitoring plan if feasible. The monitoring program could pilot the use of Microbial Source Tracking DNA markers such as HF183 to better understand the cause of bacteria impairments. Use of a viability-based test could assist in determining the extent and timing of fresh sewage contamination.

d) Developing a publicly-facing platform to share and communicate the information gathered from this monitoring program.

Costs: $200,000 per greened acre; variable costs of inlet filters and netting systems depending on number, size, materials; reprioritizing relining projects should not require significant resources; resolving dry weather exceedances could have a wide cost range; minimum of $20,000 per monitoring season and location; modest additional resources for public-facing data platform.

Leads: PFBC, PWD, Tookany/Tacony-Frankford Watershed Partnership.

5   Conclusion

Overall, this report evaluates the occurrence and sources of fecal indicator bacteria in the Camden-Chester-Philadelphia Region with the goal of helping stakeholders achieve swimmable waters within this Study Area. The project was structured around three objectives:

> (1) understanding existing FIB water quality conditions and identifying knowledge gaps,

> (2) understanding the timing and extent of future FIB water quality improvements from committed investments, and

> (3) identifying additional opportunities for improved FIB water quality.

While this report does not address public health or water safety specifically, CSO remediation measures in the Study Area can not only improve water quality but also create other benefits for the community.

The report identifies sources of fecal indicator bacteria (FIB) in the Study Area both from existing bacteria monitoring efforts and a supplemental one, evaluates current work on CSO remediation through established LTCPs and their timing and extent as well as LTCPs beyond the study area to identify best practices, utilizes stakeholder engagement through group meetings and interviews to understand stakeholder concerns and how they might constrain opportunities for remediation, and conducted a suitability analysis of existing recreation access sites to identify potential focus areas for further investment. In addition, the review of relevant CWA programs and policies identified the need for better understanding about the location and extent of MS4 impacts in the Study Area. This mixture of desktop review, bacteria monitoring, and stakeholder engagement allowed for an overarching picture of the FIB water quality in the Study Area and the identification of target areas for CSO and other remediation actions.

Most importantly, it brought into focus potential opportunities that could help reduce bacteria levels and improve recreational opportunities at six selected sites in the Study Area: Pyne Poynt Park, Chester Riverfront, Bartram's Garden, John Heinz National Wildlife Refuge, River Fields, and Frankford Arsenal Boat Ramp.

The general and focus area recommendations are meant to be scalable, equitable, fundable, cost effective, and realistic to complete within a five-year period. We hope that stakeholders, including but not limited to decision makers, utilities along the Delaware River, community residents, business owners, elected officials, water system managers, clean water advocates, and funders will use this report as a resource in review and implementation of their LTCPs and MS4 programs and to implement our recommended actions to reduce CSO overflows, additional other local sources to reduce FIB levels, and achieve swimmable waters in the Delaware River. All stakeholders have a meaningful role in accelerating the pace to a cleaner Delaware River and tidal tributaries in the Study Area, and this report provides some tools towards that goal.

Appendix 1: Water-Based Recreation in the Study Area

This Appendix provides a detailed review of water-based recreation in the Study Area. It documents the project team's findings on historic activity, current activity, and resilience and equity considerations.

- **Historical Context**: The first section is a brief history of recreational uses and water quality conditions in the Study Area. It is based on a literature review and highlights inflection points.

- **Current State of Recreation**: The second section is an inventory of current recreational activities in the Study Area. It was developed by compiling existing lists of recreation access sites in the Study Area and gathering stakeholder feedback.

- **Resilience and Equity Considerations**: The third section discusses the concepts of climate resilience and water equity and how they relate to water-based recreation in the Study Area. It includes an analysis of the spatial distribution of social vulnerability in the Study Area. It also highlights selected equity initiatives in Camden.

Historical Context

Pre-Industrialization

For thousands of years, the Native American Lenape people were stewards of the Delaware River and its watershed. They lived along the banks of the Study Area and traveled by water using dugout canoes. They fished throughout the Delaware River basin, hunted, and grew food. For the Lenape people, there were no conflicts between different river uses. Transportation, fishing, and recreational activities coexisted side by side. By the beginning of the 19th century, most of the Lenape people had left the area by force or choice.[53]

Industrialization

Beginning in the 19th century, commercial and industrial uses in the Study Area intensified, and increasingly conflicted with recreational uses. Commercial and industrial uses included deep water navigation, water supply, waste disposal, and commercial fishing. Both commercial and recreational fishing along the Delaware River were supported by the prevalence of American shad. Prior to 1905, fishermen would catch approximately 16 million shad each year, and the river was known as the Nation's Shad Capital. Gloucester

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[53] Lenape Nation of Pennsylvania, https://www.lenape-nation.org; Lenape Indian Tribe Delaware, Kent County, http://www.lenapeindiantribeofdelaware.com; Nanticoke Lenni, https://nanticoke-lenape.info; West Philadelphia Collaborative History, The Original People and Their Land: The Lenape, Pre-History to the 18th Century, https://collaborativehistory.gse.upenn.edu/stories/original-people-and-their-land-lenape-pre-history-18th-century

City, New Jersey was the "symbolic center" of the river's shad industry. By the 1920s, however, the impacts of industrialization and overfishing had devastated fish populations and aquatic life. The shad fishing industry collapsed. Restocking efforts continued at the demand of veteran fishermen but remained unsuccessful. [54] At the same time, water quality was degraded by massive wastewater flows. In 1940, it was reported that more than 400 million gallons of untreated domestic wastewater and industrial waste were discharged into the Delaware River each day along the reach from Philadelphia to Chester. [55]

By the mid-19th century, industry dominated most of the waterfront and limited public access. Private boating and yacht clubs supported some recreational activity. These clubs required potential members to apply through a series of interviews, limiting club acceptance to those the club committee and members deemed suitable. Some of the yacht and boating clubs in Camden, Chester, and Philadelphia also required members to pay annual fees.

Revitalization

In the mid-20th century, several trends converged to improve water quality and expand recreational access within the Study Area. The economy began to shift and commercial and industrial activity along the Delaware River began to slow. Philadelphia and Camden constructed their first sewage treatment facilities. Then, in 1961, the Delaware River Basin Commission (DRBC) was created. The DRBC is a regional agency to improve water quality and to address river planning, development, and regulation.

In Philadelphia, the city began purchasing vacant property along the river in the 1950s for redevelopment. In the early 1960s, the city announced ambitions plans for Penn's Landing including a mix of residential, commercial, and recreational uses along the waterfront. While plans for the complete build-out of the site are still under development, the project marked a notable change in approaches to waterfront use and access along the river.[56]

Water quality improvements accelerated after the passage of the Clean Water Act (CWA) in 1972. Between 1974 and 1987, improvements to wastewater treatment along the Delaware River were driven by the 1968 DRBC standards and supported by construction grant funding made available through the CWA. In the years since the passage of the CWA, the cities of Philadelphia, Camden, and Chester have made significant water

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[54] Hardy, Charles III. (2017). Fish or Foul: A History of the Delaware River Basin Through the Perspective of the American Shad, 1682 to the Present. https://www.drsfa.org/sites/default/files/attached_files/FishorFoul.pdf

[55] Kauffman Jr., Gerald J. (2010). The Delaware River Revival: Four Centuries of Historic Water Quality Change from Henry Hudson to Benjamin Franklin to JFK. http://wrc.udel.edu/wp-content/Research/The%20Delaware%20River%20Revival%20G%20J%20Kauffman%202010.pdf

[56] Gottlieb, Dylan. (2015). Penn's Landing. https://philadelphiaencyclopedia.org/essays/penns-landing/

infrastructure investments. They upgraded their wastewater treatment plants, consolidated some combined sewers, implemented solids/floatables control initiatives during wet weather, and implemented green infrastructure. By 1987, average oxygen levels in the river at Philadelphia reached fishable water quality standards for the first time since the 1940s. Water quality continued to improve through the 1990s and shad and bass returned to the river.[57]

At the same time, investments to expand recreation access in the Study Area accelerated after the establishment of Pennsylvania's Coastal Resource Management Program. Authorized under the Coastal Zone Management Act (CZMA) of 1972, the program seeks to protect natural resources and manage complex resource needs in Pennsylvania's two coastal areas. With funding from the National Oceanic and Atmospheric Administration (NOAA), the program provides annual grants to governments, nonprofit organizations, and educational institutions for projects that improve water quality, enhance public enjoyment of and access to coastal resources, and mitigate the adverse impacts of stormwater runoff and nonpoint source pollution.[58] By 1997, Philadelphia had 11 publicly owned access sites along the Delaware River. These public access sites supported a range of recreational activities, including fishing, boating, dining and nightlife.[59]

The Philadelphia region continues to show support for a recreational river. In a 2012 study conducted by researchers at Drexel University, people were observed recreating at three separate sites along the Delaware River within Philadelphia: at Pleasant Hill Park, Pennypack Park, and Frankford Arsenal. People were observed jet-skiing, kayaking, boating, fishing, wading in water, and even swimming.[60] Local non-profit organizations continue to offer new recreational resources and assess the demand for expanded river recreation in the Philadelphia region.[61]

Figure 17: DRWC Programming at Penn's Landing circa September 2016

[57] Kauffman Jr., Gerald J. (2010). The Delaware River Revival: Four Centuries of Historic Water Quality Change from Henry Hudson to Benjamin Franklin to JFK. http://wrc.udel.edu/wp-content/Research/The%20Delaware%20River%20Revival%20G%20J%20Kauffman%202010.pdf

[58] Delaware Valley Regional Planning Commission (DVRPC). Coastal Zone Management. https://www.dvrpc.org/waterquality/coastalzonemanagement/

[59] Delaware Valley Regional Planning Commission (DVRPC). (1997). Planning for Public Access to Pennsylvania's Coasts an Inventory of Existing Conditions. https://www.dvrpc.org/reports/98031.pdf

[60] Sunger, Neha et. al,. (2012) Recreational Use Assessment of Water-Based Activities, Using Time-Lapse Construction Cameras. https://www.nature.com/articles/jes20124

[61] American Water Resources Association of Philadelphia (AWRA Philadelphia). (2010). Recreational User Demand Analysis. http://awra-pmas.memberlodge.org/event-94872

The Delaware River Waterfront Corporation (DRWC) has plans to develop a six-mile length of Philadelphia's Delaware River waterfront into a destination for residents and tourists. DRWC was formed in 2009 to direct development along the Delaware River from Oregon to Allegheny Avenues including Penn's Landing. Central to their mission is the design, development, and programming of public amenities and spaces.[62] Through DRWC and other programming efforts, Philadelphia residents and visitors can now participate in on-water activities at the Independence Seaport Museum, floating fitness classes and events offered by Aqua Vida, annual tubing events, and other recreational activities.

Current State of Recreation

The project team conducted extensive research to develop an inventory of current recreation access sites. The first step was to aggregate existing lists of recreation locations published by government agencies and non-profits. These included lists developed by the Delaware River Basin Commission, the New Jersey Department of Environmental Protection, the Pennsylvania Fish and Boat Commission, and the Pennsylvania Environmental Council (www.tidaltrail.org). The second step was to conduct a desktop analysis of visible boat launches, docks, piers, and beaches using Google Earth. The third step was to search social media for posts on water-based recreation in the Study Area. The fourth and final step was to distribute the preliminary inventory of recreation access sites to stakeholders and incorporate their feedback.

This approach generated a list of 42 recreation access sites within the Study Area, 17 in New Jersey and 25 in Pennsylvania. For each site, the project team researched the owner, the types of recreational activities supported, and the year that recreational uses started. Since 2000, the Study Area has seen a notable

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[62] Delaware River Waterfront Corporation (DRWC). (2020). The Delaware River Waterfront Corporation. https://www.delawareriverwaterfront.com/

increase in access to water-based recreation. Ten sites became available for recreation in the last 25 years, and six became available in the last fifteen.

Table 22 shows the final inventory. It notes sites that are public with gray fill, and notes sites where bacteria monitoring has occurred with red text. While it is not a comprehensive inventory of every location where people swim, boat, or fish on the Delaware River, it does show how valuable the waters of the Delaware River have become as a recreational resource for the region. *Table 23* summarizes information about on-water programs and events provided by stakeholders.

To better understand the distribution of recreation activities in the Study Area, the project team also categorized each site based on its most immersive recreation activity. The three categories are as follows, from most immersive to least immersive:

❑ Most Immersive: Swimming, Wading, Jet Skiing, Paddle Boarding, Kayaking

❑ Moderately Immersive: Paddle Boating, Motor Boating, Sail Boating

❑ Least Immersive: Fishing

Figure 18: Map of Recreation Access Sites in the Study Area maps the recreation sites identified in the inventory and shows the recreation category for each site. Again, this map does not show every location where people swim, boat, or fish in the Study Area.

Figure 18: Map of Recreation Access Sites in the Study Area
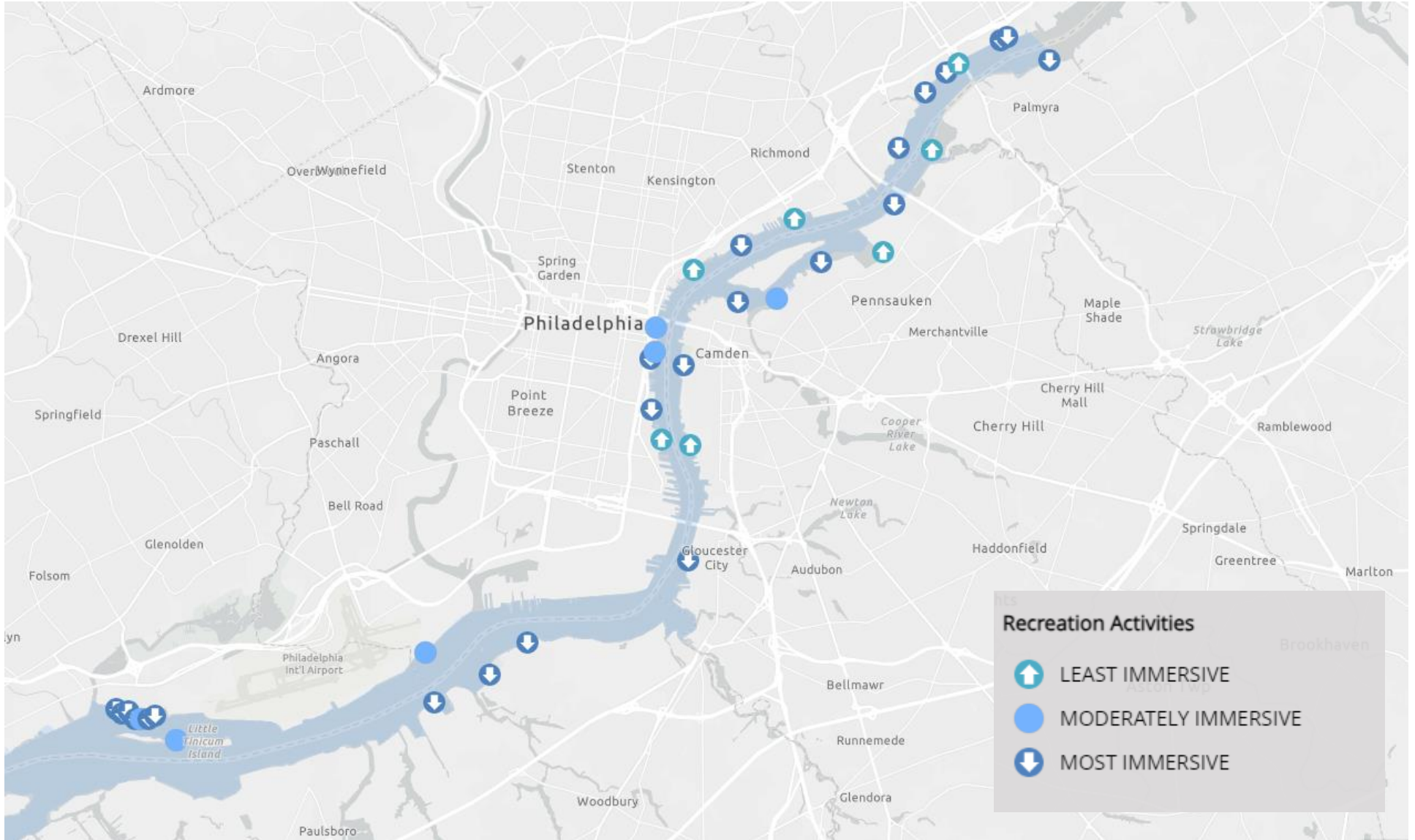
Public
Bacteria Monitoring Site

Table 22: Existing Recreation Access Locations and Activities

ID	LOCATION					RECREATION ACTIVITY		
	Name	Address	Waterbody	River Mile	Owner	Recreation Types	Description	Start Year
1	Raccoon Creek Boat Club	62 Island Rd Bridgeport, NJ 08014	Raccoon Creek	80.0	Raccoon Creek Boat Club	Jet Ski; Kayak; Motorboat; Sailboat; Fishing	Boat club at the mouth of Raccoon Creek (tributary to the Delaware)	Unknown
2	Chester City Boat Ramp	Seaport Dr & Flower St Chester Riverfront Chester, PA 19013	Delaware River	81.9	City of Chester	Jet Ski; Motorboat; Sailboat; Fishing	Paved boat ramp at Commodore Barry Bridge	1989
3	Ridley Park Boat Launch	401 S Swarthmore Ave Philadelphia, PA 19078	Darby Creek	85.5	Ridley Township	Jet Ski; Motorboat; Sailboat; Fishing	Small dock and ramp on Darby creek where creek meets the Delaware River	2017
4	John Heinz at Tinicum	8601 Lindbergh Blvd. Philadelphia, PA 19153	Darby Creek	85.5	U.S. Fish and Wildlife Service	Kayak; Seaplane; Fishing	America's First Urban Refuge was established in 1972 for the purpose of preserving, restoring, and developing the natural area known as Tinicum Marsh and promoting environmental education	1972
5	West End Boat Club	500 W 2nd St Essington, PA 19029	Delaware River	85.9	West End Boat Club	Jet Ski; Motorboat; Sailboat; Fishing	Private Yacht Club with dock and boat ramp	1898
6	Corinthian Yacht Club	300 W 2nd St Essington, PA 19029	Delaware River	86.0	Corinthian Yacht Club	Paddle Board; Kayak;	Private Yacht Club; Branch of Quaker City Yacht	1892

Delaware River Bacteria Study: Appendix 1

ID	LOCATION					RECREATION ACTIVITY		
	Name	Address	Waterbody	River Mile	Owner	Recreation Types	Description	Start Year
						Motorboat; Sailboat		
7	Governor Printz Park	Taylor Ave & W 2nd St Essington, PA 19029	Delaware River	86.1	Tinicum Township	Swim; Wading; Fishing	Small park adjacent to private boat docks and slips	1948
8	Riverside Yacht Club	95 Wanamaker Ave Essington, PA 19029	Delaware River	86.2	Private	Jet Ski; Motorboat; Sailboat	Private dock and boat ramp open to members only	1918
9	Philadelphia Sea Plane Base	2 Bartram Ave Essington, PA 19029	Delaware River	86.3	Private	Seaplane	Small dock and on-land hanger for small water planes	1939
10	Fox Grove Marina	1 Bartram Ave Essington, PA 19029	Delaware River	86.4	Private	Jet Ski; Motorboat; Sailboat	Large dock adjacent to Golden Point/Anchorage Marina; docks and boat ramps onsite	1918
11	Golden Point/Anchorage Marina	1, Jansen Ave Essington, PA 19029	Delaware River	86.5	Private	Jet Ski; Motorboat; Sailboat	Large marina with boat docks and ramps allowing access for all types of small watercraft and small yacht club; motorized and non-motorized boat launch	Unknown
12	Riverwinds Park	1000 Riverwinds Dr West Deptford, NJ 08086	Delaware River	91.1	West Deptford Township	Swim; Wading; Kayak	Boat launch, paved walking trails with river access	2002*
13	Fort Mifflin	1 Fort Mifflin Road Philadelphia, PA 19153	Delaware River	91.4	FMOD (Fort Mifflin on the Delaware)	Motorboat	Small dock for boats; may need to call prior to boating trip	1962

Delaware River Bacteria Study: Appendix 1

ID	LOCATION					RECREATION ACTIVITY		
	Name	Address	Waterbody	River Mile	Owner	Recreation Types	Description	Start Year
14	Red Bank Battlefield Park	100 Hessian Ave National Park, NJ 08063	Delaware River	91.9	Gloucester County	Swim; Wading; Kayak; Fishing	Large park open for fishing, kayaking, etc.; no motorboat launch; open Thursday-Sunday	1748
15	Rivergate Boat Ramp	1776 2nd St West Deptford, NJ 08086	Delaware River	93.1	West Deptford Township	Jet Ski; Kayak; Motorboat; Fishing	Motorized and non-motorized boat launch	Unknown
16	Westville Power Boat Association	701 Edgewater Ave Westville, NJ 08093	Big Timber Creek	95.5	Private	Jet Ski; Kayak; Motorboat; Fishing	Small private boat dock at the mouth of Timber Creek; motorized and non-motorized boat launch	1908
17	William Hargrove Marina	1210 Creek Rd Bellmawr, NJ 08031	Big Timber Creek	95.5	Private	Jet Ski; Motorboat; Sailboat	Private marina and boat yard at the mouth of the Timber Creek Tributary	1965
18	Claus Marine	101 Broadway Westville, NJ 08093	Big Timber Creek	95.5	Private	Motorboat	Small private boat dock and boat retail at the mouth of Timber Creek	Unknown
19	Gloucester City Marina	225 S King St Gloucester City, NJ 08030	Delaware River	96.1	City of Gloucester	Jet Ski; Motorboat; Sailboat; Fishing	Small Public boat dock	2004
20	Michael J Doyle Fishing Pier	12 Jackson St Camden, NJ 08104	Delaware River	98.0	CCMUA (Camden County Municipal Utilities Authority)	Fishing	Small pier dedicated to fishing with fish cleaning station and restrooms	2002
21	Pier 68	Pier 70 Blvd Philadelphia, PA 19148	Delaware River	98.2	City of Philadelphia	Fishing	Reported to be the best fishing spot on the Delaware River	2015

ID	LOCATION					RECREATION ACTIVITY		
	Name	Address	Waterbody	River Mile	Owner	Recreation Types	Description	Start Year
22	Washington Avenue Greene	S Christopher Columbus Blvd Philadelphia, PA 19147	Delaware River	98.7	DRWC (Delaware River Waterfront Corporation)	Swim; Wading; Fishing	Passive use park under the auspice of DRWC. Kayaking offered by Friends of Washington Avenue Green.	2010
23	Wiggin's Waterfront Park	2 Riverside Dr Camden, NJ 08103	Delaware River	99.4	Camden County	Jet Ski; Kayak; Motorboat	Small marina and waterfront park (no beach) adjacent to Adventure Aquarium and BB&T Pavilion	Unknown
24	Penn's Landing	301 S Christopher Columbus Blvd Philadelphia, PA 19106	Delaware River	99.5	DRWC (Delaware River Waterfront Corporation)	Paddle Board; Kayak; Paddle Boat; Sailboat	Kayaks for rent for any consumer; closes at dusk. Aqua Vida offers paddle board fitness classes, tours, yoga, and lessons	1967
25	Independence Seaport Museum	211 S. S Christopher Columbus Blvd Philadelphia, PA 19106	Delaware River	99.6	Independence Seaport Museum	Kayak; Paddle Boat	Philadelphia Maritime Museum offering on-shore and on-water programming	1960
26	Liberty Sailing Club	303 N Front St Philadelphia, PA 19106	Delaware River	99.9	Liberty Sailing Club	Sailboat	Sailing club that docks and sets off from Pier 3 marina	1967
27	Penn Treaty Park	1301 N Beach St Philadelphia, PA 19125	Delaware River	100.9	City of Philadelphia	Fishing	Park where fishing derby occurs in the summer months	1893
28	Pyne Poynt Park	1050 North 7th Street Camden, NJ 08102	Delaware River Back Channel	101.6	Camden County Parks Department	Kayak; Fishing	River access off of paved park road	1923
29	Graffiti Pier	Graffiti Pier, Philadelphia, PA 19125	Delaware River	101.8	City of Philadelphia	Wading; Fishing	Closed to the public but popular amongst fisherman and aspiring artists; all river users here are trespassing	2024

Delaware River Bacteria Study: Appendix 1

ID	LOCATION					RECREATION ACTIVITY		
	Name	Address	Waterbody	River Mile	Owner	Recreation Types	Description	Start Year
30	Boat Club	1400 N 25th St Camden, NJ 08105	Delaware River Back Channel	102.2	Farragut Sportsman's Association	Motorboat	Private Boat Dock	Unknown
31	Pulaski Park	3001 E Allegheny Ave Philadelphia, PA 19134	Delaware River	102.7	City of Philadelphia	Fishing	Small pier where fishing/biking/walking occurs	2019
32	Cramer Hill Nature Preserve	Beidman Camden, NJ 08105	Delaware River Back Channel	103.2	CCMUA (Camden County Municipal Utilities Authority)	Wading	Nature Preserve flooded normally when high rain reaches river	2019
33	Heritage Park Boardwalk	Cove Rd Pennsauken Township, NJ 08110	Delaware River Back Channel	103.5	NJ Wildlife Trails	Fishing	Nature Park (bird watching) with no access to the river; fishing has occurred but is not allowed	Unknown
34	Delair Boat Launch	471 Derousse Ave Pennsauken Township, NJ 08110	Delaware River	104.3	Pennsauken Township	Jet Ski; Motorboat; Sailboat	Small dock and ramp near confluence with Pennsauken Creek	Unknown
35	Bridesburg Outboard Club	3101 Buckius St Philadelphia, PA 19137	Delaware River	105.2	Bridesburg Outboard Club	Jet Ski; Motorboat; Sailboat	Private Yacht Club	1954
36	Palmyra Cove Nature Park	Unnamed Road Palmyra, NJ 08065	Delaware River	105.3	Burlington County Bridge Commission	Fishing	Nature Park primarily used for bird watching and walking along the river	2003
37	Frankford Arsenal	5501 Tacony St Philadelphia, PA 19137	Delaware River	106.1	City of Philadelphia	Swim; Wading; Jet Ski; Kayak; Motorboat; Sailboat; Fishing	Fishing along the shore both in the water (wading) and out of the water; kayaks set off from boat launch; motorboat launch; boat launch accessible to jet skis; wading occurs at boat launch and to the side of	Unknown

ID	LOCATION					RECREATION ACTIVITY		
	Name	Address	Waterbody	River Mile	Owner	Recreation Types	Description	Start Year
							the launch; swimming has been reported; annual	
38	Wissanoming Yacht Club	5200 Devereaux St Philadelphia, PA 19135	Delaware River	106.5	Wissanoming Yacht Club	Jet Ski; Motorboat; Sailboat	Private Yacht Club	1909
39	Lardner's Point	5202 Levick St Philadelphia, PA 19135	Delaware River	106.7	City of Philadelphia	Fishing	Fishing along the shore both in the water (wading) and out of the water sitting in chairs	2015
40	Tacony boat Launch	7071 Milnor St Philadelphia, PA 19135	Delaware River	107.5	City of Philadelphia	Jet Ski; Kayak; Motorboat; Sailboat	Currently under construction (Ramp redesign); motorized and non-motorized boat launch	Unknown
41	Quaker City Yacht Club	7101 N Delaware Ave Philadelphia, PA 19135	Delaware River	107.6	Quaker City Yacht Club	Jet Ski; Motorboat; Sailboat	Private Boat Club, organizes/runs other yacht clubs in the area	2008
42	Riverton Yacht Club	Bank Ave Riverton, NJ 08077	Delaware River	108.1	RYC (Riverton Yacht Club)	Jet Ski; Motorboat; Sailboat	Private Yacht club with dock and access to the shore; DRBC Enterococci Monitoring station	1865

Table 23: Existing Recreation Events and Programming

ID	PROGRAM				RECREATION ACTIVITY			
	Name	Location	Route Details	Activity Sponsor	Recreation Activity	Event Frequency	Average Annual Participation	Start Year
E1	Floating Stand Up Paddleboard Yoga and AcroYoga	Penn's Landing	NA	Aqua Vida and DRWC	Paddle Board	Ongoing - Summer	300-400 (for all Aquavida activities)	2014
E2	Stand Up Paddleboarding Tours	Penn's Landing	NA	Aqua Vida and DRWC	Paddle Board	Ongoing - Summer	300-400 (for all Aquavida activities)	2014
E3	Kayaking Excursions	Penn's Landing	Trips include 6-mile route from Penn's Landing to Graffiti Pier, 3-mile route from Penn's Landing to site of the Three Sisters Shipwreck, and10-mile route from Penn's Landing to Petty Island.	Independence Seaport Museum	Kayak	Ongoing	95	2018
E4	Paddle Penn's Landing	Penn's Landing	NA	Independence Seaport Museum	Kayak; Rowboat; Swan Boat	Ongoing	16376	2009
E5	Summer Camps	Independence Seaport Museum	NA	Independence Seaport Museum	Kayak; Rowboat	Ongoing - Summer	779	2010
E6	Wanut2Walnut River Challenge	Independence Seaport Museum	Route from Schuylkill Banks (along Walnut Street on the Schuylkill River) to the Independence Seaport Museum (on the Delaware River). Unload boats at South 25th and Spruce Streets.	Independence Seaport Museum	Canoe; Kayak	Ongoing - Annual Event	86	2015

ID	PROGRAM				RECREATION ACTIVITY			
	Name	Location	Route Details	Activity Sponsor	Recreation Activity	Event Frequency	Average Annual Participation	Start Year
E7	Discover the Delaware Expeditions	Independence Seaport Museum	Route from Philadelphia to Camden and on the backchannel of the Delaware River	Upstream Alliance	Canoe; Kayak	Special Event - 3 Outings	45	2019
E8	Blue Sky Funders Forum Paddle	Backchannel of the Delaware River	NA	Upstream Alliance	Kayak	Special Event - 1 Outing	20	2019
E9	Paddle with the NJDEP Commissioner	Backchannel of the Delaware River	NA	Upstream Alliance	Kayak	Special Event - 1 Outing	20	2019
E10	Paddle with the NJDEP Deputy Commissioner	Backchannel of the Delaware River	NA	Upstream Alliance	Kayak	Special Event - 1 Outing	20	2019
E11	Mayor's Paddle	Petty's Island	Route included tidal Cooper River, the Delaware River backchannel, and Petty's Island	Upstream Alliance	Kayak	Special Event - 1 Outing	32	2019
E12	Paddle for Promise Fundraiser	Petty's Island	Trips include a route from Trenton to Wilmington and a route from Wiggins Park Marina on the Camden Waterfront around Petty's Island.	UrbanPromise and the UrbanBoatworks Program	Paddle Boat	Special Event - 2 Outings	63	2018
E13	Urban BoatWorks After School Programs	Camden Shipyard & Maritime Museum	Route through the tidal portion of the Cooper River and out to the backchannel of the Delaware River	UrbanPromise and the UrbanBoatworks Program	Canoe; Kayak; Paddle Boat	Ongoing - Summer	337 (for all UrbanPromise activities)	2018

ID	PROGRAM				RECREATION ACTIVITY			
	Name	Location	Route Details	Activity Sponsor	Recreation Activity	Event Frequency	Average Annual Participation	Start Year
E14	Paddle Trips on the Tidal Cooper River and the Delaware River Backchannel	Cooper and Delaware Rivers	NA	UrbanPromise and the UrbanBoatworks Program	Paddle Boat	Ongoing - Summer, Spring, and Fall	337 (for all UrbanPromise activities)	2018
E15	RiverGuides	Cooper and Delaware Rivers	NA	UrbanPromise and the UrbanBoatworks Program	Paddle Boat	Ongoing	337 (for all UrbanPromise activities)	2018
E16	Kayak Outings	Pyne Poynt Park	Routes on the Delaware and Cooper Rivers starting from Pyne Poynt Park	Center for Aquatic Sciences at Adventure Aquarium	Kayak; Paddle Boat	Ongoing - Summer, Spring, and Fall	>400	2019
E17	William Penn Foundation Outing: Paddling for Clean Water	Pyne Poynt Park	Route from Pyne Poynt in Camden to Palmyra Cove (north of the Betsy Ross Bridge)	Upstream Alliance	Kayak	Special Event - 1 Outing	34	2019
E18	Floatopia	Pyne Poynt Park	NA	Upstream Alliance	Canoe; Kayak; Swim; Paddle Board	Special Event - 1 Outing	12	2019
E19	Trenton to Camden Paddle	Route from Trenton to Camden	NA	Upstream Alliance	Kayak	Special Event - 2 Outings	20	2017

Resilience and Equity Lens

Long-Term Resilience to Climate Change

Climate change is likely to affect recreation sites in the Study Area. It is likely to affect water quality through changes in flooding and extreme weather. The long-term success of recreation sites in the Study Area will require resilience to these long-term water quality threats. By building climate resilience into popular waterfront destinations, stakeholders can showcase creative adaptations to climate change that help maintain water quality and provide an example for other development projects in the region.[63]

Equitable Process and Outcomes

To provide the most value to the community, recreation sites should provide opportunities for safe and healthy recreation to all residents and visitors, regardless of race, ethnicity, or socioeconomic status. The US Water Alliance's "*An Equitable Water Future*" initiative suggests **three principles** to providing equitable opportunities for water recreation:

❑ Ensure all people have access to clean, safe, affordable water services;

❑ Maximize the community and economic benefits of water infrastructure investment; and

❑ Foster community resilience in the face of a changing climate.[64]

In 2019, the US Water Alliance published a community-focused water equity briefing paper for Camden, "*An Equitable Water Future: Camden*".[65] The briefing paper examines the racial disparities that drive inequality in exposure to pollution and identifies the most severe water quality challenges faced by low-income and minority populations. In Camden these include industrial pollution, groundwater vulnerability, CSOs, and lead service lines. The briefing includes several strategies for achieving an equitable water future for Camden:

❑ Build on local achievements and partnerships;

❑ Ensure long-term water quality and awareness;

[63] Penn Design, (2008), Climate Change: Impacts and Responses in the Delaware River Basin. https://planning-org-uploaded-media.s3.amazonaws.com/legacy_resources/awards/studentprojects/2009/pdf/climatechange delaware.pdf

[64] US Water Alliance (USWA). (2017). An Equitable Water Future A National Briefing Paper.http://uswateralliance.org/sites/uswateralliance.org/files/publications/uswa_waterequity_FINAL.pdf

[65] US Water Alliance (USWA). (2019). An Equitable Water Future Camden. http://www.camdencollaborative.com/uploads/6/2/8/5/6285355/_water_equity_roadmap_cam den_final_pdf.pdf

❑   Keep water rates affordable for all residents;

❑   Ensure that equity concerns are central to climate planning and investment;

❑   Build an inclusive water workforce; and

❑   Strengthen policies to evaluate cumulative environmental and equity impacts.

Ideally, any water quality improvement projects in the Study Area should include ways to maximize community involvement and education while improving water quality. They should also avoid unsustainable financial impacts on affected populations.

One important step to achieve equitable processes and outcomes is to understand the distribution of social vulnerability in the Study Area. This can be estimated using the Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (SVI). The SVI estimates which communities may be most vulnerable to external stressors (such as hazards or disease) by combining 15 different attributes measured by the US Census into a single index. These attributes include characteristics for socioeconomic status, housing, language, race, and transportation.[66]

Figure 19: Socially Vulnerable Populations by US Census Tract (CDC, 2020) shows the distribution of socially vulnerable populations in the Study Area. The higher the index value, the more vulnerable the population. Vulnerable communities in Philadelphia are most highly concentrated inland in North Philadelphia and West Philadelphia neighborhoods, further from potential recreation access sites along the Delaware River. Camden and Chester have highly vulnerable communities along the Delaware River waterfront, while Philadelphia has highly resilient communities along the Delaware River in Center City and South Philadelphia, but less resilient communities along the waterfront in Northeast Philadelphia. This may suggest that the waterfront in Philadelphia is seen as an amenity, while the waterfronts in Camden and Chester are seen as disamenities.

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[66] Centers for Disease Control (CDC). (2020). CDC Social Vulnerability Index. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

Figure 19: Socially Vulnerable Populations by US Census Tract (CDC, 2020)
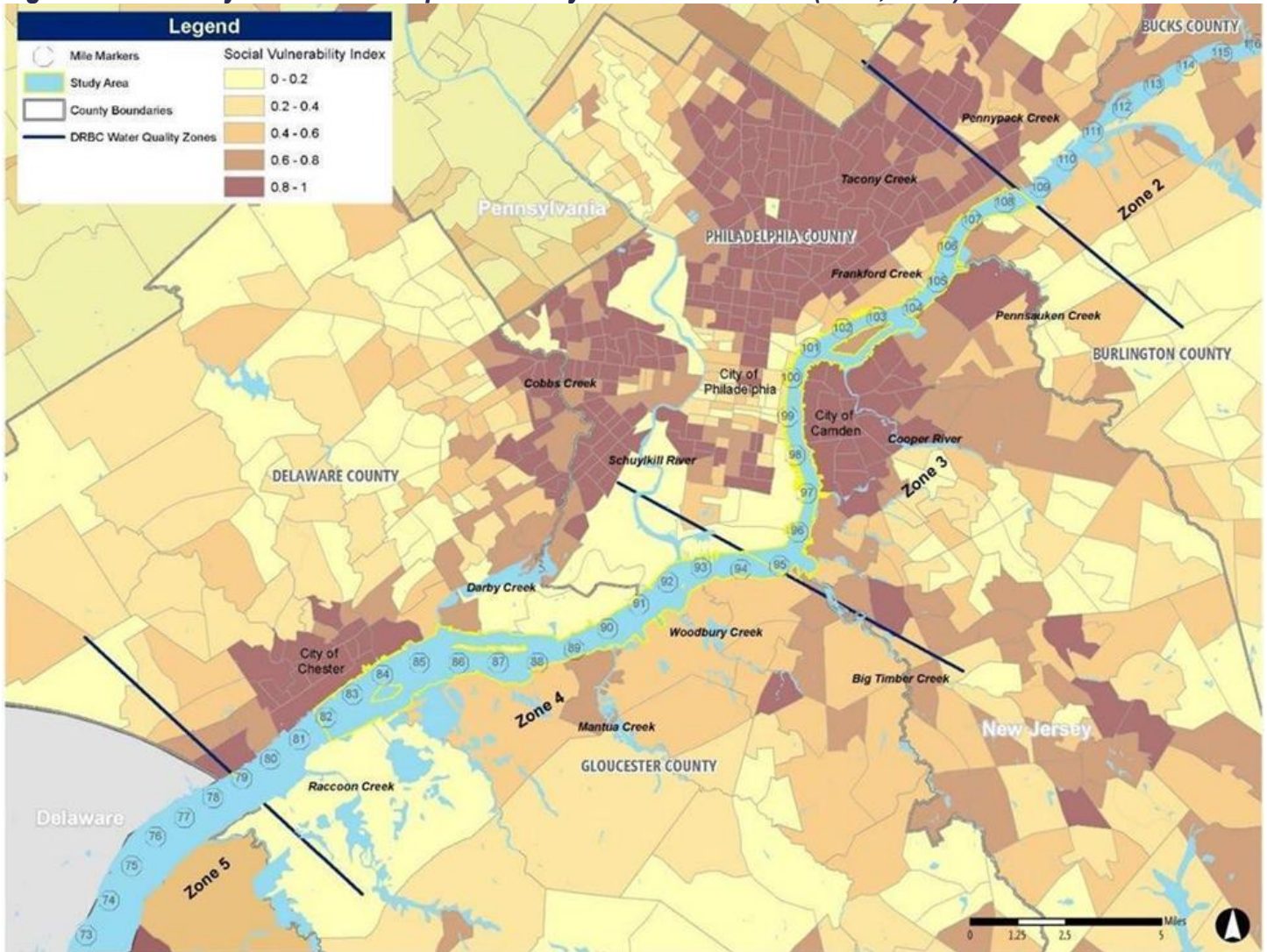
Improving water quality provides an opportunity to invest in underserved communities in the Study Area and address some of the challenges identified by the US Water Alliance. The Camden County Municipal Utilities Authority (CCMUA) has worked to provide increased riverfront access to the community by creating riverfront parks and green spaces, which also help reduce CSOs. In 2013, Camden launched the Collaborative Initiative along with several partners to maintain, restore, and enhance environmental resources in the city.[67]

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[67] Camden Collaborative Initiative (CCI). (2020). Mission. http://www.camdencollaborative.com/about.htm

The initiative has five working groups to address:

1)   Waste and recycling;

2)   Food access;

3)   Air quality;

4)   Land use and brownfields; and

5)   Stormwater

Camden created a Stormwater Management and Resource Training (SMART) working group to:

❑   Reduce neighborhood flooding;

❑   Reduce CSOs;

❑   Improve air, water, and climate quality;

❑   Develop sustainable environmental policy;

❑   Enhance economic development opportunities;

❑   Add recreational amenities and open spaces; and

❑   Beautify neighborhoods in Camden.[68]

These interrelated initiatives in Camden show the intersections between water quality, recreational access, and equity. Improving water quality is a common denominator for improving recreational access and advancing equity in the Study Area. To advance equity, projects to improve water quality must provide resources to underserved communities **and** involve invested parties in the development of the waterfront.

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[68] Camden Smart Initiative. (2020). Camden SMART Initiative. http://www.camdencollaborative.com/uploads/6/2/8/5/6285355/7_smart_steps.pdf

Appendix 2: Recreational Water Quality Criteria

The management of recreational water quality is informed by two primary regulatory structures: state environmental agencies regulate water quality in all water bodies, and state public health agencies regulate the water quality at public bathing beaches. This Appendix summarizes the project team's research on these two regulatory structures. It discusses the water quality standards enacted by Pennsylvania, New Jersey, and the DRBC; and the public bathing regulations enacted by Pennsylvania and New Jersey.

Water Quality Standards

The Clean Water Act requires that states set water quality standards for all waters in their jurisdictions. Water quality standards represent the goal for a waterbody and provide a benchmark for protecting and restoring water quality. They consist of three elements: 1) a set of designated uses that are officially recognized and protected, 2) a set of numeric and narrative criteria describing the physical, chemical, and biological conditions necessary to support the designated uses, and 3) the antidegradation policy. The water quality standards adopted by Delaware, Pennsylvania and New Jersey defer to the Delaware River Basin Commission (DRBC)'s water quality standards for the mainstem of the Delaware River.[69]

Designated Use: The designated uses must include fishing and recreational uses. All the tributary waters to the Study Area are designated for primary contact recreation, including swimming. Currently, the Study Area is designated for secondary recreation uses such as boating. However, DRBC has initiated a co-regulator process to review this designation. This study is not concerned with the appropriate designated use for the Study Area. It is assumed that the co-regulator process reviewing the use designation will result in an upgrade to primary contact recreational use.

Criteria: The EPA, DBRC, PA Department of Environmental Protection (PADEP), and New Jersey Department of Environmental Protection (NJDEP) each uses a different set of numeric criteria for primary contact recreation. In general, these criteria include one component related to the central tendency of sample values (geometric mean), and one component related to the frequency of high sample values. With the exception of PADEP, most of the criteria use two fecal indicator bacteria: Enterococci and one other. Apart from DRBC, most of the criteria assume that samples are collected at least weekly. The variability in the criteria related to central tendency is shown in *Table 24*, and the variability in the criteria related to the frequency of high sample values is shown in *Table 25*. To provide a consistent benchmark, this study uses the EPA Rec-1 criteria to evaluate whether water quality is safe for swimming.

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[69] See https://www.nj.gov/drbc/programs/quality/

Table 24: Criteria Related to Central Tendency

AGENCY	SAMPLE FREQUENCY	APPLICABILITY	MAXIMUM GEOMETRIC MEAN (CFU/100mL)		
			Fecal Coliform	*E. coli*	*Enterococci*
DRBC	As needed	-	200	NA	33
PA DEP	Five per 30-days	May 1 – Sept 30	200	NA	NA
		Oct 1 – Apr 30	2,000	NA	NA
NJ DEP	Five per 30-days	-	NA	126	35
US EPA	At least weekly	Rec-1 (36 illness / 1,000 ppl)	NA	126	35
		Rec-2 (32 illness / 1,000 ppl)	NA	100	30

Table 25: Criteria Related to High Sample Value Frequency

AGENCY	APPLICABILITY	EXCEEDANCE FREQUENCY	THRESHOLD VALUE (CFU/100ml)		
			Fecal Coliform	*E. coli*	*Enterococci*
DRBC	-	NA	NA	NA	NA
PA DEP	May 1 – Sept 30	Up to 10% of samples in 30-day period may exceed	400	NA	NA
	Oct 1 – Apr 30	NA	NA	NA	NA
NJ DEP	-	Notification is required if any sample exceeds	NA	235	104
US EPA	Rec-1	Up to 10% of samples in 30-day period may exceed	NA	410	130
	Rec-2	Up to 10% of samples in 30-day period may exceed	NA	320	110

Antidegradation: Under the Clean Water Act, one element of antidegradation policies is that they ensure that water quality in a water way protects any existing use that has occurred since 1975 when the Clean Water Act regulations went into effect.

Public Bathing Regulations

Public health regulations in Pennsylvania and New Jersey require water quality testing once a week at public beaches. This testing protocol is designed to provide baseline information without being overly burdensome. In Pennsylvania, beach water is considered contaminated if:

1. The Department determines that a substance is – or maybe – discharged into the water and may be hazardous to the health of persons using the bathing beach.
2. The *E. coli* density of a single water sample taken from the bathing beach exceeds 235 CFU/100mL.
3. The *E. coli* density in all water samples taken from the bathing beach in any 30-day period during the bathing beach's operating season exceeds a geometric mean of 126 CFU/100mL.[70]

 In New Jersey, E. coli concentrations in freshwater cannot exceed 320 CFU/100 ml, and the geometric mean cannot exceed 100 CFU/100 ml.[71]

DRBC has not developed public bathing beach regulations. While EPA is not a public health agency, the Beaches Environmental Assessment and Coastal Health (BEACH) Act amended the Clean Water Act in 2000. The BEACH Act required EPA to develop performance criteria for testing, monitoring, and notifying public users of possible coastal recreation water problems. For this reason, EPA has a role in public bathing beach monitoring but does not have the authority to set public health standards.

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[70] 28 PA Code Section 18.28.

[71] NJAC 8:26 - 7.18.

Appendix 3: Considerations for Establishing a Routine Bacteria Monitoring Program

Potential Benefits of Community Science

Ensuring long-term water quality along the 27-mile stretch of the Delaware River will take a strong foundational network of invested parties and community buy-in. Throughout the Chester, Camden, and Philadelphia community lies a vast network of individuals with the capacity to make constructive changes at a local scale by assisting with water quality initiatives. One way of ensuring community buy-in is through the promotion and development of a community science monitoring program.

Community science programs and initiatives encourage individual investment and provide the opportunity for comprehensive educational programming. Community science programs make the public a stakeholder and further the notion that their involvement is critical to ultimately improve water quality in the area. The development of community science programs in the three major areas along this 27-mile stretch of the river opens up the opportunity to have demographically representative individuals trained to be local neighborhood water scientists. Their ability to do regular monitoring of key areas puts eyes on the river and promotes community interaction and voices.

Community science programs allow the public to contribute to research efforts through volunteer monitoring. Though they are non-professionals, community members can expand the capacity to conduct routine monitoring and increase public awareness of water quality concerns. It has been found that with proper oversight and accommodations, a community science approach to biomonitoring efforts could prove cost-effective and useful in targeting, managing, and maintaining water quality information for a given water body. Examples of some community science resources and initiatives successfully working to improve water quality are summarized below.

The Water Data Collaborative

The Water Data Collaborative (WDC) is a network of academic, governmental, and non-profit groups dedicated to harnessing the power of community-based water quality monitoring data to empower communities to take action to protect water resources. WDC has supported the development of thousands of community-based organizations committed to making a difference in their nearby watershed. Some notable programs that WDC's support has inspired include; the Waterkeeper Alliance, River Network, and the Izaak Walton League.

The Directory of Community Water Science Programs (National Water Monitoring Council)

The National Water Monitoring Council maintains a directory of individual community water science programs that is accessible on their website.

River Ambassadors by the Independence Seaport Museum

The Independence Seaport Museum presents an opportunity for further development of volunteer water quality monitoring through their Citizen Science Initiatives. Many of their programmatic efforts are aimed at educating community members to support regular monitoring efforts. The Independence Seaport Museum has spent years

actively engaged in monitoring and education about the Delaware River and its water quality. Their [River Ambassadors Program](#) provides hands-on learning experiences for high school students. Students who participate learn to lead citizen science programs for the public and conduct daily water testing.

Bartram's Garden

Since 2017, Bartram's Garden has maintained a community science data collection initiative with the goal of restoring and maintaining the chemical, physical, and biological integrity of the lower Schuylkill River. They regularly test nutrient and bacteria levels to learn about the river and to help inform their public boating program. They have used their data to advocate for better water quality in the Schuylkill River. This program has evolved to include the Denkyem River Guardians program which supports interns and student volunteers.[72]

Green Ambassadors

The Green Ambassadors program serves as a great example of a Camden initiative that utilizes the power of the community to institute change and may have the capacity to support water quality monitoring efforts going forward.

The purpose of the Green Ambassadors program is to create a group of local young people who can serve as ambassadors of the environment to the people of Camden. The interns participate in hands-on work experience and classroom-style environmental education that introduces them to environmental issues, solutions, and careers. By participating in this program students work to transform the city into a greener, cleaner, safer community while experiencing meaningful employment and environmental education. [73]

Community Science Success Story: Charles River Initiative
A combined effort by the Massachusetts Water Resources Authority and Citizen Science resulted in a river that is safe for recreational boating nearly 100% of the time and safe for swimming 70% of the time. This citizen science initiative was able to determine when water quality standards were exceeding safe levels and where to focus efforts for remediation. Just four years after the start of this effort, the Lower Charles River has not received lower than a B rating on their annual report card which indicates that the water quality met swimming and boating standards most of the time for average dry and wet-weather conditions. This project constituted a massive effort to employ citizen scientists drawn from local communities to gather water quality data that assisted local, state, and federal officials in targeting resources strategically and directing efforts toward the most problematic areas. This initiative contributed to the improvement in environmental conditions. The Charles River has similar challenges to

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[72] https://www.bartramsgarden.org/water-quality-monitoring/

[73] http://www.ccmua.org/wp-content/uploads/2020/09/CCMUA-Camden-Gloucester-SIAR-09-30-20.pdf

the Delaware River that negatively impact its water quality, namely that large sections of the river have CSO discharges.

Bacteria Monitoring Methods and Tools

A comprehensive, multi-stakeholder bacterial monitoring program in the Study Area could serve two purposes:

- Understanding bacterial pollution and persistence throughout the complex environmental system represented by the Study Area, and
- Understanding bacterial sources and loading at individual sites

The program could have different elements to address each purpose. Ideally, the program would include a broad network of regulatory, academic, civic, and watershed organizations that collect and share data through a centralized database. Existing bacteria monitoring programs in the region could form the backbone of the network and support expansion to new sites and organizations.

There are different techniques and methods that could be used in the program. Certain techniques might be better implemented by certain participants. For example, monitoring techniques that require more equipment or training would likely be better matched with academic and regulatory partners.

Traditional bacteria monitoring includes several methods such as:

- Presence/absence
- Most probable number
- Direct inoculation
- Membrane filtration

All these approaches involve exposing media to a water sample to cultivate bacteria and then assessing any bacteria colonies that grow. Some of these methods are easier to conduct outside of a specialized laboratory setting.[74] EPA notes that fecal indicator bacteria are often cultured and enumerated using membrane filtration and liquid broth or using enzyme substrate tests.[75] These tests are relatively easy to perform and do not require highly trained technicians. Measuring FIB is critical in a monitoring program as it remains the regulatory standard for assessing whether waterbodies are safe for water contact recreation.

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[74] For more details, see http://cels.uri.edu/docslink/ww/BacteriaWorkshop/Guide_Bacteria_Factsheets/Bact-MethodsXIV.pdf.

[75] See chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.epa.gov/sites/default/files/2016-05/documents/tech_notes_9_dec2013_pathogens.pdf

However, more traditional water-quality testing methods to enumerate FIB cannot distinguish if contamination is coming from a human versus non-human source. Microbial Source Tracking (MST) is a DNA-based technology that enables water-quality managers to determine if humans or other animal species are the source of microbial fecal contamination in an aquatic environment. MST is used as a tool to better classify fecal contamination, particularly from nonpoint sources, once a problem is identified by zeroing in on specific DNA segments (or molecular markers) that are uniquely associated with the bacterial community inside a particular animal's digestive system. These fecal indicator bacteria and their genomic sequences are used to determine if fecal contamination is coming from either a human source or another animal (e.g., human sewage, livestock, bird droppings, or other domestic and wild animals).

Various Microbial Source Tracking (MST) Methods:

quantitative Polymerase Chain Reaction (qPCR) methods - DNA-based markers are measured using polymerase chain reaction (PCR) and real-time PCR (qPCR); these molecular methods are rapid, versatile, sensitive, precise, and allow both specific and quantitative detection of microorganisms from a variety of origins. The PCR method is sensitive enough to measure fecal pollution levels and identify the source of the pollution via amplification of different DNA genomic sequences. Researchers use qPCR methods to make millions of copies of highly diluted fecal bacterial host-associated target genes found in a contaminated water sample to determine if a particular pollution source is present and at what level. MST done in conjunction with routine monitoring can provide information to help guide remediation efforts in eliminating fecal pollution sources from the watershed (1) & https://sfamjournals.onlinelibrary.wiley.com/doi/full/10.1111/jam.12365

FRNA - Male-specific (F+) coliphages (FRNA) are an example of a source specific viral indicator organism that has been successfully used to identify the source of fecal contamination in surface waters (Cole and others, 2003; Griffin and others, 2000). Coliphage are viruses that infect the host bacteria *E.coli*, and their presence in the environment is directly related to the presence of the host. There are four genetic groupings of F+ specific RNA coliphages: Group I is indicative of an animal origin (such as cattle, sheep, pigs, and others); group II is indicative of a swine or human source, group III is exclusively human, and Group IV designates animal origin (predominantly birds) (Griffin and others, 2000; Osawa and others, 1981). FRNA source tracking would most likely detect contamination from recent fecal inputs though the persistence of coliphage that may vary significantly with temperature and host availability (Ravva, S.V., 2016). The U.S. Environmental Protection Agency (EPA) is currently developing water-quality criteria for coliphage as a formal fecal indicator organism for regulatory standards (EPA, 2016; EPA, 2015). Linking the host-source identifier for MST in this study to an impending regulatory indicator that will be routinely sampled will add value, in terms of potential sources and loads, to the results obtained by monitoring efforts in the future. (3)

   a) Although the coliphage method is highly sensitive, it is limited to four groups of animals that are only typically associated with types of mammals (Groups I-III) and birds (Groups I and IV). However, reference standards from samples collected along the shore will assist in matching the wildlife to the proper

grouping. Additionally, host-associated genetic marker (*Bacteroides*) analyses will also be conducted on about 1/3 of samples.

b) Further, the multiple-lines-of-evidence gained from the chemical and isotope analyses will aid in determining relative host contributions. When analyzed together; MST, stable isotope, and FIB data, along with ancillary data such as land use, locations of point sources, wildlife populations, and tidal exchange/circulation can indicate the sources of pathogens and allow us to make the best estimate of pathogen loading from each source.

Stable isotope analyses of Nitrogen (N) and Oxygen (O) (3)- Complementary data that can help refine the geographical origins of pathogens and, potentially, the relative contributions of the host-source include stable isotope analyses of nitrogen and oxygen in the inorganic forms of nitrate and ammonium. Ratios of the stable isotopes of nitrogen, 14N and 15N, can be helpful in differentiating atmospheric, wastewater, fertilizer, and pet waste sources (Abbene and others, 2010). Oxygen isotope ratios (18O and 16O) in nitrate can be useful to distinguish the nutrient source and process where ratios of nitrogen overlap. In this way, the relative contribution of commercial fertilizers, animal and septic waste, and organic nitrogen can be evaluated and used in conjunction with MST to provide stronger evidence of the "waste" component (human or animal) in complex mixtures of storm water and groundwater.

Detecting Only Live Bacteria using PCR Methods

PCR is highly recommended as a sampling protocol to detect the presence of bacteria in water samples and to distinguish between different types of microorganisms within samples. It can also be used to determine the presence of non-point pollution sources. One drawback of this methodology is that general PCR sampling methods do not discriminate between dead versus live bacteria. Intact DNA can be present although the organisms are dead. This is particularly relevant for pathogens that have gone through a municipality's treated water systems and clouds the association of PCR sampling results to human health risks which is why it is important to develop alternative techniques to monitor the live (or viable) versus non-live (or dead) bacteria differences in treated water. Rapid methods such as microscope-based viable versus dead methods do not provide sufficient specificity or sensitivity, while culture-based techniques are slow, expensive, and time-consuming.

While the process of differentiating between live versus non-live bacteria sources presents some difficulties, there have been methods that have been used with some measure of success. Currently, the most widely applied viable versus dead methods are based on staining, or on the ability of the bacteria to grow, using **BacLight**. Unfortunately, it is not possible to readily analyze mixed bacteria samples with this approach which is all but guaranteed to be present in Delaware River water samples. Another method pulls from the process used in testing pasteurized milk samples and uses **reverse transcriptase PCR that targets mRNA**. However, this method does have an issue with sensitivity. Measuring the RNA to DNA ratio is not sensitive enough to detect low levels of live bacteria in samples containing high levels of dead bacteria. For bacteria like *E. coli* where smaller doses are sufficient to cause illness in humans, a highly sensitive method that can detect up to and above the EPA's human

health standard is imperative. Another method that has been employed with success to discriminate between live and dead bacteria uses cross-linking agents such as psoralen and **ethidium monoazide (EMA)**. This method selectively permeates the cell walls of dead bacteria and irreversibly binds to chromosomal DNA. Using this methodology, PCR amplification of DNA from dead bacteria is inhibited.[76]

EMA-PCR: The potential benefits of EMA-PCR are **speed, specificity, and accuracy**. The EMA-PCR method allows for the development of quantitative assays for specific viable and dead bacteria in complex samples with mixed bacterial populations. Differentiation between viable versus dead bacteria is obtained by the binding of EMA to DNA in dead cells by photoactivation (i.e. the activation or control of a chemical reaction by light). EMA penetrates only dead cells with compromised membranes. DNA covalently bound to EMA cannot be PCR amplified. Thus, only DNA from viable cells can be detected. Comparison with standard fluorescence-based viable/dead techniques showed that the EMA-PCR has a broader dynamic range and enables quantification in mixed and complex samples. EMA-PCR offers a novel real-time PCR method for quantitative distinction between viable and dead cells with potentially very wide application.[77]

Cost Considerations for Bacteria Monitoring Program

There are many factors that can affect the overall costs of establishing and running a bacteria monitoring program. This section will outline some of those costs.

Laboratory Costs

Laboratory costs to process Fecal Indicator Bacteria (FIB) and qPCR water samples can cost approximately $100 to $350 to more than $750 per sample and is lab-dependent for pricing. University laboratories can run at lower overhead costs and provide more affordable pricing structures though take more time while private laboratories

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[76] See https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2446937/

Soejima, T., Iida, K., Qin, T., Taniai, H., Seki, M., & Yoshida, S. (2008). Method to detect only live bacteria during PCR amplification. Journal of Clinical Microbiology, 46(7), 2305–2313. doi:10.1128/jcm.02171-07

https://journals.asm.org/doi/full/10.1128/AEM.71.2.1018-1024.2005

Rudie, K., Moen, B., Dromtorp, S. M., & Holck, A. (2005). Use of Ethidium Monoazide and PCR in Combination for Quantification of Viable and Dead Cells in Complex Samples. Retrieved from https://pubmed.ncbi.nlm.nih.gov/15691961/

[77] See https://journals.asm.org/doi/full/10.1128/AEM.71.2.1018-1024.2005.

can have higher overall costs but shorter processing times. It is also possible to negotiate bulk price costs with an individual lab for larger sampling efforts or multi-year contracts. Negotiating a bulk price could save costs overall by decreasing the price per sample. When choosing a lab, it is important to consider the overall processing time for FIB and qPCR samples. Laboratories with fast turn around times should be prioritized. Some labs will store samples en masse and process them at a specific time period (i.e. once a month) to allay costs while others labs will process samples soon after they are received. Neither method will impact the overall sample results but knowing what the time constraints are for the needs of a particular MST program can aid the decision-making process when choosing a lab.

Sample Sites

The number of sampling sites chosen can depend on how well understood the water body is. For the Delaware River, there have been smaller scale sampling projects that have occurred since the early 2000s. The implications of these surveying efforts should be well understood in order to best utilize previous efforts and resources to determine the most worthwhile sites to sample. It is up to the overall sampling group to determine what factors would best define an ideal sampling site but it can include factors such as: frequency of visitors or likelihood of recreation, proximity to highly populous areas, proximity to CSOs, and ease of navigability/ability to monitor over the course of a sampling period.

Sampling Season

Ideal time periods for water quality sampling are typically late spring to summer (May to September). It is generally more expensive and less fruitful to sample a water body during a wet period versus a dry period. During a wet period, there are many sources of contamination that can make their way into the Delaware River that can impact the sampling process and lab results and make it more difficult to make conclusions about what is most impacting the sampling area. Additionally, water bodies during wet periods are less used so conclusions drawn during a wet period may not apply during a dry period. A dry period is more likely to have human activity on the water body and thus have an increased risk of exposure to possible contaminants. More confident conclusions can be drawn during a dry period about what contaminants are present, where they are coming from, and in what quantities that are adverse to human health since dry periods are more representative of the river at baseline.

Staff

Staffing can comprise the bulk of the cost for funding and maintaining a monitoring program. Even for smaller scale programs, costs in the realm of $20,000 or more are typical. Generally a project manager and a small team of individuals to procure the samples (2-4 persons) is sufficient to maintain a monitoring program during the most active periods. Backend staff requirements will typically include a data management team, which does not necessarily need to be a different team than the primary water collectors, and lab technicians. Staff who can take on simultaneous roles will save money over the lifetime of the program which can ultimately extend the sampling project. The data management team will typically compile, clean, analyze, and present a summary of the results to the project manager at specified intervals (monthly reports are standard but frequency of reporting can depend on the needs of the site program).

Logistical Considerations for Developing a Bacteria Monitoring Program

The bacteria monitoring program should be designed to answer specific questions raised following thorough analysis of available bacteria monitoring and sanitary survey results and to address a list of prioritized study goals and objectives. It is important to first understand the impairment and the associated areas, the timing and the overall conditions. Existing bacteria data should be analyzed to understand such things as:

- Magnitude and frequency of elevated bacteria concentrations and water quality criteria exceedances
- Spatial variation in bacteria concentrations and exceedances
- Temporal/time trends in bacteria concentrations and exceedances
- Flow conditions under which exceedances occur (e.g., baseflow vs. storm flow)

Communication Considerations

The Philadelphia Combined Sewer Overflow Public Notification System (CSOCast) is a pilot program that uses a watershed and wastewater conveyance system to estimate flow. The model is calibrated to real data to achieve a high level of accuracy but is only an estimate of actual conditions.

Because CSOs contain raw sewage along with large volumes of storm water and contribute pathogens, solids, debris, and toxic pollutants to receiving waters, CSOs can create significant public health and water quality concerns while serving as a source of impairment in the Delaware River and tributaries. Extending the area covered by CSOcast to include the full range of communities in the 27- mile portion of the Delaware River would help recreational users better assess when they are willing to recreate in waters that could be impacted by CSO outfalls. Development of this kind of tool should not fall to the wastewater treatment managers alone but to a partnership of the federal, regional, state and local entities.