# 2017

# RVA CLEAN WATER PLAN

Prepared for The City of Richmond's Department of Public Utilities

CITY OF RICHMOND
DEPARTMENT OF PUBLIC UTILITIES

RVA H2O
EVERY DROP COUNTS

LimnoTech
Water Environment | Scientists Engineers

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# RVA Clean Water Plan

## September 2017

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**Acronyms**

CBP – Chesapeake Bay Program

CFU – coliform forming units

CPMI – Coastal Plain macroinvertebrate index

CSO – combined sewer overflow

CSS – combined sewer system

CWA – Clean Water Act

DPU – Department of Public Utilities

EFDC - Environmental Fluid Dynamics Code

EPA – Environmental Protection Agency

GI – green infrastructure

GIS – geographic information system

LA – load allocation

LTCP – long term control plan

MGD – million gallons per day

MS4 – municipal separate storm sewer system

NPDES – national pollution discharge elimination system

PRCF - Parks, Recreation, and Community Facilities

SSO – sanitary sewer overflow

STV – statistical threshold value

SWMM – stormwater management model

TN – total Nitrogen

TP – total Phosphorus

TSS – total suspended solids

TMDL – total maximum daily load

UAA – use attainability analysis

USGS – United States Geological Service

VDCR – Virginia Department of Conservation and Recreation

VDEQ – Virginia Department of Environmental Quality

VSCI – Virginia Stream Condition Index

VPDES – Virginia Pollutant Discharge Elimination System

WWTP – wastewater treatment plant

# Executive Summary

The City of Richmond's Department of Public Utilities (DPU) manages five utilities, three of which address water and potentially influence local water resources: wastewater, stormwater, and drinking water. The wastewater utility operates the wastewater treatment plant (WWTP), which discharges treated effluent to the James River, a sanitary sewer and combined sewer collection system, pumping stations, the Hampton-McCloy Tunnel, and the Shockoe Retention Basin. The stormwater utility manages the stormwater that runs off impervious surfaces through underground storm sewer systems and open channels into the James River and its tributaries. Approximately two-thirds of the City of Richmond is served by a municipal separate storm sewer system (MS4). The drinking water utility manages the treatment plant and distribution system of water mains, pumping stations, and storage facilities that provide water to more than 500,000 customers in the city and surrounding area using water from the James River.

Historically, the three utilities were managed independently of one another, primarily driven by the fact the regulatory agencies implemented the regulations and permit requirements independently. This approach forced the City to make decisions related to compliance for each utility without being able to consider the interrelated impacts, especially on local waterways. Integration of all of the separate programs into a coordinated approach would eliminate redundant activities, be more efficient and effective addressing wet weather impacts, and improve water resources overall. USEPA has put a significant amount of effort in recent years into describing and publicizing holistic or integrated processes to protect water quality. Richmond has applied EPA's concepts to form a framework, documented in this Richmond, Virginia (RVA) Clean Water Plan, that allows the City to efficiently evaluate, manage, and implement water quality programs, work toward their goals and objectives, and culminate in a single, integrated VPDES permit that encompasses the City's wastewater, CSO, and stormwater discharges.

The James River and its tributaries drain a watershed of over 10,000 square miles. Within the City of Richmond, the James River flows for 24 miles, providing a substantial amount of waterfront. Major features in the river include Bosher's Dam, which is located just upstream of the City along the James River, and smaller dams, levees, and pipe crossings within the City. Just downstream of the City is the Presquile Wildlife Refuge, home to several species of birds and anadromous fish, including the endangered Atlantic sturgeon.

The focus of the RVA Clean Water Plan is on the portion of the James River watershed within the City's municipal boundary and on restoring and protecting the waterways in this watershed. This watershed-wide, water quality-based strategy allows the City to develop an effective and affordable management plan while also meeting regulatory requirements, and demonstrating to the public that the plan protects and improves the watershed and waterways. Richmond's Clean Water Plan includes six elements[1], which summarized here and discussed in more detail in this document.

[1] (1)Stakeholder Involvement; (2) Watershed Characterization; (3) Strategy Identification, Evaluation and Selection; (4) Program Implementation; (5) Progress Measurement; and (6) Adaptive Management

## Stakeholder Involvement

Stakeholders can represent many different groups with an interest in the watershed, including, for example, advocates for wildlife and habitat protection; boaters; residential, commercial and business interests; and environmental justice groups. The City has incorporated stakeholder involvement throughout the entire planning process to help ensure stakeholders understood the process from the outset and were part of decision-making efforts throughout the development of the plan. The City's Watershed Characterization Report includes additional discussion of the various stakeholders that have been invited to participate and/or are participating within this planning process.

The City created and initiated RVAH2O (RVAH2O.org), the name representing a citywide effort to arrive at "Cleaner Water Faster", to disseminate outreach information and facilitate communication with stakeholders. Beginning with an initial meeting in November 2014, the City has held technical meetings every 2-3 months. The City also initiated a public outreach effort, including several open houses, to lay a foundation of understanding before laddering up to the more technical conversation around watershed integration. The City's Public Outreach Plan, which includes online and offline communication strategies, has a goal of reaching 20% of the City's population in the MS4 area by 2018. Progress towards this and other goals are being measured by tracking RVAH2O Facebook and Twitter traffic, email campaign, and flier distributions.

## Watershed Characterization

Understanding existing water quality, along with the sources of pollutants or stressors that impact the City's waterbodies, are key elements for developing priority actions to address existing or potential problems and developing an effective integrated plan. Collection of data and characterization of the City's watersheds were the City's first steps towards development of the Clean Water Plan. Another key step towards was the development of a water quantity and quality modeling framework, that incorporates models for the CSO areas, the non-CSO areas (including Richmond's MS4 area), and for the James River itself. The purpose of the modeling framework was to quantify present day bacteria (*E. coli*) concentrations in the James River and to predict future bacteria concentrations under the Clean Water Plan strategies.

### Watershed Data and Features

The western and very northern portions of the City have experienced the least amount of hydrologic modification and possess the lowest intensely developed land use and most forested land cover. These more western areas also correspond with areas with higher soil infiltrative capacity. Alternatively, the eastern portion of the City corresponds with a higher intensity of developed land and industrial land use corridor as well as the City's urban core. Consequently, this area also corresponds to soils that are considered urban and tend to have less infiltration capacity and possesses a topography that includes some considerably steep slopes.

The James River and several of its tributaries [(Almond Creek, Falling Creek, Goode Creek, Powhite Creek, Reedy Creek, Bernards Creek, and Gillies Creek and Upham Brook (which is a tributary to the Chickahominy River and ultimately the James River)] have all been listed as impaired due to *E. coli* levels. The sources of bacteria in these streams within the City limits include CSOs, the MS4, the WWTP, direct discharge of urban runoff, and wildlife. Upstream sources also impact water quality in the City. Upstream sources include livestock, land application of manure, malfunctioning septic systems, illicit discharge of residential waste, other permitted waste treatment facilities. Reducing bacteria levels in these streams is consistent with the City's goal to provide safe recreational opportunities in the river.

The number of available water quality samples are biased heavily towards the James River, with little-to-no data available in tributary streams. Additionally, there is a lack of hydraulic data within the City, with the only local USGS gauges located outside the City limits. Biological samples and habitat assessments are also limited.

## Water Quality Modeling

Water quantity and quality modeling was conducted to allow for longer and continuous periods to be evaluated relative to the water quality monitoring program. The purpose of the modeling framework is to quantify present day bacteria (E. coli) loads and concentrations in the James River and to predict future bacteria loads and concentrations under the Clean Water Plan strategies. The modeling framework also allowed for the quantification of discharge flows and volumes, as well as the occurrence of CSO events.

Three models were used to achieve the modeling objectives and include:

- A watershed model, created using EPA's Stormwater Management Model (SWMM), to simulate flow and bacteria loads from contributing areas of tributaries to the James River within the greater Richmond area, as well as from Richmond's Municipal Separate Storm Sewer System (MS4), but excluding the combined sewer system.
- A collection system model, created using EPA's SWMM framework, to simulate flow and bacteria loads from the combined sewer system (CSS).
- A receiving water quality model, created using EPA's Environmental Fluid Dynamics Code (EFDC) model, which computes bacteria concentrations in the James River resulting from the various sources of bacteria to the river. The outputs of the watershed and CSS models are used as inputs to the receiving water quality model.

After the water quality modeling tools were developed and calibrated, they were jointly applied to assess water quality benefits associated with the selected strategies (described further below). Under current conditions, the model results illustrate that the James River is in violation of both the geometric mean and the statistical threshold value water quality standard criteria for some months out of the three year model simulation period, and the primary cause of a water quality criteria violation can sometimes be linked to Richmond's combined sewer overflows, while at other times it is due to upstream sources coming in from outside of the City. Background (mainly wildlife) and stormwater sources play a smaller overall role in the bacteria water quality violations. The WWTP does not contribute significantly to bacteria water quality violations.

# Strategy Identification, Evaluation & Selection

## Goals and Objectives Selection

The City implemented a multi-step process with stakeholders to form consolidated lists of overarching goals, refined goals, and objectives. Although a number of opinions and viewpoints were represented through the stakeholder process, ultimately, stakeholders achieved consensus on the overarching goal, refined goals, and objectives.

Weighting was incorporated into this process to reflect the priorities of the City and its stakeholders. This weighting process not only allowed for an understanding of how one goal or objective ranked in relation to another, it also provided information on the extent of the importance of these priorities to one other. The result of this process was a prioritization of refined goals as well as a prioritization of objectives associated with each of these goals.

The goals, objectives, and respective weights are summarized in Table ES.1.

*Table ES.1 Clean Water Plan goals and objectives with associated weights*

| Goals (with weights) | Objectives | Weights |
|---|---|---|
| 19%: Manage wastewater and stormwater to improve the water quality and water quantity of ground water and surface water. | Develop one stormwater management plan to cover the City's four watershed groupings based on the City's watershed characterization report. | 19% |
| | Reduce nitrogen, phosphorus, and sediment in discharges to achieve VPDES permit requirements (Chesapeake Bay TMDL). | 18% |
| | Reduce bacteria levels to achieve VPDES permit requirements (local TMDL and water quality standards). | 18% |
| | Reduce toxics (e.g., mercury, PAHs, PCBs), trash and other pollutants and address TMDLs for these pollutants. | 17% |
| | Develop green infrastructure, including riparian buffers, and removal of impervious surfaces on development, existing development, and redevelopment. | 27% |
| 15%: Protect and restore aquatic and terrestrial habitats to support balanced indigenous[2] communities | Restore streams to improve, restore, and enhance native ecological communities. | 25% |
| | Identify, protect, and restore critical habitats. | 36% |
| | Enhance aquatic and terrestrial habitat connectivity. | 23% |
| | Investigate, and where feasible, promote actions that might surpass regulatory requirements. | 16% |
| 14%: Engage and educate the public to share responsibility and take action on achieving healthy watersheds. | Engage and efficiently educate the public about standards, processes, and actions associated with watershed health and public health. | 25% |
| | Assist in the education of citizens about overall water quality issues, benefits of improved water quality. | 30% |
| | Support and encourage local action to improve water quality. | 24% |
| | Provide quicker public notifications of spills or pollution from regulators or other "river watchers" | 21% |
| 12%: Implement land | Protect, restore, and increase riparian buffers | 21% |

[2] The language included here was crafted based on Technical Stakeholder discussion and a resulting consensus process. For clarification, however, this refers to balanced indigenous ecological communities.

| | | |
|---|---|---|
| conservation and restoration and incorporate these into planning practices to improve water quality. | Reduce impervious surfaces | 19% |
| | Increase natural land cover with a focus on preserving, maintaining, and increasing tree canopy. | 24% |
| | Incorporate green infrastructure in new development and redevelopment | 18% |
| | Conserve lands where possible and consistent with Richmond's Comprehensive Plan | 18% |
| 11%: Create partnerships across the watersheds internal and external to the City of Richmond to maximize benefits and minimize impacts to all stakeholders | Develop and implement a source water prevention plan/strategy | 33% |
| | Establish public-private partnerships to secure funding, implement strategies and projects, and to achieve plan goals. | 40% |
| | Maintain and expand the RVAH20 group. | 27% |
| 10%: Maximize water availability through efficient management of potable, storm, and wastewater. | Reduce use of potable water for industry and irrigation. | 39% |
| | Achieve water conservation by improving the existing water conveyance system. | 30% |
| | Achieve water conservation by incentivizing upgrades to end-user water fixtures where appropriate. | 31% |
| 9%: Provide safe, accessible, and ecologically sustainable water-related recreational opportunities for all. | Improve water quality to promote safe recreation consistent with the City's Riverfront Plan. | 36% |
| | Promote ecologically sustainable management of riverfront and riparian areas. | 40% |
| | Improve river and waterfront access for recreation. | 24% |
| 9%: Work collaboratively to gather consistent high-quality data to characterize the status and trends of water resources and to gauge the effectiveness of restoration efforts. | Conduct water quality and biological monitoring | 28% |
| | Provide timely water quality information. | 19% |
| | Collaborate with citizens and local/state agencies for coordinated monitoring. | 23% |
| | Utilize results to target restoration efforts and convey progress. | 30% |

## Strategy Identification

The next step in this process was the identification of strategies that can be expected to achieve the previously identified goals and objectives. Strategies were defined as activities, actions, or items that will help meet goals and objectives.

The first step in brainstorming potential strategies included a workshop for DPU staff involved in stormwater, wastewater, and CSO-related projects. Because the Clean Water Plan would be implemented during the next VPDES permit cycle (2018 - 2023), staff compiled a list of projects that had been identified or proposed to meet various programmatic needs and could be implemented over that period. Because many of these projects impact small-scale areas, these City projects were "rolled up" to a strategy scale where necessary.

In addition to these DPU projects, stakeholders were also asked to submit suggestions for strategies that they felt would achieve the agreed upon goals and objectives. The Clean Water Plan development team created a synthesized set of draft strategies that consolidated ideas put forth by both stakeholders and DPU staff.

Once the draft set of strategies was identified, it was important to determine if these strategies were feasible. Because DPU is ultimately responsible for implementation of this program, the feasibility of strategies was defined as efforts that DPU has the authority to implement.

Final draft strategies and supporting actions were presented to stakeholders who were given the opportunity to edit them further. Supporting actions include efforts that may broaden the main strategy, add specificity on how a strategy could be implemented, or identify additional resources and data needs to fully implement the main strategy. Each of the strategies referenced in the remainder of the Clean Water Plan are considered to be "feasible" and agreed upon by the Technical Stakeholder group (Table ES.2).

*Table ES.2. Strategies and associated details*

| Strategy | Strategy Details |
|---|---|
| **Riparian Areas** | Replace or restore 10 acres of riparian buffers according to state guidance.<br>• In MS4 and/or CSS area<br>• Evaluate opportunities for inclusion of access points to waterbody for recreational activities |
| **Green Infrastructure in MS4** | Install or retrofit GI draining 104 acres of impervious surfaces, including efforts such as:<br>• 30 acres on DPU property<br>• 18 acres on City-owned vacant properties<br>• 20 acres on Parks department property (one playground/park per year, cemetery roadways, impervious to pervious area in park properties, vacant properties)<br>• Install 100 trees in tree boxes (e.g., Filtera-type practices); 30 acres total drained to this practice<br>• Retrofit 4 DPU stormwater BMPs (e.g., dry ponds to more efficient BMPs), draining at least 6 acres of impervious surface |
| **Green Infrastructure in CSS** | Install or retrofit GI draining 18 acres of impervious surfaces, including efforts such as:<br>• 6 acres on DPU property<br>• 2 acres on City-owned vacant properties<br>• 2 acres on Parks department property (one playground/park per year, cemetery roadways, impervious to pervious area in park properties, vacant properties)<br>• Install 24 trees in tree boxes (e.g., Filtera-type practices); 8 acres total drained to this practice |
| **Stream Restoration** | Restore 2,500 linear feet of stream:<br>• Through removal of concrete channels, repair of incised banks, etc.<br>• In MS4 and/or CSS area<br>• Evaluate opportunities for inclusion of access points to waterbody for recreational activities |
| **Natives/Invasives** | Use 80% native plants in new landscaping at public facilities by 2023. |
| **Trees** | • Increase tree canopy on City property by 5% (80 acres added)<br>• Protect existing tree canopy by following maintenance addressed in the Tree Planting Master Plan |
| **Land Conservation** | Place an additional 10 acres under conservation easement, prioritizing conservation of land that creates connected green corridors.<br>• Evaluate opportunities for inclusion of access points to waterbody for recreational |

| | |
|---|---|
| | activities |
| **Water Conservation** | Reduce water consumption by 10% through implementation of new water conservation technologies and promotion of water conservation efforts, including:<br>• Installing water-efficient fixtures as a policy by 2023 in all new public facility construction<br>• Implementing incentive programs<br>• Encouraging water conservation on City properties |
| **Pollution Identification and Reduction** | Reduce contribution of pollutants to the MS4 through:<br>• Conducting at least one special study per year in hot spot areas to identify illicit discharges/connections. (Studies will meet the criteria necessary to achieve Bay TMDL pollutant reduction requirements. Assume that, over five years, three of these studies will result in pollutant reductions that meet Bay TMDL requirements.)<br>• Collecting data associated with non-structural BMPs to facilitate quantification of pollutant reduction (e.g., storm drain clean-outs, pet waste stations, street sweeping) |
| **CSS Infrastructure** | LTCP projects, including:<br>• Installing wet weather interceptor to convey more flow to the WWTP<br>• Increasing WWT to 300 MGD at the treatment plant<br>• Expanding secondary treatment at the WWTP to 85 MGD<br>• Expanding Shockoe retention basin by 15 MG to capture more overflow<br>• Disinfecting overflow at Shockoe retention basin (wet weather disinfection facility)<br>*Note that that the modeling framework will be applied during the summer and fall of 2017 to evaluate alternative CSS reduction projects that may provide similar benefits to the LTCP projects, but at a reduced cost.* |

## Strategy Evaluation

Once strategies were drafted, an analysis was needed to determine which ones would be best for implementation. There are multiple factors at play that influence the selection of strategies. A strategy may do well with one factor, such as permit-related pollutant reductions, but not so well with others, like cost. As a result, the analysis of the various factors did not result in a clear and decisive outcome of one strategy that performed the best across all factors. What the strategy evaluation did determine was that all of the "pieces of the puzzle" needed to be evaluated collectively to achieve a complete picture of how well strategies achieve specific goals (Figure ES.1).


*Figure ES.1. Puzzle piece conceptual model demonstrating how various factors fit together to inform the decision making process*

An Excel-based strategy scoring calculator was developed to compare the various strategies proposed through this stakeholder process. This tool helped in the decision-making process by allowing the City and stakeholders to evaluate various alternatives by assigning scores to the alternative strategies.

The methodology used for this scoring calculator is a multi-objective decision analysis (MODA). A set of metrics was developed that includes a method of measurement. At least one metric was identified for each objective.

Multiple "puzzle pieces", or factors, were taken into consideration in the analysis of strategies (Figure ES.1). The **Permit** puzzle piece represents the VPDES permit-related requirements that establish pollutant reduction targets by which the strategies were compared.

The **Strategy Score** "puzzle piece" involved using the calculator tool to evaluate strategy scores in several different ways. These analyses included evaluating:

- Permit-related metrics – metrics that related to total Nitrogen (TN), total Phosphorus (TP), total suspended solids (TSS) and bacteria were isolated in the calculator and scores associated with just these metrics were used to evaluate the effectiveness of strategies in reducing these pollutants of concern
- "Standardization" of strategies addressing permit-related metrics – strategies, which varied in size, were all standardized to 10 acres to compare these permit-related metrics in an "apples to apples" manner
- All metrics – including the full set of metrics associated with all of the objectives in addition to the pollutant-related metrics
- "Standardization" of all metrics – comparing how the same sized strategies (all 10 acres) address all metrics

The calculator tool was also tied to the **Strategy Cost** information. Metrics specific to pollutant reductions (e.g., pounds of pollutant removed by a strategy) were used to calculate **Cost Effectiveness**. Overall, strategy costs were then evaluated in association with **Affordability**.

Another puzzle piece, **Modeling Results,** provided the bacteria reductions associated with several strategies that were used as raw score inputs into the calculator. Modeling results also provided information pertaining to the relative nature of bacteria sources to the James River and tributaries.

After taking the evaluation process through the "Standardization of all metrics", the following top-ranked strategies resulted:

1. Riparian Area Restoration
2. Stream Restoration
3. Green Infrastructure in the CSS area
4. Green Infrastructure in the MS4

The various "pieces of the puzzle" were used to understand how to best prioritize activities for implementation. What these analyses have shown is that no one strategy consistently scores the highest or performed the best across the analyses, however, several strategies consistently performed well (a summary of the analyses are included in Table ES.3; green highlighted information depicts those that consistently score highest).

*Table ES.3. Summary of Strategy Analysis and Strategy Prioritization*

| Rank | Pollutants of Concern Metrics | Pollutants of Concern Metrics: Standardized* | All Metrics | All Metrics: Standardized* | Cost Effectiveness (TN) | Cost Effectiveness (TP) | Cost Effectiveness (TSS) | Cost Effectiveness (bacteria) |
|---|---|---|---|---|---|---|---|---|
| **1** | **CSO Infrastructure** | **Stream restoration** | **GI in MS4** | **Riparian** | **Stream restoration** | **Stream restoration** | **Stream restoration** | **CSO Infrastructure** |
| **2** | **Stream restoration** | **GI in CSS** | **Riparian** | **Stream restoration** | Water conservation | Pollution ID and reduction | **Pollution ID & reduction** | **GI in CSS** |
| **3** | **Pollution ID & reduction** | **GI in MS4** | **Stream restoration** | **GI in the CSS** | **GI in MS4** | **GI in MS4** | **GI in MS4** | **GI in MS4** |
| **4** | **GI in MS4** | **Riparian** | **CSO Infrastructure** | **GI in MS4** | **GI in CSS** | **GI in CSS** | **GI in CSS** | **Riparian** |
| **5** | **GI in CSS** | Water conservation | Water Conservation | Water Conservation | Pollution Identification | Water conservation | Water conservation | |
| **6** | **Riparian** | Trees | Trees | Land Conservation | **CSO Infrastructure** | **Riparian areas** | **Riparian areas** | |
| **7** | Trees | Pollution ID & reduction | Natives/ invasives | Natives/ invasives | **Riparian** | **CSO Infrastructure** | **CSO Infrastructure** | |
| **8** | Water Conservation | Natives / invasives | Land Conservation | Trees | Trees | Trees | Trees | |
| **9** | Natives/ invasives | Land Conservation | **GI in the CSS** | Pollution Identification | | | | |
| **10** | Land Conservation | | Pollution ID and reduction | | | | | |

*WWTP/CSO strategy cannot be evaluated on a 10-acre basis so it is not included herein

To allow for the consideration of multiple factors in determining priorities, it was determined that rather than ranking 10 strategies individually, that strategies would be grouped into one of three tiers based on effectiveness (Figure ES.2). Tier 1 includes those strategies that best address metrics associated with the pollutants of concern (total Nitrogen, TN; total Phosphorus, TP; total suspended solids, TSS; bacteria) as well as the non-pollutant related metrics. These strategies were also the most cost effective. Tier 2 also addressed pollutant and non-pollutant related metrics, but not as efficiently or cost effectively as those in the Tier 1 grouping. Tier 3 are those strategies that do not address the pollutants of concern.

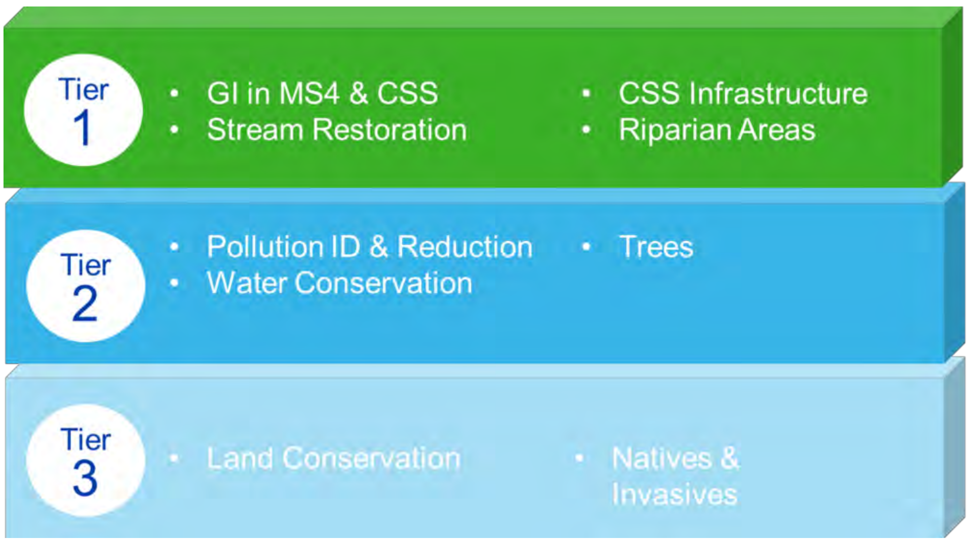



*Figure ES.2. Organization of strategies into tiers for prioritization*

It is important to note that while select strategies may be *prioritized,* it does not mean that the remaining strategies will be disregarded. Implementation of these strategies will be assessed based on additional resources available to DPU or priorities and resources available from other City departments or other partners.

It is also important to note that this analysis was done at a high level. As DPU moves toward implementation and conducts a more refined evaluation of strategies, there may be modifications to this prioritization.

## Program Implementation

An important part of this RVA Clean Water Plan is developing an approach that can help the City implement these strategies in the most efficient and cost effective manner possible. DPU will use a "Framework Planning" approach. The Framework Planning approach provides a methodology that ties together different strategies (and, subsequently, site-specific projects) and, where possible, aligns these strategies with other City or stakeholder-driven initiatives. The goal of the Framework Planning Approach is to identify and sequence a blend of activities that yield the greatest environmental benefit (as measured by identified metrics) in the most cost-effective (and affordable) manner. The Framework Planning approach includes the following elements:

1) Data and information gathering
2) Identification of potential opportunities

3) Prioritization
4) Plan development
5) Implementation

There are several important concepts that will be taken into account through implementation. For instance, it is envisioned that implementation will occur incrementally over the course of the permit cycle (e.g., 10 acres of riparian buffers will not necessarily be restored all at once or within only one project, but may be addressed through the implementation of several projects/project clusters). Flexibility is incorporated into implementation through adaptive management. If it is found that one strategy cannot be implemented in whole or in part, DPU will work to identify an alternative approach to achieving the same or similar pollutant reductions and other identified goals and objectives.

Implementation of projects, particularly those that involve stakeholders or other City departments, will require significant coordination. In addition to regular Technical Stakeholder meetings to provide updates on progress, DPU will convene a workgroup of those organizations involved in these implementation efforts. As projects are implemented, associated benefits (pollutant reductions, area treated, other metrics addressed) will be tracked as well.

## Progress Measurement

As the City's implementation moves forward, measuring progress will include determining if goals have been met, if progress has been deemed sufficient, or if changes should be made within the program to try to improve the level of progress made. Measuring progress; however, can be complex. Targets may be established at various scales (i.e., site scale, sub-watershed, watershed, city scale). Implementation actions can also include a wide range of options including structural and non-structural practices as well as practices that address various source sectors (i.e., stormwater, wastewater, non-point sources). As a result, the approach used for measuring progress under the City's program must be flexible enough to account for these variations in scale and options that will be employed to mitigate pollutants and meet the City's goals.

Measuring progress will be done in a holistic manner based on data from the City's monitoring programs, modeling efforts, and other programmatic information (e.g., implementation targets, such as miles of stream buffers restored per year or number of residents reached by outreach efforts). Each element of this process to evaluate Clean Water Plan progress will occur on a regular/annual basis over the course of the permit. Each of these elements is outlined in Table ES.4.

*Table ES.4. Monitoring activities and associated outcomes implemented under the Clean Water Plan*

| | Activities | Outcomes |
|---|---|---|
| **Water Quality Monitoring** | Instream water quality, biological (e.g., macroinvertebrates), CSO and WWTP discharge monitoring | Progress made toward pollutant reduction targets in permit |
| | | Progress toward achieving WQS (e.g., measure improvement in aquatic life designated use) |
| | | Identify sources, stressors, or pollutants of concern |
| | | Identify trends over time |
| | BMP monitoring | Effectiveness of specific BMPs or source reduction efforts |
| | | Progress toward achieving WQS (e.g., measure improvement in aquatic life designated use) |
| **Programmatic Monitoring** | Tracking strategy implementation | Progress made toward strategy implementation goals (e.g., acres of green infrastructure implemented) |
| | | Progress made in pollutant reduction through strategy implementation (e.g., pounds of TN reduced through green infrastructure implemented) |
| | | Progress made toward pollutant reduction targets identified in permit |
| **Modeling** | Receiving water, CSS, and watershed modeling and analysis | Progress made in bacteria WQS compliance |
| | | Progress made in bacteria load reduction |
| | | Progress made in reduction of CSO events or volume discharged |

## Next Steps

The RVA Clean Water Plan has resulted in a comprehensive understanding of the City's watersheds and associated water resources. The next step is to use the Clean Water Plan to develop a watershed-based VPDES permit. Watershed-based permitting has been long supported by EPA and allows multiple pollutant sources to be managed under one permit. For Richmond, these pollutant sources are CSO, wastewater, and stormwater via the MS4 and direct drainage. The Clean Water Plan provides the planning framework and strategies to manage these sources and prioritize control projects based on their improvements to local waterways. Therefore, the Clean Water Plan will be included in the VPDES permit as a source of data and provide information to be included in the "Special Condition" section related to best management practices (BMPs) to be implemented and additional monitoring to be done to track progress. The Clean Water Plan will also be included in the Permit Fact Sheet as an information source.

Once the watershed-based VPDES permit is issued to the City, next steps include implementing the projects and programs in the Clean Water Plan and conducting monitoring and modeling to measure progress towards the goals of the plan. The City will also continue to engage stakeholders to inform them of activities and associated progress towards the goals of the Plan, and solicit their input on Plan updates.

The Modeling Framework will continue to be used as needed to evaluate the water quality improvements related to the implementation of projects and strategies. Additionally, it is anticipated that the modeling framework will be applied during the summer and fall of 2017 to evaluate alternative CSS reduction projects that may provide similar benefits to the Long Term Control Plan (LTCP) projects, but at a reduced cost.

# 1. Background and Introduction

The City of Richmond's Department of Public Utilities (DPU) manages five utilities, three of which address water: wastewater, stormwater, and drinking water. As all three of these utilities can influence local water resources, such as the James River, each operates under regulations and permit requirements established to ensure protection of the environment and public health.

The Wastewater Utility was implemented to operate and maintain the wastewater treatment plant (WWTP), which discharges treated effluent to the James River (45 MGD dry weather flow and 75 MGD wet weather flow). The Utility also operates and maintains a sanitary sewer and combined sewer collection system, pumping stations, and the Hampton-McCloy Tunnel, storage capacity of 7.2 million gallons, and the Shockoe Retention Basin, a 50-million gallon reservoir used during heavy rains.

The Stormwater Utility is relatively new compared to the other utilities. It was implemented in July 2009 to manage the stormwater that runs off impervious surfaces. The Stormwater Utility also enhances public safety and health and protects property by improving the quality and decreasing the quantity of polluted stormwater runoff. Approximately two-thirds of the City of Richmond is served by a municipal separate storm sewer system (MS4). This mixture of underground storm sewer systems and open channels are separate from the sanitary sewer system.

The City of Richmond is one of the largest water producers in Virginia, with a modern plant that can treat up to 132 million gallons of water a day from the James River at the western edge of the City. The Drinking Water Utility manages the treatment plant and distribution system of water mains, pumping stations, and storage facilities that provide water to more than 200,000 customers in the city. The facility also provides water to the surrounding area through wholesale contracts with Henrico, Chesterfield, and Hanover counties. All total, this results in a facility that provides water for approximately 500,000 people.

Historically, the three utilities were managed independently of one another, primarily driven by the fact the regulations and permit requirements established by the regulatory agencies were also implemented independently. This approach forced the City to make decisions related to compliance for each utility without being able to consider the interrelated impacts. There is often overlap in these requirements and sometimes an action occurring under one regulatory program has a direct impact on another. For instance, separating a combined section of sewer leads to impacts on the separate sanitary sewer system and the storm sewer system. Integration of all of the separate programs into a coordinated approach is necessary to eliminate redundant activities and be more efficient and effective addressing wet weather impacts and improving water resources overall.

## USEPA Integrated Planning Frameworks

USEPA has put a significant amount of effort in recent years into describing and publicizing its vision of management of these separate programs through the concepts of Integrated Planning (EPA 2011, EPA 2012a), Integrated Watershed Management (EPA 1996, EPA 2008), and Watershed-based Permitting

(EPA 2007, EPA 2003). An emphasis within each of these concepts involves providing an opportunity to examine different possible ways to look at protecting water quality given very limited resources at both the City and the state level. Often these limited resources must be used to manage and implement multiple and costly regulatory requirements, such as:

- Replacing/repairing aging infrastructure;
- Developing and implementing long-term control plans (LTCPs) for combined sewer overflows (CSOs);
- Developing and implementing capacity, management, operation and maintenance programs for sanitary sewer overflows (SSOs);
- Improving peak flow management at WWTPs;
- Addressing requirements to control nutrients and emerging contaminants at the WWTP;
- Managing stormwater to mitigate flooding;
- Developing and implementing MS4 pollution prevention plans;
- Investing in treatment technologies to comply with effluent limits based on total maximum daily loads (TMDLs); and,
- Complying with Safe Drinking Water Act and/or National Pollutant Elimination Discharge System (NPDES) requirements.

All of these issues are currently of importance to the City of Richmond, or will be over time. All of these activities or requirements are rarely coordinated or considered in a holistic manner. Without coordination among these competing demands, the City's constrained resources aren't likely to achieve the maximum benefit to the utility, the public, and the environment. Too often, the need for investment (especially for wet weather controls) greatly exceeds the City's financial capacity, even over a 20-year period. As a result, there is uncertainty in prioritizing investments, and with how to create a plan that progressively moves toward meeting clean water goals.

To address these issues, Richmond is using EPA's Integrated Watershed Management and Integrated Planning frameworks for planning purposes. Because both of these have a number of consistencies between them, these approaches have been combined and organized to form a framework that allows the City to efficiently evaluate, manage, and implement water quality programs and work toward their goals and objectives (see Figure 1.1). The endpoint of this overall effort is a single, integrated VPDES permit that encompasses DPU's wastewater, CSO, and stormwater discharges.

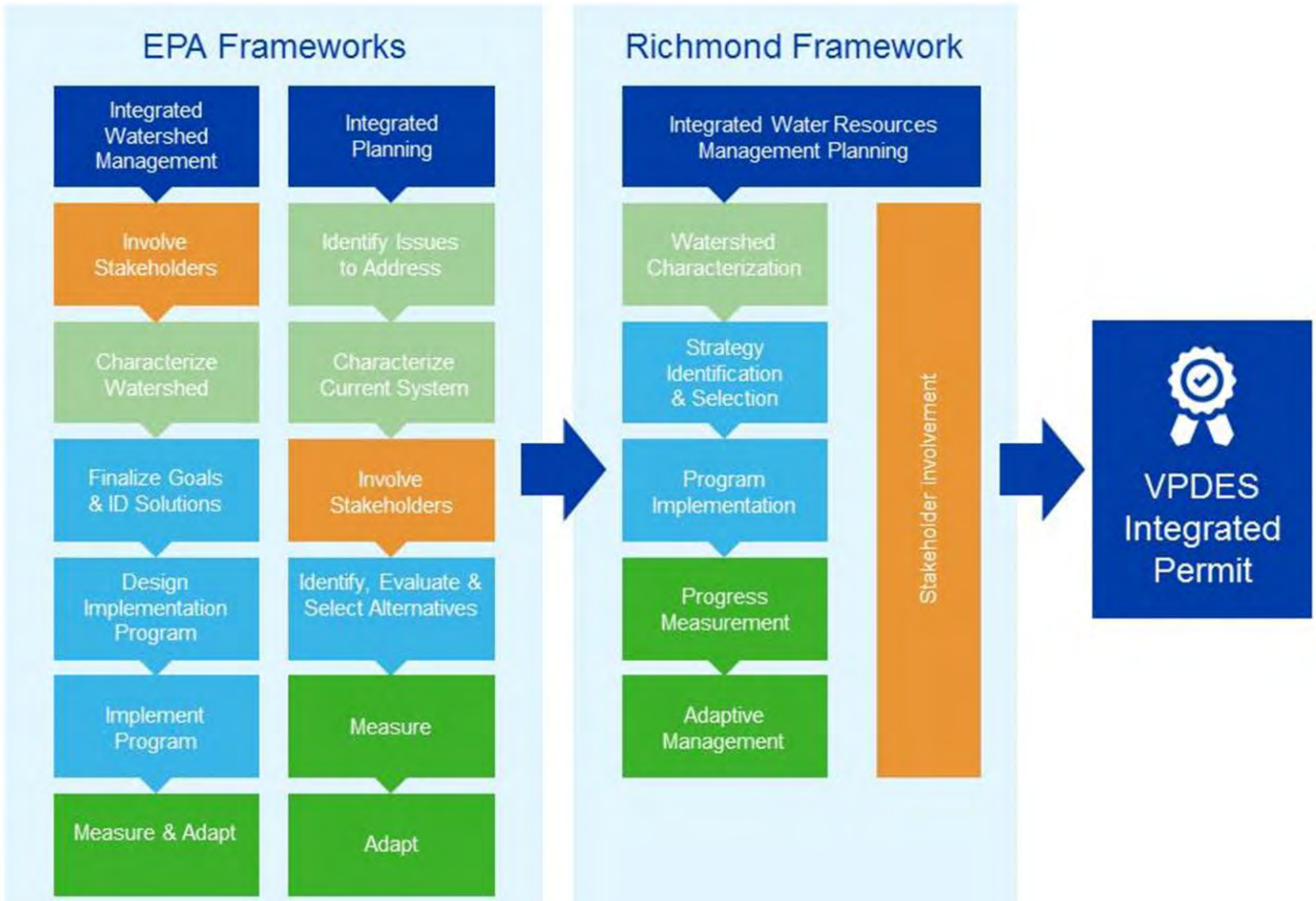



*Figure 1.1 – Demonstration of the overlap in elements between EPA's Integrated Watershed Management and Integrated Planning Approaches and how these elements have been merged to develop the framework for the Integrated Water Resources Management Plan where stakeholder involvement is a part of each step of the process.*

## Richmond's Clean Water Plan Framework

Efforts to prioritize a community's investments have traditionally tended to focus on meeting infrastructure-related goals, such as reduction in the number of CSOs. The focus of the RVA Clean Water Plan, however, is on the watershed and restoring and protecting the waterways in these watersheds. Given this focus, the Clean Water Plan is framed by water quality standards (WQS) and watershed goals rather than solely by municipal infrastructure project considerations. This watershed-wide, water quality-based strategy allows the City to develop an effective and affordable management plan while also meeting regulatory requirements and demonstrating to the public that the plan protects and improves the watershed and waterways. The integration includes the WWTP, CSO, and stormwater programs, and maintaining minimum in-stream flows. Richmond is also taking drinking water and source water protection into consideration to ensure a more comprehensive focus on overall watershed health.

The City's Department of Public Utilities began the Clean Water Planning process in March of 2014 (see Figure 1.2), with the establishment of a Technical Stakeholder Group and related outreach plan. The effort continued in January, 2015 with a watershed characterization effort that culminated in the development of a Watershed Characterization Report (Richmond DPU 2015). Work on the Clean Water Plan began in 2016, which will ultimately be used to inform the development of an integrated Virginia Pollutant Discharge Elimination System (VPDES) permit that collectively addresses DPU's discharge permit requirements. The permit application is due to VDEQ in January, 2018, with the Integrated VPDES permit expected to be reissued in June of 2018.

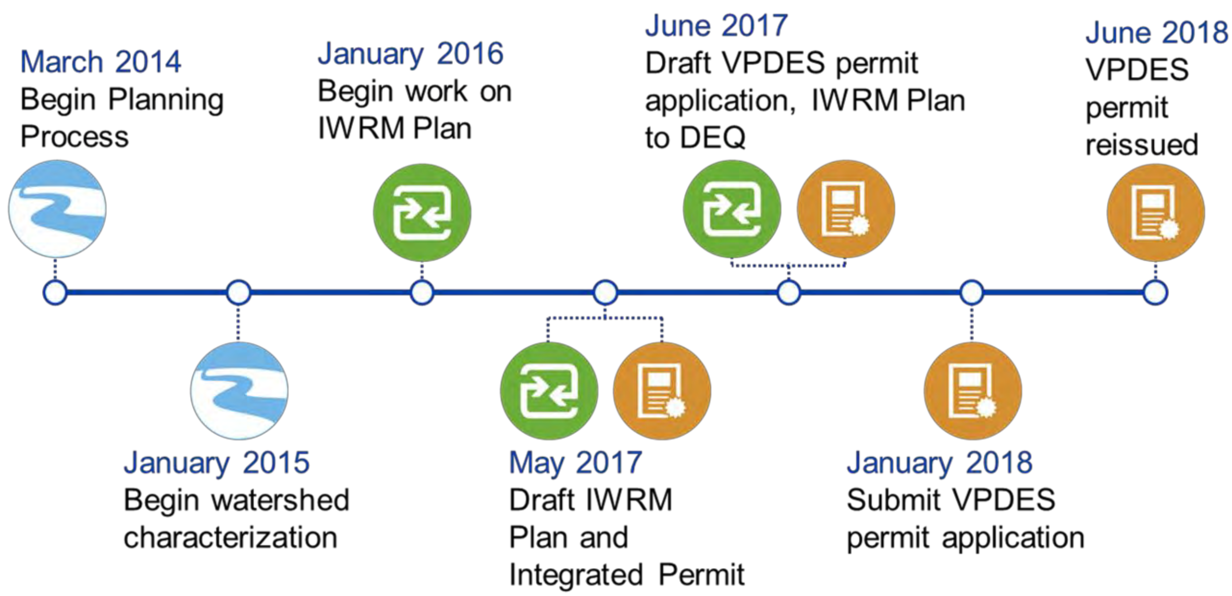



*Figure 1 .2– Richmond's schedule for the development of a Watershed Management Plan (WMP), Integrated Plan and Watershed-based Permit (WBP)*

Richmond's Clean Water Plan includes six elements, which are summarized below and discussed in more detail in the subsequent sections of this document.

## Stakeholder Involvement

DPU determined early on that community input and support would be key to the success of its Clean Water Plan as this support would facilitate development of an integrated VPDES permit as well as future implementation efforts. It was felt that this input and support could be gained by implementing a thoughtful, well-informed approach that demonstrates the Utility's commitment to improving the environment while continuing their good stewardship of their infrastructure assets and local water resources. Community support was especially important in considering priorities and options for improving and protecting the City's waters.

## Watershed Characterization

The watershed characterization process within the Clean Water Plan provides the data needed to support this process. This includes data such as monitoring related to meeting receiving water standards and goals, and characterizing receiving water conditions and sources of pollutants throughout the watershed. Existing data are compiled and, if necessary, new data are collected to provide the data needed to complete the watershed characterization. Evaluating data from a watershed perspective helps to facilitate a watershed-based approach to planning and, subsequently, implementation. Ongoing data collection will ensure the Clean Water Plan is up-to-date and accurate, and will facilitate future updates using an adaptive management approach. A beneficial outcome will be that data collected through watershed characterization efforts will serve multiple purposes. For instance the activities associated with the TMDL development and implementation will help determine appropriate targets for the Clean Water Plan.

## Strategy Identification, Evaluation, and Selection

The data collected through the watershed characterization effort serves as the basis for helping to identify and quantify problems or issues of concern within the watersheds. This helped guide the selection of goals and objectives the City and its stakeholders identified for this process. As high-level strategies to meet these goals were identified, they were incorporated into an Excel-based strategy scoring calculator that included the weighting of these goals, associated objectives, and metrics by which these strategies were measured. Other factors, such as strategy costs, cost effectiveness, and watershed and water quality modeling results, were also used to prioritize strategies.

## Program Implementation

After selection and prioritization of high-level strategies is completed, these high-level strategies (e.g., Green Infrastructure implementation in the MS4 area) will be translated into localized projects (e.g., two acres of bioretention and one acre of pervious pavement in a particular subwatershed). A "Framework Planning" approach is being used to strategically direct implementation in a way that aligns activities that yield the greatest environmental benefit in the most cost-effective manner.

## Progress Measurement

Once projects and programs have been implemented, measuring progress will be accomplished through a three-pronged approach. This will include programmatic tracking, which will involve evaluating the progress made toward strategy implementation (e.g., acres or feet of implementation, etc.) as well as the pollutant reduction calculated through this implementation. The City will also conduct water quality monitoring to evaluate progress made toward pollutant reduction targets in the permit, progress made toward achieving WQS, and trends over time. Modeling will also be used to evaluate progress made toward bacteria-related WQS, bacteria load reductions, and reduction of CSO events or volume discharged. Progress will be reported annually through VPDES permit-related reporting.

## Adaptive Management

Because the City, its waterbodies, regulatory drivers, and community needs are not static, City and stakeholder priorities may also change over time. The Clean Water Planning process incorporates flexibility to address these changing needs. This flexibility, or adaptive management, is an iterative, ongoing, learning process used to continually improve understanding of the City's programs and practices by learning from their outcomes over time.

Adaptive management will be critical for the success of Richmond's Clean Water Plan as new data collected through the course of this effort will be used to refine and modify the Plan so it is up-to-date and accurate.

# 2. Stakeholder Involvement

From the very beginning, the City knew stakeholder involvement would be a key component of developing and implementing an effective and successful integrated approach to the City's water resources management. While building partnerships is identified as one "Step" in both EPA's Integrated Watershed Management and Integrated Planning processes, the City has actually incorporated stakeholder involvement throughout the entire planning process to help ensure stakeholders understood the process from the very beginning and were part of decision-making efforts along the way. It also helped ensure that stakeholders had a voice to convey any concerns they may have or encourage sharing of data and information that could be helpful with planning, and subsequently, implementation efforts.

To aid in this communication effort as well as in the dissemination of outreach information, DPU created and initiated RVAH2O (RVAH2O.org). The name was formed from "RVA," which is popular shorthand for Richmond, Virginia, and "H2O," which is the chemical formula for water. Together, the name represents a citywide effort to arrive at "Cleaner Water Faster."

The RVAH2O.org website educates the community about ways to keep the City's waterways pollution-free and the importance of integrating drinking water, wastewater, and stormwater under one watershed management program. It is all water. The website is also used to share information conveyed during Technical Stakeholder and public meetings discussing the Clean Water Planning process. RVAH2O has also been expanded into a Facebook page and Twitter feed to reach a larger public audience. The logo and its clean water messages appear on billboards, bumper stickers, community meeting handouts, school bulletin boards, and on DPU booths and water stations at community events and water-related festivals.

A detailed discussion of each of the elements of the stakeholder involvement process is included below, as well as further detail surrounding public outreach.

## Stakeholder Identification

Stakeholders can represent many different groups with an interest in the watershed, including, for example, advocates for wildlife and habitat protection; boaters; residential, commercial and business interests; and environmental justice groups. As discussed in the City's Watershed Characterization Report, an initial step in this process was the identification of groups or individuals that would be interested in being more involved in the City's water future and/or would potentially bring data, information, and insight to the table that could assist the City with reviewing the problems and looking at the relative contribution of all sources and stressors on the watershed.

The City reached out to a variety of stakeholders in and surrounding the City, including environmental advocates, recreational users of the James River, property owners, businesses, and state and local governmental agencies and representatives.

The initial stages of the stakeholder involvement process resulted in categorizing these participants into several groups based on expected technical knowledge and perceived level of interest and involvement. As a result, a Technical Workgroup was formed to provide technical insight and feedback on the Clean Water Planning process. This group included representatives of groups such as:

- Chesapeake Bay Foundation
- James River Association & Riverkeepers
- The Nature Conservancy
- Middle James Round Table
- Alliance for the Chesapeake Bay
- Virginia Department of Environmental Quality (VDEQ)
- Virginia Department of Health (VDH)
- City Department of Public Works (DPW)
- The Reedy Creek Coalition
- Fall of the James Scenic River Group
- James River Park System
- Virginia Commonwealth University (VCU)
- Richmond Regional Planning District Commission
- James River Outdoor Coalition
- Capital Region Land Conservancy
- Marine Resources Commission
- University of Richmond
- American Water
- Tree Stewards of Richmond
- The Counties of Hanover, Chesterfield & Henrico (reached through the Planning District Commission)

Additionally, a special interest and public stakeholder group was identified with participants anticipated to have a high level of involvement. This group included representatives of organizations such as:

- Friends of James River Park
- Sierra Club – Falls of the James Group
- Home Builders Association of Virginia
- Hispanic Chamber of Commerce
- Richmond City Council Districts
- Richmond Paddle Sports and other sports organizations

Participants in this special interest and public stakeholder group with an anticipated lower level of involvement included representatives from organizations such as:

- Richmond Audubon Society
- James River Advisory Committee
- Retail Merchants Associations
- Tenant, Civic and Neighborhood Associations

The City's Watershed Characterization Report includes additional discussion of the various stakeholders that have been invited to participate and/or are participating within this planning process.

Once stakeholders were identified, kick-off meetings were held in November 2014 to speak with the technical stakeholders and the special interest/non-technical stakeholder group. A meeting schedule was developed early on to ensure consistent communication with the technical stakeholders on a quarterly basis and with the special interest/public stakeholder group approximately every six months.

## Technical Stakeholder Meetings

Since the initial meetings in November 2014, technical stakeholder meetings have been held regularly every two to three months and have accomplished several specific objectives including: identifying issues of concern, setting goals, developing indicators to track progress, and conducting public outreach. Information on the Technical Stakeholder meetings (including when and what information was discussed at each meeting) can be found on the RVAH2O.org website under meetings.

The activities of the Technical Stakeholder workgroup have included:

- Determining the overarching goal for the City of Richmond's watershed plan
- Identifying and weighting goals and multiple objectives and strategies
- Meeting bi-monthly to shape the plan's contents and discuss outstanding issues
- Forming partnership agreements that will aid in achieving cleaner water faster

The majority of technical stakeholders have found the meetings to be important opportunities to learn about and discuss watershed issues, and have expressed interest in continuing to meet regularly once the Plan and Permit are in place.

## Public Meetings

At the outset of this initiative, a survey of the Richmond public was conducted to establish a baseline of knowledge about Richmond's water systems. It was determined that Richmond residents had limited knowledge about water sources, water quality and their role in helping to keep waterways clean and litter-free. Using RVAH2O as a platform, 2015 was the start of a public outreach effort to lay a foundation of understanding before laddering up to the more technical conversation around watershed integration.

First, a flier was created to illustrate how a household contributes to stormwater pollution. This was widely distributed at libraries, schools, neighborhood meetings, and public events.

Then, a series of posters were created to be put up around the City, each with a theme related to its location: 1) Pet waste poster mounted at dog parks and veterinary offices; 2) Automotive oil poster mounted at service stations and oil-changing stations; 3) Cigarette butt poster mounted at workplaces where people take smoking breaks, etc. In all, six themed posters were created.

An initial public meeting was held in October of 2014. This provided an opportunity for a high-level introduction to the City's regulatory requirements, what has been done to date to address water quality in the City, and the City's goals moving forward. On June 9, 2015, an open house was held at the Science Museum of Virginia to provide opportunity for the general public to be introduced to the City's Integrated Planning process (Figure 2.1). Five different stations were set up, each at which a different topic area was discussed. There were over 50 attendees recorded from the general public. Each station was staffed with members of the RVAH2O team or other DPU staff. This provided a one on one opportunity for the public to ask questions about each station including:

- The watersheds

- The stormwater, sanitary, and wastewater collection systems
- Stormwater issues
- The James River and associated creeks and streams
- Outreach and educational information

A station was also set up at which the public could sit down and anonymously submit questions and comments for the RVAH2O team.

In general, it was observed that attendees expressed knowing little about the river's needs coming in, but by the end, their post-it note comments and comment cards seemed to demonstrate that they had obtained a real grasp of the needs and concerns for water quality in Richmond.

This public open house was deemed a success and in the following year, August 2016 and September 2016, two more open houses were held in local parks (Figure 2.2). Attendance at the first 2016 event was 52; at the second, due to a storm, attendance was less than 10. However, this format for sharing information as the watershed program evolves will continue.


*Figure 2.1. Flier advertising the June 9, 2015 community open house*

## Conducting Public Outreach

While technical stakeholders have been involved during each step of the Clean Water Planning process, the City also recognized the need to conduct a wider public outreach effort related to the City's water resources. The RVAH2O initiative also aims to further educate and identify ways in which the community can be involved in clean water management. The benefits of the effort are two-fold: to help ensure a wider dissemination of information associated with the RVAH2O initiative (integrated water resources planning) as well as to conduct outreach and education related to the City's various water related programs.

Outreach and involvement in association with the Clean Water Planning process are also closely coordinated and consistent with other DPU and City communication programs. For instance, a plan for public outreach and communication will be incorporated as part of the monitoring plan, to achieve the objective of making the monitoring data (historical and current) available to the public. This plan includes a web-based component as well as other print media.

Both online and offline communication strategies make up a Public Outreach Plan that builds awareness and encourages support for the goals of RVAH2O. This effort has also been designed to meet the requirement of the City's VPDES MS4 permit, which is to reach 20% of the City's population in the MS4 area by 2018.

DPU, using RVAH2O as the communications platform, has invited the public to numerous events and shared its water quality message widely through email, social media, the RVAH2O website, billboards, fliers, school education and community meetings. For example:

- Thousands of Richmonders and others were able to fuel themselves with public water at the September 2015 Union Cycliste Internationale (UCI) bike competitions, where eight drinking stations were hooked up to fire hydrants and draped with RVAH2O logo and information.
- At the 2016 Earth Day and Riverrock festivals, DPU employees at an RVAH2O booth greeted nearly 1,100 people personally, passed out literature, and held drawings for rain barrels.
- The first annual Storm Drain Art Contest attracted several dozen entries and drove hundreds of visitors to RVAH2O social media pages; over 450 people voted for their favorite Storm Drain. Each drain selected flows directly into the James River; one of the requirements was that each drain feature a stormwater/pollution message.
    - This contest's art submissions were showcased at Richmond City Hall for one month.
    - The contest received numerous online and print articles, with front page news in the Richmond Times Dispatch on two occasions when the City's mayor toured the drains in July 2016.
    - The project won a national award by the National Association of Clean Water Agencies and Richmond local ad club award, furthering the news coverage.

*Figure 2.2. Flier for Watershed Open House public meeting held at a local park*

  - A "How-To" flier was created to assist other U.S. municipalities in setting up their own storm drain projects. So far, approximately two dozen communities have requested guidance.
  - The 2017 RVAH2O Storm Drain Art Project has already launched, and storm drains for this annual promotional effort are earmarked through 2020.
- RVAH2O took its message to neighborhood associations and universities, engaging students at VCU and the University of Richmond, some of whom have joined outreach causes.
- RVAH2O representatives have met with the James River Association to help them further their outreach efforts with a storm drain stencil art project. It's anticipated that more collaboration with special interest groups will take place in the future.
- A billboard campaign took place throughout the summer of 2016 in both English and Spanish and will be repeated in 2017 and include bus wraps on routes passing through under-served neighborhoods.
- 100 sets of "James River Pollution and Water Conservation" messages have been printed for bulletin boards in elementary school classes, libraries and community centers.

## The Future of Public Outreach

The goals associated with stakeholder involvement and transparency to the public are critical and have been incorporated into this process to ameliorate concerns regarding:

- If progress is being made;
- If limited resources are being expended wisely;
- If benefits are being realized; and,
- If adjustments are being made based on what has been learned.

With a foundation of knowledge about the importance of keeping Richmond's waterways litter-free, Richmond's water sources and systems, and the public's role and responsibility in assuring a cleaner water future, DPU will turn its attention to bringing Richmonders up to speed on the Clean Water Planning process. In late 2017, it will focus more attention on business and civic leaders as well as on partnerships with the technical stakeholders to deliver a unified message to the public.

Tracking process of outreach efforts included (depicted in Figure 2.3):

- Email campaign to "public" attendees
- Flier distributed at Riverrock 2015
- Social media campaign drove up on-line engagement

On Facebook:

- RVAH2O Facebook page likes increased by 8%
- RVAH2O received at least 25 direct event responses and reached 4,967 people through Facebook Ads –on less than a $70 budget

- 45 people joined the event through Facebook (organic and paid)

On Twitter:

- Tweet mentions were up 28.6%.
- RVAH2O followers increased by 14.85%.

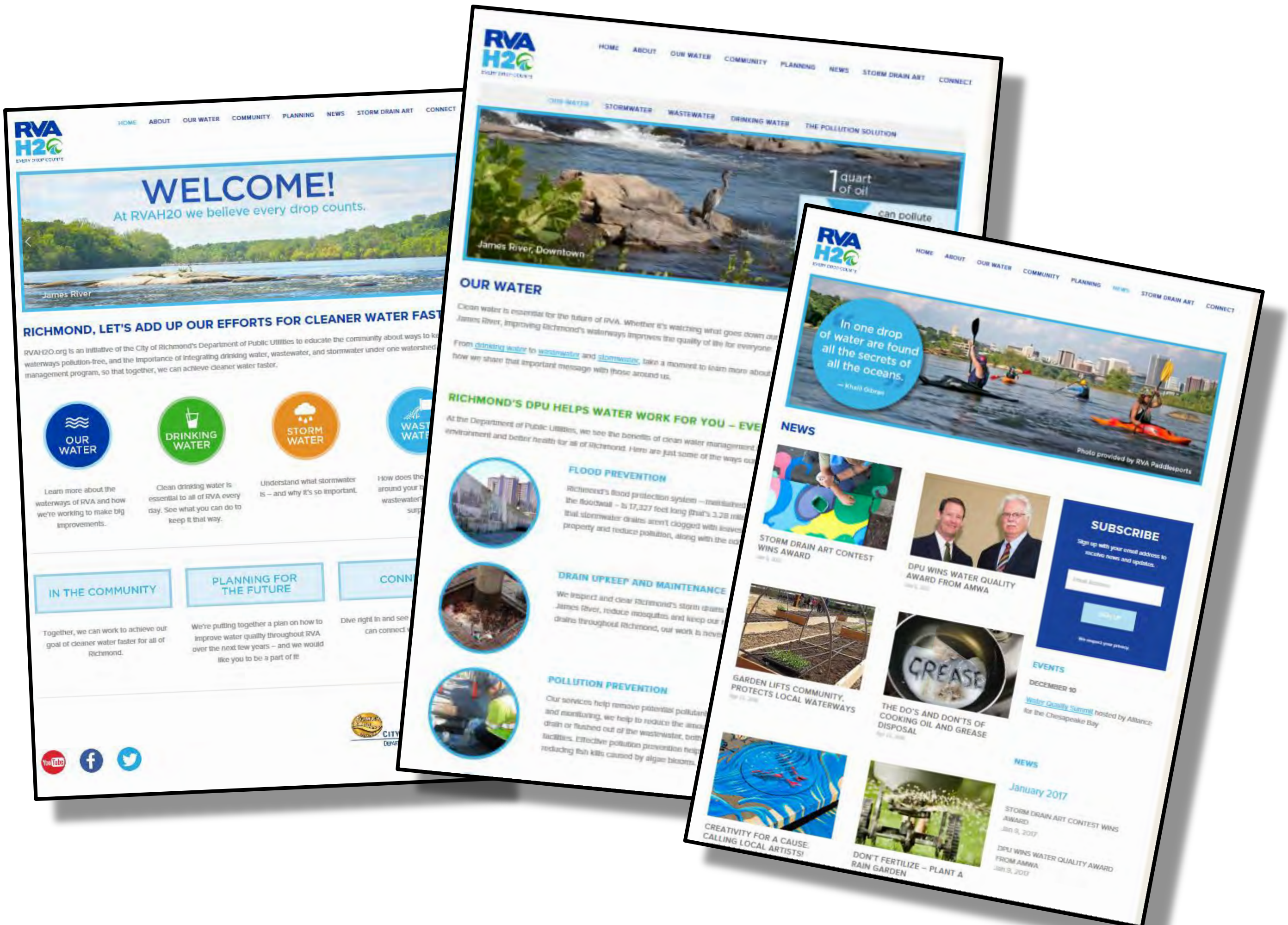



*Figure 2.3. Examples of RVAH2O website and Facebook pages.*

## Stakeholder Partnerships

As discussed further in Chapter 5 (Strategy Identification), DPU is limited in terms of the land and other resources available for strategy implementation. Opportunities to expand strategies will require tapping into the resources from other entities, including other City departments and stakeholder organizations within the City. One way to address this challenge was to create partnerships among the RVAH2O technical stakeholders who have an interest in helping the City implement the goals and objectives that form the basis for the RVA Clean Water Plan.

DPU presented on partnerships at several Technical Stakeholder meetings and discussed ways organizations may wish to partner by making commitments at varying levels of involvement. Examples include participating in the ongoing RVAH2O technical advisory committee, providing volunteer assistance for different types of work (e.g., water quality monitoring, habitat monitoring, tree planting and maintenance), or partnering on larger projects involving land conservation, green infrastructure or stream restoration.

Partnership Opportunities for Implementation
A "Declaration of Cooperation" Approach

RVAH2O Partnership Survey

1. DPU welcomes the opportunity to create partnerships among the RVAH2O technical stakeholders who have an interest in helping the City implement the Goals, Objectives and Strategies that will form the basis for an **Integrated Resources Management Plan**. Organizations may wish to partner by making commitments at varying levels of involvement – such as participating in the ongoing RVAH2O technical advisory committee, providing volunteer assistance for different types of work (e.g., water quality monitoring, habitat monitoring, tree planting and maintenance), or partnering on larger projects involving land conservation, green infrastructure or stream restoration.

For the March 21 RVAH2O Technical Stakeholder Meeting, we would like to discuss different ways that your organizations might envision partnering in the years ahead. Whatever level of detail you're able to provide would be most helpful.

First, please indicate whether you give permission to RVAH2O to share your answers with other stakeholders at the March 21 meeting.

- Yes, I give permission on behalf of my organization to share this information with other RVAH2O stakeholders.
- No, I do not give permission.

*Figure 2.4 Partnership survey circulated to technical stakeholders*

A partnership survey was circulated to stakeholders (Figure 2.4) and additional detail on partnership efforts will be documented as these conversations continue over 2017.

# 3. Watershed and System Characterization

Effective integrated planning and watershed management rely upon identification of the conditions and issues that characterize the watershed. Understanding existing water quality, along with the sources of pollutants or stressors that impact the City's waterbodies, are key elements for developing priority actions to address any existing or potential problems. Characterization of existing collection systems and drainage areas within the City also helps assist in meeting regulatory requirements and implementing other watershed improvements.

Collection of data and characterization of the City's watersheds were the City's first steps towards development of the Clean Water Plan. The City's Watershed Characterization Report (Richmond DPU 2015) includes a detailed discussion of this information. This chapter summarizes this information and highlights how the information and data collected through the effort served as the foundation for subsequent steps of the watershed planning process.

Another key step towards the development of the Plan was the development of a water quantity and quality modeling framework, that incorporates models for the CSO areas, the non-CSO areas (including Richmond's MS4 area), and for the James River itself. The purpose of the modeling framework was to quantify present day bacteria (*E. coli*) concentrations in the James River and to predict future bacteria concentrations under the Clean Water Plan strategies. The modeling framework also allowed for the quantification of discharge flows and volumes, as well as the occurrence of CSO events. The City's Clean Water Plan Modeling Report (Appendix A) includes a detailed discussion of the model development, calibration, and application.

## Regulatory Drivers

To understand how the characterization of the collection systems and the City's watersheds can help assist in meeting regulatory requirements, it is important to first understand the regulatory drivers associated with the design and management of these systems and associated programs. Each of these drivers is discussed further below.

### Water Quality Standards (WQS)

The Clean Water Act (CWA) establishes the requirement for states to develop and set WQS (see CWA § 303(c)). Once approved by EPA, the WQS are then to be used for CWA purposes, such as in establishing VPDES permit requirements.

The WQS have three distinct parts:

- A designated use;
- Criteria to protect the designated use (generally referred to as ambient water quality criteria and often expressed as chemical-specific concentration values); and

- An antidegradation policy and implementation method.

The designated uses are established based upon data available and are expected to be consistent with the goals established in § 101 of the CWA.

Virginia's regulations set at a minimum that all waters have these designated uses:

- recreational uses (e.g., swimming and boating);
- propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them;
- wildlife; and
- production of edible and marketable natural resources (e.g., fish and shellfish).

The regulations provide authority to establish more specific subcategories of designated uses, such as for the Chesapeake Bay – "Subcategories of the propagation and growth of a balanced indigenous population of aquatic life, including game fish designated use for waters in the Chesapeake Bay and its tidal tributaries are listed in this subsection."

As noted, water quality criteria are required as part of the WQS and must be established at a level to protect the designated use. Criteria protecting recreational uses rely primarily on fecal indicator bacteria levels to prevent an unacceptable level of illnesses when recreating on or in the water. Criteria for aquatic life uses, such as cold water fishery or areas designated as habitat for specific sensitive species can include temperature, dissolved oxygen, and toxic pollutant limitations designed to ensure healthy populations of organisms that are expected to be present in those areas. Criteria for aquatic life uses may also be based on biological indices. States may designate water bodies for agricultural water supply to ensure that water quality is appropriate for irrigation of crops.

*The applicable WQS can be found at:*

*9VAC25-260*
*http://leg1.state.va.us/000/lst/h2568263.HTM*

The third part of the WQS is the antidegradation policy and its purpose is to protect existing uses and the level of water quality necessary to support these uses, to protect high quality waters, and to provide a transparent analytic process for states and tribes to use to determine whether limited degradation of high quality waters is appropriate and necessary. It is important to note that antidegradation focuses on "existing uses" not "designated uses."

## Assessing Water Quality Standard Attainment and Total Maximum Daily Loads (TMDLs)

In addition to addressing state requirements to develop WQS, § 303 of the CWA requires states to periodically assess whether waters are attaining WQS and provide a list to EPA detailing the locations of nonattainment and the suspected reasons for impairments. States submit this list for EPA approval every two years and it is referred to as the "impaired waters list" or 303(d) list. For waters placed on the 303 (d) list, states are also required to develop a TMDL. A TMDL calculates the maximum pollutant load that the water body can receive and still attain WQS. The CWA requires that the "load shall be established at a level necessary to implement the applicable WQS with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality[3].”

The CWA categorizes pollutant sources as either point sources or non-point sources. A point source is defined as any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel, conduit, or container. Control of point sources is handled primarily through the NPDES permit program, in Virginia it is the state VPDES permit program. In the CWA, point sources are clearly the focal point to be controlled, as the legal prohibition against pollutant discharge without a permit or other specific allowance applies only to point source discharges.

A nonpoint source is not specifically defined in the CWA, but is any source that is not a point source. Typical nonpoint sources include runoff from rural areas, including farming, animal grazing, and timber harvesting. The CWA does not establish a control program for nonpoint sources, as it did for point sources. Nonpoint sources are primarily addressed through voluntary programs that include grant funding as incentive for reducing pollutant loads. Significant differences between the two approaches to source control are problematic, especially in situations involving TMDLs for waterbodies with both point sources and nonpoint sources. In many cases, the focus to achieve pollutant reductions will be on point sources regardless of the load delivered by point sources versus nonpoint sources.

The TMDL establishes a ceiling for the sum of individual waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, natural background sources, seasonal variations, and a margin of safety. EPA has issued numerous guidance documents and policy memos to assist states (and stakeholders) in developing TMDLs, as well as in developing permits and assessing WQS attainment[4].

## VPDES WWTP Permit

The City has a VPDES permit for discharges into the James River from the wastewater treatment plant. The permit, issued by the Virginia Department of Environmental Quality, regulates discharges from the WWTP and the CSOs, which serve as relief points in the combined sewer system (CSS). The permit includes effluent limits and monitoring requirements, as well as nine minimum control measures required for the combined sewer system under EPA’s 1994 Combined Sewer Overflow Policy. Development of a Long Term Control Plan (LTCP) for the CSS is also required under this permit.

Richmond’s CSO LTCP involves construction of conveyance systems and retention facilities to help control discharges from the combined sewer system (Richmond DPU 2002). The goals of the LTCP are to correct or minimize the public health, water quality, and aesthetic impact on the James River caused by CSOs.

## State Consent Order

Implementation of Richmond’s CSO LTCP is required under a consent order from the State Water Control Board. The consent order was issued in 2005 and includes an implementation schedule and a

[3] See CWA Section 303(d)(1)(C)

[4] Guidance and information on impaired waters and TMDLs can be found at: https://www.epa.gov/tmdl/impaired-waters-and-tmdls-tmdl-information-and-support-documents

description of LTCP projects that will be implemented. These projects were used as the basis for the CSO Infrastructure strategy that is discussed further in Chapter 5.

### VPDES General Nutrient Watershed Permit

The General VPDES Watershed Permit Regulation for Total Nitrogen and Total Phosphorus Discharges and Nutrient Trading in the Chesapeake Bay Watershed is also applicable to the City. The City's WWTP has nutrient discharge limits that are established by this permit. These limits were used in the evaluation of the Clean Water Plan strategies (see Chapter 5 for additional discussion).

### VPDES MS4 General Permit

The City's MS4 system is authorized to discharge into the James River and its tributaries under a general VPDES permit. The permit requires compliance with TMDL waste load allocations and implementation of minimum control measures, including public education/involvement, illicit discharge detection and elimination, runoff control at construction sites and new developments, and pollution prevention/good housekeeping to the maximum extent practicable.

## Watershed Data

As discussed above, the previously developed Watershed Characterization Report compiled a significant amount of information on the following elements that was used to inform the Clean Water Planning process:

- Evaluation of existing geospatial (GIS) data including watershed features
    - Physical and natural features (including topography, soils, hydrology, geology, and land cover)
    - Land use and population characteristics
    - Infrastructure features
    - Wastewater collection system
    - Wastewater treatment system
    - Stormwater system
    - Sensitive areas

- Water quality data
    - Designated uses
    - 303(d) status / TMDLs (water quality issues - identification and characterization of water quality impairments and threats - and WLAs of approved TMDLs)
    - Monitoring programs
    - Water quality data
    - Flow data
    - Biological conditions
    - Pollutant sources
    - Stressors

A summary of some of this key information is discussed below in addition to how it has helped direct the Clean Water Planning process.

## Watershed Features

The James River and its tributaries drain a watershed of over 10,000 square miles. Within the City of Richmond, the James River flows for 24 miles, providing a substantial amount of waterfront. Because of its location and access to the waterfront, Richmond was established as a shipping and industrial center. While shipping is still an important function of the river, it also provides passive and active recreation through its waterfront and rapids, and serves as the drinking water source for the City and most of the metropolitan area. Major features in the river include Bosher's Dam, which is located just upstream of the City along the James River, and smaller dams, levees, and pipe crossings within the City. There are multiple locations along the river for swimming, kayaking, and canoeing. These include:

- Huguenot Flatwater – near the crossing of N. Huguenot Road and the James River, this site provides canoes, kayaks, and inner tubes. This is also a popular fishing spot.
- Pony Pasture – a popular swimming and sunbathing area, the site provides access for Class II whitewater boating and fishing.
- Texas Beach – at the end of Texas Avenue, a trail leads to a sandy beach and sunbathing rocks and connects to the Belle Isle Pedestrian Bridge to the east.
- Ancarrow's Landing/Manchester Slave Docks – this is a popular fishing spot and includes boat ramp.
- James River Park – near the crossing of Riverside Road and Hillcrest Road, this location provides the opportunity for Class IV whitewater boating

Just downstream of the City is the Presquile Wildlife Refuge, home to several species of birds and anadromous fish, including the endangered Atlantic sturgeon.

### Physical and Natural Features and Land Use Characteristics

There are a number of observations that can be made about the City's watersheds. The western and very northern portions of the City have experienced the least amount of hydrologic modification and possess the lowest intensely developed land use and most forested land cover. These more western areas also correspond with areas with higher soil infiltrative capacity. Alternatively, the eastern portion of the City corresponds with a higher intensity of developed land and industrial land use corridor as well as the City's urban core. Consequently, this area also corresponds to soils that are considered urban and tend to have less infiltration capacity and possesses a topography that includes some considerably steep slopes.

While any project slated for implementation will require a more detailed, site-specific assessment, the watershed-scale analysis in the Watershed Characterization Report provided information that helped guide the selection of high-level strategies. These strategies were created at this larger scale, rather than at a localized or neighborhood scale at which a project would be identified, to allow flexibility in the subsequent stages of integrated planning. For instance, in the assessment of green infrastructure as a strategy, GIS data were evaluated. Given the presence of steep slopes and soils in certain areas of the City that are not conducive to the infiltration necessary for green infrastructure, the total available land for this strategy was reduced by half. This conservative approach to identifying land availability incorporates an inherent flexibility that can allow for inclusion of additional acres into the strategy as more site specific data are collected. Chapter 5 includes additional discussion on strategies identification, Chapter 6 discusses the evaluation and prioritization of these strategies and Chapter 7 discusses implementation.

### Infrastructure and Collection Systems

Similar to other older cities, especially in the eastern United States, the City of Richmond is served by both a CSS and a MS4. The distribution of area covered by these systems is shown in Table 3.1 and depicted in Figure 3.1.

*Table 3.1. Area located within sewered sections of the City*

| Sewered Area | Area Served by (acres) |
| --- | --- |
| **Combined Sewer System** | 12,000 |
| **Separate Sewer System** | 26,000<br>(24,500 in MS4; 1,500 in direct drainage) |
| **Total** | **38,000** |

In dry weather conditions, both sanitary discharges and flows from the CSS are treated by the Richmond WWTP. The capacity of the City's WWTP, which serves approximately 215,000 people, is 45 million gallons per day during dry weather and up to 75 million gallons per day during wet weather. Combined sewer flows during wet weather events which would exceed the plant's capacity can be stored at the Shockoe Retention basin with a capacity of 44 million gallons[5] as well as the Hampton / McCloy CSS retention tunnel with a capacity of seven million gallons. Any remaining wet weather flow volumes are discharged through the City's 26 active CSOs.

The MS4 system, in the remaining portion of the City, includes over 220 miles of pipe, 280 miles of open channel and 50 miles of culverts that discharge stormwater flows at over 1,200 outfalls into receiving waters. Additional discussion of the MS4 area as well as the sanitary and combined sewer systems is included in the City's Watershed Characterization Report (2015).

[5] The basin holds 35 MGD, while in-line storage holds an additional 9 MGD

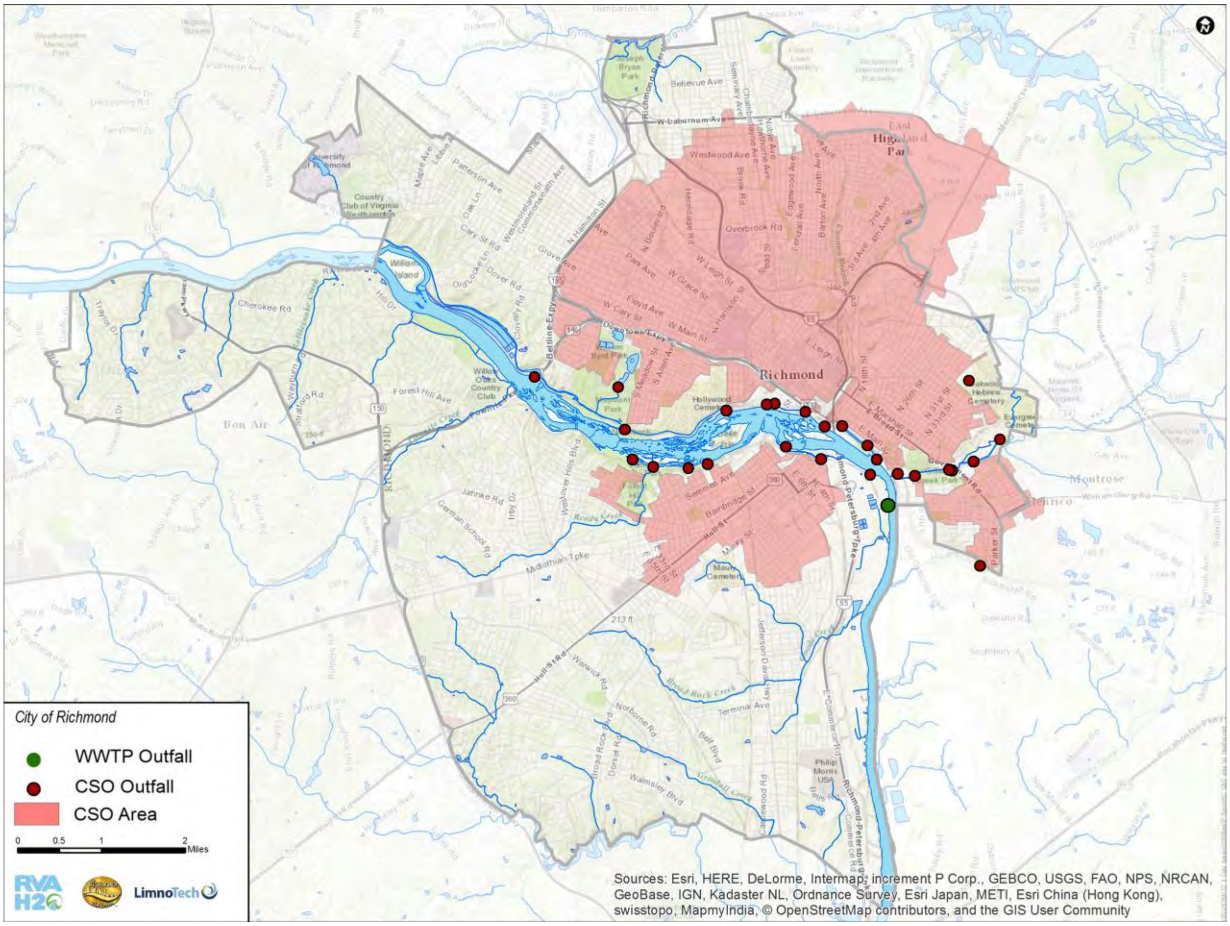



*Figure 3.1. Combined sewer overflow area within the City of Richmond and location of CSOs*

Understanding these areas within the City, and their associated sources and stressors, were essential to determining the extent to which they were contributing to impairments and the strategies that would be necessary to help the City mitigate these impacts.

### Sensitive Areas

EPA's CSO Control Policy (Federal Register 59 [April 19, 1994]: 18688-18698) provides a framework for the control of CSO discharges through the NPDES permitting process. This policy establishes the expectation that CSO communities will give the highest priority to the control of CSO discharges within "sensitive areas". The Policy and EPA Combined Sewer Overflows Guidance for Long-Term Control Plans (EPA 832-B-95-002) define sensitive areas as:

- Outstanding National Resource Waters ("Exceptional State Waters" or "Tier III" waters in Virginia)
- National Marine Sanctuaries
- Waters with threatened or endangered species or their designated critical habitat
- Primary contract recreation waters, such as bathing beaches
- Public drinking water intakes or their designated protection areas

- Shellfish beds

While this sensitive area analysis is applicable only to Richmond's CSO area, the data and information provided do help better characterize the City and potential concerns that should be taken into consideration in the development of goals, objectives, and high-level strategies for future implementation.

The City's LTCP discusses how the six criteria for sensitive areas identified in the CSO policy were evaluated for the James River and its tributaries in the vicinity of Richmond's CSO outfalls. No Outstanding National Resource Waters have been designated in the vicinity of Richmond (State of Virginia, 9 VAC 25-260). No National Marine Sanctuaries have been designated within the state of Virginia. Additionally, no commercial shellfish harvesters operate within the area.

The Virginia Department of Conservation & Recreation (DCR) Natural Heritage Program's Database was used to assess the presence of threatened or endangered species in the CSO area of Richmond. The database did not include or indicate the presence of any species on the Federal- or State-listed threatened or endangered species or critical habitat of any species in the CSO area.

Richmond's drinking water intake is on the James River over three miles upstream of the CSO area.

The original LTCP study identified the sensitive areas associated with the City's CSS as the south and north James River Park areas. These two areas are primarily in the vicinity of public contact recreation waters, especially the south side James River Park, which receives a large number of visitors each year, particularly during the summer months. CSOs in these areas discharge into canals and pools which can be slow moving and therefore have limited capability for flushing and diluting pollutants as they progress toward the main channel of the river. For this reason, CSO discharges to these areas exerted significant public health, aesthetic and water quality impacts, although the pollutant loads of these areas are relatively small compared to the total pollutant load for all CSOs in the City.

These issues are all of particular concern with regard to localized bacteria issues, especially in areas where in-stream recreation is common or where the community would like to expand on such in-stream recreational activities in the future.

## Water Quality Data

In addition to geographical data, the Watershed Characterization Report included an extensive amount of water quality-related data on the following topics:

- Pollutant sources
- Stressors
- Designated uses
- 303(d) status / TMDLs (water quality issues - identification and characterization of water quality impairments and threats - and WLAs of approved TMDLs)
- Monitoring programs
- Water quality data

- Flow data
- Biological conditions

A summary of some of this key information is also discussed below in addition to how it has helped direct the Clean Water Planning process.

## Sources and Stressors of Watershed Impacts

The 2012 Integrated Report GIS data included suspected pollutant sources for each impaired waterbody segment. Common impacts include:

- MS4 discharges
- Combined sewer overflows
- Non-point sources
- Wastewater discharges
- Industrial point source discharges
- Atmospheric deposition (nitrogen, toxics)
- Clean sediments
- Internal nutrient cycling
- Loss of riparian habitat

Waterbody stressors are described as actions or impacts that may adversely affect (apply some form of stress) the ecosystem in some way. Stressors are categorized by whether or not they have an accompanying water quality standard or screening value. Virginia DEQ has identified the following stressors as being most prevalent:

- Biomonitoring Indices (VSCI/CPMI)
- Streambed Sedimentation
- pH below 6
- Habitat Disturbance
- Nickel in Sediment
- Total Phosphorus
- Dissolved Nickel
- Total Nitrogen
- Dissolved Cadmium
- CCU Metals Index
- Mercury in Sediment
- Ionic Strength
- Dissolved Oxygen

Based on the watershed characterization analysis, key regulatory drivers, and additional modeling [discussed further in Appendix A], it was determined that the sources of particular concern include CSOs and MS4 discharges. Other sources, such as clean sediment (from in-stream erosion and scouring) and loss of riparian habitat, were taken into consideration in the development of strategies (see Chapter 5 on Strategy Identification for further discussion).

Again, key regulatory drivers, watershed analysis and modeling also focused the prioritization of stressors on total nitrogen, total phosphorus, total suspended solids, and bacteria. These key pollutants were used as a priority metric for evaluating the effectiveness of strategies in achieving goals and objectives related to water quality improvements.

## Existing Water Quality Data

Obtaining sufficient water quality data to assess the status of the City's waterbodies and impacts to these waterbodies is essential to developing an effective Clean Water Plan. As part of the City's

Watershed Characterization process, monitoring data from all available sources were compiled from entities such as Virginia DEQ, local universities, and watershed groups. These data supported the watershed characterization as well as the City's watershed and water quality monitoring (discussed further in Chapter 3). Moving forward, this data assessment can help the City determine how its existing monitoring program may need to be modified or how to better coordinate with local partners to integrate monitoring efforts.

The existing water quality data analysis showed that the number of available samples across data types (water quality sampling, biological sampling, and habitat assessments) are biased heavily towards the James River, with little-to-no data available in tributary streams. Additionally, there is a lack of hydraulic data within the City, with the only local USGS gauges located outside the City limits. Table 3.2 summarizes samples by data type and receiving water category. This table also highlights the dearth of biological samples and habitat assessments.

Dividing the data on a regional basis (watershed groupings discussed in the Watershed Characterization Report) reveals that the majority of available water quality samples were collected in the Lower James CSO and Lower James MS4 watershed groupings, while the majority of biological and habitat samples were collected in the Lower James CSO and the Middle James MS4. Table 3.3 summarizes samples by data type and watershed group.

*Table 3.2: Overall Sample/Assessment Counts by Data Type and Receiving Water Category*

| Data Type | James River | Tributaries |
|---|---|---|
| **Water Quality** | 4,759 | 368 |
| **Biological** | 44 | 5 |
| **Habitat** | 44 | 5 |

*Table3.3: Overall Sample/Assessment Counts by Data Type and Watershed Group*

| Data Type | Lower James CSO | Lower James MS4 | Lower James-Chickahominy MS4 | Middle James MS4 |
|---|---|---|---|---|
| **Water Quality** | 2,012 | 2,341 | 85 | 689 |
| **Biological** | 30 | 1 | 3 | 15 |
| **Habitat** | 30 | 1 | 3 | 15 |

Other types of data, such as hydraulic and meteorological samples, are more limited. There are no hydraulic data available within the City limits. While there are two USGS stations within the City limits (James River at Boulevard Bridge [USGS #02037618] and James River at City Locks [USGS #02037705]), neither station has flow data. The two closest USGS gaging stations with daily flow data are James River and Kanawha Canal Near Richmond (USGS #02037000) and James River Near Richmond (USGS #02037500), both of which are located upstream of the city. There is meteorological data available, but there are only two stations within the City (one in the Lower James CSO and another in the Lower James-Chickahominy MS4), both of which provide daily rainfall totals.

The lack of data in certain portions of the City and in the various tributaries emphasized the need for not only the collection of additional monitoring data, but the collection of monitoring data in a more coordinated manner between the City and various partners. Various supporting actions related to monitoring were recommended in association with the development of strategies. Part of supporting actions includes the establishment of a workgroup made up of the City and technical stakeholders to plan and implement an integrated monitoring strategy to identify efficiencies across partner monitoring efforts, coordinate efforts, and facilitate the sharing of data.

### Surface Water Quality Issues

As discussed above, all Virginia waters are designated for the following uses:

- Recreation (e.g., swimming and boating);
- Propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them;
- Wildlife; and
- Production of edible and marketable natural resources (e.g., fish and shellfish)[6].

Waterways may also be considered for primary shellfish harvesting status (Richmond DPU 2016).

The City's Watershed Characterization Report (2015) discusses the water quality criteria for the waterways in the Richmond area (Class II Estuarine waters for the tidal James River; Class III Non-tidal waters for the falls of the James and other tributaries).

Impairments to Richmond's waters are discussed further in the 2014 Integrated Report (VDEQ 2016) and are summarized in Table 3.4. Impairments include Chlorophyll-a, *E. coli,* Estuarine Bioassessments, benthic macroinvertebrate bioassessments, dissolved oxygen, PCB in fish tissue, PCB in water column, aquatic plants (macrophytes), pH, chlordane, DDE, DDT, and mercury in fish tissue.

> ### Waterbody Impairments
>
> *If a water body contains more contamination than allowed by water quality standards, it will not support one or more of its designated uses. Such waters have "impaired" water quality. In most cases, a cleanup plan (called a "total maximum daily load") must be developed and implemented to restore impaired waters.*
>
> *- Virginia DEQ*

The TMDLs applicable to the City include the James River bacteria TMDL and the Chesapeake Bay TMDL, which addresses total nitrogen, total phosphorus, and sediments. These TMDLs were identified as the main drivers behind this planning process. When other TMDLs, such as that for PCBs in the James River,

[6] See http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityStandards/DesignatedUses.aspx

are developed, the City will evaluate the need to adjust the Clean Water Plan as part of the adaptive management approach.

### Human, Aquatic Life, and Wildlife Health Issues

Several of the City's impaired waters pose health hazards for humans, aquatic life, and wildlife. The issues specifically addressed by this Clean Water Plan are those caused by bacteria, nutrients, and sediments. These are the same pollutants addressed by the TMDLs which will be included in the City's VPDES permit.

The James River (lower and tidal reaches) and several of its tributaries (Almond Creek, Falling Creek, Goode Creek, Powhite Creek, Reedy Creek, Bernards Creek, and Gillies Creek) and Upham Brook (which is a tributary to the Chickahominy River and ultimately the James River) have all been listed as impaired due to *E. coli* levels. These stream segments do not support the primary contact recreation use. The sources of bacteria in these streams within the City limits include CSOs, the MS4, the WWTP, direct discharge of urban runoff, and wildlife. Upstream sources also impact water quality in the City. Upstream sources include livestock, land application of manure, malfunctioning septic systems, illicit discharge of residential waste, other permitted waste treatment facilities. Presence of these bacteria is strongly linked with gastrointestinal illness in recreational users of the waterways. Reducing bacteria levels in these streams is consistent with the City's goal to provide safe recreational opportunities in the river.

While the James River bacteria TMDL addresses near-field water quality issues that must be addressed with localized strategies, the Chesapeake Bay TMDL, which applies to the James River and all its tributaries, sets targets for nutrient and sediment reductions downstream in the Chesapeake Bay. An excess of nutrients (nitrogen and phosphorus) in water can lead to an overgrowth of algae in water, or harmful algal blooms. Algal blooms can produce toxins harmful to humans and animals, create dead zones, and increase drinking water treatment costs for downstream communities. Sediments and algae in the water lead to murky conditions that block sunlight from underwater grasses and create low levels of oxygen for aquatic life. Safe nutrient and sediment levels are needed to maintain safe recreational opportunities and protect aquatic life in the river.

Again, while Richmond's waterbodies have impairments for a number of different pollutants (Table 3.4), the key focus for this Clean Water Plan are bacteria, nutrients, and sediment. Additional discussion of specific targets for these pollutants is included in Chapter 6.

*Table 3.4 Impairments of waterbodies within the City of Richmond*

| River Segment | Segment | HUC Code(s) | Length (miles) | Benthic | Chlorophyll *a* | DO | E. coli | Estuarine Bioassessments | Macrophytes | Mercury | Chlordane | DDE | DDT | PCB | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **North of the River** | | | | | | | | | | | | | | | |
| Upham Brook | Flippen Creek to confluence with Chickahominy River | JL18 | 1.2 | | | X | | | | | | | | | |
| Upham Brook | Headwaters to confluence with Chickahominy River | JL18 | 55.72 | | | | X | | | | | | | | |
| Stony Run Creek | Headwaters to mouth of Gillie's Creek | JL01 | 3.23 | | | | X | | | | | | | | |
| Gillie's Creek | Headwaters to mouth of James River | JL01 | 6.02 | | | | X | | | | | | | X | X |
| **South of the River** | | | | | | | | | | | | | | | |
| Powhite Creek | Headwaters to mouth of James River | JM86 | 8.05 | X | | | X | | | | | | | | |
| Rattlesnake Creek | Headwaters to mouth of James River | JM86 | 2.32 | | | | X | | | | | | | | |
| Reedy Creek | Headwaters to trib above Roanoke St. | JM86 | 2.34 | | | X | X | | | | | | | | |
| Reedy Creek | Trib above Roanoke St to Forest Hill Ave. | JM86 | 0.6 | | | | | | | | | | | | X |
| Manchester Canal | Manchester Canal | JM86 | 0.75 | | | | X | | | | | | | | |
| Pocoshock Creek | Headwaters to mouth of Falling Creek Reservoir | JL02 | 8.7 | | | | X | | | | | | | | |
| Falling Creek Reservoir | Falling Creek Reservoir | JL02 | 88.37 (acres) | | | X | X | | | | | | | | |
| Broad Rock Creek | Headwaters to mouth of Goode's Creek | JL01 | 3.15 | | | | X | | | | | | | | |
| Goode's Creek | Mouth of Broad Rock Creek to confluence with James River | JL01 | 1.25 | | | | X | | | | | | | X | |
| **James River** | | | | | | | | | | | | | | | |
| James River | Blvd bridge to fall line at Mayo's Bridge | JM86 | 2.91 | | | X | X | | | X | X | X | X | | |
| James River | Mayo Bridge to mouth of Appomattox River | JM86, JL01 | 1.47 | | X | X | X | X | X | | | | | | |
| James River | Big Island Dam to I-95 bridge | | 13.28 | | | | | | | | | | | X | |

# Water Quality Modeling

Water quantity and quality modeling was conducted to allow for longer and continuous periods to be evaluated relative to the water quality monitoring program. Therefore, a key step towards the development of the Clean Water Plan was the development of a water quantity and quality modeling framework. The purpose of the modeling framework is to quantify present day bacteria (E. coli) loads and concentrations in the James River and to predict future bacteria loads and concentrations under the Clean Water Plan strategies. The modeling framework also allowed for the quantification of discharge flows and volumes, as well as the occurrence of CSO events. The City's Clean Water Plan Modeling Report (Appendix A) includes a detailed discussion of the model development, calibration, and application. A summary of each step is provided here.

## Model Development

Three models were used to achieve the modeling objectives, and together they comprise the modeling framework. These three models include:

- A watershed model to simulate flow and bacteria loads from contributing areas of tributaries to the James River within the greater Richmond area, as well as from Richmond's Municipal Separate Storm Sewer System (MS4), but excluding the combined sewer system. This model was developed using the EPA SWMM software.
- A collection system model to simulate flow and bacteria loads from the combined sewer system (CSS). The CSS model is an existing model that is used to by the City of Richmond for Wastewater Master Planning, to support implementation of the CSO Long Term Control Plan, and to prepare the Annual CSS Reports. This model was developed using the EPA SWMM software, and was adapted for use in this study.
- A receiving water quality model that computes bacteria concentrations in the James River resulting from the various sources of bacteria to the river. The outputs of the watershed and CSS models are used as inputs to the receiving water quality model. The receiving water quality model was developed using the EPA-supported EFDC software.

## Model Calibration

Model calibration is the process of adjusting model parameters and assumptions within defensible ranges to achieve reasonable agreement between modeled and observed environmental conditions. The calibration process demonstrated that the modeling framework is sufficiently well calibrated to support the following modeling objectives:

- Design the modeling framework to provide a reliable and reasonably complete accounting of bacteria sources to the James River;
- Develop the modeling framework using sufficiently complete and accurate site specific data;
- Calibrate the models using reasonable assumptions consistent with the site data, literature, and professional judgment;
- Achieve a level of model accuracy that is adequate to support decision making;

- Apply the models for a period including a wide range of common environmental conditions (i.e. river flow and precipitation conditions); and,
- Evaluate and synthesize model output to interpret major sources of current water quality impairment and to forecast future water quality conditions.

## Model Application

After the water quality modeling tools were developed and calibrated, they were jointly applied to assess water quality benefits associated with the selected strategies. For this purpose, the model was applied for a 3-year simulation period that includes a dry year (less than normal precipitation), and average rain year, and a wet year (more than normal precipitation). To date, the model has been applied to evaluate the following conditions or strategies:

- Current conditions: Best representation of current conditions, and includes all the Phase I and Phase II CSO improvements from the CSO Long Term Control Plan (LTCP).
- Baseline Conditions: represents the current conditions, plus all the currently funded Phase III collection system improvement projects from the LTCP.
- Green Infrastructure in the MS4 area Strategy: represents the baseline conditions, plus the implementation of 104 acres of green infrastructure on city-owned area in the MS4.
- Green Infrastructure in CSS area Strategy: represents the baseline conditions, plus the implementation of 18 acres of green infrastructure on city-owned area in the CSS area.
- CSS Infrastructure Strategy: Implementation of CSS projects included in the LTCP: represents the baseline conditions, plus all the remaining unfunded Phase III collection system improvement projects from the LTCP.

These strategies were evaluated using several metrics related to bacteria reduction, including:

- Bacteria load reduction from combined sewer and tributary discharges, expressed as billion CFU per year
- Percent increase in monthly geomean water quality standard compliance in the James River at the downstream city limit
- Reduction in number of CSO events per year
- Reduction in CSO volume, expressed as million gallons per year

These water quality benefits were then entered into a calculator tool that integrates the benefits of strategies across a wide range of Goals and Objectives, as further explained in the next chapter. Water quality benefits were also assessed relative to the two existing water quality standards: a monthly geometric mean standard and a statistical threshold value (STV) standard.

## Assessing Current Conditions

The Clean Water Plan Modeling Framework was applied to better understand the sources and impacts of bacteria in the James River. The main metrics evaluated by the model include average bacteria loads entering the river from the main sources, *E.coli* concentration in the James River and comparison to the water quality standards, number of CSO discharge events, and CSO discharge volume.

An evaluation of current conditions helped assess the impact of the five major sources of bacteria in Richmond (upstream, CSO, stormwater, background, and WWTP sources), and how each contributes to water quality standard exceedances relative to the other sources. Figure 3.2 graphically shows these results for both the monthly geomean and statistical threshold value (STV) standard. The model results illustrate that the James River is in violation of both the geometric mean and the statistical threshold value water quality criteria for some months out of the three year model simulation period, and the primary cause of a water quality criteria violation can sometimes be linked to Richmond's combined sewer overflows, while at other times it is due to upstream sources coming in from outside of the City. Background (mainly wildlife) and stormwater sources play a smaller overall role in the bacteria water quality violations. The WWTP does not contribute significantly to bacteria water quality violations.

Because the model shows that Richmond's CSOs contribute in large part to the bacteria water quality criteria exceedances, this information was used to support the prioritization of strategies, such as CSO infrastructure, to address this source. Figure 3.3 shows the relative volume of CSO discharges at the CSO outfalls (based on data from 2004 to 2016), and may present potential opportunities for targeting specific CSO discharge points.

Other important metrics evaluated by the model are shown below in Table 3.5.

*Table 3.5 Model Output for Current Conditions*

| Model Output | Model Value |
|---|---|
| Average yearly E.coli load (billion cfu) | 9.65E6 |
| Average annual number of CSO events | 53 |
| Average yearly CSO volume discharged (million gallons) | 1,670 |

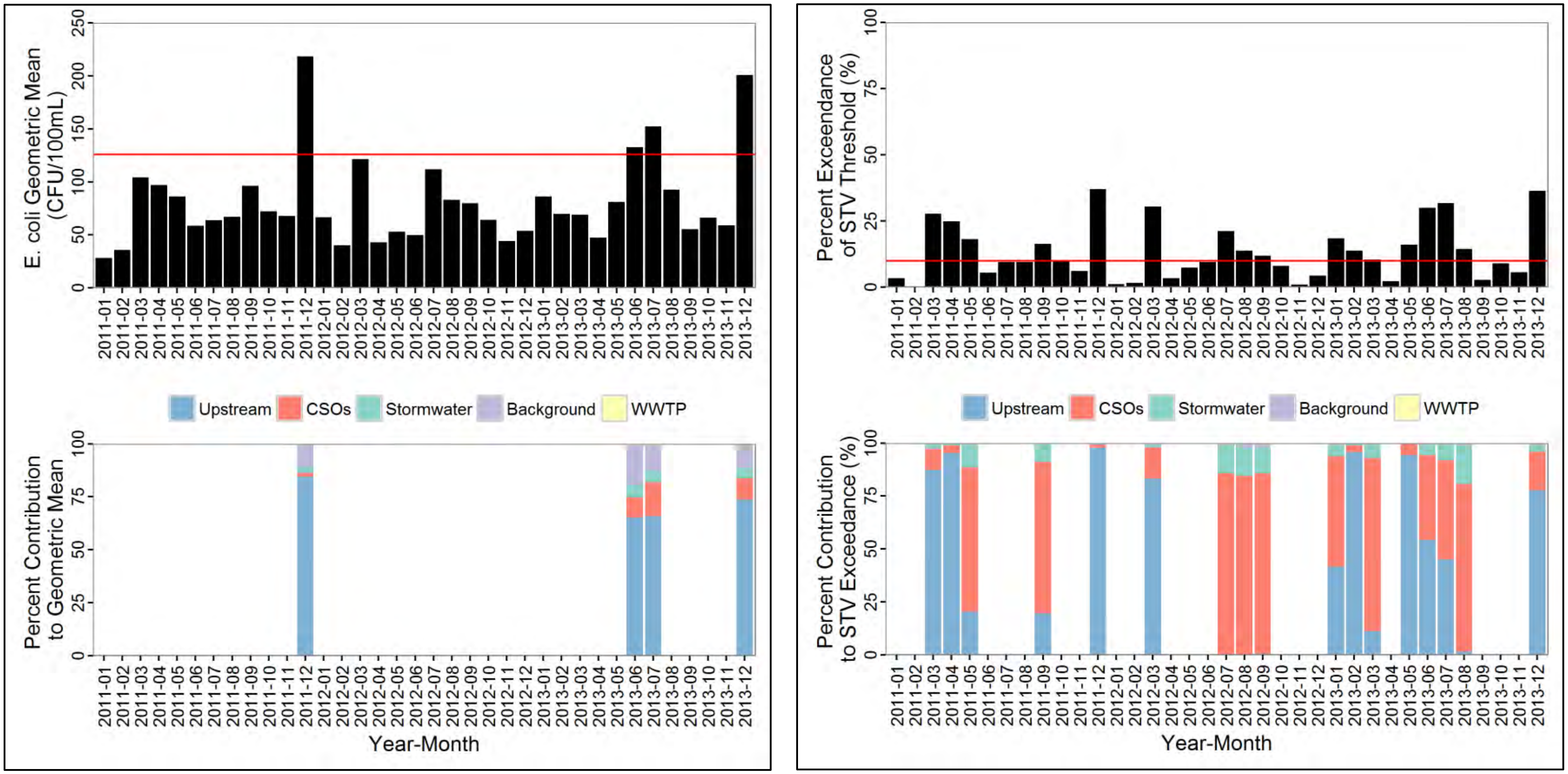



*Figure 3.2. E.coli Monthly Geometric Mean and STV Standard Model Results for Current Conditions*

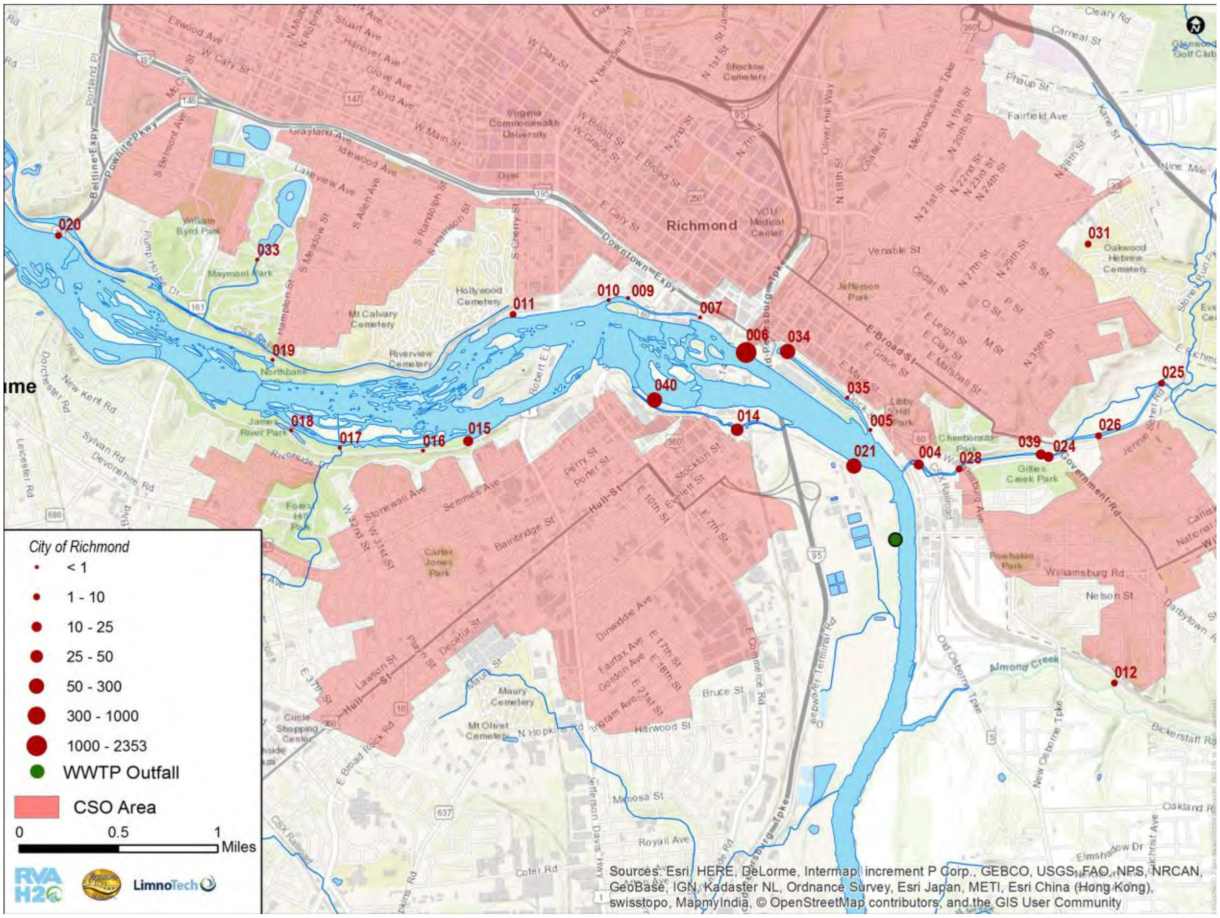



*Figure 3.3. CSO Overflow volume by CSO outfall (million gallons/year)*

Additional information on the modeling results can be found in Appendix A.

# 4. Goals & Objectives Selection

Traditional integrated planning efforts tend to focus on meeting infrastructure goals, such as reduction in the number of CSOs. The City's Clean Water Plan, however, is built around a watershed framework that accounts for the City's collective water needs and requirements (including, but not limited, to infrastructure) while considering watershed characteristics. While DPU's understanding of these needs and requirements provide a starting point for establishing the goals and objectives of the Clean Water Plan, DPU recognized that stakeholder input would also be critical to fully capturing the desired direction and outcome of the Plan. This process included not only extensive stakeholder feedback to develop the goals/objectives, but included a weighting process to assign a degree of relative importance of these goals/objectives to one another. The goals, objectives, and respective weights are summarized in Table 4.1 and the approach used to develop this is described below.

*Table 4.1 Clean Water Plan goals and objectives with associated weights*

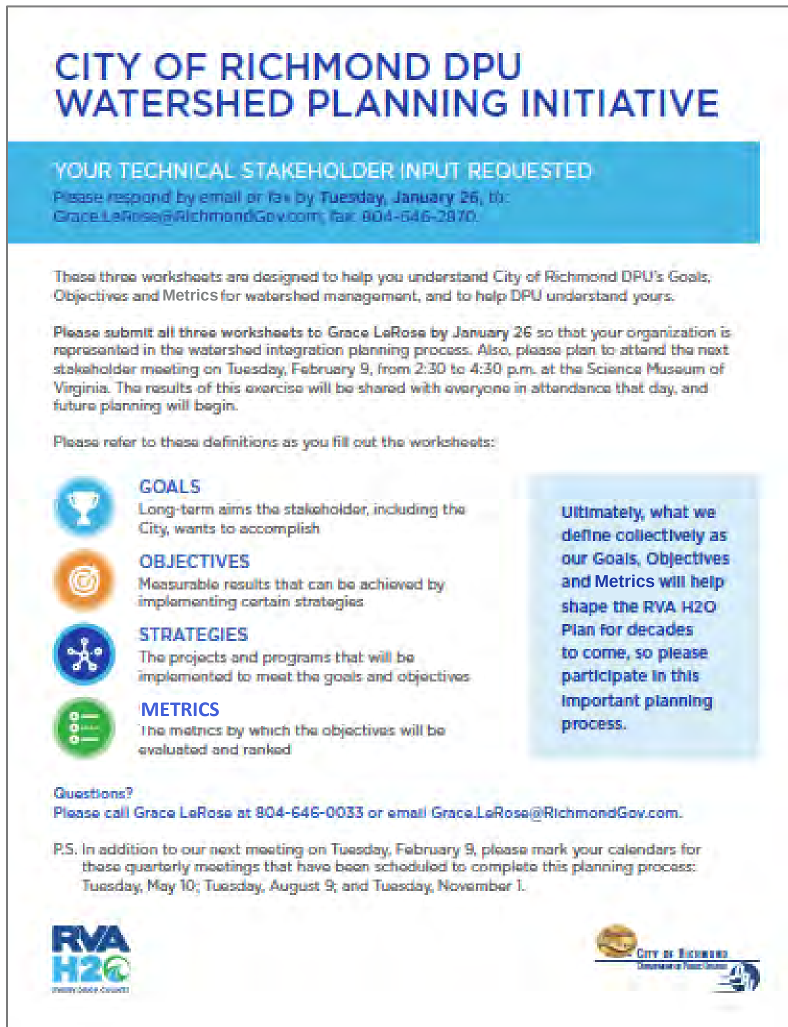
| Goals (with weights) | Objectives | Weights |
|---|---|---|
| 19%: Manage wastewater and stormwater to improve the water quality and water quantity of ground water and surface water. | Develop one stormwater management plan to cover the City's four watershed groupings based on the City's watershed characterization report | 19% |
| | Reduce nitrogen, phosphorus, and sediment in discharges to achieve VPDES permit requirements (Chesapeake Bay TMDL) | 18% |
| | Reduce bacteria levels to achieve VPDES permit requirements (local TMDL and water quality standards) | 18% |
| | Reduce toxics (e.g., mercury, PAHs, PCBs), trash and other pollutants and address TMDLs for these pollutants | 17% |
| | Develop green infrastructure, including riparian buffers, and removal of impervious surfaces on development, existing development, and redevelopment | 27% |
| 15%: Protect and restore aquatic and terrestrial habitats to support balanced indigenous communities | Restore streams to improve, restore, and enhance native ecological communities | 25% |
| | Identify, protect, and restore critical habitats | 36% |
| | Enhance aquatic and terrestrial habitat connectivity | 23% |
| | Investigate, and where feasible, promote actions that might surpass regulatory requirements | 16% |
| 14%: Engage and educate the public to share responsibility and take action on achieving healthy watersheds. | Engage and efficiently educate the public about standards, processes, and actions associated with watershed health and public health | 25% |
| | Assist in the education of citizens about overall water quality issues, benefits of improved water quality | 30% |
| | Support and encourage local action to improve water quality | 24% |
| | Provide quicker public notifications of spills or pollution from regulators or other "river watchers" | 21% |
| 12%: Implement land conservation and restoration and incorporate these into | Protect, restore, and increase riparian buffers | 21% |
| | Reduce impervious surfaces | 19% |
| | Increase natural land cover with a focus on preserving, maintaining, and increasing tree canopy | 24% |

| | | |
|---|---|---|
| planning practices to improve water quality. | Incorporate green infrastructure in new development and redevelopment | 18% |
| | Conserve lands where possible and consistent with Richmond's Comprehensive Plan | 18% |
| 11%: Create partnerships across the watersheds internal and external to the City of Richmond to maximize benefits and minimize impacts to all stakeholders | Develop and implement a source water prevention plan/strategy | 33% |
| | Establish public-private partnerships to secure funding, implement strategies and projects, and to achieve plan goals | 40% |
| | Maintain and expand the RVAH20 group | 27% |
| 10%: Maximize water availability through efficient management of potable, storm, and wastewater. | Reduce use of potable water for industry and irrigation | 39% |
| | Achieve water conservation by improving the existing water conveyance system | 30% |
| | Achieve water conservation by incentivizing upgrades to end-user water fixtures where appropriate | 31% |
| 9%: Provide safe, accessible, and ecologically sustainable water-related recreational opportunities for all. | Improve water quality to promote safe recreation consistent with the City’s Riverfront Plan | 36% |
| | Promote ecologically sustainable management of riverfront and riparian areas | 40% |
| | Improve river and waterfront access for recreation | 24% |
| 9%: Work collaboratively to gather consistent high-quality data to characterize the status and trends of water resources and to gauge the effectiveness of restoration efforts. | Conduct water quality and biological monitoring | 28% |
| | Provide timely water quality information | 19% |
| | Collaborate with citizens and local/state agencies for coordinated monitoring | 23% |
| | Utilize results to target restoration efforts and convey progress | 30% |

## Establishing Goals & Objectives

The first step of the Clean Water Planning process was determining the direction in which the City and its stakeholders wished to take this effort. To accomplish this, goals and objectives were selected through an extensive stakeholder communications process. The watershed characterization efforts, described in Chapter 3, were used as a basis for understanding the City's watershed features, water quality, and any issues of concern within the watersheds. While this helped inform the City and stakeholders, the selection of overarching goals, refined goals, and objectives was also influenced by the mission of stakeholder organizations or City department as well as stakeholder's additional first-hand knowledge of local issues.

To account for the multiple opinions and perspectives that were anticipated, the City implemented a multi-step process to form consolidated lists of overarching goals, refined goals, and objectives. The first step in this process was to survey stakeholders (Figure 4.1). The City requested that stakeholders submit what they felt were appropriate overarching goals, refined goals, objectives, and metrics (discussed further in Chapter 6) based on definitions and guidance on what these terms included.



CITY OF RICHMOND DPU
WATERSHED PLANNING INITIATIVE

YOUR TECHNICAL STAKEHOLDER INPUT REQUESTED

Please respond by email or fax by **Tuesday, January 26**, to: Grace.LeRose@RichmondGov.com; fax: 804-646-2870.

These three worksheets are designed to help you understand City of Richmond DPU's Goals, Objectives and Metrics for watershed management, and to help DPU understand yours.

**Please submit all three worksheets to Grace LeRose by January 26** so that your organization is represented in the watershed integration planning process. Also, please plan to attend the next stakeholder meeting on Tuesday, February 9, from 2:30 to 4:30 p.m. at the Science Museum of Virginia. The results of this exercise will be shared with everyone in attendance that day, and future planning will begin.

Please refer to these definitions as you fill out the worksheets:

GOALS
Long-term aims the stakeholder, including the City, wants to accomplish

OBJECTIVES
Measurable results that can be achieved by implementing certain strategies

STRATEGIES
The projects and programs that will be implemented to meet the goals and objectives

METRICS
The metrics by which the objectives will be evaluated and ranked

**Ultimately, what we define collectively as our Goals, Objectives and Metrics will help shape the RVA H2O Plan for decades to come, so please participate in this important planning process.**

Questions?
Please call Grace LeRose at 804-646-0033 or email Grace.LeRose@RichmondGov.com.

P.S. In addition to our next meeting on Tuesday, February 9, please mark your calendars for these quarterly meetings that have been scheduled to complete this planning process: Tuesday, May 10; Tuesday, August 9; and Tuesday, November 1.

*Figure 4.1. Guidance provided to technical stakeholder to support the gathering of input on goals, objectives, and metrics.*

Fifteen stakeholders provided input through responding to the request. Given the large amount of feedback to discuss, the City addressed the discussion of overarching goals and refined goals during the February, 2015 meeting and objectives during the May, 2015 meeting.

Prior to the February meeting, the City evaluated all of these submissions and identified a number of themes. It was important to the City that no feedback was lost in this process, so all input was incorporated verbatim into one of these themes:

**Overarching Goal Themes:**

- Collaboration
- Water consumption
- Preservation and restoration
- Water quality

**Refined Goal Themes:**

- Recreation
- Aquatic and riparian habitat
- Stormwater peak flows
- Pollution
- Land conservation and management
- Partnerships
- Monitoring
- Public engagement & action
- Water conservation

At the stakeholder meetings, attendees were broken into small groups with each group being provided one of these themes and its associated goals. Each small group was then asked to combine and synthesize the items within that theme. Goals could be combined, reworded, or moved to another goal topic area. Goals could also be re-categorized as an objective or a strategy if deemed more appropriate. Ultimately, one goal was developed for each topic area.

A similar approach was taken in developing a refined list of objectives. Stakeholders provided objectives associated with each of the proposed goals. Stakeholders then refined these objectives so there were between one and six objectives associated with each of the refined goals.

## Striving for Consensus

A number of opinions and viewpoints were represented through the stakeholder process. While the City felt it was important for the Clean Water Planning process to reflect these views, it was also important for the process to move forward in a timely manner. To accomplish this, the City strived to reach consensus on each of the steps of this process and the associated decisions made.

The goal behind *striving* for consensus is that everyone will be able to live with and support the idea or issue, or, at least, no one opposes it. If the group was not able to support an element of the issue/item up for discussion, additional discussion was deemed necessary.

While stakeholders were a key part of the process for identifying goals and objectives, they did represent many different groups with interests in the City. To ensure stakeholders all shared the same amount of influence during this process, each interest group was allowed one member at the table who could participate (i.e., vote) in the consensus process.

As shown in Figure 4.2, each voting stakeholder could select either “1”, “2”, or “3” to represent their level of agreement with a particular goal or objective being discussed. If any stakeholder selected “1”, then the topic was discussed further until the stakeholder agreed, the item for discussion was modified so that all stakeholders could at least live with the decision, or the item/topic was removed from the options moving forward.

Ultimately, stakeholders achieved consensus on the overarching goal, refined goals, and objectives.

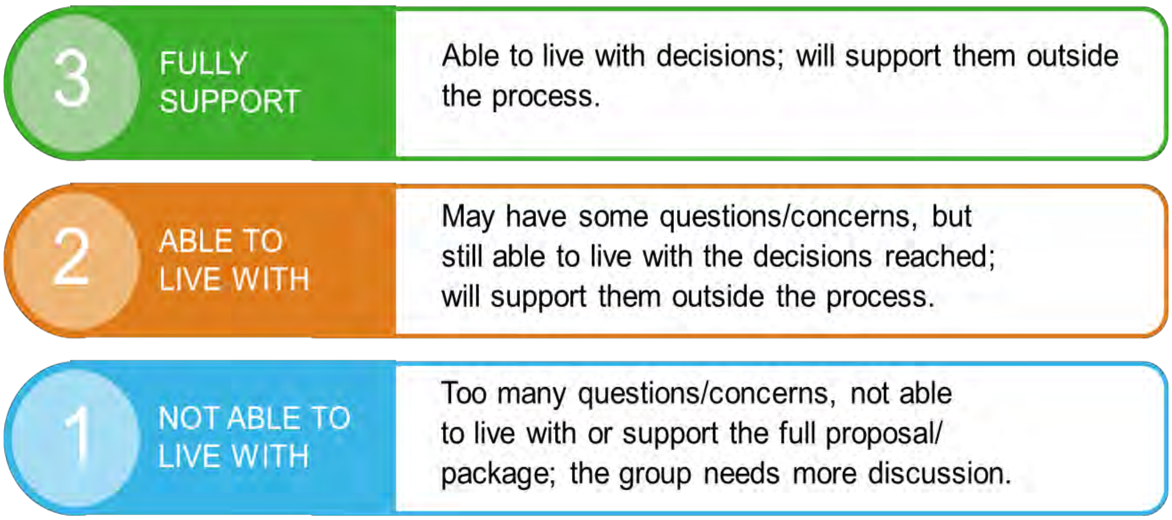



*Figure 4.2 Consensus voting process for the Clean Water Plan*

## Prioritizing through Weighting

Weighting was incorporated into this process to reflect the priorities of the City and its stakeholders. This weighting process not only allowed for an understanding of how one goal or objective ranked in relation to another, it also provided information on the extent of the importance of these priorities to one other.

*Table 4.2 Example weighting process*

| Refined Goals | Weight | Objectives | Weight | |
|---|---|---|---|---|
| Refined goal #1 | 15 | Objective #1 | 50 | Total: 100 |
| | | Objective #2 | 30 | |
| | | Objective #3 | 10 | |
| | | Objective #4 | 10 | |
| Refined goal #2 | 50 | Objective #1 | 10 | Total: 100 |
| | | Objective #2 | 60 | |
| | | Objective #3 | 30 | |
| Refined goal #3 | 30 | Objective #1 | 40 | Total: 100 |
| | | Objective #2 | 60 | |
| Refined goal #4 | 5 | Objective #1 | 20 | Total: 100 |
| | | Objective #2 | 40 | |
| | | Objective #3 | 10 | |
| | | Objective #4 | 30 | |
| Total: | **100** | | | |

Weighting included the process of assigning a portion of 100 points to each of the items in a grouping. As shown in the example in Table 4.2, 100 points are apportioned across a grouping of refined goals. In this example, refined goal #2 was given the highest priority, with 50 points. One or more objectives were assigned to each refined goal. Each grouping of objectives was also given a proportion of 100 total points.

The result of this process was a prioritization of refined goals as well as a prioritization of objectives associated with each of these goals.

Once the goals and objectives were finalized by the City and its stakeholders, Surveymonkey.com was used to circulate a questionnaire to each stakeholder organization to obtain their opinion on the weights of each goal and objective. The weights provided by each stakeholder organization were then averaged to produce a weight for each refined goal and for each objective. These averaged weights were presented and discussed at a technical stakeholder meeting. Stakeholders were allowed to suggest modifications to the weights of the goals or objectives as long as the overall ranking of these weights remained the same. Using the example in Table 4.1, while the order of the refined goals must remain #2, #3, #1, and #4, stakeholders might collectively decide that refined goal #3 should be 38 points, while refined goal #2 should be changed to 42 points.

# 5. Strategy Identification

The next step in this process was the identification of strategies that can be expected to achieve the previously identified goals and objectives. Strategies were defined as activities, actions, or items that will help meet goals and objectives. The process that was used to develop the strategies is discussed below.

## Brainstorming Potential Strategies

Implementation of projects and programs that may benefit the City's water resources are undertaken by numerous departments within the City as well as other entities, such as local universities, watershed organizations, or private developers. While the City can coordinate or partner with these entities to implement such efforts (as was discussed in Chapter 2), DPU recognized that the starting point in determining a list of strategies for the Clean Water Plan was determining what projects and programs the Department could implement and maintain itself.

> ### Strategies vs. Projects
>
> *The Clean Water Plan-related planning is occurring at the sub-watershed to the City-scale. As such, projects or programs at a finer scale needed to be "rolled up", or grouped, to produce a higher level strategy.*

The first step in brainstorming potential strategies included a workshop for DPU staff involved in stormwater, wastewater, and CSO-related projects. Staff compiled a list of projects that had been identified or proposed to meet various programmatic needs. Because the Clean Water Plan would be implemented during the next VPDES permit cycle (beginning in June of 2018), any project that would be funded, initiated, or implemented prior to this date was removed from the list. The resulting list included the remaining potential projects that could be implemented over the next VPDES permit cycle (2018 through 2023). City staff also brainstormed other ideas, such as opportunities for expanding existing efforts like the residential stormwater credit process, to help increase implementation.

It is important to note, however, that the initial stages of the Clean Water Planning process is being developed at a high-level scale (sub-watershed, watershed, to City-scale). Because many of these projects impact small-scale areas, these City projects were "rolled up" to a strategy scale where necessary. For example, several bioretention or permeable paving projects were rolled up, or grouped, into a Green Infrastructure strategy.

In addition to these DPU projects, stakeholders were also asked to submit suggestions for strategies that they felt would achieve the agreed upon goals and objectives. Numerous ideas were gathered with varying levels of detail. Because there were a number of distinct themes to these suggested strategies, the Clean Water Plan development team created a synthesized set of draft strategies that consolidated ideas put forth by both stakeholders and DPU staff.

It was determined that a number of the ideas put forth, while important, were not strategies in and of themselves. A number of these ideas could also be tied to more than one strategy. These ideas were defined as "supporting actions". Supporting actions include efforts that may broaden the main strategy, add specificity on how a strategy could be implemented, or identify additional resources and data needs to fully implement the main strategy. These supporting actions are not necessarily quantifiable in and of themselves and may be components of multiple main strategies. Actions, such as those related to partnerships, may also involve activities on non-City property and rely on resources that are outside the DPU's authority.

Supporting actions include:

- Partnerships – establishing partners to facilitate a greater level of future implementation of projects and programs (partners include those within the City, such as the Department of Public Works (DPW), as well as with non-City agencies, such as watershed groups)
- Maintenance – including resources and funding to ensure a strategy will continue to meet its intended objectives
- Monitoring, Assessment & Planning – gathering data and information and using these results to help guide and implement future implementation
- Incentives/Credits – evaluating and implementing mechanisms to incentivize new initiatives or higher levels of future implementation
- Regulations/Ordinances/Codes – analyzing and modifying, if necessary, the framework within which implementation will occur
- Outreach – including ways to potentially expand upon future implementation by conveying information on resources available or ways for partners and the public support a strategy

Some of these Supporting Actions are specific to a particular strategy, but others, such as some related to monitoring or public outreach, cut across various strategies.

## Strategy Feasibility

Once the draft set of strategies was identified, it was important to determine if these strategies were feasible. Because DPU is ultimately responsible for implementation of the Clean Water Planning program, the feasibility of strategies was defined as efforts that DPU has the authority to implement. For instance, a strategy could be identified as infeasible if it requires implementation on land not owned by the City, and where it is not possible for the City to purchase or obtain the land in some way.

Because the City's Parks, Recreation, and Community Facilities (PRCF) Department works so closely with DPU and shares similar departmental objectives for project implementation and maintenance, PRCF land was also considered to be available for the feasible implementation of a strategy.

Feasibility also takes into account the potential limitations on strategy implementation due to physical constraints such as steep slopes or soils with poor infiltration that are unsuitable for some strategies such as green infrastructure. Therefore, the acreage included in the strategies reflects a portion of DPU/PRCF in the City that is appropriate for that particular strategy. For example, based on an evaluation of slopes and soils GIS data and best professional judgement, a decision was made to conservatively include 50% of the total DPU and PRCF lands within the Green Infrastructure Strategy in both the MS4 and CSS areas. Details on assumptions made for each of the strategies is included in Appendix B.

## Final Strategies

Once feasibility was evaluated, final draft strategies and supporting actions were presented to stakeholders who were given the opportunity to edit them further. Once all feedback was incorporated, a final set of strategies and supporting actions was presented to the stakeholders for a consensus vote.

Each of the strategies referenced in the remainder of the Clean Water Plan are considered to be "feasible" and agreed upon by the Technical Stakeholder group (Table 5.1).

*Table 5.1. Strategies and associated details*

| Strategy | Strategy Details |
|---|---|
| **Riparian Areas** | Replace or restore 10 acres of riparian buffers according to state guidance.<br>• In MS4 and/or CSS area<br>• Evaluate opportunities for inclusion of access points to waterbody for recreational activities |
| **Green Infrastructure in MS4** | Install or retrofit GI draining 104 acres of impervious surfaces, including efforts such as:<br>• 30 acres on DPU property<br>• 18 acres on City-owned vacant properties<br>• 20 acres on Parks department property (one playground/park per year, cemetery roadways, impervious to pervious area in park properties, vacant properties)<br>• Install 100 trees in tree boxes (e.g., Filtera-type practices); 30 acres total drained to this practice<br>• Retrofit 4 DPU stormwater BMPs (e.g., dry ponds to more efficient BMPs), draining at least 6 acres of impervious surface |
| **Green Infrastructure in CSS** | Install or retrofit GI draining 18 acres of impervious surfaces, including efforts such as:<br>• 6 acres on DPU property<br>• 2 acres on City-owned vacant properties<br>• 2 acres on Parks department property (one playground/park per year, cemetery roadways, impervious to pervious area in park properties, vacant properties)<br>• Install 24 trees in tree boxes (e.g., Filtera-type practices); 8 acres total drained to this practice |
| **Stream Restoration** | Restore 2,500 linear feet of stream:<br>• Through removal of concrete channels, repair of incised banks, etc.<br>• In MS4 and/or CSS area<br>• Evaluate opportunities for inclusion of access points to waterbody for recreational activities |
| **Natives/Invasives** | Use 80% native plants in new landscaping at public facilities by 2023. |
| **Trees** | • Increase tree canopy on City property by 5% (80 acres added)<br>• Protect existing tree canopy by following maintenance addressed in the Tree Planting Master Plan |
| **Land Conservation** | Place an additional 10 acres under conservation easement, prioritizing conservation of land that creates connected green corridors.<br>• Evaluate opportunities for inclusion of access points to waterbody for recreational activities |
| **Water Conservation** | Reduce water consumption by 10% through implementation of new water conservation technologies and promotion of water conservation efforts, including:<br>• Installing water-efficient fixtures as a policy by 2023 in all new public facility construction<br>• Implementing incentive programs |

| | |
|---|---|
| | • Encouraging water conservation on City properties |
| **Pollution Identification and Reduction** | Reduce contribution of pollutants to the MS4 through:<br>• Conducting at least 1 special study per year in hot spot areas to identify illicit discharges/connections. (Studies will meet the criteria necessary to achieve Bay TMDL pollutant reduction requirements. Assume that, over 5 years, 3 of these studies will result in pollutant reductions that meet Bay TMDL requirements.)<br>• Collecting data associated with non-structural BMPs to facilitate quantification of pollutant reduction (e.g., storm drain clean-outs, pet waste stations, street sweeping) |
| **CSS Infrastructure** | LTCP projects, including:<br>• Installing wet weather interceptor to convey more flow to the WWTP<br>• Increasing WWT to 300 MGD at the treatment plant<br>• Expanding secondary treatment at the WWTP to 85 MGD<br>• Expanding Shockoe retention basin by 15 MG to capture more overflow<br>• Disinfecting overflow at Shockoe retention basin (wet weather disinfection facility)<br>*Note that that the modeling framework will be applied during the summer and fall of 2017 to evaluate alternative CSS reduction projects that may provide similar benefits to the LTCP projects, but at a reduced cost.* |

Table 5.2 includes the final, agreed upon supporting actions for the strategies.

*Table 5.2. Supporting Actions associated with the various strategies*

| Supporting Actions | Details |
|---|---|
| **Partnerships** | Restore 20 acres of riparian buffers on private properties through efforts such as:<br>• Purchases of land<br>• Partnerships with residents: Promote program for buffers on private properties (include tiers of level of involvement – (1) maintenance agreement with City, (2) conservation agreement/ easement.)<br>• Partnerships with Master Naturalists to enlist their support for assistance with riparian restoration. |
| | Implement 10 acres of GI on private property |
| | Implement 5 acres of GI on DPW property (rights of way, roadways, green alleys) through efforts such as:<br>• Adopt a rain garden program – coordinate with residents, non-profits, commercial entities<br>• Partnering with the City's community garden program to identify 0.5 acres of area for additional GI implementation<br>• Partnering with Public Works to ensure City greenways include GI |
| | Develop a program to encourage the use of native plants in private landscaping – sign up 20 private landscapers. |
| | Initiate an Adopt a Lot program (10 lots with invasive species removed, replanted and maintained) |
| | Partner with organizations such as the James River Park System Invasive Plant Task Force to better determine areas with significant invasive species issues and identify resources to deal with the problem. |
| | Partner with the public and other stakeholders, such as the Richmond Tree Stewards, to plant and maintain trees on public properties. |

| | |
|---|---|
| | Promote requests for stream restoration by private landowners and streamline the process by which these requests are addressed. |
| | Hire DPU staff member or assign 1 FTE to coordinate volunteers from corporate entities, watershed/environmental groups and public with partnership opportunities associated with the IP effort. Staff to enlist/maintain 6 partnerships per year. |
| | Hold 3 stakeholder meetings per year to continue communication with partners/stakeholders and add purpose to the IP effort. |
| | Evaluate partnership network in 5 years (at the end of the permit cycle) to assess gaps and identify new public/private partners. |
| | Partner with the public and other stakeholders to identify land to put in conservation easements. |
| | Partner with the Richmond Redevelopment and Housing Authority to identify homes/properties that are eligible for upgrades to water-efficient fixtures. |
| | Partner with upstream localities and Virginia Department of Health to update/maintain Source Water Protection Plan. |
| **Maintenance** | Include funding to support maintenance of newly replanted/restored riparian buffers (to ensure success of plantings, prevention of establishment of invasive species, etc.). |
| | Include funding to support maintenance of newly planted native plants and maintain newly established plantings where invasives have been removed from the landscape. |
| | Provide funding to support maintenance of trees on City property to ensure their survival and health. |
| **Monitoring, Assessments & Planning** | Inventory and map riparian areas to better understand loss or growth of riparian buffers. |
| | Inventory and map locations of trees and tree boxes to better understand loss or growth of tree coverage. |
| | Continue monitoring of 8 locations across the City for macroinvertebrate, habitat and in-stream water quality. Continue monitoring at 2 locations for flow. Evaluate opportunities to expand the flow monitoring network across the City. |
| | Evaluate the development of a monitoring data portal to facilitate sharing of data collected within the City with stakeholders and the public. |
| | Initiate monitoring work group in year one made up of technical stakeholders and other key groups/individuals to evaluate current monitoring efforts and identify potential efficiencies and additional monitoring needs moving forward. |
| | Evaluate potential for conducting pre- and post-construction monitoring of key stormwater BMPs. |
| | Conduct assessments of 4 stream segments across the 4 watershed groupings to support the development of watershed restoration plans to address pollutant sources and watershed stressors. |
| | Monitor growth/expansion of invasive species. |
| | Implement IDDE-related monitoring to support this effort – supported by a desktop analysis of high-risk dischargers. |
| **Incentives/ credits** | Reevaluate the stormwater credit program to determine potential to include practices such as replacing or restoring riparian buffers. |
| | Evaluate incentives/credits for purchasing/planting native species (such as Montgomery County, MD). |
| | Reevaluate the stormwater credit program to determine potential to include practices such as |

| | |
|---|---|
| | planting trees on private property.<br>Provide 500 trees for planting on private property or equivalent incentives to purchase native trees. |
| | Offer grants to replace 20% of inefficient fixtures in moderate- to low-income units<br>Evaluate expansion of incentive program to cover washing machines and dishwashers |
| **Regulations/ ordinances/ codes** | Evaluate expanding the regulatory buffer from 100 ft. to 200 ft. |
| | Evaluate inclusion of language in City zoning and planning-related ordinances to protect existing trees and add new trees on developed property. |
| | Adopt permitting standards for water-efficient appliances/fixtures in City code. |
| **Outreach** | Conduct outreach to educate the general public about the goals and objectives of RVAH2O, and the resources and services available through the City. |
| | Conduct outreach to advertise the resources, requirements and services available through the City related to green infrastructure for private property owners. |
| | Conduct outreach to advertise the resources, requirements and services available through City related to tree planting and maintenance. |
| | Promote ability to use grey water for toilet flushing as a way to achieve higher LEED standards |
| | Encourage and incentivize water capture and reuse for landscaping |
| | Promote water conservation for commercial, industrial and residential customers through efforts such as “Fix a Leak Week” and the City’s Every Drop Counts initiative. |
| | Conduct targeted outreach to high-risk industries, particularly in areas of the City identified as hot spots. |

# 6. Strategy Evaluation

Once strategies were drafted, an analysis was needed to determine which ones would be best for implementation. Figure 6.1 provides an overview of the multi-step strategy evaluation process that was used to make this determination. This process constrains proposed strategies by feasibility, relative achievement of goals/objectives, compliance with permit and regulatory drivers, and cost-related factors.

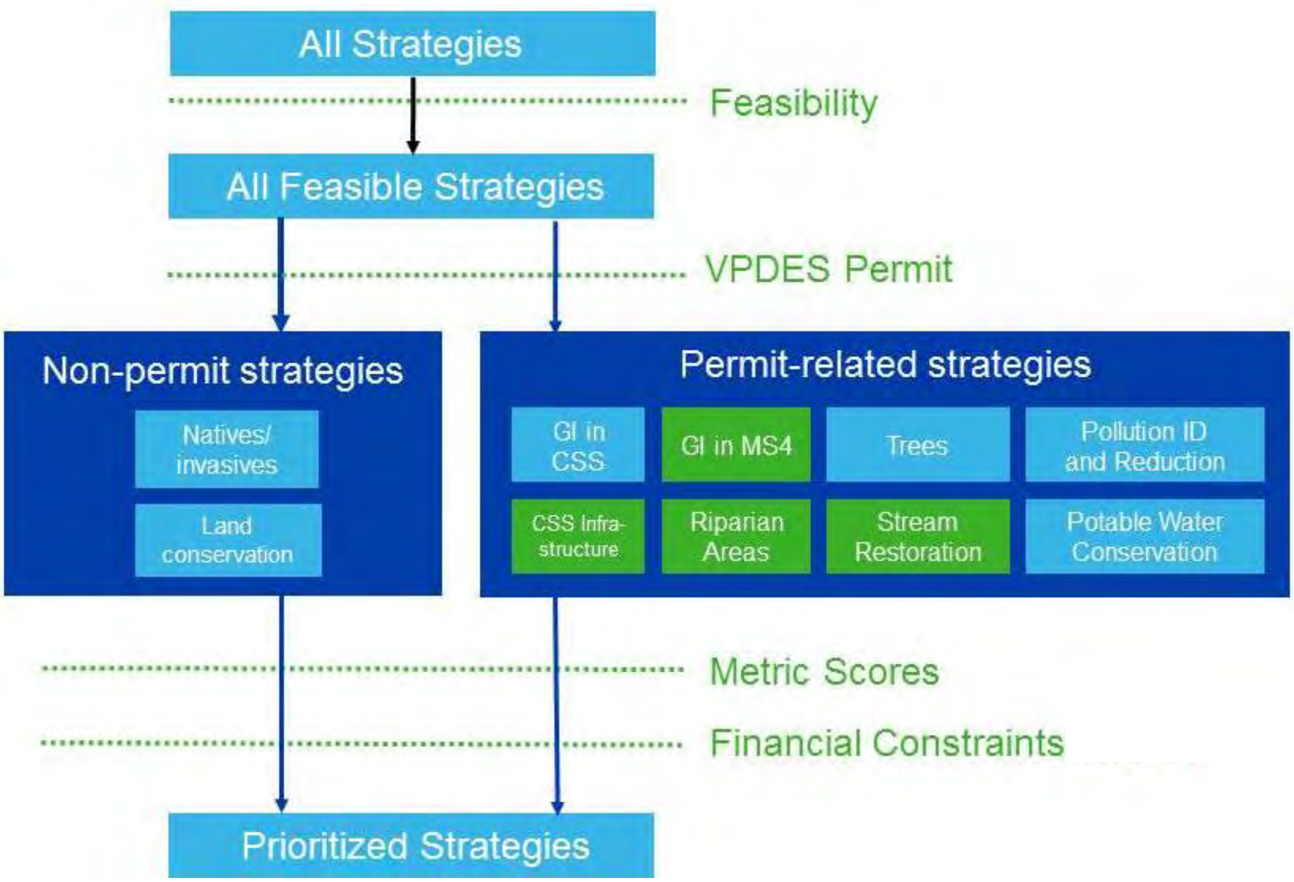



*Figure 6.1. The process used for strategy evaluation*

There are multiple factors at play that influence the selection of strategies. A strategy may do well with one factor, such as permit-related pollutant reductions, but not so well with others, like cost. As a result, the analysis of the various factors did not result in a clear and decisive outcome of one strategy that performed the best across all factors. What the strategy evaluation did determine was that all of the "pieces of the puzzle" needed to be evaluated collectively to achieve a complete picture of how well strategies achieve specific goals (Figure 6.2).


*Figure 6.2. Puzzle piece conceptual model demonstrating how various factors fit together to inform the decision making process*

Each of the "puzzle pieces" (other than Feasibility, which was discussed in Chapter 5) is discussed further below.

## Strategy Scores

A comparison of the various strategies proposed through this stakeholder process was needed. To accomplish this, an Excel-based strategy scoring calculator was developed. This tool helped in the decision-making process by allowing the City and stakeholders to evaluate various alternatives by assigning scores to the alternative strategies.

The methodology used for this scoring calculator is a multi-objective decision analysis (MODA). Decision-making based on consideration of multiple goals/objectives and metrics is a widely documented research discipline. While referred to by a variety of terms in the literature, this decision-making approach is used to evaluate how well each of the alternative strategies (e.g., management practices, policy options) achieves a desired outcome (a decision-making problem, goal, etc.) through the use of metrics[7]. This approach also helps facilitate the involvement of diverse stakeholders by accounting for competing priorities and preferences in the decision-making process through inclusion of the weighting process (Saairkoski et. al. 2015).

Development of calculator-based strategy scores to support strategy evaluation includes the development of metrics that are tied to the goals/objectives. The development of these metrics is discussed below. Also discussed is how the analysis of individual metrics helped to answer specific questions related to strategy effectiveness. These metric-based strategy scores were then used in conjunction with other factors, like cost, to comprehensively evaluate strategies.

[7] There are a number of names for this approach in the literature, which share similar methodologies. These include: Multi-Criteria Decision Analysis, Multi Criteria Evaluation, Multi-Criteria Preference Analysis, Multi Objective Evaluation, Multi-attribute Decision Analysis, Multi-attribute Utility Analysis, etc.

## Developing Metrics

An important component of strategy scoring is the development of metrics. While stakeholders and City staff dedicated significant time to the establishment of Integrated Planning goals and objectives, a standard of measurement was needed to evaluate how well the strategies achieved these goals and objectives and how well the strategies compared to one another.

**Metrics:**
*Measurable properties by which efficiency, performance, or progress can be assessed*

To accomplish this, a set of metrics was developed that includes a method of measurement. Table 4.2 provides examples of several metrics that were identified and how these are measured. Because metrics must be measureable, they are often quantitative. They may also be qualitative as long as there is a translation into a quantitative format. For instance, the "Stormwater Management Plan produced" in Table 6.1, is qualitative, but it is translated to a quantitative metric by incorporating a measuring

*Table 6.1 Example metrics and associated methods of measurement*

| Metric | Method of Measurement |
|---|---|
| Average yearly pollutant load reduction | Pounds of TN, TP, and TSS reduced<br>Billion CFU of E.coli reduced |
| Percent increase towards meeting monthly geomean WQS compliance | Comparison of modeled E.coli concentration in the James River with the WQS standard |
| Riparian buffer restored/increased | Acres of riparian buffer |
| Partnerships implemented for Integrated Planning | Number of partnerships |
| Stormwater Management Plan produced | 1=yes, 0=no |
| Amount of water conserved | Gallons |

scheme of a scale of 0 or 1.

At least one metric was identified for each objective. An example is included in Table 6.2, which shows one of the Clean Water Planning goals. This goal includes several objectives (three of which are included here). Each objective is evaluated by at least one metric.

*Table 6.2 Example of goal, objectives, metrics, and how metric is measured*

| Goal | Objectives | Metric | Measure of Metric |
|---|---|---|---|
| Protect and restore aquatic and terrestrial habitats to support balanced indigenous communities | Restore streams to improve, restore, and enhance native ecological communities. | Streams restored | Feet (of stream restored) |
| | | Reduce stormwater volume discharging to streams | Millions of gallons |
| | | Riparian buffers restored and/or increased | Acres (of buffer restored) |
| | Identify, protect, and restore critical habitats. | Habitat protected or restored | Acres (protected or restored) |
| | Enhance aquatic and terrestrial habitat connectivity. | Habitat connected by green corridor | Acres (included in "green corridor") |

Appendix C includes the complete list of the goals, objectives, metrics, and Appendix D (the Excel-based Strategy calculator tool, discussed below) also includes the raw scores that were identified for each strategy.

## Raw Scores for Metrics

Each strategy was then given a raw score for each metric. Table 6.3 takes the example from Table 6.2 a step further and shows how a raw score is assigned to a metric. These scores can come from sources, such as the Integrated Plan model (e.g., number of extra days of bacteria compliance), from the literature (e.g., nitrogen reduced by an infiltration-based stormwater BMP), or from stakeholder input (e.g., number of acres of conservation easements that can be added).

*Table 6.3. Example of how raw scores are assigned to each metric*

| | Riparian Areas Strategy | MS4 Green Infrastructure Strategy | Stream Restoration Strategy |
|---|---|---|---|
| **Goal:** Protect and restore aquatic and terrestrial habitats to support balanced indigenous communities | | | |
| **Objective:** Restore streams to improve, restore, and enhance native ecological communities | | | |
| **Metric:** Streams restored (in feet) | 0 | 0 | 2,500 |
| **Metric:** Reduce stormwater volume discharging to streams (in millions of gallons) | 3 | 30 | 0 |
| **Metric:** Riparian buffers restored and/or increased (in acres) | 10 | 0 | 6 |

Once the raw scores were input into the calculator tool they were normalized and weighted. Normalization was performed to account for the various units represented (acres, pounds, feet, etc.). The normalized, weighted scores for each of strategies were summed to produce one score for each strategy. These final scores allowed strategies to be compared to one another. The calculator tool (in

Appendix D) includes all of the formulas necessary for one to understand how these final scores are developed. Additionally, a call-out box on page 53, explains the concept of normalization further.

# Strategy Analysis

As discussed above, there are multiple "puzzle pieces", or factors, that were taken into consideration in the analysis of strategies (Figure 6.2). The **Permit** puzzle piece represents the VPDES permit-related requirements that establish pollutant reduction targets by which the strategies were compared.

The Strategy Score "puzzle piece" involved using the calculator tool to evaluate **strategy scores** in several different ways. These analyses included evaluating:

- Permit-related metrics – metrics that related to total Nitrogen (TN), total Phosphorus (TP), total suspended solids (TSS) and bacteria were isolated in the calculator and scores associated with just these metrics were used to evaluate the effectiveness of strategies in reducing these pollutants of concern
- Standardization of strategies addressing permit-related metrics – strategies, which varied in size, were all standardized to 10 acres to compare these permit-related metrics in an "apples to apples" manner
- All metrics – including the full set of metrics associated with all of the objectives in addition to the pollutant-related metrics
- Standardization of all metrics – comparing how the same sized strategies (all 10 acres) address all metrics

The calculator tool was also tied to the **Strategy Cost** information. Metrics specific to pollutant reductions (e.g., pounds of pollutant removed by a strategy) were used to calculate Cost Effectiveness. Overall, strategy costs were then evaluated in association with Affordability.

Another puzzle piece, **Modeling Results**, provided the bacteria reductions associated with several strategies that were used as raw score inputs into the calculator. Modeling results also provided information pertaining to the relative nature of bacteria sources to the James River and tributaries.

Each of these specific analyses is discussed in more detail below.

## The Permit

### Establishing Targets

Stakeholders and City staff have dedicated significant time to the establishment of Integrated Planning goals and objectives as well as strategies to help ensure these are achieved. While stakeholder concerns ranging from pollutant reduction to habitat restoration and invasive species removal are all considered in the Clean Water Plan, it is essential to remember that there are VPDES permit-related requirements that must be addressed and therefore, these requirements are key drivers behind the Plan. Therefore, it is important to understand that these VPDES permit requirements are water quality-focused and this permit-driven approach inherently prioritizes efforts that help improve water quality in Richmond's waters. Determining the extent to which water quality needs to be improved and the targets that help guide these improvements is a key step in the strategy analysis. Once these targets are determined, the next step is to evaluate how the strategies themselves help the City best (efficiently and effectively) achieve these targets.

One pollutant the City must work toward reducing is bacteria. Table 6.4 includes the existing bacteria (*E.coli*) loads and the allowable pollutant loading (the Waste Load Allocation, or WLA) for the City's MS4 (as documented in the Bacteria TMDL Action Plan based upon the James River Bacteria TMDL) and for the CSO/WWTP discharges (as documented in the James River Bacteria TMDL). These loads and the WLAs are summed in this table to provide an overall bacteria reduction by watershed addressed by the TMDL.

*Table 6.4. E.coli Bacteria reduction requirements for Richmond's WWTP/CSS and MS4 systems*

| | MS4 | | | WWTP | | | CSO | | |
|---|---|---|---|---|---|---|---|---|---|
| | Existing Load | WLA | Load Reduction Target | Existing Load | WLA | Load Reduction Target | Existing Load | WLA | Load Reduction Target |
| Bacteria (BCFU) | 606,312 | 221,842 | 384,470 | 6,792 | 444,000 | (437,208) | 16,511,684 | 3,025,710 | 13,485,974 |

What Table 6.4 shows is that the MS4 and CSOs in particular are still the biggest sources of bacteria and will drive additional reductions. The WWTP is reducing bacteria efficiently. The existing bacteria load from the plant, therefore, is far below the WLA, which produces a "credit" for bacteria (this negative number is denoted by parenthesis around the load reduction target).

The City also has total Nitrogen (TN), total Phosphorus (TP), and total suspended solids (TSS) pollutant loading reduction targets driven by the Chesapeake Bay TMDL. TN and TP reductions are also reflected in the VPDES Watershed General Permit for Nutrient Discharges to the Chesapeake Bay. Table 6.5 identifies the WLA and reduction goals associated with the City's WWTP and its CSOs as well as with its MS4 program.

*Table 6.5. TN, TP, and TSS reduction requirements for Richmond's WWTP/CSS and MS4 systems*

| | MS4 | | | WWTP | | | CSO | | |
|---|---|---|---|---|---|---|---|---|---|
| | Existing Load | Waste Load Allocation | Load Reduction Target | Existing Load | Waste Load Allocation | Load Reduction Target | Existing Load | Waste Load Allocation | Load Reduction Target |
| TN (lbs) | 166,955 | 154,901 | 12,054 | 338,328 | 1,093,652 | (755,324) | 141,759 | 409,557 | (267,798) |
| TP (lbs) | 19,813 | 17,262 | 2,550 | 29,411 | 55,754 | (26,343) | 17,720 | 31,642 | (13,922) |
| TSS (lbs) | 6,327,579 | 5,223,204 | 1,104,375 | 361,031 | 847,754 | (486,723) | 2,303,581 | 3,396,550 | (1,092,969) |

Table 6.5 shows that the WWTP is very efficient in reducing these pollutants and resulting load reduction targets for Nitrogen, Phosphorus, and sediment are not only met, but exceeded.

As will be discussed in further in Chapter 9, the intent of the watershed-based integrated VPDES permit is to look at the City's source sectors collectively to determine greatest impacts. In an effort to do this, bacteria, nutrient and sediment targets for the MS4, WWTP, and CSOs are aggregated (Table 6.6).

*Table 6.6. Aggregated annual load reduction targets*

| | Waste Load Allocation | Existing Load | Load Reduction Target |
|---|---|---|---|
| TN (lbs) | 1,658,110 | 647,042 | (1,011,068) |
| TP (lbs) | 104,658 | 66,943 | (37,715) |
| TSS (lbs) | 9,467,508 | 8,992,191 | (475,317) |
| Bacteria (BCFU) | 3,691,552 | 17,124,789 | 13,433,236 |

These aggregated annual load reduction targets reflect the effectiveness of the WWTP in reducing nutrients and sediment in general. While this Clean Water Plan will still continue to emphasize additional reductions of these pollutants in the MS4 and its impacts to tributaries in particular, this information helps inform DPU as to where its most significant pollutant reductions are needed. This information will be taken into consideration in the following analyses and how this influences strategy prioritization.

## Strategy Scores

### Permit-Related Metrics

Permit-related metrics are defined as those that address TN, TP, TSS, or bacteria (the pollutants of concern). Through the population of the Excel-based strategy scoring calculator, each strategy was evaluated to determine what amount of, if any, pollutant reduction was achieved. Table 6.7 includes the strategies that are expected to result in reductions in permit-targeted pollutants associated with the Chesapeake Bay TMDL (TN, TP, and TSS) and bacteria TMDL (for compliance with recreational water quality standards). The values in Table 6.7 are excerpted from the strategy scoring calculator. How well each of these strategies addresses these pollutants is also conveyed in this table by color coding the cells based on the strategies that best address these pollutants of concern:

- **Green** – address all pollutants of concern (light green addresses fewer metrics)
- **Orange** – Address nutrients and sediments, but not bacteria
- **Red** – don't address any pollutants of concern, but can be used as supplemental strategies that can be incorporated as appropriate and as resources and opportunities allow

*Table 6.7. How strategies address pollutants of concern**

| | Riparian areas | GI in MS4 | GI in CSS | Stream restoration | Natives/ invasives | Trees | Land conservation | Water conservation | Pollution ID | CSOs / WWTP Infrastructure |
|---|---|---|---|---|---|---|---|---|---|---|
| Objective: Reduce nitrogen, phosphorus, and sediment in discharges to achieve VPDES permit requirements (Chesapeake Bay TMDL). | | | | | | | | | | |
| Average yearly TN load reduction (lbs) | 19 | 414 | 74 | 188 | 0 | 30 | 0 | 11 | 448 | 7,066 |
| Average yearly TP load reduction (lbs) | 4 | 90 | 16 | 170 | 0 | 4 | 0 | 1 | 162 | 903 |
| Average yearly TSS load reduction (lbs) | 1,081 | 42,397 | 7,393 | 75,013 | 0 | 447 | 0 | 422 | 57,893 | 116,843 |
| Objective: Reduce bacteria levels to achieve VPDES permit requirements (local TMDL and water quality standards). | | | | | | | | | | |
| Percent increase in monthly geomean WQS compliance | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| Average yearly E.coli load reduction (billion cfu) | 83 | 3,531 | 40,642 | 0 | 0 | 0 | 0 | 0 | 0 | 3,551,112 |
| Average yearly reduction in CSO events (number) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Average yearly reduction in CSO volume discharged (million gallons) | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 962 |

*(Associated with the goal: Manage wastewater and stormwater to improve the water quality and water quantity of ground water and surface water.)

The results of this comparison show the following:

- Strategies that address all pollutants including TN, TP, TSS and bacteria
  - CSO/WWTP Infrastructure
  - Green Infrastructure (in the MS4/CSS areas)
  - Riparian Areas
- Strategies that address TN, TP, TSS, but not bacteria
  - Stream restoration
  - Trees
  - Water conservation
  - Pollution identification

Additionally, strategies that can be implemented, but do not help achieve permit requirements include:

- Native/invasives
- Land conservation

The "raw" scores in Table 6.7 were then normalized and weighted (additional information on these processes is included on the call-out box on the following page). These values are included in Table 6.8.

*Table 6.8. Normalized and weighted scores of strategies in addressing pollutants of concern**

| | Riparian areas | GI in MS4 | GI in CSS | Stream restoration | Natives/ invasives | Trees | Land conservation | Water conservation | Pollution ID | CSOs / WWTP Infrastructure |
|---|---|---|---|---|---|---|---|---|---|---|
| Objective: Reduce nitrogen, phosphorus, and sediment in discharges to achieve VPDES permit requirements (Chesapeake Bay TMDL). | | | | | | | | | | |
| Average yearly TN load reduction (lbs) | 0.3** | 6.8 | 1.2 | 3.1 | 0.0 | 0.5 | 0.0 | 0.2 | 7.4 | 116.0 |
| Average yearly TP load reduction (lbs) | 0.5 | 11.6 | 2.0 | 21.8 | 0.0 | 0.5 | 0.0 | 0.2 | 20.9 | 116.0 |
| Average yearly TSS load reduction (lbs) | 1.1 | 42.1 | 7.3 | 74.5 | 0.0 | 0.4 | 0.0 | 0.4 | 57.5 | 116.0 |
| Objective: Reduce bacteria levels to achieve VPDES permit requirements (local TMDL and water quality standards). | | | | | | | | | | |
| Percent increase in monthly geomean WQS compliance | 0.0 | 0.8 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 87.0 |
| Ave. yearly E.coli load reduction (billion cfu) | 0.0 | 0.1 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 87.0 |
| Average yearly reduction in CSO events (number) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 87.0 |
| Average yearly reduction in CSO volume discharged (million gallons) | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 87.0 |
| **Score** | 1.9 | 61.4 | 12.9 | 99.4 | 0.0 | 1.5 | 0.0 | 0.8 | 85.7 | 696.2 |
| **Rank** | **6** | **4** | **5** | **2** | **9** | **7** | **9** | **8** | **3** | **1** |

*(Associated with the goal: Manage wastewater and stormwater to improve the water quality and water quantity of ground water and surface water.)

** All scores multiplied by 100 for clarification purposes. Total score may be off due to rounding.

### *Normalizing & Weighting Scores*

The intent of the strategy scoring process is to produce a value that demonstrates how well each strategy addresses the metrics of interest. The metrics used to evaluate the strategies; however, can vary in the way they are measured (e.g., pounds of total Nitrogen reduced, acres of impervious surface treated, etc.). Because of the varying units represented, raw scores cannot simply be added together to obtain a score for each strategy. A normalization process is required to adjust these raw scores to a common scale.

To accomplish the normalization process, the raw score is divided by the maximum of the raw scores associated with that particular metric. In the example below, each of the numbers in the red box would be divided by 7,066 to produce the associated normalized scores for this metric.

Additionally, because the metrics may not all be of equal importance, various weights were also applied to them. In the example below TN reduction was considered most important and given a higher weight (50%) than the other metrics. Normalized scores are multiplied by the associated weight to produce a final weighted, normalized score. In the example below, each of the normalized scores in the orange box is multiplied by 50% to produce the associated values in the green box. A strategy's weighted, normalized scores are added together to produce a final score for that strategy. In the example below, Strategy B, with a score of 30, best achieves these four metrics.

***Example scoring process***

| | | Raw Scores | | | Normalized Scores | | | Weighted, Normalized Scores | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | Strategy A | Strategy B | Strategy C | Strategy A | Strategy B | Strategy C | Strategy A | Strategy B | Strategy C |
| **Average yearly TN load reduction (lbs)** | 50% | 19 | 11 | 7,066 | 0.003 | 0.002 | 1.0 | 0 | 0 | 1.2 |
| **Average yearly E. coli load reduction (BCFU)** | 20% | 83 | 0 | 3,551,112 | 0 | 0 | 1 | 0 | 0 | 0.9 |
| **Impervious Surface reduced or treated (acres)** | 15% | 2 | 5 | 0 | 0.4 | 1 | 0 | 6 | 15 | 0 |
| **Potable water consumption reduced (gallons)** | 15% | 0 | 0 | 250 | 0 | 1.0 | 0 | 0 | 15 | 0 |
| **Total** | 100% | | | | | | | 6 | 30 | 2.1 |

The normalized, weighted scores for each strategy are summed, which results in a final score for the strategy. The top ranked strategies for achieving key pollutant reduction include:

1. CSO/WWTP Infrastructure
2. Stream Restoration
3. Pollution Identification
4. GI in MS4

### "Standardization" of Permit-Driven Metrics

As previously stated, the numeric targets of the strategies were based on the amount of DPU/PRCF land/resources available for that particular strategy. As a result, each strategy addresses a different amount of area (e.g., 10 acres of land for riparian area restoration vs. 104 acres of land in the MS4 for implementation of green infrastructure, etc.). To evaluate strategies in a "standardized" manner (all strategies being comparable in size to one another in an "apples to apples" manner), strategies were evaluated as if they would be implemented on 10 acres of land (Table 6.9).

It is important to note that the CSO/WWTP strategy is based on reducing the combined sewer overflow volume and frequency, which is not based on acreage of implementation. As such, this strategy cannot be standardized in this way and is not included in the analysis reflected in Table 6.9.

*Table 6.9. How "standardized" strategies address pollutants of concern**

| | Riparian areas | GI in MS4 | GI in CSS | Stream restoration | Natives/ invasives | Trees | Land conservation | Water conservation | Pollution ID |
|---|---|---|---|---|---|---|---|---|---|
| Objective: Reduce nitrogen, phosphorus, and sediment in discharges to achieve VPDES permit requirements (Chesapeake Bay TMDL). | | | | | | | | | |
| Average yearly TN load reduction (lbs) | 19 | 40 | 41 | 327 | 0 | 4 | 0 | 22 | 1 |
| Average yearly TP load reduction (lbs) | 4 | 9 | 9 | 296 | 0 | 4 | 0 | 1 | 0 |
| Average yearly TSS load reduction (lbs) | 1,081 | 4,077 | 4,107 | 130,702 | 0 | 56 | 0 | 845 | 341 |
| Objective: Reduce bacteria levels to achieve VPDES permit requirements (local TMDL and water quality standards). | | | | | | | | | |
| Percent increase in monthly geomean WQS compliance | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average yearly E.coli load reduction (billion cfu) | 83 | 340 | 22,579 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average yearly reduction in CSO events (number) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Average yearly reduction in CSO volume discharged (million gallons) | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |

*(Associated with the goal: Manage wastewater and stormwater to improve the water quality and water quantity of ground water and surface water.)

Table 6.10 shows the normalized, weighted scores for these strategies standardized across 10 acres. Again, note that the CSO/WWTP strategy is not included in Table 6.10 as it cannot be standardized across 10 acres of land.

*Table 6.10. Standardized strategies that have been normalized and weighted for pollutants of concern**

| | Riparian areas | GI in MS4 | GI in CSS | Stream restoration | Natives/ invasives | Trees | Land conservation | Water conservation | Pollution ID |
|---|---|---|---|---|---|---|---|---|---|
| Objective: Reduce nitrogen, phosphorus, and sediment in discharges to achieve VPDES permit requirements (Chesapeake Bay TMDL). | | | | | | | | | |
| Average yearly TN load reduction (lbs) | 6.6 | 14.1 | 14.7 | 116.0 | 0.0 | 1.4 | 0.0 | 8.0 | 0.5 |
| Average yearly TP load reduction (lbs) | 1.5 | 2.8 | 3.0 | 116.0 | 0.0 | 0.2 | 0.0 | 1.1 | 0.0 |
| Average yearly TSS load reduction (lbs) | 1.0 | 2.4 | 2.5 | 116.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.3 |
| Objective: Reduce bacteria levels to achieve VPDES permit requirements (local TMDL and water quality standards). | | | | | | | | | |
| Percent increase in monthly geomean WQS compliance | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ave. yearly E.coli load reduction (billion cfu) | 0.3 | 1.3 | 87 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average yearly reduction in CSO events (number) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average yearly reduction in CSO volume discharged (million gallons) | 0.0 | 0.0 | 87.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Score** | 9.4 | 22.5 | 195.8 | 348 | 0 | 1.6 | 0 | 9.9 | 0.8 |
| **Rank** | **5** | **3** | **2** | **1** | **8** | **6** | **8** | **4** | **7** |

*(Associated with the goal: Manage wastewater and stormwater to improve the water quality and water quantity of ground water and surface water.)

** All scores multiplied by 100 for clarification purposes

## All Metrics

While evaluating key permit related pollutants is important, numerous other metrics were also identified for other goals and objectives (Appendix C). Table 6.11 shows the score (obtained from the strategy scoring calculator) for each strategy that takes all of the metrics collectively into consideration.

*Table 6.11 – Scores and ranks of all feasible strategies – total acres/resources available*

| | Riparian | GI in MS4 | GI in CSS | Stream Restoration | Natives/ Invasives | Trees | Land Conservation | Water Conservation | Pollution ID | CSO/ WWTP |
|---|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 54.90 | 57.53 | 39.88 | 47.82 | 43.10 | 44.80 | 42.02 | 45.00 | 35.29 | 46.22 |
| **Rank** | 2 | 1 | 9 | 3 | 7 | 6 | 8 | 5 | 10 | 4 |

The results of the scoring process (including all metrics and strategies) results in the following ranking of strategies:

1. Green Infrastructure in the MS4
2. Riparian Area Restoration
3. Stream Restoration
4. CSO/WWTP Infrastructure

## "Standardization" of All Metrics

While these available acreages are very important for future implementation purposes, a "standardized" comparison of the strategies with regard to all other metrics was also performed. Again, this analysis assumed 10 acres of implementation for each of the strategies and, as discussed above, the CSO/WWTP strategy was not included in this standardized analysis as it cannot be evaluated on a 10-acre basis. The CSO/WWTP strategy is therefore evaluated separately below. Table 6.12 shows the scoring of the strategies if all were implemented on the same amount of acreage.

*Table 6.12 – Scores and ranks of feasible strategies – 10 acres for each strategy*

| | Riparian | GI in MS4 | GI in CSS | Stream Restoration | Natives/ Invasives | Trees | Land Conservation | Water Conservation | Pollution ID |
|---|---|---|---|---|---|---|---|---|---|
| **Scores** | 66.87 | 55.46 | 57.67 | 67.74 | 44.44 | 43.83 | 46.49 | 56.33 | 36.27 |
| **Rank** | 2 | 5 | 3 | 1 | 7 | 8 | 6 | 4 | 9 |

The results of these scores produce in the following top-ranked strategies:

1. Stream Restoration
2. Riparian Area Restoration
3. Green Infrastructure in the CSS area
4. Water Conservation

## Evaluation of CSS Infrastructure Projects

The CSS Infrastructure strategy was evaluated in previous sections as a whole, but this strategy consist of several different projects outlined in the LTCP, including:

- Installing wet weather interceptor in Lower Gillies to convey more flow to the WWTP
- Increasing WWT (wet weather treatment) at the WWTP to 300 MGD and expanding secondary treatment at the WWTP to 85 MGD
- Replacement of CSO 021 regulator and additional 2MG storage at CSO 021
- Expanding Shockoe retention basin by 15 MG to capture more overflow
- Disinfecting overflow at Shockoe retention basin (wet weather disinfection facility)

Each project was evaluated in isolation to determine individual impact on bacteria load reduction. These CSS "scenarios" are summarized in Table 6.13, below.

*Table 6.13. Description of CSS Projects Evaluated by the Water Quality Model*

| CSS Scenario | CSS Project Name | CSS Project Description |
|---|---|---|
| **Existing** | Existing Conditions | Existing sewer conditions, including all LTCP Phase I and Phase II projects. |
| **14-3** | Baseline Conditions | Includes the currently funded projects:<br>--CSO 028A & 028E disconnection<br>--WWTP wet weather treatment up to 140 MGD |
| **14-2** | Gillies Conveyance | Lower Gillies Wet Weather Conveyance Interceptor to convey more flow to the WWTP |
| **15-4** | 300 MGD Wet Weather Treatment | WWTP wet weather treatment up to 300 MGD |
| **15-5** | CSO 21 Replacement | Replacement of the CSO 21 regulator and additional 2MG storage |
| **18-4** | SRB Expansion | Shockoe retention basin (SRB) expansion to 15MG |
| **18-5** | SRB Expansion and Disinfection | SRB Expansion to 15MG and chlorine disinfection of the SRB discharge at CSO 06 |
| **19-3A** | Full LTCP | All 10 Phase III projects, Full LTCP achieved. |

Bacteria load reductions from each CSS scenario is shown in Figure 6.4, below.

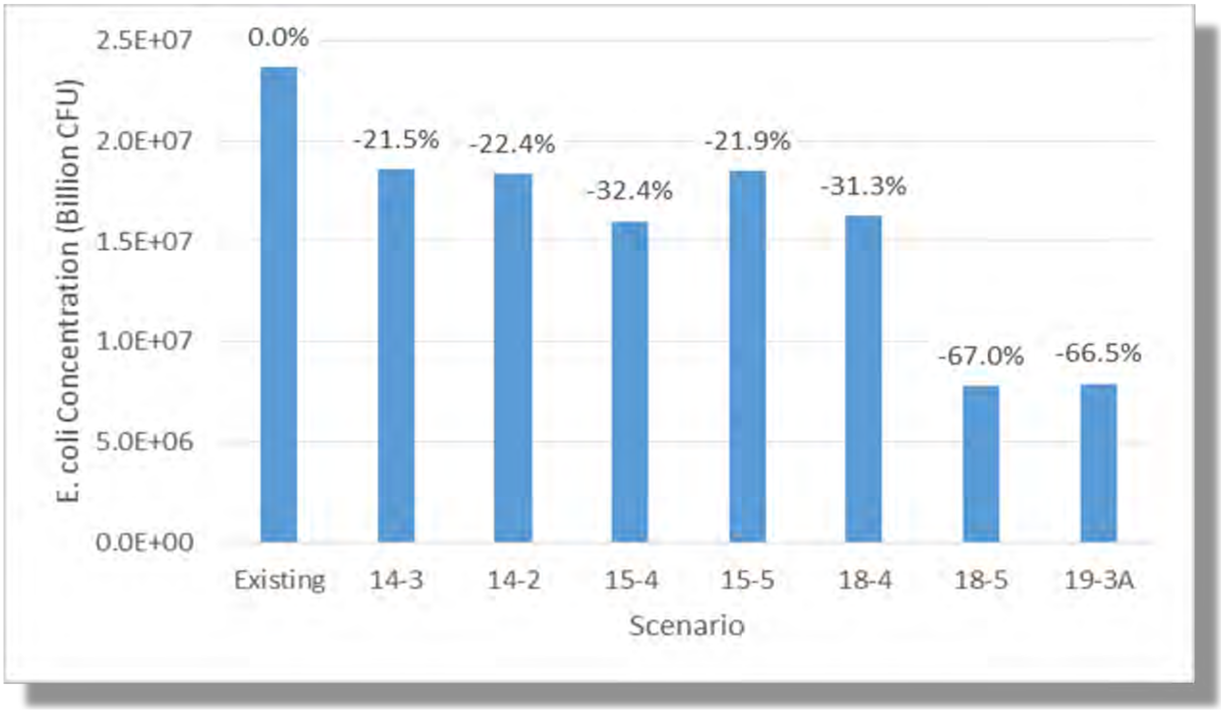



*Figure 6.4 Bacteria load reductions from each CSS Infrastructure Project*

Additional new projects, or variations to the existing projects, are currently being evaluated to determine if these alternative projects could accomplish similar or greater bacteria load reductions compared to the existing projects, and if this could be done in a more cost efficient way. Those alternative evaluations are currently ongoing, and include projects such as controlling discharge from CSO-040 and other combined sewer outfalls, and different types of disinfection for wet weather treatment at the wastewater treatment plant and at Shockoe retention basin.

## Comparison of Targets with Load Reductions

The aim of the Integrated VPDES permit is to more efficiently control the discharge of pollutants from all DPU sources. In order to do this, it is necessary to look at the ultimate targets and all the sources together and assess where it is possible to get the greatest gains. It is also important to recognize not all pollutants will be assessed in the same way, different pollutants have different impacts. Some pollutants have far field effects and can be assessed based upon total load delivered while others must be looked at based on localized effects. For instance, an aggregate approach can be done for TN, TP, and TSS because the TMDL allows the targets to be assessed for the City as a whole to ultimately achieve improvements downstream to the Chesapeake Bay. The bacteria numbers can also be aggregated to show the overall scale of needed reductions, but it must be remembered that bacteria allocations exist for specific watersheds, and those need to be met at the local scale, rather than at the aggregate scale. These aggregated targets are depicted in Table 6.14.

*Table 6.14. Aggregated Annual Load Reduction Targets*

| | Existing Load | Waste Load Allocation | Load Reduction Target |
|---|---|---|---|
| TN (lbs) | 647,042 | 1,658,110 | (1,011,068) |
| TP (lbs) | 66,943 | 104,658 | (37,715) |
| TSS (lbs) | 8,992,191 | 9,467,508 | (475,317) |
| Bacteria (BCFU) | 17,124,789 | 3,691,552 | **13,433,236** |

While Table 6.14 shows (on an aggregated scale) targets for TN, TP, TSS are already met, bacteria still needs additional reductions in order to meet targets. These targets can be compared to the load reductions achieved by the strategies, shown previously in Table 6.6.

## Costs

Financial constraints referred to in Figure 6.1 include the costs of the strategies and supporting actions and cost effectiveness of these strategies. Affordability is considered the overarching mechanism within which these elements can be paid for in an affordable manner by DPU. Each of these factors is discussed in more detail below.

### Strategy Costs

The cost associated with the full implementation of the strategies included in Table 5.1 was also estimated (Table 6.15). For the purpose of estimating costs most consistently across strategies, the assumption was that the strategy would be implemented in the first year of the permit (capital costs) with maintenance being required for the strategy in years two through five of the permit.

*Table 6.15. Cost of main strategies broken out by capital and maintenance*

| Main Strategy | Capital | O&M | Total |
|---|---|---|---|
| Riparian Areas | $900,000 | $200,000 | $1,100,000 |
| Green Infrastructure in the MS4 | $10,500,000 | $2,000,000 | $12,500,000 |
| Green Infrastructure in the CSS | $2,600,000 | $750,000 | $3,350,000 |
| Stream Restoration | $1,700,000 | $1,200,000 | $2,900,000 |
| Native/ Invasives | $70,000 | $95,000 | $165,000 |
| Trees | $1,600,000 | $600,000 | $2,200,000 |
| Land Conservation | $ - | $ - | $ - |
| Water Conservation | $220,000 | $ 50,000 | $270,000 |
| Pollution Identification & Reduction[8] | $16,385,000 | $ - | $16,385,000 |
| CSO Infrastructure[9] | $374,800,000 | $17,400,000 | $392,200,000 |
| **Total** | **$408,775,000** | **$22,295,000** | **$431,070,000** |

The cost of additional supporting actions was also estimated in Table 6.16.

[8] As street sweeping and catch basin clean-outs are ongoing efforts for the City, these activities are calculated for each of the five years of the permit.

[9] Note that the cost for the CSO Infrastructure strategy is over 30 years, while the costs of the other nine strategies are over five years.

*Table 6.16. Cost of supporting actions*

| Supporting Actions | |
|---|---|
| Partnerships | $700,000 |
| Monitoring, Assessments & Planning | $1,300,000 |
| Incentives/ Credits | $1,250,000 |
| Regs/ Ordinance/ Code | $ - |
| Outreach | $500,000 |
| **Total** | **$ 3,750,000** |

The source of all cost information as well as any assumptions that were made in association with the calculation of final cost estimates is discussed further in Appendix E.

## Cost Effectiveness

While cost is important from the perspective of how it can be achieved within a certain budget, cost effectiveness of a particular strategy can be more informative because it provides an indication of the return on the investment. Cost effectiveness was evaluated for each strategy for the permit-driven metrics (TN, TP, TSS, bacteria) discussed above, and expressed as cost per unit pollutant removed. Cost effectiveness comparisons in Table 6.17 are also based on the strategies that included the fill size/acreage/ resources (again it should be noted that the Natives & Invasives strategy and the Land Conservation strategy are not included in this table because neither, as they are written, results in the reduction of these key pollutants).

*Table 6.17. Pollutant reduction and associated cost effectiveness of strategies*

| | Riparian areas | GI in MS4 | GI in CSO | Stream restoration | Trees | Water conservation | Pollution Identification | CSOs / WWTP Infrastructure |
|---|---|---|---|---|---|---|---|---|
| **Average yearly TN load reduction (lbs)** | 19 | 414 | 74 | 188 | 30 | 11 | 448 | 7,066 |
| **Average yearly TP load reduction (lbs)** | 4 | 90 | 16 | 170 | 4 | 1 | 162 | 903 |
| **Average yearly TSS load reduction (lbs)** | 1,081 | 42,397 | 7,393 | 75,013 | 447 | 422 | 57,893 | 116,843 |
| **Average yearly E.coli load reduction (billion cfu)** | 83 | 3,531 | 40,642 | 0 | 0 | 0 | 0 | 3,551,112 |
| **Cost** | $1,100,000 | $12,500,000 | $3,350,000 | $2,900,000 | $2,200,000 | $270,000 | $16,385,000 | $392,200,000 |
| **Cost per pound TN removed** | $58,902 | $30,181 | $45,270 | $15,467 | $72,158 | $24,092 | $36,597 | $55,507 |
| **Cost per pound TP removed** | $292,553 | $138,687 | $209,375 | $17,059 | $520,833 | $195,744 | $100,882 | $434,293 |
| **Cost per pound TSS removed** | $1,017 | $295 | $453 | $39 | $4,925 | $639 | $284 | $3,357 |
| **Cost per billion E.coli removed** | $13,190 | $3,540 | $82 | -- | -- | -- | -- | $110 |

The green highlighted items in Table 6.17 identify those strategies that are most cost effective for the various pollutants.

## Affordability

The intent of the Clean Water Planning process is to make sure that each dollar spent gets the greatest environmental benefit. While this is important to rate payers in general, it is additionally important because the City already has a large number of people who are below the poverty line and currently can't afford their utility bills. So, while the City was evaluating ways to make smart water quality decisions, it was also looking for ways to keep rates affordable.

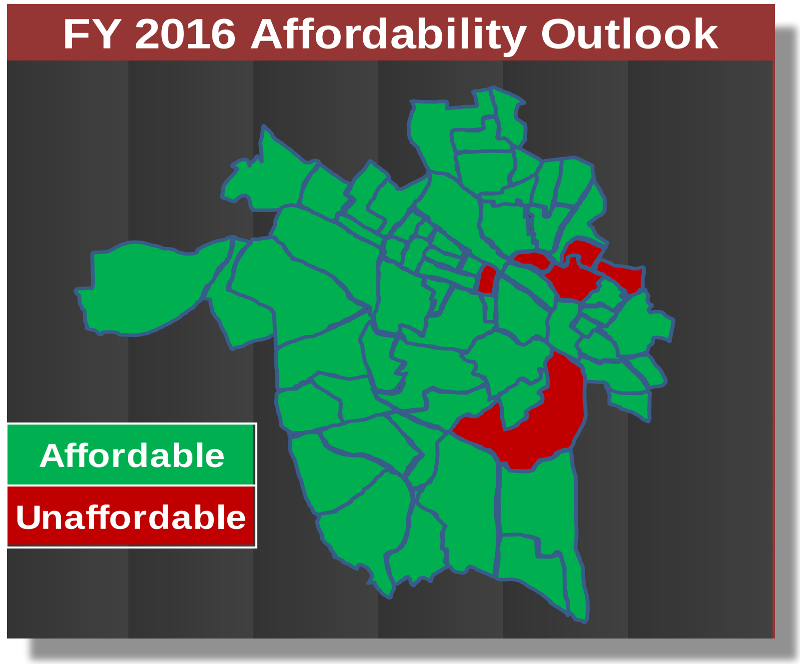



*Figure 6.2 With current rates, those census tracks that cannot afford utility rates in 2016*

While developing its Integrated Plan, DPU analyzed the impact annual spending would have on rates over time, and subsequently customer bills. This analysis was done to define and measure affordability, so that unaffordable bills and financial impacts can be mitigated to the greatest degree on an annual basis.

To accomplish this, DPU evaluated customer impacts on a localized level (at the census track level shown here) throughout the City by measuring bill impacts against various affordability and income metrics, like "living wages".

The results of this affordability analysis are summarized in Figure 6.2, demonstrating where rates are unaffordable by census tract. Between 2016 and 2045, the financial model shows the situation would get much worse (assuming rate increases remain at their current pace and economic conditions remain constant).

What this also shows is that if the City continues to attempt to comply with various water quality regulations with the "do everything, everywhere simultaneously" approach this is the probable outcome. Alternatively, the Clean Water Plan focuses strategic decisions for cleaner water faster, but in a more affordable way.

The budget within which strategies will be implemented within the Clean Water Planning effort have been set, or constrained, by affordability. It is important to note that a high cost of a given strategy may not take it off the table, but simply require it to be implemented over time or other strategies are prioritized ahead of it.

## Strategy Prioritization

The various "pieces of the puzzle", discussed above, were used to understand how to best prioritize activities for implementation. As each of these analyses tells only a piece of the story, it is important to look at these analyses collectively. What these analyses have shown is that no one strategy consistently scores the highest or performed the best across the analyses, however, several strategies consistently performed well (a summary of the analyses are included in Table 6.18; green highlighted information depicts those that consistently score highest).

To allow for the consideration of multiple factors in determining priorities, it was determined that rather than ranking 10 strategies individually, that strategies would be grouped into one of three tiers based on effectiveness (Figure 6.3). Tier 1 includes those strategies that best address metrics associated with the pollutants of concern (TN, TP, TSS, bacteria) as well as the non-pollutant related metrics. These strategies were also the most cost effective. Tier 2 also addressed pollutant and non-pollutant related metrics, but not as efficiently or cost effectively as those in the Tier 1 grouping. Tier 3 includes those strategies that do not address the pollutants of concern.

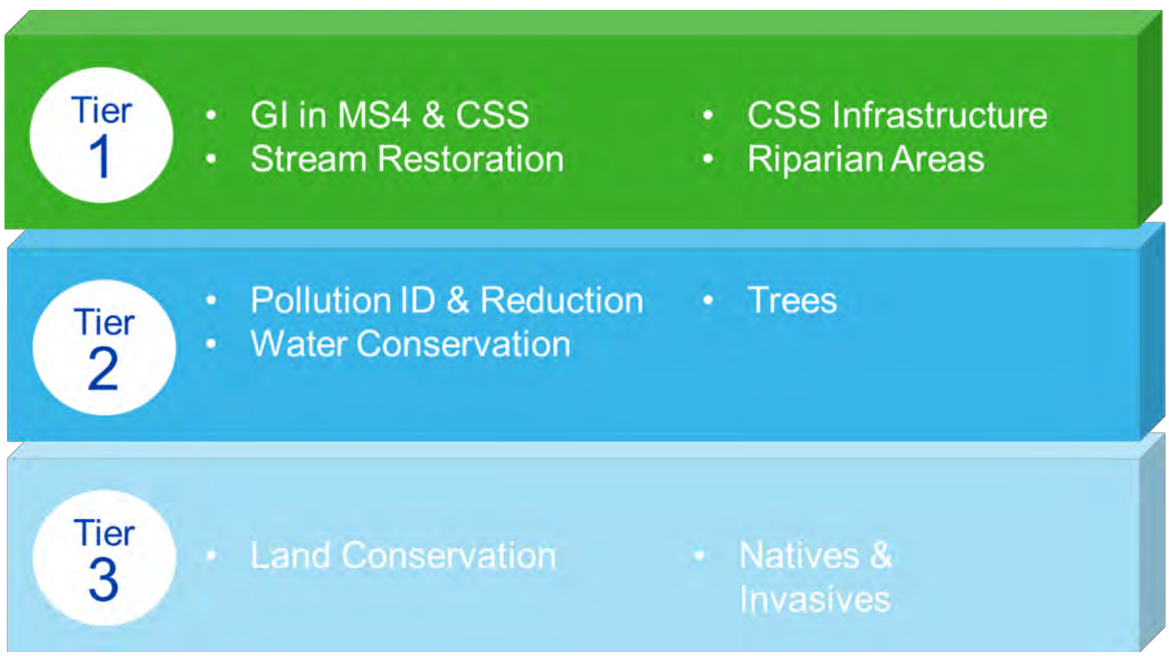



*Figure 6.3. Organization of strategies into tiers for prioritization*

It is important to note that while select strategies may be *prioritized* it does not mean that the remaining strategies will be disregarded. Implementation of these strategies will be assessed based on additional resources available to DPU or priorities and resources available from other City departments or other partners.

It is also important to note that this analysis was done at a high level. As DPU moves toward implementation and conducts a more refined evaluation of strategies, there may be modifications to this prioritization. For instance, the Green Infrastructure strategy includes bioretention, green roofs, permeable pavement, engineered tree boxes, rain barrels, and stormwater pond retrofits. If other green infrastructure practices are identified as alternatives, details, such as cost, amount of pollutant reduction, and how the practices achieves other metrics, will all be taken into consideration.

*Table 6.18 Summary of Strategy Analysis and Strategy Prioritization*

| Rank | Pollutants of Concern Metrics | Pollutants of Concern Metrics: Standardized* | All Metrics | All Metrics: Standardized* | Cost Effectiveness (TN) | Cost Effectiveness (TP) | Cost Effectiveness (TSS) | Cost Effectiveness (bacteria) |
|---|---|---|---|---|---|---|---|---|
| **1** | **CSO Infrastructure** | **Stream restoration** | **GI in MS4** | **Stream restoration** | **Stream restoration** | **Stream restoration** | **Stream restoration** | **GI in CSS** |
| **2** | **Stream restoration** | **GI in CSS** | **Riparian areas** | **Riparian areas** | Water conservation | Pollution ID and reduction | Pollution ID & reduction | **CSO Infrastructure** |
| **3** | Pollution ID & reduction | **GI in MS4** | **Stream restoration** | **GI in the CSS** | **GI in MS4** | **GI in MS4** | **GI in MS4** | **GI in MS4** |
| **4** | **GI in MS4** | Water conservation | **CSO Infrastructure** | Water Conservation | Pollution Identification | Water conservation | **GI in CSS** | **Riparian areas** |
| **5** | **GI in CSS** | **Riparian areas** | Water Conservation | **GI in MS4** | **GI in CSS** | **GI in CSS** | Water conservation | Water conservation |
| **6** | **Riparian areas** | Trees | Trees | Land Conservation | **CSO Infrastructure** | **Riparian areas** | **Riparian areas** | |
| **7** | Trees | Pollution ID & reduction | Natives/ invasives | Natives/ invasives | **Riparian areas** | **CSO Infrastructure** | **CSO Infrastructure** | |
| **8** | Water Conservation | Natives / invasives | Land Conservation | Trees | Trees | Trees | Trees | |
| **9** | Natives/ invasives | Land Conservation | **GI in the CSS** | Pollution Identification | | | | |
| **10** | Land Conservation | | Pollution ID and reduction | | | | | |

*WWTP/CSO strategy cannot be evaluated on a 10-acre basis so it is not included herein

# 7. Implementation Program

As discussed in Chapter 5, high-level strategies to achieve goals and objectives were developed to include quantifiable targets that DPU can work towards implementing (e.g., 10 acres of riparian buffer restoration, implementation of 104 acres of green infrastructure in the MS4 area of the City, etc.). An important part of this Clean Water Plan is developing an approach that can help the City implement these strategies in the most efficient and cost effective manner possible.

## Framework Planning

In order to most efficiently and effectively implement its IWPM Plan, DPU will use a "Framework Planning" approach. The Framework Planning approach provides a methodology that ties together different strategies (and, subsequently, site-specific projects) and, where possible, aligns these strategies with other City or stakeholder-driven initiatives.

This Framework Planning approach is intended to be:

- A comprehensive and action-oriented blueprint for near- and long-range decision making
- A planning guide for the implementation of a set of strategies and serves to create a "framework" around multiple other efforts (e.g. Master Plan, guidelines for new/existing development, other City planning efforts, etc.) to guide planning in a cohesive way
- Designed for flexibility and choices that will enable different entities (City Departments, partners, etc.) to act both collaboratively and independently, over different periods of time, but in a coordinated way

The goal of the Framework Planning approach is to identify and sequence a blend of activities that yield the greatest environmental benefit (as measured by identified metrics) in the most cost-effective (and affordable) manner.

### Framework Planning Process

As discussed in previous chapters, the Clean Water Planning process involved the development of goals and objectives, and high-level strategies that could meet these goals and objectives. For implementation purposes, these strategies will be translated into projects (e.g., 104 acres for the Green Infrastructure in the MS4 strategy could be implemented as 50 engineered tree boxes, 10 acres of permeable pavers, etc., which will, in total, drain 104 acres).

As depicted in Figure 7.1, strategies are prioritized (into Tiers, as discussed in Chapter 6) (#1), but they are still disparate strategies (#2). An example is the Green Infrastructure in the MS4 area strategy (which targeted 104 acres, 44 acres of which were estimated to include bioretention). Assuming each of these bioretention facilities drains one acre, 44 facilities would then be implemented across the City's MS4 area. Implementing these facilities in a piecemeal approach would still meet the target of implementing 44 acres and would still achieve pollutant load reductions estimated for these facilities.

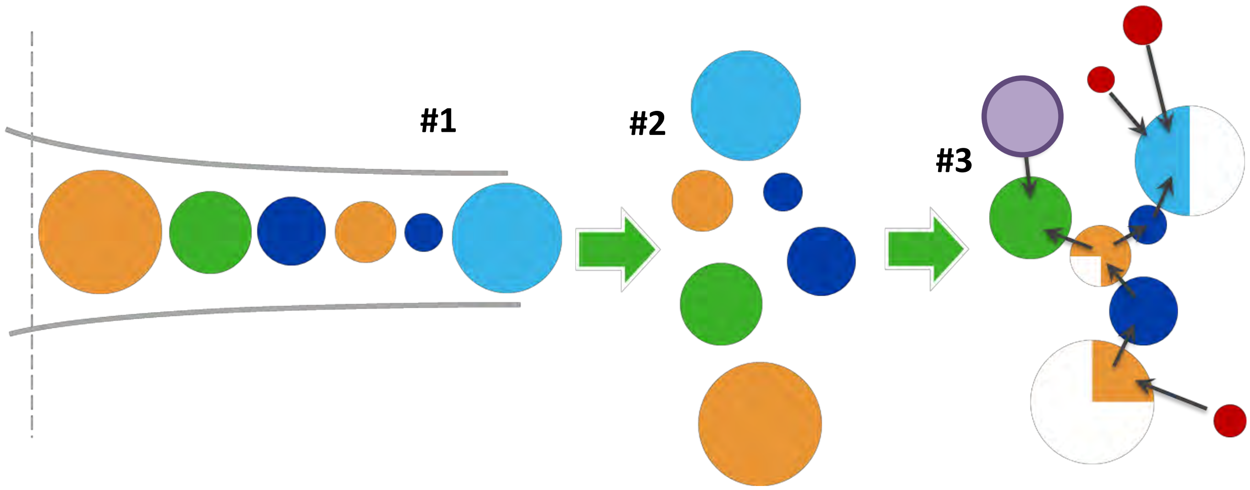



*Figure 7.1 Framework Planning includes the interface of various elements together in the landscape in a way that makes the most sense for implementation.*

Alternatively, DPU and its stakeholders can look collectively at the City for not only where the opportunities are for implementing bioretention, but where these practices can be implemented within the context of a more comprehensive planning and coordination effort under a Framework Planning umbrella. This Framework Planning process provides the structure for implementation of strategies/projects in a more integrated and cohesive way by leveraging opportunities with other city-led projects such as, for example, Richmond's Riverfront Plan, or stakeholder efforts such as, for example, EnRichmond's tree planting efforts (shown with the red and purple circles in Figure 7.1, #3). The Framework Planning process may also lead to the identification of new ideas and opportunities that can be pushed forward by DPU itself.

While DPU recognizes that some implementation may need to occur in a piecemeal fashion, its goal, where feasible, is that Framework Planning will drive implementation of the strategies. Framework Planning will meet the objectives and goals of the Clean Water Plan, while at the same time supporting and leveraging the overall growth and planning at the City or Stakeholder level.

An example of a Framework Planning-based clustered project is depicted in Figure 7.2, which is included in Arkansas' Conway Urban Watershed Framework Plan (2016). This example depicts Green Streets and parks that tie together the implementation of various types of green infrastructure while addressing other community needs, such as traffic calming, inclusion of recreational opportunities, and expanding parking. Figure 7.3 shows another example from the Conway Urban Watershed Framework Plan, which includes transportation corridors (streets and trails) and recreational amenities with riparian area restoration and green infrastructure. Additional detail on the Conway Framework Plan is included in the Case Study below, and provides additional context about what Framework Planning includes, and is consistent with the Clean Water Plan Framework Planning approach.

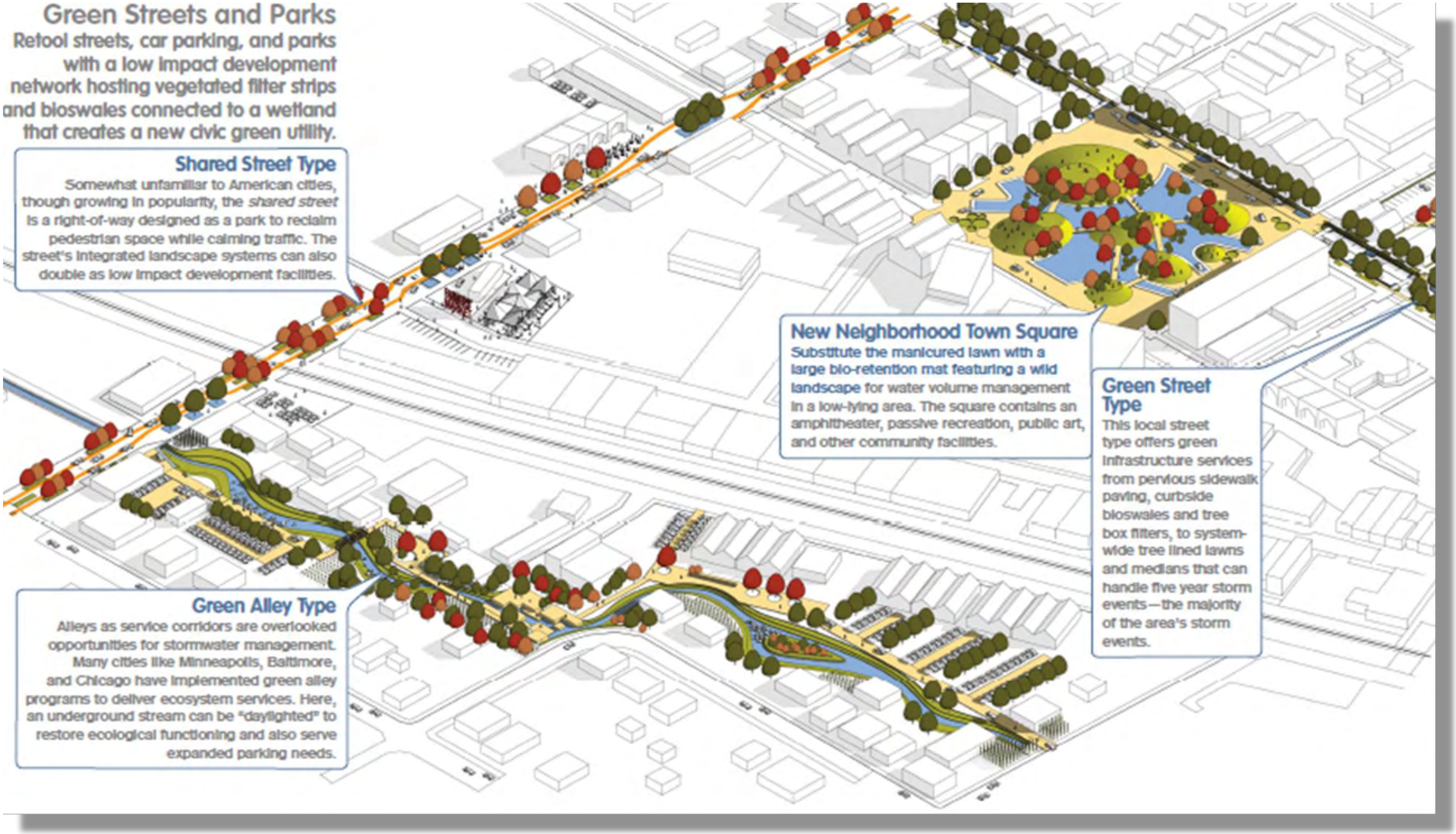



*Figure 7.2. Example from the Conway Urban Watershed Framework Plan that shows how multiple strategies (green infrastructure, trees, riparian areas, natives/invasives) can be implemented in holistic way that also addresses other City priorities (traffic calming, recreation, beautification, etc.)*

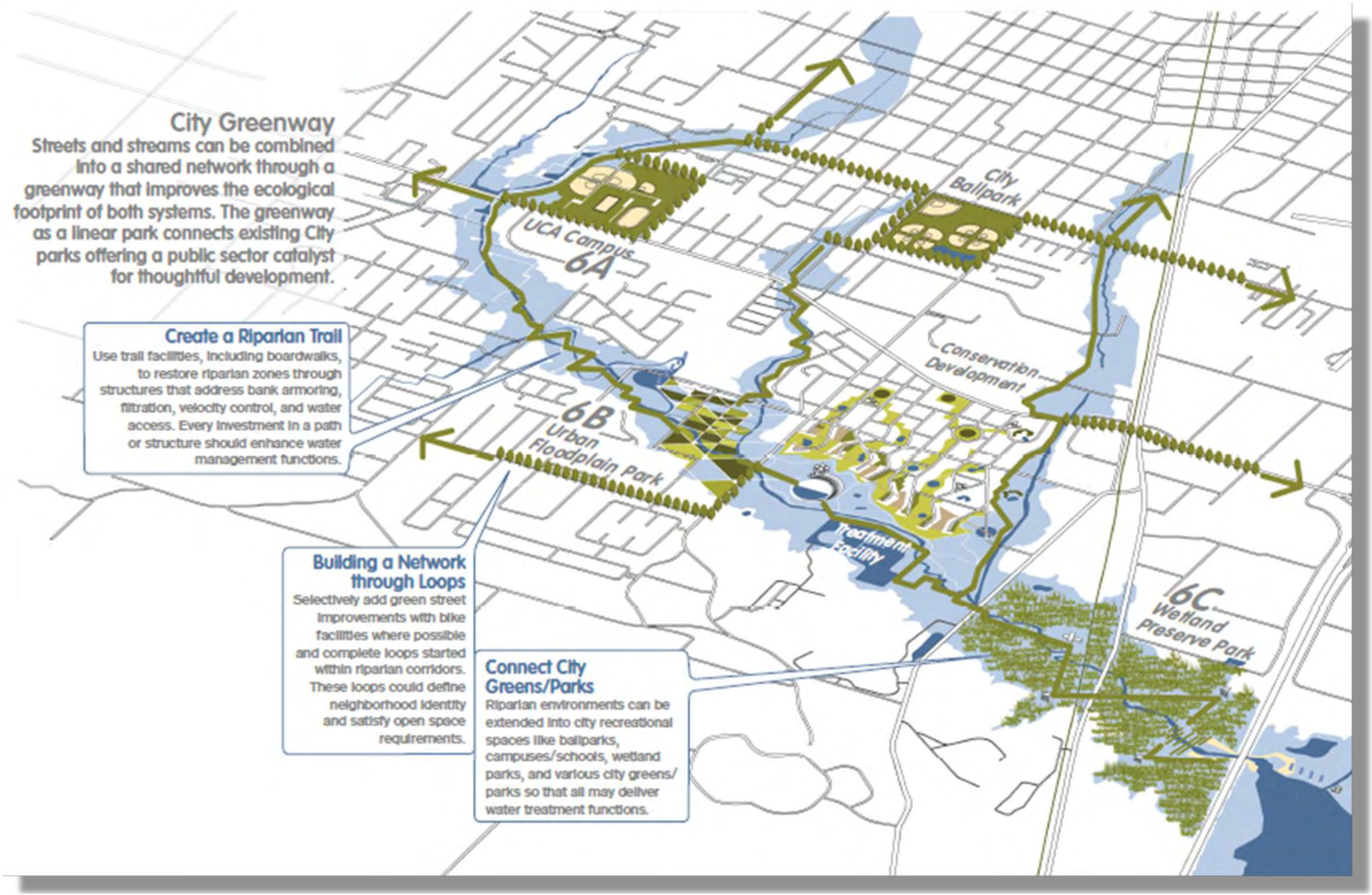



*Figure 7.3. Example from the Conway Urban Watershed Framework Plan that shows how Greenways can incorporate strategies like green infrastructure and riparian area restoration with transportation corridors, parks, etc.*

## *Case Study on Urban Framework Planning: Conway, Arkansas*

### *An excerpt from the Conway Urban Watershed Framework Plan*

*The Framework Plan operates evolutionarily through a set of retrofit types that are incremental, contextual, and successional. The Framework Plan is incremental, relying on participation from various interests— public, private, or a combination thereof—to develop projects as funding and opportunity permit. Projects can be implemented step-wise and successively across various fronts in the urbanized area. Unlike the master plan which is totalizing and shows only a climax condition, the Framework Plan can be pioneered beginning with modest cumulative efforts that cohere from shared ecological design practices.*

*The Framework Plan is contextual, working through landscape architectural adaptations responsive to local ecologies and urban water problems. Soft engineering accounts for local soils, and vegetative and wildlife communities in place-based solutions that substitute for universal metrics and costly "over-engineered" outcomes driven by worst-case scenarios. The goal is to deliver ecological services through installing sustainable soft infrastructure. Soft engineering's use of adaptive management lessens long-term maintenance burdens associated with hard-engineered infrastructure.*

*The Framework Plan is successional, understanding that cities are not built at once and that pioneer stages of development are rudimentary as they minimize start-up costs. The Framework Plan works initially through tactical demonstration projects, which if approved after assessment, can be mainstreamed into future projects and policies. This way the city or project developer can evaluate new practices without committing permanently to an untested development and business model. Cities do not have to retool policies without the chance to pursue due diligence. Stakeholders in decision-making, including the city and the area's new watershed alliances (e.g., the Lake Conway-Point Remove Watershed Alliance), can collaborate as learning communities removing adversarial relationships so redolent in municipal planning processes. Without demonstration projects, conventional development approaches will remain entrenched despite the presence of more value-added approaches.*

*The Framework Plan places Conway ahead of the curve in addressing the greatest ongoing challenge to planning: development of urban form in human-dominated ecosystems. More cities are tasking urban infrastructure with regeneration of diminished ecosystems to support livable communities. Besides solving for water management problems like flooding, the collateral benefits of implementing the plan include greater livability, sustained economic development, improved community resilience to disruption and shocks, and exemplary beauty in the civic realm that creates enduring value and symbolism.*

*(University of Arkansas Community Design Center 2016)*

The Framework Planning approach includes the following elements that are discussed further below:

1) Data and information gathering
2) Identification of potential opportunities
3) Prioritization
4) Plan development
5) Implementation

## Data and Information Gathering

A significant data gathering effort was undertaken early in the City's Clean Water Planning process with the development of the Watershed Characterization Plan and Water Quality Model that helped characterize Richmond's watersheds and the James River and tributaries. The type of data that was collected for these two efforts included, for example, impervious surfaces, impaired waterways, City-owned properties, existing stormwater BMPs, and water quality sampling data. The Framework Planning process will facilitate the identification of additional information deemed important to the City and stakeholders, including information such as, for example, ongoing or planned restoration projects or watershed-scale initiatives, places (parks, neighborhoods) that draws people in, and areas challenged by socio-economic issues. DPU initiated discussion of such information at its March 21, 2017 Technical Stakeholder meeting (Figure 7.4). This initial meeting included discussion of what stakeholders felt were existing needs or challenges in the City. This included not only water quality-related issues, but transportation or other socially-driven challenges.

*Figure 7.4. Initial Technical Stakeholder brainstorming session on challenges and opportunities to be considered in the Framework planning process*

Figure 7.5 depicts examples of other data types that will be looked at collectively through this process, including location of parks (or lack thereof), bike paths, priority conservation areas, commercial areas targeted for revitalization, etc.

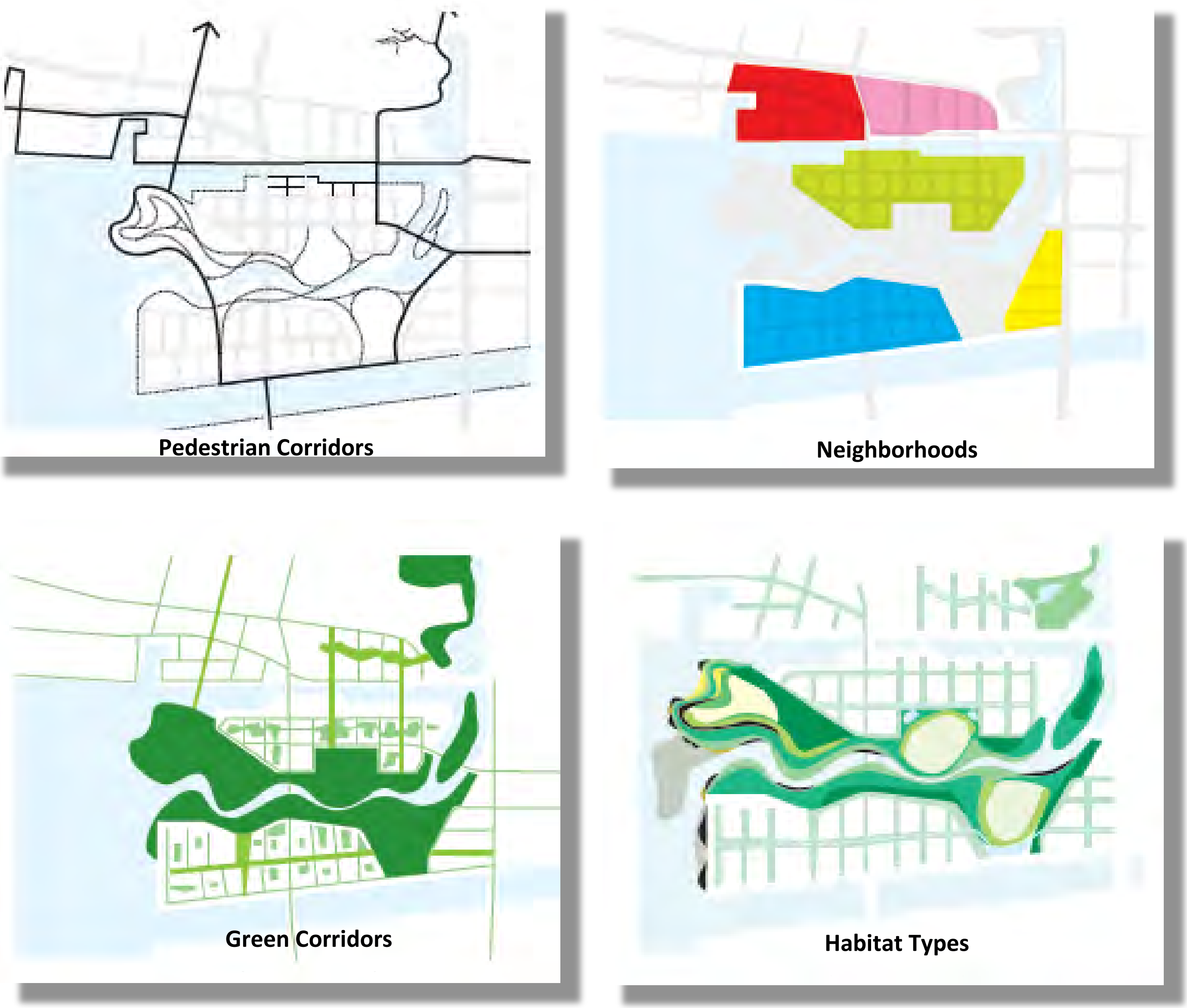



*Figure 7.5 Examples of data types that will be considered within the Framework Planning Process*

Several additional brainstorming meetings are scheduled to occur with Technical Stakeholders over the course of this project. Additionally, DPU will meet with other City departments to discuss opportunities for collaboration that will allow DPU to not only address its goals and objectives, but those of the City as a whole.

## Identification of Potential Opportunities

As meetings with stakeholders and City staff continue, they are expected to evolve from identifying available information, concerns, and areas of interest within the City, to evaluating and assessing this information, and ultimately identifying areas of potential opportunities where strategy implementation could occur through the leveraging of planned or existing initiatives.

For example, a stream, such as Goodes Creek requires bacteria reductions per the James River bacteria TMDL. In this same watershed, there are also Commercial Area Revitalization Effort (CARE) neighborhoods (yellow areas in Figure 7.6) that could be targeted for tree planting or implementation of green infrastructure for beautification purposes. Additionally, GIS analysis has identified stretches of Goode Creek as having deficient stream buffers (pink lines within the circled area in Figure 7.6). DPU and

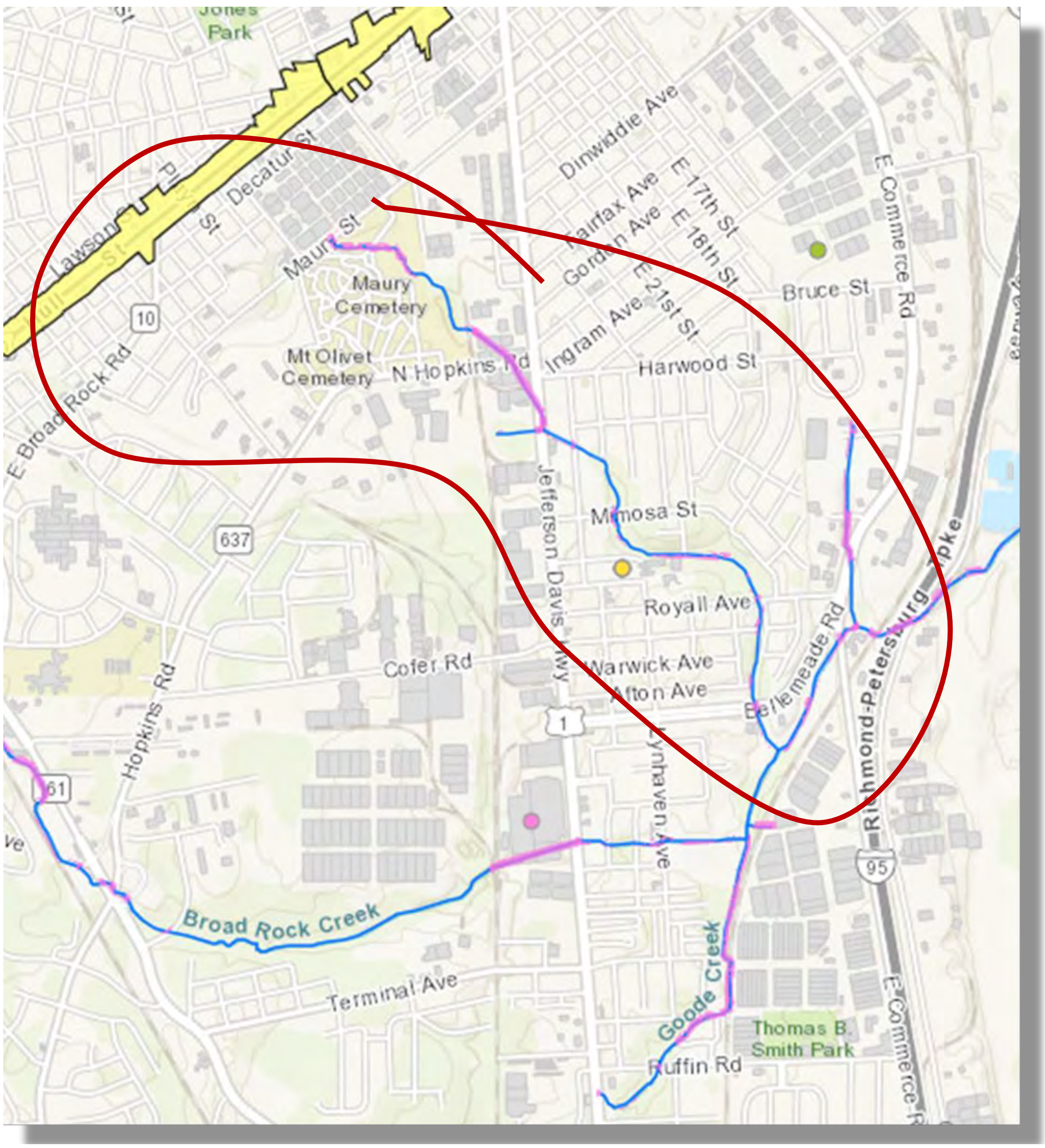



*Figure 7.6. ArcGIS online map depicting the region near Goode Creek that contains City park property (Maury Cemetery), CARE neighborhoods (yellow), and buffer deficient streams (pink)*

its stakeholders could identify potential project clusters such as these for additional evaluation of opportunities for strategy implementation.

## Prioritization

Once data and information have been assessed and opportunities for projects or project clusters have been identified, these must be prioritized for further analysis and subsequent implementation. Regardless of projects being implemented piecemeal or in an integrated manner, there may continue to be diverging priorities driving implementation. A key element of this Framework Planning effort will involve identifying criteria by which these projects or project clusters are prioritized. This criteria development process will involve discussions with Technical Stakeholders over the summer of 2017. Several examples of criteria that may be used to evaluate projects or project clusters include if they:

- Address priority pollutants (and how much)
- Address other metrics identified by stakeholders (and how much)
- Address public health concerns
- Can be enhanced by partner resources (staff, funding, etc.)
- Include an educational component
- Address the social or economic elements of the Triple Bottom Line (Figure 7.7)
    - Are environmental justice concerns addressed?
    - Are lower SES neighborhoods targeted?
- Account for the City's Affordability Analysis
    - Can it be implemented with existing resources or does it require additional funding?
- Have stakeholder support

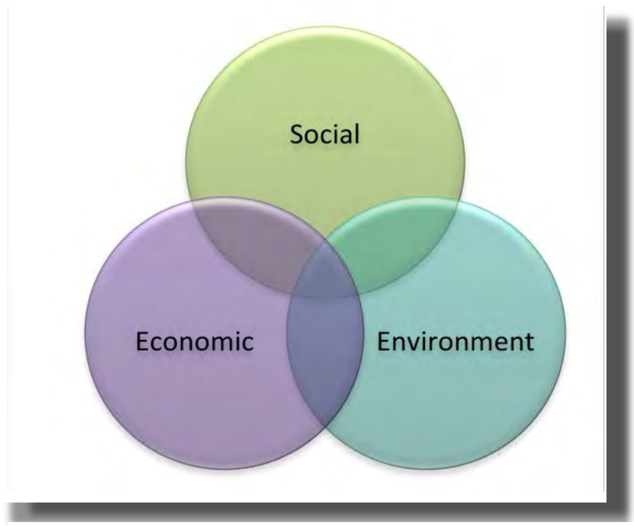



*Figure 7.7 Elements of the Triple Bottom Line*

Based on the number of criteria met, the projects/project clusters will be sorted into "very high", "high", "medium", and "low" priority projects. Additional detail on this prioritization process will be developed over the summer of 2017.

## Plan Development

The Framework Planning process and the identification and prioritization of projects and project clusters will be documented in the Framework Plan. The Framework Plan will also demonstrate how the projects and project clusters will meet the goals and objectives of the Clean Water Plan, including the numeric targets of the strategies.

### Schedule

The Framework Plan will reflect efforts to be implemented over the course of the five year permit cycle. While most of the strategies that have been developed for the Clean Water Plan are based on a five year timeframe, other, more resource intensive projects, such as those related to the CSO Infrastructure strategy, may require a longer time frame for full implementation. NPDES permits typically allow flexible compliance schedules for meeting the state WQS. These schedules can be as long as necessary to achieve the water quality objectives. The federal regulations specifically require the schedule in the permit to achieve limits "as soon as possible."

### Funding

An appropriate level of funding will be important to the success of the City's approach to integrated planning on a watershed basis. The various programs involved in this planning process (i.e., stormwater, wastewater, CSOs, drinking water) have funding mechanisms available to them. Specific project funding will be developed concurrently with the development of the City's annual budget cycle. DPU's funding sources will be evaluated to determine the anticipated costs, funds available, and any anticipated funding gaps. Overall, it will be imperative that implementation takes into account the findings of the City's affordability analysis, which is expected to be finalized in 2017.

## Implementation

The framework planning process will lead to the identification and prioritization of projects or project clusters that the City will fund for implementation. The sum of these projects will be consistent with the high level strategies defined in the Clean Water Plan.

There are several important concepts that will be taken into account through implementation. For instance, it is envisioned that implementation will occur incrementally over the course of the permit cycle (e.g., 10 acres of riparian buffers will not necessarily be restored all at once or within only one project, but may be addressed through the implementation of several projects/project clusters). Additionally, it may be determined that once more refined analysis is performed during or prior to the design/build phase of a project, that a particular project or project element cannot be achieved in its entirety. Flexibility is incorporated into implementation through adaptive management. If it is found that one strategy cannot be implemented in whole or in part, DPU will work to identify an alternative approach to achieving the same or similar pollutant reductions and other identified goals and objectives.

Implementation of projects, particularly those that involve stakeholders or other City departments, will require significant coordination. In addition to regular Technical Stakeholder meetings to provide updates on progress, DPU will convene a workgroup of those organizations involved in these implementation efforts. As projects are implemented, associated benefits (pollutant reductions, area treated, other metrics addressed) will be tracked as well. Measuring progress made under the Clean Water Plan as a result of project implementation is discussed further in Chapter 8.

# 8. Measuring Progress

Once targets have been established and strategies have been identified to address watershed goals, an approach must be developed to monitor and measure progress made in association with these implementation efforts. As the City's implementation moves forward, measuring progress will include determining if goals have been met, if progress has been deemed sufficient, or if changes should be made within the program to try to improve the level of progress made.

Determining the level of progress that has been made as a result of the City's investments is a key element to the success of the Clean Water Plan and its ultimate support by the public, stakeholders, and elected officials. Measuring progress; however, can be complex. Targets may be established at various scales (i.e., site scale, sub-watershed, watershed, city scale). Implementation actions can also include a wide range of options including structural and non-structural practices as well as practices that address various source sectors (i.e., stormwater, wastewater, non-point sources). As a result, the approach used for measuring progress under the City's program must be flexible enough to account for these variations in scale and options that will be employed to mitigate pollutants and meet the City's goals.

Measuring progress will be done in a holistic manner based on data from the City's monitoring programs, modeling efforts, and other programmatic information (e.g., implementation targets, such as miles of stream buffers restored per year or number of residents reached by outreach efforts). Each of these elements is outlined in Table 8.1 and is discussed further below.

*Table 8.1. Monitoring activities and associated outcomes implemented under the Clean Water Plan*

| | Activities | Outcomes |
|---|---|---|
| **Water Quality Monitoring** | Instream water quality, biological (e.g., macroinvertebrates), CSO and WWTP discharge monitoring | Progress made toward pollutant reduction targets in permit |
| | | Progress toward achieving WQS (e.g., measure improvement in aquatic life designated use) |
| | | Identify sources, stressors, or pollutants of concern |
| | | Identify trends over time |
| | BMP monitoring | Effectiveness of specific BMPs or source reduction efforts |
| | | Progress toward achieving WQS (e.g., measure improvement in aquatic life designated use) |
| **Programmatic Monitoring** | Tracking strategy implementation | Progress made toward strategy implementation goals (e.g., acres of green infrastructure implemented) |
| | | Progress made in pollutant reduction through strategy implementation (e.g., pounds of TN reduced through green infrastructure implemented) |

| | | |
|---|---|---|
| | | Progress made toward pollutant reduction targets identified in permit |
| **Modeling** | Receiving water, CSS, and watershed modeling and analysis | Progress made in bacteria WQS compliance |
| | | Progress made in bacteria load reduction |
| | | Progress made in reduction of CSO events or volume discharged |

Each element of this process to evaluate Clean Water Plan progress will occur on a regular/annual basis over the course of the permit. Reporting on each of these elements will occur annually per VPDES permit requirements. At the end of the permit cycle a more comprehensive review of the progress made within this integrated planning framework will be compiled and included with the next VPDES permit application.

## Water Quality Monitoring

As part of the watershed characterization effort, described in Chapter 3, historical water quality monitoring was compiled and evaluated including:

- James River monitoring carried out by VCU and other agencies
- In-stream monitoring of streams like Gillies Creek and other small tributaries within the city
- End-of pipe monitoring of CSO and WWTP discharges
- Data on other sources of pollution within the City

These data were organized and incorporated into a GIS-based geo-database. These water quality data were used to assess spatial and temporal trends, identify data gaps, and provide the water quality monitoring data needed to assess baseline conditions. Once implementation of the projects and programs in the Clean Water Plan has commenced, newly collected monitoring data can be used to evaluate changes from these baseline conditions.

### Monitoring Program Development

Drivers behind the development of a monitoring program are often the regulatory requirements specifying monitoring objectives or collection of specific data elements. For DPU, these requirements will stem from the VPDES permit. As the Clean Water Plan and associated integrated watershed-based VPDES permit is finalized, DPU will assess its existing monitoring program to determine if it will provide the data needed to achieve the objectives of the permit. Examples of monitoring objectives include:

- Assess spatial and temporal trends of monitoring sites along the James River and its tributaries
- Evaluate the performance of specific BMPs or source reduction efforts
- Evaluate the health of the City's waterbodies
- Identify or evaluate parameters of concern
- Identify or evaluate potential sources of stressors
- Assess progress toward permit targets

Permit-driven objectives along with the identification of any additional data needs will ultimately determine the monitoring design. For instance, to evaluate stressors in a watershed, targeted monitoring would be conducted upstream and downstream of a key source(s). Monitoring could include sampling during different environmental conditions (e.g. dry and wet weather, high and low flow, seasonal effects), and point source and BMP flow and quality sampling. Conducting biological and habitat assessments also provide links between instream conditions and pollutants.

Alternatively, to evaluate the overall health of the City's waterbodies, a probabilistic monitoring design would be developed that includes multiple randomly selected sites throughout the City. This approach would allow DPU to show overall conditions and, as Clean Water Plan implementation occurs over time, how integrated planning is benefitting the City's waterbodies.

In addition to DPU's own objectives, the City may want to determine if other local stakeholders have monitoring objectives that complement its own. Broader coordination can result in the development an integrated monitoring program that could broaden the scope of the monitoring plan while identifying efficiencies to reduce resources directed at monitoring efforts.

## Programmatic Monitoring

As a number of the City's watersheds reach past Richmond's borders and are impacted by sources outside the City's control, water quality monitoring efforts alone will not necessarily provide an accurate representation of the City's progress in achieving the goals and objectives of the Clean Water Plan. In addition to water quality monitoring, a programmatic approach will be evaluated to determine its effectiveness.

As discussed in Chapter 4, an extensive effort was undertaken to develop goals and objectives for this Clean Water Plan as well as strategies that would achieve these goals and objectives. Tracking these strategies to measure progress will occur in several ways.

### Tracking Strategy Implementation Targets

Each strategy was written to include quantifiable targets for implementation (e.g., acres of green infrastructure, acres of riparian area restored, miles of stream reengineered, etc.). Evaluating the extent to which the strategies are being implemented and targets are being met will be an important mechanism for tracking progress. If targets are not being met or strategies are not being implemented, the City will evaluate why this is the case and determine if other alternatives are available that will result in achieving the same or similar progress towards goals and objectives.

Strategies are comprised of multiple implementation efforts (e.g., all of the projects that would result in 104 acres of green infrastructure implementation in the MS4 area). DPU will continue to use several tools to track these projects. Currently, a database is used to track practices as they are implemented. The City's existing GIS will also serve as the basis for this tracking effort.

### Tracking Strategy Pollutant Reductions

Tracking the anticipated pollutant reductions associated with these strategies will also be an important component of measuring progress of the Clean Water Plan. EPA's Chesapeake Bay Program (CBP) has established pollutant reduction credits for many of the stormwater BMPs proposed in association with the Clean Water Plan strategies. To ensure consistency with the CBP and the targets established for the City through the Chesapeake Bay TMDL, these BMP credits will be used as the basis for tracking of pollutant reductions through implementation of strategies.

As strategies are implemented, associated pollutant reductions for total nitrogen, total phosphorus, and total suspended solids will be calculated. These credits will be tracked in a geodatabase, which will allow for the geolocation of associated projects within the City's various watersheds.

While the Chesapeake Bay TMDL pollutants have established pollutant reduction credits assigned to various practices, bacteria, the other key pollutant in this Clean Water Plan does not. As a result, bacteria reductions achieved through strategy implementation will be based on literature values as well as the results of modeling efforts (discussed further below).

### Comparing Pollutant Reductions to Targets

As discussed previously in Chapter 6, pollutant reduction targets (see Table 6.6) will be included in the City's VPDES permit. Tracking of progress toward these targets will help assess strategy implementation in the various watersheds[10]. This will help DPU determine if sufficient progress is being made, if larger implementation efforts are required, if more funding is necessary, or if additional partners are needed to increase implementation. To help make these determinations, funding and other staff resources and amount of stakeholder participation will be evaluated in comparison to implementation of programs and practices and, ultimately to environmental improvements. Based on Clean Water Plan evaluation, modifications will be made to the program as part of the Plan's adaptive management approach.

Evaluating pollutant reductions as well as locations of these reductions within the City will help DPU not only determine if targets are being achieved, but if various watersheds or sections of the City should receive additional focus for implementation.

## Modeling

The Modeling Framework will continue to be used as needed to evaluate the water quality improvements related to the implementation of projects and strategies. Metrics that will be evaluated by the Modeling Framework include progress made in bacteria WQS compliance, progress made in overall bacteria load reduction, and progress made in reducing CSO events or volume discharged. The quantification of these metrics will be used as part of the programmatic monitoring efforts (as discussed in the previous section).

[10] While water quality monitoring will be used, in part, to evaluate progress toward achieving targets, EPA's CBP promotes tracking of progress through credits applied to various implementation types. This approach will also be used to evaluate Clean Water Plan progress.

# 9. Next Steps

The Clean Water Plan has resulted in a comprehensive understanding of the City's watersheds and associated water resources. This includes an understanding of the pollutant sources and stressors within the City; the monitoring data that has been collected to date, as well as where additional data area needed; and the characteristics of the watersheds, such as soils and impervious surfaces. Additionally, the Clean Water Planning process has identified the goals and objectives and associated metrics that will guide the City moving forward. It also includes a plan for identifying control projects and programs that can be updated and adapted throughout the plan's implementation.

The next step is to use the Clean Water Plan to develop a watershed-based VPDES permit. Watershed-based permitting has been long supported by EPA and allows multiple pollutant sources to be managed under one permit. For Richmond, these pollutant sources are CSO, wastewater, and stormwater via the MS4 and direct drainage. The Clean Water Plan provides the planning framework and strategies to manage these sources and prioritize control projects based on their improvements to local waterways. Therefore, the Plan will be included in the VPDES permit as a source of data and provide information to be included in the "Special Condition" section related to BMPS to be implemented and additional monitoring to be done to track progress. The Clean Water Plan will also be included in the Permit Fact Sheet as an information source.

Once the watershed-based VPDES permit is issued to the City, next steps include implementing the projects and programs in the Clean Water Plan and conducting monitoring and modeling to measure progress towards the goals of the plan. While this first permit cycle will include targets consistent with the strategies identified in the planning process, continued implementation will be a long-term process that will span multiple five-year VPDES permit cycles. Therefore, the Clean Water Plan will require updating for each successive VPDES permit using the adaptive management approach described in the previous section. Future VPDES permits will be pursued as watershed-based permits until the Clean Water Plan is fully implemented.

The City will also continue to engage stakeholders to inform them of activities and associated progress towards the goals of the Clean Water Plan, and solicit their input on Plan updates. This engagement process will likely be simplified now that the considerable effort to develop the initial Plan has been completed.

More information on EPA's perspective on watershed-based permitting as it pertains to a watershed-based VPDES permit for the City is provided in the following section to illustrate the consistency between its requirements and the Clean Water Plan elements.

## Adaptive Management

The adaptive management approach to water resources and regional wastewater management is increasingly recognized as the most appropriate and economically efficient way to identify problems, assess alternative solutions, and implement targeted corrective actions.  The adaptive management approach has been, and will continue to be, implemented during each step of the Clean Water Planning process.

Adaptive management will be critical for the success of Richmond's plan as any new data collected through the course of this effort will need to be reviewed on a regular basis and used to refine/modify the Clean Water Plan so it is up-to-date and accurate. An adaptive management approach will also be a key component of the framework the City will use to monitor the progress made through the Clean Water Plan. As mentioned above, assessment of progress will involve periodic comparison to the various targets established through previous steps of this process.

While strategies include targets, the Clean Water Planning process includes an adaptive management component that provides flexibility should some unforeseen issue arise regarding a particular strategy. For example, it may be determined over time that green infrastructure in the MS4 is only feasible on 80 acres (rather than 104 acres), or it may be riparian area restorations will require more implementation on private land than originally calculated. In such situations, the City will have to evaluate ways to expand other strategies/opportunities to work toward achieving the Clean Water Plan's goals and objectives. This may include expanding other strategies so that a similar pollutant reduction is accomplished or measures of additional metrics are reached. Alternatively, as implementation moves forth, stakeholders or additional Departments within the City may participate more than originally planned. This could add resources, expand implementation, and potentially result in efficiencies that can further streamline the Clean Water Plan effort.

Adaptive management can also be informed by the monitoring conducted by the City. If water quality monitoring data are not showing expected improvements, the Clean Water Plan can be modified to increase levels of implementation, accelerate implementation schedules, alter BMP types planned for the watershed, etc. For example, a watershed where BMPs have been implemented, but in which the water quality or biological communities do not show improvement, may need additional implementation efforts. Alternatively, upstream water quality monitoring (e.g., from outside the City's boundaries) may show that the water quality upstream is also not meeting WQS, which may explain the lack of improvement despite BMP implementation. In contrast, improved water quality or functioning of biological communities may show that the implementation has been successful. It should be emphasized, however, that BMP implementation often results in a significant (years, decades) lag time in instream response to this implementation. This will be taken into consideration when evaluating progress. An alternative situation may occur where WQS are not being met, but a local biological community is no longer impaired. In such an instance, a use attainability analysis (UAA) may be warranted and would offer an alternative to expending money and resources to implement projects in areas that are not causing exceedance of the WQS.

While adaptive management will play a key role in keeping the City's planning efforts on track, it should be noted that implementation of a sufficient amount of control to meet the City's goals may take many years. Once controls are implemented, it may take even more time for in-stream benefits to be measurable, especially in the biological community or habitat conditions. The tracking framework will take long-term implementation into account and will be reflected within the tracking of targets.

## Watershed-based VPDES Permit

The intent of the Clean Water Plan is to feed into an Integrated VPDES permitting process. The CWA (§ 402) established the NPDES permit (VPDES in Virginia) as the primary tool for controlling point source discharges, and therefore municipal discharges. An integrated approach would then allow the City to address all of its regulatory requirements (stormwater, CSOs, wastewater) as well as source water protection within the same plan thereby providing better and more efficient coordination of requirements.

Watershed-based permitting is an integrated approach to developing VPDES permits for multiple point sources within a defined geographic area (watershed boundaries).

The primary difference between this and the traditional approach to permitting is the consideration of watershed goals and the impact of multiple pollutant sources and stressors, including nonpoint source contributions, to receiving waters.

For many years, the EPA has supported and encouraged a watershed approach to addressing water quality problems. The approach is very flexible so watershed-based permitting can encompass a variety of activities ranging from synchronizing permit issuance, review and renewal of NPDES permits within a basin, to developing water quality-based effluent limits using a multiple discharger modeling analysis. One key component in the overall watershed-based permitting process is the integration of programmatic requirements. The watershed-based permitting framework provides the structure for examining a specific area and all of the stressors within that area, data related to the stressors and water quality goals, and prioritizing actions based on those data.

### US EPA Support of Watershed-based Permitting

*As discussed in more detail in Richmond's Methodology for Integrated Watershed Management (2014), EPA developed several guidance documents upon which the City has based its approach for Watershed-based permitting. These guidance documents include:*

*- Committing EPA's Water Program to Advancing the Watershed Approach (2002)*

*- Watershed-based National Pollutant Discharge Elimination System (NPDES) Permitting Implementation Guidance (2003)*

*- Watershed-based NPDES Permitting Technical Guidance (2007)*

Additionally, as described in EPA's 2003 Watershed-based Permitting Policy:

> *A holistic watershed management approach provides a framework for addressing all stressors within a hydrologically defined drainage basin instead of viewing individual sources in isolation. Within a broader watershed management system, the watershed-based permitting approach is a tool that can assist with implementation activities. The utility of this tool relies heavily on a detailed, integrated and inclusive watershed planning process. Watershed planning includes monitoring and assessment activities that generate the data necessary for clear watershed goals to be established and permits to be designed to specifically address the goals.*

This Clean Water Plan provides the mechanism for identifying goals and pollutant sources that may impact the goals. This Plan also provides the framework for consolidating DPU's sources (MS4, CSO, WWTP) together and determining the best distribution of investment in these sources to produce the greatest environmental gain.

The watershed-based permitting process provides the tools to apply resources to protect the goals and serves as the mechanism to drive integrated planning in the City. The permit will include a "Special Condition" that will recognize specific components of the Clean Water Plan. The permit will require data collection that will serve to support the evaluation of program effectiveness. The permit will also include controls (limits or pollutant reduction targets) that look collectively at DPU's various sources and allow the City to work toward the goal of greater environmental benefit.

This approach was successfully demonstrated with the issuance of the watershed-based permit to Clean Water Services in Oregon. The permit provided for trading between point and nonpoint sources to address temperature issue in the receiving water. Additionally, the Neuse River Compliance Association holds a permit for discharges from 20 WWTPs in the watershed. These entities all share a collective nutrient limits that they must achieve collectively.

In the case of Richmond, a single permit will be appropriate given the discharges are all controlled by DPU. Regardless of format, the permit will focus on watershed needs.

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# Appendix 1. Modeling Report

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# 1 Executive Summary

## 1.1 Introduction

In 2014, the City of Richmond began a multi-year effort to develop an Integrated Water Resources Management Plan (herein after called the RVA Clean Water Plan). The goal of this plan is to achieve improvements to water quality that will help the city meet its regulatory obligations under the Clean Water Act (CWA). Part of the Clean Water Plan involves developing strategies for the coordinated management of the City's water utilities, including wastewater treatment, drinking water treatment, stormwater runoff, combined sewer overflows (CSOs), and sanitary sewer overflows (SSOs), all of which are assets that are typically permitted and managed separately. By holistically considering all of the City's water utilities in the development of the Clean Water Plan, the City will be more efficient and cost-effective with their ratepayer-funded resources, and provide greater benefit to local waterways than the traditional siloed approach used for permitting and management.

A key step towards the development of the Clean Water Plan was the development of a water quantity and quality modeling framework. The purpose of the modeling framework is to quantify present day bacteria (*Escherichia coliform [E.coli]*) loads and concentrations in the James River and to predict future bacteria loads and concentrations under the RVA Clean Water Plan-related strategies. The modeling framework also allowed for the quantification of discharge flows and volumes, as well as the occurrence of CSO events. Additionally, the modeling framework provides a platform for comparing the CSO reduction projects included in the City's CSO Long Term Control Plan (LTCP) against alternative CSO reduction projects that may provide similar benefits but at a reduced cost.

The purpose of this report is to document the development, calibration, and application of these models.

## 1.2 Model Development

Three models were used to achieve the modeling objectives, and together they comprise the modeling framework (Figure 1-1). These three models include:

- A watershed model to simulate flow and bacteria loads from contributing areas of tributaries to the James River within the greater Richmond area, as well as from Richmond's Municipal Separate Storm Sewer System (MS4), but excluding the combined sewer system (CSS) service area. This model was developed using the EPA Storm Water Management Model (SWMM) software.
- A collection system model to simulate flow and bacteria loads from the CSS. The CSS model is an existing model that is used by the City of Richmond for Wastewater Master Planning to support implementation of the CSO Long Term Control Plan and to prepare the Annual CSS Reports. This model was developed using the EPA SWMM software, and was adapted for use in this study.
- A receiving water quality model that computes bacteria concentrations in the James River resulting from the various sources of bacteria to the river. The outputs of the watershed and CSS models are used as inputs to the receiving water quality model. The receiving water quality model was developed using the EPA-supported Environmental Fluid Dynamics Code (EFDC) software.

Water quality data were used to inform the development and calibration of the models. Section 2.2 contains detailed figures showing the extent and key features included for each model.

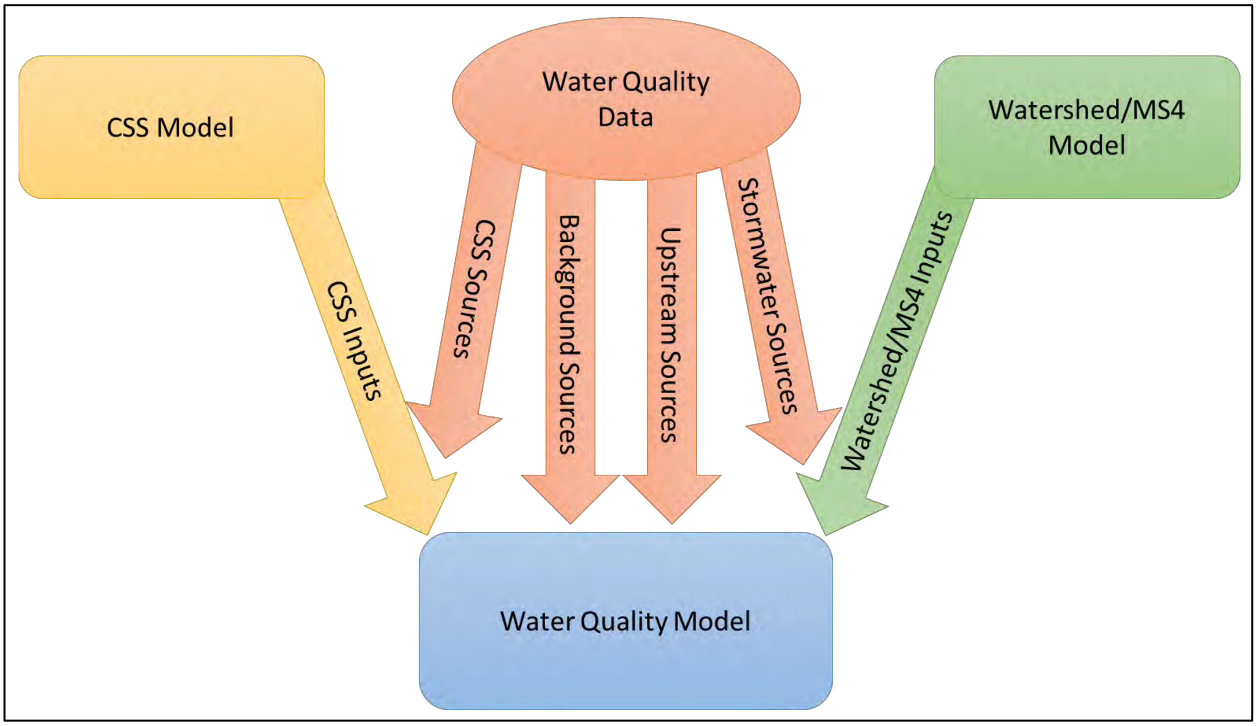



**Figure 1-1: Modeling Framework Schematic**

## 1.3 Model Calibration

- Model calibration is the process of adjusting model parameters and assumptions within defensible ranges to achieve reasonable agreement between modeled and observed environmental conditions. The calibration process demonstrated that the modeling framework is sufficiently well calibrated to support the following modeling objectives:
- Design the modeling framework to provide a reliable and reasonably complete accounting of bacteria sources to the James River;
- Develop the modeling framework using sufficiently complete and accurate site specific data;
- Calibrate the models using reasonable assumptions consistent with the site data, literature, and professional judgment;
- Achieve a level of model accuracy that is adequate to support decision making;
- Apply the models for a period including a wide range of common environmental conditions (i.e. river flow and precipitation conditions); and,
- Evaluate and synthesize model output to interpret major sources of current bacteria water quality impairment and to forecast future bacteria water quality conditions.

## 1.4 Model Application

After the water quality modeling tools were developed and calibrated, they were jointly applied to assess water quality benefits associated with the selected strategies. For this purpose, the model was applied for a 3-year simulation period, 2011 through 2013, that includes an average rain year (2011), a dry year (2012, less than normal precipitation), and a wet year (2013, more than normal precipitation). To date, the model has been applied to evaluate the following conditions or strategies:

- Current conditions: Best representation of current conditions, and includes all the combined sewer system improvement projects that were included in Phase I and Phase II of the CSO Long Term Control Plan.
- Baseline Conditions: represents the current conditions, plus all the currently funded Phase III CSS improvement projects from the LTCP.
- Green Infrastructure in the MS4 Area Strategy: represents the baseline conditions, plus the implementation of 104 acres of green infrastructure on city-owned area in the MS4.
- Green Infrastructure in CSS Area Strategy: represents the baseline conditions, plus the implementation of 18 acres of green infrastructure on city-owned area in the CSS area.
- CSS Infrastructure Strategy: Implementation of CSS projects included in the LTCP: represents the baseline conditions, plus all the remaining unfunded Phase III collection system improvement projects from the LTCP.

The sequencing of the modeling applications is shown in the figure below.

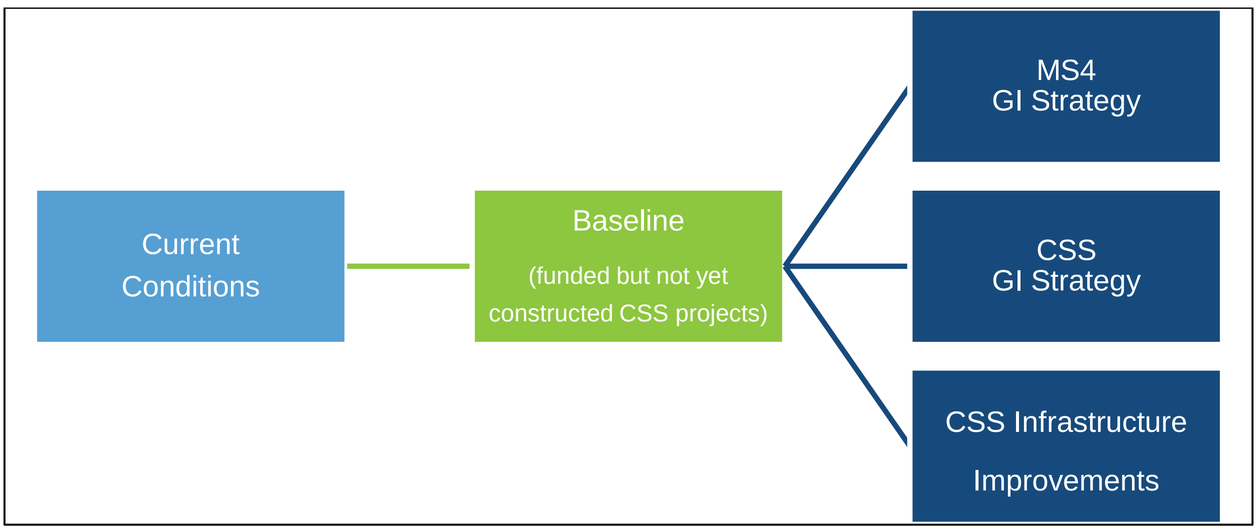



**Figure 1-2: Sequencing of Model Applications**

These strategies were evaluated using several metrics related to bacteria reduction, including:

- Bacteria load reduction from combined sewer and tributary discharges (which can include pollutant loads from the City's MS4), expressed as billion CFU per year
- Overall average percent increase in monthly geometric mean (geomean) water quality standard (WQS) compliance in the James River at the downstream city limit
- Reduction in number of CSO events per year
- Reduction in CSO volume, expressed as million gallons per year

These water quality benefits were then entered into an Excel-based strategy scoring calculator tool that integrates the benefits of strategies across a wide range of Goals and Objectives. More information on the strategy calculator can be found in Appendix D of the RVA Clean Water Plan. Water quality benefits were also assessed on a monthly basis relative to the two existing water quality standards: a monthly geometric mean standard and a statistical value threshold (STV) standard.

## 1.5 Major Model Findings

Major findings of the water quality modeling are as follows:

- Current *E.coli* bacteria water quality standards are sometimes exceeded in the James River in Richmond.
- The two largest contributors to exceedances of WQS are sources upstream of the City of Richmond and CSOs.
- Eliminating the City of Richmond bacteria sources alone would not achieve compliance with WQS in the James River.
- Reducing CSOs via the RVA Clean Water Plan strategies would improve compliance with WQS.

## 1.6 Future Use of Model

The Modeling Framework will continue to be used as needed to evaluate the water quality improvements related to the implementation of projects and strategies. Additionally, it is anticipated that the modeling framework will be applied during the summer and fall of 2017 to evaluate alternative CSS reduction projects that may provide similar benefits to the LTCP projects, but at a reduced cost. Metrics that will be evaluated by the Modeling Framework include progress made in bacteria WQS compliance, progress made in overall bacteria load reduction, and progress made in reducing CSO events and volume discharged.

# 2 Introduction

In 2014, the City of Richmond began a multi-year effort to develop an Integrated Water Resources Management (IWRM) Plan (herein after called the RVA Clean Water Plan). The goal of this plan is to achieve improvements to water quality that will help the city meet its regulatory obligations under the Clean Water Act (CWA). Part of the Clean Water Plan involves developing strategies for the coordinated management of many of the City's water utilities, including wastewater treatment, drinking water treatment, stormwater runoff, combined sewer overflows (CSOs), and sanitary sewer overflows (SSOs), all of which are assets that are typically permitted and managed separately. By holistically considering all of the City's water utilities in the development of the Clean Water Plan, the City will be more efficient and cost-effective with their ratepayer-funded resources, and provide greater benefit to local waterways than the traditional siloed approach used for permitting and management.

A key step towards the development of the RVA Clean Water Plan was the development of a water quantity and quality modeling framework. The purpose of the modeling framework is to quantify present day bacteria (*Escherichia coliform [E.coli]*) loads and concentrations in the James River and to predict future bacteria loads and concentrations under the Clean Water Plan-related strategies. The modeling framework also allowed for the quantification of discharge flows and volumes, as well as the occurrence of CSO events. The purpose of this report is to document the development, calibration, and application of these models.

## 2.1 Model Purpose, Objectives, and Functions

The purpose of the modeling framework is to quantify present day *E.coli* concentrations in the James River and to predict future *E.coli* concentrations under management strategies that were developed by the city and stakeholders. The following modeling objectives supported the attainment of this project goal:

- Design the modeling framework to provide a reliable and reasonably complete accounting of *E.coli* sources to the James River;
- Develop the modeling framework using sufficiently complete and accurate site specific data;
- Calibrate the models using reasonable assumptions consistent with the site data, literature, and professional judgment;
- Achieve a level of model accuracy that is adequate to support decision making;
- Apply the models for a period including a wide range of common environmental conditions (i.e. river flow and precipitation conditions); and,
- Evaluate and synthesize model output to interpret major sources of current water quality impairment and to forecast future water quality conditions.

The following report documents how these objectives were achieved through the process of selecting, developing, calibrating, and applying the water quality modeling framework.

## 2.2 Model Selection

Three models, which comprise the Modeling Framework (Figure 2-1), were used to achieve the modeling objectives. These three models include:

- A watershed model to simulate flow and *E.coli* loads from contributing areas of tributaries to the James River within the greater Richmond area, as well as from Richmond's Municipal Separate Storm Sewer System (MS4), but excluding the combined sewer system service area;
- A collection system model to simulate flow and *E.coli* loads from the combined sewer system (CSS); and
- A receiving water quality model that computes *E.coli* concentrations in the James River resulting from the various sources of *E.coli* to the river.

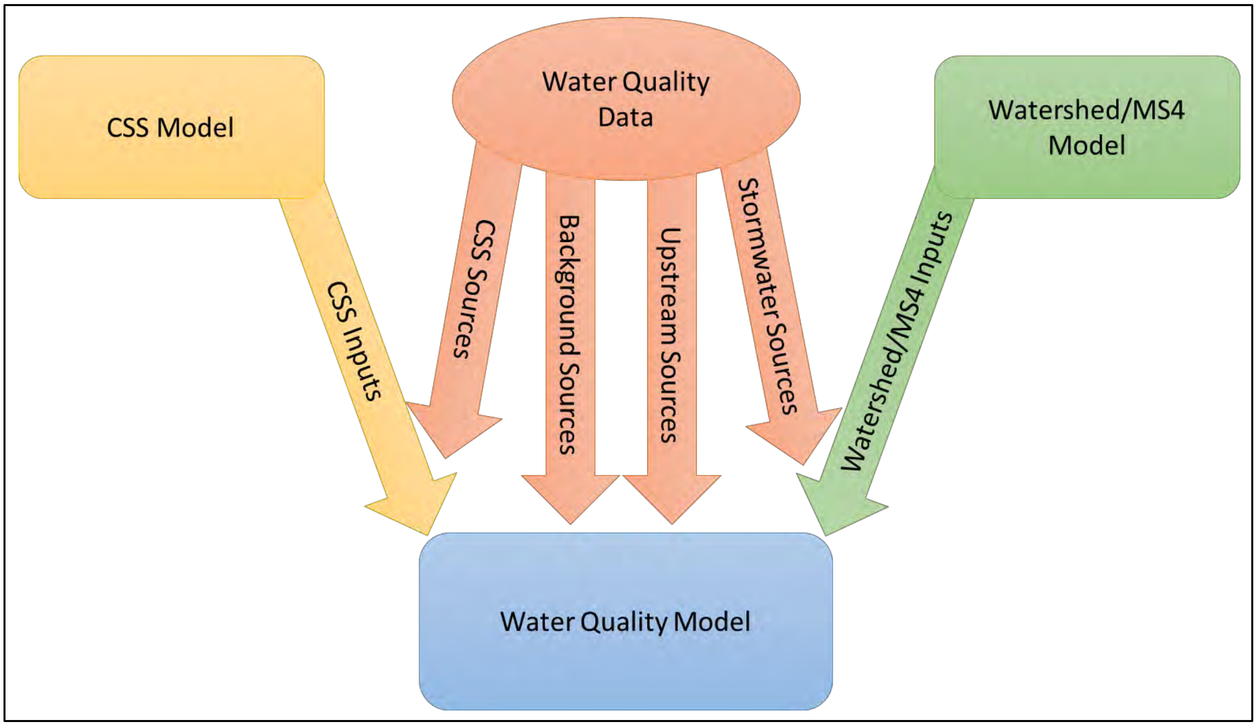



**Figure 2-1: Modeling Framework Schematic**

### 2.2.1 Watershed Model

Many watershed model software packages are available and these models vary in their recognition by USEPA and their applicability to the James River and its tributaries. The watershed model framework applied for this project is EPA Storm Water Management Model (SWMM), which is supported by the USEPA and has been successfully applied by the project team at similar sites and for related purposes. SWMM is a dynamic rainfall-runoff simulation model used for single event or continuous simulation of runoff quantity and quality from primarily urban areas (USEPA, 2015). Additionally, the CSS model was also developed using the SWMM software, so choosing SWMM for the watershed model provides consistency.

A variety of enhanced SWMM platforms are available that integrate the EPA SWMM software with user friendly interfaces and GIS capabilities. For this project, PCSWMM, developed by Computational

Hydraulics International (CHI), was used. The watershed model was developed using SWMM engine version 5.1.010, which is consistent with the version used for the CSS model.

### 2.2.2 CSS Model

The combined sewer system (CSS) model used for this study is based on the Wet Weather Combined Sewer (WWCS) model developed by Greeley and Hansen (GH) to support Richmond's wastewater collection system master planning, Long Term Control Plan (LTCP) implementation, and combined sewer system annual reporting. The CSS model is based upon the EPA Storm Water Management Model (SWMM) framework and uses the SWMM engine version 5.1.010. The model is operated within the PCSWMM environment.

### 2.2.3 Receiving Water Quality Model

The receiving water quality model was developed based on the EFDC modeling framework (Environmental Fluid Dynamics Code). This model has been applied to support numerous CSO water quality projects and is suitable for representing hydrodynamic conditions occurring in the James River, including the transition from riverine to estuarine conditions, and low head dam hydraulics. EFDC is a state-of-the-art finite difference model that can be used to simulate hydrodynamic and water quality behavior in one, two, or three dimensions in riverine, lacustrine, and estuarine environments (TetraTech 2007a, 2007b). The model was developed by John Hamrick at the Virginia Institute of Marine Science in the 1980s and 1990s, and it is currently maintained under support from the USEPA. The model has been applied to hundreds of water bodies, including Chesapeake Bay and the Delaware River.

The EFDC model is both public domain and open source, meaning that the model can be used free of charge, and the original source code can be modified to tailor the model to the specific needs of a particular application. As a result, EFDC provides a powerful and highly flexible framework for simulating hydrodynamic behavior and water quality dynamics in the James River.

## 2.3 Model Extent

The model extent defines the spatial or geographic boundary to which the model applies. The extents of the three models are described further below.

### 2.3.1 Watershed Model

The watershed model incorporates watersheds for 23 tributaries that contribute flow to the portion of the James River that falls within the receiving water quality model extent, and is shown in Figure 2-2 below. The tributaries represented in the watershed model were selected based on two criteria: they have been classified as impaired for *E.coli* on the 2014 VADEQ 303(d) list, or they are expected to contribute significant flows or *E.coli* loads to the James River receiving water quality model. Key features represented in the model include time-variable meteorology, watershed land use and land cover, topography (slopes), land use based pollutant loading, CSO flows and *E.coli* loads (simulated with the CSS model) to tributaries, and basic stream network geometry. The area serviced by the combined sewer system was excluded from the watershed model, as this area is represented in the CSS model. The final watershed model includes 44 square miles within the City of Richmond and 133 square miles outside the city.

### 2.3.2 CSS Model

The City of Richmond Collection System model simulates all sanitary flows from areas that are connected to the wastewater treatment plant as well as surface runoff from within the combined area. The model is described in the Wastewater Collection System Master Plan (Greeley and Hansen, 2015), and includes the following major features, as shown in Figure 2-3:

- The model contains 227 subsheds, including 99 subsheds representing 44,346 acres of sanitary area and 128 subsheds representing 11,523 acres of combined area. Storm water runoff from the sanitary areas is included in the watershed model.
- The total length of sewer pipes in the model is 235,683 ft. (44.6 miles) distributed over 1,020 individual pipe elements with diameters between 12 inches and 120 inches.
- The model represents all currently active CSO outfalls (29) plus the WWTP outfall used to discharge treated effluent.
- The model represents the Shockoe Retention Basin as well as the Hampton – McCloy Storage Tunnel.

### 2.3.3 Receiving Water Quality Model

The James River receiving water quality model extends from South Gaskins Road upstream of the Richmond city boundary, to Osborne Park downstream of the Richmond city boundary. The upstream limit of the model was chosen to be just upstream of Richmond's city limits. The downstream limit was chosen to be downstream of Cornelius Creek and near a frequently sampled water quality station. Twenty three miles of the James River are represented in the model with average grid cell dimensions of 140 feet wide and 340 feet long. Each grid cell spans the average depth of the river within their cell boundary. Six cells typically span the width of the river. Key features represented in the model include upstream James River flows; low head dams; the James River Falls near downtown Richmond, runoff; base flow, and *E.coli* loads from tributaries and MS4 areas; the City wastewater treatment plant, CSO discharges and *E.coli* loads; and tidal conditions in the Lower James River. Several of these features are shown in Figure 2-4.

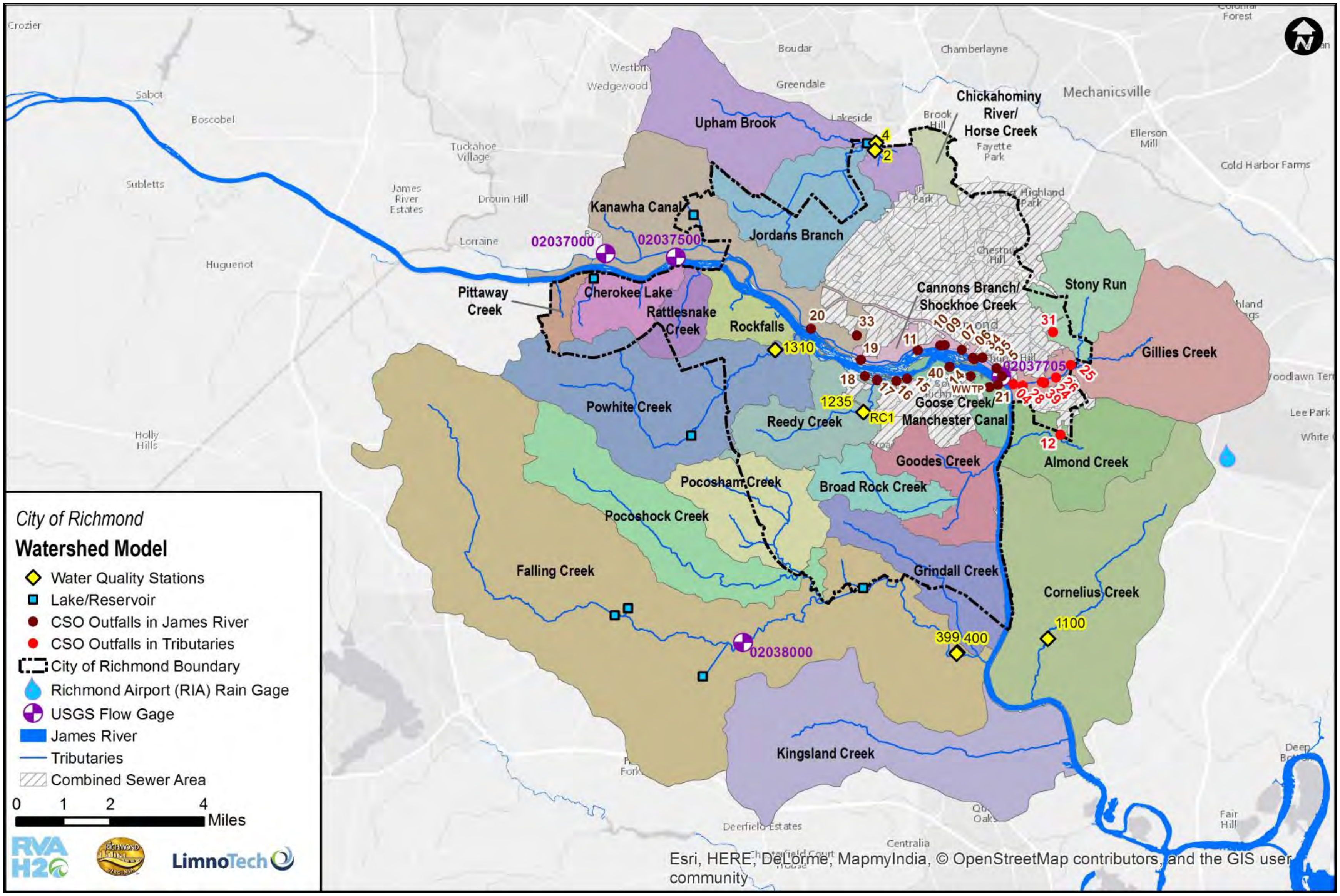



**Figure 2-2: Extent and Key Features of the Watershed Model**

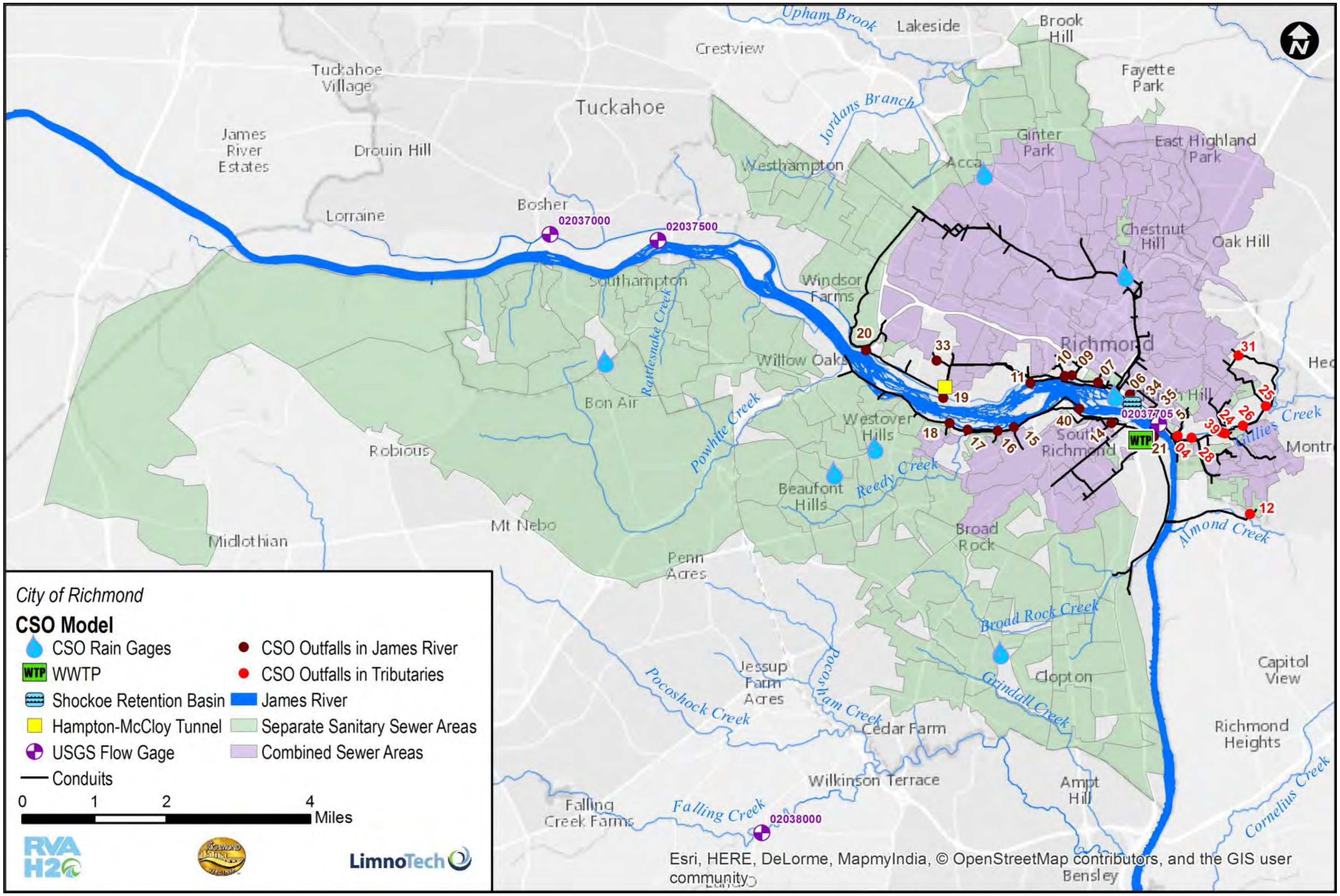



**Figure 2-3: Extent and Key Features of the Richmond CSS Model**

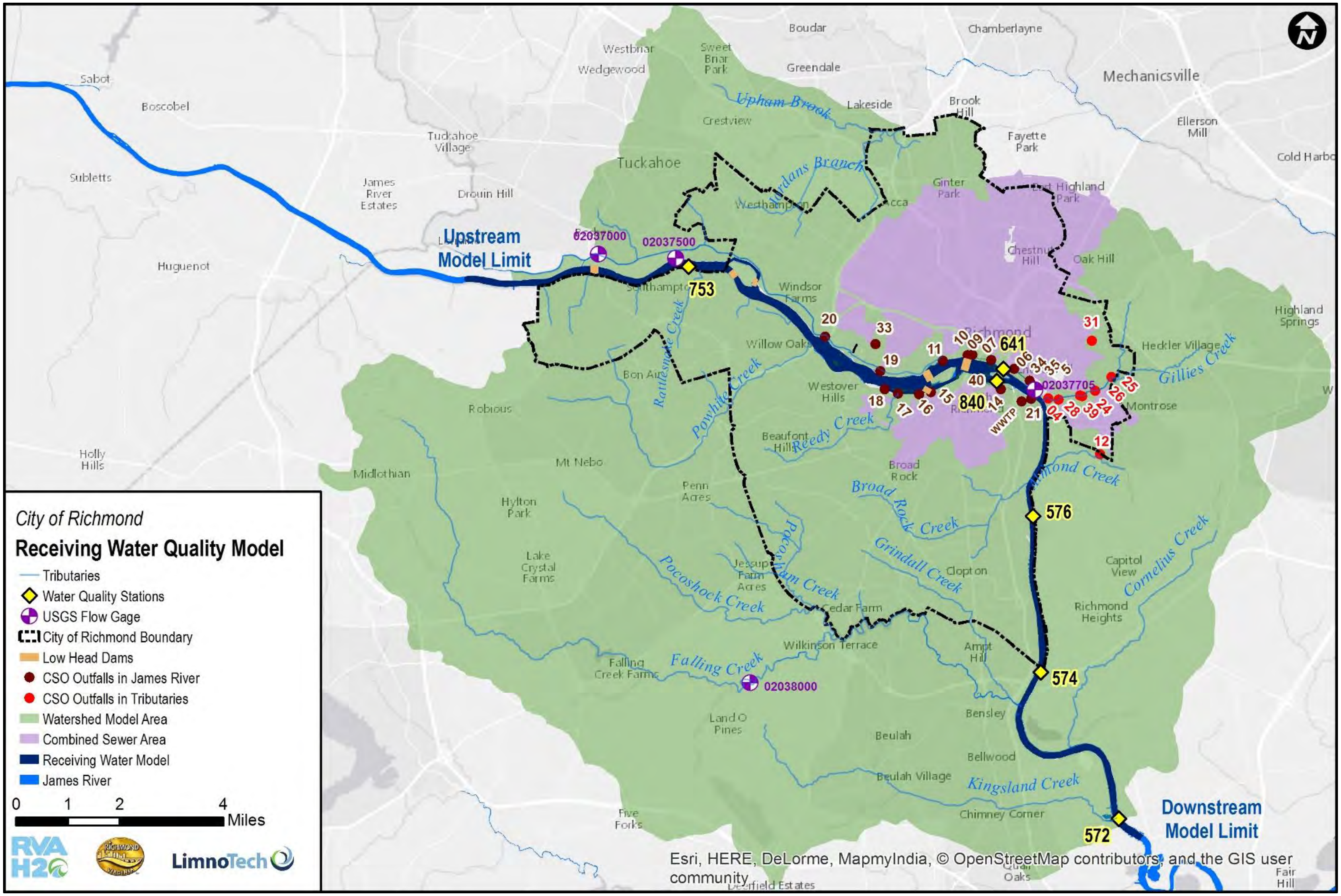



**Figure 2-4: Extent and Key Features of the Receiving Water Quality Model**

# 3 Model Development

Model development is the process of configuring a model to represent certain conditions of interest (e.g. combined sewer overflows, or bacteria concentrations) at a particular site. The model development process for the James River water quality modeling framework included definition of 1) important physical and chemical processes, 2) model inputs and assumptions influencing the modeled processes, 3) the spatial extent of model calculations, and 4) the time span of model calculations. This process is described below for each of the three components of the modeling framework.

## 3.1 Watershed Model

The Richmond watershed model consists of a set of subcatchments (representing the hydrology of the system) that are connected to a network of streams and impoundments (representing the hydraulics of the system). During wet weather events, runoff and associated pollutants are transported from the subcatchments to the stream network, and ultimately discharge to the James River (representing water quality in the system). To set up the watershed model in SWMM, processes influencing the system's hydrology, hydraulics, and pollutant transport must first be characterized. Several different types of data are needed to properly develop a SWMM model. These data characterize the properties that affect the hydrology and hydraulics of a SWMM model. The processes that were modeled and the relevant data that were collected and analyzed for the purpose of setting up the Richmond watershed model are described below.

### 3.1.1 Process Model Selection

The first step in model development is determining what hydraulic and water quality processes should be included. SWMM is capable of modeling six processes: rainfall/runoff, infiltration, snow melt, groundwater, flow routing, and water quality. To meet the objectives of this model four of these processes were used: rainfall/runoff, infiltration, flow routing, and water quality. It was assumed that snow melt typically does not generate significant runoff in the Richmond area. The contribution of groundwater to stream flow was approximated using a baseflow time pattern for select model nodes, so explicitly modeling groundwater was unnecessary.

### 3.1.2 Hydrology

#### *3.1.2.a Subcatchments*

The 23 tributary watersheds (Figure 2-2) were divided into smaller subcatchments through interpretation of a digital elevation model (DEM), political boundaries, and consideration of culverts, major roads, and water quality stations.

For several watersheds, delineated subcatchments existed from previous modeling efforts by Greeley and Hansen for the Richmond Stormwater Master Watershed Plans (Greeley and Hansen, 2012-2014). For these watersheds, the Greeley and Hansen delineations were re-evaluated using the above considerations, and the subcatchment boundaries were adjusted to meet the needs of this modeling effort. In total, the watershed model is comprised of 427 subcatchments.

To simplify model characterization, some subcatchments located outside of the Richmond city limits were replaced with inflow time series when data was available. Four subcatchments in the upstream portion of the Kanawha Canal watershed were replaced with data from USGS gage #02037000, which had an instantaneous flow time series available from 2007-2015.

### *3.1.2.b Meteorology*

SWMM requires two meteorological inputs: a precipitation time series to generate runoff, and temperature data to calculate evaporation. Complete time series for precipitation (hourly and daily), daily minimum temperatures, and maximum temperatures were available at Richmond International Airport (RIA) from 1949 through current condition. All meteorological data at RIA were obtained from the National Centers for Environmental Information[1] (NCEI) which is operated by the National Oceanic and Atmospheric Administration (NOAA).

### *3.1.2.c Baseflow*

Baseflow comprises the majority of stream flow during extended periods of dry weather, and can be estimated from measured flow data time series. The only gaged tributary within the model extent is in the upper portion of the Falling Creek watershed (USGS 02038000, Figure 2-2), so the flow record from this gage was used to approximate baseflow for all tributaries within the model. Using 30 years of flow data (1965-1994), monthly 7Q10 flows were calculated using methods from Risley et al (2008). These values were then normalized to watershed area (in $mi^2$) and applied to subcatchments that contribute to the streams and creeks that are included in the watershed model (Figure 3-1).

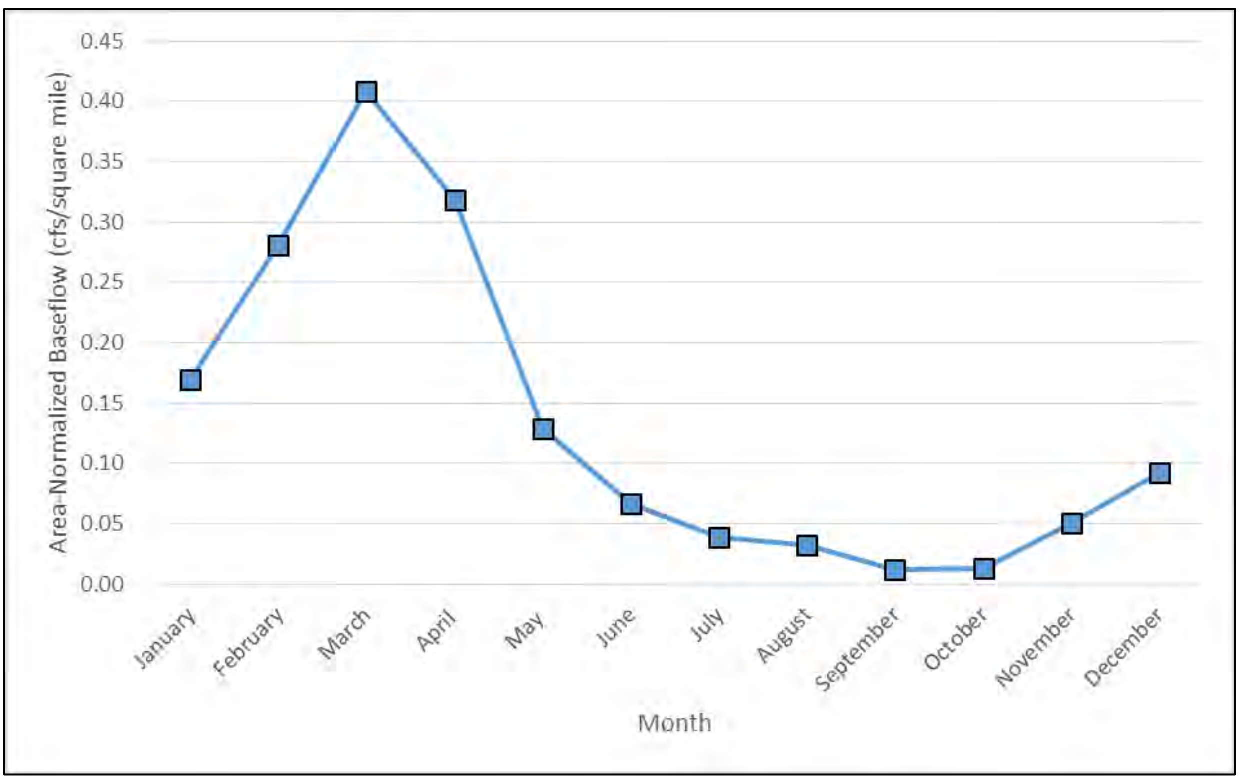



**Figure 3-1: Monthly Baseflow Values Used in the Watershed Model**

[1] Formerly the National Climatic Data Center (NCDC). In 2015 NCDC merged with the National Geophysical Data Center (NGDC) and the National Oceanic Data Center (NODC).

### *3.1.2.d Soil infiltration*

SWMM offers several methods for soil infiltration (listed in order of increasing complexity): Curve Number, Horton's, and Green-Ampt. The Green-Ampt method requires site-specific knowledge to characterize infiltration parameters, which were not readily available for this project. Therefore, the Horton method was selected for the watershed model. Horton's method uses a set of parameters that defines the maximum infiltration rate, the minimum infiltration rate, the decay rate for changing from maximum to minimum infiltration rates, a recovery rate for changing from minimum to maximum infiltration rates, and an overall maximum infiltration volume. These parameters are determined based on the hydrologic soil groups that are present in the watershed model extent.

The hydrologic properties of soils influence the how quickly and how much precipitation is converted to runoff. In general, soils can be classified by hydrologic soil group (HSG). There are four basic HSGs, called HSG A, HSG B, HSG C, and HSG D. Soils in group A have the lowest runoff potential, while soils in group D have the greatest runoff potential (Mockus et al., 2004). These four basic classifications can then be broken down into dual classifications such as A/D or B/D. Dual classifications represent soils that are classified as group D because of a high water table, making them behave as though they have a high runoff potential. However, if the water table were lowered, these soils would have a lower runoff potential (such as group A or B).

To characterize the soils within the model extent, data were downloaded from the Soil Survey Geographic (SSURGO) database provided by the National Resources Conservation Service (NRCS). A wide range of HSGs are represented within the SWMM model extent (Table 3-1). In addition to the four standard categories (HSG A through D), several dual classifications are also represented. These dual classifications were assumed to be undrained, and were therefore assigned the same soil properties as HSG D. There were also nine soil types with no official hydrologic soil group classification (Table 3-2). Based on the descriptions provided by NRCS, it was assumed that most of these unclassified soils were poorly drained and would have a high potential for runoff (Mockus et al., 2004). Therefore, they were assigned the same soil properties as HSG D.

The soil infiltration parameters associated with each HSG were estimated from tables provided in the *User's Guide to SWMM 5* (James et al., 2010). An average minimum and average maximum value from the suggested range was used for the infiltration rate. In the absence of detailed soil data, the decay constant and drying time were assumed to be the same for all soil types within the model extent, and a maximum infiltration volume was not specified.

**Table 3-1: Description of hydrologic soil groups within watershed model extent**

| Hydrologic Soil Group | Description | Area ($mi^2$) | % Total |
|---|---|---|---|
| A | Soils with low runoff potential | 17.9 | 9.1% |
| A/D | Soils with high runoff potential unless drained. Otherwise classified as HSG A. | 0.4 | 0.2% |
| B | Soils with moderately low runoff potential | 75.8 | 38.7% |
| B/D | Soils with high runoff potential unless drained. Otherwise classified as HSG B. | 20.0 | 10.2% |
| C | Soils with moderately high runoff potential | 30.3 | 15.5% |
| C/D | Soils with high runoff potential unless drained. Otherwise classified as HSG C. | 10.9 | 5.6% |
| D | Soils with high runoff potential | 5.5 | 2.8% |

| Table 3-1: Description of hydrologic soil groups within watershed model extent | | | |
|---|---|---|---|
| **Hydrologic Soil Group** | **Description** | **Area ($mi^2$)** | **% Total** |
| Unknown | See Table 3-2 | 33.0 | 16.8% |
| Water | N/A | 2.2 | 1.1% |
| | **TOTAL** | **196.0** | **100.0%** |

| Table 3-2: Description of the "Unknown" Hydrologic Soil Group within watershed model extent | | | |
|---|---|---|---|
| **Hydrologic Soil Group** | **Soil Type** | **Area ($mi^2$)** | **% Total** |
| Unknown | Urban land | 20.1 | 10.2% |
| Unknown | Udorthents-Dumps complex, pits | 6.7 | 3.4% |
| Unknown | Udorthents, loamy, borrow pits | 0.2 | 0.1% |
| Unknown | Udorthents, loamy | 1.4 | 0.7% |
| Unknown | Gravel pit | 2.2 | 1.1% |
| Unknown | Udorthents, clayey | 0.001 | 0.0% |
| Unknown | Borrow pit | 0.004 | 0.0% |
| Unknown | Orthents-Udults-Mine pits complex | 0.4 | 0.2% |
| Unknown | Made land | 2.0 | 1.0% |
| | **TOTAL** | **33.0** | **16.8%** |

#### *3.1.2.e Impervious Area and Slope*

Percent impervious area and percent slope strongly influence the amount of precipitation that becomes stormwater runoff. Large amounts of impervious area and/or high slopes can lead to high-volume and "flashy" runoff. To estimate median percent impervious area for each subcatchment, a percent impervious area raster was downloaded from National Land Cover Database (NLCD) (Xian et al., 2011). Percent slope for each subcatchment was estimated using the National Elevation Dataset (NED) (Gesch et al., 2002).

#### *3.1.2.f Additional Subcatchment Parameters*

In addition to the major subcatchment parameters listed in the sections above, there are five additional parameters that were characterized for each subcatchment: Manning's n coefficient for overland flow over pervious and impervious areas, depression storage for pervious and impervious areas, and percent of impervious area with zero depression storage. These parameters can be used to adjust the shape and the timing of the hydrograph. For simplicity, these parameters were set to constant values for all subcatchments. The values were selected based on literature values from the SWMM5 manual (James et al., 2010)

| Table 3-3: Additional SWMM Subcatchment Parameters | | | |
|---|---|---|---|
| **Parameter** | **Value** | **Description** | **Source** |
| Manning's n for overland flow over impervious area | 0.018 | Average value | Mc Cuen et al. (1996) |
| Manning's n for overland flow over pervious area | 0.25 | Dense grass | Mc Cuen et al. (1996) |
| Depression storage for impervious area | 0.075 | Average value for impervious surfaces | ASCE (1992) |
| Depression storage for pervious areas | 0.15 | Average value for lawns | ASCE (1992) |
| Percent of impervious area with no depression storage | 25% | Default value in SWMM | |

### 3.1.3 Hydraulics and Routing

SWMM offers three methods for routing water through the stream network (listed in order of increasing complexity): steady flow, kinematic wave, and dynamic wave. Dynamic wave was selected for the routing portion of the model. The dynamic wave model can account for channel storage, backwater, entrance/exit losses, flow reversal, and pressurized flow. The dynamic wave model allows for more complex flow conditions than the other routing methods, but requires the use of smaller computational time steps, so choosing this method generally increases the model run times. Theoretically, it produces more accurate results.

#### *3.1.3.a Stream network*

Modeling efforts focused on tributaries within the watershed model extent that are currently impaired for bacteria or have active or planned stream restoration projects. Some of these streams originate outside of the city of Richmond, but flow through the city. Two types of small, intermittent streams were not explicitly modeled: unimpaired tributaries within the City of Richmond and unimpaired tributary streams outside the City of Richmond. Unimpaired small tributaries within the city limits were omitted largely because there were no data on stream geometry or characteristics. Upon visual inspection of aerial photography, it was noted that most of these waterbodies were ditches. The small, intermittent streams outside the city were omitted because they are not within Richmond's service area.

The network of streams modeled was developed using two sources. Hydrography data were acquired from the National Hydrography Dataset (NHD Plus), which is developed by USEPA Office of Water and the US Geological Survey (USGS) (USEPA, 2005). This dataset includes nationwide spatial information about a variety of waterbodies, including streams, rivers, lakes, and ponds. NHD Plus was modified using a digital elevation model developed from LiDAR mass points. Modifications of the NHD Plus flow lines were made to align with the lowest nearby digital elevation model (DEM) elevation and with aerial photographs.

The DEM was also used to characterize irregular transects for each section of the stream channel. Using the DEM, one transect was drawn for each subcatchment in the model. Each transect was drawn at a location that was considered to be most representative of the stream channel within a subcatchment.

#### *3.1.3.b Infrastructure*

The modeling of culverts was limited to structures that were located on modeled tributaries. Culvert data were provided by the City of Richmond for portions of the watersheds within the city limits. Culvert locations and geometry were estimated for culverts located outside of the city. An initial estimate of culvert geometry was based on aerial photos from Bing maps and the DEM. Initial estimates were then adjusted during calibration under the assumption that culverts were designed to avoid flooding roadways.

The hydrology calibration process revealed that lakes and reservoirs significantly influence the timing of peak flows and their magnitudes. Nine lakes and impoundments were identified through the NHD dataset and subsequently modeled within the model extent, including Cherokee Lake, Cornelius Creek Lake, Falling Creek Reservoir, Gregory's Pond, Lower Beaver Pond, Lower Young's Pond, Rock Creek Park Lake, Upper Lake Bexley, Upper Young's Pond, and Westhampton Lake. When possible, data for these impoundments, associated weirs, and spillways were obtained from the US Army Corps of Engineers (USACE, 1979-1981). Otherwise, impoundment, weir, and spillway characteristics were estimated from aerial photographs, 2-ft contours created from Light Detection and Radar (LiDAR) data, and the DEM. Two conditions constrained the hydraulic behavior of impoundments in the model. First, impoundments were assumed to have a minimum constant water depth that was equal to the primary spillway elevation. Second, it was assumed that lakes and impoundments did not regularly overflow their banks. This seemed like a reasonable assumption because several of the impoundments are surrounded by buildings. If an impoundment regularly flooded in the model, the depth of the storage node was increased and the stage-storage curve was linearly extrapolated.

### 3.1.4 Water Quality

#### *3.1.4.a Land use/land cover*

For water quality modeling in SWMM, land uses must be defined in order to assign pollutant loading. To characterize land use within the model extent, land use data were acquired from the National Land Cover Database (NLCD). The data are generated by the Multi-Resolution Land Characteristics (MRLC) consortium and provided in a raster data format with a spatial resolution of 30 meters (MRLC 2016). NLCD 2011, the most recent version of this dataset, was used to characterize land use in the SWMM model (Homer et al., 2011).

The NLCD also provides data on percent impervious area (Xian et al., 2011), and this dataset was modified and used to estimate the median percent impervious area for each subcatchment. The modification of these data was necessary because the initial model runs during the hydrology calibration process underestimated gaged flows. This discrepancy was discovered through a watershed-scale analysis comparing NLCD impervious cover and a planimetric impervious layer provided by the City of Richmond. It revealed that the NLCD impervious layer underestimated the median percent impervious area, especially in less urban areas. A linear regression was used to develop a relationship between the two datasets and to adjust the NLCD impervious area to better match the planimetric data from the City. After the initial adjustment, the percent impervious area for each subcatchment was adjusted downward by 15%, in order to account for impervious areas that are not directly connected to a waterway or storm sewer. This is standard practice in watershed modeling because runoff from unconnected impervious areas typically first flow onto pervious areas where infiltration can occur, and any excess is then routed to the stream or storm sewer. Because the amount of directly connected impervious area is not known, this adjustment factor was used as a calibration parameter.

#### *3.1.4.b Pollutant loading*

In the watershed model, pollutants enter the tributaries in three ways: runoff from the tributary watersheds, baseflow, and CSO overflows. Build-up of pollutants on the watershed and their subsequent wash-off during runoff events are the dominant mechanisms for pollutant loading into tributaries. Pollutant concentrations in baseflow is effectively a calibration parameter that is set for consistency with dry weather pollutant data in the streams. CSO overflows to the tributaries are estimated using combined sewer model output and event mean concentrations (as described below in Section 3.3).

During dry weather periods, pollutants accumulate on subcatchments through a process called build-up. The two parameters that govern build up are the build-up rate, which is the rate at which pollutant accumulates on a subcatchment (expressed in units of cfu/acre/day), and the maximum buildup, which is the maximum amount of pollutant that can accumulate on a subcatchment (expressed in units of cfu/acre). Both of these parameters are represented in the model as a function of land use. To assign reasonable build-up rates and maximum build up to each land use, a review of literature values from across the country was conducted (see tables below). Literature values were not available for all land uses in the model, so in the absence of available data, the build-up parameters for the most similar land use were assigned. Initial model runs used the median build-up rate and the median of maximum build-up for each land use. These parameters were then were fine-tuned during calibration, using the 25$^{th}$ and 75$^{th}$ percentiles as reasonable limits on the range of potential values.

**Table 3-4: Land Use Build-Up Rates (cfu/acre/day) Used in the Watershed Model**

| Land Use | Count | Q1 | Median | Q3 |
|---|---|---|---|---|
| Developed - High Intensity | 21 | 6.24E+07 | 1.27E+09 | 2.12E+09 |
| Developed - Low Intensity | 12 | 8.13E+07 | 1.65E+09 | 2.60E+09 |
| Developed - Medium Intensity | 14 | 9.09E+07 | 1.50E+09 | 2.60E+09 |
| Developed - Open Space | 8 | 2.31E+08 | 1.57E+09 | 7.81E+09 |
| Undeveloped | 32 | 1.09E+08 | 1.43E+09 | 9.62E+09 |
| Forest | 9 | 5.07E+06 | 8.52E+06 | 1.41E+08 |

**Table 3-5: Maximum Build-Up Rates Used in the Watershed Model**

| Land Use | Count | Q1 | Median | Q3 |
|---|---|---|---|---|
| Developed - High Intensity | 7 | 9.57E+09 | 1.06E+10 | 1.41E+10 |
| Developed - Low Intensity | 4 | 1.06E+10 | 1.14E+10 | 3.44E+11 |
| Developed - Medium Intensity | 5 | 5.33E+09 | 1.02E+10 | 2.33E+11 |
| Developed - Open Space | 4 | 1.03E+10 | 1.40E+10 | 1.75E+11 |
| Undeveloped | 9 | 1.53E+09 | 2.95E+10 | 8.51E+10 |
| Forest | 5 | 1.53E+09 | 1.53E+09 | 1.67E+09 |

During wet weather periods, pollutants are depleted from subcatchments and delivered to streams through a process called wash-off. Similar to build-up, the amount of pollutant that washes off during a runoff event is dictated by land use-specific wash-off rate called the event mean concentration (EMC). EMCs for each land use were informed by a literature review. Runoff will continue to generate pollutant load until the available source of pollutant build-up has been exhausted. Literature values were not available for all land uses in the model, so in the absence of available data, the build-up parameters for the most similar land use were assigned. Initial model runs used the median EMC for each land use, and were then were fine-tuned during calibration, using the 25$^{th}$ and 75$^{th}$ percentiles as reasonable limits.

**Table 3-6: Landuse Based E.Coli EMC Values Used in the Watershed Model**

| NLCD 2011 | *E.coli* (CFU/100 mL) | | |
|---|---|---|---|
| Cultivated Crops | 1,945 | 8,440 | 26,567 |
| Pasture/Hay | 2,682 | 3,989 | 28,102 |
| Forest | 380 | 504 | 565 |
| Wetlands (Woody/Herbaceous) | 565 | 10,339 | 10,756 |

| Table 3-6: Landuse Based E.Coli EMC Values Used in the Watershed Model | | | |
|---|---|---|---|
| **NLCD 2011** | ***E.coli* (CFU/100 mL)** | | |
| Developed - Open | 2,479 | 2,479 | 25,856 |
| Developed - Low Intensity | 3,157 | 15,294 | 29,723 |
| Developed - Medium Intensity | 4,480 | 5,620 | 15,527 |
| Developed - High Intensity | 884 | 3,700 | 11,000 |

An *E.coli* baseflow concentration was assigned at each model location where baseflow was added. A literature review of urban TMDLs was conducted to determine a reasonable range of values. Initial model runs used the median *E.coli* concentration of 50 CFU/100 mL, which was then were fine-tuned during calibration, using the $25^{th}$ (28 CFU/100 mL) and 75th (599 CFU/100 mL) percentiles as reasonable limits. The assigned baseflow *E.*coli concentration is the same for each tributary, and is a constant value over time.

CSO flows from the CSS model and *E.coli* concentrations were added to more accurately reflect water quality within CSO-impacted tributaries. There are eight CSOs that overflow into two tributaries in the model: Gillies Creek and Almond Creek. Inflow time series for these eight CSOs were generated by the CSS model. EMCs were assumed for the CSO discharges and were based on previous work on typical fecal coliform concentrations for CSOs in Richmond. The fecal coliform values were then adjusted to represent *E.coli* concentrations using the VADEQ translator (Lawson, 2003). An *E.coli* EMC of 205,000 CFU/100 mL was used for seven of eight CSOs in Gillies Creek. An EMC of 215,000 CFU/100 mL was used for the remaining Gillies Creek CSO and the one CSO in Almond Creek. Further information on the values selected for the CSO EMCs can be found in Section 4.1.

#### *3.1.4.c In-Stream Decay Rate*

In-stream bacteria fate and transport processes include die-off, settling to and resuspension from the streambed. The net effect of these processes are represented in the model through the use of a first-order decay rate. Typically, all of the streams in a modeled system will have the same decay rate, with the resulting losses of bacteria in each waterbody varying as a function of travel time through the stream network. An initial in-stream decay rate was set to 1.0/d based on the initial decay rate estimated in the 2010 James River TMDL (MapTech, 2010). This parameter was then adjusted during calibration. The decay rate was varied incrementally between 0.5/d and 2.0/d during the calibration phase.

## 3.2 CSS Model

The combined sewer system (CSS) model used for this study is based on the Wet Weather Combined Sewer (WWCS) model developed to support Richmond's Long-Term Control Plan Re-Evaluation (Greeley and Hansen, 2002). This CSS model was recalibrated and revised by Greeley and Hansen (GH) between 2010 and 2015 as part of the Wastewater Collection System Master Plan (Greeley and Hansen, 2015). This version of the CSS model is currently used by the city to produce the Combined Sewer System Annual Reports. This CSS model relies on boundary forcings (operating rules, observed flow time series and control decisions) that makes it unsuitable for hindcasting extended time periods and modeling CSS operational alternatives.

The primary SWMM processes and parameters used in the CSS model are similar to the ones described in Section 3.1 above with the exception that the CSS model does account for evapotranspiration as part of the rainfall - runoff process and does not include any internal system pollutant loading (pollutant EMC are assigned to the outfall discharge only). During the CSS model calibration process, 7 local rain gages were used while the NCDC gage at Richmond Airport was used for the IRWMP, due to limited data availability and reliability of the 7 local rain gages.

To prepare the CSS model for use in this study, it was reviewed and modified by Brown and Caldwell, as described in the “CSO Model Review and Advancement Strategy” technical memorandum by Brown and Caldwell (Brown and Caldwell, 2016). As part of this work, the following major changes and modifications were done:

- Reduction of the number of pipe elements to focus on the main interceptor network and improve model stability. This reduced the number of model pipes from 2,357 to 1,019.
- Definition of standard operating procedures for the WWTP by replacing the flow boundary condition, which required an observed plant influent time series with a simple outflow pipe limited to the plant capacity (e.g. 75 MGD for the model calibration)
- Definition of standard operating rules to control the major facilities like the Shockoe Retention Basin and eliminating the need of an external time series forcing for flow boundary condition at this location.
- Elimination of various inactive control rules
- Reduction of the number of subcatchments (and receiving nodes) by deleting those that flow to the neighboring county collection system
- Reduction of the number of unit hydrographs describing the baseflow I & I conditions

These changes were necessary in order to be able to run the model in hindcast mode for a long-term continuous period, and in order to operate the model for evaluating CSS alternatives.

## 3.3 Receiving Water Quality Model

Site specific data supported the development of both the hydrodynamic and water quality components of the EFDC receiving water model. Bathymetric data from the current FEMA Flood Insurance Study (FEMA, 2014) and from a USACE survey of the estuarine reach (USACE, 2013) were averaged over the model grid. In the upper, riverine reach, a cross-sectional average bed elevation was computed for each row of grid cells. In the lower, estuarine reach, a DEM was computed from the detailed USACE elevation data and averaged over the model grid. The modeled James River bed elevation profile is illustrated in the figure below.

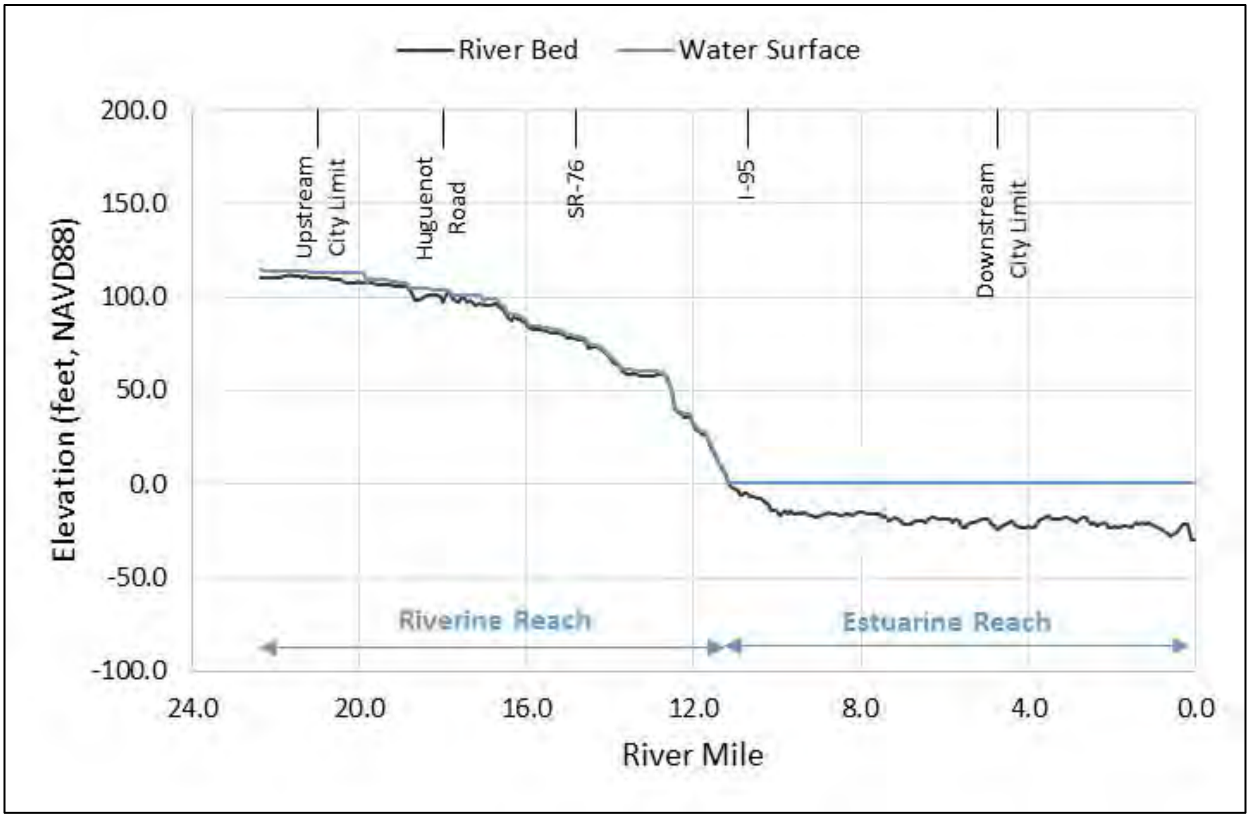



**Figure 3-2: James River Elevation Profile**

Tidal water levels from USGS Station #02037705 (James River at City Locks at Richmond, VA) were applied at the downstream boundary and the model was calibrated to adjust for the change in water levels between the gauging station and the downstream model boundary. This calibration, which is described in Section 4, accounts for differences in timing (phasing) of the tides between the two locations, and differences in non-tidal water levels associated with river flows.

Upstream James River flows from USGS Station 02037500 (James River near Richmond, VA) were directly applied at the upstream model boundary. For days when *E.coli* were sampled near the upstream boundary, these data were directly inputted to the model. For days when *E.coli* data were unavailable, upstream James River *E.coli* concentrations were estimated based on sampling data from a station at Huguenot Bridge. 112 samples at this location collected between 2011 and 2013 were used to develop a regression of flow and *E.coli* using the USGS LOADEST software package.

LOADEST is a program for "estimating constituent loads in streams and rivers" (USGS, 2017). The figure below illustrates the predicted relationship between James River flow and *E.coli* concentrations upstream of Richmond. The regression equation is as follows:

$$a_0 + a_1 * \ln Q + a_2 * lnQ^2 + a_3 * \sin(2pi * dtime) + a_4 * \cos(2pi * dtime)$$

Where:

- $a_0$, $a_1$, $a_2$, $a_3$, and $a_4$ are constants equal to 3.17, 1.27, 0.41, -0.79, and -0.04 respectively,
- Q is streamflow (cubic feet per second), and,
- dtime is time relative to the center time (days)

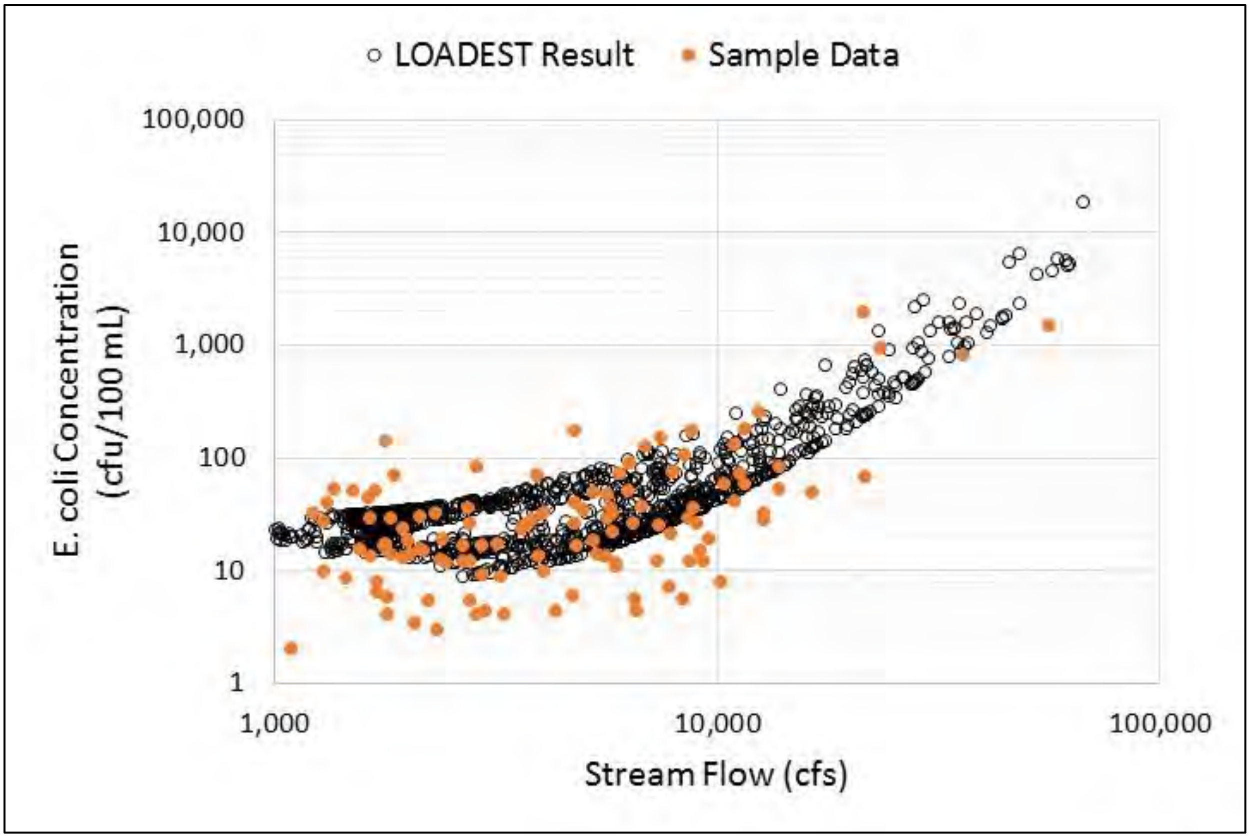



**Figure 3-3: Regression of James River flow and *E.coli* concentration**

Flows and *E.coli* concentrations associated with MS4 and watershed areas, and CSO discharges were computed from the watershed and CSS models, respectively. Flows and concentrations from the watershed model were input to EFDC at an hourly interval. Flows from the CSS model were input to EFDC at a five-minute interval due to the faster response time of the combined sewer system to rainfall relative to the watershed.

Fecal coliform event mean concentrations (EMCs) were previously calculated (and accepted by VADEQ) for the CSO discharges during the development of the Long Term Control Plan. These EMCs were calculated based on CSO outfall monitoring at several CSOs (Greeley and Hansen, personal communication, 11/15/2016). For this modeling effort, fecal coliform EMC concentrations were converted to *E.coli* concentrations using the VADEQ translator (Lawson, 2003). Table 3-7 summarizes the original fecal coliform EMCs and the translated *E.coli* values.

Consistent with the Long Term Control Plan, all influent to the WWTP was assumed to have an *E.coli* concentration of 235,000 CFU/100mL. It was assumed that influent receiving full treatment would result in an effluent concentration of 126 CFU/100 mL, consistent with the effluent concentration guidelines in the VAPDES permit (#VA0063177). For model application scenarios in which WWTP wet weather flow upgrades are proposed, effluent discharge concentrations were estimated based on the methods described in Section 5.

| Table 3-7: Summary of fecal coliform and *E.coli* CSO EMCs | | | | |
|---|---|---|---|---|
| **CSO Districts** | **CSO Drainage Areas** | | | |
| | **Outfall Serial No.** | **Outfall Location** | **Fecal Coliforms (#/100 mL)** | ***E.coli* (#/100 mL)** |
| **South Side James River Park** | 018 | 42nd Street | 986,775 | 318,000 |
| | 017 | Reedy Creek | 986,775 | 318,000 |
| | 016 | Woodland Heights | 986,775 | 318,000 |
| | 015 | Canoe Run | 986,775 | 318,000 |
| | 040 | CSO-1 OUT/SSJRP | 986,775 | 318,000 |
| **North Side James River Park** | 011 | Park Hydro | 437,343 | 150,000 |
| | 010 | Gambles Hill | 437,343 | 150,000 |
| | 009 | Seventh Street | 437,343 | 150,000 |
| | (008)[a] | (Sixth Street)[a] | 437,343 | 150,000 |
| | 007 | Byrd Street | 437,343 | 150,000 |
| | (036)[b] | (Virginia Street)[b] | 437,343 | 150,000 |
| **Manchester Area (WWTP Area)** | 014 | Stockton Street | 86,266[d] | 34,000 |
| | 013 | Maury Street | 86,266[d] | 34,000 |
| | 021 | Gordon Avenue | 86,266[d] | 34,000 |
| **Gillies Creek** | 005 | Peach Street | 612,230 | 205,000 |
| | 002 | Orleans Street | 612,230 | 205,000 |
| | 004 | Bloody Run | 612,230 | 205,000 |
| | 003 | Nicholson Street | 612,230 | 205,000 |
| | (023)[c] | (Old Fulton Street Bridge)[c] | 612,230 | 205,000 |
| | 024 | White and Varina Streets | 612,230 | 205,000 |
| | 025 | Briel Street and Gilles Creek | 612,230 | 205,000 |
| | 026 | 1250 feet east of Government Road | 612,230 | 205,000 |
| | (027)[c] | (Williamsburg Road and Gillies Creek)[c] | 612,230 | 205,000 |
| | 028 | 800' North of Nicholson Street | 612,230 | 205,000 |
| | 035 | 25th and Dock Streets | 612,230 | 205,000 |
| | 039 | 550 feet Downstream from Government Road | 612,230 | 205,000 |
| **Shockoe Creek** | 006 | Shockoe Creek | 315,369[d] | 111,000 |
| | 034 | 19th and Dock Street | 315,369[d] | 111,000 |
| **Remote Locations** | 020 | McCloy Street | 647,000 | 215,000 |
| | 019 | Hampton Street | 647,000 | 215,000 |
| | 033 | Shields Lake | 647,000 | 215,000 |
| | 012 | Hilton Street | 647,000 | 215,000 |
| | 031 | Oakwood Cemetery | 647,000 | 215,000 |

# 4 Model Calibration

Model calibration is the process of adjusting model parameters and assumptions within defensible ranges to achieve reasonable agreement between modeled and observed conditions. Model parameters and assumptions are set to the extent possible based on site specific data. However, in some cases, calibration is necessary because site specific data are either limited or unavailable. The calibration process fine-tunes these parameters, within reasonable bounds, to improve model calculations.

## 4.1 Calibration Data

The calibration process relies heavily on site-specific data to guide the tuning of model inputs. Site specific data support identification of important spatial patterns or time trends in environmental conditions. These patterns often lend insights into the processes or sources most strongly influencing environmental conditions. In this way, the model calibration process involves interpreting site data to understand and bring the model into agreement with important conditions. Site data vary in their capacity to support such an interpretation depending largely on their quantity and locations. The following sections describe the site specific data available for calibration of the modeling framework and also describe the interpretation of these data.

### 4.1.1 Watershed Model

#### *4.1.1.a Hydrology*

The hydrology calibration for the watershed model relied on data from Falling Creek (USGS #02038000), which was the only continuous flow and water depth gage within the modeled area (

Figure 2-2). Daily average flow data was available from 1955-1994. It was assumed that calibrated parameters related to in-channel roughness, overbank roughness, and impervious area would be similar between Falling Creek and the remainder of the watershed. This assumption seems reasonable based on a comparison of key watershed characteristics that influence runoff, including impervious area, slope, and soil infiltration, in Falling Creek versus the other model subcatchments. This comparison is shown in the table below.

**Table 4-1: Median value of key runoff parameters in Falling Creek compared to the rest of the model subcatchments**

| Key Runoff Parameter | Median Value in Model Subcatchments | Median Value in the Falling Creek Subcatchment |
|---|---|---|
| **% impervious area** | 26% | 22% |
| **% slope** | 5% | 7% |
| **Min infiltration** | 2.5 | 2.7 |
| **Max infiltration** | 0.161 | 0.178 |

#### *4.1.1.b Water quality*

The selected water quality calibration period was calendar years 2011 through 2013. This time period had the greatest quantity of sampling data available and the greatest range of *E.coli* results, including high values that would be indicative of wet weather source impacts. Seven stations on five different tributaries were chosen to evaluate the water quality calibration (Table 4-2). Station selection was based on the quantity of available data during the calibration period, the proximity of the station to the mouth of the stream, distribution of stations in the model extent, and the size of the tributary. Stations near stream mouths were selected because they more accurately reflect the total *E.coli* load delivered to the James River for each tributary. Stations representing a varied spatial distribution and a variety of sizes were selected to evaluate the robustness of the calibrated parameters.

**Table 4-2: Water quality monitoring stations used for watershed model calibration**

| Tributary | Station ID | *E.coli* Data (#) |
|---|---|---|
| **Falling Creek** | 399/400 | 30 |
| **Cornelius Creek** | 1310 | 15 |
| **Powhite Creek** | 1100 | 12 |
| **Upham Brook** | 4 | 14 |
| **Upham Brook** | 2 | 7 |
| **Reedy Creek** | 1235/RC1 | 6 |

Similar to the hydrology calibration, the water quality calibration was limited by the available data. Because of the data limitations, the water quality calibration was viewed not so much as a definitive calibration, but as a reasonable estimate of tributary loads and their timing so that calibration of the James River receiving water quality model could move forward. If necessary, the watershed model calibration would be revisited if the results from the receiving water quality model indicated it was necessary. The final calibration of the watershed model would be considered complete once the water quality calibration of the James River model was complete. After initial tuning of the watershed model water quality parameters, tributary *E.coli* loads were passed forward to the James River receiving water model. The effect of these tributary loads on James River water quality was assessed through calibration of the James River model which is further described in 4.4.

Water quality data in the tributaries were limited in their capacity to describe wet weather conditions. Most of the data collected appeared to be sampled during dry weather periods, a time when *E.coli* concentrations are expected to be low. Additionally, for almost all stations, samples were collected once per day, and therefore do not capture the temporal variability of bacteria (also known as the "pollutograph") that is expected during a rainfall event.

### 4.1.2 CSS Model

The CSS model was calibrated by Greeley and Hansen in 2015 during the initial model development as described in the CSS model documentation of the Waste Water Collection System Master Plan (Greeley and Hansen, 2015). The calibration was done using monitoring data from 16 flow meters, 7 rain gauges, and one river level sensor near outfall CSO 06 (Figure 2-3). The monitoring period lasted 11 months, from July 2012 to June 2013. Several issues related to the metering were identified in the report, and not all data collected was suitable to be used for model calibration. Ten (10) wet weather events were selected from the monitoring period to perform the wet weather calibration.

### 4.1.3 Receiving Water Quality Model

The hydrodynamic calibration period for the James River receiving water quality model was calendar years 2011 through 2013. This is the same period used for the water quality calibration, and includes a wide range of James River flow conditions. Data from two USGS stations supported the hydrodynamic model calibration: one in the riverine reach (Station 02037500 at Huguenot Bridge) and one in the estuarine reach (Station 02037705 at the City Locks). Data from the riverine USGS station quantify the change in stream depth and velocity with river flow. Data from the estuarine USGS station quantify the amplitude and phasing of tidal water levels.

The water quality calibration period for the James River receiving water model was calendar years 2011 through 2013. As shown in Figure 4-1, this period contains nearly the greatest density of sampling data in the James River. It also represents a typical range of flow and precipitation conditions. While calendar year 2010 had the highest sample count, several of the samples resulted in non-detected *E.coli* concentrations so they were less informative for the model calibration.

Data from the six locations with the greatest quantity of samples with detectable *E.coli* concentrations guided the calibration. Three of these locations occur in the riverine reach and three occur in the estuarine reach. One station (#753) is upstream of all Richmond sources, two are near downtown Richmond and are influenced by CSOs (#641 and #840), and the remaining three are downstream of CSOs and beyond Richmond (#576, #574, and #572). These stations are shown in Figure 2-4.

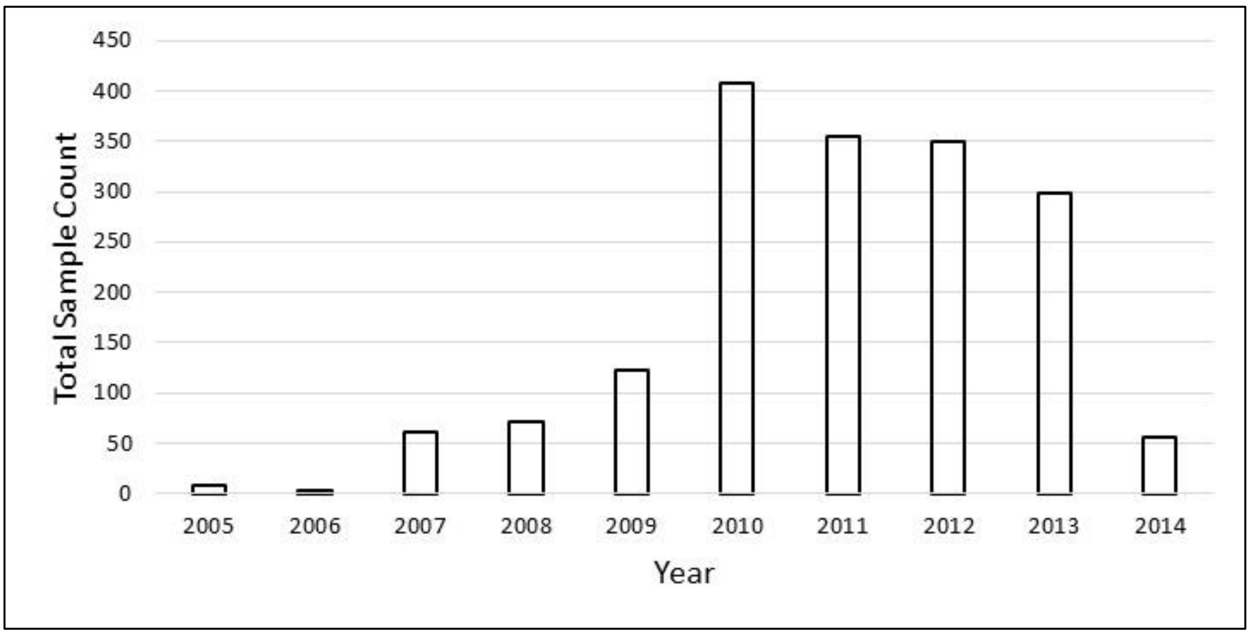



**Figure 4-1: James River E.coli Water Quality Sample Count by Year**

The calibration data were analyzed to identify patterns in water quality along the James River that would guide model calibration. Three significant observations were made. First, dry weather *E.coli* concentrations increase significantly moving from the upstream most station at Huguenot Bridge (station

753) to the downtown area (station 840).

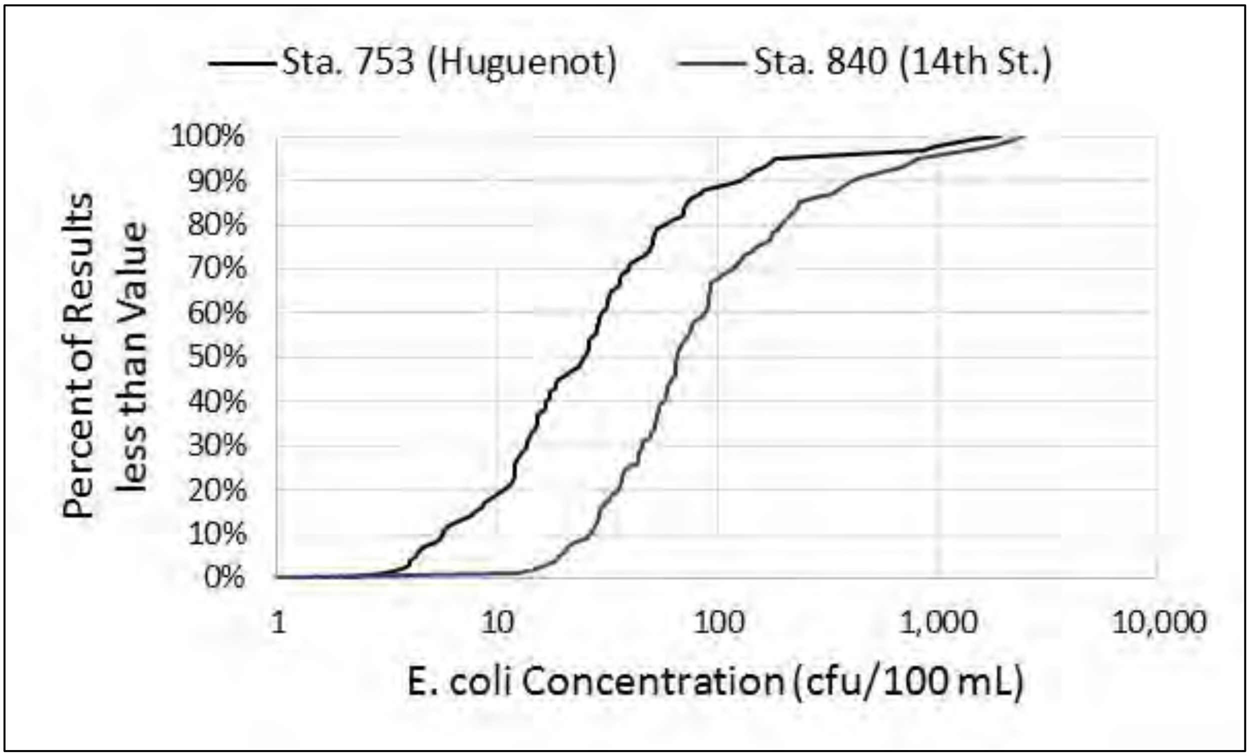



Figure 4-2 compares cumulative frequency distributions (CFDs) at the upstream station and a station near downtown. Median (50th percentile) *E.coli* concentrations increase from 25 to 66 CFU/100 mL, indicating a significant persistent source of *E.coli* to the river between these locations.

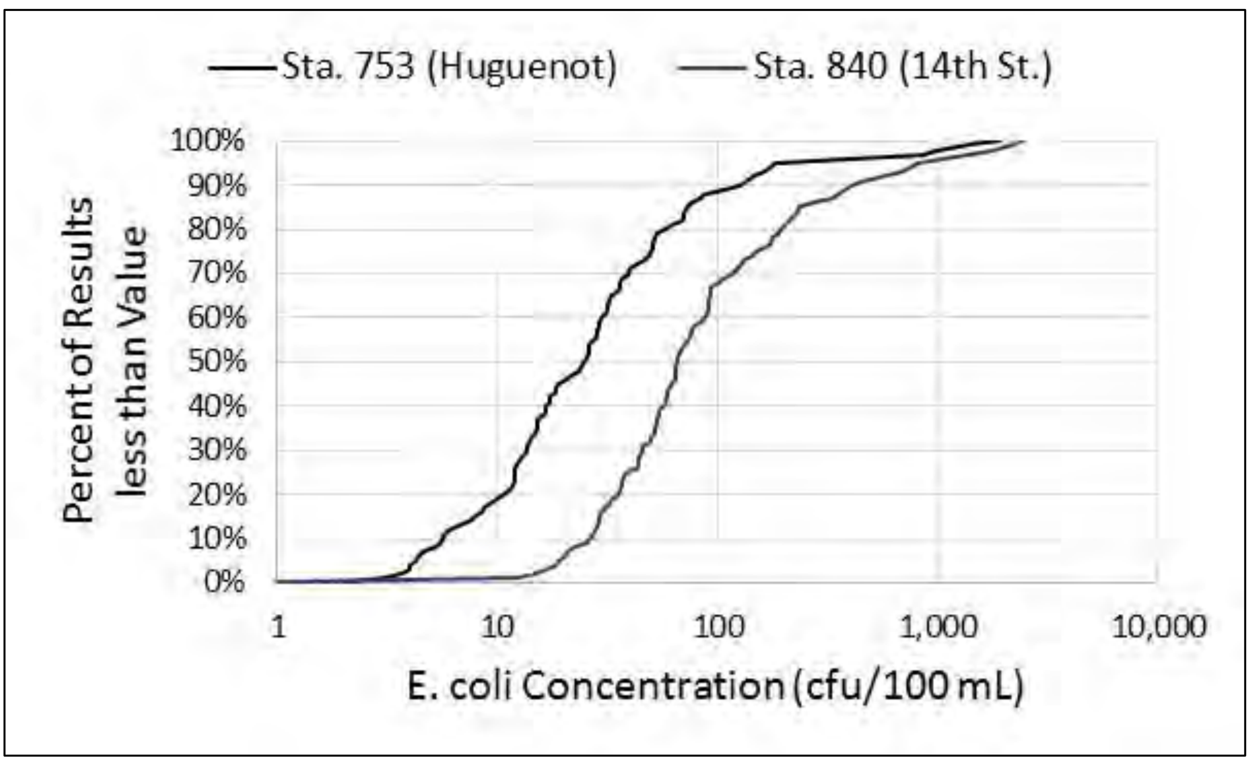



**Figure 4-2: Increase in *E.coli* Concentrations from Huguenot Bridge to 14th St. Bridge**

Second, *E.coli* concentrations are similar among station 840 on the south side of Mayo Island at 14th Street and stations 576, 574, and 572 which occur farther downstream in the estuarine reach.

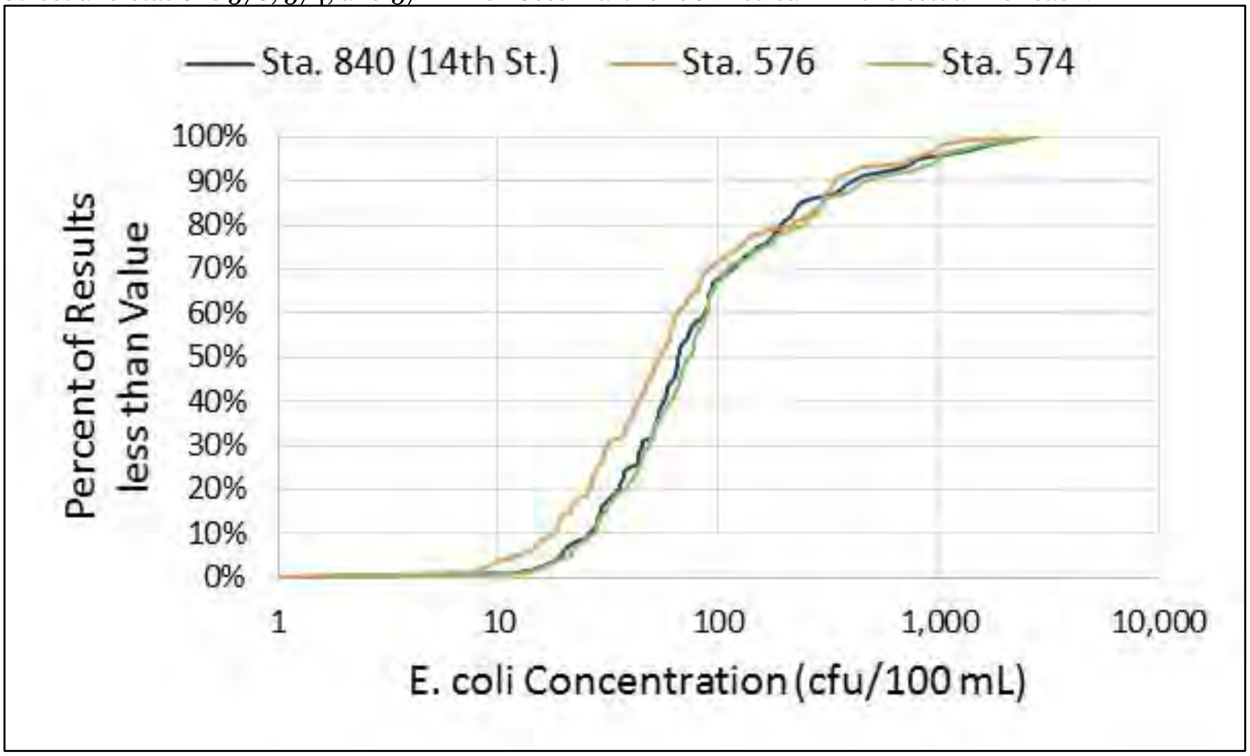



Figure 4-3 compares the cumulative frequency distributions (CFDs) among these stations. Similarities in the *E.coli* concentrations among these stations indicate that, most of the time, additional pollutant loads downstream of station 840 and on the north side of Mayo Island are small relative to the upstream *E.coli* load. Similarity in *E.coli* concentrations at these three locations also indicates that in-stream losses of bacteria are minor between stations 840, 576, and 574. Median (50th percentile) E.coli concentrations at stations 840, 576, and 574 are 66, 74, and 55 CFU/100 mL respectively.

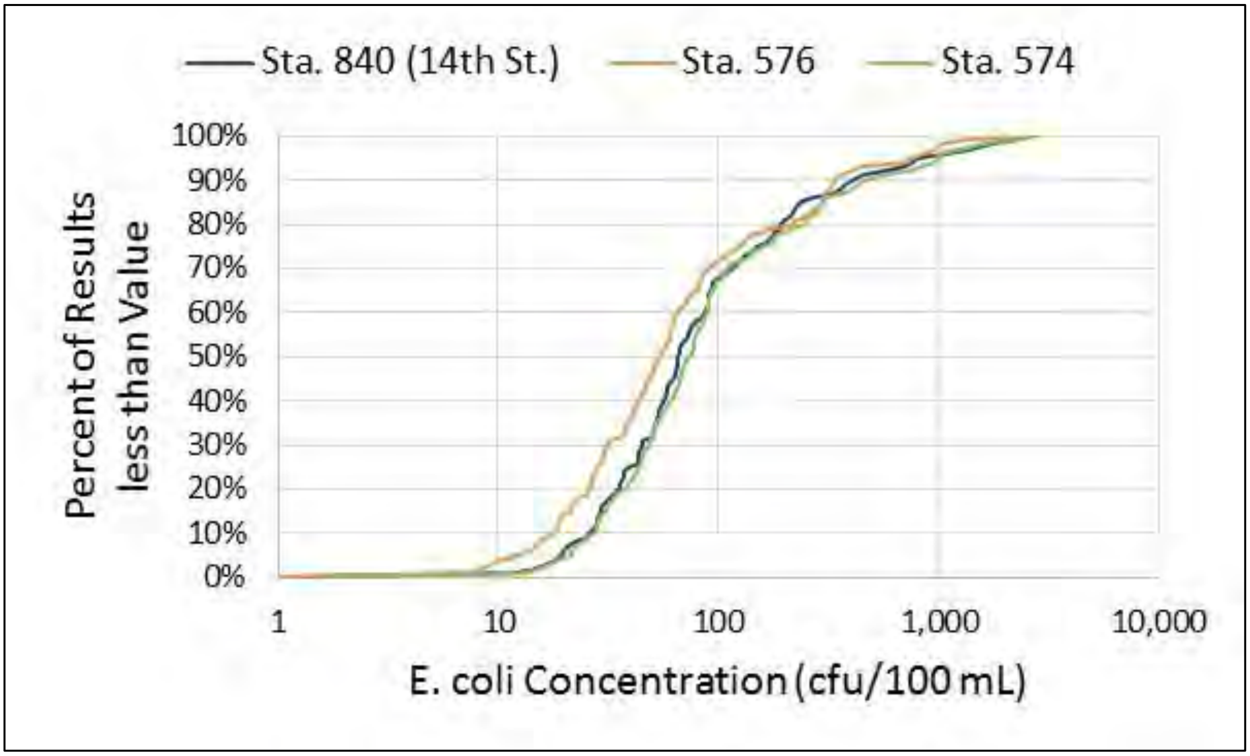



**Figure 4-3: Similarity in *E.coli* Concentrations among Stations 840, 576, and 574**

Third, *E.coli* concentrations at station 641 are significantly higher than at stations 840, 576, 574, and 572 and are assumed to be unrepresentative of ambient conditions on the north side of the island. If these data were representative of the total flow north of the island, then *E.coli* concentrations at downstream stations would be higher than data at station 841 on the south side of the island. Given the similarity in concentrations between stations 841, 576, and 574, it is assumed that samples at station 640 are not representative of the broader river flow north of the island. Samples at this location were taken within a protected embayment that receives discharge from CSO 06 (Shockoe Retention Basin discharge). The protected embayment may have flow properties different from the main section of James River (e.g. sheltered location, stagnant water, little flushing from the James River, direct CSO discharge) that may relate to the unrepresentatively high *E.coli* concentrations observed there.

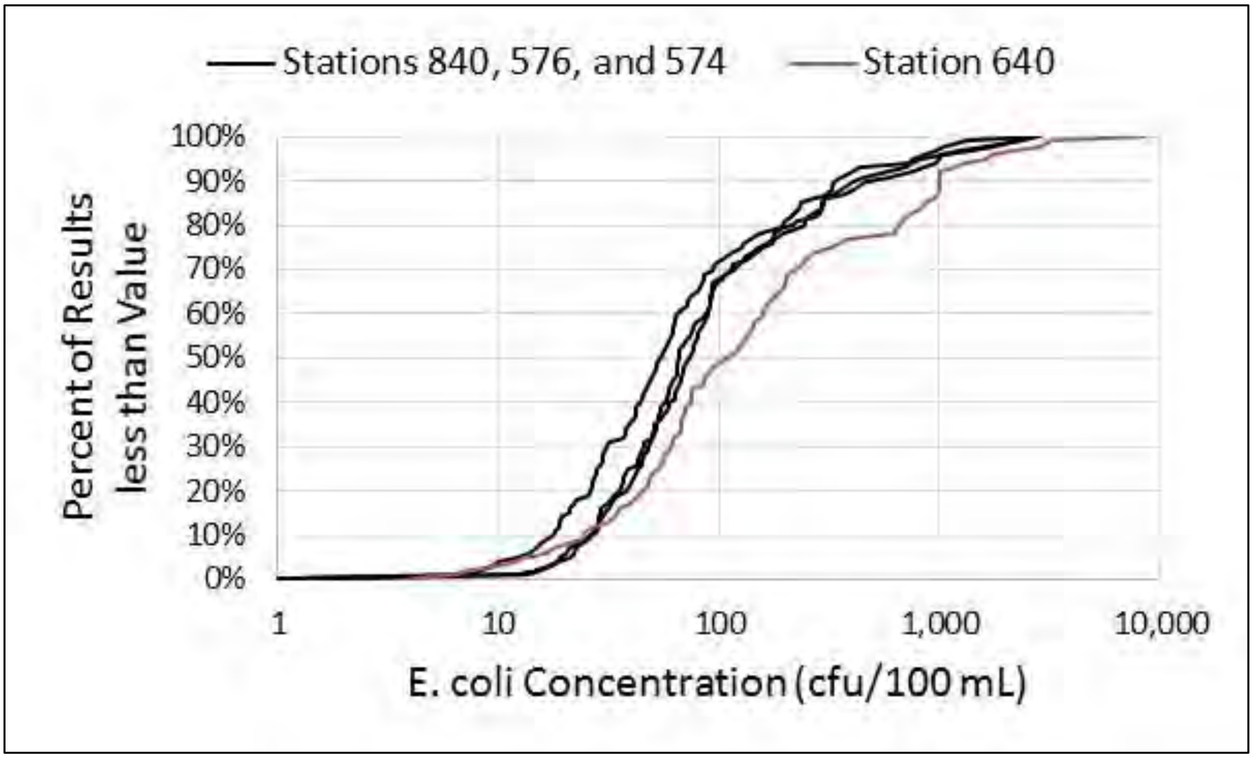



Figure **4-4** illustrates differences between *E.coli* concentrations at station 640 and the surrounding stations.

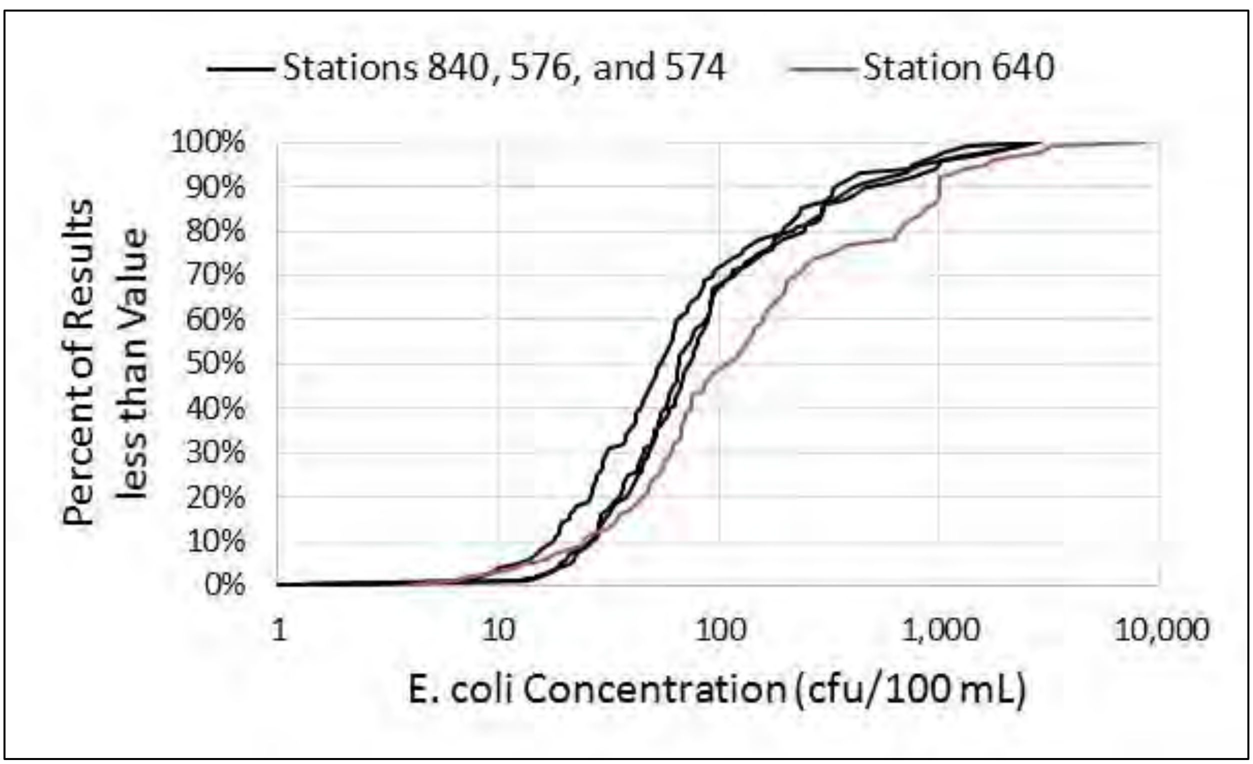



**Figure 4-4: Differences in *E.coli* Concentrations between station 640 and other surrounding stations**

These observations from the data represent the understanding of water quality patterns that guided James River water quality model calibration decisions, which are further described in the sections below.

## 4.2 Model Evaluation and Performance Criteria

Model evaluation and performance criteria are principles and standards for evaluating the success of a model calibration. In some cases, statistical evaluations of model output are useful in that they can be related to industry standards. In other cases, reliable statistical standards are unavailable and model calibration is guided primarily by visual evaluation of graphics comparing model and data. Considerations that guided the model calibration process are described for each model below.

### 4.2.1 Watershed Model

The evaluation of the hydrology calibration involved statistical and visual comparisons between the modeled flows at the outlet of the upstream portion of the Falling Creek watershed and observed flows at the Falling Creek USGS gage. Annual and cumulative modeled flow volume were evaluated. Comparisons were also made between model results and gaged flows for 18 individual storm events. For each event, model results were qualitatively and statistically evaluated based on the shape of the hydrograph, total event volume, and event peak flows.

The evaluation of the water quality calibration relied upon graphical summaries of model results. These summaries included boxplots, cumulative frequency distributions, and one-to-one plots of model results versus observed data. The primary calibration parameters were pollutant build-up and wash-off, baseflow concentration of *E.coli*, and in-stream *E.coli* decay rate. Due to the lack of available water quality data, the final calibration of the watershed model was completed as part of the water quality calibration for the James River EFDC model.

### 4.2.2 CSS Model

The performance evaluation of the original Wet Weather Combined Sewer (WWCS) model was conducted by Greeley and Hansen and included visual comparisons of flow hydrographs for individual wet weather events at the metering locations as well as 1:1 plots for comparisons of wet weather event flow volume and peak flows. The model evaluation is described in the Collection System Hydraulic model report of the Wastewater Collection System Master Plan by GH (Greeley and Hansen, 2012).

Brown and Caldwell evaluated the adjusted Clean Water Plan version of the CSS model (described in Section 3.2) against available flow observations as well as the underlying WWCS model by GH and the comparison described in detail in the IP Model Development documentation (Brown and Caldwell, 2016). This includes flow comparisons for individual wet weather events at meter locations (against observations) as well as volumetric comparisons at CSO locations on an event and annual basis against the WWCS model.

### 4.2.3 Receiving Water Quality Model

Evaluation of the hydrodynamic model performance relied on graphical summaries of model output. In the riverine reach, modeled depths and velocities were plotted against modeled discharge and compared against observed depths and velocities plotted against observed discharge. These relationships of depth and velocity versus discharge are strongly influenced by the hydraulic characteristics of the James River including bed slope, width, and channel roughness. In the estuarine reach, the model was evaluated using two other graphic types: time series and one-to-one plots. These tools were used to assess the phasing and amplitude of the modeled tides and the effect of river flows on water levels in the estuarine reach.

Evaluation of the water quality model performance also relied on graphical summaries of model output, including time series plots and cumulative frequency distributions (CFDs). Emphasis was placed on evaluating the model's consistency with elevated *E.coli* concentrations which would most significantly influence compliance with water quality standards.

## 4.3 Hydrology and Hydrodynamics Calibration Results

Hydrology and hydrodynamics describe the quantities and rates of water moving through a system. In the James River water quality modeling framework, this includes movement of storm runoff from the watershed into and through tributaries and storm water sewers, movement of water and wastewater into and through the combined sewer system and through the wastewater treatment plant and combined sewer overflows, and movement of water into and through the James River. Calibration of hydrology and hydrodynamics is important in that it strongly influences the concentrations and persistence of pollutants in an environmental system.

### 4.3.1 Watershed Model

The purpose of the hydrology calibration was to: 1) reasonably approximate the volume and timing of observed flows in Falling Creek and 2) develop hydrologic parameters that could be used for all subcatchments and stream channels in the watershed model extent. In the absence of robust site-specific data, it was assumed that all subcatchments and stream channels in the model would have similar hydrologic properties. This assumption was considered reasonable because median values are similar for subcatchment parameters, such as impervious area, percent slope, and soil properties between the gaged portion of the Falling Creek watershed and the other watersheds included in the model extent. The model was run for calendar years 1985 to 1994, and modeled cumulative flows and storm event hydrographs were compared to observed flows at the USGS gage. Subcatchment percent impervious area and stream channel roughness values were adjusted to bring the modeled results into alignment with observed values.

On a cumulative basis, the model results reasonably match observed flows for all years until spring of 1993 and spring of 1994 (Figure 4-5).

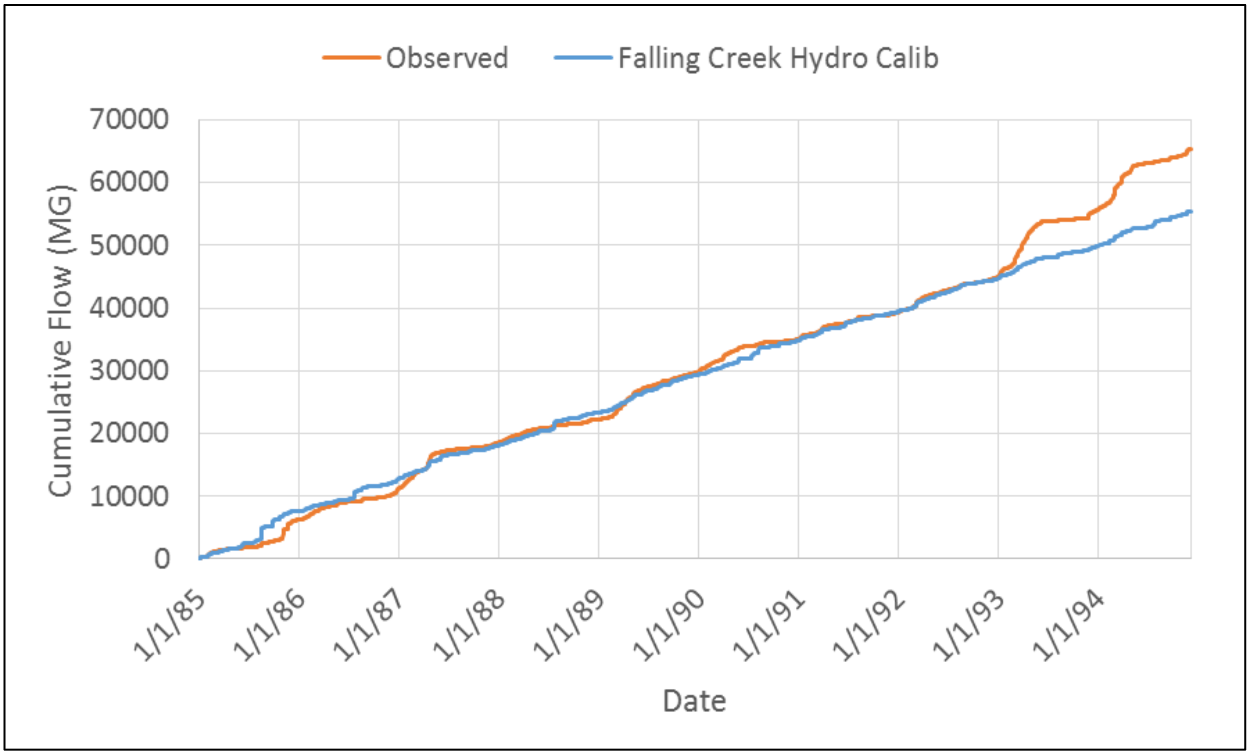



**Figure 4-5: Observed and Modeled Cumulative Flow Volume at the Falling Creek Gage**

For the period 1985 to 1994, the model underpredicted observed flows by approximately 15%. However, when the flows from 1993 and 1994 were excluded, the difference in cumulative volume between modeled and observed flows decreased to -0.5% (Table 4-3). The cause for the 1993 and 1994 increases in observed flows are unknown, but similar increases were observed in four other USGS gages in the region: Totopotomoy Creek near Studley, VA (USGS 01673550); James River near Richmond, VA (USGS 02037500); Appomattox River at Mattoax, VA (USGS 02040000); and Chickahominy River near Providence Forge, VA (USGS 02042500), indicating that this is not merely an instrumental problem at a single gage (Figure 4-6). Variations could be attributable to differences in rainfall in the Falling Creek watershed and at the Richmond Airport, which are approximately 11.7 miles apart as the crow flies.

**Table 4-3: Observed and Modeled Annual Flow Volumes at the Falling Creek Gage**

| Year | Observed Total Annual Flow (MG) | Modeled Total Annual Flow (MG) | Percent Difference Between Modeled and Observed |
|---|---|---|---|
| **1994** | 9,614 | 5,584 | -41.9% |
| **1993** | 10,740 | 5,181 | -51.8% |
| **1992** | 5,678 | 5,209 | -8.3% |
| **1991** | 4,214 | 4,609 | 9.4% |
| **1990** | 5,253 | 5,521 | 5.1% |
| **1989** | 7,566 | 6,110 | -19.2% |
| **1988** | 3,677 | 5,143 | 39.9% |
| **1987** | 7,435 | 5,417 | -27.1% |
| **1986** | 4,875 | 5,066 | 3.9% |

| Table 4-3: Observed and Modeled Annual Flow Volumes at the Falling Creek Gage | | | |
|---|---|---|---|
| **Year** | **Observed Total Annual Flow (MG)** | **Modeled Total Annual Flow (MG)** | **Percent Difference Between Modeled and Observed** |
| **1985** | 6,262 | 7,639 | 22.0% |
| **OVERALL** | **65,313** | **55,477** | **-15.1%** |
| **OVERALL (excl. '93-'94)** | **44,959** | **44,712** | **-0.5%** |

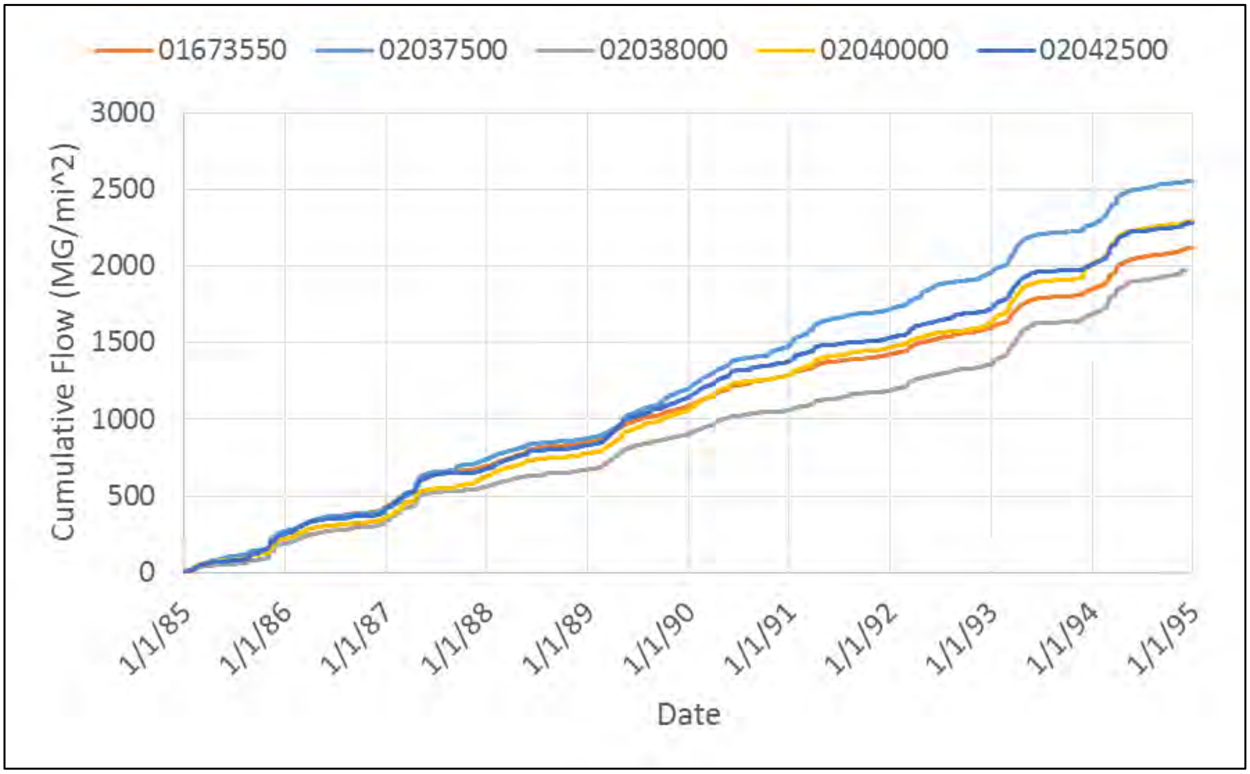



**Figure 4-6: Area Normalized Cumulative Flow Volume for USGS Gages in the Richmond Region**

On an event basis, model results tend to over predict event volumes and peak flows (Figure 4-7 and Figure 4-8), but the general shape of the hydrographs tend to match (Figure 4-9). The model currently only uses precipitation from one gage at Richmond International Airport (RIA). Variations on an event basis could be attributable to differences in rainfall in the Falling Creek watershed and at the Richmond Airport, which are approximately 11.7 miles apart as the crow flies.

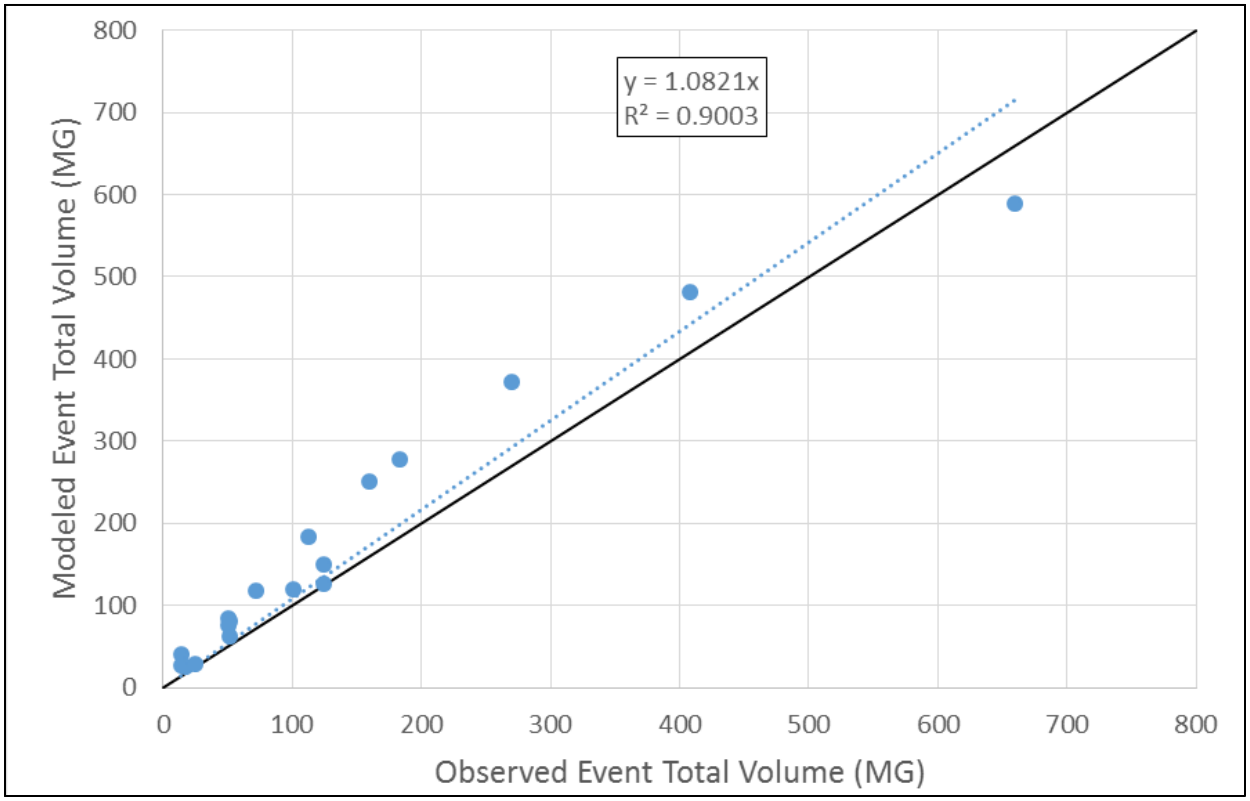



**Figure 4-7: Modeled vs Observed Event Volume**

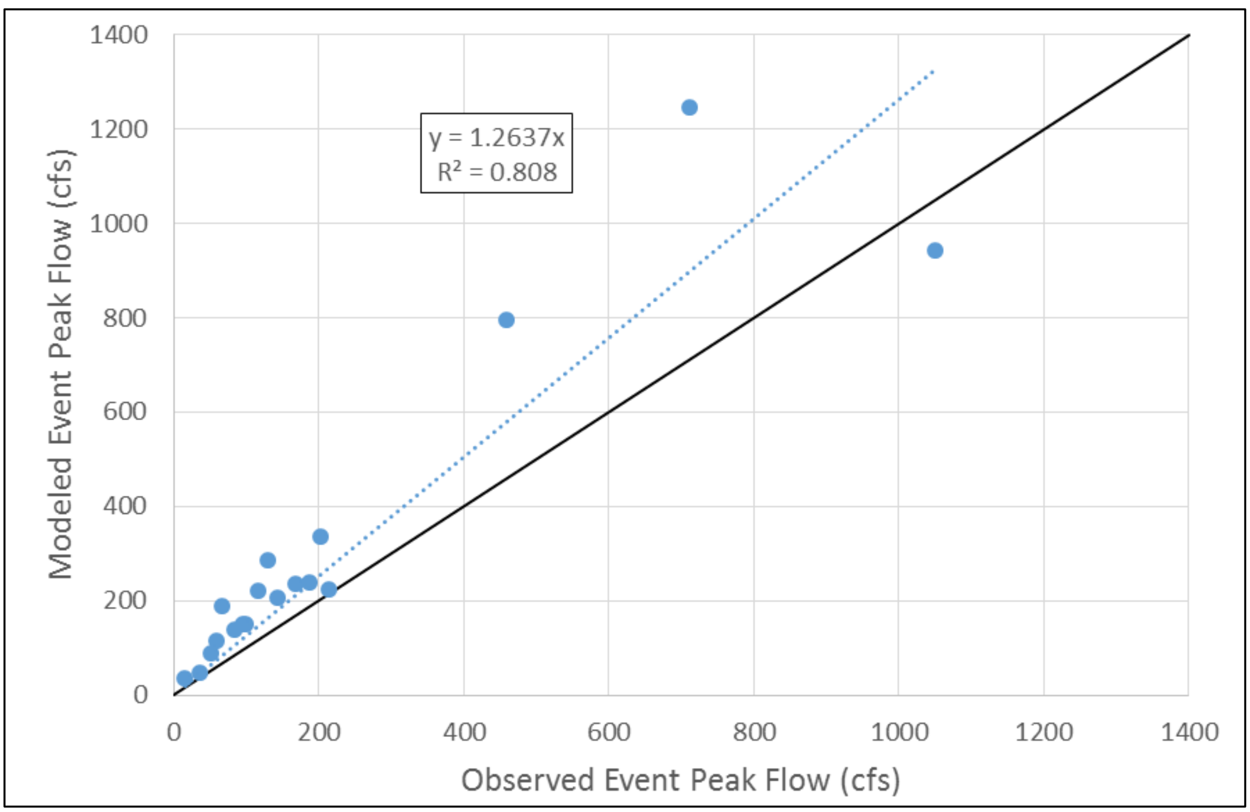



**Figure 4-8: Modeled vs. Observed Event Peak Flow Rate**

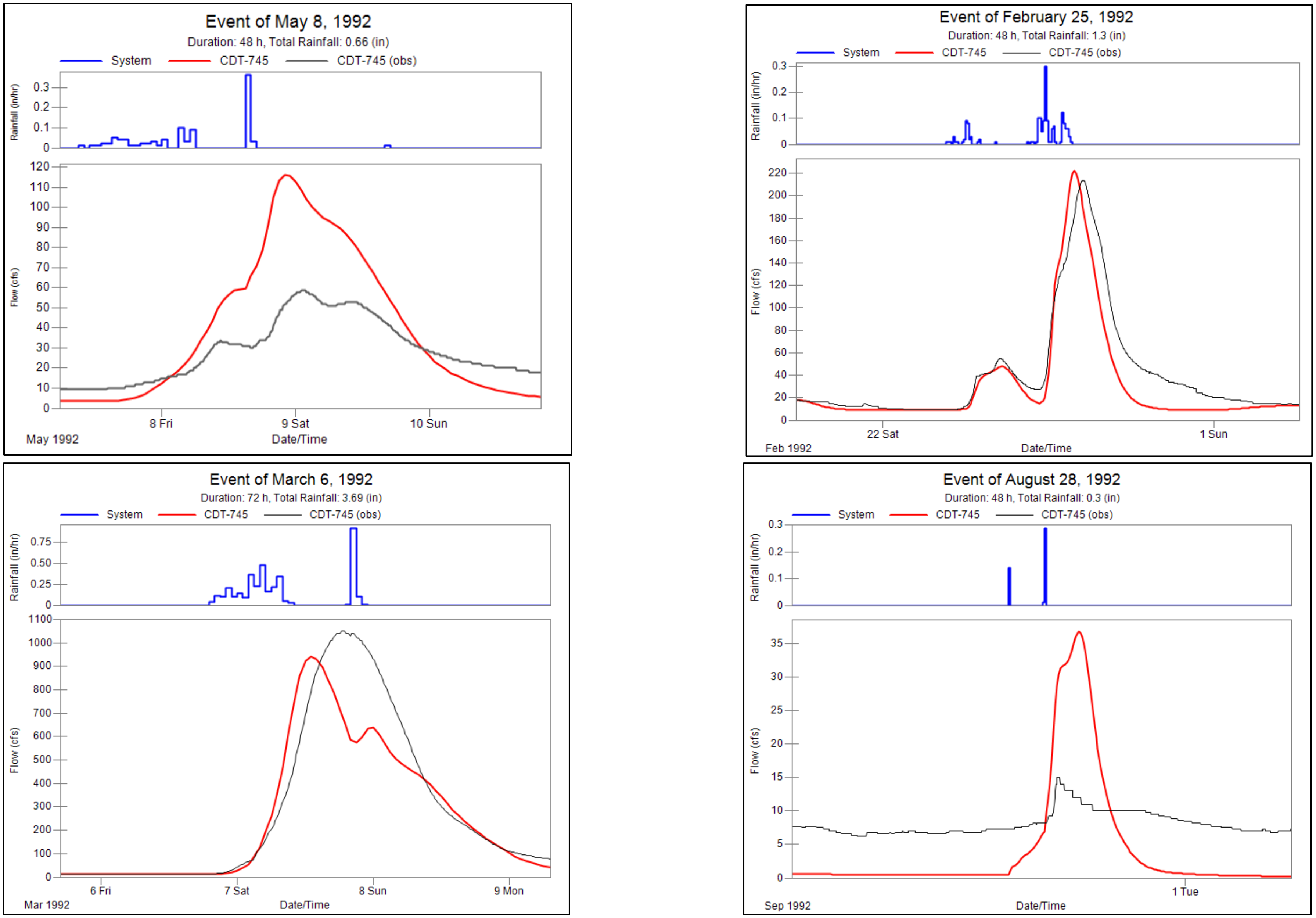



**Figure 4-9: Modeled vs Observed hydrographs for four events at Falling Creek Gage**

Three calibration parameters were used to adjust cumulative volumes, event volumes, and event peak flows: percent impervious area, Manning's N for in-channel roughness, and Manning's N for overbank roughness. Adjustments to modeled cumulative volume were made by adjusting the percent impervious area. Adjustments to event peak flows and the timing of peak flows were made by adjusting in-channel and overbank Manning's values. Manning's N for in-channel roughness was varied between 0.035 and 0.05 for a main channel that was assumed to be clean, winding and have some pools and shoals. Manning's N for overbank roughness was varied between 0.04 and 0.08 for overbanks that were assumed to have light brush and trees (Chow, 1959).

Impervious area is not typically a calibrated parameter, but initial model runs underestimated observed cumulative flows (dotted green line in Figure 4-10). To determine the cause of the underestimated flows, NLCD impervious cover data were compared to a planimetric impervious layer provided by the City of Richmond. The analysis revealed that the NLCD impervious layer underestimated the median percent impervious area, especially in less urban areas. To correct the underestimation of impervious area a linear regression was used to adjust the NLCD impervious area upwards for consistency with the planimetric data (dotted blue line in figure below). Finally, because the amount of directly connected impervious area is not known, the percent impervious area for each subcatchment was adjusted downward to account for impervious areas that are not directly connected to a waterway (solid blue line in figure below). Results from each run are summarized in Figure 4-10.

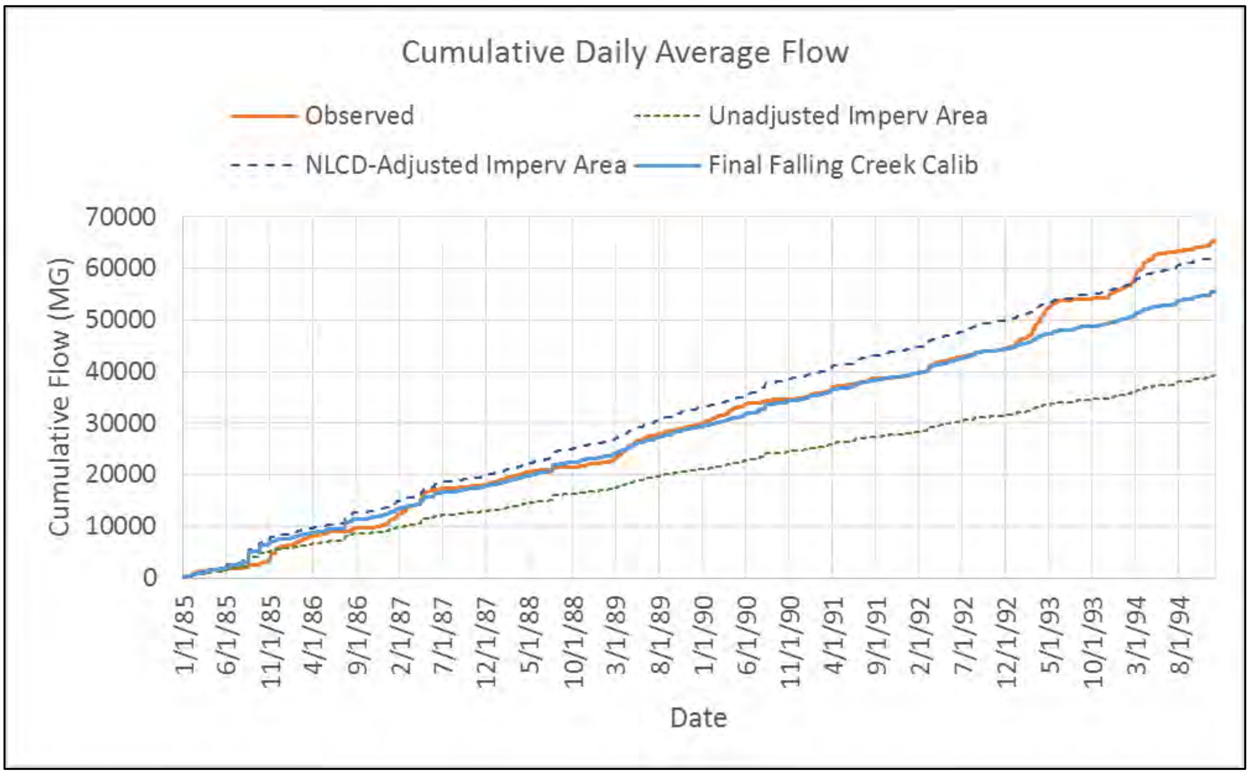



**Figure 4-10: Model calibration results (impervious area)**

### 4.3.2 CSS Model

The CSS calibration of the original Wet Weather Combined Sewer (WWCS) model focused both on achieving the appropriate volume and peak flows within the sewer system and on characterizing the discharge at the combined sewer outfalls, specifically at CSO 06 (Shockoe Retention Basin). While calibration within the sewer system was deemed acceptable and representative of conditions at that time, calibration at the Shockoe Retention Basin was more difficult to achieve due to the complex hydraulic situation in this area as well as to the manual overflow operations that occur at this location (Greeley and Hansen, 2015).

The original WWCS model was modified and adapted so that it could be used in hindcast mode for a long-term continuous period, and in order to operate the model for evaluating CSS alternatives. After the modifications, the performance of the resulting CSS IP model was checked against monitoring data as well as against the results from the underlying original WWCS model. A discussion of the results is included in the CSS model review memorandum (Brown and Caldwell, 2016). Overall, the CSS IP model predicts lower overall CSS volume discharges and events compared to the results documented in the 2002 LTCP re-evaluation report, as well as compared to the CSS Annual Reports. These differences can be attributed to two main reasons:

- Numerous changes to the CSS model were performed since the 2002 LTCP re-evaluation, and the CSS model was re-calibrated on a few different occasion. This results in the CSO discharge volumes and number of CSO events to be different from those reported in the 2002 LTCP re-evaluation. These differences are deemed justified based on the additional monitoring data that was used to conduct the re-calibration, and on the CSS model revisions, including operational and physical changes to the combined sewer system and waste water treatment plant system that were implemented since the 2002 Long Term Control Plan Re-Evaluation.
- The CSS IP model uses standard operating rules to model the CSO operations at the Shockoe Retention Basin, causing the CSO discharges modeled at this location to be different from those reported in the CSS Annual Report, where the CSO discharges are calculated by using the real-time operator logs and which are interweaved with the results from the CSS model.

### 4.3.3 Receiving Water Quality Model

The purpose of the hydrodynamic model calibration was to adjust model parameters within defensible ranges to achieve reasonable agreement between modeled and observed water levels and velocities. The model was run for calendar years 2011 through 2013, and the modeled relationships between river discharge and water level, as well as river discharge and velocity were compared to the observed relationships in the riverine reach. Modeled roughness heights, which represent both grain roughness associated with substrate and larger scale bed forms, were adjusted within bounds consistent with Manning's N roughness values cited in the FEMA Flood Insurance Study (FEMA, 2014). These adjustments were made to bring the modeled water levels and velocities in closer agreement with the observed data.

Figure 4-11 and Figure 4-12 illustrate the riverine model calibration and show sensitivity of the model results to varying roughness height inputs. The calibrated bed roughness heights varied from 5 to 50 millimeters corresponding to Mannings N values from 0.03 to 0.045. Roughness heights were halved in the sensitivity test named "Lower Roughness Test," and they were doubled in the sensitivity test named "Higher Roughness Test." Increases in bed roughness caused increases in modeled water surface elevations and decreases in current velocities. The calibrated roughness inputs provided a balance of accurately simulating both water surface elevations and current velocities.

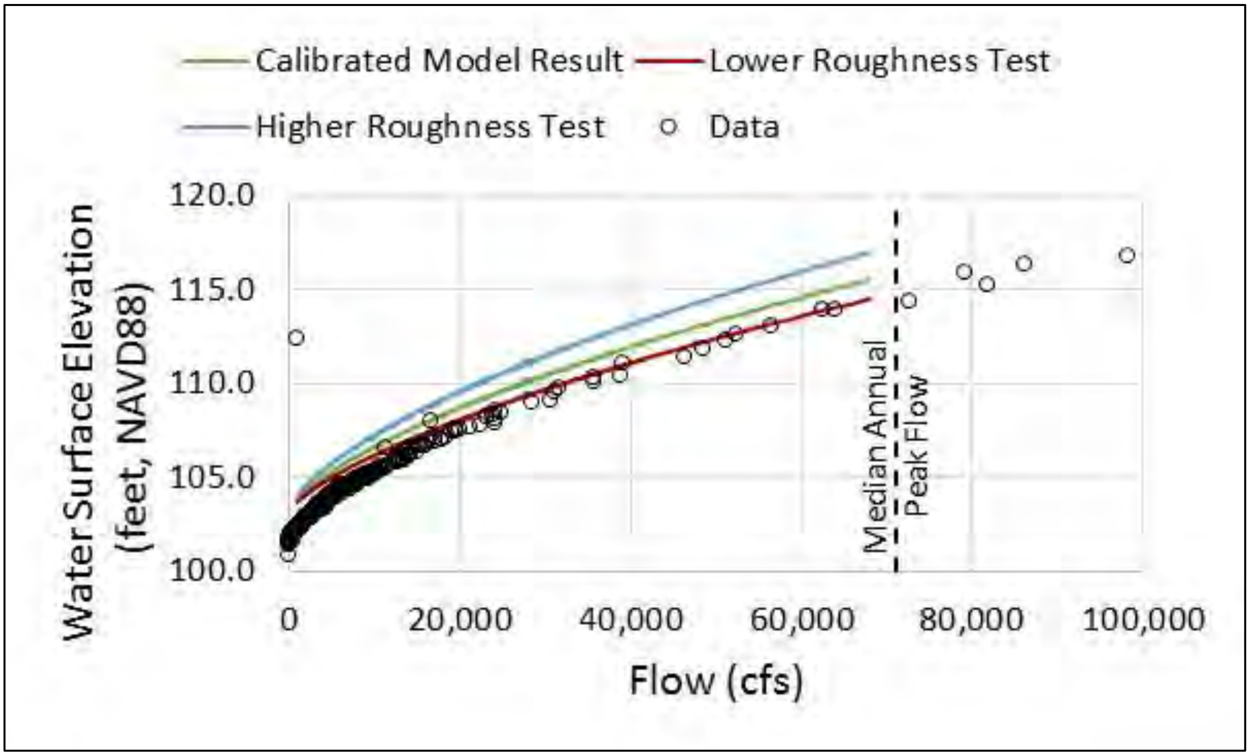



**Figure 4-11: Comparison of Modeled and Observed Water Levels at upstream USGS gage**

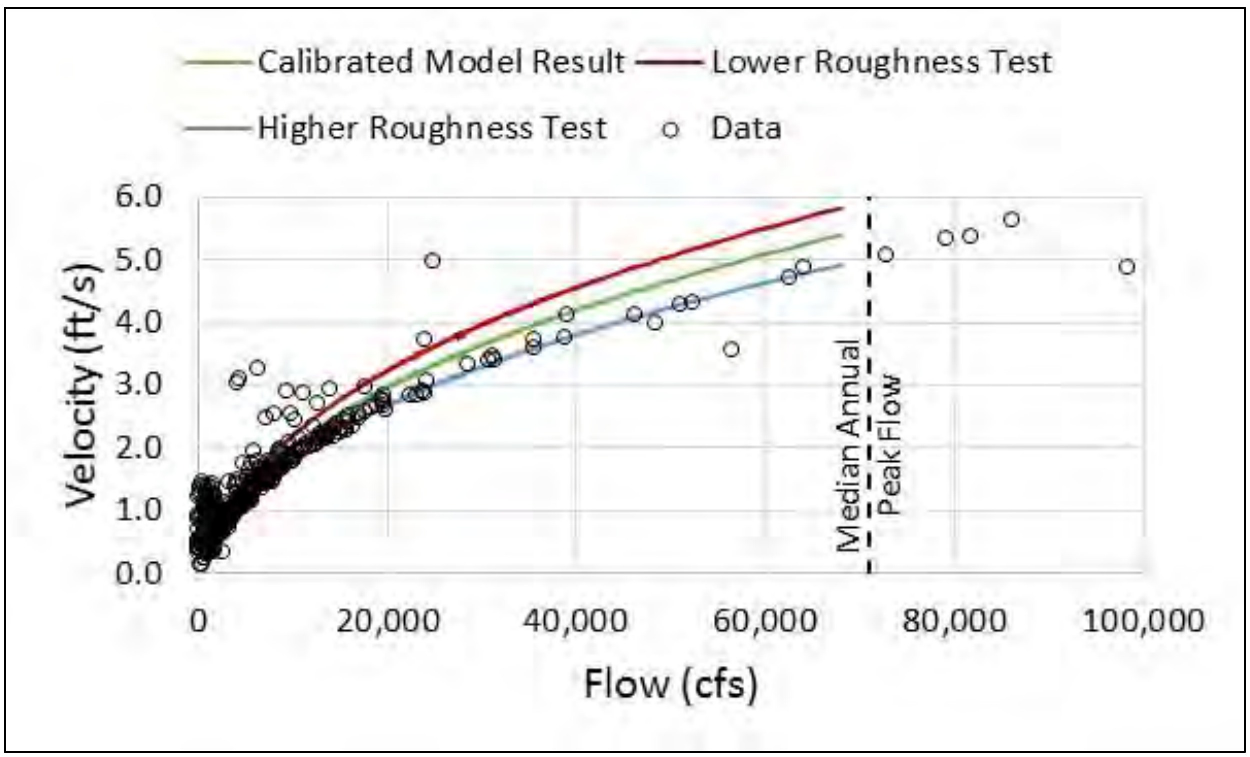



**Figure 4-12: Comparison of Modeled and Observed Velocities at upstream USGS gage**

Calibration to USGS water level data in the estuarine reach was achieved by adjusting the water level at the boundary to account for the effect of river flow on water levels. Water levels at the boundary were reduced relative to the gaged water levels to account for changes in water level between the gage and the model boundary. The data were adjusted according to the expression:

$$Z_{boundary} = Z_{Gage} - C * Q^{n}$$

Where:

- $Z_{boundary}$ is the estimated water level at the downstream boundary in feet
- $Z_{gage}$ is the observed water surface elevation at the USGS gage (#02037705) in feet,
- C and n are constants which were determined via calibration to be 4.4e-7 and 1.5; and,
- Q is the James River flow rate in cubic feet per second

The data were also shifted by approximately three minutes backward in time to account for propagation of the tides from the model boundary to the gage location.

Figure 4-13 and Figure 4-14 illustrate the estuarine model calibration and Figure 4-15 shows how the model performed in the absence of this flow-based water level adjustment at the downstream boundary. Without this flow-based adjustment to water levels, modeled water levels are biased four feet high relative to the data during the highest flow conditions.

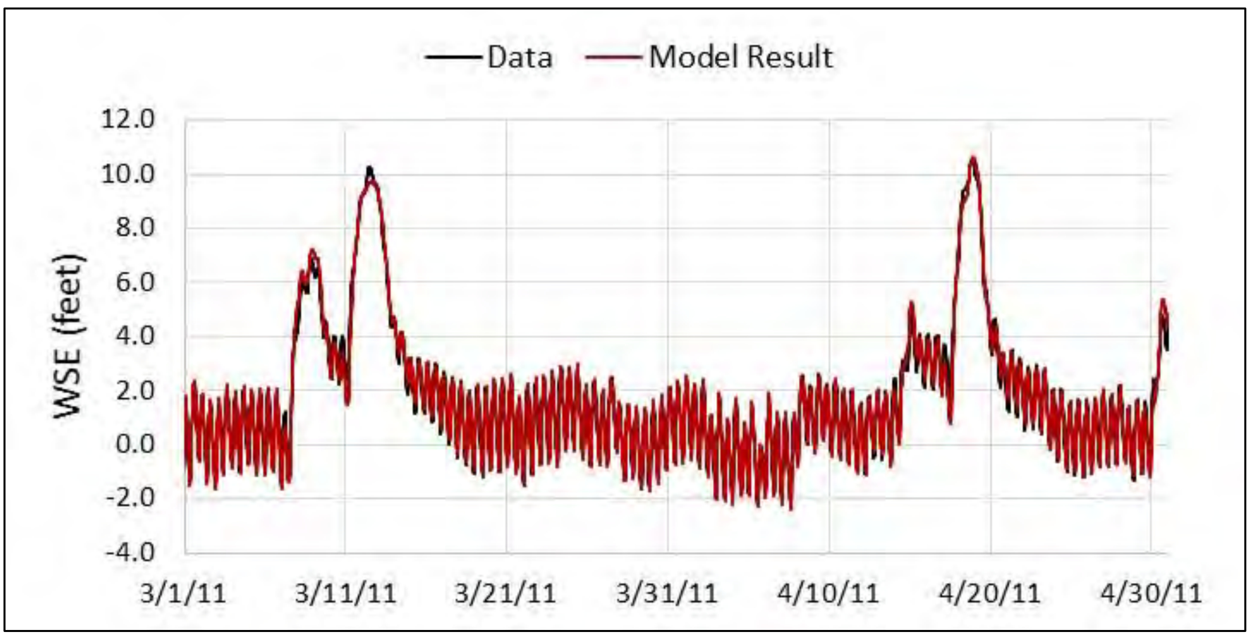



**Figure 4-13: Time Series Comparison of Modeled and Observed Water Levels at downstream USGS gage**

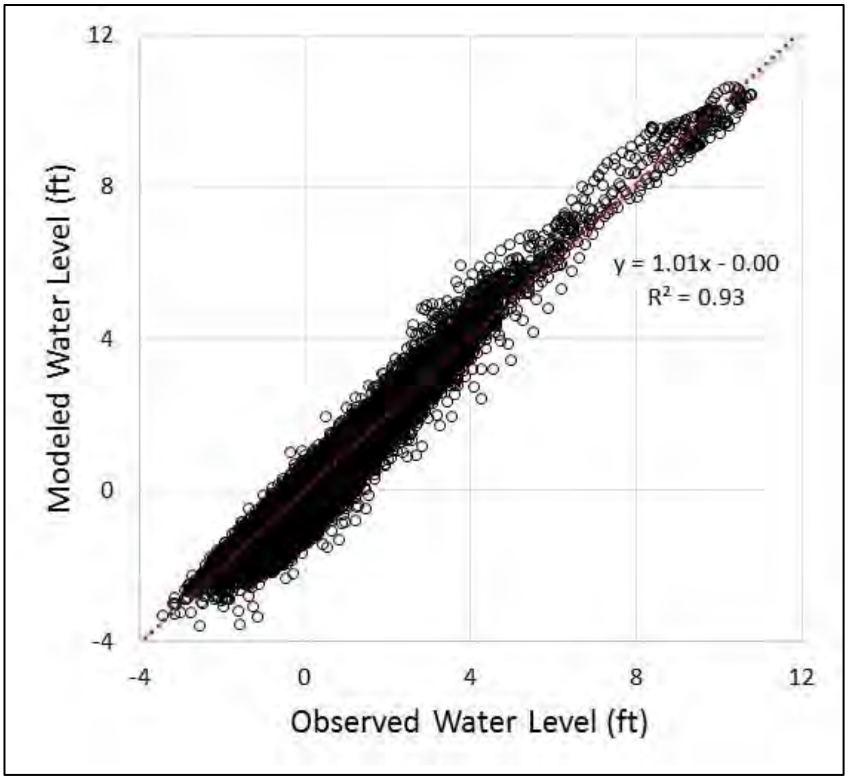



**Figure 4-14: One-to-one Comparison of Modeled and Observed Water Levels at downstream USGS gage**

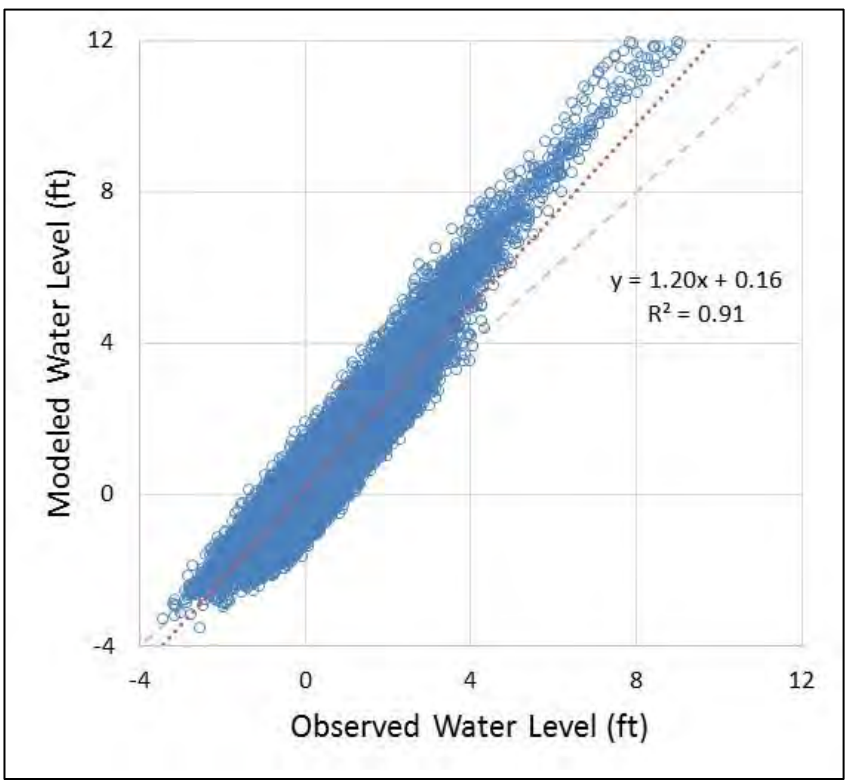



**Figure 4-15: One-to-one Comparison of Modeled and Observed Water Levels at downstream USGS gage without calibration of water levels at the boundary**

## 4.4 Water Quality Calibration Results

Calibration of water quality conditions involved adjusting inputs that influence the quantity, timing, and locations of *E.coli* delivered to the receiving waters and adjusting inputs that influence the survival of *E.coli* in the streams. *E.coli* sources in the water quality modeling framework include *E.coli* washoff from the watershed, persistent background sources of *E.coli* (e.g.: wildlife), *E.coli* in combined sewer overflows and treatment plant effluent, and *E.coli* originating from upstream locations in the James River watershed.

### 4.4.1 Watershed Model

The main objectives of the watershed water quality calibration were to estimate *E.coli* loading to the receiving water quality model and the approximate timing of these loads. To evaluate the first objective, the distribution of modeled *E.coli* concentrations was compared to observed data using boxplots. To evaluate the second objective, model results were compared to observed data using one-to-one plots, where the observed data is compared to the modeled data for a given model time step.

Data from the Falling Creek location were primarily used to calibrate the watershed model for two reasons: First, Falling Creek stations 399/400 have the greatest quantity of observed data. Second, since Falling Creek is the only tributary in the watershed model with a USGS flow gage, the modeled flows are likely to be the most accurately represented. Therefore, accurately modeling observed concentrations in Falling Creek would result in the best estimation of *E.coli* loads delivered to the receiving water quality model. Since there is a limited amount of data available in the tributaries, the initial calibration was considered complete and satisfactory once the modeled results from Falling Creek and the majority of the other five tributaries matched observed values within reason.

The model was run for the calendar years 2011 to 2013 and modeled *E.coli* concentrations were compared to observed results for six tributaries. Figure 4-16 and Figure 4-17 illustrate the watershed model water quality calibration. Model results at Falling Creek reasonably approximate the median observed concentration and the distribution of observed values. Modeled median values for four out of the other five tributaries also appear to be reasonable, with the modeled medians within one order of magnitude of the observed medians. Maximum modeled *E.coli* concentrations are generally greater than the observed data, which is assumed to be due to the lack of wet weather data collected in the tributaries. One-to-one plots were evaluated in light of the fact that in-stream *E.coli* concentrations can vary greatly in time and space (USEPA, 2010). To account for the natural variability that can occur when sampling *E.coli*, two additional sets of lines were added to the 1-to-1 plot: the first set of dashed lines represent a two-times (2x) confidence interval representing the variability in monitoring data results associated with field-collection efforts. The second set of dotted lines represents a ten-time (10x) confidence interval which represents the possible variability in monitoring data results associated with both the field collection efforts and the laboratory methods. The majority of points on the one-to-one plots fall within the 10x confidence interval for all stations.

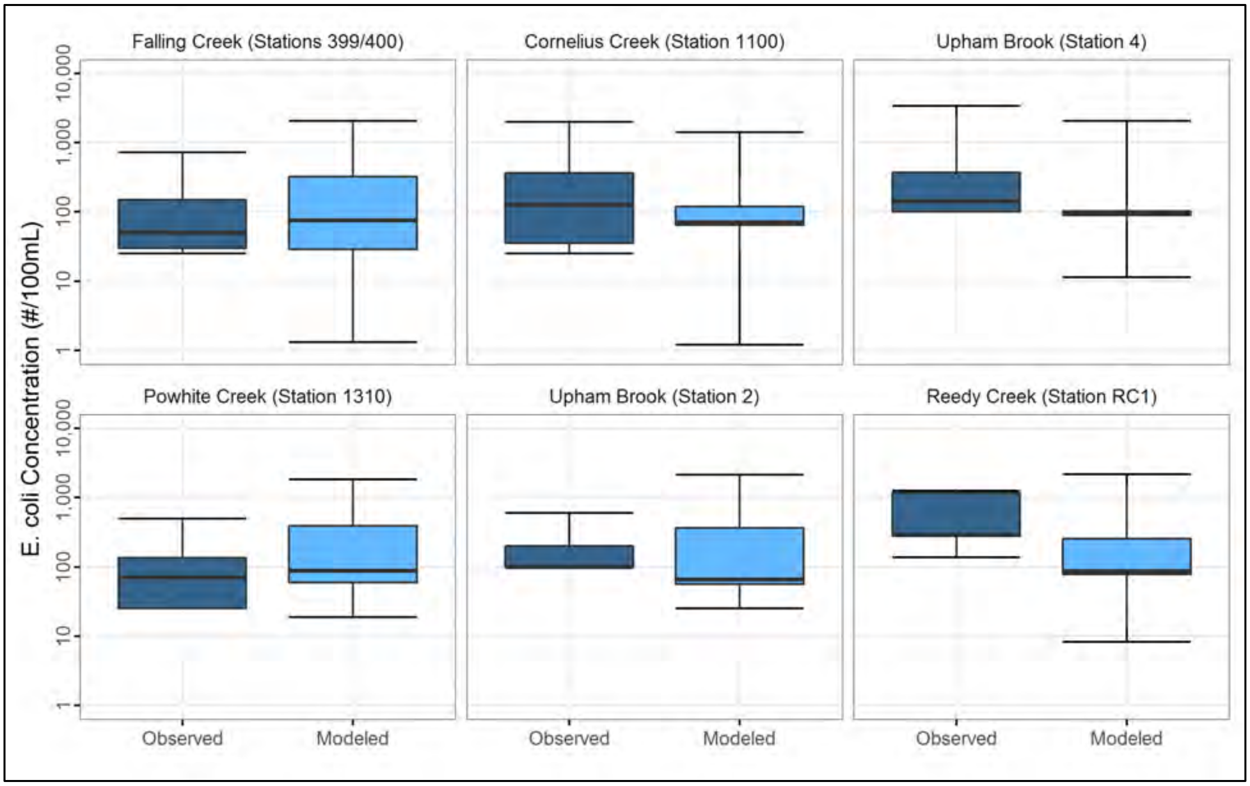



**Figure 4-16: Boxplots of Modeled vs. Observed E.coli Concentrations in Select Richmond Tributaries**

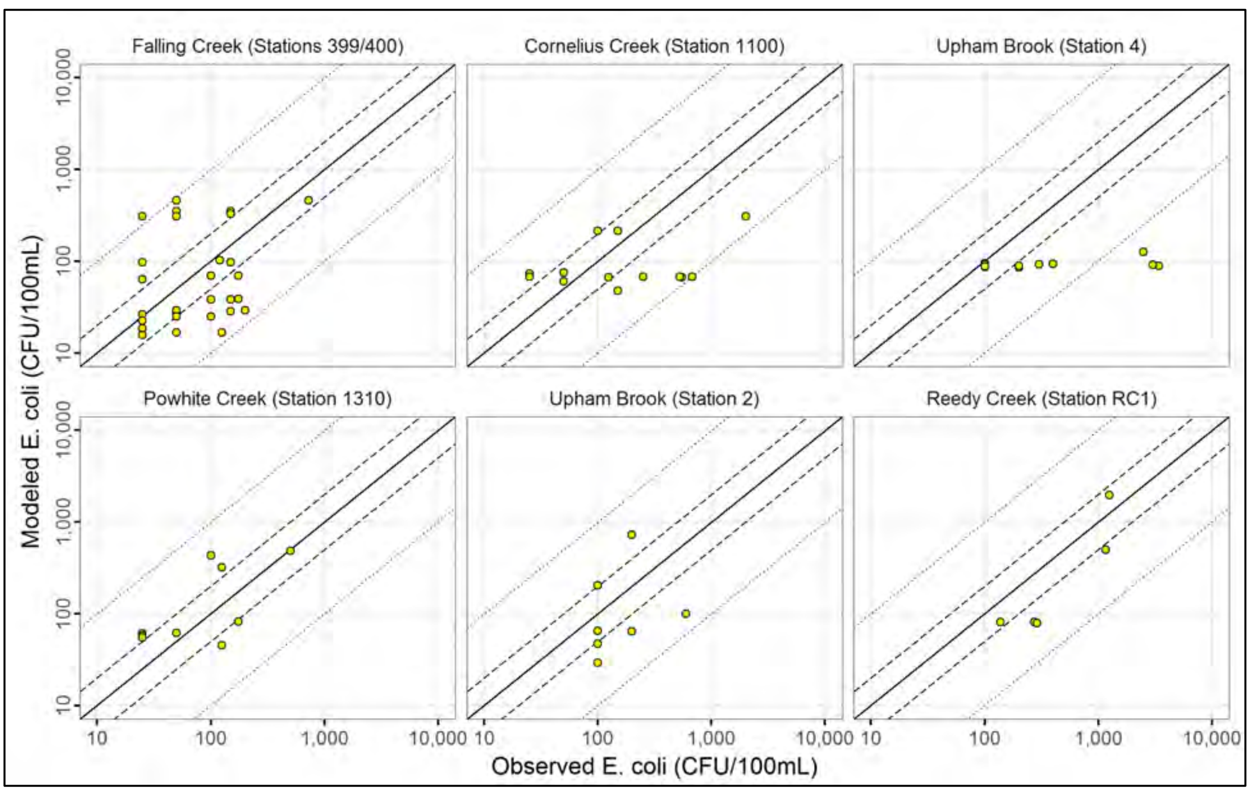



**Figure 4-17: One-to-One Plots of Modeled vs Observed E.coli Concentrations in Select Richmond Tributaries**

Calibration of the watershed model to better represent the *E.coli* concentrations was achieved by adjusting the values of four main parameters: pollutant build-up rate, pollutant wash-off rate, baseflow *E.coli* concentration, and in-stream decay rate. Pollutant build-up and wash-off had the greatest influence on wet weather in-stream concentrations, while baseflow *E.coli* concentration had the greatest influence on dry weather concentrations. Of the six stations evaluated, *E.coli* decay rate was found to have the greatest influence on Falling Creek, the largest tributary in the model extent. The impact of in-stream decay rate for the other five stations was nominal because travel times in these tributaries was generally shorter.

### 4.4.2 CSS Model

Explicit water quality calibration of the CSS model was not conducted. Rather, the CSO discharges were assigned bacteria concentrations based on monitoring results conducted for the development of the original LTCP. Additionally, the WWTP discharges were assigned bacteria concentrations based on the current bacteria water quality standards. Section 3.3 and 5.2 discusses the pollutant concentrations assigned to the various CSS outfalls and the WWTP discharge streams in more detail.

### 4.4.3 Receiving Water Quality Model

The primary objectives of the James River water quality model calibration were to: 1) evaluate the reasonableness of modeled *E.coli* loadings by source type and 2) evaluate the completeness of modeled *E.coli* sources. These objectives were achieved by evaluating consistency between modeled and observed *E.coli* concentrations and identifying and resolving any significant biases. The water quality model calibration is controlled in large part by estimates of *E.coli* concentrations from upstream of the study area and by estimates of *E.coli* loads from the watershed model and CSO model. Because of this, the water quality model calibration is a consistency check between the load estimates and sampling data in the James River.

The model was run for calendar years 2011 through 2013 and modeled *E.coli* concentrations were compared to observed concentrations at six stations. Figure 4-18 and Figure 4-19 illustrate the James River water quality model calibration. Median modeled *E.coli* concentrations are within 15% of median observed *E.coli* concentrations except at Station 641 where, as described in Section 4.1.3, the sampling data are anomalously high and not suitable for model calibration. Maximum modeled *E.coli* concentrations are all higher than observed *E.coli* concentrations. This is because model results are computed for every hour of the three year period, while samples were only taken occasionally, making it unlikely that the samples would capture the highest *E.coli* concentrations that actually occur in the river.

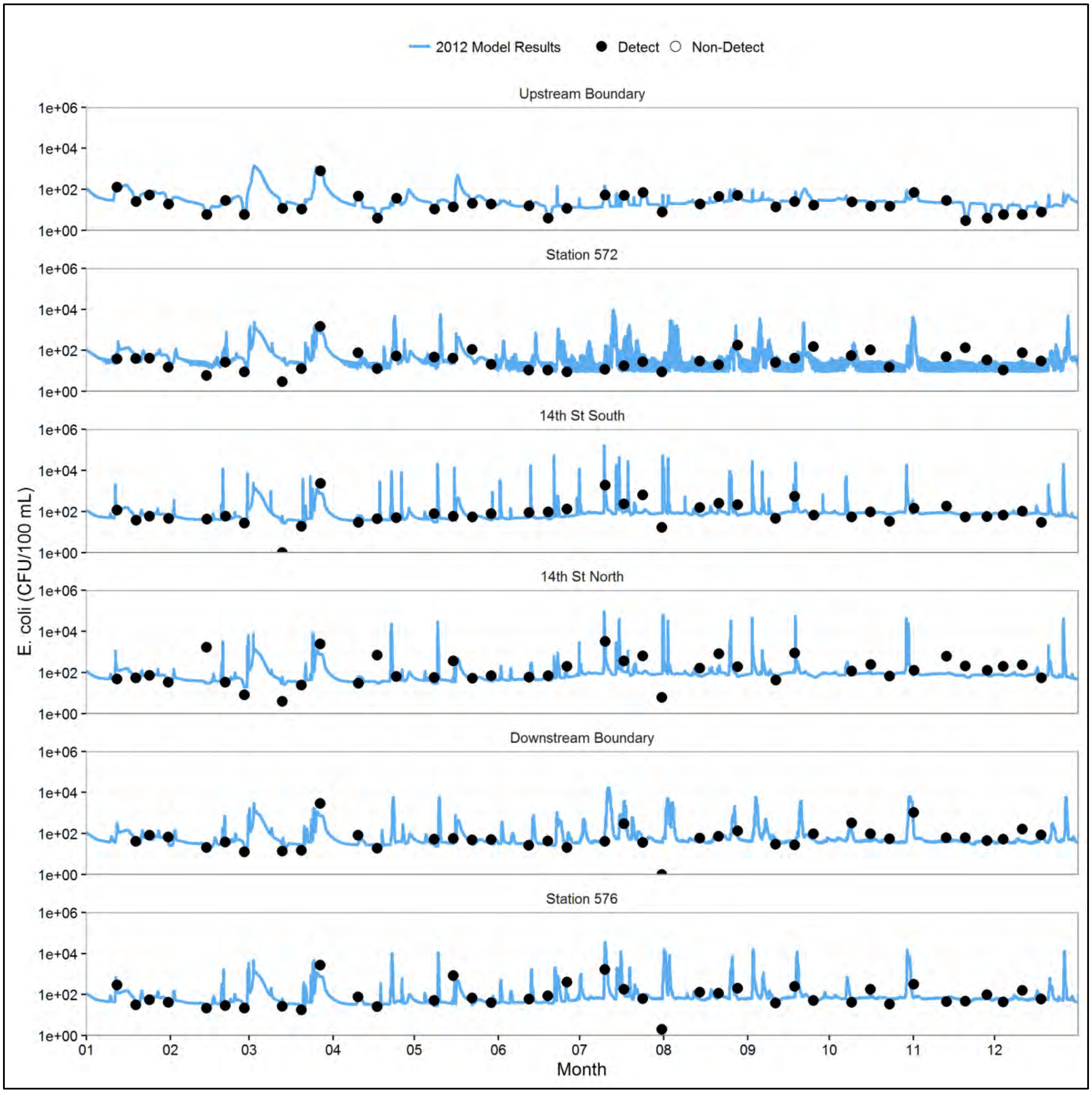



**Figure 4-18: Time Series Comparison of Modeled and Observed *E.coli***

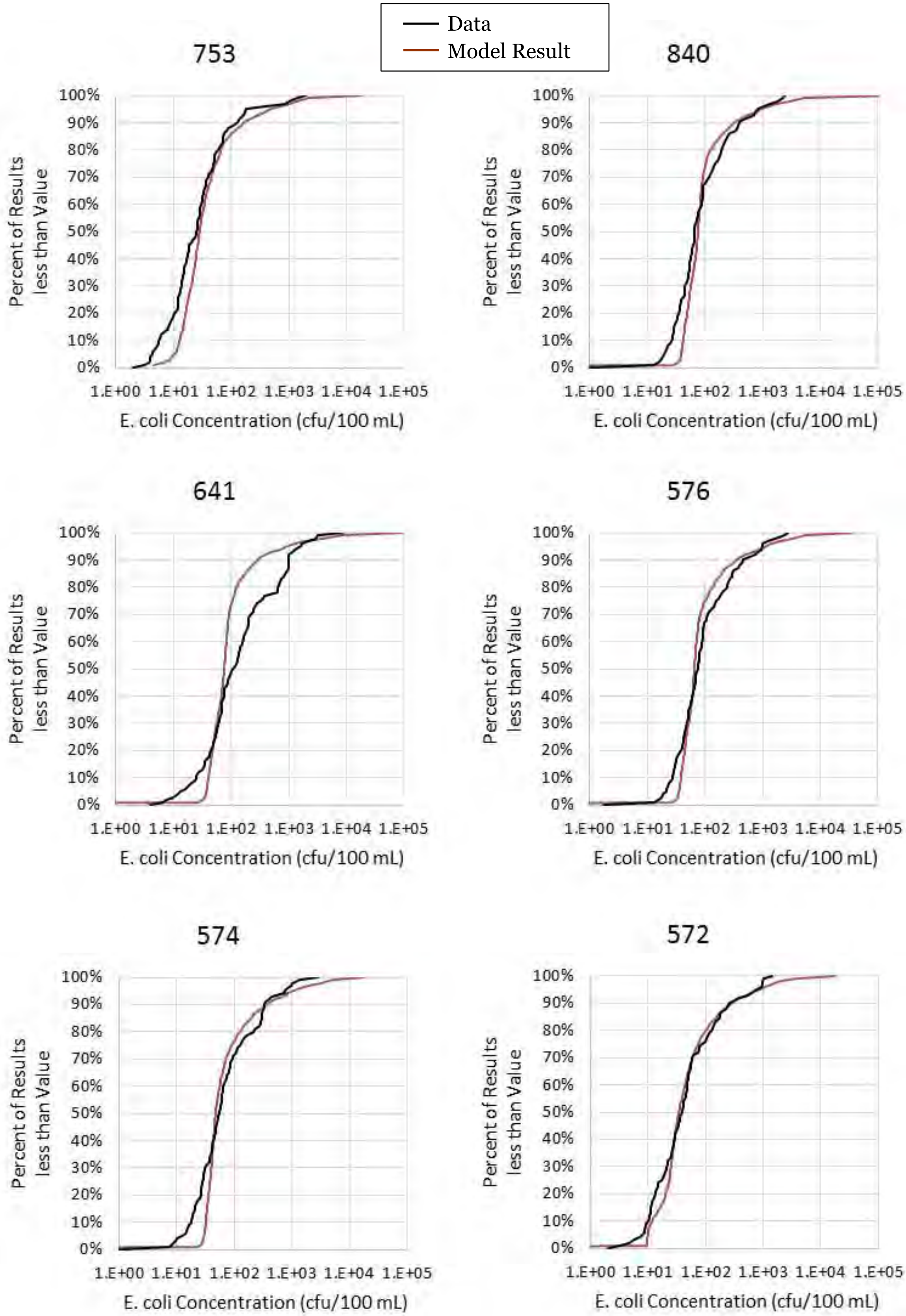



**Figure 4-19: Cumulative Frequency Distribution Comparisons of Modeled and Observed *E.coli***

Calibration of the water quality model required the introduction of a significant unknown source between the Huguenot Bridge and the 14th Street Bridge (Figure 4-20). It is assumed that this source represents bacteria contributions from common background sources such as wildlife and failing septic systems. This source was introduced to the model at a constant rate of 3.2E+12 CFU/day just downstream of the Poney Pasture Park. This assumed loading rate is of the same order of magnitude as the loading rate estimated for failing septic systems and wildlife in the James River Richmond Bacteria TMDL (MapTech, 2010). Increases to instream *E.coli* concentrations due to the background source are generally between 30 and 40 CFU/100 mL. The decision to input this load near the park is not meant to indicate that the source(s) necessarily originates there. Additional sampling data would be required to identify the spatial distribution of this source(s) between the Huguenot Bridge and the 14th Street Bridge.

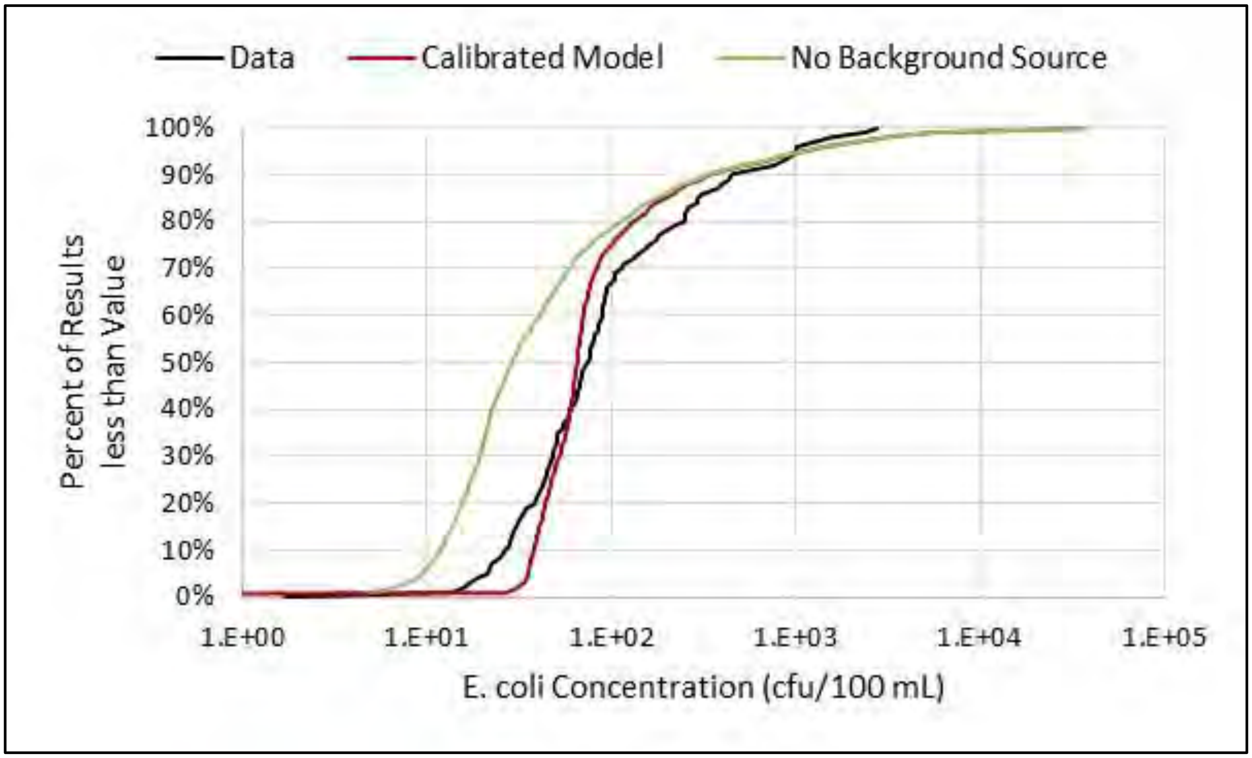



**Figure 4-20: Sensitivity of Model Calibration to the Background Source**

Figure 4-21 and Figure 4-22 illustrate sensitivity of the model results to adjustments of all major *E.coli* loading assumptions. In each plot, the source type of interest was reduced by 50% to evaluate its influence on modeled *E.coli* concentrations. Model results at the downstream city limit are shown. In these figures, the green dashed line represents the difference between the calibrated model result and the source reduction sensitivity test result. Reductions in persistent sources such as the James River upstream of Richmond and the background source always have some influence on *E.coli* concentrations. However, wet weather sources only reduce *E.coli* concentrations when precipitation has occurred. As a result, CSOs, for instance, only reduce concentrations thirty-five percent of the time (i.e. for the 65th to 100th percentile on the plots).

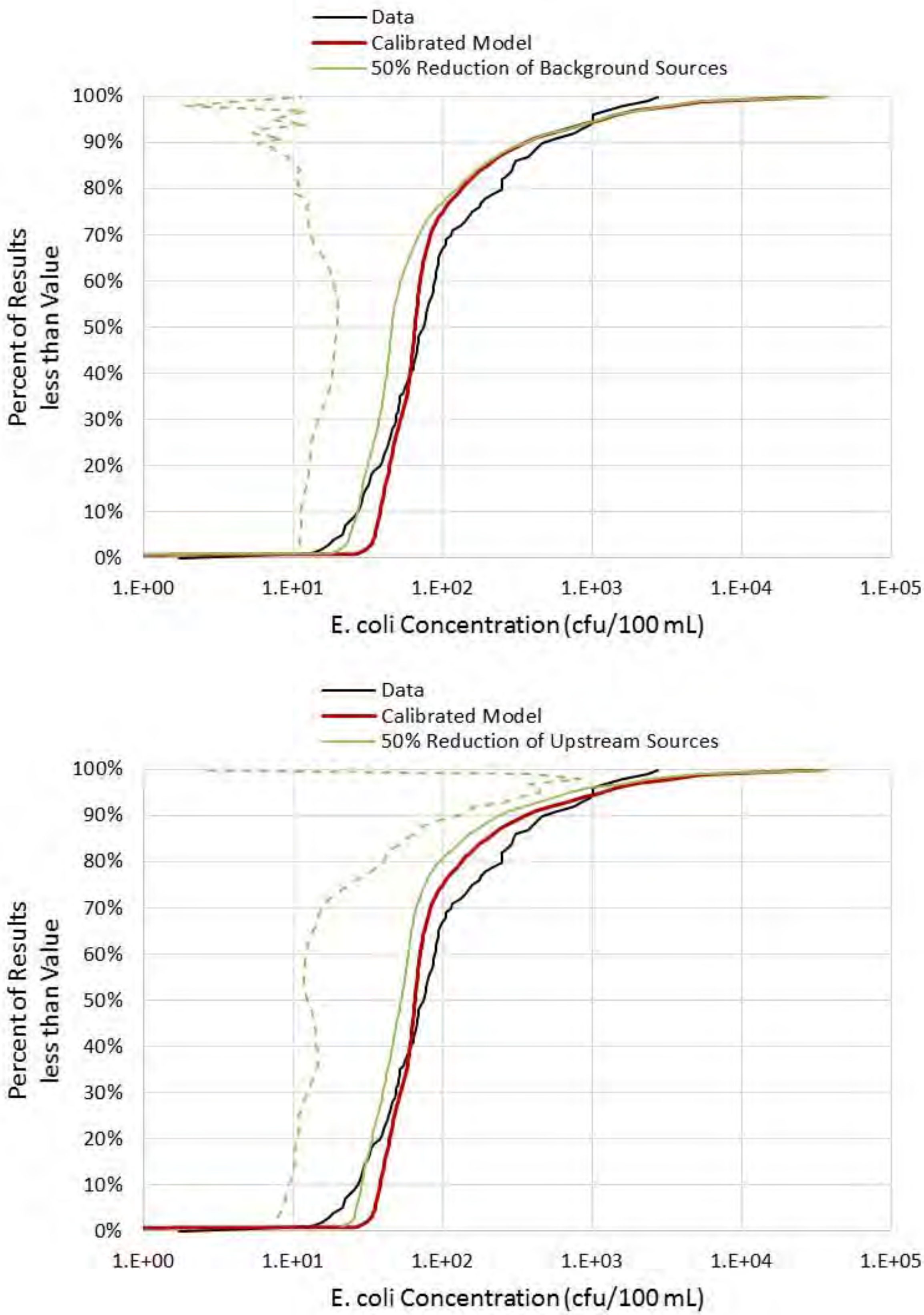
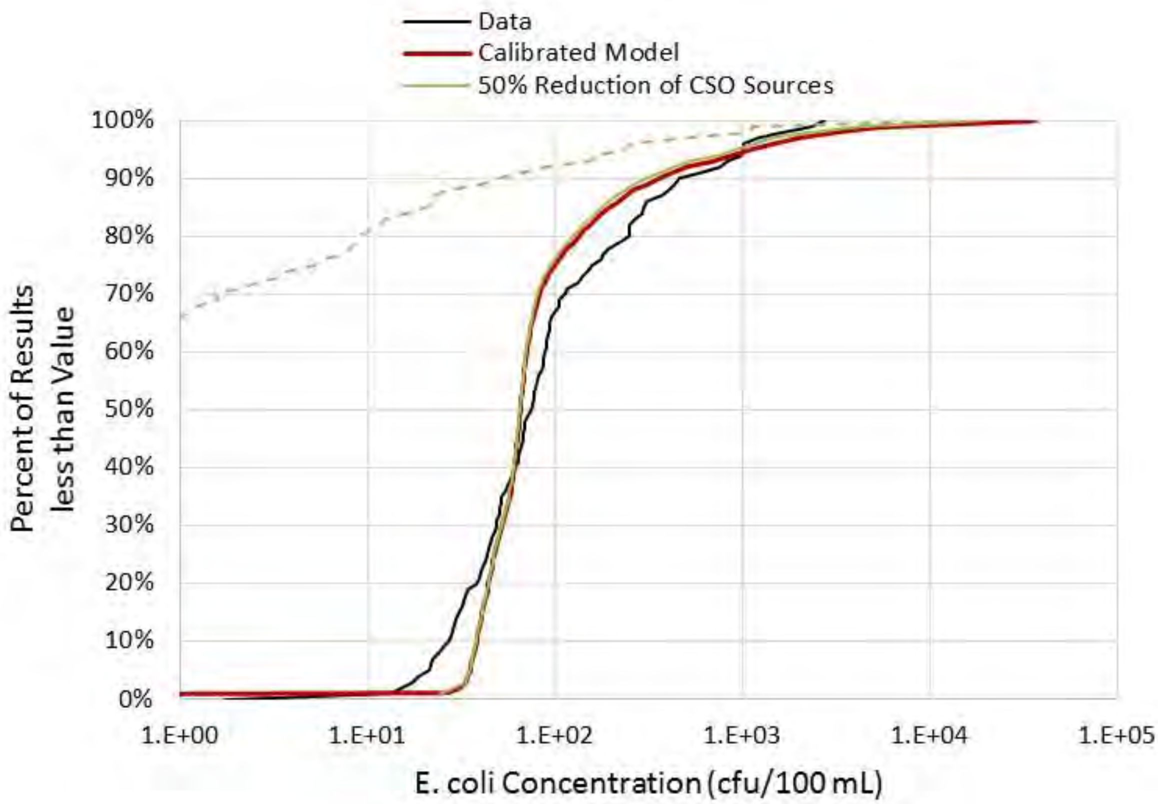



**Figure 4-21: Sensitivity of Model Results to 50% Reduction of Persistent Sources**



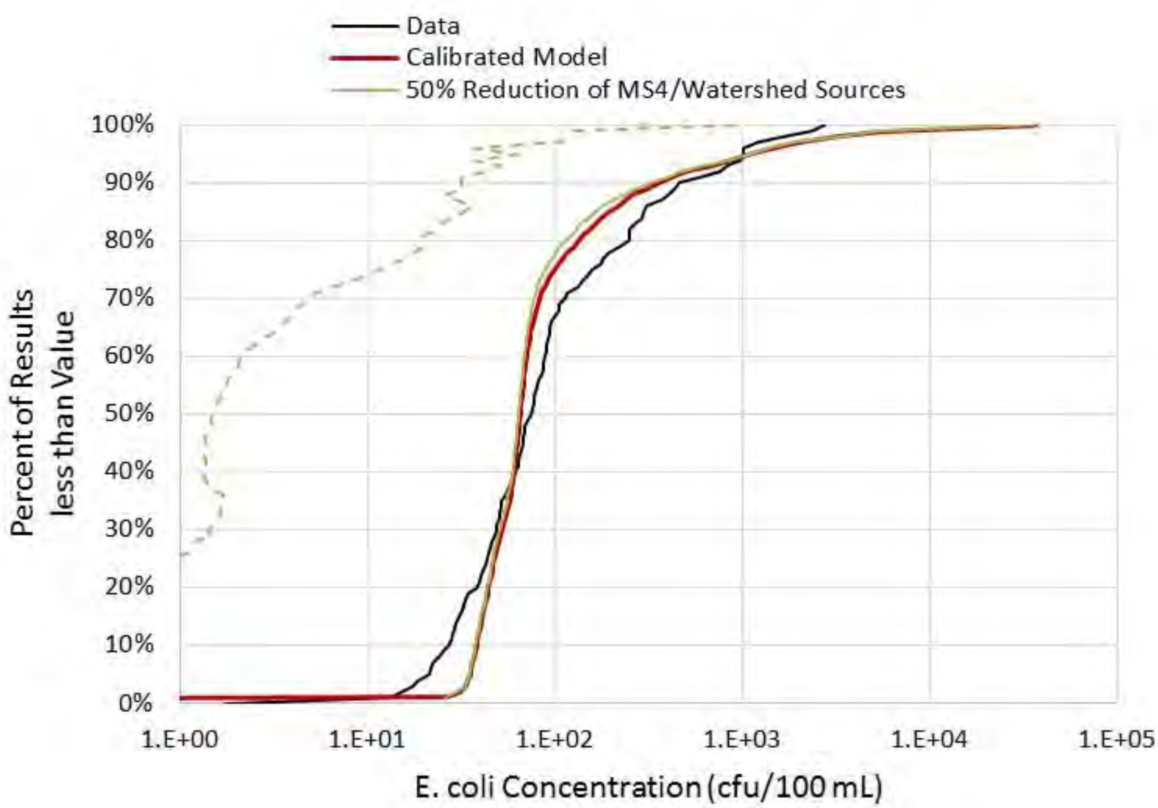




**Figure 4-22: Sensitivity of Model Results to 50% Reduction of Wet Weather Sources**

# 5 Model Application and Results

## 5.1 Overview

To date, the model has been applied to evaluate the following:

- Current conditions: Best representation of current conditions, and includes all the Phase I and Phase II CSO improvements from the LTCP.
- Baseline Conditions: represents the current condition, plus all the currently funded Phase III collection system improvement projects from the LTCP.
- Green Infrastructure in the MS4 Area Strategy: represents the baseline conditions, plus the implementation of 104 acres of green infrastructure on city-owned area in the MS4.
- Green Infrastructure in CSO Area Strategy: represents the baseline conditions, plus the implementation of 18 acres of green infrastructure on city-owned area in the CSS area.
- CSS Infrastructure Improvements Strategy: represents the baseline conditions, plus all the remaining unfunded Phase III collection system improvement projects from the LTCP.

The sequencing of the modeling applications is shown in the figure below.

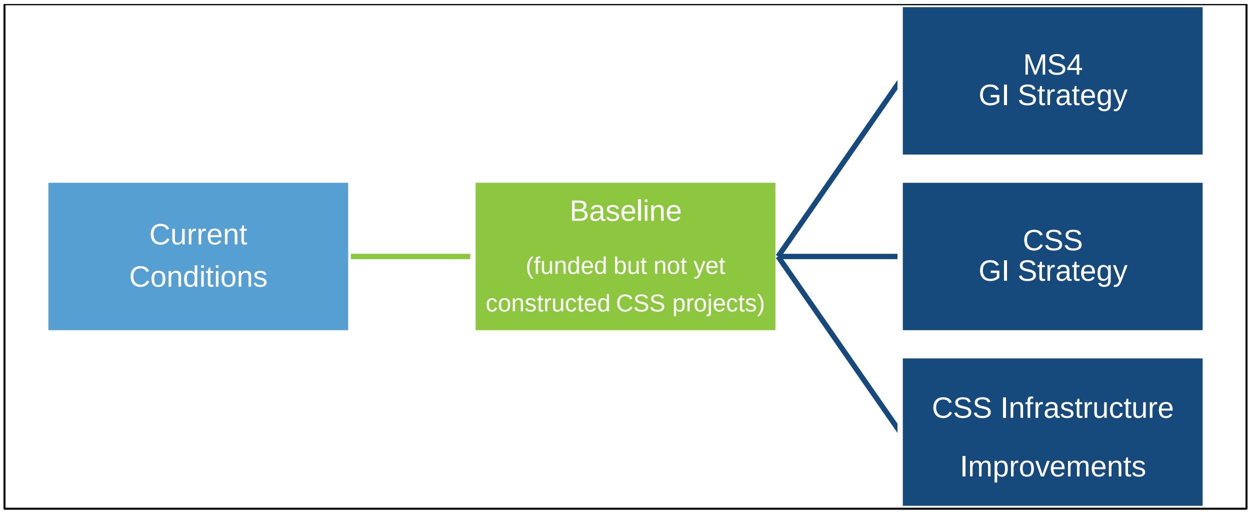



**Figure 5-1: Sequencing of Model Applications**

These conditions and strategies were evaluated using several metrics related to bacteria reduction, including:

- Bacteria load reduction from combined sewer and tributary discharges, expressed as Billion CFU
- Overall average percent improvement in monthly geomean water quality standard compliance at the downstream city limit
- Reduction in number of CSO events

- Reduction in CSO volume (Million gallons)

These four metrics are used in the Strategy Calculator, a spreadsheet tool that is used to evaluate and score the different management strategies across a wide range of goals and objectives (LimnoTech, 2017).

The model is further used to evaluate water quality benefits relative to the monthly geometric mean standard and the statistical threshold value (STV) standard, on a monthly basis. The geometric mean standard states that the monthly geometric mean *E.coli* concentration must fall below 126 cfu/100 mL to be in compliance. The VDEQ statistical threshold value standard states that no more than 10% of *E.coli* concentrations in a month may exceed 235 cfu/100 mL to be in compliance.

## 5.2 Methodology for Model Application and for Evaluating Model Results

The three-year period of 2011 through 2013 was selected as the application period because it represents a continuous time period that includes typical wet, dry, and average precipitation conditions, with corresponding responses in James River flow conditions. This is shown in Figure 5-2.

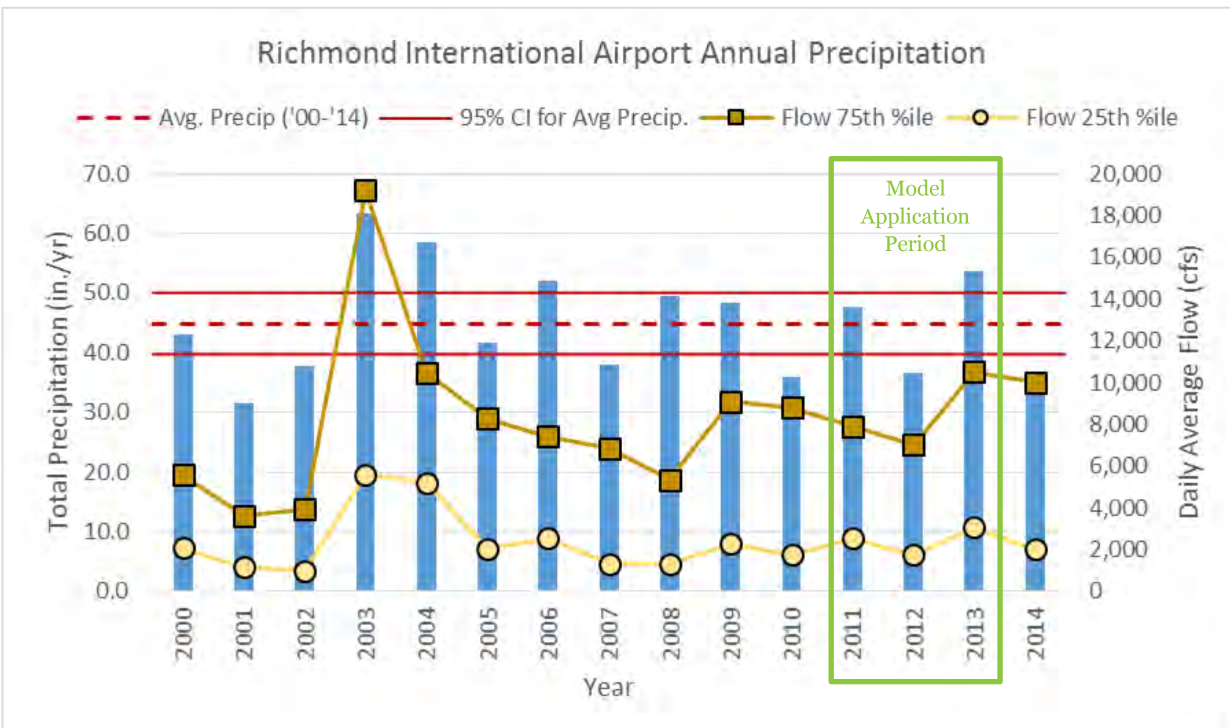



**Figure 5-2: Precipitation and Daily Average Flow at Richmond International Airport**

The following process was followed when applying the water quality model components to evaluate the various strategies:

1. Simulate any improvements to the combined sewer system or treatment plan with the CSS model;
2. Relay model results from potential CSS improvements in the Gillies or Almond Creek tributaries to the watershed model;
3. Simulate any MS4 strategies or CSS improvements in the Gillies or Almond Creek improvements with the watershed model;

4. Simulate the impact of improvements in the James River by relaying CSS model results (i.e. time series of overflow discharge and bacteria load) and watershed model results (i.e. time series of tributary flows and bacteria loads) to the James River Receiving Water Quality Model.
5. Summarize the results of the model runs using the metrics described in the previous section.

After running the water quality modeling framework through the process described above, water quality compliance was evaluated at the downstream boundary of the city, Richmond's National Pollutant Discharge Elimination System (NPDES) compliance point. *E.coli* concentrations at this point were compared to the monthly geometric mean of 126 CFU/100 mL and the STV of <10% of all samples exceeding 235 CFU/100mL. For each month that violated the water quality standard, a detailed component analysis was completed. The component analysis tracks the relative contribution of each *E.coli* source (upstream, CSOs, watershed/MS4, background, and WWTP) to the modeled concentration in the James River. This type of analysis is useful to evaluate which sources of bacteria have the greatest impact on water quality conditions in the James River for a given point in time or location in the river.

Additionally, model results were summarized to determine the overall bacteria load reduction, CSO volume reduction, reduction in number of CSO overflow events, and to evaluate the percent improvement towards monthly geomean water quality standard compliance at the downstream city limit. The "percent improvement towards monthly geometric mean compliance", also dubbed "percent improvement" for convenience, ranges from 0% to 100%, with 0% corresponding to the existing state of compliance and 100% corresponding to full compliance with the monthly geomean water quality standard. The "percent improvement" is computed as follows:

$$I_p = \frac{\sum_1^n V_{n,scenario} - \sum_1^n V_{n,current}}{\sum_1^n V_{n,current}}$$

Where:

- "$I_p$" is Percent Improvement,
- "V" is the compliance metric value for a given month, (e.g. the geometric mean value for December 2011),
- "n" is an index for the month, and
- the subscripts "scenario" and "current" correspond to a scenario of interest and the current condition, respectively.

Graphically, each summation term in this equation is the total bar height above the water quality standard as shown in Figure 5-3. If, under a particular scenario, the total bar height above the standard is small compared to the current conditions, then the "percent improvement" will be nearly 100% and the system will be near full compliance. If the total bar height under a particular scenario is similar to that of the current condition, then the "percent improvement" will be nearly 0%.

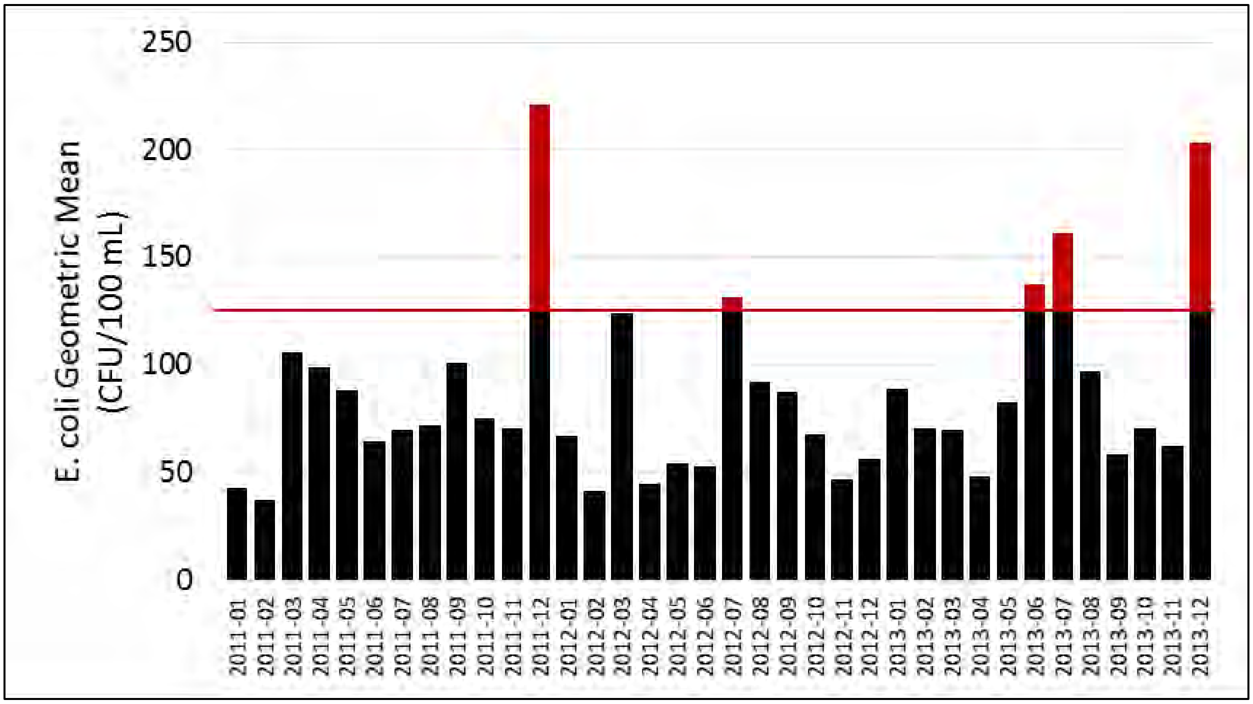



**Figure 5-3: Graphical Depiction of the "Percent Improvement" Metric**

## 5.3 Overview of Model Scenarios

Each strategy that was evaluated by the water quality model required unique changes to the model inputs, as further described in the sections below.

### 5.3.1 Current Conditions

Because the model calibration period and model application period are the same, no further changes were implemented to assess the current conditions.

### 5.3.2 Baseline Conditions

The baseline conditions represents the current conditions plus the addition of all the currently funded Phase III collection system improvement projects from the LTCP. These projects include the sewer separation of CSO 028A and CSO 028E, replacement of the CSO 04 regulator, and increasing the wet weather treatment capacity of the treatment plant to 140 MGD. These three projects were modeled in the CSS model, and results were passed down to the watershed model and the receiving water quality model. Because these projects are already funded and included in the City's planning documents, this condition was considered to be the baseline condition against which other additional strategies would be compared for the purpose of evaluating the metrics used in the Strategy Calculator.

Additional discussion of the projects included in the baseline conditions is presented in Section 5.3.5

### 5.3.3 Green Infrastructure in the MS4 Area Strategy

The "green infrastructure in the MS4 area" strategy proposed to implement green infrastructure to treat 104 acres of impervious area owned by the Department of Public Utilities (DPU) or Department of Parks & Recreation (DPR), in addition to all the currently funded phase III collection system improvement projects included in the baseline conditions. The acreage of green infrastructure was determined by identifying the total area of land that is owned by either DPU or DPR, using ArcGIS. Additional information such as topography and soil type was then superimposed over the DPU and DPR properties. Through this visual analysis, it was determined that roughly 50% of the DPU/DPR land would likely not be conducive to the implementation of green infrastructure without significant engineered modifications such as land leveling or soil amendments. Therefore the total available land for this strategy was reduced by half. The remaining area was summarized by subwatershed so that it could be simulated in the watershed model.

All area available for green infrastructure implementation within a subwatershed was modeled as one representative green infrastructure practice since the specific types of green infrastructure are unknown at this planning stage. The generic practices were modeled using SWMM storage nodes with an assumed effective depth of 1.5 feet and sized in area to capture a 1.2 inch storm (90th percentile storm on an average annual basis). The modeled generic green infrastructure practices account for evaporation and bottom infiltration into the native soil. It was assumed that all green infrastructure is being drained within 48 hours to provide storage volume for back-to-back rainfall events. This was simulated by using an appropriately sized orifice to simulate practice underdrains. Potential flows exceeding the green-infrastructure capacity in the model were handled by a weir simulating practice overflow or flow rejection. Water quality routines were applied to the water volumes stored in the practices.

### 5.3.4 Green Infrastructure in the CSS Area Strategy

The "green infrastructure in the CSS area" strategy proposed to implement green infrastructure to treat 18 acres of impervious area owned by the Department of Public Utilities (DPU) or Department of Parks & Recreation, in addition to all the currently funded phase III collection system improvement projects included in the baseline conditions. The acreage of green infrastructure included in this strategy was determined through the same process as described in the previous section. Additionally, green infrastructure in the CSS model was simulated in the same way as is done in the MS4 area, as described in the previous section.

### 5.3.5 CSS Infrastructure Improvements Strategy

The "*CSS Infrastructure Improvements*" strategy[2] includes ten projects that are included in the Phase III collection system upgrades described in the LTCP (Greeley and Hansen, 2002):

1. CSO 14 regulator upgrade
2. CSO 028A & 028E sewer separation
3. CSO 04 & CSO 05 regulator replacement
4. Lower Gillies sewer conveyance
5. WWTP wet weather treatment to 140 MGD
6. WWTP wet weather treatment to 300 MGD
7. CSO 21 replacement
8. CSO 21 additional 2 MG storage
9. Shockoe Retention Basin (SRB) expansion
10. SRB disinfection

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[2] Alternative LTCP projects are currently being evaluated by Brown and Caldwell but results are not yet available to be included as of March 2017.

Of those ten projects, #1-#3 and #5 are included in the Baseline Conditions, since these projects are currently funded by the City of Richmond. Implementation of all ten projects represents the obligations under the LTCP, and is commonly referred to as the "*full LTCP*" scenario.

The unfunded projects were modeled in isolation to determine individual impact on CSO volume discharge, bacteria load reduction, and impact on the receiving water quality. These CSS "scenarios" are summarized in Table 5-1 and Table 5-2.

**Table 5-1: Description of CSS Projects Evaluated by the Water Quality Model**

| CSS Scenario | CSS Project Name | CSS Project Description |
|---|---|---|
| **Current** | Current Conditions | Current sewer conditions, including all LTCP Phase I and Phase II projects. |
| **14-3** | Baseline Conditions | Includes the currently funded projects:<br>-- CSO 04, 014, and 05 regulator upgrades<br>-- CSO 028A & 028E disconnection<br>-- WWTP wet weather treatment up to 140 MGD |
| **14-2** | Gillies Conveyance | Lower Gillies Wet Weather Conveyance Interceptor to convey more flow to the WWTP |
| **15-4** | 300 MGD Wet Weather Treatment | WWTP wet weather treatment up to 300 MGD |
| **15-5** | CSO 21 Replacement | Replacement of the CSO 21 regulator and additional 2MG storage |
| **18-4** | SRB Expansion | Shockoe retention basin (SRB) expansion to 15MG |
| **18-5** | SRB Expansion and Disinfection | SRB Expansion to 15MG and chlorine disinfection of the SRB discharge at CSO 06 |
| **19-3A** | Full LTCP | All 10 Phase III projects, Full Long-term Control Plan (LTCP) achieved. |

**Table 5-2: CSS Water Quality Model Matrix**

| CSS Project | CSS Scenario | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Baseline (14-3)** | **14-2** | **15-4** | **15-5** | **18-4** | **18-5** | **Full LTCP (19-3A)** |
| **CSO 14 regulator upgrade** | X | X | X | X | X | X | X |
| **CSO 028A & 028E separation** | X | X | X | X | X | X | X |
| **CSO 04 & CSO 05 replacement** | X | X | X | X | X | X | X |
| **Lower Gillies Conveyance** | | X | | | | | X |
| **WWTP wet weather treatment to 140 MGD** | X | X | | X | X | X | |
| **WWTP wet weather treatment to 300 MGD** | | | X | | | | X |
| **CSO 21 replacement and additional 2MG storage** | | | | X | | | X |
| **SRB expansion** | | | | | X | X | X |
| **SRB disinfection** | | | | | | X | X |

In addition to making changes to the CSS model elements and configuration to represent the individual CSS improvements, the E.coli concentrations associated with the WWTP were also modified depending on the CSS project. Under current conditions, the WWTP treats inflows up to 75 MGD, with no supplemental treatment during wet weather flows. Several CSS scenarios simulate wet weather treatment up to 140 MGD, and yet others simulate wet weather treatment up to 300 MGD. The WWTP treatment scheme for each scenario is summarized in Table 5-3.

**Table 5-3: WWTP Treatment for Each CSS Scenario**

| CSS Scenario | Full Treatment (MGD) | Primary Treatment (MGD) | Preliminary Treatment (MGD) | Total Treatment (MGD) |
|---|---|---|---|---|
| **Current** | 75 | -- | -- | 75 |
| **14-3** | 75 | 65 | -- | 140 |
| **14-2** | 75 | 65 | -- | 140 |
| **15-4** | 85 | 55 | 160 | 300 |
| **15-5** | 75 | 65 | -- | 140 |
| **18-4** | 85 | 55 | -- | 140 |
| **18-5** | 85 | 55 | 160 | 140 |
| **19-3A** | 85 | 55 | 160 | 300 |

*E.coli* concentrations associated with each treatment pathway were estimated based on previous modeling, and a flow-weighted average *E.coli* concentration was calculated to estimate the total *E.coli* contribution from the WWTP. All influent to the WWTP was assumed to have an *E.coli* concentration of 235,000 CFU/100mL. It was assumed that influent receiving full treatment would result in an effluent concentration of 126 CFU/100 mL, consistent with the effluent concentration guidelines in the VAPDES permit (#VA0063177). Effluent concentrations from primary and preliminary treatment facilities were calculated according to the following formula:

$$Effluent\ E.coli\ concentration = \frac{influent\ concentration}{reduction\ factor}$$

The effluent reduction factors for primary and preliminary treatment were calculated using formulas that were developed as part of ongoing modeling efforts by Greeley and Hansen (Greeley and Hansen, personal communication, 11/15/2016).). The primary treatment reduction factor is governed by the following equation:

$$Log\ reduction\ factor = 0.76 * \ 10^{2.57904-1.2563*\log(Q)}$$

Where: Q is the inflow in MGD

The preliminary treatment reduction is governed by the following equation:

$$Log\ reduction\ factor = 0.76 * \ 10^{2.77053-1.2563*\log(Q)}$$

Where: Q is the inflow in MGD

For both treatment pathways, the reduction factor is large when flows are small due to increased contact time with the UV disinfection system. Therefore, a treatment floor of 126 cfu/100 mL was set because it was assumed that the treatment capacity of the primary and preliminary pathways could not exceed full treatment.

Post-processing was also required to simulate disinfection at SRB. All influent to SRB was assumed to have an *E.coli* concentration of 111,000 CFU/100 mL, consistent with *E.coli* EMC for CSO 06. The effluent reduction factor for SRB was calculated using a formula that was developed as part of ongoing modeling efforts by Greeley and Hansen (Greeley and Hansen, personal communication, 11/15/2016.)

$$Log\ reduction\ factor = 11.8102 - 3.1211 * \log(Q)$$

Where: Q is the flow rate in MGD

Similar to the WWTP alternative treatment pathways, the SRB reduction factor is large when flows are small due to increased contact time with the chlorine disinfection system. Therefore, a treatment floor of 126 cfu/100 mL was set because it was assumed that the SRB treatment capacity could not exceed full treatment at the WWTP.

## 5.4 Results

The James River water quality model was configured to compute *E.coli* concentrations at an hourly interval for the three year typical period. These results were compared against the monthly water quality standards and summarized at key locations of interest along the river. Additionally, results were also summarized to show the overall bacteria load reduction, CSO volume reduction, and reduction in number of CSO events.

### 5.4.1 Current Conditions

Figure 5-4 show the modeled monthly geomean concentrations and the percent exceedance of the STV standards at the downstream boundary of the city. For each month that violated the water quality standard, a detailed component analysis was completed. The component analysis tracks the relative contribution of each *E.coli* source (upstream, CSOs, watershed/MS4, background, and WWTP) to the modeled concentration in the James River. This type of analysis is useful to evaluate which sources of bacteria have the greatest impact on water quality conditions in the James River for a given point in time or location in the river.

Under current conditions, the geometric mean water quality standard is violated at the downstream city limit (the compliance evaluation point) for 4 months of the 36 month typical period. Significant contributors to non-compliance are upstream sources, the background sources, and CSOs. Non-compliance tends to occur when James River flows and upstream James River concentrations are high or when James River flows are low and significant precipitation events cause combined sewer discharges.

The statistical threshold value standard is more frequently violated, with 16 of 36 months exceeding the standard at the downstream City limit. Significant contributors to non-compliance of the STV standards are mainly CSOs and upstream sources, and to a lesser extent, the MS4/Watershed source. The CSOs are a more frequent and greater contributor to water quality violations using the STV standard than using the monthly geometric mean standard.

These results illustrate that:

- The James River is in violation of both the geometric mean and the statistical threshold value water quality standards for some months out of the three year simulation period.
- The primary cause of a water quality standard violation can sometimes be linked to Richmond combined sewer overflows, while at other times it is due to upstream sources. Background and MS4/Watershed sources play a smaller overall role in the bacteria water quality violations. The WWTP does not contribute significantly to bacteria water quality violations.

Figure 5-5 illustrates the E.coli monthly geometric mean in the James River, from a few miles upstream of the city limits to a few miles past the downstream city limits. During some months, for example in April 2012 (orange line), the James River is compliant upstream of the city and local *E.coli* sources are small enough that the James River is also compliant downstream of the city. During other months, like in June of 2013 (blue line), the James River is compliant upstream of the city but because of the contributions from background, watershed, and CSO sources, the James River exceeds the water quality standards at the downstream city limit. Finally during some months, like December 2011 (dark green line), the river is non-compliant with the water quality standards upstream of the city and remains non-compliant downstream of the city.

Table 5-4 shows the E.coli load, CSO volume, and number of CSO events under the existing conditions.

**Table 5-4: Existing Condition: E.coli Load, CSO Volume, and Number CSO Events**

| Metric | Value |
|---|---|
| Average yearly E.coli load (billion cfu) | 9,651,987 |
| Average annual number of CSO events | 53 |
| Average yearly CSO volume discharged (million gallons) | 1,670 |

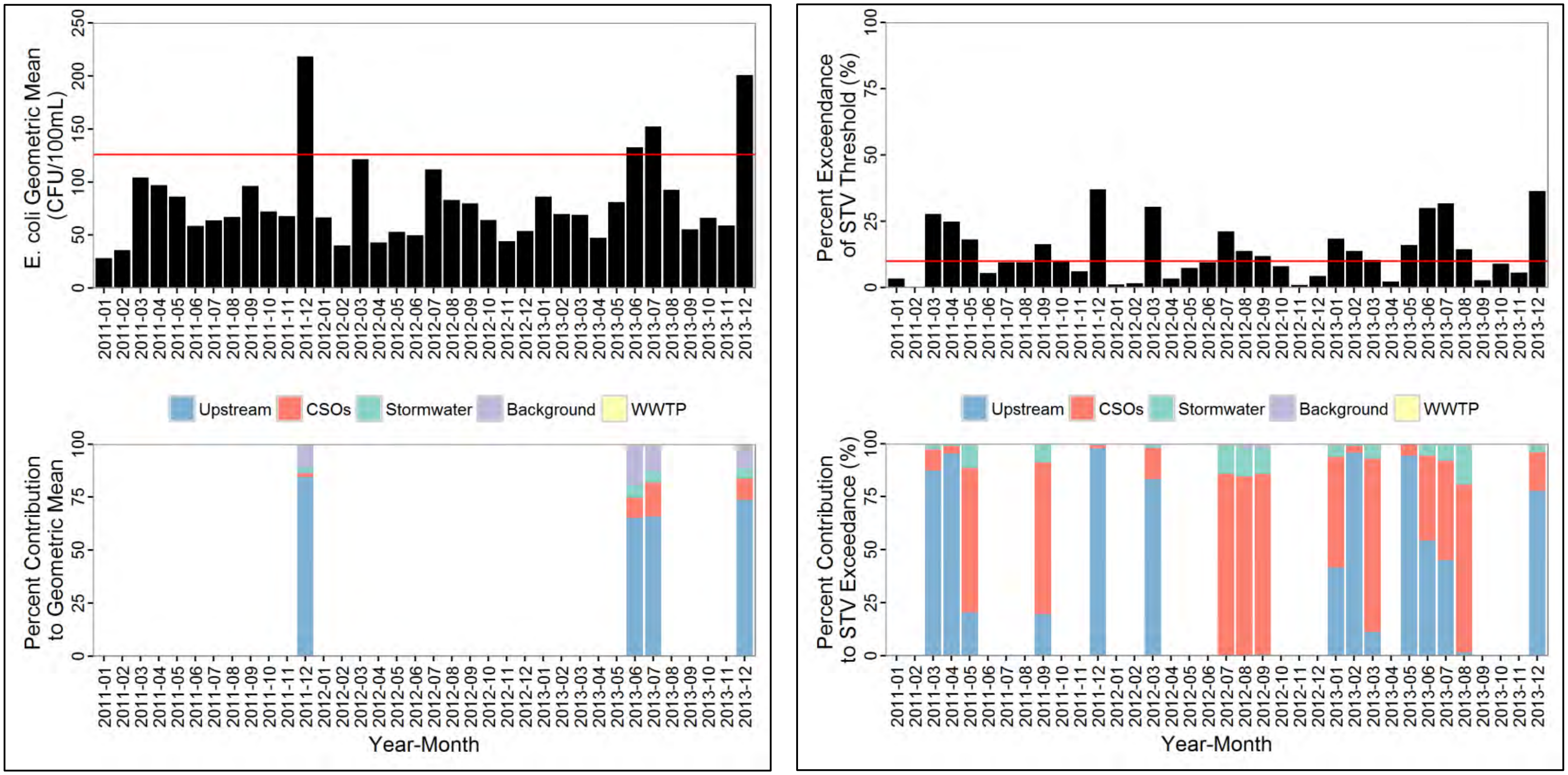


**Figure 5-4: Existing Condition: Monthly Geometric Mean and STV Standard Model Results**

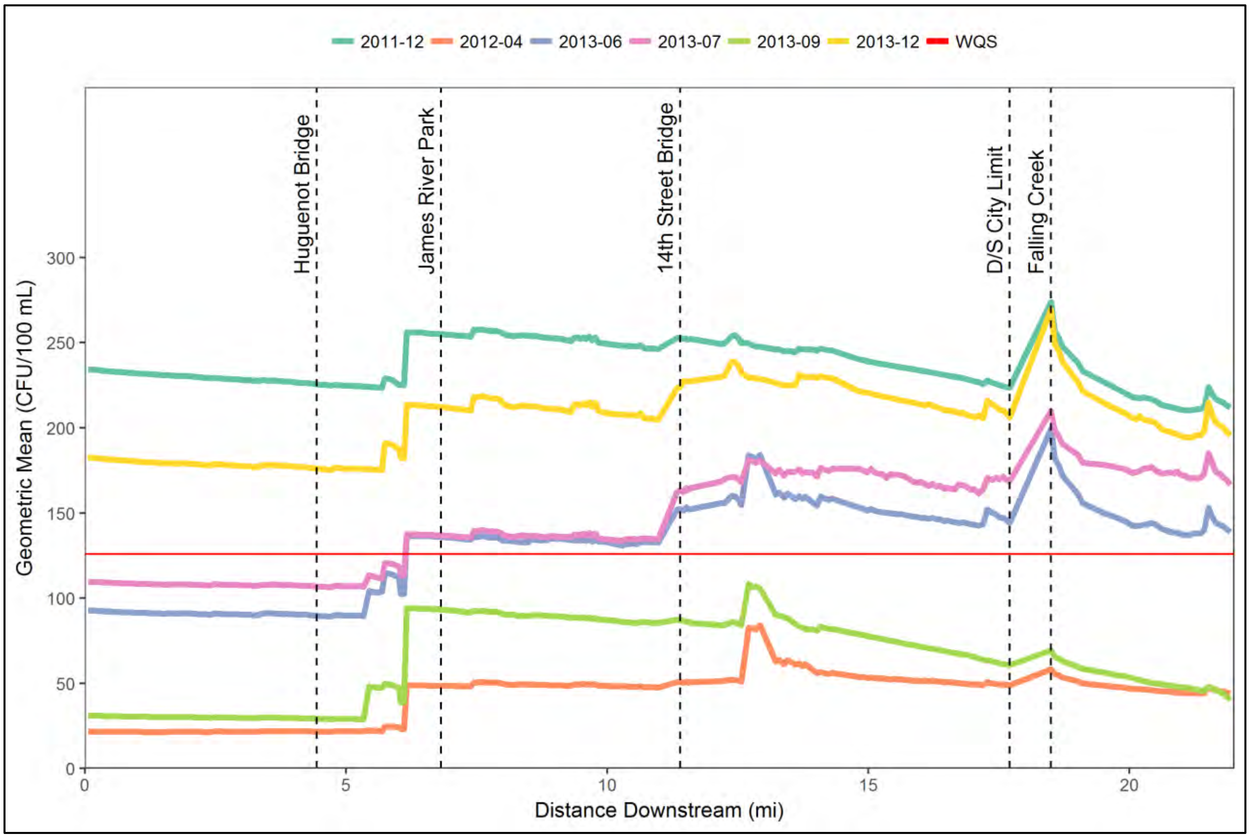


**Figure 5-5: Lateral and temporal variability in E.coli concentration in the James River**

### 5.4.2 Baseline Conditions

Figure 5-6 shows the modeled monthly geomean concentrations and the percent exceedance of the STV standards at the downstream boundary of the city for the baseline condition. For each month that violated the water quality standard, a detailed component analysis was completed. Similar to current conditions, under baseline conditions, the geometric mean water quality standard is violated at the downstream city limit (the compliance evaluation point) for 4 months of the 36 month typical period. Significant contributors to non-compliance are upstream sources, the "background" or "unknown" source, and CSOs. Non-compliance tends to occur when James River flows and upstream James River concentrations are high or when James River flows are low and significant precipitation events cause combined sewer discharges.

The statistical threshold value standard is more frequently violated, with 16 of 36 months exceeding the standard at the downstream City limit. Significant contributors to non-compliance of the STV standards are mainly CSOs and upstream sources, and to a lesser extent, the MS4/Watershed source. Though the baseline projects significantly reduce CSOs, these projects alone are not sufficient to bring the James River into compliance with water quality standards.

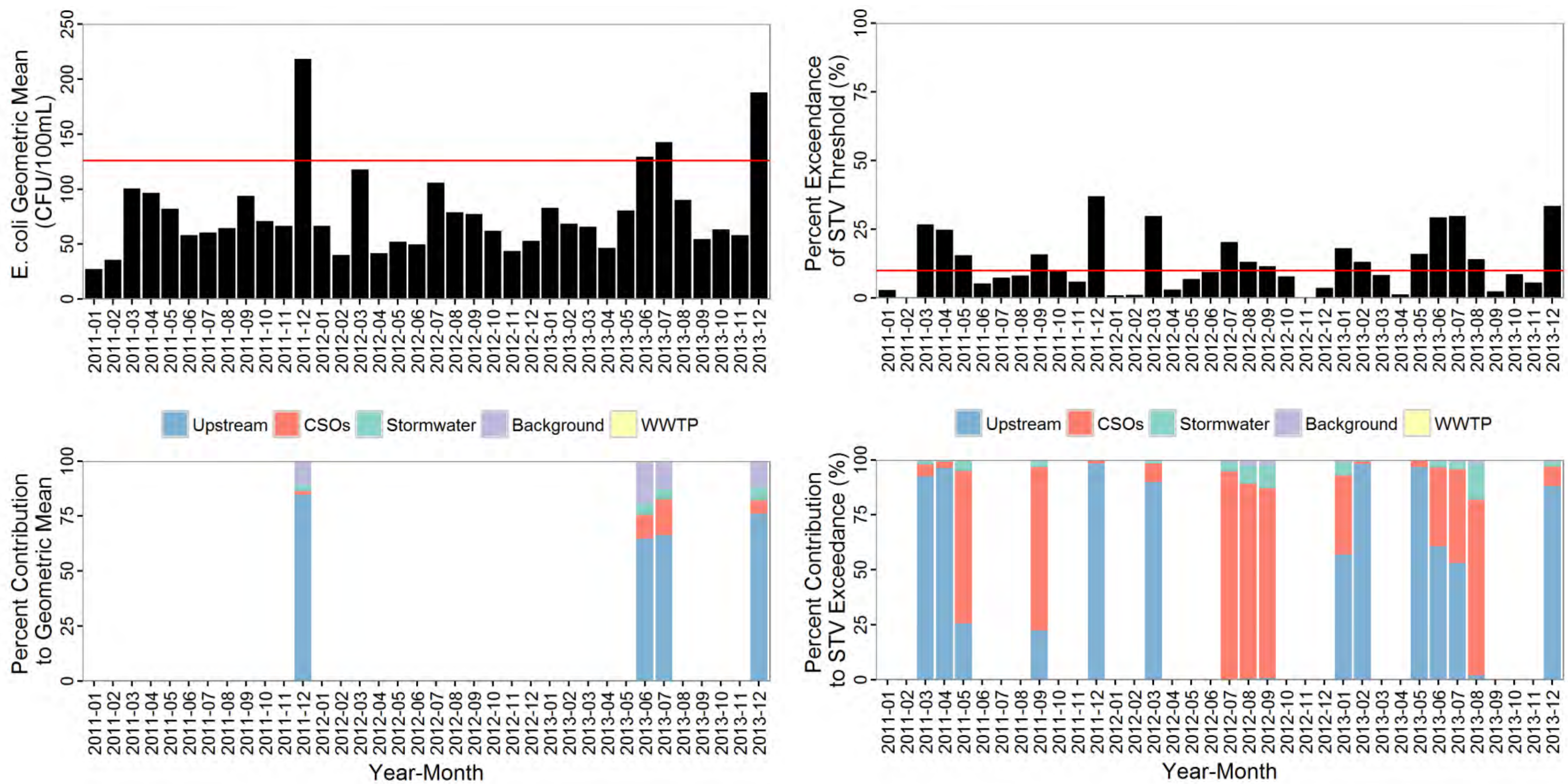


**Figure 5-6: Baseline Condition: Monthly Geometric Mean and STV Standard Model Results**

Table 5-5 shows the E.coli load, CSO volume, and number of CSO events under the existing conditions. The baseline conditions represent the improvements due to the implementation of several CSO improvement projects. Compared to the existing conditions, these projects collectively reduce the E.coli loads by approximately 18%, reduce the number of overflows by 2 events, and reduce the yearly CSO volume discharged by approximately 29%.

**Table 5-5: Baseline Condition: E.coli Load, CSO Volume, and Number CSO Events**

| Metric | Value |
|---|---|
| Average yearly E.coli load (billion cfu) | 7,958,183 |
| Average annual number of CSO events | 51 |
| Average yearly CSO volume discharged (million gallons) | 1,190 |
| Percent improvement compared to current conditions (%) | 12.8 |

### 5.4.3 Green Infrastructure in the MS4 Area Strategy

The "*green infrastructure in the MS4 area*" strategy proposed to implement green infrastructure to treat 104 acres of impervious area owned by the Department of Public Utilities (DPU) or Department of Parks & Recreation, in addition to all the currently funded phase III collection system improvement projects included in the baseline conditions. Table 5-6 shows the E.coli load, CSO volume, and number of CSO events under the "Green Infrastructure in the MS4 Area" strategy. This strategy reduces the E.coli load entering the James River only slightly compared to the baseline conditions (<0.6% reduction). This strategy only targets Richmond's MS4 area, so the number of CSO events and the yearly CSO volume are not affected compared to the baseline scenario.

**Table 5-6: Green Infrastructure in MS4 Strategy: E.coli Load, CSO Volume, and Number CSO Events**

| Metric | Value |
|---|---|
| Average yearly E.coli load (billion cfu) | 7,954,132 |
| Average annual number of CSO events | 51 |
| Average yearly CSO volume discharged (million gallons) | 1,190 |
| Percent improvement compared to current conditions (%) | 13.0 |

### 5.4.4 Green Infrastructure in the CSS Area Strategy

The *"green infrastructure in the CSS area*" strategy proposed to implement green infrastructure to treat 18 acres of impervious area owned by the Department of Public Utilities (DPU) or Department of Parks & Recreation, in addition to all the currently funded phase III collection system improvement projects included in the baseline conditions. Table 5-7 shows the E.coli load, CSO volume, and number of CSO events under the "Green Infrastructure in the CSS Area" strategy. This strategy reduces the E.coli load entering the James River only slightly compared to the baseline conditions (<0.6% reduction). This strategy specifically targets the CSS area. The area of GI implementation (18 acres) is not significant enough to reduce the number of CSO events, but it does reduce the annual CSO volume discharged slightly compared to the baseline scenario.

| Table 5-7: Green Infrastructure in CSS Strategy: E.coli Load, CSO Volume, and Number CSO Events | |
|---|---|
| **Metric** | **Value** |
| Average yearly E.coli load (billion cfu) | 7,905,833 |
| Average annual number of CSO events | 51 |
| Average yearly CSO volume discharged (million gallons) | 1,180 |
| Percent improvement compared to current conditions (%) | 12.9 |

### 5.4.5 CSS Infrastructure Improvement Strategy

Table 5-6 shows the E.coli load, CSO volume, and number of CSO events under the "CSS Infrastructure Improvement" strategy. This strategy includes numerous projects intended to reduce the number of CSO events and CSO volume discharged.

| Table 5-8: CSS Infrastructure Improvement Strategy: E.coli Load, CSO Volume, and Number CSO Events | | | |
|---|---|---|---|
| **Metric** | **Value** | **Reduction Compared to Baseline Conditions** | **Reduction Compared to Existing Conditions** |
| Average yearly E.coli load (billion cfu) | 4,407,072 | 45% | 54% |
| Average annual number of CSO events | 50 | 2% | 5% |
| Average yearly CSO volume discharged (million gallons) | 228 | 81% | 86% |
| Percent improvement compared to current conditions (%) | 21.3% | - | - |

Figure 5-7 illustrates water quality compliance at the downstream City limit for the CSS Infrastructure Improvement strategy. Under this strategy, the geometric mean water quality standard is violated at the downstream city limit (the compliance evaluation point) for 3 months of the 36 month typical period. Non-compliance occurs because the upstream sources contribute significant flow and high bacteria loads.

The statistical threshold value standard is more frequently violated, with 16 of 36 months exceeding the standard at the downstream City limit. Significant contributors to non-compliance of the STV standards are mainly CSOs and upstream sources, and to a much lesser extent, the MS4/Watershed source. The CSOs continue to contribute to non-compliance under the STV standards, especially during the summer months. The CSOs are a more frequent and greater contributor to water quality violations using the STV standard than using the monthly geometric mean standard.

These results illustrate that:

- Controlling City of Richmond bacteria sources alone would not achieve compliance with water quality standards.
- Reducing combined sewer overflows via the CSS Infrastructure Improvement strategies would significantly reduce the average yearly CSO volume discharged (81% reduction compared to the baseline conditions). It would also improve compliance with water quality standards, especially during times when upstream sources are not significantly contributing to water quality violations.

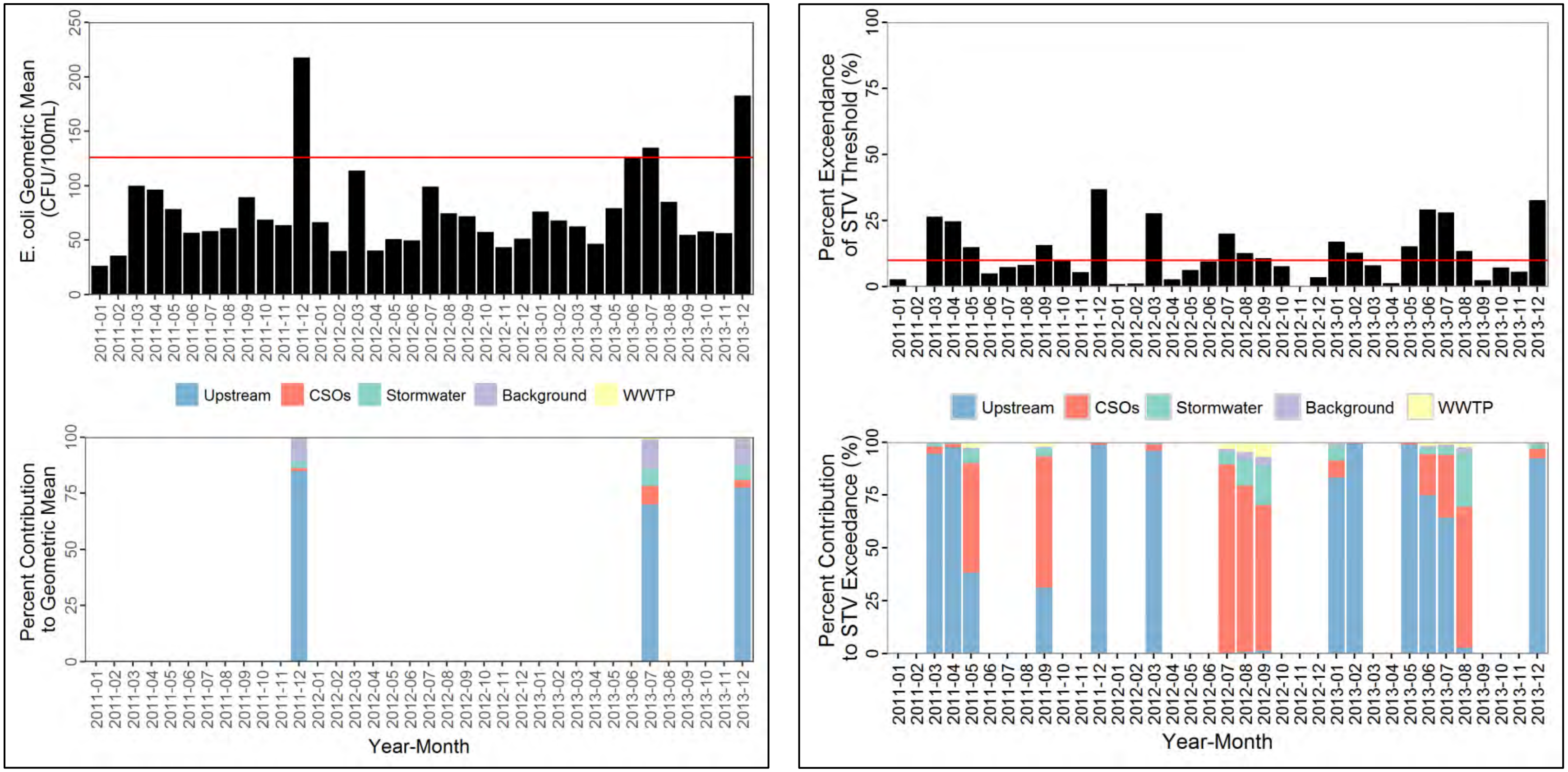


**Figure 5-7: CSS Improvement Infrastructure Strategy: Monthly Geometric Mean and STV Standard Model Results**

#### *5.4.5.a CSS Infrastructure Improvement Strategy with Upstream Load Reductions*

The James River Bacteria TMDL (MapTech, 2010) details the *E.coli* load reductions that would be necessary to achieve water quality compliance upstream of the City. These reductions, which were based on an independent analysis of water quality, were generally greater than 50%. Based on this information, the Water Quality model was applied for the CSS Infrastructure Strategy, whereby upstream load reductions were incrementally reduced until the downstream water quality criteria would be achieved under the monthly geomean standard. If all other sources remain the same, and with the CSS Infrastructure improvements in place, upstream sources would need to be reduced by 50% in order to meet the monthly geomean standard. These results are shown in

Figure 5-8.

#### *5.4.5.b Evaluating Individual CSS Infrastructure Improvement Projects*

The CSS Infrastructure Improvement Strategy consists of several different projects as outlined in the LTCP, and shown in Table 5-1 and Table 5-2. Each project was evaluated in isolation to determine individual project impact on bacteria load reduction and on the percent improvement towards meeting the monthly E.coli geometric mean water quality standard. Figure 5-9 summarizes the *E.coli* load reductions and Table 5-9 shows the "percent improvement" for each project scenario. Even though the individual scenarios can achieve significant E.coli load reductions (22%-67% reductions), the "percent improvement" shows smaller gains that vary between 13% and 21%. This is because E.coli loads from the CSS system make up only a fraction of the total *E.coli* load in the James River.

#### *5.4.5.c Evaluating Alternative CSS Improvement Projects*

It is anticipated that the modeling framework will be applied during the summer and fall of 2017 to evaluate alternative CSS reduction projects that may provide similar benefits to the LTCP projects, but at a reduced cost. These alternatives will be evaluated against the existing LTCP projects, and results will be presented as they become available.

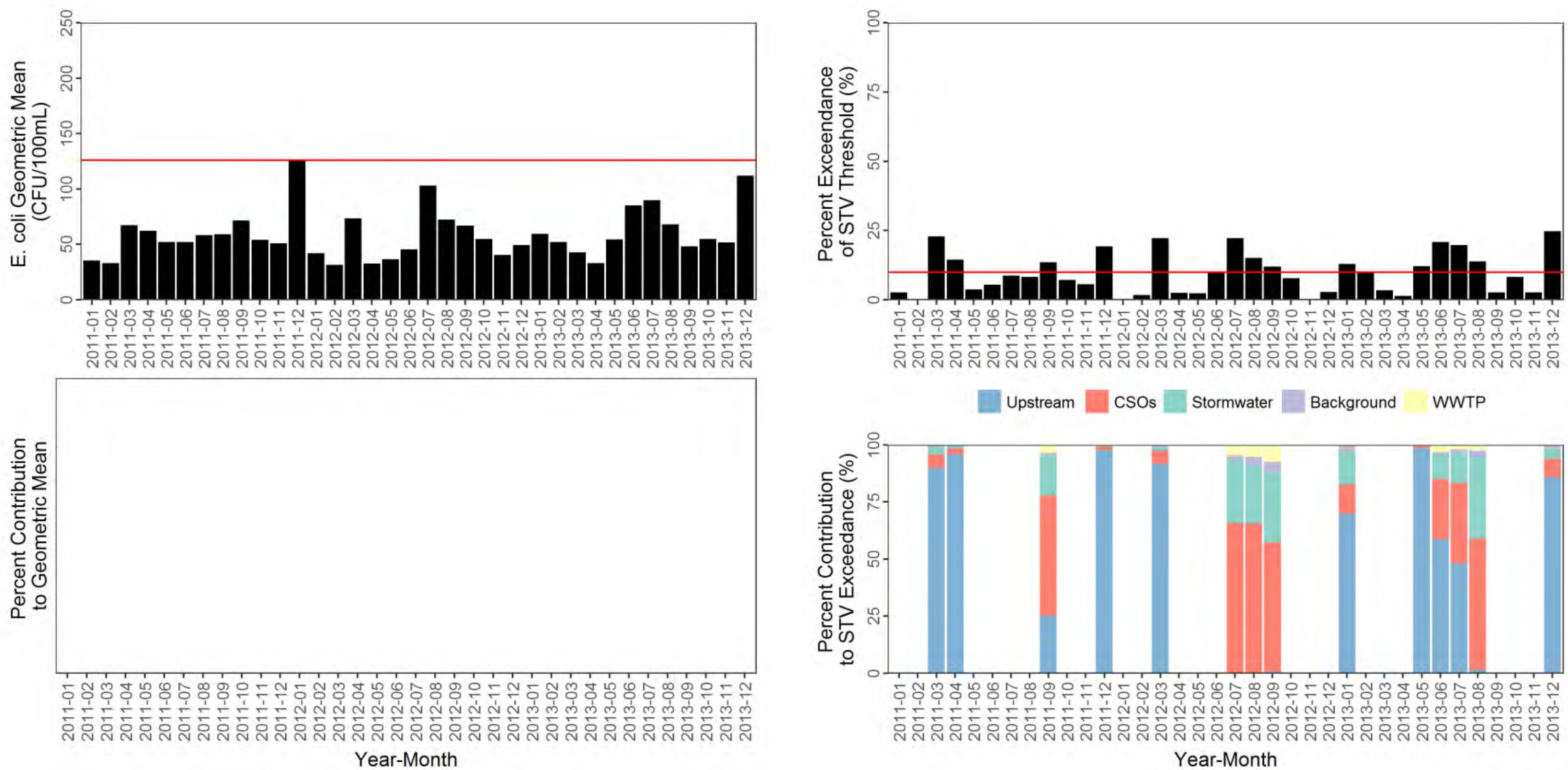


**Figure 5-8: Modeled Water Quality Concentration with CSS Improvement Infrastructure Strategy and a 50 Percent Reduction in Upstream Loads**

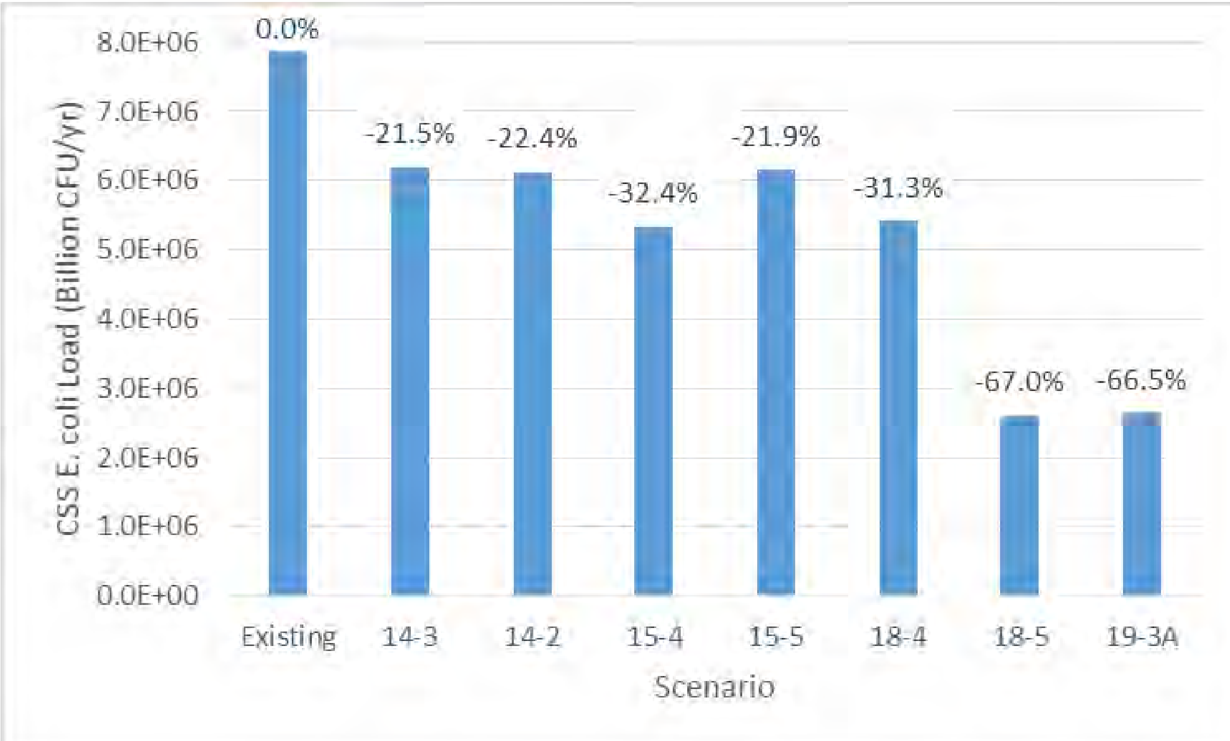


**Figure 5-9: E.coli Load Reduction for Each CSS Infrastructure Improvement Project**

**Table 5-9: Percent Improvement Over Current Conditions for each CSS Infrastructure Improvement Project**

| CSS Scenario | Project | 3-year Aggregate CSO Event Reduction (#) | 3-year Aggregate CSO Volume Reduction (MG) | 3-year Aggregate Exceedance of Geomean Standard (CFU/100ml) | Percent Improvement Over Current Conditions |
|---|---|---|---|---|---|
| **Current** | Current Conditions | -- | -- | 200 | -- |
| **14-3** | Baseline Conditions | 5 | 1,439 | 174 | 12.8% |
| **14-2** | Gillies Conveyance | 5 | 1,468 | 174 | 13.2% |
| **15-4** | 300 MGD Wet Weather Treatment | 5 | 2,488 | 167 | 16.6% |
| **15-5** | CSO 21 Replacement | 6 | 1,634 | 175 | 12.5% |
| **18-4** | SRB Expansion | 1 | 1,950 | 168 | 16.1% |
| **18-5** | SRB Expansion and Disinfection | 5 | 3,993 | 158 | 21.0% |
| **19-3A** | CSS Infrastructure Improvement Strategy (Full LTCP) | 8 | 4,325 | 157 | 21.3% |

### 5.4.6 Summary of Results for the Strategy Calculator

The strategies were evaluated using several metrics related to bacteria reduction, including:

- Bacteria load reduction from combined sewer and tributary discharges, expressed as Billion CFU
- Percent improvement in monthly geomean water quality standard compliance at the downstream city limit
- Reduction in number of CSO events
- Reduction in CSO volume (Million gallons)

These four metrics are used in the Strategy Calculator, a spreadsheet tool that is used to evaluate and score the different management strategies across a wide range of goals and objectives (LimnoTech, 2017). The results for the Strategy Calculator are summarized in Table 5-10.

**Table 5-10: Strategy metric results used in the Strategy Calculator**

| Metric | GI in MS4 | GI in CSS | CSS Infrastructure |
|---|---|---|---|
| Average yearly E.coli load reduction compared to the baseline (billion cfu) | 4,051 | 52,350 | 3,551,112 |
| Average reduction in annual number of CSO events compared to the baseline conditions | 0 | 0 | 1 |
| Average reduction in annual CSO volume discharged compared to the baseline conditions (million gallons) | 0 | 9 | 962 |
| Percent improvement compared to baseline conditions (%) | 0.1 | 0.1 | 10 |

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# 7 Glossary

CSO: Combined sewer overflow

CSS: Combined sewer system

CWA: Clean Water Act

DCIA: Directly connected impervious area

DEM: Digital elevation model

EFDC: Environmental Fluid Dynamic Code

EMC: Event mean concentration

HSG: Hydrologic soil group

LiDAR: Light detection and ranging

MRLC: Multi-Resolution Land Characteristics

MS4: Municipal separate storm sewer system

NCDC: National Climatic Data Center

NLCD: National Land Cover Database

NRCS: National Resources Conservation Service

NOAA: National Oceanic and Atmospheric Administration

NRCS: National Resources Conservation Service

RIA: Richmond International Airport

SSO: Sanitary sewer overflow

SSURGO: Soil Survey Geographic database

SWMM: Storm Water Management Model

USGS: United States Geological Survey

# Appendix 2. Strategy Fact Sheets

# STRATEGY: RIPARIAN AREAS

Replace or restore 10 acres of riparian buffers according to state guidance. This may include:

- Implementing in the MS4 and / or the CSS areas of the City
- Replacing grassed buffers and impervious surfaces with a forested buffer
- Evaluating opportunities for inclusion of access points to waterbody for recreational activities

Riparian areas within urban environments often face numerous pressures from encroachment to increased pollutant impacts. The Riparian Area strategy includes the identification of areas within a 100 foot riparian buffer that have been compromised by insufficient vegetation to perform its function. This can stem from factors such as the removal of trees, lack of an understory, or presence of impervious surfaces.

A GIS analysis of the City's streams and the land cover surrounding these streams identified locations where these stream buffer deficiencies exist. The intent of the Riparian Area strategy is to replace or restore these deficient buffers. Several assumptions were made in association with this strategy including:

- Removal of two acres of impervious surfaces
- Restoration of eight acres of grassed areas to forest buffer
- Planting 125 trees per acre

Additionally, because one objective is to facilitate recreational access to the streams, this strategy will also incorporate four access points within these 10 acres of restored riparian area (1 access point per 1,000 feet of buffers replaced/restored).

This strategy also makes the assumption that there will be an investigation of the possibility to increase the width of riparian buffers within the City to 200 feet. If determined feasible, riparian buffers will be expanded upon where possible.

While this strategy is not traditionally considered "green infrastructure," it was characterized as such for the scoring of the strategies due to elements of the strategy, such as removal of impervious surfaces and tree planting.

## STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Riparian Area strategy was included in **TIER 1** of priorities for implementation.

## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC | | METRIC | | METRIC |
|---|---|---|---|---|---|
| √ | TN reduction | √ | Riparian buffers restored/increased | √ | Area treated by GI |
| √ | TP reduction | √ | Habitat protected or restored | | Streams restored |
| √ | TSS reduction | √ | Habitat connected by green corridor | √ | Stormwater volume reduction |
| √ | Bacteria reduction | √ | Impervious surface reduced or treated | √ | Stream access points added |
| | Reduction in no. of CSO events | √ | Trees planted | √ | Streams buffers added |
| | Reduction in CSO volume | | Potable water consumption reduced | | Conservation easements added |
| √ | PCB, metals, and toxics reduction | | Rain or storm water used for irrigation | | Trash reduction |
| | Amount of water conserved | | Percent increase in WQS compliance at James River compliance point | | |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | 19 |
| Average yearly TP load reduction (lbs/yr) | 4 |
| Average yearly TSS load reduction (lbs/yr) | 1,081 |
| Average yearly E.coli load reduction (billion cfu/yr) | 83 |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $58,902 |
| Cost per pound TP removed | $292,553 |
| Cost per pound TSS removed | $1,017 |
| Cost per billion cfu E.coli removed | $13,190 |

# STRATEGY: GREEN INFRASTRUCTURE IN THE MS4

Install or retrofit green infrastructure (GI) draining 104 acres of city-owned impervious surfaces (50% of all city-owned impervious area) through efforts such as:

- Installing GI on DPU property, specifically targeting city-owned vacant properties for stormwater management
- Installing a mix of GI, including bioengineered tree boxes (like Filtera-type practices)
- Installing GI on Parks department property (e.g.: playgrounds, parks, cemetery roadways, vacant properties, etc.)
- Retrofitting four DPU stormwater BMPs (e.g., dry ponds to more efficient BMPs); draining at least 6 acres of impervious surface

This green infrastructure (GI) strategy is intended to represent a general mix of practices typically included in GI implementation efforts. As part of the development of this high-level strategy, the IWRM Planning Team made a variety of assumptions and decisions with regard to the GI types included, area treated, and load reductions efficiencies, and other benefits provided by the GI practices. These assumptions and decisions were necessary so that this strategy could be modeled at a high level in order to calculate expected load and stormwater volume reductions, and provide metric scores to assess how well the strategy meets the goals and objectives of the IWRM.

*The Mix of GI and Associated Acres Assumed for GI in the MS4*

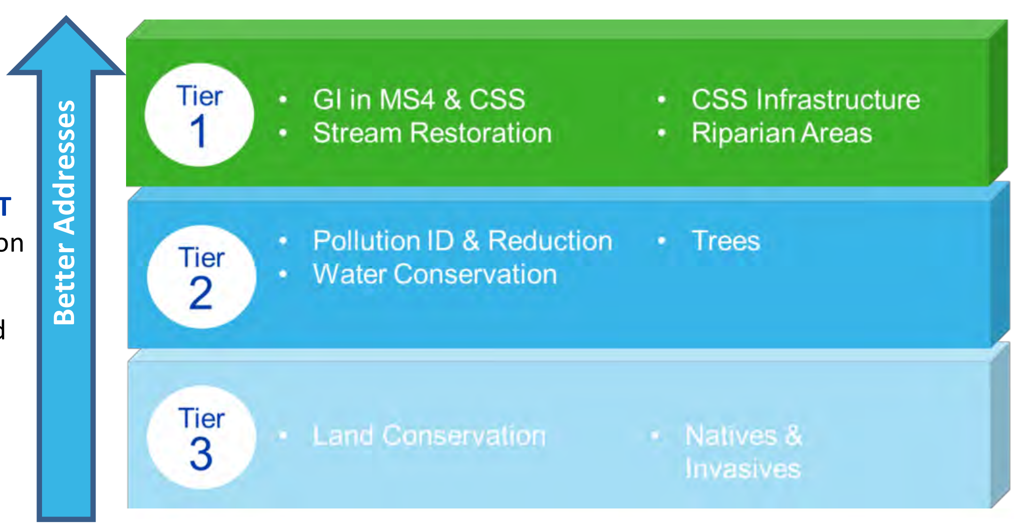
| Green Infrastructure Practice | Area Treated (acres) |
|---|---|
| Engineered tree boxes | 17 |
| Stormwater pond retrofit (dry pond to wet pond) | 6 |
| Green roofs | 1 |
| Rainbarrels | 16 |
| Permeable pavement - A/B soils, underdrain | 10 |
| Permeable pavement - C/D soils, underdrain | 10 |
| Bioretention/raingardens - A/B soils, underdrain | 21 |
| Bioretention/raingardens - C/D soils, underdrain | 23 |
| **Total Area Treated by Green Infrastructure in the MS4 area** | **104** |

The mix of GI types included and shown below is based on some of the more common GI types that are routinely implemented in the region. The practices assumed for this strategy are not meant to be exclusive or all-encompassing; other practices such as constructed wetlands, impervious surface disconnection, or nutrient management, could also be included under this strategy. The "final" list of GI practices will be determined though the Framework Planning process, as the City and stakeholders move closer to evaluating projects for implementation (see Chapter 7 of the City's Integrated Water Resources Management Plan for additional discussion on Framework Planning).

## STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, GI in the MS4 was included in **TIER 1** of priorities for implementation.



## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC |
|---|---|
| √ | TN reduction |
| √ | TP reduction |
| √ | TSS reduction |
| √ | Bacteria reduction |
| | Reduction in no. of CSO events |
| | Reduction in CSO volume |
| √ | PCB, metals, and toxics reduction |
| | Amount of water conserved |

| | METRIC |
|---|---|
| | Riparian buffers restored/increased |
| √ | Habitat protected or restored |
| | Habitat connected by green corridor |
| √ | Impervious surface reduced or treated |
| √ | Trees planted |
| | Potable water consumption reduced |
| √ | Rain or storm water used for irrigation |
| √ | Percent increase in WQS compliance at James River compliance point |

| | METRIC |
|---|---|
| √ | Area treated by GI |
| | Streams restored |
| √ | Stormwater volume reduction |
| | Stream access points added |
| | Streams buffers added |
| | Conservation easements added |
| | Trash reduction |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs) | 414 |
| Average yearly TP load reduction (lbs) | 90 |
| Average yearly TSS load reduction (lbs) | 42,397 |
| Average yearly E.coli load reduction (billion cfu) | 3,531 |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $30,181 |
| Cost per pound TP removed | $138,687 |
| Cost per pound TSS removed | $295 |
| Cost per billion cfu E.coli removed | $3,540 |

# STRATEGY: GREEN INFRASTRUCTURE IN THE COMBINED SEWER SYSTEM (CSS)

Install or retrofit green infrastructure (GI) draining 18 acres of city-owned impervious surfaces through efforts such as:

- Installing GI on DPU property, specifically targeting city-owned vacant properties for stormwater management
- Installing a mix of GI, including bioengineered tree boxes (like Filtera-type practices)
- Installing GI on Parks department property (e.g.: playgrounds, parks, cemetery roadways, vacant properties, etc.)

This green infrastructure (GI) strategy is intended to represent a general mix of practices typically included in GI implementation efforts. As part of the development of this high-level strategy, the IWRM Planning Team made a variety of assumptions and decisions with regard to the GI types included, area treated, and load reductions efficiencies, and other benefits provided by the GI practices. These assumptions and decisions were necessary so that this strategy could be modeled at a high level in order to calculate expected load and stormwater volume reductions, and provide metric scores to assess how well the strategy meets the goals and objectives of the IWRM.

*The Mix of GI and Associated Acres Assumed for GI in the CSS*

| Green Infrastructure Practice | Area Treated (acres) |
|---|---|
| Engineered tree boxes | 2.9 |
| Green roofs | 0.2 |
| Rainbarrels | 2.7 |
| Permeable pavement - A/B soils, underdrain | 1.8 |
| Permeable pavement - C/D soils, underdrain | 1.8 |
| Bioretention/raingardens - A/B soils, underdrain | 4.1 |
| Bioretention/raingardens - C/D soils, underdrain | 4.5 |
| **Total Area Treated by Green Infrastructure in the MS4 area** | **18** |

The mix of GI types included and shown here is based on some of the more common GI types that are routinely implemented in the region. The practices assumed for this strategy are not meant to be exclusive or all-encompassing; other practices such as constructed wetlands, impervious surface disconnection, or nutrient management, could also be included under this strategy. The "final" list of GI practices will be determined though the Framework Planning process, as the City and stakeholders move closer to evaluating projects for implementation (see Chapter 7 of the City's Integrated Water Resources Management Plan for additional discussion on Framework Planning).

## STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, GI in the CSS was included in **TIER 1** of priorities for implementation.

## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC |
|---|---|
| √ | TN reduction |
| √ | TP reduction |
| √ | TSS reduction |
| √ | Bacteria reduction |
| | Reduction in no. of CSO events |
| √ | Reduction in CSO volume |
| √ | PCB, metals, and toxics reduction |
| | Amount of water conserved |

| | METRIC |
|---|---|
| | Riparian buffers restored/increased |
| √ | Habitat protected or restored |
| | Habitat connected by green corridor |
| √ | Impervious surface reduced or treated |
| √ | Trees planted |
| | Potable water consumption reduced |
| √ | Rain or storm water used for irrigation |
| √ | Percent increase in WQS compliance at James River compliance point |

| | METRIC |
|---|---|
| √ | Area treated by GI |
| | Streams restored |
| √ | Stormwater volume reduction |
| | Stream access points added |
| | Streams buffers added |
| | Conservation easements added |
| √ | Trash reduction |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs) | 74 |
| Average yearly TP load reduction (lbs) | 16 |
| Average yearly TSS load reduction (lbs) | 7,393 |
| Average yearly E.coli load reduction (billion cfu) | 40,642 |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $45,270 |
| Cost per pound TP removed | $209,375 |
| Cost per pound TSS removed | $453 |
| Cost per billion cfu E.coli removed | $82 |

# STRATEGY: STREAM RESTORATION

This strategy includes the rehabilitation of 2,500 linear feet of stream, including activities such as removal of concrete channels and repair of incised banks. These streams can be located within the MS4 or the CSS areas of the City. This strategy also includes the evaluation of opportunities for inclusion of access points to a waterbody for recreational activities.

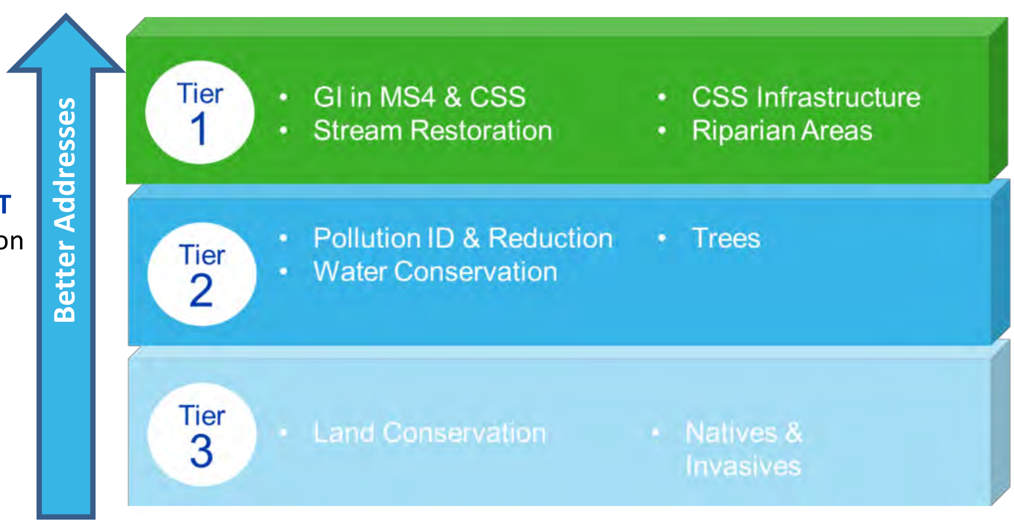
The 2,500 linear feet selected for this Stream Restoration Strategy was based upon a similar expanse included within the City's Chesapeake Bay TMDL Action Plan. Several assumptions were made in the development of this strategy including the following:

- The EPA CBP-approved pollutant reduction for this practice considers the ecoregion within which the stream restoration takes place. Because Richmond is split approximately in half between the Coastal Plain and the Piedmont ecoregions, it was assumed that 50% of the stream rehabilitation efforts would occur in each.
- Stream restoration projects will include a riparian buffer of 100 feet, but, where possible, the buffer will be increased to 200 feet.
- The average width of the streams restored was assumed to be 50 feet.
- This 100-foot buffer along the 2,500 linear feet of stream restoration results in almost 6 acres of riparian buffer restored or increased.
    - This is separate from what is included in the Riparian Area Strategy.
- Trees would be planted at a density of 125 trees per acre with over 700 trees planted.
    - This is separate from what is included in the Tree Strategy.
- Because improving waterfront access for recreation is an objective for the IWRM Plan, an access point for residents was assumed to be included for every 1,000 feet of stream restored. Two access points are therefore assumed for this 2,500 linear feet of stream restoration.

### STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Stream Rehabilitation strategy was included in **TIER 1** of priorities for implementation.



## METRICS

The table below shows the metrics that are addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC |
|---|---|
| √ | TN reduction |
| √ | TP reduction |
| √ | TSS reduction |
| | Bacteria reduction |
| | Reduction in number of CSO events |
| | Reduction in CSO volume |
| | PCB, metals, and toxics reduction |
| | Amount of water conserved |

| | METRIC |
|---|---|
| √ | Riparian buffers restored/increased |
| √ | Habitat protected or restored |
| √ | Habitat connected by green corridor |
| | Impervious surface reduced or treated |
| √ | Trees planted |
| | Potable water consumption reduced |
| | Rain or storm water used for irrigation |
| | Percent increase in WQS compliance at James River compliance point |

| | METRIC |
|---|---|
| √ | Area treated by GI |
| √ | Streams restored |
| | Stormwater volume reduction |
| √ | Stream access points added |
| | Stream buffers added |
| | Conservation easements added |
| | Trash reduction |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | 188 |
| Average yearly TP load reduction (lbs/yr) | 170 |
| Average yearly TSS load reduction (lbs/yr) | 75,013 |
| Average yearly E.coli load reduction (billion cfu/yr) | -- |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $15,467 |
| Cost per pound TP removed | $17,059 |
| Cost per pound TSS removed | $39 |
| Cost per billion cfu E.coli removed | -- |

# STRATEGY: TREE PLANTING

Increase natural land cover by focusing on tree planting, including:

- Increasing tree canopy on City property by 5%
- Protecting existing tree canopy by following maintenance addressed in the Tree Planting Master Plan

The tree planting strategy is intended to protect as well as increase the amount of tree canopy that covers Richmond. As part of the development of this high-level strategy, the IWRM Planning Team made a variety of assumptions and decisions with regard to the number and density of trees planted, area treated, load reduction efficiencies, and other benefits provided by tree planting. These assumptions and decisions were necessary so that this strategy could be modeled at a high level in order to calculate expected load and stormwater volume reductions, and provide metric scores to assess how well the strategy meets the goals and objectives of the IWRM. For example, it was assumed that 2,000 trees per year would be planted at a density of 125 trees/acre and that a single tree could reduce up to 466 gallons of storm water per year.

In addition to reducing target pollutant loads and stormwater volume, increasing the tree canopy also provides additional benefits to the public and to wildlife. As part of the tree planting strategy, trees planted in 50% of targeted areas are intended to increase or protect existing habitat, and 25% of the areas targeted for tree planting will be part of green corridors.

*Acres Assumed for Tree Planting in the MS4*

| Tree Planting Practice | Area (acres) |
|---|---|
| Total area targeted for tree planting | 80 |
| Effective tree canopy area | 33 |
| Tree canopy area over impervious area | 7 |
| Tree canopy area over pervious areas | 26 |
| Habitat protected/restored | 17 |
| Habitat protected by green corridor | 8 |

### STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Tree Planting strategy was included in **TIER 2** of priorities for implementation.

## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC |
|---|---|
| √ | TN reduction |
| √ | TP reduction |
| √ | TSS reduction |
| | Bacteria reduction |
| | Reduction in no. of CSO events |
| | Reduction in CSO volume |
| √ | PCB, metals, and toxics reduction |
| | Amount of water conserved |

| | METRIC |
|---|---|
| | Riparian buffers restored/increased |
| √ | Habitat protected or restored |
| √ | Habitat connected by green corridor |
| √ | Impervious surface reduced or treated |
| √ | Trees planted |
| | Potable water consumption reduced |
| | Rain or storm water used for irrigation |
| | Percent increase in WQS compliance at James River compliance point |

| | METRIC |
|---|---|
| √ | Area treated by GI |
| | Streams restored |
| √ | Stormwater volume reduction |
| | Stream access points added |
| | Streams buffers added |
| | Conservation easements added |
| | Trash reduction |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | 30 |
| Average yearly TP load reduction (lbs/yr) | 4 |
| Average yearly TSS load reduction (lbs/yr) | 447 |
| Average yearly E.coli load reduction (billion cfu/yr) | -- |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $72,158 |
| Cost per pound TP removed | $520,833 |
| Cost per pound TSS removed | $4,925 |
| Cost per billion cfu E.coli removed | -- |

# STRATEGY: NATIVE PLANT RESTORATION/INVASIVE PLANT REMOVAL

Increase the number and variety of native plants in the City of Richmond by:

- Using 80% native plants in new landscaping at public facilities by 2023
- Removing 5% of invasive plant species on DPU and park properties and replace with native species

The native plant restoration/invasive plant removal strategy focuses on populating new landscaping projects with plant species native to Richmond, actively removing invasive plant species and replacing them with native, and promoting public awareness of invasive plants. As part of the development of this high-level strategy, the IWRM Planning Team made a variety of assumptions and decisions with regard to the area treated, load reductions efficiencies, and other benefits provided by the native plant restoration/invasive plant removal. These assumptions and decisions were necessary so that this strategy could be modeled at a high level in order to calculate expected load and stormwater volume reductions, and provide metric scores to assess how well the strategy meets the goals and objectives of the IWRM.

There are two main components of the native restoration/invasive removal. The first component focuses on native plant restoration and invasive plant removal on City property. The native plant restoration/invasive plant removal strategy will also take several other factors into account such as biodiversity and the suitability of a species for a given location. Plantings of native species will focus on a wide variety of plants that are commonly found in the Coastal Plain/Piedmont region. In areas of the city that are not expected to receive supplemental watering, only drought-tolerant, native species will be considered. The second component of this strategy will be to develop a "do not plant" list of invasive species to raise awareness of problem species and to help guide local gardeners.

| Strategy Elements | |
|---|---|
| 20 | Acres of native planting and/or invasive removal |
| 2,000 | Trees planted |

While this Strategy does not offer significant reductions in target pollutants, they do provide a number of other benefits for the public, the city, and local wildlife, including: increased recreational space, plant biodiversity that will support a wider range of wildlife, and decreased watering costs associated with maintaining appropriately placed native plant species.

## STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Native Plant Restoration/Invasive Plant Removal strategy was included in **TIER 3** of priorities for implementation.

## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| METRIC |
|---|
| TN reduction |
| TP reduction |
| TSS reduction |
| Bacteria reduction |
| Reduction in no. of CSO events |
| Reduction in CSO volume |
| PCB, metals, and toxics reduction |
| Amount of water conserved |

| | METRIC |
|---|---|
| | Riparian buffers restored/increased |
| √ | Habitat protected or restored |
| √ | Habitat connected by green corridor |
| | Impervious surface reduced or treated |
| √ | Trees planted |
| | Potable water consumption reduced |
| | Rain or storm water used for irrigation |
| | Percent increase in WQS compliance at James River compliance point |

| METRIC |
|---|
| Area treated by GI |
| Streams restored |
| Stormwater volume reduction |
| Stream access points added |
| Streams buffers added |
| Conservation easements added |
| Trash reduction |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness for various strategies is evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) only. Because this strategy doesn't result in reduction of these pollutants, cost effectiveness could not be calculated.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | -- |
| Average yearly TP load reduction (lbs/yr) | -- |
| Average yearly TSS load reduction (lbs/yr) | -- |
| Average yearly E.coli load reduction (billion cfu/yr) | -- |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | -- |
| Cost per pound TP removed | -- |
| Cost per pound TSS removed | -- |
| Cost per billion cfu E.coli removed | -- |

# STRATEGY: WATER CONSERVATION

Reduce water consumption by 10% (from 2009-2014 baseline) through efforts such as:

- Installing water efficient fixtures as a policy by 2023 in all new public facility construction
- Implementing incentive programs that provide retrofits for low income households
- Encouraging water conservation on City properties
- Installing conservation landscaping on city-owned properties

This water conservation strategy is intended to represent a general mix of practices typically included in water conservation implementation efforts. As part of the development of this high-level strategy, the IWRM Planning Team made a variety of assumptions and decisions with regard to the conservation measures included, gallons of water conserved, load reductions efficiencies, and other benefits provided by the conservation practices. These assumptions and decisions were necessary so that this strategy could be modeled at a high level in order to calculate expected load and stormwater volume reductions, and provide metric scores to assess how well the strategy meets the goals and objectives of the IWRM.

*The Mix of Conservation Practices and Associated Gallons Conserved Assumed for Water Conservation*

| Water Conservation Practice | Water Conserved (million gallons) |
|---|---|
| 1,000 New rain barrels | 0.52 |
| Conservation incentives | 250 |
| Improvements in the water distribution system | 250 |
| **Total Water Conserved by Water Conservation Practices (over five years)** | **500.52** |

The mix of conservation activities included and shown here is based on incorporation of common water conservation practices, such as rain barrels and encouraging water conservation by City staff. An incentive program is also planned that will include retrofits of low flush toilets and other fixtures. The "final" list of water conservation practices will be determined though the Framework Planning process, as the City and stakeholders move closer to evaluating projects for implementation (see Chapter 7 of the City's Integrated Water Resources Management Plan for additional discussion on Framework Planning).

### STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Water Conservation strategy was included in **TIER 2** of priorities for implementation.

## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the Water Conservation strategy*

| | METRIC |
|---|---|
| √ | TN reduction |
| √ | TP reduction |
| √ | TSS reduction |
| | Bacteria reduction |
| | Reduction in no. of CSO events |
| | Reduction in CSO volume |
| | PCB, metals, and toxics reduction |
| √ | Amount of water conserved |

| | METRIC |
|---|---|
| | Riparian buffers restored/increased |
| | Habitat protected or restored |
| | Habitat connected by green corridor |
| √ | Impervious surface reduced or treated |
| | Trees planted |
| √ | Potable water consumption reduced |
| √ | Rain or storm water used for irrigation |
| | Percent increase in WQS compliance at James River compliance point |

| | METRIC |
|---|---|
| √ | Area treated by GI |
| | Streams restored |
| √ | Stormwater volume reduction |
| | Stream access points added |
| | Streams buffers added |
| | Conservation easements added |
| | Trash reduction |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | 11 |
| Average yearly TP load reduction (lbs/yr) | 1 |
| Average yearly TSS load reduction (lbs/yr) | 422 |
| Average yearly E.coli load reduction (billion cfu/yr) | -- |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $24,092 |
| Cost per pound TP removed | $195,744 |
| Cost per pound TSS removed | $639 |
| Cost per billion cfu E.coli removed | -- |

# STRATEGY: LAND CONSERVATION

Place an additional 10 acres of city-owned land under conservation easement. When selecting acreage to include in the easement consideration will be given to the following factors:

- Prioritizing the conservation of land that creates connected green corridors
- Evaluating opportunities for inclusion of access points to waterbodies for recreational activities

The land conservation strategy focuses on placing an additional 10 acres of City-owned land under conservation easement. As part of the development of this high-level strategy, the IWRM Planning Team made a variety of assumptions and decisions with regard to implementation. It was assumed that 50% of the land included in the conservation easement would create connected green corridors. Green corridors are areas of open space that connect fragmented green spaces together allowing for the improved movement of people and wildlife.

| Land Conservation Benefits |
|---|
| Conservation/restoration of habitat |
| Improved connectivity between habitats |
| Increased public open space |
| Increased mobility for wildlife |
| Increased access to recreational opportunities |

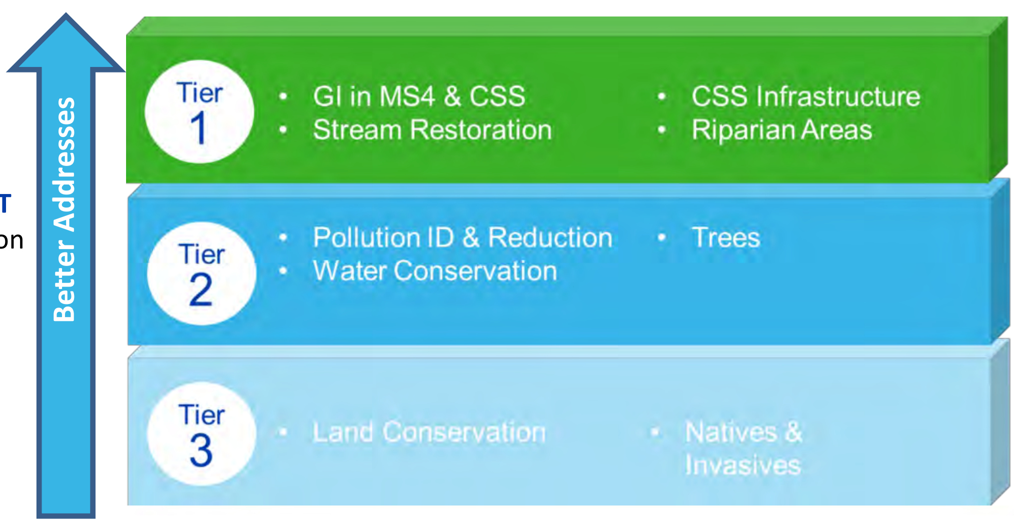
While the land conservation strategy does not offer significant reductions in target pollutants, they do provide a number of other benefits for both local wildlife and the public, including: habitat protection, habitat restoration, increased recreational space, and an increased number of access points to waterbodies within the City.

Because there are no regulatory requirements driving land conservation in the City, this strategy also helps the City address the IWRM Plan objective to exceed regulatory requirements, when possible.

## STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Land Conservation strategy was included in **TIER 3** of priorities for implementation.



## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC | | METRIC | | METRIC |
|---|---|---|---|---|---|
| | TN reduction | | Riparian buffers restored/increased | | Area treated by GI |
| | TP reduction | √ | Habitat protected or restored | | Streams restored |
| | TSS reduction | √ | Habitat connected by green corridor | | Stormwater volume reduction |
| | Bacteria reduction | | Impervious surface reduced or treated | √ | Stream access points added |
| | Reduction in no. of CSO events | | Trees planted | | Streams buffers added |
| | Reduction in CSO volume | | Potable water consumption reduced | √ | Conservation easements added |
| | PCB, metals, and toxics reduction | | Rain or storm water used for irrigation | | Trash reduction |
| | Amount of water conserved | | Percent increase in WQS compliance at James River compliance point | | |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness for various strategies is evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) only. Because this strategy doesn't result in reduction of these pollutants, cost effectiveness could not be calculated.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | -- |
| Average yearly TP load reduction (lbs/yr) | -- |
| Average yearly TSS load reduction (lbs/yr) | -- |
| Average yearly E.coli load reduction (billion cfu/yr) | -- |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | -- |
| Cost per pound TP removed | -- |
| Cost per pound TSS removed | -- |
| Cost per billion cfu E.coli removed | -- |

# STRATEGY: POLLUTANT IDENTIFICATION AND REDUCTION

Reduce the contribution of pollutants to the municipal separate stormwater sewer system (MS4) area by:

- Conducting at least one special study per year in hot spot areas to identify illicit discharges/connections
- Collecting data associated with non-structural BMPs to facilitate quantification of pollutant reduction

The first part of this strategy involves identifying and eliminating illicit discharges within the MS4 area. Illicit discharges are sources of pollutants collected to storm drains that contribute contaminants to the system during periods of dry weather. This strategy will find and eliminate illicit discharges by conducting at least one special study each year in an area that has been deemed a "hot spot" for pollutant loading. By targeting "hot spots" the city can effectively and efficiently target relatively large sources of pollutants by eliminating the source of the discharge or by implementing a best management practice (BMP) to reduce the pollutant loading. Over five years, at least 3 of these studies will be used to meet pollutant reductions required by the Chesapeake Bay TMDL.

The second part of this strategy involves data collection for non-structural best management practices (BMPs). Currently, the assumptions associated with implementing non-structural BMPs such as catch basin clean outs and street sweeping are based on region-specific literature reviews. Because there is not an approved or commonly used methodology in place to account for pollutant reductions associated with pet waste removoal, this practice was not accounted for quantitatively in the strategy calculator. By collecting site-specific data on pollution reduction practices, the City will be able to refine the pollutant removal rates associated with these projects and to better quantify their impact on the James River. As additional data and research substantiate the quantification of additional pollutant removal practices, these will also be taken into consideration.

### STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Pollutant Identification and Reduction strategy was included in **TIER 2** of priorities for implementation.

## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC | METRIC | | METRIC |
|---|---|---|---|---|
| √ | TN reduction | Riparian buffers restored/increased | | Area treated by GI |
| √ | TP reduction | Habitat protected or restored | | Streams restored |
| √ | TSS reduction | Habitat connected by green corridor | | Stormwater volume reduction |
| | Bacteria reduction | Impervious surface reduced or treated | | Stream access points added |
| | Reduction in no. of CSO events | Trees planted | | Streams buffers added |
| | Reduction in CSO volume | Potable water consumption reduced | | Conservation easements added |
| √ | PCB, metals, and toxics reduction | Rain or storm water used for irrigation | √ | Trash reduction |
| | Amount of water conserved | Percent increase in WQS compliance at James River compliance point | | |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | 448 |
| Average yearly TP load reduction (lbs/yr) | 162 |
| Average yearly TSS load reduction (lbs/yr) | 57,893 |
| Average yearly E.coli load reduction (billion cfu/yr) | -- |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $36,597 |
| Cost per pound TP removed | $100,882 |
| Cost per pound TSS removed | $284 |
| Cost per billion cfu E.coli removed | -- |

# STRATEGY: IMPLEMENT CSS INFRASTRUCTURE PROJECTS

Implement projects outlined in Richmond's combined sewer overflow long-term control plan (CSO LTCP), including:

- Installing wet weather interceptor in Lower Gillies Creek to convey more flow to the WWTP
- Increasing wet weather treatment to 300 MGD at the WWTP
- Expanding Shockoe Retention Basin by 15 MG to capture more combined sewer overflow
- Adding disinfection at the Shockoe outfall to reduce bacteria in combined sewer overflow
- Expanding secondary treatment at the WWTP to 85 MGD

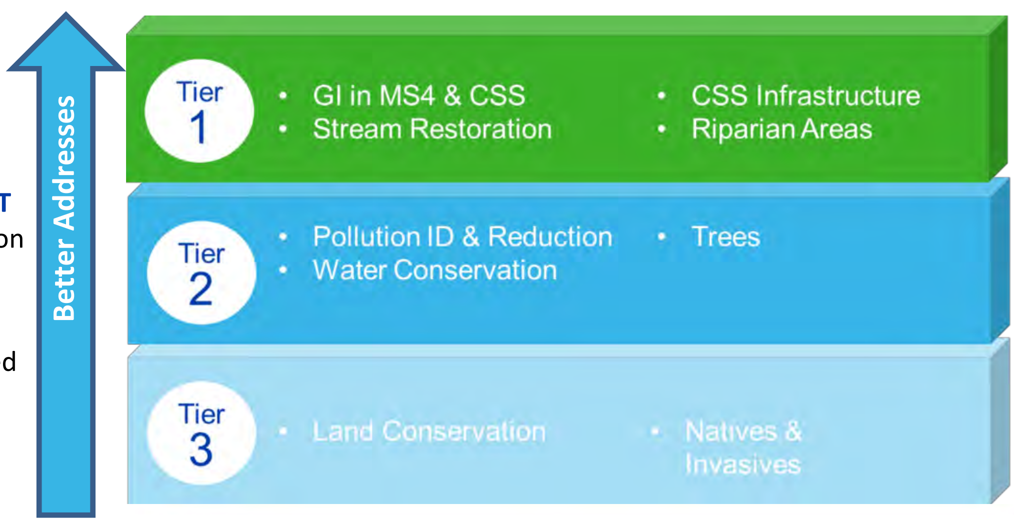
Implementation of Richmond's combined sewer overflow long-term control plan (CSO LTCP) is required under a consent order from the State Water Control Board. The consent order was issued in 2005 and includes an implementation schedule and a description of LTCP projects that will be implemented. Projects that are part of this strategy are aimed at decreasing the volume of CSOs by rerouting flows from the combined sewer outfalls to the Richmond waste water treatment plan (WWTP) and Shockoe retention basin (SRB), where those flows can then receive some level of treatment before being released into the James River. Increasing the treatment capacity of the WWTP and SRB, will result in smaller pollutant loads entering the James River, thereby improving water quality.

| Strategy Elements |
|---|
| Expanding wet weather treatment at the waste water treatment plant |
| Improving wet weather conveyance in Lower Gillies Creek to the waste water treatment plant |
| Expanding the Shockoe Retention Basin and disinfecting combined sewer overflows at SRB |
| Expanding secondary treatment at the waste water treatment plant |

## STRATEGY TIERS

Priorities for implementation are based on how well the strategy addresses selected **METRICS, POLLUTANT REDUCTION**, and **COST EFFECTIVENESS**. Each is discussed on the following page.

Overall, the Implement CSS Infrastructure Strategy was included in **TIER 1** of priorities for implementation.



## METRICS

The table below shows the metrics that were addressed by this strategy. Additional details regarding information and assumptions related to this strategy and the numeric metric results can be found in the IWRM Planning Spreadsheet Calculator Tool, located at RVAH2O.org.

*Metrics evaluated for the GI in the MS4 strategy*

| | METRIC |
|---|---|
| √ | TN reduction |
| √ | TP reduction |
| √ | TSS reduction |
| √ | Bacteria reduction |
| √ | Reduction in no. of CSO events |
| √ | Reduction in CSO volume |
| √ | PCB, metals, and toxics reduction |
| | Amount of water conserved |

| | METRIC |
|---|---|
| | Riparian buffers restored/increased |
| | Habitat protected or restored |
| | Habitat connected by green corridor |
| | Impervious surface reduced or treated |
| | Trees planted |
| | Potable water consumption reduced |
| | Rain or storm water used for irrigation |
| √ | Percent increase in WQS compliance at James River compliance point |

| | METRIC |
|---|---|
| | Area treated by GI |
| | Streams restored |
| | Stormwater volume reduction |
| | Stream access points added |
| | Streams buffers added |
| | Conservation easements added |
| √ | Trash reduction |

√ = metric was addressed by the strategy

## POLLUTANT REDUCTION & COST EFFECTIVENESS

Cost effectiveness was evaluated for the permit-driven metrics (TN, TP, TSS, bacteria) and expressed as cost per unit pollutant removed.

| Pollutant Removal | |
|---|---|
| Average yearly TN load reduction (lbs/yr) | 7,066 |
| Average yearly TP load reduction (lbs/yr) | 903 |
| Average yearly TSS load reduction (lbs/yr) | 116,843 |
| Average yearly E.coli load reduction (billion cfu/yr) | 3,551,112 |

| Cost Effectiveness | |
|---|---|
| Cost per pound TN removed | $55,507 |
| Cost per pound TP removed | $434,293 |
| Cost per pound TSS removed | $3,357 |
| Cost per billion cfu E.coli removed | $110 |

# SUPPORTING ACTIONS TO MAIN STRATEGIES

While strategies have been defined as "activities, actions, or items that will help meet goals and objectives" of the Integrated Water Resources Management (IWRM) Plan, a number of additional actions have been identified to support or facilitate the implementation of these strategies. These supporting actions to the main strategies include efforts that may broaden the main strategy, additional specificity on how a strategy could be implemented, or identify additional resources and data needs to fully implement the main strategy. These supporting actions are not necessarily quantifiable in and of themselves and may be components of multiple main strategies. They may also involve efforts on non-City property and rely on resources that are outside the DPU's authority.

The development of strategies that meet the goals and objectives of the IWRM Plan resulted in a number of supporting actions related to:

- Partnerships
- Maintenance
- Monitoring, assessment & planning
- Incentives & credits
- Regulations, ordinances & codes
- Outreach

A summary of each of the supporting actions is discussed below and specific examples of these actions are included in the following tables.

The following table identifies which of these supporting actions are included in each strategy. For instance, the Riparian Area, Green Infrastructure (GI) in the municipal separate storm sewer system (MS4), and Tree Strategies address each of the six supporting actions. Alternatively the Pollution Identification (ID), Combined Sewer System (CSS) Infrastructure, and Land Conservation Strategies address only two supporting actions.

| | Riparian Area | GI in MS4 | GI in CSS | Stream Restor. | Natives/ Invasives | Trees | Land Cons. | Water Cons. | Pollution ID | CSS Infrast. |
|---|---|---|---|---|---|---|---|---|---|---|
| Partnerships | √ | √ | √ | √ | √ | √ | √ | √ | | |
| Maintenance | √ | √ | √ | √ | √ | √ | | | | |
| Monitoring | √ | √ | √ | √ | √ | √ | | | √ | √ |
| Incentives | √ | √ | | | √ | √ | | √ | | |
| Regulations | √ | √ | √ | | | √ | | √ | | |
| Outreach | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |

## Partnerships

The purpose of establishing partnerships is to facilitate a greater level of future implementation. This could be as the result of partnerships within the City, such as with Department of Planning or the Parks, Recreation, and Community Facilities. Partnerships may also include non-City agencies, such as watershed groups or neighborhood associations that can help facilitate implementation of strategies on private property. Non-DPU City departments, watershed groups, or neighborhood associations could work collectively with DPU to cost share implementation of strategies through shared staff and resources or through collaboration of actions. Additional specificity related to partnerships (along with other supporting actions) are expected to be refined over time as additional discussions and agreements are made with potential partners.

### Maintenance

Many of the selected strategies require maintenance to ensure the strategy is performing as it should and will continue to meet its intended objectives. Part of this supporting action includes ensuring that sufficient funding is available and is part of each applicable strategy.

### Monitoring, Assessment & Planning

The intent of this supporting action is to gather data and information and use these results to help inform and guide future implementation. This can include monitoring of specific practices, such as pre- and post-construction monitoring of a stream restoration project. It could also include the inventory and mapping of areas associated with the various strategies, such as riparian buffers or invasive species. Monitoring also includes the continuation of the James River and tributary sampling that is being used to evaluate the status and trends that are seen in the City's water quality and aquatic biological communities. As DPU is just one of the organizations that is conducting monitoring, another supporting action could include the initiation of a workgroup to improve coordination of data collection efforts.

### Incentives & Credits

These supporting actions are intended to further evaluate, develop, and implement mechanisms to incentivize new initiatives or higher levels of future implementation. Specific actions can relate to expansion of the stormwater credit program to include reference to additional strategies, such as restoration of riparian buffers or removal of invasive and planting of native species on private land.

### Regulations, Ordinances & Codes

This includes analyzing and modifying, if necessary, the framework within which implementation will occur. For instance, the Riparian Area Strategy is based on implementation within a 100 foot stream buffer. This supporting action could include evaluating expansion of this buffer to a 200 foot buffer. Additionally, City zoning and planning-related ordinances could be reevaluated to include language related to impervious area or to protect existing trees on developed property.

### Outreach

Each of the 10 main strategies includes opportunities for education and outreach. This can include identifying ways to potentially expand upon future implementation by conveying information on resources available or ways for partners and the public support implementation of a strategy. As the implementation portion of the IWRM Plan is developed in more detail, specific activities will be identified and opportunities to implement these activities will be discussed with partner organizations.

## COSTS

Costs were evaluated for each of the Supporting Actions. This information is summarized in the table below and detailed further in Appendix 5 (Strategy Cost Estimation) of the IWRM Plan.

| Supporting Action | Estimated Cost |
|---|---:|
| Partnerships | $655,000 |
| Maintenance | Cost was included in association with the individual strategies |
| Monitoring | $1,208,000 |
| Incentives/ Credits | $500,000 |
| Regulations | Assumed to be part of City staff's normal job duties |
| Outreach | $500,000 |

| | Riparian Areas | Green Infrastructure (in MS4) | Green Infrastructure (in CSS) | Stream Restoration | Native/ Invasives | Trees | Land Conservation | Water Conservation | Pollution Identification | CSS Infrastructure |
|---|---|---|---|---|---|---|---|---|---|---|
| **Supporting Actions** | | | | | | | | | | |
| **Partnerships** | **20** acres of riparian buffers on private properties:<br>* Through purchase of land<br>* Partnerships with residents: Promote program for buffers on private properties (include tiers of level of involvement - (1) maintenance agreement with city, (2) conservation agreement/ easement.)]<br>* Partner with Master Naturalists to enlist their support to assist with riparian restoration | * **5** acres on DPW property (rights of way, roadways, green alleys)<br><br>Implement **10** acres of GI on private property:<br><br>* Adopt a rain garden program - coordinate with residents, non-profits, commercial entities<br><br>* Partner with City's community garden program to identify **3** acres of area for additional GI implementation<br><br>* Partner with Public Works to ensure City greenways include GI (**5** acres of GI) | * **5** acres on DPW property (rights of way, roadways, green alleys)<br><br>Implement **10** acres of GI on private property. :<br>* Adopt a rain garden program - coordinate with residents, non-profits, commercial entities<br><br>* Partner with City's community garden program to identify **1** acres of area for additional GI implementation<br><br>* Partner with Public Works to ensure City greenways include GI (**2** acres of GI) | Promote requests for stream restoration by private landowners. Streamline the process by which these requests are addressed. | * Develop a program to encourage the use of native plants in private landscaping - sign up **20** private landscapers.<br><br>* Initiate an adopt-a-lot program (**10** lots with invasive species removed, replanted, and maintained)<br><br>* Partner with organizations, such as the James River Park System Invasive Plant Task Force, to better determine areas with significant invasive species issues and resources to deal with the problem. | * Partner with the public and other stakeholders, such as the Richmond Tree Stewards, to plant and maintain trees on public properties. | Partner with the public and other stakeholders to identify land to put in conservation easements.<br><br>Include an additional **100** acres of non-City property in conservation easements. | * Partner with Richmond Redevelopment and Housing Authority to identify homes/properties that are eligible for upgrades to water efficient fixtures.<br><br>* Partner with upstream localities and Virginia Department of Health to update/maintain Source Water Protection Plan | | |
| | Hire DPU staff or assign 1 FTE to coordinate volunteers from corporate entities, watershed/environmental groups, and public with partnership opportunities associated with the IP effort. Staff to enlist/maintain **6** of partnerships per year | | | | | | | | | |
| | Hold **3** stakeholder meetings per year to continue communication with partners/stakeholders and add purpose to the IP effort. | | | | | | | | | |
| | Evaluate partnership network in 5 years (at the end of the permit cycle) to assess gaps and identify new public/private partners. | | | | | | | | | |
| **Maintenance** | Include funding to support maintenance of newly replanted / restored riparian buffers (to ensure success of plantings, prevention of establishment of invasive species, etc.) | Include funding to support maintenance of green infrastructure practices based on findings of the inspection program to ensure continued pollutant reduction credit. | | Include funding to support maintenance of restored streams. | Include funding to support maintenance of newly planted native plants as well as to maintain newly established plantings where invasives have been removed from the landscape | Provide funding to support maintenance of trees on city property to ensure their survival and health. | | | | |
| **Monitoring, Assessments & Planning** | Inventory and map riparian areas to better understand loss or growth of riparian buffers | Evaluate potential for conducting pre and post construction monitoring of key stormwater BMPs. | | Conduct pre and post restoration monitoring per Chesapeake Bay Program requirements | Monitor growth/expansion of invasive species. | Inventory and map locations of trees and tree boxes to better understand loss or growth of tree coverage. | | | Implement IDDE-related monitoring to support this effort - supported by a desktop analysis of high risk dischargers | Continue monitoring effort associated with the CSO and WWTP discharge programs. |
| | Continue monitoring of 8 locations across the city for macroinvertebrate, habitat, and instream water quality. Continue monitoring at two locations for flow. Evaluate opportunities to expand the flow monitoring network across the City. | | | | | | | | | |
| | Evaluate the development of a monitoring data portal to facilitate sharing of data collected within the City with stakeholders and the public. | | | | | | | | | |

| | Riparian Areas | Green Infrastructure (in MS4) | Green Infrastructure (in CSS) | Stream Restoration | Native/ Invasives | Trees | Land Conservation | Water Conservation | Pollution Identification | CSS Infrastructure |
|---|---|---|---|---|---|---|---|---|---|---|
| | Initiate monitoring workgroup in year one made up of technical stakeholders and other key groups/individuals to evaluate current monitoring efforts and identify potential efficiencies and additional monitoring needs moving forward. | | | | | | | | | |
| | Conduct assessments of **4** stream segments across the four watershed groupings to support the development of watershed restoration plans to address pollutant sources and watershed stressors. | | | | | | | | | |
| **Incentives/ Credits** | Reevaluate the stormwater credit program to determine potential to include practices such as replacing or restoring riparian buffers. | * Reevaluate the stormwater credit program (through updates to the credit manual) to include additional practices including tree planting, green roofs, etc. Reevaluation of the credit program will also include increases of funding available for these credits to incentivize implementation on private property.<br>* Provide credits for residential and non-residential properties to reduce stormwater fees based on implementation of "green practices". | | | Evaluate incentives/credits for purchasing / planting native species (such as Montgomery County, MD). | * Reevaluate the stormwater credit program to determine potential to include practices such as planting trees on private property.<br><br>* Provide **500** trees for planting on private property or equivalent incentives to purchase native trees. | | * Offer grants to replace **20** % of inefficient fixtures in moderate to low-income units.<br><br>* Evaluate expansion of incentive program to cover washing machines and dishwashers | | |
| **Regs/ Ordinance/ Code** | Evaluate expanding the regulatory buffer from 100ft to 200ft | Evaluate inclusion of language in City zoning and planning-related ordinances to limit impervious area on developed property. | | | | Evaluate inclusion of language in City zoning and planning-related ordinances to protect existing trees and add new trees on developed property. | | Adopt permitting standards for water efficient appliances/ fixtures in city code | | |
| **Outreach** | | Conduct outreach to advertise the resources, requirements, and services available through city related to green infrastructure for private property owners | | | | Conduct outreach to advertise the resources, requirements, and services available through city related to tree planting and maintenance. | | * Promote ability to use grey water for toilet flushing. Promote as way to achieve higher LEED standards.<br>* Encourage and incentivize water capture and reuse for landscaping<br>* Promote water conservation for commercial, industrial, and residential customers through efforts such as "Fix a Leak Week" and the City's Every Drop Counts initiative. | Conduct targeted outreach to high-risk industries, particularly in areas of the city identified as hot spots. | |
| | Conduct outreach to educate the general public about the goals and objectives of RVAH2O, and the resources and services available through the city. | | | | | | | | | |

# Appendix 3. RVA Clean Water Plan Goals, Objectives & Metrics

# RVAH2O WATERSHED METRICS

| GOAL | OBJECTIVES | METRICS |
|---|---|---|
| **Manage wastewater and stormwater to improve the water quality and water quantity of ground water and surface water.** | Develop one stormwater management plan to cover the City's four watershed groupings based on the City's watershed characterization report. | Plan produced (yes=1, no=0) |
| | Reduce nitrogen, phosphorus and sediment in discharges to achieve VPDES permit requirements (Chesapeake Bay TMDL). | • N reduction (lbs.)<br>• P reduction (lbs.)<br>• TSS reduction (lbs.) |
| | Reduce bacteria levels to achieve VPDES permit requirements (local TMDL and water quality standards). | • Percent increase in monthly geomean WQS compliance<br>• Average yearly E. coli load reduction (billion cfu)<br>• Average yearly reduction in CSO events (number)<br>• Average yearly reduction in CSO volume discharged (million gallons) |
| | Reduce toxics (e.g., mercury, PAHs, PCBs), trash and other pollutants and address TMDLs for these pollutants. | • PCB, metals and toxics reduction (yes=1, no=0)<br>• Trash reduction (lbs.) |
| | Develop green infrastructure, including riparian buffers and removal of impervious surfaces on development, existing development and redevelopment. | • Area treated by GI (acres)<br>• Impervious surface reduced or treated (acres) |
| **Protect and restore aquatic and terrestrial habitats to support balanced indigenous communities.** | Restore streams to improve, restore and enhance native ecological communities. | • Streams restored (miles of streams)<br>• Reduce stormwater volume discharging to streams (gallons)<br>• Riparian buffers restored and/or increased (acres) |
| | Identify, protect and restore critical habitats. | Critical habitat protected or restored (acres) |
| | Enhance aquatic and terrestrial habitat connectivity. | Habitat connected by green corridor (acres) |
| | Investigate and, where feasible, promote actions that might surpass regulatory requirements. | Exceeds regulatory requirements (yes=1, no=0) |
| **Engage and educate the public to share responsibility and take action on achieving healthy watersheds.** | Engage and efficiently educate the public about standards, processes and actions associated with watershed health and public health. | Residents reached by effort (# of people) |
| | Assist in the education of citizens about overall water quality issues and benefits of improved water quality. | Residents reached by effort (# of people) |
| | Support and encourage local action to improve water quality. | • NGOs/community groups provided support by City (# of groups)<br>• Money available for incentives (dollars) |
| | Provide quicker public notifications of spills or pollution from regulators or other "river watchers." | Time to notify (days) |
| **Implement land conservation and restoration and incorporate these into planning practices to improve water quality.** | Protect, restore and increase riparian buffers. | Riparian buffers restored and/or increased (acres) |
| | Reduce impervious surfaces. | Impervious surface reduced or treated (acres) |
| | Increase natural land cover with a focus on preserving, maintaining and increasing tree canopy. | Trees planted (acres) |
| | Incorporate green infrastructure in new development and redevelopment. | Area treated by GI (acres) |
| | Conserve lands where possible and consistent with Richmond's Comprehensive Plan. | Conservation easements added (acres) |
| **Create partnerships across the watersheds internal and external to the City of Richmond to maximize benefits and minimize impacts to all stakeholders.** | Develop and implement a source water prevention plan/strategy. | Plan produced (yes=1, no=0) |
| | Establish public-private partnerships to secure funding, implement strategies and projects, and achieve plan goals. | Partnerships implemented (# of) |
| | Maintain and expand the RVAH20 group. | Meetings held (# of) |
| **Maximize water availability through efficient management of potable water, stormwater and wastewater.** | Reduce use of potable water for industry and irrigation. | • Potable water consumption reduced (gallons)<br>• Rainwater and stormwater used for irrigation (gallons) |
| | Achieve water conservation by improving the existing water conveyance system. | Amount of water conserved (gallons) |
| | Achieve water conservation by incentivizing upgrades to end-user water fixtures where appropriate. | Money available for incentives (dollars) |
| **Provide safe, accessible, ecologically sustainable water-related recreational opportunities for all.** | Improve water quality to promote safe recreation consistent with the City's Riverfront Plan. | • Percent increase in monthly geomean WQS compliance<br>• Average yearly E. coli load reduction (billion cfu)<br>• Average yearly reduction in CSO events (number)<br>• Average yearly reduction in CSO volume discharged (million gallons) |
| | Promote ecologically sustainable management of riverfront and riparian areas. | Streams with buffers (length of streams with 100-foot buffer added) |
| | Improve river and waterfront access for recreation. | Access points (yes=1, no=0) |
| **Work collaboratively to gather consistent high-quality data to characterize the status and trends of water resources and to gauge the effectiveness of restoration efforts.** | Conduct water quality and biological monitoring. | Stations monitored (# of stations) |
| | Provide timely water quality information. | Time necessary for monitoring results (days) |
| | Collaborate with citizens and local/state agencies for coordinated monitoring. | Citizen groups/agencies coordinated with (# of) |
| | Utilize results to target restoration efforts and convey progress. | Project with monitoring component (yes=1, no=0) |

RVA H2O
EVERY DROP COUNTS

CITY OF RICHMOND
DEPARTMENT OF PUBLIC UTILITIES

# Appendix 4. Calculator Spreadsheet Tool

See attached Excel document.

# Appendix 5. Strategy Cost Estimation

See attached Excel document.