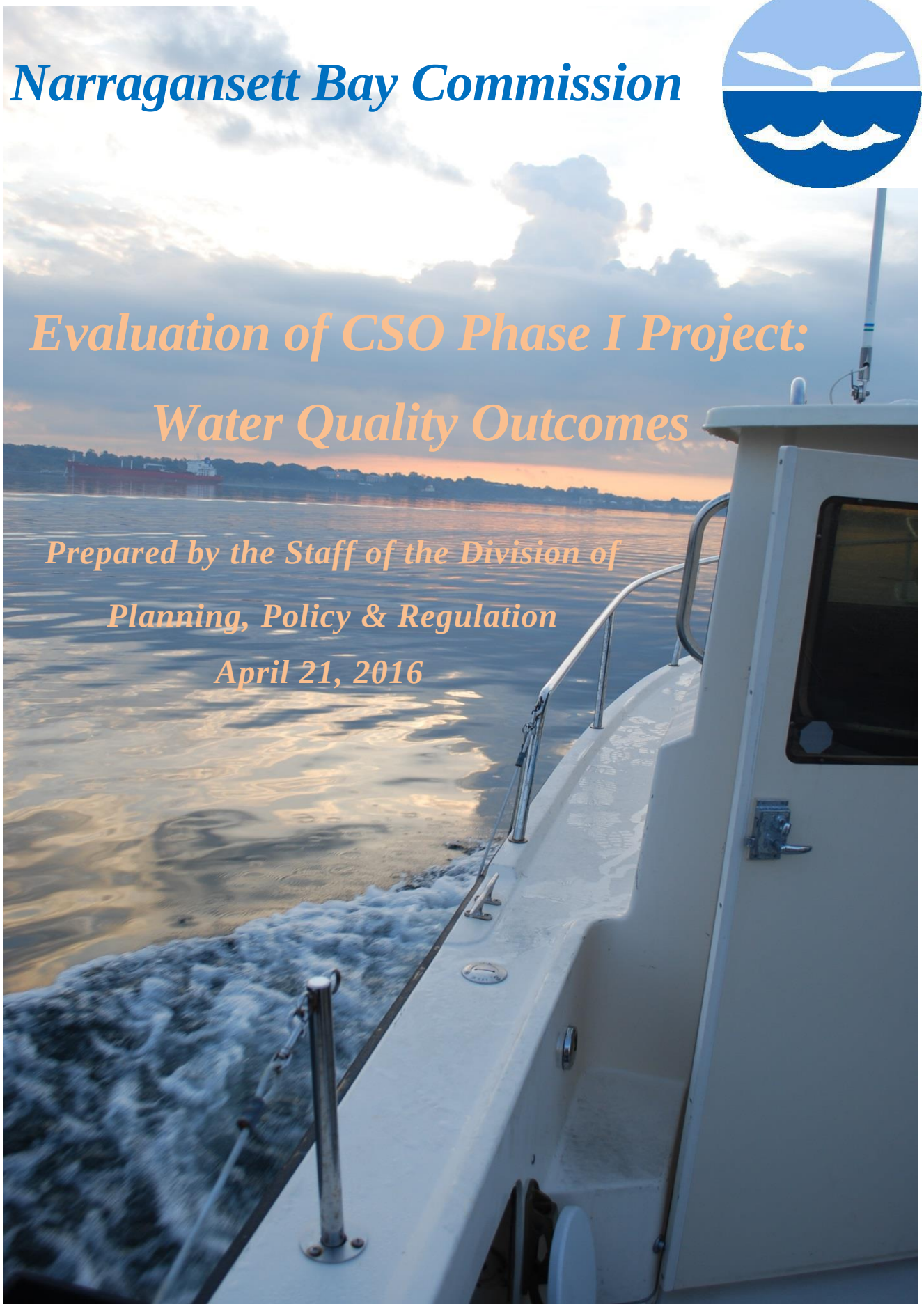
Narragansett Bay Commission



Evaluation of CSO Phase I Project: Water Quality Outcomes

Prepared by the Staff of the Division of

Planning, Policy & Regulation

April 21, 2016

Narragansett Bay Commission Mission Statement:

To maintain a leadership role in the protection and enhancement of water quality in Narragansett Bay and its tributaries by providing safe and reliable wastewater collection and treatment services to its customers at a reasonable cost.

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Executive Summary

The Narragansett Bay Commission (NBC) completed Phase I of the three phase Combined Sewer Overflow (CSO) Abatement Project in 2008, which reduced the discharge of untreated wastewater and stormwater from the NBC's CSOs by approximately 50%. In addition, Phase I included construction of a new wet weather treatment facility at the Bucklin Point wastewater treatment facility (WWTF) which was completed in 2006. Initial upgrades to remove nitrogen were also completed in 2006 at the Bucklin Point WWTF. The new wet weather facility at the Bucklin Point WWTF provides primary treatment and disinfection for up to 116 million gallons per day (MGD), which has reduced the amount of untreated flow discharged from the North Diversion Structure by 95%. In the Field's Point service area, Phase I provides storage for the CSO flows diverted to the CSO tunnel, which then receive secondary and tertiary treatment at the Field's Point facility once flows decrease. The storage capacity of the CSO tunnel has reduced the amount of flow receiving only primary treatment and disinfection at the Field's Point WWTF by 87%. Additional nitrogen treatment upgrades were completed at the Bucklin Point and Field's Point WWTFs to each meet a 5 mg/L total nitrogen effluent limit in the 2014 permit season. The purpose of this report is to assess the effect that these improvements have had on water quality and to determine if water quality standards are now being met based on sampling conducted by NBC's Environmental Monitoring and Data Analysis (EMDA) section.

Through the end of 2014, 6.15 billion gallons of sewage contaminated stormwater have been captured in the CSO tunnel over the first six years of operation, which equates to approximately 50% of the volume estimated to discharge from NBC's CSOs. Since the CSO tunnel has come online, the annual reduction in fecal coliform bacteria load is also estimated to be 50%. Based on sampling by the NBC to characterize pollutant concentrations in CSO discharges, capture of the CSO flows and treatment at the Field's Point facility is estimated to annually remove 431,853 lbs/yr of total suspended solids (TSS), 267,371 lbs/year of biochemical oxygen demand (BOD), 13,422 lbs/year of metals and 52,413 lbs/year of total nitrogen now that the Field's Point WWTF is upgraded with Biological Nutrient Removal (BNR). Despite this capture, stormwater sampling by the NBC as well as the stormwater data available in the Woonasquatucket and Blackstone River Total Maximum Daily Load reports (TMDLs), confirmed that stormwater contains fecal coliform bacteria and Enterococci in excess of Rhode Island Department of Environmental Management (RIDEM) water quality standards. Though the data are limited, these samples illustrate that stormwater pathogen pollution from non-CSO discharges alone could prevent attainment of water quality standards.

NBC conducted sampling for fecal coliform in the urban rivers that receive NBC's CSO discharges to determine if there was any improvement in river water quality as a result of the Phase I project. Fecal coliform levels decreased at most of the stations downstream of the CSOs, but the primary contact criteria were not met at any of the river stations, even upstream of all CSOs. The Moshassuck River had some of the highest fecal coliform levels followed by the

West River and the station at the confluence of the Providence, Moshassuck and Woonasquatucket Rivers. Fecal coliform concentrations at stations upstream of the CSOs increased during wet weather suggesting that stormwater discharges may preclude compliance with water quality standards even if CSOs were eliminated. NBC's efforts to eliminate dry weather overflows from CSOs have resulted in decreased fecal coliform levels in dry weather.

In the Providence River, the NBC sampled for both fecal coliform and Enterococci bacteria to evaluate water quality as a result of the Phase I project. Sample results show that fecal coliform concentrations in the Providence River have decreased by 41% since completion of Phase I. Most of the CSOs that were incorporated into the tunnel were in the area of the upper Providence River, which had a 52% decrease in fecal coliform bacteria levels. The data also suggest that Phase I is having a positive impact on fecal coliform levels in the lower Providence River, which had a 24% decrease in fecal coliform levels. The NBC's more limited sample results for Enterococci bacteria in the Providence River also show decreases at most stations after Phase I. Similar to the fecal coliform bacteria results, the monitoring station nearest the CSOs that were tied into the tunnel in the upper Providence River had the greatest decrease in Enterococci bacteria levels since the tunnel went online. Enterococci bacteria levels at the remaining stations have remained essentially the same before and after Phase I.

Although bacteria levels have decreased in the Providence River as a result of Phase I, primary contact criteria are still not consistently met. Most of the stations in the upper Providence River never met the fecal coliform primary contact criteria, though some have met the criteria in a limited number of years since the tunnel has gone online. In the lower Providence River, the fecal coliform primary contact criteria are met at most of the sampling locations in most years. The primary contact criteria for Enterococci bacteria, which are now used to replace fecal coliform analysis at designated beaches, were not met at the upper Providence River station closest to the CSOs tied into the tunnel in any year. In contrast, the stations further downstream met the criteria in all years. Since the standards were met in roughly equal numbers of years prior to Phase I and after Phase I, it does not appear that Phase I had much of an effect on meeting the Enterococci bacteria standards.

In the Seekonk River, the NBC sampled for fecal coliform bacteria to assess improvements in water quality as a result of the upgrades to the facility, as well as the Phase I project. Fecal coliform bacteria levels decreased after the wet weather facilities were constructed at the Bucklin Point WWTF in 2006. The level further decreased after the Phase I CSO tunnel went online in 2008 due to improvements in water quality in the upper Providence River, which affects the Seekonk River due to tidal influence. The Seekonk River did not meet fecal coliform primary contact criteria before or after Phase I.

Shellfishing is prohibited in the Providence River; however, the NBC evaluated Providence River bacteria levels against the shellfishing bacteria standards to measure potential improvements. Shellfishing bacteria standards were not met in most years at any of the NBC

monitoring stations in the Providence River. In 2013 and 2014, the three stations furthest south in the lower Providence River met the geometric mean criterion of the shellfishing standards. This indicates improvements in meeting water quality standards since Phase I, though the standards are not consistently being achieved. Some of the most productive and economically valuable shellfishing grounds are located south of the Providence River, in Conditional Shellfishing Areas A and B. Due to historic bacterial contamination, these shellfishing beds are conditionally closed, depending on rainfall amounts. As a result of Phase I of the CSO Program, the Rhode Island Department of Environmental Management (RIDEM) has changed the closure criteria for shellfishing for Conditional Areas A and B. The rainfall criterion for closure of Area A was changed from 0.5" to 0.8" of rainfall. For Area B, the criterion was changed from 1.0" to 1.5" of rainfall. Due to these changes, on average, Area A is expected to be open 65 more days/year and Area B is projected to be open 45 more days/year to shellfishing.

Another testament to the success of Phase I was realized through the Rhode Island Department of Health (RIDOH) data, which showed a decrease in beach closures events. When the saltwater beach closures from 2010 were compared to the summer of 2006, years of similar rainfall, a 44% decrease in closure events and an 82% decrease in closure days occurred at the three upper Bay beaches affected by the NBC's CSOs. The reductions in beach closure events can be attributed to the NBC's investments in Phase I. A RIDOH study, entitled the "Urban Beach Initiative", sampled three beaches, expanding to six in subsequent years, in the Providence River area for their potential use as licensed beaches. The Providence River beaches sampled as part of this initiative have a high compliance rate with pathogen standards, similar to what was found in beaches in areas not impacted by CSOs and suggests that these beaches are safe for recreational use; in fact, the city of East Providence is moving forward to open Sabin's Point as a licensed beach, which will be the first in the Providence River.

Lastly, the Biological Nutrient Removal improvements at each NBC facility have resulted in an 80% decrease in total nitrogen loading from the Bucklin Point WWTF and an 82% reduction at the Field's Point WWTF as of the date of publication of this report. The decrease in nitrogen loading has resulted in decreased nitrogen concentrations in the Seekonk and Providence Rivers. In 2014, the dissolved inorganic nitrogen (DIN) concentrations at all stations decreased to their lowest average seasonal concentration since monitoring began, with the exception of Conimicut Point, which remained the same. Also in 2014, DIN levels at Bullock's Reach were within the "good" category for the first time since 2007, based on the National Coastal Conditions Report classifications.

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Chapter I – Introduction

Narragansett Bay Commission Service Area

The Narragansett Bay Commission (NBC) is Rhode Island's largest wastewater authority, dedicated to providing reliable, cost-effective wastewater collection and treatment services to over 360,000 residents and 8,000 businesses in ten Rhode Island communities in the metropolitan Providence and Blackstone Valley areas. These communities include: Providence, North Providence, Johnston, Pawtucket, Central Falls, Cumberland, Lincoln, the northern portion of East Providence and small sections of Cranston and Smithfield (Figure 1).

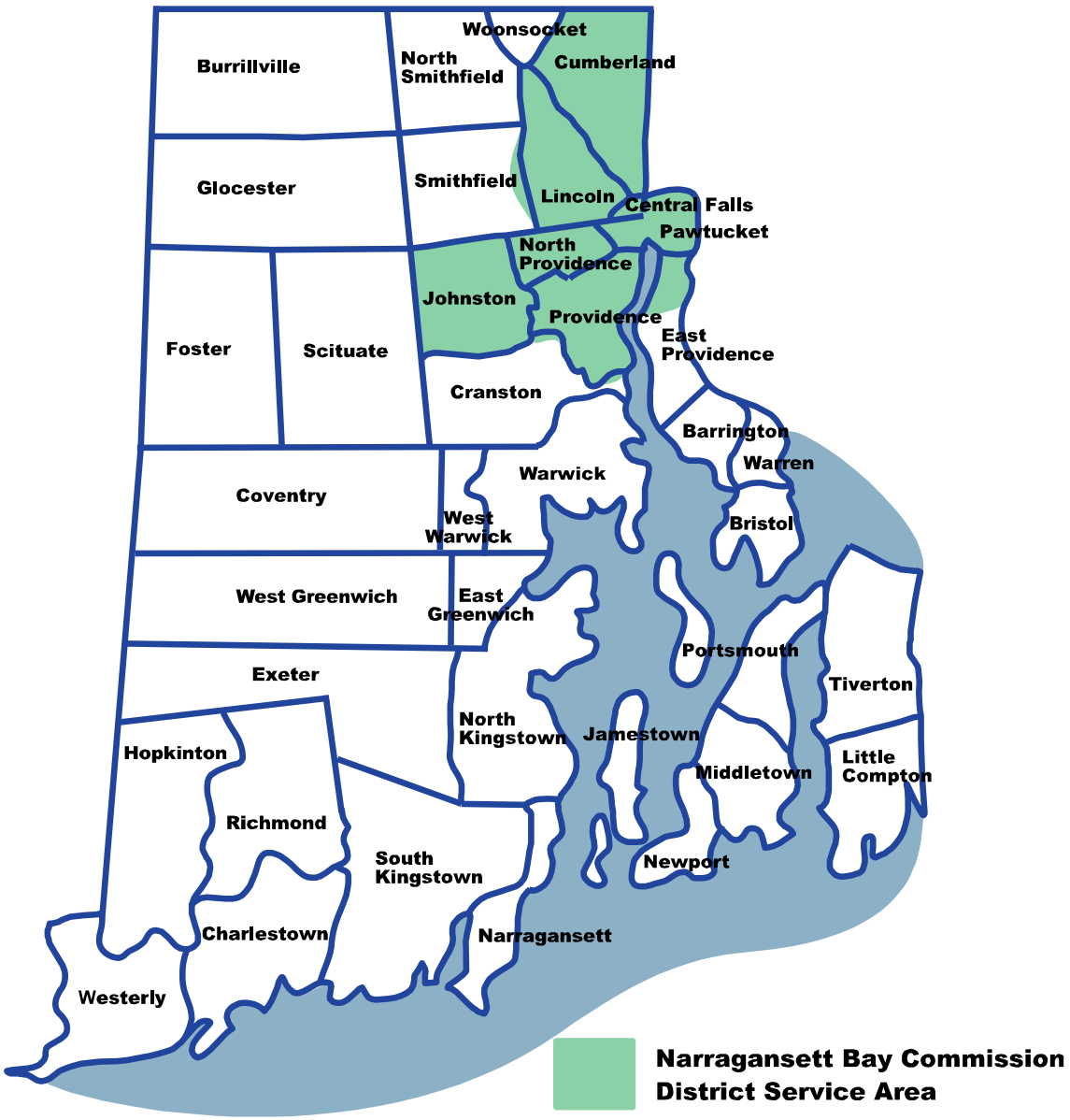

Figure 1. *Map of the state of Rhode Island with the NBC Service District shown in green.*

The NBC is a quasi-public agency, which owns and operates the two largest wastewater treatment facilities (WWTFs) in Rhode Island. The NBC is governed by a Board of Commissioners, which is composed of gubernatorial appointees, as well as representatives from the municipalities within the NBC's service district. The NBC was created in 1980 by the Rhode Island General Assembly to rehabilitate and manage the then failing Field's Point WWTF in Providence. At the time, this facility served the City of Providence and the Towns of Johnston and North Providence. By 1987, the NBC had completed a major upgrade to this facility, turning it from one of the worst polluting facilities in New England to one of the best in the nation. In 1992, the NBC assumed ownership of the Bucklin Point WWTF in East Providence. NBC owns 108 miles of sewer interceptor pipes, a three mile Combined Sewer Overflow (CSO) tunnel and six pumping stations. Lateral sewer lines are owned and maintained by the local cities and towns.

The NBC Collection System

The NBC collection system is one of the oldest in the nation. The sewage collection system dates back to the 1870's and was created in response to a cholera epidemic, which was spread through the unsanitary conditions that were present at the time. To help solve the problem, both wastewater and stormwater were directed to underground pipes where flows were discharged through 64 outfalls directly into the urban rivers and Narragansett Bay without treatment. In 1901, the sewage was directed to a centralized location at the Field's Point facility for treatment. Over time, the collection system expanded and grew within Providence and into the surrounding cities. As wastewater technologies improved, pathogens and contaminants present in the wastewater and stormwater that reached the plant were treated to better protect human health, as well as improve water quality in the region. Unfortunately, under certain conditions, not all wastewater and stormwater reached the plant for treatment at that time and still doesn't today.

Collection systems as described above are known as "combined sewer systems", referring to the sanitary pipes that collect wastewater from residential, commercial and industrial properties, as well as receive stormwater. In undeveloped areas, most rainfall is able to absorb into the ground, recharging natural sources of groundwater. In cities, much of the landscape is manmade and impervious to water. Such impervious area includes parking lots, sidewalks, and roof tops, where water collects before it travels down streets to storm drains or, in the case of combined sewers, combined sewer pipes. The NBC service district includes combined sewer systems in Providence, Pawtucket and Central Falls, collecting both sanitary flow and stormwater in the same pipes; the sewers in the rest of the district have separate sewers for sanitary flow and stormwater.

Figure 2 illustrates how a combined sewer system operates. During dry weather and small rain events, the combined sewer system functions efficiently, capturing wastewater and stormwater from various sources, and directing it to the WWTF where it is treated prior to being discharged to receiving waters. During larger or more intense storms, the interceptors do not have sufficient

capacity to convey all the flow to the WWTFs. The excess flows are discharged untreated to receiving waters through CSOs. During storm events, the NBC combined system is inundated with stormwater, increasing the average flow at the NBC treatment facilities by as much as 400%. If this excess flow was not discharged through CSOs, it could cause the flooding of homes, businesses and roads. Combined systems are plentiful in the older cities and communities throughout the country, such as the Northeast and the Great Lakes regions, as well as in the Pacific Northwest.

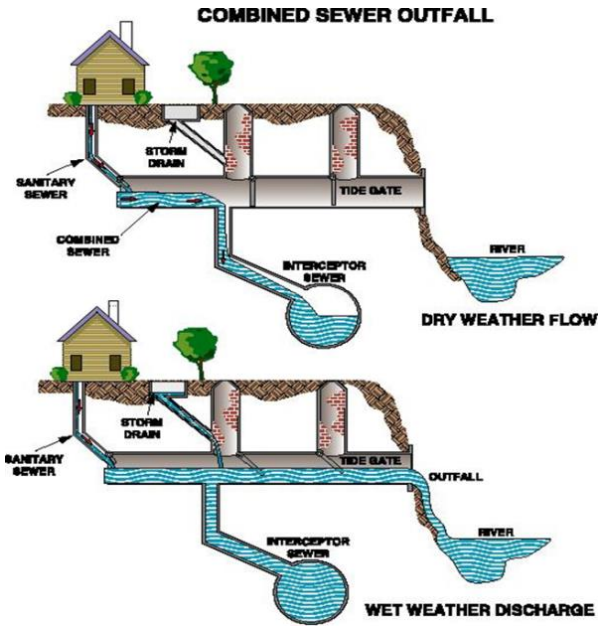

Figure 2. *A combined sewer system functioning in both dry and wet weather. Note the wet weather discharge to the river.*

NBC Combined Sewer Overflow Abatement Program Overview

The receiving waters of the NBC's two WWTFs include the Seekonk and Providence Rivers, which make up the headwaters for Narragansett Bay. Permitted CSO discharges managed by the NBC also flow into the Seekonk and Providence Rivers as well as the Woonasquatucket, West, Blackstone, and Moshassuck Rivers, each of which also feed the headwaters of the Bay (Figure 3). Narragansett Bay is a highly productive tidal estuary, whose watershed covers almost 2,000 square miles including regions in both Rhode Island and Massachusetts. The majority of the freshwater flow enters from the northern end of the estuary, with the largest riverine inputs including the Pawtuxet, Blackstone and Taunton Rivers.

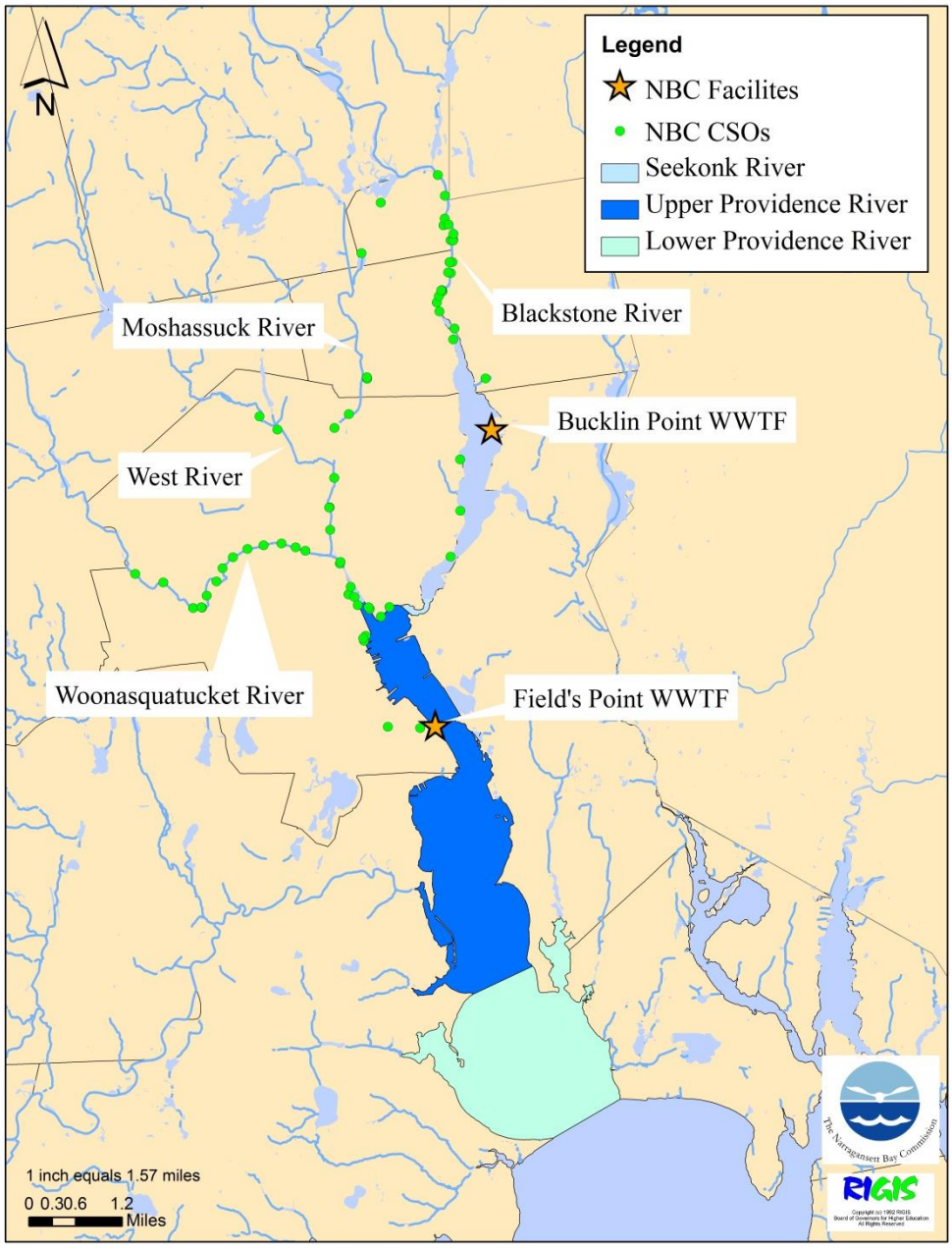

Figure 3. *Map of the NBC's receiving waters, treatment facilities and CSOs.*

While combined sewer systems under dry conditions are an effective means of transporting contaminated stormwater for treatment at the WWTFs, in wet weather such systems can be highly detrimental to the health of the receiving water environment. Sections of the Upper Bay and the Providence and Seekonk Rivers are classified as not meeting water quality standards for pathogens, nutrients and dissolved oxygen, in part due to discharges from CSOs. The Federal Clean Water Act of 1972 required communities with CSOs to develop a program to reduce or eliminate CSO discharges. The Rhode Island Department of Environmental Management

(RIDEM) is the delegated authority responsible for ensuring that the requirements of the Clean Water Act are met in Rhode Island.

To determine the impact of CSO discharges from the NBC system on Narragansett Bay, the NBC conducted two modeling investigations. The first involved hydraulic modeling of the NBC sewer system. This model estimated that 2.2 billion gallons of combined sewage flow was discharged out of the NBC's CSOs during a three-month storm event. A three-month storm is defined as a storm of a particular magnitude that happens on average once every three months. For this region, the three-month storm is classified as a rain event in which 1.65 inches of rain falls over a 6 hour period. The 2.2 billion gallon volume was then input into a hydrodynamic model of Narragansett Bay to determine the water quality impacts of this discharge. With this foundation the NBC was able to start determining the best way to address their CSOs.

After several years of study, the NBC approved its first CSO plan in 1993, with an estimated project cost of $467 million, in 1992 dollars. This plan was then approved by the RIDEM in 1994. However, also in 1994, the United States Environmental Protection Agency (USEPA) amended its federal CSO policy to allow for cost-effective CSO controls for municipalities. This led the NBC to reassess its proposed program to determine if a less expensive program could be developed and still meet regulatory requirements. In 1996, the NBC initiated a series of workshops to familiarize key stakeholders with the proposed CSO abatement plan and regulatory requirements and to determine if a reassessment was warranted. More than 40 stakeholders took part in this process, representing business, environmental and governmental interests. During these stakeholder meetings, 16 alternatives were presented for consideration. After much deliberation, the stakeholders selected an additional CSO abatement plan, alternative number 17, which consisted of five miles of underground storage tunnels, one sedimentation/disinfection treatment facility at the Bucklin Point WWTF, one wetland treatment system and sewer separation of 12 areas (Figure 4). This alternative, outlined in the 1998 Conceptual Design Report Amendment, would complete the project in three phases over 20 years and became the NBC's plan for the Combined Sewer Overflow Abatement Project. Also, as part of this plan and in response to issues of concern to the stakeholders, the NBC also agreed to continue with its water quality monitoring program for bacteria in the tributary rivers, conduct a stormwater attenuation study to explore potential ways of preventing stormwater from entering the combined sewer system and thereby reducing overflow volume, continuously assess developing technology for cost effective CSO control methods, and participate as a stakeholder in a watershed management program managed by others.

In 2000, the NBC submitted its final design plans for the Phase I main spine tunnel and tunnel pumping station to RIDEM and final approval was granted in April 2001. In June 2001, the NBC broke ground on the first of 10 construction contracts in Phase I. Due to its underground construction, it was known as "The Biggest Project You'll Never See". Phase I involved the construction of the CSO tunnel, a 26 foot diameter, 3-mile long tunnel, built under the City of Providence to capture untreated wastewater and stormwater flow from 12 CSOs

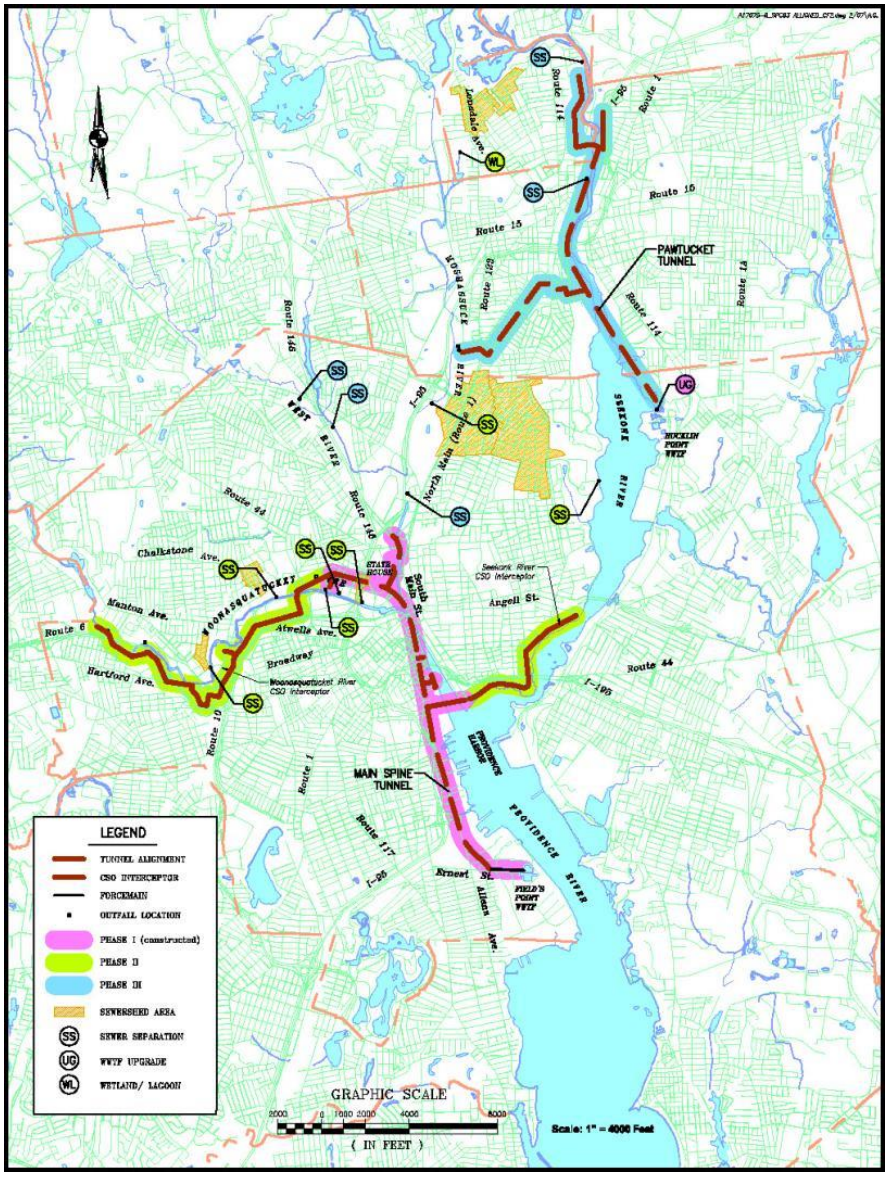

Figure 4. *Map showing Phase I construction in pink, Phase II construction plans in green and proposed Phase III in blue (map prepared by Louis Berger Group, Inc.).*

along the Providence River in the Field's Point service area. To create the tunnel, a 690-ton hard rock tunnel boring machine (TBM) was utilized (Figure 5). The cutter head on the TBM was 30 feet in diameter, with 17 inch cutters. The TBM cut approximately 40 to 45 feet per day of the mainspine of the tunnel, running from 6:30 am to 6:00 pm five days a week and ultimately removing approximately 400,000 tons of dirt from the tunnel. As the tunnel was bored through the rock, 16,000 10-inch thick segments of precast concrete were put in place to provide initial support for the mining operation (Figure 5). After the mining was completed, the entire tunnel was lined with a cast-in-place concrete final liner that measured 12-inches thick. To connect the tunnel to the current system, seven drop shafts were bored into the ground at various locations along the three mile span of the tunnel. The rate of completion for these shafts was to bore

approximately one foot per hour. At tunnel level, approximately 4,000 feet of connecting tunnels, called adits, were constructed through the use of drilling and blasting. All of the adits and deaeration chambers were lined with concrete (Figure 5). Near the ground surface, consolidation conduits connected the existing CSO pipes to the drop shafts. These conduits were constructed using direct burial, micro-tunneling and pipe-jacking methods. At the downstream end of the tunnel, a large underground cavern was mined by blasting methods. The cavern houses a pumping facility to send the stored tunnel flow to the Field's Point WWTF.

Figure 5. *The cutterhead on the tunnel boring machine used to dig Phase I of NBC's CSO tunnel (left) and the nearly completed adit (on left) inside the CSO tunnel (right).*

The CSO tunnel, designed to accommodate flows up to a three-month storm intensity, was officially opened in November 2008 to receive flows from CSOs during storms. With the completion of Phase I, this excess tunnel now stores up to 65 million gallons of combined sewage for eventual treatment at the Field's Point WWTF (Figure 6).

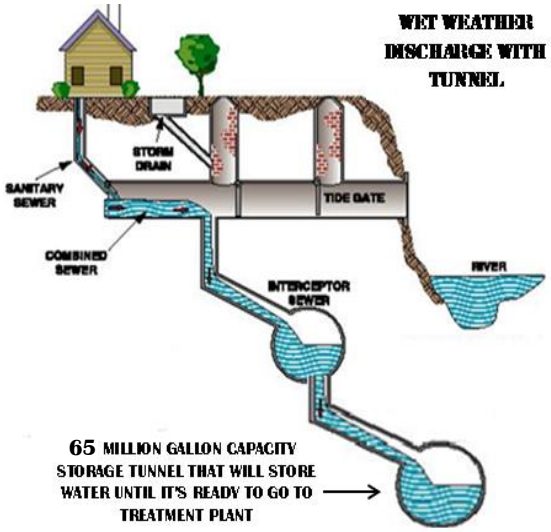

Figure 6. *Combined system with the 65 million gallon CSO tunnel, which captures & stores stormwater until it can be treated at the WWTF.*

As flows decrease at the Field's Point facility after the storm event, the volume of wastewater and stormwater stored in the CSO tunnel is pumped to the facility and receives advanced secondary treatment. Since Phase I was put into operation, the CSO tunnel has captured over 6.15 billion gallons (as of December 2014) of untreated wastewater and stormwater that would have otherwise been discharged through CSOs directly into local rivers and the Bay. Every time precipitation falls in the NBC district, the total volume of untreated wastewater and stormwater the CSO tunnel captures increases. To keep track of the volume of stormwater collected, the NBC has provided a running tally for the public on the NBC website (www.narrabay.com; Figure 7). Visit this site for the most current total.

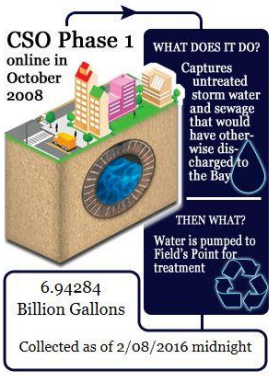

Figure 7. *The running tally of the volume the CSO tunnel has captured on the NBC's website.*

Phase I of the CSO Abatement Project was, at the time of construction, the largest public works project in Rhode Island's history. The work for each of the different sections of the project was established to promote bidding from local construction firms. It was completed on time and under budget and was a major success for the small state of Rhode Island. The construction of the CSO tunnel has earned the NBC various awards, including "Project of the Year" by the Underground Construction Association in 2009 and a "National Engineering Excellence Award" from the American Council of Engineering Companies in 2010. Phase I of the CSO Abatement Project was also recognized for its environmental impact by the Water Environment Federation in 2014 with their "Water Quality Improvement Award". An excellent video overview of the construction project entitled "The Biggest Project You'll Never See" is available on the NBC website at the following location: http://www.narrabay.com/sitecore/content/Narrabay/Education/Videos/2008/April/the_biggest_project_youll_never_see.aspx.

With Phase I of the CSO Abatement Program complete, construction on Phase II began in the summer of 2011. Phase II of the program redirected 14 more CSOs in the Field's Point service district into the CSO tunnel via the construction of two new near surface interceptors located along the Woonasquatucket River and the lower Seekonk River (Figure 4). Also included in

Phase II was the separation of stormwater and sanitary sewer lines from two CSOs and the construction of a wetlands treatment facility at Higginson Park in Central Falls. This wetlands facility treats the CSO discharge through natural processes. Phase II was completed in 2015 at an estimated cost of $213 million. Just prior to completion of Phase II, another major project at both NBC WWTFs was completed as Biological Nutrient Removal (BNR) upgrades went online at both facilities to meet new nitrogen permit limits in 2014.

When Phase II was nearing completion, the NBC began a reevaluation of Phase III of the CSO Abatement Program. The 1998 Conceptual Design Report Amendment planned for another large scale project to design and build a second deep rock tunnel to direct CSO flow to the Bucklin Point facility in East Providence (Figure 4). In addition, two interceptors were planned with five sewer separation projects. This phase of the CSO Abatement Program was estimated to cost approximately $603 million and was scheduled to be completed in 2020. The 2014 stakeholder process evaluated this plan to determine if water quality standards were being met after Phase II, evaluate alternative technologies, and verify if the plan was affordable. It was determined that water quality standards were still not going to be met after Phase II and that other available technologies were not able to address the CSO flow suitably. The deep rock tunnel approach was still considered the best option; however, it posed a financial burden to the NBC ratepayers. To attempt to alleviate this financial burden, the NBC Commissioners voted to lengthen the original schedule, extending the plan to be completed in 2038. The NBC submitted a report on this new plan to address the CSOs in the Bucklin Point district to RIDEM in June 2015. If this plan is approved, the NBC will move forward with Phase III. The NBC CSO Abatement Program was initiated to minimize CSO discharges throughout the NBC service area. By reducing CSO discharges into the local urban rivers and the Bay, the NBC is improving water quality and protecting human health.

NBC CSO Abatement Program Goals

The overall goals of Phase I of the CSO Abatement Program were to reduce:

- the annual CSO discharge volume by 39%;
- the fecal coliform loads by 40%;
- the total suspended solids (TSS) load by 30%;
- the biochemical oxygen demand (BOD) load by 31%;
- the floatables by approximately 40%; and
- the acre-days of shellfish closure in the northern half of upper Narragansett Bay by 47% 77% in the southern half of upper Narragansett Bay.

The combined benefits of Phases I, II & III, when completed, are predicted to result in:

- a 95% reduction in number of overflows/year (with overflows only 4 times/year);
- an overflow volume reduced by 98%;
- a 98% reduction in CSO fecal coliform load;

- the CSO TSS and BOD loads reduced by 78% and 80%, respectively; and
- acre-days of shellfish closure would be reduced by 65% in the northern half of Upper Narragansett Bay and 95% in the southern half of Upper Narragansett Bay.

Field's Point Wastewater Treatment Facility Upgrades

The Field's Point WWTF can currently provide advanced secondary treatment for flows up to 77 million gallons per day (MGD) and solids settling and full disinfection for flows up to 200 MGD through its wet weather facilities (Figure 8). When the CSO tunnel began operation in 2008, flows in excess of 77 MGD that would have gone to the wet weather treatment facilities were able to be stored in the tunnel and given secondary treatment after the storm. The ability for the tunnel to store 65 MG of increased wet weather flow has resulted in a significant reduction in the use the wet weather treatment system.

Figure 8. *Aerial photograph of the Field's Point WWTF in Providence, RI*

An upgrade to the Field's Point WWTF to provide BNR technology was completed in 2013. This upgrade allowed the NBC to meet the new Rhode Island Pollutant Discharge Elimination System (RIPDES) May to October seasonal total nitrogen (TN) limit of 5 mg/L, which went into effect in May 2014.

Bucklin Point Wastewater Treatment Facility Upgrades

The Bucklin Point WWTF is currently designed to provide advanced secondary treatment for flows up to 46 MGD and wet weather treatment for up to 116 MGD (Figure 9). Prior to an upgrade in 2006, the facility had a maximum capacity of 60 MGD and flows in excess of 60 MGD were diverted to the Seekonk River, without treatment, through the North Diversion Structure (NDS). As part of the upgrade, new primary clarifiers were built and the existing primary clarifiers were converted to wet weather treatment facilities. With these improvements,

the increased capacity of the Bucklin Point WWTF to treat up to 116 MGD has resulted in a substantial reduction of untreated flows from the NDS.

Upgrades to reduce nitrogen loadings were also completed in 2006, but RIDEM subsequently issued a revised RIPDES permit, which required further reductions to achieve 5 mg/L TN in the effluent during the May to October season. Construction began in 2012 on additional modifications to the nitrogen removal process and was completed in 2014 to meet the new TN limit, which became effective in July 2014.

Figure 9. *Aerial photograph of the Bucklin Point WWTF in East Providence, RI*

Report Overview

To document the effect that the NBC's operations have on water quality, the NBC has a comprehensive and well established receiving waters monitoring program. This program, executed by the Environmental Monitoring and Data Analysis (EMDA) section of NBC, started in 2001 and has continued to develop with each successive year. The NBC monitoring program includes sampling local urban freshwater rivers and the estuarine Providence and Seekonk Rivers for a suite of nutrient parameters, bacteria, water clarity, as well as mapping of surface water quality, performing water column profiles, documenting the plankton community and completing underwater benthic video transects. The NBC also maintains two water quality monitoring stations, which provide near real-time water quality data at two locations in the Bay. The depth and span of the data collected through this program provides an excellent characterization of the past and present water quality status, so that advancements in treatment can be evaluated. The NBC provides all water quality monitoring data to the public on its website "Snapshot of Upper Narragansett Bay", found at http://snapshot.narrabay.com/app/. The goal of this report is to evaluate the suite of data generated from the NBC monitoring programs to determine if water quality improvements in bacterial contamination have occurred as a result of the completion of the Phase I of NBC's CSO Abatement Program.

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Chapter II – Change in Wet Weather Discharges from NBC Treatment Facilities

Methods

During wet weather, flow in excess of the secondary treatment capacity of the Field's Point and Bucklin Point WWTFs is directed to the wet weather treatment facilities for primary treatment and disinfection. Influent, final effluent, wet weather influent and effluent, as well as the North Diversion Structure (NDS) are continuously monitored, as required by the NBC's RIPDES permit. A wet weather event is initiated when flow is actually discharged from the wet weather facility; if the wet weather flow does not exceed the capacity of the wet weather tanks, the volume will ultimately be pumped back for secondary treatment and no wet weather event is considered to have occurred. Wet weather events are considered separate as long as 6 hours or more elapsed between when flow from the wet weather facility ends and begins again. These classifications were used to analyze the wet weather data for the NBC's facilities.

Results

Field's Point Wastewater Treatment Facility

In the Field's Point service district, excess flow that would have been diverted to wet weather treatment is now directed to the CSO tunnel for storage of up to 65 million gallons (MG). Figure 10 shows the number of wet weather discharge events per year at Field's Point pre-Phase I (2004 – October 2008) and post-Phase I (November 2008 – 2014), as well as the annual rainfall totals. Figure 11 shows the volume of wet weather flow treated in the wet weather facilities prior to the tunnel coming online (2004 – October 2008) and after the tunnel came online (November 2008 – 2014). In the nearly five years before the tunnel went online, there was an average 42 wet weather events per year, treating an average of 681 MG per year. After the tunnel came online, from November 2008 through the end of 2014, there was an average of 8 wet weather events per year and an average of 180 MG treated per year. These post-Phase I averages equate to an 80% decrease in events and 74% decrease in treated volume compared to pre-Phase I.

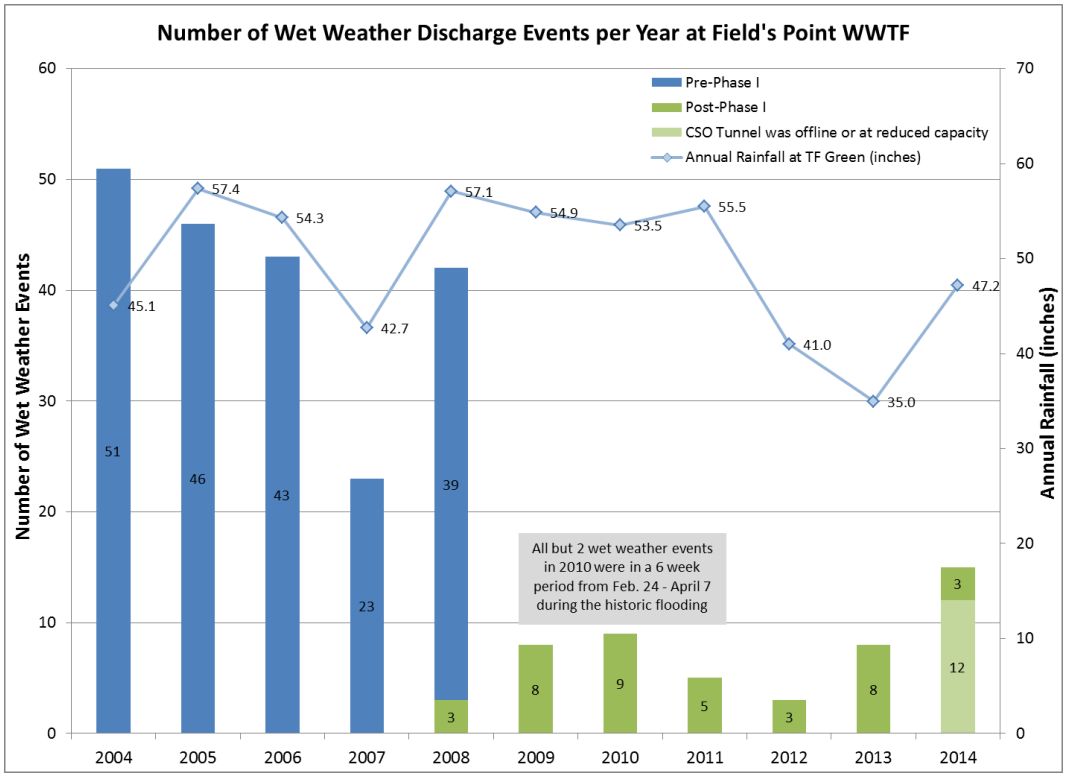

Figure 10. *Comparison of wet weather events at Field's Point WWTF. From March to July of 2014, the CSO tunnel was at reduced capacity as interceptors were being constructed for Phase II.*

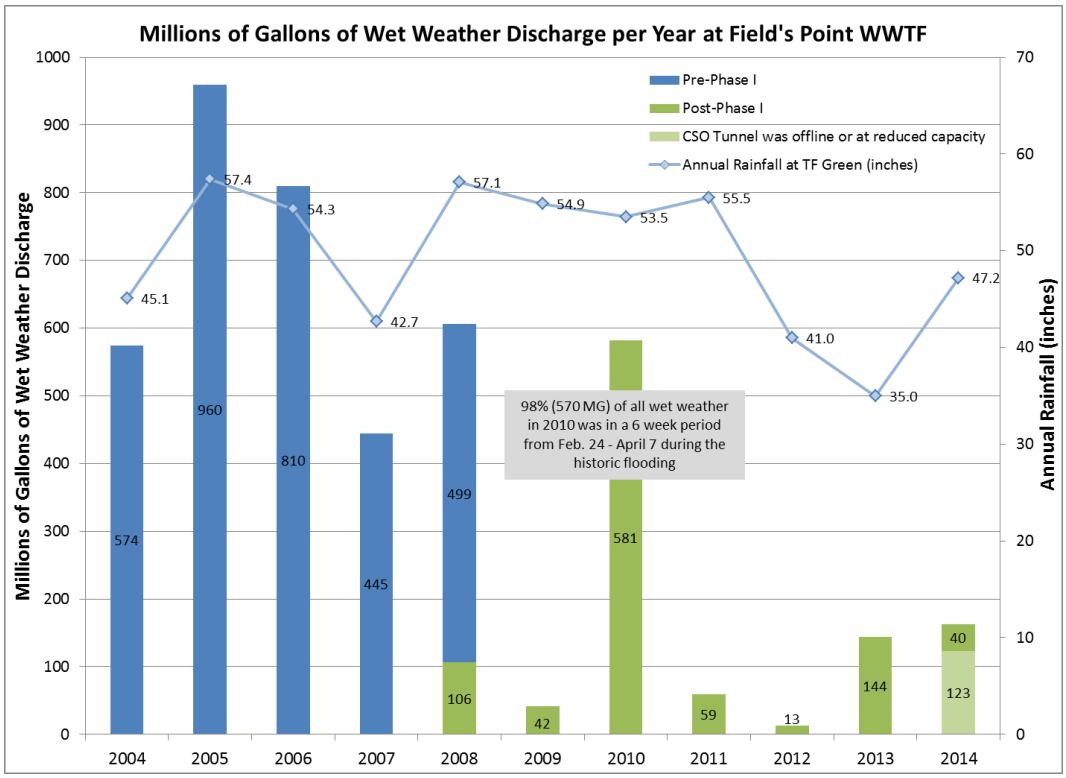

Figure 11. *Comparison of the annual wet weather flows at Field's Point WWTF. From March to July of 2014, the CSO tunnel was at reduced capacity as interceptors were being constructed for Phase II.*

During the post-Phase I years, two unusual events occurred affecting the number of events and volume treated by the wet weather facilities. First, an unprecedented amount of rainfall fell over the region starting in late February through early April 2010, equating to a 100-year storm event. Second, from March through July 2014, the CSO tunnel was offline or at reduced capacity due to the construction of the new interceptors for Phase II. Excluding these time periods, the wet weather events and the flow that occurred during these unusual events, the post-Phase I average was 6 wet weather events per year and an average of 73 MG captured and treated in the wet weather facilities. Based on this exclusion, in a typical year, there has been an 88% reduction in wet weather events and a 90% reduction in wet weather volume.

Bucklin Point Wastewater Treatment Facility

Prior to 2006, the maximum capacity at the Bucklin Point WWTF was 60 MGD, allowing for only 14 MGD of wet weather flow to be treated at the facility. When flow rates exceeded 60 MGD, flow was diverted through the NDS and discharged to the Seekonk River without treatment. After plant upgrades, the expanded capacity of the new wet weather treatment facility of 70 MGD allowed for a maximum plant capacity of 116 MGD.

From 2000 through 2005, there was an average of 49 NDS events per year (Figure 12), discharging an average annual volume of 316 MG (Figure 13). Since the new wet weather facilities went online in 2006 through 2014, the number of discharge events from the NDS was reduced by 83% to an annual average of 8 events per year (Figure 12). Similarly, the flow from the NDS after the wet weather upgrade was reduced to an annual average of 16 MG per year (Figure 13), an impressive 95% decrease in volume.

Prior to the wet weather facility upgrade at Bucklin Point, there was an average of 52 wet weather events per year. During this time period, the 14 MGD wet weather facility treated an average of 142 MG per year. After the upgrade was complete, the annual average number of events decreased by 28% to 37 per year. Flow treated by the wet weather facilities showed the opposite trend due to the capacity expanding from 14 MGD to 70 MGD. After the upgrades were complete (2006 – 2014), an average volume of 292 MG per year was treated at the Bucklin Point wet weather facility. The expanded capacity of the wet weather facilities allowed for a 106% increase in flow receiving primary treatment and disinfection, as well as increased capacity to store wet weather flows for later pump-back and secondary treatment.

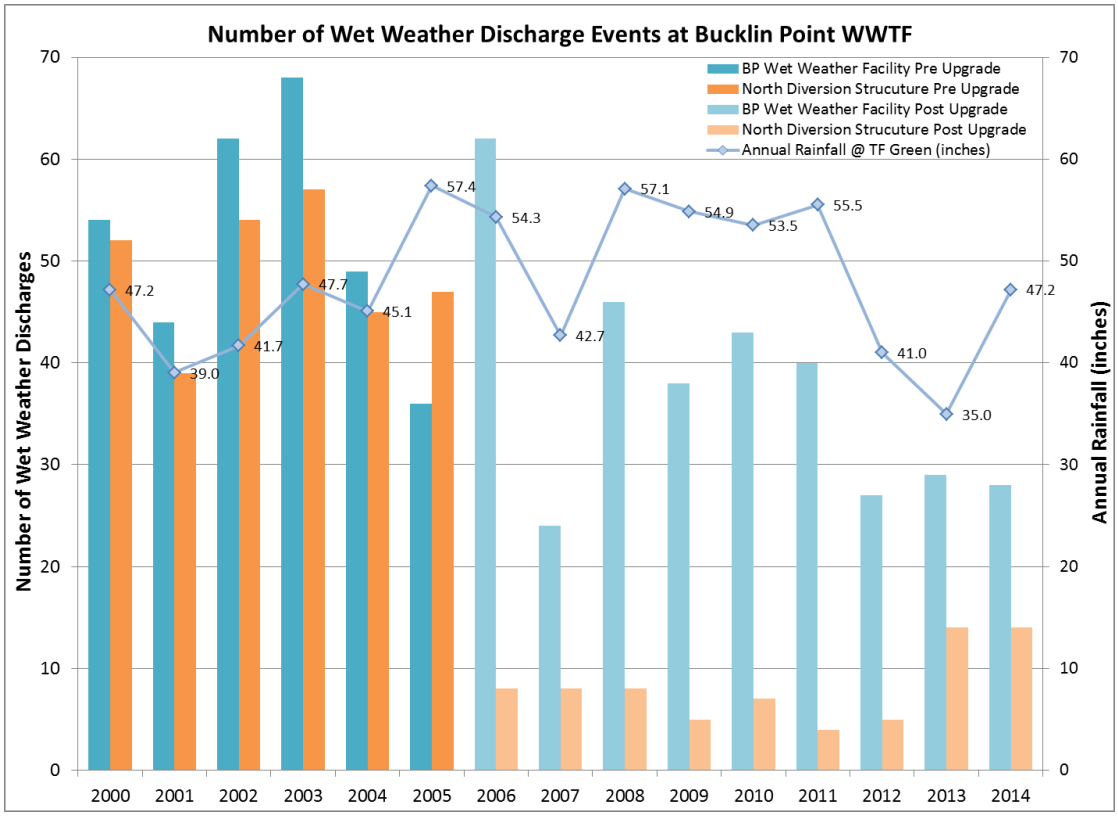

Figure 12. *Comparison of wet weather events at Bucklin Point WWTF.*

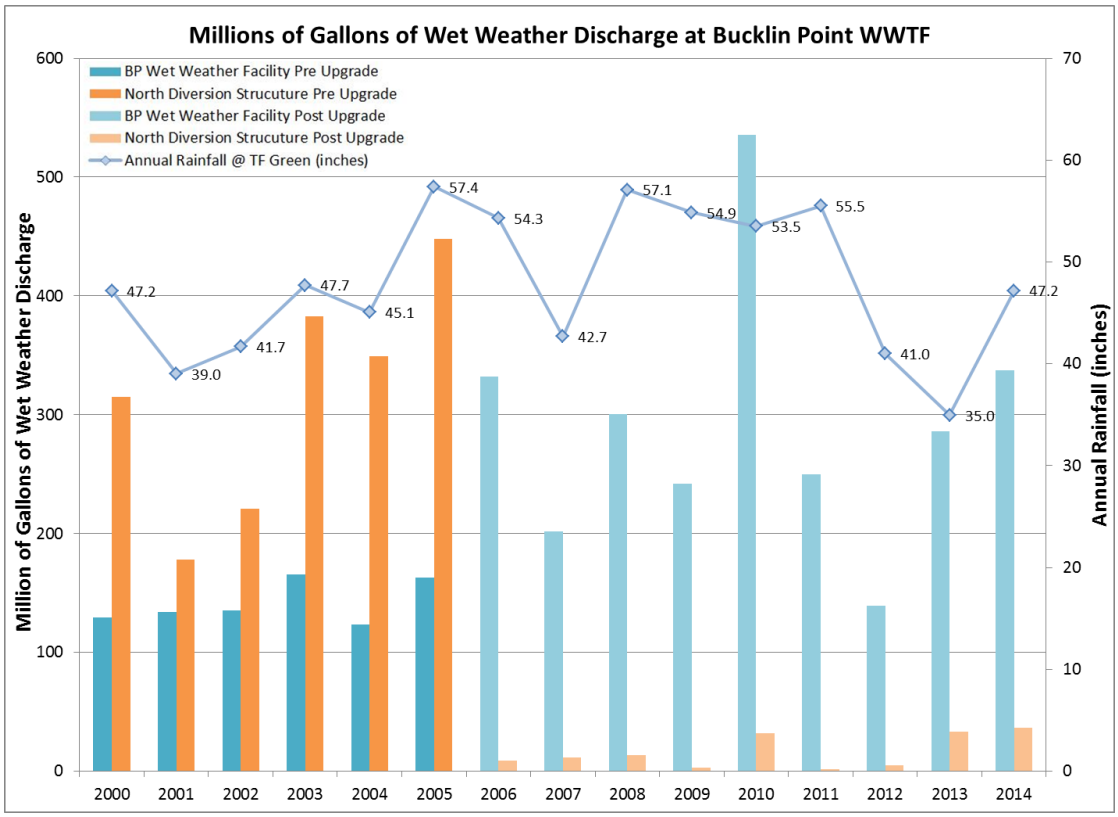

Figure 13. *Comparison of the annual wet weather flows at Bucklin Point WWTF.*

Results Summary

If the large storm event of March 2010 and the period of decreased capacity of the tunnel in 2014 are excluded, the Phase I tunnel at Field's Point decreased the number of wet weather events by 87% and the wet weather volume receiving only primary treatment and disinfection was reduced by 89%.

The new wet weather treatment facility at Bucklin Point increased the plant's maximum capacity from 60 MG to 116 MG through expanding the wet weather facilities from 14 to 70 MG. This increase allowed for a 106% increase in flow receiving primary treatment and disinfection. The expanded capacity of the wet weather treatment facility also reduced the amount of flow discharged untreated through the NDS by 95%.

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Chapter III – Combined Sewer Overflow and Stormwater Sampling

Combined Sewer Overflow Sampling

Monitoring & Analytical Methods

In implementing NBC's policy to protect the Narragansett Bay and its tributary rivers, as well as fulfilling the requirements of the USEPA and RIDEM Nine Minimum Controls Program, the NBC staff sample CSO wet weather overflows during a rain event each year. The aim of these wet weather sampling events is to characterize the impact of CSO discharges and the efficacy of NBC's current controls. The CSOs located in the Field's Point and Bucklin Point districts, as well as CSO sites downstream of industrial areas, are targeted for sample collection to measure contaminant levels during CSO wet weather overflow events. The NBC collected a total of 75 wet weather sample sets from nine CSO locations within the NBC service area from 2004 through 2014. These locations are shown on the map in Figure 14 and one of the samples outfalls is pictured in Figure 15. Rainfall amounts during sampling events ranged from 0.16 to 4.11 inches.

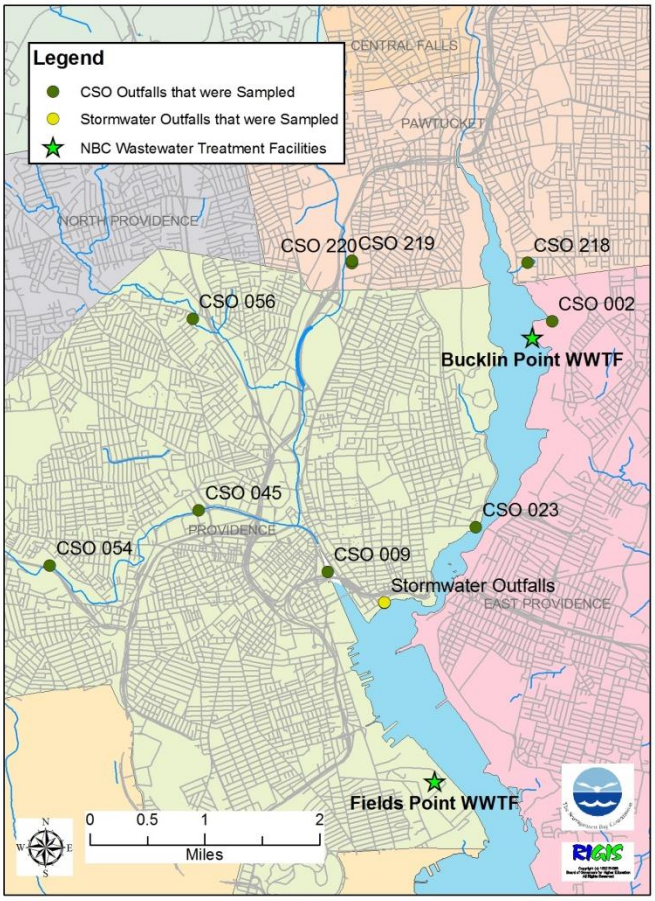

Figure 14. *Sample locations of CSO and stormwater outfalls.*

The sampling plan included collecting three sets of samples at each outfall during each sampled overflow event. The first set was collected at the beginning of the event. This "first flush" is expected to contain the highest concentrations of materials washed from street and land surfaces into the combined sewer system. The goal was to collect this sample within thirty minutes of the beginning of the discharge event. It should be noted that the "first flush" from a CSO discharge is not the same as the "first flush" term utilized to discuss stormwater, a term which is standardized within the Rhode Island State Stormwater Manual. A second set of CSO samples was collected during the middle of the storm event when flows were expected to be at "steady state conditions." A third set was collected near the end of the event. Occasionally, due to event timing and unpredictability, field crews were unable to collect the complete suite of three samples. The collected samples were analyzed by the NBC laboratory for 20 parameters that are commonly found in CSO discharges, including fecal coliform, TSS, BOD, oil and grease, volatile organic compounds (VOCs), nutrients (ammonia, nitrate+nitrite, total Kjeldahl nitrogen, total phosphorus, total nitrogen), metals (aluminum, cadmium, chromium, copper, iron, lead, mercury, nickel, silver, zinc) and cyanide. All sample collection and laboratory analysis was done in accordance with standard methodology used throughout the NBC monitoring program (NBC 2015). The parameters analyzed varied somewhat with each event monitored, but the majority of the events were analyzed for the parameters listed. The parameter detection limits also varied with the events being sampled, but became more standardized in recent years. For data analysis, any parameter result less than the detection limit was treated as zero for all statistical data calculations. If the result was qualified as greater than an upper detection limit, the upper detection limit value was used in data calculations. One sampling event was excluded from the dataset, as it was suspected to be contaminated with sea water since the sample was collected at high tide.

Figure 15. *NBC CSO-054 that was sampled as part of the CSO monitoring program.*

Results

The primary pollutant of concern in CSO discharges is bacteria. Twelve rain events and eight CSO locations were sampled for fecal coliform (no bacteria samples were collected at CSO-009); Table 1 provides a summary of the results of these analyses. The results ranged between 24,000 and 3,000,000 MPN/100 mL, with many samples having a result greater than the detection limit, which was usually >240,000 MPN/100 mL. Table 2 shows the geometric mean of all samples, first flush, mid-storm and end of storm. The geometric mean for all samples was >200,690 MPN/100 mL, with decreasing concentrations as events progressed.

Table 1. *CSO fecal coliform sampling results.*

Combined Sewer Overflow	Date	11/22/2005	1/30/2008	2/6/2008	12/3/2009	10/1/2010	10/27/2011	4/12/2013	6/7/2013	11/13/2013	5/1/2014	8/13/2014	11/17/2014
	Rainfall (inches)	2.24	0.16	0.30	1.71	0.39	0.90	0.54	4.11	0.05	1.28	2.26	1.50
CSO-002 (North Diversion Structure)	1st Flush				>240,000								
	Mid-storm				>240,000				>160,000		>240,000		
	Storm End				>240,000						>240,000		
CSO-023 (Pitman St.)	1st Flush			230,000									
	Mid-storm			230,000									
	Storm End			230,000									
CSO-045 (Rathbone St.)	1st Flush				90,000								
	Mid-storm				90,000								
	Storm End				30,000								
CSO-054 (Sheridan St.)	1st Flush	2,100,000						160,000					
	Mid-storm	430,000											
	Storm End	220,000											
CSO-218 (Bucklin Brook)	1st Flush	150,000			160,000		>240,000						
	Mid-storm	930,000			160,000		>240,000			>240,000*			
	Storm End	230,000			>240,000		240,000						
CSO-219 (Esten St.)	1st Flush			230,000		>240,000							
	Mid-storm			230,000		>240,000							
	Storm End			230,000		>240,000							
CSO-220 (Moshassuck St.)	1st Flush		3,000,000										240,000
	Mid-storm		500,000										>240,000
	Storm End		350,000										>240,000
CSO-056 (Vandewater St.)	1st Flush											>240,000	
	Mid-storm											24,000	
	Storm End											46,000	

* Only one sample was collected during this event. It was unknown at what point during the event this sample was collected.

Table 2. *CSO fecal coliform geometric means.*

CSO Fecal Coliform Data 2004 - 2014	Geometric Mean (MPN/100 mL)
All Samples	>200,690
1st Flush	>287,507
Mid-storm	>182,814
Storm End	>152,779

In addition to bacteria, Table 3 shows the results of the analyses for additional parameters measured and also shows the range of concentrations of various pollutants in CSO discharges as reported in the 2004 USEPA "Report to Congress: Impacts and Control of CSOs and SSOs." These reference values provide a point of comparison to the concentrations of pollutants found in the NBC CSO discharges.

The NBC CSO data for bacteria are comparable to the USEPA data, falling within the range of reference values provided. The NBC CSO discharge data ranged from 4 to 459 mg/L for TSS and less than detection to 238 mg/L for BOD. The median value of 127 mg/L TSS in the USEPA data is twice as high as the median of the NBC CSO samples (62 mg/L), while the BOD

medians are similar (43 mg/L and 36 mg/L, respectively). The USEPA median for total Kjeldahl nitrogen (TKN) of 3.6 mg/L was consistent with the NBC median of 4.1 mg/L and the NBC range of TKN concentrations was well below the maximum USEPA value. The medians for Total Phosphorous (TP) in both data sets are almost identical, at 0.7 mg/L TP in the USEPA data set and 0.8 mg/L TP for the NBC data. As with the TKN values, the NBC TP maximum levels are much lower than the listed USEPA values.

Table 3. *Comparison of 2004-2014 NBC CSO discharge monitoring results with data from the USEPA national data set (2004)*

Contaminant	Units	USEPA 2004		NBC CSO Monitoring 2004 - 2014					
		Range	Median	All Data Average	All Data Range			All Data Median	Bucklin Point Average	Field's Point Average
Fecal coliform	MPN/100mL	3 - 40,000,000	215,000	200,690	24,000	-	> 240,000 *	240,000	226,292	166,361
TSS	mg/L	1 - 4,420	127	95	4.00	-	459	62	107	75
BOD	mg/L	3.9 - 696	43	47	< 63 *	-	238	36	51	42
Ammonia	mg/L			1.7	< 0.10	-	6.87	1.40	1.89	1.32
NO3+NO2	mg/L			0.44	0.13	-	1.85	0.31	0.50	0.35
TKN	mg/L	0 - 82.1	3.6	4.7	< 0.60	-	20.3	4.14	5.04	4.13
Total Nitrogen	mg/L			5.0	0.18	-	21.1	3.43	5.52	4.23
Total Phosphorus	mg/L	0.1 - 20.8	0.7	0.9	< 0.20	-	3.40	0.75	1.00	0.76
Oil & Grease	mg/L			7.6	< 4.0	-	36.1	5.42	8.56	6.30
Cyanide	µg/L			5.6	< 2.0 *	-	138	< 4.0	8.3	1.4
Aluminum	µg/L			1,391	100	-	17,130	651	1,768	858
Cadmium	µg/L	0.16 - 30	2	0.1	< 0.30 *	-	3.40	< 2.5	0.19	0.06
Chromium	µg/L			3.1	< 2.1	-	69	< 10	4.4	1.0
Copper	µg/L	10-1,827	40	41	<10	-	606	26	51	27
Iron	µg/L			2,500	153	-	40,480	1,120	3,262	1,427
Lead	µg/L	5 - 1,013	48	30	< 10 *	-	295	19	30	31
Mercury	µg/L			0.033	0.003	-	0.152	0.026	0.035	0.029
Nickel	µg/L			4.0	< 10 *	-	58	< 10	5.3	2.2
Silver	µg/L			0.5	< 0.45	-	11.9	< 4.0	0.61	0.32
Zinc	µg/L	10 - 3,740	156	133	23	-	2,115	80	166	87

* Detection limits for each parameter have changed throughout the monitoring period, and numerical "detected" results exist outside of the limits presented here. These numerical values are: Fecal coliform 3,000,000 MPN/100 mL, BOD 6.97 mg/L, Cyanide 1.92 µg/L, Cadmium 0.11 µg/L, Lead 9.20 µg/L and Nickel 1.52 µg/L.

The USEPA report provided results for four different metals commonly found in CSO discharges: cadmium, copper, lead and zinc (all representing total concentration). The USEPA range for these metals was comparable to the range found in the NBC CSO discharge samples, though the maximum of each metal was much higher in the USEPA data. The median value of cadmium in the NBC data set was < 2.5 µg/L and the USEPA median was 2 µg/L; however, for copper, lead and zinc the NBC results were close to half the USEPA median values.

With the collection of three samples over the CSO discharge period, it is possible to evaluate the varying concentrations during the first flush, mid-storm and the end of the event. The first flush sample had the highest concentrations for all of the 20 parameters found to be in CSO discharges, with decreasing concentrations for the second and third samples (Table 4). There were a few exceptions. For oil & grease, there was a very small increase from the mid-storm

sample average (6.3 mg/L) to the end of the storm sample average (6.7 mg/L). The nitrate+nitrite concentrations for the mid-storm samples were nearly the same as the end of the storm samples. For a few other parameters, there was only very small changes present between the samples collected throughout the storm.

Table 4. *Average, minimum and maximum concentrations of contaminants present in CSO discharge in samples collected at first flush, mid-storm and termination of a storm event.*

Contaminant	units	First Flush		Height of the Storm		Termination of the Storm	
		Average	Range	Average	Range	Average	Range
Fecal coliform	MPN/100mL	287,507	90,000 - > 240,000 *	182,814	24,000 - 930,000	152,779	24,000 - 350,000
TSS	mg/L	115	24 - 459	100	18 - 335	67	4 - 250
BOD	mg/L	65	< 85.7 - 238	43	< 63 - 191	36	10 - 90
Ammonia	mg/L	2.44	0.21 - 6.87	1.41	< 0.10 - 3.72	1.27	0.28 - 4.09
NO3+NO2	mg/L	0.51	0.13 - 1.32	0.42	0.13 - 1.25	0.42	0.13 - 1.85
TKN	mg/L	6.25	1.20 - 20.3	4.40	< 0.60 - 12.7	3.67	1.27 - 11.6
Total Nitrogen	mg/L	6.89	1.51 - 21.1	4.69	0.18 - 13.4	3.64	1.61 - 9.75
Total Phosphorus	mg/L	1.25	0.21 - 3.40	0.82	0.27 - 2.55	0.65	< 0.20 - 1.83
Oil & Grease	mg/L	9.90	< 4.0 - 36.1	6.33	< 4.0 - 12.44	6.74	< 4.0 - 21.9
Cyanide	µg/L	10.2	< 2.0 - 138	3.7	< 2.0 - 35.9	3.1	< 2.0 - 32.1
Aluminum	mg/L	2,230	297 - 17,130	1,157	161 - 6,030	855	100 - 3,670
Cadmium	µg/L	0.32	< 2.5 - 3.40	0.08	< 0.50 - 0.99	0.03	< 0.30 - 0.30
Chromium	µg/L	5.7	< 2.1 - 69	2.0	< 2.1 - 14	1.8	< 2.1 - 11
Copper	µg/L	72	11 - 606	26	< 10 - 67	24	< 10 - 71
Iron	µg/L	4,445	503 - 40,480	1,834	224 - 8,710	1,385	153 - 5,332
Lead	µg/L	45	< 10 - 295	25	<10 - 79	24	< 10 - 149
Mercury	µg/L	0.041	0.006 - 0.152	0.032	0.008 - 0.084	0.027	0.003 - 0.072
Nickel	µg/L	7.0	< 10 - 58	3.2	< 10 - 20	2.0	< 10 - 27
Silver	µg/L	1.0	< 0.45 - 12	0.44	< 0.45 - 4.0	ND	< 0.45 - < 4.0
Zinc	µg/L	228	34 - 2,115	89	26 - 292	86	23 - 260

* Detection limits for each parameter have changed throughout the monitoring period, and numerical "detected" results exist outside of the limits presented here. This numerical value is: Fecal coliform 3,000,000 MPN/100 mL.
ND = not detected

Results Summary

The maximum results for the NBC CSO discharge samples were, in all cases, much lower than the maximum values of the USEPA national data set, while the median values of the USEPA data set were often very similar to the NBC data set. Fecal coliform bacteria, the pollutant of greatest concern in NBC CSO discharges, was elevated throughout the sampled rain events, with results ranging from 24,000 to >240,000 MPN/100 mL; samples analyzed with a higher upper detection limit had detected results of up to 3,000,000 MPN/100 mL.

A comparison of samples collected at the start, mid-point and end of the storms indicated that the first sample had the highest concentration of pollutants and that the concentrations tended to decrease in the second and third samples.

Stormwater Sampling

Monitoring & Analytical Methods

To determine the concentration of contaminants in local urban stormwater, the NBC collected a discrete sample from each of two stormwater drains during the "first flush" of a storm event to compare to local and nationwide data sets. The "first flush" of stormwater is defined in the RIDEM Stormwater Design and Installation Manual (2010) as the first half-inch to one-inch of runoff. The NBC sought to collect a stormwater sample during this "first flush" occurrence following an extended dry period when runoff is expected to be more contaminated, due to the buildup of pollutants on surfaces. Two stormwater pipes (east and west) discharging in the India Point Park region were selected as the sampling locations. The storm drains are identified as the Stormwater Outfall on Figure 14 and pictured below in Figure 16.

Figure 16. *Photographs showing the eastern and western stormwater outfalls, as well as the Vortechnics manhole cover just upstream of the outfalls.*

The stormwater pipes sampled are 48 inches in diameter. Several Vortechnics treatment systems, designed to remove trash (floatable solids), oil and suspended solids, were installed on smaller diameter stormwater pipes upstream of the outfall discharge. The solids removal efficiency of these systems can be as high as 100% or as low as 10% depending on the specific equipment installed, storm intensity and maintenance of the system.

The NBC collected stormwater samples during a thunderstorm on August 22, 2013. This was a high intensity storm with 0.44 inches of rainfall measured in just 13 minutes, with a total of 0.49 inches over the duration of the storm. Prior to this storm event, there was no rainfall recorded over 0.1 inches for thirteen days. The first rainfall began at 1:13 pm. Samples were collected

between 1:25 pm and 1:30 pm on August 22nd from the east and west stormwater outfalls and were analyzed by the NBC laboratory for bacteria, nutrients, total suspended solids, and dissolved and total metals.

Results

The results of the stormwater sampling are provided in Table 5. Also provided in this Table is a comparison to a nationwide data set of stormwater samples from the USEPA (2004), the average pollutant concentrations in urban stormwater listed in the RIDEM Stormwater Design and Installation Manual (2010) and the pollutant concentrations listed in two RIDEM TMDLs for the Woonasquatucket and Blackstone Rivers. The stormwater pollutant values from the USEPA's report entitled "Report to Congress: Impacts and Control of CSOs and SSOs," provides a range of concentration of various pollutants, the number of samples collected and the median concentration (2004). The RIDEM Stormwater Manual provides a table of the average pollutant concentrations in urban stormwater from various sources.

Table 5. *Concentration of a range of pollutants in samples collected from the stormwater outfalls at India Point Park in comparison to stormwater reference concentrations from national and local environmental regulatory organizations.*

Constituent	Units	India Point East	India Point West	USEPA 2004	RIDEM 2010	Woonasquatucket River[a]		Blackstone River
						Range of Means	Range of Maxes	Range of Maxes[b]
Fecal Coliform	MPN/100 mL	24,000	819,756[c]	1 - 5,230,000	15,000	10,900 - 83,280	240,000 - 31,000	110 - >16,000
Enterococci	MPN/100 mL	>2419.6	>2419.6		35,400			
Total Suspended Solids	mg/L	130.00	118.00	0.5 - 4,800	54.50			
Total Nitrogen	mg/L	4.65	2.74		2.00			
Total Kjeldahl Nitrogen	mg/L	3.37	1.60	0.05 - 66.4	1.47			
Nitrite + Nitrate	mg/L	1.28	1.14		0.53			
Ammonia	mg/L	1.92	0.85					
Dissolved Aluminum	µg/L	57.54	69.03					
Dissolved Silver	µg/L	<0.02	<0.02					
Dissolved Cadmium	µg/L	0.09	0.10			0.043 - 0.130	0.073 - 0.212	
Dissolved Chromium	µg/L	1.64	4.38					
Dissolved Copper	µg/L	51.68	59.65			2.97 - 10.82	5.80 - 24.00	1.4 - 23.0
Dissolved Iron	µg/L	169.30	196.60					
Dissolved Nickel	µg/L	1.75	2.42					
Dissolved Lead	µg/L	36.15	27.16			0.337 - 2.56	0.860 - 2.94	0.19 - 11.0
Dissolved Zinc	µg/L	93.05	140.80			26.97 - 110.8	45 - 287	
Total Silver	µg/L	0.07	0.19					
Total Cadmium	µg/L	0.24	0.30	0.04 - 16,000				
Total Chromium	µg/L	2.57	9.19					
Total Copper	µg/L	91.95	152.78	0.6 - 1,360	11.10[d]			
Total Iron	µg/L	1,898	1,757					
Total Nickel	µg/L	<10	<10					
Total Lead	µg/L	121.86	194.38	0.2 - 1,200	50.70[d]			
Total Zinc	µg/L	290.50	220.86	0.1 - 22,500	129[d]			
Total Arsenic	µg/L	1.59	1.49					
Total Selenium	µg/L	1.06	0.56					
Total Aluminum	µg/L	1,446.10	921.13					
Total Molybdenum	µg/L	1.35	2.52					

a RIDEM 2007

b RIDEM 2013

c Listed results represents geometric mean of both samples collected at the India Point Parkwestern sampling location

d Represents "extractable metal" concentration regulatory organizations.

The concentrations of pollutants in the stormwater samples varied slightly between the two stormwater pipes and were similar to local and national stormwater data. The fecal coliform bacteria results for the western outfall varied greatly between the sample and a duplicate sample collected: one result was > 24,000,000 MPN/100 mL, while the duplicate result was 28,000 MPN/100 mL. The geometric mean of the western outfall results was > 819,756 MPN/100 mL , compared to the eastern outfall fecal coliform sample result of 24,000 MPN/100 mL. The result from the eastern outfall and geometric mean result from the western outfall were well within the national range of data from the USEPA. However, the maximum concentration and the geometric mean of the fecal results from the western stormwater outfall greatly exceed the levels listed in the RIDEM Stormwater Manual and the RIDEM TMDLs. In contrast, the result from the eastern stormwater outfall was comparable to both the RIDEM Stormwater Manual and the RIDEM TMDLs.

The Enterococci results for both samples exceeded the maximum detectable value, with concentrations > 2,420 MPN/100 mL. The RIDEM Stormwater Manual was one of the few references which listed Enterococci stormwater concentrations; however, the values listed exceeded the range of the NBC's laboratory's analysis, so these values cannot be compared.

TSS concentrations were relatively similar between the two outfalls, at 130 and 118 mg/L for the eastern and western outfalls, respectively. These results were approximately double the values listed in the RIDEM Stormwater Manual; however, the results were well within the national range of data from the USEPA. Of the nutrient parameters measured, the greatest difference between the two outfalls was for TKN, which includes particulate and soluble organic nitrogen, as well as ammonia. The eastern outfall sample had a higher TKN result at 3.37 mg/L, more than double the result from the western outfall of 1.60 mg/L; the TKN result from the western outfall was similar to the values listed in the in RIDEM Stormwater Manual. As with other parameters, TKN results from both outfalls were comparable to the national range of data from the USEPA. TN results were calculated for each outfall by adding the TKN results and the nitrate+nitrite results. Both the TN from the eastern outfall (4.65 mg/L) and the western outfall (2.74 mg/L) exceeded the 2.00 mg/L average TN concentration in the RIDEM Stormwater Manual. No national data from the USEPA was available for TN comparison.

The USEPA and the RIDEM Stormwater Manual provide reference values for comparison to total metals concentrations, while the reference values provided in the RIDEM TMDLs of the Woonasquatucket and Blackstone Rivers are for dissolved metal forms. Comparisons to the stormwater outfall metals analysis results were made accordingly. A range of metals were analyzed in the stormwater discharge from the east and west outfalls, including aluminum, silver, cadmium, chromium, copper, iron, nickel, lead and zinc. The sum of the dissolved metals analyzed in the two samples ranged from 411 µg/L from the eastern outfall to 500 µg/L from the western outfall. The total metals analysis included the metals analyzed above in dissolved form, as well as arsenic, selenium and molybdenum. The sum of the total metals analyzed in these samples ranged from 3,855 µg/L in the eastern outfall to 3,260 µg/L in the western outfall.

Results Summary

This limited stormwater sampling exercise, as well as the stormwater data available from other sources demonstrate that stormwater can be a significant source of pollutants. The bacteria samples from the two separate stormwater outfalls demonstrate the high variability that can occur between stormwater outfalls, even those in the same drainage district, and between samples from a single outfall. It is possible that the elevated bacteria levels in the India Point Park stormwater samples could be due to illicit sewer cross connections. The Enterococci data confirm high bacteria levels in stormwater discharges. The NBC is continuing this monitoring in the future to collect more data on the impact of stormwater on their receiving waters.

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Chapter IV – Effect of Phase I CSO Tunnel on Pollutant Loadings

Pre-Phase I CSO Pollutant Loads

Previous hydraulic models conducted by NBC estimated that approximately 2.2 billion gallons per year (BGY) of combined sewage was discharged from the NBC's 64 CSOs. Table 6 shows the estimated annual pollutant load from all CSOs for BOD, TSS, fecal coliform and a suite of other parameters based on the median concentration of pollutants discharged from CSOs from 2004 to 2014 (Table 3) and a volume of 2.2 BGY. Note that to calculate these loadings for some parameters the detection limit was used.

Table 6. *Median concentration of contaminants from CSOs within the NBC district and estimated amount of pollutants being discharged annually from CSOs prior to the completion of Phase I.*

Contaminant	Median CSO Concentration	Pre-Phase I Estimated CSO Loadings
CSO Annual Discharge Volume	2,200,000,000 gals/yr	
Fecal Coliform	240,000 MPN/100mL	2.0×10^{16} MPN/yr
Total Suspended Solids	62 mg/L	1,137,576 lbs/yr
Biochemical Oxygen Demand	36 mg/L	652,271 lbs/yr
Total Nitrogen	3.4 mg/L	62,860 lbs/yr
Cyanide	< 4.0* µg/L	73 lbs/yr
Aluminum	651 µg/L	11,945 lbs/yr
Cadmium	< 2.5* µg/L	46 lbs/yr
Chromium	< 10* µg/L	183 lbs/yr
Copper	26.3 µg/L	483 lbs/yr
Iron	1,120 µg/L	20,550 lbs/yr
Lead	19.4 µg/L	357 lbs/yr
Nickel	< 10* µg/L	183 lbs/yr
Silver	< 4.0* µg/L	73 lbs/yr
Zinc	80 µg/L	1,469 lbs/yr

* For loading calculations, the detection limit was utilized.

As seen in the NBC CSO sampling study, fecal coliform bacteria constitute one of the major contaminants found in CSO discharges. In addition, another large pollutant loading in pounds per year is from TSS at an estimated 1,137,576 lbs/yr, followed by BOD at 652,271 lbs/yr. Total nitrogen discharges are estimated to be 62,860 lbs/yr and metals combine to an estimated total of 35,289 lbs/yr.

Post-Phase I Pollutant Loads

From November 2008, when the tunnel became operational, through the end of 2014, the NBC's CSO tunnel captured a total of 6.15 BG. This represents an average of 1.1 BGY (using the time period the tunnel was in full operation), which equates to 50% of the volume predicted to

discharge annually from the CSOs and slightly more than the 39% reduction goal for Phase I. To determine the amount of pollutants entering the CSO tunnel, the NBC has collected and analyzed samples from the CSO tunnel effluent, prior to it entering the Field's Point WWTF where it ultimately receives full secondary treatment. Table 7 displays the average concentrations of several parameters measured in the CSO tunnel effluent, as well as the removal efficiency of the Field's Point WWTF for each parameter. The removal efficiencies listed in the table are based on Field's Point WWTF data from 2008 through 2014, with the exception of total nitrogen. Since the BNR upgrade at the facility was complete in June 2013, the total nitrogen data was calculated for the entire period the tunnel was online (Nov 2008 – 2014), the pre-BNR period (Nov 2008 – May 2013), and the post-BNR time period (June 2013 – Dec 2014). Over these times periods, the total nitrogen concentration of the CSO tunnel effluent varied only slightly, however the removal efficiency of the plant differed greatly from 45% prior to the BNR upgrade to 80% removal efficiency after the BNR system was complete. The BNR system was not thought to greatly change the removal efficiencies of the other parameters included in Table 7. Due to complications with analysis and holding times, the NBC does not have any CSO tunnel effluent data for fecal coliform and it is therefore not presented in Table 7.

***Table 7**. Average concentration of contaminants in the CSO tunnel effluent with the removal efficiency of the Field's Point WWTF.*

Contaminant	Average Concentration of CSO Tunnel Effluent	Removal Efficiency of Field's Point WWTF
Total Suspended Solids	51 mg/L	92%
Biochemical Oxygen Demand	31 mg/L	93%
Total Nitrogen (2008 - 2014)	8.3 mg/L	56%
Total Nitrogen Pre-BNR	8.9 mg/L	45%
Total Nitrogen Post-BNR	7.1 mg/L	80%
Cyanide	6.3 µg/L*	26%
Aluminum	238 µg/L	94%
Cadmium	0.1 µg/L	94%
Chromium	1.6 µg/L	87%
Copper	11 µg/L	84%
Iron	1,403 µg/L	85%
Lead	10 µg/L	91%
Nickel	16 µg/L	30%
Silver	0.15 µg/L	96%
Zinc	27 µg/L	75%

* Limited sampling results for this parameter.

The total pounds of pollutants removed through capture in the tunnel and treatment at Field's Point was determined for the approximate volume of CSO capture of 1.1 BGY and the CSO tunnel effluent concentrations and Field's Point WWTF removal efficiencies presented in

Table 8. Due to the absence of fecal coliform data from the CSO tunnel effluent, the median concentration of fecal coliform discharged from CSOs from 2004 to 2014 was utilized for these calculations (Table 6).

***Table 8**. Estimated pre-phase I CSO loadings compared to the pounds of pollutants removed by capture in the tunnel and treatment at Field's Point.*

Contaminant	Pre-Phase I Estimated CSO Loadings	Removed by capture in Tunnel & Treatment at Field's Point WWTF
Volume	2,200,000,000 gals/yr	1,100,000,000 gals/yr
Fecal Coliform	2.0×10^{16} MPN/yr	9.99×10^{15} MPN/yr*
Total Suspended Solids	1,137,576 lbs/yr	431,853 lbs/yr
Biochemical Oxygen Demand	652,271 lbs/yr	267,371 lbs/yr
Total Nitrogen (2008 - 2014)	62,860 lbs/yr	42,189 lbs/yr
Total Nitrogen Pre-BNR	---	36,957 lbs/yr
Total Nitrogen Post-BNR	---	52,413 lbs/yr
Cyanide	73 lbs/yr	15 lbs/yr
Aluminum	11,945 lbs/yr	2,059 lbs/yr
Cadmium	46 lbs/yr	0.88 lbs/yr
Chromium	183 lbs/yr	13 lbs/yr
Copper	483 lbs/yr	88 lbs/yr
Iron	20,550 lbs/yr	10,957 lbs/yr
Lead	357 lbs/yr	78 lbs/yr
Nickel	183 lbs/yr	44 lbs/yr
Silver	73 lbs/yr	1.3 lbs/yr
Zinc	1,469 lbs/yr	182 lbs/yr

* Fecal coliform data based on the median concentration of pollutants discharged from CSOs from 2004 to 2014 (Table 6).

Results Summary

Since the Phase I tunnel went online, it is estimated that the annual CSO discharge volume was reduced by 50%, from an estimated 2.2 BGY to approximately 1.1 BGY. The annual reduction in fecal coliform bacteria is also estimated to be nearly 50%, exceeding the bacteria reduction goal for Phase 1; however, note that this estimate is based only on pre-Phase I concentrations being reduced proportionally with the flow reduction as fecal coliform concentrations in tunnel effluent were not measured and the removal efficiency of the WWTF is not known. The Phase I tunnel, through capture of combined sewage for treatment at Field's Point, is estimated to facilitate the annual removal of 431,853 lbs/yr of TSS, 267,371 lbs/year of BOD, 13,422 lbs/year of metals and 52,413 lbs/year of total nitrogen since the Field's Point WWTF was upgraded with BNR.

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Chapter V – Evaluation of Bacterial Contamination in Rivers

Monitoring & Analytical Methods

Consistent monitoring for fecal coliform in the Providence area urban rivers by the NBC began in 1997. In 2005, a station on the Pawtuxet River was added as a reference station, because this river does not have any CSOs. The river pathogen monitoring plan was developed in conjunction with the CSO remediation stakeholder efforts and has developed into a tool of the Interceptor Maintenance (IM) section as a check for potential problems occurring at any of the NBC's CSOs. Routine sample collections for analysis of fecal coliform are made each week, with stations on the Blackstone, Woonasquatucket, Moshassuck, Seekonk, Providence and Pawtuxet Rivers sampled on Mondays and stations on the West, Woonasquatucket, Moshassuck and Providence Rivers on Tuesdays (Figures 17 & 18). In the event of a holiday, or any unforeseen circumstance arising that would prevent the regular schedule, the sampling routine will begin the next day sampling is possible. Samples are collected by EMDA staff in the morning, and delivered to the lab at Field's Point no later than 11:30 AM the day of sampling. NBC's IM, EMDA and Engineering departments determine locations to be added or omitted as needed.

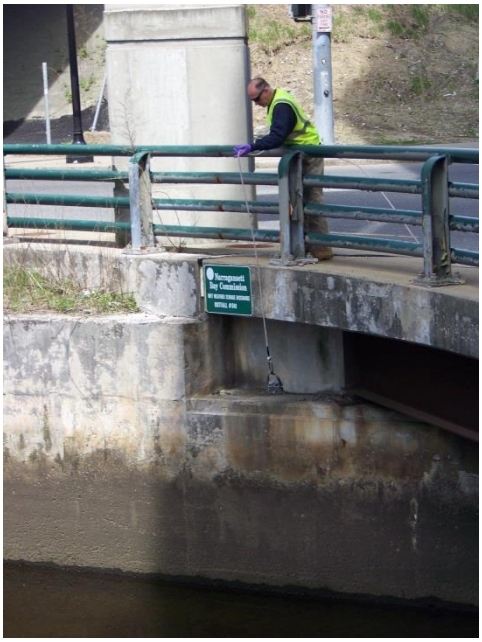


Figure 17. *NBC staff collecting a river fecal coliform sample on the Woonasquatucket River near CSO 41.*

In order to improve NBC's identification of dry weather overflows (DWOs), EMDA resamples weekly collections when DWOs are suspected, and to identify other sources of bacterial contamination in the rivers. Rivers are not resampled when collections have occurred in times of wet weather, since analytical results are expected to be high due to the normal functioning of CSOs. When results from collections are high (greater than 1,000 MPN/100 mL) and there has

been dry weather (i.e., no rain or less than 0.1 inches in the preceding four days), EMDA will resample those stations a second time within the week. Resampling will also occur when results are very high (greater than 10,000 MPN/100 mL) when no rain has occurred in the preceding two days. These general resampling criteria are subject to change based on river flow, fecal bacteria level at background stations, and staff availability. More detail on sampling procedures, laboratory analysis and standard methodology for the NBC urban river bacteria sampling can be found in the EMDA's annual data reports (Figure 19; NBC 2015).

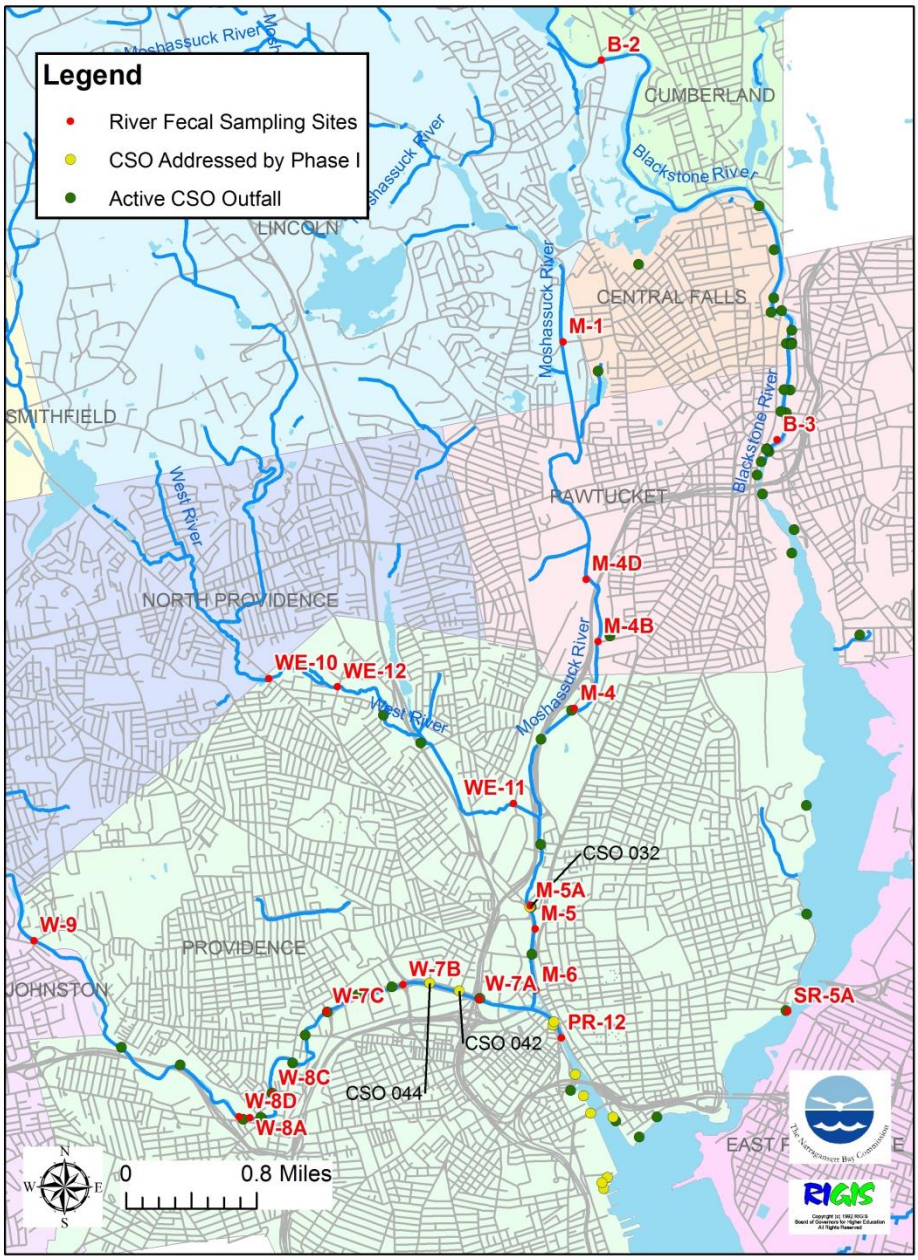


Figure 18. *NBC river sampling locations for fecal coliform bacteria. CSO 032 on the Moshassuck River was tied into the CSO tunnel, while CSOs 042 and 044 on the Woonasquatucket River had modifications to their regulator structures as part of Phase I.*

This section of the report evaluates results from fecal coliform bacteria monitoring in the urban rivers impacted by NBC CSOs. As part of this monitoring program, one station is monitored upstream of all CSOs, as well as one or more downstream of CSOs on each river. The bacteria levels at upstream sampling locations and on the Pawtuxet River indicate baseline conditions without CSOs. The results from stations downstream of CSOs are used to indicate the effectiveness of CSO Abatement Program facilities in meeting water quality standards for bacteria. In this report, the data analysis included results from the pre-Phase I period from 2004 through October 2008, and the post-Phase I period from November 2008 through 2014.

Figure 19. *NBC laboratory staff preparing fecal coliform samples for analysis*

All regularly scheduled sampling results were included in this analysis, including resampling events. Special sampling of the Pawtuxet River was conducted in March and April 2010 after several extreme wet weather events occurred in the region over a six-week period, causing damage to the three WWTFs on the Pawtuxet River with two losing disinfection for a short time. The regularly scheduled sampling over this period was included in this analysis, but all special samples collected on the Pawtuxet River were excluded. Other sampling that was excluded from this report includes data from the West, Woonasquatucket and Seekonk Rivers. Data from station WE-12 on the West River were excluded as monitoring of this site began in 2011, after Phase I was online. On the Woonasquatucket River, the sample location at Atwells Ave (W-8) had to be changed to Eagle Street (W-7C), due to bridge damage at the original location after the Woonasquatucket River flooded in April of 2010. Due to this change of location in 2010 and the fact that these stations are not completely representative of each other, the results at these stations were not included in the analysis for this report. Also on the Woonasquatucket River, the Footbridge at Olneyville station W-8A was moved slightly upstream due to safety concerns in October 2013. As with the other station change, these stations are not completely representative of each other, so the data from the new station, Parking Bridge at Olneyville W-8D, were excluded from this report. However, since a substantial amount of data was available

for station W-8A through September 2013, this station was included in this report and this is highlighted in the results. Data exclusions for the Seekonk River bacteria sampling will be discussed in the next chapter.

For all statistical data analyses, any parameter result less than the detection limit (e.g, < 30 MPN/100 mL) was replaced with the value of the detection limit. If the result was qualified as greater than an upper detection limit (e.g., > 240,000 MPN/100 mL), the upper detection limit value was used in data calculations.

For the purposes of this analysis, the data were separated into wet weather and dry weather results. If the rainfall totals over the three days prior to the sampling date were equal to 0.1 inch or greater, the sample day was considered to be "wet". If rainfall totals were less than 0.1 inch on the three days prior, the sample day was considered to be "dry". On the day of sampling, if the rainfall fell before 11:30 AM it was added to the three days prior total, but if the rainfall occurred after the samples were collected then it was not included in the rainfall total to evaluate a "wet" or "dry" sample day.

The analysis also included an assessment of whether state water quality standards for bacteria were being met in each river. The freshwater primary contact criteria for bacteria are that the geometric mean of all samples must be below 200 MPN/100 mL (i.e., the geometric mean criterion) and not more than 10% of the samples collected shall exceed 400 MPN/100 mL (i.e., the 10% criterion). Although this standard applies over the entire year, RIDEM's policy is to use only data from May to October to determine compliance with the geometric mean standard and the 10% criterion. For this reason, compliance with standards is presented for data collected during only ***May to October*** for each year.

The sampling locations, with the exception of the Pawtuxet River, are shown on Figure 18. Figure 18 also shows the locations of CSOs along the rivers, with active CSOs in green and those that were addressed as part of Phase I in yellow. Those addressed as part of Phase I include the CSOs that were modified and those that were tied into the Phase I tunnel. Most of the CSOs on the freshwater rivers were not tied into the Phase I tunnel, with the exception of one CSO (CSO 032) near the southern end of the Moshassuck River. Two CSOs on the Woonasquatucket River (CSO 042 and CSO 044) were addressed by modifications to the regulator structures. The majority of CSOs tied into the Phase I tunnel were in the upper Providence River estuary. The CSOs on the Woonasquatucket and lower Seekonk Rivers will be addressed in Phase II of the CSO Abatement Program and CSOs on the West and lower Moshassuck Rivers will be addressed in Phase III of the Program, so this analysis also serves as a foundation to assess future infrastructure improvements.

Results

Dry Weather Overflows

As part of USEPA's Nine Minimum Controls Program, the NBC takes precautions to prevent DWOs, including inspection, maintenance, and cleaning of its sewer lines by the IM section, as well as monitoring of the flow discharged from CSOs by the Engineering department. The NBC has been steadily reducing the number of dry weather overflow events since 2004 as shown on Figure 20.

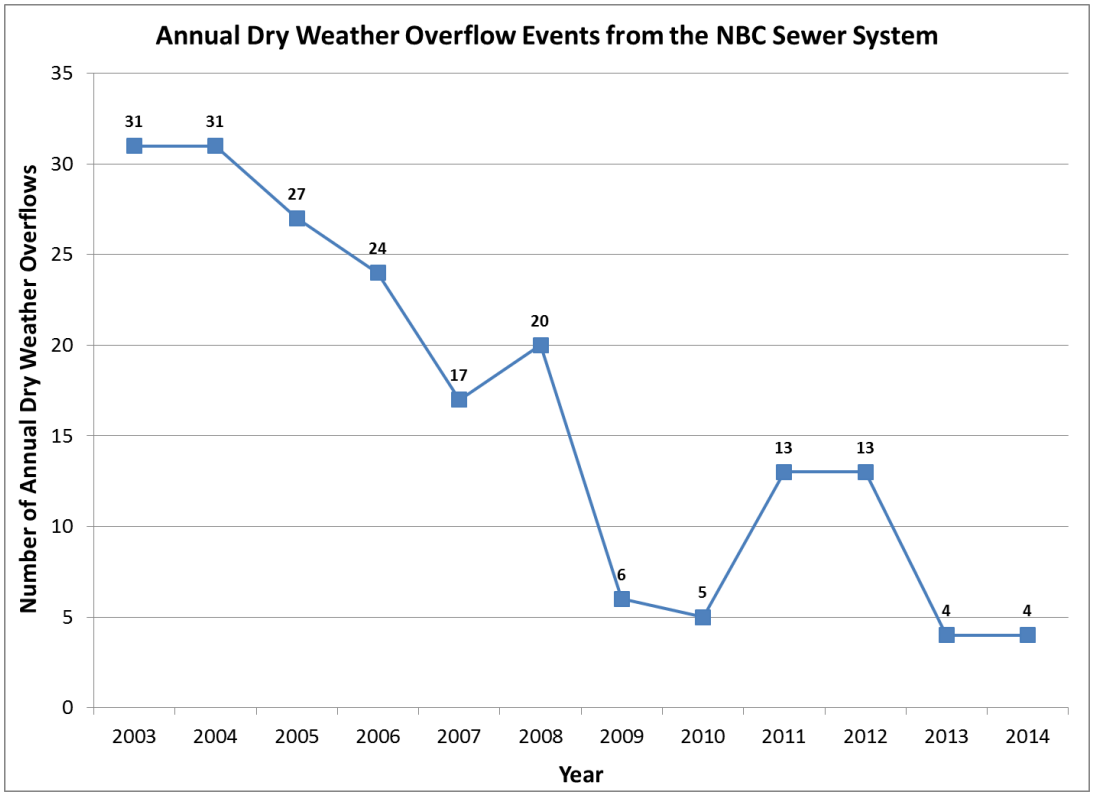


Figure 20. *Number of annual dry weather overflow events from the NBC sewer system.*

Urban Rivers

Tables 9 and 10 show the pre- and post-Phase I wet weather and dry weather fecal coliform geometric mean results for all the river monitoring stations. The data in these tables are calculated using all the sample results for the ***entire year*** in the first two columns and for ***May to October*** in the second two columns. The geometric mean for the ***entire year*** tends to be substantially lower than for the ***May to October*** period for almost all the sampling stations in both dry and wet weather. This difference may be due to a lower fecal die-off rate in the May to October period. The results shown in Tables 9 and 10 are discussed for each river.

Table 9. *Pre- and post-Phase I wet weather fecal coliform geometric means.*

River	Location	Wet Weather Fecal Coliform Geometric Mean (MPN/100 mL)			
		All Year		May - October	
		Pre-Phase I	Post-Phase I	Pre-Phase I	Post-Phase I
Moshassuck	M-1	170	210	387	480
	M-4D	637	782	1,241	1,984
	M-4B	1,385	1,299	2,681	2,804
	M-4	1,092	981	2,244	2,735
	M-5A	1,427	1,416	2,617	4,064
	M-5	1,601	1,344	3,251	3,363
	M-6	1,630	1,368	3,756	3,656
Woonasquatucket	W-9	206	220	467	476
	W-8A*	511	335	989	814
	W-8C	520	402	1,097	1,030
	W-7B	898	572	2,303	1,603
	W-7A	991	810	2,552	2,813
West	WE-10	372	579	1,000	2,298
	WE-11	1,134	1,072	2,921	4,497
Prov/Woon/Mosh	P-12	1,371	1,072	3,193	3,379
Blackstone	B-2	307	144	284	194
	B-3	416	242	547	477
Pawtuxet	PX-13	222	157	524	292

* Post Phase I data only through 9/9/13

Table 10. *Pre- and post-Phase I dry weather fecal coliform geometric means.*

River	Location	Dry Weather Fecal Coliform Geometric Mean (MPN/100 mL)			
		All Year		May - October	
		Pre-Phase I	Post-Phase I	Pre-Phase I	Post-Phase I
Moshassuck	M-1	171	110	363	185
	M-4D	479	344	837	628
	M-4B	623	421	1,066	844
	M-4	573	430	1,291	1,019
	M-5A	953	574	1,542	1,177
	M-5	1,129	763	2,260	1,505
	M-6	897	574	1,764	1,226
Woonasquatucket	W-9	117	117	181	239
	W-8A*	285	156	598	338
	W-8C	264	204	580	498
	W-7B	539	309	1,167	1,034
	W-7A	503	350	1,141	1,189
West	WE-10	226	278	435	673
	WE-11	890	584	1,883	1,935
Prov/Woon/Mosh	P-12	750	499	1,355	1,283
Blackstone	B-2	111	70	105	82
	B-3	169	87	214	117
Pawtuxet	PX-13	153	77	255	141

* Post Phase I data only through 9/9/13

Moshassuck River

The NBC samples seven stations along the Moshassuck River. One station is located upstream of all NBC CSOs (M-1) and the remaining stations are situated downstream of CSOs. Only one CSO on this river was addressed by Phase I, located upstream of two stations, M-5 and M-6 (Figure 18). The data for both dry and wet weather for the ***entire year*** for each station were analyzed to determine any differences between the pre-Phase I period and the post-Phase I period. The fecal coliform geometric means for each station in all weather conditions are shown in relation to the primary contact geometric mean criterion of 200 MPN/100 mL on Figure 21. The pre-Phase I fecal coliform geometric means ranged from 170 MPN/100 mL at the station upstream of all CSOs (M-1) to 1,358 MPN/100 mL at station M-5, while post-Phase I geometric means ranged from 149 MPN/100 mL at M-1 to 1,007 MPN/100 mL at station M-5. The geometric mean for station M-1, upstream of the CSOs, decreased by 12% from the pre-Phase I time period to the post-Phase I time period. The decrease in bacteria levels at stations downstream of CSOs ranged from 10% to 30%, with the greatest decrease at station M-6, which is furthest downstream and may have seen improvement due to the CSO that was addressed in Phase I. Geometric means for all stations downstream of the CSOs in all weather conditions exceeded the primary contact criterion, while the means from station M-1, upstream of the CSOs, were below the criterion.

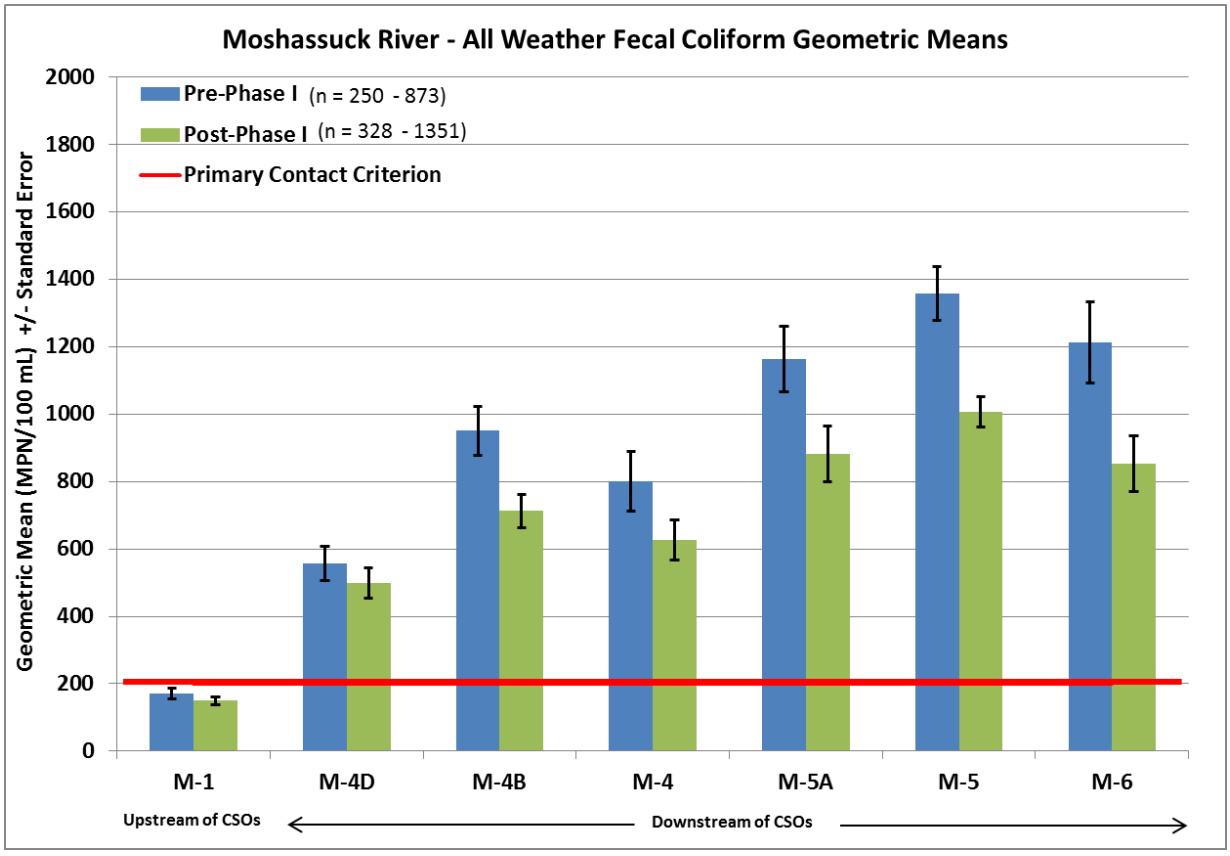


Figure 21. *Moshassuck River geometric means pre- versus post-Phase I in all weather conditions.*

The wet weather fecal coliform geometric means pre-and post-Phase I are shown on Figure 22, as well as in Table 9. The fecal coliform levels were variable and ranged from 170 MPN/100 mL at station M-1 to 1,630 MPN/100 mL at station M-6, during the pre-Phase I time period. The wet weather results from Moshassuck River stations downstream of CSOs were the highest post-Phase I results of any of the rivers. The post-Phase I wet weather results ranged from 210 MPN/100 mL at station M-1 to 1,416 MPN/100 mL at station M-5A. Overall, concentrations increased at the station upstream of CSOs (M-1) by 24% and at one station downstream (M-4D) by 23%, pre- versus post-Phase I. At the remaining stations, wet weather bacteria geometric means decreased between 1% and 16% pre- versus post-Phase I. The greatest percent decrease, 16%, was seen at stations M-5 and M-6, the two locations downstream of CSO 032, addressed in Phase I. As in all weather conditions, geometric means at all stations downstream of the CSOs in wet weather conditions were above the primary contact criterion, while the means from station M-1, upstream of the CSOs, were below the criterion.

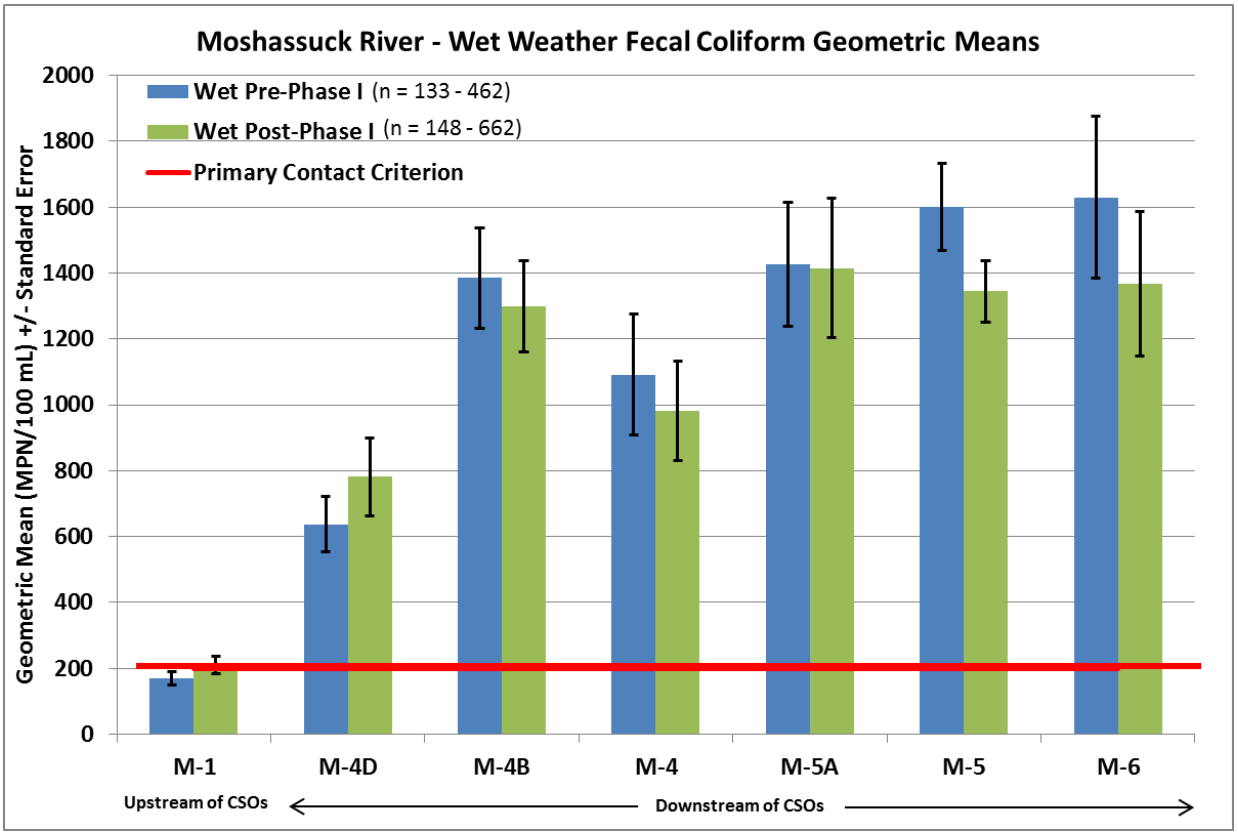


Figure 22. *Moshassuck River geometric means pre- versus post-Phase I in wet weather.*

In dry weather during the pre-Phase I time period, bacteria levels, shown in Figure 23 and Table 10, ranged from 171 MPN/100 mL at station M-1 to 1,129 MPN/100 mL at station M-5. After Phase I was complete, fecal coliform geometric means ranged from 110 MPN/100 mL at station M-1 to 763 MPN/100 mL at station M-5. Concentrations at the upstream station, M-1, decreased by 36% pre- to post-Phase I. At the downstream stations, concentrations decreased between 25% and 40%, with the largest decrease at station M-5A. Large decreases during dry weather were also seen at the two stations downstream of CSO 032, stations M-5 and M-6, with a 32% to 36% decrease, respectively. As in wet weather, the dry weather fecal coliform geometric mean concentrations at stations downstream of CSOs exceeded the primary contact criterion, while the geometric means from the upstream station were below the criterion.

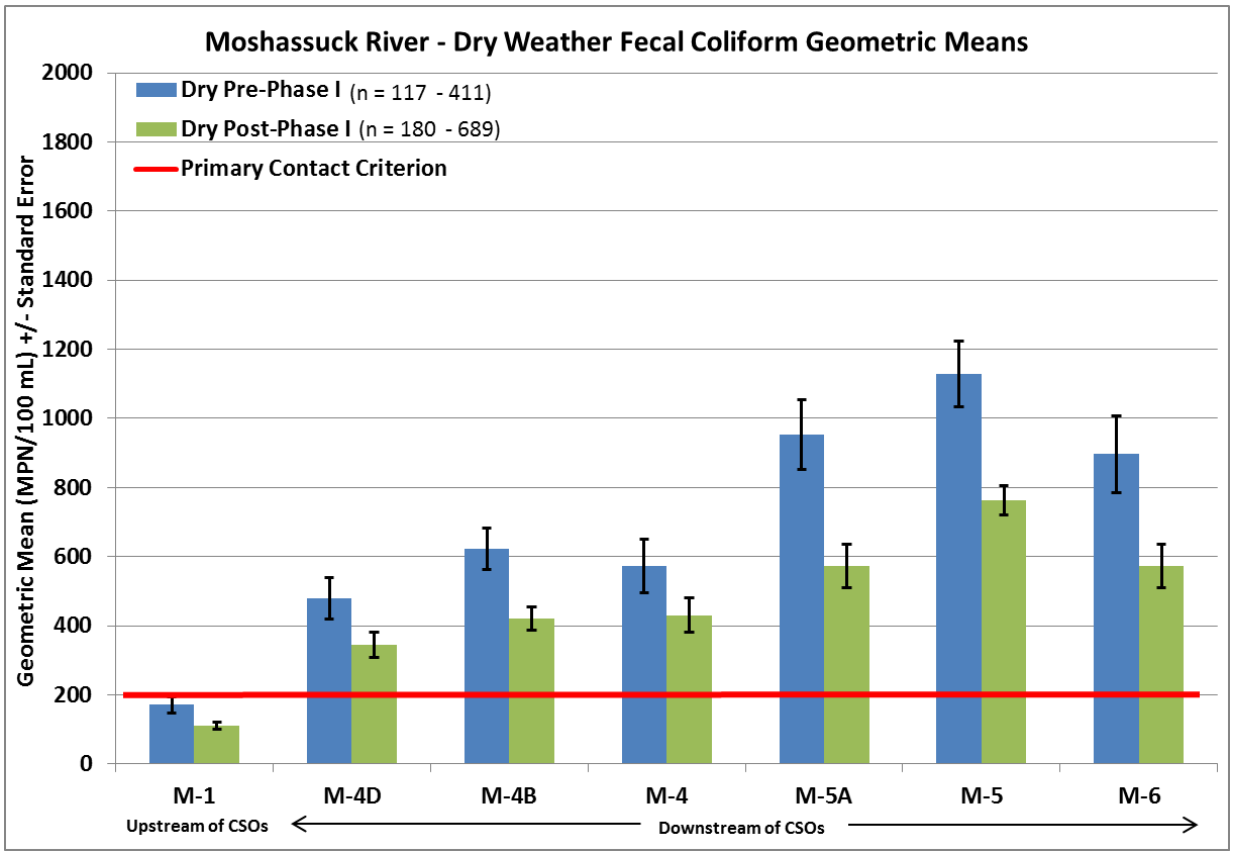


Figure 23. *Moshassuck River geometric means pre- versus post-Phase I in dry weather.*

The wet and dry fecal coliform geometric means for ***May to October*** are presented in Tables 9 and 10. Each station was evaluated to determine if results met the geometric mean and 10% primary contact criteria each year. None of the stations downstream of CSOs met either criterion when evaluated during all weather, during only wet weather, nor during only dry weather. In wet weather, the pre-Phase I concentrations downstream of CSOs ranged from 1,241 to 3,756 MPN/100 mL, while in dry weather bacteria concentrations range was expectedly smaller, from 837 to 2,260 MPN/100 mL. The post-Phase I wet weather values ranged from 1,984 to 4,064 MPN/100 mL, while in dry weather, as during pre-Phase I, they were much reduced at 628 to 1,505 MPN/100 mL. The wet weather results are the second highest of any of the rivers, just slightly less than the West River. The wet weather results post-Phase I were higher than pre-Phase I at all stations, except for station M-6 downstream of CSO 032, which was addressed in the Phase I construction. Results for station M-1, upstream of all CSOs, occasionally met the geometric mean criterion in all weather or dry weather conditions, but never met the 10% criterion. This station never met the geometric mean criterion during wet weather conditions. A compliance breakdown for station M-1 is presented in Table 11.

Table 11. *Moshassuck River primary contact criteria compliance for station M-1, monitoring location upstream of all CSOs.*

Compliance of Moshassuck River Monitoring Location Upstream of CSOs						
Year	All Weather		Wet Weather		Dry Weather	
	Geometric mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL
2004	414	46%	522	53%	268	33%
2005	864	74%	779	69%	951	79%
2006	334	44%	252	36%	452	54%
2007	331	38%	364	40%	311	38%
2008	177	24%	206	25%	154	23%
2009	280	47%	331	55%	205	33%
2010	331	53%	340	56%	328	52%
2011	188	48%	360	77%	103	21%
2012	356	50%	760	73%	127	18%
2013	353	50%	886	64%	180	40%
2014	268	36%	536	67%	181	19%

Green highlight = met this criterion

This is seasonal data from May - October of each year.

Woonasquatucket River

The NBC samples six stations along the Woonasquatucket River. As stated in the methods section, Atwells Ave (W-8) was discontinued and replaced with Eagle Street (W-7C) in 2010; due to this change, the results at these stations were not included in the analysis for this report. A station location change was also made at station W-8A in September 2013; however, since an ample amount of data was available for this station, it was kept in this analysis, with the new station data (W-8D, October 2013 – 2014) excluded.

Station W-9 is located upstream of all NBC CSOs, with the remaining stations downstream of the NBC's CSOs (Figure 18). Two CSOs on this river were addressed by Phase I modifications; only station W-7A is downstream of these improvements. Results from the ***entire year*** were analyzed to determine if there were any differences in fecal coliform levels between the pre-Phase I period and the post-Phase I period. Figure 24 shows the fecal coliform geometric means during all weather. Pre-Phase I geometric means ranged from 156 MPN/100 mL at station W-9, upstream of CSOs, to 716 MPN/100 mL at station W-7A; post-Phase I geometric means ranged from 161 MPN/100 mL at station W-9 to 531 MPN/100 mL at station W-7A. Fecal coliform levels at station W-9, upstream of the CSOs, increased 3% from the pre-Phase I time period to the post-Phase I time period. The bacteria levels at stations downstream of CSOs all decreased, ranging from a 24% decrease to a 41% decrease pre- versus post-Phase I. The greatest decrease in fecal coliform concentrations occurred at two stations, stations W-8A and W-7B. Only the results for station W-9 were below the primary contact criterion, though the post-Phase I geometric mean for station W-8A was just above the criterion at 228 MPN/100 mL.

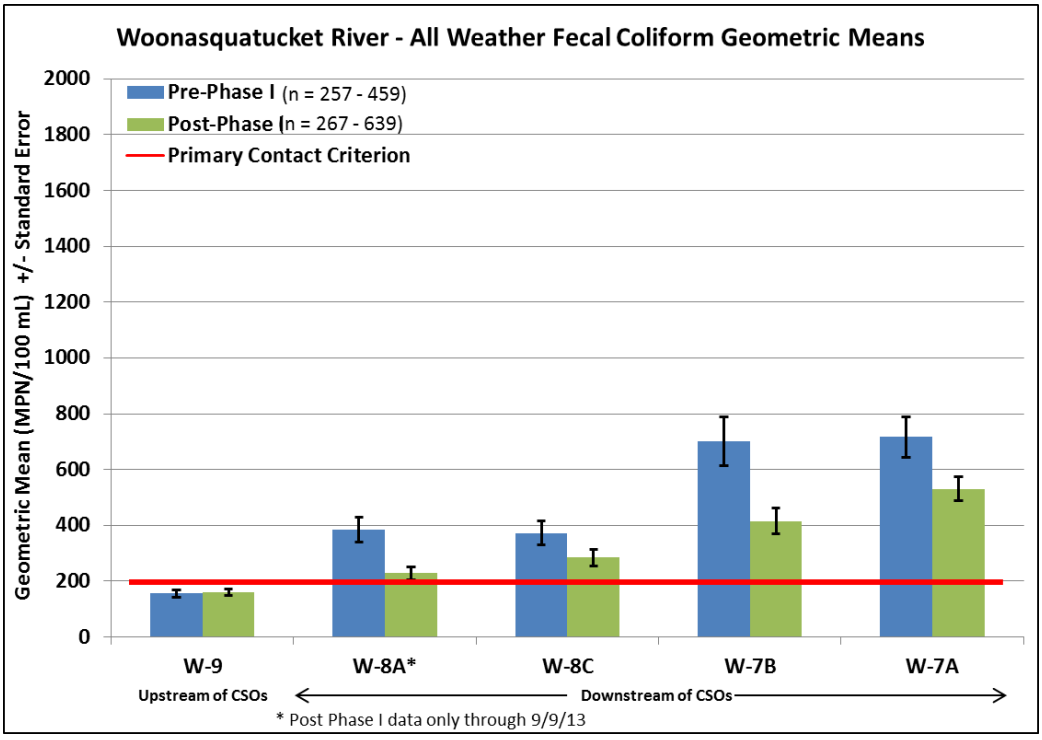


Figure 24. *Woonasquatucket River geometric means pre- versus post-Phase I in all weather conditions.*

Wet weather results are shown in Figure 25 and Table 9. The wet weather fecal coliform geometric mean concentrations ranged from 206 MPN/100 mL at station W-9 to 991 MPN/100 mL at station W-7A during the pre-Phase I period. After Phase I, concentrations were slightly lower, with geometric means ranging from 220 MPN/100 mL at station W-9 to 810 MPN/100 mL at station W-7A. The geometric mean at the upstream station, W-9, increased 7% pre- to post-Phase I; the geometric means decreased for all stations downstream of CSOs after Phase I by 18% to 34%. The largest percent decrease occurred at station W-8A, the first station downstream of CSOs, though upstream of all Phase I CSO improvements. Geometric means of all stations were above the 200 MPN/100 mL primary contact criterion, although results from upstream station W-9 were just above with 206 MPN/100 mL pre-Phase 1 and 220 MPN/100 mL post-Phase 1.

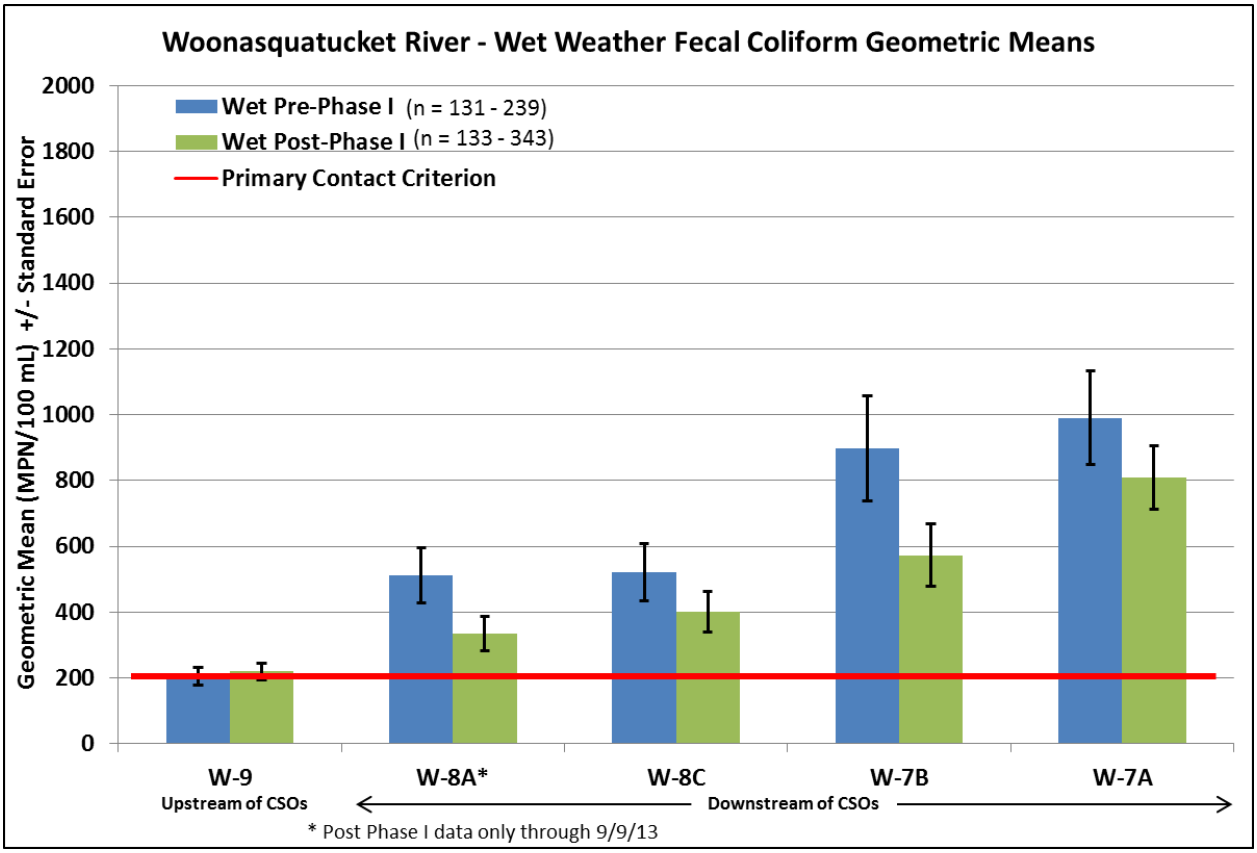


Figure 25. *Woonasquatucket River pre- versus post-Phase I geometric means in wet weather.*

Figure 26 and Table 10 display the fecal coliform geometric means in dry weather conditions. Pre-Phase I geometric mean concentrations ranged from 117 MPN/100 mL at station W-9 to 539 MPN/100 mL at station W-7B, while post-Phase I levels ranged from 117 MPN/100 mL at station W-9 to 350 MPN/100 mL at station W-7A. Dry weather bacteria levels remained the same at station W-9 pre- versus post-Phase I, but decreased at all other downstream stations by 22% to 45%. The largest decrease was again at station W-8A. Geometric means at station W-9 were below the primary contact criterion both pre- and post-Phase I; the post-Phase I geometric mean for station W-8A was also below the primary contact criterion, while station W-8C was just above the criterion (204 MPN/100 mL).

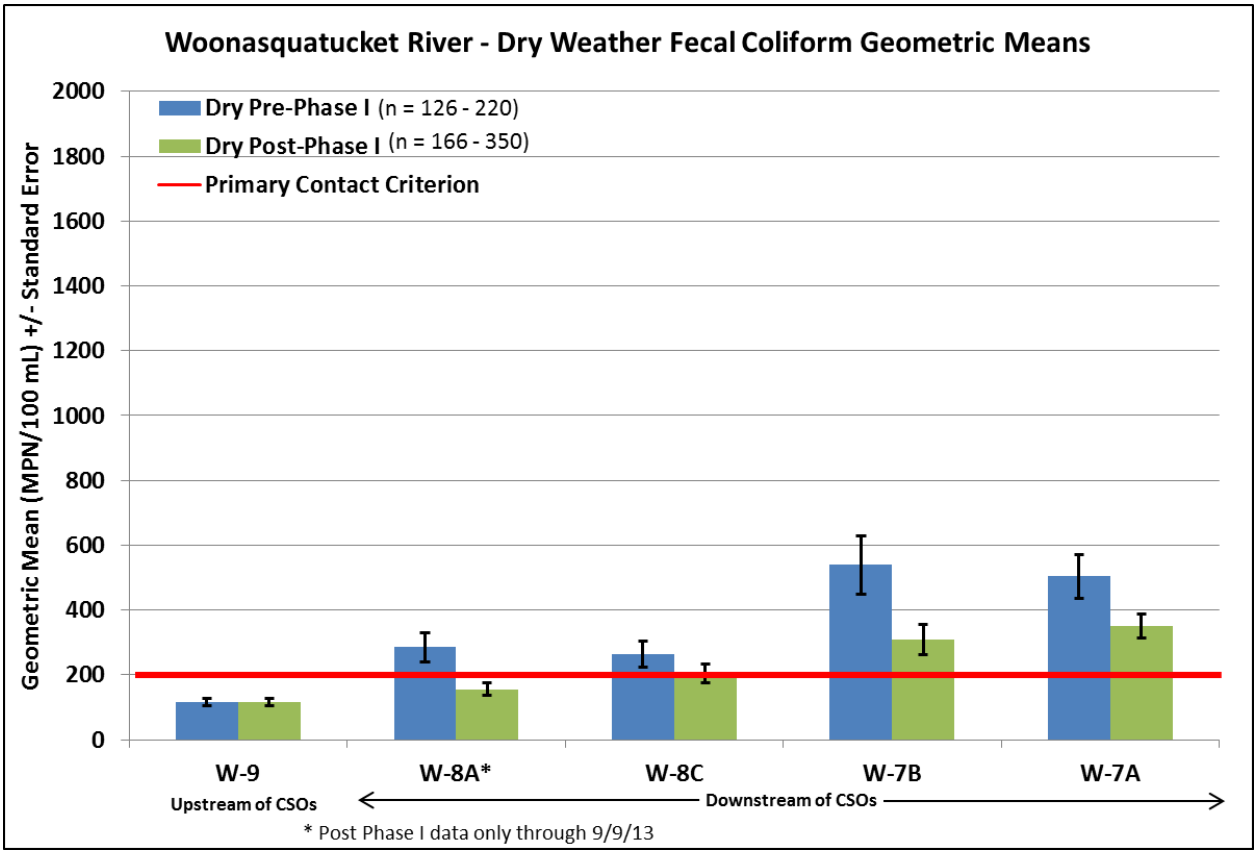


Figure 26. *Woonasquatucket River pre- versus post-Phase I geometric means in dry weather.*

The wet and dry fecal coliform geometric means for ***May to October*** are presented in Tables 9 and 10. Each station was evaluated to determine if results met primary contact criteria each year. None of the stations downstream of CSOs met the criteria in any year when evaluated during all weather, during wet weather, or during dry weather. In wet weather, the pre-Phase I concentrations downstream of CSOs ranged from 989 to 2,552 MPN/100 mL, while in dry weather bacteria concentrations ranged from 580 to 1,167 MPN/100 mL. After Phase I, bacteria concentrations ranged from 814 to 2,813 MPN/100 mL in wet weather and from 338 to 1,189 MPN/100 mL in dry weather. Wet weather geometric means for most stations decreased post-Phase I, except at upstream station W-9 and station W-7A, downstream of Phase I improvements. Results for upstream station W-9 occasionally met primary contact criteria, as shown in the evaluation of compliance on Table 12. This station never met either criterion under wet weather conditions. Under dry weather conditions, this station met both primary contact criteria in the pre-Phase I year 2008 and post-Phase I year 2014.

Table 12. *Woonasquatucket River primary contact criteria compliance for station W-9, monitoring location upstream of all CSOs.*

Compliance of Woonasquatucket River Monitoring Location Upstream of CSOs						
Year	All Weather		Wet Weather		Dry Weather	
	Geometric mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL
2004	295	54%	541	75%	176	36%
2005	158	30%	229	50%	127	18%
2006	454	52%	628	56%	283	45%
2007	370	56%	705	70%	254	47%
2008	220	32%	358	54%	130	8%
2009	290	49%	384	50%	158	45%
2010	492	66%	554	70%	462	63%
2011	541	63%	923	75%	294	50%
2012	384	55%	441	46%	344	63%
2013	276	54%	366	62%	207	46%
2014	167	19%	381	45%	95	0%

Green highlight = met this criterion

This is seasonal data from May - October of each year.

Providence River Headwaters

One station sampled on the upper Providence River, PR-12, is included with the river analysis section because of its location close to the mouths of the Woonasquatucket and Moshassuck Rivers and therefore downstream of NBC CSOs (Figure 18); these CSOs include several that were eliminated or improved during Phase I and several that were unchanged. This station is sampled on the same schedule and using the same techniques as the other river bacteria stations. However, station PR-12 is considered an estuarine site, due to the saltwater mixing from the Bay at this location and would therefore be required to meet the saltwater primary contact criteria. The RIDEM saltwater criteria state that results cannot exceed a geometric mean value of 50 MPN/100 mL and not more than 10% of the total samples taken shall exceed a value of 400 MPN/100 mL. Bacteria levels at this station are presented along with bacteria levels at the stations just upstream on the Woonasquatucket and Moshassuck Rivers for comparison purposes. Figure 27 displays the geometric mean of results from the ***entire year*** from the Providence River station PR-12 and the two upstream Woonasquatucket and Moshassuck Rivers stations and includes both the freshwater and saltwater primary contact geometric mean criteria. Under all weather conditions, the fecal coliform geometric means at station PR-12 were 1,022 MPN/100 mL prior to Phase I and 724 MPN/100 mL after Phase I, a 30% decrease. Similarly, the bacteria levels at the stations nearby on the Woonasquatucket (W-7A) and Moshassuck Rivers (M-6) decreased 26% and 29% pre- versus post-Phase I, respectively. Results from all stations remained above both the freshwater and saltwater primary contact criteria.

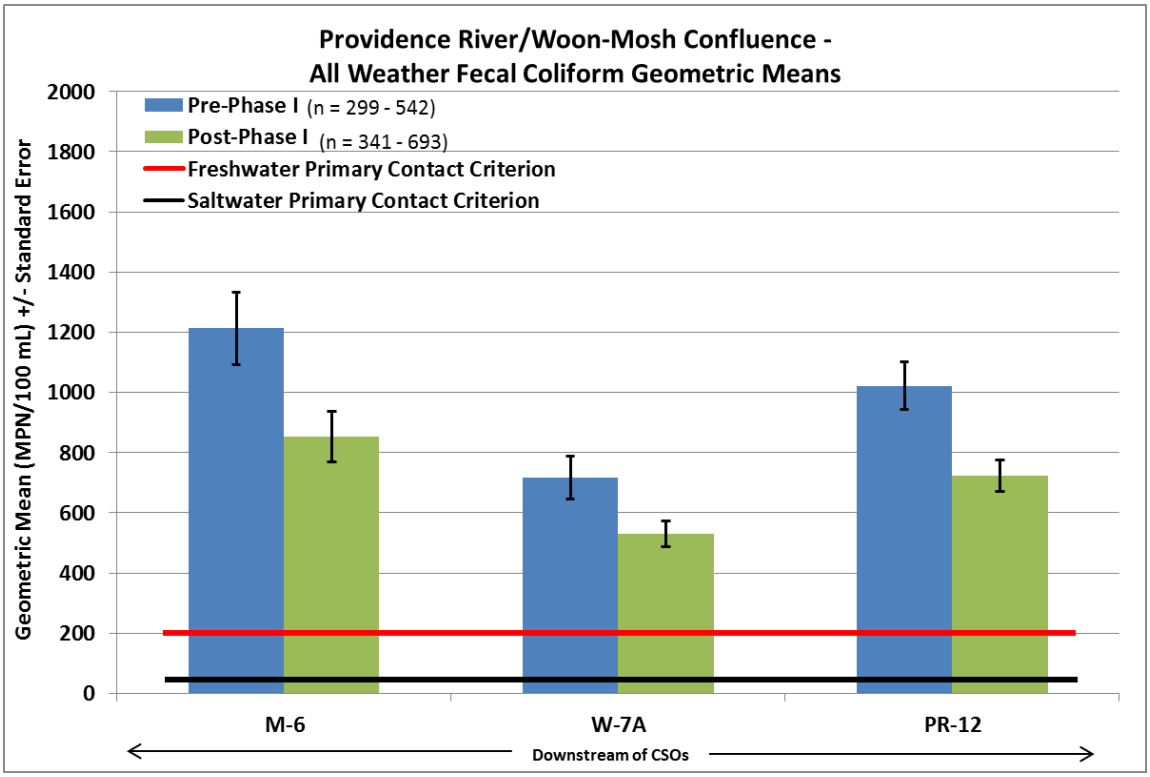


Figure 27. *Providence River pre- versus post-Phase I geometric means in all weather conditions.*

Wet weather fecal coliform levels are shown in Figure 28 and Table 9. The fecal coliform bacteria geometric means at station PR-12 were 1,371 MPN/100 mL prior to Phase I and 1,072 MPN/100 mL after Phase I. This decrease of 16% pre- versus post-Phase I was comparable to the decreases at the stations found just upstream on the Woonasquatucket and Moshassuck Rivers, 18% and 22%, respectively. In wet weather, results from all stations remained above both the freshwater and saltwater primary contact criteria.

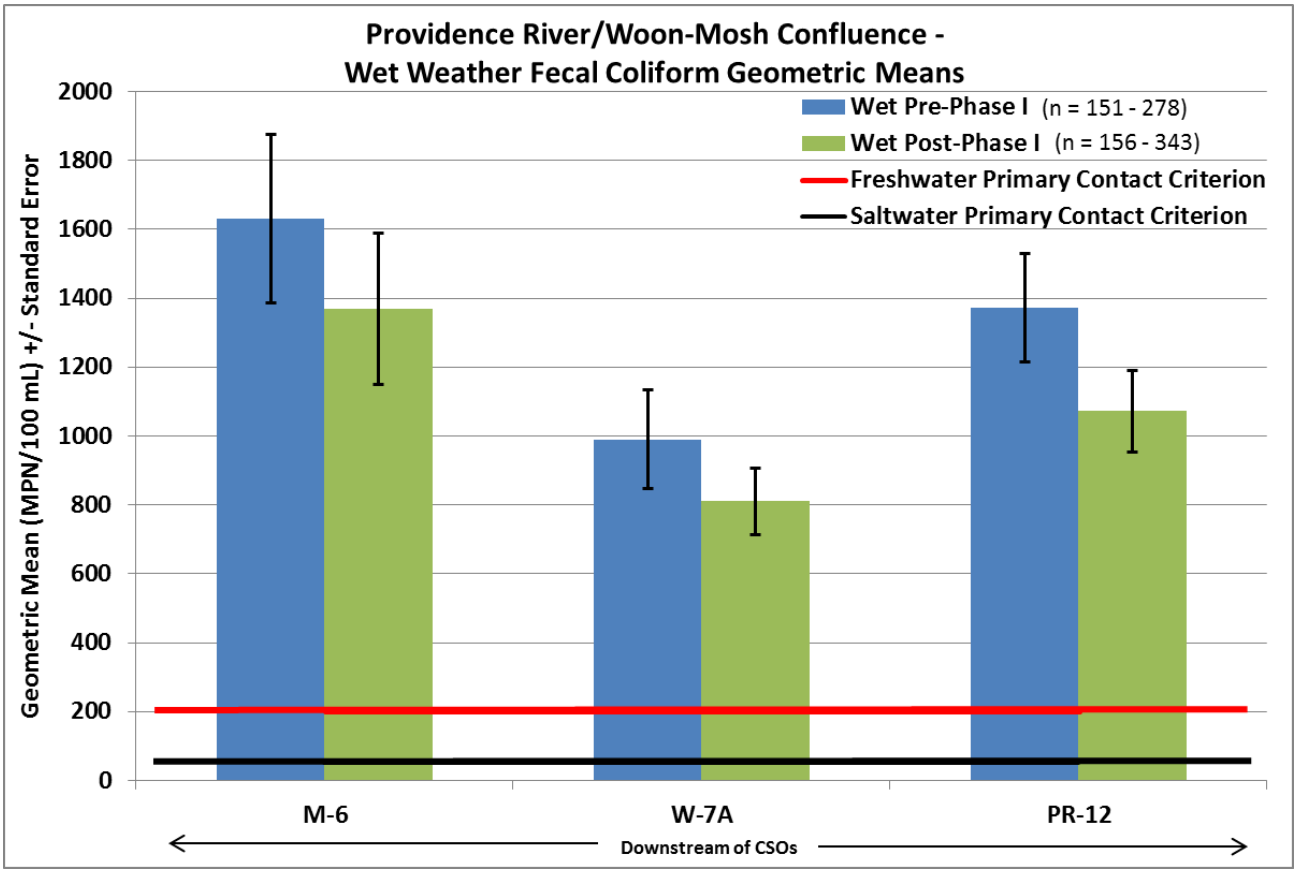


Figure 28. *Providence River pre- versus post-Phase I geometric means in wet weather.*

The dry weather fecal coliform results are presented in Figure 29 and Table 10. Dry weather fecal coliform levels at station PR-12 were 750 MPN/100 mL prior to Phase I and decreased by 36% to 499 MPN/100 mL after Phase I was complete. Similarly, stations W-7A and M-6 decreased by 30% and 33%, respectively. In dry weather, results from all stations remained above both the freshwater and saltwater primary contact criteria.

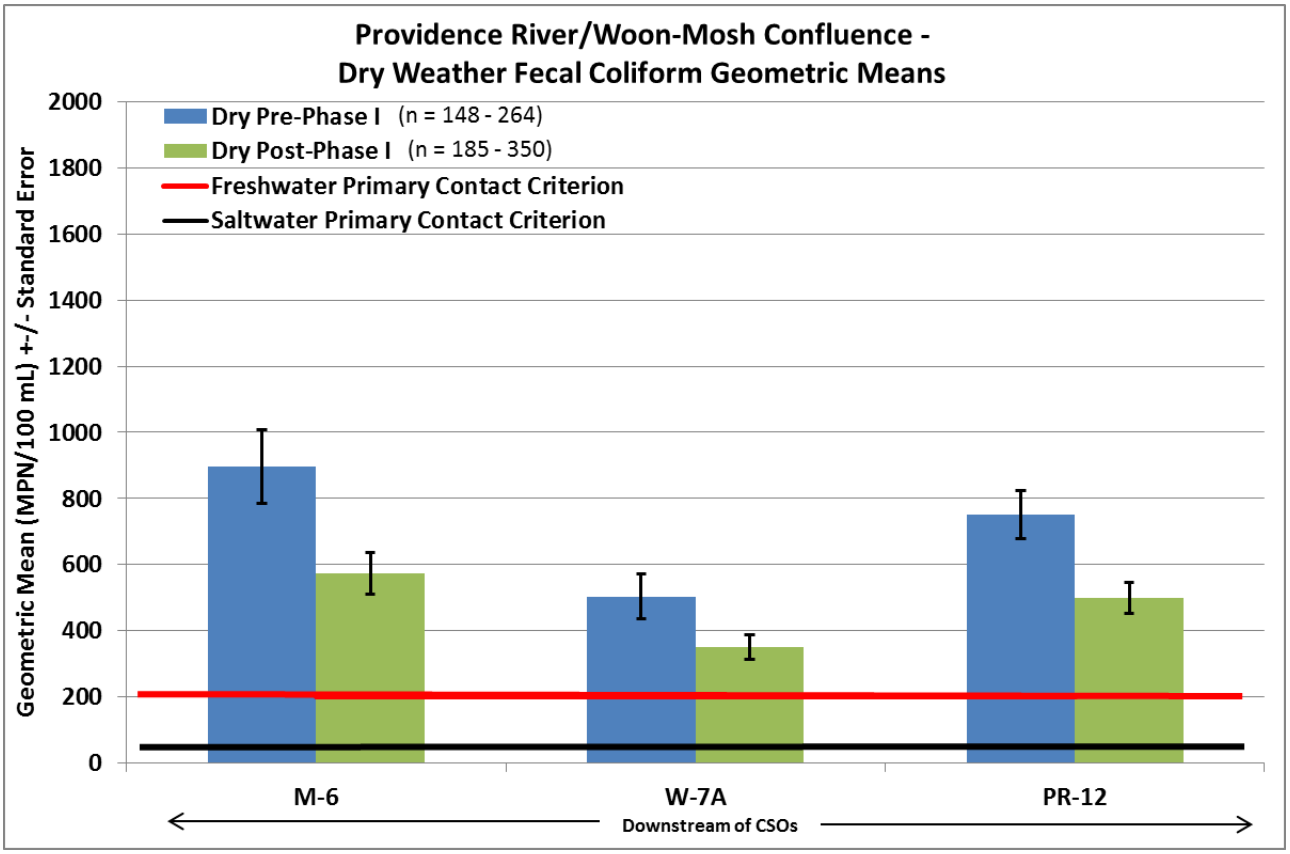


Figure 29. *Providence River pre- versus post-Phase I geometric means in dry weather.*

The ***May to October*** results at station PR-12 are presented in Tables 9, 10 and 13. The pre- and post-Phase I wet weather results were very high at 3,193 MPN/100 mL and 3,379 MPN/100 mL, respectively, while in dry weather results were elevated, but lower than in wet weather at 1,355 MPN/100 mL and 1,283 MPN/100 mL. PR-12 did not meet saltwater fecal coliform criteria in all weather, wet weather or dry weather conditions, as shown in the compliance evaluation in Table 13. Since station PR-12 is downstream of CSOs on both the Moshassuck and Woonasquatucket Rivers, it is not surprising that this station did not meet the criteria under any weather conditions.

Table 13. *Primary contact criteria compliance of Providence River headwaters at station PR-12, monitoring location downstream of CSOs.*

Compliance of Providence River Headwaters Monitoring Location (PR-12) Downstream of CSOs						
Year	All Weather		Wet Weather		Dry Weather	
	Geometric mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL
2004	2,375	90%	4,174	97%	1,193	81%
2005	2,241	84%	3,246	88%	1,740	82%
2006	2,200	93%	2,912	94%	1,647	93%
2007	2,204	83%	3,990	79%	1,467	86%
2008	1,222	84%	1,996	88%	733	79%
2009	1,855	93%	2,203	91%	1,417	95%
2010	2,277	85%	4,080	100%	1,674	78%
2011	2,461	89%	5,441	93%	985	85%
2012	2,341	94%	3,759	100%	1,458	88%
2013	1,406	84%	2,371	100%	938	71%
2014	1,965	86%	3,712	90%	1,342	83%

Green highlight = met this criterion

This is seasonal data from May - October of each year.

West River

None of the CSOs on the West River, a tributary of the Moshassuck River, were addressed by Phase I. The NBC currently samples three stations on the West River; however, the third station was added in May 2011, after Phase 1 had come online, and is therefore excluded from the following analysis. Of the two remaining stations, station WE-10 is located upstream of NBC CSOs while station WE-11 is located downstream (Figure 18). Figure 30 displays the pre- versus post-Phase I fecal coliform levels for the ***entire year*** in all weather conditions for the two stations on the West River. The geometric mean fecal coliform concentration at upstream station WE-10 increased by 35% from 295 MPN/100 mL pre-Phase I to 399 MPN/100 mL post-Phase I. In contrast, fecal coliform geometric means at downstream station WE-11 decreased by 23% from 1,009 MPN/100 mL pre-Phase I to 774 MPN/100 mL post-Phase I. Results from both stations remained above the primary contact criterion.

In wet weather, fecal coliform geometric means, shown in Figure 31 and Table 9, increased at upstream station WE-10 by 56% from 372 MPN/100 mL pre-Phase I to 579 MPN/100 mL post-Phase I. This post-Phase I geometric mean was the highest result of all upstream stations during the report period. At the downstream station WE-11, fecal coliform concentrations decreased by 5% from 1,134 MPN/100 mL pre-Phase I to 1,072 MPN/100 mL post-Phase I. Results from both stations remained above the primary contact criterion.

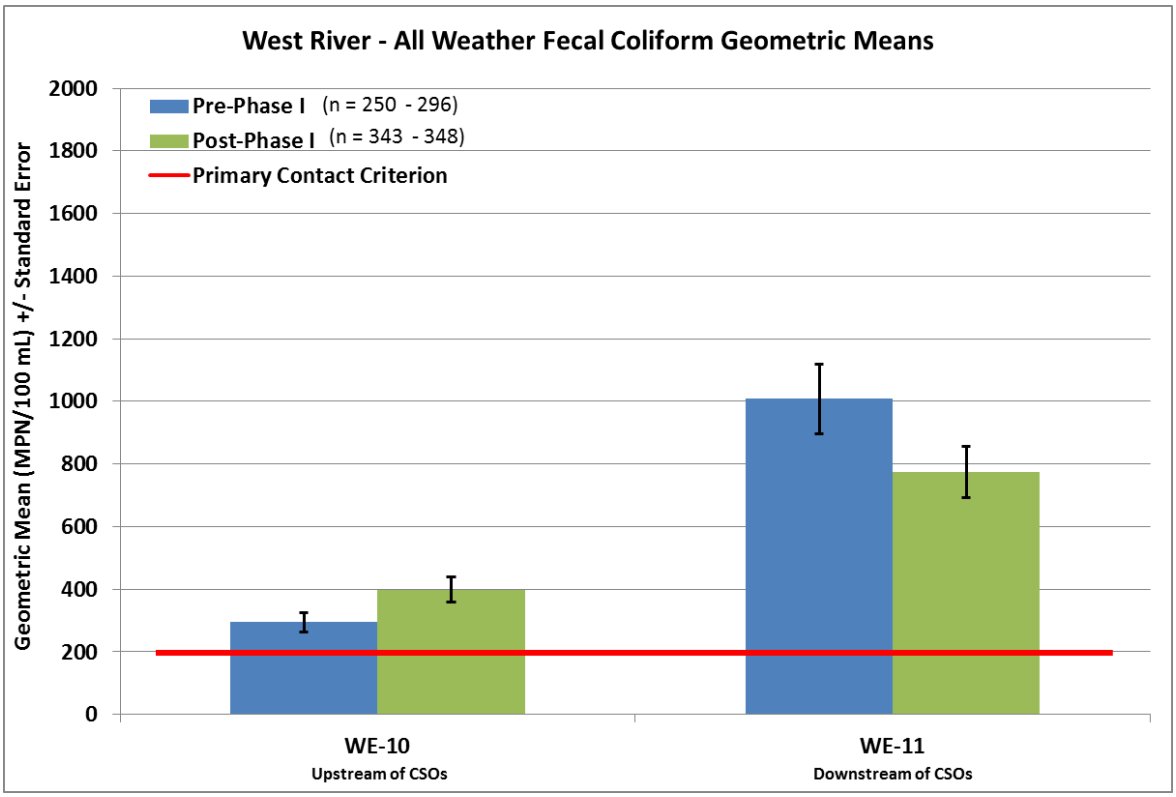


Figure 30. *West River pre- versus post-Phase I geometric means in all weather conditions.*

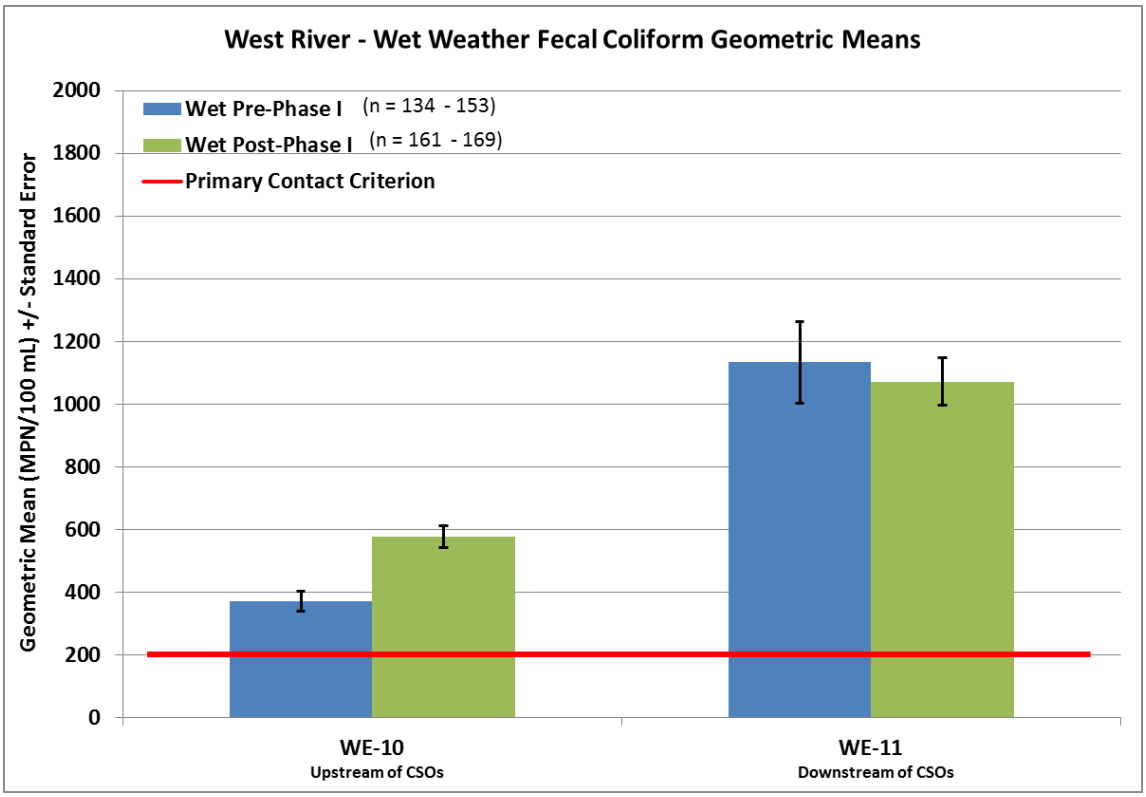


Figure 31. *West River pre- versus post-Phase I geometric means in wet weather.*

The dry weather results for the West River are shown in Figure 32 and Table 10. Fecal coliform concentrations at upstream station WE-10 increased by 23% from 226 MPN/100 mL pre-Phase I to 278 MPN/100 mL post-Phase I. At the downstream station WE-11, fecal coliform concentrations decreased by 34% from 890 MPN/100 mL pre-Phase I to 584 MPN/100 mL post-Phase I. Looking at the entire year in dry weather, results from both stations were still above the primary contact criterion of 200 MPN/100 mL.

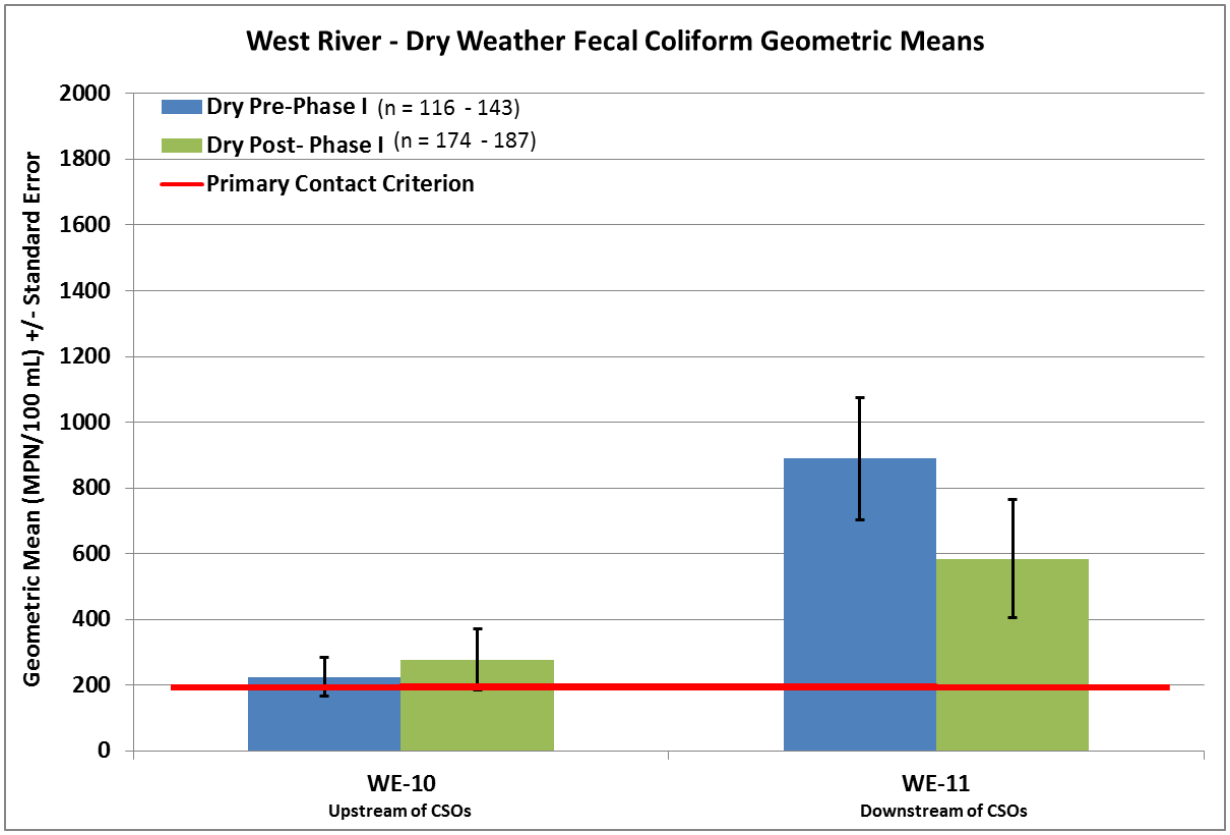


Figure 32. *West River pre versus post Phase I geometric means in dry weather.*

The wet and dry fecal coliform geometric means for ***May to October*** are presented in Tables 9 and 10. Each station was evaluated to determine if results met primary contact criteria each year. Neither station met the criteria when evaluated during all weather, only wet weather, or during only dry weather. The post-Phase I fecal coliform geometric means at downstream station WE-11 were 4,497 MPN/100 mL in wet weather and 1,935 MPN/100 mL in dry weather, the highest of any downstream CSO stations on any river. Similarly, for station WE-10, upstream of the CSOs, pre-Phase I and post-Phase I geometric means in wet weather (1,000 MPN/100 mL and 2,298 MPN/100 mL, respectively) and in dry weather (435 MPN/100 mL and 673 MPN/100 mL, respectively) were twice as high as any of the upstream CSO stations on any river. These high results suggest that non-CSO sources of fecal coliform bacteria on the West River could have a substantial impact on compliance with water quality standards. A further in-depth evaluation of compliance with these criteria for upstream station WE-10 is shown on Table 14. Station WE-10

met the geometric mean criterion in 2007 in dry weather conditions, but never met the 10% criterion.

Table 14. *West River primary contact criteria compliance for station WE-10, monitoring location upstream of all CSOs.*

Compliance of West River Monitoring Location Upstream of CSOs						
Year	All Weather		Wet Weather		Dry Weather	
	Geometric mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL
2004	890	78%	1,317	83%	407	67%
2005	1,089	77%	1,153	75%	1,037	79%
2006	698	68%	693	57%	703	79%
2007	419	46%	1,665	67%	149	31%
2008	457	58%	529	67%	394	50%
2009	1,056	77%	1,718	83%	415	67%
2010	1,543	83%	3,243	100%	1,105	75%
2011	1,418	86%	3,077	100%	618	71%
2012	2,206	81%	2,307	80%	2,077	82%
2013	881	64%	2,422	85%	366	47%
2014	792	75%	1,971	90%	478	67%

Green highlight = met this criterion

This is seasonal data from May - October of each year.

Blackstone River

Though the Blackstone River was not affected by Phase I of the CSO Abatement Project, it was still evaluated in the same way as the other rivers for comparison purposes and to assist in the future evaluation of Phase III. The NBC samples two stations on the Blackstone River (Figure 18), upstream station B-2 and downstream station B-3. The fecal coliform data for the ***entire year*** under all weather conditions are presented in Figure 33. Fecal coliform geometric means prior to Phase I were 186 MPN/100 mL at upstream station B-2 and 267 MPN/100 mL at downstream station B-3. Both stations saw a 46% decrease in concentrations post-Phase I, where the concentrations at upstream station B-2 dropped to 101 MPN/100 mL and at downstream station B-3 dropped to 145 MPN/100 mL. Only the upstream station was below the primary contact criterion prior to Phase I; however, both stations were below the primary contact criterion after Phase I was complete.

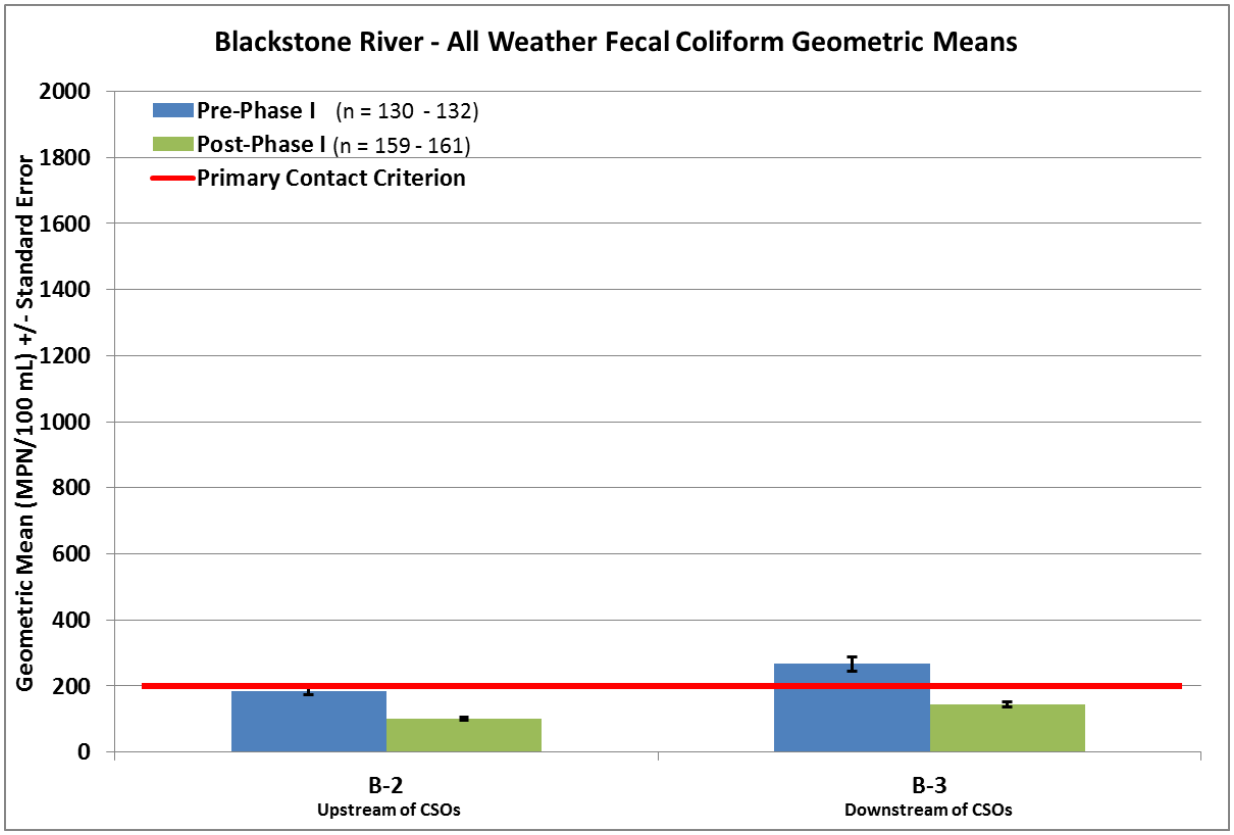


Figure 33. *Blackstone River pre- versus post-Phase I geometric means in all weather conditions.*

Figure 34 and Table 9 depict the wet weather fecal coliform geometric mean concentrations on the Blackstone River. The fecal coliform geometric mean at upstream station B-2 decreased by 53% from 307 MPN/100 mL pre-Phase I to 144 MPN/100 mL post-Phase I. This was the largest percent reduction observed in any upstream station in any river. Downstream station B-3 also saw a large decrease of 42% from 416 MPN/100 mL pre-Phase I to 242 MPN/100 mL post-Phase I. Upstream station B-2 met the primary contact criterion post-Phase I, while station B-3 remained above the criterion in both time periods. Note, however, that downstream station B-3 had the lowest pre- and post-Phase I fecal coliform concentrations of any station downstream of CSOs in any of the rivers surveyed.

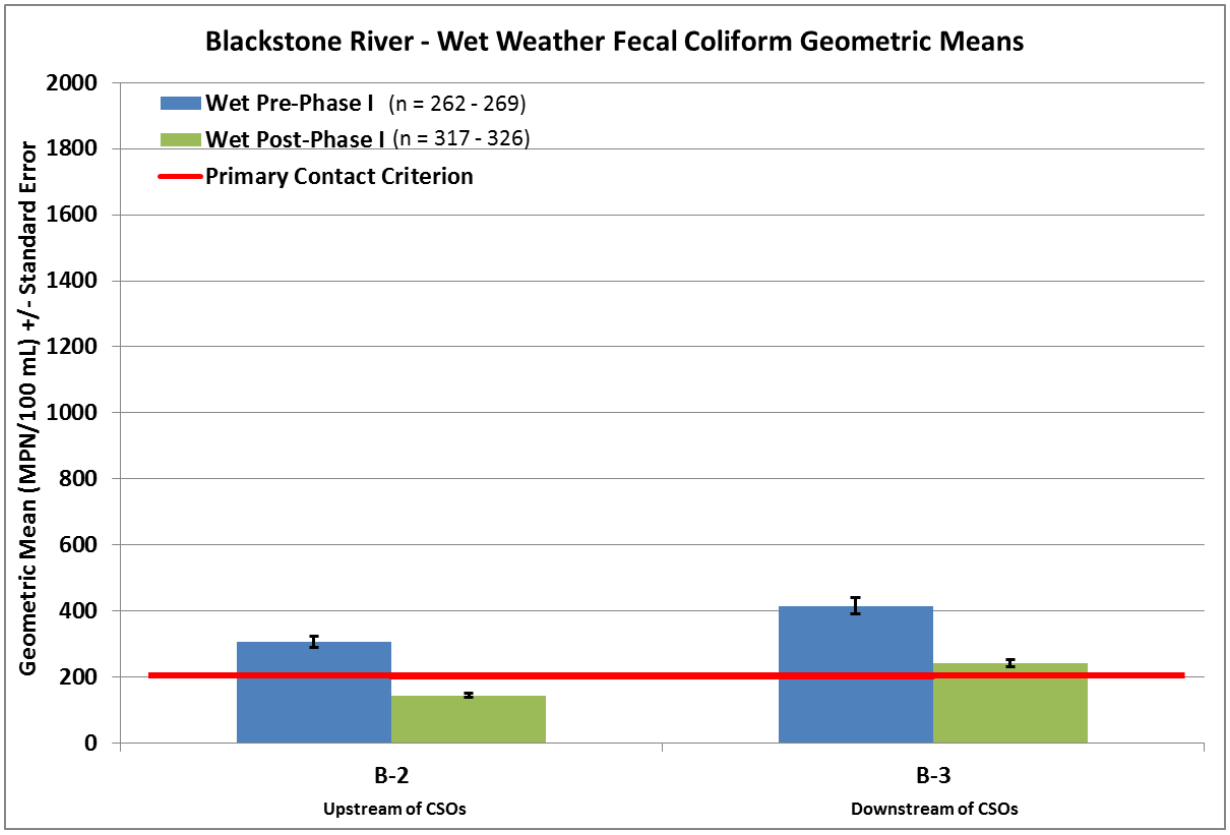


Figure 34. *Blackstone River pre- versus post-Phase I geometric means in wet weather.*

Dry weather fecal coliform geometric mean concentrations, presented in Figure 35 and Table 10, decreased at upstream station B-2 by 37% from 111 MPN/100 mL pre-Phase I to 70 MPN/100 mL post-Phase I. Concentrations decreased at downstream station B-3 by 49% from 169 MPN/100 mL pre-Phase I to 87 MPN/100 mL post-Phase I. Results from both stations remained below the primary contact criterion, and post-Phase I results from both sites were the lowest of all sites surveyed in all rivers.

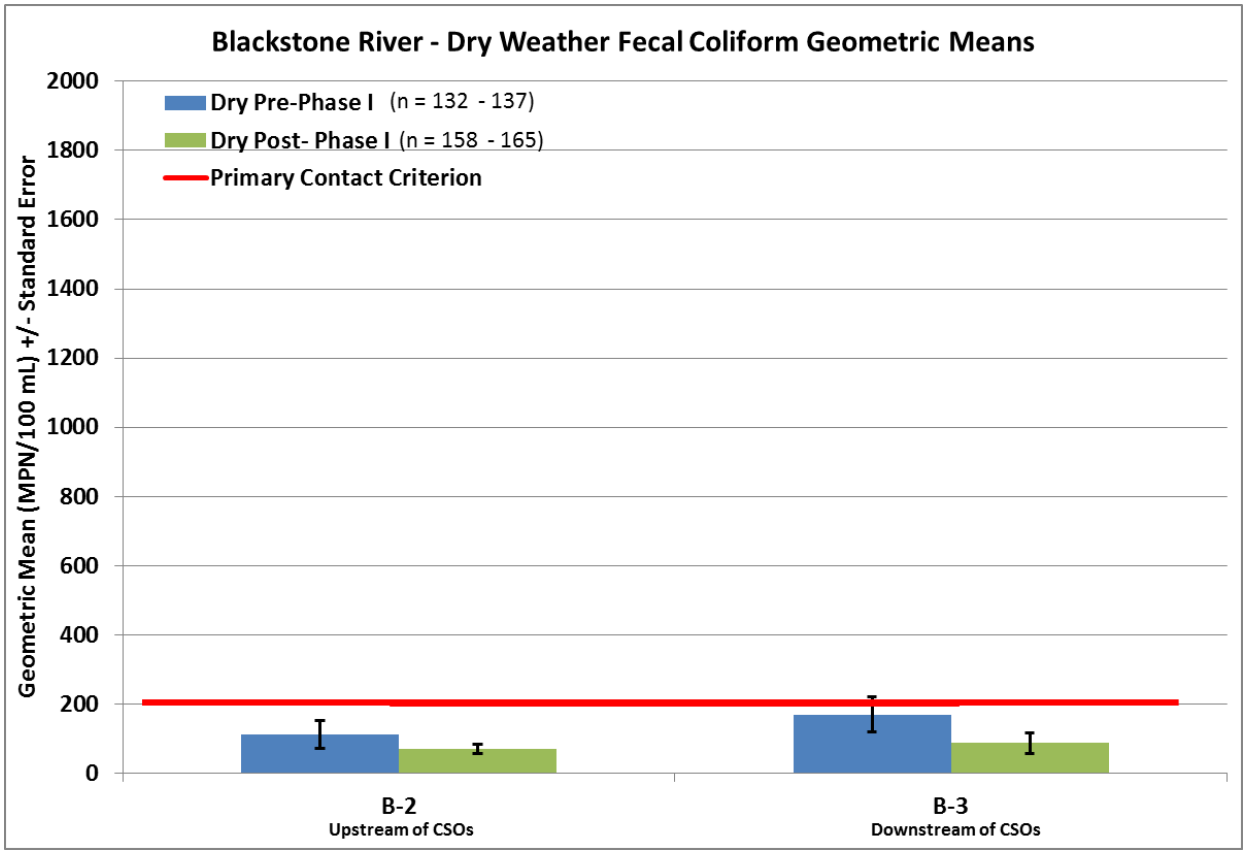


Figure 35. *Blackstone River pre- versus post-Phase I geometric means in dry weather.*

The ***May to October*** geometric means in wet and dry weather are shown in Tables 9 and 10. In wet weather, the pre-Phase I fecal coliform means were 284 MPN/100 ML at upstream station B-2 and 547 MPN/100 mL at downstream station B-3. Dry weather concentrations were lower, at 105 MPN/100 mL at upstream station B-2 and 214 MPN/100 mL at downstream station B-3. The post-Phase I concentrations at upstream station B-2 were the lowest of any station sampled, at 194 MPN/100 mL in wet weather and 82 MPN/100 mL in dry weather. The downstream station B-3 post-Phase I dry weather concentration was 117 MPN/100 mL; the wet weather concentration of 477 MPN/100 mL was the lowest of any station downstream of CSOs. For upstream station B-2, a detailed evaluation of compliance with primary contact criteria is shown on Table 15. In all weather, station B-2 met the geometric mean criterion in all years analyzed except for 2011 when it only slightly exceeded the standard at 202 MPN/100 mL; however, it did not meet the 10% criterion in any year. In wet weather, station B-2 met the geometric mean

criterion in three years, but again did not meet the 10% criterion. In dry weather, station B-2 both criteria in eight out of eleven years.

Table 15. *Primary contact criteria compliance of Blackstone River at station B-2, monitoring location upstream of all CSOs.*

Compliance of Blackstone River Monitoring Location B-2, Upstream of CSOs						
Year	All Weather		Wet Weather		Dry Weather	
	Geometric mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL
2004	182	31%	370	50%	99	14%
2005	174	20%	262	40%	142	10%
2006	162	37%	318	56%	61	9%
2007	139	12%	208	20%	108	6%
2008	174	25%	262	38%	107	9%
2009	108	12%	142	17%	53	0%
2010	128	15%	224	30%	90	6%
2011	202	28%	275	33%	145	21%
2012	139	26%	290	44%	86	14%
2013	106	15%	171	31%	66	0%
2014	101	15%	177	36%	67	0%

Green highlight = met this criterion

This is seasonal data from May - October of each year.

The Blackstone River station downstream of CSOs also occasionally met the geometric mean criterion in all weather conditions, and frequently in dry weather conditions, as shown in Table 16. In 2012, under dry weather conditions, this station met both primary contact criteria.

Table 16. *Primary contact criteria compliance of Blackstone River at station B-3, monitoring location downstream of NBC CSOs.*

Compliance of Blackstone River Monitoring Location B-3, Downstream of CSOs						
Year	All Weather		Wet Weather		Dry Weather	
	Geometric mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL
2004	256	44%	489	62%	141	29%
2005	444	58%	852	64%	321	55%
2006	279	48%	571	69%	99	18%
2007	309	37%	464	45%	233	31%
2008	378	62%	464	64%	298	58%
2009	208	33%	271	41%	110	14%
2010	273	42%	896	90%	130	13%
2011	373	56%	643	79%	207	31%
2012	190	31%	494	58%	83	7%
2013	207	38%	360	46%	119	31%
2014	199	42%	592	73%	89	20%

Green highlight = met this criterion

This is seasonal data from May - October of each year.

Pawtuxet River

The NBC began sampling one station, PX-13, at the terminus of the Pawtuxet River as shown on Figure 36, in 2005. There are no CSO discharges to the Pawtuxet River, but the Warwick, West Warwick and Cranston WWTFs discharge to the river. As previously mentioned, all routine weekly monitoring results were included in this analysis however the special sampling conducted in spring of 2010 when two of the treatment plants were flooded and unable to provide disinfection was excluded. Since there are no CSOs on the Pawtuxet River, station PX-13 was compared to the sampling locations upstream of CSOs on the other urban rivers and evaluated during the pre- and post-Phase I periods.

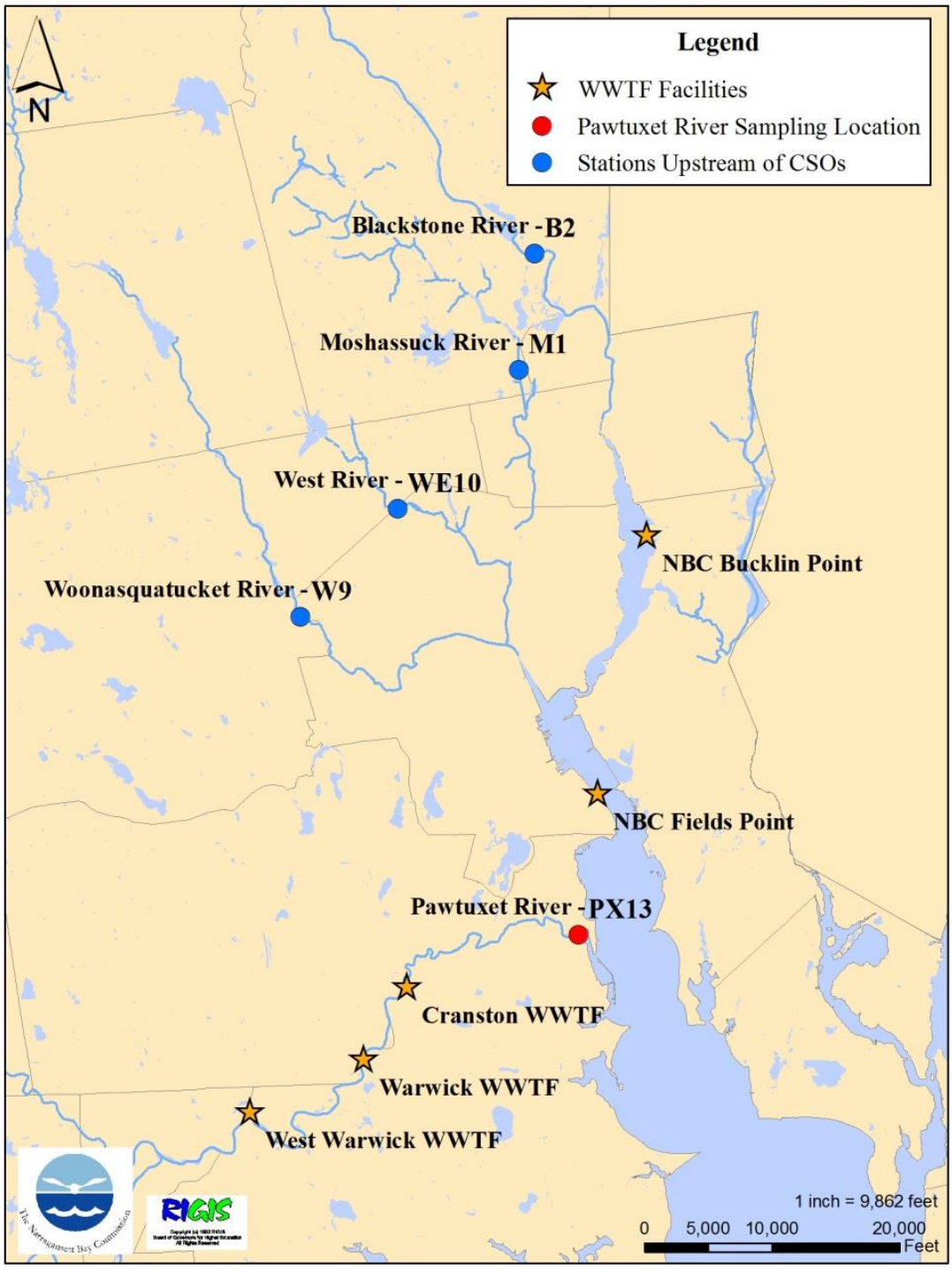


Figure 36. *Pawtuxet River and fecal coliform sampling locations upstream of CSOs along with WWTFs.*

The fecal coliform geometric means for the ***entire year*** in all weather conditions on the Pawtuxet River, shown in Figure 37, were 186 MPN/100 mL prior to Phase I and 118 MPN/100 mL after Phase I was complete. This reduction equated to a decrease of 37% pre-Phase I to post-Phase I. In comparison, the bacteria concentrations at the other stations upstream of CSOs ranged from a 46% decrease on the Blackstone River to a 35% increase on the West River. The Pawtuxet River station displayed very similar geometric means to the stations upstream of CSOs on the Moshassuck, Woonasquatucket and Blackstone Rivers, which were all below the primary contact geometric mean criterion of 200 MPN/100 mL.

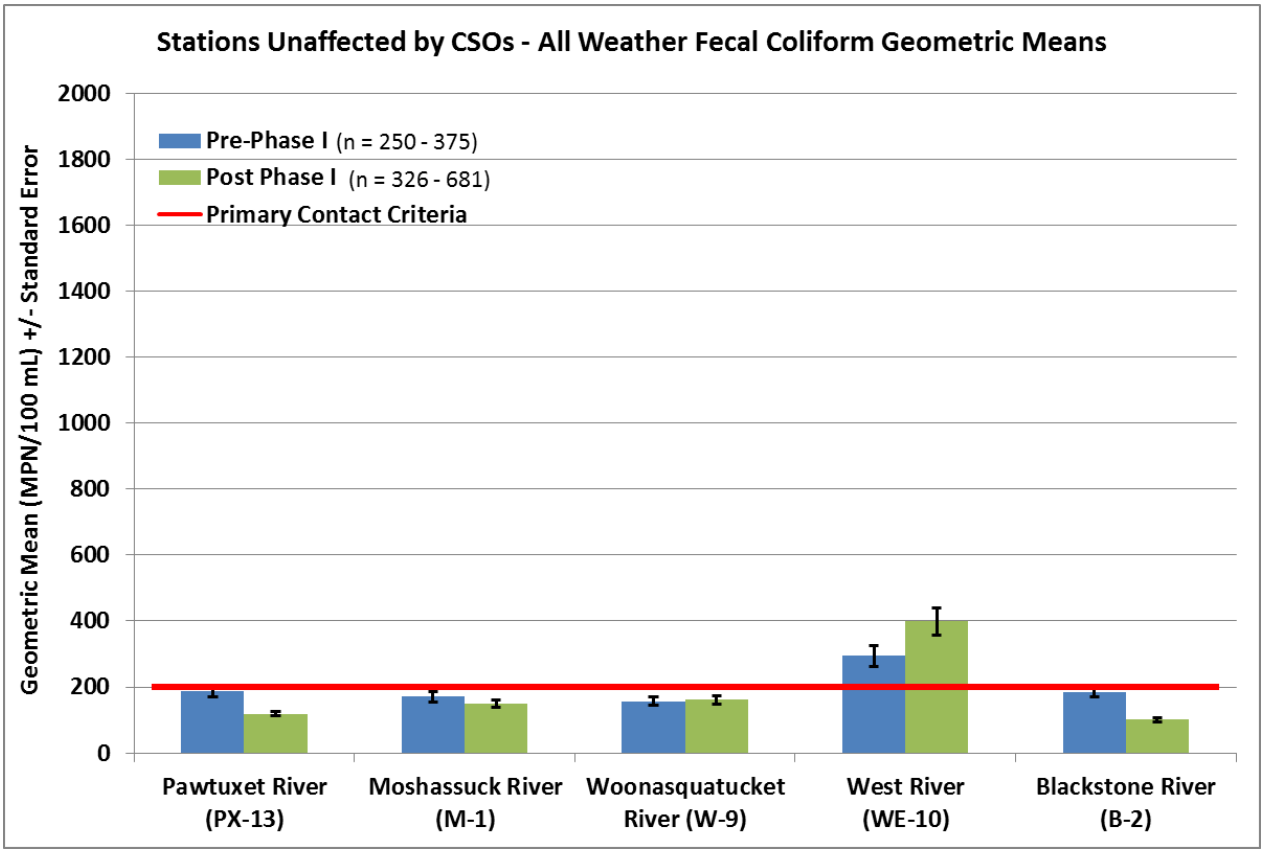


Figure 37. *Geometric means of stations unaffected by CSOs pre- versus post-Phase I in all weather conditions.*

Wet weather fecal coliform geometric means for the Pawtuxet River and other stations upstream of CSOs are presented in Figure 38 and Table 9. Pre-Phase I fecal coliform concentrations on the Pawtuxet River averaged 222 MPN/100 mL, while post-Phase I levels had decreased by 29% to 157 MPN/100 mL. Although the upstream station on the Blackstone River saw a 53% decrease post-Phase 1, all other stations upstream of CSOs on the other three rivers saw an increase pre-Phase I versus post-Phase I from 7% on the Woonasquatucket River to 56% on the West River. Only the Moshassuck River had a wet weather pre-Phase I geometric mean below the primary contact criterion, while during the post-Phase I time period, the Pawtuxet and Blackstone Rivers were the only two rivers below the 200 MPN/100 mL limit.

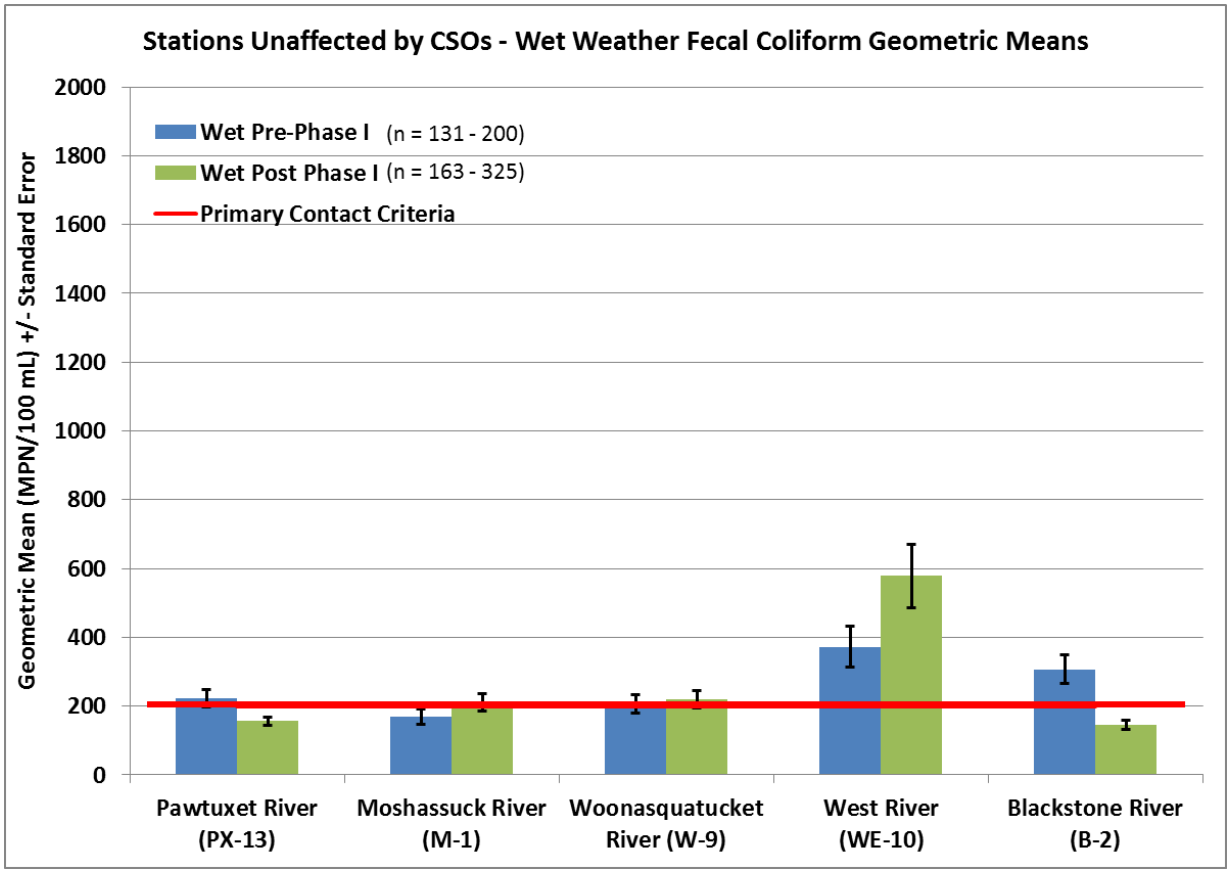


Figure 38. *Geometric means of stations unaffected by CSOs pre- versus post-Phase I in wet weather.*

The dry weather geometric means for fecal coliform in the Pawtuxet River, displayed in Figure 39 and Table 10, were 153 MPN/100 mL pre-Phase I and 77 MPN/100 mL post-Phase I. This equates to a decrease of 50% from the pre-Phase I period to the post-Phase I period, which was the highest percent reduction in dry weather of the stations unaffected by CSOs. The geometric means for the upstream stations on the Moshassuck and Blackstone Rivers decreased 36% and 37%, respectively. The geometric means for the Woonasquatucket River upstream station remained the same, while the West River upstream station increased 28% from the pre- to the post-Phase I time period. The geometric means of all upstream stations on all rivers, with the exception of the West River, were below the primary contact criterion during both the pre-Phase I and post-Phase I time periods in dry weather conditions.

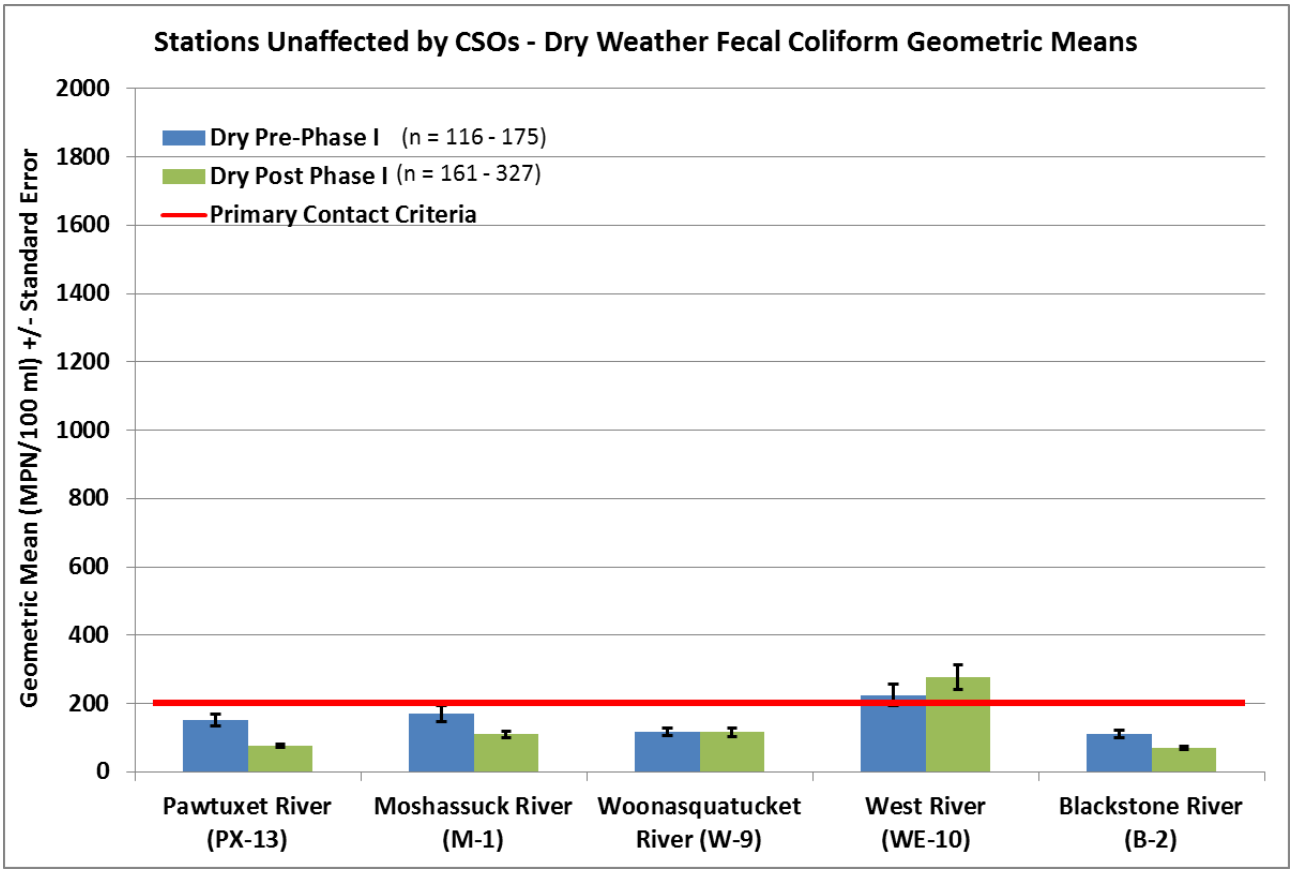


Figure 39. *Geometric means of stations unaffected by CSOs pre- versus post-Phase I in dry weather.*

The ***May to October*** results for the Pawtuxet River are presented in Tables 9 and 10. The pre-Phase I fecal coliform concentrations at station PX-13 were 524 MPN/100 mL in wet weather and 255 MPN/100 mL in dry weather. The post-Phase I concentration in wet weather was 292 MPN/100 mL, while in dry weather the concentration was 141 MPN/100 mL, representing the second lowest of all the stations measured. An evaluation of results from station PX-13 for compliance with primary contact criteria is presented in Table 17. The Pawtuxet River station frequently met the geometric mean criterion, including one year during wet weather conditions. However, both criteria were only met under dry conditions and in two years, 2008 and 2009. Though the concentrations were low compared to the other sampling stations, this station still did not regularly meet water quality standards; bacteria concentrations coupled with the high flows in the Pawtuxet River may contribute to non-compliance with water quality criteria in the Providence River.

Table 17. *Primary contact criteria compliance of the Pawtuxet River at station PX-13, with no CSO influence*

Compliance of Pawtuxet River Monitoring Location (No CSOs on River)						
Year	All Weather		Wet Weather		Dry Weather	
	Geometric mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL	Geometric Mean	Percent above 400 MPN/100 mL
2005	605	64%	640	65%	589	64%
2006	378	49%	658	67%	165	23%
2007	373	42%	744	55%	242	34%
2008	175	29%	264	46%	107	9%
2009	140	17%	179	21%	77	7%
2010	230	38%	482	52%	138	27%
2011	353	46%	574	63%	192	25%
2012	189	23%	206	36%	178	15%
2013	163	30%	248	38%	108	15%
2014	186	27%	253	36%	148	20%

Green highlight = met this criterion

This is seasonal data from May - October of each year.

Results Summary

Since most of the CSOs on the urban rivers were not directly addressed in Phase I, there was not an expectation that bacteria levels would be reduced after Phase I was complete; however, there were substantial reductions in bacteria concentrations at stations downstream of the NBC's CSOs. Bacteria reductions in dry weather can be attributed to a reduction in dry weather overflows, with an increase in inspection, maintenance, and cleaning of the NBC's sewer lines. Since 2004, the NBC has been steadily reducing the number of dry weather overflow events it its

district (Figure 20). In wet weather, reductions in bacteria concentrations in the urban rivers within the Field's Point district (Moshassuck, Woonasquatucket, West and Providence Rivers) could possibly be due to the added capacity within the collection system from the newly built interceptors and adits, which deliver flow to the CSO tunnel. This added volume within the collection system could mean that the pipes do not reach capacity as readily; therefore, more of the contaminated first flush could be captured or retained within the collection system and not discharged out CSOs. Wet weather bacteria reductions in the NBC district as a whole could also be attributed to the NBC's stormwater mitigation program. This program works with developers and land owners to treat stormwater onsite and keep it out of the NBC's collection system. Since its inception in 2003 through mid-2015, NBC's stormwater mitigation program has captured approximately 7.4 million gallons from the combined system (based upon 3-month storm event). This volume equates to approximately 10% of the CSO tunnel volume, meaning that the NBC's stormwater mitigation program has freed 10% more volume in the CSO tunnel for flows during each storm event. Other investments in stormwater management throughout the region could also explain the decreased wet weather bacteria concentrations observed in the urban rivers.

While there have been decreases in bacteria concentrations at monitoring stations downstream of CSOs, there have also been increases at some of the monitoring locations unaffected by CSOs. In fact, most of these stations are not meeting water quality criteria and until the pollution impacts upstream are identified and addressed, the downstream stations will be unlikely to meet water quality criteria.

Chapter VI – Evaluation of Bacterial Contamination in the Providence and Seekonk Rivers

Monitoring & Analytical Methods

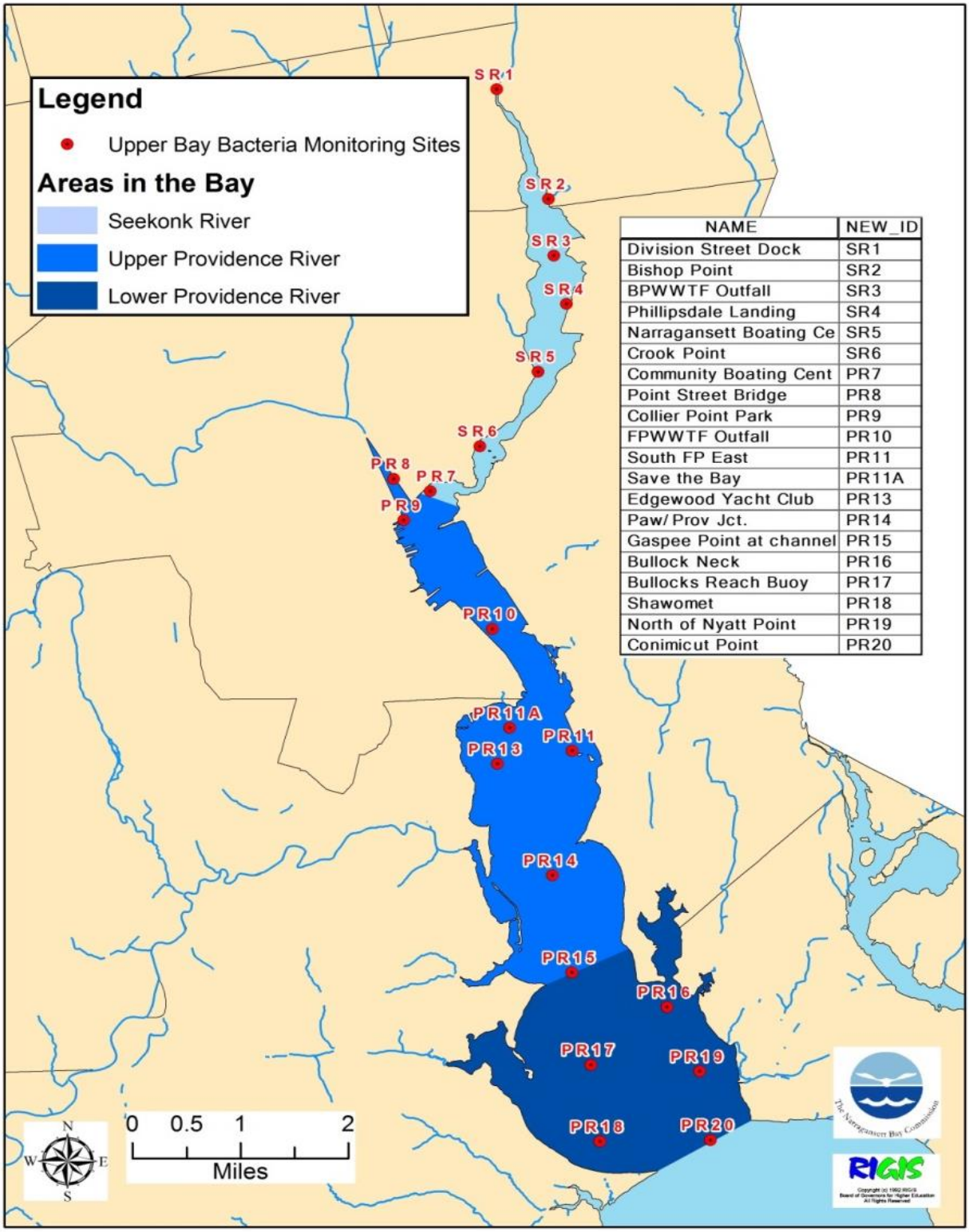
NBC sampling for fecal coliform in the Providence and Seekonk Rivers began in 2004. The NBC often refers to these sampling stations as the "upper Bay" since they are saltwater and to distinguish them from the urban river sampling. Routine sample collections at 20 stations for the analysis of fecal coliform are made biweekly, usually on Wednesdays or Thursdays, throughout the year, dependent on weather (Figure 40). All station samples are collected within a three-hour interval on the same day.

Figure 40. *NBC fecal coliform sample collection device (left) and NBC staff collecting a bay fecal sample (right).*

Bay bacteria samples are collected at six sites in the Seekonk River and at fourteen sites in the Providence River. Four of the Providence River sites are north of Field's Point WWTF and ten sites are south of Field's Point WWTF. Bay bacteria sampling locations are shown on Figure 41. During special events, including after some heavy rainfalls, special sampling may be conducted that includes collecting bay fecal samples consecutively over several days or increasing the number of sample stations to include additional stations further down the bay. More detail on sampling procedures, laboratory analysis and standard methodology for the NBC bay bacteria sampling can be found in the EMDA's annual data reports (NBC 2015).

For all statistical data analyses of fecal coliform, any parameter result less than the detection limit (e.g., < 3 MPN/100 mL) was replaced with the value of the detection limit. If the result was qualified as greater than an upper detection limit (e.g., > 240,000 MPN/100 mL), the upper detection limit value was used in data calculations.

Similar to the urban river analyses in Chapter 5, the data were separated into wet weather and dry weather results. If the rainfall totals over the three days prior to the sampling date were equal to 0.1 inch or greater, the sample day was considered to be "wet". If rainfall totals were less than 0.1 inch on the three days prior, the sample day was considered to be "dry". On the day of



NAME	NEW_ID
Division Street Dock	SR1
Bishop Point	SR2
BPWWTF Outfall	SR3
Phillipsdale Landing	SR4
Narragansett Boating Ce	SR5
Crook Point	SR6
Community Boating Cent	PR7
Point Street Bridge	PR8
Collier Point Park	PR9
FPWWTF Outfall	PR10
South FP East	PR11
Save the Bay	PR11A
Edgewood Yacht Club	PR13
Paw/ Prov Jct.	PR14
Gaspee Point at channel	PR15
Bullock Neck	PR16
Bullocks Reach Buoy	PR17
Shawomet	PR18
North of Nyatt Point	PR19
Conimicut Point	PR20

Figure 41. *Locations of the NBC upper bay bacteria sampling stations.*

sampling, if the rain fell before 11:30 AM it was added to the three days prior total, but if the rainfall occurred after the samples were collected then it was not included in the rainfall total to evaluate a "wet" or "dry" sample day.

Since 2004 samples have been collected on 273 days, 124 in dry weather and 149 in wet weather (Table 18). Of these, 95 dry weather and 89 wet weather samples were taken from May to October, the period during which the RIDEM saltwater primary contact geometric mean criterion of 50 MPN/100 mL applies. For the Providence River samples, the pre-Phase I period is from May 2004 to October 2008. The post-Phase I period is from November 2008 to December 2014. For the Seekonk River, the post-Phase I period begins in 2006, as new wet weather facilities at Bucklin Point WWTF that were a part of the Phase I construction project went online at the end of 2005. Data that were collected by NBC as part of a special study in April 2010 to examine the effect of the historic floods on fecal coliform contamination in the Bay were not included in the analyses unless otherwise noted. Separate data analyses are provided below for the Providence River and the Seekonk River.

Table 18. *Number of sample days at the 20 bay stations for fecal coliform.*

Year	Annual			May - October		
	All Weather	Dry	Wet	All Weather	Dry	Wet
2004	17	4	13	16	4	12
2005	32	20	12	22	16	6
2006	19	8	11	12	3	9
2007	14	6	8	12	6	6
2008	30	16	14	25	13	12
2009	31	13	18	20	8	12
2010	31	12	19	17	12	5
2011	22	9	13	13	7	6
2012	30	13	17	16	7	9
2013	24	12	12	14	8	6
2014	23	11	12	17	11	6
Total	**273**	**124**	**149**	**184**	**95**	**89**

In 2006, in conjunction with bay fecal sampling, the NBC began collecting samples to be analyzed for Enterococci bacteria from five of the fecal coliform sampling locations, four in the Providence River and one in the Seekonk River. Enterococci data were used as the primary pathogen indicator to determine the closure of the state beaches. These data were also analyzed in the same pre- and post-Phase I time-frame as the fecal coliform data.

Results from fecal coliform and Enterococci testing were also compared to saltwater primary contact criteria and shellfishing criteria used by the RIDEM to determine a water body's compliance with such standards.

Unlike most of the urban river sampling locations discussed in Chapter 5, all of the upper bay sampling locations are considered "downstream" of Phase I improvements, including the CSO tunnel and other modifications along the collections system and at the WWTFs. While Phase I did have an impact on urban river bacteria concentrations (e.g., through increased capacity in the collections system), the direct goal of Phase I was to improve water quality in the upper bay, particularly following wet weather conditions. While this chapter includes a limited discussion of dry weather results, bacteria concentrations under wet weather conditions are more thoroughly explored to fully evaluate the impact of Phase I on upper bay water quality.

Providence River Results

Providence River Fecal Coliform Results

The Providence River data were split into two regions for data analysis (Figure 41). The upper Providence River includes the Point Street Bridge, Community Boating Center, Collier Point Park, Off Field's Point (FP) Outfall, Save the Bay, South F.P. East, Edgewood Yacht Club and Pawtuxet/Providence Junction sampling sites. The lower Providence River includes the Gaspee Point at Channel, Bullock Neck, Bullock's Reach Buoy, North of Nyatt Point, Shawomet and Conimicut Point sampling sites.

The pre- and post-Phase I fecal coliform geometric mean concentrations for the ***entire year*** at all sampling locations in the Providence River and locations split into the upper Providence River versus the lower Providence River are shown on Figure 42. Overall, the Providence River has seen a 41% reduction in fecal coliform since Phase I came online. Geometric means were substantially higher in the upper Providence River than the lower. Pre- to post-Phase I, the fecal coliform concentrations in the upper Providence River decreased by 52%, from 167 to 81 MPN/100 mL; concentrations in the lower Providence River decreased by 24%, from 29 to 22 MPN/100 mL.

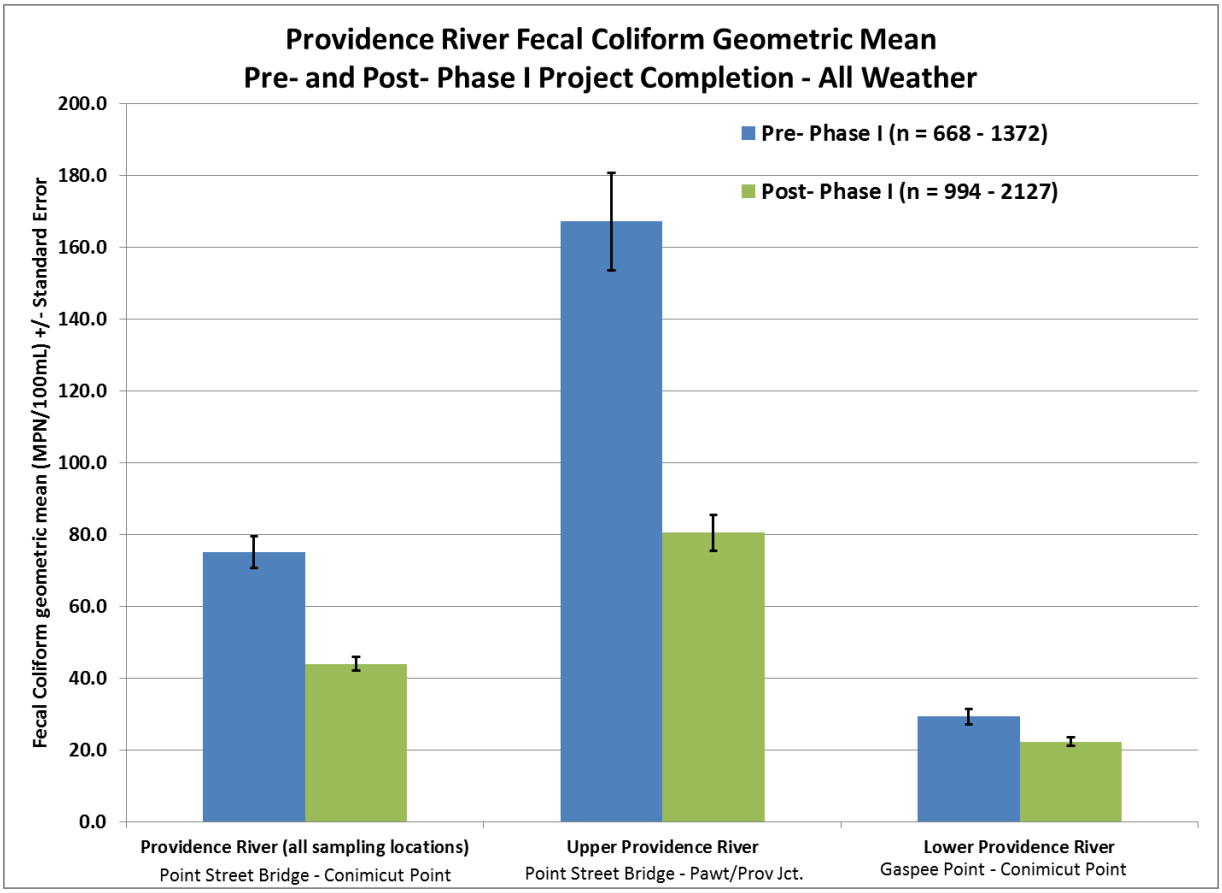


Figure 42. *Providence River fecal coliform geometric means, pre- and post-Phase I.*

Wet versus Dry Weather Conditions

Data for the ***entire year*** for the upper and lower Providence River areas are shown in Figure 43, separated into wet weather and dry weather geometric means, pre- and post-Phase I. As expected, bacteria concentrations in both regions were higher under wet weather conditions than dry. In the upper Providence River, both dry and wet weather concentrations of fecal coliform decreased by approximately 53% post-Phase I. In the lower Providence River, wet weather fecal coliform concentrations decreased by 44%. Dry weather concentrations were essentially unchanged, but were very low (11 and 10 MPN/100 mL).

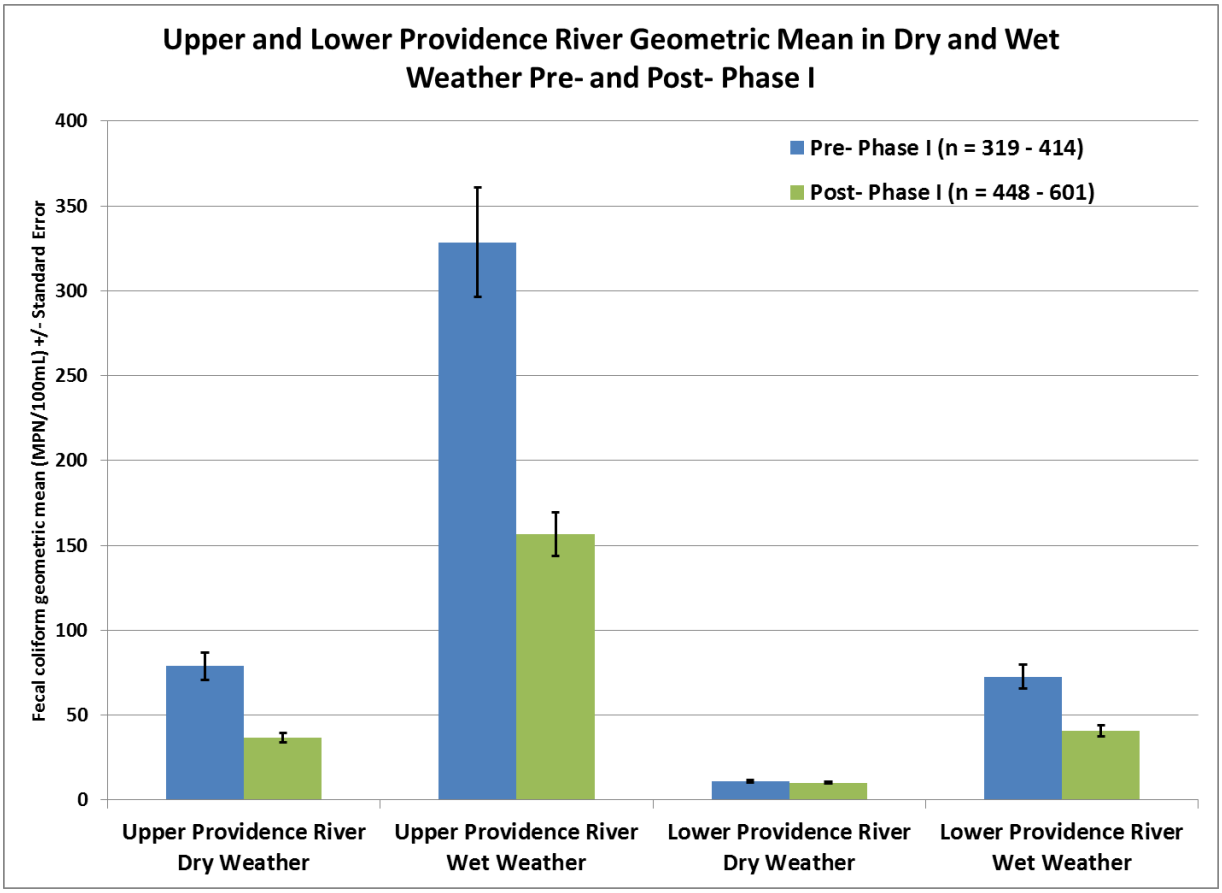


Figure 43. *Comparison of the upper and lower Providence River fecal coliform geometric means in dry and wet weather pre- and post-Phase I project completion.*

Grouping these data for the Providence River as a whole, as shown in Figure 44, the overall wet weather fecal coliform concentration decreased by 50%, from 165 MPN/100 mL pre-Phase I to 83 MPN/100 mL post-Phase I. Phase I improvements under dry weather conditions are less pronounced, with an overall decrease in fecal coliform concentrations of 36%, from 32 to 20 MPN/100 mL.

The wet weather results shown in Figure 44 are expanded upon in Figure 45. Here the wet weather data are split based on three intervals of rainfall: 0.1 to 0.49 inches; 0.5 to 0.99 inches; and > 1.0 inch. Dry weather data are reproduced as in Figure 44 below. As expected, overall fecal coliform concentrations increase and are more variable with increasing total rainfall. Under the lowest rainfall conditions, concentrations decreased 57% after Phase I came online. At the higher rainfall intervals, concentrations decreased 32% when rainfall amounted to 0.5 to 0.99 inch, and 54% following rainfall greater than 1.0 inch.

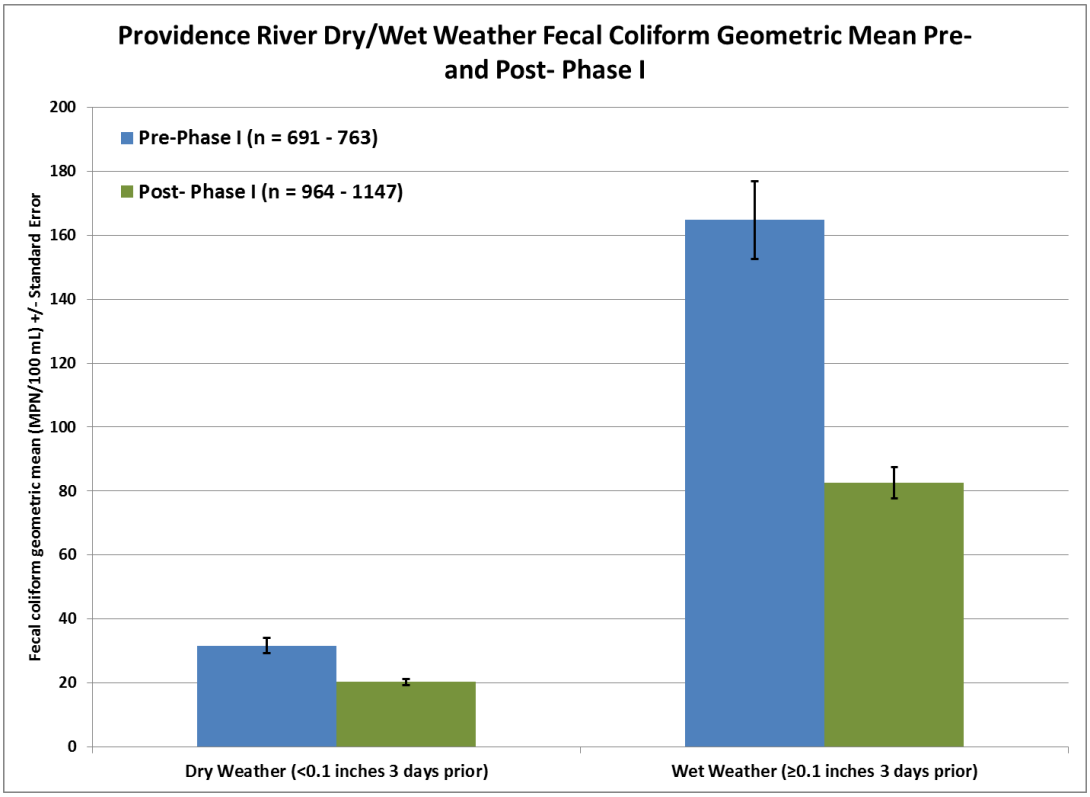


Figure 44. *Pre- and post-Phase I Providence River fecal geometric means in dry weather and wet weather.*

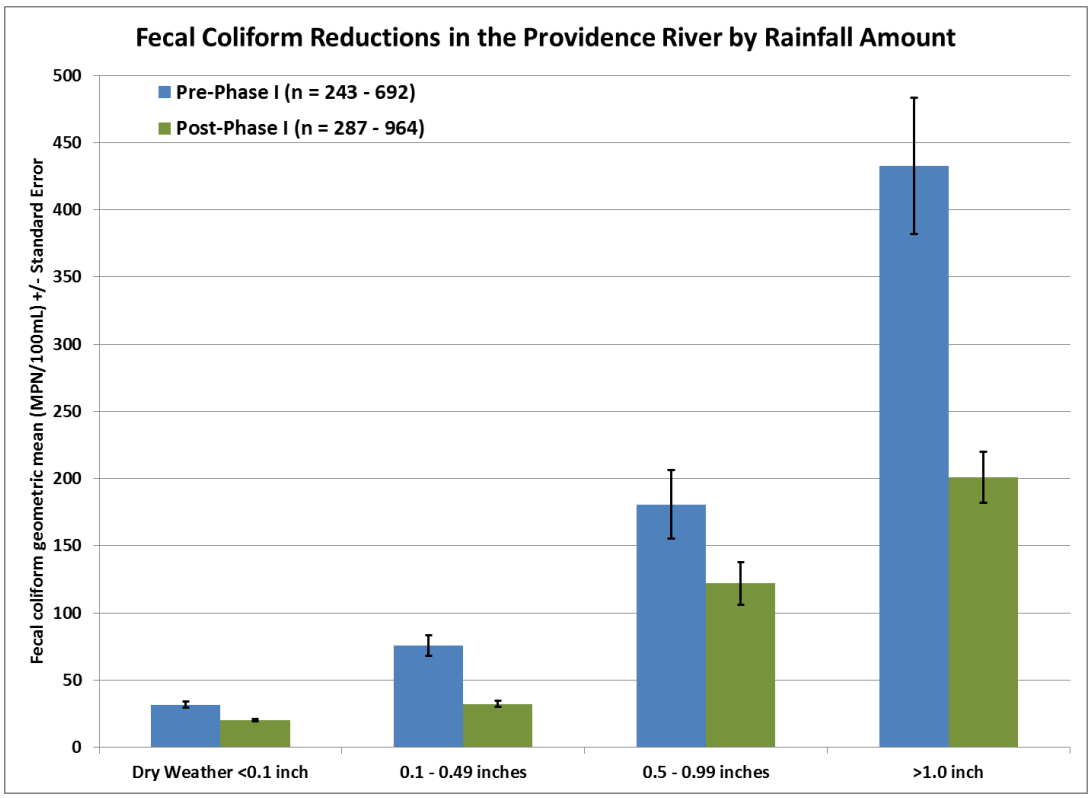


Figure 45. *Pre- and post-Phase I fecal coliform geometric means in the Providence River in varying rainfall.*

Wet weather fecal coliform data pre- and post-Phase I for all 14 sampling locations are shown in Figure 46. As this Figure illustrates, wet weather fecal coliform concentrations decreased at all stations after Phase I facilities came online. The percent decrease across the eight upper Providence River locations ranged from 26% at Collier Point Park to 58% at the Edgewood Yacht Club. Of the six locations in the lower Providence River, the percent decrease ranged from 22% at Bullock Neck to 57% at Shawomet. Fecal coliform concentrations generally decreased from the northern to the southern sampling locations from the pre- to post-Phase I time frame.

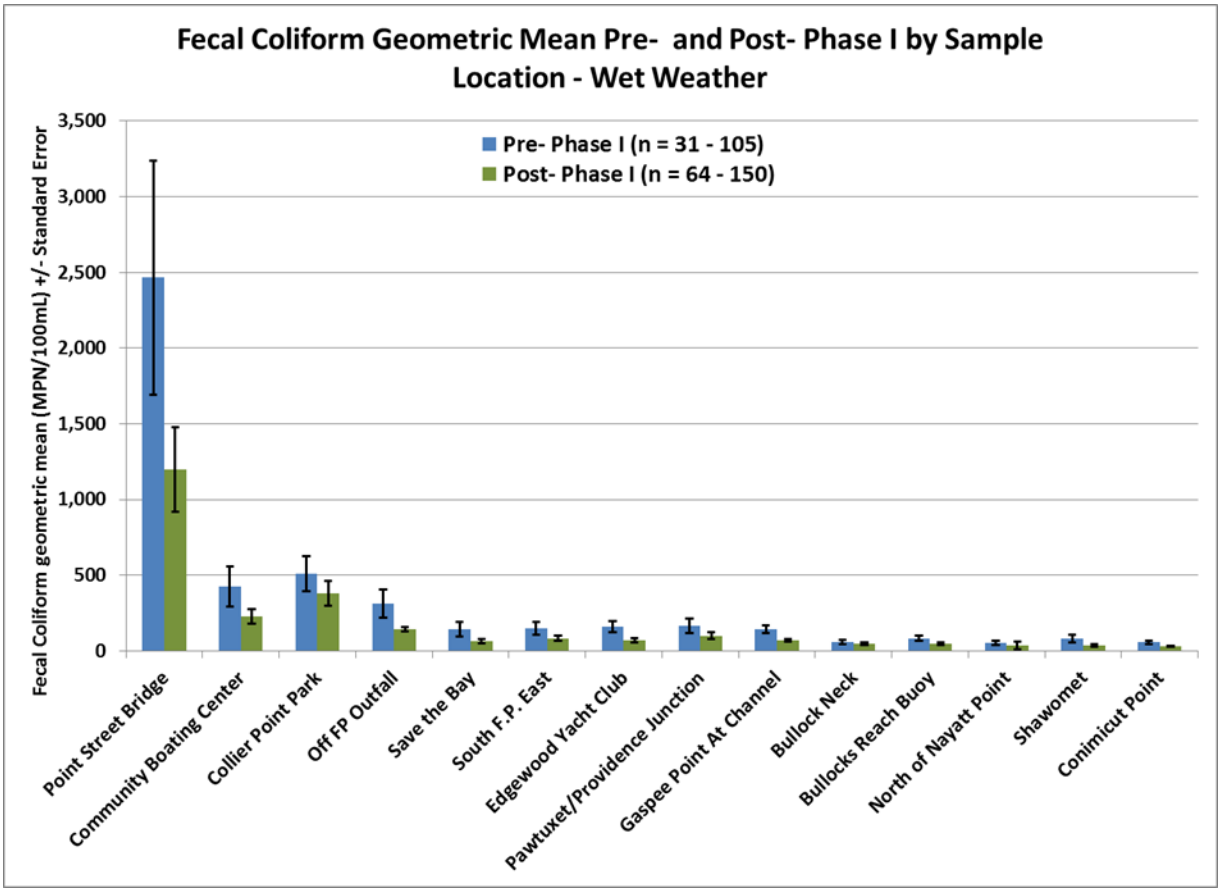


Figure 46. *Pre- and post-Phase I fecal coliform geometric means by sampling location.*

Compliance with Fecal Coliform Water Quality Standards

The fecal coliform primary contact water quality criteria for salt water includes a geometric mean no greater than 50 MPN/100 mL and no more than 10% of the sample results above 400 MPN/100 mL. As described in Chapter 5, the RIDEM evaluates compliance with these criteria based on samples taken from ***May to October***, and the analysis herein also considers data collected only during that season. Data were also compared with established RIDEM shellfishing criteria which specify a maximum geometric mean of 14 MPN/100 mL and that 10% of the samples analyzed must not exceed a value of 49 MPN/100 mL. Compliance with

shellfishing criteria are based on sampling conducted over an ***entire year***. The data were evaluated for compliance with the primary contact criteria and shellfishing criteria separately for all weather conditions, under dry weather conditions, and under wet weather conditions. It should be noted that for May through October data for each year, some data sets have a limited number of samples (i.e., <10; Table 18).

Compliance with Fecal Coliform Criteria for Primary Contact Use

The upper Providence River sample results and evaluation for compliance with fecal coliform standards for primary contact use for the ***May to October*** season are shown on Table 19. Overall, compliance rates were higher post-Phase I and in dry weather; only a single location in a single year (i.e., Edgewood Yacht Club in 2010) achieved compliance during wet weather. Two locations, Point Street Bridge and Collier Point Park, never achieved compliance with the criteria in any year under any weather conditions. The Community Boating Center station did not meet the primary contact criteria in any of the years prior to Phase I, but met them 33% of the time after Phase I in dry weather. The Off of FP Outfall station did not meet the criteria prior to Phase I, but did 67% of the time after Phase I in dry weather and 33% of the time when sample results were analyzed regardless of wet/dry determination. Prior to Phase I, the Save the Bay location met the criteria 50% of the time during dry weather; after Phase I, this compliance rate increased to 67% during dry weather. In 2014, this location also met the criteria in all weather. The South F.P. East location, Edgewood Yacht Club and the Pawtuxet/Providence River Junction locations all met the primary contact criteria in dry weather in 40% or more of the years prior to Phase I. All three locations met the contact criteria in dry weather 83% to 100% of the years after Phase I. In all weather conditions combined, there was an increase in compliance with the criteria post-Phase I at these three locations.

The results for the lower Providence River are shown on Table 20. Overall, compliance was higher in the lower Providence River than the upper. As in the upper Providence River, compliance was generally higher in dry weather and post-Phase I, though several stations also had high compliance pre-Phase I. Prior to Phase I, three of the six lower Providence River stations (Bullock Neck, Bullocks Reach, and North of Nyatt Pt.) met the criteria every year in dry weather; two stations also met the criteria each year under all weather conditions combined pre-Phase I. Under wet weather conditions pre-Phase I, compliance rates ranged from 0% to 60% of years monitored. During the post-Phase I time period, all stations met the criteria in every year under dry conditions. In the all-weather analysis, most sites achieved compliance each year post-Phase I except for 2012; only Conimicut Point achieved compliance in every post-Phase I year. In wet weather post-Phase I, improvement was seen at half of the stations in meeting the primary contact criteria compared to pre-Phase I.

Table 19. *Upper Providence River May-October fecal coliform geometric mean data. Green boxes – site met all primary contact criteria in all weather; yellow boxes – site met all primary contact criteria in dry weather; blue boxes – site met all primary contact criteria in wet weather.*

	Point Street Bridge			Community Boating Center			Collier Point Park			Off FP Outfall			Save the Bay			South F.P. East			Edgewood Yacht Club			Pawtuxet/Providence Junction		
	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET
2004	2,267	822	3,277	296	63	496	241	203	257	183	61	274	NO DATA			69	21	101	59	28	72	61	71	19
2005	2,953	3,180	2,365	389	271	1,149	294	193	955	242	184	557	51	30	268	91	76	157	58	33	335	81	50	299
2006	8,258	16,807	6,517	270	150	303	354	318	368	235	341	207	79	162	60	59	50	63	105	41	148	187	349	156
2007	945	370	2,417	169	71	401	242	114	512	101	48	213	81	14	455	50	21	118	52	14	193	106	39	290
2008	1,013	702	1,572	163	96	279	416	162	844	162	55	514	43	20	96	70	14	297	59	13	235	79	16	263
2009	2,534	701	9,153	185	85	345	269	76	628	211	65	611	54	18	160	36	10	101	31	7	73	111	33	367
2010	533	144	2,733	98	40	381	179	61	528	42	18	127	52	24	140	20	9	68	25	17	43	17	8	58
2011	725	200	4,403	230	79	802	330	161	765	170	101	310	70	44	121	45	23	99	30	15	66	54	29	111
2012	1,023	269	1,996	211	58	403	461	99	912	94	15	259	72	54	83	82	28	132	43	15	68	102	36	227
2013	664	314	2,193	247	126	610	258	105	855	98	33	418	63	27	196	57	24	180	39	11	208	41	18	127
2014	429	344	570	62	35	180	114	84	179	40	19	118	18	12	39	23	14	62	16	7	52	34	25	67

Table 20. *Lower Providence River May-October fecal coliform geometric mean data. Green boxes – site met all primary contact criteria in all weather; yellow boxes – site met all primary contact criteria in dry weather; blue boxes – site met all primary contact criteria in wet weather.*

	Gaspee Point At Channel			Bullock Neck			Bullocks Reach Buoy			North of Nayatt Point			Shawomet			Conimicut Point		
	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET
2004	48	10	85	28	9	42	33	6	61	NO DATA			NO DATA			25	6	43
2005	55	33	211	14	9	51	29	16	125	11	7	32	16	11	49	20	11	108
2006	80	65	86	33	31	34	62	40	73	19	23	17	52	83	44	36	49	33
2007	40	16	105	22	6	82	17	5	63	14	4	44	18	5	71	8	3	20
2008	51	11	206	23	8	59	33	11	87	19	4	82	42	9	121	21	9	59
2009	20	6	64	13	5	32	26	6	64	11	7	16	16	7	34	14	7	22
2010	18	11	37	10	7	15	13	10	23	6	3	12	10	5	26	12	5	41
2011	27	20	40	16	11	25	19	9	46	15	5	48	19	24	15	11	8	17
2012	51	11	96	28	11	46	35	20	51	14	5	29	25	22	26	19	10	27
2013	21	14	36	17	8	46	22	11	57	9	6	15	15	8	38	10	5	28
2014	10	4	41	8	4	25	9	4	34	6	3	16	12	6	51	7	3	27

Compliance with Shellfishing Criteria

The upper Providence River sample results and evaluation of compliance with the shellfishing criteria are shown on Table 21. As noted above, this analysis included results from samples over the ***entire year***. Though there was an overall decrease in geometric means from pre- to post-Phase I, none of the eight stations met the shellfishing criteria in any year under any weather conditions.

The lower Providence River results are shown on Table 22. Three stations, North of Nyatt Point, Shawomet, and Conimicut Point, met the shellfishing criteria in post-Phase I years 2013 and/or 2014 in all weather. None of the stations met either criterion in wet weather or dry weather in any of the years surveyed. Lack of compliance rates in dry weather may be an artifact of low sample size, though overall, improvement in fecal coliform numbers were realized.

Table 21. *Upper Providence River annual fecal coliform geometric mean data.*

	Point Street Bridge			Community Boating Center			Collier Point Park			Off of FP Outfall			Save the Bay			South F.P. East			Edgewood Yacht Club			Pawtuxet/Providence Junction		
	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET
2004	2,043	822	2,767	303	63	490	262	203	286	190	61	277	NO DATA			76	21	113	64	28	79	72	19	107
2005	2,054	2,004	2,186	353	227	1,102	349	221	1,057	245	165	671	54	29	306	84	61	191	67	37	194	77	45	233
2006	3,981	3,422	4,264	255	128	303	167	57	352	183	125	214	61	64	60	49	25	65	98	36	148	157	124	173
2007	845	370	1,570	189	71	394	277	114	540	102	48	181	75	14	257	65	21	151	65	14	201	116	39	264
2008	925	766	1,149	182	95	316	387	171	733	159	55	515	46	15	135	78	17	331	55	13	238	81	20	270
2009	945	410	2,390	117	57	241	220	77	491	120	47	318	42	19	100	42	15	115	35	11	83	59	20	178
2010	439	143	1,206	83	35	168	158	43	408	45	20	90	37	24	53	28	11	59	39	30	48	42	20	80
2011	550	186	1,239	193	91	325	208	142	270	134	61	228	46	34	58	44	19	79	48	20	88	77	37	127
2012	531	175	1,149	95	29	221	188	40	529	66	16	175	38	19	65	46	17	87	40	14	80	69	32	131
2013	408	241	1,012	167	115	291	161	97	346	60	38	96	34	20	79	33	15	72	31	11	86	43	32	56
2014	600	344	912	74	35	155	149	84	238	36	19	59	21	12	36	34	14	83	16	7	30	40	25	62

Table 22. *Lower Providence River annual fecal coliform geometric mean data. Green colored blocks indicate compliance with both the 14 MPN/100mL and 10% shellfishing water quality criteria.*

	Gaspee Point At Channel			Bullock Neck			Bullocks Reach Buoy			North of Nayatt Point			Shawomet			Conimicut Point		
	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET
2004	55	10	97	35	9	55	40	6	76	NO DATA			NO DATA			32	6	55
2005	67	35	199	16	9	67	35	17	110	14	9	54	22	14	73	27	11	116
2006	70	30	94	31	19	39	71	47	84	20	14	23	43	36	46	35	34	35
2007	48	16	112	27	6	86	21	5	61	20	4	65	23	5	77	11	3	27
2008	61	14	270	23	8	72	33	10	91	21	5	84	49	12	148	23	9	74
2009	30	12	76	18	9	38	31	11	65	17	10	26	23	14	36	20	10	33
2010	38	19	60	25	13	38	23	16	31	21	8	38	25	14	37	16	9	26
2011	37	22	52	25	12	45	28	13	47	25	8	58	31	24	37	20	9	36
2012	64	14	166	46	22	76	37	19	62	23	9	45	31	25	36	24	12	41
2013	18	12	34	19	11	45	19	10	31	11	8	16	13	8	27	11	7	20
2014	15	4	40	14	4	34	14	4	34	11	3	29	13	6	27	9	3	21

Yearly Trends

Figure 47 shows the fecal coliform geometric mean for all samples by year compared to annual rainfall from 2004 to 2014. Looking at all sampling locations grouped as the Providence River, the annual fecal coliform concentrations ranged 59-108 MPN/100 mL pre-Phase I and decreased to 28-57 MPN/100 mL post-Phase I. Annual concentrations were substantially higher in the upper Providence River than in the lower Providence River in every year. From 2004 to 2008, pre-Phase I, the geometric means in the upper Providence River ranged from 133 to 225 MPN/100 mL. From 2009 to 2014 , post-Phase I, the range decreased to 57 to 108 MPN/100 mL. The geometric mean range for the lower Providence River was 20 to 40 MPN/100 mL before Phase I and 12 to 33 MPN/100 mL after Phase I. Note that the lower Providence River geometric means were below the 50 MPN/100 mL criterion for primary contact use in every year and below the 14 MPN/100 mL shellfishing criterion in 2013 and 2014. The lowest concentrations of fecal coliforms measured over the entire ten year period occurred in 2014, despite rainfall having increased over the previous two years.

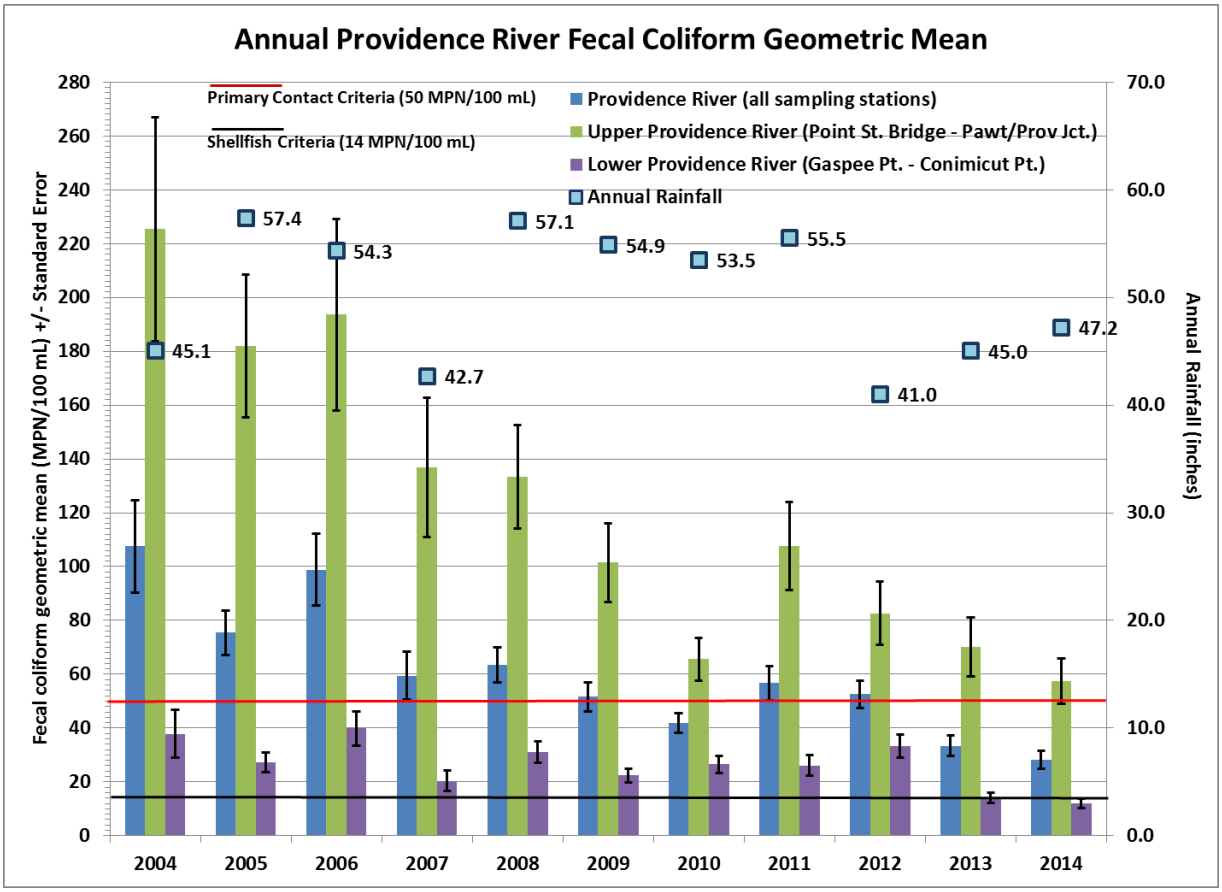


Figure 47. *Annual Providence River fecal coliform geometric means.*

Providence River Enterococci Results

In 2006, expanding upon the existing upper bay bacteria sampling, the NBC began collecting samples to be analyzed for Enterococci bacteria from five of the fecal coliform sampling locations, four in the Providence River and one in the Seekonk River. Enterococci data are used as the primary pathogen indicator to determine the closure of the state beaches. This section will focus on the Providence River data, while a later section will discuss Seekonk River results. Enterococci are sampled in 25% of the fecal coliform sample locations. Table 23 below shows the number of sample days since 2006 on an annual basis.

The pre- and post-Phase I Enterococci geometric means from the four sample locations in the Providence River are shown in Figure 48. When grouped overall, there has been very little change in Enterococci bacteria concentrations in the Providence River since 2006; the pre-Phase I and post-Phase I geometric mean concentrations were both 23 MPN/100 mL. The Point Street Bridge sample site, the furthest north on the Providence River, is located downstream of the confluence of the Woonasquatucket and Moshassuck Rivers in downtown Providence, and is the closest sampling location to the majority of Phase I improvements. This location has had the largest decrease in Enterococci and, similarly, is the same location that the NBC observed the largest decline in fecal coliform bacteria pre- to post-Phase I. Post-Phase I, there has been a 38.3% decrease in Enterococci bacteria at this site. Despite the decrease, the Point Street Bridge location has consistently had the highest Enterococci results of all the 5 sample locations since sampling began in 2006.

Table 23. Number of sample days for Enterococci in the Providence River.

	Annual			May - October		
	All weather	**Dry**	**Wet**	**All weather**	**Dry**	**Wet**
2006	15	8	7	12	5	7
2007	13	6	7	11	6	5
2008	14	10	4	10	7	3
2009	17	9	8	9	5	4
2010	20	9	11	9	5	4
2011	22	9	13	13	7	6
2012	27	11	16	13	4	9
2013	20	12	8	14	8	6
2014	18	7	11	12	7	5
Total	**166**	**81**	**85**	**103**	**54**	**49**

The sampling location that is furthest south in the Providence River, closest to open bathing beaches, is Conimicut Point. This site, for the most part, has consistently had the lowest Enterococci concentrations of the four Providence River sampling locations despite a 24% increase in Enterococci after the completion of Phase I. As for the other two Providence River sampling locations, Gaspee Point saw a slight decrease in Enterococci of 7% since Phase I was completed. South F.P. East saw a slight increase of 2% since Phase I was completed.

Wet versus Dry Weather Conditions

The same trends in Enterococci concentrations pre- versus post-Phase I observed in "all weather" data were evident in wet and dry weather data analyzed separately, as shown in Figure 49. Enterococci concentrations were relatively low and similar pre- versus post-Phase I at the three southern locations and for the Providence River as a whole. In dry weather, the overall Providence River concentrations decreased by 11% pre- to post-Phase 1, from 17 to 15 MPN/100 mL. In wet weather, the Enterococci geometric mean was 33 MPN/100 mL for both pre- and post-Phase I. The Point St. Bridge station had the highest Enterococci concentrations in both dry and wet weather; concentrations decreased by 51% in dry weather and 37% in wet weather post-Phase I at this location. The furthest downstream location, Conimicut Point, actually had a 38% increase in Enterococci bacteria concentrations after Phase I was completed.

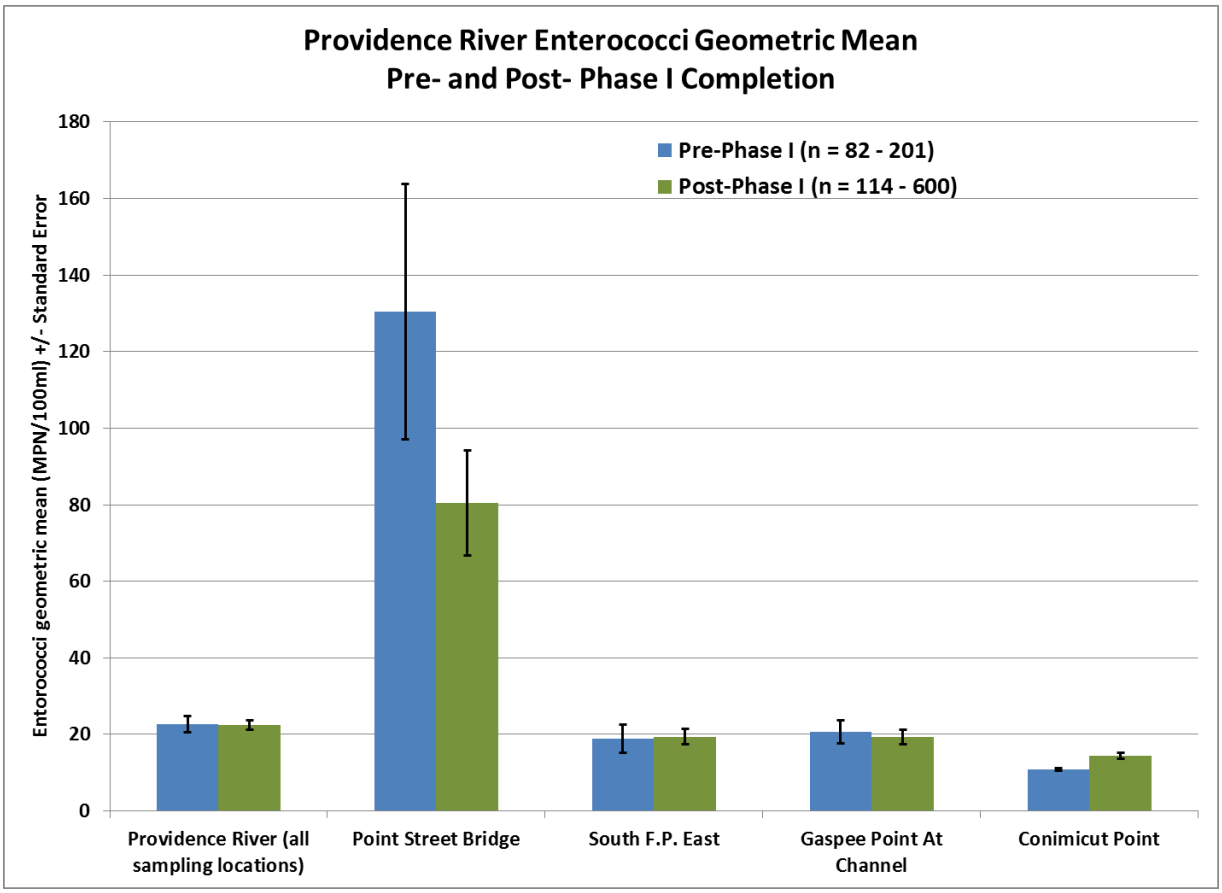


Figure 48. *Providence River Enterococci geometric means by sampling location before and after completion of Phase I.*

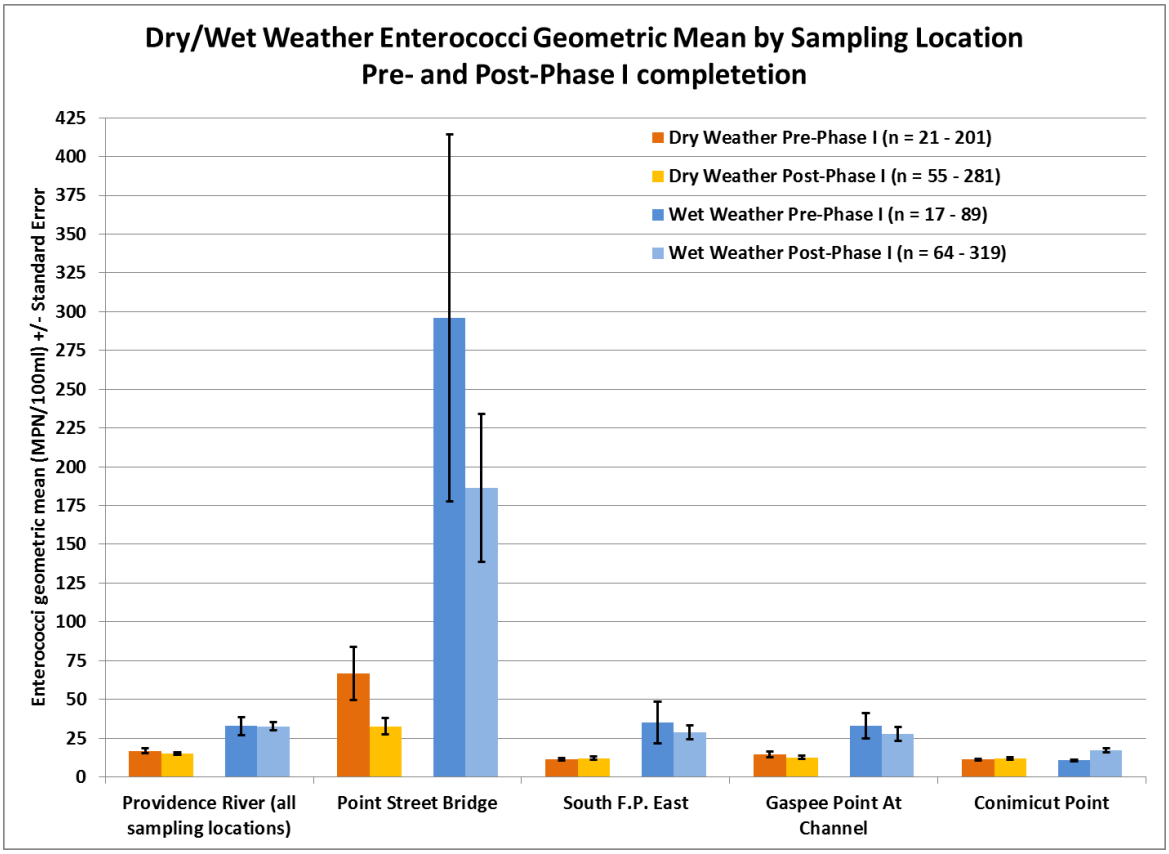


Figure 49. *Wet and dry weather Enterococci geometric mean by sampling location before and after the completion of Phase I.*

Comparison to Enterococci Primary Contact Water Quality Criteria

Enterococci data were analyzed for the ***May to October*** season and compared to the RIDEM primary contact water quality criterion of a geometric mean not greater than 35 MPN/100 mL. Evaluation of Enterococci data for designated beaches uses an additional criterion of no sample results greater than 60 MPN/100 mL. Since the waters in which the NBC takes Enterococci samples are not designated as beach waters, data were only compared to the geometric mean primary contact criterion. As is seen in Figure 50 and Table 23 below, three of the four sites consistently met the water quality criterion for Enterococci in each year pre- and post-Phase I. Only the Point Street Bridge location remained above this criterion in every year, despite a significant decrease in Enterococci concentration after 2006.

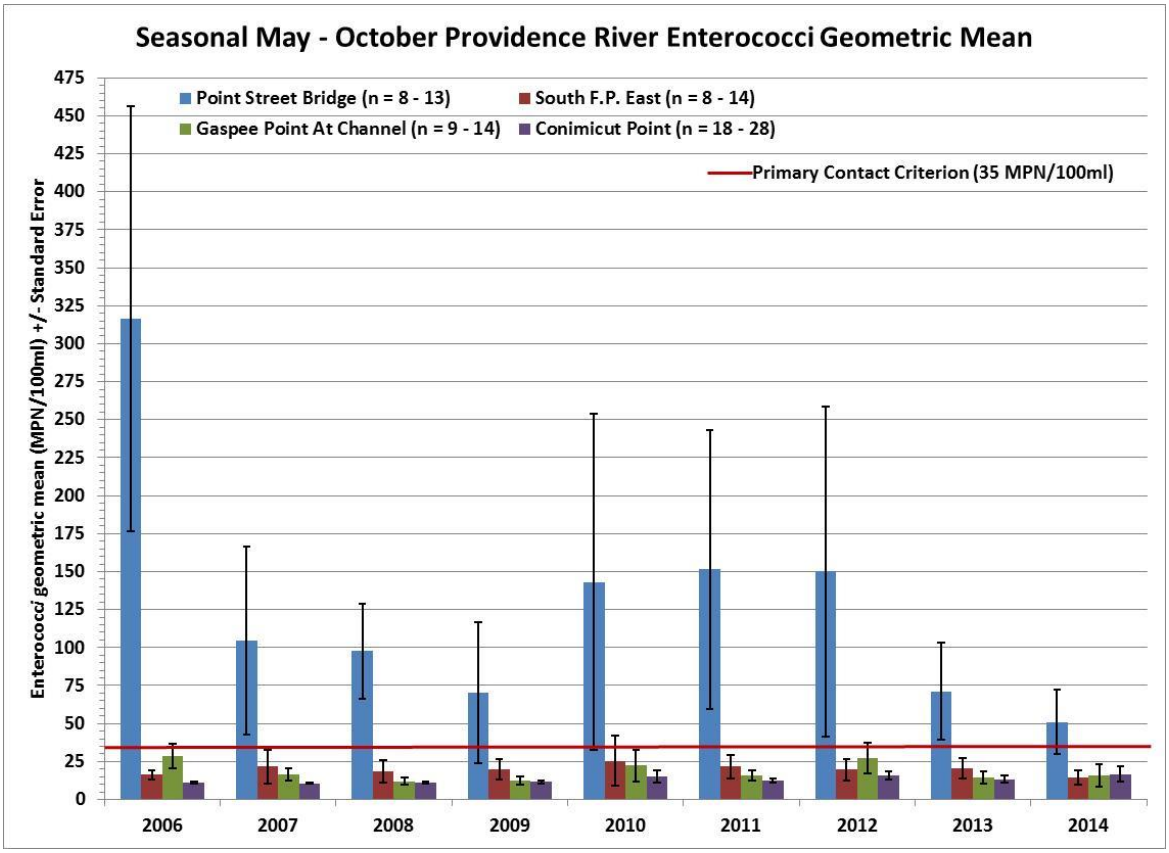


Figure 50. *May to October annual Enterococci geometric means in the Providence River 2006 – 2014.*

Table 24. *May to October geometric means at each Enterococci sampling station. Green boxes indicate compliance with primary contact criteria.*

	Point Street Bridge	South of F.P. East	Gaspee Point	Conimicut Point
2006	316	16	29	11
2007	105	22	17	11
2008	98	18	12	11
2009	70	20	13	12
2010	143	26	22	15
2011	152	22	16	12
2012	150	20	27	16
2013	71	20	14	13
2014	51	15	16	17

Yearly Trends

Annual geometric mean Enterococci concentrations in the Providence River are shown in Figure 51, along with annual rainfall totals. Over the course of the sampling period for Enterococci from 2006 to 2014, there has been no distinct increase or decrease in the overall Providence River Enterococci geometric mean, nor do concentrations appear correlated with rainfall. The lowest overall Enterococci geometric means occurred in 2008 and 2013, each with an annual geometric mean of 18 MPN/100 mL, though with fairly different annual rainfall amounts. The low geometric mean in 2008 was associated with the highest annual rainfall total, 57.1 inches, of all

the years surveyed. The highest overall Enterococci geometric mean occurred in 2010 at 27 MPN/100 mL, with an annual rainfall total of 53.5 inches. From 2010 to 2013, Enterococci showed a decreasing trend in the Providence River, before increasing again in 2014. Overall, annual geometric means were all below the 35 MPN/100 mL primary contract criterion for Enterococci.

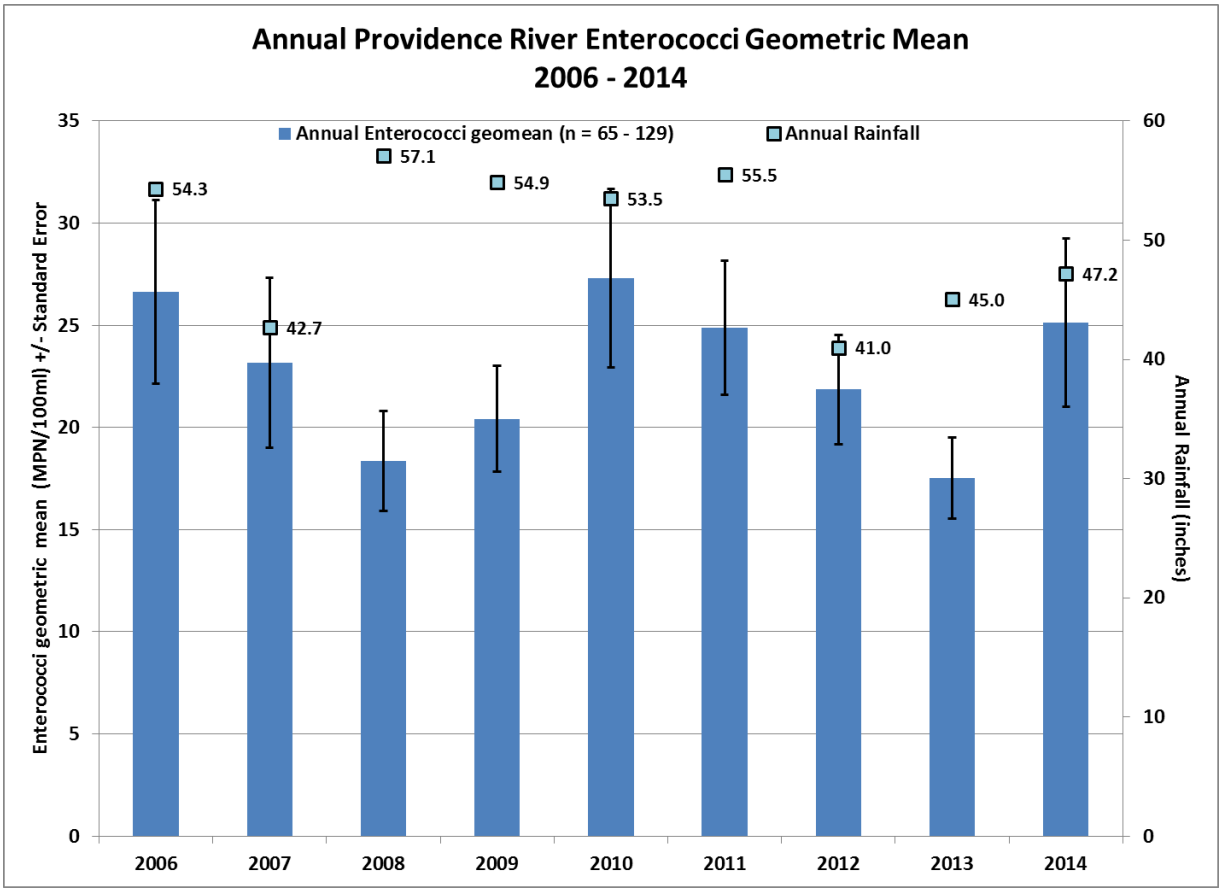


Figure 51. *Annual Providence River Enterococci geometric means and rainfall, 2006 – 2014.*

Annual geometric mean data by sampling location are presented in Figure 52. From this comparison, it is clear that the post-Phase I decline in Enterococci at Point Street Bridge was mainly attributable to a precipitous decline from 2006 to 2007; Since 2007, Enterococci results have been variable, though not showing a distinct increase or decrease overall. As shown in previous figures, there was evidence of a down bay gradient in Enterococci concentrations, where the lowest concentrations were consistently observed at the southernmost site, Conimicut Point. Though Enterococci were variable at this and the other two southern sites, there was no clear increasing or decreasing trend over the years.

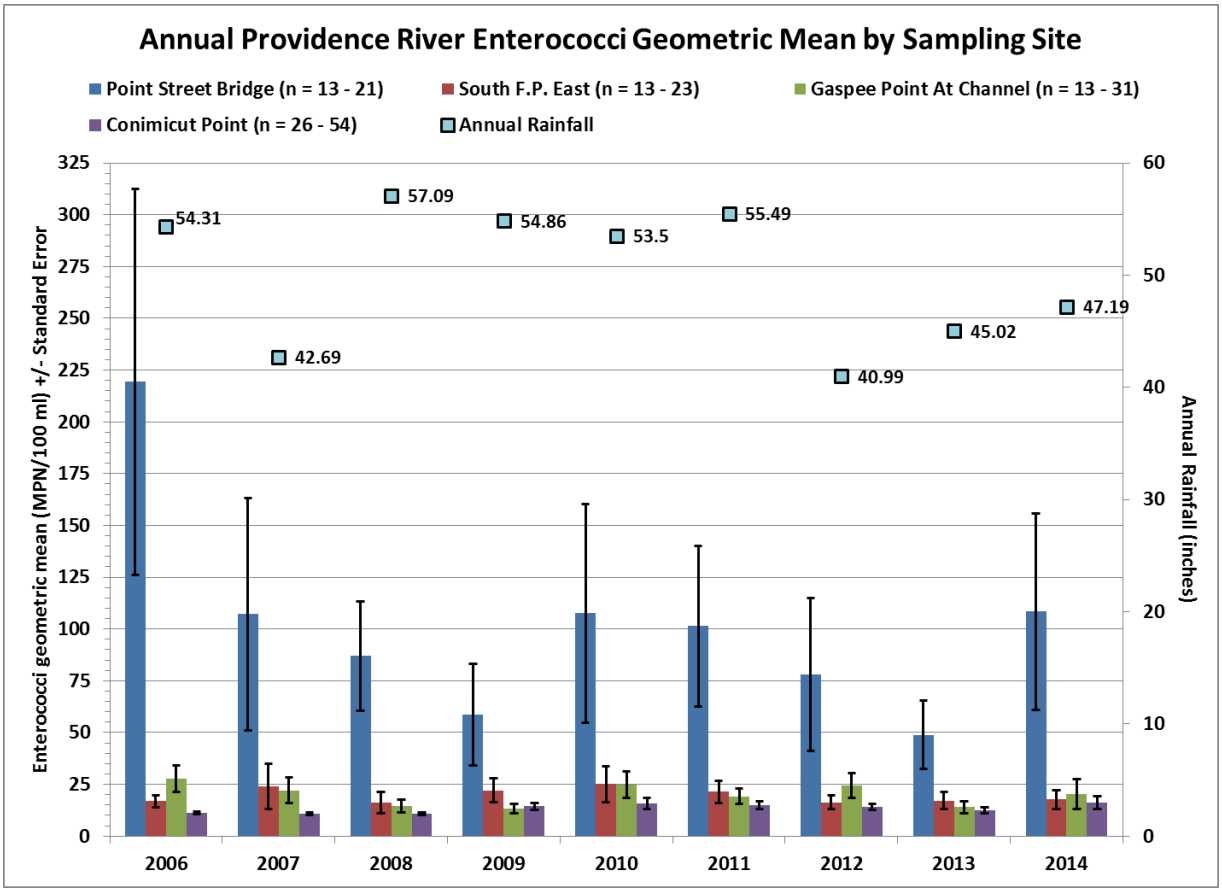


Figure 52 . *Annual Enterococci geometric means by sampling location, 2006 – 2014.*

Seekonk River Results

Seekonk River Fecal Coliform Results

During Phase I, the wet weather treatment capacity at the Bucklin Point WWTF was increased from 60 MGD to 116 MGD when the existing primary clarifiers were converted to wet weather treatment facilities. Prior to these facilities going online, wet weather flow above 60 MGD was diverted through the North Diversion Structure untreated into the Seekonk River. Though this North Diversion Structure is still occasionally utilized in wet weather, the number of overflows has greatly decreased (see Chapter II). Because these improvements were completed by the end

of 2005, pre-Phase I for the Seekonk River data analysis is from 2004 to 2005. Post-Phase I is from 2006 through the end of 2014.

Table 25. *Number of Fecal coliform sample days in the Seekonk River.*

	Annual			May - October		
Year	**All weather**	**Dry**	**Wet**	**All weather**	**Dry**	**Wet**
2004	18	4	14	17	4	13
2005	25	18	7	20	15	5
2006	15	5	10	11	3	8
2007	14	6	8	12	6	6
2008	14	7	7	10	5	5
2009	28	12	16	19	7	12
2010	29	12	17	10	6	4
2011	22	9	13	13	7	6
2012	28	11	17	13	4	9
2013	21	13	8	15	9	6
2014	22	11	11	17	11	6
TOTAL	**236**	**108**	**128**	**157**	**77**	**80**

Fecal coliform samples are taken at six sampling locations in the Seekonk River. Table 25 above shows the number of samples days of fecal coliform collections in the Seekonk River since 2004. The most upstream site is at the Division Street Dock which is just downstream from Slater Dam where the Blackstone River becomes the tidally influenced Seekonk River. The most downstream sampling location is at Crook Point. The following graphs in which all sampling locations are displayed show the sites in order from upstream to downstream. These sampling locations are mapped in Figure 41.

As can be seen in Figure 53, the fecal coliform concentrations for the Seekonk River, under all weather conditions, decreased for all six sampling locations post-Phase I compared to pre-Phase I. The largest decrease, 62%, occurred at Phillipsdale Landing. The smallest decrease was 21% at the Division Street Dock location, the most upstream sampling site. The geometric mean concentrations at the other sampling locations decreased between 39% and 52%.

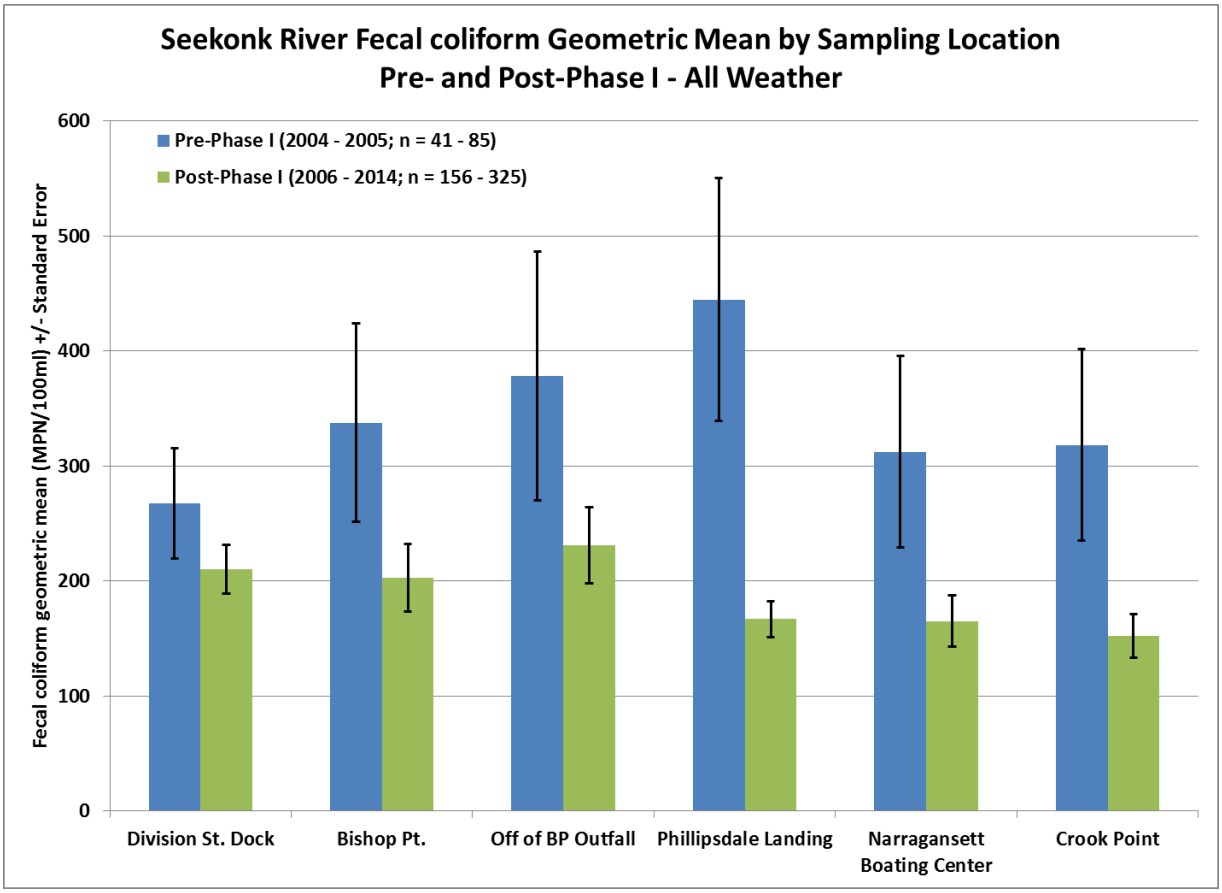


Figure 53. *Seekonk River fecal coliform geometric means pre- and post-Phase I completion at individual sampling locations.*

Figure 54 shows the wet weather fecal coliform geometric means for the Seekonk River for the ***entire year*** pre- and post-Phase I. Except for the most upstream station, Division Street Dock, which was essentially unchanged, decreasing by only 3%, the results at the other stations decreased more substantially post-Phase I. The greatest decrease was 72% at Phillipsdale Landing. Reductions at the other stations ranged from 43% to 54%. These results demonstrate that the Phase I improvements at the Bucklin Point WWTF resulted in a substantial decrease in bacterial concentrations in the Seekonk River.

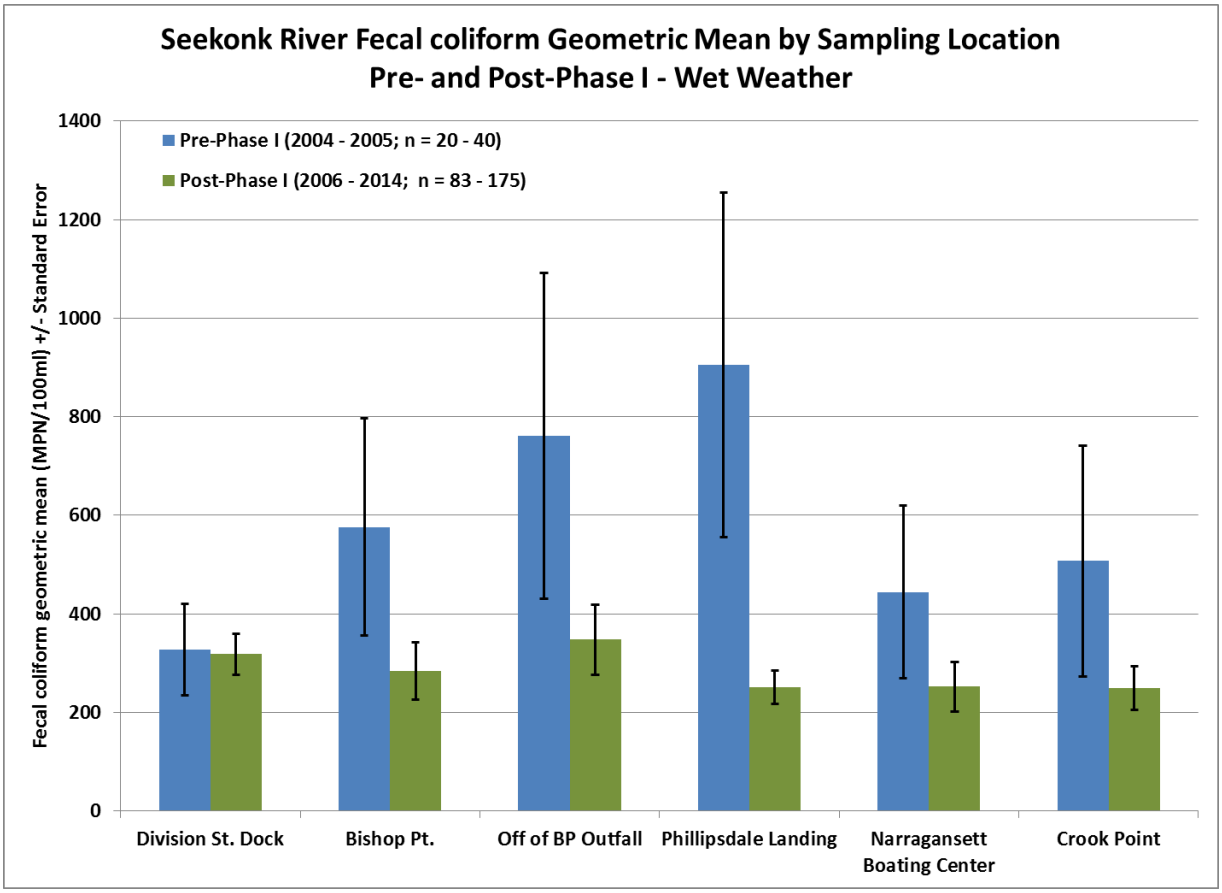


Figure 54. *Wet weather fecal coliform geometric means in the Seekonk River by sampling location.*

Compliance with Fecal Coliform Water Quality Standards

A detailed evaluation of the ***May to October*** compliance of Seekonk River sampling data with the RIDEM primary contact water quality criteria is shown in Table 24 and Figure 48. Overall compliance at these locations was low. Only the Narragansett Boating Center met the criteria in a single year, 2014, and only during dry weather.

Table 26. *All weather, dry and wet weather fecal coliform geometric means May – October at Seekonk River sampling locations. Orange colored blocks indicate compliance with both the 50 MPN/100mL and 10% criteria.*

May - Oct	Division St. Dock			Bishop Pt.			Off of BP Outfall			Phillipsdale Landing			Narragansett Boating Center			Crook Point		
	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET	ALL	DRY	WET
2004	178	82	231	322	96	482	448	173	615	727	210	970				320	234	355
2005	432	319	1097	394	304	819	339	239	966	320	267	533	263	207	517	295	210	819
2006	229	168	257	280	182	329	352	311	368	223	246	214	234	366	198	328	334	326
2007	441	257	756	410	204	822	211	144	310	156	103	236	126	56	285	177	71	440
2008	222	167	293	364	217	608	565	380	841	542	740	396	240	204	282	193	156	239
2009	205	100	422	136	95	194	163	84	316	209	132	332	210	48	911	200	64	388
2010	441	154	1445	216	76	609	342	43	2712	120	44	426	159	66	381	118	43	541
2011	430	325	637	338	223	606	509	510	507	190	124	312	221	136	388	108	89	135
2012	437	109	874	200	132	246	371	56	959	296	70	609	354	45	855	398	68	772
2013	185	86	447	314	137	811	250	127	542	208	100	480	233	99	701	191	102	426
2014	295	194	628	236	121	1019	147	147	147	64	51	97	57	44	90	57	27	170

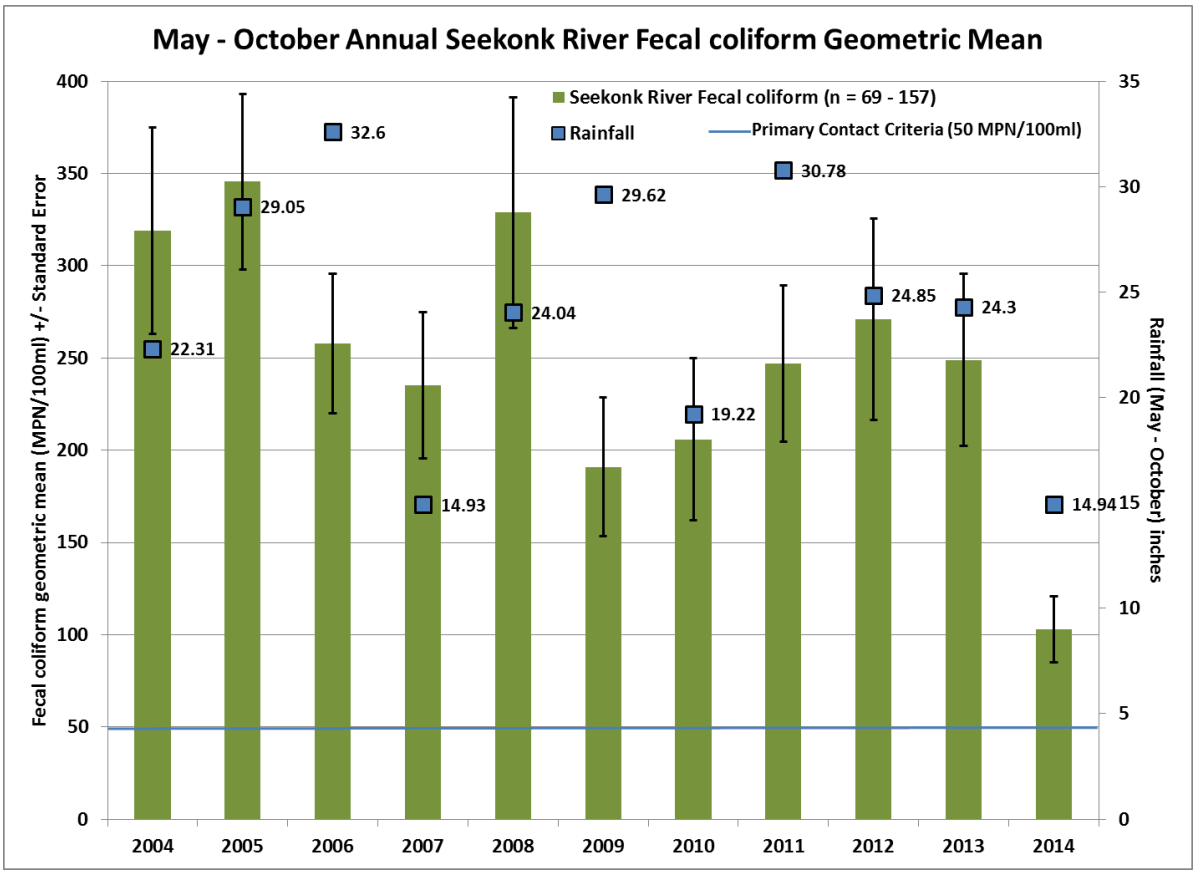


Figure 55. *Seasonal Seekonk River fecal coliform geometric means compared to seasonal rainfall totals and water quality standards.*

Yearly Trends

Annual Seekonk River fecal coliform data are shown in Figure 56. There appear to be two periods of decline in Seekonk River fecal coliform geometric means. The first occurred after wet weather facility upgrade construction was completed at Bucklin Point and came online in 2006, and the second after the completion of Phase I in 2008. From 2004 to 2005, overall fecal coliform geometric means in the Seekonk River were in the 330 MPN/100 mL range. In the 2006 to 2008 time period, they had decreased to the 260 MPN/100 mL range. After the final completion of Phase I in 2008, there was a noticeable decline in fecal coliform to a range from 135 to 200 MPN/100 mL. This post-Phase I decline may be due to a decrease in fecal coliform bacteria being carried upstream into the Seekonk River from the Providence River at high tide.

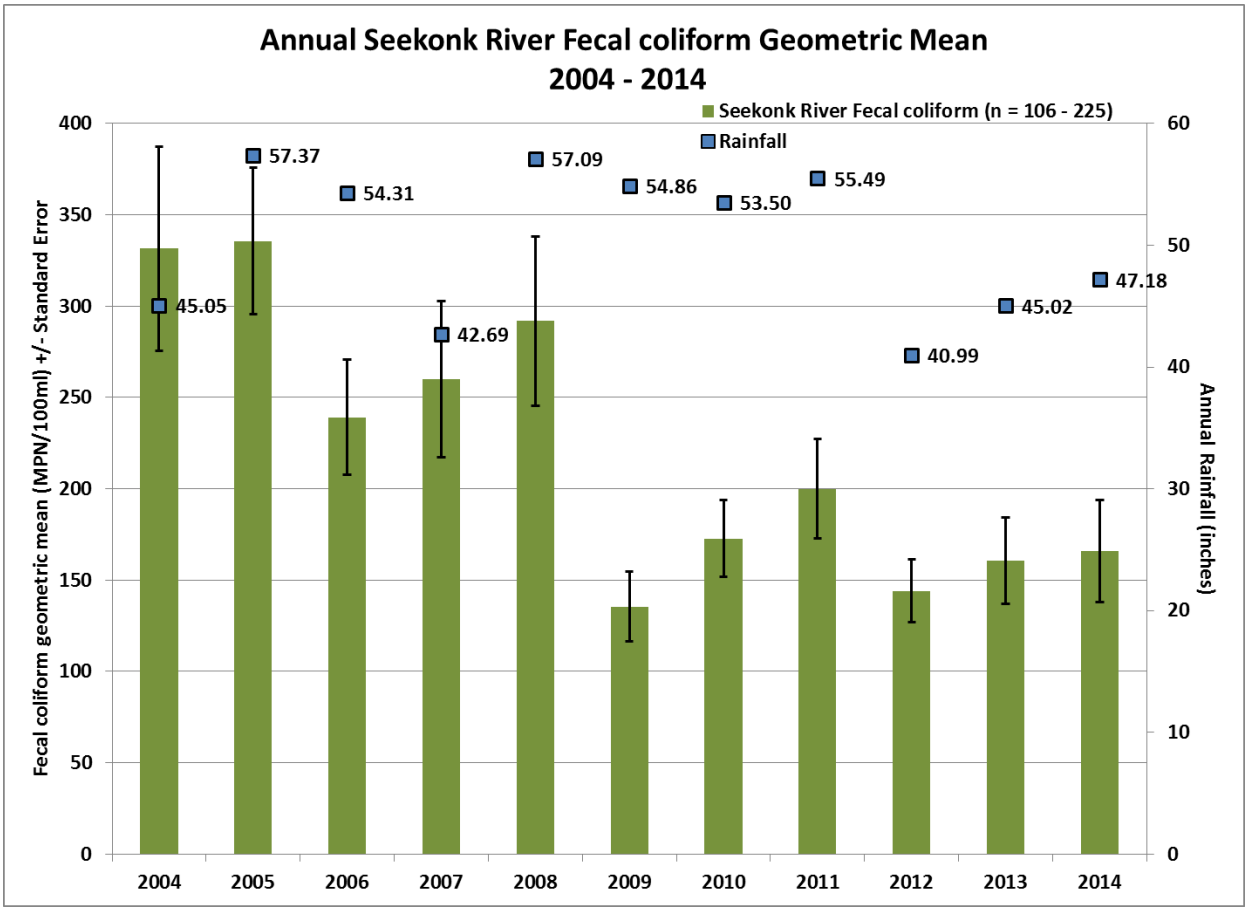


Figure 56. *Annual Seekonk River fecal coliform geometric mean 2004 – 2014. Data for all sampling locations was combined on an annual basis.*

Figure 57 presents these data separated into the three time periods discussed above: 2004 to 2005, 2006 to 2008 and 2009 through 2014. The overall decline observed during these time periods was observed at every station monitored.

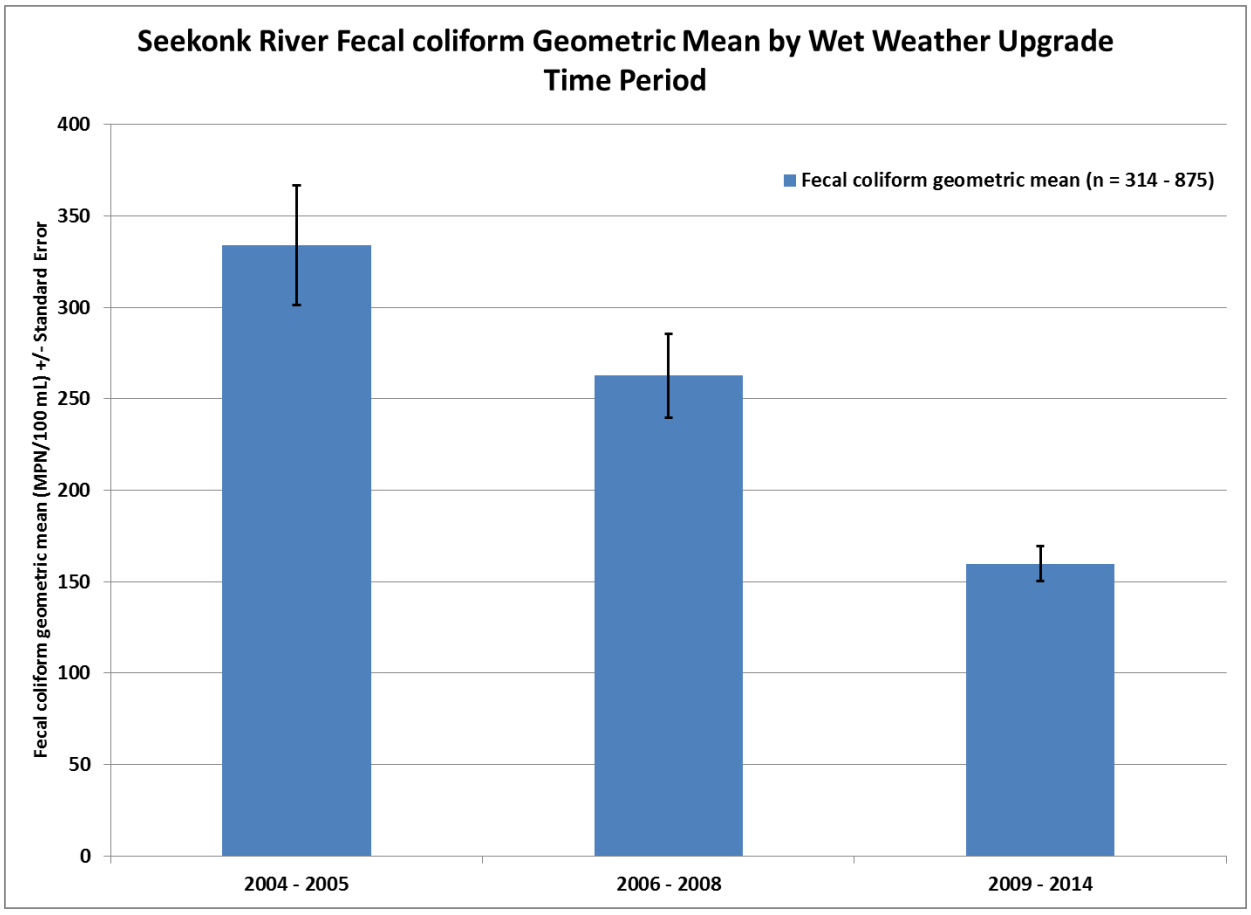


Figure 57. *Fecal coliform data separated by time period and sampling location.*

Seekonk River Enterococci Results

In addition to the four sample locations monitored for Enterococci in the Providence River, one station in the Seekonk River, Phillipsdale Landing, is also sampled for Enterococci. Figure 58 below shows both the annual geometric mean and the ***May to October*** geometric mean for Enterococci. In all years from 2006 – 2014, Enterococci has met the primary contact criterion of a geometric mean below 35 MPN/100 mL, except for 2008. As in the Providence River, there is no clear increasing or decreasing trend over the years. Since there are no data prior to 2006, the effects of the wet weather facilities at Bucklin Point cannot be evaluated.

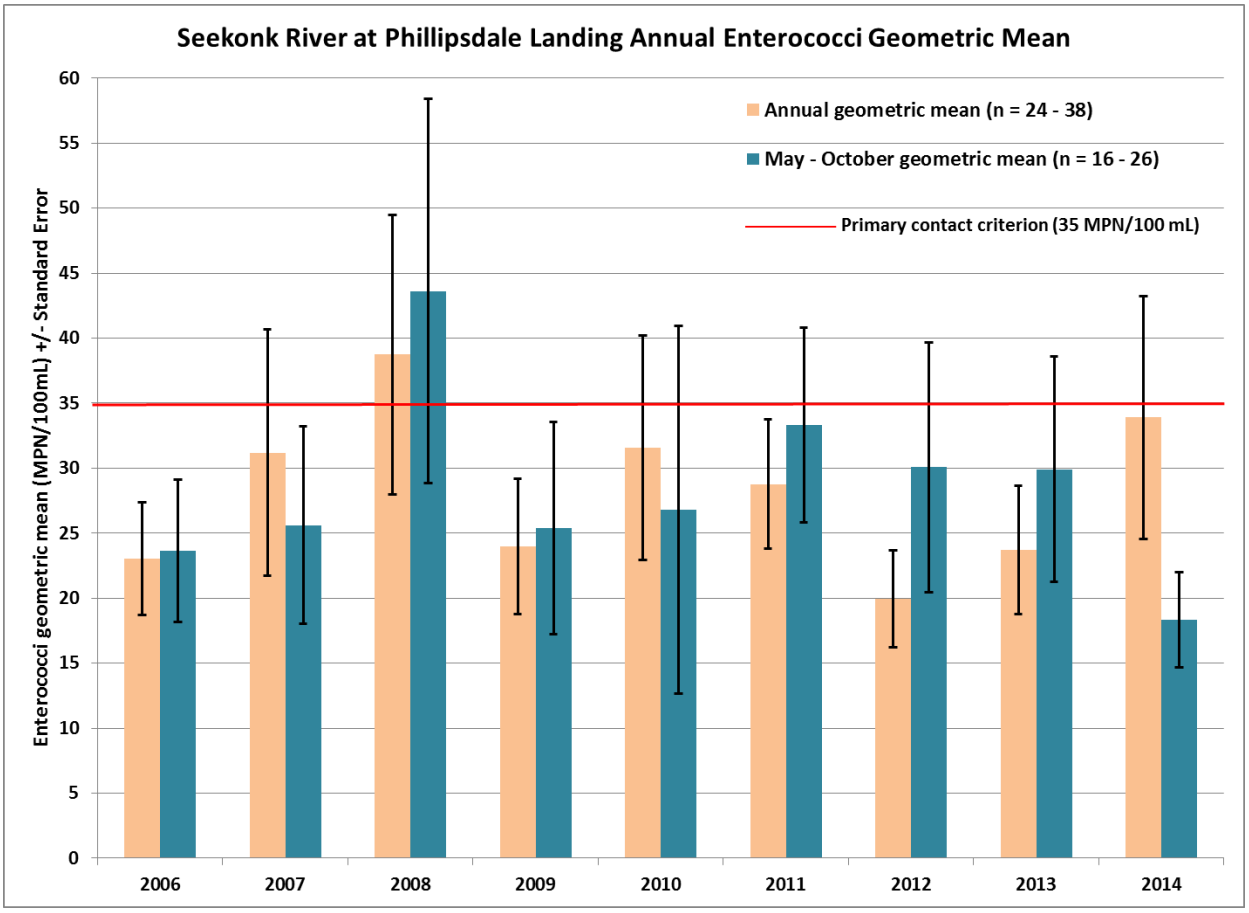


Figure 58. *Seekonk River Enterococci geometric mean from 2006 to 2014.*

Documented Benefits of Improved Upper Bay Water Quality

In addition to the extensive monitoring completed by the NBC, other organizations have documented improvements in upper Bay water quality and have attributed the improvements to the success of Phase I of the CSO Abatement Program. Shellfishing is a multi-million dollar industry in Rhode Island, for which clean water is essential. Historically, when wet weather and CSO discharges occurred from the NBC treatment facilities, RIDEM would close the two most northern shellfishing areas in Narragansett Bay, Conditional Areas A and B, shown in Figure 59. Before Phase I, Area A was closed after 0.5 inches of rainfall within a 24 hour period and Area B

after 1.0 inch of rain. In 2011, RIDEM changed the closure threshold for Conditional Area A to 0.8 inches of rain or greater and Conditional Area B to 1.5 inches of rain or greater. On average, Area A is expected to be open 65 more days per year and Area B is projected to be open 45 more days per year. Data from two years with similar rainfall (i.e., 2004, pre-Phase I, compared to 2013, post-Phase I) there was a 36% increase in the number of acre-days that the Conditional Areas were open to shellfishing after Phase I came online (Watershed Counts 2014). In a press release from the RIDEM announcing these changes, Phase I was specifically cited as the reason for the changes: "*…the changes are a result of water quality improvements associated with the completion of Phase I of the three-phase Narragansett Bay Commission (NBC) combined sewer overflow (CSO) program in 2008*" (DEM Press Release, May 26th, 2011).

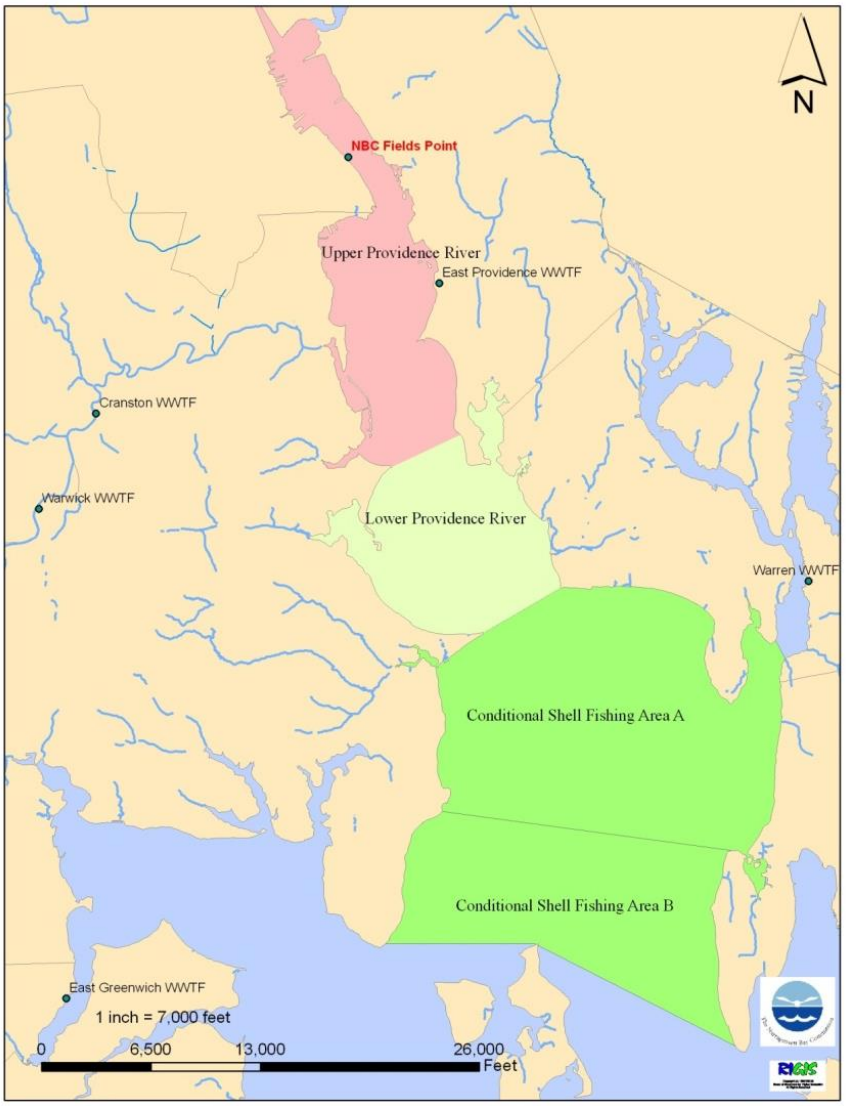


Figure 59. *Map of upper Narragansett Bay displaying Conditional Shellfishing Areas A & B.*

Beach closures have also decreased as a result of the Phase I CSO Abatement Program. There are three beaches in upper Narragansett Bay that the Rhode Island Department of Health (RIDOH) considers to be impacted by the CSOs: Bristol Town Beach, Barrington Town Beach, and Conimicut Point Beach, each of which are shown on Figure 60. During the 2010 beach season, the RIDOH found marked improvement in the number of beach closures. When they compared the saltwater beach closures from 2010 (post-Phase I) to the summer of 2006 (pre-Phase I), years of similar rainfall, they found a 41% decrease in closure events and a 73% decrease in closure days as shown in Figure 61. Specifically, the decrease was even greater at the three upper Bay beaches affected by the NBC's CSOs, with a 44% decrease in closure events and an 82% decrease in closure days. In March 2011, the RIDOH cited the CSO tunnel Project as one reason for beach improvements: *"Improvements in water quality and decrease in beach closures can be attributed to implementation of the Providence CSO tunnel Project…" (From a presentation entitled Rhode Island Department of Health Beach Program: 2011 Land and Water Conservation Summit March 26, 2011)*. Since 2010, beach closures have continued to be reduced compared to pre-Phase I.

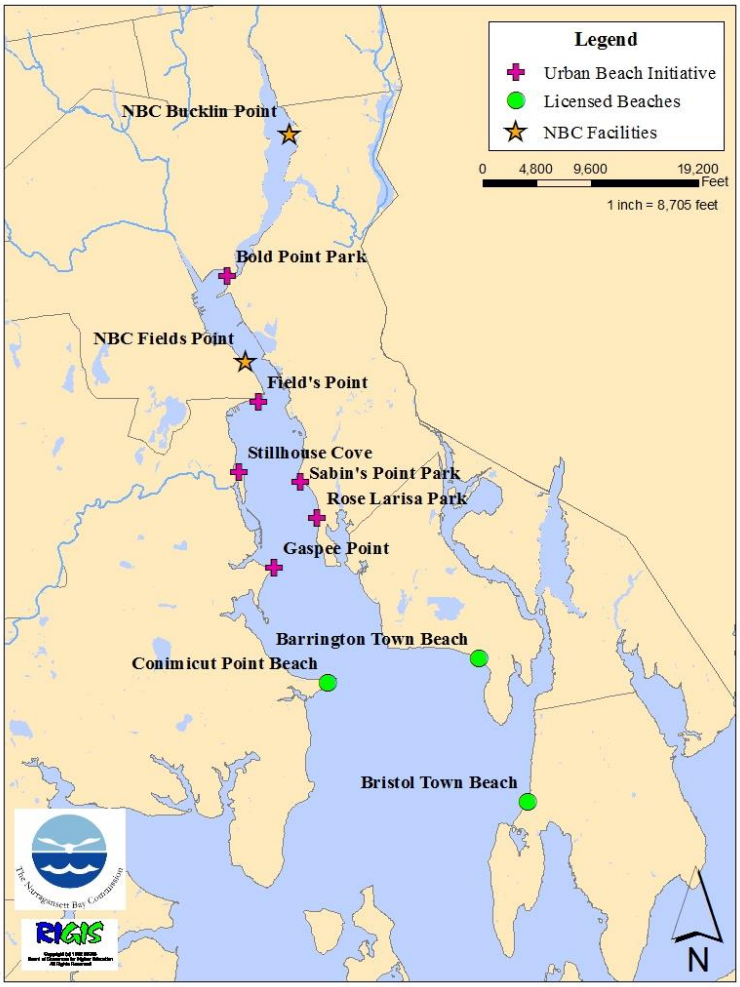


Figure 60. *Map of Licensed and Urban Beaches in upper Narragansett Bay.*

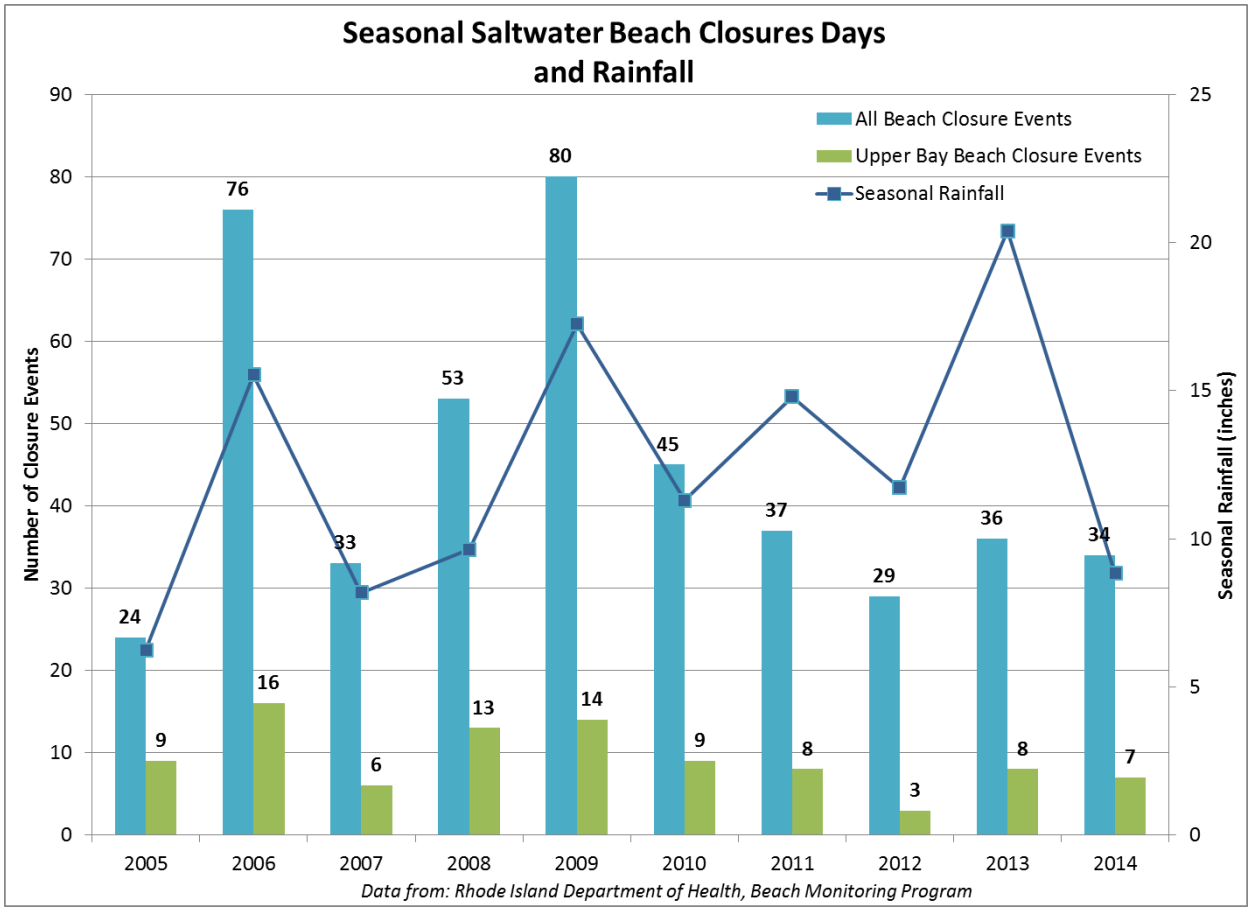


Figure 61. *Seasonal saltwater beach closure events at all Rhode Island beaches and the three upper Bay beaches affected by CSOs from 2005 through 2014.*

Since rainfall is a major influence on the number of beach closure events each year, the number of closure events per inch of rainfall during each beach season was calculated and shown in Figure 62. Prior to the completion of Phase I, there was an average of 4.6 beach closures at all of Rhode Island's saltwater beaches per inch of rain. Since the completion of Phase I, a remarkable decrease in beach closure events per inch of rainfall at RI saltwater beaches has been realized, with a low of 1.8 in 2013 and an overall post-Phase I average of 3.2. The same trend is apparent when the three upper Bay beaches are evaluated alone. Prior to Phase I, beach closures per inch of rainfall averaged 1.1, while after the completion of Phase I the value decreased to a low of 0.26 and an average of 0.6 beach closures per inch of rainfall. The reductions in beach closure events can be attributed to the NBC's investments in Phase I, as well as other infrastructure improvements around the state, such as green infrastructure improvements at Bristol Town Beach and an ultraviolet disinfection system installed at Easton's Beach in Newport, RI.

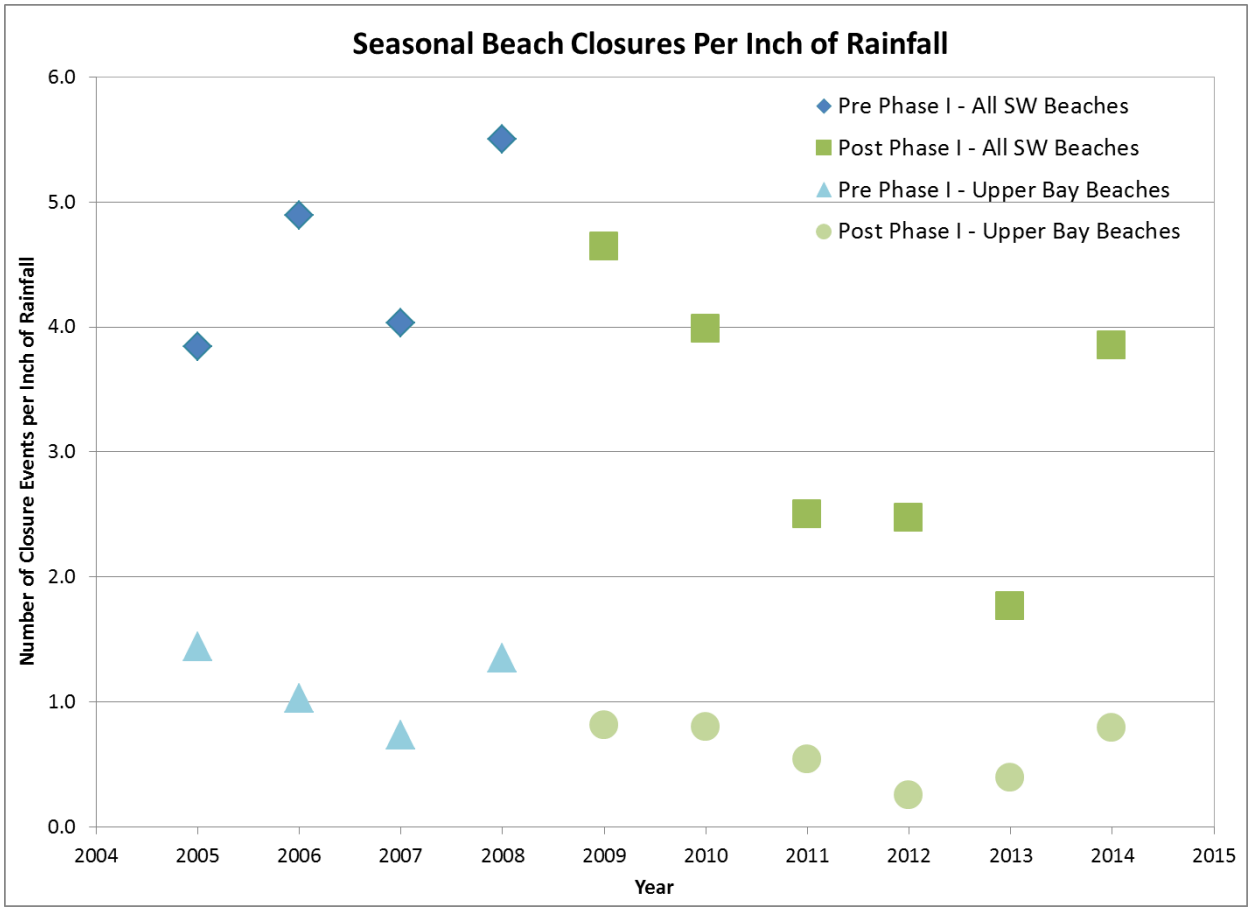


Figure 62. *Seasonal saltwater beach closure events at all Rhode Island beaches and the three upper Bay beaches affected by CSOs per inch of rainfall.*

In 2010, the RIDOH initiated a study entitled the "Urban Beach Initiative", which sampled three beaches in the Providence River area: Sabin's Point, Gaspee Point and Rosa Larisa Park, for their potential to become licensed beaches (Figure 60). These access points were already being utilized by the area's population, so the RIDOH's intent was to determine if they were safe for this recreational use. The results showed that these beaches had a compliance rate with primary contact pathogen standards ranging from 85% to 91%. In 2011, the program was expanded to include Bold Point and Field's Point. Since there was more rainfall during the beach season in 2011 (14.8 inches) than 2010 (11.29 inches), it was not surprising that the compliance rate with pathogen standards decreased to 74%. Sampling at all five stations continued in 2012, where the compliance rate was 88%, comparable to 2010, a year with similar rainfall. In 2013, due to budget cuts the program was drastically cut to include only two urban beaches, Sabin's Point and Field's Point. Though the sampling was reduced, the 78% compliance rate with pathogen standards was impressive considering the large amount of rain that fell in 2013 over the beach season, 20.39 inches, almost double the amount in 2010 and 2012. In 2014, the program continued with three of the previous stations and the addition of a new station, Stillhouse Cove. Compliance at these beaches ranged from 79% at Sabin's Point to 100% at Stillhouse Cove where limited sampling was conducted. The relatively high compliance rates at the Providence River beaches sampled as part of the "Urban Beach Initiative" suggests that these beaches are safe for recreational use; in fact, the city of East Providence is moving forward to open Sabin's Point as a licensed beach.

Results Summary

Providence River Fecal Coliform

Fecal coliform concentrations in the Providence River have decreased 41% since the completion of Phase I. Most of this decrease was in the upper Providence River where concentrations decreased by 52%. This decrease is similar to the percent reduction in CSO flow since the completion of Phase I. The decrease in the lower Providence River was lower at 24%, likely because these stations are further away from the CSO discharges and are not as greatly affected by the reduction in volume. All fourteen sampling locations in the Providence River have seen a decrease in fecal coliform concentrations after Phase I completion, with the largest overall decrease observed at the Point Street Bridge sampling site; the largest percent decrease was observed at Edgewood Yacht Club. In wet weather, the decrease in fecal coliform concentrations in the Providence River was 50%, similar to the decrease observed under all weather conditions. The majority of this decrease was in the upper Providence River, which saw a 53% decrease in wet weather; the decrease in the lower Providence River was 44% in wet weather. Since the completion of Phase I, there has been a substantial decrease in fecal coliform concentrations in the Providence River after small wet weather events between 0.1 - 0.49 inches of 57%. In rainfall greater than 1.0 inch, there has been a 54% decline in fecal coliform concentrations in the Providence River.

Most stations showed some improvement in attaining compliance with the primary contact water quality standards post-Phase I in dry weather. In wet weather, improvements in attaining compliance with this standard were mostly in the lower Providence River locations. The three stations in closest proximity to the Conditional Shellfishing grounds had much improved results in 2013 and 2014, meeting shellfishing criteria in both years. The reductions in bacterial loadings due to Phase I allowed RIDEM to change the closure policy for shellfishing for Conditional Area A from 0.5 inches of rainfall within a 24 hour period to 0.8 inches, and for Conditional Area B from 1 inch to 1.5 inches of rain.

Providence River Enterococci

Since 2006, NBC monitoring data shows no remarkable change in Enterococci bacteria in the Providence River. Of the four stations sampled in the Providence River, three of them have had a decrease in Enterococci bacteria post-Phase I completion. The largest decrease was observed at the Point Street Bridge location, the same location that had the largest decrease in fecal coliform bacteria. Comparison of annual data by site revealed that the post-Phase I decline in Enterococci at Point Street Bridge was largely attributable to a precipitous drop in concentrations from 2006 to 2007. While significant upgrades to the wet weather facilities at Bucklin Point came online in 2006, it is unclear if the drop in Enterococci could be attributable to these improvements. Without data on Enterococci concentrations in the years prior to the upgrade, it is difficult to know if 2006 was representative of earlier years, had already shown improvement over previous years, or was simply an anomalously high year. Conimicut Point, the furthest downstream sampling location in the Providence River, has actually had an increase in Enterococci after Phase I was completed. In comparing wet and dry weather Enterococci concentrations, three of the four sites have had a decrease in wet weather Enterococci concentrations, including the Point Street Bridge, the South F.P. East, and Gaspee Point at Channel locations. Conimicut Point had an increase in wet weather Enterococci concentrations post-Phase I.

Seekonk River Fecal Coliform and Enterococci

The Seekonk River is not meeting fecal coliform water quality standards even after the Bucklin Point WWTF wet weather facility improvements came online; however, most Seekonk River sampling locations have seen decreases in wet weather fecal coliform concentrations of 43% to 72%. Analysis of the NBC river fecal data shows that in wet weather, the sampling location upstream of all CSOs on the Blackstone River also does not meet water quality standards. This suggests that additional pollution control initiatives addressing sources upstream of NBC CSOs and the Bucklin Point WWTF are needed to meet water quality standards in the Seekonk River.

Enterococci results at the single monitoring location at Phillipsdale Landing have met the primary contact criterion of a geometric mean below 35 MPN/100 mL in nearly every year since monitoring began in 2006; the criterion was not met in 2008. As in the Providence River, there is no clear increasing or decreasing trend in Enterococci concentrations over this time frame. Since

there are no data prior to 2006, the effects of the wet weather facilities at Bucklin Point cannot be evaluated for Enterococci.

Documented Benefits of Improved Upper Bay Water Quality

Due to decreases in bacteria concentration in the Conditional Shellfishing areas, the RIDEM was able to change the closure policy for Conditional Area A to 0.8 inches of rain or greater and Conditional Area B to 1.5 inches of rain or greater, allowing for more potential days shellfishing each year. Decreased bacteria concentrations have also reduced beach closures in the state. The RIDOH's "Urban Beach Initiative" suggests that additional beaches in the Providence River are safe for recreational use, and the city of East Providence is moving forward to open Sabin's Point as a licensed beach.

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Chapter VII – Evaluation of WWTF Nutrient Loading and Bay Concentrations

This chapter summarizes reductions in nitrogen loading to the receiving waters following nitrogen removal upgrades at each of the NBC WWTFs. Like fecal coliform contamination, excess nitrogen loading can lead to water quality impairments that may impact recreational and commercial uses of the upper Bay, and are thus of great concern to the RIDEM and NBC. Major reductions in total nitrogen from the NBC facilities began in 2006 with the completion of the first nutrient upgrade to Bucklin Point. Further upgrades to Biological Nutrient Removal (BNR) technologies were completed at Field's Point in 2013 and at Bucklin Point in 2014, drastically reducing total nitrogen concentrations in the final effluent to meet stringent new seasonal (May-October) RIPDES permit limits (i.e., 5 mg/L). In addition to the BNR upgrades, Phase I of the CSO Abatement Project was expected to contribute to improvements in nitrogen loading through capture of untreated stormwater and domestic wastewater flows for ultimate treatment through the BNR process at the WWTFs.

Monitoring & Analytical Methods

The BNR process at each WWTF is monitored through routine sampling of a wide variety of nutrient parameters to ensure that both the Field's Point and Bucklin Point WWTFs are effectively meeting operational and RIPDES permit requirements. An extensive sampling schedule employing composite and grab samples at multiple locations from influent to final effluent is necessary to keep abreast of nutrients concentrations and rates of nitrification and denitrification throughout the process. Clean sampling and sample-handling techniques, high quality laboratory measurements, and ease of access to these data are necessary to provide accurate information to quickly identify potential problems within the plant, and to routinely reassess process controls. All sample collection, preservation, and storage at the Field's Point and Bucklin Point WWTFs is performed with strict adherence to USEPA protocols. More detail on sampling procedures, laboratory analysis, and standard methodology for NBC WWTF process monitoring for nutrients and other parameters can be found in the EMDA's annual data reports (NBC 2015).

To measure any direct changes in nutrients in the upper Bay as a result of WWTF upgrades and the CSO Abatement Project, the NBC began sampling for nutrients at six stations in the Providence and Seekonk Rivers during the summer of 2007, adding a seventh, the Pawtuxet Cove station, in 2013. The direct water column nutrient measurements provide an important look at the amount of nutrients in the upper Bay from all sources, including river loading, surrounding WWTFs, atmospheric deposition, groundwater, runoff, leaky septic systems and nutrients from the middle and lower Bay area, as well as from offshore. As seen in Figure 63, the Conimicut Point, Bullock's Reach Buoy, Pawtuxet Cove, Edgewood Shoals, Pomham Rocks, and India Point Park stations are located in the Providence River and the Phillipsdale Landing

site is located in Seekonk River. A suite of nutrient parameters are sampled at these stations every other week throughout the entire year. Since the Pawtuxet Cove location was only added in 2013, data for that station are not presented in this report.

Bay samples were collected, filtered, and preserved on-board the NBC research vessel, the R/V *Monitor*. The NBC Laboratory analyzes both freshwater and saltwater nutrient samples for nitrite/nitrate, nitrite, total dissolved nitrogen, ammonia, orthophosphate and silicate, and, as of November 2012, total nitrogen as well. Grab samples for TSS and chlorophyll are also collected at the same time as nutrient samples and analyzed by the NBC Laboratory. More detail on sampling procedures, laboratory analysis and standard methodology for the NBC bay and river nutrients sampling can be found in the EMDA's annual data reports (NBC 2015).

To put the Bay nutrient concentrations in context, the NBC consults the National Coastal Condition report, which determined concentration thresholds of dissolved inorganic nitrogen (DIN) for a healthy estuary (USEPA 2012). The National Coastal Condition report classifies DIN levels of less than 0.1 mg/L in good condition, from 0.1 to 0.5 mg/L in fair condition, and concentrations above 0.5 mg/L in poor condition.

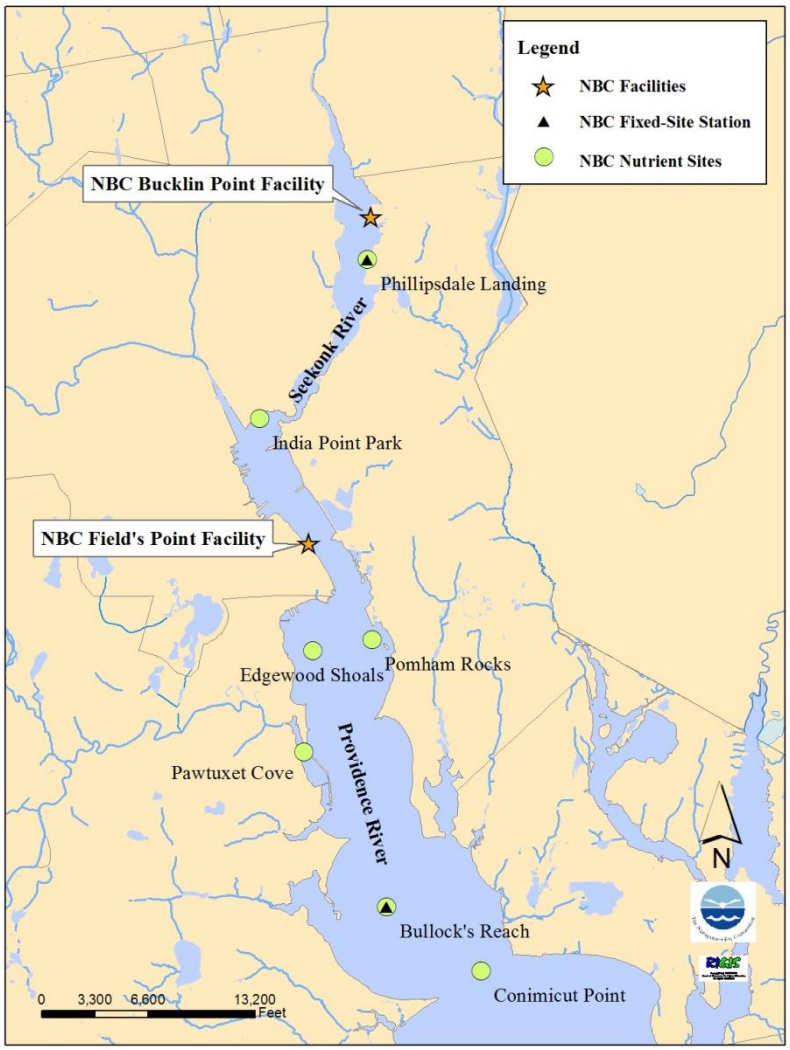

Figure 63. *NBC bay nutrient sampling locations.*

Results

Effluent total nitrogen concentrations and loading for 2003 through 2014 for both the Bucklin Point and Field's Point WWTFs are shown on Figure 64. Though construction to meet the 5 mg/L total nitrogen limit was not complete at Bucklin Point until July 2014, the 2014 permit season was still the lowest seasonal average concentration recorded at the facility (4.0 mg/L). The effluent loading in 2014 decreased to 584 lbs/day TN representing an 80% decrease in total nitrogen loading since 2003, the year of the Greenwich Bay fish kill. The 2014 permit season was also record setting for the Field's Point facility, which also recorded the lowest average total nitrogen concentration for any summer season, 3.4 mg/L. Total nitrogen loading was also the lowest measured in the history of the plant and represented an impressive 82% reduction in loading since 2003.

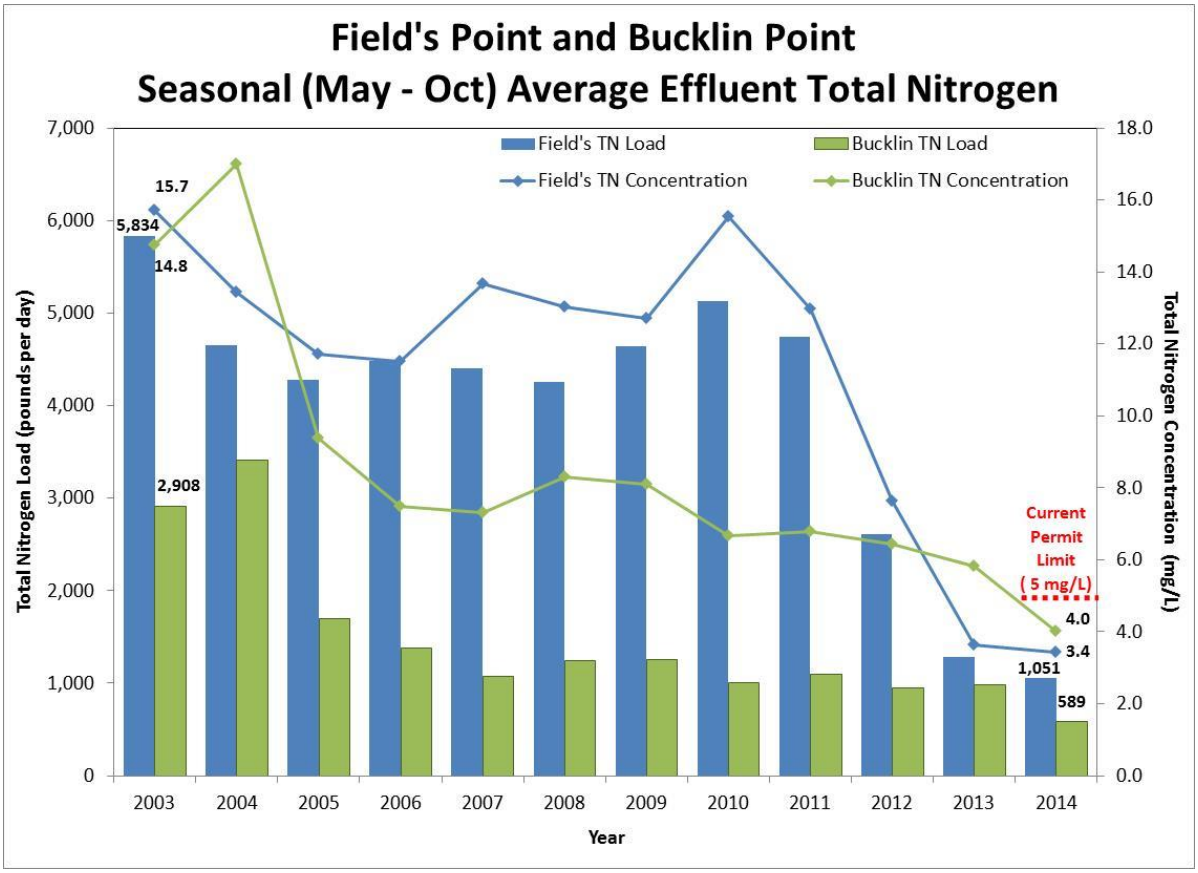

Figure 64. *Total nitrogen concentration and loading during the permit season from the Field's Point and Bucklin Point facilities from 2003 through 2014.*

The reductions in total nitrogen at both NBC facilities have contributed to profound reductions in nitrogen concentrations in the upper Bay, as shown in Figure 65. At the NBC's Conimicut Point monitoring station, the 2012 seasonal average DIN concentration fell within the National Coastal Condition's "good" category for the first time since the NBC began monitoring in 2007. In 2014, the DIN concentrations at all stations decreased to their lowest average seasonal concentration since monitoring began. The only exception to this was Conimicut Point, which remained the same in 2014 as in 2013, 0.02 mg/L higher than in 2012. Also in 2014, DIN levels at Bullock's Reach were within the "good" category for the first time since monitoring began.

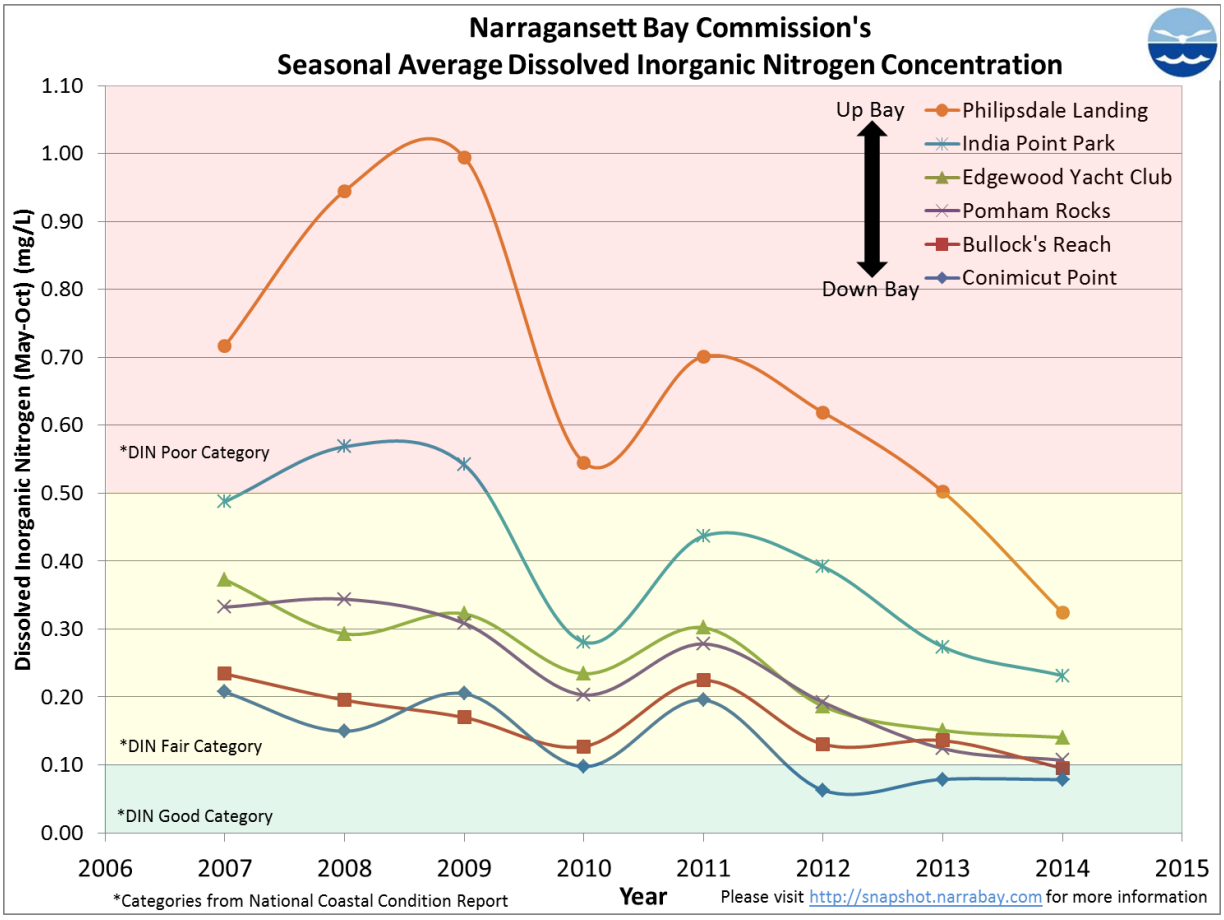

Figure 65. *Seasonal (May – October) average dissolved inorganic nitrogen concentrations at the NBC's nutrient monitoring stations in the upper Bay, presented in relation to the National Coastal Conditions thresholds (good : 0 to 0.1 mg/L, fair: 0.1 – 0.5 mg/L, poor: 0.5 mg/L and higher).*

Results Summary

The impressive reductions in total nitrogen loading from the NBC facilities, 80% at Bucklin Point and 82% at Field's Point, have been realized with the installation of BNR technology at both plants. These reductions have already made a difference in the nutrient concentrations measured by the NBC in the Providence and Seekonk Rivers, with some of the lowest concentrations on record measured in 2014. For the first time, none of the NBC Bay monitoring stations were in the "poor" category for dissolved inorganic nitrogen levels based upon the National Coastal Condition Report classifications for 2014 data. Conimicut Point has been in the "good" category since 2012, and 2014 was the first year that Bullock's Reach concentrations have also fallen into the "good" category. The NBC believes that these reduced concentrations are the result of the NBC and other WWTF investments in upgrading their infrastructure to reduce nutrient discharges. The NBC hopes to see continued improvement in DIN concentrations, and water quality in general, in the future as a result of completion of facility upgrades.

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Chapter VIII – Discussion

The NBC is committed to the protection and enhancement of the water quality of upper Narragansett Bay and the completion of Phase I of the CSO Abatement Project demonstrated this commitment by significantly reducing the discharge of untreated wastewater and stormwater from the NBC's CSOs. Since the completion of Phase I and the opening of the tunnel in November 2008 until the end of 2014, 6.15 billion gallons of untreated wastewater and stormwater have been averted from being discharged to the urban rivers and Narragansett Bay, equating to approximately 50% of the volume estimated to discharge from CSOs prior to Phase I. The tunnel has allowed this sewage-contaminated stormwater that would have otherwise been discharged, to be captured, stored and then processed at the Field's Point facility to receive full advanced secondary treatment.

A review of the NBC urban river sample results revealed that at most river stations downstream of NBC CSOs there has been a decrease in fecal coliform levels since the Phase I CSO Abatement Project was completed, even when some stations upstream of NBC's CSOs increased, as on the Woonasquatucket and West Rivers. This suggests that even though not many CSOs on these rivers were addressed in Phase I, the interceptor relief that the tunnel provided for the Woonasquatucket and Moshassuck River interceptors has helped to decrease the frequency and volume of combined sewage overflows. The decrease in fecal coliform levels seen in dry weather shows that the regulator modifications and other preventive measures that have been taken by NBC over the years are decreasing the dry weather overflows as well. In fact, the river stations upstream of NBC CSOs only meet the RIDEM primary contact water quality criteria during dry weather and only in some years. This emphasizes the importance of addressing non-point pollution sources, such as stormwater. It also suggests that even if the CSOs did not overflow at all, the rivers most likely would still not meet primary contact criteria.

The evaluation of NBC sample results in the upper Bay revealed that the fecal coliform concentrations in the Providence River have also decreased since Phase I of the CSO Abatement Project was completed. When evaluating only wet weather sample results, fecal coliform bacteria concentrations showed an even greater decrease following the completion of Phase I. This emphasizes the main function of the CSO tunnel to reduce overflows during wet weather and shows that the tunnel is being effective in reducing fecal coliform bacteria levels in the Providence River during rain events. Though both the upper and lower areas of the Providence River have seen a decreasing trend of fecal coliform concentrations over the course of sampling, the decline has been more pronounced in the upper Providence River, closer to the improvements made as part of Phase I. There may be several reasons for the reduced impact on bacteria levels in the lower Providence River. For example, bacteria levels have always been lower in that area, therefore any reduction would not be as visible as at the stations with the highest bacteria levels.

Fecal coliform bacteria levels in the Seekonk River have also decreased since Phase I of the CSO Abatement Project was completed, showing the same percent decrease as in the upper

Providence River. The data indicate that there was an improvement in fecal coliform levels in the Seekonk River after the wet weather facilities were constructed at Bucklin Point in 2005 and further improvement after the Phase I CSO tunnel went online. The updated wet weather treatment system at Bucklin Point resulted in a substantial decrease in flow diverted to the North Diversion Structure, a significant decrease in the discharge of untreated wastewater to the Seekonk River.

Shellfishing standards, which are quite a bit lower than the primary contact standards, have not been met in most years at any of the NBC monitoring stations. However, in 2013 and 2014, two the three stations furthest south in the lower Providence River met the shellfishing standards. Although stations in the Providence River are not all consistently meeting shellfishing standards, as a result of the fecal coliform reductions after the completion of Phase I there has been a relaxation of the state shellfishing regulations for the regions just south of the Providence River, which is a major success. Higher amounts of precipitation are now allowed to fall in a 24 hour period before these Conditional Shellfishing areas are closed to harvesting, a great benefit for local shellfishermen.

This review of NBC's data results indicates that there remain sources of bacteria in both wet and dry weather that need to be addressed and that perhaps even if all the NBC CSO discharges are eliminated, other remaining sources of bacteria may prevent NBC receiving waters from continuously meeting all water quality standards for bacteria.

In addition to the CSO Abatement Project, there have been several infrastructure improvement projects that have taken place over the last several years at both the Bucklin Point and Field's Point facilities. This includes the upgrade to provide wet weather treatment at Bucklin Point that was completed at the end 2005, and the BNR upgrades to remove nitrogen that were first completed in 2006 at Bucklin Point and then later at Field's Point and Bucklin Point to meet a new permit limit effective in 2014. With the completion of Phase I of the CSO project in late 2008, evaluation of the full effect that these improvements have had on the NBC's receiving waters was necessary to assess if water quality standards are now being met. Phase II of the NBC CSO Abatement project is scheduled to be completed at the end of 2014 and further evaluation will be done to determine additional impacts of this phase on water quality.

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