Executive Summary of RI Municipal WWTF Total Residual Chlorine (TRC) Limits History and Status

RIDEM Office of Water Resources

October 4, 2016, updated September 12, 2017, November 2, 2017, and September 30, 2021

Summary of TRC reductions by RI WWTFs

- As a result of discharge limits established to protect aquatic life, the harmful effects of total residual chlorine (TRC) from every RI Wastewater Treatment Facility WWTF have been eliminated for more than 15 years (since February 2004). **By 2001, an 85% reduction in the total amount of TRC released from all RI WWTFs from 1997 levels was achieved (200 versus 1,340 lbs/day).** By 2003, the reduction was 95 % and has remained between 96% and 98% since. **In 2016 only 20.2 lbs/day was discharged, less than 1/10 of the permitted levels (i.e. the levels that will not cause adverse impacts to aquatic organisms)**. **Between January 2005 and December 2016, the monthly average TRC limit compliance rate for all RI WWTFs was 99.9%.**

- Completion of Phase I of the CSO tunnel (in November 2007) and Phase II (in December 2014) have substantially reduced any chlorinated discharges from the Fields Point wet weather facility (from an average of 32.6 days per year with a discharge from 2000 to 2007 to an average of 6.5 days from 2015 – 2020). In Newport, discharges from the Wellington Avenue CSO Facility were virtually eliminated June 30, 2017 and the Washington Street CSO facility completed installation of dechlorination at the end of June 2016.

- Beginning more than 20 years ago, WWTFs in RI were required to achieve discharge limits that protect aquatic life from the toxic effects of chlorine. By September 1999 many of the RI WWTFs (12 of 19) achieved significant reductions in levels of TRC discharged. Of the remaining 7 WWTFs, the last facility completed modifications to reduce TRC discharges in 2004. Prior to this time, limits for TRC were established as a technology-based limit of 2.0 mg/l (2,000 µg/l). **Between January 2005 and December 2016, the monthly average TRC limit compliance rate for all RI WWTFs was 99.9%.**

- WWTFs achieved TRC reduction by improving the chlorine addition methods to minimize the amount of chlorine used, adding sodium bisulfite to neutralize the toxic effects (i.e. dechlorination), or by using ultraviolet light (UV) disinfection. Four RI WWTFs eliminated the use of chlorine by switching to the use of UV light to disinfect their wastewater (one of these, the NBC Bucklin Point WWTF continues to use chlorination/dechlorination for treatment of combined sewer overflows (CSO) at their CSO wet weather treatment facility).

- Each WWTF completed a Facility Plan which evaluated the cost and effectiveness of alternatives for compliance with discharge limits and selected a preferred alternative. DEM approves the selected alternative providing that the Facilities Plan follows proper engineering procedures. For example, in 2014 Newport decided to upgrade their

existing chlorination/dechlorination system after determining that doing so would involve construction costs of $1,500,000 with annual O&M cost of $120,000 versus UV construction cost of $6,300,000 with annual O&M cost of $340,000. However, during the final design it was determined that UV could be added to the existing chlorine contact tanks (rather than building additional tankage as proposed in 2014) thereby reducing the cost for UV. As a result, construction of UV disinfection was approved by DEM and construction was completed in late summer 2018. In 2014 the Town of Warren evaluated UV disinfection as an alternative to the existing chlorination/dechlorination system and estimated that it would cost 1.0 to 1.5 million dollars. In 2018, after inquiries from local commercial fishermen, the Town indicated that they plan to re-evaluate converting to UV as part of their capital planning process. Twenty-one percent of RI WWTFs use UV for disinfection compared to 42%, nationwide.

- A concern has been voiced regarding the discharge of sulfate from the dechlorination process. Based on a literature review the only potential concerns are the formation of a small amount of acidity that is neutralized by the wastewater and reduced dissolved oxygen if excess sodium bisulfite is added. As documented in Attachment 2, **the concentration of sulfate naturally present in seawater is 1,000 times higher than in dechlorinated wastewater. Automated feed systems prevent the use of excessive amounts of sodium bisulfite.**

- As a standard method to check whether chemicals not measured in the discharge (e.g. personal care products or pharmaceuticals) or combinations of chemicals are more toxic than the aquatic life criteria suggest, WWTFs are required to expose aquatic organisms to samples of their discharge to determine if there are any acute or chronic effects. This technique is referred to as bioassay testing or whole effluent toxicity testing. Typically, the samples that were chlorinated but not dechlorinated had to be diluted 100 times to eliminate acute effects while dechlorinated samples show no acute effects. **Samples collected after dechlorination have typically shown no acute or chronic toxicity. From October 2014 - June 2017, RI WWTFs achieved 93% compliance with no chronic (i.e. sub-lethal) effects beyond the mixing zone. Of the 9 cases of noncompliance, 6 were from one WWTF and the cause was traced to an industrial wastewater discharge to the WWTF.**

RI Municipal WWTF Total Residual Chlorine (TRC) Limits History and Status

RIDEM Office of Water Resources

October 4, 2016, updated September 12, 2017, November 2, 2017, and September 28, 2021

Background

In 1984, Rhode Island was delegated authority by the Environmental Protection Agency to implement the National Pollutant Discharge Elimination System (NPDES) program (known as RIPDES in RI). The RIPDES program's responsibilities include developing, tracking compliance and enforcing permit limitations that apply to municipal and industrial wastewaters, stormwater and combined sewer overflows discharged directly into the waters of the State. RIPDES also oversees local municipalities' programs that regulate industrial wastewaters discharged into publicly-owned treatment facilities (Pretreatment Program).

Chlorine addition continues to be the most common practice in the US to disinfect wastewater prior to discharge to receiving waters. This is supported by a September 2021 data analysis that RIDEM conducted of all NPDES permittees nationwide (see below). This practice has evolved to include dechlorination to reduce the toxic impacts of chlorine on aquatic life. In the early 1990s, RIDEM began revising limits for total residual chlorine (TRC) in RIPDES permits for municipal wastewater treatment facilities so the receiving waters would meet concentrations established by EPA to prevent acute and chronic toxicity impacts to aquatic life. The acute and chronic criteria for freshwater are 19 µg/l and 11 µg/l and for saltwater 13 µg/l and 7.5 µg/l. To establish the saltwater criteria EPA reviewed toxicity data from 24 species. The most sensitive organisms were Coho salmon, silversides, copepods and eastern oyster. EPA TRC Criteria Development Document (USEPA 1985)

For WWTFs that discharge to tidal waters, the RIPDES limits are based on meeting the water quality criteria at the edge of acute and chronic mixing zones near the point of the discharge (determined from dye studies or computer modeling). For discharges to freshwater rivers, the criteria must be met at the lowest seven consecutive day river flow expected to happen once every ten years (7Q10 flow) when the facility is discharging at its 20-year design flow. For a summary of limits and the dates that they became effective, see Table 1.

For example, the largest WWTF in RI, the Narragansett Bay Commission's (NBC) Fields Point WWTF, must meet the acute limit within 375 feet of its outfall and the chronic limit within 550 feet from shore and 6000 feet down downstream, as illustrated in Attachment 1. It is important to note that the size and location of the wastewater plume within the mixing zone changes with the tide.

Chlorination of Combined Sewer Overflows (CSOs) – The NBC Fields Point and NBC Bucklin Point facilities and Newport are the only WWTF sewer systems with CSOs in RI.

NBC Fields Point – Beginning in 1995, NBC constructed a wet weather treatment facility to provide primary treatment and chlorination of combined sewer flows that exceed the design

capacity of the WWTF. Completion of Phase I (CSO storage tunnel) in November 2008 and Phase II in December 2014 have substantially reduced discharges from the Fields Point wet weather facility. Prior to construction of the Phase I CSO tunnel, there were an average of 32.6 days per year with a discharge from the wet weather treatment facility at Fields Point (from 2000 to 2007). Since completion of Phase II, the number of days with a discharge from the wet weather facility has dropped to an average of 6.5 per year (2015 – 2020).

NBC Bucklin Point - A wet weather treatment facility was constructed in December 2005 to provide primary treatment, chlorination and dechlorination of combined sewer flows that exceed the design capacity of the WWTF. These flows were previously discharged untreated from the "North Diversion Structure" bypass overflow located just upstream of the WWTF. In December 2017 DEM approved changes to Phase III of NBC's CSO control plan (i.e. CSO Control Facilities Plan Phase III Amended Reevaluation Report) that includes a CSO storage tunnel. The NBC started construction of the Phase III CSO tunnel in 2021 and construction is scheduled to be completed in 2027. When operational the Phase III CSO tunnel will greatly reduce flows discharged from the wet weather facility.

Newport Wellington Avenue CSO Facility – began primary treatment and chlorination in 1978. System modifications have significantly reduced the number of discharges and there have been no discharges since December 2015
https://www.cityofnewport.com/CityOfNewport/media/City-Hall/Departments/Utilities/W%20P%20C/CSO-Summary-2001-current-01-05-21.pdf

Newport Washington Street CSO facility – constructed primary treatment and chlorination in 1991. System modifications have reduced the number of discharges and construction of dechlorination was completed at the end of June 2016. From January 2017 through December 2020 the number of overflows per year has ranged from 2 to 10 (average of 5.2 per year).

Disinfection Methods Used to Comply with TRC limits.
The reduction in the amount of chlorine discharged cited above, has been achieved at most WWTFs in RI by improving the chlorine addition methods to minimize the amount of chlorine used and adding sodium bisulfite to neutralize the toxic effects and reduce TRC (i.e. de-chlorination). Two facilities optimized TRC addition (i.e. dechlorination was not needed to meet the TRC limit) and four RI WWTFs eliminated the use of chlorine by switching to the use of UV light to disinfect their wastewaters (one of these, the NBC Bucklin Point WWTF continues to use chlorination/dechlorination for treatment of CSOs at their combined sewer overflow (CSO) wet weather treatment facility). The disinfection practice used at each WWTF is shown in Table 1. In summary, 13 RI WWTFs use chlorination/dechlorination, 2 have optimized chlorine dosage rates, and 4 use UV (of these, 3 used chlorination/dechlorination before switching to UV).

Each WWTF completed a Facilities Plan which evaluated the cost and effectiveness of alternatives for compliance with discharge limits and selected a preferred alternative. DEM approves the selected alternative provided the Facilities Plan followed proper engineering procedures. For example, in 2014 Newport decided to upgrade their existing

chlorination/dechlorination system after determining that doing so would involve construction costs of $1,500,000 with annual O&M cost of $120,000 versus UV construction cost of $6,300,000 with annual O&M cost of $340,000. However, during the final design it was determined that UV could be added to the existing chlorine contact tanks (rather than building additional tankage as proposed in 2014) reducing costs. As a result, Newport changed their preferred disinfection alternative selection to UV. Construction of UV at the Newport WWTF was completed in October 2018.

On September 21, 2021 RIDEM queried the EPA's National Pollutant Discharge Elimination System (NPDES) Integrated Compliance Information System (ICIS) database to determine the type of wastewater disinfection used by major Publicly Owned Treatment Works (POTWs) aka municipal wastewater treatment facilities (WWTFs) or sewage treatment plant. Of the 4,458 Major POTWs, 826 or 18.5 % reported the type of disinfection used (i.e., reported disinfection as a Permit Feature Treatment Type). Of those reporting the disinfection type, 42% use UV disinfection and 55% use chlorine (3% use Ozone or Other process). As of September 2021, 21% of RI's major POTWs disinfect using UV (79% use chlorine). Two of the 15 RI facilities using chlorine were able to meet their aquatic toxicity-based limits without dechlorination the other 13 dechlorinate prior to discharge.

Depending on the amount of flow the WWTF is designed to treat, RIPDES permit TRC monitoring requirements range from three times a week to daily. All monitoring data is submitted to DEM and is entered into the US EPA national database for NPDES permit information that is available to the public at EPA's Enforcement and Compliance History Online (ECHO) website http://echo.epa.gov/

Table 1. Summary of RI WWTF TRC limits (µg/l)

Treatment Plant	Date Final Limits Became Effective	Final Limits (µg/l)	
		Daily Max (Acute)	Monthly Ave (Chronic)
Bristol	May 1, 1996	364	364
Burrillville	May 1, 1991	71	41
Cranston	January 1, 2001	38.9	22.5
East Greenwich	February 1, 2004	UV Disinfection (No TRC Limits)	
East Providence	July 1, 1998	260	260
Jamestown	Prior to 1996	2 mg/l[1]	2 mg/l[1]
NBC Bucklin Point	January 1, 2000	50	50
	June 1, 2005	UV Disinfection (No TRC Limits)	
NBC Fields Point	September 1, 1999	65	65
New Shoreham	November 1, 1995	228	185
Newport	September 30, 2002	860	590
		UV disinfection commenced Oct. 2018 (no TRC limits)	
RI Economic Development Corporation (Quonset)	February 1, 2000	1300[1]	1300[1]
Scarborough	November 1, 1996	325	325
Smithfield	July 1, 1996	34	20
South Kingstown	December 1, 1997	1040	885
Warren	February 1, 1999	267 (Nov – Apr) 361 (May – Oct)	267 (Nov – Apr) 361 (May – Oct)
Warwick	January 18, 2002	34	20
West Warwick	January 1, 2001	50	50
	January 1, 2005	UV Disinfection (No TRC Limits)	
Westerly	January 17, 2002	65	65
Woonsocket	August 10, 1999	97	56

[1]Achieved TRC limit by optimizing chlorine treatment (i.e. dechlorination was not needed to meet the TRC limit)

Chlorination Process.

When liquid chlorine (sodium hypochlorite – NaOCL) is added to wastewater it results in the formation of free chlorine (hypochlorous acid - HOCl, hypochlorite ion – OCL^-) which combines with organic matter to form chlorinated organic compounds and with ammonia to form chloramines (USEPA 2000). These combined forms of chlorine plus any free chlorine are collectively known as Total Residual Chlorine (USEPA 2015). When discharged into salt water similar bromide compounds are formed, referred to as Chlorine Produced Oxidants.

Dechlorination Process

The 14 (13 by late summer 2018) RI WWTFs that dechlorinate, add sodium bisulfite – $NaHSO_3$ after chlorination. Sodium bisulfite neutralizes chlorine and reduces and prevents the formation of chlorinated compounds (Fam and Stenstrom, 1988; USEPA, 2000). This reaction results in the formation of small amounts of sulfate and small amounts of acidity that is neutralized by the WWTF prior to discharge. If sodium bisulfite is added in excess, it can reduce dissolved oxygen. Facilities that dechlorinate use continuous chlorine residual monitors and/or ORP (oxidation reduction potential) monitors to add the amount of sodium bisulfite necessary to achieve dechlorination.

Concerns have been raised over the toxicity of chloramines in WWTF discharges that have been treated with chlorine. When sodium bisulfite ($NaHSO_3$) is used to dechlorinate wastewater, chloramines are reduced by the following reactions:

$$SO_3^- + NH_2Cl + H_2O \Leftrightarrow SO_4^{-2} + Cl^- + NH_4^+$$

chlorine is removed from chloramine molecules which results in Sulfate (SO4-2) ions, chloride ions (Cl-) and ammonium ions (NH4+) (Water Pollution Control Federation Task Force on Wastewater Disinfection II 1996). Although the amount of chloramines present in WWTF discharges has not been measured separately, much can be learned from reviewing changes that have occurred in the ammonia and TRC present in WWTF discharges. Chloramines are measured as part of the total residual chlorine tests that WWTFs are required to perform, and as noted above since 2003 the total amount of TRC discharged from WWTFs has been reduced between 95% and 98 % compared to levels prior to 1997. Significant reductions in summer WWTF ammonia levels have been achieved to meet total nitrogen and ammonia limits. Lowering the amount of ammonia present in wastewater prior to the addition of chlorine results in less chloramine formation.

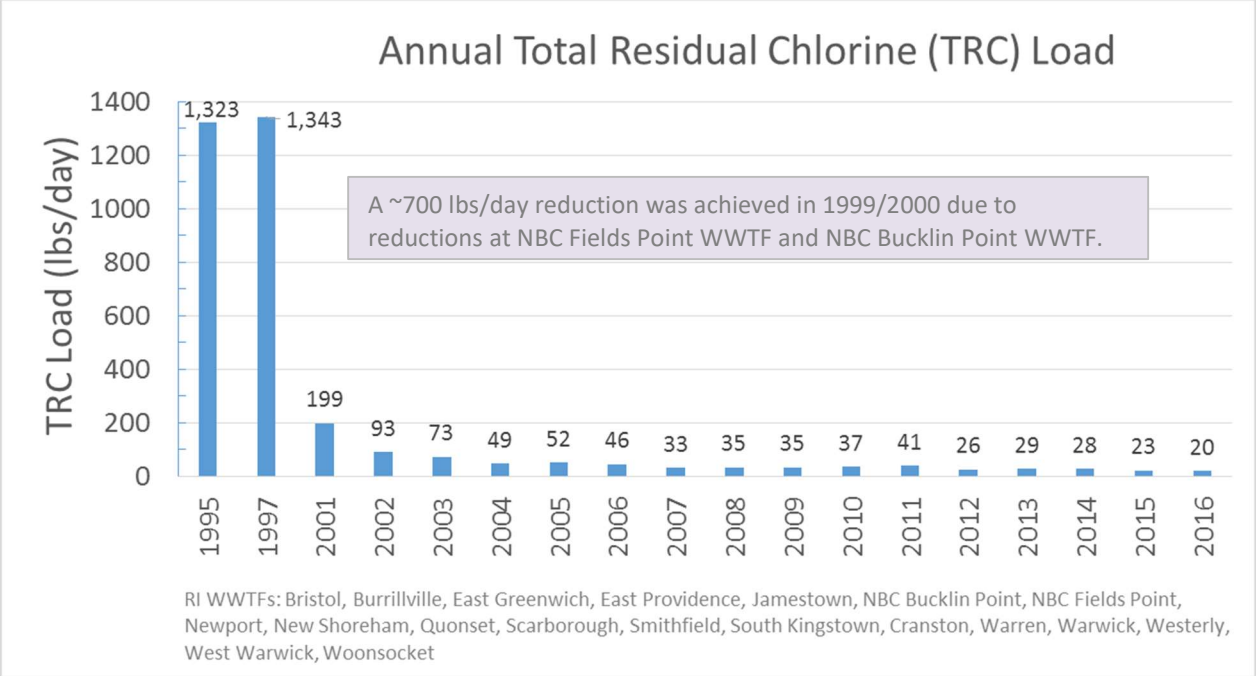
Furthermore, by late summer 2018, 4 facilities no longer apply chlorine, 13 facilities dechlorinate prior to discharge and the 2 that don't dechlorinate have optimized the amount of chlorine added. While significant reductions in the discharge of chloramines have been achieved the discharge has not been eliminated for the following reasons: 2 facilities have met TRC limits by more efficient use of chlorine and do not dechlorinate, the amount of sodium bisulfate added to dechlorinate the wastewater and achieve the TRC limit but does not completely eliminate chloramines and inherent variations in wastewater flows, wastewater composition and the treatment process.

A concern has been voiced regarding the discharge of sulfate from the dechlorinating process. As indicated above, the only potential concerns are the formation of small amounts of acidity that are neutralized by the wastewater and if sodium bisulfite is added in excess can reduce dissolved oxygen. As documented in Attachment 2 the concentration of sulfate naturally present in seawater is 1,000 times higher than the sulfate concentrations in wastewater that has been dosed with Sodium Bisulfite to remove 2 mg/l of TRC (the design TRC concentration in

the WWTF's chlorine disinfection system). Automated feed systems prevent the use of excessive amounts of sodium bisulfite.

Compliance with TRC limits

As a result of discharge limits established to protect aquatic life, the harmful effects of total residual chlorine (TRC) from every RI Wastewater Treatment Facility WWTF has been eliminated for more than 15 years. **By 2001, an 85% reduction in the total amount of TRC released from all RI WWTFs from 1997 levels was achieved (200 versus 1,340 lbs/day). By 2003 the reduction was 95 % and has remained between 96% and 98% since. In 2016 only 20.2 lbs/day was discharged, less than 1/10 of the permitted levels (i.e. the levels that will not cause adverse impacts to aquatic organisms). Between January 2005 and December 2016, the monthly average TRC limit compliance rate for all RI WWTFs was 99.9%.**



Bioassay results

In addition to pollutant specific monitoring and limits, WWTFs are required to conduct a standard method to check whether chemicals not measured in the discharge (e.g. personal care products or pharmaceuticals) or combinations of chemicals are more toxic then the aquatic life criteria suggest, WWTFs are required to expose aquatic organisms to samples of their discharge to determine if there are any acute or chronic effects. This technique is referred to as a bioassay test (i.e. whole effluent toxicity "WET"). The EPA approved organisms for acute and chronic WET testing were selected since they are easily cultured in the laboratory, are sensitive to a variety of pollutants and are generally available throughout the year from commercial sources (EPA 1993).

The approved estuarine and marine WET tests methodologies were developed by the EPA Environmental Research Laboratory in Narragansett, RI (USEPA 2002). All the approved

organisms are native to RI marine and estuarine waters, including the acute toxicity testing using the mysid shrimp *Mysidopsis bahia* and the chronic toxicity fertilization test for the atlantic purple sea urchin, *Arbacia punctulata*, currently in use. This chronic test determines whether the test substance (i.e. WWTF effluent) causes a reduction in fertilization.

In the early 1990s WET testing was conducted on wastewater prior to and after chlorination on both an invertebrate and a fish. Examples using readily available data are presented in Table 2. Samples tested after chlorination were consistently more toxic than prior to chlorination (i.e. the NOAEL occurred in a lower percentage effluent). When interpreting WET results, please note that a sample reported as a No Adverse Effects Level (NOAEL) of 100% effluent is less toxic than a result of 10% effluent. After chlorination, the sample typically needed to be diluted 10 to 100 times to eliminate toxicity (i.e. NOAEL 1 to 10% effluent) and prior to chlorination no toxicity was found in the effluent or after diluting the effluent 4 times or less (i.e. NOAEL 25% or greater).

Table 2. No Observed Adverse Effects Level acute WET results reported as percent effluent.

Quarterly Reporting Date	***Mysidopsis bahia*** **(mysid shrimp)**		***Menidia beryllina*** **(inland silverside)**	
	Pre Chlorination (NOAEL % effluent)	**Post Chlorination (NOAEL % effluent)**	**Pre Chlorination (NOAEL % effluent)**	**Post Chlorination (NOAEL % effluent)**
Bristol WWTF				
2/24/92	75	1	75	10
5/11/92	25	10	100	25
9/2/92	25	1	100	25
11/30/92	1	1	100	25
Newport WWTF				
2/24/92	75	1	75	10
5/5/92	25	1	75	10
8/3/92	50	10	50	10
11/16/92	75	10	10	10

Once WWTFs achieved compliance with their TRC limit, all acute and chronic bioassay testing has been done on samples of the final discharge (i.e. after dechlorination for those facilities that chlorinate and dechlorinate)). This testing conducted since 2003 has confirmed earlier results; samples collected after dechlorination are far less toxic than chlorinated samples. For example: NBC Fields Point WWTF, the largest WWTF in RI, is required to conduct both acute testing using mysid shrimp (*Mysidopsis bahia* or *Americamysis bahia*) and chronic toxicity testing checking for impacts to sea urchin egg fertilization on samples collected after dechlorination. The acute testing shows no toxicity in the effluent (see Attachment 3). The chronic testing is a much more sensitive test than the prior acute toxicity tests. Based on quarterly testing between March 2013 and December 2015 (See Attachment 3): 75% of the samples show no chronic toxicity impacts in the effluent (i.e. the chronic no observed effect concentration is 100% effluent) and the remainder showed no toxicity prior to the end of the

chronic mixing zone (i.e. the chronic no observed effect concentration is greater than 5% effluent).

Eleven of the 19 municipal WWTF in the state are required to conduct chronic toxicity testing (effluent from the remaining 8 facilities have sufficient dilution close to the outfall so only acute toxicity testing is required). Once WWTFs achieved compliance with their TRC limit , acute and chronic bioassay testing has been done on samples collected from the final discharge (i.e. after dechlorination for those facilities that chlorinate and dechlorinate). This testing (conducted since 2003) has confirmed earlier results that samples collected after dechlorination are far less toxic that chlorinated samples. For example, data from these 11 WWTFs are summarized in attachment 4. Permit limits have been established to ensure that there are no chronic effects measured either in the effluent or in-stream at the edge of the WWTF's mixing zone. Of the 122 data points collected between October 2014 and June 2017, 113 of the data points, or 93% of the samples, showed no in-stream toxicity beyond the mixing zone (i.e., the chronic test results complied with the chronic toxicity permit limits). Additionally, 93 data points, or 76% of the samples, showed no toxicity in the effluent (i.e., the chronic test result was 100%, indicating that there were no adverse effects in 100% effluent). Of the 9, violations 6 are from one WWTF and have been traced to an industrial wastewater discharge to the WWTF. This data indicates that dechlorinated effluent does not cause adverse toxic impacts.

Summary

As noted above, beginning more than 20 years ago, the 19 municipal WWTFs in RI were required to achieve discharge limits that protect aquatic life from the toxic effects of TRC. Since 2002 all WWTFs have achieved compliance with their TRC discharge limits. As of September 2021, RI WWTFs use the following methods of disinfection: UV at 4 WWTFs , chlorination followed by de-chlorination at 13, and 2 optimized chlorine addition (i.e. dechlorination not needed to meet TRC limit). Therefore, 21% of RI WWTFs currently use UV disinfection.

Efforts to reduce the discharge of TRC and reduce associated toxicity has been highly successful. By 2001, an 85% reduction in the total amount of TRC released from all RI WWTFs was achieved and has remained between 96% and 98% since 2003. Bioassay tests confirm that these WWTF modifications have greatly reduced the toxicity of the discharge. Typically, samples collected from the prior practice of chlorination without dechlorination needed to be diluted 100 times to eliminate acute toxicity while samples collected after de-chlorination have typically shown no acute or chronic effects.

Next Steps

Disinfection equipment at many of the WWTFs need or will soon need repair or replacement. The practices in place since 2003 have proven to be highly successful at reducing the aquatic life impacts associated with the use of chlorine as a disinfectant by WWTFs. The Department is urging WWTFs to consider use of UV or other alternatives (e.g. ozone, peracetic acid) to the use of chlorine for the following reasons.

Potential Hazards from Chemical Storage and Handling.

In their undiluted form, chlorine and sodium bisulfite (used for dechlorination) are strong chemicals (oxidizing/reducing agents) whose storage and use represent potential hazardous for WWTF workers. Including the potential for releases during transport to the WWTFs.

Potential to Reduce Shellfish Closure Zones

To sell shellfish outside RI, the State must comply with the requirements of the National Shellfish Sanitation Program (NSSP). The U. S. Food and Drug Administration (FDA) is responsible for formal approval of the NSSP and compliance oversight. The NSSP requires that shellfish harvesting be prohibited in waters that may be impacted by WWTF discharges. The NSSP has found that UV disinfection can be more effective at reducing viral pathogens and has established evaluation protocols which have the potential to result in smaller shellfish closure zones. Whether UV use will result in smaller shellfish closure zones depends on several site-specific considerations such as time for water to flow from the WWTF to the shellfishing grounds, other pollutant sources, etc.

Reduction of Chlorine By-Products.

Though reduced considerably, some concern remains regarding the production of potentially toxic byproducts (chlorinated organic compounds and chloramines) from the continued use of chlorine by RI WWTFs, particularly when not followed by de-chlorination (2 RI WWTFs since May 2018). Facilities that dechlorinate by adding sodium bisulfite may not completely eliminate chlorinated by-products due to inherent variations in wastewater flows, wastewater composition and the treatment process.

In 2003 RI adopted EPA's recommendation that the contact recreation criteria should be based on enterococci to provide greater protection against possible illness than fecal coliform. As permits were reissued, WWTF discharge limits were changed to enterococci, those with the potential to impact shellfishing are required to continue monitoring and reporting fecal coliform concentrations Some WWTFs have reported a need to increase the quantity of chlorine and sodium bisulfite used when the indicator bacteria permit limits were changed from fecal coliform to enterococci (Sharp et.al. 2016, Kelly 2012, and Wu 2016).

Favorable Financing Terms

Under the State Revolving Fund program, projects that significantly reduce or eliminate the use of chemicals in wastewater treatment are considered "Green Projects" and are eligible for principal forgiveness loans when available.

The decision of which method of disinfection to be used is a site-specific decision that must be made by each WWTF (with approval by DEM) to result in safe, effective, sustainable, and cost-effective wastewater disinfection.

Attachment 1. NBC Fields Point Mixing Zones

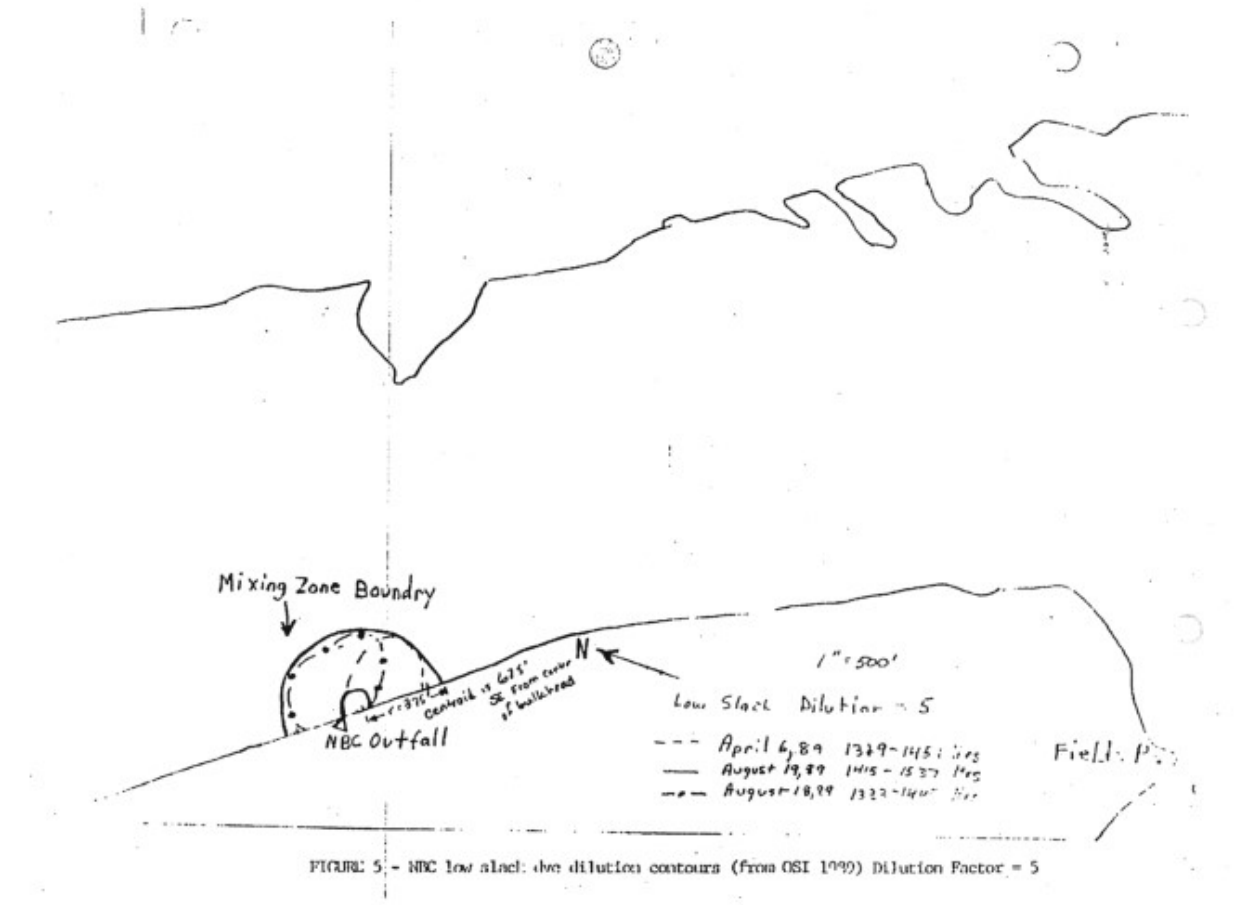


FIGURE 5 - NBC low slack dye dilution contours (from OSI 1989) Dilution Factor = 5

Narragansett Bay Commission Fields Point WWTF Acute Mixing Zone

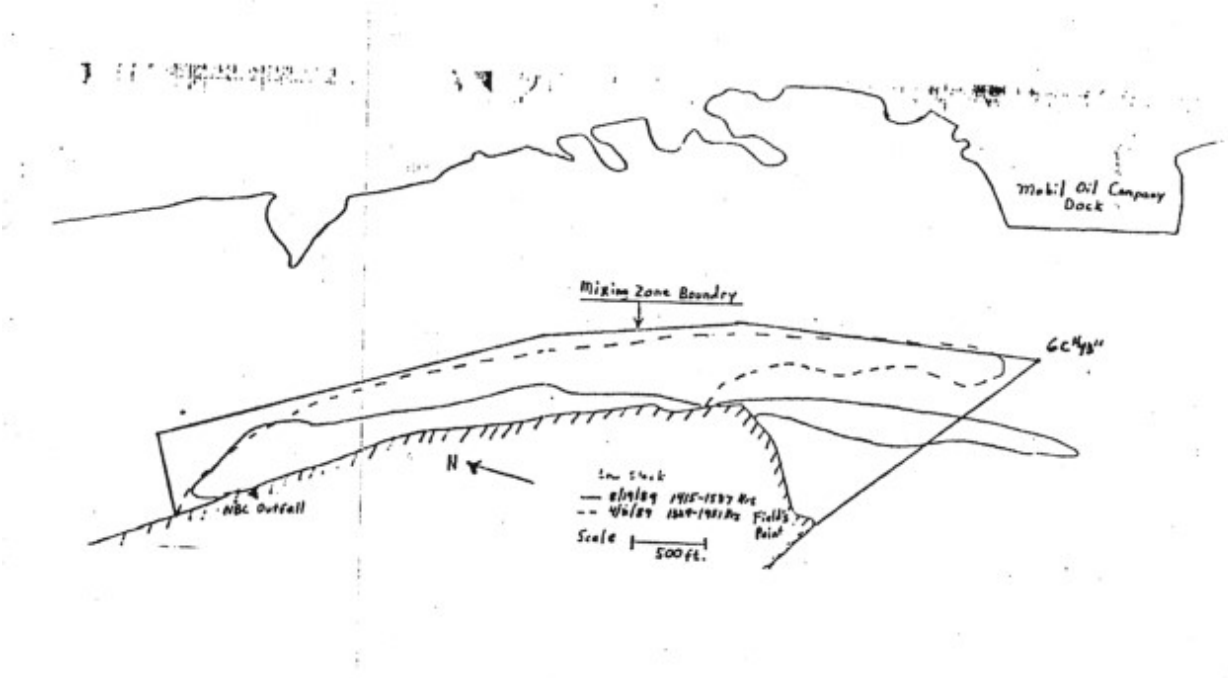


FIGURE 4 - NBC low slack dye dilution contours (from OSI 1989) Dilution Factor = 20

Narragansett Bay Commission Fields Point WWTF Chronic Mixing Zone.

Attachment 2. Calculation of Sulfate Concentrations Formed by Dechlorination

Using the following:

1. Chemical equation for dechlorination: $SO_3^{-2} + HOCl \rightarrow SO_4^{-2} + Cl^- + H^+$
2. A typical dosing rate of 1.46 parts Sodium Bisulfite ($NaHSO_3$) per part of residual chlorine, on a mass basis
3. Target Total Residual Chlorine (TRC) concentration of 2.0 mg/l prior to dechlorination (the design TRC concentration in the WWTF's chlorine disinfection system).

Mass of $NaHSO_3$ added = 2.0 mg TRC/l * 1.46 mg $NaHSO_3$/mg TRC = 2.92 mg $NaHSO_3$/l

Equivalent mass of SO_3^{-2} added

= 2.92 mg $NaHSO_3$/l * (32.064 + 15.9994 * 3 mg SO_3^{-2})/(22.9898 + 1.00797 + 32.064 + 15.9994 * 3 mg $NaHSO_3$) = 2.25 mg/l SO_3^{-2}

Moles of SO_3^{-2} added

= 2.25 mg SO_3^{-2}/l * (g/1000 mg) * (mol SO_3^{-2}/(32.064 + 15.9994 * 3) g SO_3^{-2}) = 0.0000281 mol/l SO_3^{-2}

Moles of SO_4^{-2} produced

= 0.0000281 mol/l SO_3^{-2} * (1 mol SO_4^{-2} produced/ 1 mol SO_3^{-2} consumed) = 0.0000281 mol SO_4^{-2}/l

Mass of SO_4^{-2} produced

= 0.0000281 mol SO_4^{-2}/l *((32.064 + 15.9994 * 4) g SO_4^{-2}/mol SO_4^{-2}) * (1000 mg/g) = 2.70 mg SO_4^{-2}/l

2.70 mg SO_4^{-2}/l * (1 g SO_4^{-2}/1000 mg SO_4^{-2}) * (1 l seawater/ 1.05 kg seawater) = 0.00257 g SO_4^{-2}/kg

Typical SO_4^{-2} concentrations in Seawater:

From http://www.ocean.washington.edu/courses/oc400/Lecture_Notes/CHPT4.pdf: 2.712 g SO_4^{-2}/kg

From http://www.marinebio.net/marinescience/02ocean/swcomposition.htm: 2.701 g SO_4^{-2}/kg

From http://ocean.stanford.edu/courses/bomc/chem/lecture_04.pdf: 2.712 g SO_4^{-2}/kg

Conclusion:

SO_4^{-2} concentrations generated by dechlorination are approximately 0.1% the SO_4^{-2} in typical seawater (i.e., the typical seawater concentration is 1,000 times that produced by the dechlorination reaction). Therefore, dechlorination will not have a significant impact to the SO_4^{-2} concentrations.

Attachment 3. Fields Point WWTF WET Testing

Acute WET testing using mysid shrimp (*Mysidopsis bahia* or *Americamysis bahia)*

Sample Period End Date	No Observed Adverse Effect Level Acute (% effluent)	Location Where No Chronic Effects Occur
03/31/2012	=100 %	Effluent
06/30/2012	=100 %	Effluent
09/30/2012	=100 %	Effluent
12/31/2012	=100 %	Effluent
03/31/2013	=100 %	Effluent
06/30/2013	=100 %	Effluent
09/30/2013	=100 %	Effluent
12/31/2013	=100 %	Effluent
03/31/2014	=100 %	Effluent
06/30/2014	=100 %	Effluent
09/30/2014	= 50 %	Within Acute Mixing Zone
12/31/2014	Not Calculated	
03/31/2015	=100 %	Effluent
06/30/2015	=100 %	Effluent
09/30/2015	=100 %	Effluent
12/31/2015	Not Calculated	

Attachment 3 (cont.).

Chronic WET sea urchin fertilization testing using Arbacia punctulata.

Sample Period End date	No Observed Chronic Effect Level (% effluent)	Location Where No Chronic Effects are Occur
03/31/2012	=100 %	Effluent
06/30/2012	=100 %	Effluent
09/30/2012	=100 %	Effluent
12/31/2012	=100 %	Effluent
03/31/2013	=100 %	Effluent
06/30/2013	=50 %	Within Acute Mixing Zone
09/30/2013	=100 %	Effluent
12/31/2013	=50 %	Within Acute Mixing Zone
03/31/2014	=100 %	Effluent
06/30/2014	=12.5 %	Within Chronic Mixing Zone
09/30/2014	=50 %	Within Acute Mixing zone
12/31/2014	=100 %	Effluent
03/31/2015	=100 %	Effluent
06/30/2015	=100 %	Effluent
09/30/2015	=100 %	Effluent
12/31/2015	=100 %	Effluent

Attachment 4. RI Municipal WWTFs Chronic WET testing results October 2014 through June 2017

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2014		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2015		50	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2015		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2015		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2015		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2016		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2016		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2016		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2016		100	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2017		50	
EAST GREENWICH WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2017		100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2014	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2015	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2015	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2015	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2015	50	50	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2016	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2016	50	100	

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2016	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2016	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2017	50	100	
NBC - BUCKLIN POINT WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2017	50	100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2014		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2015		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2015		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2015		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2015		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2016		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2016		50	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2016		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2016		100	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2017		12.5	
NBC - FIELD'S POINT	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2017		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2014		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2015		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2015		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2015		100	

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2015		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2016		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2016		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2016		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2016		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2017		100	
NEW SHOREHAM WPCF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2017		50	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2014	10	25	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2015	10	50	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2015	10	50	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2015	10	100	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2015	10	25	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2016	10	50	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2016	10	100	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	9/30/2016	10	100	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	12/31/2016	10	100	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	3/31/2017	10	100	
WESTERLY WWTF	Noel Static 1Hr Fert. Chronic Arbacia	6/30/2017	10	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2014	50	50	

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2015	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2015	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2015	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2015	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2016	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2016	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2016	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2016	50	100	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2017	50	50	
SMITHFIELD WASTEWATER TREATMENT PLANT	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2017	50	100	
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2014	50	100	
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2015	50	50	
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2015	50	13	1
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2015	50	25	1

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2015	50	38	1
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2016	50	50	
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2016	50	50	
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2016	50	25	1
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2016	50	25	1
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2017	50	100	
VEOLIA WATER-CRANSTON WPCF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2017	50	25	1
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2014	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2015	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2015	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2015	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2015	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2016	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2016	50	100	

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2016	50	50	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2016	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2017	50	100	
WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2017	50	6.25	1
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2014	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2015	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2015	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2015	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2015	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2016	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2016	50	6	1
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2016	50	6	1
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2016	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2016	50	100	

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2017	50	100	
WEST WARWICK WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2017	50	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2014	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2015	20	50	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2015	20	50	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2015	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2015	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2016	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2016	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	9/30/2016	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	12/31/2016	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	3/31/2017	20	100	
WOONSOCKET WWTF	Noel Statre 7Day Chronic Ceriodaphnia	6/30/2017	20	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	12/31/2014	25	100	

Permittee	Parameter Description	Monitoring Period End Date	Permit Limit (% Effluent) Test Must Be >= Limit	Test Result	"1" indicates violation
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	3/31/2015	25	50	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	6/30/2015	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	9/30/2015	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	12/31/2015	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	3/31/2016	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	6/30/2016	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	9/30/2016	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	12/31/2016	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	3/31/2017	25	100	
BURRILLVILLE WWTF	Noael Statre 7Day Chronic Ceriodaphnia	6/30/2017	25	100	

Total Number of Samples **122**

Total Number of Violations **9**

RI0100013 **6**

RI0100153 **2**

RI0100234 **1**

% of Total Measurements in Compliance **93%**

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