TOTAL MAXIMUM DAILY LOAD ANALYSIS FOR
BUCKEYE BROOK AND TRIBUTARIES TO WARWICK POND

Benthic-Macroinvertebrate, Cadmium, Copper, Iron, Dissolved Oxygen Impairments

DRAFT REPORT
DECEMBER 2017

303(d) listings addressed in this study:
Buckeye Brook and Unnamed Tributaries (RI0007024R-01):
Benthic-Macroinvertebrate, Dissolved Oxygen, Cadmium, Copper, Iron
Tributaries to Warwick Pond (RI0007024R-05):
Benthic-Macroinvertebrate, Cadmium, Iron

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LIST OF ACRONYMS AND TERMS

Best Management Practice (BMP). Schedules of activities, prohibitions of practices, maintenance procedures, and other management practice to prevent or reduce the pollution of and impacts upon waters of the State. BMPs also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Bypass. The diversion of waste streams from any portion of a treatment works.

Code of Federal Regulations (CFR). Document that codifies all rules of the executive departments and agencies of the federal government. It is divided into fifty volumes, known as titles. Title 40 of the CFR (referenced as 40 CFR) lists all environmental regulations.

Designated uses are those uses specified in water quality standards for each waterbody or segment whether or not they are being attained. In no case shall assimilation or transport of pollutants be considered a designated use.

Loading capacity means the maximum amount of loading that a surface water can receive without violating water quality standards.

Margin of Safety (MOS). Because bacteria levels are variable, it is possible that the specified reductions may not be adequate to allow water quality to meet standards. To account for this uncertainty, an additional reduction in bacteria levels beyond the required numeric bacteria concentration is specified. This can be achieved using conservative assumptions, an explicitly allocated reduction, such as a level 10% below the standard, or a combination of both techniques.

Natural background conditions are all prevailing dynamic environmental conditions in a waterbody or segment thereof, other than those human-made or human-induced.

Nonpoint Source (NPS). Any discharge of pollutants that does not meet the definition of Point Source in section 502.(14) of the Clean Water Act and these regulations. Such sources are diffuse, and often associated with land-use practices, and carry pollutants to the waters of the State, including but not limited to, non-channelized land runoff, drainage, or snowmelt; atmospheric deposition; precipitation; and seepage.

Point source means any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation or vessel, or other floating craft, from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture.

Primary contact recreational activities are those activities in which there is prolonged and intimate contact by the human body with the water, involving considerable risk of ingesting water, such as swimming, diving, water skiing and surfing.

Rhode Island Geographic Information System (RIGIS). A consortium of government and private organizations employing computer and communications technology to manage and use a collective database of comprehensive geographically related information.

Rhode Island Pollutant Discharge Elimination System (RIPDES). The Rhode Island system for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing point source discharge permits and imposing and enforcing pretreatment requirements pursuant to Title 46, Chapter 12 of the General Laws of Rhode Island and the Clean Water Act.

Runoff means water that drains from an area as surface flow.

Secondary contact recreational activities are those activities in which there is minimal contact by the human body with the water, and the probability of ingestion of the water is minimal, such as boating and fishing.

Storm water means precipitation-induced runoff.

Surface waters are any waters of the state that is not groundwater.

Total Maximum Daily Load (TMDL). The amount of a pollutant that may be discharged into a waterbody and still maintain water quality standards. The TMDL is the sum of the individual wasteload allocations for point sources and the load allocations for nonpoint sources and natural background taking into account a margin of safety.

Wasteload allocation means the portion of a receiving water's loading capacity that is allocated to its point sources of pollution.

Water quality criteria means the elements of the State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use.

Water quality standard means provisions of State or Federal law, which consist of designated use(s) and water quality criteria for the waters of the State. Water Quality Standards also consist of an antidegradation policy.

1.0 INTRODUCTION

1.1 Purpose

The State of Rhode Island Department of Environmental Management (RIDEM) has identified water quality impairments in Buckeye Brook and in the Tributaries to Warwick Pond. Section 303(d) of the Clean Water Act and EPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require States to develop Total Maximum Daily Loads (TMDL's) for waterbodies that are not meeting designated uses. As confirmed by the 2008 benthic macroinvertebrate bioassessments (RIDEM, 2008) that included assessment of both habitat and biological condition, RIDEM finds that Buckeye Brook and Tributaries to Warwick Pond do not support aquatic life uses and are considered impaired for fish and wildlife habitat.

A TMDL is a tool for implementing state water quality standards and is based on the relationship between pollution sources in the watershed and water quality in the affected waterbody. The TMDL establishes the allowable pollutant loading to a waterbody and provides the basis for states to establish water quality-based controls. The TMDL provides a framework for identifying specific actions needed to reach water quality standards. The goal of the TMDL process is to reduce pollutant loadings to a waterbody in order to improve water quality to the point where state water quality Standards are met.

One of the major components of a TMDL is to establish instream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. Instream numeric endpoints represent the water quality goals that are to be achieved by implementing the load or pollutant reductions specified in the TMDL. The endpoints allow for a comparison between current instream water quality conditions and those conditions that are expected to restore beneficial uses. The endpoints are usually based on either the narrative or numeric criteria documented in Rhode Island's Water Quality Regulations as the state water quality standards (RIDEM, 2006).

The requirements of the TMDL process helped determine the scope of the Buckeye Brook Watershed study (as defined here to be inclusive of the Tributaries to Warwick Pond). The goal of this sampling was to characterize water quality of these brooks and to provide a more robust dataset for use in developing a TMDL that would address this impairment.

Buckeye Brook is on the State of Rhode Island's 2014 303(d) list as being impaired because it does not support fish and wildlife habitat (Aquatic Life Use) based upon Benthic-Macroinvertebrate Bioassessments (RIDEM, 2009). Earlier 303(d) lists also identified Buckeye Brook as being impaired because it does not support Primary Contact Recreation (Swimming/Recreation Uses) based upon pathogen data. RIDEM completed a water quality investigation and TMDL addressing pathogen impairments within the watershed, which was approved by US EPA in December 2008. Since a TMDL has been completed addressing the pathogen related impairments, that impairment listing was removed from the 303(d) list (also

referred to as Category 5 waters in the state's Integrated Report) and placed in Category 4A in the Integrated Report (impaired waters for which a TMDL has been completed). Also in 2008, this TMDL project was commenced with goals to: further characterize the biological condition impairment of Buckeye Brook (through macroinvertebrate and periphyton sampling); document water quality conditions; identify potential contributing pollution sources or stressors; and develop a TMDL to address the fish and wildlife habitat impairment.

Aquatic Life Use in Buckeye Brook was first listed as impaired in 1998 based upon macroinvertebrate sampling conducted by RIDEM's contractor, Roger Williams University. Subsequent sampling conducted by ESS, Inc. as part of RIDEM's Wadeable Stream Biomonitoring and Habitat Assessment Program, confirmed Buckeye Brook's impairment (ESS, 2002). Samples were collected annually at a station located at Old Warwick Avenue in Warwick, Rhode Island 2002-2005. Possible stressors contributing to the observed impairments at this location include runoff from nearby roads in this highly urbanized watershed, runoff from T.F. Green Airport (including use of glycol as a de-icing agent during the winter months), and runoff and/or groundwater leachate from an uncapped landfill (Truk-Away Landfill) located in the easternmost section of the airport property – along the western bank of Buckeye Brook.

1.2 Study Area

The focus of the TMDL study was the portion of the watershed that includes the mainstem stream system for Buckeye Brook as well as the Tributaries to Warwick Pond located in the northern part of the watershed. Prior to the 2014 303(d) listing, the Tributaries to Warwick Pond were included as part of the Buckeye Brook waterbody assessment unit ID. The new listings show a separate waterbody ID for the stream system north of Warwick Pond. As a result of RIDEM creating this separate waterbody ID for the upstream tributaries, the watershed for Buckeye Brook is redefined as the drainage area that extends from the exit of Warwick Pond to where the brook crosses under Tidewater Drive as it empties into Old Mill Creek. The field work for the data report covered approximately 55 percent of the full watershed for the areas surrounding T.F. Green Airport and Warwick Pond. Figure 1.1 shows the two areas of the watershed where the field work for this TMDL was conducted and Table 1.1 shows the waterbody IDs with their current water quality classifications in the 2014 303(d) listing.

Table 1.1 Applicable Waterbodies in the Buckeye Brook Watershed

Waterbody ID Number	Waterbody Description	Water Quality Classification	Water Quality Impairment
R10007024R-01	Buckeye Brook, Warwick, RI	B	Benthic-Macroinvertebrate Bioassessments, Cd, Cu, Fe, Dissolved Oxygen
RI00007024R-05	Tributaries to Warwick Pond	B	Benthic-Macroinvertebrate Bioassessments, Cd, Fe

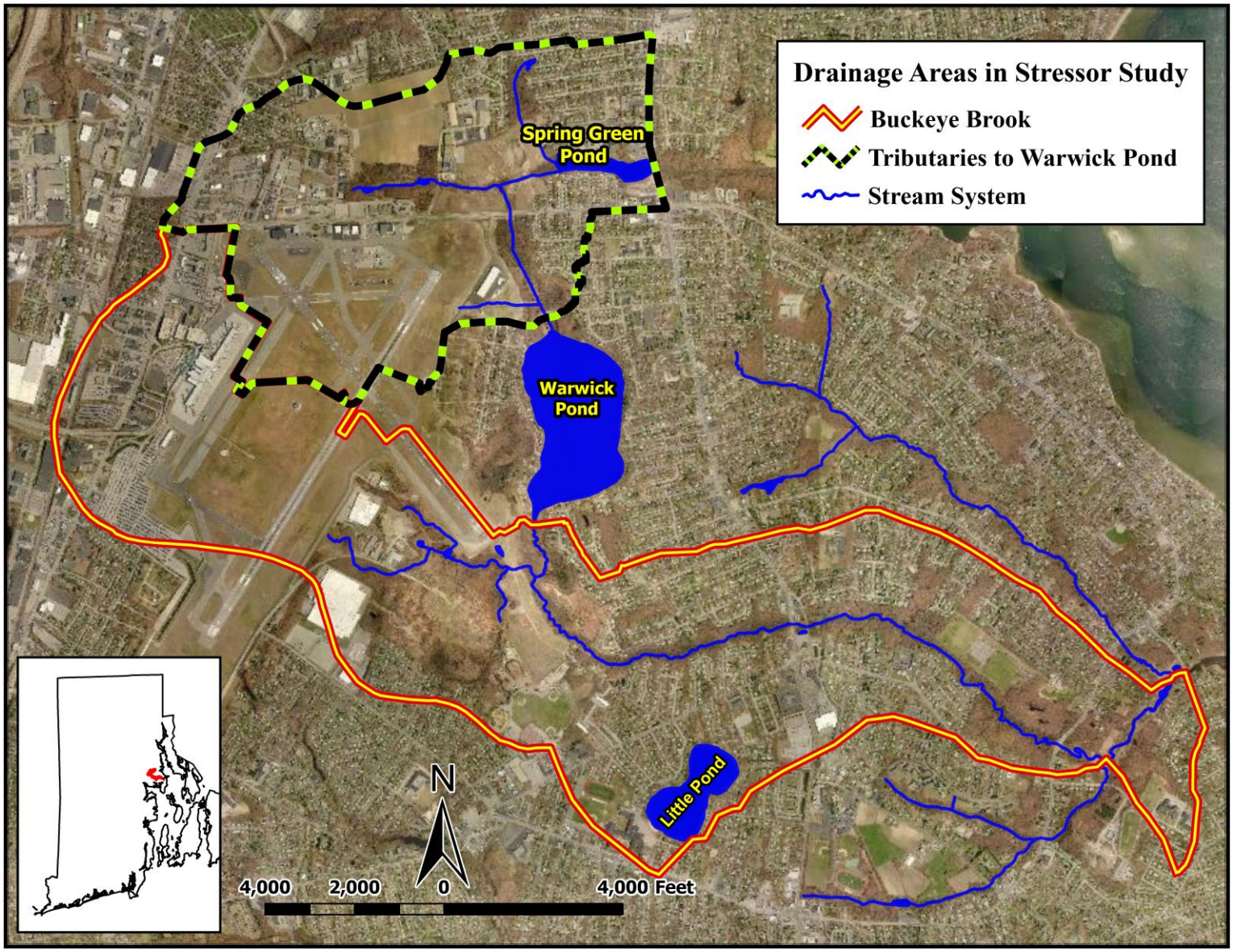

Figure 1.1 Biodiversity TMDL Study Areas

1.3 Pollutants of Concern

The goal of the field work for the current study was to identify the source or sources that contribute to the aquatic life use (macroinvertebrate biodiversity) impairment in the Buckeye Brook Watershed.

Analysis of the data collected during the field work portion of the study has identified exceedances (violations) of numerous water quality criteria: dissolved oxygen, total iron and dissolved cadmium and copper. A weight of evidence approach suggests that these pollutants along with impacts associated with stormwater runoff from the highly urbanized watershed are contributing to the macroinvertebrate biodiversity impairment. These pollutants are therefore the focus of this TMDL. These pollutants of concern were added to the 2014 303(d) list.

Stormwater runoff can transport a complex array of pollutants to waterbodies and as a result, aquatic life communities may be subjected to many stressors associated with stormwater runoff. These stressors are related either directly or indirectly to stormwater runoff volumes and include increased watershed pollutant load (e.g. sediment), increased pollutant load from in-stream sources (e.g., bank erosion), habitat degradation (e.g. siltation, scour, over-widening of stream channel), washout of biota, and reduced groundwater recharge resulting in the loss of habitat due to reductions in stream base flows. The stressors associated with stormwater runoff may act individually or cumulatively to degrade the overall biological community in a stream to a point where aquatic life uses are not fully supported.

Impervious cover can be directly related to the amount of human disturbance occurring within a watershed and how it relates to the overall health of aquatic communities. Certain studies have documented aquatic life use impairments in relation to the extent of impervious surfaces in the watershed and have used impervious cover (IC) as a surrogate for stormwater related impacts to aquatic life (Maine IC TMDL, 2012). Analysis of the data used in this TMDL shows that while there were some dry weather exceedances of the freshwater water quality criteria, most exceedances occurred under wet weather conditions.

Higher concentrations of copper are usually from anthropogenic sources such as WWTF, industrial facilities, and urban runoff. These sources include corrosion of brass and copper pipes by acidic waters, industrial effluents and fallout, sewage treatment plant effluents, and the use of copper compounds as aquatic plant controls.

Cadmium (Cd) is a soft, bluish-white metal and is used in batteries (especially rechargeable nickel-cadmium batteries). As a result of its low coefficient of friction and its high fatigue resistance, cadmium is used in alloys for bearings.

Iron (Fe) in water can be precipitated as a hydroxide $Fe(OH)_3$ or as ferric oxide (Fe_2O_3) which form a gel or floc that, when suspended in water, may be detrimental to fishes and other aquatic

life. They can settle to form flocculent materials that cover stream bottom, thereby destroying bottom-dwelling invertebrates, plants or incubating fish eggs.

The amount of Dissolved Oxygen (DO) in the water column is indicative of the aesthetic qualities of the water as well as an important gage of existing water quality and the ability of a water body to support a well-balanced aquatic fauna. For freshwater aquatic life, a minimum concentration of 5.0 mg/L is required to maintain good fish populations. The minimum criterion for salmonid spawning beds is an instantaneous DO of 5.0 mg/L.

Potential sources of contaminants include stormwater discharges from T.F. Green Airport and Truk-Away landfill as well as runoff from the highly urbanized watershed. Stormwater outfalls from T.F. Green Airport (PVD) discharge to the Tributaries of Warwick Pond above Lakeshore Drive and into Buckeye Brook between the exit of Warwick Pond and Warwick Avenue. Historically, during winter de-icing operations, the stormwater discharging from several outfalls on the airport property has contained varying amounts of propylene glycol, the major constituent in aircraft deicing fluid (ADF). During the course of this study, the RI Airport Corporation had begun implementation of structural controls to reduce propylene glycol being discharged. One concern of the study was the effects of the biological oxygen demand caused by the breakdown of deicing and anti-icing compounds.

Truk-Away Landfill is another potential source of pollutants to the brook. The landfill is located southwest of the approach end of Runway 34. Landfill operations were ceased in 1977, but the landfill was never properly capped and the potential exists for waste material to be in the stream that meanders along the southern edge of the landfill and to ultimately end up in Buckeye Brook. The stream has very low flows and it joins with the flow from Outfall 08 prior to the confluence with Buckeye Brook.

As will be discussed in detail in the following sections, the sampling completed as part of this study has identified exceedances (violations) of numerous water quality criteria: dissolved oxygen, total iron, and dissolved cadmium and copper

This TMDL establishes numeric water quality targets for iron, copper, and cadmium. The TMDL must ensure that the water quality criteria for dissolved oxygen are also met. As will be discussed in greater detail, controls of glycol discharges and reductions in iron levels are expected to prevent dissolved oxygen violations. Thus, dissolved oxygen targets are not set explicitly by the TMDL.

1.4 Priority Ranking

Buckeye Brook and the Tributaries to Warwick Pond are Category 5 waterbodies on the RIDEM 2014 303(d) List of Impaired Waters for Benthic-Macroinvertebrate Bioassessments; the Buckeye Brook impairment was first placed on the list for this impairment in 1998. This Category constitutes the 303(d) List of waters impaired or threatened by a pollutant(s) for which one or more TMDL(s) are needed.

1.5 Applicable Water Quality Standards

As stated in 40 CFR 131.2, "[water quality] standards serve the dual purposes of 1) establishing the water quality goals for a specific waterbody and 2) serving as the regulatory basis for the establishment of water-quality based treatment controls and strategies beyond the technology-based levels of treatment required by section 301(b) and 306 of the Act." The primary aim of a TMDL is to bring a waterbody back into compliance with applicable water quality regulations.

Therefore, it is important to know exactly which regulations apply to the waterbody for which a TMDL is developed. The regulations, which are specifically applicable to the impairments that caused Buckeye Brook and its tributaries to be listed on the State's 2014 303(d) list, are listed below.

1.5.1 Waterbody Class and Designated Use

Section 8.B of the Water Quality Regulations (RIDEM, 2006, Amended 2010) describes the water use classification. All surface waters shall be assigned to a class that is defined by the designated uses, which are the most sensitive, and therefore, governing water uses which it is intended to protect. Surface waters may be suitable for other beneficial uses, but shall be regulated to protect and enhance the designated uses. In no case shall waste assimilation or waste transport be considered a designated use.

Section 8.C(3) states that all freshwaters hydrologically connected to and upstream of Class B, B1, SB, SB1, C, or SC waters shall be Class B unless otherwise identified in the regulations. Buckeye Brook is listed as Class B.

The following excerpt from Rule 8.B (1) of the Regulations describes Class B freshwaters and their designated uses:

> *These waters are designated for fish and wildlife habitat and primary and secondary contact recreational activities. They shall be suitable for compatible industrial processes and cooling, hydropower, aqua cultural uses, navigation, and irrigation and other agricultural uses. These waters shall have good aesthetic value.*

1.5.2 Numeric Water Quality Criteria

The water quality standards for toxics, including dissolved metals, set forth in Appendix B of the State of Rhode Island Department of Environmental Management Water Quality Regulations

(DEM December 2010) state that "to protect aquatic life, the one-hour average concentration of a pollutant should not exceed the acute criteria more than once every three years on the average. The four-day average concentration of a pollutant should not exceed the chronic criteria more than once every three years on the average. These aquatic life criteria shall be achieved in all waters, except mixing zones, regardless of the waters' classification.

Hardness is a measure of the concentration of cations in solution (Minton 2002), with hardness usually measured as calcium carbonate ($CaCO_3$) equivalents in mg/l. An increase in hardness decreases the toxicity of metals, because calcium and magnesium cations compete with the metal ions for complexing sites, allowing fewer metal complexes to form and therefore resulting in a lower level of toxicity (Minton 2002).

The chronic and acute freshwater criteria of metals apply to the dissolved form and are calculated using water hardness (in mg/l as CaCO3) based on equations in Table 2-Appendix B of Rhode Island's Water Quality Regulations shown below in Table 1.2. The criterion for iron is not dependent upon the hardness of the water sample but is a single chronic value of 1000 µg/L for all conditions.

Table 1.2 Applicable Freshwater Criteria Equations

Parameter	**ACUTE (µg/L)** $CF \times e^{(m_a[\ln Hardness] + b_a)}$			**CHRONIC (µg/L)** $CF \times e^{(m_c[\ln Hardness] + b_c)}$		
	CF =	m_a	b_a	CF =	m_c	b_c
Cadmium (Cd)	@	1.0166	-3.924	@	0.7409	-4.719
Copper (Cu)	0.96	0.9422	-1.700	0.96	0.8545	-1.702
Lead (Pb)	#	1.273	-1.46	#	1.273	-4.705
Zinc (Zn)	0.978	0.8473	0.884	0.986	0.8473	0.884

@ = Cadmium Conversion Factors: Acute CF= 1.136672 – [(ln H) x 0.041838]; Chronic CF= 1.101672 – [(ln H) x 0.041838]

= Lead Conversion Factors: Acute and Chronic CF= 1.46203 – [(ln H) x 0.145712]

One exceedance of the chronic criteria is acceptable given that the State's WQRs stipulate "the four-day average concentration of a pollutant should not exceed the chronic criteria more than once every three years on the average". However, more than one exceedance would constitute a violation of chronic criteria and would necessitate calculating a required reduction.

Similarly, one exceedance of the acute criteria is acceptable given that the State's WQRs stipulate "the one-hour average concentration of a pollutant should not exceed the acute criteria more than once every three years on the average". However, more than one exceedance would constitute a violation of acute criteria and would necessitate calculating a required reduction.

In some instances, a single exceedance of the criteria may be viewed as non-compliance with the standards if there is strong evidence that the criteria could be exceeded again within a three-year period. More specifically, one exceedance may be considered a violation of criteria where

RIDEM has knowledge of an actual or potential upstream pollution source or where the exceedance occurred during a wet weather event, and it is considered likely that the condition would reoccur and the criteria would be exceeded again within a three-year period.

The observed hardness values for the stream stations over the dry weather surveys varied more during the first survey than they did for the second. For the first survey, "main stem" stream stations ranged from 47 mg/L to 66 mg/L; whereas the landfill stream station had the highest value of 91 mg/L. The second dry weather survey had observed values for all stations that ranged from 40 mg/L to 45 mg/L. Wet weather values ranged from an observed low of 15 mg/L during Runs 2 and 3 of Wet Weather 1 at the airport outfall OF08 to a high of 98 mg/L observed during the Pre-storm run at the landfill stream station. The resulting range of numeric water quality concentration criteria for dissolved cadmium (Cd) and copper (Cu) are shown in Table 1.3, and the data tables and criteria evaluations are in Appendix A.

Table 1.3 Range of Water Quality Criteria Utilized for the Buckeye Brook TMDL

Hardness as $CaCO_3$ (mg/L)	Cadmium (µg/L)		Copper (µg/L)	
	Acute Criteria	Chronic Criteria	Acute Criteria	Chronic Criteria
15.00	0.31	0.07	2.25	1.78
30.00	0.62	0.11	4.32	3.20
60.00	1.23	0.18	8.31	5.79
90.00	1.82	0.24	12.2	8.19
120.0	2.40	0.29	15.9	10.5
150.0	2.99	0.34	19.7	12.7

The criterion for iron is not dependent upon the hardness of the water sample but is a single chronic value of 1000 µg/L for all conditions. The target criteria concentrations for copper and cadmium were calculated using the observed hardness values of the field samples. RIDEM evaluated hardness value distributions during both dry and wet weather conditions, as follows:

Dry weather acute and chronic criteria were calculated for all sampling stations using the dissolved metals data and the associated hardness values for each survey date to determine the applicable criteria. The resultant criteria were compared against the observed dissolved metal collected at each sample location for each survey date to determine if an exceedance occurred.

The criteria for the wet weather surveys were calculated as follows:

1. Acute criteria: For both wet weather surveys, the observed hardness values associated with each station and for each sampling run, including the pre-storm sample, were used to determine the criteria using the equations in Table 1.2. The resulting criteria were then compared against the observed dissolved metal at each station to determine the required reduction.

2. Chronic criteria:
    a. Wet Weather 1 averaged the hardness values for all runs from each station and this average value was then used to calculate the chronic criteria for that event. The calculated criteria were compared against each observed value for that station to determine the required reduction.
    b. Wet Weather 2 was conducted over an 8-day period from February 1st to February 8th, 2011. The temporal spacing of the samples did not allow for the averaging of four samples for each station to calculate the criteria. Instead, the hardness values were averaged for the Pre-storm and Run 1 samples, the Run 1 and Run 2 samples, and the Run 2 and Run 3 samples. This resulted in three hardness values for each station for the storm and these values were used to determine the criteria for each pair of samples collected. Similarly, the observed dissolved metals values were averaged together, Pre-storm + Run 1, Run 1+Run 2, and Run 2+ Run 3. The calculated criteria were compared to the averaged observed metals values to determine the required reduction.

This TMDL finds that a combination of stressors is contributing to the observed biodiversity impairments in Buckeye Brook and the Tributaries to Warwick Pond. The uncontrolled discharge of stormwater and hydrologic alterations associated with the highly urbanized watersheds combined with violations of ambient water quality criteria for various metals, previously uncontrolled discharge of propylene glycol (occurring prior to and at the time of sampling in 2008 – 2011) and extensive growth of iron fixing bacteria on substrates downstream of the airport outfalls and the Truk Away Landfill are all believed to be stressors contributing to the observed biodiversity impairments.

A stormwater permit (RIPDES RI0021598) issued by RIDEM to the RI Airport Corporation in July 2012 requires the collection and treatment of glycol-impacted stormwater and discharge to the City of Warwick's sanitary sewer system. These permit requirements strictly control the discharge of glycol to Buckeye Brook and the Tributaries to Warwick Pond. The permit contains effluent discharge limitations, consisting of narrative/numeric effluent discharge limits based on Technology-based effluent limitations and water quality based effluent limitations as well as Special conditions – supplemental controls and Best Management Practices that may be needed in order to ensure that the goals of the CWA are met.

This TMDL does establish numeric water quality targets for iron, copper, and cadmium. The TMDL must ensure that the water quality criteria for dissolved oxygen are also met. Based on historical monitoring of in-stream dissolved oxygen levels, RIDEM has determined that implementation of new aircraft/airfield source water contamination prevention measures at T.F. Green Airport (including construction of glycol treatment and diversion structures completed in the fall of 2014) will prevent violations of in-stream DO criteria associated with glycol discharges. This TMDL requires reductions in iron levels and in turn prevent the dissolved oxygen violations observed in the summer months associated with their growth. Thus, dissolved oxygen targets are not set explicitly by the TMDL.

Among the physical, chemical and biological criteria set forth in Rule 8D(1)(a) of RI's Water Quality Regulations are that waters shall be free of pollutants in concentrations or combinations or from anthropogenic activities…that adversely affect the physical, chemical, or biological integrity of habitat (DEM December 2010). Mitigation of the hydrologic alterations and pollutant loads associated the discharge of uncontrolled runoff from the highly impervious watersheds are addressed by stormwater control requirements placed on both the Rhode Island Department of Transportation and the City of Warwick to implement the Buckeye Brook Bacteria TMDL. Both MS4 operators are required to undertake structural improvements to eliminate or treat impervious cover to act as if it were eliminated to achieve a 10% impervious cover. This TMDL does not establish separate targets to address hydrologic alterations.

2.0 DESCRIPTION OF THE STUDY AREA

2.1 Project Stream Systems

There are two primary stream systems in this study: Tributaries to Warwick Pond and Buckeye Brook, a third order stream system that originates at the outlet of Warwick Pond in Warwick, Rhode Island. Buckeye Brook flows in a southeast direction from the southernmost point of Warwick Pond into Old Mill Creek, which is south of Conimicut Point, and ultimately Narragansett Bay. Buckeye Brook Watershed has three tributaries, Lockwood, Warner and Knowles (Parsonage) Brooks, with the exception of Warner Brook, none were included in the biodiversity study for this TMDL. A station on Warner Brook was established to document water quality conditions in a highly urbanized sub-watershed not influenced by either TF Green Airport or the landfill. Results from this station are presented in the Final Data Report however, they are not included here because the station is not within the watershed boundaries of the two areas that are the focus of this TMDL.

The Tributaries to Warwick Pond are made up of a small stream system north of the airport that empties into Spring Green Pond and the outlet of the pond joins another first order stream that drains an agricultural area located north of Airport Road. Table 1.1 listed the applicable waterbodies in this TMDL and Figure 1.1 showed the hydrologic boundaries of the stream systems.

The two watersheds are highly urbanized and encompass the majority of the area that is the site of Rhode Island's primary airport, T.F. Green. The tributaries north of Warwick Pond have a drainage area of 1.2 mi^2 and the Buckeye Brook watershed drainage area is 2.55 mi^2.

As part of the airport expansion project, an Engineered Materials Arrestor System (EMAS) safety over-run was constructed at the approach end of runway 34. The tributary stream that receives the discharges from outfalls 008 and 009 was diverted around a cofferdam for the project. When completed, the re-routed stream bed will remain as a permanent change.

Another part of the T.F. Green expansion was the relocation of the Winslow Park athletic fields to a site that is adjacent to the maintenance building on the north-eastern side of the airport property. The project is complete and open for operation. Rain gardens and infiltration ponds were constructed in this area to handle the storm water runoff for the new fields.

The tributary reach that flows along the east side of the airport property between Airport Road and Lake Shore Drive was redesigned to make a meandering stream system in this area and the culverts under the drive were replaced with larger conduits to compensate for the increased storm water flows observed at Airport Road and Outfalls 002 and 003 during some wet weather events, and to provide enhanced accessibility for the annual alewife passage to upstream spawning areas. The old system with the smaller culverts under the drive could not handle some of the larger storm water flows, resulting in a flooded road crossing. The replacement with larger culverts and the channel modifications up-stream of Lake Shore Drive will reduce the velocity of the flows and eliminate the flooding issues associated with the increased storm water flows.

The perimeter road and other low berms were removed as well as the airport chain link fence to allow more freedom of movement within the wetland area by native animals. Construction for these improvements started in July 2015 and was completed by September of the same year. The US Army Corps of Engineers report dated January 3, 2017 stated that performance standards are being met at all mitigation sites that no additional remedial actions were recommended at this time.

2.2 Watershed History

The recorded history of Warwick and the Buckeye Brook watershed area began with the arrival of the Europeans in 1636. The attractions of the region to colonists were: the natural resources afforded by the geographic and topographic diversity that allowed settlers to hunt, fish, and farm in abundance. The lowland and central portions of Warwick, in which the study areas are found, is generally composed of glacial outwash soils. These soils are well sorted, well drained, sandy, and loosely packed. They are especially amenable to farming and building construction.

Hillsgrove State Airport (now T.F. Green Airport) was constructed in 1931. In the same year, Warwick transformed from a town to a city, complete with a mayor-city council form of government. The post WWII era brought a rash of newcomers and development to the area, filling the area with gas stations, restaurants and the necessary municipal developments to support the expanding population. As transportation in the area gradually improved, many residents began to transform their summer houses along the coast into year-round residences. In spite of this development, a few areas have managed to remain as open green space. The entire study area, situated among the residential developments, industrial parks and the airport, has continued to provide a habitat for a diversity of wildlife. Buckeye Brook itself remains one of the only undimmed herring runs left in the region.

2.3 Water Quality History

RIDEM's Baseline Monitoring Program has a biological sampling station on the main stem of Buckeye Brook at the Old Warwick Road crossing. The ESS Group had conducted several biological surveys at this site starting in 2003 (ESS, 2004, ESS, 2005), with the last one occurring in 2008. Because the monitoring at this locale was strictly biological, only field water quality measurements are collected that included dissolved oxygen, temperature and specific conductivity. Chemistry and pathogen sampling was not conducted for these surveys. This location has been rated as moderately impaired for fish and wildlife habitat.

University of Rhode Island's Watershed Watch has performed volunteer monitoring on the brook and its tributaries since 2008, collecting grab samples twice a month from April through October. Two main stem stations were monitored by the volunteers in Warwick, RI. One was located at the end of Novelty Road, and the other was at the entrance to Old Mill Creek at Tidewater Drive. Constituents sampled included enterococci, chloride, pH, dissolved nitrogen-nitrate, dissolved nitrogen-ammonia, dissolved ortho-phosphate, total nitrogen, and total phosphorus.

Watershed Watch added a winter sampling event in 2012 – 2013. Dissolved oxygen and temperature was measured at six locations within the watershed. The sampling period was once a month from July 2012 to January 2013, with four chlorophyll *a* samples collected from August to November. Four stations were on the mainstem of Buckeye Brook and two were on Spring Green Pond and Warwick Pond. The four main stem stations for Buckeye Brook were located at Lakeshore Drive, Warwick Avenue, Novelty Road, and Tidewater Drive. A second winter sampling effort is scheduled to commence in November 2013 at the same six stations. The constituents being sampled include propylene glycol, total dissolved solids, dissolved oxygen and temperature.

The watersheds are dominated by the presence of Rhode Island's major airport, T. F. Green. During the winter months, aircraft de-icing and anti-icing operations are conducted; historically the excess propylene glycol runoff would flow into the stream systems at two primary locations. One site discharges to the tributary stream segment of Warwick Pond above Lake Shore Drive, and the other site, which is the largest outfall from the airport, discharges to Buckeye Brook, downstream of the outflow from Warwick Pond. The presence of compounds used in anti-icing and de-icing operations (propylene glycol) was detected in the brook downstream of Warwick Pond during winter surveys conducted on behalf of the Rhode Island Airport Corporation (RIAC) in the winter of 2000-2001.

On September1, 2012, a new RIPDES permit for T.F. Green was implemented that required RIAC to develop and implement BMPs to promote source reduction and pollution prevention that will be protective of fresh water quality standards and criteria in receiving waters to include dissolved oxygen, aquatic toxicity, foaming, nuisance odors and nuisance bacteria growth. The system that went operational in October 2014 is designed to divert the excess glycol from the

passenger and cargo terminal areas to storage tanks, treat it on-site, and later discharge the treated solution to the Warwick Sewer Authority sanitary sewer system.

Additionally, the Truk-Away Landfill, located to the west of Buckeye Brook, had a site inspection performed in 1993 by CDM Federal Programs Corporation (CDM, 1993), and several monitoring wells on the landfill property were sampled by Lincoln Environmental for RIDEM in December 2004 (Lincoln Environmental, 2005). Table 2.1 lists historic monitoring conducted in the Buckeye Brook watershed.

2.4 Impervious Cover as Predictor of Biodiversity Impacts

The watershed's impervious cover (IC) is considered separate from the rest of the land use categories and is often considered a standalone value that directly relates to the health of a waterbody (Center for Watershed Protection, 2003). The percentage of impervious cover increases as the urbanization of a watershed progresses over time. Impacts due to increased imperviousness can manifest in many areas other than water quality. Hydrologic impacts such as decreased groundwater recharge, lower base flows and increased runoff can also cause changes in stream morphology. Altered morphology can result in a flashier, less stable stream that degrades the quality of habitats for aquatic life. Elevated pollutant loads, temperatures, as well as increased sediment transport are some of the water quality impacts associated with high IC watersheds. All this together can impact not only aquatic life but degrade the waterbody's recreational potential. Figure 2.1 shows the impacts associated with impervious cover.

Table 2.1 Historic Monitoring Conducted in Buckeye Brook Watershed

Primary Organization	Sample Location	Time Period	Analyte
U.S. Environmental Protection Agency (USEPA)	Main area of Truk-Away Landfill	1993	Soil and Leachates
RI Dept. of Environmental Management (RIDEM)	Buckeye Bk at Old Warwick Avenue Bridge crossing	2002-2005	Biological Assessment
RI Dept. of Environmental Management (RIDEM)	Truk-Away Landfill groundwater from monitoring wells	2005	VOCs
RI Dept. of Environmental Management (RIDEM)	Buckeye Bk, Warner Bk, Lockwood Bk, Knowles Bk, Old Mill Creek, Tributaries to Warwick Pond	2006	Field measurements (Dissolved Oxygen, Temperature, Specific Conductivity), Fecal Coliform, Enterococci
Watershed Watch, URI	Buckeye Bk, Lockwood Bk, Warner Bk	2004 - 2012	Fecal Coliform, Enterococci, Dissolved Nitrates, Dissolved Ammonia, Dissolved Ortho-phosphate, Total Nitrogen, Total Phosphorus, pH, Chlorides

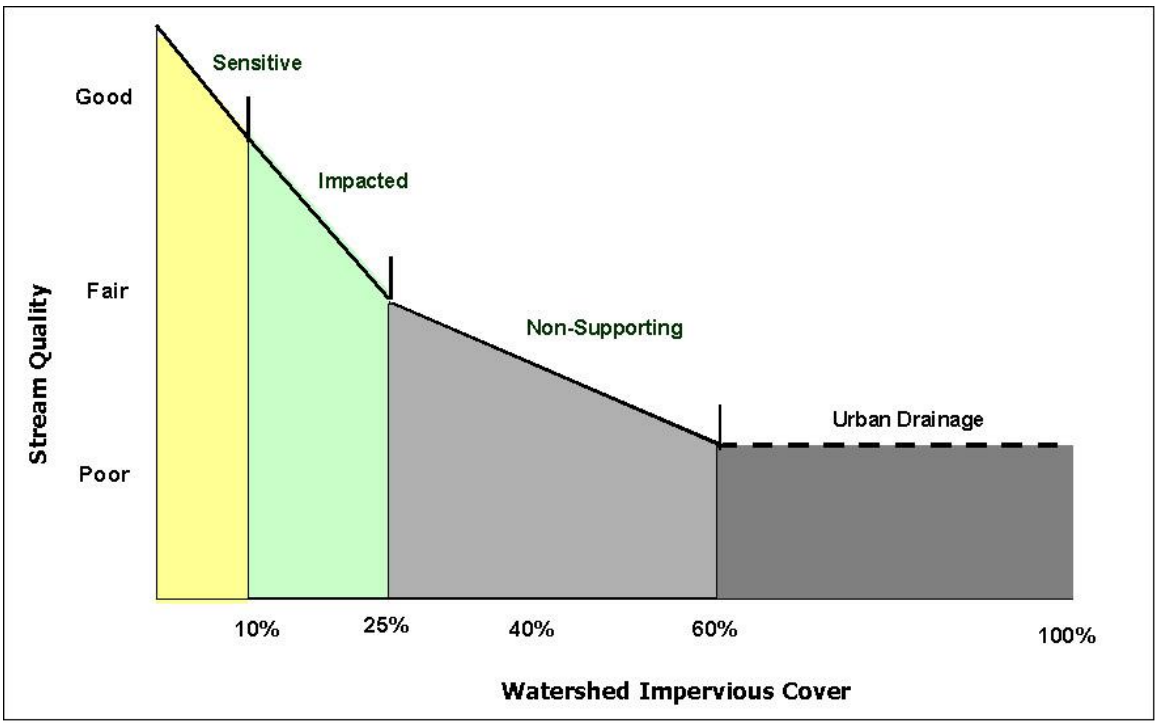

Figure 2.1 Watershed Impervious Cover versus Stream Quality (EPA/ENSR, 2005)

3.0 RIDEM AQUATIC LIFE USE STRESSOR STUDY

The state's 2012 Integrated Water Quality Monitoring and Assessment Report 305(b) and 303(d) list identified Buckeye Brook (at that time, inclusive of the Tributaries to Warwick Pond) as non-supporting for fish and wildlife habitat. The cause of the impairment is attributed to the poor comparability of bioassessment metrics evaluating these brooks' benthic-macroinvertebrate community and habitat to a reference site. The Rhode Island Department of Environmental Management conducted a sampling project to characterize the geographic extent and severity of the Buckeye Brook Aquatic Life Use (AQLU) impairment and to identify potential causes and/or pollution sources contributing to the impairment. Water quality and/or benthic biological samples were collected from nine sites in the Buckeye Brook watershed over the course of four surveys from July 2008 through February 2009 that consisted of two dry weather and two wet weather surveys, one of which was during a winter icing event.

3.1 Methodology

3.1.1 Stations

Eight stations were selected in the two watersheds for the surveys. Three stations were located on airport property, two on tributaries to Warwick Pond and three on the Buckeye Brook stream system. A ninth station for Adamsville Brook in Adamsville, RI was used as a biological reference site by the ESS Group, Inc. Table 3.1 lists the stations as well as their location,

description, type of sampling conducted, and the reasoning or purpose of the selection. Figure 3.1 shows the location of the sampling stations within the watershed, and Figure 3.2 is a more detailed view of the stations sampled within T.F. Green Airport property.

Table 3.1 Biodiversity Sampling Station Locations and Description

Station ID	Location	Description	Type	Purpose
BB00	Unidentified tribs to Buckeye Brook above Airport Road	In-stream: Upstream of Airport Road culvert	Water Quality, Biological, CPOM, FPOM, TOC	Background sample of stream away from airport and landfill influence
BB02	Buckeye Brook @ Lakeshore Drive	In-Stream, Downstream of culverts under Lakeshore Dr.	Water Quality, Toxicity, Biological, CPOM, FPOM, TOC	Brackets airport Outfalls 002 and 003 with background site BB00
BB03	Buckeye Brook @ Lakeshore Drive	In-stream, Exit of Warwick Pond	Water Quality, Toxicity	Separates Warwick Pond from confluence of airport Outfalls 008 and 009 with Buckeye Bk
BB04	Buckeye Brook @ Rufus Road	In-stream: Downstream of confluence of Buckeye Brook and airport outfall flows	Water Quality, Toxicity, Biological, CPOM, FPOM, TOC	Samples the brook after the confluence of all airport outfalls and the landfill
BB05A	Buckeye Brook downstream of Old Warwick Avenue	In-stream and approximately 1000 ft downstream of the ESS Biological Monitoring Site	Water Quality, Toxicity, Biological, CPOM, FPOM, TOC	To compare the 2008-09 monitoring results to the ESS biomonitoring at BB05 located at Old Warwick Avenue
OF08	Discharge point of outfall 008	TF Green Airport Outfall 008 discharge	Water Quality, Habitat Assessment, Toxicity	Isolates Outfall 008 flows from landfill influence
TA01	Stream from Truk-Away Landfill	In-stream, prior to confluence with stream from Outfall 008	Water Quality, Habitat Assessment, Toxicity	Isolates landfill stream from outfall stream coming from airport
AP01	Combined flow of channels from outfall 008 and landfill	In-stream, prior to discharge into Buckeye Brook upstream of airport service road.	Biological, CPOM, FPOM, TOC	Evaluates biological community in stream downstream of landfill and airport
Adamsville Brook	@ USGS Gage off Route 81 in Little Compton, RI	In-stream sampling	Macroinvertebrate	Biological Reference Site

3.1.2 Parameters

Samples were collected four times for water quality (WQ), with biological and toxicity sampling conducted during the second dry weather survey. The water quality samples were analyzed for dissolved trace metals that included Arsenic (As), Copper (Cu), Cadmium (Cd), Manganese (Mn), Lead (Pb) and Zinc (Zn) as well as Total Iron (Fe). Other constituents included Hardness as $CaCO_3$, five-day Biological Oxygen Demand (BOD_5), Chloride (Cl), Ammonia-Nitrogen (NH_3-N), Nitrate+Nitrite-Nitrogen (NO_2+NO_3-N), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), Total Suspended Solids (TSS), Total Organic Carbon (TOC), pH, and Propylene Glycol. All water quality and toxicity samples were collected by RIDEM staff.

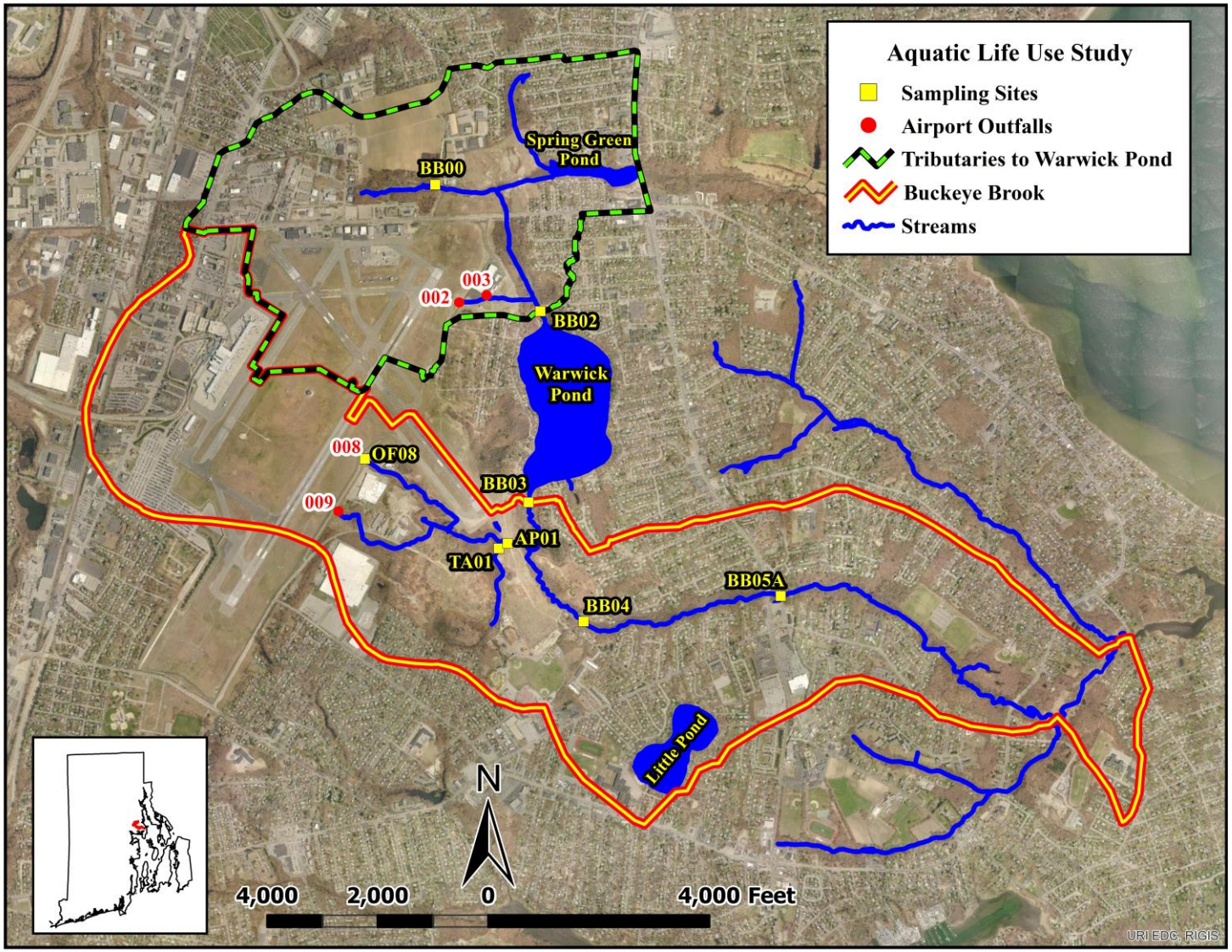

Figure 3.1 Sampling Sites for Aquatic Life Use Stressor Study

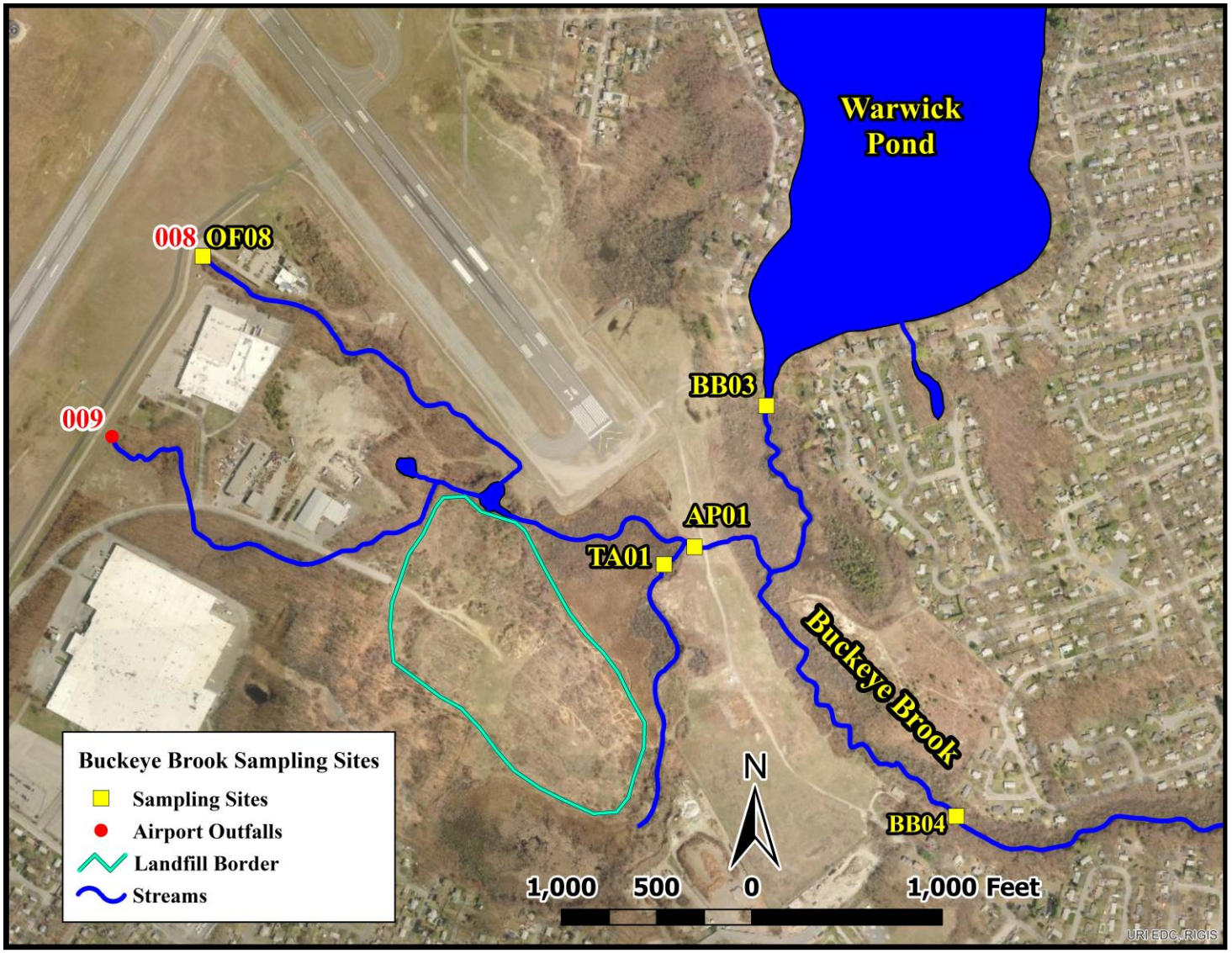

Figure 3.2 Buckeye Brook Tributary and Mainstem Sampling Sites

The water quality analyses, with some exceptions were conducted at the RI State Health Laboratories in Providence, RI. ESS Laboratories in Cranston, RI conducted the NH_3-N, TKN, TOC and Propylene Glycol analysis. Field measurements consisting of dissolved oxygen (D.O.), temperature in degrees centigrade (° C), and specific conductance in microsiemens per centimeter (µS/cm) were measured by RIDEM staff the field using an YSI-85 meter. Field data was collected during all sampling events. All constituents listed were analyzed for all surveys with the exception of TOC, which was only analyzed for the second dry weather survey when biological sampling was conducted, and Propylene Glycol, which was analyzed for the wet surveys only. The toxicity samples collected by RIDEM staff were delivered to the EPA Region 1 Laboratory at Chelmsford, MA where the toxicity testing was conducted by the laboratory staff. A Two Species – 7 Day Chronic Toxicity Test was done for *Ceriodaphnia dubia* (daphnid) and the *Pimephales promelas* (fathead minnow). Toxicity sampling was conducted during the first dry weather and winter wet weather surveys. Toxicity sampling runs were conducted every other day to collect water to replenish the specimen tank. The Quality Assurance Project Plan (QAPP) is available on the RIDEM website at: http://www.dem.ri.gov/pubs/qapp/buckbio.pdf

Biological sampling was done by ESS Group, Inc. and accompanied by RIDEM staff at selected stations. The biological survey included a combination of any or all of the following: Macroinvertebrate sampling, Periphyton sampling, Stream Habitat Assessments, CPOM (coarse particulate organic matter >1mm), and FPOM (fine particulate organic matter, less than 1mm and more than .05 mm).

3.1.3 Land Use

The current land use in the study area (RIGIS2011) is 43% residential (75% of this value, or 32% of the total land use is medium to high density residential), 19.7% forest and wetland, 16.1% airport, 11.4% commercial-industrial, 5.2% open, 3.3% agricultural, and 2.2% institutional. Figure 3.3 shows a map of the land use for the entire study area. Table 3.2 shows the drainage area associated with each station as well as the acres of impervious cover within each station. Stations BB06 through BB08 were used in the Buckeye Brook Pathogen TMDL field study and are included in this table even though they were not sampled as part of the biodiversity field work.

The watershed's impervious cover (IC) is considered in addition to the land use categories, as studies show that it directly relates to the health of a waterbody (Center for Watershed Protection, 2003). The current land use for the study area (RIGIS2011) shows that 78.2% of the area can be classified as urban. The remaining 21.8% of the area falls under the general land use categories for agriculture, forest, wetland, and water. A breakdown of the urban development land use shows that the impervious cover (IC) within the study area is significant at 42.1%.
At this level of impervious coverage, if no treatment is provided, stormwater impacts on water quality and aquatic biota (as indicated by benthic macroinvertebrate communities) is almost inevitable, as further discussed in Section 6.1.

Table 3.2 Study Site Land Use, Drainage Area (Acres) and Impervious Cover Percentages

Land Use Type	Tributaries to Warwick Pond			Buckeye Brook				
	BB00	BB02	Sub-Total	BB04	BB05	BB06	BB07-08	Sub-Total
Residential	27.6	122.5	150.1	54.26	146.52	228.25	105.77	534.8
Commercial	28.5	32.1	60.5	80.8	10.0	63.3	10.2	164.3
Industrial	44.5	19.4	63.9	34.1				34.1
Airport/Transportation	23.6	252.0	275.6	422.0	4.7	0.3		427.0
Developed Recreational	0.4		0.4	24.7		40.1	10.6	75.4
Pasture and Cropland	51.3	0.1	51.4					
Mixed Forest	22.7	49.2	71.9	103.1	35.0	60.7	64.8	263.7
Brushland		1.6	1.6	43.4				43.4
Vacant/Urban Open	1.2	39.9	41.1	18.3		0.5	3.2	22.0
Wetland		1.6	1.6	22.5			13.6	36.1
Water	0.6	9.2	9.8	1.4		29.3	0.2	30.9
Impervious Cover Percentages for Study Areas								
Total Station Drainage Area	200.4	527.5	727.9	804.7	196.2	422.4	208.4	1631.7
Impervious Cover	100.6	227.0	327.6	351.7	86.3	172.9	55.6	666.5
Percentage Impervious Cover	50.2%	43.0%	**45.0%**	43.7%	44.0%	40.9%	26.7%	**40.8%**

3.2 Dry Weather Surveys

The first dry weather survey was on July 16, 2008 where single grab samples were collected at eight stations for water quality analysis. Station AP01 was not sampled for the first dry weather survey since it was located downstream of Stations OF08 and TA01, and represented the total of these latter two stations. This survey was the first toxicity sampling event for the watershed and water samples were collected and transported to EPA Region 1 Laboratory at Chelmsford, MA for toxicity tests. The first set of toxicity samples were collected along with the water chemistry samples on July 16th, and additional toxicity water samples only were collected on July 18th and July 20th that were used to replenish the water for the 2-species toxicity test. Table 3.2 shows the dates of the biodiversity dry weather surveys and the type of sampling that took place during those events.

ESS Group, Inc. accompanied RIDEM personnel for the second dry weather survey on September 10, 2008 and collected biodiversity samples for selected stations as noted in Table 3.3. During the second dry survey, grab samples were collected for water quality chemical analysis from all stations except BB03. This station was not a viable candidate for biodiversity sampling and following the recommendation by ESS Group, it was decided to skip this station for the second dry survey.

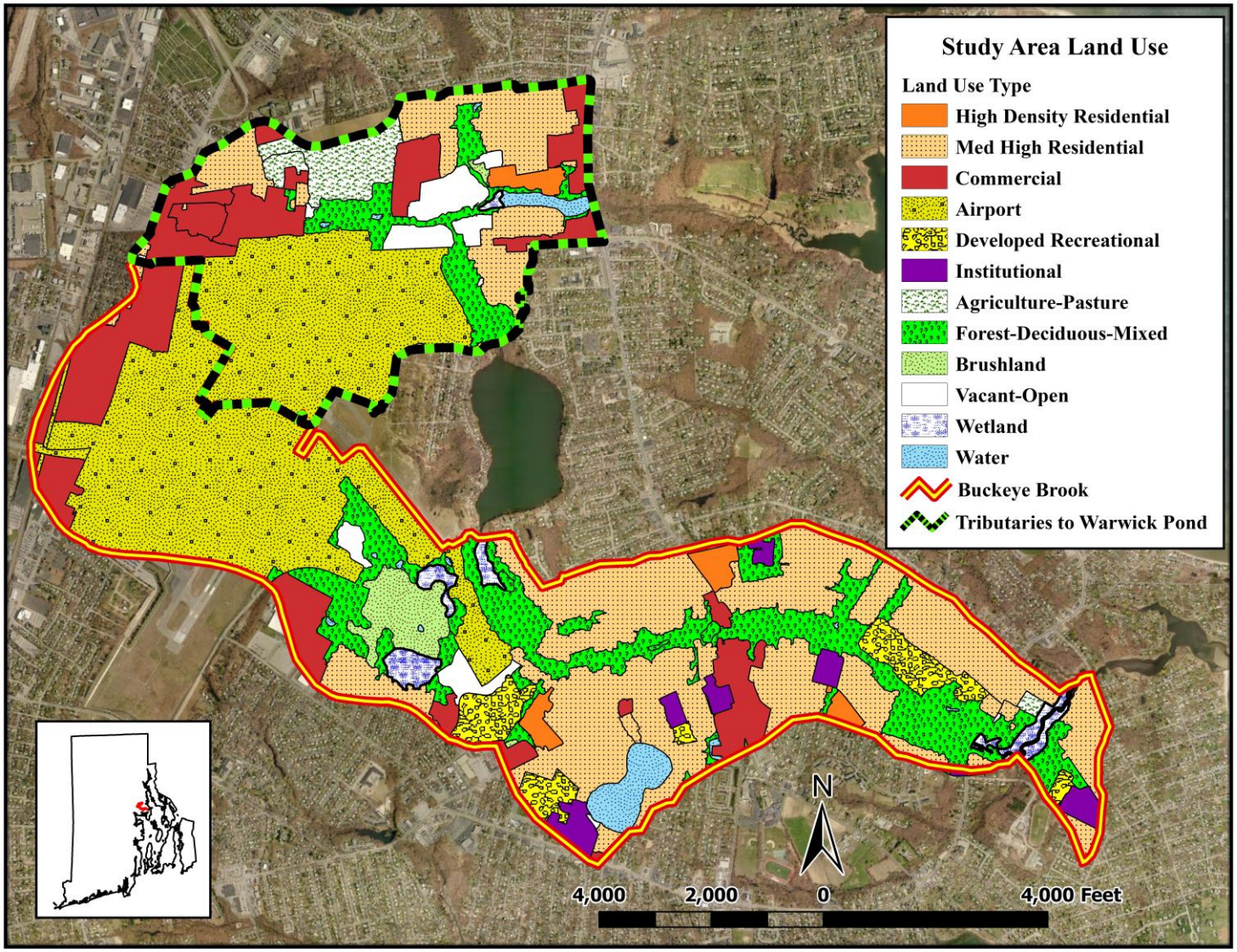

Figure 3.3 Biodiversity Study Area Land Use

Table 3.3 Dry Weather Sampling Dates and Sample Type

Station	BB00	BB02	BB03	BB04	BB05A	OF08	TA01	AP01
DW01 July 16-20, 2008	Chem	Chem, Tox	Chem, Tox	Chem, Tox	Chem, Tox	Chem, Tox	Chem, Tox	NS
DW02 September 10, 2008	Chem, Bio	Chem, Bio	NS	Chem, Bio	Chem, Bio	Bio	Bio	Chem, Bio

Notes: Chem – Water Quality Chemistry samples; Tox – Toxicity samples; Bio – Biodiversity samples; NS – Not Sampled

3.3 Wet Weather Surveys

Two wet weather studies were conducted, the first from December 9-11, 2008 and a second from February 1-8, 2011. The first wet survey in December 2008 was during a rainfall event with an average high temperature of 53°F and a total precipitation of 2.27 inches recorded at T.F. Green Airport. The survey consisted of three runs, a pre-storm on December 9th to check baseline conditions in the brook, and two more survey runs on consecutive days. A fourth run was planned on December 12th, however, between the end of the December 11th run until the planned start of the last run, 3.56 inches of rainfall was recorded at T.F. Green Airport, and it was decided to terminate the survey at three sampling runs. During this event, the samples were analyzed for water chemistry only. A total of eight stations were sampled during the first wet weather event. AP01 was not sampled as it was downstream of TA01 and outfall OF08, and represented the total of the two upstream stations. Table 3.4 shows the dates of the wet weather surveys and the type of sampling conducted.

The second wet weather survey was a winter survey in February 1-8, 2011. The purpose of this survey was to collect water quality and toxicity samples during a winter storm when de-icing and anti-icing solutions were being applied to departing aircraft at T.F. Green Airport. The winter survey proved to be a difficult storm to capture due to the constraints imposed by the EPA laboratory for sample drop-off times and dates when the lab would be available to provide the toxicity analysis. Additionally, the unpredictability of the weather patterns to provide a discrete storm that provided a worst-case scenario to collect runoff from deicing operations was also a challenge. For these reasons, the second wet weather survey was not completed until February of 2011. During this survey, approximately 6 inches of snowfall was recorded at the airport and the average temperature ranged from 20° to 38°F. The survey consisted of four runs, a prestorm on February 1st, Run 1 at the start of the storm (2/3/11), Run 2 (2/6/11) and a final Run 3 (2/8/11).

Table 3.4 Wet Weather Sampling Stations Dates and Sample Type

Station	BB00	BB02	BB03	BB04	BB05A	OF08	TA01	AP01
WW01 December 9-11, 2008	Chem	Chem	Chem	Chem	Chem	Chem	Chem	NS
WW02 February 1-8, 2011	Chem, Tox	Chem, Tox	Chem, Tox	Chem, Tox	Chem	Chem, Tox	Chem, Tox	NS

Notes: Chem – Water Quality Chemistry samples; Tox – Toxicity samples; NS – Not Sampled

Two stations sampled during the first toxicity survey were swapped for the winter survey at the suggestion of the EPA laboratory staff. Station BB05A was not sampled for toxicity and Station BB00 was added. As show in Figure 3.1, BB05A was located downstream of Station BB04, and any suspected pollutants being discharged from the airport stations would be in the sample collected at BB04. Station BB00 also provided another station that would not have been directly influenced by airport de-icing operations or by runoff from the landfill. Its location north of Warwick Pond in a wetland area served as neutral background sampling location for the toxicity analysis being conducted by the EPA laboratory in Chelmsford, MA.

3.4 Other Studies - Rhode Island Airport Corporation (RIAC)

RIAC's RIPDES Permit (RI0021598) requires that they annually conduct wet weather monitoring during a frozen precipitation event (i.e. snow, sleet, freezing rain) during the deicing season (October 1 – March 31) at the T.F. Green Airport while aircraft deicing was occurring. Locations to be sampled included the stormwater outfalls that discharge to the Buckeye Brook stream system both above and below Warwick Pond. These include airport outfalls 002, 003 and 008 (RIDEM station OF08). Receiving water sample sites included the Tributaries to Warwick Pond at the pond's inlet (BB02), the exit of Warwick Pond (BB03), Buckeye Brook at West Shore Road (BB07) and Buckeye Brook at Tidewater Drive (BB08). Flows from airport outfalls 002 and 003 entered the tributary stream approximately 200 feet above Warwick Pond inlet, while the flow from airport outfall 008 (OF08) entered Buckeye Brook approximately 0.25 miles downstream of the exit of Warwick Pond (BB03). The next two sampling stations are located 1.8 miles (BB07) and 2.4 miles (BB08) downstream from the confluence of Buckeye Brook and OF08. After the January 2012 winter monitoring event, sampling site BB08 was dropped and station BB04 was added to provide a sampling site closer to the confluence of the brook and the airport discharge.

Constituents sampled at the airport outfalls by RIAC that were common to the RIDEM study included Arsenic, Copper, Iron, Manganese, Zinc, BOD_5, TOC, TSS, and propylene glycol. The receiving waters were sampled for dissolved oxygen, pH, temperature, BOD_5, TSS, chloride, and propylene glycol. The sampling frequency for the airport outfalls (002, 003, and 008) was every hour for the first 12 hours of the storm, while the RIAC Buckeye Brook sites were sampled every four hours for a period of 48 hours. The RIAC sampling for the airport and stream stations commenced on February 1st at 1000 and continued until 1054 on February 3, 2011.
Although the data from the 2011 RIAC sampling event was not a part of the RIDEM field survey portion of the study, it is presented in the TMDL alongside the RIDEM data for comparison.

3.5 Results of Water Chemistry Study

This section presents the results of both the dry and wet weather surveys, including water chemistry analytical results and field measurements of dissolved oxygen, temperature, and specific conductance. Table 3.17 shows the field data collected from both the dry and wet weather surveys. Table 3.18 shows the water chemistry results for all dry weather surveys.

Tables 3.19 and 3.20 show the water chemistry results for Wet Weather Survey One and Two, respectively. The tables are located at the end of this section.

3.5.1 Dry Weather

Dissolved Oxygen

The waters of Buckeye Brook Watershed are considered Class B, warm water fish habitat waterbodies. The Rhode Island Water Quality Regulations (December 2010) state that these waterbodies must maintain an instantaneous minimum dissolved oxygen concentration of at least 5.0 mg/l, except as naturally occurs. During both dry weather surveys, the dissolved oxygen levels at four of the nine water quality stations violated the 5 mg/L minimum concentration portion of the criteria. Station BB00 is not affected by the airport discharges but had values below criteria for three of the four field measurements. This station is in the middle of an urban wetland area and the low stream flow may account for the low D.O. values, as stagnant water can produce low D.O readings.

Dissolved oxygen measurements were also collected at the two stations monitoring discharge from the landfill and the airport. At the landfill station (TA01), dissolved oxygen values were only measured during the first dry weather survey with all values below criteria, averaging 3.00mg/L. Observed stream velocities at TA01 were very low during the survey, (estimated <0.10 ft^3/sec) which may contribute to the low D.O. values. The dissolved oxygen levels at OF08 which drains the airport tarmac were well above the criteria averaging 9.01mg/L for dry weather. There was a significant decrease in the dissolved oxygen levels observed between Stations BB03 (exit of Warwick Pond) and BB04 (Rufus Road). The dissolved oxygen level at BB04 was an average of 4.01 mg/L lower than the level at BB03 for the two dry weather surveys. During the pathogen field surveys in 2006, the average dissolved oxygen deficit between the two stations from August to October was 2.73 mg/L. After Station TA01, with an average of 3.0 mg/L, Station BB04 had the next lowest overall dissolved oxygen level averaging 3.86 mg/L for the dry weather surveys.

Five-day Biological Oxygen Demand (BOD_5)

The mean BOD_5 ranged from 1 to 4 mg/L at the stream stations, and was 4 mg/L at both OF08 and TA01 for the first dry survey. The lowest BOD_5 observed was at Station BB02 with an observed value of 1.0mg/L for both dry surveys

Hardness as $CaCO_3$

Hardness, which is used to calculate dissolved metals criteria, averaged between 44 and 55 mg/L. The Buckeye Brook stream station with the highest observed hardness value was Station BB04, which was downstream from the confluence of the airport and landfill discharges, which had the highest hardness for all stations at 91 mg/L.

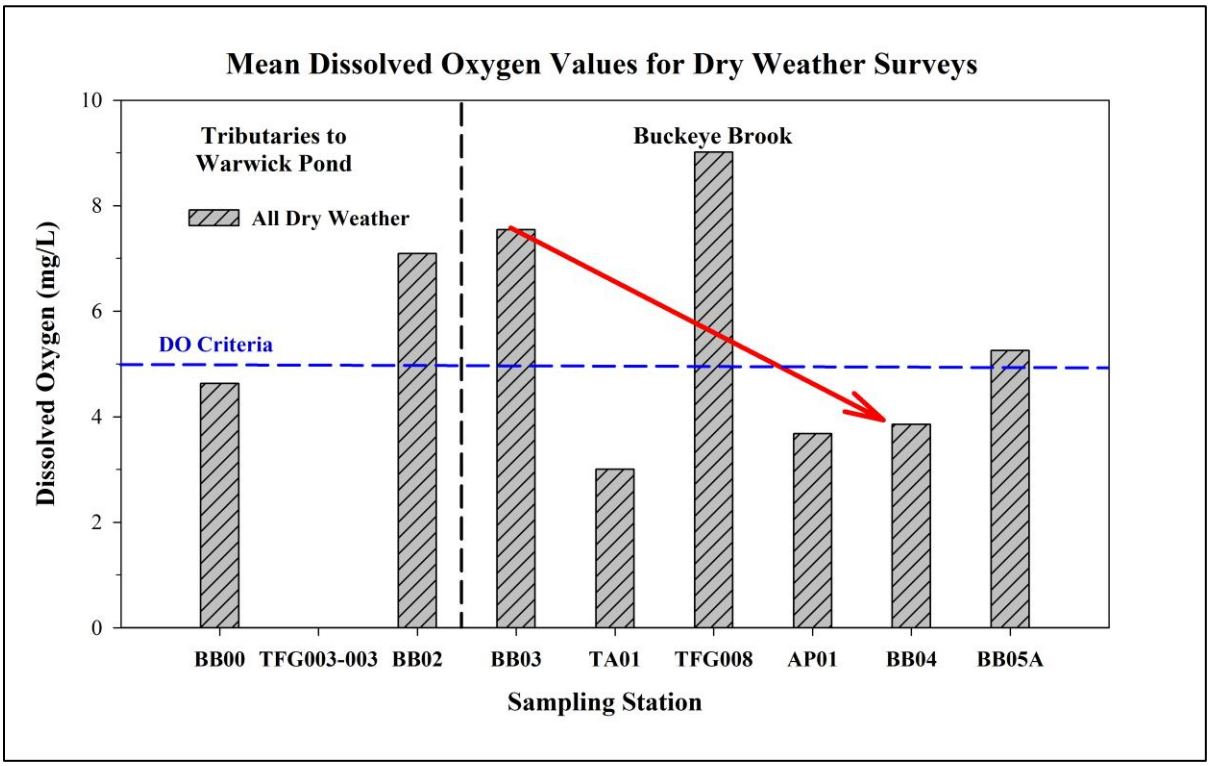

Figure 3.4 Mean Dry Weather Dissolved Oxygen Values for Watershed Survey Sites

pH

The pH values for the stations were in the normal range for stream systems in the state, with averages between 7.1 and 7.4 for all stations except BB03. The observed pH at this station was at the upper limit of the criterion, with a value of 9.2 during the first dry survey.

Total Suspended Solids (TSS)

TSS was very low for both dry weather surveys, ranging between a low of 1 mg/L to a high of 7 mg/L at the stream station. As expected, the highest TSS observed was at Station TA01, with a value of 39 mg/L for dry weather survey one.

Chlorides

Chlorides were also measured at all stations. The stream stations averaged from 47 mg/L at BB03 to 84 mg/L at Station BB00. The observed chloride at the landfill (TA01) and airport stations (OF08) were 46 and 79 mg/L respectively.

Nutrients

Figures 3.5 and 3.6 show the dry weather concentrations for Total Kjeldahl Nitrogen (TKN) and Ammonia (NH_3-N). While there appears to be no significant dry weather sources of nitrogen or phosphorus in the main stem portion of Buckeye Brook, the landfill TKN and NH_3-N samples were above 2.5 mg/L for the first dry survey, and the combined flow from the landfill and airport outfall had the highest TKN and NH_3-N values for dry survey two. TKN ranged from 0.23 mg/L

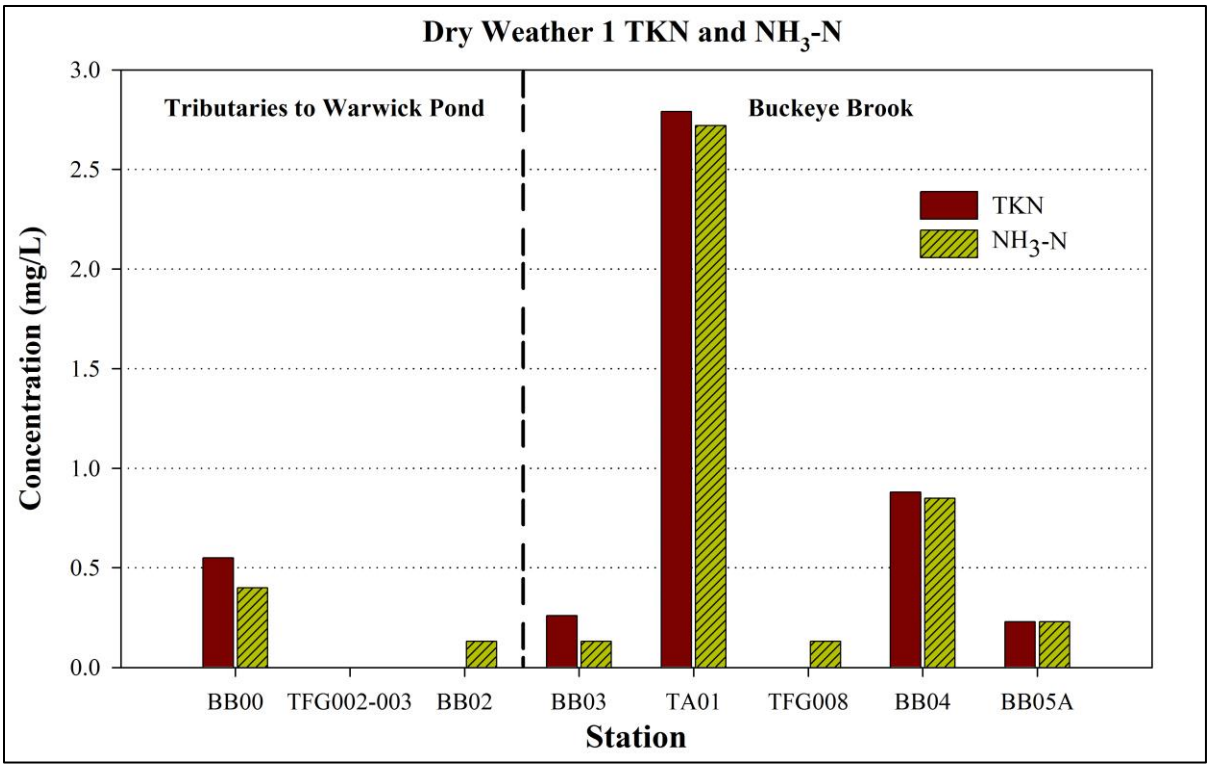

Figure 3.5 Dry Weather 1 TKN and NH_3-N Concentrations

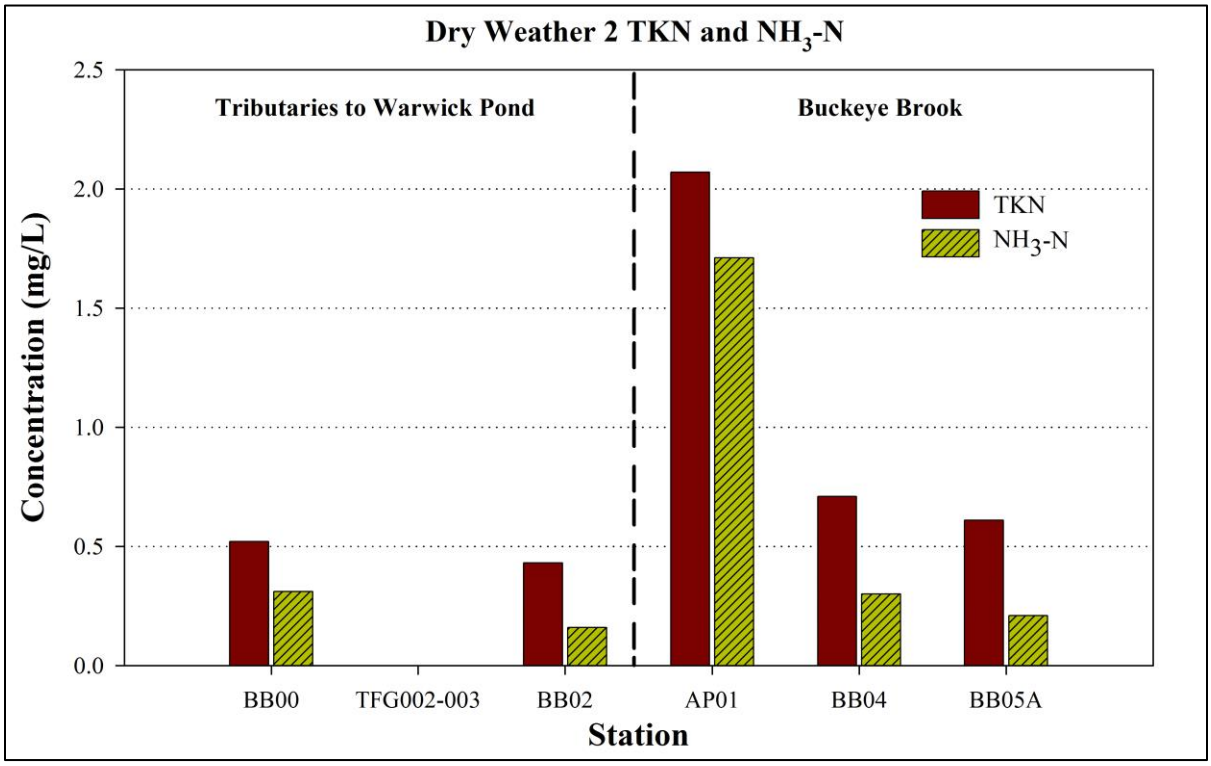

Figure 3.6 Dry Weather 2 TKN and NH_3-N Concentrations

at BB05 to 0.88 mg/L at BB04. The highest TKN levels were at the Truk-Away station with 2.79 mg/L at TA01 for the first dry survey. Ammonia (NH_3-N) levels ranged from 0.13 mg/L at BB03 to a maximum of 0.85 mg/L observed at BB04 during the first dry survey. Of all the stations, TA01 had the highest level at 2.72 mg/L for the first dry weather survey. The airport outfall (OF08) had TKN and NH_3-N values of 0.10 mg/L and 0.13 mg/L respectively for the first dry survey. The second survey only took samples from the AP01, which was the combined flow from the airport and the landfill. TKN and NH_3-N levels at AP01 for the second dry survey were 2.07mg/L and 1.79 mg/L respectively for dry survey two. The TKN and NH_3-N values for the landfill station were significantly higher than any stream station on Buckeye Brook as well as the outfall from T.F. Green. While not the highest observed nitrate values, OF08 at 0.67 mg/L during the first survey would appear to be contributing to increases in nitrate levels from less than 0.05 mg/L at BB03 to 0.24 mg/L at BB04. With the exception of Truk-Away sampling station (TA01), Total Phosphorus (TP) levels were uniformly low during dry weather, with concentrations ranging from below the reporting limit of 0.02 mg/L to a high value of 0.19 mg/L at the landfill station, TA01. There were no exceedances of ammonia criteria, the only nutrient for which RI's Water Quality Standards establish a numeric criterion for rivers and streams.

Trace Metals

The trace metals sampled for during the biodiversity field surveys were dissolved Arsenic (As), Cadmium (Cd), Copper (Cu), Lead (Pb), Manganese (Mn), Zinc (Zn) and Total Iron (Fe). The procedure for determining the acute and chronic criteria used to assess the metals data are described in detail in Section 1.5.2 above. There were dry weather exceedances of the fresh water criteria for cadmium and total iron. During the first dry survey, one station on Buckeye Brook (BB00) exceeded the cadmium chronic criteria, as did Truk-Away Landfill (TA01) and the airport station (OF08). The freshwater chronic criterion for iron is 1000µg/L. This limit was exceeded during both dry surveys at Stations BB04 and BB05. The landfill and airport stations, which ultimately discharge into Buckeye Brook above BB04 and BB05, both had high values for the first dry survey, with a total iron value of 11,586µg/L and 2,844 for Truk-Away and the airport station respectively during the first dry survey. Given the relatively low value of the upstream station at BB03, these two stations are the likely source of iron observed at the downstream stations BB04 and BB05A. These stations were not sampled for the second dry survey because it was decided that chemistry samples would be collected only at the stations sampled by the ESS Group. Station AP01 was sampled during the second dry survey, which is downstream of the confluence of the discharges from TA01 and OF08, and had a total iron value of 3,008µg/L.

Elevated levels of other metals were observed, but none in concentrations that exceeded criteria. Manganese also had some high values, ranging from 12µg/L at BB03 to a high of 988µg/L at TA01 for the first dry survey, while the arsenic concentrations were well below the criterion, averaging between 0.29 and 0.72µg/L for all stream stations. The highest arsenic value of 1.87µg/L was for Station TA01 during the first dry survey. Copper, lead and zinc criteria were not exceeded at any station for the dry surveys. Of any stream station, the highest mean copper concentration of 3.49µg/L was observed at BB04, which also had the maximum single grab

value (5.73µg/L) for dry weather. Copper concentrations from both Truk-Away and the airport station were two to three times lower than values observed in Buckeye Brook.

Total Organic Carbon (TOC)

TOC samples were collected during the second dry survey at the stations visited by the ESS Group during their biology field sampling of Buckeye Brook. TOC is often a source of food for benthic organisms; however, high levels of sediment TOC can result in significant changes in a benthic community structure and the predominance of pollution-tolerant species. The TOC values ranged from a low of 580 mg/L at BB02 to a high of 17,000 mg/L at AP01, which represents the combined flows from airport outfall OF08 and the landfill, TA01. BB00, chosen because it is not influenced by airport run-off, had a TOC level of 1,900 mg/L. BB00 is located in the wetland area that is northwest of the intersection of Commerce Drive and Airport Road.

3.5.2 Wet Weather

Two wet weather surveys were conducted for the biodiversity field program. The first survey, which consisted of three consecutive sampling days, was to capture a storm event that would generate run-off for the watershed but one that did not require the airport to commence de-icing operations. The second wet survey was under icing conditions where the airport had commenced de-icing of aircraft, and also had intermittent rain/sleet as well as snow during the first day of sampling, and totaled four sampling runs for the event. The same constituents that were sampled for the dry surveys were also collected during the wet weather surveys with the exception of TOC, which was dropped. However, propylene glycol was added to the constituent list to determine if significant amounts were being discharged to Buckeye Brook during storm events.

Dissolved Oxygen

The dissolved oxygen levels for both wet weather events were well above instantaneous criteria for all the Buckeye Brook stream stations. The dissolved oxygen levels fell below criteria during both wet weather events for the landfill station (TA01), with the lowest observed value at 1.38mg/L occurring during the prestorm sampling run for Storm 1, and averaging 3.79mg/L for the event. Again, with the stagnant, low flow discharge from the landfill, this was to be expected. T.F. Green airport outfall OF08, like the stream stations, was well above criteria, averaging 9.96 mg/L for all wet weather runs.

As with the dry surveys, there was a dissolved oxygen drop observed between Stations BB03 and BB04 for both storm events. The prestorm sample for the first storm event, which had the higher flows of the two wet surveys, had a small deficit of 0.7 mg/L between the stations. However, as the survey continued, the D.O. drop was significant, averaging 4.7 mg/L for the next two runs. The second wet weather also had significant D.O. drops that ranged between 2.8 mg/L for the last run to 4.8 mg/L for Run 2. Figure 3.7 is a plot of the instantaneous dissolved oxygen concentrations for Stations BB03 and BB04 for the first dry weather and both wet weather surveys and shows the drop in D.O. that occurred between the two Buckeye Brook stations.

Propylene Glycol

Propylene Glycol is one of the main constituents used in de-icing solutions, and concentrated glycol has a potential BOD_5 demand of 200,000 mg/L. Although glycol samples were collected during both wet weather events, active aircraft deicing operations occurred only during the second storm event. Wet weather samples from five stations were analyzed for propylene glycol for each storm. One station, BB05A was dropped for the second storm and BB03 added in its place. BB00 was selected as a background station that would allow a comparison for a station that would not be likely to have any propylene glycol in the samples. BB02 is the inlet of Warwick Pond and receives stormwater discharges from those outfalls draining the aircraft parking area for cargo operations. BB03 and BB04 bracketed the confluence of the flows discharging from the main airport outfall (OF08) with Buckeye Brook. OF08 is the primary outfall for the aircraft parking area of the main airport passenger terminal and the largest contributor of stormwater to the lower segment of Buckeye Brook.

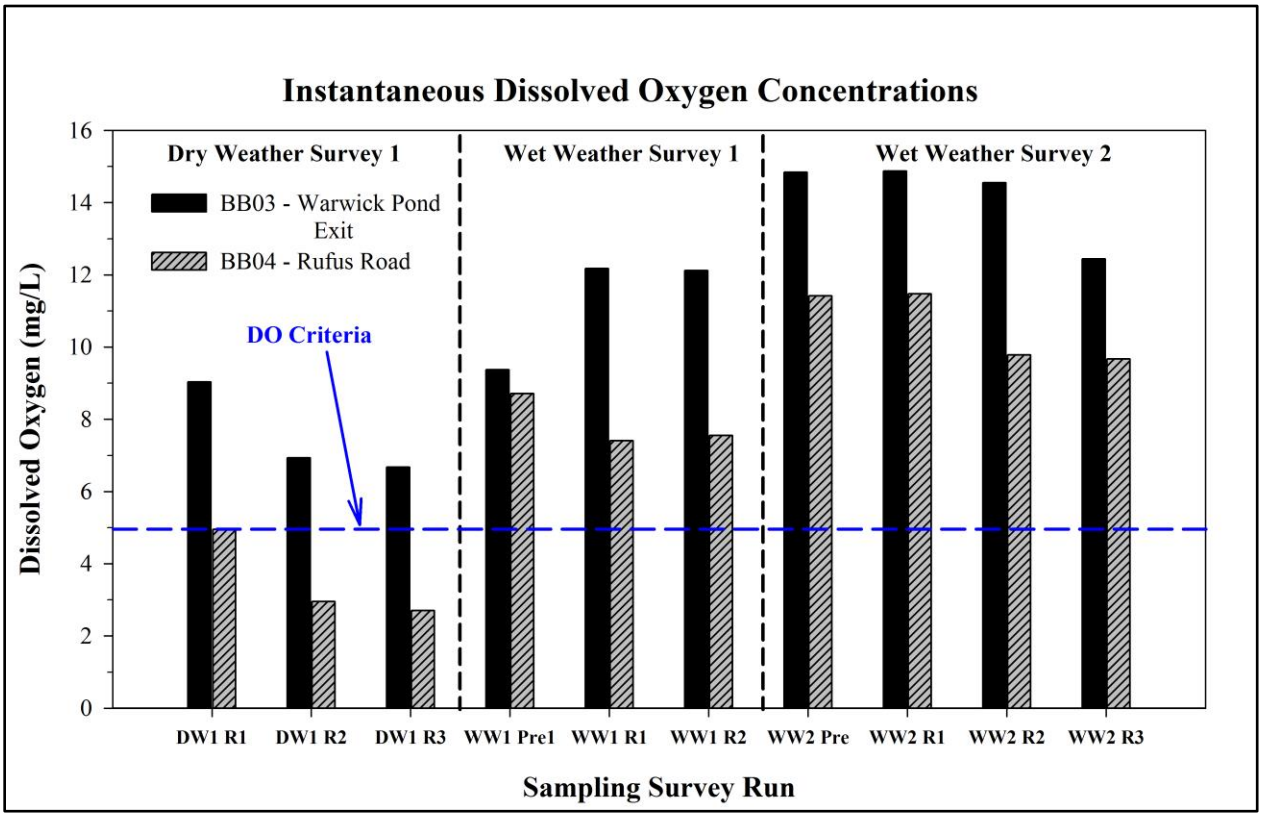

Figure 3.7 Instantaneous Dissolved Oxygen Values for RIDEM Stations BB03 and BB04

During Storm 1, no de-icing activities occurred and no propylene glycol was detected at any of the sampled stations. During Storm 2, in February 2011, de-icing activities did occur and three of the five stations had detectable levels of propylene glycol. The mean values ranged from 22 mg/L at Station BB04 to 79 mg/L at the airport outfall, Station OF08. BB02, which receives the discharge from the airport outfalls that are north of Warwick Pond and service the aircraft cargo area, had a mean propylene glycol value of 45 mg/L. The highest single value of 105 mg/L was

collected on the last run of the storm event at OF08, more than a week after the winter storm began. The higher propylene glycol concentrations at OF08 coincide with the higher BOD_5 observed at that station during the second storm.

As stated previously, RIAC is required to sample the airport outfalls and several stations along the mainstem of Buckeye Brook during a de-icing event, and coincidentally also sampled during the February 2011 survey. The stream stations were sampled every four hours for a period of 48 hours after the start of the storm. The Buckeye Brook stations sampled as part of the RIAC monitoring requirements included BB02, BB07 and BB08. Figure 3.8 shows how the concentrations of propylene glycol changes over the 48-hour sampling period for this storm. The time of travel for propylene glycol from the airport cargo parking area outfalls 002 and 003 appears to be approximately 24 hours after the storm event starts, and 36 hours for the increased glycol concentrations to travel from airport outfall 008 (OF08) to West Shore Road (BB07) and Tidewater Drive (BB08). The maximum observed concentrations of propylene glycol were 210 mg/L at BB02 and 291 mg/L at BB07 and BB08.

Five-day Biological Oxygen Demand (BOD_5)

The five-day biological oxygen demand (BOD_5) for all stations was slightly higher for the first wet survey, as compared to dry weather, with mean values ranging from 2.0 mg/L at Stations BB00 and BB03 to 6.7 mg/L at BB04, and the landfill station (TA01) and airport outfall (OF08) stations at 3.0 and 5.7 mg/L respectively. The BOD_5 concentrations for the second storm during which de-icing activities occurred were two to three times higher than the values observed during storm one. Station BB00 was not influenced by airport de-icing operations had the lowest mean value at 1.7 mg/L. The mean BOD_5 values for the stream stations that receive the discharges from those areas on the airport property where de-icing operations are conducted were significantly greater with BB02 at 11.8 mg/L and BB04 at 12.5 mg/L. The highest BOD_5 storm values were at the airport outfall OF08, which had a mean value of 16.3mg/L for storm two and the highest single grab value at 20.0 mg/L for the prestorm sample. OF08 is the largest airport outfall and had the greatest observed flows during the wet weather events

Figure 3.9 shows RIAC BOD_5 sampling results for the inlet of Warwick Pond (BB02) and the two stream stations on Buckeye Brook (BB07 and BB08). As with propylene glycol, the BOD5 signal appears to lag the start of the storm by 24 to 32 hours at the Buckeye Brook sites, with maximum concentrations ranging from 160mg/L at BB02 to 63mg/L and 73mg/L at BB07 and BB08 respectively.

Hardness as $CaCO_3$

The hardness values observed during both storms were similar to the dry weather values. The stream stations averaged between 36 mg/L at BB02 for the first wet weather event to 53 mg/L at BB03 for the second storm. The highest observed value was the prestorm sample from TA01 at 98 mg/L, while outfall OF08 had the lowest hardness for either storm at 15 mg/L for Run 2 and 3 of Storm 1. The highest single grab sample for the stream stations during either wet weather was during Run 1 of Storm 2 at BB03 with a hardness value 79.2 mg/L.

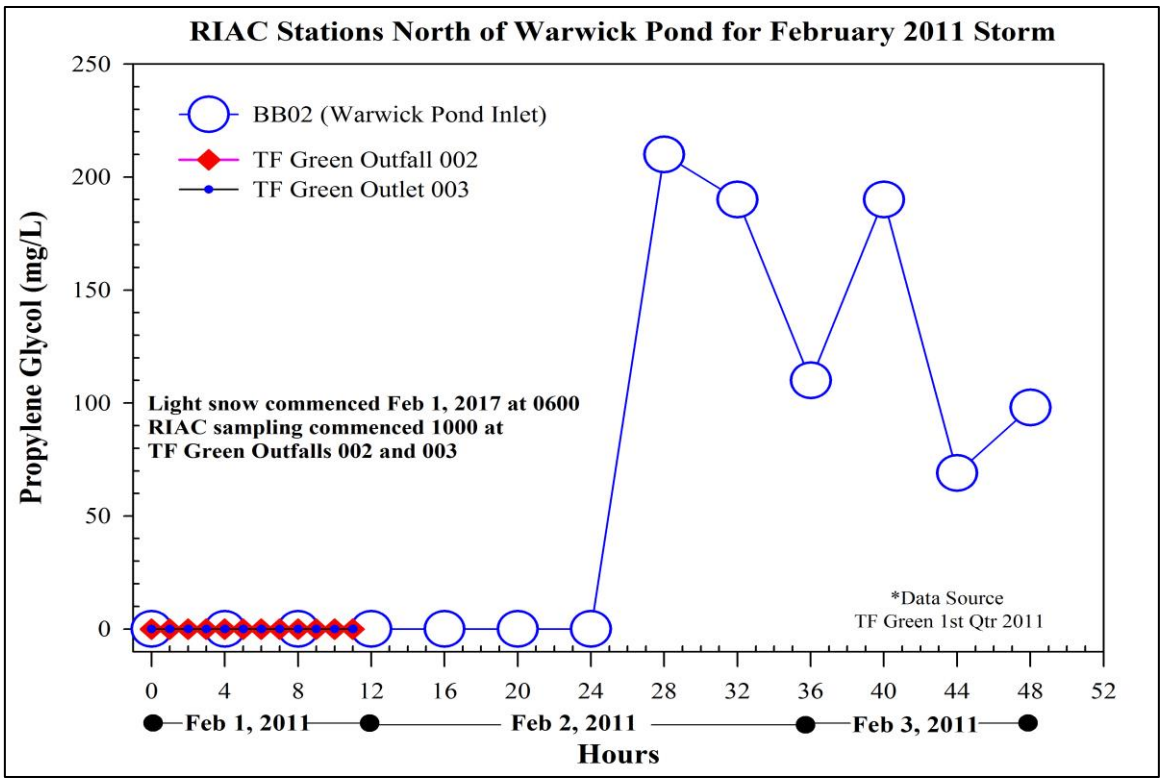

Figure 3.8 Storm 2 Propylene Glycol Concentrations for Warwick Pond Tributary Stations

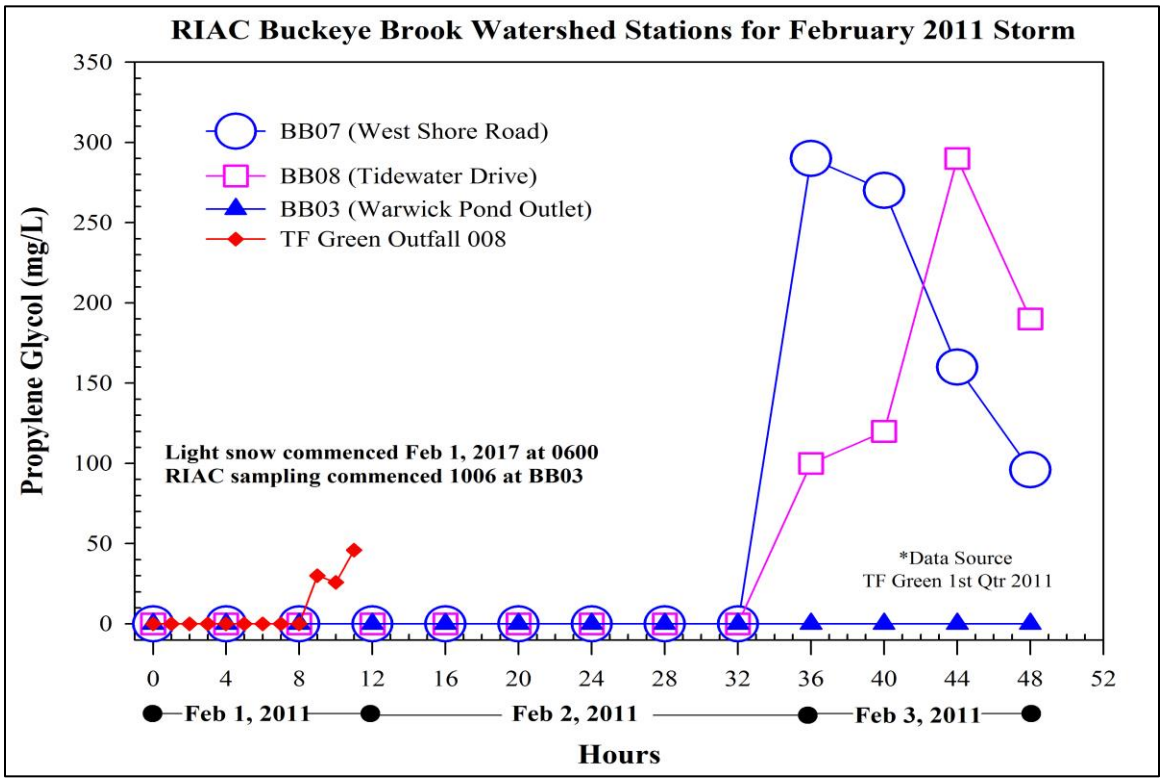

Figure 3.9 Storm 2 Propylene Glycol Concentrations for Buckeye Brook Watershed Stations

pH

As with the dry surveys, pH was consistent across all stations, averaging from 6.3 to 7.5 for the two storms. The lowest single grab value, 6.08, occurred at Station BB00 during Storm 2, while the highest pH of 7.8 was observed at Station BB03 during Storm 1.

Total Suspended Solids (TSS)

TSS values were very low for the first storm in December 2008. Several stations had samples that were below the 0.10 mg/L detection limit for the method. The mean TSS values for the stream stations were between 4.0 to 7.0 mg/L, while the airport outfall OF08 and Truk-Away TA01 stations recorded mean values of 8.5 and 18 mg/L, respectively. The second wet weather event had slightly higher TSS levels for the stream stations, averaging between 1.5 mg/L at BB03 to 13.0 mg/L at BB00. Again, several samples had values below the detection limit, but the lowest reported value was at BB03 with a value of 1.0 mg/L. BB00 had the highest TSS value for any stream station at 28.0 mg/L during Run 3 of the second storm. The most consistent site was TA01, which averaged 22.0 mg/L, and had the highest TSS value at 37.0 mg/L for the Storm 2 Prestorm sample.

Chlorides

The chloride values for the first storm, when no de-icing occurred, were very similar to the dry weather values, with the lowest mean value of 33.8 mg/L at Station BB03, and the high storm mean of 70.9 mg/L occurring at BB00. The second storm was much different, with mean values nearly six times the averages from Storm 1, though no exceedances of the chloride criteria were observed. T.F. Green outfall OF08 had the highest average with a mean value at 224.9 mg/L and the highest observed chloride concentration of 544 mg/L for Run 3. This outfall drains the main terminal aircraft parking area, and the high concentrations may be attributed to the deicing material applied to the tarmac in this location. BB02, which receives stormwater from the integrated cargo tarmac, also had high chloride values, averaging 153 mg/L, which was the highest of the Buckeye Brook stations.

Nutrients

Buckeye Brook stream concentrations for individual nitrogen forms (TKN, NH_3, and NO_3) were lower during the first storm, and depending upon the nitrogen form, were two to three times higher during the second storm event. Comparing the total nitrogen values for the stations (the sum of the TKN and nitrate concentrations), Buckeye Brook averaged from 0.65 to 1.9 mg/L for Storm 1, and from 1.5 to 2.6 mg/L for Storm 2. The mean nitrogen concentrations for the airport and landfill stations were the highest for Storm 1, with an observed mean of 14.6 mg/L at TA01 to 0.47 mg/L at outfall OF08. For both wet weather events, the mean total nitrogen concentrations (sum of TKN and nitrate values) for the two stations above Warwick Pond were almost twice as high as the observed mean at Station BB03 (Warwick Pond exit).

The Total Kjeldahl Nitrogen (TKN-N) values at the Buckeye Brook stations were two to three times higher for Storm 2 while the ammonia levels were similar. Mean TKN concentrations for these stations ranged from below detection (0.20 mg/L) at BB02 for Storm 1 to a high average of

1.75 mg/L at BB04. TA01 mean TKN concentrations were the highest observed for either storm during the first wet event, with an average of 14.6 mg/L for Storm 1 and 2.7 mg/L for the second event. The mean TKN values for the stations above Warwick Pond (BB00 and BB02) were less than half the mean concentrations observed at BB04 and BB05A, both of which are located below the confluence of Buckeye Brook with the landfill discharges from TA01 indicating the possible influence of the landfill runoff on the water quality of the brook.

The TKN value at the airport outfall (OF08) was below the detection limit of 0.20 mg/L for Wet Weather 1, and generally lower than other sampling locations for Wet Weather 2.

Ammonia (NH_3-N) mean concentrations were similar for both storm events at the Buckeye Brook stations. Buckeye Brook sites averaged between 0.13 mg/L at BB02 for the first storm to 0.63 mg/L at BB04 for Storm 2. Station TA01 had the highest mean ammonia concentrations for either storm, averaging 2.9 mg/L for Storm 1 and 1.5 mg/L for Storm 2. There were no exceedances of ammonia criteria for either wet weather event.

Nitrate (NO_3-N) concentrations for Buckeye Brook during wet weather were consistent for all the stations, and comparable to observed dry weather values. The landfill and airport stations were below 0.5 mg/L for both storms, averaging between 0.10 mg/L for TA01 to 0.47 mg/L for outfall OF08.

The Total Phosphorus (TP) values were very low for all stream stations for both wet weather events. The average TP concentration range for both storms was 0.03 to 0.05 mg/L. The highest observed values occurred at the landfill station. TA01 mean TP concentration was 0.45 mg/L for the first storm, and 0.27 mg/L for Storm 2. The airport outfall station (OF08) was slightly elevated during Storm 1 with a mean TP concentration of 0.09 and 0.03 mg/L for Storm 1 and 2, respectively.

Trace Metals

For the wet weather surveys, the acute criteria were calculated using the actual hardness values for each station by survey run. The acute criteria were then compared against the actual observed metals values for each station. For the chronic criteria calculations, the hardness values were averaged for all runs for each station for Wet Weather Survey One. For survey two, the prestorm and the first run's hardness values were averaged, as were runs 1 and 2, and runs 2 and 3. The criteria were then calculated using the averaged hardness values. The observed metal values were similarly averaged for Storm 1 and 2. The calculated criteria were then compared against the averaged observed dissolved metal values that were collected at each sample location for each storm. Appendix A contains the tables that show these calculations and comparison to criteria and Table 3.5 shows trace metals criteria exceedances that occurred during the biodiversity surveys. These are discussed in the section below.

Cadmium (Cd)

There were ten exceedances of the dissolved cadmium freshwater chronic criteria for the two wet weather events. Seven occurred at Buckeye Brook stream stations, two at the airport outfall (OF08) and one at Truk-Away landfill (TA01). BB00 exceeded criteria for three of the seven samples collected over the two events, with BB00 cadmium concentration averaging 0.24µg/L for Storm 1, and 0.18µg/L for Storm 2. Station BB02 also had three exceedances of criteria, with dissolved cadmium averages of 0.26 and 0.12µg/L for Storms 1 and 2, respectively. The last stream station, BB05A had one chronic exceedance which for Storm 1, averaging 0.30µg/L. TA01 had one exceedance for cadmium during the first storm with an average concentration of

Table 3.5 Dry and Wet Weather Trace Metal Criteria Exceedances

Station	Cadmium				Copper				Lead			
	DW1	DW2	WW1	WW2	DW1	DW2	WW1	WW2	DW1	DW2	WW1	WW2
Tributaries to Warwick Pond (RI0007024R-05)												
BB00	C		C	C								
BB02			C	C				C				
Buckeye Brook (RI0007024R-01)												
BB03	C									C		
TA01	C		C									
OF08	C		C	C			A	A, C				C
AP01												
BB04	C									C		
BB05A			C					A, C				

Station	Zinc				Iron			
	DW1	DW2	WW1	WW2	DW1	DW2	WW1	WW2
Tributaries to Warwick Pond (RI0007024R-05)								
BB00								C
BB02							C	C
Buckeye Brook (RI0007024R-01)								
BB03	A, C							C
TA01					C		C	C
OF08			A		C		C	C
AP01						C		
BB04					C	C	C	C
BB05A					C	C	C	C

A= Acute Criteria Exceeded; C = Chronic Criteria Exceeded; DW1-07/16/08; DW2-09/10/08; WW1-12/09-11/08; WW2-02/02-08/11
OF08 is an outfall and is not considered an instream monitoring station.

0.25µg/L, and also had the highest single grab value for either storm with a concentration of 0.58µg/L during the prestorm sample run for Storm 1. OF08, with the largest airport stormwater outfall discharge, had four exceedances total, three during Storm 1 and one in Storm 2. The average cadmium concentrations for OF08 were 0.18 µg/L and 0.12µg/L for Storms 1 and 2, respectively.

Lead (Pb)
There were two exceedances of the freshwater chronic criteria for dissolved lead during the second wet weather event, both occurring at the airport outfall, OF08, however, no downstream receiving waters (stations BB04 and BB05A) exceeded the criteria. The landfill (TA01) and airport (OF08) stations had the highest mean dissolved lead values for either storm with TA01 averaging 1.38µg/L for Storm 1 and OF08 with a mean concentration of 0.98µg/L for Storm 2. TA01 had the highest single grab value for lead during Storm 1 at 1.70µg/L, while the lead concentration of 2.62µg/L at outfall OF08 was the maximum value for Storm 2. There were no exceedances of lead criteria at any Buckeye Brook stream stations during the wet weather sampling surveys.

Copper (Cu)
Copper was the exception for the wet weather events as there were both acute and chronic violations of the freshwater criteria at the airport and Buckeye Brook sampling sites. The airport outfall OF08 had four acute criteria exceedances (two per storm) and one chronic exceedance during Storm 2. Outfall OF08 had a mean dissolved copper value of 2.55µg/L for Storm 1 and the higher value of 2.65µg/L for Storm 2. BB05A had one acute and one chronic criteria exceedance during Storm 2, with the highest single grab sample value for any station for the wet weather events occurring Run 1 of the second storm, with an observed copper concentration of 8.48µg/L.

Zinc (Zn)
There were two exceedances of the dissolved zinc acute freshwater criteria during the first wet weather event at the airport outfall OF08 however, no downstream receiving waters (stations BB04 and BB05A) exceeded the criteria. The acute criterion was exceeded during the last two sampling runs, with concentrations of 33.5 and 26.2µg/L. The mean wet weather zinc concentrations for all stations sampled were three times higher during Storm 1, with the highest zinc concentration occurring at BB00 with a mean value of 25.9µg/L. There were no wet weather exceedances of zinc criteria for any stream station.

Iron (Fe)
Total iron had numerous exceedances of the criterion during both storm events, with 67% of the samples collected exceeding the 1000µg/L limit. The landfill and airport stations both exceeded the criterion for every sample collected, with TA01 having the highest mean iron concentrations for both storms with levels of 14,272 and 4,752µg/L during Storm 1 and 2 respectively. The tributary station to Warwick Pond, BB02 and the Buckeye Brook stations BB04 and BB05A also exceeded criterion for all samples collected, with BB04 averaging the highest for the stream stations with total iron concentrations levels of 2,928µg/L during Storm 1 and 2,102µg/L for Storm 2. The influence of the high levels coming from the landfill and airport stations are the most likely reasons for the high iron concentrations observed at Stations BB04 and BB05A. Figure 3.10 shows the mean iron concentrations for the airport (Outfalls 002, 003 and 008) compared with the Wet Weather 2 prestorm values at the stations for the landfill (TA01), Tributaries (BB00, BB02) and Buckeye Brook (BB04, BB05A).

Manganese (Mn)

There were not any exceedances of criteria for manganese during the wet weather surveys. The highest mean value for all stations was observed at the airport station TA01, with an overall wet weather mean of 819µg/L. The stream stations north of Warwick Pond had the highest mean wet weather concentration for Buckeye Brook at 744µg/L.

Arsenic (As)

There were no exceedances of the freshwater criteria for arsenic at any station during wet weather events. The mean arsenic values for the wet surveys ranged from 0.22 to 1.36µg/L, with Storm 1 concentrations being slightly higher that the Storm 2 values. Overall, TA01 had the highest mean concentration of all sampling stations at 0.92µg/L for all wet events. Station BB03 had the highest mean wet weather concentration for the stream stations at 0.61µg/L.

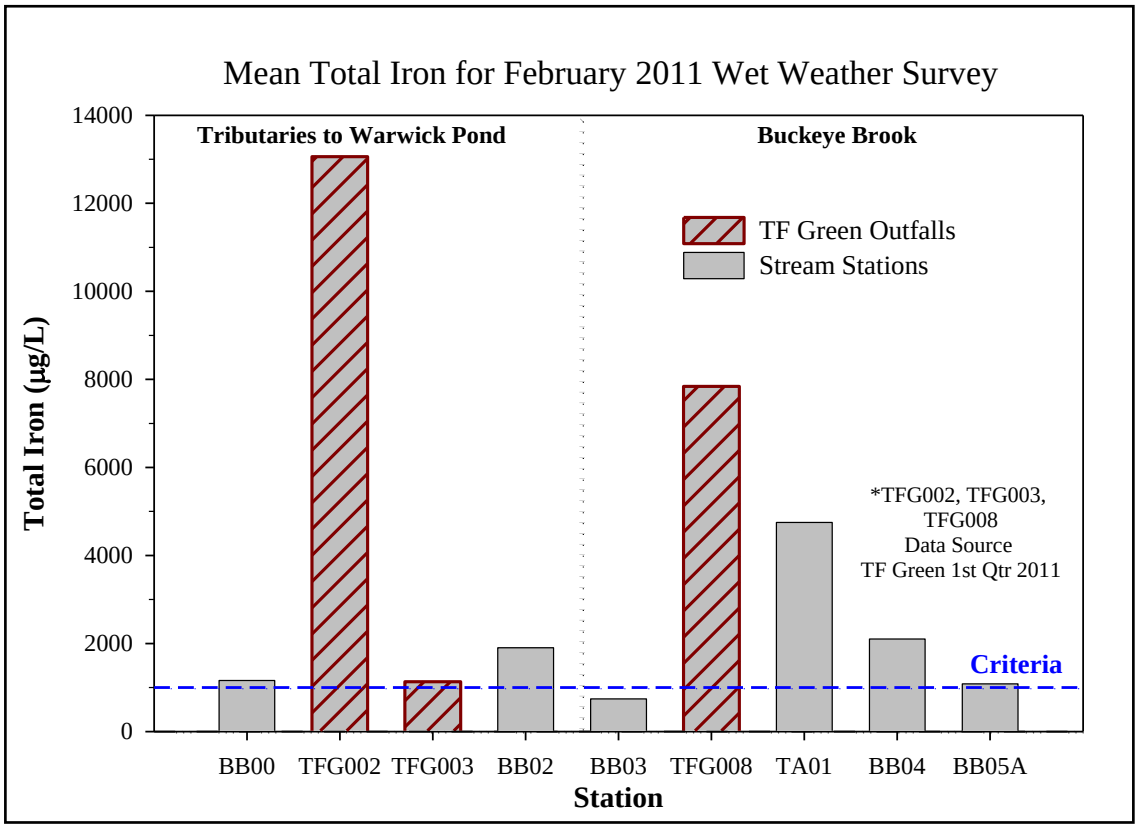

Figure 3.10 Mean Total Iron Concentrations for Wet Weather 2 Survey

Table 3.6 Field Data Summaries

Dissolved Oxygen (mg/L)

Survey Type	DW1			DW2	WW1			WW2				Mean
Station	7/16/08	7/18/08	7/21/08	9/10/08	12/9/08	12/10/08	12/11/08	2/1/11	2/3/11	2/6/11	2/8/11	
BB00	4.24	4.58	5.18	4.52	9.75	8.11	9.23	16.85	12.32	11.52	10.38	8.79
BB02	7.55	7.33	7.07	6.41	9.45	7.63	9.58	10.93	10.87	11.14	10.24	8.93
BB03	9.03	6.93	6.67	NS	9.37	12.17	12.12	14.84	14.87	14.55	12.44	11.30
TA01	3.41	2.55	3.05	NS	1.38	4.93	5.05	6.53	4.93	4.84	5.13	4.18
OF08	9.29	8.90	8.85	NS	7.20	9.02	10.45	13.00	9.94	12.03	10.91	9.96
AP01				3.68								3.68
BB04	4.95	2.95	2.70	4.83	8.71	7.41	7.55	11.42	11.47	9.78	9.67	7.40
BB05A	5.39	4.82	4.80	6.01	10.24	7.27	8.57	10.12	11.30	9.84	10.91	8.12

Temperature (°C)

Survey Type	DW1			DW2	WW1			WW2				Mean
Station	7/16/08	7/18/08	7/21/08	9/10/08	12/9/08	12/10/08	12/11/08	2/1/11	2/3/11	2/6/11	2/8/11	
BB00	18.6	20.1	22.0	16.0	2.6	11.2	7.1	0.4	1.6	1.9	3.4	9.5
BB02	21.3	27.3	27.8	17.6	4.6	11.7	8.0	0.8	3.1	4.0	4.3	11.9
BB03	29.2	18.3	20.0	NS	2.8	5.2	5.0	2.1	2.2	2.6	2.6	9.0
TA01	17.5	17.9	18.9	NS	0.9	6.9	5.1	0.3	1.0	0.7	0.8	7.0
OF08	14.7	14.7	15.0	NS	11.2	13.0	8.0	7.8	7.5	4.7	6.1	10.3
AP01				16.7								16.7
BB04	26.5	23.2	24.5	21.0	2.7	8.7	6.4	0.9	2.5	2.3	2.9	11.1
BB05A	24.5	23.2	24.6	19.8	2.5	9.5	6.5	0.1	0.3	1.5	2.3	10.4

Specific Conductance (µS/cm)

Survey Type	DW1			DW2	WW1			WW2				Mean
Station	7/16/08	7/18/08	7/21/08	9/10/08	12/9/08	12/10/08	12/11/08	2/1/11	2/3/11	2/6/11	2/8/11	
BB00	359	395	386	370	399	366	378	444	501	378	390	397
BB02	301	270	271	262	286	339	505	370	693	505	882	426
BB03	272	304	300	NS	218	218	214	219	210	214	195	236
TA01	416	417	415	NS	472	265	284	86	353	448	482	364
OF08	322	337	338	NS	268	207	91	333	624	456	1920	490
AP01				277								277
BB04	346	356	360	245	284	331	491	295	605	491	450	387
BB05A	344	343	349	241	279	292	688	308	760	688	498	435

NS = Not Sampled

Table 3.7 Buckeye Brook Chemistry Data for Dry Weather Surveys

Station	BOD_5 (mg/L)			Chloride (mg/L)			TSS (mg/L)			pH			Hardness (mg/L)			TP (mg/L)		
	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean
BB00	2.00	1.00	1.5	92.2	76.20	84.2	0.0	1.00	0.5	7.66	6.55	7.1	50.0	40.0	45.0	0.03	0.03	0.03
BB02	1.00	1.00	1.0	56.1	46.90	51.5	1.0	4.00	2.5	7.39	6.90	7.1	48.0	41.0	44.5	0.02	<0.02	0.02
BB03	4.00	NS	4.0	46.9	NS	46.9	3.0	NS	3.0	9.22	NS	9.2	47.0	NS	47.0	0.02	NS	0.02
TA01	4.00	NS	4.0	46.2	NS	46.2	39.0	NS	39.0	7.41	NS	7.4	91.0	NS	91.0	0.19	NS	0.19
OF08	4.00	NS	4.0	79.0	NS	79.0	0.0	NS	0.0	7.22	NS	7.2	50.0	NS	50.0	<0.02	NS	<0.02
AP01	NS	1.00	1.0	NS	39.70	39.7	NS	5.00	5.0	NS	7.06	7.1	NS	43.0	43.0	NS	0.09	0.09
BB04	4.00	1.00	2.5	62.1	39.20	50.7	1.0	4.00	2.5	7.33	7.01	7.2	66.0	45.0	55.5	0.03	0.03	0.03
BB05A	3.00	1.00	2.0	59.2	38.60	48.9	0.0	**R**	0.0	7.53	7.13	7.3	64.0	44.0	54.0	0.03	0.03	0.03

Station	TKN (mg/L)			Ammonia-N (mg/L)			Nitrate- N (mg/L)			Arsenic (µg/L)			Cadmium (µg/L)			Copper (µg/L)		
	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean
BB00	0.55	0.52	0.54	0.40	0.31	0.36	0.78	0.82	0.80	0.38	0.29	0.34	0.16	0.08	0.1	1.82	2.10	1.96
BB02	ND	0.43	0.43	0.13	0.16	0.15	1.90	1.16	1.53	0.27	0.42	0.35	0.10	0.11	0.1	3.53	1.19	2.36
BB03	0.26	NS	0.26	0.13	NS	0.13	<0.05	NS	<0.05	0.66	NS	0.66	0.28	NS	0.3	2.35	NS	2.35
TA01	2.79	NS	2.79	2.72	NS	2.72	<0.05	NS	<0.05	1.87	NS	1.87	0.30	NS	0.3	1.40	NS	1.40
OF08	ND	NS	ND	0.13	NS	ND	0.67	NS	0.67	0.39	NS	0.39	0.16	NS	0.2	0.67	NS	0.67
AP01	NS	2.07	2.07	NS	1.71	1.71	NS	0.41	0.41	NS	0.97	0.97	NS	<0.06	<0.06	NS	1.08	1.08
BB04	0.88	0.71	0.80	0.85	0.30	0.58	0.24	<0.05	0.24	0.61	0.82	0.72	0.39	<0.06	0.4	5.73	1.24	3.49
BB05A	0.23	0.61	0.42	0.23	0.21	0.22	1.01	0.26	0.64	0.33	**R**	0.49	0.13	<0.06	0.1	1.62	1.68	1.65

Station	Lead (µg/L)			Manganese (µg/L)			Total Iron (µg/L)			Zinc (µg/L)			TOC (mg/L)	
	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08	Mean	7/16/08	9/10/08
BB00	0.59	<0.07	0.59	637	732	685	732	522	627	35.7	28.2	32.0	NA	1,900
BB02	0.44	<0.07	0.44	469	448	459	648	824	736	57.9	13.9	35.9	NA	580
BB03	1.93	NS	1.93	12	NS	12	186	NS	186	137.0	NS	137.0	NA	NS
TA01	0.90	NS	0.90	988	NS	988	11,586	NS	11,586	48.9	NS	48.9	NA	NS
OF08	0.45	NS	ND	880	NS	880	2,844	NS	2,844	22.1	NS	22.1	NA	NS
AP01	NS	<0.07	<0.07	NS	505	505	NS	3,008	3,008	NS	10.4	10.4	NA	17,000
BB04	1.62	0.18	0.90	335	142	239	2,078	1,258	1,668	30.2	7.1	18.7	NA	1,700
BB05A	0.51	<0.07	0.51	321	203	262	1,347	1,439	1,393	17.2	7.8	12.5	NA	2,500

NS = Not Sampled; ND = Non Detect; NA = Not Applicable; R=Rejected because data did not meet data quality objectives.

Table 3.8 Buckeye Brook Chemistry Data for Wet Weather 1 (December 9-11, 2008)

	BOD$_5$ (mg/L)				Chloride (mg/L)				TSS (mg/L)				pH			
Station	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean
BB00	<1.0	2.0	2.0	2.0	80.4	77.8	54.6	70.9	<1.0	3.0	7.0	5.0	6.67	6.15	6.52	6.45
BB02	2.0	6.0	3.0	3.7	46.6	70.8	31.0	49.5	4.0	9.0	8.0	7.0	7.23	6.30	6.58	6.70
BB03	1.0	2.0	3.0	2.0	33.8	33.8	33.7	33.8	2.0	9.0	3.0	4.7	7.76	7.29	7.46	7.50
TA01	2.0	2.0	5.0	3.0	44.5	29.6	34.3	36.1	5.0	9.0	40.0	18.0	7.18	6.80	6.99	6.99
OF08	5.0	6.0	6.0	5.7	51.7	47.1	14.7	37.8	<1.0	9.0	8.0	8.5	7.21	6.47	6.72	6.80
BB04	6.0	5.0	9.0	6.7	44.0	22.7	38.5	35.1	6.0	10.0	6.0	7.3	7.05	6.60	6.89	6.85
BB05A	6.0	5.0	7.0	6.0	44.7	47.6	35.8	42.7	4.0	8.0	9.0	7.0	7.44	6.90	7.18	7.17

	Hardness (mg/L)				Total Phosphorus (mg/L)				TKN (mg/L)				Ammonia-N (mg/L)			
Station	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean
BB00	51.0	44.0	37.0	44.0	<0.02	0.03	0.04	0.04	0.37	ND	ND	0.37	0.26	0.15	0.16	0.16
BB02	52.0	32.0	24.0	36.0	<0.02	0.05	0.03	0.04	ND	ND	ND	ND	0.14	0.14	0.11	0.13
BB03	51.0	42.0	52.0	48.3	<0.02	0.03	0.03	0.03	0.31	0.25	0.36	0.31	0.29	0.30	0.26	0.28
TA01	98.0	45.0	50.0	64.3	0.20	0.24	0.92	0.45	7.28	31.10	5.26	14.55	5.87	2.68	3.12	2.90
OF08	42.0	15.0	15.0	24.0	<0.02	0.11	0.07	0.09	ND	ND	ND	ND	ND	0.13	ND	0.13
BB04	58.0	53.0	45.0	52.0	<0.02	0.03	0.04	0.04	0.80	0.96	0.66	0.81	0.85	1.02	0.64	0.83
BB05A	57.0	52.0	44.0	51.0	0.03	0.04	0.04	0.04	0.82	0.75	0.49	0.69	0.75	0.66	0.44	0.55

	Nitrate-N (mg/L)				Arsenic (µg/L)				Cadmium (µg/L)				Copper (µg/L)			
Station	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean
BB00	1.53	1.07	0.98	1.19	0.50	0.28	0.38	0.39	0.40	0.17	0.16	0.24	1.80	2.04	2.22	2.02
BB02	1.59	0.83	<0.05	1.21	0.46	0.24	0.53	0.41	0.18	0.22	0.39	0.26	1.03	3.37	2.19	2.20
BB03	0.34	0.34	0.36	0.35	0.67	0.96	0.81	0.81	0.15	<0.06	<0.06	0.15	0.98	0.89	0.72	0.86
TA01	<0.05	0.10	0.09	0.10	1.80	0.88	1.41	1.36	0.58	0.08	0.09	0.25	2.01	1.04	1.83	1.63
OF08	0.79	0.30	0.31	0.47	1.36	0.66	0.62	0.88	0.17	0.19	0.19	0.18	0.74	4.26	2.66	2.55
BB04	0.34	0.30	0.30	0.31	0.94	0.52	0.65	0.70	0.11	<0.06	<0.06	0.11	1.21	0.90	0.88	1.00
BB05A	0.64	0.56	0.46	0.55	0.62	0.62	0.40	0.55	0.31	0.29	<0.06	0.30	3.24	1.56	1.63	2.14

	Lead (µg/L)				Manganese (µg/L)				Total Iron (µg/L)				Zinc (µg/L)			
Station	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean	Pre-storm	Run 1	Run 2	Mean
BB00	0.27	0.30	0.49	0.35	932	821	598	784	654	897	1,082	878	24.88	25.48	27.19	25.85
BB02	R	0.78	0.49	0.64	796	382	387	522	1,185	1,377	1,419	1,327	R	28.71	24.48	26.60
BB03	0.18	<0.07	0.18	0.18	220	199	176	198	308	296	470	358	6.93	<6.46	<6.46	6.93
TA01	1.51	0.94	1.70	1.38	1,197	489	389	692	19,180	4,725	18,912	14,272	27.20	9.18	21.80	19.39
OF08	0.08	1.08	0.20	0.45	962	228	176	455	4,334	2,049	1,726	2,703	10.46	33.51	26.17	23.38
BB04	0.61	<0.07	<0.07	0.61	621	634	528	594	3,112	2,385	3,287	2,928	12.21	7.09	8.25	9.18
BB05A	0.66	0.24	0.22	0.37	613	365	382	453	1,112	1,991	1,423	1,509	9.87	20.64	25.43	18.65

	Propylene Glycol (mg/L)		
Station	Pre-storm	Run 1	Run 2
BB00	ND	ND	ND
BB02	ND	ND	ND
BB03	---	---	---
TA01	---	---	---
OF08	ND	ND	ND
BB04	ND	ND	ND
BB05A	ND	ND	ND

Sampling Dates: Prestorm -12/09/08; Run 1-12/10/08; Run 2- 12/11/08; ND = Non-Detect; R=Rejected because data did not meet data quality objectives

Table 3.9 Buckeye Brook Chemistry Data for Wet Weather 2 (February 1-8, 2011)

BOD_5 (mg/L)

Station	Pre-storm	Run 1	Run 2	Run 3	Mean
BB00	1.0	2.0	2.0	<1.0	1.7
BB02	3.0	15.0	15.0	14.0	11.8
BB03	1.0	1.0	R	<1.0	1.0
TA01	2.0	4.0	14.0	4.0	6.0
OF08	20.0	15.0	15.0	15.0	16.3
BB04	5.0	15.0	15.0	15.0	12.5
BB05A	4.0	15.0	14.0	11.0	11.0

Chloride (mg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
98.9	136.0	91.0	88.0	103.5
81.4	175.0	119.0	233.0	152.1
40.4	39.0	29.8	33.8	35.8
52.5	49.8	81.0	89.6	68.2
74.6	168.0	113.0	544.0	224.9
53.6	150.0	106.0	94.6	101.1
55.3	203.0	156.0	93.6	127.0

TSS (mg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
3.0	13.0	8.0	28.0	13.0
4.0	2.0	3.0	12.0	5.3
1.0	2.0	R	<1.0	1.5
37.0	14.0	7.0	30.0	22.0
2.0	2.0	1.0	4.0	2.3
2.0	6.0	<1.0	R	4.0
5.0	<1.0	7.0	4.0	4.0

pH

Pre-storm	Run 1	Run 2	Run 3	Mean
6.08	6.38	6.18	6.58	6.31
6.48	6.62	6.52	7.21	6.71
7.06	7.31	6.81	6.89	7.02
6.45	7.27	6.48	6.78	6.75
6.93	6.89	6.46	6.67	6.74
6.76	6.80	6.66	7.13	6.84
6.81	7.07	6.72	6.98	6.90

Hardness (mg/L)

Station	Pre-storm	Run 1	Run 2	Run 3	Mean
BB00	59.4	52.2	32.3	43.4	46.8
BB02	49.9	41.0	28.4	34.4	38.4
BB03	53.7	79.2	43.8	35.2	53.0
TA01	96.6	42.7	62.2	77.4	69.7
OF08	45.3	33.0	16.2	24.2	29.7
BB04	59.1	56.8	40.4	50.7	51.8
BB05A	60.4	59.0	36.2	44.4	50.0

Total Phosphorus (mg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
0.03	0.09	0.06	0.03	0.05
0.03	0.04	0.04	0.05	0.04
0.03	<0.02	<0.02	0.03	0.03
0.23	0.18	0.22	0.45	0.27
0.02	0.03	0.02	0.04	0.03
0.04	0.03	0.03	0.03	0.03
0.04	0.02	0.04	0.03	0.03

TKN (mg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
1.19	1.03	1.06	1.15	1.11
1.07	1.33	1.34	1.42	1.29
1.18	1.22	1.21	1.16	1.19
2.80	2.47	2.33	3.07	2.67
0.87	1.10	1.05	1.22	1.06
1.63	2.21	1.57	1.57	1.75
1.74	1.86	1.53	1.43	1.64

Ammonia-N (mg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
0.28	0.21	0.26	0.25	0.25
0.22	0.20	0.18	0.18	0.20
0.15	ND	0.16	0.20	0.17
1.99	1.14	1.44	1.38	1.49
0.13	ND	0.11	ND	0.12
0.74	0.64	0.62	0.53	0.63
0.66	0.62	0.53	0.45	0.57

Nitrate-N (mg/L)

Station	Pre-storm	Run 1	Run 2	Run 3	Mean
BB00	1.65	1.66	0.97	1.36	1.41
BB02	1.79	1.64	0.92	1.01	1.34
BB03	0.35	0.36	0.32	0.33	0.34
TA01	<0.05	<0.05	0.14	0.10	0.12
OF08	0.53	0.51	0.39	0.43	0.47
BB04	0.32	0.31	0.26	0.34	0.31
BB05A	0.42	0.39	0.30	0.38	0.37

Arsenic (µg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
0.14	0.26	0.38	0.27	0.26
0.21	0.37	0.52	0.41	0.38
0.27	0.35	0.57	0.44	0.41
0.24	0.61	0.49	0.55	0.47
0.67	0.37	0.64	0.48	0.54
0.24	0.30	0.35	0.25	0.29
0.17	0.27	0.24	0.62	0.33

Cadmium (µg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
0.26	0.21	0.09	0.16	0.18
0.09	0.14	0.12	0.13	0.12
<0.05	<0.05	<0.05	<0.05	<0.05
0.09	<0.05	<0.05	<0.05	0.09
0.06	0.10	<0.05	0.20	0.12
0.14	<0.05	<0.05	0.06	0.10
0.05	0.06	<0.05	0.14	0.08

Copper (µg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
1.33	2.16	2.17	1.53	1.80
1.30	2.32	4.05	3.32	2.75
2.94	1.05	1.63	0.81	1.61
1.40	1.48	1.34	1.36	1.40
1.03	1.74	3.59	4.22	2.65
1.52	1.71	2.35	1.46	1.76
2.51	8.48	2.02	1.26	3.57

Lead (µg/L)

Station	Pre-storm	Run 1	Run 2	Run 3	Mean
BB00	0.09	0.16	1.28	0.16	0.42
BB02	0.11	0.35	0.51	0.17	0.29
BB03	0.29	0.10	0.33	<0.08	0.24
TA01	0.73	0.19	0.22	0.37	0.38
OF08	<0.08	2.62	0.22	0.11	0.98
BB04	1.50	0.13	0.38	<0.08	0.67
BB05A	0.37	0.53	0.15	0.20	0.31

Manganese (µg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
768	810	512	726	704
858	1,169	481	526	759
393	467	433	391	421
1,247	1,012	689	835	946
1,599	945	383	494	855
663	713	555	550	620
724	723	713	398	640

Total Iron (µg/L)

Pre-storm	Run 1	Run 2	**Run 3**	Mean
741	2,307	948	648	1,161
1,989	1,747	1,475	2,403	1,904
432	449	462	1,617	740
9,088	4,976	1,250	3,693	4,752
3,954	2,454	1,928	2,441	2,694
1,892	3,112	1,605	1,799	2,102
1,010	1,168	981	1,172	1,083

Zinc (µg/L)

Pre-storm	Run 1	Run 2	Run 3	Mean
4.49	17.51	21.13	5.55	12.17
<1.12	13.60	22.60	<1.13	18.10
1.97	1.15	1.94	<1.13	1.69
3.36	1.44	1.91	<1.13	2.24
2.86	10.29	15.40	9.26	9.45
5.99	<1.13	3.30	<1.13	4.65
4.13	14.86	2.68	<1.13	7.22

Propylene Glycol (mg/L)

Station	Pre-storm	Run 1	Run 2	Run 3	Mean
BB00	ND	ND	ND	ND	ND
BB02	ND	45	44	45	45
BB03	ND	ND	ND	ND	ND
TA01	---	---	---	---	
OF08	ND	99	34	105	79
BB04	ND	23	ND	21	22
BB05A	---	---	---	---	

Sampling Dates: Prestorm -02/01/11; Run 1-02/03/11; Run 2- 02/06/11; Run 3- 02/08/11; ND = Non-Detect; R=Rejected because data did not meet data quality objectives.

3.6 Biological Field Survey

The Biological Field survey for Buckeye Brook was conducted on September 10, 2008 to further characterize the extent and severity of the impairment while bracketing potential stressors from outfalls and tributaries to Warwick Pond and Buckeye Brook. Table 3.10 lists those stations selected for biological sampling, their locations and the type of assessment that was conducted by ESS Group, Inc (ESS). Stations that were tested for toxicity are listed in Tables 3.2 and 3.3 for the dry and wet weather events.

Table 3.10 Buckeye Brook Stations Sampled by ESS in September, 2008

Station	Location	Assessments Conducted
Tributaries to Warwick Pond (RI0007024R-05)		
BB00	Tributary to Warwick Pond above Airport Road	Habitat Periphyton/Macroinvertebrate CPOM/FPOM
BB02	Tributary to Warwick Pond at Lakeshore Drive	Habitat Periphyton/Macroinvertebrate CPOM/FPOM
Buckeye Brook Watershed (RI0007024R-01)		
BB04	Buckeye Brook at Rufus Road	Habitat Periphyton/Macroinvertebrate CPOM/FPOM
BB05A	Buckeye Brook downstream of Old Warwick Avenue	Habitat Periphyton/Macroinvertebrate CPOM/FPOM
TA01	Unnamed tributary channel from Truk-Away Landfill	Habitat
OF08	T.F. Green Airport Outfall 008	Habitat
AP01	Downstream channel combining flows from the outfall OF08 and landfill stationTA01	Habitat Periphyton/Macroinvertebrate CPOM/FPOM
Adamsville Bk Reference Site	At the USGS Gage off of Route 81 in Little Compton, RI	Macroinvertebrate

Macroinvertebrates and periphyton are useful in biological monitoring because of the wide range of tolerances among taxa to various physical, chemical, and biological stressors. Coarse particulate organic matter (CPOM) and fine particulate organic matter (FPOM) were evaluated to assess the potential contribution of carbon availability and processing on observed patterns in the biological community. An evaluation of habitat quality is critical to any assessment as habitat and biological diversity in streams are closely linked. Habitat incorporates all aspects of

physical and chemical constituents along with the biotic interactions. The presence of an altered habitat structure is considered one of the major stressors of aquatic systems.

3.7 Results of Biological Sampling

The full report for the biological sampling conducted by ESS Group within the study areas for Warwick Pond tributaries and Buckeye Brook can be requested through RIDEM. Excerpts from the full report summarizing the conditions found in the Buckeye Brook watershed when compared against a reference site at Adamsville Brook (ESS45) are provided.

3.7.1 Stream Habitat

Overall stream habitat scores ranged from 83 to 144 on a 200-point scale and were compared against the reference site at Adamsville Brook (ESS45). Although the reference site was not assessed for stream habitat as part of the field surveys, it was assessed in 2008 by ESS Group as part of the statewide wadeable stream biomonitoring effort. Table 3.11 lists the EPA stream habitat classifications and Table 3.12 shows the total habitat scores for each sampling location within the study area as compared against the reference site.

Stream habitat was in the best condition above the T.F. Green Airport (BB00) and below Warwick Pond (BB04 and BB05A) and poorest in the tributary channels sourced from the airport outfalls and the Truk-Away Landfill. Compared to the reference site (ESS45), which received a score of 142, three stations (BB00, BB04, and BB05A) were comparable to reference, one station (BB02) was supporting and three stations (AP01, OF08, and TA01) were partially supporting. One station (BB05A) scored marginally higher on the stream habitat assessment than the reference site. These results indicate fairly poor stream habitat conditions exist throughout these two watershed areas and may be contributing to these stream's poor biological health. Stormwater discharges are likely contributing to at least some of these degraded habitat conditions (e.g. embeddedness, channel alteration, and sediment deposition).

3.7.2 Macroinvertebrate Results

Assessment of macroinvertebrate community in the study areas for Warwick Pond tributaries and Buckeye Brook suggests that moderate to severe biological impairment exists across most, if not all, of the watershed. The moderate level of impairment at BB05A is consistent with assessments conducted by ESS just upstream at BB05 in previous years, as part of the statewide wadeable stream biomonitoring program. However, stations on and just downstream of the tributary channels sourced by T.F. Green Airport and the Truk-Away Landfill (BB02, AP01, and BB04) appear to be more severely impaired. At these stations, sensitive taxa are found in very low abundances, if at all, indicating high levels of disturbance. Table 3.13 shows the dominant taxon for the six biological stations.

Table 3.11 US EPA Habitat Attributes Assessed and Stream Habitat Classification

Site	Total Habitat Score	Instream Cover	Epifaunal Substrate	Embeddedness	Channel Alteration	Sediment Deposition	Frequency of Riffles	Channel Flow Status	Bank Vegetation Status	Bank Stability	Riparian Vegetative Zone Width
Tributaries to Warwick Pond (RI0007024R-05)											
BB00	SO	SO	M	SO	SO	SO	O	O	O	O	SO
BB02	SO	SO	M	**M**	SO	**M**	**M**	SO	O	O	O
Buckeye Brook Watershed (RI0007024R-01)											
BB04	SO	SO	M	M	O	O	M	SO	O	O	O
BB05A	SO	SO	M	M	O	O	M	SO	O	O	O
OF08	M	M	SO	O	SO	**M**	SO	**M**	SO	**P**	M
TA01	M	**P**	**P**	**P**	SO	O	**P**	**M**	O	O	SO
AP01	M	**P**	M	**P**	SO	**M**	M	O	SO	O	M
ESS45*	SO	O	M	O	SO	O	SO	O	SO	SO	SO

Classification Range: Poor (P) = 0-5; Total Score <50; Marginal (M) = 6-10; Total Score 51-100; Sub-optimal (SO) = 11-15; Total Score 101-150; Optimal (O) = 16-20; Total Score>150; **Bold indicates values were <58% of the Reference Station**

Table 3.12 Summary Statistics for Stations Assessed under the Biological Survey

Summary Statistic	Tributaries to Warwick Pond		Buckeye Brook			ESS45
	BB00	BB02	BB04	BB05A	AP01	
Total Taxa Richness	8.7	9.0	10.0	12.0	10.7	18.7
EPT Taxa Richness	1	0.7	1.7	2.0	0.0	7.0
EPT Abundance Per Kick Sample	94	1	16	80	0	282
Hilsenhoff-Biotic Index	5.94	8.26	8.02	6.26	7.59	4.08
Hilsenhoff-Water Quality	Fair	Poor	Poor	Fair	Poor	Very Good
Shannon Weaver Diversity Index	1.77	1.37	1.69	1.86	1.30	2.51
% Contribution of Dominant Taxon	45.1	56.2	46.0	34.5	65.2	22.0
Ratio of EPT to Chironomid Abundance	1.26	0.13	0.99	0.40	0.00	6.01
% Hydropsychidae to Total Trichoptera*	100	0.00	44.05	86.03	NA	45.53
Ratio Shredders/Total Number of Invertebrates	.02	0.03	0.00	0.03	0.00	0.02
Ratio Scrapers/Filterers	0.00	0.00	0.00	0.00	0.50	9.26
Community Loss Index	1.35	1.19	0.97	0.64	1.00	0.00
Relative Percent Similarity	30.4	26.1	17.4	39.1	17.4	NA
Biological Impairment Category	Moderately Impaired	Moderately Impaired	Severely Impaired	Moderately Impaired	Severely Impaired	Reference

Table 3.13 Dominant Taxon at the Biological Sampling Sites

Station	Dominant Taxon	Number
Tributaries to Warwick Pond		
BB00	Trichoptera (*Cheumatopsyche sp.*)	281
BB02	Oligochaeta (Tubifucudae)	101
Buckeye Brook		
BB04	Amphipoda (*Gammarus sp.*)	284
BB05A	Diptera (*Tanytarsus sp.*)	214
AP01	Diptera (Tanytarsini)	427
ESS45	Trichoptera (*Chimarra sp.*)	208

Although measurements of dissolved oxygen in 2006 and 2008 have consistently shown a dissolved oxygen sag to marginal levels (near 5 mg/L) in the vicinity of BB04 and BB05A, there was no obvious sign of additional metabolic stress due to low dissolved oxygen within the macroinvertebrate community at these stations. However, the overall level of impairment within the study areas and the fact that riffle habitats - generally the best oxygenated habitats of each stream reach - were sampled for macroinvertebrates make it difficult to discern the specific biological impacts of the observed low dissolved oxygen concentrations. Overall, the macroinvertebrate sampling results indicate moderate to severe biological impairments across

most if not all of the watershed. The most severe impairments are found downstream of the tributaries fed by the airport outfalls and the landfill.

3.7.3 Periphyton Results

In the absence of a true reference site for periphyton, it is difficult to quantify the level of biological impairment over the drainage areas for the Warwick Pond tributaries and for Buckeye Brook as a whole. However, there is some indication that certain periphyton metrics, such as taxa richness, may be somewhat less than expected for small streams in the ecoregion. Additionally, the relatively high contribution of taxa that tend to be associated with some form of instream disturbance (e.g., siltation, nutrient enrichment, flashiness) may be reflective of an overall depression in biological and habitat condition throughout the study area. Habitat observations by ESS and nutrient data collected by RIDEM would appear to support this connection. Table 3.14 shows the Periphyton summary for the Buckeye Brook surveys while Table 3.15 shows the dominant Periphyton Taxa collected during the field surveys.

Table 3.14 Periphyton Summary Table for the Buckeye Brook Study, September 10, 2008

Site	Average Generic Richness	Average % *Achanathes minutissima*	Average Diatom Pollution Tolerance Index	Average Biovolume ($\mu m^3/cm^2$)	Species Group	Average Biovolume ($\mu m^3/cm^2$)	Relative Biovolume (%)
Tributaries to Warwick Pond							
BB00	9.0	32.3	2.8	2.75E+05	blue-green	954	0.3
					cryptophyte	166	0.1
					diatom	210,728	76.7
					euglenoid	62,752	22.9
BB02	16.3	3.8	2.6	1.80E+06	blue-green	80,682	4.5
					cryptophyte	1,504	0.1
					diatom	1,665,236	92.6
					euglenoid	6,617	0.4
					green	43,303	2.4
Buckeye Brook							
BB04	14.7	5.2	2.4	5.46E+07	cryptophyte	510,937	0.9
					diatom	49,723,045	91.0
					euglenoid	1,132,075	2.1
					green	3,263,984	6.0
BB05A	16.7	1.0	2.3	7.52E+06	blue-green	581,101	7.7
					cryptophyte	340,210	4.5
					diatom	6,082,084	80.9
					euglenoid	483,790	6.4
					green	31,192	0.4
AP01	8.3	17.9	2.6	1.60E+07	cryptophyte	193,269	1.2
					diatom	11,365,208	69.3
					green	4,844,355	29.5

Table 3.15 Dominant Periphyton Taxa Collected for Buckeye Brook Biological Survey

Station	Group	Dominant Taxa (by Biovolume)
Tributaries to Warwick Pond		
BB00	Crytophytes	Rhodomonas
	Diatoms	Achnanthes, Cymbella, Epithemia, Cocconeis, Gomphonema, Tabellaria
	Euglenoids	Trachelomonas
BB02	Blue-greens	Oscillatoria
	Diatoms	Eunotia, Synedra, Nitzschia
Buckeye Brook		
BB04	Diatoms	Eunotia, Synedra, Navicula, Gomphoneis, Frustrulia
BB05A	Blue-greens	Oscillatoria
	Diatoms	Eunotia, Fragilaria, Synedra
	Euglenoids	Trachelomonas
AP01	Diatoms	Eunotia, Gomphonema, Synedra, Navicula, Achnanthes
	Greens	Cladophora

However, the trends in the periphyton community do not implicate a particular stressor or source in Buckeye Brook or the Tributaries to Warwick Pond. This may be due, in part, to the fact that the periphyton community is generally responsive to shorter term impacts than the macroinvertebrate community.

The presence of an orange to brown-colored flocculent was noted at several stations but was heaviest at OF08, AP01, and TA01. This flocculent material is characteristic of the bacterial colonies that oxidize the iron associated with both natural sources and landfill groundwater leachate, including *Gallionella ferruginea* and *Leptothrix ochracea*. In excess, the flocculent material can smother coarse substrates and clog the interstitial areas used as refuge by macroinvertebrates.

Patterns in the concentration of CPOM and FPOM did not display any significant trend in the downstream direction. However, when the two size fractions are combined, a trend of steady increase is apparent in the downstream direction. Nonetheless, it is difficult to infer an association with the observed biological patterns from a single measurement of POM. Adjustment of sampling frequency to include additional samples, especially over a full event hydrograph, may be useful for future efforts.

3.8 Aquatic Toxicity Study

Two of the four surveys conducted for the biodiversity study had stations that were tested for aquatic toxicity by the EPA Laboratory in Chelmsford, MA. The following sections of this report discuss the type of testing conducted, the stations selected for the testing, and summarizes the results of the dry and wet weather toxicity study. The full report is available at RIDEM upon request.

3.8.1 Dry Weather Toxicity Study

The dry weather toxicity survey was conducted from July 16-21, 2008 on six of the nine stations that were sampled during the biodiversity study for the Tributaries to Warwick Pond and Buckeye Brook. The first sampling run on July 16, 2008 collected field data (Dissolved Oxygen, Specific Conductivity, and Temperature), chemistry and toxicity samples at Stations BB02, BB03, BB04, BB05A, as well as the Truk-Away landfill (TA01) and airport outfall (OF08) stations. Two other sampling runs were conducted every other day to collect water samples to replenish the water used in the toxicity tests at the EPA laboratory. This ensured that the water used in the toxicity tests would be fresh throughout the 7-day testing period.

Pimephales promelas (fathead minnow)
The results for the fathead minnow showed that neither the survivability nor the growth test (biomass) showed any statistically significant impact. One location (BB03) had a 5% lower survival rate when compared to the control and is not considered to be statistically and even less likely to be biologically significant. Examination of the test endpoint, growth, as shown by mean biomass, indicates that all but BB03 was equal to or greater than the mean biomass of the laboratory control sample. The biomass for the sample from BB03 was 18% lower, but not statistically different than the laboratory control as the 18% represents a difference of 0.11mg.

Ceriodaphnia dubia (daphnid)
The results for the *C. dubia* indicate that there was no statistically significant reduction in survival for any of the site location samples when compared to the laboratory control. However, statistical analysis of the reproduction data does show a statistically significant reduction in the number of neonates produced in samples from Truk-Away landfill (TA01) and from the airport outfall (OF08). Both TA01 and OF08 reproduction mean values were 44% below the laboratory control sample.

In summary, during the dry weather sampling, there were not any significant toxicity issues for the fathead minnow at any station but the daphnid did show some effects from the landfill and from the discharge for outfall OF08 which drains the main passenger terminal at the airport. Results from the chemical analysis show that at these stations, total iron and dissolved cadmium exceeded the chronic fresh water criteria for the dry survey. The criteria for iron is 1000 µg/L and the values at TA01 and OF08 were 11, 586 µg/L and 2,844 µg/L respectively. The chronic criteria for iron was also exceed at Stations BB04 and BB05A but the results from the toxicity tests did not indicate any impact on the fathead minnow or the daphnid at these locations. The

dissolved cadmium at TA01 and OF08 exceeded the chronic criteria by 30% and 6% respectively.

3.8.2 Wet Weather Toxicity Study

The second toxicity study was conducted during a winter, deicing conditions. Four sampling runs were conducted over a period of eight days starting February 1, 2011. Field measurements and chemistry samples were collected for all stations on every run, while toxicity sampling was only conducted at Stations BB00, BB02, BB03, BB04, outfall OF08, and TA01 for the last three runs of the storm event. A summary of the results from the winter toxicity survey is given below.

The test acceptability criteria (TAC) and nonlethal variability limits (PMSDs) were met for *Pimephales promelas* (fathead minnow). TAC for the *Ceriodaphnia dubia* (daphnid) was met for the survival endpoint, however the test TAC for reproduction fell below criteria.

Pimephales promelas (fathead minnow)
All but one field sample, BB02, showed no significant statistical effect for survival. However, it was noted that due to the filamentous floc that developed in the test sample, it was a distinct possibility that the reduction in survival for BB02 may have been due to a physical impairment, rather than a true chemical effect. The survival rate for BB02 was 48% below the control sample, while all other stations were not affected.

There was a statistically significant reduction in biomass observed for Stations BB02, BB04, outfall OF08, and TA01, while Stations BB00 and BB03 showed no signs of growth impairment. However, interpretation of the results for the stations showing growth impairment was difficult base solely upon the test findings due in part to difficulties maintaining dissolved oxygen levels throughout the test period. While dissolved oxygen levels for these samples dropped below the minimum 4 mg/L, it may have been more a physical entrainment issue caused by the filamentous floc which contributed to the reduction in growth. Station BB02 had the largest biomass deficit below the control sample at 64%, with stations BB04 at 22%, TA01 at 20% and OF08 at 34% below the control for the wet weather survey. The dissolved oxygen sags that occurred during the toxicity test may have been influenced by the propylene glycol levels for these samples. The mean glycol at BB02 was 45 mg/L and the associated BOD_5 demand was 16.3 mg/L. Outfall station OF08 and BB04 had mean glycol values of 79 mg/L and 22 mg/L respectively, with the BOD_5 levels at 16.3 mg/L and 11.8 mg/L respectively.

Ceriodaphnia dubia (daphnid)
No significant effect on survival was observed for any sample stations for *Ceriodaphnia dubia*. The test failed to meet reproduction criteria. However, due to the difficulties capturing a winter storm event that met the parameters that occurred in this storm and the associated cost that would be incurred in doing so, the laboratory staff made the following observations in order to glean as much information from this test.

"The TAC are measured on the laboratory control organisms to evaluate, at least in part, test organism health. The laboratory controls represent the test organisms in the absence of any stressors. Therefore, it would be assumed that, barring lab personnel performance issues, any improvement in health would be reflected across all test exposures. The current neonate production data indicates a maximum reduction in production at 10% is associated with sample location at BB02. All other neonate production is equal to or greater than the laboratory control response."

The laboratory staff stated that if the test organism health was improved and the test did meet TAC or it was redone, a finding of no significant difference in reproduction for any of the samples would be the same. Therefore, it was decided to accept the results of the testing conducted on the *C. dubia* for this storm event.

In summary, the fathead minnow survival rate was not significantly impacted at any station except BB02 during the wet weather de-icing study. The reduced survival rate for BB02 was not a toxic response but likely due to a physical impairment from the filamentous floc in the sample. There was a significant difference in biomass growth for the minnow at stations BB02, BB04, TA01, and outfall OF08 which may again be connected to the filamentous floc that developed in the test sample. The dissolved oxygen sag observed in the samples could be in response to the propylene glycol which uses oxygen during the degradation process.

The daphnid survival rate was not affected for the toxicity testing but the reproduction data failed to meet test criteria. Again, the dissolved oxygen levels in the test samples may have been the cause of the low reproduction rather than any toxic effects from pollutants in the water column.

3.9 Aquatic Life Use Impairment Stressor Analysis

The primary objective of Rhode Island Department of Environmental Management's sampling effort was to characterize the geographic extent and severity of the Buckeye Brook Aquatic Life Use (AQLU) impairment and to identify potential causes and/or pollution sources contributing to the impairment. Water quality and/or benthic biological samples were collected from nine sites in the Buckeye Brook watershed over the course of four surveys from July 2008 through February 2011 that consisted of two dry weather and two wet weather surveys, one of which was during a winter icing event. The results of the sampling program led to the identification of new impairments which were added to the state's 2014 303d list.

The results of macroinvertebrate sampling on Tributaries to Warwick Pond and Buckeye Brook found moderate to severe impairments of the biological community in these streams, with the more severe impairments associated with areas in the vicinity of the airport and landfill. Poor stream habitat is contributing to degraded aquatic life use in these stream systems. The smothering of the streambed habitat by iron flocculent material was evident in each of the tributaries originating from the airport and/or landfill including stations OF08, AP01, and TA01. While this flocculent material was less visible in the Buckeye Brook station (BB04) downstream of the confluence with

the tributaries' confluence with the brook, analysis of macroinvertebrate samples confirms its presence at this station. The hydrologic impacts (decreased groundwater recharge, lower base flows and increased runoff) associated with these streams' highly impervious watersheds alter stream morphology resulting in flashier, less stable streams which also degrade the quality of habitats for aquatic life.

The results of toxicity testing reveal that for the majority of the stations, there were no dry weather toxicity issues except for those stations receiving flow from the landfill and airport, TA01 and OF08 respectively, where there was a significant reduction in the number of neonates produced in samples from Truk-Away landfill (TA01) and from the airport outfall (OF08) for the daphnid. The conditions (dry weather) leading to the observed toxic effects are likely contributing to the severity of the impairment of the biological community at these locations.

Toxicity testing conducted on samples collected during a winter storm requiring use of deicing compounds, revealed statistically significant reduction in minnow biomass at stations located downstream of the airport and landfill which was notably not observed at stations located upstream of the airport and at the outlet of Warwick Pond. It was noted that the observed effects were likely due to physical entrainment in the filamentous floc growing in the sample and not a toxic effect.

Instream copper criteria were exceeded at several stations, both in the tributaries to Buckeye Brook as well as at stations located on the mainstem of the brook. A single dry weather exceedance was observed at Station BB04 during the first dry weather event. Stations BB05A and OF08 both exceeded the criteria for dissolved copper during the wet weather events. OF08 has multiple wet weather exceedances during both wet events while a single exceedance was observed at BB05A during the February 2011 winter monitoring event.

Total iron levels criterion was exceeded at the sampling stations located downstream of the airport and landfill (TA01, OF08, and AP01) and in Buckeye Brook downstream of these sources (BB04 and BB05A) during both dry weather events; notably there were no exceedances at the stations in watershed for the Warwick Pond tributaries. During both wet weather events, nearly all stations exceeded the iron criterion, with the highest exceedances occurring at the landfill and airport sampling locations. It is noted that concentrations of iron are comparable between the Tributaries to Warwick Pond and Buckeye Brook in wet weather. Dissolved cadmium aquatic life criteria were exceeded at stations (BB00 and BB02) in the Warwick Pond tributaries and at one station (BB05A) in Buckeye Brook during wet weather; concentrations between the two reaches were comparable. It is noted that levels in the stream channels originating at the airport and landfill were similar to the Warwick Pond Tributaries and the Buckeye Brook values. These concentrations of iron and cadmium, in exceedance of DEM's aquatic life criteria, are thought to be contributing to the observed aquatic life impairments.

RIDEM staff reviewed the monitoring data from 2012 through 2017 submitted by RIAC as part of the permit requirements. Analysis of this data show that the levels of iron and copper (no cadmium

data is currently collected by RIAC) in the discharges from airport outfalls 002 and 003 to the tributaries of Warwick Pond and outfall 008 to Buckeye Brook are similar to levels observed from RIDEM's field work in 2008 – 2011 time period – confirming the airport as an ongoing source of these metals contributing to observed impairments in the receiving waters.

Iron fixing bacteria (*Sphaerotilus*) were observed to completely cover the streambed in the tributary channels originating at the landfill and the airport property (stations TA01, outfall OF08, and AP01) during the field sampling conducted by ESS, and historically have been observed in the channel flowing from airport outfalls (#002 and 003) that flow into the Warwick Pond Tributaries (Berger, 2007). These bacteria were also observed in Buckeye Brook downstream of the confluence with the airport and landfill though not completely covering the streambed. These bacteria have been documented at other locations to cover entire streambeds near airports crowding out indigenous forms of aquatic life. In the process of metabolizing carbonaceous materials, such as propylene glycol, the bacteria consume available oxygen in the stream's water column, and are believed to be contributing to the observed dissolved oxygen levels below the minimum 5.0 mg/L in Buckeye Brook. The extent of iron fixing bacteria in the channels leading from the airport and landfill, and covering the substrate in Buckeye Brook is believed to be significantly impacting aquatic life in these stream systems (ESS, 2008).

Dissolved oxygen sags were observed in Buckeye Brook in different seasons and under various flow and weather conditions. Sampling conducted by RIAC during the February 2011 de-icing event documented spikes in BOD_5 and propylene glycol at stations located on the Tributaries to Warwick Pond and Buckeye Brook downstream of airport outfalls; these spikes coincide with dissolved oxygen sags documented by DEM during the same storm event though no violations of DO criteria were observed. DEM has also observed dissolved oxygen sags between the exit of Warwick Pond and the stream channel originating from the airport and landfill in dry weather summer conditions (with dissolved oxygen levels dropping an average of 3.2 mg/l). The observed DO concentrations at the BB04 station was in violation of RIDEM's instantaneous dissolved oxygen criteria. BOD5 was not elevated – and thus not a factor in the summer time DO sag. However, as noted above iron fixing bacteria was observed to be covering the substrate of this reach of Buckeye Brook and oxygen consumed by these bacteria is believed to be the cause of the dissolved oxygen sag in this reach.

In conclusion, this analysis of Aquatic Life Use stressors finds that a combination of stressors is contributing to the observed biodiversity impairments in Buckeye Brook and the Tributaries to Warwick Pond, as evident from benthic macroinvertebrate bioassessments. The uncontrolled discharge of stormwater and related hydrologic and stream habitat alterations associated with the highly urbanized watersheds combined with violations of ambient water quality criteria for various metals, previously uncontrolled discharge of propylene glycol and extensive growth of iron fixing bacteria on substrates downstream of the airport outfalls and the Truk Away Landfill are all believed to be stressors contributing to the observed biodiversity impairments.

4.0 POLLUTION SOURCES

Sources of impairments in the watersheds were identified using the analytical results from water samples collected during the two dry weather and two wet weather surveys. The results from the biological survey were also utilized in determining the sources of the impairments to portions of Buckeye Brook. The TMDL examination of actual and potential sources of metals contamination to the brook and its tributaries are summarized in Table 4.1 and further discussed below.

Table 4.1 Actual and Potential Pollution Sources

Source	Location/ Explanation
Stormwater Runoff	Throughout these highly urbanized watersheds including T.F. Green Airport. Runoff from impervious areas such as parking lots, streets, roofs, and runoff contaminated with heavy metals (Cd, Cu, and Fe) among other pollutants.
Waste Sources	Waste sources include landfills such as the Truk Away Landfill.
Contaminated Groundwater	Potential sources of contaminates to groundwater can be historic in origin and originate in landfills, open areas of unsupervised dumping, construction operations, backfilled areas with contaminated soils.
Non-Stormwater Urban Runoff	Overland flows from various land use practices enter storm drains, which including lawn irrigation runoff, car washing, sidewalk washing and commercial pavement washing. These urban flows can contain metals among other pollutants.

4.1 Stormwater

With 42% of the combined watersheds covered by impervious surfaces, stormwater runoff is a significant source of pollution to the area. Throughout both watersheds, storm drainage systems collect, concentrate and route polluted runoff from streets and highways directly to the mainstem and tributaries. T.F. Green Airport operates a separate stormwater collection system to convey runoff from runways, terminal, parking lots, and other impervious surfaces. Stormwater from parking lots and the commercial and industrial areas surrounding the airport may be discharged into municipal or state-owned drainage systems or may be conveyed directly to stream systems via overland flow, stormwater pipes, or other conveyances. Recent improvements by RI Airport Corporation include the construction of structural stormwater controls at select locations to treat runoff discharged from its facilities. The amount of impervious areas in a watershed also affects the water quality of rivers and streams within the watershed. Recent study results from USGS in the New Hampshire seacoast region confirm that the percent impervious surface in a watershed can be used as an indicator of stream quality: the biological condition score was negatively correlated with the percent impervious surface (Deacon, et.al. 2005). Furthermore, a growing number of northeastern states are recognizing the relationship between impervious cover and

water quality impairments, and are utilizing percent impervious cover as a surrogate target for TMDL analyses.

Urban land uses change watershed hydrology by affecting the quantity and quality of runoff. A combination of pollutants found in stormwater contributes to aquatic life impairments in streams, along with habitat destruction by flash floods and bank erosion. Often there is not a direct link to a specific source that is causing or contributing to exceedances of a pollutant specific water quality criterion. Quantifying pollutant loadings is especially difficult given the variability in types and amounts of pollutants associated with impervious cover. Aquatic life impairments associated with stormwater are not always caused by a single pollutant and are most often due to a complex array of pollutants transported by stormwater and other impacts of urban development.

Urban development also results in increases in stormwater runoff peaks and volumes and increased frequency of runoff from smaller storms. With increasing impervious cover within a watershed, the greater quantities of stormwater runoff wreak havoc with the physical structure and stability of streams and the habitat for aquatic life, and less base flow is available to aquatic life in streams during low flow periods.

4.2 Waste Sources

There are two waste sources within the watershed boundaries. One is the Truk-Away Landfill that is located off the departure end of Runway 16 and the other is the other is the Municipal Recycling Facility located behind the Mickey Stevens Sports Complex off Sandy Lane.

The landfill was in operation through the 1970s and was closed for operation in 1977 but never capped. In 1977, the property was sold to the state Department of Transportation (DOT) and ceased operations because of the hazards posed to air traffic by sea gulls attracted to the landfill. The landfill has never been “clean closed,” meaning not all hazardous waste has been removed. The landfill is also listed on the Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS) and is listed on RIDEM’s Management Landfill Closure Program.

Since the landfill is not capped hydraulically, any precipitation is allowed to infiltrate through the buried waste and eventually reach the groundwater table which may be flowing to the brook. Surface flow over the landfill also ends up discharging into the brook through an adjacent wetland area.

The City of Warwick’s Municipal Recycling facility, located adjacent to the Mickey Stevens Sports Complex off Sandy Lane, processes yard waste for compost on a concrete pad that is adjacent to a large wetland area. This area was investigated and it was determined that based upon the operating procedures followed and the layout of the site that this facility was not a source of concern relative to pollutants or nutrients discharged to Buckeye Brook.

4.3 Contaminated Groundwater

Groundwater contamination can come from a number of sources, some of which include improperly maintained or closed landfills, leaking underground storage tanks, chemicals and road salts used to melt ice, and atmospheric deposition.

In 2007, the RIAC contracted a consultant (Louis Berger Group, 2007) to investigate the odor issues associated with airport operations and on the proliferation of bacteria in the areas downstream of the airport's stormwater outfalls. The study showed high levels of iron and that iron bacteria growth was prevalent in the stormwater systems for those outfalls that discharge directly to the tributaries to Warwick Pond and Buckeye Brook. The outfalls were flowing during dry weather conditions and had iron levels high enough which provided a food source for the bacteria. The report states that the outfall drainage channels received the groundwater recharge as a point source at the headwaters, where the iron rich groundwater is seeping into the storm water piping system. Additionally, the RIDEM field study showed that discharge from the largest outfall at the airport (008) had exceedances of cadmium during dry (as well as wet) weather.

Another source of contaminated groundwater comes from the leachate that percolates through the Truk-Away landfill. The presence of rust-orange sediments in the water at the landfill station TA01 verifies that the leachate from the landfill is rich in iron which provides a food source for the iron bacteria. The samples collected during dry weather by RIDEM staff at station TA01 on the small tributary fed by groundwater that drains the landfill also exceeded the fresh water criteria for cadmium.

Sampling of the monitoring wells along the eastern perimeter of the landfill show that there are volatile organic compounds (VOCs) present but no evidence of metals identified in this TMDL. Soil samples from the area around the wells did contain some metals, but only arsenic exceeded the RIDEM industrial/ commercial direct exposure or leachability criteria of 3.8 mg/Kg. Samples from TA01 did contain arsenic but at levels well below the freshwater criteria. Testing by EPA and toxicity testing conducted as part of this study do not show evidence that these contaminants are contributing to biodiversity impairments seen in the Brook.

5.0 TMDL ANALYSIS

This TMDL establishes numeric water quality targets for iron, copper, and cadmium. Dissolved oxygen targets are not explicitly set by this TMDL. Actions to mitigate the cause of the dissolved oxygen impairment and to avoid future violations of the in-stream dissolved oxygen criteria are either in place (RIAC's stormwater permit requiring construction of a glycol treatment and diversion structures that went online in October 2014), or will be addressed by this TMDL's required reductions in the discharge of iron. This TMDL also does not establish a separate target to address hydrologic alterations associated with the discharge of uncontrolled runoff from the highly impervious watersheds believed to be contributing to these river's aquatic life use

impairments. Actions to mitigate the uncontrolled discharge of runoff from the Rhode Island Department of Transportation and the City of Warwick as required by the Buckeye Brook Bacteria TMDL also address the associated hydrologic alterations. This TMDL requires RIAC to also manage stormwater to reduce runoff volumes consistent with requirements established for MS4 operators.

5.1 Metals Analysis

5.2 Applicable Water Quality Criteria

Freshwater aquatic life criteria for certain metals are expressed as a function of hardness because hardness can affect the toxicities of these metals. Increasing hardness has the effect of decreasing the toxicity of metals. The water quality standards for toxics, including dissolved metals, are set forth in Appendix B of Rhode Island's Water Quality Regulations (DEM December 2009). The chronic and acute fresh water aquatic life criteria of most metals apply to the dissolved form and are calculated using water hardness (in mg/l as CaCO3) based on equations in Table 2-Appendix B of Rhode Island's Water Quality Regulations. As described in Section 1.5.2, a range of hardness values were used to calculate chronic and acute criteria reflecting the actual hardness values observed under both dry and wet weather flow conditions and the varying frequency of sampling (dry vs. wet). This resulted in a range of water quality criteria being calculated for both dry and wet weather. Table 5.1 reflects the range of criteria that were utilized in determining the required reductions for this TMDL. This approach to determine which hardness values would be used to establish the criteria was necessary in order to be conservative enough to provide adequate protection under all flow conditions.

Table 5.1 Range of Water Quality Criteria Utilized for the Buckeye Brook TMDL

Hardness as $CaCO_3$ (mg/L)	**Cadmium (µg/L)**		**Copper (µg/L)**	
	Acute Criteria	**Chronic Criteria**	**Acute Criteria**	**Chronic Criteria**
15.00	0.31	0.07	2.25	1.78
30.00	0.62	0.11	4.32	3.20
60.00	1.23	0.18	8.31	5.79
90.00	1.82	0.24	12.2	8.19
100.0	2.01	0.26	13.4	8.96

5.3 Water Quality and Resource Impairments

Data collected by RIDEM over the course of two dry and two wet surveys conducted in the study areas confirm that portions of both watersheds exceed certain dissolved metals aquatic life criteria as stated in Appendix B of the State's Water Quality Regulations. In this case, the impaired use is the protection of aquatic life.

5.4 Critical Conditions and Seasonal Variation

The Clean Water Act, Section 303(d)(1)(C) requires that TMDLs "be established at a level necessary to implement the applicable water quality standards with seasonal variations…" The current regulation also states that determination of "TMDLs shall take into account critical conditions for stream flow, loading, and water quality parameters" [40 CFR 130.7(c)(1)].

Elevations of metals concentrations occur throughout the year and under various flow regimes and weather conditions, depending upon the location and metal in question. However, as documented in Table 3.5, exceedances of applicable metals criteria occur more frequently in wet weather than dry weather. Critical conditions vary by station; therefore, the TMDL analysis is inclusive of all seasons and all weather conditions.

5.5 Margin of Safety

A margin of safety (MOS), designed to account for uncertainty in TMDL calculations, is a required element of a TMDL [40 CFR 130.33(b) 7]. The MOS may be incorporated into the TMDL in two ways. One can implicitly incorporate the MOS by using conservative assumptions throughout the TMDL development process or one may explicitly allocate a portion of the TMDL as the MOS. An explicit margin of safety of 10% was used for this TMDL.

An explicit MOS was calculated by taking 10 percent of the concentrations as determined by multiplying the applicable water quality criteria (generated from the equations in Table 1.2 for dissolved Cu and Cd and the sampled hardness concentrations) and subtracting it from the criteria for each sample collected. This 10 percent amount is essentially reserved: it is not available for wasteload or load allocation and therefore makes the allocations smaller and thus, more protective. For example, if the calculated criterion for dissolved copper at a particular survey site is 10µg/L, then 10% or 1µg/L would be allocated to the MOS. Therefore, the wasteload and load allocation would have to equal 9µg/L (10µg/L minus 1µg/L).

5.6 Technical Analysis

The technical analysis for the metals used the data collected during the field investigation by RIDEM staff. Because the aquatic life criteria are required to be met under all flow conditions, wet and dry weather data were used to evaluate both the existing and allowable daily concentrations. The final analysis evaluated all samples together in determining the required reductions. The largest reduction from either the dry or wet weather analysis was used to set the required reduction for Buckeye Brook and the Tributaries to Warwick Pond.

This TMDL is evaluated under conditions that likely reflect worst-case (critical) conditions for both point and nonpoint source loadings (i.e. low flow and high flow conditions). Data were evaluated under both conditions to ensure that the final loading capacity is protective of water quality and will support all uses during critical conditions.

The total assimilative capacity, or loading capacity, is the maximum amount of pollutant that a waterbody can assimilate while maintaining water quality standards. The loading capacity is a function of different hydrodynamic processes that affect the environmental fate and transport of dissolved metals as they move through the system. For this TMDL the allowable load or loading capacity is expressed as a concentration set equal to the applicable state water quality standard for each dissolved metal. This concentration is considered to apply daily, in that daily values are used to compare against the acute and chronic criteria. The allowable daily load is the criteria concentration times the flow in the receiving water. For the purposes of implementation, it is recommended that the concentration and percent reduction dissolved metals TMDL targets be used.

The dissolved metals dataset used in this TMDL analysis contains a combination of data collected during base flow and high flow conditions. However, data characteristics such as overall quantity of samples and frequency of sample collection do not allow for direct comparison against either acute or chronic criteria. For acute criteria, EPA has established an averaging period of 1-hour and for chronic criteria, EPA has established an averaging period of 4 days.

5.7 Establishing the Allowable Loading (TMDL)

EPA guidelines specify that a TMDL identify the pollutant loading that a waterbody can assimilate per unit time without violating water quality standards, with loads expressed as mass per time, toxicity, or any other appropriate measure (40 CFR§130.2).

Trace metal reductions are unique in that the TMDL endpoints (acute and chronic criteria) must be met during a range of flows for a waterbody to maintain water quality standards and meet its designated uses. Consistent with EPA's Technical Support Document for Water Quality-based Toxics Control (1991), this dissolved metals TMDL was evaluated under both steady state and wet weather conditions.

5.8 Metals Evaluation

The samples for trace metals were collected under dry and wet weather conditions. The dry weather conditions are considered to be during the low flow, steady- state period that would be bounded by runoff events, including a four-day period of time. The wet weather surveys are considered to be a time when the flows in the stream system are the highest. The exception to this premise is during winter icing conditions when the flows in the stream system are at a reduced level, but still above the base flows observed during dry weather periods. The fourth survey on the Buckeye Brook stream system was conducted in icing conditions during a winter snow event in February 2011.

As shown in Table 5.1, the range of observed hardness values in the stream system was significant, with an observed low of 15mg/L at outfall station OF08 during the first wet survey,

to 98mg/L at Station TA01 during the first wet weather survey. To ensure the waterbodies are protected under all flow regimes, the observed hardness values associated with each sample collected for all surveys was used to determine the acute and chronic criteria for each sample. These values were then reduced by ten percent to provide the required margin of safety and then compared against the samples collected at each station with the lowest criteria used for the allowable concentration in the waterbody and compared against the observed concentrations in the river.

5.8.1 Dry Weather, Low Flow Analysis

The dissolved metals TMDLs are concentration-based. The more protective of the criterion is the chronic criteria, and the allowable level is determined by taking ninety percent of the lowest chronic criteria for a station. The existing concentration used was the maximum dry weather dissolved metal concentration during any dry weather survey. The allowable and existing concentrations under low flow conditions are expressed as follows and are shown in Table 5.2. Since iron has only a single chronic criteria limit which is set at 1000µg/L for any hardness value, the allowable limit for low or high flow is 900µg/L.

Allowable Dry Weather Concentration = Chronic Criteria Concentration in µg/L x 90%

Existing Dry Weather Concentration = Maximum Dry Weather Concentration in µg/L

The required concentration reductions are determined by subtracting the allowable concentration from the observed concentration. This reduction is expressed as a percent reduction and is determined by taking the required value and dividing it by the observed value and then multiplying the result by 100 to get the percentage reduction required.

Percent Reduction = (Observed Value-Allowable Value/ Observed Value) x 100

5.8.2 Dry Weather, Low Flow Reductions

No reductions are required for dissolved copper under low flow conditions at any station sampled in the Buckeye Brook Watershed. There were required reductions for dissolved Cadmium and Iron under low flow conditions and are shown in Table 5.3.

5.8.3 Wet Weather, High Flow Analysis

The first wet weather dataset contains samples collected before and during a rain event. Multiple samples were collected over a three-day period and approximately 24 hours apart.

The second wet weather dataset was collected during a winter storm where icing conditions occurred and samples were collected before, during and after the storm event, however, each sampling run was two days apart, covering eight days from the pre-storm samples to Run 3 samples eight days later. As further described below, individual data points were considered to be representative of concentrations in that waterbody for a period of one hour and compared against the acute criteria. Samples collected within four days of one another were averaged and compared against chronic criteria.

Table 5.2 Allowable Chronic Criteria and Observed Concentrations at Stations

Station	Cadmium (µg/L)			Copper (µg/L)			Iron (µg/L)		
	Criteria	Allowable	Observed	Criteria	Allowable	Observed	Criteria	Allowable	Observed
Tributaries to Warwick Pond (RI0007024R-05)									
BB00	0.15	0.14	**0.16**	4.09	3.68	2.10	1,000	900	732
BB02	0.13	0.12	0.11	4.18	3.76	1.19	1,000	900	824
Buckeye Brook (RI0007024R-01)									
BB03	0.15	0.14	**0.28**	4.70	4.23	2.35	1,000	900	186
TA01	0.23	0.21	**0.30**	8.26	7.43	1.40	1,000	900	**11,586**
OF08	0.15	0.14	**0.16**	4.95	4.46	0.67	1,000	900	**2,844**
AP01*	0.14	0.13	<0.06	4.35	3.92	1.08	1,000	900	**3,008**
BB04	0.18	0.16	**0.39**	6.28	5.65	5.73	1,000	900	**2,078**
BB05A	0.18	0.16	0.13	4.44	4.00	1.68	1,000	900	**1,439**

* AP01 is the combined stream flow from OF08 and TA01 and was only sampled during the second Dry weather survey

Table 5.3 Low Flow Required Reductions for Cadmium, Copper and Iron in Buckeye Brook

Station	Required Reduction (%)		
	Cadmium	Copper	Iron
Tributaries to Warwick Pond			
BB00	14.6%		
BB02			
Buckeye Brook			
BB03	53.2%		
TA01	30.9%		92.2%
OF08	14.6%		68.4%
AP01*			70.1%
BB04	57.8%		56.7%
BB05A			37.5%

Wet weather criteria were calculated using the observed hardness values from each sampling location with ninety percent of the calculated values used as the allowable concentration in the waterbody to provide the required margin of safety.

Acute Criteria Evaluation

Appendix B of the State's WQR states that "the one-hour average concentration of a pollutant should not exceed the acute criteria more than once every three years on the average". The available wet weather data do not lend themselves to a "one-hour" calculation of a mean that can be compared to the acute criteria, therefore each data value collected under high-flow conditions is considered to be representative of a concentration in that waterbody for a period of one hour. All data collected within the storm flow portion of the hydrograph is compared to the allowable acute criteria and the maximum value is considered to conservatively represent existing conditions.

If the acute criteria were exceeded once during a wet weather event then RIDEM considers it likely that the criteria would be exceeded again within a three-year period and therefore, the data would represent a violation of water quality standards. Under these assumptions, only one exceedance of the acute criteria during wet weather is needed in order to represent a violation of the acute criteria.

Chronic Criteria Evaluation

Appendix B of the State's WQR states that "the four-day average concentration of a pollutant should not exceed the chronic criteria more than once every three years on the average". It some cases, aquatic life may be exposed to wet weather-related pollutants for a long enough period of time (> 4 days) whereby chronic effects may be seen. A detailed analysis of both precipitation and flow records would be required to determine the exact conditions where this may occur. In addition, two key assumptions would need to be made in order for this analysis to be used in TMDL development. One key assumption is that point and nonpoint pollution sources are constant during the duration of elevated flows. This runs counter to the widely accepted concept of "first-flush", whereby the majority of pollutant load enters a waterbody during the rising limb of the hydrograph. The second key assumption is that reported daily precipitation values represent an actual intensity of rainfall that could produce runoff. In reality, a reported daily rainfall value may be spread out over a long enough period of time whereby surface runoff is minimal.

Given these restrictions, and in order to satisfy the four-day chronic requirement, RIDEM chose to average sampling results collected within four days of one another, and conservatively assume that these conditions represent a four-day average. For the first wet weather survey, since samples were collected over a three-day period, all results were averaged and compared against the chronic criteria. To evaluate the second wet event against the chronic criteria, RIDEM averaged samples from the following runs; Pre-storm and Run 1, Run 1 and Run 2, and Run 2 and Run 3. The average hardness was used to calculate criteria and then compared against the averaged observed value for each station.

5.8.4 Wet Weather, High Flow Reductions

The acute and chronic criteria for cadmium and copper were calculated for each water quality station for both wet weather events. The acute criteria were calculated using the hardness values from each station for each run for both wet weather events. The chronic criteria for wet weather one were calculated using the averaged hardness values for all runs from each station. Wet weather survey two covered a span of eight days so to get a four-day average for the chronic criteria, the hardness values from two runs were averaged for each station and the criteria was calculated using the average value. This resulted in the average hardness values from the Pre-storm Run plus Run 1, Run 1 plus Run 2, and Run 2 plus Run 3 to be used to calculate chronic criteria. The chronic criterion for iron is not hardness dependent but is a constant value of 1,000µg/L for all surveys.

Once the criteria are calculated, a ten percent reduction was subtracted to get the allowable criteria for each station and run. Iron allowable criterion is the same for all flow conditions and set to 900µg/L.

The observed values for high flow conditions are evaluated against the allowable concentrations as follows:

Maximum high flow concentration compared to the allowable acute criteria
Average high flow concentrations compared to the allowable chronic criteria.

5.8.5 Final Reductions

Once the comparison of the allowable criteria to the observed values for each metal is done, the percent reduction is determined. To determine the final, require reductions for the Buckeye Brook TMDL, the reduction percentages from low flow, dry weather and high flow, wet weather surveys are compared and the maximum percent reduction from the surveys for each waterbody segment are used for the final required reductions for trace metals in the two watersheds. These final reduction percentages are show in Table 5.4 below for the waterbody segments above and below Warwick Pond as well as the reductions required from the tributaries to Buckeye Brook that flow from Truk-Away landfill and the airport property.

All dry and wet weather tables used for calculating the trace metal percent reductions for both watersheds can be found in Appendix B.

Table 5.4 High Flow, Wet Weather Percent Reductions for Buckeye Brook Watershed

Station	Cadmium (%)				Copper (%)				Iron (%)	
	WW1		WW2		WW1		WW2		WW1	WW2
	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Chronic	
Tributaries to Warwick Pond (RI0007024R-05)										
BB00		48.6%		37.2%						44.7%
BB02		***58.7%***		20.9%				***18.7%***	32.2%	***53.6%***
Buckeye Brook (RI0007024R-01)										
BB03		11.0%								13.4%
TA01		34.8%							***93.7%***	87.2%
OF08		53.9%		***63.7%***	***52.5%***	6.8%	39.4%	47.4%	66.7%	71.9%
BB04									69.3%	64.0%
BB05A		53.8%		16.0%			13.2%	18.6%	40.3%	17.4%

Final Reductions shown in ***bold italics***.

5.9 Wasteload and Load Allocations

A TMDL is the combination of a total wasteload allocation (WLA) that allocates loadings for point sources, a total load allocation (LA) that allocates loadings for nonpoint sources and background sources and a Margin of Safety (MOS). In TMDL development, allowable WLA and LA from pollutant sources that cumulatively amount to no more than the TMDL must be

established; this provides the basis to establish water quality-based controls. TMDLs can be expressed on a mass loading basis or as a concentration in accordance with provisions in federal regulations [40 CFR 130.2(1)]. This TMDL and consequently the WLAs and LAs are expressed as concentration targets and the percent reductions required to meet standards.

The LAs are assigned to nonpoint sources and natural background sources in the watershed. These sources include air deposition of metals and groundwater contributions and may or may not include anthropogenic sources. Since it is not possible to separate out the load allocation, it is included in the WLA and the MOS is implicit, therefore the TMDL equals the WLA.

The Tributaries to Warwick Pond are characterized by stations BB00 and BB02.This segment of the watershed requires a cadmium reduction of 59%, a copper reduction of 19% and an iron reduction of 54%. The Tributaries to Warwick Pond watershed has two large outfalls (outfall 002 and 003) from the cargo and maintenance areas of the airport that discharge upstream of station BB02 that routinely contain high concentrations of iron in their flows (as evident from outfall monitoring by RIAC). Runoff from the industrial park that borders the area between BB00 and BB02 as well as the runoff from non-airport roadways, buildings and parking lots are also potential sources of copper and cadmium.

The main stem of Buckeye Brook is characterized by stations BB03, BB04, and BB05A, and the tributary channels are characterized by stations TA01, outfall OF08, and AP01). This segment requires a cadmium reduction of 64%, a copper reduction of 53% and an iron reduction of 94%. The Buckeye Brook watershed is home to the Truk-Away landfill that when sampled, the channel had concentrations for cadmium and iron that exceeded the state's freshwater chronic criteria by 35% and 94% respectively during wet weather events. The channel that receives the largest discharge of stormwater from T.F. Green airport also had exceedances of the criteria for cadmium and iron during wet weather surveys conducted by RIDEM staff. The Buckeye Brook and Tributaries to Warwick Pond watersheds are highly urbanized and contain dense residential neighborhoods and commercial development in addition to the airport. Stormwater discharges from these highly developed watersheds must be addressed to mitigate the observed water quality and habitat impacts in Buckeye Brook and the Tributaries to Warwick Pond.

Contaminated groundwater is another source as evidenced by dry weather results of samples collected in the channel downstream of the airport's largest outfall (008), and in the channel that is downgradient of Truck-Away Landfill that exhibited exceedances of both iron and cadmium criteria. Precipitation that percolates though contaminated soils can transport pollutants to the groundwater table which in turn may seep directly into streams (as is the case with the landfill) or into storm water systems via underdrains and/or cracks in pipes and discharge to nearby streams. Under dry weather conditions, groundwater flows may not be enough to flush the pollutants from the storm drain network. However, when wet weather events occur, the higher storm flows flush any accumulated contaminants out of the drainage system and into stream systems or nearby waterbodies. For these reasons, RIDEM expects the iron and cadmium contaminated groundwater to be contributing to both dry weather and wet weather impacts.

Contaminated groundwater from Truk-Away Landfill and TF Green Airport must be addressed to mitigate the observed water quality and habitat impacts in Buckeye Brook and the Tributaries to Warwick Pond

5.10 Strengths and Weaknesses in the Technical Approach

Strengths

- The TMDL is based on extensive data and knowledge of the area.
- The TMDL incorporates the finding of 4 field surveys conducted under both dry and wet conditions.
- The TMDL is based on actual data collected by RIDEM staff
- Following a weight of evidence approach to analyzing stressors finds that conditions associated with elevated metals concentrations (Fe, Cd, Cu), dense growth of iron fixing bacteria, and dissolved oxygen sags contribute to the observed benthic macroinvertebrate impairments.

Weaknesses

- The area is complex due to the characteristics of the watershed.
- Loadings could not be calculated because flow data was not collected.
- Additional site-specific information is required for identification and specification of BMPs to achieve TMDL targets.

6.0 IMPLEMENTATION

Efforts to implement this TMDL must ensure that Buckeye Brook and the Tributaries to Warwick Pond meet water quality criteria for iron, copper, cadmium, dissolved oxygen, and narrative criteria for protection of aquatic life. Compliance with the TMDL will be accomplished by ensuring that all point source discharges (stormwater) and nonpoint sources meet the wasteload allocations for metals set forth in section 5.0 of this report.

Implementation activities must focus on mitigating contaminated groundwater from TF Green Airport, leachate from the Truk-Away landfill, and managing stormwater to reduce runoff volumes and metals concentrations throughout the watersheds. These efforts combined with actions implemented by RIAC to control the discharge of propylene glycol and actions to mitigate the uncontrolled stormwater discharges from the Rhode Island Department of Transportation and the City of Warwick as required by the Buckeye Brook Bacteria TMDL will lead to improvements in these streams' aquatic life as measured by benthic macroinvertebrate bioassessments. Both RIDOT and the City are required to undertake structural improvements to eliminate or treat impervious cover to act as if it were eliminated to achieve a 10% impervious cover.

6.1 Stormwater Runoff

The study area is highly impervious and contains a mix of urban and mixed rural areas. Work done by the Center for Watershed Protection (www.cwp.org) has shown that several stream quality indicators decrease as impervious cover (IC) percentages increase, as shown in Figure 2.1 (Schueler, 2003). The trend becomes more pronounced within the 10-25% IC range, and impairment is almost inevitable when the watershed IC exceeds 25%.

Results from this TMDL's investigations corroborate these findings. Results of macroinvertebrate sampling conducted as part of these investigations, presented in Table 3.12, show that the Tributaries to Warwick Pond and Buckeye Brook are moderately to severely impaired for aquatic life use. Table 3.2 presents the results from the analysis of the land use within these watersheds with the IC for the Tributaries to Warwick Pond averaging 45% while Buckeye Brook watershed is 41% IC.

Available literature (EPA/ENSR, 2005) suggests that stormwater management plans for these watersheds should establish a goal of achieving an effective impervious cover of 10% to reduce stormwater-associated pollutants, along with the other stressors to aquatic life such as channel scour and loss of pool/riffle habitat. Consistent with this literature finding, consent decrees established by EPA and RIDEM require that RIDOT and City of Warwick respectively apply the Impervious Cover Standard to manage stormwater to achieve Buckeye Brook Bacteria TMDL requirements. The concept behind the approach is that it is desirable for a watershed to be similar, in terms of water quality effects, to a watershed with 10% or less impervious cover overall. Accordingly, the amount of impervious cover that would need to be eliminated or

treated to act as if it were eliminated to reach the 10% target is calculated. The target impervious cover condition represents the condition in which all these stressors are reduced to levels compatible with attainment of the aquatic life criteria as indicated by benthic macroinvertebrate metrics. No separate impervious cover targets are established by this TMDL.

When possible, efforts by the city, land trusts and others to preserve open space should continue. As land is developed, it is critical that significant natural hydrologic features be protected to maintain the area's unique characteristics and to prevent further degradation of water quality – as can be achieved through use of conservation development and LID techniques. Redevelopment projects represent opportunities to reduce the water quality impacts from the watershed's urbanized land uses by reducing impervious cover and/or attenuating runoff on-site. As described below, municipal ordinances must be reviewed and revised to make sure that future development projects do not add to water quality problems and that redevelopment projects reduce contributions to the water quality problems in either watershed.

In 2007, Rhode Island adopted the Smart Development for a Cleaner Bay Act (General Laws Chapter 45-61.2), requiring RIDEM and CRMC to update the Rhode Island Stormwater Design and Installations Manual to: maintain groundwater recharge at pre-development levels, maintain post-development peak discharge rates to not exceed pre-development rates, and use low impact development techniques as the primary method of stormwater control to the maximum extent practicable. The revised manual, adopted January 2011, provides twelve minimum standards addressing LID Site Planning and Design Strategies, Groundwater Recharge, Water Quality, Redevelopment Projects, Pollution Prevention, Illicit Discharges, and Stormwater Management System Operation and Maintenance, among other concerns. This revised manual (March 2015) provides appropriate guidance for stormwater management on new development and redevelopment projects and, most importantly, incorporates LID as the "industry standard" for all sites, representing a fundamental shift in how development projects are planned and designed. The revised stormwater manual is available on-line at:
www.dem.ri.gov/programs/water/permits/ripdes/stormwater/stormwater-manual.php

A companion manual on LID site planning and design has also been prepared by RIDEM to provide Rhode Island-specific guidance regarding the site planning, design, and development strategies that communities should adopt to encourage low impact development. This manual is also available on-line at the above link. Rhode Island joins a growing number of states and localities including the Puget Sound area that rely heavily on LID techniques to protect and restore their waters. (www.psp.wa.gov/downloads/LID/20121221_LIDmanual_FINAL_secure.pdf)

Achieving water quality standards requires that both the *quantity* of stormwater and the pollutant concentrations in that storm water reaching waterbodies be reduced. Best Management Practices (BMPs) are effective, practical, structural, or non-structural methods which prevent or reduce the movement of pollutants from the land to surface or ground water. BMPs are designed to protect water quality and to prevent new pollution.

Structural BMPs are engineered constructed systems that can be designed to provide water quality and/or water quantity control benefits. The Rhode Island Stormwater Design and Installation Standards Manual (December 2010) contains detailed specifications for the design of these BMPs that can be used to meet water quality objectives. Common structural BMPs include the following:

Green Infrastructure systems: designed to treat runoff through vegetative uptake and filtration through soils (examples include bioretention cells, bioswales, and tree filters);
Infiltration systems: designed to capture stormwater runoff, retain it, and encourage infiltration into the ground;
Detention systems: designed to temporarily store runoff and release it at a gradual and controlled rate (considered acceptable for flood control only);
Retention systems: designed to capture a volume of runoff and retain that volume until it is displaced in part or whole by the next runoff event (considered acceptable for flood control only);
Wet vegetated treatment systems: designed to provide both water quality and water quantity control; and
Filtration systems: designed to remove particulate pollutants found in stormwater runoff through the use of media such as sand, gravel or peat.

Non-structural BMPs are a broad group of practices designed to prevent pollution through maintenance and management measures. They are typically related to the improvement of operational techniques or the performance of necessary stewardship tasks that are of an ongoing nature. These pollution-prevention practices are designed to control pollutants at their source and to prevent pollutants from entering stormwater runoff. Non-structural measures can be very effective at controlling pollution generation at the source, thereby reducing the need for costly "end-of-pipe" treatment by structural BMPs. Examples of non-structural BMPs include maintenance practices to help reduce pollutant contributions from various land uses and human operations, such as street sweeping, road and ditch maintenance, or specifications regarding how and when to spread manure or sludge.

Structural and non-structural BMPs are often used together. Effective pollution management is best achieved from a management systems approach, as opposed to an approach that focuses on individual practices. Some individual practices may not be very effective alone, but in combination with others, may be more successful in preventing water pollution.

6.1.1 RIPDES Phase II Stormwater Management Programs – SWMPPs and Six Minimum Measures

Stormwater runoff is most often carried to waterways by publicly owned drainage networks. Historically, storm drain networks were designed to carry stormwater away from roadways and other developed land as quickly as possible to prevent flooding with little to no treatment of

pollutants. In 1999, EPA finalized its Stormwater Phase II rule, which required the operators of small municipal separate storm sewer systems (MS4s) to obtain permits and to implement a stormwater management program to control polluted discharges that is based on six minimum measures. Operators develop Stormwater Management Program Plans (SWMPPs) that detail how their stormwater management programs comply with the Phase II regulations. SWMPPs describe BMPs for the six minimum measures, including measurable goals and schedules. The implementation schedules include interim milestones, frequency of activities, and result reporting. Plans also include any additional requirements that are mandated for stormwater that discharges to impaired waters.

In Rhode Island, the RIDEM RIPDES Program administers the Phase II program using a General Permit that was established in 2003 (RIDEM, 2003a). The Cities of Warwick and the Rhode Island Department of Transportation (RIDOT) are regulated under the Phase II program.

The six minimum measures are listed below.

- A public education and outreach program to inform the public about the impacts of stormwater on surface water bodies.
- A public involvement/participation program.
- An illicit discharge detection and elimination program.
- A construction site stormwater runoff control program for sites disturbing 1 or more acres.
- A post construction stormwater runoff control program for new development and redevelopment sites disturbing 1 or more acres.
- A municipal pollution prevention/good housekeeping operation and maintenance program.

In general, municipalities and RIDOT were automatically designated as part of the Phase II program if they were located either completely or partially within census-designated urbanized or densely populated area. The City of Warwick is a densely populated municipality with greater than 80,000 residents with a density of approximately 2300 people per square mile. Both Warwick and RIDOT have submitted the required Stormwater Management Program Plans (SWMPPs) for those areas of the study that are located within the densely populated areas.

6.1.2 Required SWMPP Amendments to TMDL Provisions

In Rhode Island, Part IV.D of the Phase II General Permit requires MS4 operators to address TMDL provisions in their SWMPP if the approved TMDL identifies stormwater discharges that directly or indirectly contain the pollutant(s) of concern (Part II.C3). Operators must comply with Phase II TMDL requirements if they contribute stormwater to priority outfalls via system interconnections, even if they do not own the outfall. Operators must identify amendments needed to their current SWMPP to comply with TMDL requirements. To avoid confusion and to better track progress, the SWMPP amendments should be addressed in a separate TMDL Implementation Plan (TMDL IP).

It is common for state-owned and municipal-owned storm drains to interconnect. RIDEM encourages cooperation between the city and RIDOT when developing and implementing the six minimum measures and in conducting feasibility analyses and determining suitable locations for the construction of BMPs. An important first step in implementing this TMDL is to confirm the ownership of the priority outfalls for the affected watersheds. The Buckeye Brook Pathogen TMDL (December 2008) listed a number of priority outfalls for Buckeye Brook, which should have been investigated by the city to determine if there were any interconnections of the storm drain system. The list is a good starting point to help identify additional outfalls that may be contributing to the biodiversity impairments for the stream systems in this study.

6.1.3 TMDL Implementation Plan (IP) Requirements

The TMDL IP must address all parts of the watershed that discharge to the impaired water and all impacts identified in the TMDL. The TMDL IP must describe the six minimum measures and other additional controls that are or will be implemented to address the TMDL pollutants of concern. The operators must provide measurable goals for the development and/or implementation of the six minimum measures and additional structural and non-structural BMPs that will be necessary to address provisions for the control of storm water identified in this TMDL including an implementation schedule, which includes all major milestone deadlines including the start and finish calendar dates, the estimated costs and proposed or actual funding sources, and the anticipated improvement(s) to water quality. If no structural BMPs are recommended, the operator must evaluate whether the six minimum measures alone (including any revisions to ordinances) are sufficient to meet the TMDL's goals. As mentioned previously, these requirements apply to any operators of MS4s contributing stormwater to specifically identified outfalls, regardless of outfall ownership.

The TMDL IP must specifically address the following requirements that are described in Part IV.D of the RIPDES Stormwater General Permit (RIDEM, 2003a).

1. Determine the land areas contributing to the discharges identified in TMDL using sub-watershed boundaries as determined from USGS topographic maps or other appropriate means.
2. Address all contributing areas and the impacts identified by the Department.
3. Assess the six-minimum control measure BMPs and additional controls currently being implemented or that will be implemented to address the TMDL provisions and pollutants of concern and describe the rationale for the selection of controls including the location of the discharge(s), receiving waters, water quality classification, and other relevant information.
4. Identify and provide tabular description of the discharges identified in the TMDL including:
    a. Location of discharge (latitude/longitude and street or another landmark).
    b. Size and type of conveyance (e.g. 15" diameter concrete pipe).
    c. Existing discharge data (flow data and water quality monitoring data).
    d. Impairment of concern and any suspected sources(s).

e. Interconnections with other MS4s within the system.
f. TMDL provisions specific to the discharge.
g. Any additional outfall/drainage specific BMP(s) that have or will be implemented to address TMDL provisions.
h. Schedule for construction of structural BMPs including those for which a Scope of Work is to be prepared, as described below.

5. If the TMDL does not recommend structural BMPs, the TMDL IP must evaluate whether the six minimum measures alone (including any revisions to ordinances) are sufficient to meet the TMDL's goals. The TMDL IP should describe the rationale used to select BMPs.
6. This TMDL has determined that structural BMPs are necessary in the watersheds of both the Tributaries to Warwick Pond and Buckeye Brook and the TMDL IP must describe the tasks necessary to design and construct BMPs that reduce pollutants of concern (Cd, Cu, Fe) and stormwater volumes to the *maximum extent feasible,* and otherwise manage runoff towards a watershed target of 10% impervious cover. The TMDL IP must describe the process and the rationale that will be used to select structural BMPs (or LID retrofits) and measurable goals to ensure that the TMDL provisions will be met. In a phased approach, operators must identify any additional outfalls that may contribute the greatest pollutant load and prioritize these for BMP construction. Referred to as a Scope of Work in the current permit, this structural BMP component of the TMDL IP must also include a schedule and cost estimates for the completion of the following tasks:

    a. Prioritization of drainage systems where BMPs are necessary. If not specified in TMDL, priority can be assessed using relative contribution of the pollutant of concern, percent effective impervious area, or pollutant loads as drainage area, pipe size, land use, etc. A targeted approach to construct stormwater retrofit BMPs at state and locally owned stormwater outfalls is recommended.
    b. Delineation of the drainage or catchment area.
    c. Determination of interconnections within the system and the approximate percentage of contributing area served by each operator's drainage system, as well as a description of efforts to cooperate with owners of the interconnected system.
    d. Completion of catchment area feasibility analyses to determine drainage flow patterns (surface runoff and pipe connectivity), groundwater recharge potentials(s), upland and end-of-pipe locations suitable for siting BMPs throughout the catchment area, appropriate structural BMPs that address the pollutants of concern, any environmental (severe slopes, soils, infiltration rates, depth to groundwater, wetlands or other sensitive resources, bedrock) and other siting (e.g. utilities, water supply wells, etc.) constraints, permitting requirements or restrictions, potential costs, preliminary and final engineering requirements.
    e. Design and construction of structural BMPs.
    f. Identification and assessment of all remaining discharges not identified in the TMDL owned by the operator contributing to the impaired waters addressed by the TMDL taking into consideration the factors discussed above.

7. This TMDL has determined that structural BMPs are necessary, but has not identified or prioritized outfalls/drainage systems for BMP construction. The TMDL IP must first identify and assess outfalls owned by the operator discharging directly to the impaired waterbody. The operator must then complete all tasks described in section f above.

In summary, the SWMPPs must be revised to describe the six minimum measures and other additional controls that are or will be implemented to address the TMDL pollutants of concern. The operators must provide measurable goals for the development and/or implementation of the six minimum measures and additional structural and non-structural BMPs that will be necessary to address provisions for the control of storm water identified in this TMDL including an implementation schedule, which includes all major milestone deadlines including the start and finish calendar dates, the estimated costs and proposed or actual funding sources, and the anticipated improvement(s) to water quality. If no structural BMPs are recommended, the operator must evaluate whether the six minimum measures alone (including any revisions to ordinances) are sufficient to meet the TMDL's goals.

6.2 Modifications to Six Minimum Measures

As described previously, MS4 operators must assess the six-minimum control measure BMPs included in their SWMPPs for compliance with this TMDL plan's provisions and provide measurable goals in the TMDL IP for any needed amendments. The operator must also describe the rationale for the selection of controls including the location of the discharge(s), receiving waters, water quality classification, and other relevant information (General Permit Part IV.D.3.c). The following sections outline activities that the city and RIDOT should or must implement and/or consider when modifying their six minimum measures.

6.2.1 Public Education/Public Involvement

The public education program must focus on both water quality and water quantity concerns associated with stormwater discharges within the watershed. Public education material should target the audience being addressed, while public involvement programs should actively involve the community in addressing stormwater concerns.

An educational campaign targeted to residential land uses should include activities that residents can take to minimize water quality and water quantity impacts. Reducing trace metals can include measures that can reduce the quantity of water that runs off during a wet weather event can aid in preventing these pollutants from reaching impaired waterbodies. These include decreasing effective impervious area and by providing on-site attenuation of runoff. Roof runoff can be infiltrated using green roofs, dry wells, or by redirecting roof drains to lawns and forested areas. Reducing land runoff can be accomplished by grading the site to minimize runoff and to promote storm water attenuation and infiltration, creating rain gardens, and reducing paved areas such as driveways. Driveways can be made of porous materials such as crushed shells, stone, or porous pavement. Buffer strips and swales that add filtering capacity through vegetation can

also slow runoff. Properties adjacent to connected streams and wetland areas should establish and maintain natural buffers, planted with native plants, shrubs and/or trees to minimize impacts of development and restore valuable habitat.

Other audiences include commercial, industrial, and institutional property owners, land developers, and landscapers. In addition to the activities discussed above for residential land use, educational programs for these audiences could discuss BMPs that should be used when redeveloping or re-paving a site to minimize runoff and promote infiltration. Measures such as minimizing road widths, installing porous pavement, infiltrating catch basins, breaking up large tracts/areas of impervious surfaces, sloping surfaces towards vegetated areas, and incorporating buffer strips and swales should be used where possible. Section 6.2 discusses changes to the RI Stormwater Design and Installation Standards Manual (RIDEM and CRMC, 2010) that promote these measures using low impact development (LID) techniques.

The University of Rhode Island Cooperative Extension's Storm Water Phase II Public Outreach and Education Project provides participating MS4s with education and outreach programs that can be used to address TMDL public education recommendations. This project is funded by RIDOT and has many partners, including RIDEM. More information may be found on the URI website http://www.ristormwatersolutions.org/.

In addition to the more generalized outreach and education efforts described above, MS4 operators are required to provide public education materials to the highly impervious industrial, commercial, and institutional property owners informing them of good housekeeping and pollution prevention techniques, and other practices to reduce runoff volumes.

6.2.2 Construction/Post Construction

MS4 operators are required to establish post construction storm water runoff control programs for new land development and redevelopment at sites disturbing *one or more acres*. Land development and re-development projects must utilize best management practices if the waterbodies in this TMDL are to be successfully restored. Consistent with the revised RI Stormwater Design and Installation Manual (RIDEM and CRMC, 2010), local ordinances meant to comply with the post construction minimum measures (General Permit Part IV.B.5.a.2.) must require that applicable development and re-development projects use Low Impact Development (LID) techniques as the primary method of stormwater control to the maximum extent practicable and maintain groundwater recharge to predevelopment levels.

New land development projects must employ stormwater controls to prevent any net increase in runoff volume and metals to the impaired waterbodies in the Tributaries to Warwick Pond and Buckeye Brook Watersheds, specifically for cadmium, copper, and iron.

As mentioned previously, examples of acceptable reduction measures include reducing impervious surfaces, sloping impervious surfaces to drain towards vegetated areas, using porous pavement, and installing infiltration catch basins where feasible. Other reduction measures to

consider are the establishment of buffer zones, vegetated drainage ways, cluster zoning or low impact development, transfer of development rights, and overlay districts for sensitive areas. The revised RI Stormwater Design and Installation Standards Manual (RIDEM and CRMC, 2010) contains detailed information on use of low impact development (LID) techniques.

6.2.3 Good Housekeeping/ Pollution Prevention

The Storm Water General Permit (see Part IV.B.6.a.2 and Part IV.B.6.b.1) extends storm water volume reduction requirements to operator-owned facilities and infrastructure. Similarly, municipal and state facilities could incorporate measures such as reducing impervious surfaces, sloping impervious surfaces to drain towards vegetated areas, incorporating buffer strips and swales, using porous pavement and infiltration catch basins where feasible. In addition, any new municipal construction project or retrofit should incorporate BMPs that reduce storm water and promote infiltration such as the before-mentioned measures.

The TMDL Implementation Plan should provide a list of municipally owned properties and any BMPs that may have been implemented to date, and/or where opportunities exist for future implementation. As part of their Good Housekeeping/Pollution Prevention requirements, municipal MS4 operators and RIDOT must investigate the feasibility of increased street sweeping and/or stormwater system maintenance to address loads of copper, cadmium and iron to the stream systems. At least one street sweeping and storm drain cleaning should be conducted in the spring when the last reasonable chance of snowfall has past.

6.2.4 Structural BMP Requirements in Rhode Island

As described previously, this TMDL finds that the six minimum measures alone are insufficient to restore water quality and that structural BMPs are needed. MS4 owners must identify priority outfalls as discussed above in section 6.1.3. As described in detail in section 6.1.3, an Implementation Plan must be completed that details the tasks necessary to design and construct BMPs that reduce the pollutants of concern and stormwater volumes to the maximum extent feasible. As noted previously, TMDL provisions apply to any MS4 operators contributing stormwater to identified outfalls regardless of outfall ownership. The BMP study should include all the components of Part IV.D.4 (RIDEM, 2003b) that were previously described in the TMDL IP section. It must evaluate the feasibility of distributing infiltration or equivalent BMPs throughout the drainage area of the priority outfalls as an alternative to end of pipe technologies since the amount of land available for BMP construction is limited.

6.3 MS4 Operator Specific Stormwater Measures

City of Warwick

The City of Warwick (Permit RIR40031) is authorized to discharge stormwater under the General Permit listed above. Upon notification by RIDEM of the US Environmental Protection Agency's approval of this TMDL, the city will have 180 days to amend its SWMPP consistent with Part IV.D of the General Permit. The City of Warwick must evaluate the sufficiency of its six minimum measures to meet the TMDL water quality objectives as outlined in Section 6.2 and at a minimum must modify its ordinances related to post construction stormwater controls to prevent further degradation of these impaired waters, as detailed in Section 6.2.2. In addition, the City of Warwick must also assess and prioritize drainage systems for the design and construction of BMPs that reduce the pollutants of concern and stormwater volumes to the *maximum extent feasible* as detailed in Section 6.1.3. The evaluation of six minimum measures, all modifications and proposed BMPs must be documented in the TMDL Implementation Plan along with a schedule for implementation.

RIDOT

RIDOT is authorized to discharge stormwater under the RIPDES Phase II Stormwater General Permit (Permit RIR040036). Upon notification by RIDEM of the US Environmental Protection Agency's approval of this TMDL, RIDOT will have 180 days to amend their SWMPP consistent with Part IV.D of the General Permit. In addition to the modifications to the six minimum measures described in Section 6.2, RIDOT must also assess and prioritize drainage systems for the design and construction of BMPs that reduce the pollutants of concern and stormwater volumes to the *maximum extent feasible* as detailed in Section 6.1.3. The evaluation of six minimum measures, all modifications and proposed BMPs must be documented in the TMDL Implementation Plan along with a schedule for implementation.

6.4 Stormwater from Industrial Activities

6.4.1 Industrial Activities covered by Individual Permits

The Rhode Island Airport Corporation (RIAC) has applied for and obtained an individual permit (RI0021598) to discharge stormwater to the Tributaries to Warwick Pond and to Buckeye Brook. It is the only facility covered by an individual permit that discharges to the receiving waters addressed by this TMDL. The permit requires the implementation of the permittee's existing Storm Water Pollution Prevention Plan (SWPPP) as of the effective date of the permit. The permit establishes a schedule that requires the permittee to amend the SWPPP to include additional BMPs as specified in the permit. The goal of the SWPPP is to help identify the source of pollutants in the discharge of storm water and to ensure practices are being implemented to minimize pollutants associated with industrial activities from entering any storm water discharge.

This Plan emphasizes the use of Best Management Practices (BMPs) to provide the flexibility to address different sources of pollutants.

The SWPPP includes required elements and BMPs to mitigate the impacts of the following: aircraft, vehicle, and equipment maintenance, aircraft and pavement deicing/anti-icing fueling and washing, aircraft lavatory service, illicit discharge detection and elimination, pesticide management, building and grounds maintenance, chemical and fuel handling and storage, materials handling, stormwater pollution prevention education, outdoor area and floor wash-down, and water quality monitoring.

A revised RIPDES Stormwater permit went into effect for T.F. Green Airport on September 1, 2012[1] that required RIAC to develop and implement BMPs to promote source reduction and pollution prevention that will be protective of water quality standards and criteria in receiving waters to include dissolved oxygen, aquatic toxicity, foaming, nuisance odors and nuisance bacteria growth. The long-term deicing management system became operational in October 2014. It is constructed and sized to collect greater than 99% of all flows above the glycol diversion concentrations of 2,950 mg/L for the terminal area and 1,000 mg/L for the cargo area. Glycol is collected in two enclosed storage tanks, treated on-site, and later discharged to the Warwick Sewer Authority sanitary sewer system. Glycol impacted snow is also collected and snow-melt diverted to storage at concentrations above 2,950 mg/L for the terminal area and 1,000 mg/L at the cargo pad. These snow piles are melted with a snow melter and discharged to the collection system, and on-site monitoring of the major outfalls that discharge to Buckeye Brook are to be monitored quarterly.

Major components of the improved Deicer Management System include the following:

- Terminal pump station
- Terminal online monitoring system
- Force main from terminal pump station to storage tanks
- Cargo pump station
- Cargo online monitoring system
- Force main from cargo pump station to storage tanks
- Portable snow melter
- Two above ground storage tanks
- Biological treatment system
- Force main from treatment to sanitary sewer

The 2012 RIPDES permit fact sheet (RI0021598) for T.F. Green Airport states that during 1999-2001 when RIAC first evaluated the airport's impact on instream dissolved oxygen levels, the annual efficiency for glycol collection was 18 to 28 percent. Since that time, the airport has implemented best management practices and improved collection efficiencies such that the

[1] The permit is available on RIDEM's website at http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/pdfs/tfgreenfinal.pdf

annual 2010-2011 collection efficiency averaged 44 percent, with a 50 percent average for the February 2011 winter monitoring event. With construction of the glycol treatment and diversion structures that went online in October 2014, the collection efficiency is expected to increase such that RIDEM believes that this will be sufficient to avoid future violations of the in-stream dissolved oxygen criteria due to propylene glycol discharges.

The permit also requires the airport to conduct instream water quality monitoring at four locations on the main stem of Buckeye Brook in order to evaluate storm water impacts to the brook. The monitoring is to be conducted during a frozen precipitation event (i.e. snow, sleet, freezing rain) during the deicing season (October 1 – March 31) at the T.F. Green Airport while aircraft deicing is occurring and must be coordinated with storm water outfall sampling.

A review of the monitoring reports required by the permit from the 2012 through the 2017 deicing seasons shows that the deicing management system that became operational at T.F. Green Airport in October 2014 has markedly improved the propylene glycol collection efficiencies and reduced propylene glycol concentrations in stormwater. Monitoring of deicing events for the 2014-2015 through 2016-2017 seasons after the facility became operational finds an average propylene glycol collection efficiency of 65%. These results show a marked improvement from propylene glycol collection efficiencies reported prior to the facility becoming operational which averaged 39% for the 2011-2012 through 2013-2014 seasons. It also compares favorably with the expected collection efficiency of 60% reported in the 2012 RIPDES Permit Fact Sheet. Concentrations of propylene glycol in stormwater discharged from the airport's outfalls reflect improvements made to their deicing management system. Comparing outfall monitoring results from pre- and post- facility operations finds Outfalls 002 and 003 which discharge to Tributaries to Warwick Pond had an average decrease of propylene glycol concentrations of 69%, whereas Outfall 008 had a 97% reduction.

Comparing stream monitoring results for the same periods finds propylene glycol concentrations to have decreased 100% from an average of 14 mg/L before the facility was operational to below detection (<10 mg/L) for deicing events after the facility was operational. In-stream concentrations of COD and BOD for the same period finds average decreases of 77% and 82%, respectively. Consistent with the 2012 RIPDES Permit Fact Sheet's determination that the proposed glycol propylene controls required by the permit would prevent violations of in-stream DO criteria, no violations of either the instantaneous (> 5 mg/l) or percent saturation (> 60%) DO criteria were observed. Appendix C contains the results of deicing event monitoring of the outfalls and stream stations as well as the propylene glycol collection efficiencies.

Section 4.3 referenced a RIAC contracted study that showed high levels of iron and iron bacteria were present in the outfalls that discharge to the Tributary to Warwick Pond and Buckeye Brook. The high iron levels are present in the dry weather flows as well and that the seepage of iron rich groundwater into these storm drainage systems is the source of contamination. As previously documented, iron and cadmium concentrations in the channel receiving the discharge from Outfall 008 exceed ambient water quality criteria. Review of data from 2012 to 2017 collected

by RIAC as required by their RIPDES permit show that Outfalls 002A, 003A and 008A continue to exceed the freshwater criteria for iron and copper (no cadmium data are collected). This TMDL finds that dry and wet weather discharges of iron and cadmium and wet weather discharges of copper must be reduced in order to address water quality and habitat impairments in the Tributary to Warwick Pond and that portion of Buckeye Brook that receives discharges from Outfall 008. It is noted that iron contaminated groundwater is thought to be contributing to elevated levels of iron in both wet and dry weather flows.

The field investigation by the ESS Group (Buckeye Brook Biodiversity Impairment Data Report, 2008, ESS Group. Inc., April 2009) found that smothering of habitat by iron flocculent material was noted within each of the tributaries originating from the airport and/or landfill. Examination of the macroinvertebrates at Stations BB04 and BB02 also showed evidence of impact from the iron flocculent. In excess, this material can smother coarse substrates and clog interstitial areas used as refuge by macroinvertebrates. The report found that the impairment was most readily detected in the biological communities at BB02, BB04, and TA01. It concluded that some degree of improvement could be achieved by addressing the leachate issues at the landfill and through implementation of new aircraft/airfield source water contamination prevention measures at the airport.

RIDEM Office of Water Resources is currently working to re-issue RIAC's RIPDES permit which expired in September 2017. The revised permit will incorporate requirements to address dry and wet weather discharges of the pollutants of concern identified in this TMDL (Cd, Cu, Fe) from outfalls that discharge to Tributaries to Warwick Pond and Buckeye Brook and to otherwise manage stormwater to reduce runoff volumes consistent with requirements established for MS4 operators.

6.4.2 Industrial Activities covered by the Statewide Multi-Sector General Permit

The TMDL has shown that stormwater is a major source contributing to the impairments to the watershed. Stormwater discharges from industrial activities may be discharged to these waters directly or via the MS4s and may contain metals that contribute to these impairments. Stormwater discharges from facilities that discharge "stormwater associated with industrial activity" are regulated under the statewide general RIPDES permit prescribed in Chapter 46-12, 42-17.1 and 42-35 of the General Laws of the State of Rhode Island.

In accordance with Part I.B.3.j of the RIPDES Multi-Sector General Permit, prior to authorization to discharge stormwater associated with industrial activity, the applicant is required to demonstrate that the stormwater discharge is consistent with the requirements of the TMDL. With completion of this TMDL, consistent with Part I.C. of the general permit, facilities currently authorized to discharge under the permit must either demonstrate that the existing Storm Water Pollution Prevention Plan (SWPPP) is consistent with the TMDL or amend their plan demonstrating consistency with the TMDL. More specifically, the TMDL requires that facilities currently authorized or seeking authorization to discharge to the ponds must

demonstrate that their SWPPP reduces copper, cadmium, and iron to the maximum extent feasible. Permittees will have 90 days from written notification by RIDEM to submit this documentation including revised SWMPPs to RIDEM.

The owner/operators of facilities currently authorized to discharge to the streams within the watershed are listed below:

- Jay Packing Group (Buckeye Brook)

This facility (covered by MSG Permit RIR 50X002) discharges stormwater to the channel which also receives drainage from Outfall 008 from TF Green Airport and flows into Buckeye Brook. Jay Packaging Group's SWPPP must identify the potential sources of pollution, including specifically the TMDL pollutants of concern (Cd, Cu, and Fe), which may reasonably be expected to affect the quality of storm water discharges from the facility; and describe and ensure implementation of practices, which the permittee will use to reduce metals in storm water discharges from the facility, and to attenuate runoff on-site. The SWPPP must address all areas of the facility and describe existing and/or proposed BMPs that will be used and, at a minimum, must include the following:

- Frequent sweeping of roads, parking lots and other impervious areas
- Effective management (storage and disposal) of solid waste and trash
- Regular inspection and cleaning of catch basins and other stormwater BMPs
- Other pollution prevention and stormwater BMPs as appropriate

Where structural BMPs are necessary, as stated in Part IV.F.7 of the permit, selection of BMPs should take into consideration:
1) The quantity and nature of the pollutants, and their potential to impact the water quality of receiving waters;
2) Opportunities to combine the dual purposes of water quality protection and local flood control benefits (including physical impacts of high flows on streams - e.g., bank erosion, impairment of aquatic habitat, etc.); and
3) Opportunities to offset the impact of impervious areas of the facility on ground water recharge and base flows in local streams.
For existing facilities, the SWPPP must include a schedule specifying when each control will be implemented. Facilities that are not currently authorized will be required to demonstrate compliance with these requirements prior to authorization.

6.5 Truk-Away Landfill

Truk-Away landfill is located at the end of Industrial Drive and was open from 1970 until 1977. The landfill has an area of 52 acres. Approximately 32 acres was used for waste disposal with the remaining area consisting of open land and freshwater wetlands. A small tributary stream to Buckeye Brook flows in a northeasterly direction along the southern edge of the landfill property where it merges with another unnamed tributary that receives discharges from the airport outfall

008. The confluence of these tributaries with Buckeye Brook is approximately 430 yards (400 meters) from the exit of Warwick Pond. As documented in Section 3.5, leachate from the landfill contributes to elevated levels of cadmium and iron in the tributary stream flowing to Buckeye Brook. To meet the water quality criteria requirements for Buckeye Brook, leachate from the landfill will need to be controlled.

Since 2003, the Rhode Island Department of Administration has been the responsible agency for the Truk-Away Landfill. The landfill was closed in 1977 and has not been properly capped. As documented by sampling results at station TA01, pollutants of concern originating from the landfill and contributing to cadmium, iron, and aquatic life impairments of Buckeye Brook during wet and dry weather. The landfill must be properly closed to prevent leachate and stormwater runoff of these pollutants of concern. There are efforts currently underway to bring together the identified stakeholders who used the dump prior to its closing. Letters of Responsibility (LOR) were sent to representatives from the state, municipalities, and private companies, referred to as the Potentially Responsible Parties (PRP), to set up a meeting with all the concerned entities to coordinate a group effort to investigate the extent of contamination from the landfill, and to set a schedule for a plan to permanently close the landfill. The first meeting was held in January 2016, and the next step of the process will be to form a core RRP group to facilitate the initiation of a new site investigation.

7.0 PUBLIC PARTICIPATION

RIDEM will present the draft TMDL plan to the general public and stakeholders, including public officials and other agencies, in a public meeting on January 9, 2018. Letters will be sent to key stakeholders in advance of the meeting. In addition, the meeting will be publicized through public notices that posted at the Warwick City Hall and the Warwick Public Library. The draft TMDL has been made available to the public on RIDEM's website approximately one month prior to the public meeting. The public comment period is slated to close on February 9, 2018.

8.0 FUTURE MONITORING

This is a phased implementation TMDL. Results of water quality monitoring by various entities will allow RIDEM to track compliance with the water quality objectives as remedial actions are accomplished. RIDEM anticipates re-visiting Buckeye Brook and Tributaries to Warwick Pond as part of the state's ambient water quality monitoring efforts. To assess the effectiveness of stormwater and other controls implemented at the airport, RIDEM will review both outfall and ambient stream monitoring data collected by RIAC, as required by their stormwater permit. RIDEM will also evaluate the ambient monitoring data that is being collected on these stream systems by the Buckeye Brook Coalition and other volunteers participating in URI's Watershed Watch Program.

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APPENDIX A

Dry Weather Trace Metal Criteria Evaluations

CADMIUM (Cd)

Hardness as $CaCO_3$ (mg/L)		
Station	7/16/08	9/10/08
BB00	50.0	40.0
BB02	48.0	41.0
BB03	47.0	NS
BB04	66.0	45.0
BB05A	64.0	44.0
TA01	91.0	NS
OF08	50.0	NS
AP01	NS	43.0

Cadmium Criteria (µg/L)				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00	1.03	**0.15**	0.83	0.13
BB02	0.99	0.15	0.85	0.13
BB03	0.97	**0.15**	NS	NS
BB04	1.34	**0.18**	0.93	0.14
BB05A	1.30	0.18	0.91	0.14
TA01	1.84	**0.23**	NS	NS
OF08	1.03	**0.15**	NS	NS
AP01	NS	NS	0.89	0.14

Cadmium Observed (µg/L)		
Station	7/16/08	9/10/08
BB00	**0.16**	0.08
BB02	0.10	0.11
BB03	**0.28**	NS
BB04	**0.39**	<0.06
BB05A	0.13	<0.06
TA01	**0.30**	NS
OF08	**0.16**	NS
AP01	NS	<0.06

Dry Wx Cadmium Exceedances				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00		**EXD**		
BB02				
BB03		**EXD**		
BB04		**EXD**		
BB05A				
TA01		**EXD**		
OF08		**EXD**		
AP01				

COPPER (Cu)

Hardness as $CaCO_3$ (mg/L)		
Station	7/16/08	9/10/08
BB00	50.0	40.0
BB02	48.0	41.0
BB03	47.0	NS
BB04	66.0	45.0
BB05A	64.0	44.0
TA01	91.0	NS
OF08	50.0	NS
AP01	NS	43.0

Copper Criteria (µg/L)				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00	6.99	4.95	5.67	4.09
BB02	6.73	4.78	5.80	4.18
BB03	6.60	4.70	NS	NS
BB04	9.09	6.28	6.33	4.53
BB05A	8.83	6.12	6.20	4.44
TA01	12.30	8.26	NS	NS
OF08	6.99	4.95	NS	NS
AP01	NS	NS	6.07	4.35

Copper (µg/L) Observed		
Station	7/16/08	9/10/08
BB00	1.82	2.10
BB02	3.53	1.19
BB03	2.35	NS
BB04	5.73	1.24
BB05A	1.62	1.68
TA01	1.40	NS
OF08	0.67	NS
AP01	NS	1.08

Dry Wx Copper Exceedances				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00				
BB02				
BB03				
BB04				
BB05A				
TA01				
OF08				
AP01				

LEAD (Pb)

Hardness as $CaCO_3$ (mg/L)		
Station	7/16/08	9/10/08
BB00	50.0	40.0
BB02	48.0	41.0
BB03	47.0	NS
BB04	66.0	45.0
BB05A	64.0	44.0
TA01	91.0	NS
OF08	50.0	NS
AP01	NS	43.0

Lead Criteria (µg/L)				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00	30.14	1.17	23.51	0.92
BB02	28.80	1.12	24.17	0.94
BB03	28.13	**1.10**	NS	NS
BB04	40.97	**1.60**	26.81	1.04
BB05A	39.60	1.54	26.14	1.02
TA01	58.27	2.27	NS	NS
OF08	30.14	1.17	NS	NS
AP01	NS	NS	25.48	0.99

Lead Observed (µg/L)		
Station	7/16/08	9/10/08
BB00	0.59	<0.07
BB02	0.44	<0.07
BB03	**1.93**	NS
BB04	**1.62**	0.18
BB05A	0.51	<0.07
TA01	0.90	NS
OF08	0.45	NS
AP01	NS	<0.07

Dry Wx Lead Exceedances				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00				
BB02				
BB03		**EXD**		
BB04		**EXD**		
BB05A				
TA01				
OF08				
AP01				

ZINC (Zn)

Hardness as $CaCO_3$ (mg/L)		
Station	7/16/08	9/10/08
BB00	50.0	40.0
BB02	48.0	41.0
BB03	47.0	NS
BB04	66.0	45.0
BB05A	64.0	44.0
TA01	91.0	NS
OF08	50.0	NS
AP01	NS	43.0

Zinc Criteria (µg/L)				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00	65.13	65.66	53.91	54.35
BB02	62.92	63.43	55.05	55.50
BB03	**61.81**	**62.31**	NS	NS
BB04	82.41	83.08	59.57	60.06
BB05A	80.28	80.94	58.45	58.92
TA01	108.18	109.07	NS	NS
OF08	65.13	65.66	NS	NS
AP01	NS	NS	57.32	57.79

Zinc Observed (µg/L)		
Station	7/16/08	9/10/08
BB00	35.70	28.20
BB02	57.90	13.90
BB03	**137.00**	NS
BB04	30.20	7.14
BB05A	17.20	7.75
TA01	48.90	NS
OF08	22.10	NS
AP01	NS	10.40

Dry Wx Zinc Exceedances				
Station	7/16/08		9/10/08	
	Acute	Chronic	Acute	Chronic
BB00				
BB02				
BB03	**EXD**	**EXD**		
BB04				
BB05A				
TA01				
OF08				
AP01				

Bold and Shaded = Exceeded Criteria

Cadmium (Cd) Wet Weather 1 Chronic Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

AVE Hardness	
Station	**(mg/L)**
BB00	44.0
BB02	36.0
BB03	48.3
BB04	52.0
BB05A	51.0
TA01	64.3
OF08	24.0

WW1 Cd Chronic Criteria	
Station	**(µg/L)**
BB00	**0.14**
BB02	**0.12**
BB03	0.15
BB04	0.16
BB05A	**0.15**
TA01	**0.18**
OF08	**0.09**

Cadmium Observed (µg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	0.40	0.17	0.16
BB02	0.18	0.22	0.39
BB03	0.15	<0.06	<0.06
BB04	0.11	<0.06	<0.06
BB05A	0.31	0.29	<0.06
TA01	0.58	0.08	0.09
OF08	0.17	0.19	0.19

AVE Observed Cd	
Station	**(µg/L)**
BB00	**0.24**
BB02	**0.26**
BB03	0.15
BB04	0.11
BB05A	**0.30**
TA01	**0.25**
OF08	**0.18**

WW1 Cadmium Chronic Exceedances	
Station	**Chronic**
BB00	**EXD**
BB02	**EXD**
BB03	
BB04	
BB05A	**EXD**
TA01	**EXD**
OF08	**EXD**

Cadmium (Cd) Wet Weather 1 Acute Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

WW1 Cd Acute Criteria (µg/L)			
Station	**Prestorm**	**Run 1**	**Run 2**
BB00	1.05	0.91	0.77
BB02	1.07	0.66	0.50
BB03	1.05	0.87	1.07
BB04	1.19	1.09	0.93
BB05A	1.17	1.07	0.91
TA01	1.97	0.93	1.03
OF08	0.87	0.32	0.32

Cadmium Observed (µg/L)			
Station	**Prestorm**	**Run 1**	**Run 2**
BB00	0.40	0.17	0.16
BB02	0.18	0.22	0.39
BB03	0.15	<0.06	<0.06
BB04	0.11	<0.06	<0.06
BB05A	0.31	0.29	<0.06
TA01	0.58	0.08	0.09
OF08	0.17	0.19	0.19

WW1 Cadmium Acute Exceedances			
Station	**Prestorm**	**Run 1**	**Run 2**
BB00			
BB02			
BB03			
BB04			
BB05A			
TA01			
OF08			

Bold and Shaded = Exceeded Criteria

Cadmium (Cd) Wet Weather 2 Chronic Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

AVE Hardness (mg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	55.8	42.3	37.9
BB02	45.5	34.7	31.4
BB03	66.5	61.5	39.5
BB04	58.0	48.6	45.6
BB05A	59.7	47.6	40.3
TA01	69.7	52.5	69.8
OF08	39.2	24.6	20.2

WW2 Cd Chronic Criteria (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	**0.16**	**0.14**	0.13
BB02	0.14	**0.12**	**0.11**
BB03	0.19	0.18	0.13
BB04	0.17	0.15	0.14
BB05A	0.17	0.15	0.13
TA01	0.19	0.16	0.19
OF08	0.13	0.09	**0.08**

Cadmium Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	0.26	0.21	0.09	0.16
BB02	0.09	0.14	0.12	0.13
BB03	<0.05	<0.05	<0.05	<0.05
BB04	0.14	<0.05	<0.05	0.06
BB05A	0.05	0.06	<0.05	0.14
TA01	0.09	<0.05	<0.05	<0.05
OF08	0.06	0.10	<0.05	0.20

AVE Observed Cd (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	**0.24**	**0.15**	0.13
BB02	0.12	**0.13**	**0.13**
BB03	<0.05	<0.05	<0.05
BB04	0.14	<0.05	0.06
BB05A	0.06	0.06	0.14
TA01	0.09	<0.05	<0.05
OF08	0.08	0.10	**0.20**

WW2 Cadmium Chronic Exceedances			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	**EXD**	**EXD**	
BB02		**EXD**	**EXD**
BB03			
BB04			
BB05A			
TA01			
OF08			**EXD**

Cadmium (Cd) Wet Weather 2 Acute Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

WW2 Cd Acute Criteria (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	1.21	1.07	0.67	0.89
BB02	1.02	0.85	0.59	0.71
BB03	1.10	1.61	0.90	0.73
BB04	1.21	1.16	0.83	1.04
BB05A	1.23	1.21	0.75	0.91
TA01	1.95	0.88	1.27	1.57
OF08	0.93	0.68	0.34	0.50

Cadmium Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	0.26	0.21	0.09	0.16
BB02	0.09	0.14	0.12	0.13
BB03	<0.05	<0.05	<0.05	<0.05
BB04	0.14	<0.05	<0.05	0.06
BB05A	0.05	0.06	<0.05	0.14
TA01	0.09	<0.05	<0.05	<0.05
OF08	0.06	0.10	<0.05	0.20

WW2 Cadmium Acute Exceedances				
Station	Prestorm	Run 1	Run 2	Run 3
BB00				
BB02				
BB03				
BB04				
BB05A				
TA01				
OF08				

Bold and Shaded = Exceeded Criteria

Copper (Cu) Wet Weather 1 Chronic Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

AVE Hardness	
Station	**(mg/L)**
BB00	44.0
BB02	36.0
BB03	48.3
BB04	52.0
BB05A	51.0
TA01	64.3
OF08	24.0

WW1 Cu Chronic Criteria	
Station	**(µg/L)**
BB00	4.44
BB02	3.74
BB03	4.81
BB04	5.12
BB05A	5.04
TA01	6.14
OF08	2.65

Copper Observed (µg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	1.80	2.04	2.22
BB02	1.03	3.37	2.19
BB03	0.98	0.89	0.72
BB04	1.21	0.90	0.88
BB05A	3.24	1.56	1.63
TA01	2.01	1.04	1.83
OF08	0.74	4.26	2.66

AVE Observed Cu	
Station	**(µg/L)**
BB00	2.02
BB02	2.20
BB03	0.86
BB04	1.00
BB05A	2.14
TA01	1.63
OF08	2.55

WW1 Copper Chronic Exceedances	
Station	**Chronic**
BB00	
BB02	
BB03	
BB04	
BB05A	
TA01	
OF08	

Copper (Cu) Wet Weather 1 Acute Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

WW1 Cu Acute Criteria (µg/L)			
Station	**Prestorm**	**Run 1**	**Run 2**
BB00	7.13	6.20	5.27
BB02	7.26	4.59	3.50
BB03	7.13	5.93	7.26
BB04	8.04	7.39	6.33
BB05A	7.91	7.26	6.20
TA01	13.2	6.33	6.99
OF08	5.93	**2.25**	**2.25**

Copper Observed (µg/L)			
Station	**Prestorm**	**Run 1**	**Run 2**
BB00	1.80	2.04	2.22
BB02	1.03	3.37	2.19
BB03	0.98	0.89	0.72
BB04	1.21	0.90	0.88
BB05A	3.24	1.56	1.63
TA01	2.01	1.04	1.83
OF08	0.74	**4.26**	**2.66**

WW1 Copper Acute Exceedances			
Station	**Prestorm**	**Run 1**	**Run 2**
BB00			
BB02			
BB03			
BB04			
BB05A			
TA01			
OF08		**EXD**	**EXD**

Bold and Shaded = Exceeded Criteria

Copper (Cu) Wet Weather 2 Chronic Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

AVE Hardness (mg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	55.8	42.3	37.9
BB02	45.5	34.7	31.4
BB03	66.5	61.5	39.5
BB04	58.0	48.6	45.6
BB05A	59.7	47.6	40.3
TA01	69.7	52.5	69.8
OF08	39.2	24.6	20.2

WW2 Cu Chronic Criteria (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	5.44	4.29	3.90
BB02	4.57	3.63	**3.33**
BB03	6.32	5.91	4.05
BB04	5.62	4.83	4.57
BB05A	5.76	**4.75**	4.12
TA01	6.57	5.16	6.59
OF08	4.02	2.70	**2.28**

Copper Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	1.33	2.16	2.17	1.53
BB02	1.30	2.32	4.05	3.32
BB03	2.94	1.05	1.63	0.81
BB04	1.52	1.71	2.35	1.46
BB05A	2.51	8.48	2.02	1.26
TA01	1.40	1.48	1.34	1.36
OF08	1.03	1.74	3.59	4.22

AVE Observed Cu (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	1.75	2.17	1.85
BB02	1.81	3.19	**3.69**
BB03	2.00	1.34	1.22
BB04	1.62	2.03	1.91
BB05A	5.50	**5.25**	1.64
TA01	1.44	1.41	1.35
OF08	1.39	2.67	**3.91**

WW2 Copper Chronic Exceedances			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00			
BB02			**EXD**
BB03			
BB04			
BB05A		**EXD**	
TA01			
OF08			**EXD**

Copper (Cu) Wet Weather 2 Acute Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

WW2 Cu Acute Criteria (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	8.23	7.28	4.63	6.12
BB02	6.98	5.80	4.10	4.92
BB03	7.48	10.8	6.17	5.02
BB04	8.19	7.89	5.72	7.09
BB05A	8.36	**8.17**	5.16	6.25
TA01	13.0	6.03	8.59	10.6
OF08	6.37	4.73	**2.42**	**3.53**

Copper Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	1.33	2.16	2.17	1.53
BB02	1.30	2.32	4.05	3.32
BB03	2.94	1.05	1.63	0.81
BB04	1.52	1.71	2.35	1.46
BB05A	2.51	**8.48**	2.02	1.26
TA01	1.40	1.48	1.34	1.36
OF08	1.03	1.74	**3.59**	**4.22**

WW2 Copper Acute Exceedances				
Station	Prestorm	Run 1	Run 2	Run 3
BB00				
BB02				
BB03				
BB04				
BB05A		**EXD**		
TA01				
OF08			**EXD**	**EXD**

Bold and Shaded = Exceeded Criteria

Lead (Pb) Wet Weather 1 Chronic Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

AVE Hardness	
Station	(mg/L)
BB00	44.0
BB02	36.0
BB03	48.3
BB04	52.0
BB05A	51.0
TA01	64.3
OF08	24.0

WW1 Pb Chronic Criteria	
Station	Pb (µg/L)
BB00	1.02
BB02	0.81
BB03	1.13
BB04	1.23
BB05A	1.20
TA01	1.55
OF08	0.52

Lead Observed (µg/L)			
Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	0.27	0.30	0.49
BB02	0.34	0.78	0.49
BB03	0.18	<0.07	0.18
BB04	0.61	<0.07	<0.07
BB05A	0.66	0.24	0.22
TA01	1.51	0.94	1.70
OF08	0.08	1.08	0.20

AVE Observed Pb	
Station	(µg/L)
BB00	0.35
BB02	0.54
BB03	0.18
BB04	0.61
BB05A	0.37
TA01	1.38
OF08	0.45

WW1 Lead Chronic Exceedances	
Station	Chronic
BB00	
BB02	
BB03	
BB04	
BB05A	
TA01	
OF08	

Lead (Pb) Wet Weather 1 Acute Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

WW1 Pb Acute Criteria (µg/L)			
Station	Prestorm	Run 1	Run 2
BB00	30.81	26.14	21.55
BB02	31.48	18.32	13.26
BB03	30.81	24.82	31.48
BB04	35.52	32.15	26.81
BB05A	34.84	31.48	26.14
TA01	63.18	26.81	30.14
OF08	24.82	7.30	7.30

Lead Observed (µg/L)			
Station	Prestorm	Run 1	Run 2
BB00	0.27	0.30	0.49
BB02	0.34	0.78	0.49
BB03	0.18	<0.07	0.18
BB04	0.61	<0.07	<0.07
BB05A	0.66	0.24	0.22
TA01	1.51	0.94	1.70
OF08	0.08	1.08	0.20

WW1 Lead Acute Exceedances			
Station	Prestorm	Run 1	Run 2
BB00			
BB02			
BB03			
BB04			
BB05A			
TA01			
OF08			

Lead (Pb) Wet Weather 2 Chronic Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

AVE Hardness (mg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	55.8	42.3	37.9
BB02	45.5	34.7	31.4
BB03	66.5	61.5	39.5
BB04	58.0	48.6	45.6
BB05A	59.7	47.6	40.3
TA01	69.7	52.5	69.8
OF08	39.2	24.6	20.2

WW2 Pb Chronic Criteria (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	1.33	0.97	0.86
BB02	1.06	0.78	0.70
BB03	1.61	1.48	0.90
BB04	1.38	1.14	1.06
BB05A	1.43	1.11	0.92
TA01	1.69	1.24	1.70
OF08	**0.89**	**0.53**	0.43

Lead Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	0.09	0.16	1.28	0.16
BB02	0.11	0.35	0.51	0.17
BB03	0.29	0.10	0.33	<0.08
BB04	1.50	0.13	0.38	<0.08
BB05A	0.37	0.53	0.15	0.20
TA01	0.73	0.19	0.22	0.37
OF08	<0.08	2.62	0.22	0.11

AVE Observed Pb (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	0.13	0.72	0.72
BB02	0.23	0.43	0.34
BB03	0.20	0.22	0.33
BB04	0.82	0.26	0.38
BB05A	0.45	0.34	0.18
TA01	0.46	0.21	0.30
OF08	**2.62**	**1.42**	0.17

WW2 Lead Chronic Exceedances			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00			
BB02			
BB03			
BB04			
BB05A			
TA01			
OF08	**EXD**	**EXD**	

Lead (Pb) Wet Weather 2 Acute Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

WW2 Pb Acute Criteria (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	36.47	31.61	18.51	27.75
BB02	30.07	24.17	16.02	19.86
BB03	32.62	50.06	26.01	20.38
BB04	36.27	34.71	23.77	30.60
BB05A	37.15	36.20	21.03	26.41
TA01	62.19	25.29	38.37	48.81
OF08	37.01	18.96	8.50	13.38

Lead Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	0.09	0.16	1.28	0.16
BB02	0.11	0.35	0.51	0.17
BB03	0.29	0.10	0.33	<0.08
BB04	1.50	0.13	0.38	<0.08
BB05A	0.37	0.53	0.15	0.20
TA01	0.73	0.19	0.22	0.37
OF08	<0.08	2.62	0.22	0.11

WW2 Lead Acute Exceedances				
Station	Prestorm	Run 1	Run 2	Run 3
BB00				
BB02				
BB03				
BB04				
BB05A				
TA01				
OF08				

Bold and Shaded = Exceeded Criteria

Zinc (Zn) Wet Weather 1 Chronic Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

AVE Hardness	
Station	(mg/L)
BB00	44.0
BB02	36.0
BB03	48.3
BB04	52.0
BB05A	51.0
TA01	64.3
OF08	24.0

WW1 Zn Chronic Criteria	
Station	(µg/L)
BB00	58.92
BB02	49.71
BB03	63.81
BB04	67.88
BB05A	66.78
TA01	81.30
OF08	35.26

Zinc Observed (µg/L)			
Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	24.88	25.48	27.19
BB02	13.32	28.71	24.48
BB03	6.93	<6.46	<6.46
BB04	12.21	7.09	8.25
BB05A	9.87	20.64	25.43
TA01	27.20	9.18	21.80
OF08	10.46	33.51	26.17

AVE Observed Zn	
Station	(µg/L)
BB00	25.9
BB02	22.2
BB03	6.93
BB04	9.18
BB05A	18.6
TA01	19.4
OF08	23.4

WW1 Zinc Chronic Exceedances	
Station	Chronic
BB00	
BB02	
BB03	
BB04	
BB05A	
TA01	
OF08	

Zinc (Zn) Wet Weather 1 Acute Criteria Evaluation

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0

WW1 Zn Acute Criteria (µg/L)			
Station	Prestorm	Run 1	Run 2
BB00	66.23	58.45	50.47
BB02	67.33	44.62	34.97
BB03	66.23	56.19	67.33
BB04	73.86	68.43	59.57
BB05A	72.78	67.33	58.45
TA01	115.19	59.57	65.13
OF08	56.19	**23.48**	**23.48**

Zn Observed (µg/L)			
Station	Prestorm	Run 1	Run 2
BB00	24.88	25.48	27.19
BB02	13.32	28.71	24.48
BB03	6.93	<6.46	<6.46
BB04	12.21	7.09	8.25
BB05A	9.87	20.64	25.43
TA01	27.20	9.18	21.80
OF08	10.46	**33.51**	**26.17**

WW1 Zinc Acute Exceedances			
Station	Prestorm	Run 1	Run 2
BB00			
BB02			
BB03			
BB04			
BB05A			
TA01			
OF08		**EXD**	**EXD**

Bold and Shaded = Exceeded Criteria

Zinc (Zn) Wet Weather 2 Chronic Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

AVE Hardness (mg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	55.8	42.3	37.9
BB02	45.5	34.7	31.4
BB03	66.5	61.5	39.5
BB04	58.0	48.6	45.6
BB05A	59.7	47.6	40.3
TA01	69.7	52.5	69.8
OF08	39.2	24.6	20.2

WW2 Zn Chronic Criteria (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	72.06	56.93	51.87
BB02	60.56	48.19	44.27
BB03	83.56	78.25	53.78
BB04	74.41	64.10	60.68
BB05A	76.31	62.98	54.70
TA01	86.96	68.38	87.11
OF08	53.37	36.00	30.47

Zinc Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	4.49	17.51	21.13	5.55
BB02	<1.12	13.60	22.60	<1.12
BB03	1.97	1.15	1.94	<1.12
BB04	5.99	<1.12	3.30	<1.12
BB05A	4.13	14.86	2.68	<1.12
TA01	3.36	1.44	1.91	<1.12
OF08	2.86	10.29	15.40	9.26

AVE Observed Zn (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	11.00	19.32	13.34
BB02	13.60	18.10	22.60
BB03	1.56	1.55	1.94
BB04	5.99	3.30	3.30
BB05A	9.50	8.77	2.68
TA01	2.40	1.68	1.91
OF08	6.58	12.85	12.33

WW2 Zinc Chronic Exceedances			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00			
BB02			
BB03			
BB04			
BB05A			
TA01			
OF08			

Zinc (Zn) Wet Weather 2 Acute Criteria Evaluation

WW2 Hardness as $CaCO_3$ (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2

WW2 Zn Acute Criteria (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	75.37	67.55	44.98	57.77
BB02	65.02	55.05	40.33	47.44
BB03	69.19	96.17	58.22	48.38
BB04	75.04	72.56	54.37	65.90
BB05A	76.44	74.94	49.54	58.90
TA01	113.80	56.98	78.37	94.32
OF08	59.91	45.80	25.07	35.22

Zinc Observed (µg/L)				
Station	Prestorm	Run 1	Run 2	Run 3
BB00	4.49	17.51	21.13	5.55
BB02	<1.12	13.60	22.60	<1.12
BB03	1.97	1.15	1.94	<1.12
BB04	5.99	<1.12	3.30	<1.12
BB05A	4.13	14.86	2.68	<1.12
TA01	3.36	1.44	1.91	<1.12
OF08	2.86	10.29	15.40	9.26

WW2 Zinc Acute Exceedances				
Station	Prestorm	Run 1	Run 2	Run 3
BB00				
BB02				
BB03				
BB04				
BB05A				
TA01				
OF08				

Total Iron (Fe) Chronic Criteria Evaluation

Total Iron (µg/L) Dry Weather Chronic Criteria Evaluation

Station	7/16/08	9/10/08
BB00	732	522
BB02	648	824
BB03	186	NS
BB04	**2,078**	**1,258**
BB05A	**1,347**	**1,439**
TA01	**11,586**	NS
OF08	**2,844**	NS
AP01	NS	**3,008**

Total Iron (µg/L) Wet Weather 1 Chronic Criteria Evaluation

Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08	Average
BB00	654	897	1,082	878
BB02	1,185	1,377	1,419	**1,327**
BB03	308	296	470	358
BB04	3,112	2,385	3,287	**2,928**
BB05A	1,112	1,991	1,423	**1,509**
TA01	19,180	4,725	18,912	**14,272**
OF08	4,334	2,049	1,726	**2,703**

Total Iron (µg/L) Wet Weather 2 Chronic Criteria Evaluation

Station	Prestorm 02/01/11	Run 1 02/03/11	Average Pre + Run1	Run 2 02/06/11	Average Runs 1+2	Run 3 02/08/11	Average Runs 2+3
BB00	741	2,307	**1,524**	948	**1,628**	648	798
BB02	1,989	1,747	**1,868**	1,475	**1,611**	2,403	**1,939**
BB03	432	449	441	462	456	1,617	**1,040**
BB04	1,892	3,112	**2,502**	1,605	**2,359**	1,799	**1,702**
BB05A	1,010	1,168	**1,089**	981	**1,075**	1,172	**1,077**
TA01	9,088	4,976	**7,032**	1,250	**3,113**	3,693	**2,472**
OF08	3,954	2,454	**3,204**	1,928	**2,191**	2,441	**2,185**

Bold and Shaded = Exceeded Criteria (1000 µg/L)

APPENDIX B

Cadmium, Copper and Iron Dry Weather Reductions

Station	Cadmium Criteria (µg/L)				90% of Cadmium Criteria (µg/L)				Cd Observed (µg/L)		Reduction (µg/L)		% Reduction	
	7/16/08		9/10/08		7/16/08		9/10/08		7/16/08	9/10/08	7/16/08	9/10/08	7/16/08	9/10/08
	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic						
BB00	1.03	0.152	0.83	0.130	0.92	0.14	0.74	0.12	0.16	0.08	0.02	--	14.6%	--
BB02	0.99	0.148	0.85	0.132	0.89	0.13	0.76	0.12	0.10	0.11	--	--		--
BB03	0.97	0.145	NS	NS	0.87	0.13	NS	NS	0.28	NS	0.15	--	53.2%	--
TA01	1.84	0.230	NS	NS	1.65	0.21	NS	NS	0.30	NS	0.09	--	30.9%	--
OF08	1.03	0.152	NS	NS	0.92	0.14	NS	NS	0.16	NS	0.02	--	14.6%	--
AP01	NS	NS	0.89	0.137	NS	NS	0.80	0.12	NS	<0.06		--	--	--
BB04	1.34	0.184	0.93	0.141	1.21	0.17	0.83	0.13	0.39	<0.06	0.22	--	57.5%	---
BB05A	1.30	0.180	0.91	0.139	1.17	0.16	0.82	0.13	0.13	<0.06	--	--	--	--

Station	Copper Criteria (µg/L)				90% of Copper Criteria (µg/L)				Cu Observed (µg/L)		Reduction (µg/L)		% Reduction	
	7/16/08		9/10/08		7/16/08		9/10/08		7/16/08	9/10/08	7/16/08	9/10/08	7/16/08	9/10/08
	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic						
BB00	6.99	4.95	5.67	4.09	6.29	4.46	5.10	3.68	1.82	2.10				
BB02	6.73	4.78	5.80	4.18	6.06	4.30	5.22	3.76	3.53	1.19				
BB03	6.60	4.70	NS	NS	5.94	4.23	NS	NS	2.35	NS				
TA01	12.30	8.26	NS	NS	11.07	7.44	NS	NS	1.40	NS				
OF08	6.99	4.95	NS	NS	6.29	4.46	NS	NS	0.67	NS				
AP01	NS	NS	6.07	4.35	NS	NS	5.46	3.92	NS	1.08				
BB04	9.09	6.28	6.33	4.53	8.18	5.65	5.70	4.07	5.73	1.24				
BB05A	8.83	6.12	6.20	4.44	7.94	5.50	5.58	4.00	1.62	1.68				

Station	90% of Iron Criteria (µg/L)		Iron Observed (µg/L)		Fe Reduction Required (µg/L)		Fe Reduction Required (%)	
	7/16/08	9/10/08	7/16/08	9/10/08	7/16/08	9/10/08	7/16/08	9/10/08
BB00	900	900	732	522				
BB02	900	900	648	824				
BB03	900	900	186	NS				
TA01	900	900	11,586	NS	10,686		92.2%	
OF08	900	900	2,844	NS	1,944		68.4%	
AP01	900	900	NS	3,008		2,108		70.1%
BB04	900	900	2,078	1,258	1,178	358	56.7%	28.5%
BB05A	900	900	1,347	1,439	447	539	33.2%	37.5%

NS= Not Sampled

Cadmium Wet Weather Acute Reductions

WW1 Hardness as $CaCO_3$ (mg/L)

Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0

Cd WW1 Acute Criteria (µg/L)

Station	Prestm	Run 1	Run 2
BB00	1.05	0.91	0.77
BB02	1.07	0.66	0.50
BB03	1.05	0.87	1.07
TA01	1.97	0.93	1.03
OF08	0.87	0.31	0.31
BB04	1.19	1.09	0.93
BB05A	1.17	1.07	0.91

Cd WW1 90% Acute Criteria (µg/L)

Station	Prestm	Run 1	Run 2
BB00	0.94	0.82	0.69
BB02	0.96	0.60	0.45
BB03	0.94	0.78	0.96
TA01	1.78	0.83	0.92
OF08	0.78	0.28	0.28
BB04	1.07	0.98	0.83
BB05A	1.05	0.96	0.82

Cadmium WW1 Observed (µg/L)

Station	Prestorm	Run 1	Run 2
BB00	0.40	0.17	0.16
BB02	0.18	0.22	0.39
BB03	0.15	<0.06	<0.06
TA01	0.58	0.08	0.09
OF08	0.17	0.19	0.19
BB04	0.11	<0.06	<0.06
BB05A	0.31	0.29	<0.06

Cadmium WW1 Reduction (µg/L)

Station	Prestorm	Run 1	Run 2
BB00	--	--	--
BB02	--	--	--
BB03	--	--	--
TA01	--	--	--
OF08	--	--	--
BB04	--	--	--
BB05A	--	--	--

Cd WW1 Reduction Required (%)

Station	Prestorm	Run 1	Run 2
BB00	--	--	--
BB02	--	--	--
BB03	--	--	--
TA01	--	--	--
OF08	--	--	--
BB04	--	--	--
BB05A	--	--	--

WW2 Hardness as $CaCO_3$ (mg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4

Cd WW2 Acute Criteria (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	1.21	1.07	0.67	0.89
BB02	1.02	0.85	0.59	0.71
BB03	1.10	1.61	0.90	0.73
TA01	1.95	0.88	1.27	1.57
OF08	0.93	0.68	0.34	0.50
BB04	1.21	1.16	0.83	1.04
BB05A	1.23	1.21	0.75	0.91

Cd WW2 90% Acute Criteria (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	1.09	0.96	0.60	0.80
BB02	0.92	0.76	0.53	0.64
BB03	0.99	1.44	0.81	0.66
TA01	1.75	0.79	1.14	1.41
OF08	0.84	0.62	0.30	0.45
BB04	1.09	1.05	0.75	0.94
BB05A	1.11	1.08	0.67	0.82

Cadmium WW2 Observed (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	0.26	0.21	0.09	0.16
BB02	0.09	0.14	0.12	0.13
BB03	<0.05	<0.05	<0.05	<0.05
TA01	0.09	<0.05	<0.05	<0.05
OF08	0.06	0.10	<0.05	0.20
BB04	0.14	<0.05	<0.05	0.06
BB05A	0.05	0.06	<0.05	0.14

Cadmium WW2 Reduction Required (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	--	--	--	--
BB02	--	--	--	--
BB03	--	--	--	--
TA01	--	--	--	--
OF08	--	--	--	--
BB04	--	--	--	--
BB05A	--	--	--	--

Cadmium WW2 Reduction Required (%)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	--	--	--	--
BB02	--	--	--	--
BB03	--	--	--	--
TA01	--	--	--	--
OF08	--	--	--	--
BB04	--	--	--	--
BB05A	--	--	--	--

Cadmium Wet Weather 1 Chronic Reductions

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0

WW1 Average Hardness (mg/L)	
Station	**As $CaCO_3$ (mg/L)**
BB00	44.0
BB02	36.0
BB03	48.3
TA01	64.3
OF08	24.0
BB04	52.0
BB05A	51.0

Cd WW1 Chronic Criteria (µg/L)	
Station	**Cd (µg/L)**
BB00	0.14
BB02	0.12
BB03	0.15
TA01	0.18
OF08	0.09
BB04	0.16
BB05A	0.15

Cd WW1 90% Chronic Criteria (µg/L)	
Station	**Cd (µg/L)**
BB00	0.13
BB02	0.11
BB03	0.13
TA01	0.16
OF08	0.08
BB04	0.14
BB05A	0.14

Cd WW1 Observed (µg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	0.40	0.17	0.16
BB02	0.18	0.22	0.39
BB03	0.15	<0.06	<0.06
TA01	0.58	0.08	0.09
OF08	0.17	0.19	0.19
BB04	0.11	<0.06	<0.06
BB05A	0.31	0.29	<0.06

Cd WW1 Average Observed (µg/L)	
Station	**Average Cd (µg/L)**
BB00	0.24
BB02	0.26
BB03	0.15
TA01	0.25
OF08	0.18
BB04	0.11
BB05A	0.30

Cd WW1 Reduction (µg/L)	
Station	**Chronic**
BB00	0.12
BB02	0.15
BB03	0.02
TA01	0.09
OF08	0.10
BB04	--
BB05A	0.16

Cd WW1 Reduction Required (%)	
Station	**Chronic**
BB00	48.6%
BB02	58.7%
BB03	11.0%
TA01	34.8%
OF08	53.9%
BB04	--
BB05A	53.8%

Cadmium Wet Weather 2 Chronic Reductions

WW2 Hardness as $CaCO_3$ (mg/L)

Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4

WW2 Average Hardness (mg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	55.8	42.3	37.9
BB02	45.5	34.7	31.4
BB03	66.5	61.5	39.5
TA01	69.7	52.5	69.8
OF08	39.2	24.6	20.2
BB04	58.0	48.6	45.6
BB05A	59.7	47.6	40.3

Cd WW2 Chronic Criteria (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	0.16	0.14	0.13
BB02	0.14	0.12	0.11
BB03	0.19	0.18	0.13
TA01	0.19	0.16	0.19
OF08	0.13	0.09	0.08
BB04	0.17	0.15	0.14
BB05A	0.17	0.15	0.13

Cd WW2 90% Chronic Criteria (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	0.15	0.12	0.11
BB02	0.13	0.11	0.10
BB03	0.17	0.16	0.12
TA01	0.17	0.14	0.17
OF08	0.12	0.08	0.07
BB04	0.15	0.13	0.13
BB05A	0.15	0.13	0.12

Cd WW2 Observed (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	0.26	0.21	0.09	0.16
BB02	0.09	0.14	0.12	0.13
BB03	<0.05	<0.05	<0.05	<0.05
TA01	0.09	<0.05	<0.05	<0.05
OF08	0.06	0.10	<0.05	0.20
BB04	0.14	<0.05	<0.05	0.06
BB05A	0.05	0.06	<0.05	0.14

Cd WW2 Average Observed (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	0.24	0.15	0.13
BB02	0.12	0.13	0.13
BB03	<0.05	<0.05	<0.05
TA01	0.09	<0.05	<0.05
OF08	0.08	0.10	0.20
BB04	0.14	<0.05	0.06
BB05A	0.06	0.06	0.14

Cd WW2 Reduction Required (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	0.09	0.03	0.012
BB02	--	0.02	0.03
BB03	--	--	--
TA01	--	--	--
OF08	--	0.02	0.13
BB04	--	--	--
BB05A	--	--	0.022

Cd WW2 Reduction Required (%)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	37.2%	19.0%	9.9%
BB02	--	18.5%	20.9%
BB03	--	--	--
TA01	--	--	--
OF08	--	16.6%	63.7%
BB04	--	--	--
BB05A	--	--	16.0%

Copper Wet Weather Acute Reductions

WW1 Hardness as $CaCO_3$ (mg/L)

Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0

Cu WW1 Acute Criteria (µg/L)

Station	Prestorm	Run 1	Run 2
BB00	7.13	6.20	5.27
BB02	7.26	4.59	3.50
BB03	7.13	5.93	7.26
TA01	13.19	6.33	6.99
OF08	5.93	2.25	2.25
BB04	8.04	7.39	6.33
BB05A	7.91	7.26	6.20

Cu WW1 90% Acute Criteria (µg/L)

Station	Prestorm	Run 1	Run 2
BB00	6.41	5.58	4.74
BB02	6.53	4.13	3.15
BB03	6.41	5.34	6.53
TA01	11.87	5.70	6.29
OF08	5.34	2.02	2.02
BB04	7.24	6.65	5.70
BB05A	7.12	6.53	5.58

Copper WW1 Observed (µg/L)

Station	Prestorm	Run 1	Run 2
BB00	1.80	2.04	2.22
BB02	1.03	3.37	2.19
BB03	0.98	0.89	0.72
TA01	2.01	1.04	1.83
OF08	0.74	4.26	2.66
BB04	1.21	0.90	0.88
BB05A	3.24	1.56	1.63

Copper WW1 Reduction (µg/L)

Station	Prestorm	Run 1	Run 2
BB00	--	--	--
BB02	--	--	--
BB03	--	--	--
TA01	--	--	--
OF08	--	2.24	0.64
BB04	--	--	--
BB05A	--	--	--

Cu WW1 Reduction Required (%)

Station	Prestorm	Run 1	Run 2
BB00	--	--	--
BB02	--	--	--
BB03	--	--	--
TA01	--	--	--
OF08	--	52.5%	23.9%
BB04	--	--	--
BB05A	--	--	--

WW2 Hardness as $CaCO_3$ (mg/L)

Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4

Cu WW2 Acute Criteria (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	8.23	7.28	4.63	6.12
BB02	6.98	5.80	4.10	4.92
BB03	7.48	10.8	6.17	5.02
TA01	13.0	6.03	8.59	10.6
OF08	6.37	4.73	2.42	3.53
BB04	8.19	7.89	5.72	7.09
BB05A	8.36	8.17	5.16	6.25

Cu WW2 90% Acute Criteria (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	7.40	6.56	4.17	5.51
BB02	6.28	5.22	3.69	4.43
BB03	6.73	9.71	5.56	4.52
TA01	11.71	5.43	7.73	9.50
OF08	5.74	4.26	2.18	3.18
BB04	7.37	7.10	5.15	6.38
BB05A	7.52	7.36	4.64	5.63

Copper WW2 Observed (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	1.33	2.16	2.17	1.53
BB02	1.30	2.32	4.05	3.32
BB03	2.94	1.05	1.63	0.81
TA01	1.40	1.48	1.34	1.36
OF08	1.03	1.74	3.59	4.22
BB04	1.52	1.71	2.35	1.46
BB05A	2.51	8.48	2.02	1.26

Copper WW2 Reduction (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	--	--	--	--
BB02	--	--	--	--
BB03	--	--	--	--
TA01	--	--	--	--
OF08	--	--	1.41	1.04
BB04	--	--	--	--
BB05A	--	1.12	--	--

Copper WW2 Reduction Required (%)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	--	--	--	--
BB02	--	--	--	--
BB03	--	--	--	--
TA01	--	--	--	--
OF08	--	--	39.4%	24.7%
BB04	--	--	--	--
BB05A	--	13.2%	--	--

Copper Wet Weather 1 Chronic Reductions

WW1 Hardness as $CaCO_3$ (mg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	51.0	44.0	37.0
BB02	52.0	32.0	24.0
BB03	51.0	42.0	52.0
TA01	98.0	45.0	50.0
OF08	42.0	15.0	15.0
BB04	58.0	53.0	45.0
BB05A	57.0	52.0	44.0

WW1 Average Hardness (mg/L)	
Station	**As $CaCO_3$ (mg/L)**
BB00	44.0
BB02	36.0
BB03	48.3
TA01	64.3
OF08	24.0
BB04	52.0
BB05A	51.0

Cu WW1 Chronic Criteria (µg/L)	
Station	**Cu (µg/L)**
BB00	4.44
BB02	3.74
BB03	4.81
TA01	6.14
OF08	2.65
BB04	5.12
BB05A	5.04

Cu WW1 90% Chronic Criteria (µg/L)	
Station	**Cu (µg/L)**
BB00	4.00
BB02	3.37
BB03	4.33
TA01	5.53
OF08	2.38
BB04	4.61
BB05A	4.53

Cu WW1 Observed (µg/L)			
Station	**Prestorm 12/9/08**	**Run 1 12/10/08**	**Run 2 12/11/08**
BB00	1.80	2.04	2.22
BB02	1.03	3.37	2.19
BB03	0.98	0.89	0.72
TA01	2.01	1.04	1.83
OF08	0.74	4.26	2.66
BB04	1.21	0.90	0.88
BB05A	3.24	1.56	1.63

Cu WW1 Average Observed (µg/L)	
Station	**Ave Cu (µg/L)**
BB00	2.02
BB02	2.20
BB03	0.86
TA01	1.63
OF08	2.55
BB04	1.00
BB05A	2.14

Cu WW1 Reduction (µg/L)	
Station	**Chronic**
BB00	--
BB02	--
BB03	--
TA01	--
OF08	--
BB04	--
BB05A	--

Cu WW1 Reduction Required (%)	
Station	**Chronic**
BB00	--
BB02	--
BB03	--
TA01	--
OF08	--
BB04	--
BB05A	--

Copper Wet Weather 2 Chronic Reductions

WW2 Hardness as $CaCO_3$ (mg/L)

Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	59.4	52.2	32.3	43.4
BB02	49.9	41.0	28.4	34.4
BB03	53.7	79.2	43.8	35.2
TA01	96.6	42.7	62.2	77.4
OF08	45.3	33.0	16.2	24.2
BB04	59.1	56.8	40.4	50.7
BB05A	60.4	59.0	36.2	44.4

WW2 Average Hardness (mg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	55.8	42.3	37.9
BB02	45.5	34.7	31.4
BB03	66.5	61.5	39.5
TA01	69.7	52.5	69.8
OF08	39.2	24.6	20.2
BB04	58.0	48.6	45.6
BB05A	59.7	47.6	40.3

Cu WW2 Chronic Criteria (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	5.44	4.29	3.90
BB02	4.57	3.63	3.33
BB03	6.32	5.91	4.05
TA01	6.57	5.16	6.59
OF08	4.02	2.70	2.28
BB04	5.62	4.83	4.57
BB05A	5.76	4.75	4.12

Cu WW2 90% Chronic Criteria (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	4.90	3.86	3.51
BB02	4.11	3.26	3.00
BB03	5.68	5.32	3.64
TA01	5.92	4.64	5.93
OF08	3.62	2.43	2.05
BB04	5.06	4.35	4.12
BB05A	5.19	4.27	3.71

Copper WW2 Observed (µg/L)

Station	Prestorm	Run 1	Run 2	Run 3
BB00	1.33	2.16	2.17	1.53
BB02	1.30	2.32	4.05	3.32
BB03	2.94	1.05	1.63	0.81
TA01	1.40	1.48	1.34	1.36
OF08	1.03	1.74	3.59	4.22
BB04	1.52	1.71	2.35	1.46
BB05A	2.51	8.48	2.02	1.26

Copper WW2 Average Observed (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	1.75	2.17	1.85
BB02	1.81	3.19	3.69
BB03	2.00	1.34	1.22
TA01	1.44	1.41	1.35
OF08	1.39	2.67	3.91
BB04	1.62	2.03	1.91
BB05A	5.50	5.25	1.64

Cu WW2 Reduction Required (µg/L)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	--	--	--
BB02	--	--	0.69
BB03	--	--	--
TA01	--	--	--
OF08	--	--	1.85
BB04	--	--	--
BB05A	--	0.98	--

Cu WW2 Reduction Required (%)

Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	--	--	--
BB02	--	--	18.7%
BB03	--	--	--
TA01	--	--	--
OF08	--	--	47.4%
BB04	--	--	--
BB05A	--	18.6%	--

Iron Wet Weather Chronic Reductions

Iron WW1 Observed (mg/L)			
Station	Prestorm 12/9/08	Run 1 12/10/08	Run 2 12/11/08
BB00	654	897	1,082
BB02	1,185	1,377	1,419
BB03	308	296	470
TA01	19,180	4,725	18,912
OF08	4,334	2,049	1,726
BB04	3,112	2,385	3,287
BB05A	1,112	1,991	1,423

Fe Average Observed (µg/L)	
Station	Average Fe
BB00	878
BB02	1,327
BB03	358
TA01	14,272
OF08	2,703
BB04	2,928
BB05A	1,509

Fe WW1 90% Chronic Criteria (µg/L)	
Station	Fe (µg/L)
BB00	900
BB02	900
BB03	900
TA01	900
OF08	900
BB04	900
BB05A	900

Fe WW1 Reduction (µg/L)	
Station	Fe (µg/L)
BB00	--
BB02	427
BB03	--
TA01	13,372
OF08	1,803
BB04	2,028
BB05A	609

Fe WW1 Reduction Required (%)	
Station	Fe (µg/L)
BB00	--
BB02	32.2%
BB03	--
TA01	93.7%
OF08	66.7%
BB04	69.3%
BB05A	40.3%

Iron WW2 Observed (mg/L)				
Station	Prestorm 02/01/11	Run 1 02/03/11	Run 2 02/06/11	Run 3 02/08/11
BB00	741	2,307	948	648
BB02	1,989	1,747	1,475	2,403
BB03	432	449	462	1,617
TA01	9,088	4,976	1,250	3,693
OF08	3,954	2,454	1,928	2,441
BB04	1,892	3,112	1,605	1,799
BB05A	1,010	1,168	981	1,172

Fe WW2 Average Observed (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	1,524	1,628	798
BB02	1,868	1,611	1,939
BB03	441	456	1,040
TA01	7,032	3,113	2,472
OF08	3,204	2,191	2,185
BB04	2,502	2,359	1,702
BB05A	1,089	1,075	1,077

Fe WW2 Reduction Required (µg/L)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	624	728	--
BB02	968	711	1,039
BB03	--	--	140
TA01	6,132	2,213	1,572
OF08	2,304	1,291	1,285
BB04	1,602	1,459	802
BB05A	189	175	177

Fe WW2 Reduction Required (%)			
Station	Ave Pre+R1	Ave R1+R2	Ave R2+R3
BB00	40.9%	44.7%	--
BB02	51.8%	44.1%	53.6%
BB03	--	--	13.4%
TA01	87.2%	71.1%	63.6%
OF08	71.9%	58.9%	58.8%
BB04	64.0%	61.8%	47.1%
BB05A	17.4%	16.2%	16.4%

APPENDIX C

Average deicing event values for RIAC waterbody stream stations before and after the Propylene Glycol facility commenced operations in October 2014.

Surveys Before Glycol Facility Operational

January 17-19, 2012

Station	DO (mg/L)	DO % Saturation	COD (mg/L)	BOD_5 (mg/L)	Propylene Glycol (mg/L)
BB02	10.7	84.3	35	12	9
BB03	10.9	85.1	24	4	<10
BB07	10.7	82.6	80	24	29
BB08	10.9	85.9	44	16	34

January 21-23, 2013

Sample ID:	DO (mg/L)	DO % Saturation	COD (mg/L)	BOD_5 (mg/L)	Propylene Glycol (mg/L)
BB02	10.1	72.6	29	16	12
BB03	10.7	76.2	19	9	8
BB04	9.8	71.7	114	27	26
BB07	10.8	77.5	28	15	15

February 13-15, 2014

Sample ID:	DO (mg/L)	DO % Saturation	COD (mg/L)	BOD_5 (mg/L)	Propylene Glycol (mg/L)
BB02	10.8	82.9	91	40	2
BB03	10.9	83.4	126	52	1
BB04	10.6	85.6	73	28	5
BB07	10.6	88.9	120	32	18

Surveys After Glycol Facility Operational

March 20-22, 2015

Station	DO (mg/L)	DO % Saturation	COD (mg/L)	BOD5 (mg/L)	Propylene Glycol (mg/L)
BB02	12.0	89.8	41	11	<10
BB03	11.6	84.9	18	<12	<10
BB04	11.1	84.0	16	<12	<10
BB07	11.6	87.1	17	<12	<10

January 23-25, 2016

	Sample ID:	DO % Saturation	COD (mg/L)	BOD5 (mg/L)	Propylene Glycol (mg/L)
BB02	11.3	82.8	7	<12	<10
BB03	13.1	91.3	13	<12	<10
BB04	11.3	86.3	26	<12	<10
BB07	11.8	92.5	13	<12	<10

February 1-3, 2017

Sample ID:	DO (mg/L)	DO % Saturation	COD (mg/L)	BOD5 (mg/L)	Propylene Glycol (mg/L)
BB02	12.2	93.4	8	4	<10
BB03	12.7	99.7	1	1	<10
BB04	11.0	80.6	11	1	<10
BB07	12.7	92.5	10	<6	<10

Average deicing event values for RIAC outfall stations before and after the Propylene Glycol facility commenced operations in October 2014.

Surveys Before Glycol Facility Operational

January 17, 2012					
Station	COD (mg/L)	BOD_5 (mg/L)	P. Glycol (mg/L)	TOC (mg/L)	Iron (µg/l)
002A	202	71	95	78	5,720
003A	37	13	9	2	950
008A	944	219	580	305	2,556

January 21-22, 2013					
Station	COD (mg/L)	BOD_5 (mg/L)	P. Glycol (mg/L)	TOC (mg/L)	Iron (µg/l)
002A	158	71	117	53	9,978
003A	<10	<12	<10	<5	645
008A	33	14	16	26	5,675

February 13, 2014					
Station	COD (mg/L)	BOD_5 (mg/L)	P. Glycol (mg/L)	TOC (mg/L)	Iron (µg/l)
002A	386	64	<10	116	12,738
003A	259	54	<10	70	3,386
008A	312	49	<10	65	6,386

Surveys After Glycol Facility Operational

March 20-21, 2015					
Station	COD (mg/L)	BOD_5 (mg/L)	P. Glycol (mg/L)	TOC (mg/L)	Iron (µg/l)
002A	247	151	43	65	14,833
003A	50	28	14	14	1,262
008A	55	27	12	15	2,389

January 23-24, 2016					
Station	COD (mg/L)	BOD_5 (mg/L)	P. Glycol (mg/L)	TOC (mg/L)	Iron (µg/l)
002A	27	15	<10	9	9,024
003A	5	2	<10	0.7	2,337
008A	41	22	7	12	2,424

February 1, 2017					
Station	COD (mg/L)	BOD_5 (mg/L)	P. Glycol (mg/L)	TOC (mg/L)	Iron (µg/l)
002A	124	62	18	32	5,430
003A	122	76	20	32	1,692
008A	40	25	4	12	1,291

T. F. Green Seasonal Propylene Glycol Collection Efficiencies

Season Before Glycol Facility Operational			
Season	PG Applied (gal)	PG Collected (gal)	Collection Efficiency (%)
2011-2012	18,405	6,244	34%
2012-2013	44,046	16,407	37%
2013-2014	61,835	26,236	42%

Season After Glycol Facility Operational			
Season	PG Applied (gal)	PG Collected (gal)	Collection Efficiency (%)
2014-2015	42,352	28,304	67%
2015-2016	27,731	17,359	63%
2016-2017	31,068	20,313	65%