City of Cambridge Water Department 2008-2011 Source Water Quality Report

July, 2012

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Executive Summary

This report presents the results of an ongoing study conducted by the City of Cambridge, Massachusetts Water Department to assess reservoir and tributary-stream quality in the Cambridge drinking water source area. The 2008 – 2011 sampling results are compared to State ambient and drinking water quality standards, and historic data primarily from a USGS/CWD comprehensive assessment conducted in 1997/1998 (Water Year 1998). With the departure of the previous Watershed Protection Supervisor in 2008, non-mandated ambient source water quality sampling has been sporadic during the transition. Watershed staff is working to better meet recommended water quality sampling frequencies (Appendix A).

Assessments of the quality and trophic state of the three primary storage reservoirs, Hobbs Brook, Stony Brook, and Fresh Pond reservoirs, were conducted to provide information on the state of these resources and to determine their vulnerability to increased loads of nutrients and other contaminants. Data collected from 11 stream tributaries that contribute water to the reservoirs are compared to historic results.

Water quality in the reservoir system was generally lower in the Hobbs Brook Reservoir, and improved as it flowed through the system via Stony Brook Reservoir in Weston to Fresh Pond, in Cambridge. The highest sodium and chloride concentrations were measured in Hobbs Brook Reservoir, which is influenced by runoff from Route 2 and Interstate 95, and other salt-treated impervious surfaces. The less developed Stony Brook Reservoir watershed exhibited lower sodium, chloride, and nutrient concentrations than those measured in Hobbs Brook Reservoir. The quality of water at the intake to the treatment plant in Fresh Pond was high throughout the study period. Analytical results of samples collected in Fresh Pond yielded consistently low concentrations of nutrients and selected total metals, with manganese, sodium, and chloride being the most abundant of the constituents sampled.

Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs generally met Massachusetts Class A Surface Water Quality Standards. Under periods of reservoir stratification, lower depth dissolved oxygen consistently fell below the 5 mg/L threshold in all three reservoirs. Sporadic exceedances of bacteria standards in Hobbs and Stony Brook weekly samples happened in only 1% of all reporting period samples.

All three reservoirs exhibited thermal and chemical stratification, despite artificial mixing by air hoses in Stony Brook Reservoir and Fresh Pond. The stratification produced anoxic or hypoxic conditions in the deepest parts of all the reservoirs and these conditions resulted in the release of phosphorus, iron and manganese from reservoir bed sediments. Trophic state indices (TSI), indicated that the lower basin of Hobbs Brook Reservoir and Stony Brook Reservoir were both intermediate in productivity with the potential to support algae blooms, and Fresh Pond was relatively unproductive and unlikely to produce algal blooms. These results show no significant differences from 1997/1998 measured TSI.

Major tributary stream sampling compared study period water quality to ambient Class A standards and historic results. Sampling frequency and lack of concurrent flow information made direct comparisons for some sights impossible. In general, stream water quality in dry weather for all contributing streams is good and meets Class A standards. Clear trends in increasing salt concentrations are apparent for

most streams where there are many salt treated impervious surfaces. Chloride levels in five streams exceed EPA recommended criteria for chronic aquatic toxicity and secondary limits for drinking water. Developed subbasins show significantly higher levels of measured constituents in wet weather from urban runoff.

The mass water balance estimates in Hobbs Brook Reservoir show that the time required for complete flushing of the reservoir during this study period averaged 7.7 months. Hobbs Brook reservoir retained much of the sodium, chloride, nitrogen and phosphorus from the tributary streams and discharges from Routes 2 and 128. Waterfowl and precipitation were insignificant as sources of nitrogen to the reservoir but may have been important as sources of phosphorus. The average detention time of Stony Brook Reservoir was approximately 11.9 days, with an average annual output to the Charles River of 8.2 billion gallons during the study period. The detention time for Fresh Pond during this period was approximately 3.8 months.

Introduction

This report describes the results of water quality monitoring efforts between 2008-2011, as part of a long-term ongoing study of the health and overall state of the City of Cambridge's drinking water supply. The water quality monitoring program was designed by the U.S. Geological Survey (USGS), in cooperation with the Cambridge Water Department (CWD), and is based in part on the results of a 1998 assessment of reservoir and stream quality (USGS, 2001). The assessment, which was conducted jointly by the USGS and the CWD, included a detailed analysis of the drainage basin and the identification of subbasins exporting disproportionate amounts of pollutants to the reservoirs. This information was then used to design the monitoring network which now makes up CWD's long-term water quality monitoring program.

The USGS/CWD partnership continues to this day and funds "real-time" water quantity and quality monitoring stations, data collection, and interpretive analysis. All data by USGS is public record and can be retrieved online at this URL.

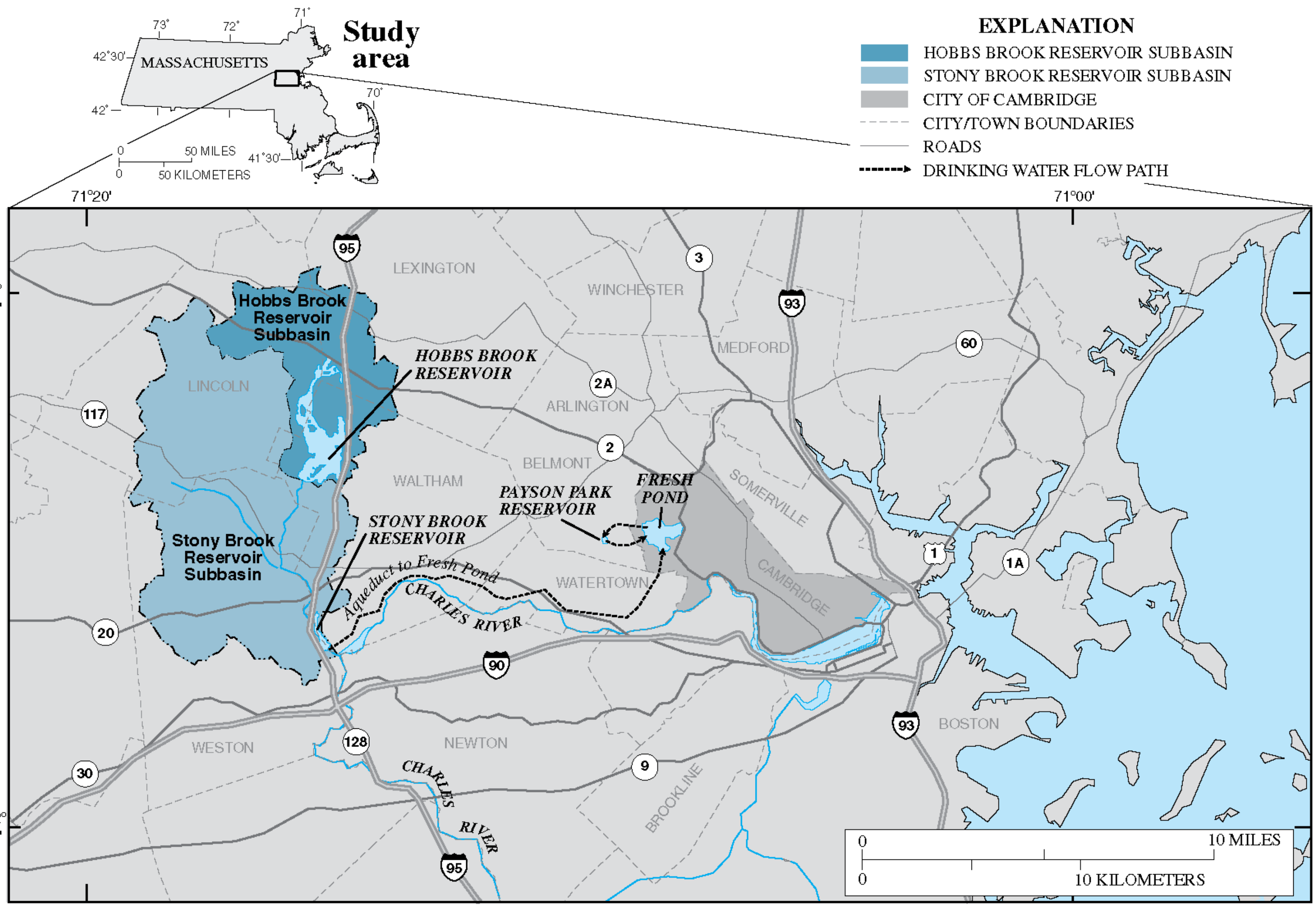
http://waterdata.usgs.gov/ma/nwis/current?type=cambrid&group_key=NONE&search_site_no_station_nm=&format=html_table

Purpose

The purpose of this report is to characterize source water quality for the City of Cambridge for the four year period ending in December 2011. The report uses water quality data from the 1998 USGS/CWD study as a baseline for comparison with data collected during the reporting period. Obtaining long-term water quality information is essential in guiding watershed management practices and informing water treatment operations. By understanding where certain water quality problems exist, City resources can be focused on these areas known to contribute contaminants to the reservoirs; in addition, watershed staff can evaluate the efficacy of management initiatives and re-prioritize their efforts if necessary.

The following sections describe the results of the water quality analyses conducted in each tributary and reservoir and provide a comparison to the USGS water quality study conducted in Water Year 1998. For a detailed discussion on the methods and process overview of the water quality monitoring program, refer to Appendix A.

Figure 1: Cambridge Water Supply Source Area



Water Supply Overview

The City of Cambridge obtains its water from the 24 square mile Stony Brook watershed located in the towns of Lincoln, Weston, and Lexington and the City of Waltham. This "upcountry" watershed is nested within the Charles River Basin and contains two major impoundments constructed in the 1890's, the Hobbs Brook and Stony Brook Reservoirs. Hobbs Brook Reservoir (also known as the Cambridge Reservoir) receives water from a 7 square mile subbasin and discharges into Hobbs Brook through a gatehouse on Winter Street in Waltham. Hobbs Brook joins Stony Brook further downstream, which flows into the Stony Brook Reservoir on the Weston, Waltham town line. From the Stony Brook Reservoir, water is fed by gravity through a 7.7 mile underground pipeline to Fresh Pond, a kettle pond in western Cambridge, located in the Mystic River Basin.

During high flow periods (mainly winter and spring), the primary source area for the water supply is the Stony Brook Reservoir and its watershed. During low flow periods (mainly summer and autumn), water is released at the Hobbs Brook dam to supply most of the City's daily water demand.

The Walter J. Sullivan Water Purification Facility within the Fresh Pond Reservation treats water from the Fresh Pond Reservoir. Treated water is pumped to Payson Park underground storage/treatment facility in Belmont, and then gravity fed to the City's distribution system. Capacity at full pool for the Hobbs, Stony, and Fresh Pond reservoirs is roughly 2.8 billion, 418 million, and 1.5 billion gallons respectively.

Monitoring Parameters

CWD monitors source water quality to assess general stream health and to inform treatment plant operators during the water treatment process. The most common parameters are listed and explained below.

E. coli – This *E. coli* bacteria serotype is found in the digestive systems of warm-blooded animals and is used as an indicator for sewage-related pathogens. Massachusetts Class A ambient water quality standards[1] state that no single sample shall exceed 235 Colonies/100mL.

Phosphorus – In this water supply, phosphorus is the limiting nutrient for aquatic plant and algae growth. Excessive phosphorus input can cause increased rates of eutrophication (water body productivity), leading to water quality impairments including, but not limited to, taste and odor problems in water supplies, and low dissolved oxygen availability for fish and wildlife. EPA phosphorus targets in this region are 0.02375 mg/L for streams and 0.008 mg/L for lakes/reservoirs.

Nitrate – Nitrate (NO_3), is a common inorganic form of nitrogen. In ambient waters, it is a nutrient for plant and algae growth, with EPA targets set at 0.31 mg/L for area streams, and 0.05 mg/L for lakes/reservoirs. Sources include septic systems and fertilizer runoff from agricultural uses, lawn maintenance, and turf-management. The drinking water maximum containment levels (MCL) is 10 mg/L.

[1] http://www.mass.gov/dep/service/regulations/314cmr04.pdf

Chlorophyll-*a* – Analyzing chlorophyll-*a* in the water column is a measure of suspended algae biomass and is used to characterize a reservoir's productivity/trophic state.

Dissolved Oxygen (DO) – Dissolved oxygen in water is critical to supporting a healthy fish and wildlife population. Low dissolved oxygen and anoxic conditions can mobilize nuisance metals such as iron and manganese and release nutrients from sediments. The first step in treating Cambridge Water is water oxidation through ozonation. Massachusetts Class A ambient water quality standards state that dissolved oxygen should not be less than 6 mg/L in cold water fisheries and 5 mg/L in warm water fisheries, unless natural background conditions are lower.

Specific Conductance – Specific conductance is the ability of water to conduct electrical current, normalized to 25°C. In the field, it is used as a surrogate for sodium and calcium chloride deicing agents. Abrupt changes in specific conductance can also be an indicator of pumping, dumping or other activities requiring investigation.

Iron/Manganese[2] – Iron and manganese in drinking water are not considered health hazards, but an excess can lead to staining and other aesthetic issues. These metallic elements are naturally-occurring in the earth's crust and soils. EPA Secondary Drinking Water standards for iron are 0.3 mg/L and 0.05 mg/L for manganese.

Sodium/Chloride– Sodium chloride is the most commonly used winter deicing agent in the Cambridge source watershed. Tracking sodium and chloride levels in the water supply helps steer efforts to reduce their use without compromising public roadway safety, thereby protecting long term water quality. High sodium levels are linked to hypertension in some individuals. Drinking two liters (~8 glasses) of Cambridge water is equivalent to ingesting approximately 140 milligrams of sodium (roughly equivalent to eating 1 tablespoon of catsup or margarine, or drinking 1½ cups of whole milk). Chloride concentrations above 250 mg/L in drinking water can give it a "salty" taste. According to EPA, chloride is considered toxic to aquatic life at 230 mg/L (four day average exceeds criteria at least once every three years; considered chronic toxicity)

Total Organic Carbon – TOC is used to quantify naturally-occurring organic matter in the water supply. When mixed with chlorine, carbon can react to form disinfection byproducts (Haloacetic acids and Trihalomethanes) nationally regulated and monitored by CWD.

Cambridge drinking-water source area water quality results are presented as box plots or truncated box plots. Box plots provide information on both the central value (median concentration) of each constituent and the variability and skewness of the data through quartile representation. In regular box plots, the maximum and minimum values are represented by the whisker ends, and the data quartiles are represented by boxes and the line between the box and the whisker end. In truncated box plots, the highest and lowest 10 percent of the data are not represented, and whiskers are drawn to the 10th and 90th percentiles of the data. Truncation allows the majority of the data to be plotted without

[2] http://water.epa.gov/drink/contaminants/index.cfm, a list of primary and secondary drinking water contaminants and their maximum contaminant levels (MCL). http://www2.cambridgema.gov/CWD/WaterQualityInformation.cfm, CWD drinking water testing results.

compressing the scale of the box to show extreme outliers; when appropriate, maximum measured concentrations will be reported in the discussion that follows.

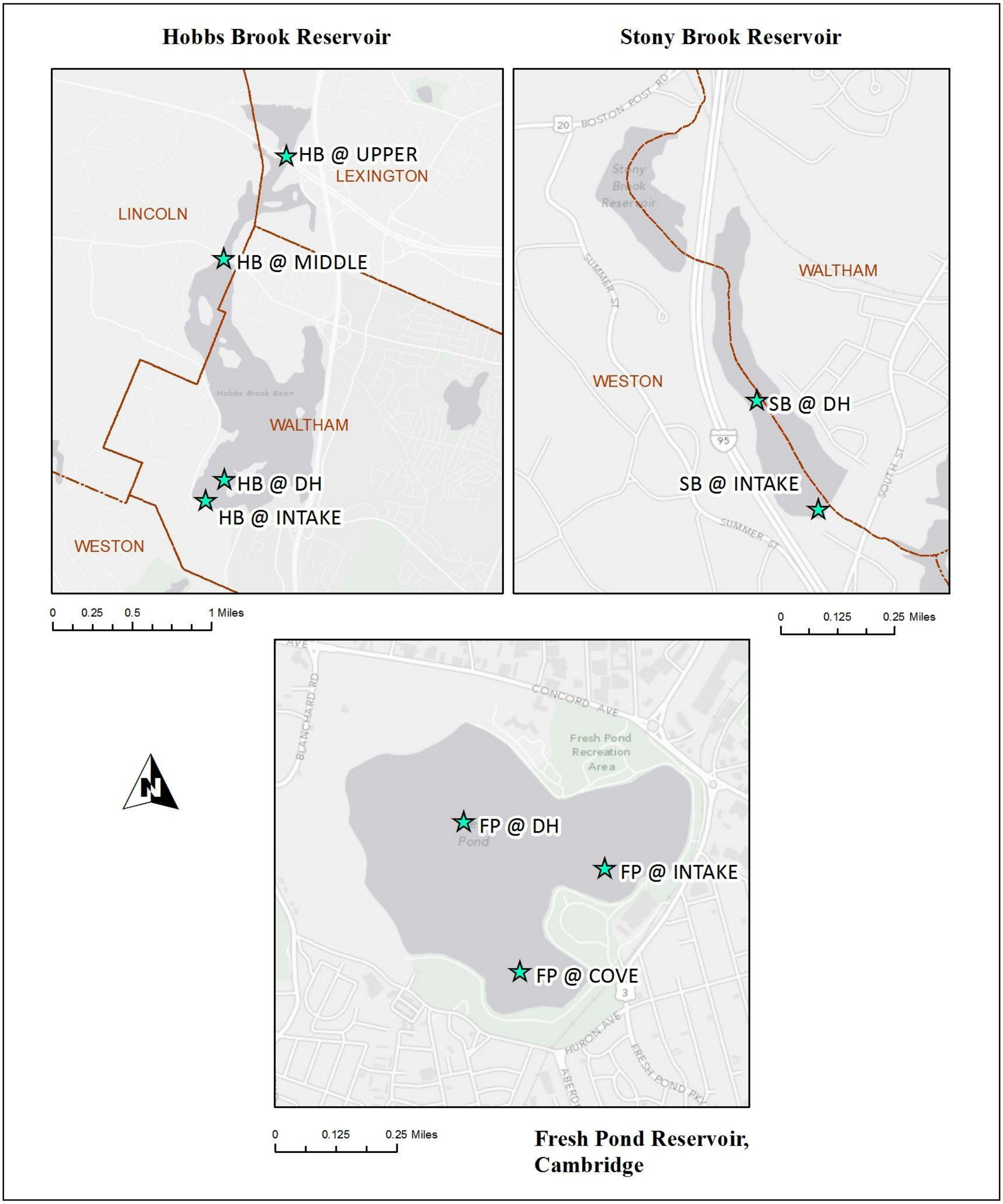
Reservoir Water Quality

The Hobbs Brook, Stony Brook, and Fresh Pond reservoirs are monitored for water quality on a regular basis. Hobbs Brook reservoir has four monitoring sites, two of which are sampled from the shoreline (HB@UPPER & HB@MIDDLE), and the other two (HB@DH and HB@INTAKE), sampled by boat at fixed mooring buoy locations. Stony Brook reservoir has two sampling sites sampled by boat (SB@DH, and SB@INTAKE), and Fresh Pond Reservoir has three sites (FP@COVE, FP@DH, FP@INTAKE) all sampled by boat (Figure 2).

Surface samples of chlorophyll-*a*, nutrients, selected metals samples and Secchi measurements are taken at the each reservoir's deep hole buoy (deepest point of the reservoir). During periods of thermal stratification, additional samples are taken at the hypolimnion. Depth profiles of dissolved oxygen, temperature, pH, turbidity, and specific conductance, are made both at deep hole sites and buoys close to the gatehouse or intake structures. In addition to in situ parameters, surface *E. coli* bacteria samples are taken at "intake" buoys.

Seasonal thermal stratification occurs in all reservoirs with implications on source water quality. In the spring, surface water begins to warm up, forming a distinct upper layer (epilimnion) of less dense water that will not mix with colder, denser bottom waters (hypolimnion). Biochemical processes in the isolated bottom waters require oxygen and can form reduced (anoxic) conditions. Nuisance metals and plant/algae nutrients normally bound to sediments can be released into the water column in the absence of an oxygenated environment.

Figure 2: Reservoir Sampling Locations



Hobbs Brook Reservoir

Hobbs Brook Reservoir is divided into three basins by State Route 2, Trapelo Road, and Winter Street. The upper and middle basins were not sampled during this reporting period (HB@UPPER and HB@MIDDLE), while the lower basin at the deep hole and intake buoys (HB@DH, HB@INTAKE) were sampled 12 times. The water column at the deep hole in Hobbs Brook reservoir generally shows signs of thermal and chemical stratification in April and fully stratifies by July, as shown in the figures below. By November, the water column can show relatively uniform temperature, but dissolved oxygen concentrations can still decrease with increasing depth, most likely due to incomplete physical mixing.

Figure 3: HB@DH Profile, April 2011

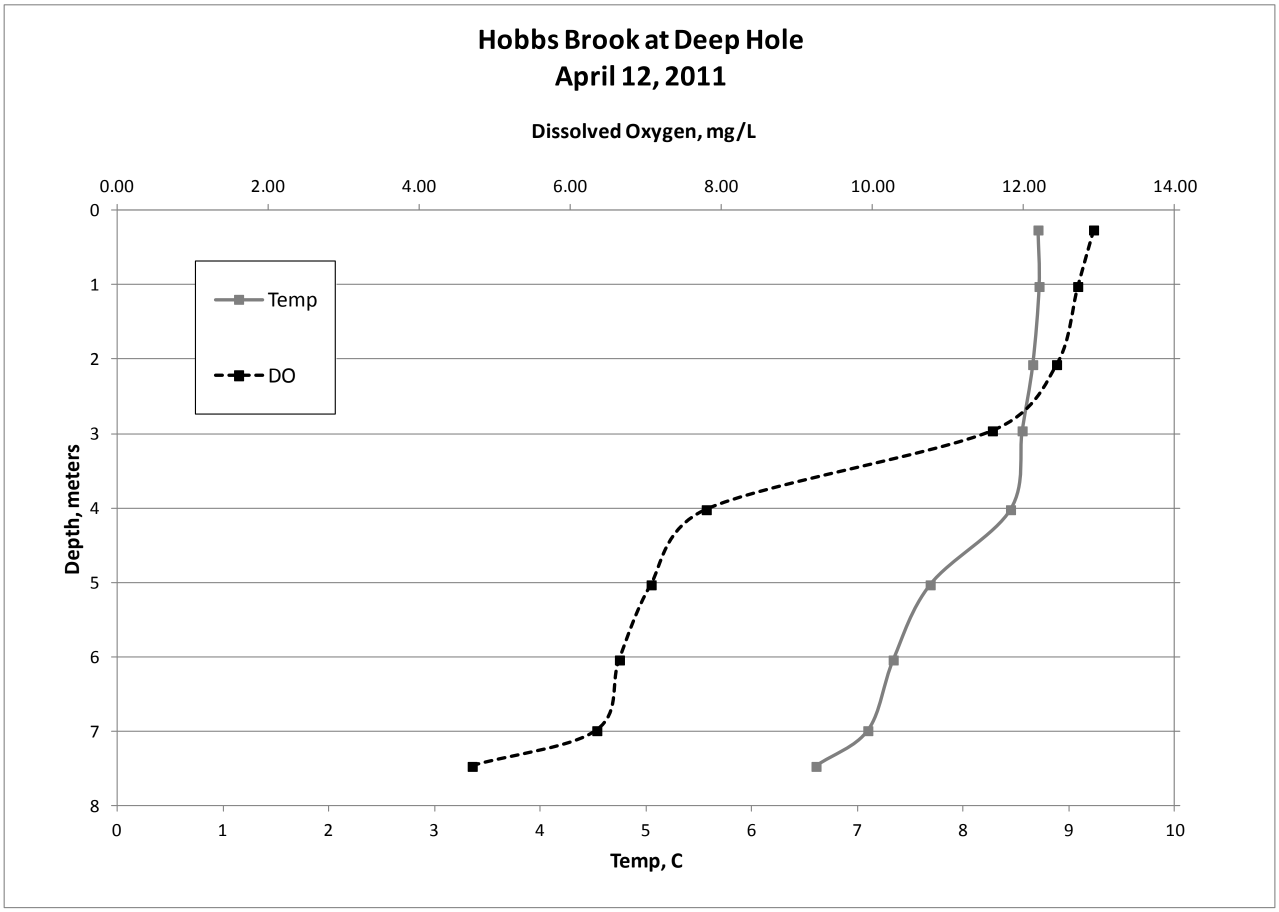


Figure 4: HB@DH Profile, August 2009

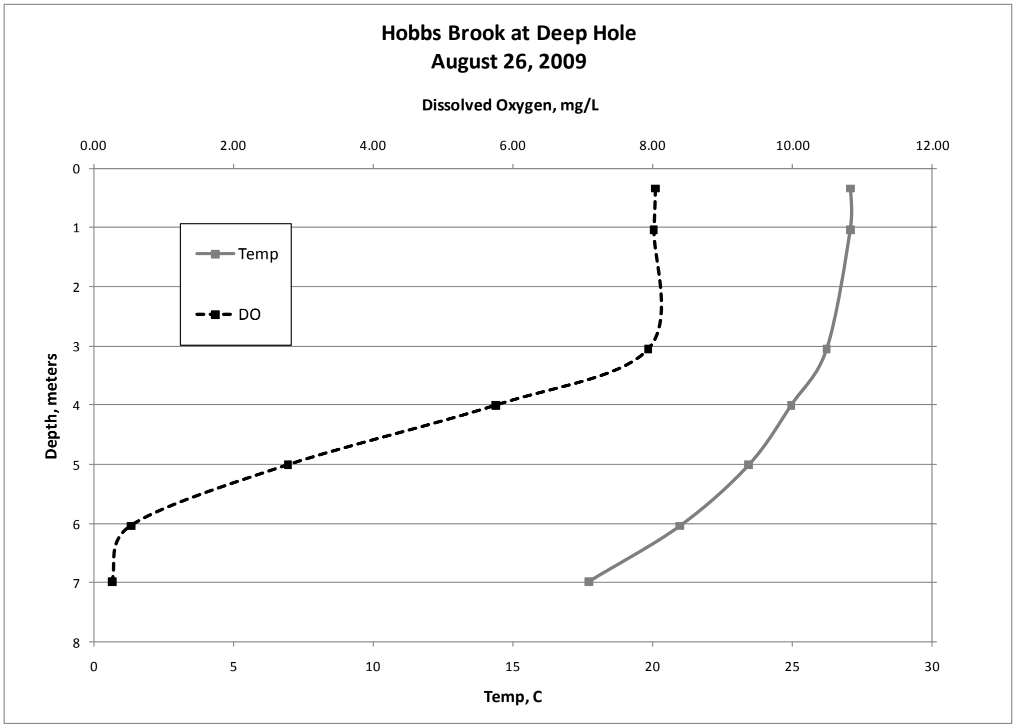
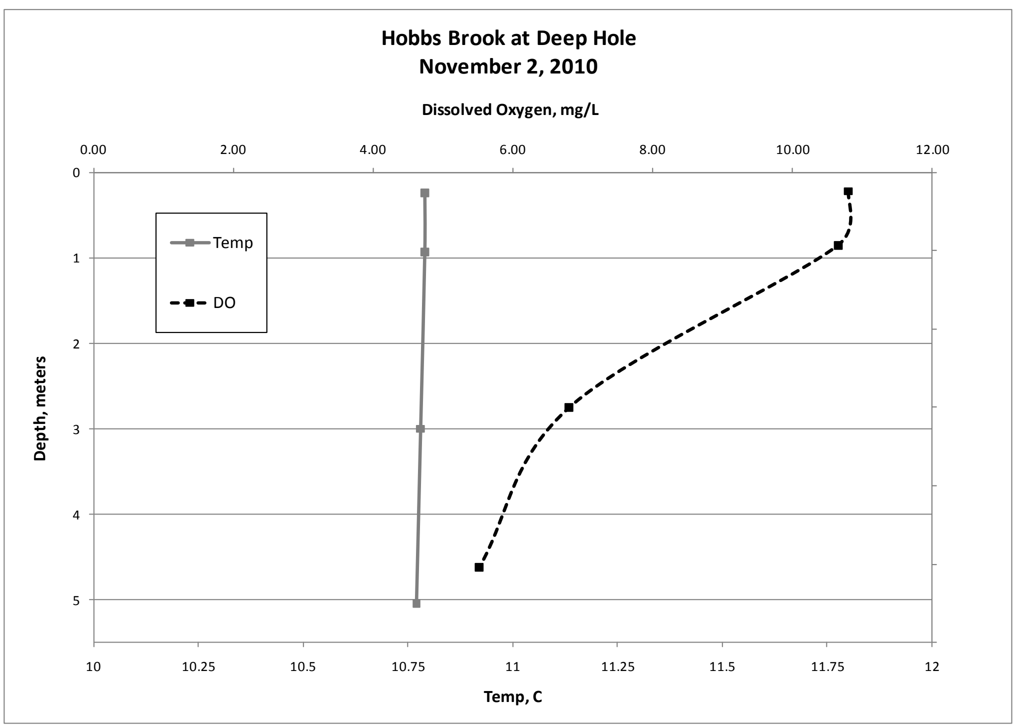


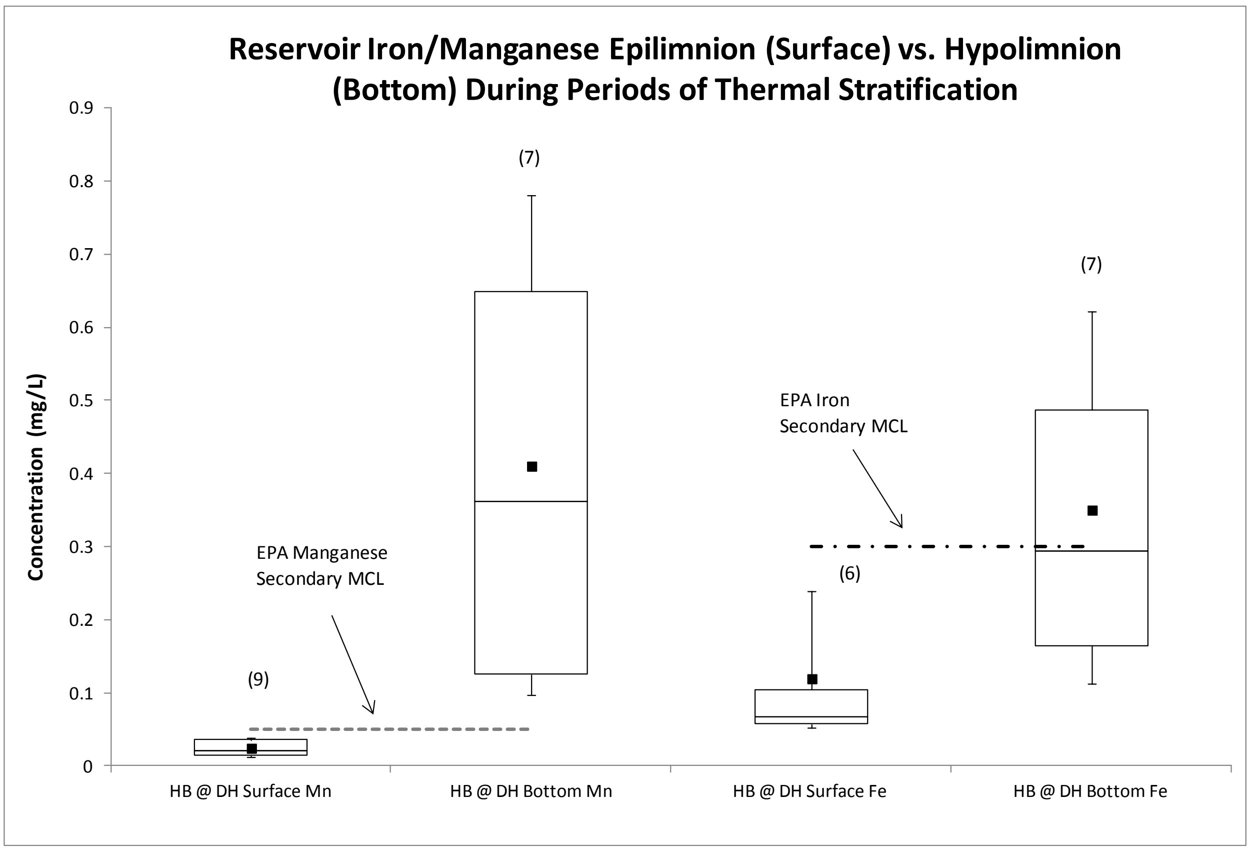
Figure 5: HB@DH Profile, November 2010

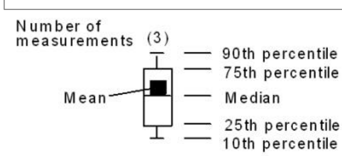


Under anoxic conditions, in addition to being a stressor to fish and other aquatic fauna, nuisance metals such as iron (Fe) and manganese (Mn) are reduced and released from benthic sediments into the water column. These metals are mixed into the water supply during spring and autumn turnovers. In finished (treated) drinking water, the EPA recommends a limit of 0.05 mg/L Mn, and 0.3 mg/L Fe. The CWD Water Treatment Facility consistently meets these standards in produced water, and reservoir sampling helps steer treatment adjustments.

During this study period, Hobbs Brook iron and manganese median concentrations differed by an order of magnitude from surface to bottom during periods of thermal stratification. Median manganese and iron concentrations at the surface are 0.021 mg/L and 0.068 mg/L, respectively; whereas median hypolimnion results are 0.362 (Mn) and 0.294 (Fe) mg/L (figure 6).

Figure 6: Hobbs Brook Reservoir Iron and Manganese, 2008 - 2011





Stony Brook Reservoir

Water-column sampling at the Stony Brook Reservoir was conducted 11 times from 2008 – 2011. During most years, Stony Brook is artificially mixed with an aeration system; however, the system was operated sporadically during this period and only consistently at the end of summer, 2011 for general maintenance. Similarly to Hobbs Brook Reservoir, and even with the aeration system operating, stratified conditions are generally observed from April to October, with select metals released from the sediments.

Figure 7: SB@DH Profile May, 2010

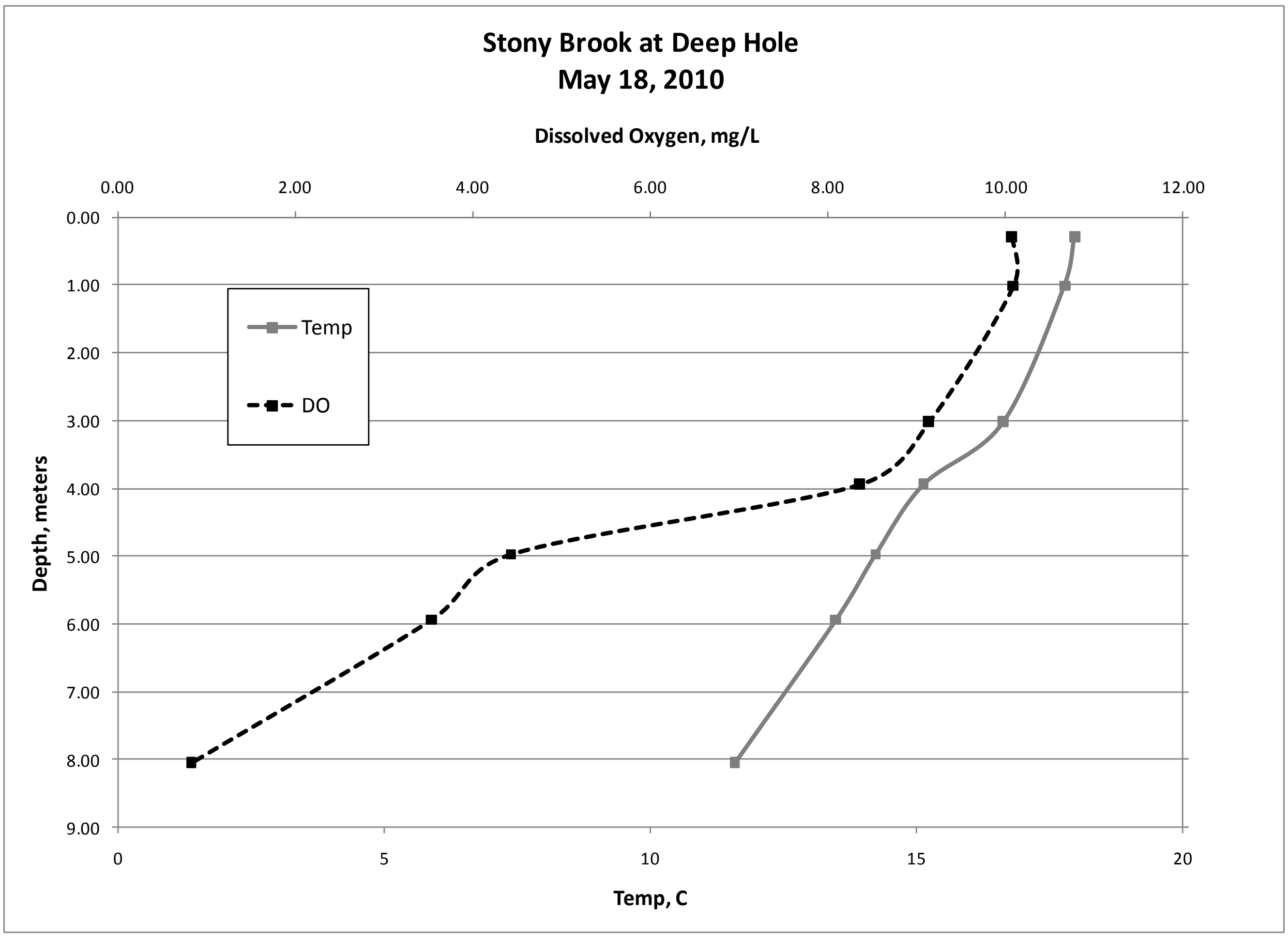


Figure 8: SB@DH Profile August, 2009

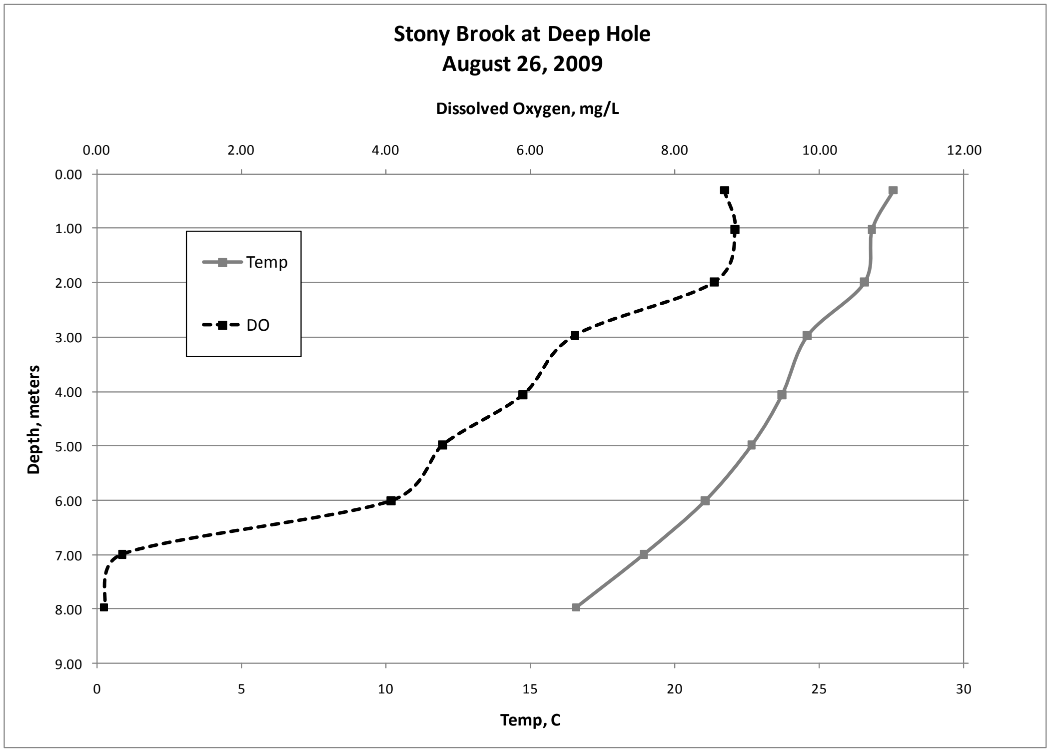
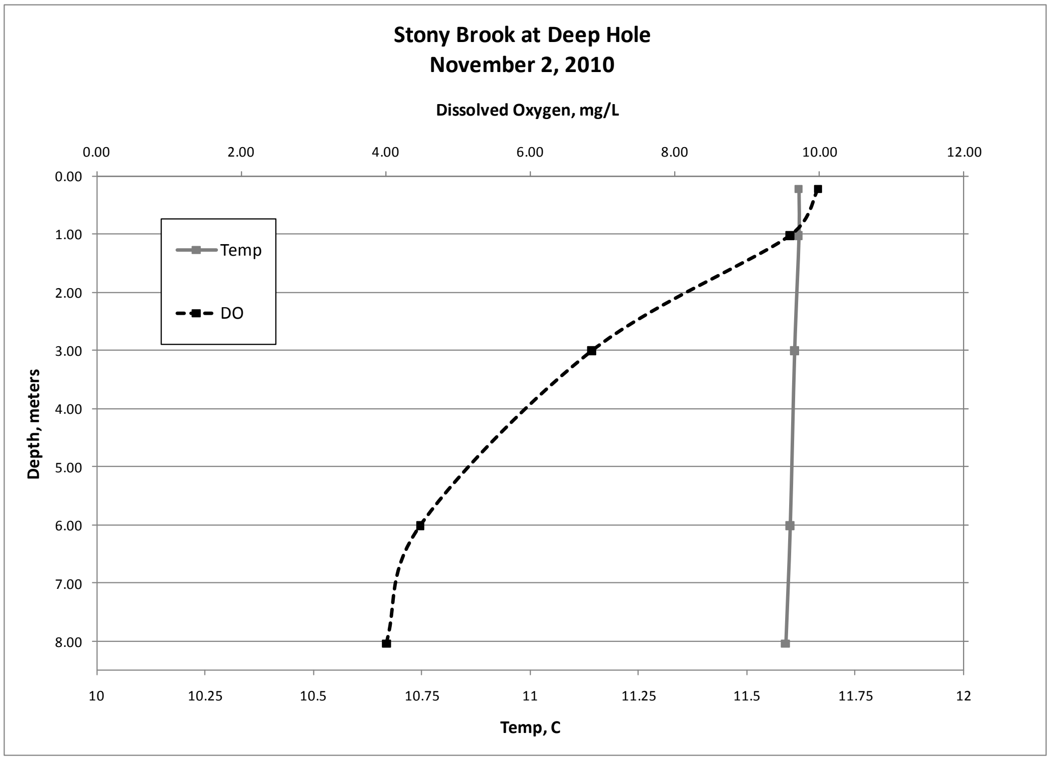
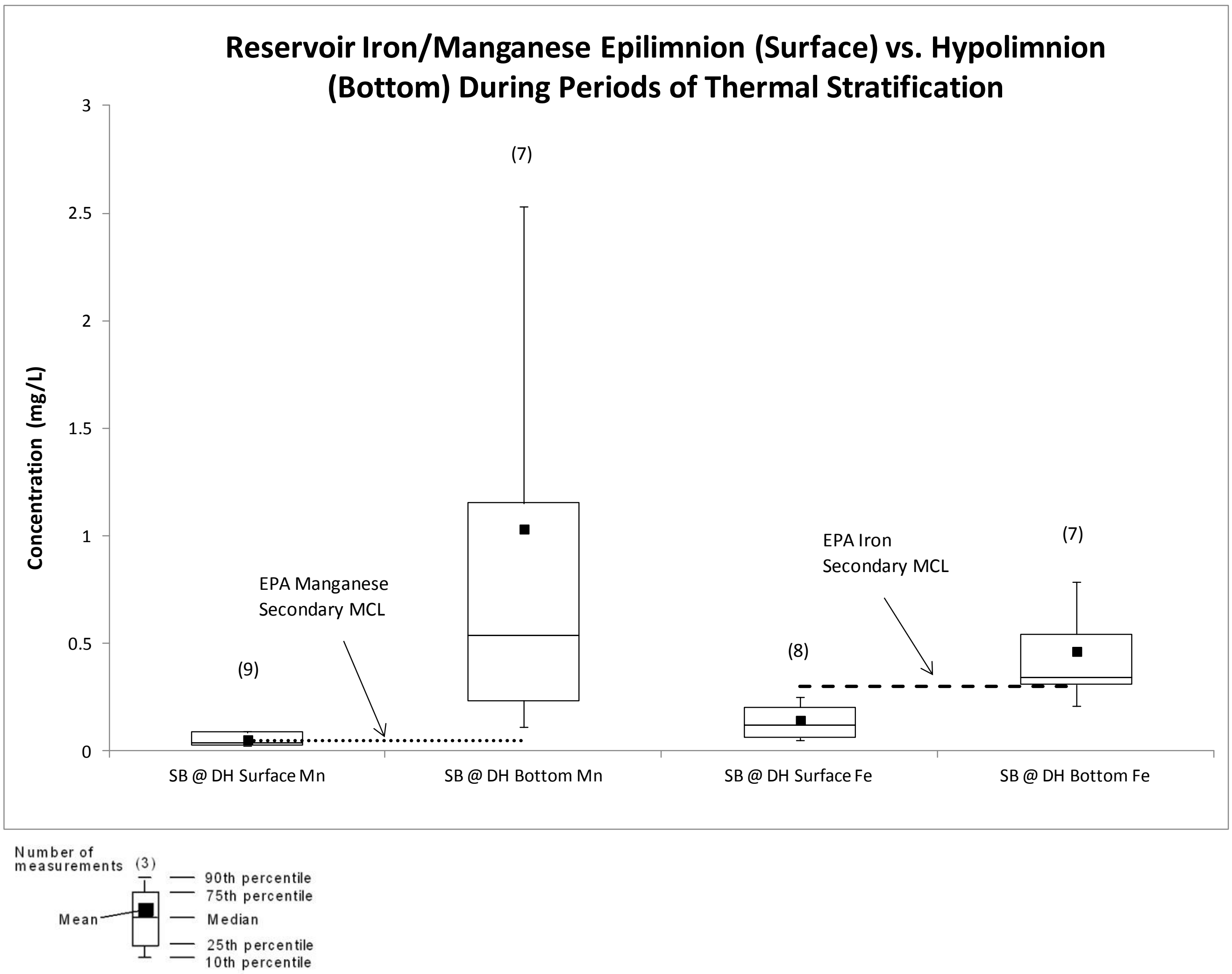


Figure 9: SB@DH Profile November, 2010



As in the Hobbs Brook reservoir, under anoxic conditions, nuisance iron and manganese were reduced and released from benthic sediments into the water column. During this study period, Stony Brook iron and manganese concentrations differed by 3 and 14 times respectively from surface to bottom during periods of thermal stratification. Median surface manganese and iron concentrations are 0.039 mg/L, and 0.122 mg/L and respectively, whereas median hypolimnion results are 0.537 (Mn) mg/L and 0.341 (Fe) (figure 10).

Figure 10: Stony Brook Reservoir Iron and Manganese, 2008 - 2011



Fresh Pond Reservoir

Because Fresh Pond is the terminal water supply reservoir, and its water is directly treated for drinking water purposes, monitoring and managing thermal stratification is particularly important. Spikes in nuisance metals concentrations, if not controlled in a timely fashion through the treatment process, could produce drinking water with taste, odor, color, or other aesthetic issues. Unlike Stony Brook reservoir, an aeration system operates continuously (overnight) throughout spring until the autumn turnover.

Water-column sampling was conducted a total of 13 times during this reporting period. In general, even with the aeration system, Fresh Pond will start to stratify in April and will begin to mix towards the end of September, beginning of October, depending on climate.

Figure 11: FP@DH Profile January, 2008

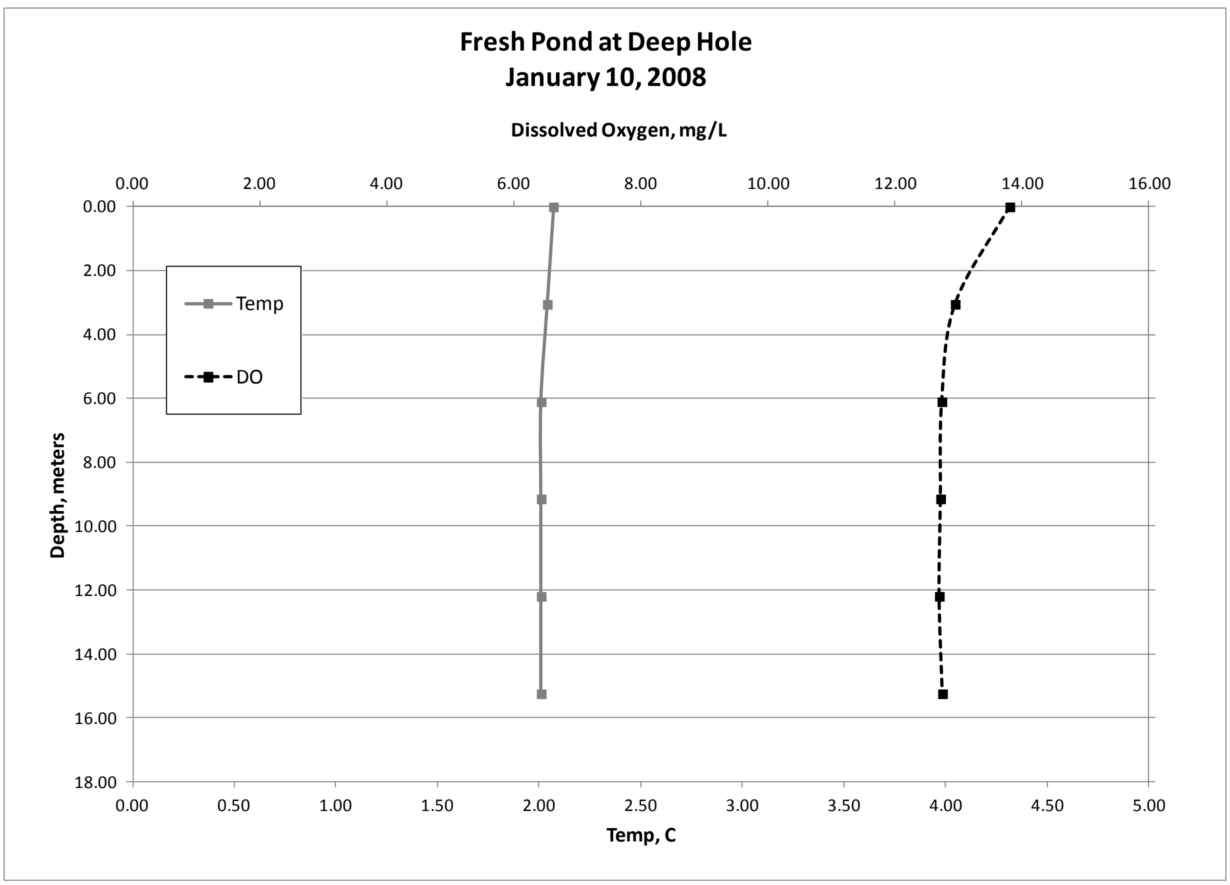


Figure 12: FP@DH Profile April, 2010

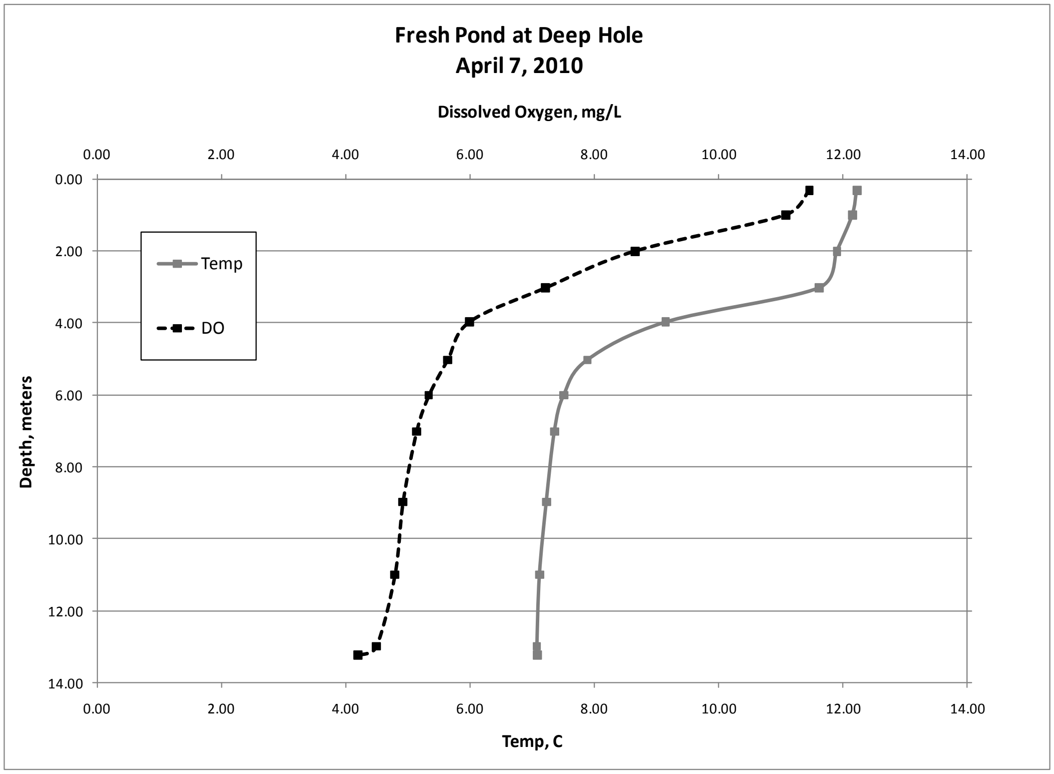


Figure 13: FP@DH Profile August, 2008

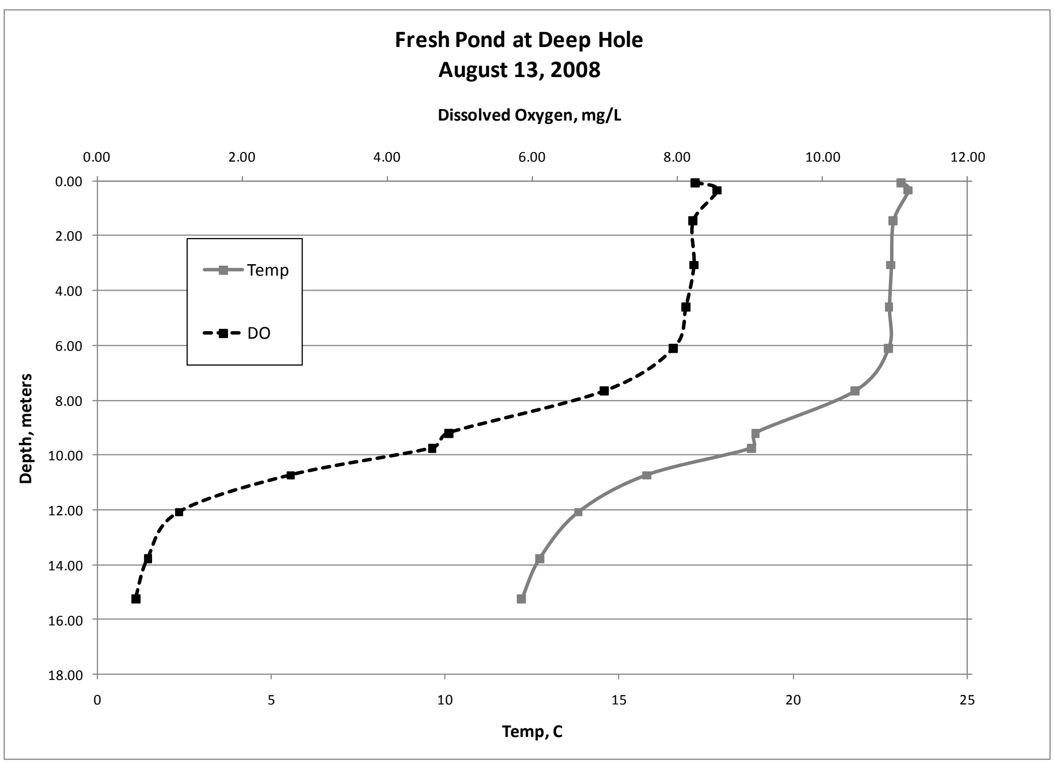
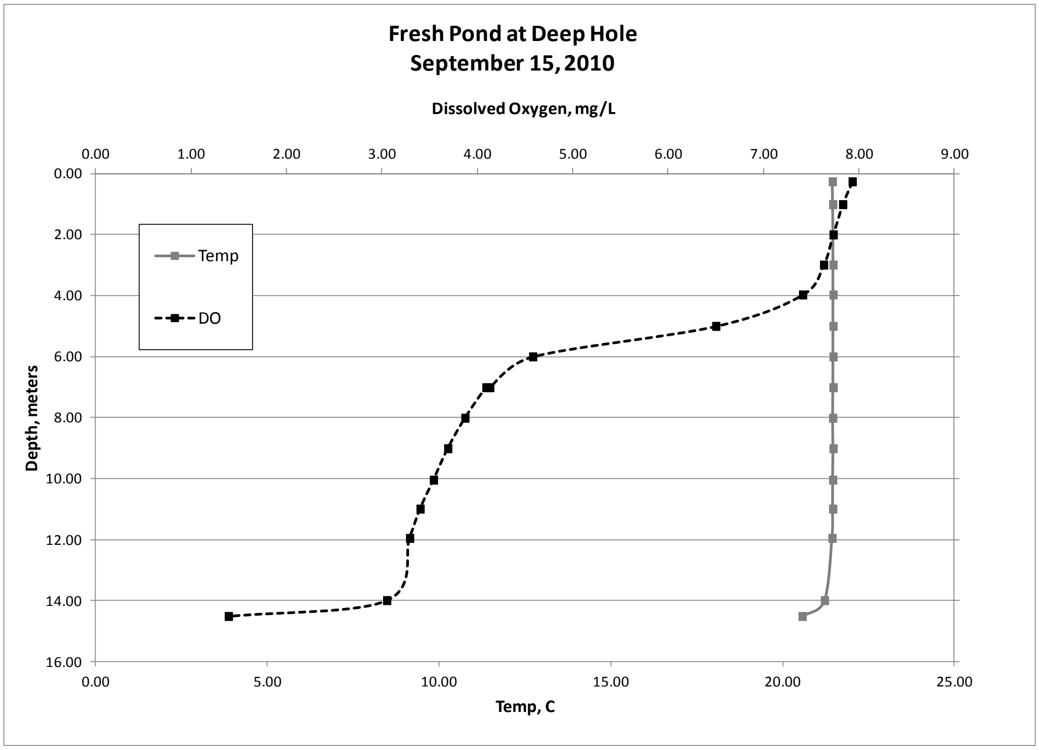
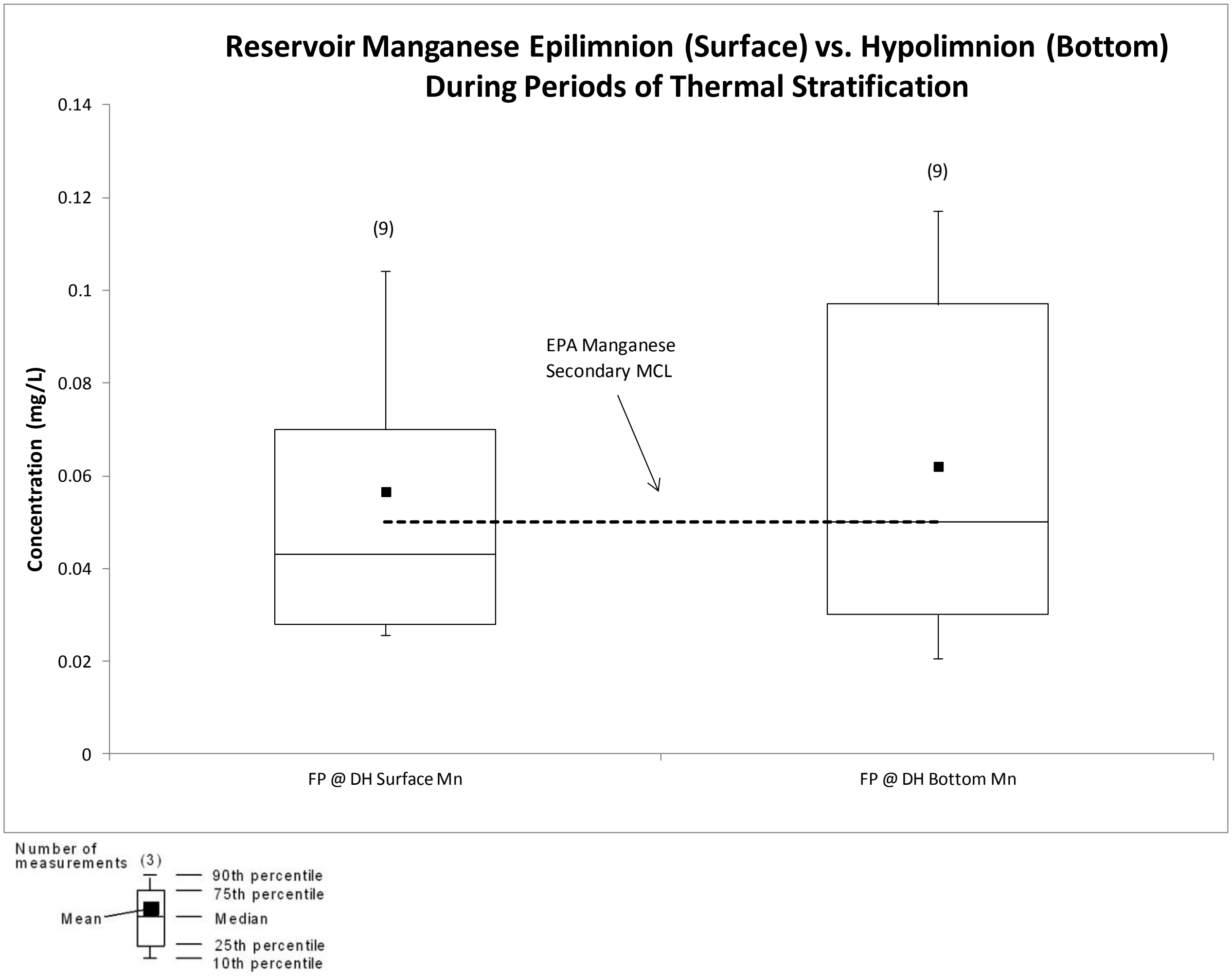


Figure 14: FP@DH Profile September, 2010



Fresh Pond iron and manganese concentrations were similar between surface and bottom samples (Figure 15). Unlike in Stony or Hobbs Brook reservoirs, median bottom manganese concentrations (0.05 mg/L) are only slightly higher than surface samples (0.043 mg/L) (Figure 10). Iron concentrations were most often below detection limit (0.05 mg/L) during this period. These results could be explained by the aeration system providing enough oxygen in the hypolimnion to avoid reducing conditions.

Figure 15: Fresh Pond Reservoir, Manganese 2008 - 2011



Reservoir Trophic State

Carlson's trophic state index (TSI) is a dimensionless numerical index ranging from 0 – 100, indicating the degree of nutrient enrichment of a water body. TSI values less than 40 indicate low productivity (oligotrophic) and minimal external nutrient loading. Values ranging between 40 and 50 indicate moderate productivity (mesotrophic) and intermediate external nutrient loading. Values greater than 50 are considered highly productive (eutrophic) and likely to produce algal blooms.

Table 1: Trophic State Index Explanation, Water Quality Implications

A list of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient

TSI	Chl (ug/L)	SD (m)	TP (ug/L)	Attributes	Water Supply
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Water may be suitable for an unfiltered water supply.
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	
40-50	2.6-7.3	4-2	12-24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Iron, manganese, taste, and odor problems worsen. Raw water turbidity requires filtration.
50-60	7.3-20	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Episodes of severe taste and odor possible.
70-80	56-155	0.25-0.5	96-192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	

*http://www.secchidipin.org/tsi.htm#Relating%20Trophic%20State%20to%20the%20State%20of%20the%20Waterbody

TSI was calculated from chlorophyll-*a* concentrations collected during the growing season and compared to the TSI values from the 1997/1998 USGS/CWD study to determine general, long-term trends. Chlorophyll-*a* is directly affected by nutrients in the water column and therefore provides a good indicator of overall water quality.

During this reporting period, the median TSI (44) for Hobbs Brook reservoir lower basin (HB@DH) was slightly higher than that of the 1997/1998 USGS study (38). Compared to USGS results (TSI = 35), median Stony Brook TSI between 2008 and 2011 (41) is also higher, yet median Fresh Pond TSI (31) was lower than the USGS median value (33). Although in two instances, higher median TSI values were observed, ranges of values are very similar, indicating that the three reservoirs have not significantly changed in terms of their productivity when compared to 1997/1998 results. Due to the variability of TSI between growing seasons, further analysis is needed to determine a statistical trend in reservoir productivity over the years.

Figure 16: Three Reservoir Chlorophyll-*a* Comparison

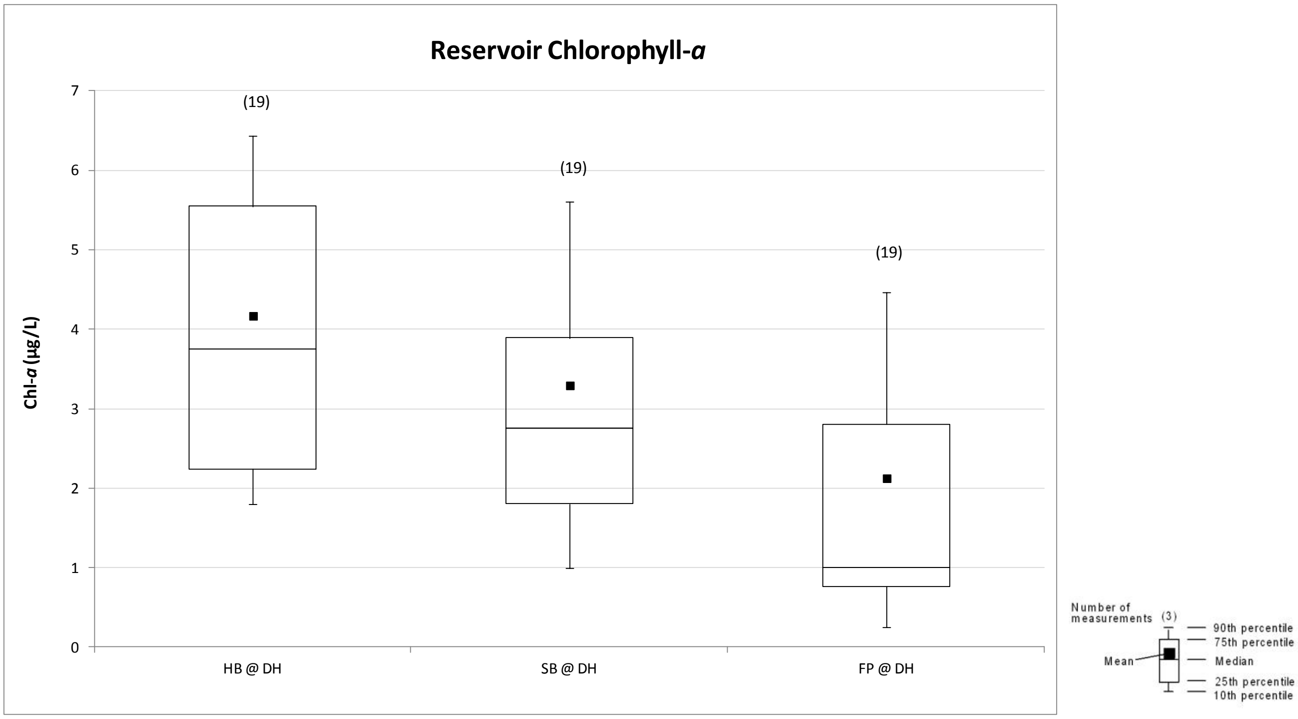
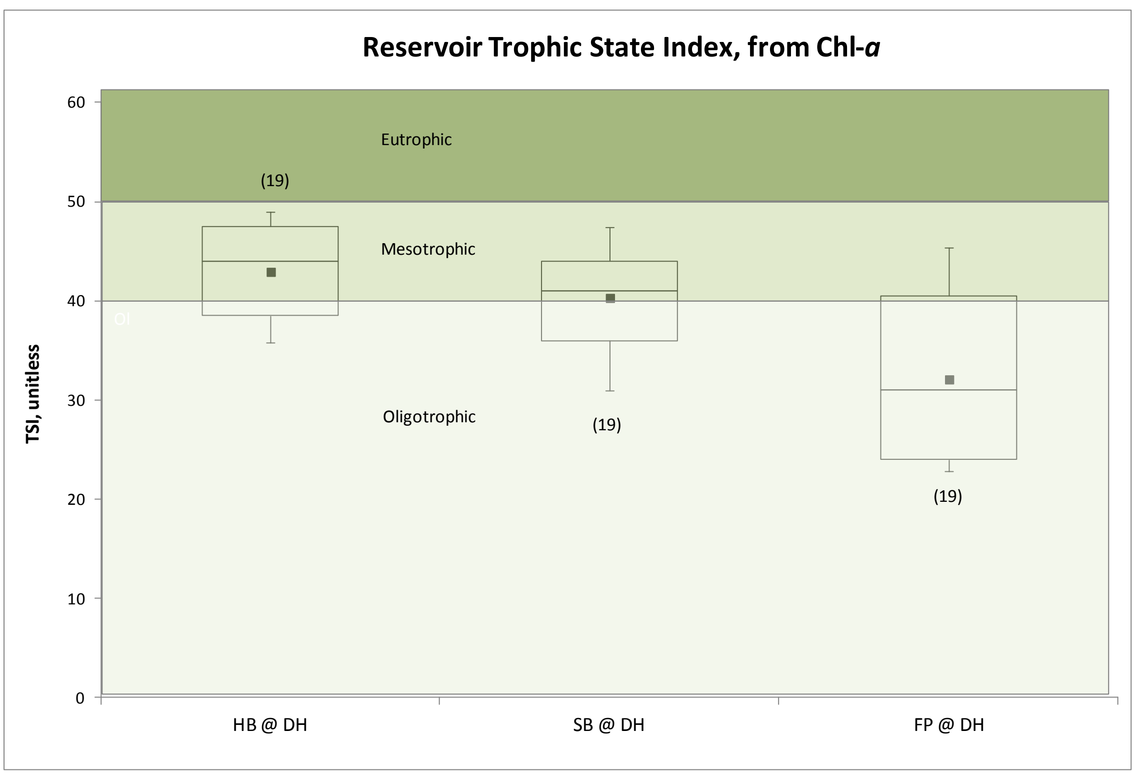


Figure 17: Reservoir Trophic State Indices, from Chlorophyll-*a*



The decrease in TSI values from Hobbs Brook Reservoir to Fresh Pond (figure 16) indicates an overall cascade effect in the Cambridge water supply system. Each reservoir acts as a settling basin which allows suspended sediments and associated constituents to settle to the bottom of each reservoir thereby improving the quality of the water as it moves through the watershed. By the time source water reaches Fresh Pond, it is relatively free of suspended solids. Sampling results over the years support this phenomenon.

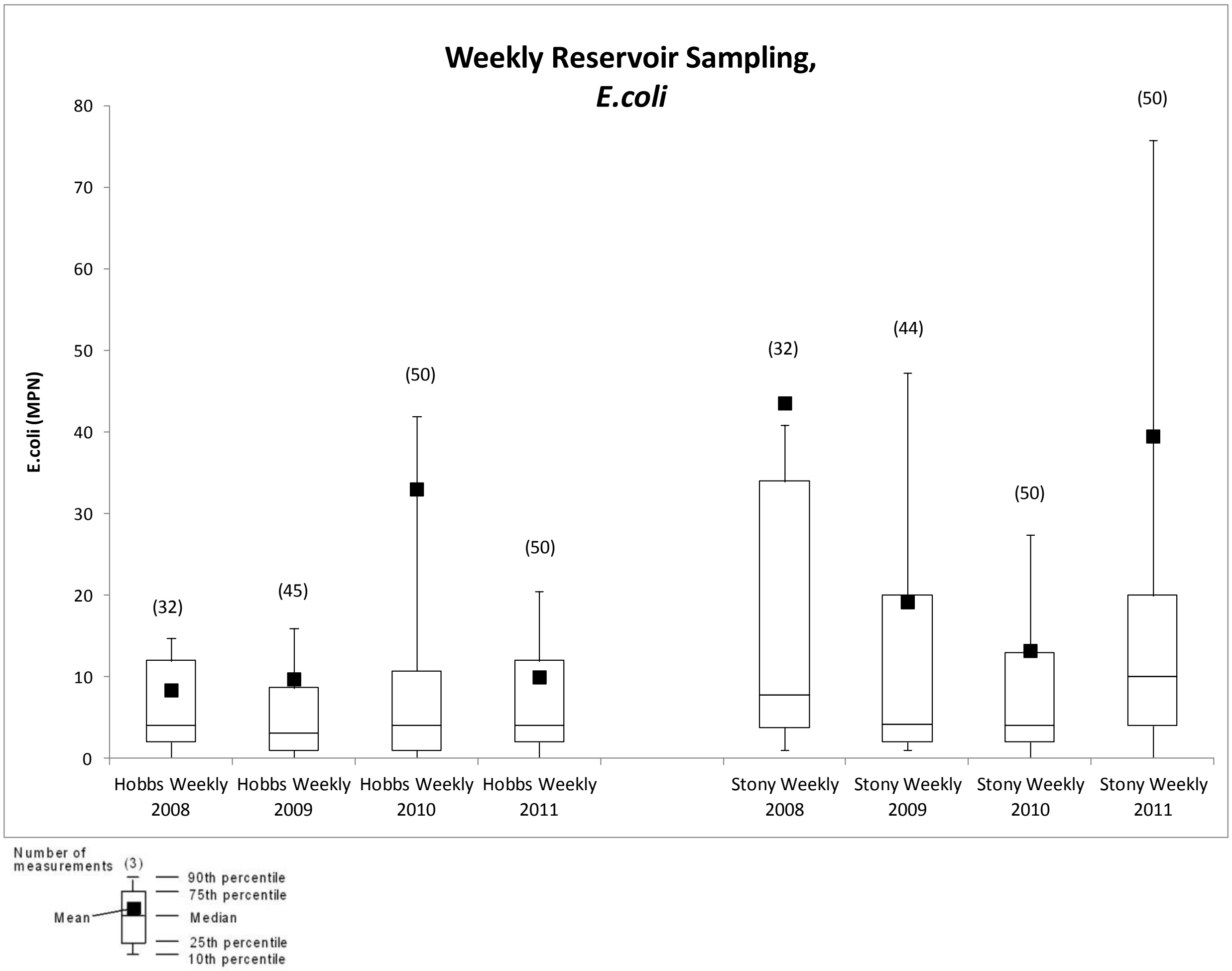
Weekly Reservoir Samples

Reservoir samples are collected weekly by Watershed Division staff and analyzed in-house to help steer treatment efforts. These frequent monitoring events capture seasonal and climatic variability and can be used to track chemical concentration changes over time. Samples are analyzed primarily for *E. coli* bacteria, select metals, TOC, and Specific Conductance.

At Hobbs Brook Dam, surface grab samples are collected inside the gatehouse, or when the reservoir is frozen over, from the dam outlet. At Stony Brook Dam, samples are pulled from spigots that draw water from the reservoir at three different depths, roughly corresponding to gate invert elevations. The sample is pulled from whichever gate is contributing the most flow to Fresh Pond via the Stony Brook Conduit.

In the past four years of weekly reservoir bacteria sampling, only 4 violations of single sample water quality criteria were captured in the Hobbs and Stony Brook reservoirs, meaning water quality for bacteria meets or exceeds Massachusetts Class-A water quality standards 99% of the time. Distributions of bacteria results are illustrated in figure 18. Wider bacteria ranges and larger averages for Stony Brook reservoir relative to Hobbs Brook reservoir could be from its "flashiness" or greater influence to stormwater runoff from its smaller storage and larger contributing area.

Figure 18: Weekly Bacteria Monitoring, Hobbs and Stony Brook Reservoirs



The Cambridge source watershed contains much impervious cover in the form of major highways (State Routes 2 and 128), smaller roads, and parking areas that contribute deicing chemicals to the water supply. In an effort to track changes over time, sodium and chloride are also analyzed in weekly grab samples. Because neither ion can be removed in the water treatment process, CWD strongly encourages MassDOT, watershed municipalities, and large commercial properties to adopt technologies that quantify, minimize, and target applications to decrease the amount of chemical used, and ultimately, reduce the burden placed on receiving waters in their attenuation. As a surface water supply, freshwater dilution is currently the most effective way to treat road salts to acceptable concentrations.

Median chloride concentrations in the Hobbs Brook Reservoir are below, but close to State and Federal drinking water and ambient toxicity standards (figure 19). In 2008, 21% of samples were above the EPA/DEP chronic aquatic life exposure limit, 11% in 2009, zero in 2010, and 12% in 2011. Further analysis is recommended to track changes in exceedance frequencies over time. No chloride standard exceedances were observed in weekly samples collected at Stony Brook reservoir between 2008 and 2011. Median chloride concentrations from this study period are higher in both reservoirs compared to 1997/1998 USGS results (figures 20 and 21).

Figure 19: Weekly Chloride Monitoring, Hobbs and Stony Brook Reservoirs

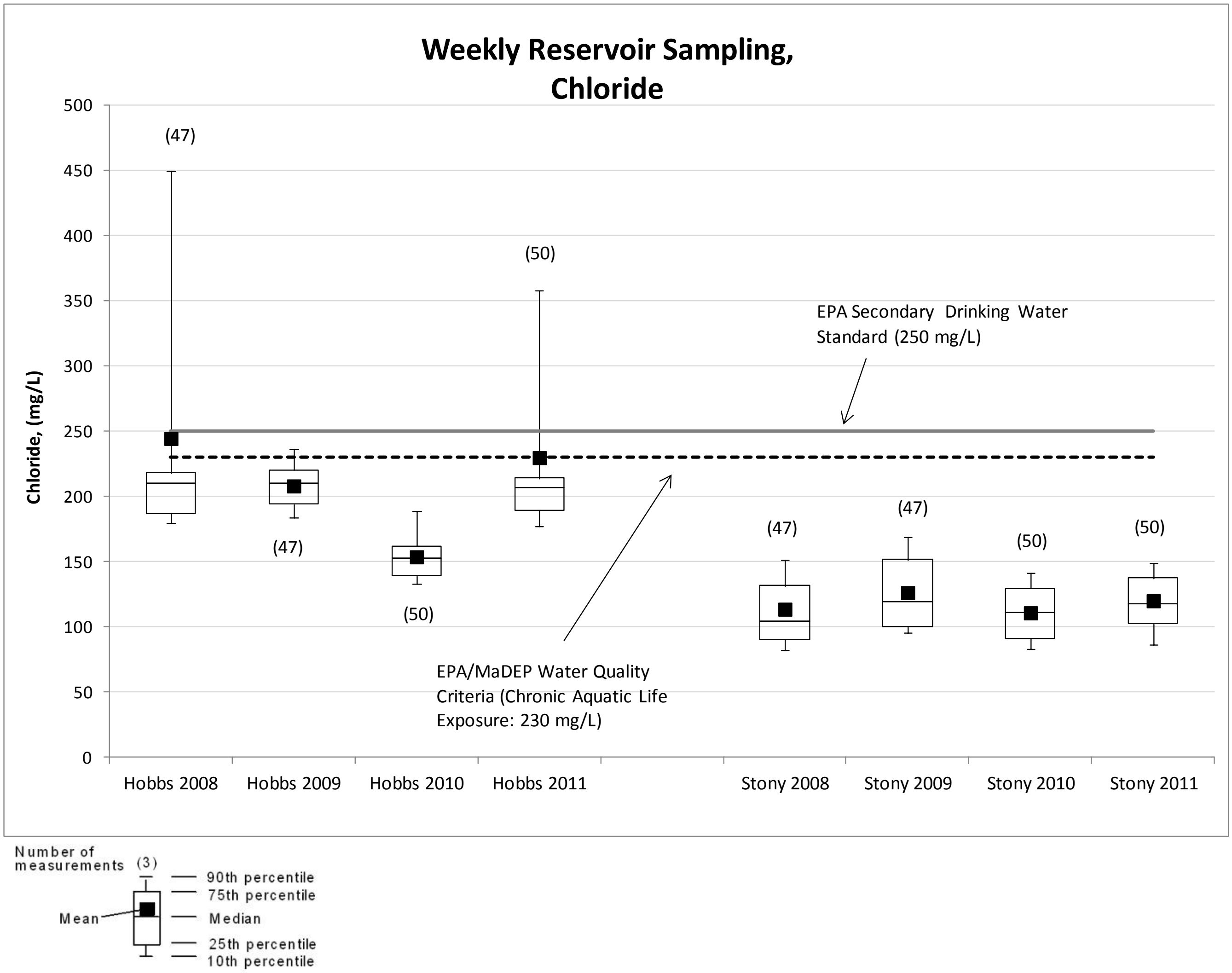


Figure 20: Chloride Comparison, Hobbs Brook Reservoir

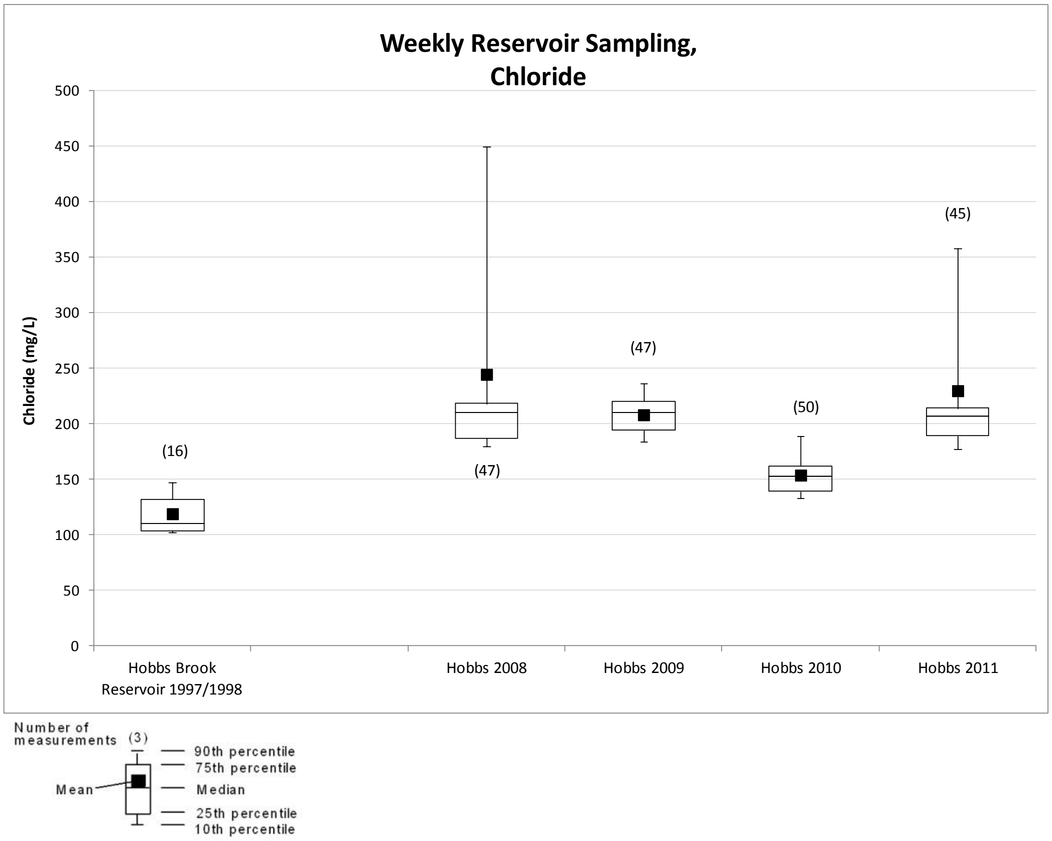
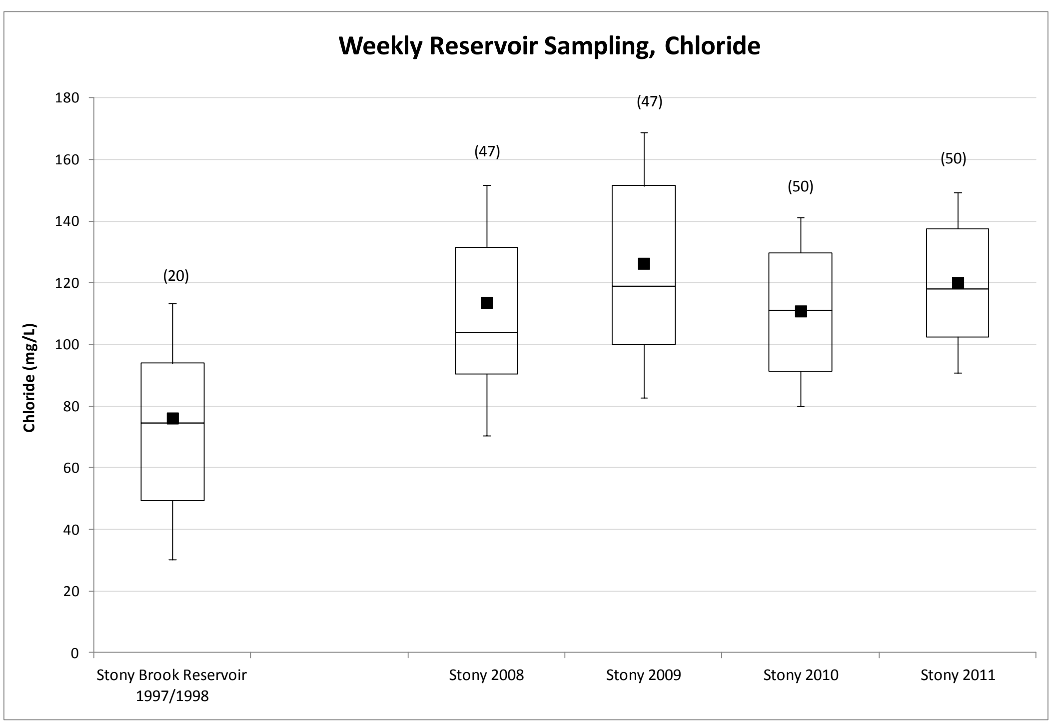
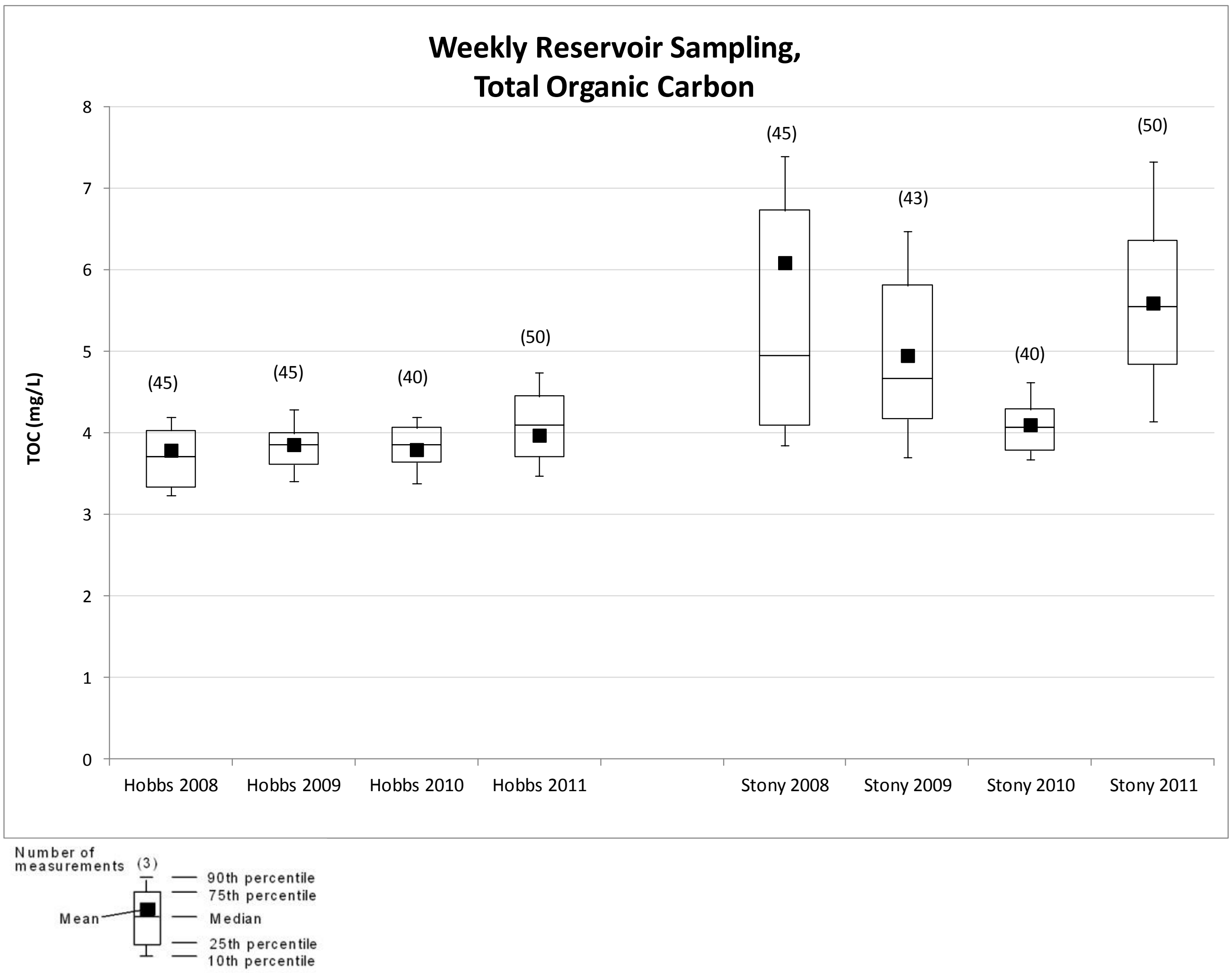


Figure 21: Chloride Comparison, Stony Brook Reservoir



Review of the total organic carbon results from 2008 - 2011 (figure 22) showed consistently lower median concentrations at both Hobbs Brook and Stony Brook reservoirs when compared to the 1997/8 median results (5.8, 7.4 mg/L respectively). Ranges of values are similar with no clear indicators of significant changes over time. Differences in median values could also be explained by the higher sampling frequency during this study period.

Figure 22: 2008 - 2011 Upcountry Reservoir Total Organic Carbon



Tributary Water Quality

Sources of sewage-related bacteria, sodium, chloride, nitrate, total phosphorus, and manganese (among other parameters) entering Hobbs Brook and Stony Brook Reservoirs were identified and quantified over a 4-year period. In situ measurements were taken concurrently with a calibrated water quality multiprobe for temperature, pH, specific conductance, dissolved oxygen and turbidity. For water quality samples with concurrent streamflow measurements, load estimates were normalized to subbasin areas to calculate instantaneous yields.

Stream discharge was measured with an acoustic doppler velocimeter according to Rantz and others, 1982. Stage was converted to discharge based on measured stage-discharge relations. When flow measurements were not made in areas with staff gages, the stage-discharge relation established from previous measurements was used to determine discharge. Currently eight of the 11 primary tributary monitoring stations are equipped to continuously monitor stream stage, temperature and specific conductance. Characteristics of each subbasin in terms of percent areal coverage of 21 land use/land cover categories, minimum, maximum, and mean, slope, and surficial geology are provided in the 2001 USGS report (See *References* Section). Updates using 2005 MassGIS 37 land use/land cover categories are provided in the following table (table 2).

All 11 primary tributary sampling sites (Figure 23) were sampled approximately eight times during the study period. Water samples for chemical analyses were collected at stream and reservoir sampling stations using clean-sampling protocols (Wilde and others, 1999) for all aspects of sample collection, preservation, and transport. Samples were collected by the centroid dip technique (Edwards and Glysson, 1999).

Figure 23: Tributary Monitoring Stations

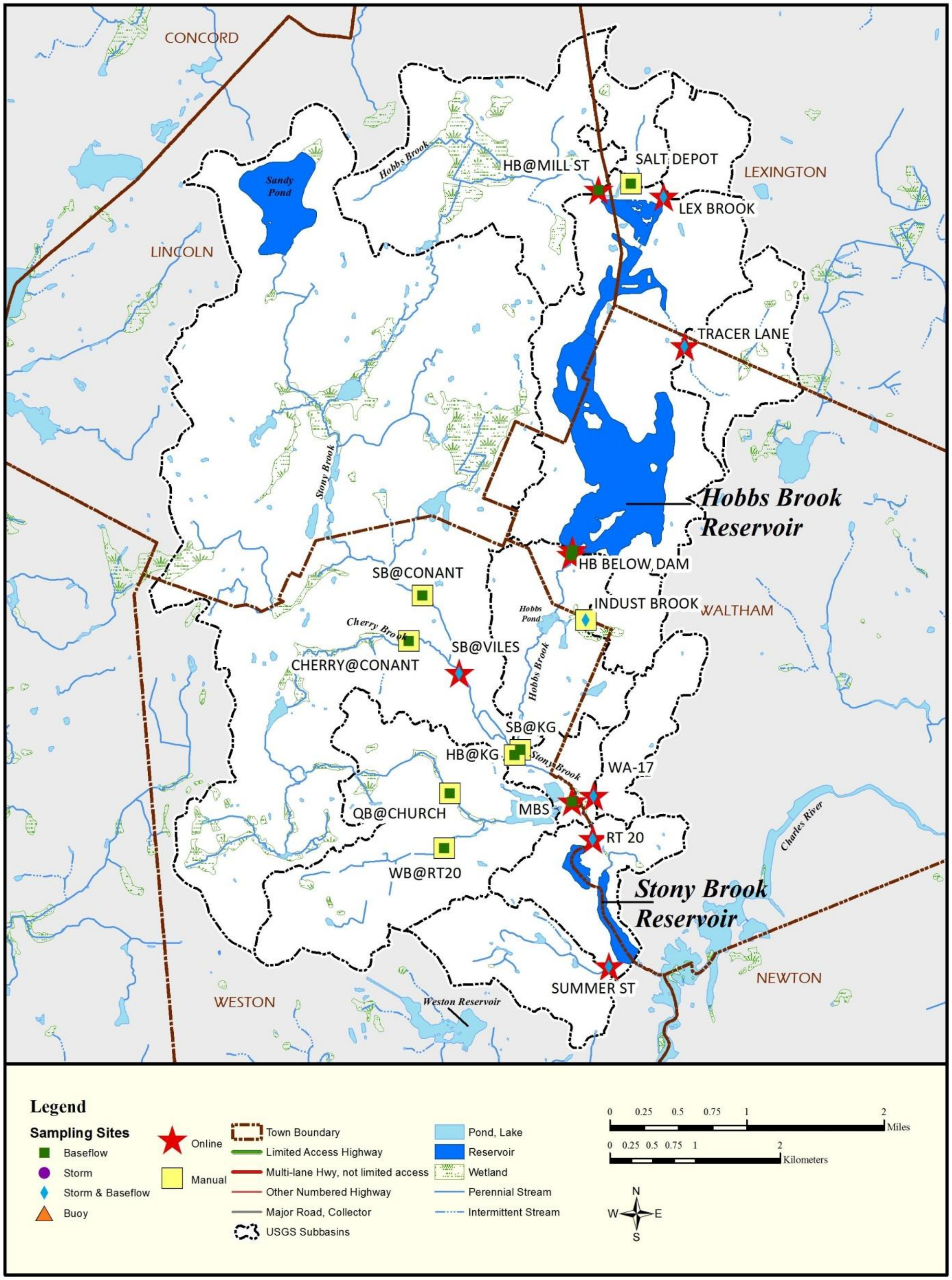


Table 2: 2005 MassGIS Land Use Classification, Percent by Area per USGS Subbasin

	Sampling Station ID													
2005 MA Land Use	**01104405**	**01104410**	**01104415**	**01104420**	**01104430**	**01104433**	**01104370**	**01104440**	**01104453**	**01104455**	**01104460**	**01104475**	**01104480**	**Watershed Total**
Forest	56.58	50.35	27.05	27.2	32.68	12.13	47.1	49.2	42.3	39.77	23.17	45.07	38.66	43.26
Low Density Residential	7.23	0.14	6.94	7.33	2.59	0.06	18.08	18.75	21.31	0.04	9.41	20.6	19.21	13.86
Forested Wetland	20.79	10.5	0.28	11.16	2.62	8.09	11.49	5.11	9.42	0.92	2.47	3.01	1.13	9.33
Water	0.29			0.13	29.33	0.26	3.78	1.47	0.43	0.17	8.48	1.27	16.31	6.49
Commercial		8.29	3.4	9.26	8.19	35.77	0.82	5.01	1.21	7.92	15.98		1.58	3.32
Cropland	3.17		0.97	0.27	0.05		4.89	1.25	1.21			1.87		2.74
Non-Forested Wetland	1.95	7.26	1.27	1.71	0.84	0.63	3.71	3.41	3.46		4.61	0.63	0.4	2.73
Medium Density Residential			24.46	10.48	9.52		0.33		2.84	6.62	0.15	0.29	0.32	2.69
Very Low Density Residential	3.13	0.01		0.14	0.73		3.89	1.22	3.69	0.25		3.38	0.45	2.66
Transportation		0.1	16.12	6.61	5.89	10.82	0.54	0.04		10.6	4.12		6.27	2.24
Industrial		5.41		5.98	4.92	32.03	0.11	5.7		17.19	3.17	0.04		2.16
Urban Public/Institutional	1.55	4.56	2.24	1.7	0.67	0.21	1.03	1.73	4.58	0.06	1.54	1.38	7.09	1.69
High Density Residential			15.48	16.27	0.07					6.78			7.26	1.24
Pasture	1.58	1.36			0.17		1.27	1.16	1.64			4.23		1.11
Multi-Family Residential			0.09	0.22	0.02		1.22	3.21	0.45	0.48	7.82			0.88
Open Land	1.09	3.68	0.47	1.55	0.37		0.8	0.92	0.87		4.1	0.37	0.56	0.84
Golf Course									1.16			16.75		0.71
Participation Recreation	1.17	0.82	1.22		0		0.49	1.82	2.25			0.61	0.14	0.69
Powerline/Utility	0.08	7.51			1.34		0.13		0.68	7.45	1.86			0.6
Cemetery	0.72								2.17					0.27
Mining									0.36	0.15	12.33		0.32	0.23
Brushland/Successional	0.3						0.02					0.48		0.06
Orchard	0.15						0.07							0.05
Spectator Recreation	0.05						0.08						0.3	0.05
Junkyard										1.61	0.6			0.04
Waste Disposal	0.18						0.06							0.04
Transitional							0.03		0		0.19			0.02
Water-Based Recreation							0.05							0.02

The following discussion highlights significant findings of tributary monitoring from north (upstream) to south (downstream), throughout the watershed and provides a qualitative comparison of these findings with the 1998 USGS Study in order to observe any potential long-term trends in water quality. These findings relate to land use within each drainage area and implications for further study as well as watershed protection practices.

Hobbs Brook at Mill Street (01104405)

Hobbs Brook is one of three stream-tributaries that convey water to the upper basin of Hobbs Brook Reservoir. The subbasin defined by station 4405 (Hobbs Brook at Mill Street, near Lincoln, MA), at 2.15 mi^2, is the largest of the three. The subbasin is comprised of a large proportion of wetland and forested cover (~77% by area) relative to the other tributaries in the basin.

During this study period, "HB@MILL ST" was sampled seven times under baseflow conditions. No wet weather samples were collected. For each sample, water quality met Class A standards for temperature (< 28.3°C), dissolved oxygen (> 5mg/L), and pH (between 6.5 – 8.3). Two of 6 samples exceeded single sample *E.coli* thresholds of 235 MPN (most probable number). Average turbidity readings (3.14 NTU) indicated good water clarity. Due to the lack of concurrent flow measurements, estimated loads and yields were not calculated for water quality parameters. After this reporting period, USGS has reestablished this site as a continuously monitored stream. Flow estimates, stream temperature and specific conductance are now available in real-time.

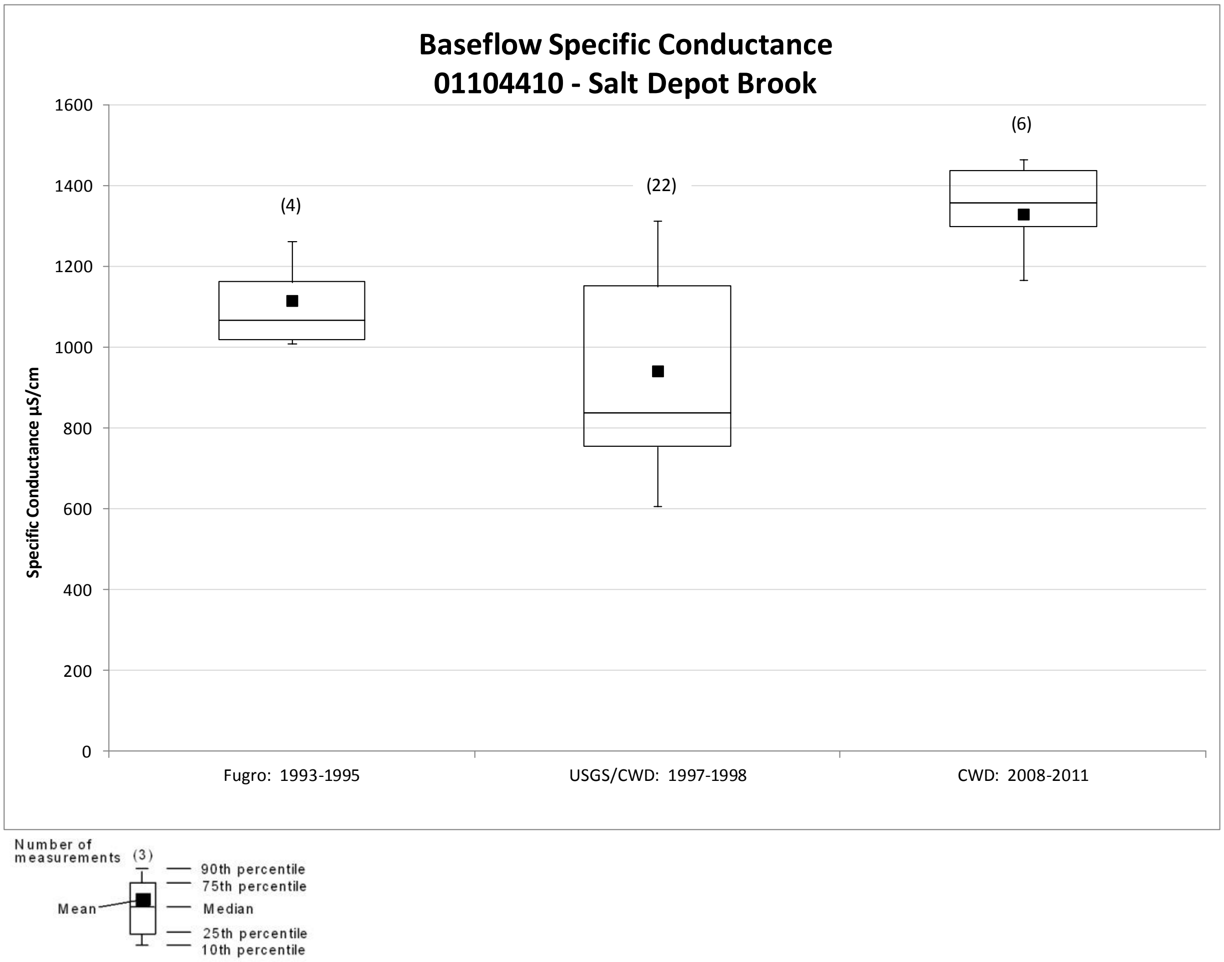
Overall manganese, nitrate, and sodium concentrations were higher than those found in the Water Year 1998 USGS study. Baseflow total phosphorus concentrations were relatively high compared to the other sampling stations (the highest value being 0.055 mg/L in October, 2011), and could be explained by anoxic wetland release and high organic content. Median sodium concentrations (50.3 mg/L) increased two-fold since the 1998 study (25 mg/L, table 3) and could possibly be attributed to local effects from continual build-up and soil/groundwater migration of road salt in Route 2 shoulder areas. Compared to other stations, HB@MILL ST yielded relatively low baseflow sodium concentrations, with the highest being 53 mg/L sampled February, 2009.

Salt Depot Brook (01104410)

"SALT DEPOT" has an estimated 0.34 mi^2 drainage area and was monitored seven times during baseflow conditions. No stormwater samples were collected. This site met Class A water quality standards for temperature, pH, and dissolved oxygen for all samples. Single sample *E. coli* limits were exceeded in half of the samples taken (figure 31). Relatively high bacteria concentrations could be explained by the upstream wetland that contributes to this sampling station. Wetland habitats typically provide for an abundance of wildlife/bacteria sources.

High specific conductance, sodium and chloride results can be explained by continuous movement of a mapped hyper-saline groundwater plume from the upgradient MassDOT salt storage depot where they used to store road salts uncovered on bare ground. Over time, stored salts leached into the surrounding soils and groundwater. In addition, the percentage of floodplain alluvium in the subbasin is more than five times that of any other subbasin in the source area and this could account for the highest observed baseflow total phosphorus measurement (0.11 mg/L) since a high proportion of streamflow in the tributary enters as low oxygen, phosphorus-rich groundwater (USGS).

Figure 24: Baseflow Specific Conductance Time Series, Salt Depot Brook



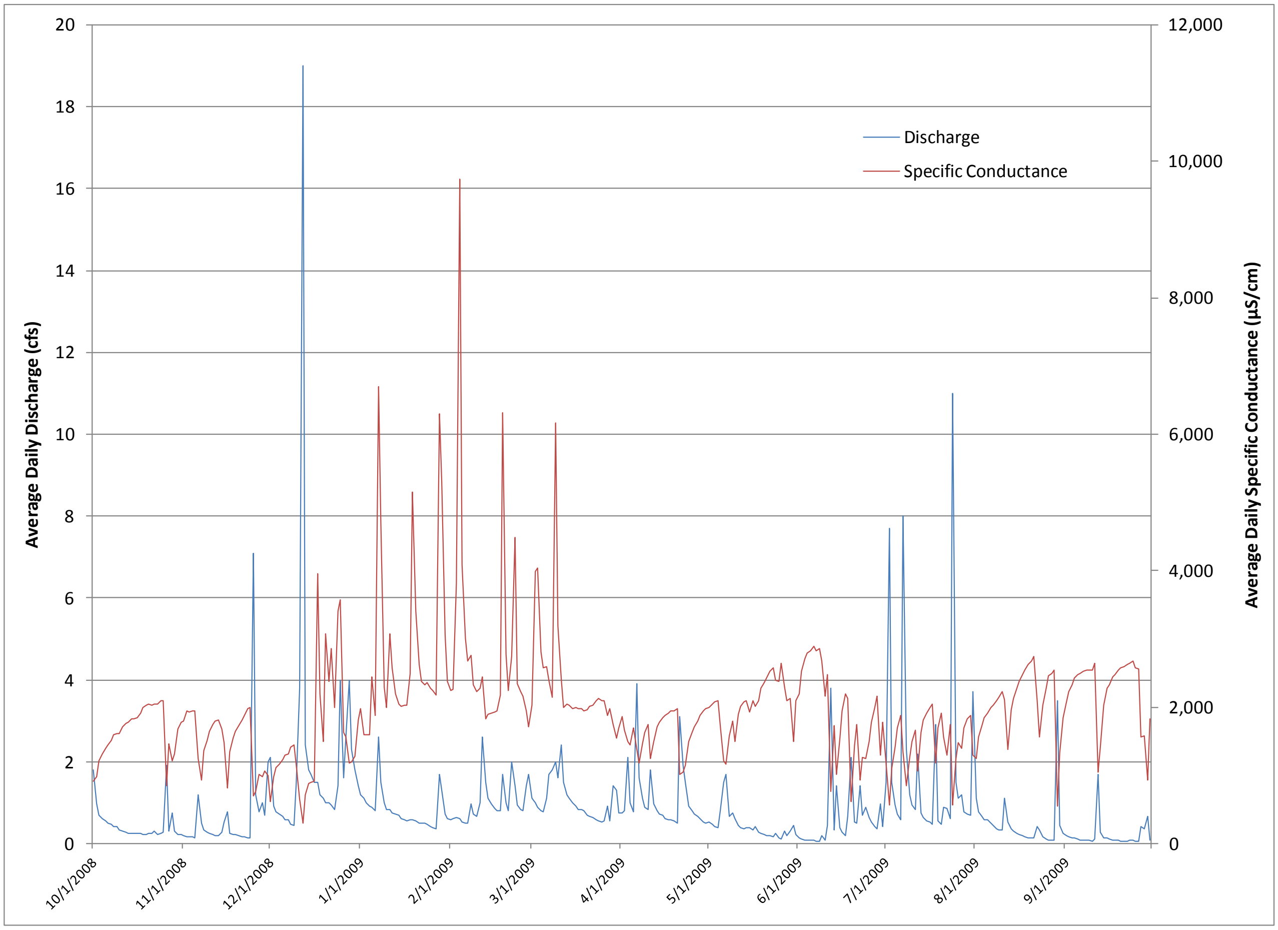
Lexington Brook (01104415)

With a drainage area of 0.41 mi^2, LEX BROOK station drains the second largest area to the Cambridge reservoir's upper basin. LEX BROOK is dominated by residential land uses (table 2), but receives many direct, untreated stormwater discharges from the adjacent highway. USGS-maintained automated equipment continuously records temperature, stage, and specific conductance.

For dry-weather sampling, median temperature, dissolved oxygen, pH, and bacteria did not exceed MA Class A surface water quality standards. One slightly acidic sample was taken November, 2008 (pH = 6.35), and one bacteria exceedance (750 MPN) occurred September, 2011.

This site continues to exhibit the highest median specific conductance, sodium and chloride concentrations in the entire source water area; these values were also significantly higher than those found in the 1998 USGS study (figure 26, table 3). Median nitrate nitrogen concentration was lower than that found in the 1998 USGS study (table 3), but is the third highest in the entire source water area (figure 33). Median manganese concentrations compared closely to 1998 findings.

Figure 25: Example Time Series Instantaneous USGS Data for Lexington Brook – Average Daily Discharge and Specific Conductance for Water Year 2009



The above figure (25) illustrates published automated stream flow and specific conductance (indicator of sodium and chloride concentrations in the water) records for Water Year 2009. During non-winter months when no deicing chemicals are used, the graph depicts an inverse relationship between flow and specific conductance. This phenomenon is the result of storm water dilution of high salinity in-stream groundwater flows. Conversely, in the winter months, the relationship between specific conductance and streamflow is proportional, and large conductance spikes follow melt events or runoff-generating mixed precipitation. On an annual basis, preliminary data analysis by USGS and UMass Amherst show that the majority of salt contributions to Hobbs Brook Reservoir via LEX BROOK are from high salinity groundwater (base) flows rather than from runoff generating events.

More than 13 percent of the drainage area for this tributary is covered by roads, the highest coverage of any drainage area in the source watershed. Contributing drainage area includes a major highway interchange connecting State routes 2A and 128 and a salt storage area managed by the MassHighway Department. State highways cover twice as much area in this subbasin as any other and are in close proximity to the sampling station, the tributary, and the reservoir. The inclusion of this station in a water quality monitoring program is essential because of the serious continued rising trend in sodium concentrations (figures 26, and 27) and the contributions of urban and highway runoff contaminants to the water supply.

Due to the watershed's developed nature, this site is also monitored during wet weather to better characterize runoff-generated water quality. USGS included this site when studying storm flows and their impacts on the water supply (report yet unpublished, but data approved and available online). Monitoring and results are discussed briefly in the following "Wet Weather Monitoring" section.

Figure 26: Periodic Sodium Comparison, Lexington Brook

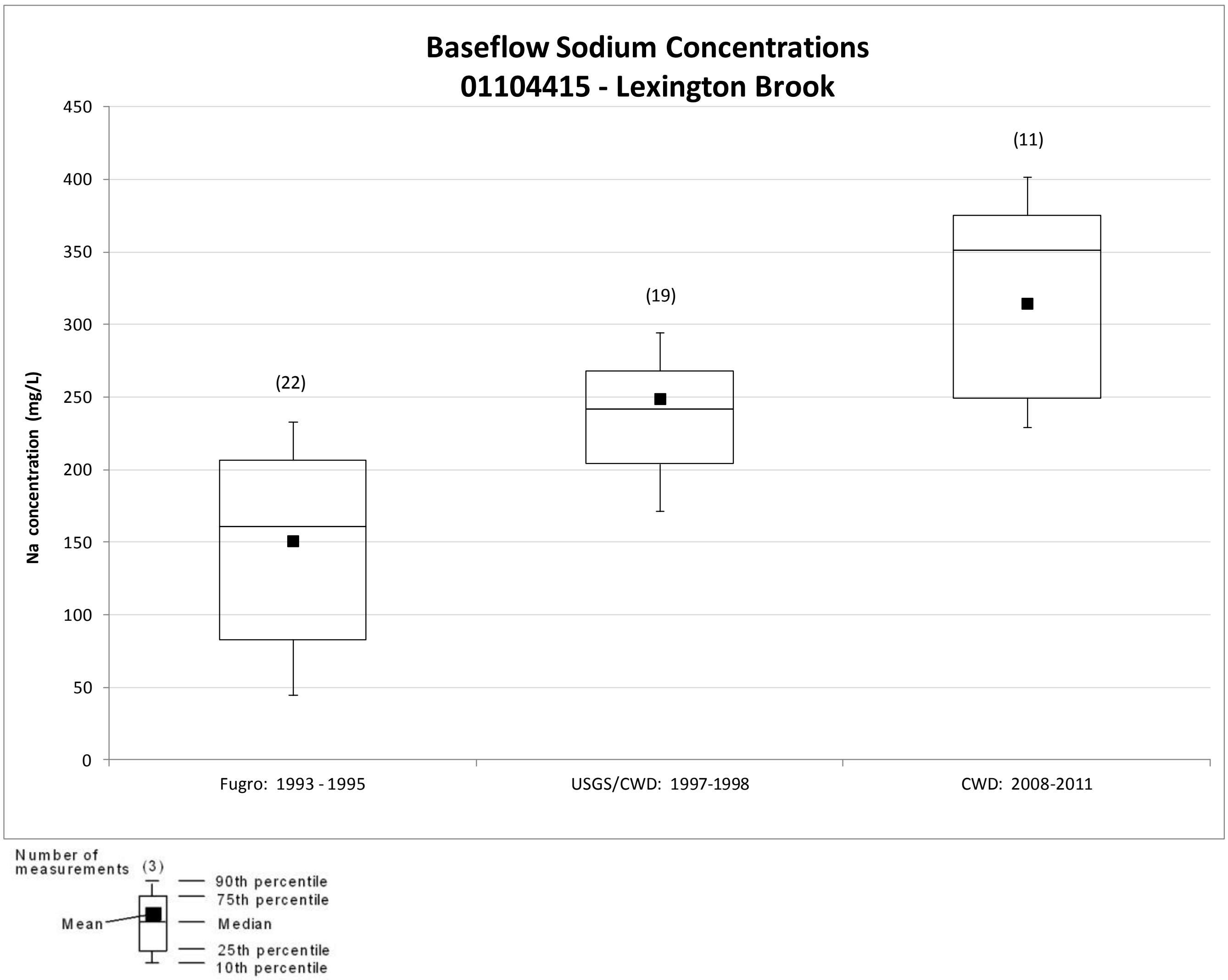
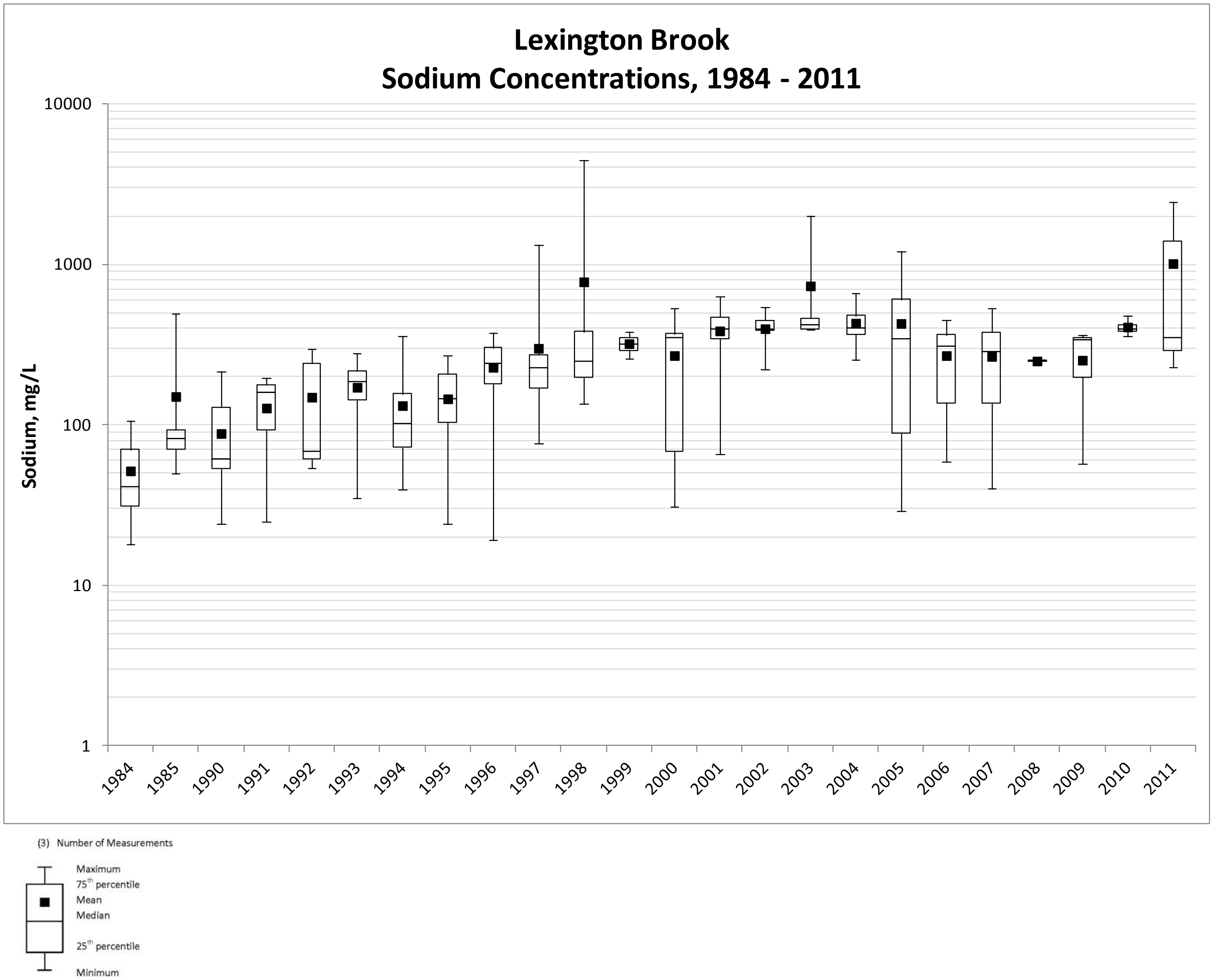


Figure 27: Long-Term Lexington Brook Sodium Trend – All Weather



Tracer Lane (01104420)

The TRACER LANE tributary enters the middle basin of Hobbs Brook Reservoir and receives runoff from State Routes 2, 128, an adjacent commercial parking lot, and a mix of wetland, residential and commercial areas (table 2). Median dry-weather bacteria and dissolved oxygen met Class A standards. Two bacteria samples exceeded 235 MPN *E.coli* and 3 dissolved oxygen samples were less than 5mg/L. All samples for temperature and pH met Class A standards. Median baseflow phosphorus, manganese, sodium and chloride were all higher than 1998 USGS results (table 3). No wet-weather samples were collected during this monitoring period.

Compared to other sites, this site had the second highest baseflow phosphorus concentrations, which could be explained by the relatively high percentage of forested wetland and impervious area source loading (table 2). Relatively high organic carbon and manganese results are also consistent with wetland chemical characteristics and function. This site had the highest recorded concentration of manganese for all sites during this study period (1.68 mg/L June, 2011, figure 34).

After this reporting period, USGS has reestablished this site as a continuously-monitored station for temperature and specific conductance. Backwater issues prohibited accurately developing a stage-discharge relationship for real time flow monitoring.

Hobbs Brook Below Dam (01104430)

This sampling station is located at the discharge outlet of the Hobbs Brook Dam on Winter Street in Waltham. In addition to taking open-water samples in the reservoir, sampling at the outlet provides further information on water quality released into the stream channel for which subsequent constituent loads and yields can be calculated.

Figure 28: Example Time Series Instantaneous USGS Data for HB BELOW DAM – Average Daily Discharge and Specific Conductance for Water Year 2009

Figure 28 (above) illustrates managed flows from the reservoir its specific conductance throughout the year. The flow fluctuates as floodwater passed over the spillway and as the gates were either opened or shut. Hobbs Brook gatehouse is typically shut for the duration of the winter when enough precipitation is recharging Stony Brook Reservoir. As the above graph illustrates, sluice gates were closed in the spring to recharge the reservoir (while maintaining a downstream baseflow). The graph also shows a recurring rise in winter specific conductance due to road salt applications. Monitoring of other tributary sites supports this phenomenon.

Because of dilution and settling throughout the reservoir, concentrations of most constituents were relatively low compared to other subbasins throughout the system. During this study period, HB BELOW DAM met MA Class A water quality standards for bacteria, temperature, pH, and dissolved oxygen for all sampling events. Median nitrate, manganese, sodium, and chloride concentrations are all higher than median 1997/1998 USGS results (table 3).

Industrial Brook (01104433)

This small tributary enters Hobbs Brook approximately 0.5 miles downstream from the dam (figure 23) at Lexington Street in Weston. The subbasin drains a small forested wetland and has the greatest densities of commercial and industrial land use of any subbasin. Sixty five percent of the subbasin by area is impervious surfaces including Route 128, other roads, parking lots, and rooftops.

During dry weather sampling, all but one *E.coli*, and dissolved oxygen sample met MA Class A water quality standards (figures 31 and 39). This site had the lowest single sample dissolved oxygen concentration of 1.96 mg/L sampled in November, 2009. Temperature and pH met state standards for all samples. Median sodium and chloride concentrations from this site are the second highest compared to all other primary tributary monitoring stations (figures 35, 36 and table 3) and higher than concentrations observed in water year 1998. Median total phosphorus and manganese were also higher than water year 1998 USGS results, and dissolved oxygen was lower.

Due to its developed nature, this site is also monitored during wet weather. USGS included this site when studying storm flows and their impacts on the water supply (report yet unpublished, but data approved and available online). See below "Wet Weather Monitoring" section for more discussion, results. USGS current and historic water quality data for this and other sites can be accessed here http://nwis.waterdata.usgs.gov/ma/nwis/qwdata.

Hobbs Brook at Kendal Green (01104440)

Station "HB@KG" is the furthest downstream sampling site on Hobbs Brook before its confluence with Stony Brook (figure 23), and thus is representative entire subbasin flows. The station affords useful comparisons with monitoring data collected at the adjacent Stony Brook station.

This site met Class A water quality standards for *E.coli*, pH, temperature, and dissolved oxygen for all samples taken during this study period. Median nitrate and phosphorus levels in dry weather were below EPA recommended nutrient criteria for this ecoregion, but of the two constituents, only median phosphorus concentrations were higher than 1997/1998 USGS results (figures 32, 33 and table 3). Median manganese, sodium, and chloride concentrations were also higher than water year 1998 USGS results. Concurrent streamflow measurements were taken with only two sampling events, so no loads or yields were estimated for this period.

Stony Brook at Kendal Green (01104390)

This station is located on Stony Brook just upstream from its confluence with Hobbs Brook, next to the Weston Transfer Station (figure 23). As such, water quality data from the station integrates and represents conditions in a subbasin that comprises more than half of the total source-water area. Land use and land cover are appreciably different in the two integrator subbasins. The Stony Brook subbasin contains significantly less commercial and industrial land and a larger amount of low-density residential land use on septic systems (table 2). This site was sampled five times in dry weather during this study period and met Class A water quality standards for bacteria, temperature, pH, and dissolved oxygen for all events.

This site was last sampled on 11/10/2009 is no longer actively monitored since the establishment of Stony Brook at Viles Street "SB@VILES" (USGS ID 01104370) automated monitoring station for temperature, specific conductance, and discharge. This site is located approximately ¾ of a mile upstream of the Kendal Green site and is not effected by backwater influences from the Hobbs Brook confluence. A staff gage and access remains for the Kendal Green site for future monitoring.

Stony Brook at Viles Street (01104370)

Station "SB@VILES" is the newly established monitoring station characterizing flows from the Stony Brook watershed before its confluence with the Hobbs Brook. In theory, water quality should be similar to that of the Stony Brook at Kendal Green site. After more data is collected from this site, comparisons will be made. Forests, residential development, and wetlands dominate contributing land uses (table 2) with far less salt-treated impervious surfaces. As such, sodium, chloride and specific conductance measurements on the Stony Brook are significantly less than those observed in the more developed Hobbs Brook save for the HB@MILL ST subbasin, which has similar land uses (figures 35-37).

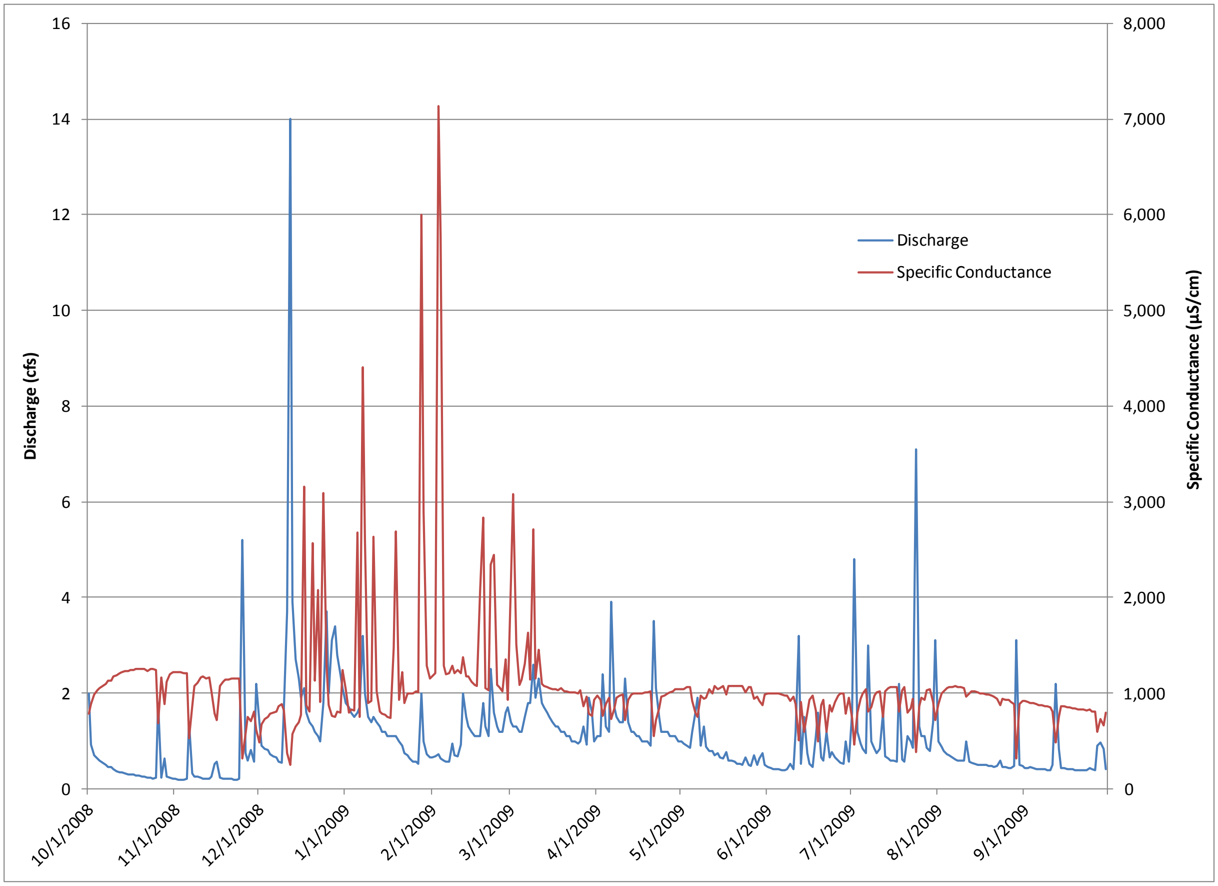
During this period, SB@VILES was sampled four times in dry weather. Stony Brook is a state-designated cold water fish resource, so temperature standards are lower to accommodate temperature-sensitive fluvial fish. Preliminary USGS temperature data at this site indicate that in Summer 2010 and 2011, daily maximum 7-day temperatures exceed the 20°C temperature standard. However, the regulations state that temperatures can exceed these standards when "naturally occurring". CWD water supply management has no influence on this station's temperature.

CWD dry weather sampling indicated that SB@VILES met MA Class A water quality standards for temperature, pH, and dissolved oxygen for all four events. Half of the samples did not meet *E.coli* standards (single sample > 235 MPN). Bacteria sources at this site are most likely wildlife, but could be from septic breakthrough from one of the many residences abutting the river. In the future, this site will be sampled in wet weather to better understand storm water influences on water quality.

WA-17 (01104455)

This USGS operated real-time station discharges through a small wetland to Stony Brook approximately 0.4 miles upstream from Stony Brook Reservoir. In addition to flow, temperature and specific conductance, this site is also equipped with a turbidimeter and transforms conductivity data to real time chloride concentrations (Granato and Smith, 1999). The subbasin drains significant amounts of State and locally-maintained roads, and commercial and industrial land uses, most notably the old Polaroid facility currently being redeveloped. Much of the lower subbasin is paved and the tributary is routed through culverts draining Routes 128 and the interchange connecting Routes 128 and 20.

Figure 29: Example Time Series Instantaneous USGS Data for WA-17. Average Daily Discharge and Specific Conductance for Water Year 2009



As described earlier for Lexington Brook, data for the WA-17 tributary shows dramatic changes in specific conductance directly related to sodium and chloride concentrations in the water. During warmer months, the graph depicts an inverse relationship between flow and specific conductance. Conversely, in the winter months under icing conditions, the relationship between specific conductance and flow is proportional, and salt-laden runoff generates large conductance spikes (figure 29).

During the reporting period, WA-17 met MA Class A water quality standards for temperature, pH, and dissolved oxygen (figure 41) for dry weather all samples. All but one sample met the state *E.coli* standard. Compared to 1998 USGS results, median dry weather results were higher for sodium and chloride (table 3), with median baseflow chloride exceeding federal chronic aquatic toxicity standards. Relative to other monitoring stations, this site has the lowest dry weather phosphorus and total organic carbon concentrations, but the second highest nitrate concentrations. In this subbasin, the most likely nitrate sources are from commercial and residential fertilizer applications.

As this site drains a considerable amount of developed, urbanized area, the Watershed Division attempts to sample in wet weather on a regular basis. Results are discussed in the following "Wet Weather Monitoring" section. USGS has sampled multiple storm events and will soon publish a report characterizing and quantifying stormwater quality.

Currently, MassDOT is constructing a 3.5 acre stormwater retention and treatment basin in the Route 128/Route 20 rotary that will capture approximately the first inch of stormwater runoff from the entire subbasin. In addition to this "end of pipe" stormwater treatment system, the old Polaroid facility on Main Street, Waltham is currently being redeveloped to include a state of the art stormwater treatment train. CWD is anticipating considerable wet weather water quality improvements after both of these treatments come online. USGS and CWD will continue monitoring stormwater at this site to quantify water quality differences.

Mass Broken Stone (01104453)

The "MBS" site was not studied during the water year 1998 USGS baseline assessment, but based on report recommendations, was added by CWD in 2000. This site's relatively large drainage area (2.23 mi^2) consisting of primarily of forested and residential land use, and the surrounding active rock quarry made it a good candidate for monitoring. The quarry has since been closed and redeveloped into an expected LEED Core and Shell Platinum office complex that has no stormwater discharges to the tributary; rather stormwater is pre-treated and routed to quarry ponds. As part of the redevelopment, the stream channel was relocated and restored, and owners agreed to establish a USGS-maintained real-time flow, temperature and conductivity monitoring station at the culverted tributary inlet from an approximately 36-acre shallow, highly productive pond.

During this period, in dry conditions, this site met MA Class A water quality standards for temperature, pH, and *E.coli* bacteria for all sampling events. Median dissolved oxygen concentrations met Class A standards, but three of seven samples were below the 5 mg/L threshold. This is most likely due to oxygen demand from microbial activity breaking down organic matter in the shallow, slow moving upstream pond. Relative to other Stony Brook subbasins, this site has a somewhat high specific conductance which is influenced by salt-treated local roadways, commercial and residential impervious surfaces and State Route 20.

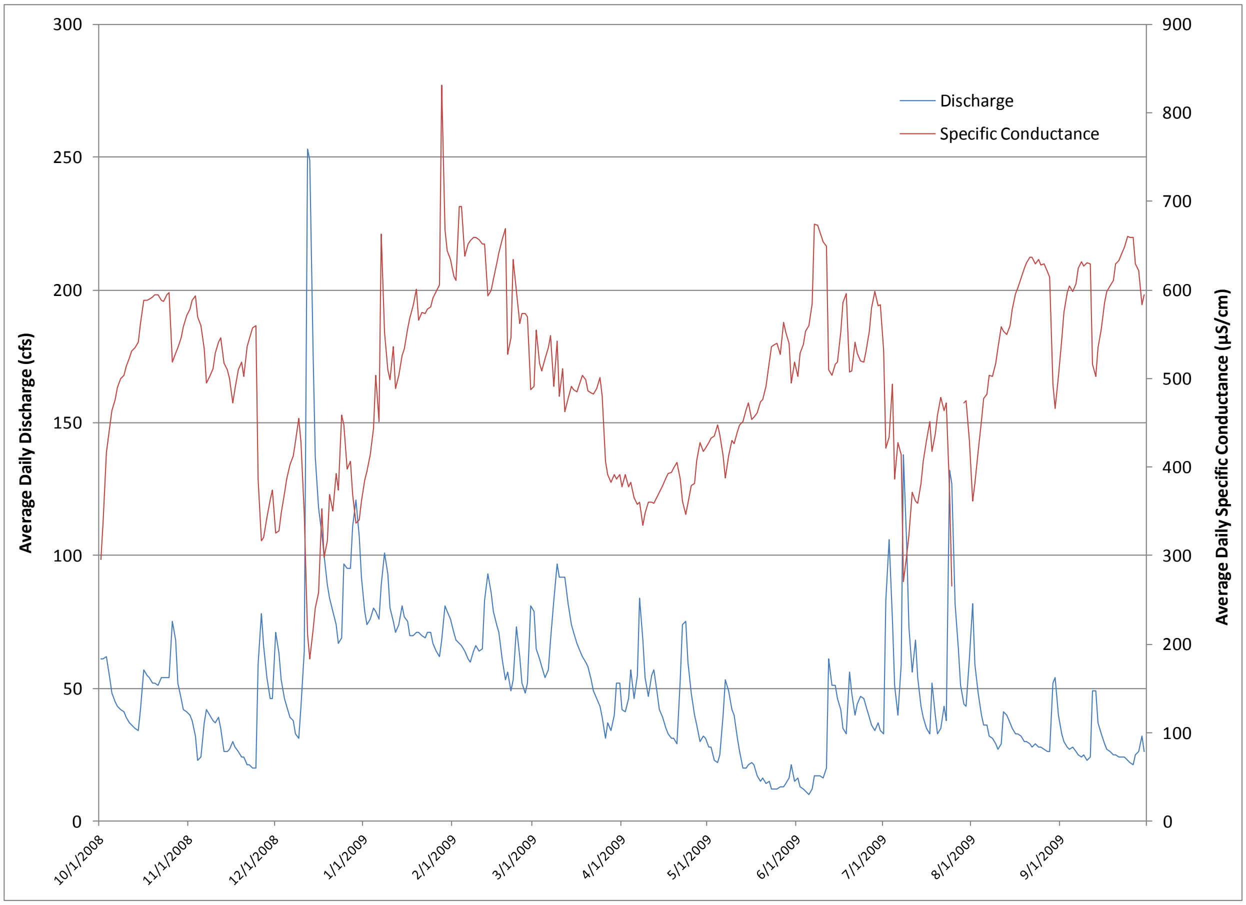
Stony Brook at Route 20 (01104460)

This station integrates both Stony and Hobbs Brook and represents water quality from the majority (93%) of the watershed before entering the Stony Brook Reservoir. A USGS-maintained monitoring station measures flow, temperature and specific conductance in real-time. Surface water inflow estimates to the Stony Brook reservoir are calculated from measured flows at this station plus the "SUMMER ST" (01104475) station.

During dry weather, this site met MA Class A water quality standards for bacteria, dissolved oxygen, and pH for all sampling events. In the summer, according to USGS approved and provisional data at this site, like SB@VILES, daily max temperatures can and do exceed 20°C for periods of 7 days or greater.

The below graph shows the same seasonal relationships between flows and specific conductance, although much more attenuated due to the larger volumes of water (effectively diluting salt concentrations) passing through this station and the influence of flows from the less developed section of the Stony Brook.

Figure 30: Example Time Series Instantaneous USGS Data for RT 20 – Average Daily Discharge and Specific Conductance for Water Year 2009



Summer Street (01104475)

This station is located just west of Route 128 in Weston before the stream is culverted under the highway. This stream discharges directly into the Stony Brook Reservoir close to the intake structure. Land use in the subbasin differs from the others in that there are no State-maintained roads, and no commercial or industrial development. The predominant land uses in the subbasin are forests, low density residential, and the Weston Golf Club.

This station met MA Class A water quality standards for bacteria, pH, temperature, and dissolved oxygen for all dry weather monitoring events. This site exhibited the highest median nitrate yields and concentrations (1.58 mg/L), which are also significantly higher than 1998 USGS median dry weather results (0.94 mg/L). Of all monitored tributaries, this site had the lowest median sodium, chloride, and specific conductance values. Figure 31 shows a tight range of conductance values and inverse relationship between flow and conductance in most runoff generating events, indicating the lack of significant deicing chemical influences on stream chemistry. Periodic conductance data comparisons (figure 32) could indicate that no significant increases have been realized for 20 years. High nitrate concentrations and yields are most likely from golf course and lawn fertilizer applications, as well as septic flow-through.

Figure 31: Example Time Series Instantaneous USGS Data for Summer St Station - Average Daily Discharge and Specific Conductance for Water Year 2009

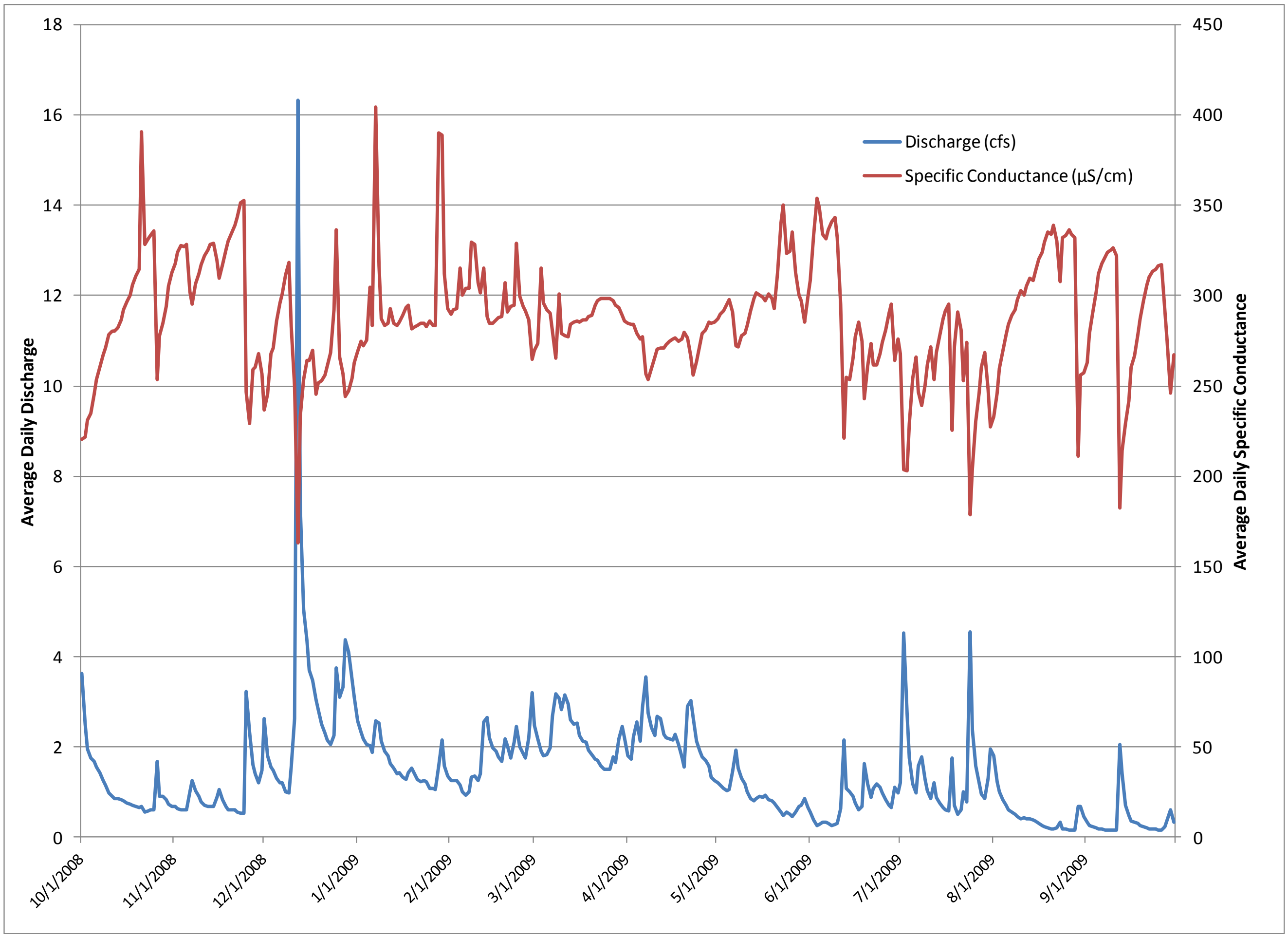


Figure 32: Periodic Baseflow Specific Conductance Comparison

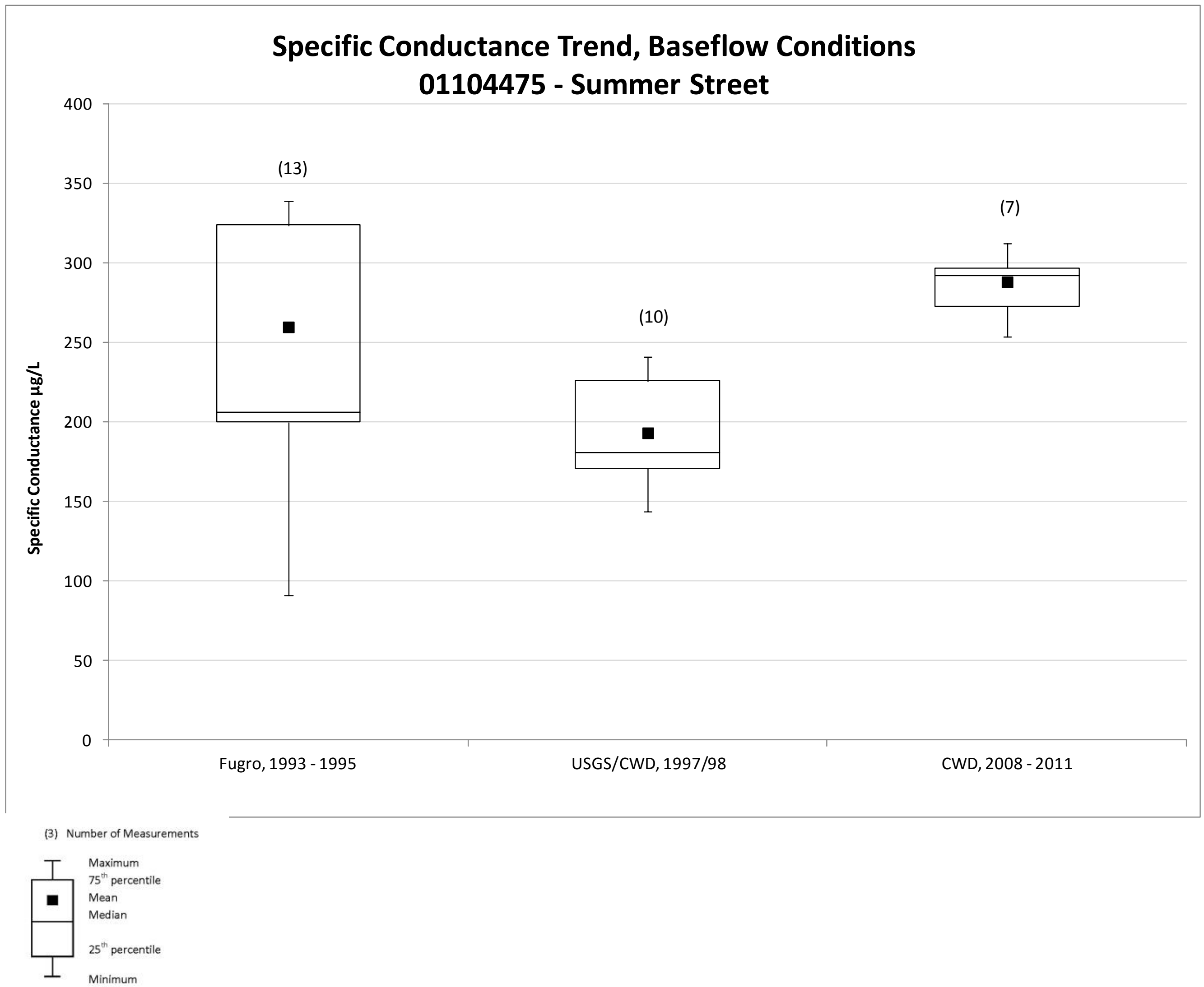


Figure 33: Baseflow *E. coli* Concentrations for Tributary Stations, 2008 - 2011

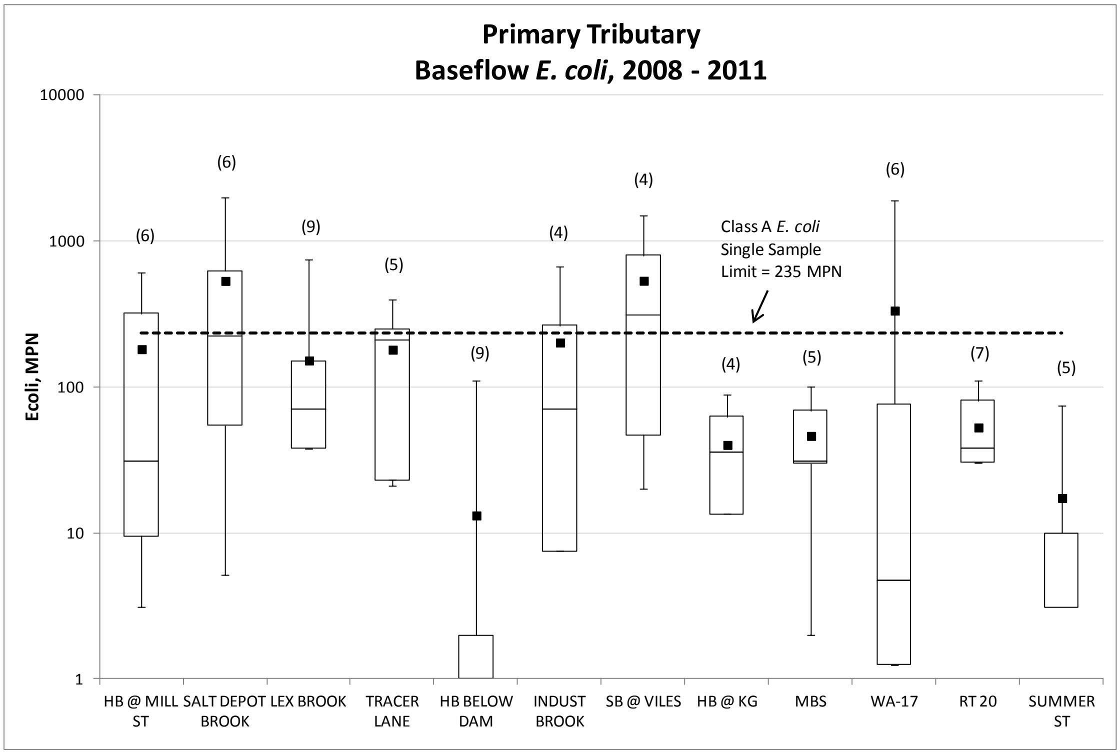


Figure 34: Baseflow Total Phosphorus Concentrations for Tributary Stations, 2008 - 2011

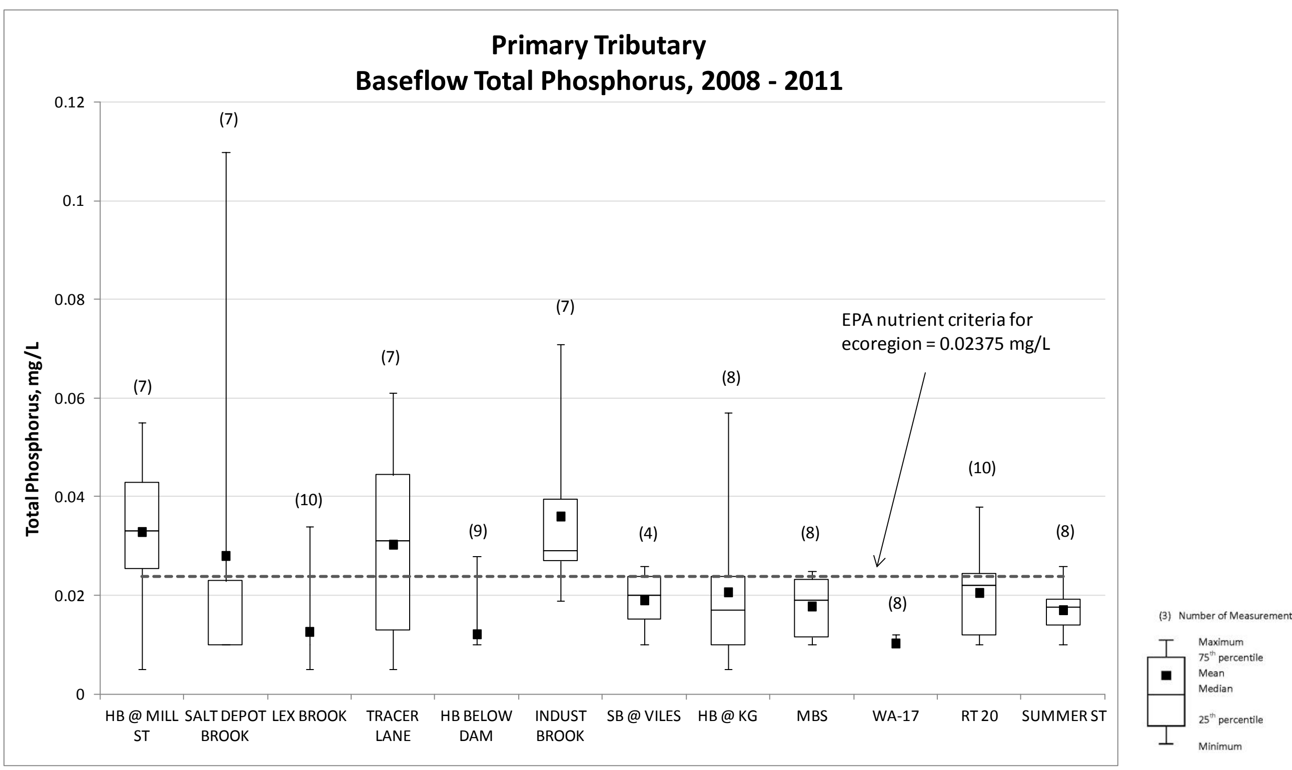


Figure 35: Baseflow Nitrate Concentrations for Tributary Stations 2008 - 2011

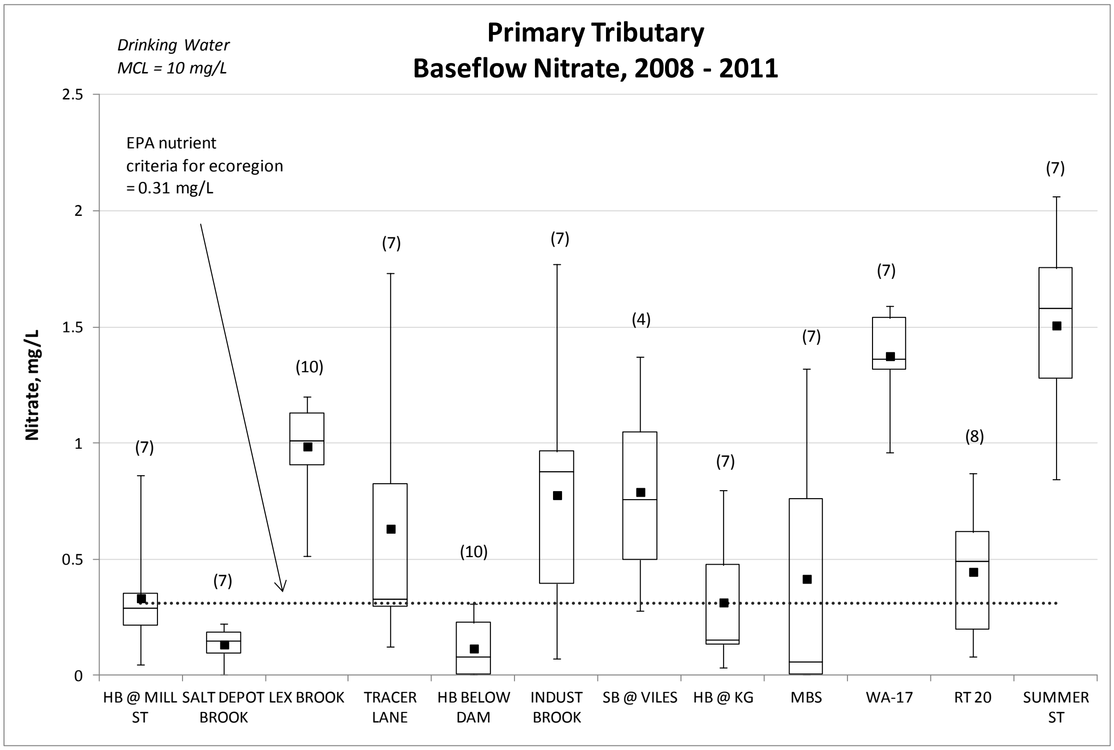


Figure 36: Baseflow Manganese Concentrations for Tributary Stations 2008 - 2011

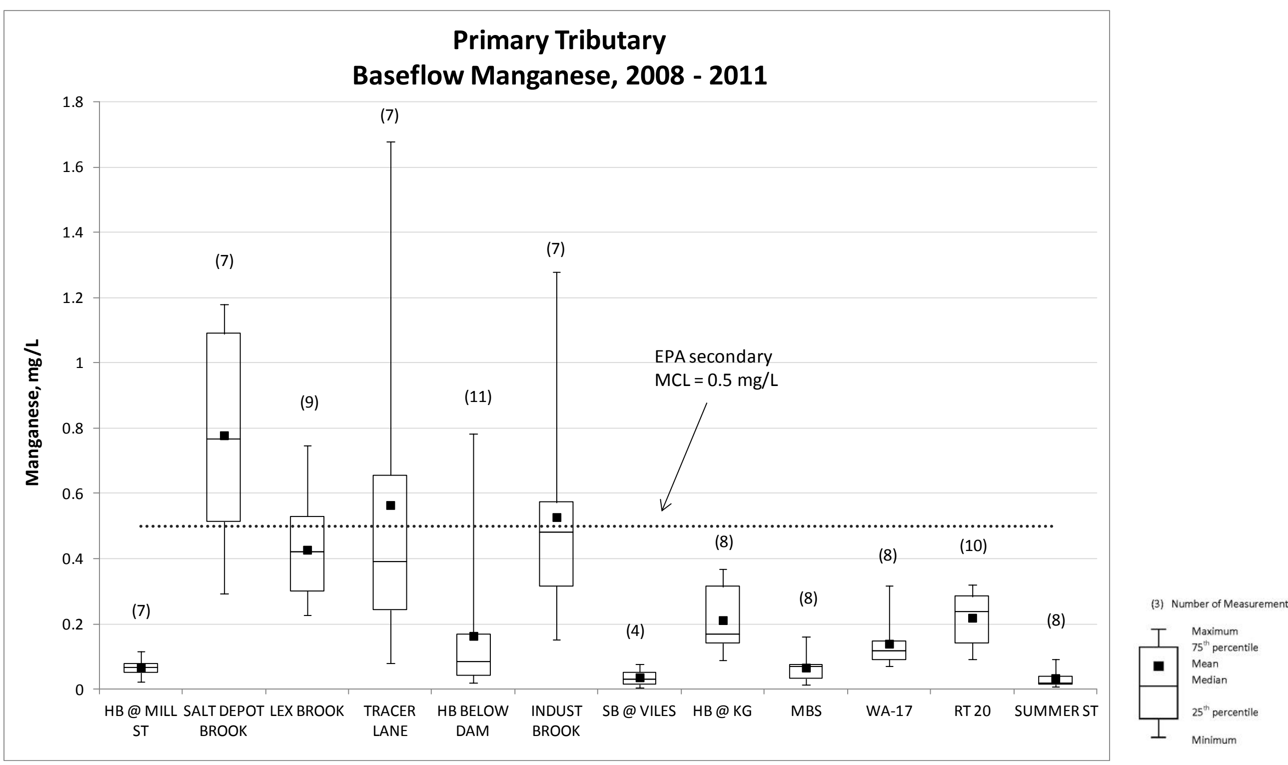


Figure 37: Baseflow Sodium Concentrations for Tributary Monitoring Stations 2008 - 2011

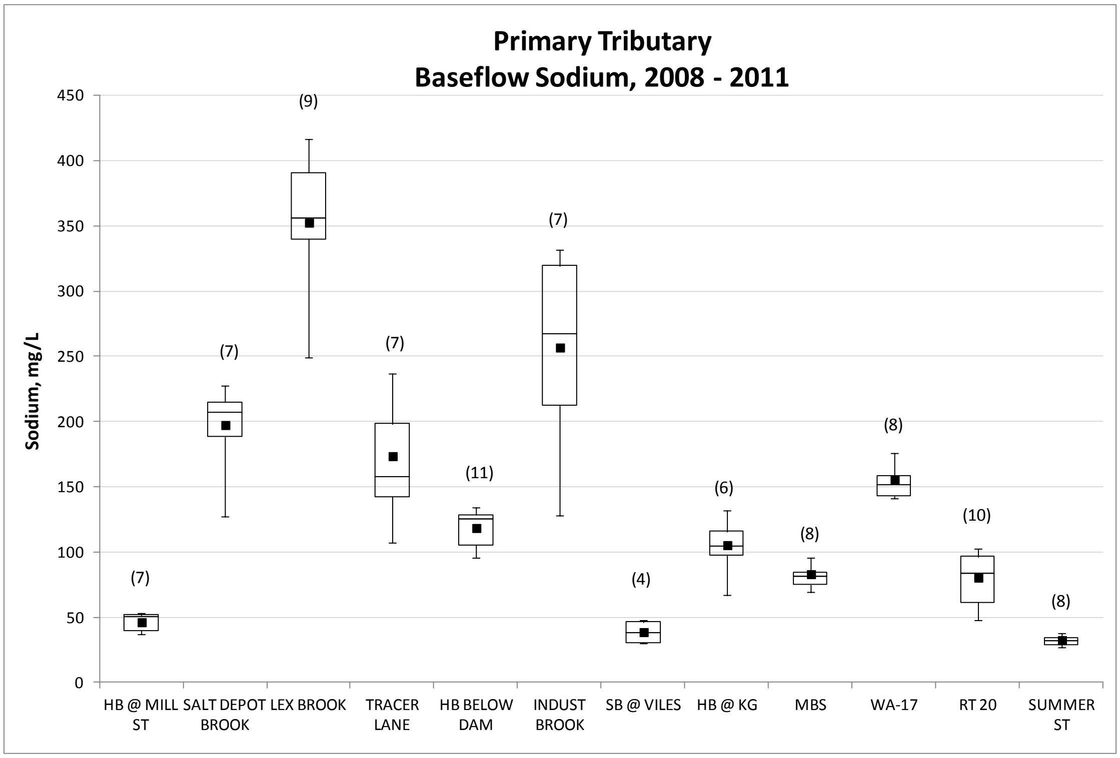


Figure 38: Baseflow Chloride Concentrations for Tributary Monitoring Stations 2008 - 2011

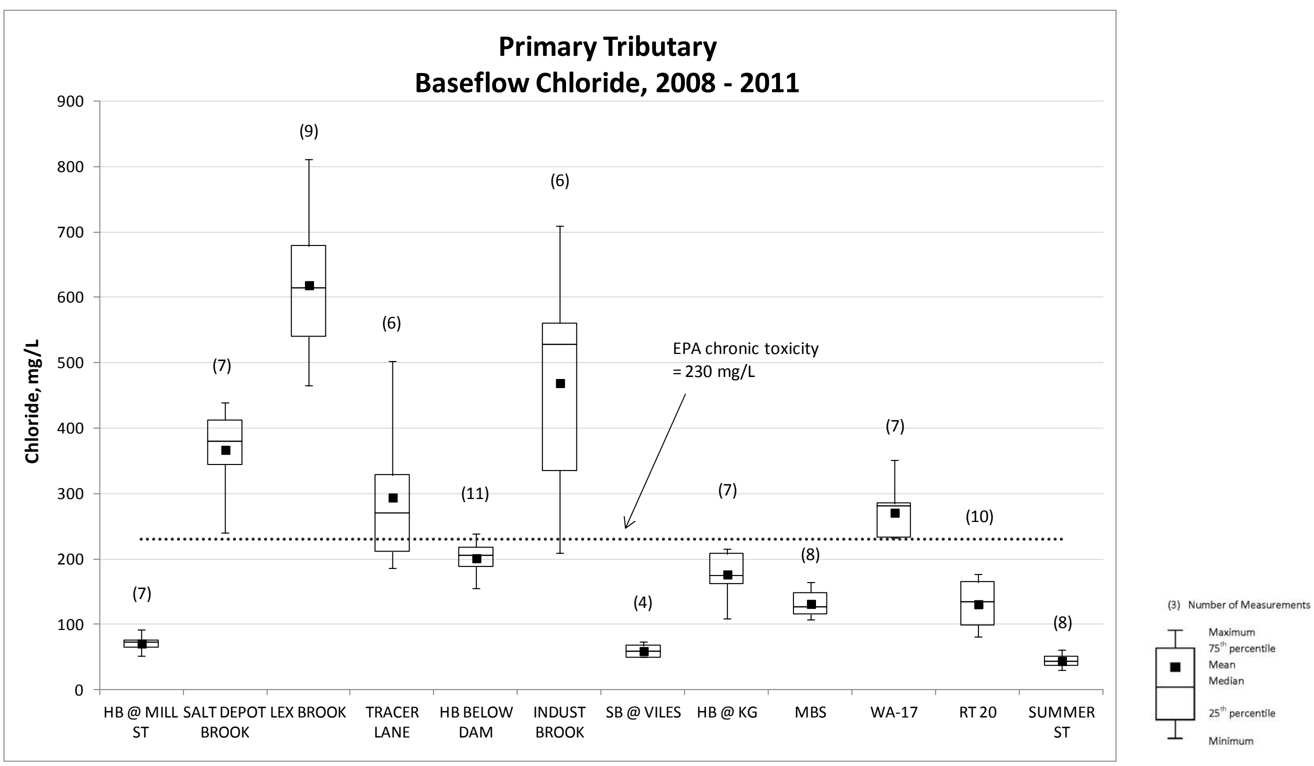


Figure 39: Baseflow Specific Conductance for Tributary Monitoring Stations 2008 - 2011

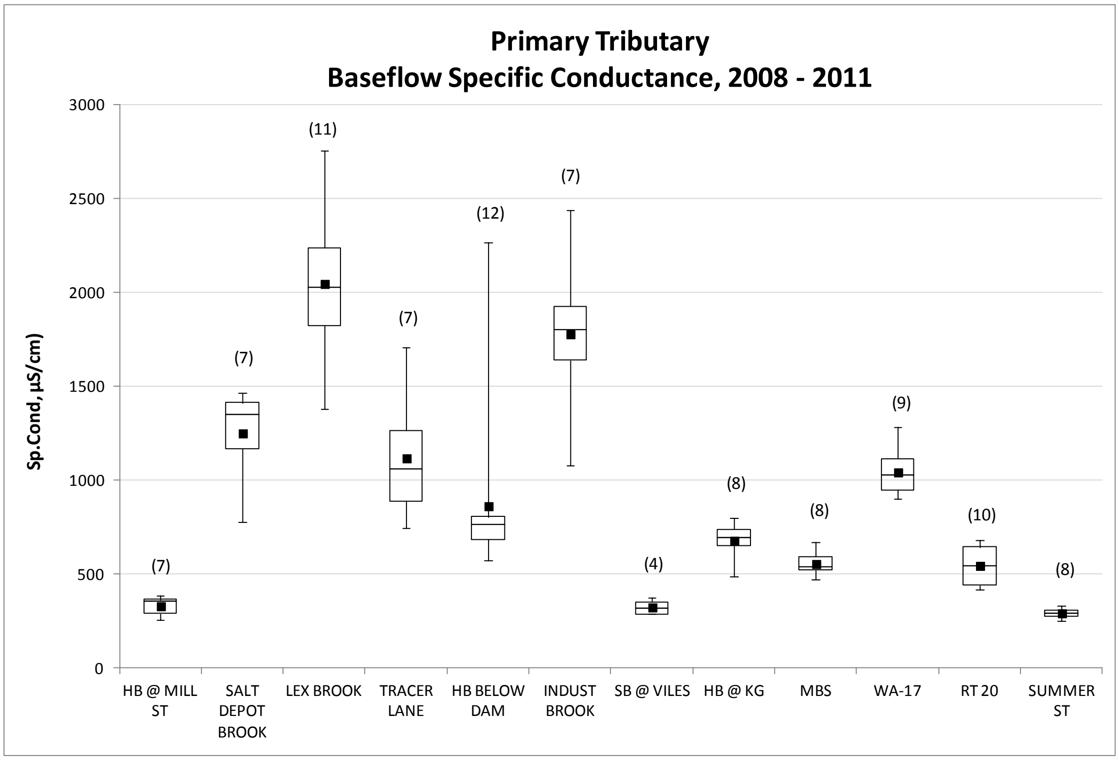


Figure 40: Baseflow Total Organic Carbon Concentrations for Tributary Monitoring Stations 2008 - 2011

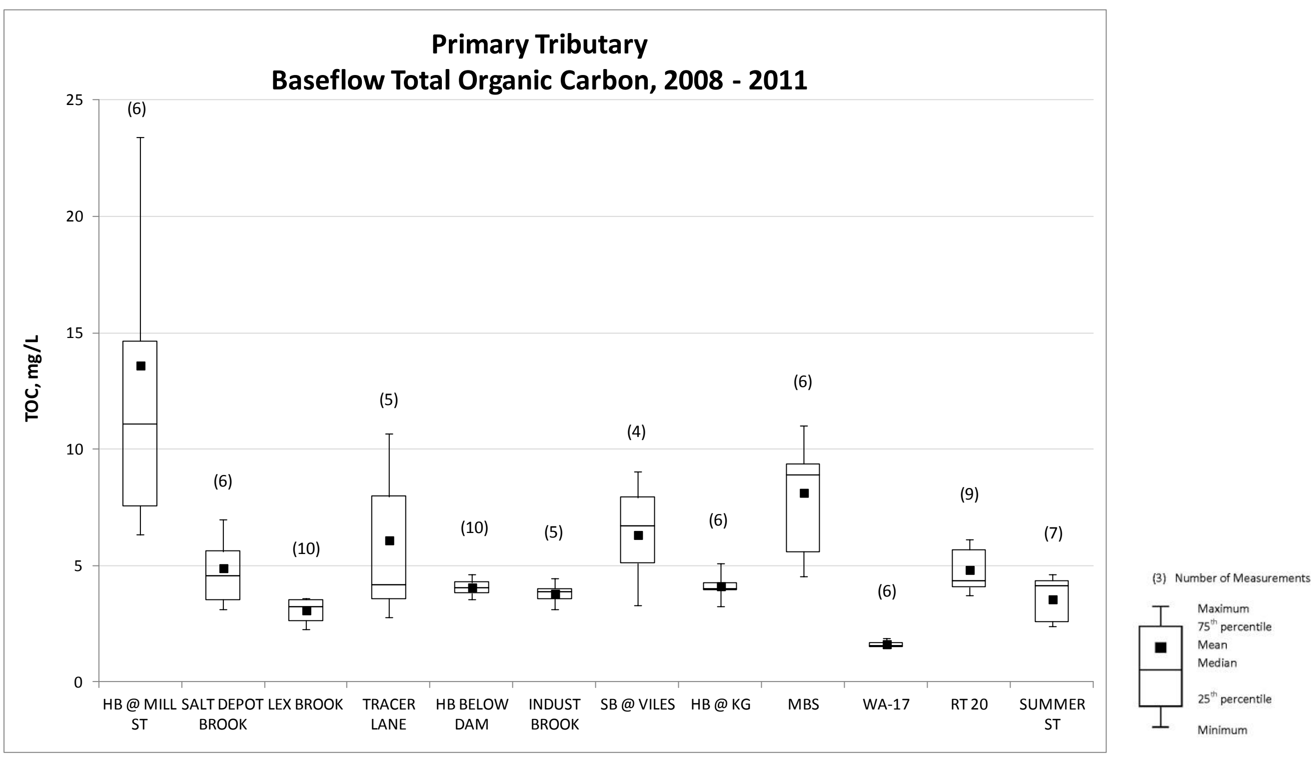


Figure 41: Baseflow Dissolved Oxygen Concentrations for Tributary Monitoring Stations 2008 - 2011

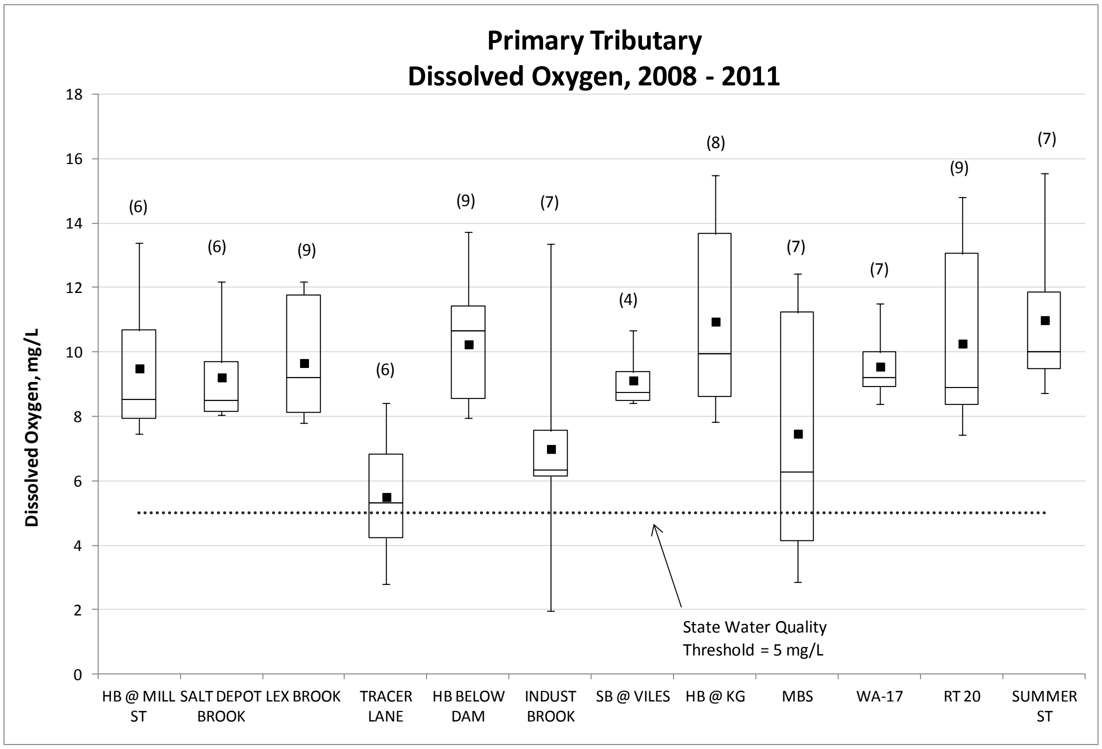


Figure 42: Baseflow Median Chloride Instantaneous Yields by Subbasin

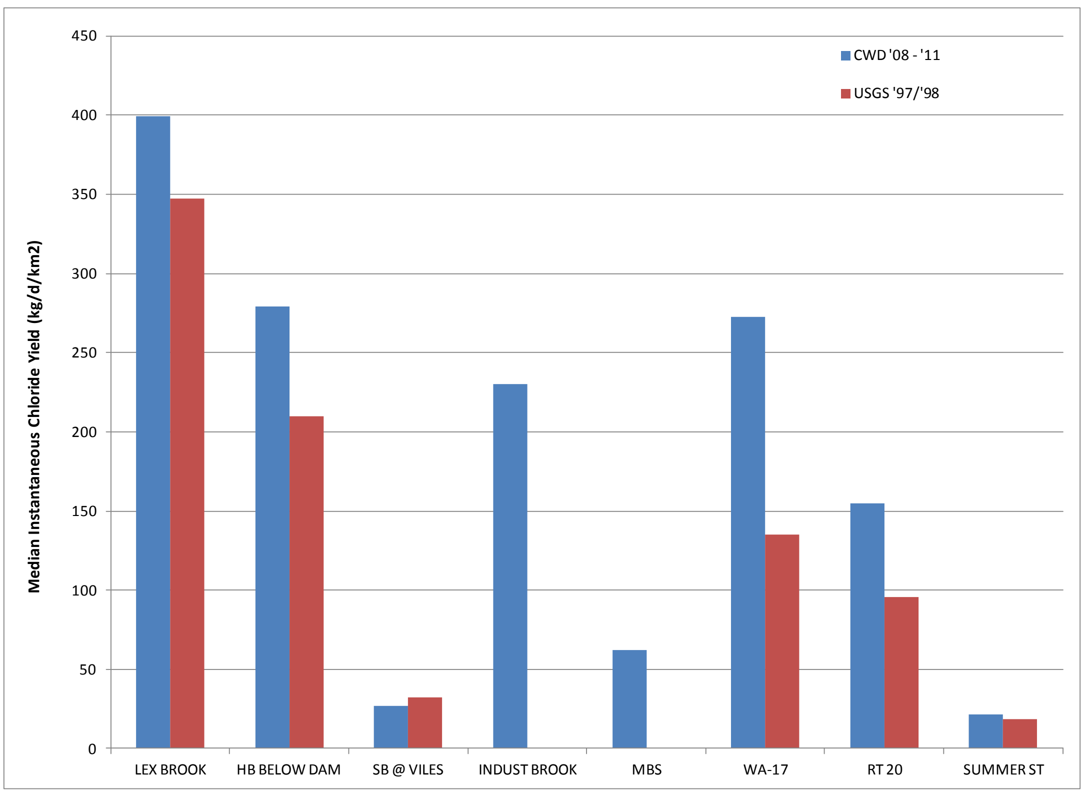


Figure 43: Baseflow Median Nitrate Instantaneous Yields by Subbasin

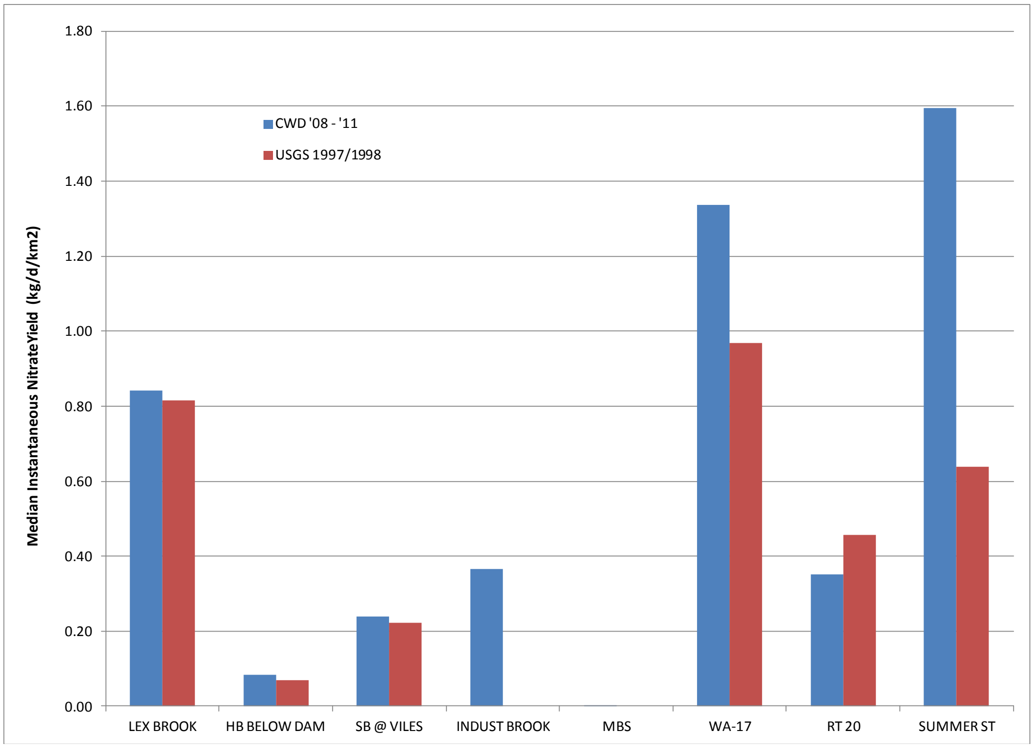


Figure 44: Baseflow Median Manganese Instantaneous Yields by Subbasin

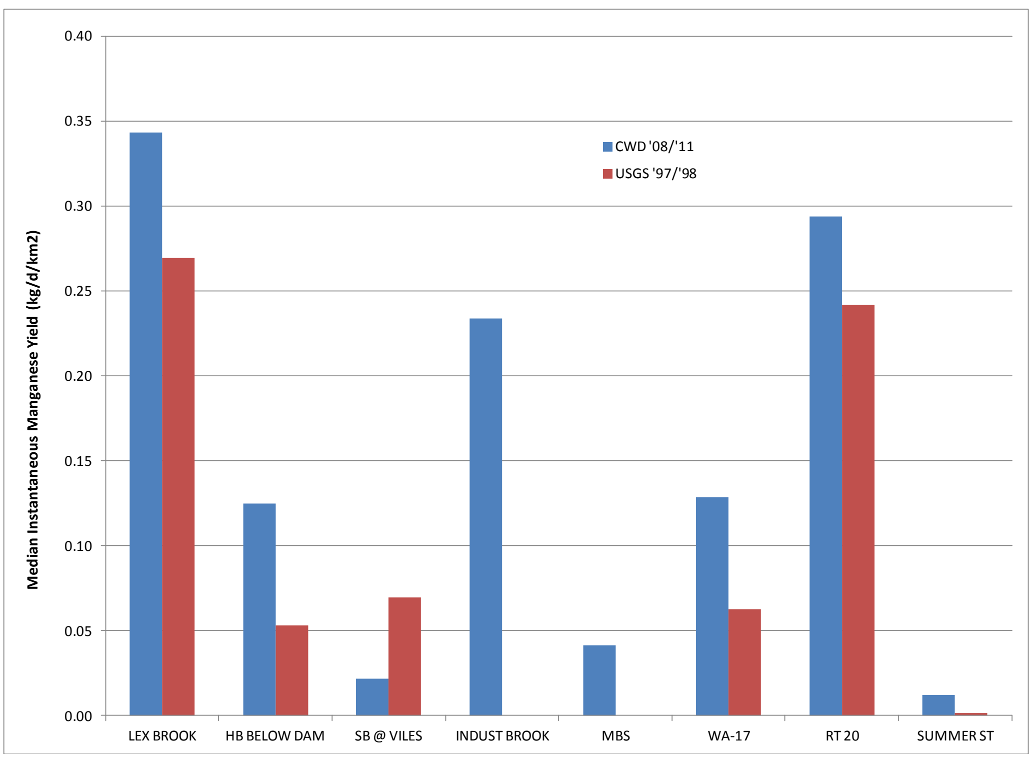


Figure 45: Baseflow Median *E. coli* Instantaneous Yields by Subbasin

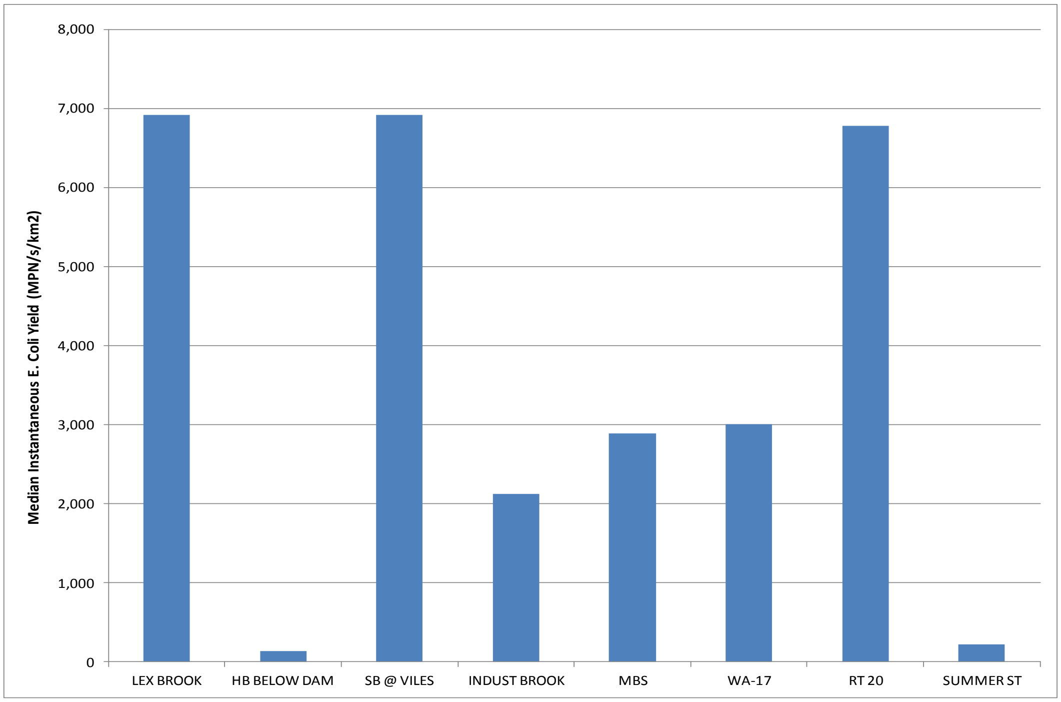


Table 3: Baseflow Water Quality Data Comparison

CWD Site ID	USGS Site ID	Water Quality Parameter, Units	2008 - 2011 CWD Median	USGS Water Year 1998 Median	Water Quality Standard	Water Quality Standard Source
HB@MILL ST	01104405	*E.coli*, MPN	31	N/A	235	State Class A Water Quality Standards
HB@MILL ST	01104405	Nitrate, mg/L	0.29	0.17	0.31	EPA Nutrient Criteria
HB@MILL ST	01104405	Total Phosphorus, mg/L	**0.033**	0.02	0.02375	EPA Nutrient Criteria
HB@MILL ST	01104405	Manganese, mg/L	**0.065**	0.043	0.05	EPA Secondary MCL, Drinking Water
HB@MILL ST	01104405	Sodium, mg/L	**50.3**	**25**	20	EPA Drinking Water Equivalent Level
HB@MILL ST	01104405	Chloride, mg/L	73.5	41.5	230	EPA Chronic Water Quality Criteria
HB@MILL ST	01104405	Dissolved Oxygen, mg/L	8.54	10.95	5	State Class A Water Quality Standards
SALT DEPOT	01104410	*E.coli*, MPN	225	N/A	235	State Class A Water Quality Standards
SALT DEPOT	01104410	Nitrate, mg/L	0.15	0.14	0.31	EPA Nutrient Criteria
SALT DEPOT	01104410	Total Phosphorus, mg/L	0.01	0.01	0.02375	EPA Nutrient Criteria
SALT DEPOT	01104410	Manganese, mg/L	**0.768**	**0.372**	0.05	EPA Secondary MCL, Drinking Water
SALT DEPOT	01104410	Sodium, mg/L	**207**	**112.5**	20	EPA Drinking Water Equivalent Level
SALT DEPOT	01104410	Chloride, mg/L	**380**	214.5	230	EPA Chronic Water Quality Criteria
SALT DEPOT	01104410	Dissolved Oxygen, mg/L	8.51	8.1	5	State Class A Water Quality Standards
LEX BROOK	01104415	*E.coli*, MPN	70	N/A	235	State Class A Water Quality Standards
LEX BROOK	01104415	Nitrate, mg/L	**1.01**	**1.06**	0.31	EPA Nutrient Criteria
LEX BROOK	01104415	Total Phosphorus, mg/L	0.01	0.01	0.02375	EPA Nutrient Criteria
LEX BROOK	01104415	Manganese, mg/L	**0.421**	**0.207**	0.05	EPA Secondary MCL, Drinking Water
LEX BROOK	01104415	Sodium, mg/L	**358**	**239**	20	EPA Drinking Water Equivalent Level
LEX BROOK	01104415	Chloride, mg/L	**614**	**418.5**	230	EPA Chronic Water Quality Criteria
LEX BROOK	01104415	Dissolved Oxygen, mg/L	9.19	7.85	5	State Class A Water Quality Standards
TRACER LANE	01104420	*E.coli*, MPN	210	N/A	235	State Class A Water Quality Standards
TRACER LANE	01104420	Nitrate, mg/L	**0.329**	**0.44**	0.31	EPA Nutrient Criteria
TRACER LANE	01104420	Total Phosphorus, mg/L	**0.031**	0.01	0.02375	EPA Nutrient Criteria
TRACER LANE	01104420	Manganese, mg/L	**0.39**	**0.14**	0.05	EPA Secondary MCL, Drinking Water
TRACER LANE	01104420	Sodium, mg/L	**170**	**92**	20	EPA Drinking Water Equivalent Level
TRACER LANE	01104420	Chloride, mg/L	**271**	165	230	EPA Chronic Water Quality Criteria
TRACER LANE	01104420	Dissolved Oxygen, mg/L	5.33	9.7	5	State Class A Water Quality Standards
HB BELOW DAM	01104430	*E.coli*, MPN	1	N/A	235	State Class A Water Quality Standards
HB BELOW DAM	01104430	Nitrate, mg/L	0.078	0.05	0.31	EPA Nutrient Criteria
HB BELOW DAM	01104430	Total Phosphorus, mg/L	0.01	0.01	0.02375	EPA Nutrient Criteria
HB BELOW DAM	01104430	Manganese, mg/L	**0.083**	**0.058**	0.05	EPA Secondary MCL, Drinking Water
HB BELOW DAM	01104430	Sodium, mg/L	**120.5**	**64**	20	EPA Drinking Water Equivalent Level
HB BELOW DAM	01104430	Chloride, mg/L	205	116	230	EPA Chronic Water Quality Criteria
HB BELOW DAM	01104430	Dissolved Oxygen, mg/L	10.65	11.1	5	State Class A Water Quality Standards

BOLD	exceeds water quality standard
BOLD (shaded)	exceeds both USGS dry weather median and water quality criteria

Table 3 Continued: Baseflow Water Quality Data Comparison

CWD Site ID	USGS Site ID	Water Quality Parameter, Units	2008 - 2011 CWD Median	USGS Water Year 1998 Median	Water Quality Standard	Water Quality Standard Source
INDUST BROOK	01104433	*E.coli*, MPN	70	N/A	235	State Class A Water Quality Standards
INDUST BROOK	01104433	Nitrate, mg/L	**0.876**	**0.51**	0.31	EPA Nutrient Criteria
INDUST BROOK	01104433	Total Phosphorus, mg/L	**0.029**	**0.03**	0.02375	EPA Nutrient Criteria
INDUST BROOK	01104433	Manganese, mg/L	**0.481**	**0.247**	0.05	EPA Secondary MCL, Drinking Water
INDUST BROOK	01104433	Sodium, mg/L	**255.5**	**148**	20	EPA Drinking Water Equivalent Level
INDUST BROOK	01104433	Chloride, mg/L	**528.5**	**281.5**	230	EPA Chronic Water Quality Criteria
INDUST BROOK	01104433	Dissolved Oxygen, mg/L	6.33	5.5	5	State Class A Water Quality Standards
SB@VILES	01104370	*E.coli*, MPN	**313**	N/A	235	State Class A Water Quality Standards
SB@VILES	01104370	Nitrate, mg/L	**0.76**	**0.57**	0.31	EPA Nutrient Criteria
SB@VILES	01104370	Total Phosphorus, mg/L	0.02	0.01	0.02375	EPA Nutrient Criteria
SB@VILES	01104370	Manganese, mg/L	0.031	**0.21**	0.05	EPA Secondary MCL, Drinking Water
SB@VILES	01104370	Sodium, mg/L	**39.4**	15.4	20	EPA Drinking Water Equivalent Level
SB@VILES	01104370	Chloride, mg/L	58.4	27.2	230	EPA Chronic Water Quality Criteria
SB@VILES	01104370	Dissolved Oxygen, mg/L	8.73	11.1	6	State Class A Water Quality Standards
HB@KG	01104440	*E.coli*, MPN	36	N/A	235	State Class A Water Quality Standards
HB@KG	01104440	Nitrate, mg/L	0.153	0.19	0.31	EPA Nutrient Criteria
HB@KG	01104440	Total Phosphorus, mg/L	0.017	0.01	0.02375	EPA Nutrient Criteria
HB@KG	01104440	Manganese, mg/L	**0.168**	**0.167**	0.05	EPA Secondary MCL, Drinking Water
HB@KG	01104440	Sodium, mg/L	**104.4**	**61.1**	20	EPA Drinking Water Equivalent Level
HB@KG	01104440	Chloride, mg/L	174	105	230	EPA Chronic Water Quality Criteria
HB@KG	01104440	Dissolved Oxygen, mg/L	9.95	10.5	5	State Class A Water Quality Standards
MBS	01104453	*E.coli*, MPN	31	N/A	235	State Class A Water Quality Standards
MBS	01104453	Nitrate, mg/L	0.057	N/A	0.31	EPA Nutrient Criteria
MBS	01104453	Total Phosphorus, mg/L	0.019	N/A	0.02375	EPA Nutrient Criteria
MBS	01104453	Manganese, mg/L	**0.07**	N/A	0.05	EPA Secondary MCL, Drinking Water
MBS	01104453	Sodium, mg/L	**81.65**	N/A	20	EPA Drinking Water Equivalent Level
MBS	01104453	Chloride, mg/L	127.5	N/A	230	EPA Chronic Water Quality Criteria
MBS	01104453	Dissolved Oxygen, mg/L	6.26	N/A	5	State Class A Water Quality Standards
WA-17	01104455	*E.coli*, MPN	4.75	N/A	235	State Class A Water Quality Standards
WA-17	01104455	Nitrate, mg/L	**1.36**	**1.74**	0.31	EPA Nutrient Criteria
WA-17	01104455	Total Phosphorus, mg/L	0.01	0.01	0.02375	EPA Nutrient Criteria
WA-17	01104455	Manganese, mg/L	**0.118**	**0.154**	0.05	EPA Secondary MCL, Drinking Water
WA-17	01104455	Sodium, mg/L	**150**	**94.4**	20	EPA Drinking Water Equivalent Level
WA-17	01104455	Chloride, mg/L	**281**	166.5	230	EPA Chronic Water Quality Criteria
WA-17	01104455	Dissolved Oxygen, mg/L	9.19	9.2	5	State Class A Water Quality Standards

BOLD	exceeds water quality standard
BOLD (shaded)	exceeds both USGS dry weather median and water quality criteria

Table 3 Continued: Baseflow Water Quality Data Comparison

CWD Site ID	USGS Site ID	Water Quality Parameter, Units	2008 - 2011 CWD Median	USGS Water Year 1998 Median	Water Quality Standard	Water Quality Standard Source
RT20	01104460	*E.coli,* MPN	38	N/A	235	State Class A Water Quality Standards
RT20	01104460	Nitrate, mg/L	**0.49**	0.27	0.31	EPA Nutrient Criteria
RT20	01104460	Total Phosphorus, mg/L	0.022	0.01	0.02375	EPA Nutrient Criteria
RT20	01104460	Manganese, mg/L	**0.236**	**0.159**	0.05	EPA Secondary MCL, Drinking Water
RT20	01104460	Sodium, mg/L	**74**	**41.9**	20	EPA Drinking Water Equivalent Level
RT20	01104460	Chloride, mg/L	134	74	230	EPA Chronic Water Quality Criteria
RT20	01104460	Dissolved Oxygen, mg/L	8.89	11.7	6	State Class A Water Quality Standards
SUMMER ST	01104475	*E.coli,* MPN	3.1	N/A	235	State Class A Water Quality Standards
SUMMER ST	01104475	Nitrate, mg/L	**1.58**	**0.94**	0.31	EPA Nutrient Criteria
SUMMER ST	01104475	Total Phosphorus, mg/L	0.018	0.02	0.02375	EPA Nutrient Criteria
SUMMER ST	01104475	Manganese, mg/L	0.0195	0.005	0.05	EPA Secondary MCL, Drinking Water
SUMMER ST	01104475	Sodium, mg/L	**31.7**	17.3	20	EPA Drinking Water Equivalent Level
SUMMER ST	01104475	Chloride, mg/L	44.2	24.4	230	EPA Chronic Water Quality Criteria
SUMMER ST	01104475	Dissolved Oxygen, mg/L	10.01	10.4	5	State Class A Water Quality Standards

BOLD	exceeds water quality standard
BOLD (shaded)	exceeds both USGS dry weather median and water quality criteria

Wet Weather Monitoring

Stormwater runoff disproportionally impairs water bodies in more developed watersheds. Impervious surfaces such as parking lots and roadways store metals, oils, and sediments from cars, aerial deposition, and other sources, which, during storms, are rapidly shunted to streams via piped drainage networks at erosive velocities. In undeveloped watersheds, trees, uncompacted soils, and vegetation capture and recharge most of the storm water before it runs off. What runoff does make it to streams does not exacerbate erosion and is generally of high quality.

Samples analyzed for nutrients, major ions, and selected metals were collected during one to four storm events throughout this reporting period for four USGS-recommended stations. CWD event monitoring targets the worst case in-stream stormwater pollutant concentrations or the "first flush" of runoff into the stream.

Concurrently, USGS has conducted comprehensive stormwater studies where instead of taking one-time samples on the rising limb of the hydrograph (stream flows begin increasing from stormwater runoff contributions), automated samples are taken throughout the entire storm, mixed together, then analyzed for chemical concentrations. Data are available online by station ID# and are used in comparing dry weather to wet weather results below. By next year, a USGS interpretive report will explain wet weather versus dry weather constituent contributions to the water supply and help focus Watershed Division stormwater management programs. Due to the anticipated release of this comprehensive report, discussion on stormwater results, monitoring and implications will be brief.

During this period, the LEX BROOK, INDUST BROOK, WA-17 and SUMMER ST stations were monitored. Significant increases in constituent concentrations are realized in stream flows dominated by stormwater generally throughout the Cambridge source watershed. The below graphs illustrate this phenomenon for wet weather and dry weather samples from stormwater-impacted subbasins for two pollutants of concern, bacteria and phosphorus. In figure 46, Watershed Division sampling for phosphorus at SUMMER ST did not agree with USGS wet weather concentrations. Differences are most likely due to the timing of CWD sampling events vs. comprehensive aggregated pollutant concentrations captured by USGS throughout entire storms.

Figure 46: Total Phosphorus Dry and Wet Weather Comparisons

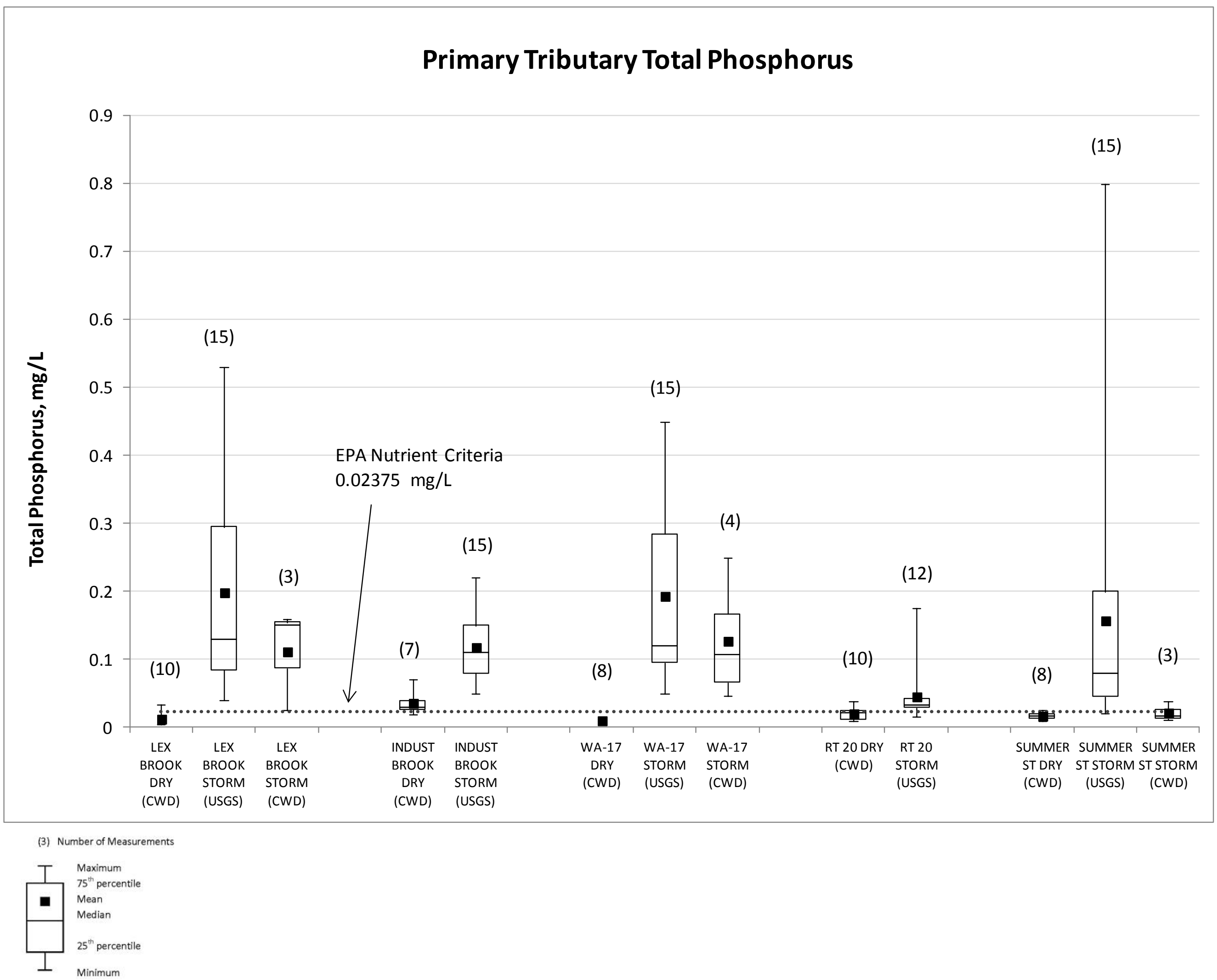
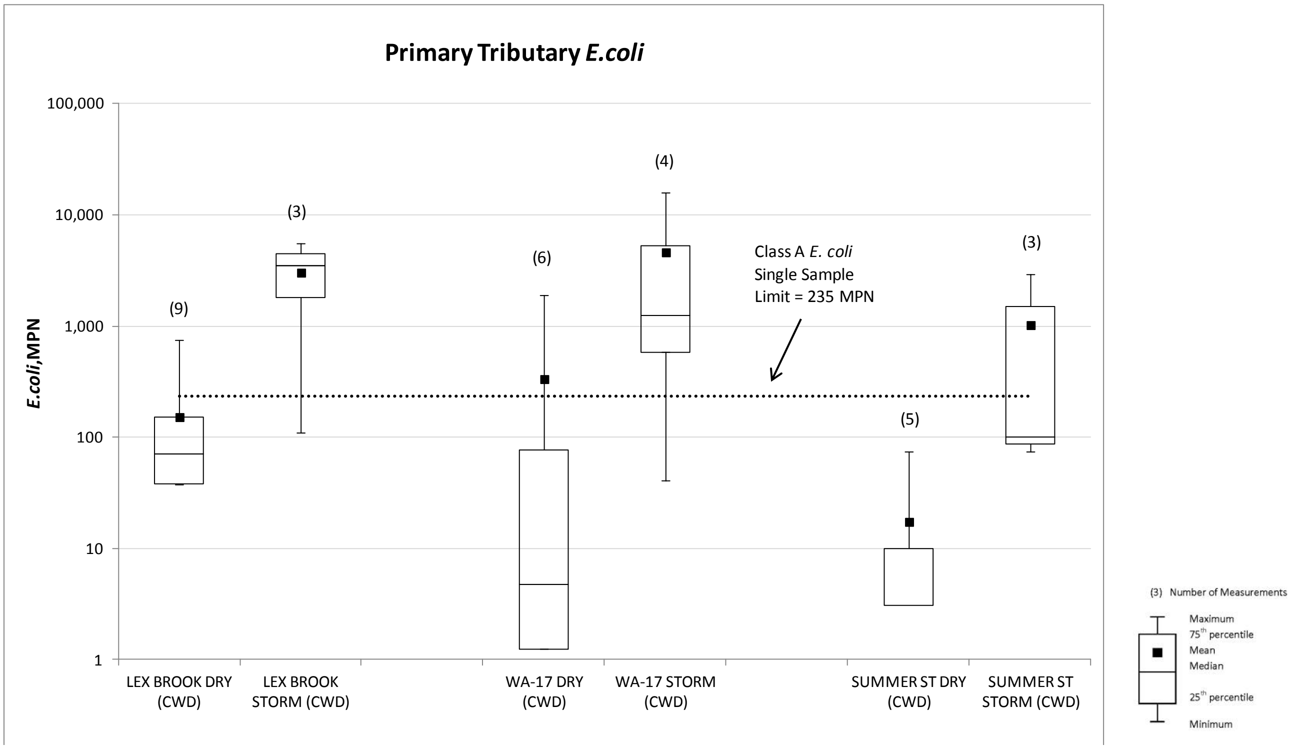


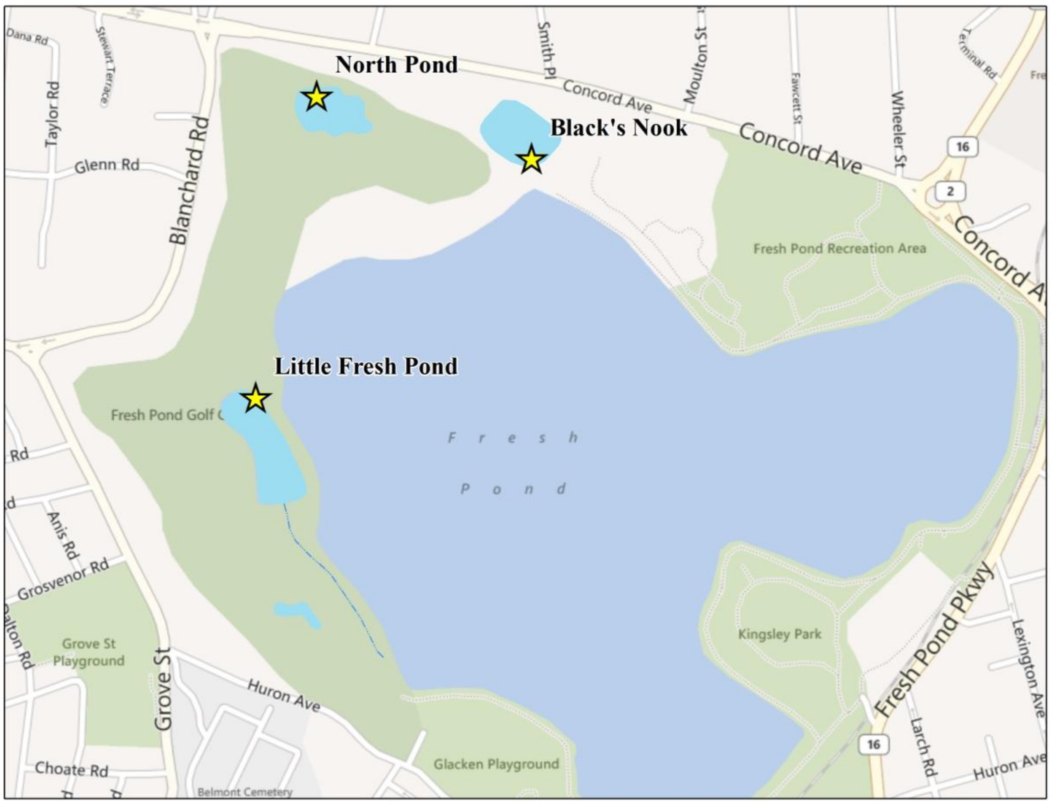
Figure 47: *E.coli* Dry and Wet Weather Comparisons



Class-B Waters on Fresh Pond Reservation

As part of the Fresh Pond Reservation Master Plan implementation, water quality monitoring was conducted at three small ponds within the Fresh Pond Reservation; Black's Nook, Little Fresh Pond, and North Pond (figure 48). Each of the ponds drains the nine-hole Cambridge Municipal Golf Course. There are no natural surface water connections between Fresh Pond Reservoir and any of these ponds; however the potential exists for groundwater communication between them. Under the Massachusetts State regulations, these ponds are considered to be Class B water bodies, thus water quality should support primary contact recreation, and are not considered to be part of the drinking water supply.

Figure 48: Fresh Pond Reservation Sampling Locations



During this period, reservation ponds were sampled between seven and eight times, primarily through shoreline wading and taking a surface grab sample with an extended telescoping pole. No wet weather samples were taken. These ponds are physically, chemically, and ecologically different from any of the reservoirs in the drinking water supply in that they are significantly smaller, shallower, and more productive. Average pond depth is approximately 6 feet.

In this study period, median temperature, pH, dissolved oxygen and bacteria met Class B water quality standards. Black's Nook had one sample above the bacteria standard and two instances of dissolved oxygen below 5 mg/L. All other chemistry samples met water quality standards in all events. High phosphorus (figure 50) and chlorophyll (figure 52) results are consistent with expectations of highly productive eutrophic ponds. Sodium concentrations in Little Fresh Pond are consistent with those in Fresh Pond Reservoir, supporting the assumptions of good groundwater communication and also the influence of Fresh Pond water being diverted into Little Fresh Pond through a gated pipe for golf course irrigation in dry periods. TSI values are all in the eutrophic range for all three ponds, with one Little Fresh Pond sample showing a hypereutrophic classification.

Figure 49: Fresh Pond Reservation Class B Waters – *E. coli* Bacteria Concentrations

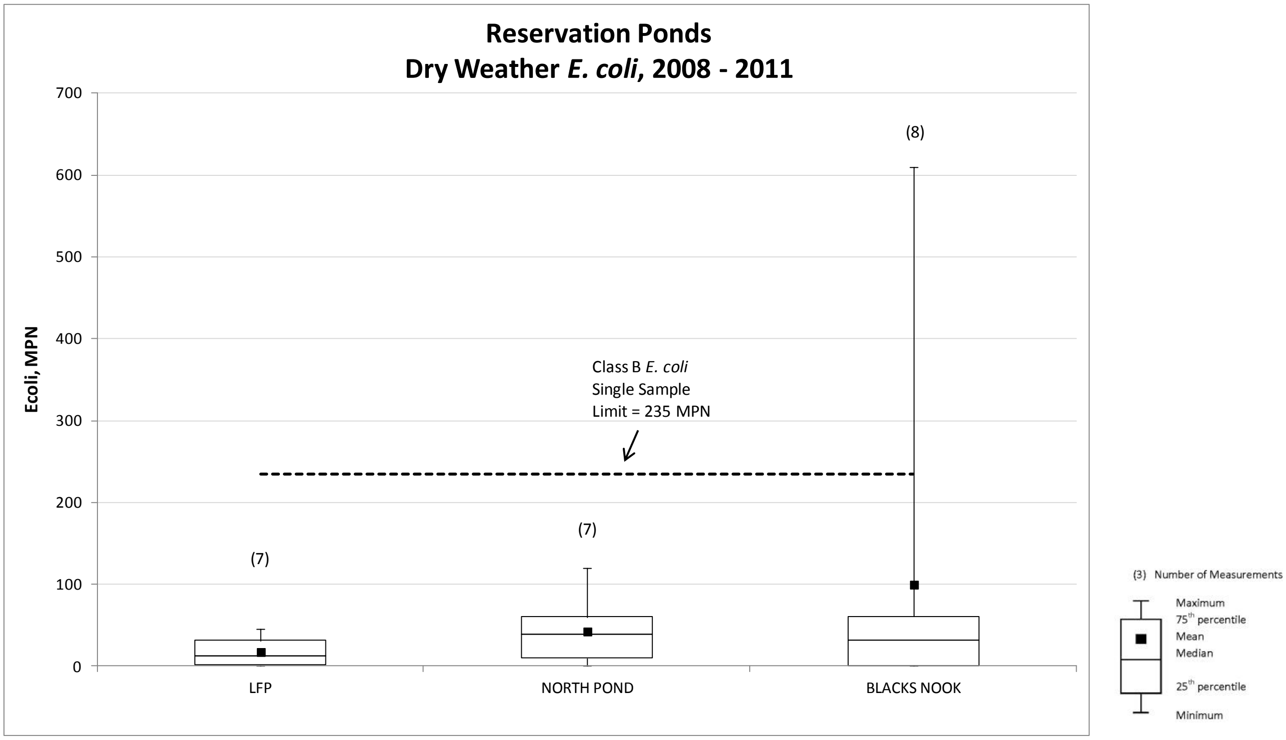


Figure 50: Fresh Pond Reservation Class B Waters – Total Phosphorus Concentrations

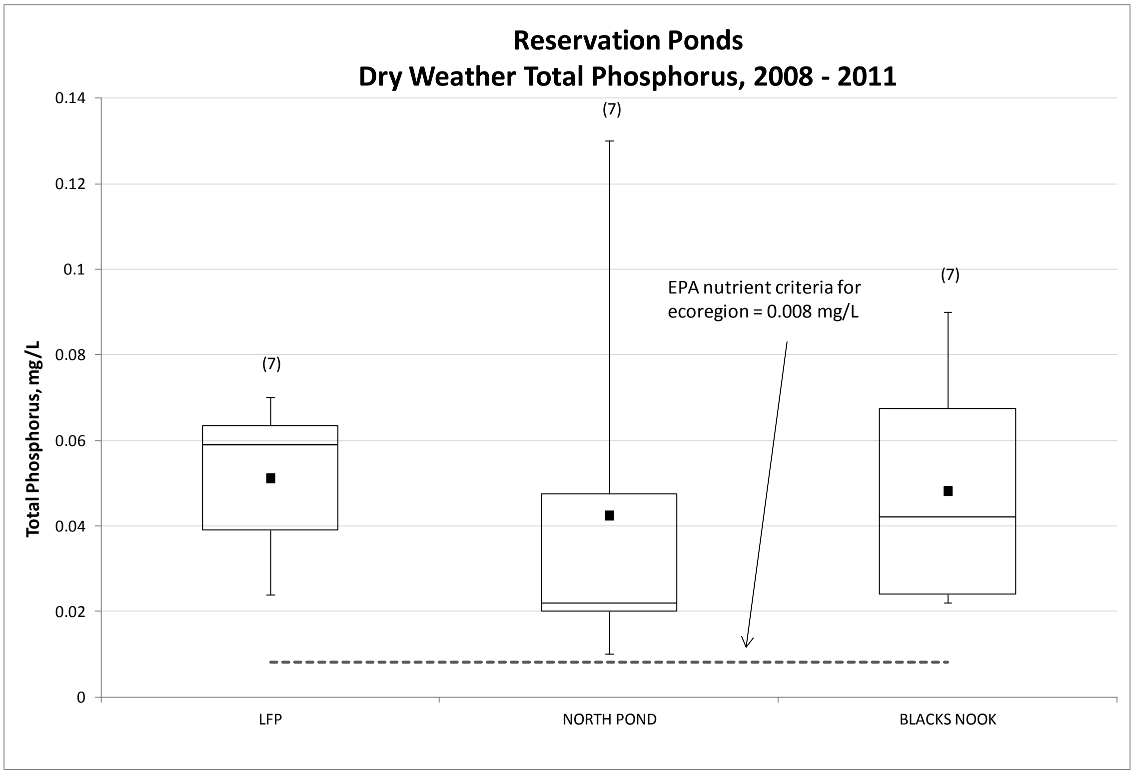


Figure 51: Fresh Pond Reservation Class B Waters – Sodium Concentrations

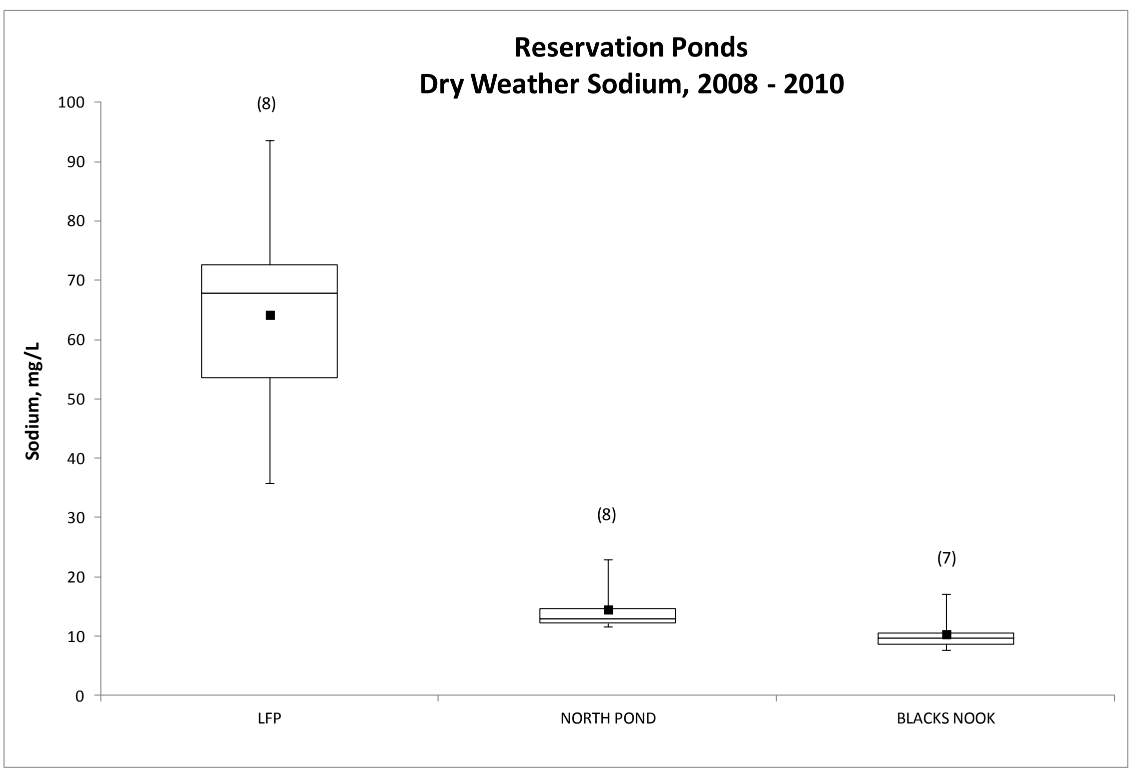


Figure 52: Fresh Pond Reservation Class B Waters – Chlorophyll-*a* Concentrations

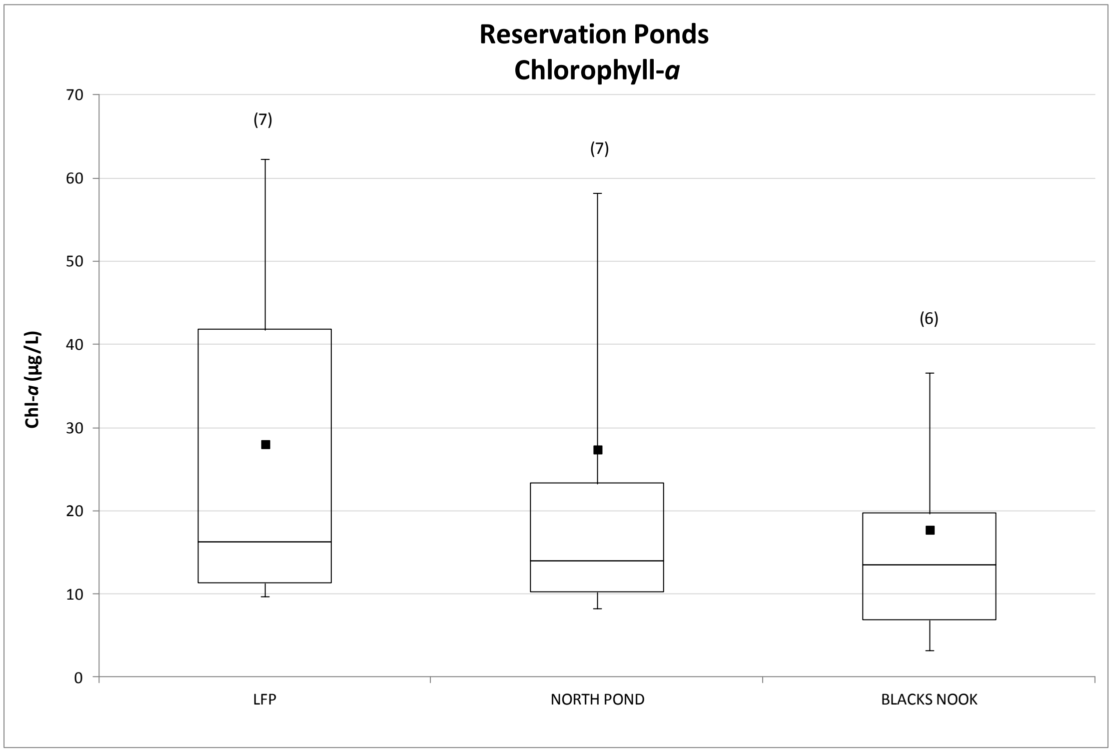
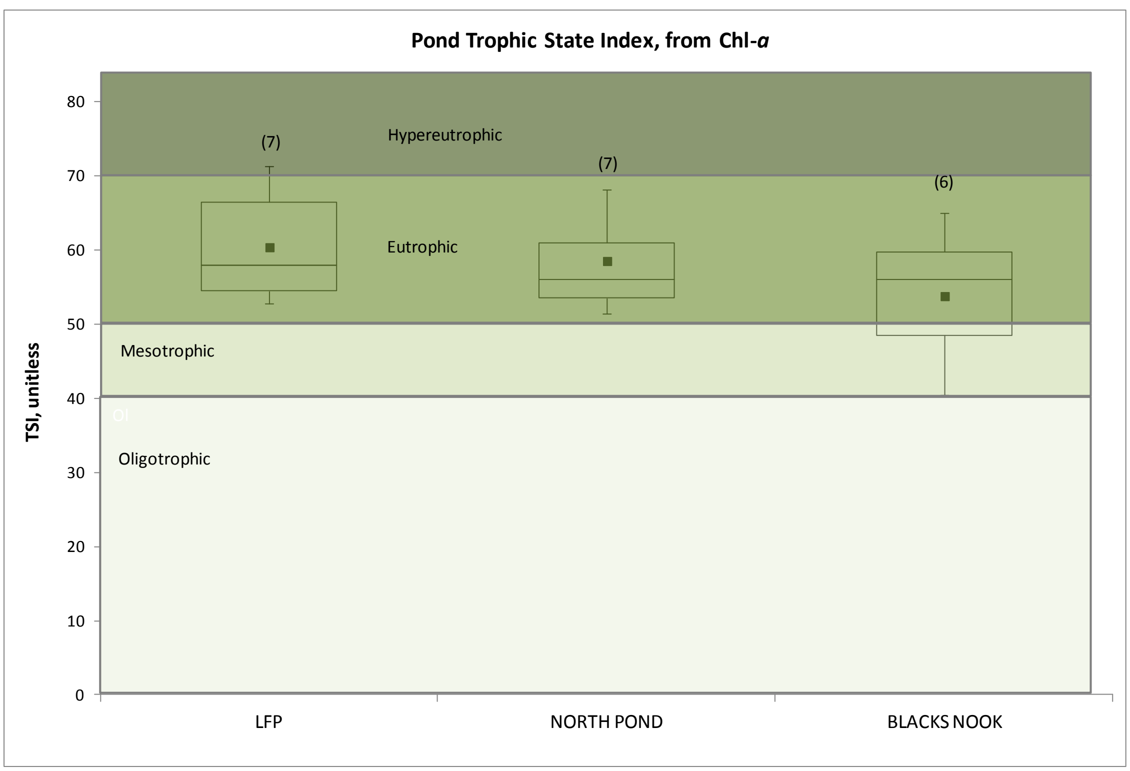


Figure 53: Fresh Pond Reservation Class B Waters - TSI



Special Water Quality Investigations

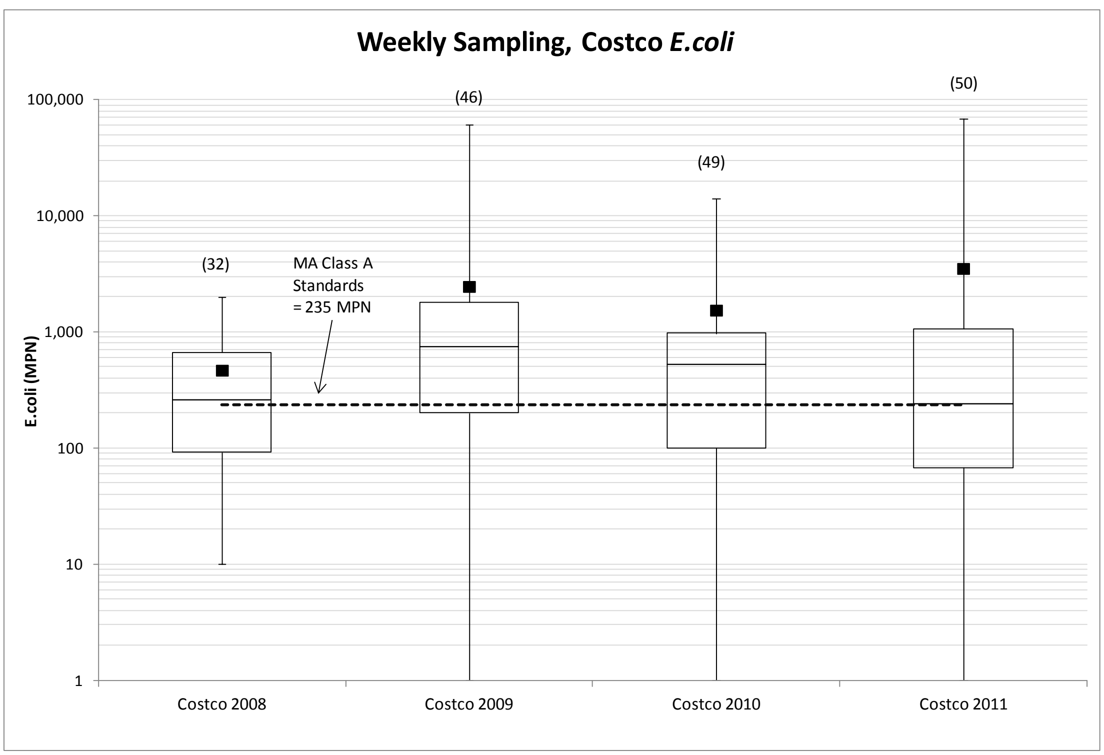
The water quality monitoring program includes the investigation of specific point-source locations that contribute contaminants to the water supply. These locations are not tributary sampling stations, rather outfalls, or other discharges, whose sources were detected by routine or stormwater sampling in the tributaries and traced back upstream to their specific location. During this study period one location was regularly investigated as a result of water quality degradation detected at routine sampling stations: an historic illicit sewage discharge at a detention basin in Waltham.

Costco Drainage Canal

Located downstream of a recently improved stormwater pond on Winter Street in Waltham, this site has shown extremely high bacteria concentrations that were at once from and are thought perhaps to still be from underground sewerage communication. Other theories identify Canada geese as the bacteria source. Canada geese do frequent the upstream stormwater pond. Goose bacteria sources plus the relatively stagnant nature of the canal could explain high measured concentrations of *E.coli* bacteria.

Further chemical screening of fluoride and chlorine residual (both found in drinking water, and as such, wastewater) showed average concentrations an order of magnitude less than what would be expected in wastewater, with no direct correlations between chlorine and fluoride to bacteria concentrations. These data support the theory that the primary bacteria source is from wildlife, not sewage. Other tests such as surfactants and optical brighteners could be use to further rule out sewage sources. Bacteria results below do not yet show any clear trends of improvement from the recently completed pond project, yet likely more geese use this area post construction due to mowing and landscaping.

Figure 54: Weekly *E.coli* Results, Costco Drainage Ditch



Water Balance

The water balance, which defines the balance between water gains (inflow components) and losses (outflow components) over a given period of time, is a useful tool for general management decisions. The water balance determined for Hobbs Brook Reservoir during this reporting period can be considered a generalized approximation of the overall water availability. Between 2008 and 2011, at the USGS monitoring station immediately downstream of Hobbs Brook Reservoir, annual outflows ranged between 2.47 billion gallons (2008) to 4.90 billion gallons (2010), with a four year average of 3.4 billion gallons. All annual outflows are larger than the estimated total storage capacity of the reservoir which is 2.52 to 2.88 billion gallons (depending on the installation of spillway flashboards). The hydraulic detention time can be defined as the time it would take for the reservoir to empty out if all inputs of water to the reservoir ceased. Average Hobbs Brook reservoir detention time ranged from 6 months (2010) to 14 months (2008) and averaged 10 months throughout the study period.

Table 4: Hobbs Brook Reservoir Water Balance

Year	Hobbs Outflow (MG)	Storage Capacity (MG)	Estimated Detention Time (months)
2008	2465	2885	14
2009	3615	2885	10
2010	4892	2518	6
2011	2654	2518	11

total outflow = sum of avg. daily flows

Inputs to Stony Brook Reservoir are contributed mostly by its watershed during winter and spring and from the Hobbs Brook Reservoir during the summer and fall. Outflow from the Cambridge source water area to the Charles River was estimated from the USGS gaging station located near the Stony Brook gatehouse. The total outflow to the Charles ranged from 6.7 billion gallons (2009) to 10.6 billion gallons (2010). In addition to the volume of water that passes to the Charles, sluice gates were opened to allow water to Fresh Pond in Cambridge, in order to meet the City's drinking water demand. Based on the small reservoir storage capacity and large drainage area, the majority of annual flows need to be diverted to the Charles River to maintain safe reservoir operating levels.

Total output from Stony Brook Reservoir is the sum of water to Fresh Pond and the Charles River. The best estimate of water sent to Cambridge from the Stony Brook Reservoir is based on measured flows at the Stony Brook Conduit outlet into the Fresh Pond Reservoir. When not available, because Fresh Pond is maintained at roughly the same elevation, measured water treatment plant usage can be used. Charles River flows from Stony Brook are measured at a downstream USGS gaging station. In this reporting period, total output from Stony Brook Reservoir ranged from 11.8 (2009) to 15.5 (2010) billion gallons. The total estimated detention time in Stony Brook Reservoir was between 11 and 15 days, indicating a high flushing rate.

Table 5: Stony Brook Reservoir Water Balance

Year	Stony to Charles (MG)	Stony to Fresh Pond (MG)	Storage Capacity (MG)	Estimated Detention Time (days)
2008	7730	7730	418	11
2009	6672	6672	418	11
2010	10551	2483	418	11
2011	7668	3167	418	15

total outflow = sum of avg. daily flows

Total estimated output from Fresh Pond to the treatment plant ranged from 4.71 to 4.88 billion gallons. The four year average detention time is 3.78 months.

Table 6: Fresh Pond Reservoir Water Balance

Year	Fresh Pond to WTP (MG)	Storage Capacity (MG)	Estimated Detention Time (months)
2008	4878	1507	3.72
2009	4748	1507	3.84
2010	4850	1507	3.72
2011	4709	1507	3.84

*Taken from *Monthly Water Quantity and Quality Report, Decembers 2008-2012*

References Cited

American Public Health Association, American Water Works Association, and Water Pollution Control Commission, 1995, Standard methods for the examination of water and wastewater (19th ed.): Washington, D.C., APHA, variously paginated.

Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, chap. C2, book 3, 89 p.

Granato, G.E., and Smith, K.P., 1999. Estimating concentrations of road-salt constituents in highway runoff from measurements of specific conductance: U.S. Geological Survey, Water-Resources Investigations Report 99-4077, 22 p.

Intergovernmental Task Force on Monitoring Water Quality, 1995, The strategy for improving water-quality monitoring in the United States—Final report of the Intergovernmental Task Force on Monitoring Water Quality: Reston, Va., U.S. Geological Survey Office of Water Data Coordination, 25 p. plus Appendixes.

Lind, O.T., 1974, Handbook of common methods in limnology: St. Louis, The C.V. Mosby Co., 145 p.

New England Interstate Water Pollution Control Commission, 1996, Source protection. A guidance manual for small surface water supplies in New England: New England Interstate Water Pollution Control Commission, 77 p. plus Appendices.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow—Volume 1. Measurement of stage and discharge—Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

U.S. Environmental Protection Agency, 1999, Region I, EPA-New England Compendium of Quality Assurance Project Plan Requirements and Guidance: U.S. EPA- New England, Region I, Office of Environmental Measurement and Evaluation, variously paginated.

Waldron, Marcus C., Bent, Gardner C, 2001, Factors Affecting Reservoir and Stream-Water Quality in the Cambridge, Massachusetts, Drinking-Water Source Area and Implications for Source-Water Protection: U.S. Geological Survey, Water Resources Investigations Report 00-4263.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., 1999, Collection of water samples, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, 103 p.

Glossary

Algal bloom—The rapid proliferation of passively floating, simple plant life in and on a body of water.

Anoxic—The absence of oxygen; anaerobic.

Atmospheric deposition—The transfer of substances from the atmosphere to the surface of the Earth or to objects on its surface. Transfer can be either by wet-deposition processes (rain, snow, dew, fog, frost, hail) or by dry deposition (gases, aerosols, fine to coarse particles) in the absence of water.

Bed sediment —The material that temporarily is stationary in the bottom of a stream or other water body.

Colony-forming units (CFU)—Unit of bacterial population size referring to the colonies that appear on a nutrient-agar plate following inoculation of the plate with a sample of water. Each colony may arise from a single bacterial cell or from a small cluster of cells; hence, the colony is reported as a CFU and the bacterial population density is reported as the number of CFUs per unit volume (usually 100 milliliters) of water.

Contamination—Change of water quality by the addition of constituents as a result of human activity or natural processes.

Constituent—A compound such as a chemical species or biological population whose magnitude in water, sediment, biota, or other matrix is determined by an analytical method.

Correlation coefficient—A statistic that can be used to measure the strength of a relation between two variables.

Discharge (hydraulics)—Rate of flow, especially fluid flow; a volume of liquid passing a point per unit of time, commonly expressed in cubic feet per second, million gallons per day, or liters per second.

Dissolved oxygen (DO)—Oxygen dissolved in water; one of the most important indicators of the condition of a water body. Dissolved oxygen is necessary for the life of fish and most other aquatic organisms.

Drainage basin—Land area drained by a river or stream; watershed.

Epilimnion—Warm, oxygen-rich, upper layer of water in a lake or other body of water, usually seasonal. *See also* Metalimnion, Hypolimnion

Eutrophic—Term applied to a body of water with a high degree of nutrient enrichment and high productivity.

Eutrophication—Process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Fecal coliform bacteria—Group of several types of bacteria that are found in the alimentary tract of warm-blooded animals. The bacteria commonly are used as an indicator of animal and fecal contamination of water.

Ground water—In the broadest sense, all subsurface water, as distinct from surface water; as more commonly used, that part of the subsurface water in the saturated zone. *See also* Surface water.

Hypolimnion—Cold, oxygen-poor, deep layer of water in a lake or other water body. *See also* Epilimnion, Metalimnion.

Hypoxic—The near absence of oxygen.

Kettle-hole lake—Glacially-formed lake with no surface water inflows or outflows.

Limnology—Scientific discipline dealing with the physics, chemistry, and biology of inland waters such as lakes, ponds, reservoirs, streams, and wetlands.

Load—Material that is moved or carried by streams, reported as the weight of the material transported during a specific time period, such as kilograms per day or tons per year.

Main stem—The main trunk of a river or stream.

Maximum contaminant level (MCL)—Maximum permissible level of a contaminant in water that is delivered to any user of a public water system, established by a regulatory agency such as the U.S. Environmental Protection Agency. *See also* Secondary maximum contaminant level.

Mean—The arithmetic average obtained by dividing the sum of a set of quantities by the number of quantities in the set.

Median—The middle or central value in a distribution of data ranked in order of magnitude. The median also is known as the 50th percentile.

Mesotrophic—Term applied to a body of water with intermediate nutrient content and intermediate productivity.

Metalimnion—Transition zone between the warm upper layer and the cold deep layer of a lake or other water body, characterized by rapidly decreasing temperature with increasing depth. *See also* Epilimnion, Hypolimnion.

Minimum reporting limit (MRL)—The lowest measured concentration of a constituent that can be reported reliably using a given analytical method.

Monitoring station—A site on a stream, canal, lake, or reservoir used to observe systematically the chemical quality and discharge or stage of water.

Nutrient—An element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Oligotrophic—Term applied to a body of water low in nutrients and in productivity.

pH—The logarithm of the reciprocal of the hydrogen ion concentration of a solution; a measure of the acidity (pH less than 7) or alkalinity (pH greater than 7) of a solution; a pH of 7 is neutral.

Phytoplankton algae—Free-floating, mostly microscopic aquatic plants.

Phytoplankton chlorophyll *a*—Primary light-trapping pigment in most phytoplankton algae. Concentration can be used as an indirect indicator of the abundance of phytoplankton algae in a lake or other water body.

Runoff—That part of precipitation that appears in surface streams. It is equivalent to streamflow unaffected by artificial diversions, storage, or other human works in or on the stream channel.

Secondary maximum contaminant level (SMCL)— Maximum recommended level of a contaminant in water that is delivered to any user of a public water system. These contaminants affect the esthetic quality of the water such as odor or appearance; therefore, the levels are intended as guidelines. *See also* Maximum contaminant level.

Specific conductance—A measure of the ability of a sample of water to conduct electricity.

Subbasin—Drainage basin or watershed defined by a specific monitoring station and representing the land area that contributes water to that station.

Surface water—An open body of water, such as a stream or lake. See also Ground water.

Swamp—A forested wetland that has standing water during most or all of the growing season.

Thermal stratification—Seasonal division of a lake or other water body into a warm upper layer and a cold deep layer that is no longer in contact with the atmosphere. In some lakes, thermal stratification can result in a loss of oxygen in the deep layer and subsequent chemical stratification.

Trihalomethane formation potential (THMFP)— Tendency of naturally occurring organic compounds in a water supply to form toxic trihalomethanes during water treatment.

Trophic state—The extent to which a body of water is enriched with plant nutrients. *See also* Eutrophic, Mesotrophic, Oligotrophic.

Trophic state index (TSI)—A numerical index indicating the degree of nutrient enrichment of a body of water.

Turbidity—The opaqueness or reduced clarity of a fluid due to the presence of suspended matter.

Water year—The continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with the surface-water supply. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1998, is referred to as the "1998" water year.

Wetlands—Lands that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

Yield—The weight of material transported during any given time divided by unit drainage area, such as kilograms per day per square kilometer or tons per year per square mile.

Appendix A – Project Description

Monitoring Objectives

Given the City's lack of ownership and control of most watershed lands, water quality monitoring is a necessary and effective means of identifying sources of pollution and tracking water quality changes over time. The primary goal of the Cambridge Source Water Quality Monitoring Program is to ensure that water withdrawn from Fresh Pond Reservoir for treatment is as free as possible from contaminants, thereby minimizing the costs of treatment and protecting overall water quality. Specific objectives of the program are to:

- Monitor the condition of source waters in the Cambridge drinking water supply system;
- Determine where, when, and how water quality conditions are changing over time;
- Identify actual and potential problems related to source water quality;
- Evaluate the effectiveness of programs designed to prevent or remediate water quality problems;
- Ensure that all applicable water quality goals, standards, and guidelines are being met; and
- Provide for rapid response to real-time and emerging problems.

The Cambridge Source Water Quality Monitoring Program consists of four major elements: (1) routine monitoring of reservoirs and tributary streams during base flow (dry weather) conditions, (2) event-based monitoring of streams, storm drains, and other outfalls during wet weather and special water quality investigations, (3) continuous recording of stage and selected water quality characteristics at critical sites within the drainage basin, and (4) data management, analysis, reporting, and review.

Routine Water Quality Monitoring

Under base flow (dry-weather) conditions, CWD staff members collect discrete grab samples and measure streamflow and in situ parameters (dissolved oxygen, specific conductance, temperature, oxidation-reduction potential, and pH) throughout the watershed at regular intervals during the year. Base flow sampling, conducted on days with no more than 0.10 in of rain 72 hours prior, provides a representative measurement without the influence of stormwater. Sampling is conducted at 8 reservoir-monitoring stations, and at 12 primary and 4 secondary tributary-monitoring stations. The distinction between primary and secondary monitoring stations is based on the location of sampling station in relation to the watershed system, which dictates the frequency of sampling, as well as the number and type of analyses performed on the samples.

Reservoir Sampling Process Overview

The Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs are all sampled regularly using USGS *Clean Water* sampling protocols. Each reservoir is sampled for nutrients, metals, chlorophyll-*a*, bacteria and in-situ parameters. During summer months, when the water column is thermally stratified, additional water samples at deepest hole sites are pumped from below the thermocline (the point of maximum rate of change in water temperature with depth) with a peristaltic pump through pre-cleaned Tygon tubing. Studies conducted by the USGS have shown that under most conditions, water quality data collected in depth profiles at these stations are indicative of conditions throughout the reservoirs.

Samples are analyzed at the CWD laboratory for volatile organic compounds, total organic carbon, color, alkalinity, turbidity, bacteria, concentrations of major ions (sodium, calcium, chloride, and sulfate), and selected metals (aluminum, iron, and manganese) using standard approved methods. Nutrients (ammonia nitrogen, total Kjeldahl nitrogen, and total phosphorus) and chlorophyll-a are analyzed at contracted laboratories.

Routine Tributary Monitoring Process Overview

Water entering the reservoirs is monitored at 12 primary and 4 secondary tributary monitoring stations. Primary monitoring stations are sampled 4 - 8 times a year. Specific conductance, pH, water temperature, and dissolved oxygen concentration are measured in situ and water samples are collected at the stream channel center in accordance with clean-sampling protocols. The samples are analyzed at both CWD and contracted laboratories for the same suite of parameters as the reservoir samples except for chlorophyll-*a*.

The four secondary stream monitoring stations are monitored 1 - 2 times a year, usually during base flow conditions. These stations are located higher up in the drainage basin on smaller tributaries that feed into larger tributaries that have primary monitoring stations. The secondary stations are sampled for the same constituents as the primary stations to provide indicators of potential changes in water quality or of base flow conditions.

Event-Based Water Quality Monitoring

Stormwater Sampling

CWD staff members conduct storm event sampling at primary stream monitoring stations, Fresh Pond Reservation, and at major pipes and other discharge locations. The goal of the storm event sampling is to collect samples of the first flush of runoff from storms producing 0.5 inches or more of rain after a period of at least 3 days of dry weather.

Storm water samples are analyzed for color, *E.coli* bacteria, alkalinity, total suspended solids, and concentrations of major ions, nutrients, and selected metals. Stormwater sample results are compared to baseline levels from routine, dry-weather monitoring in order to assess the effects of storms on introducing sediment and associated constituent loads to the reservoir.

Continuous-Record Surface-Water Monitoring

Continuous (15 minute interval) monitoring is conducted at nine primary tributary monitoring stations and three reservoir monitoring stations. These stations are operated and maintained by the USGS and CWD for continuous measurement of stream and reservoir stage, discharge (eight sites only), temperature, and temperature-corrected specific conductance. Precipitation is monitored at the three reservoir stations, and wind speed and direction is measured at the Stony Brook reservoir. Late in 2001, a more elaborate water quality monitoring system was installed at Stony Brook Reservoir which measures turbidity, temperature, specific conductance and chlorophyll-*a* at three different reservoir depths (USGS unpublished data).

All continuous monitoring information is uploaded on a real-time basis to the USGS internet site, which can be accessed from the hyperlink below.

http://waterdata.usgs.gov/ma/nwis/current?type=cambrid&group_key=NONE&search_site_no_station_nm=&format=html_table

Data Management, Interpretation, Reporting, and Review

All water quality monitoring and quality-assurance data are entered into a CWD-maintained database that enables the CWD analyze, track, and report changes in water quality efficiently. Data is compared to the 1998 water year baseline study conducted by the USGS. This report is the result of the reporting portion of the water quality monitoring program.

Table A-1 Water Quality Monitoring Schedule

Event Sites (3 times a year)

Continuous (bottles)	Partial (pipes/streams)
7	**7**
Discharge	Discharge
Temperature	Temperature
Conductance	DO
Turbidity	pH
Color	Conductance
Nutrients	Turbidity
Metals	Color
Ions	Nutrients
	Metals
	Ions
	Fecal Coliform

Primary Streams	freq.	Secondary Streams	freq.
10		**6**	
Station Maintenance	monthly	Discharge	quarterly
Discharge	monthly	Temperature	quarterly
Temperature	monthly	DO	quarterly
DO	monthly	pH	quarterly
pH	monthly	Conductance	quarterly
Conductance	monthly	Turbidity	quarterly
Turbidity	monthly	Nutrients	quarterly
Nutrients	monthly	Metals	quarterly
Fecal Coliform	monthly	Ions	quarterly
Color	quarterly	Fecal Coliform	quarterly
Alkalinity	quarterly		
Metals	quarterly		
Ions	quarterly		

Primary Reservoirs	freq.	Secondary Reservoirs	freq.
3		**5**	
Temperature	monthly	Temperature	quarterly
DO	monthly	DO	quarterly
pH	monthly	pH	quarterly
Conductance	monthly	Conductance	quarterly
Turbidity	monthly	Turbidity	quarterly
Nutrients	monthly	Nutrients	quarterly
Fecal Coliform	monthly	Metals	quarterly
Chlorophyll	monthly	Ions	quarterly
Secchi Disk	monthly	Secchi Disk	quarterly
Alkalinity	quarterly		
Metals	quarterly		
Ions	quarterly		
Color	quarterly		

Nutrients: TKN, TP, NO3-N, PO4-P(SRP)
Metals: Al, Mn, Fe, Na, Ca
Ions: Cl