City of Cambridge Water Department
2012 Source Water Quality Report

April, 2013

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List of Abbreviations

CWD	Cambridge Water Department
DO	Dissolved oxygen
EPA	Environmental Protection Agency
LEED	Leadership in Energy and Environmental Design
LOWESS	Locally Weighted Scatterplot Smoothing
MassDOT	Massachusetts Department of Transportation
MassGIS	Massachusetts Office of Geographic Information
MCL	Maximum contaminant level
MPN	Most probable number
ORP	Oxidation reduction potential
SPC	Specific conductance
TKN	Total Kjeldahl nitrogen
TSI	Trophic State Index
TOC	Total organic carbon
UMass	University of Massachusetts
USGS	United States Geological Survey

Executive Summary

This report presents the results of the Source Water Quality Monitoring Program; 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 2012 sampling results are compared to Federal and Massachusetts ambient and drinking water quality standards, as well as with past data primarily from the 2008-2011 report and a USGS/CWD comprehensive assessment conducted in 1997/1998 (Water Year 1998). This report is intended to help aid managers and decision makers and educate others who are interested in the Cambridge water supply.

Non-mandated source water sampling was conducted to assess the quality and trophic state of the three primary storage reservoirs, Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs. Additionally, water quality data was collected from 12 stream tributaries that contribute water to the reservoirs and are compared to historic results. The goal of source water quality sampling is to provide information on the state of these resources, inform the drinking water treatment process, and to determine their vulnerability to increased loads of nutrients and other contaminants.

Source water quality sampling was more frequent in 2012 than past years but still did not meet the recommended water quality sampling frequencies proposed in the Water Quality Monitoring Plan created in 2001 in collaboration with the USGS. A smaller sampling target will be considered for future years due to staffing and weather constraints that make scheduling difficult.

Source water quality in 2012 was mostly consistent with the results and expectations set from previous years of sampling. 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/Waltham to Fresh Pond in Cambridge. The highest sodium and chloride concentrations were measured in Hobbs Brook Reservoir, which is strongly influenced by runoff from Route 2 and Interstate 95, and other deicing salt-treated impervious surfaces. The less developed Stony Brook Reservoir watershed exhibited lower sodium and chloride 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 sodium and chloride having the highest concentrations of the constituents sampled.

The Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs generally met Massachusetts Class A Surface Water Quality Standards. Under periods of reservoir thermal stratification, lower depth dissolved oxygen consistently fell below the 5 mg/L threshold in all three reservoirs. Sporadic exceedances of bacteria standards in Hobbs Brook and Stony Brook weekly samples occurred in only 3% of all samples in 2012. 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 all three reservoirs were intermediate in productivity with the potential to support algae blooms; while the upper range of TSI values for Stony Brook indicated eutrophic states with high productivity and likelihood of algal blooms. These results are slightly higher than results from the 2008-2011 reporting period.

In general, tributary water quality in dry weather for all contributing streams is good and meets Class A standards. Two streams, Tracer Lane and MBS, fell below the recommended 5 mg/L dissolved oxygen (DO) level. Salt Depot and WA-17 both exceeded the *E.coli* single sample limit of 235 MPN. Four sites exceeded the manganese standard; and eight sites exceeded the total phosphorus region criteria. All sites except Salt Depot exceeded the region nitrate criteria, indicating a need to curb nutrient use, specifically lawn fertilizers, throughout the watershed.

Significant trends in increasing salt concentrations are apparent for most streams where there are many salt treated impervious surfaces. Chloride levels in four primary tributary streams consistently exceed EPA recommended criteria for chronic aquatic toxicity and secondary limits for drinking water.

Water availability was lower in 2012 than previous years. Using precipitation amounts from the Hobbs Brook Dam precipitation gage, the watershed received an estimated 13 inches less of rain than in 2011, resulting in less water available than the average year. The water balance estimates in Hobbs Brook Reservoir show that the time required for complete flushing of the reservoir (detention time) in 2012 took 16 months. The average detention time of Stony Brook Reservoir was approximately 26 days, with total annual diversion to the Charles River of roughly 2.2 billion gallons. The detention time for Fresh Pond during this period was approximately 3.8 months.

Additional analysis and results, including the results of the hydrograph baseflow-stormflow separation and annual yield estimations, can be found in the Appendices of this report.

Introduction

This report describes the results of the Cambridge Water Department's source water quality monitoring efforts in the year 2012, as part of a long-term ongoing study of the health and overall state of the City's drinking water supply. The City obtains water from the Stony Brook watershed located in the towns of Lincoln, Weston, and Lexington and the City of Waltham. Water travels to the Walter J. Sullivan Purification Facility through a network of reservoirs, tributaries, and brooks (Figure 1). The Stony Brook watershed is relatively urbanized and has the potential for an increase in impervious surfaces and commercial areas, which may negatively impact water quality. This leads to a distinct need to monitor raw water quality and ensure water security for the City of Cambridge.

The water quality monitoring program, as implemented, 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 (Waldron and Bent, 2001). The assessment, conducted jointly by the USGS and the CWD, included a detailed analysis of the watershed 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 source 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 from the calendar year 2012. The report uses water quality data from CWD 2008-2011 monitoring report for comparison, as well as data compiled from past water quality monitoring databases for trend analyses and illustration. 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.

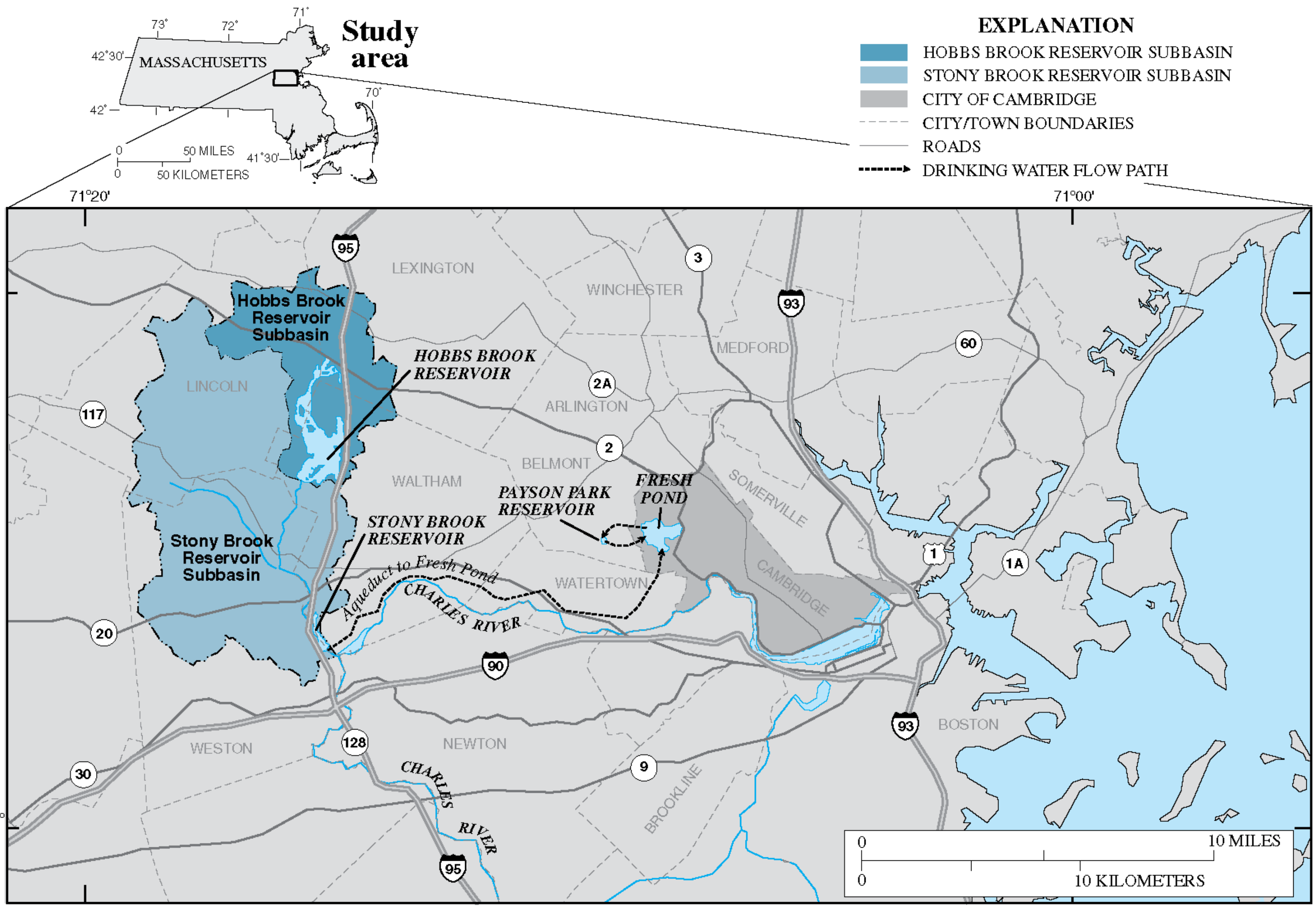


Figure 1: Cambridge Water Supply Source Area

Water Supply Network

The City of Cambridge obtains its water from the 24 square mile Stony Brook watershed located in the towns of Lincoln, Weston, 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. The 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 subbasin. 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, where it is then fed by gravity to the City's distribution system. Capacity at full pool for the Hobbs, Stony, and Fresh Pond reservoirs is roughly 2.5 billion, 418 million, and 1.5 billion gallons respectively.

Methodology

Monitoring Procedure and Changes

Water samples are taken from all sampling sites using *Clean Water* techniques (Wilde and others, 1999). For a more detailed discussion on the methods and process overview of the water quality monitoring program, please refer to Appendix A. Ideally, the primary monitoring sites would be sampled eight times per site per year according to the Water Quality Monitoring Program as developed by the USGS in cooperation with the CWD. The CWD staff was only able to complete four sampling events per site in 2012 due to staffing and weather constraints. A more manageable schedule of 4 to 6 sampling events per site will be considered for the 2013 sampling period.

Unlike previous years, turbidity was not measured in situ for all samples taken in 2012. Samples taken in February of 2012 indicated problems with the turbidity sensor on the Manta Multiprobe, and thus turbidity measurements were not used in sampling results. It is unlikely that a new field turbidity probe will be purchased as turbidity is measured in the lab and field turbidity measurements are highly variable and inconsistent. Total Kjeldahl nitrogen (TKN) was added to the monitoring parameters highlighted in this report due to the significant upward trend in long term TKN concentrations throughout many of the monitoring stations.

Monitoring Equipment

The CWD measures in situ parameters, such as temperature, dissolved oxygen, specific conductivity, pH, and oxidation reduction potential (ORP), using a calibrated Eureka Manta Multiprobe. Grab samples are taken from streams and reservoirs using 1 Liter Teflon bottles for nutrients and HPDE bottles for all other parameters. A peristaltic pump and pre-cleaned Tygon tubing is used for taking bottom samples from the reservoirs. All samples are transported back to the Walter J. Sullivan Purification Facility on ice for processing and are analyzed through a subcontractor for nutrients and chlorophyll-a, and in-house for all other parameters.

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 – The *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 (measured as *most probable number* [MPN] by the CWD laboratory).

Phosphorus – In the Cambridge 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 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 level (MCL) is 10 mg/L.

Chlorophyll-*a* – The measured amount of chlorophyll-*a* in the water column is indicative 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. 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 (SPC) – 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

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

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 are 0.3 mg/L for iron 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 significantly compromising public roadway safety, thereby protecting long term water quality. 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). Chloride concentrations in drinking water above 250 mg/L (Secondary EPA Drinking Water standard) can give it a noticeably "salty" taste.

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.

Total Kjeldahl Nitrogen – TKN is a measure of total nitrogen minus nitrate and nitrite. The EPA has not specified a MCL for TKN specifically, but has for NO_3 and NO_2. CWD tracks TKN in addition to NO_3 and NO_2 to provide a more detailed depiction of the total nitrogen in the CWD water supply system.

The following sections describe the results of the water quality analyses conducted for all sampling locations in 2012 and provide a comparison to the water quality monitoring conducted from the 2008-2011 study. Averages and result highlights are provided in the following sections, and a complete summary of results is available upon request.

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 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, bacteria, and selected metals are taken at the each reservoir's deep hole buoy (deepest point of the reservoir) along with Secchi depth measurements. During periods of thermal stratification, additional samples are taken from the bottom layer

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

(hypolimnion) of the reservoir. Depth profiles of dissolved oxygen, temperature, pH, and specific conductance are taken at both deep hole sites and buoys close to the gatehouse or intake structures. In addition to in situ parameter measurements, surface *E. coli* bacteria samples are taken at "intake" buoys.

Seasonal thermal stratification occurs in all reservoirs with implications on water quality. CWD staff has been monitoring reservoir thermal stratification since at least the 1970s. 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. Chemical stratification may also occur in the reservoirs as a result of the hypolimnion trapping the denser, more saline water. Specific conductance readings have been included on the reservoir depth profiles to illustrate chemical stratification development in the warmer months.

On several occasions in the summer months, negative DO saturation values were measured at both the Hobbs Brook and Stony Brook Reservoirs. These values suggest a pressure-related malfunction with the probe during the sampling event. The probe was sent to the manufacturer at the end of sampling in December, and was returned with no sensor issues found. One negative value on May 31st at 6.43 meters at Hobbs Brook was omitted from the profile chart; three negative values at depths greater than 7 meters at Stony Brook were omitted from the May 31st profile chart. All three reservoirs exhibited slightly super-DO saturations (greater than 100%) in the surface layer during spring and summer months: March 15th and July 3rd at Fresh Pond, August 7th at Stony Brook, and May 31st and August 7th at Hobbs Brook. This is indicative of algal photosynthesis in the reservoirs during these times.

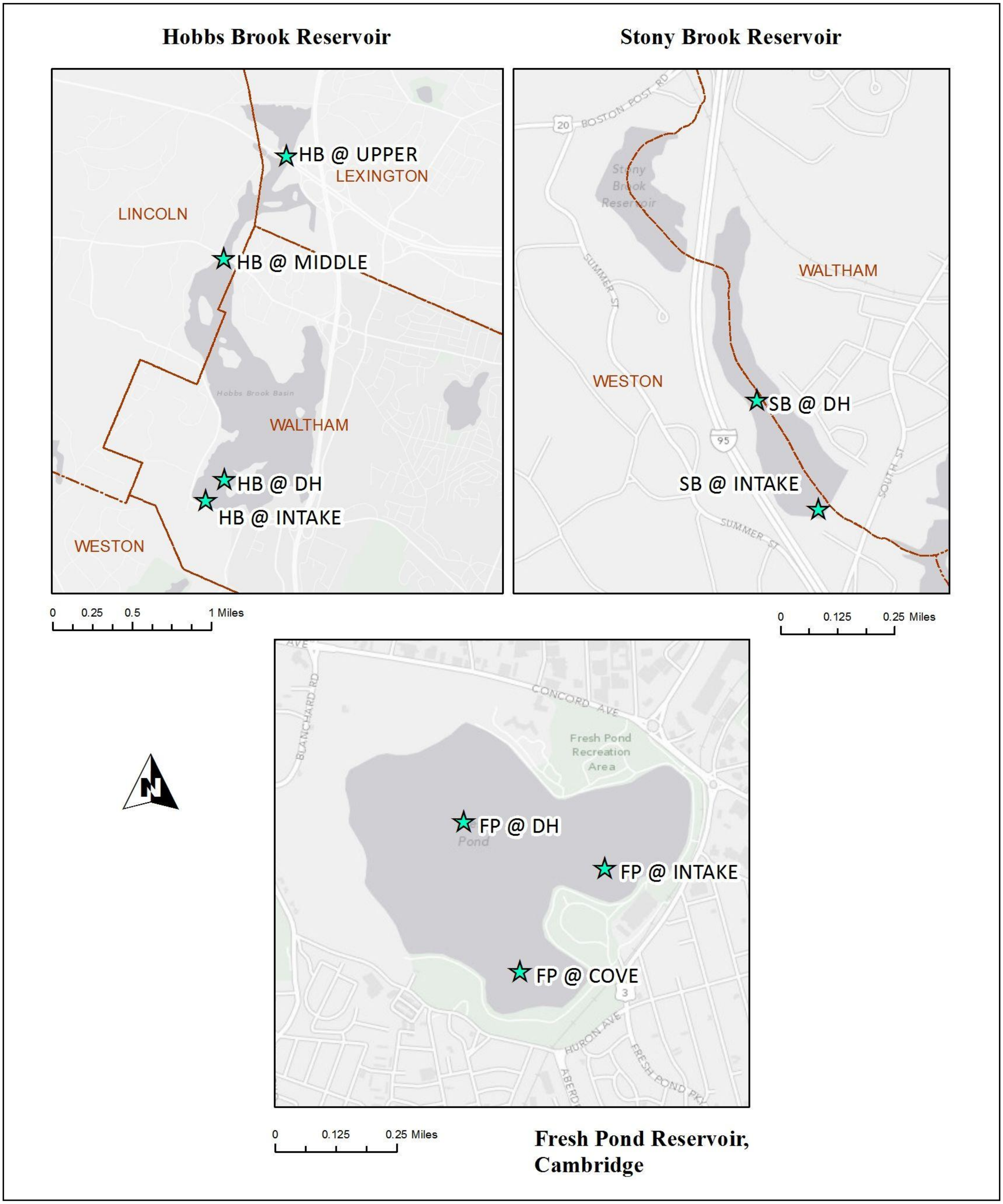


Figure 2: Reservoir Sampling Locations

Hobbs Brook Reservoir

The Hobbs Brook Reservoir is divided into three basins by State Route 2, Trapelo Road, and Winter Street. The upper and middle basins were sampled three times 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 four times. Generally, the water column at the deep hole buoy in Hobbs Brook Reservoir shows signs of thermal and chemical stratification in April and fully stratifies by July. By November, the water column generally exhibits relatively uniform temperature (isothermal), but dissolved oxygen concentrations can still decrease with increasing depth, most likely due to incomplete physical mixing.

The 2012 depth profiles taken by CWD staff exhibit the expected behavior of thermal stratification in the warmer months, as evident in the May and August profiles. The reservoir completely mixes in the colder months (October and November profiles, Figure 3). There is a slight indication of chemical stratification in the reservoir during the August 7th sampling event, which dissipates before the October sampling event.

During the May 31st and August 7th 2012 sampling events, DO readings measured greater than 100% at depths less than 3 meters at the Hobbs Brook Reservoir. These values could be attributed to increased algal productivity at the surface of the reservoir. The high pH levels of about 7.8 support this theory for both events as photosynthesis removes dissolved carbon dioxide and reduces carbonic acid.

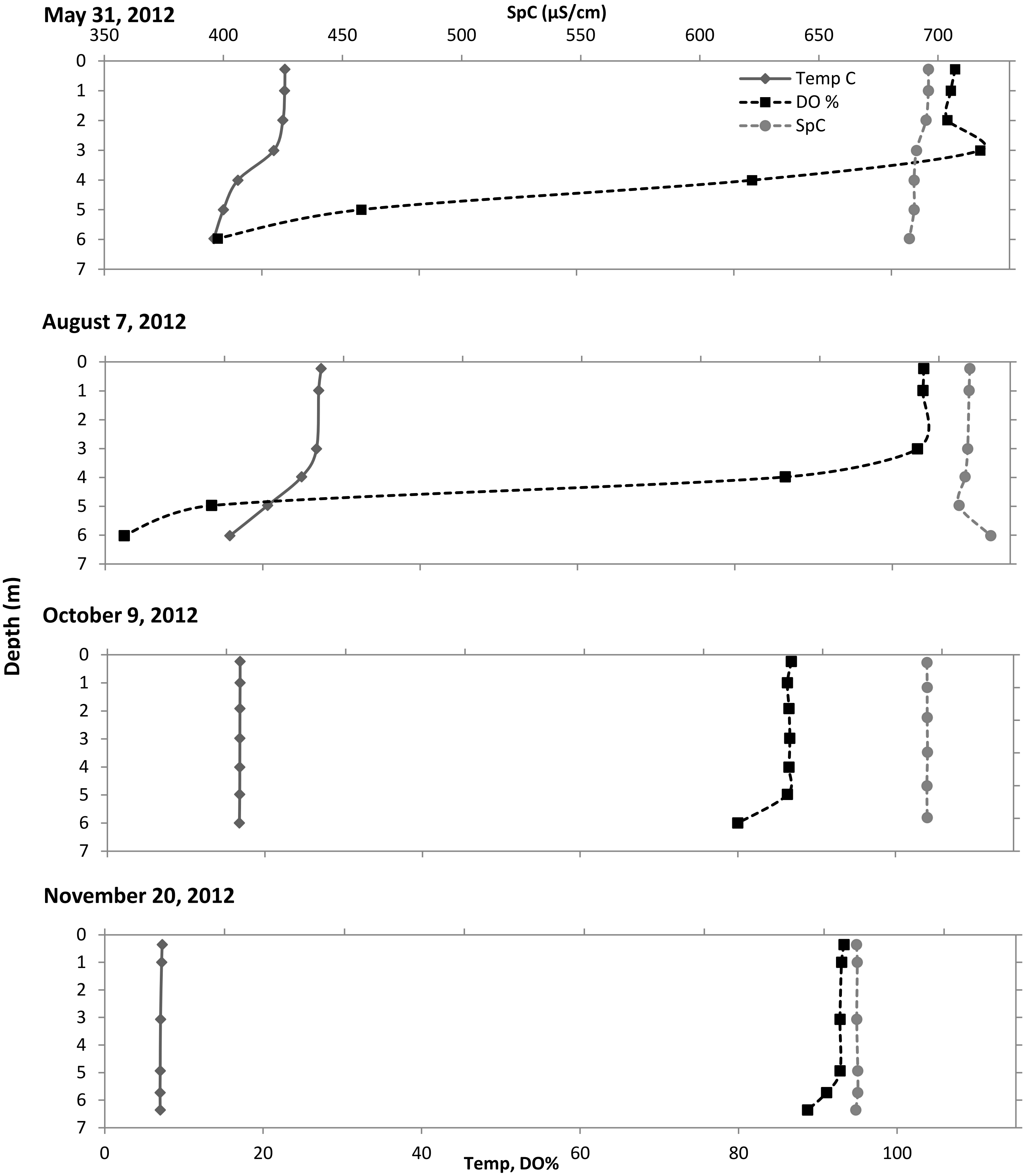


Figure 3: Hobbs Brook @ Deep Hole Depth Profiles, May – August 2012

Anoxic conditions are both a stressor to fish and other aquatic fauna and an opportunity for nuisance metals, such as iron (Fe) and manganese (Mn), to be reduced and released from benthic sediments into the water column. These released 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. 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 for both the surface and bottom samples for all Cambridge surface reservoirs are provided in Table 1. The CWD 2008-2011 sampling events yielded similar results for all surface samples. The 2012 bottom samples generally had higher concentrations than the 2008-2011 results, which could be the result of more severe or prolonged stratification.

Table 1: Watershed Reservoirs Iron and Manganese Concentration Medians [mg/L], 2012 and 2008-2011 Reporting Periods

	Surface Manganese	Bottom Manganese	Surface Iron	Bottom Iron
HB @ DH '12	0.011	**0.536**	0.086	**0.384**
HB @ DH '08-'11	0.021	**0.362**	0.068	**0.294**
SB @ DH '12	0.042	**3.383**	0.152	**2.313**
SB @ DH '08-'11	0.039	**0.537**	0.122	**0.341**
FP @ DH '12	0.018	**0.054**	0.128	**0.143**
FP @ DH '08-'11	0.043	**0.05**	0.064	**0.05**

Stony Brook Reservoir

The Stony Brook Reservoir is bisected by Interstate 95, with twin box culverts under the interstate directly connecting the two basins. As such, the two sections are assumed to be completely mixed and the two samples taken in the lower section are a good representation of the quality of the reservoir as a whole. Samples are taken from the deepest part of Stony Brook (SB@DH) and at the southern gatehouse (SB@INTAKE, Figure 2).

Water-column sampling at the Stony Brook Reservoir was conducted by CWD staff four times in 2012. Three aeration lines were operated sporadically during the months that the reservoir exhibited thermal stratification, generally from April to October. These aeration lines are designed to aid mixing throughout the reservoir and to help avoid thermal stratification and anoxic conditions from forming in the hypolimnion. Contractors perform regular maintenance on the aeration generator. Maintenance on the underwater diffuser lines is needed and is in the pipeline for future projects.

The 2012 Stony Brook Reservoir depth profiles are provided in Figure 4. As with Hobbs Brook Reservoir, Stony Brook exhibited thermal stratification in the warmer months despite the sporadic use of the aeration lines in Stony Brook. DO values greater than 100% at depths less than 3 meters during the August 7th sampling event indicate high productivity in the upper layer of the reservoir. The pH range of 7.2-7.8 for these measurements support this theory. Additionally, the bottom three DO readings taken for May 31, 2012 all measured saturations less than 0% and are attributed to sensor error, therefore these negative readings were not included in Figure 4. Slight chemical stratification is evident in the May and August profiles. The significant increase in specific conductance from May to August can be explained by the majority of August flows into the Stony Brook reservoir coming from the Hobbs Brook reservoir dam release.

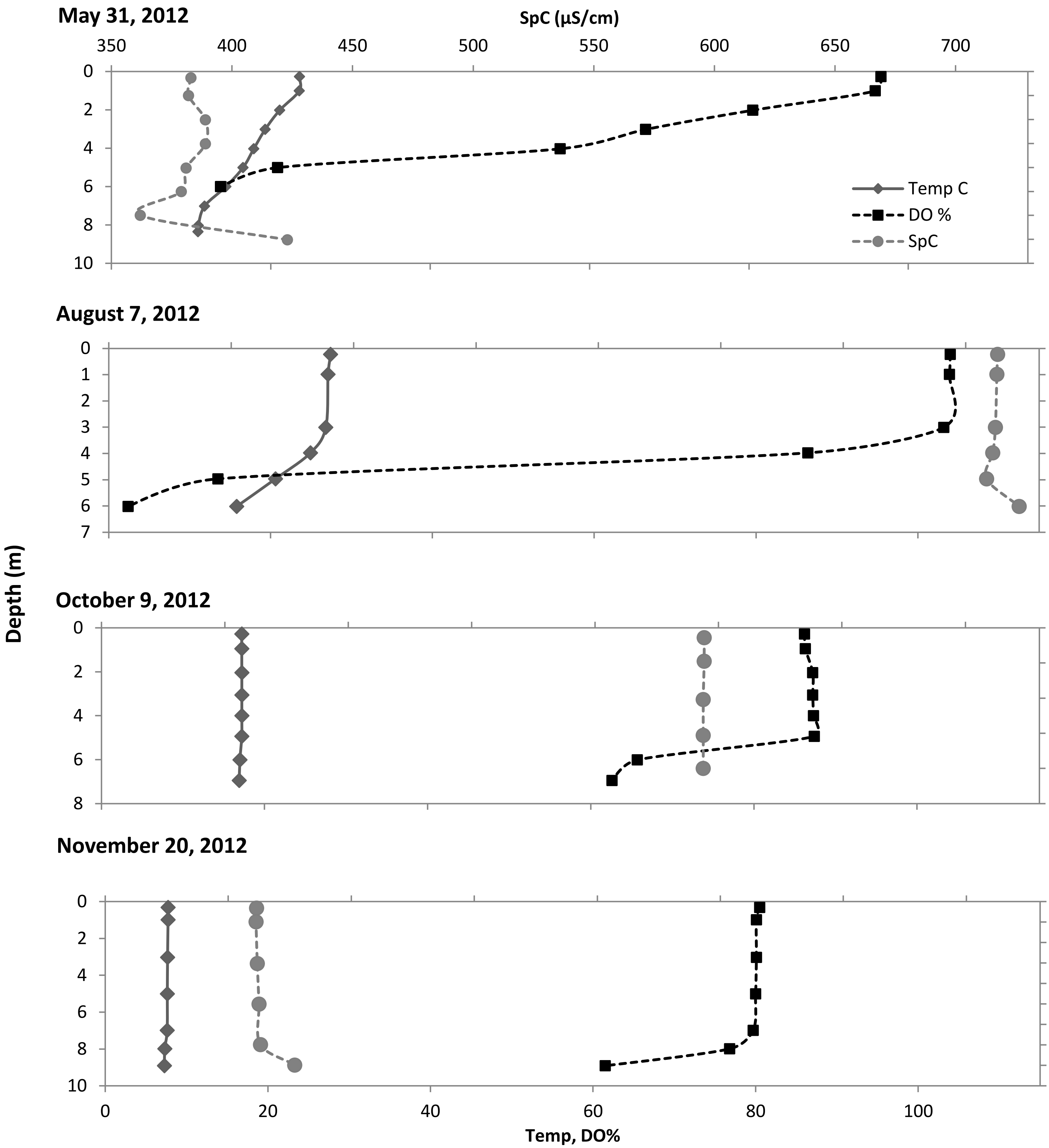


Figure 4: Stony Brook @ Deep Hole Depth Profiles, May -- November 2012

As in the Hobbs Brook Reservoir, under hypoxic conditions, nuisance iron and manganese were reduced and released from benthic sediments into the water column. A more severe magnitude of difference between the surface and bottom heavy metal samples during thermal stratification is generally measured at the Stony Brook Reservoir as compared to the Hobbs Brook Reservoir likely because of the differences in bed-sediment composition. Results from bed-sediment analyses conducted by the USGS in water year 1998 yielded much higher concentrations of trace metals (approximately three times higher) in the Stony Brook Reservoir sediments as compared to the Hobbs Brook Reservoir sediments. In addition to the increased availability of these metals, the thermocline in the Stony Brook Reservoir generally develops much deeper than the thermocline in the Hobbs Brook Reservoir. The lower thermocline depth, combined with the bathymetry of the Stony Brook Reservoir, creates a much smaller volume of water in the hypolimnion of the Stony Brook Reservoir. The smaller volume may exacerbate the release of iron and manganese due to the lower availability of dissolved oxygen as a direct result of the smaller volume and limited mixing.

During this study period, Stony Brook iron and manganese concentrations differed by 81 and 15 times respectively from surface to bottom during periods of thermal stratification. Median surface concentrations for both parameters were similar for surface samples from previous years of sampling, but median bottom concentrations were much higher in 2012 (Table 1). This indicates more severe or prolonged stratification of the reservoir in 2012 than 2008-2011. The increased or prolonged stratification could be the result of the relatively low rainfall received by the reservoir in 2012 and associated longer reservoir residence time and reduced mixing.

Fresh Pond Reservoir

Monitoring and managing thermal stratification is particularly important in Fresh Pond because it is the terminal water supply reservoir in the system. Water is pumped directly from Fresh Pond and treated in the Walter J. Sullivan Purification Facility for potable uses. 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 to help avoid anoxic conditions in the reservoir.

Water-column sampling was conducted at Fresh Pond four 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 or beginning of October, depending on climate. In 2012, Fresh Pond was thermally stratified from April to September.

In addition to thermal stratification, DO measurements greater than 100% on March 15th and July 3rd indicate high levels of algal growth in the upper layer of the reservoir. The corresponding pH levels between 7 – 8 support this theory.

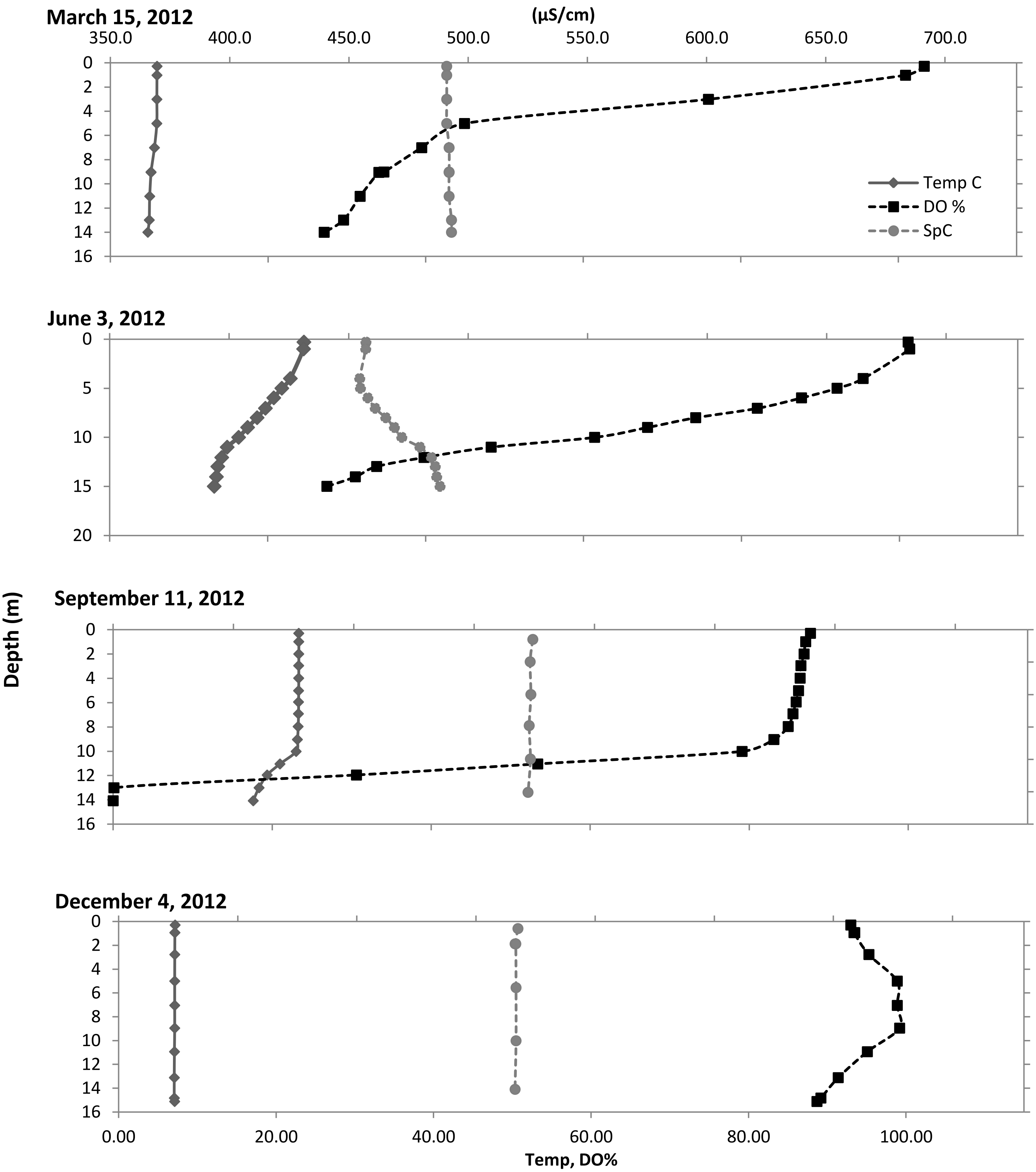


Figure 5: FP@DH Profile March – December, 2012

In past years, the aeration system in the Fresh Pond Reservoir has been effective at providing enough oxygen in the hypolimnion to avoid reducing conditions, as evident in the 2008-2011 manganese and iron concentrations measured in both the surface and bottom samples. Bottom manganese concentrations were only slightly higher than surface sample concentrations in 2008-2011, and iron concentrations were most often below the detection limit (0.05 mg/L) for both layers.

Unlike previous years, surface and bottom samples in 2012 for manganese did show significant differences, increasing as the season progressed and the hypolimnion was further isolated. Iron concentrations did not show differences in the surface and bottom samples, likely because manganese is a stronger reducing agent than iron and is released from sediments more easily. The manganese and iron median concentrations for Fresh Pond are provided in Table 1.

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 a low productivity state (oligotrophic) and minimal external nutrient loading. Values ranging between 40 and 50 indicate moderate productivity (mesotrophy) and intermediate external nutrient loading. Values greater than 50 indicate a water body that is considered highly productive (eutrophic) and likely to produce algal blooms.

Table 2: 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

As TSI is an estimator of algal biomass weight in the reservoir, chlorophyll-*a* concentrations are the best parameter to use to calculate TSI. Chlorophyll-*a* is directly affected by nutrients in the water column and therefore provides a good indicator of overall water quality. When available, TSI was calculated from chlorophyll-*a* concentrations collected during the growing season. When chlorophyll-*a* concentrations were below the limit of detection, secchi depth and total phosphorus were used as a surrogate to calculate reservoir TSI. The chlorophyll-*a* concentrations, total phosphorus concentrations, secchi depths, and corresponding TSI values are provided in Table 3. A box plot of the reservoir TSI values and trophic state categories is provided in Figure 6. TSI values were taken from chlorophyll-*a* readings when available, and supplemented with total phosphorus TSI values. When available, measurements were averaged with field duplicates to help provide a more accurate representation of the true value of the parameter in the reservoirs.

Table 3: Reservoir Chlorophyll-*a*, Total Phosphorus, Secchi Depth, and Corresponding TSI Value, 2012

	Sampling Date	Chlorophyll-*a* (µg/L)	TSI	Total Phosphorus (µg/L)	TSI	Secchi Depth (m)	TSI
Hobbs Brook	5/31/2012	4.01*	**44**	<10		4	**40**
	8/7/2012	5.39	**47**	<10		4.5	**38**
	10/9/2012	2.10	**38**	13	**41**	3	**44**
	11/20/2012	<2		<10			
Stony Brook	5/31/2012	2.5	**40**	18*	**46**	2.5	**47**
	8/7/2012	***25.5***	**62**	<10		4.75	**38**
	10/9/2012	<2		23	**49**	4	**40**
	11/20/2012	<2		15	**43**		
Fresh Pond	3/15/2012	4.02*	**44**	<10		3.5	**42**
	7/3/2012	<2		11.5*	**39**	3.5	**42**
	9/11/2012	<2.0		10.5*	**38**	4	**40**
	12/4/2012	ND		26	**51**	3.5	**42**

*Average value of sample and field duplicate
ND : Not Detected

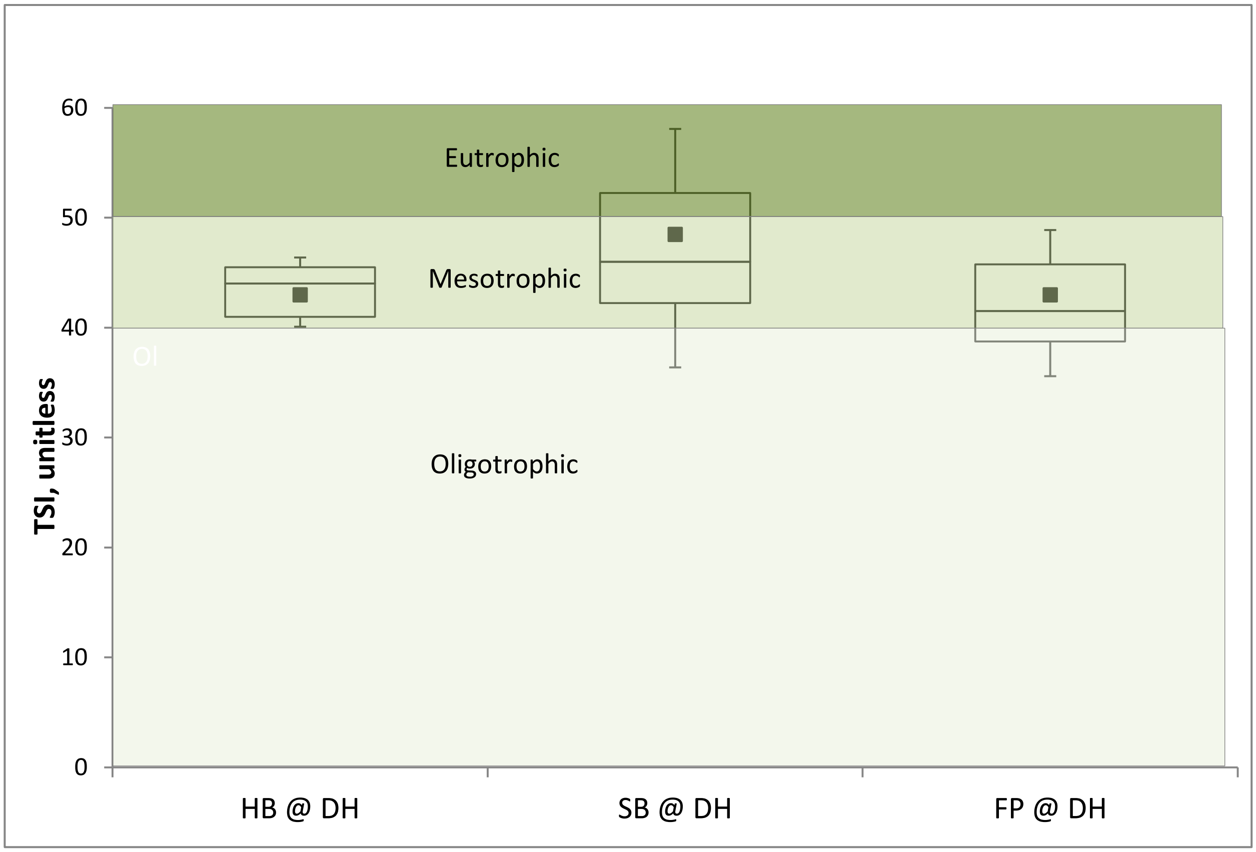


Figure 6: Reservoir Trophic State Index, from Chlorophyll-*a* and Total Phosphorus, 2012

Unlike previous years, in which the median TSI values have decreased from Hobbs Brook to Fresh Pond, the median TSI value for each reservoir in 2012 was approximately the same. The median TSI for Hobbs Brook, Stony Brook, and Fresh Pond (43, 48.5, 43) were all higher than the TSI values from the 1997/1998 USGS study (38, 35, 33); whereas the median TSI values from 2012 was approximately the same for the 2008-2011 Hobbs Brook TSI, but was higher than the Stony Brook and Fresh Pond TSI values (44, 41, 31). This could be due to this year's dryer than normal conditions and resulting longer reservoir water residence times providing a better environment for algae growth.

In general, the Cambridge water supply system exhibits an overall cascade effect as water travels from Hobbs Brook Reservoir to Fresh Pond. Each reservoir acts as a settling basin which allows suspended sediments and associated constituents to settle to the bottom of each reservoir. The quality of water improves as it moves through the watershed reservoirs, and by the time source water reaches Fresh Pond, it is relatively free of suspended solids. Sampling results from previous years support this theory.

Reliance on particulate settling, however, does not address the growing concern over soluble ions, such as sodium and chloride. Commonly used in the watershed for deicing materials, these ions have shown increasing concentrations over the years in the Cambridge watershed. Fresh water dilution continues to maintain drinking water standards, but controlled use of deicing substances in the watershed is crucial to maintaining a viable drinking water source.

Weekly Reservoir Samples

To aid water treatment decisions, reservoir samples are collected weekly by Watershed Division staff and analyzed in-house. 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 2012, water quality for bacteria in the Hobbs and Stony Brook Reservoirs met or exceeded Massachusetts Class A water quality standards 97% of the time, as only 3 samples exceeded the 235 MPN limit for single sample water quality criteria in the weekly samples for both reservoirs. Distributions of bacteria results for 2012, along with the results from the 2008-2011 reporting period, are illustrated in Figure 7. 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 subbasin area.

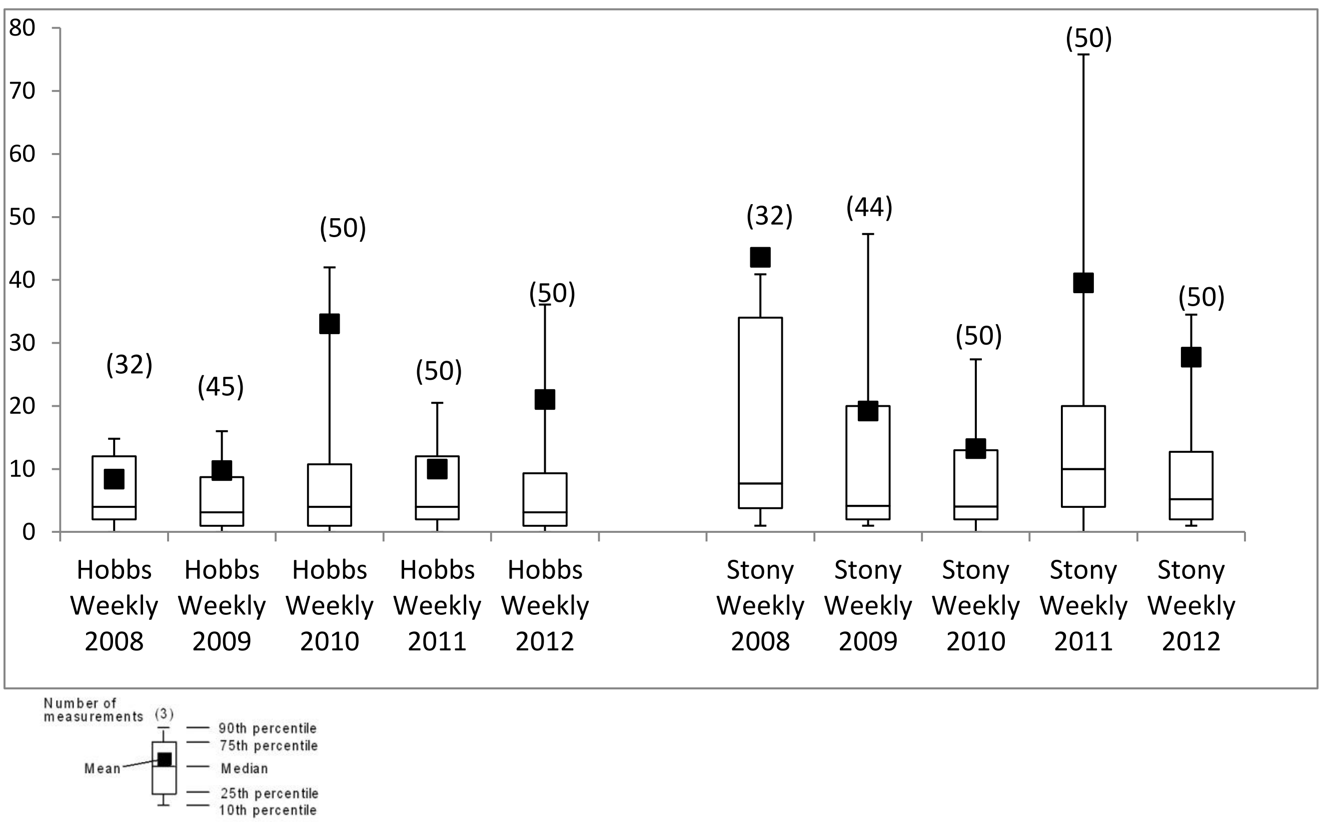


Figure 7: Weekly Bacteria Monitoring [MPN], Hobbs and Stony Brook Reservoirs

The Cambridge source watershed contains a high percentage of 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 (Massachusetts Department of Transportation), 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 8). In 2008, 21% of samples were above the EPA/DEP chronic aquatic life exposure limit, 11% in 2009, zero in 2010, 12% in 2011, and zero in 2012. 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 2012. Median chloride concentrations in both reservoirs from this study period are consistent with results from the 2008-2011 samples and are higher than 1997/1998 USGS results (Figure 9).

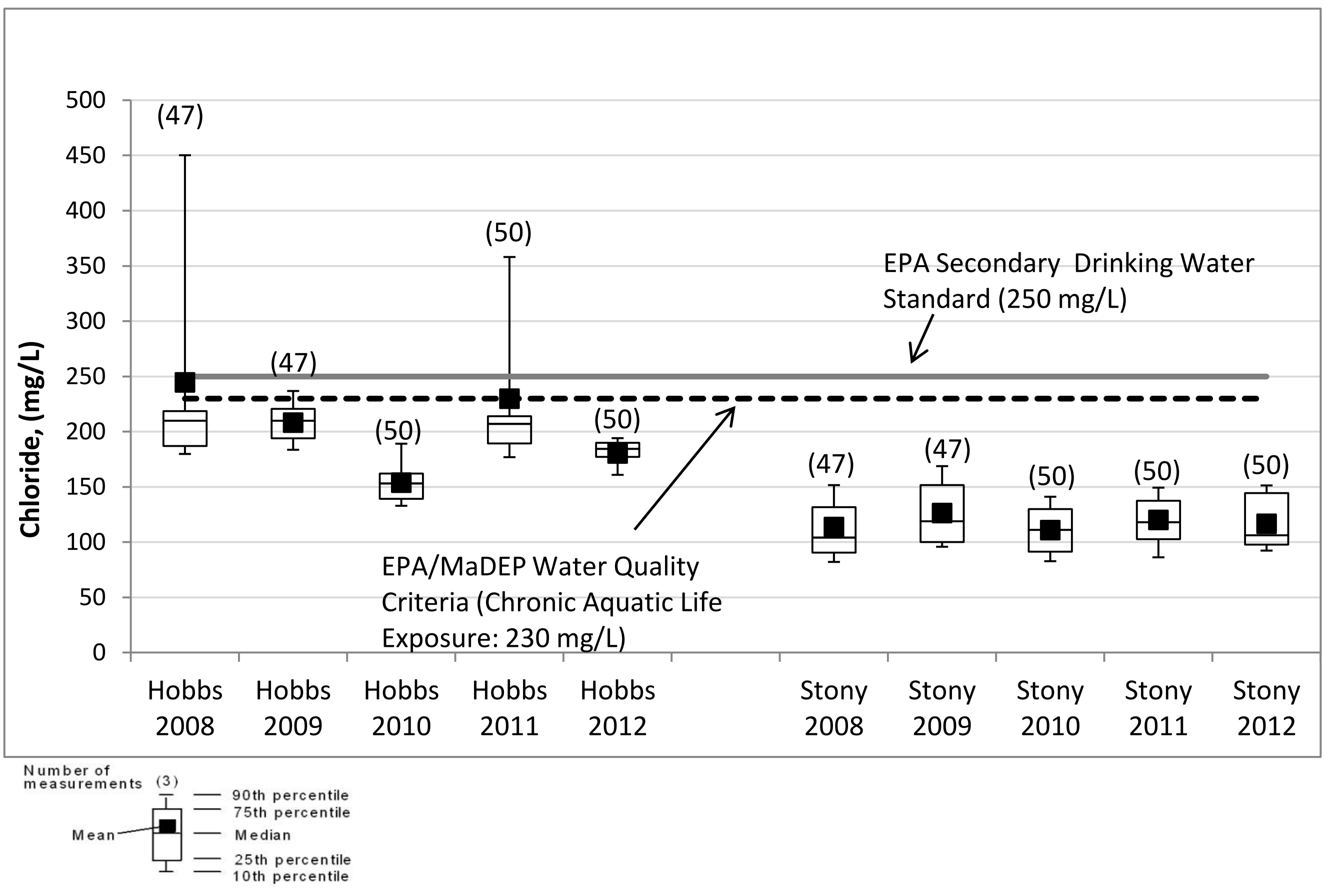
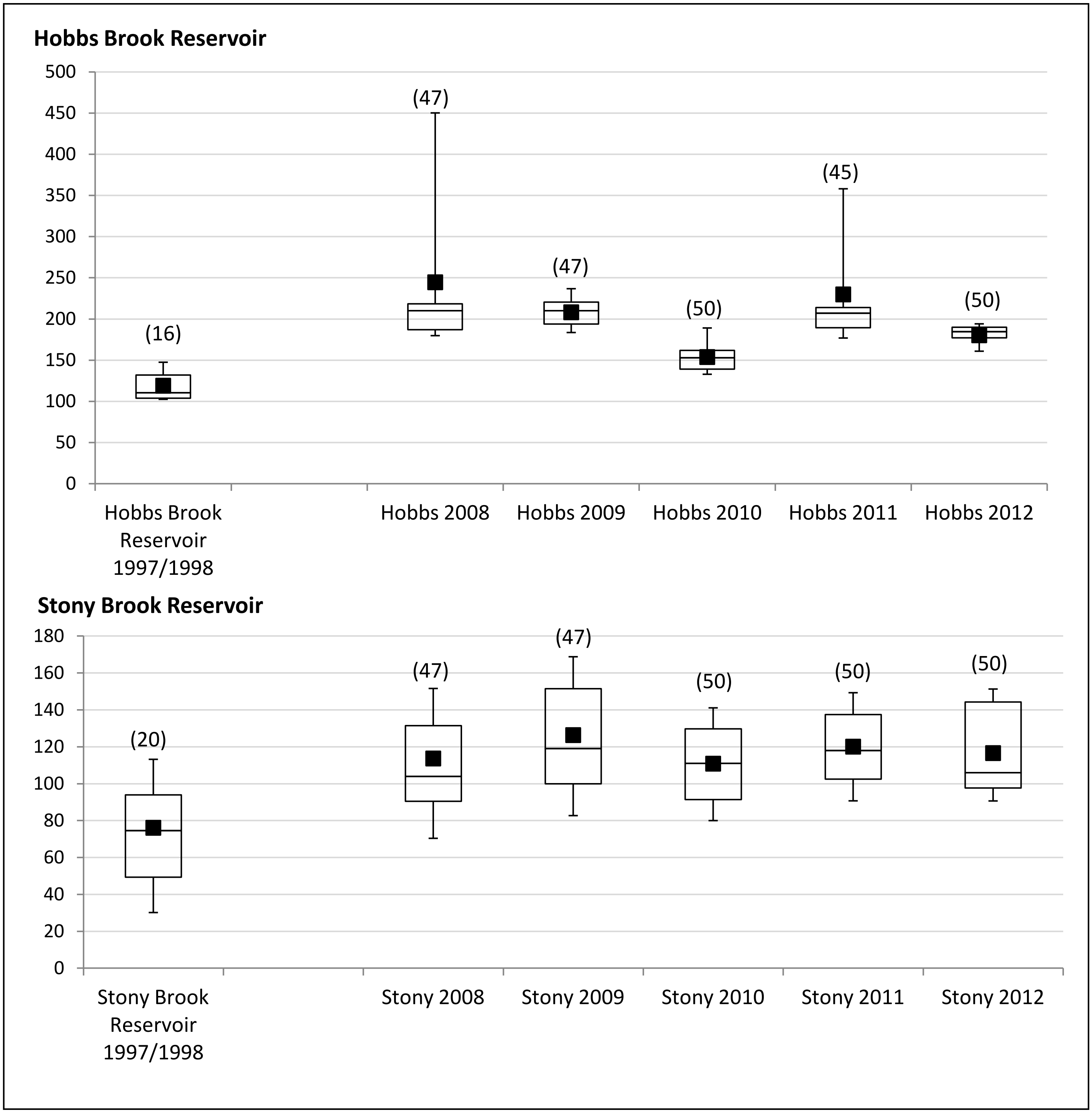


Figure 8: Weekly Chloride Monitoring [mg/L], Hobbs and Stony Brook Reservoirs



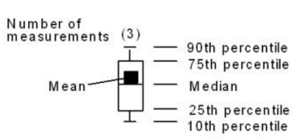
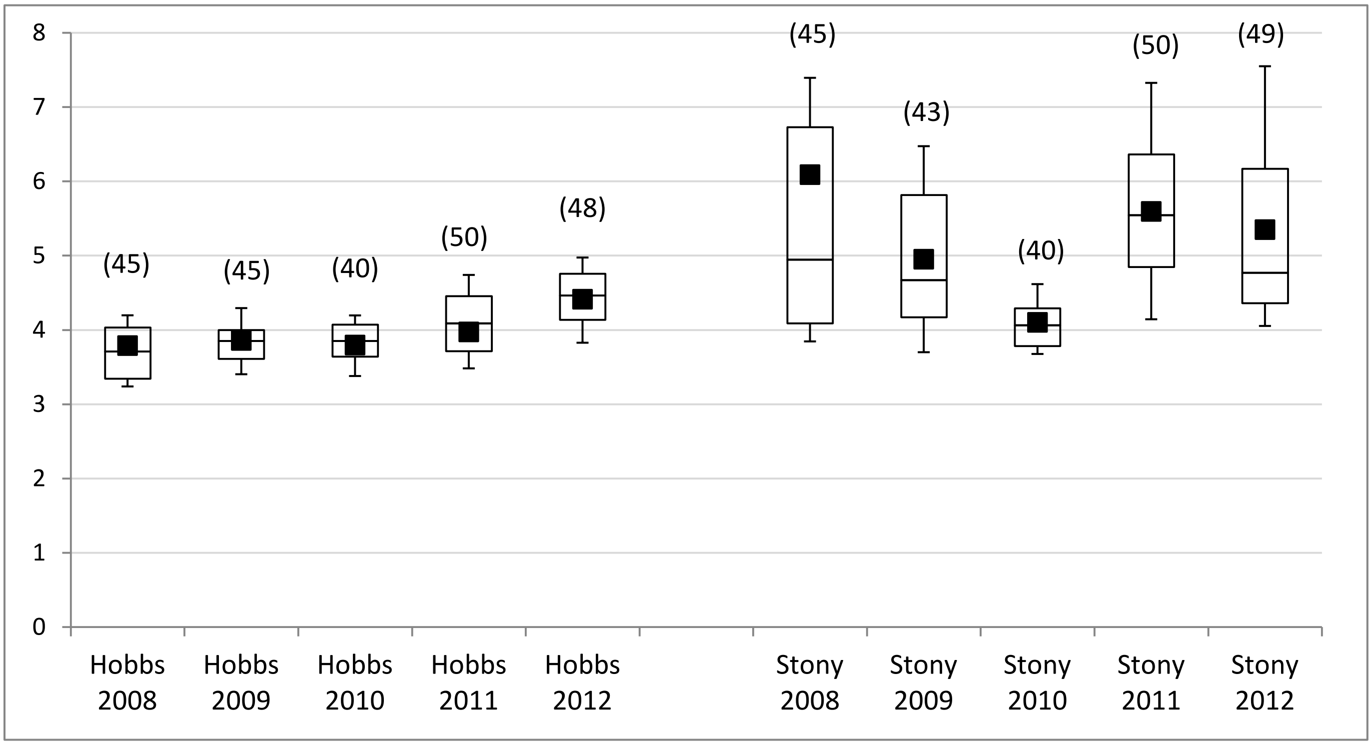


Figure 9: Chloride Comparison [mg/L], Hobbs Brook and Stony Brook Reservoirs, 1997-98 to 2008-2012

Review of the total organic carbon results from 2008 - 2012 (Figure 10) showed consistently lower median concentrations at both Hobbs Brook and Stony Brook Reservoirs when compared to the 1997-1998 median results (5.8, 7.4 mg/L respectively). Ranges of values are similar with no clear indicators of significant changes over time in the Stony Brook Reservoir, and results from the past three years at the Hobbs Brook Reservoir may indicate a slow increase in TOC concentrations.



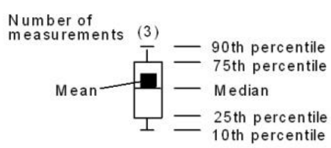


Figure 10: 2008 - 2012 Upcountry Reservoir Total Organic Carbon, [mg/L]

Tributary Water Quality

All 12 primary tributary sampling sites (Figure 11) were sampled approximately four times during 2012. The Stony Brook at Kendall Green site (SB@KG) is no longer sampled regularly due to backflow issues at the Stony Brook and Hobbs Brook confluence. Samples are now taken from the Stony Brook at Viles station (SB@VILES) for a more accurate representation of the water quality of Stony Brook.

Water samples for chemical analyses were collected at stream and reservoir sampling stations using *Clean Water* protocols (Wilde and others, 1999) for all aspects of sample collection, preservation, and transport. Samples were physically collected from the streams by the centroid dip technique (Edwards and Glysson, 1999). In addition to CWD water quality measurements, the nine primary tributary sites with USGS monitoring stations are equipped to continuously monitor stream stage, temperature, and specific conductance.

Through the tributary monitoring program, sources of sewage-related bacteria, sodium, chloride, nitrate, total phosphorus, and manganese (among other parameters) entering Hobbs Brook and Stony Brook Reservoirs are continuously identified and quantified throughout the watershed. In addition to nutrient, ion, and heavy metal samples, in situ measurements are taken concurrently with a calibrated water quality multiprobe for temperature, pH, specific conductance, and dissolved oxygen. For water quality samples with continuous streamflow measurements, load estimates were normalized to subbasin areas to calculate instantaneous yields (Appendix B).

Discharge data was collected through various methods. The nine primary tributary sites with USGS continuous monitoring stations measure stage at 15 minute intervals and use a USGS calibrated relation to estimate discharge. The Industrial Brook site does not have a continuous monitoring station; instead, discharge is estimated by CWD staff using a USGS published stage-discharge relationship and stage readings taken at the time of the sampling event. Stream discharge was similarly estimated at Tracer Lane for all 2012 sampling events using the measured stage heights and a CWD-developed stage-discharge relation. This relation was developed using previous year's stage heights and corresponding discharge measurements from both the CWD and USGS. Discharge was manually measured using an acoustic Doppler velocimeter (Rantz and others, 1982) for all HB @ KG 2012 sampling events.

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 (Waldron and others, 2001). Subbasin updates using 2005 MassGIS (Massachusetts office of Geographic Information) 37 land use/land cover categories are provided in Table 4.

The following discussion highlights significant findings of tributary monitoring from north (upstream) to south (downstream) along with significant results from historical trending analysis. These findings relate to land use within each drainage area and implications for further study as well as watershed protection practices. An average concentration was calculated in instances with field duplicates in order to give a more representative depiction of the real stream concentration without skewing the median value. A discussion of the statistical methods used is provided in Appendix C.

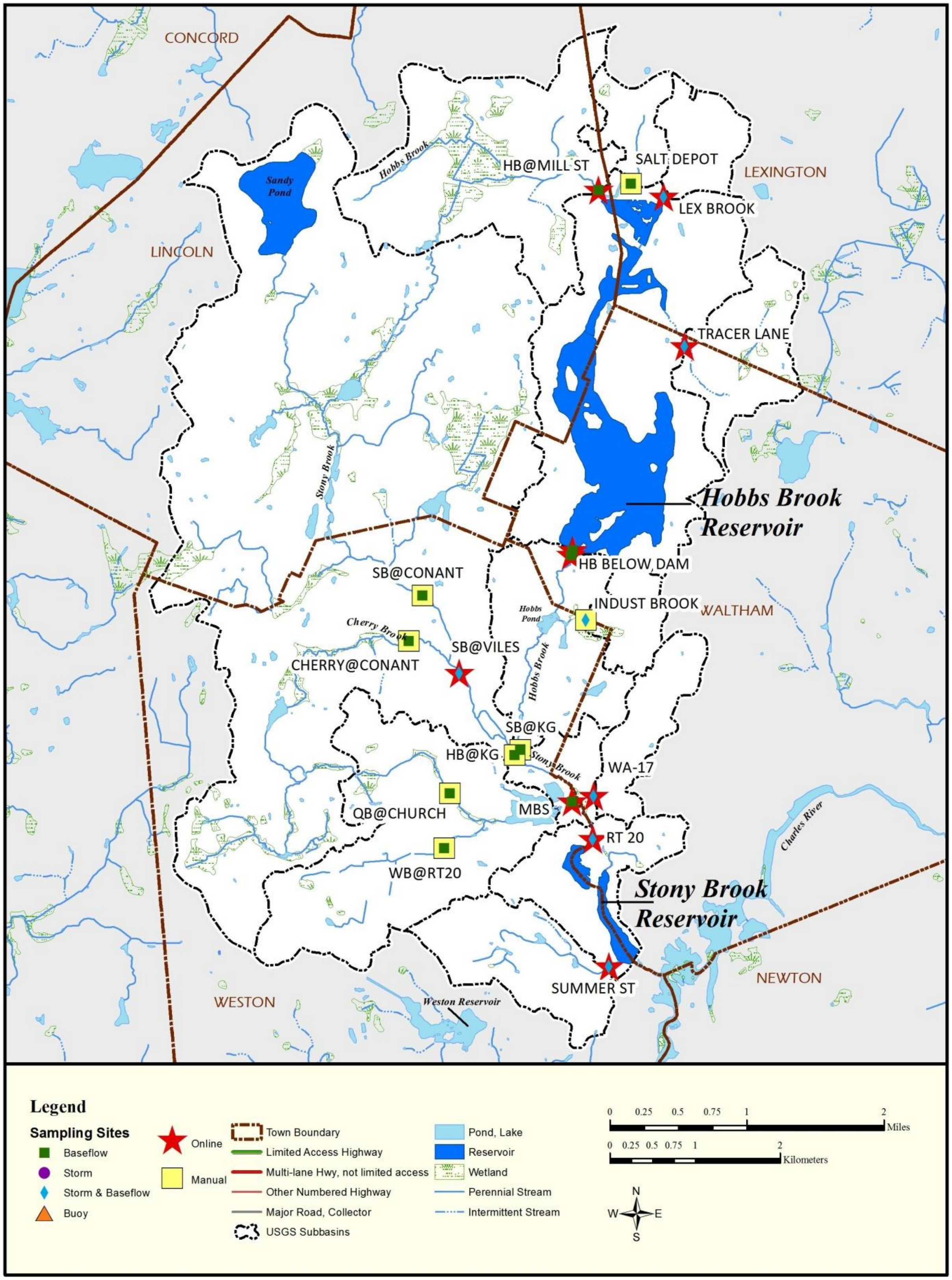


Figure 11: Tributary Monitoring Stations

Table 4: 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

Hobbs Brook at Mill Street (01104405)

Hobbs Brook is one of three 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 (Table 4). The USGS reestablished this site at the end of 2011 as a continuously monitored stream. Flow estimates, stream temperature and specific conductance are available online in real-time.

During the 2012 study period, “HB@MILL ST” was sampled four 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). No samples exceeded single sample *E. coli* thresholds of 235 MPN (most probable number).

E.Coli count and chloride concentration medians were higher in 2012 than those found in the 2008-2011 reporting period. Baseflow total phosphorous concentrations were slightly lower than concentrations measured during the 2008-2011 reporting period. This may indicate less anoxic wetland release than exhibited in the previous reporting period. Median sodium concentrations (46.2 mg/L) are slightly lower than the 2008-2011 period (50.3 mg/L) but exhibit a significant increasing trend ($p = 0.02$) for the years 1995-2012 with the discharge effects removed. The increase in sodium concentrations could be attributed to local effects from continual build-up and soil/groundwater migration of road salt in Route 2 shoulder areas; however, baseflow sodium concentrations in HB@MILL ST continue to be much lower than the other tributaries sampled.

Total Kjeldahl nitrogen concentrations also show long-term increasing trends ($p= 0.03$) at the station, which may indicate either an increase in residential areas (increased lawn fertilizer applications, septic systems), or a shift in the biogeochemical conditions of the wetlands in the subbasin. The wetlands comprise ~23% of the area of the Hobbs Brook at Mill Street subbasin and could have significant impacts on water quality depending on multiple factors. Wetlands are the most effective surface water body for nitrogen retention and atmospheric release with denitrification as the most effective removal pathway; however, the multiple steps required to decompose organic material into gaseous nitrogen forms require both aerobic and anaerobic conditions. Specifically, the formation of an oxidized soil layer above anaerobic soils is critical to several steps of the nitrogen removal process.

In the wetlands draining to the Hobbs Brook at Mill Street monitoring station, several factors could be contributing to the increased TKN concentrations measured by CWD. NH_3/TKN percentages of ~20-30% from 2008-2012 data indicate that most of the TKN measured is in the organic form. This may be the result of increased flow rates[3] through the wetlands reducing residence times and allowing organic materials to escape from the wetlands before decomposition. Alterations in the biogeochemical conditions may also be contributing to the release of TKN, such as the lack of an oxidized soil layer above anaerobic soils or the pH levels in the wetlands. Acidic soils inhibit denitrification, and the lower range of pH levels at the Mill Street station may indicate the presence of acidic soils within the

[3] No supporting evidence available.

wetlands. More detailed analysis of the conditions within the wetlands may be needed if TKN levels continue to rise at the site.

Salt Depot Brook (01104410)

"SALT DEPOT" has an estimated 0.34 mi^2 drainage area and drains water into the Hobbs Brook Reservoir. The station was named for the nearby MassDOT road salt storage facility that previously stored deicing salt uncovered on bare ground. Over the years, salt leached into the surrounding soils and groundwater, thereby creating a hyper-saline groundwater plume that was studied and mapped in 1985.

The site was monitored four times during baseflow conditions in 2012. No stormwater samples were collected. For this site, water quality met Class A standards for temperature (< 28.3°C), dissolved oxygen (> 5mg/L), and pH (between 6.5 – 8.3). One sample exceeded the single sample *E. coli* threshold (235 MPN) with a measurement of 2000 MPN. 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.

SALT DEPOT's high specific conductance, sodium and chloride results may be attributed to the continuous movement of the hyper-saline groundwater plume from the MassDOT salt storage facility. The statistical analysis of sodium concentrations from 1995-2012 showed a significant increasing trend over time (p= 0.00). This trend may be the result of increased deicing salt applications as well as the migrating plume.

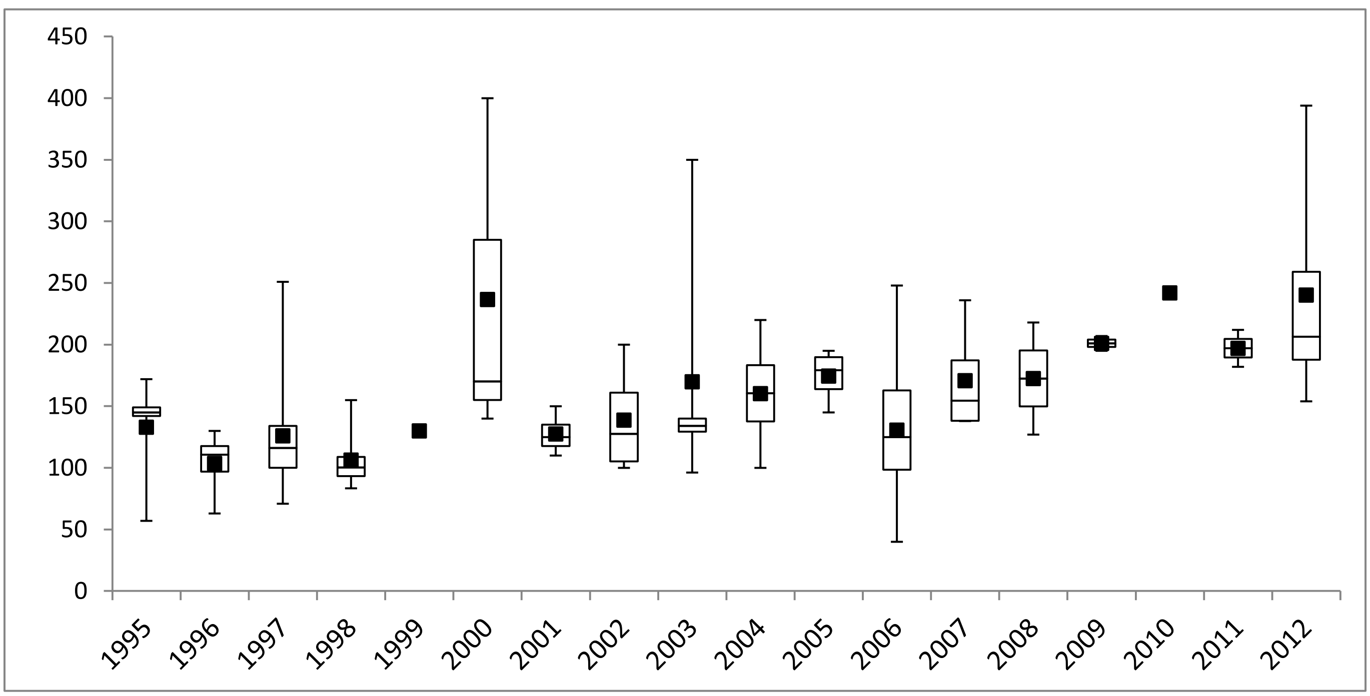


Figure 12: Boxplot of Historic Sodium Concentrations [mg/L], Salt Depot Brook

The percentage of floodplain alluvium in the subbasin is more than five times that of any other subbasin in the source area and has been significantly correlated to high baseflow total phosphorus measurements in past years (USGS, 2001). The 2012 observed maximum was less than the 2008-2011 reporting period (0.031 mg/L compared to 0.11 mg/L), but the overall median was twice as much in 2012 (0.02 mg/L). High phosphorus concentrations could be attributed to the high proportion of streamflow in the tributary entering as low oxygen, phosphorus-rich groundwater (USGS). Statistical analysis of total phosphorus concentrations from 1995-2012 showed no significant increasing or decreasing trends (Appendix C).

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. Lexington Brook is dominated by residential land uses (Table 4), but receives many direct, untreated stormwater discharges from the adjacent highway. USGS-maintained automated equipment continuously records temperature, stage, and specific conductance.

For all dry-weather sampling events, temperature, dissolved oxygen, pH, and bacteria did not exceed MA Class A surface water quality standards. Due to the watershed's developed nature, this site is also monitored during wet weather to better characterize runoff-generated water quality (See *Wet Weather Monitoring Section* for sampling results and discussion). USGS included this site when studying storm flows and their impacts on the water supply from 2005 - 2007 (publication pending, but data approved and available online).

This site continues to exhibit the highest median specific conductance and sodium concentrations in the entire source water area, and these values are also significantly higher than those found in the 1998 USGS study (Figures 13 and 14), although preliminary analysis did not conclusively yield significant trends with discharge effects removed. Discharge effects may account for the observed increase in sodium concentrations over the years; a more detailed analysis including the seasonal effects of discharge on concentrations is recommended. Lexington Brook has historically yielded the highest concentrations for road-salt related parameters; however, INDUST BROOK concentrations in 2012 were comparable and the chloride median concentration was slightly higher than LEX BROOK (Figure 20).

More than 13% of the drainage area for this tributary is covered by roads, the highest coverage of any subbasin in the source watershed. Contributing drainage area includes a major highway interchange connecting State routes 2A and 128 and the MassDOT salt storage facility. 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. Inclusion of this station in a water-quality monitoring program is essential because of the apparent continued rising trend in sodium concentrations (Figures 13 and 14) and the contributions of urban and highway runoff contaminants to the water supply.

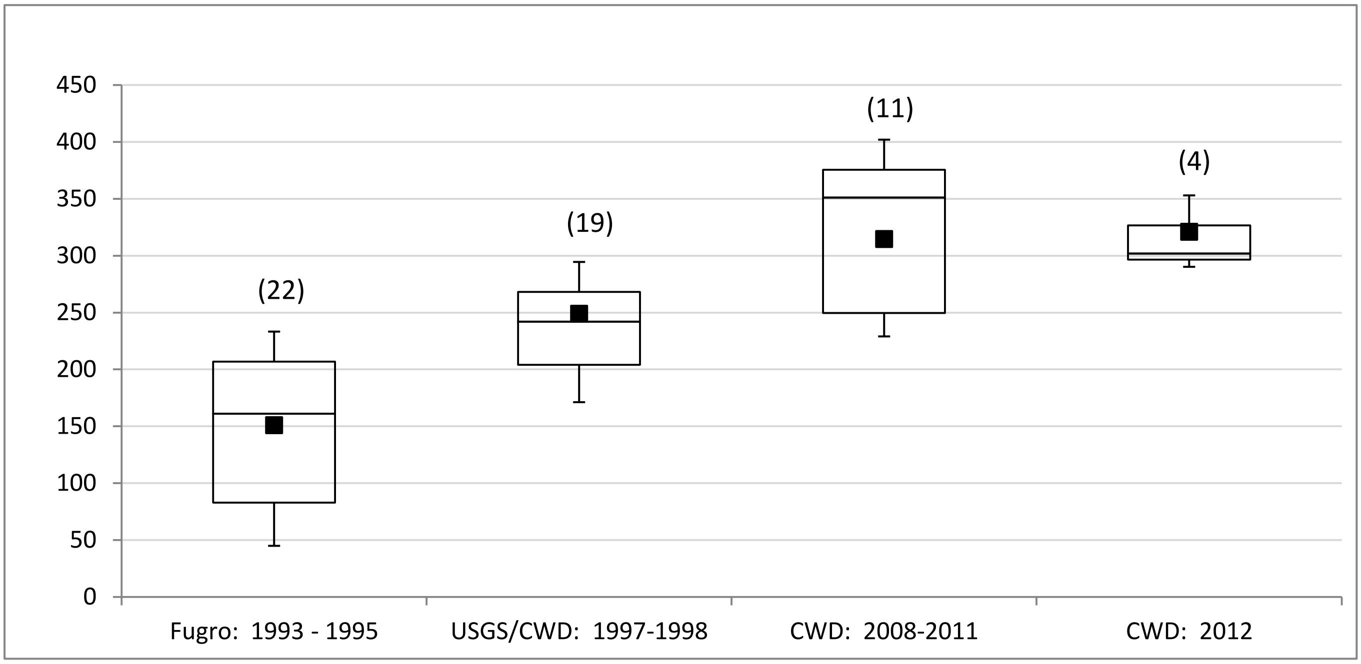


Figure 13: Periodic Sodium Comparison, Lexington Brook, [mg/L]

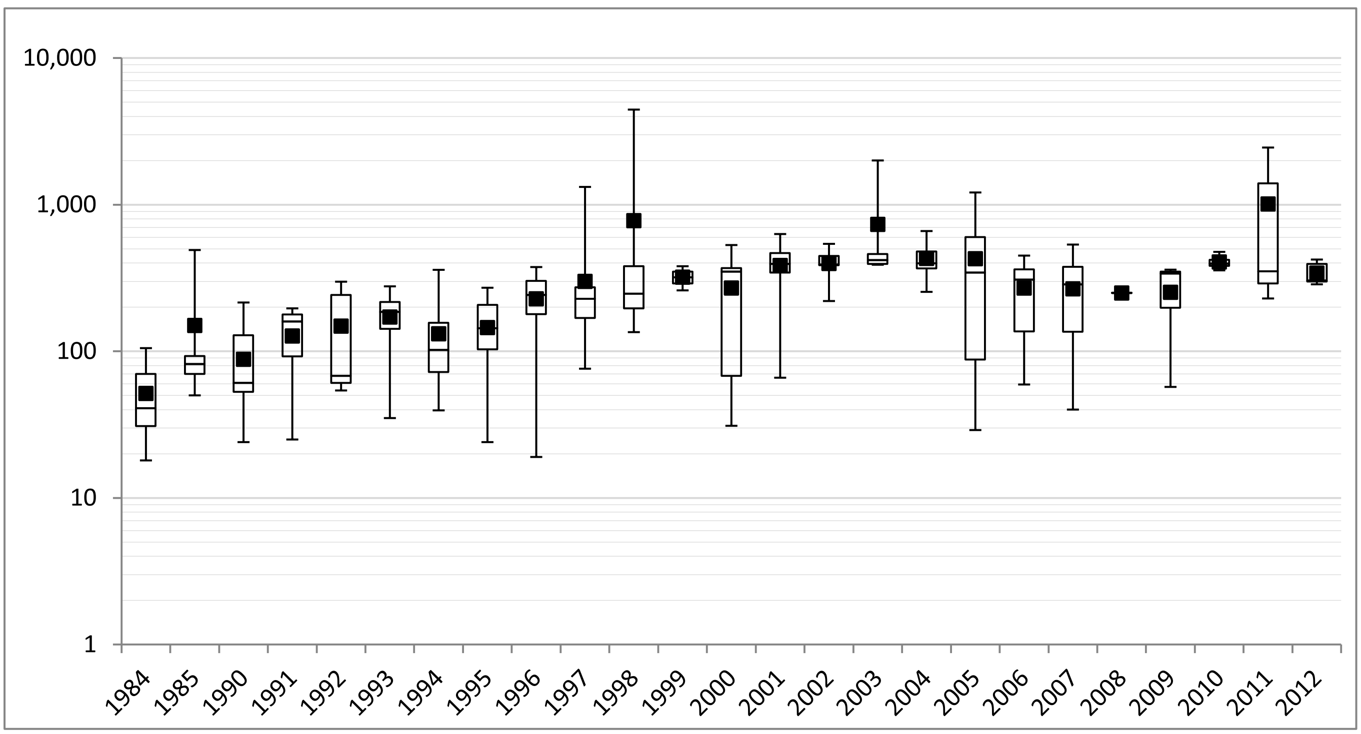


Figure 14: Long-Term Lexington Brook Sodium Trend – All Weather

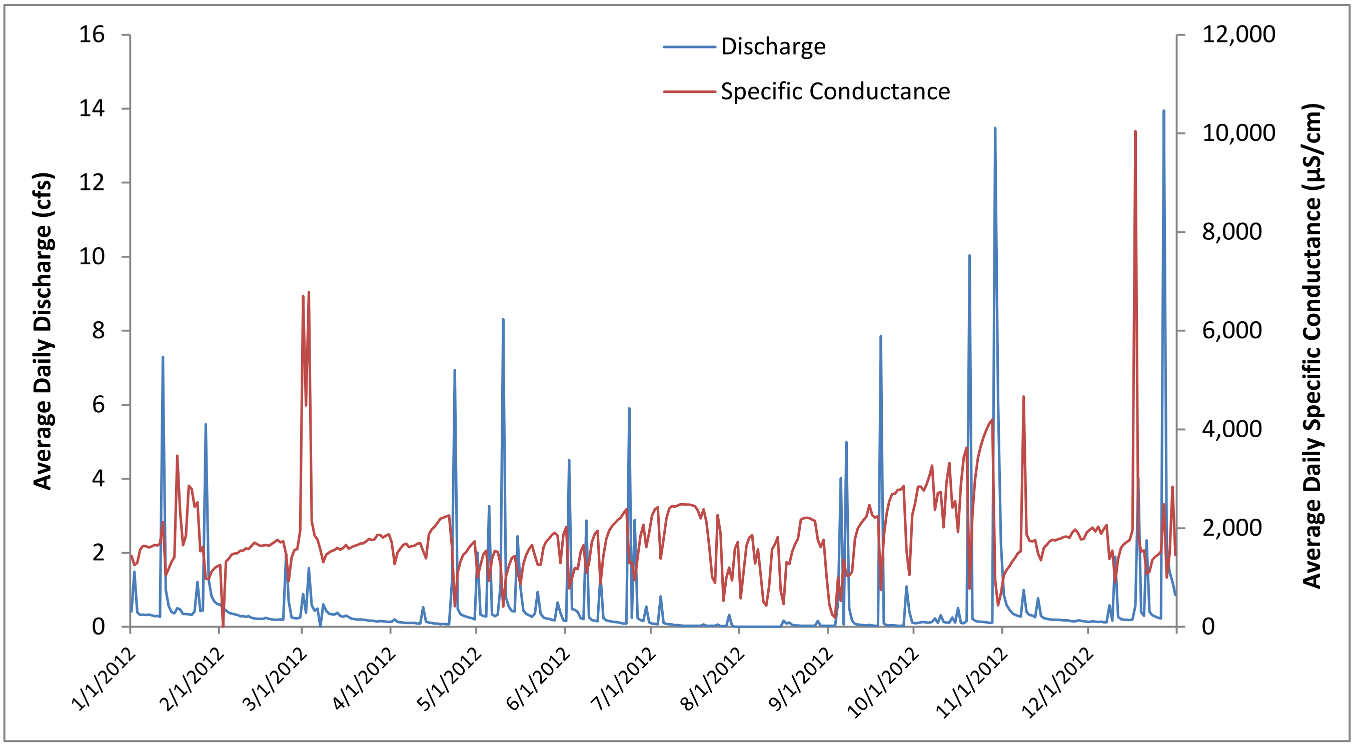


Figure 15: Instantaneous USGS Data for Lexington Brook – Average Daily Discharge and Specific Conductance, 2012

The above figure (Figure 15) illustrates published automated stream flow and specific conductance (indicator of sodium and chloride concentrations in the water) records for 2012. 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 CWD, 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.

Median nitrate nitrogen concentration was lower than that found in both the 2008-2011 reporting period. Lexington Brook continues to yield the third highest nitrate concentrations in the entire source water area (Figure 26). There was no change in the median manganese concentration (0.42 mg/L) from the 2008-2011 reporting period.

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 4). The USGS reestablished Tracer Lane as a continuously-monitored station for temperature and specific conductance on January 31, 2012.

All samples for temperature and *E.coli* met Class A standards. Median dissolved oxygen and pH met Class A standards. Two DO samples were less than 5 mg/L and one pH sample was lower than 6.5. No wet-weather samples were collected during this monitoring period. Sodium, total Kjeldahl nitrogen, and manganese concentrations all have significant increasing trends ($p = 0.01$ for all) over time.

Compared to other sites, this site had the second highest baseflow phosphorus concentrations (Figure 26), which could be explained by the relatively high percentage of forested wetland and impervious area source loading (Table 4). Relatively high organic carbon and manganese results are also consistent with wetland chemical characteristics and function.

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 (Appendix B).

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 Massachusetts Class A water quality standards for bacteria, temperature, pH, and dissolved oxygen for all sampling events. Results from the trending analysis show sodium and total Kjeldahl nitrogen concentrations tending to increase ($p = 0.04$ and $p = 0.01$ respectively).

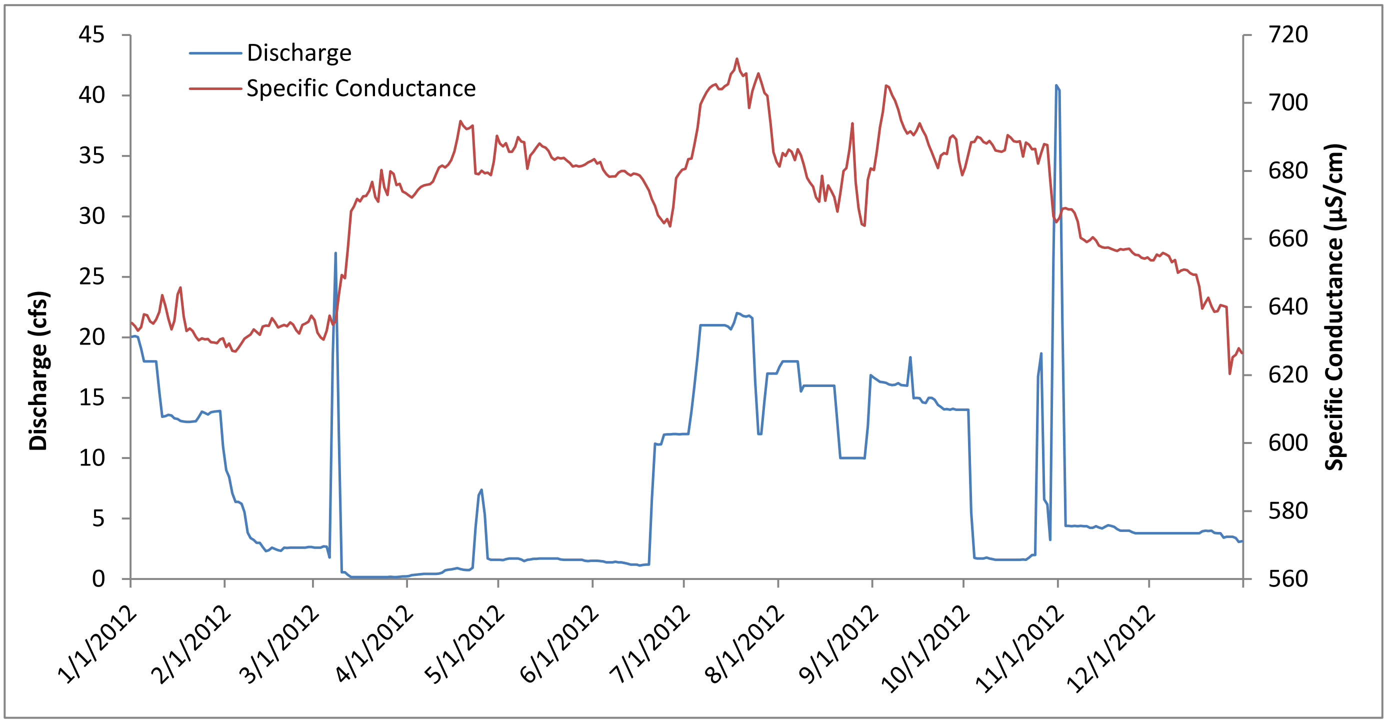


Figure 16: Instantaneous USGS Data for HB BELOW DAM – Average Daily Discharge and Specific Conductance, 2012

Figure 16 illustrates managed flows from the reservoir and 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 and spring when precipitation from the Stony Brook subbasin adequately supplies Cambridge demand. Specific conductance rises in the spring months, which reflects the delayed effect of winter road salt applications.

Industrial Brook (01104433)

This small tributary enters Hobbs Brook approximately 0.5 mile downstream from the dam (Figure 11) 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 covered by impervious surfaces including Route 128, municipal roads, parking lots, and rooftops.

During dry weather sampling, temperature, DO, and *E.coli* met state standards. One sample exceeded the Massachusetts Class A range with a pH reading of 8.46 on February 21st; however, although this high of a pH reading is not unprecedented, the lab pH measurement of 6.99 from this sampling event suggests that the in situ measurement is incorrect (lab and field pH samples have previously agreed within 0.5 units). Median sodium concentrations from Industrial Brook are the highest compared to all other primary tributary sites (Figure 25), and median chloride concentrations are essentially tied with Lexington Brook (Figure 20). Statistical analysis yielded significant increasing trends for both sodium and specific conductance (p = 0.00 and 0.03 respectively).

Due to its developed nature, this site is also monitored during wet weather (See *Wet Weather Monitoring* Section for sampling results and discussion). USGS included this site in the report on storm flows and their impacts on the water supply (publication pending, available online).

Hobbs Brook at Kendal Green (01104440)

The Hobbs Brook at Kendal Green (HB@KG) monitoring station is the furthest downstream sampling site on Hobbs Brook before its confluence with Stony Brook (Figure 11), and therefore is representative of the entire Hobbs Brook 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. One sample exceeded the EPA Nutrient criteria of 0.31 mg/L nitrate for the ecoregion. Statistical analysis yielded significant increasing trends for sodium, specific conductance, and pH ($p = 0.00$, 0.00, and 0.05 respectively).

Stony Brook at Viles Street (01104370)

The Stony Brook at Viles Street station was established in 2009 as an automated monitoring station for temperature, specific conductance, and discharge. This site is located approximately ¾ of a mile upstream of the previously used Stony Brook at Kendal Green site (Figure 11) 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.

Water quality data from Stony Brook at Viles Street integrates and represents conditions for the subbasin that comprises more than half of the total Cambridge source-water area. The Stony Brook subbasin contains significantly less commercial and industrial land and a larger amount of wetlands and low-density residential land use on septic systems (Table 4) than the Hobbs Brook subbasin. Sodium, chloride and specific conductance measurements on the Stony Brook, except for the HB@MILL ST station, are significantly less than those observed in the more developed Hobbs Brook subbasin, which has considerably more salt-treated impervious surfaces.

During this period, SB@VILES was sampled four times with one field duplicate, all taken in dry weather. As Stony Brook is a state-designated cold water fish resource, temperature standards are lower to accommodate temperature-sensitive fluvial fish. Preliminary USGS temperature data at this site indicates that daily maximum 7-day temperatures exceeded the 20°C temperature standard seven times during the summer months. CWD water supply management has no influence on this station's temperature and state regulations allow exceedances when "naturally occurring".

CWD dry weather sampling indicated that SB@VILES met MA Class A water quality standards for temperature, pH, dissolved oxygen, and *E.coli* for all four events. Statistical analysis of past data showed significant decreasing trends for specific conductance and manganese ($p = 0.00$ for both parameters), and a significant increasing trend in pH ($p = 0.04$). In past years of monitoring, more bacteria hits have been captured at this station as a result of wildlife or possible septic breakthroughs from the many residences abutting the river. This site is currently being considered for wet weather sampling to better understand storm water influences on water quality throughout the watershed.

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 equipped with a real-time turbidimeter and is calibrated to estimate chloride concentrations from conductivity data (Granato and Smith, 1999). The subbasin is mostly developed and drains significant amounts of State and municipal roads along with commercial and industrial lands, most notably the old Polaroid facility currently under redevelopment. A large percentage of the lower subbasin is paved and the tributary is routed through pipes and culverts draining Route 128 and the Route 128/Route 20 rotary.

During the reporting period, WA-17 met Massachusetts Class A water quality standards for temperature, pH, and dissolved oxygen for dry weather all samples. Two samples exceeded the state *E.coli* standard and median baseflow chloride exceeded the federal chronic aquatic toxicity standard (250 mg/L). Compared to other monitoring stations, this site had relatively low dry weather phosphorus (Figure 29) and total organic carbon concentrations (Figure 22), but by far the highest nitrate concentrations (Figure 26). In this subbasin, the most likely nitrate sources are from commercial and residential fertilizer applications. Statistical analysis showed no significant long-term trends for all parameters studied with the discharge effects removed.

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 from changes in discharge and season (Figure 17). 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.

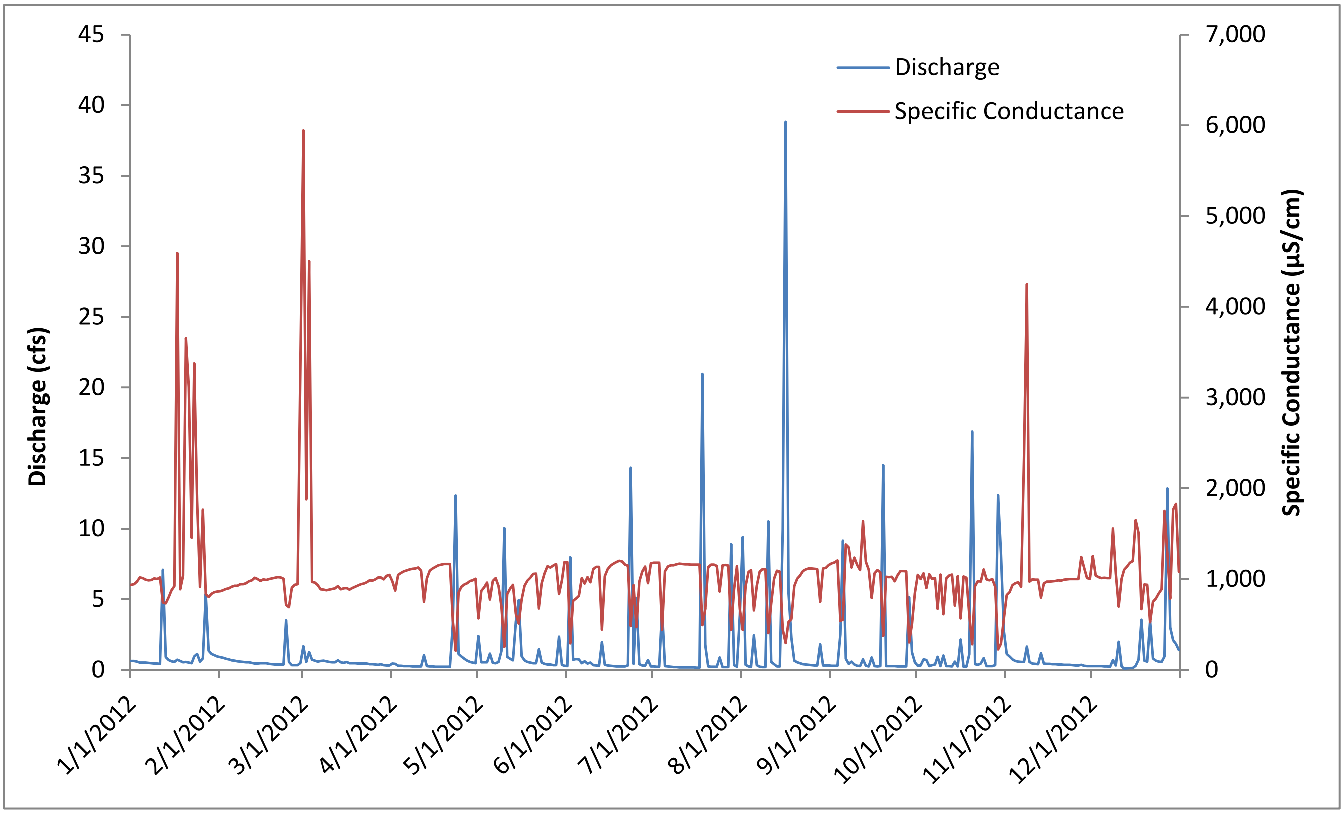


Figure 17: Instantaneous USGS Data for WA - 17 – Average Daily Discharge and Specific Conductance, 2012

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.

Construction is still in progress on the 3.5 acre stormwater retention and treatment basin in the Route 128/Route 20 rotary by MassDOT 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 anticipates considerable wet weather water quality improvements after the completion of these projects. USGS and CWD will continue monitoring stormwater at this site to quantify water quality differences.

Mass Broken Stone (01104453)

The "MBS" station was added in 2000 to the CWD source water quality monitoring program as a recommendation from the Water Year 1998 USGS baseline assessment. This site's relatively large drainage area (2.23 mi^2) consists primarily of forested and residential land use and was the former location of an active rock quarry. The quarry has since been closed and redeveloped into a LEED (Leadership in Energy and Environmental Design) Core and Shell Platinum office complex that has no stormwater discharges to the tributary; instead 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.

The MBS station was sampled four times with two field duplicates during the 2012 reporting period. All baseflow samples for temperature, pH, and *E.coli* met Massachusetts Class A water quality standards. Two samples did not meet standards for dissolved oxygen, and a third sample was barely above the threshold with a concentration of 5.03 mg/L. The median dissolved oxygen concentration did not meet the standard as well. This is most likely due to oxygen demand from microbial activity breaking down organic matter in the shallow, slow moving upstream pond. Statistical analysis shows significant decreasing trends over time in specific conductance and manganese concentrations ($p = 0.04$ and 0.00) respectively.

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.

Baseflow sampling was conducted at this station four times with one field duplicate sample taken. During dry weather, this site met Massachusetts Class A water quality standards for bacteria, dissolved oxygen, and pH for all sampling events. According to USGS approved and provisional data at this site, similar to SB@VILES, daily max temperatures can and do exceed 20°C for periods of 7 days or greater during summer months. Significant increasing trends were found for both sodium concentrations and specific conductance ($p = 0.00$ for both).

The time series graph in Figure 18 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. The increase in specific conductance readings during the summer months can be attributed to the much larger volume of supplementary water released from the Hobbs Brook Reservoir, in which road salt-related constituents have built up during the winter months.

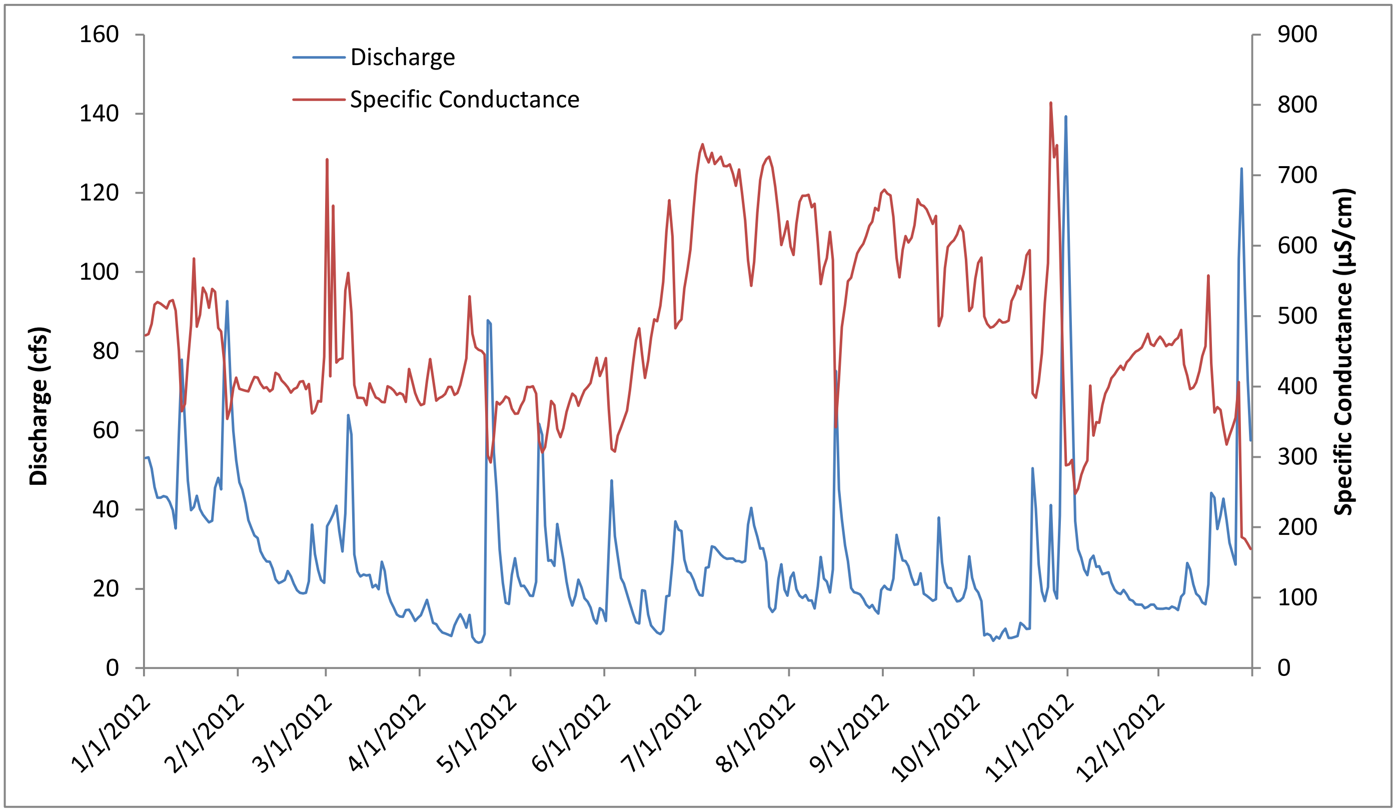


Figure 18: Instantaneous USGS Data for SB @ RT 20 – Average Daily Discharge and Specific Conductance, 2012

Summer Street (01104475)

The Summer Street monitoring 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 Massachusetts Class A water quality standards for bacteria, pH, temperature, and dissolved oxygen for all dry weather monitoring events. This site exhibited the second highest median nitrate yields and concentrations (1.7 mg/L). Of all monitored tributaries, this site had the lowest median sodium, chloride, and specific conductance values (Figures 25, 20, and 27 respectively).

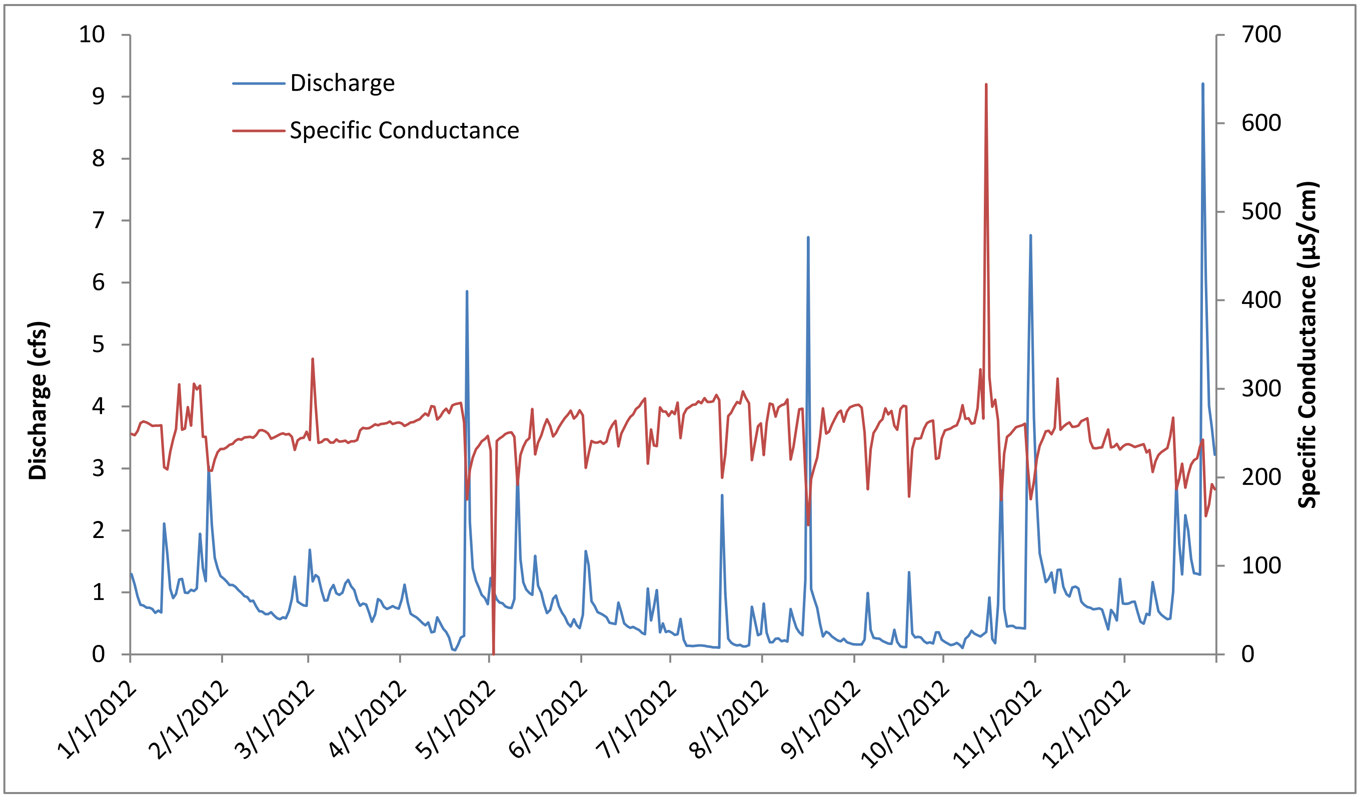


Figure 19: Instantaneous USGS Data for Summer Street – Average Daily Discharge and Specific Conductance, 2012

Figure 19 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. No significant long term trends were found for any parameter at Summer Street. High nitrate concentrations and yields are most likely from golf course and lawn fertilizer applications, as well as septic flow-through.

Primary Tributary Boxplots

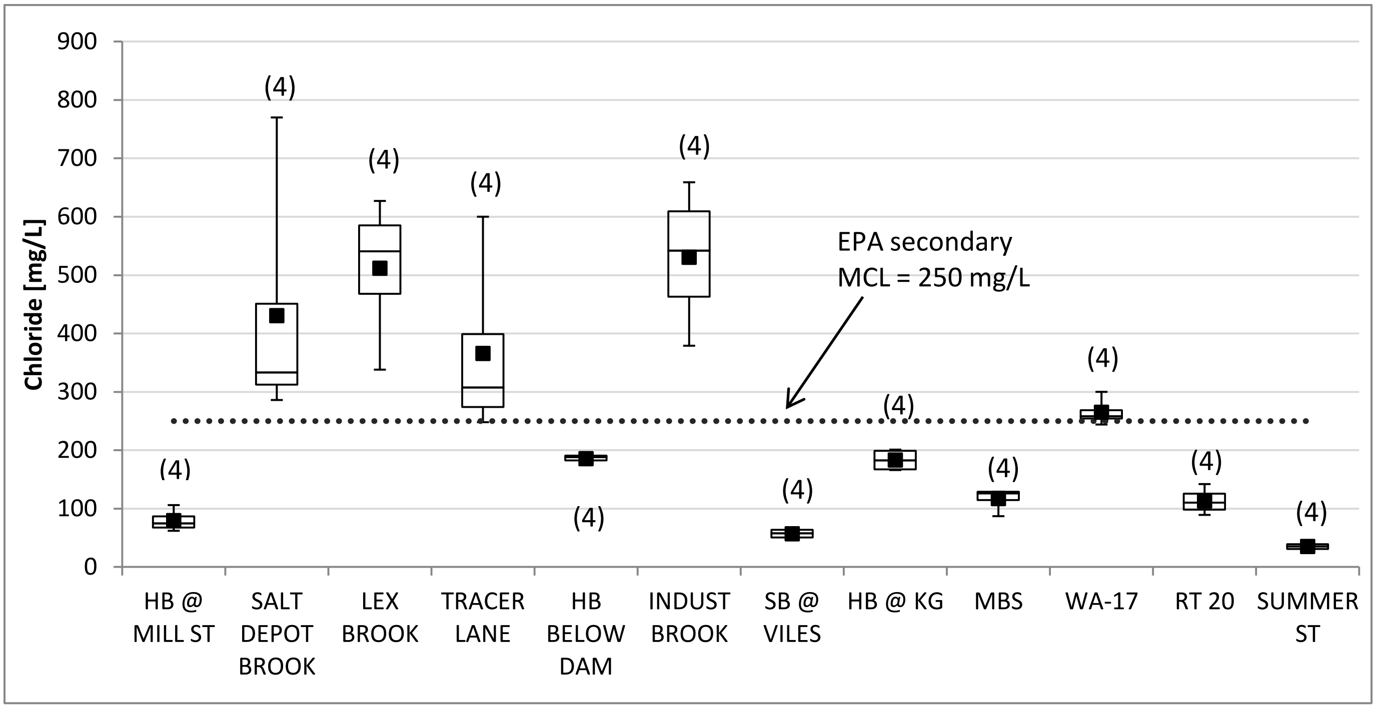


Figure 20: Primary Tributary Base flow Chloride [mg/L] Concentrations, 2012

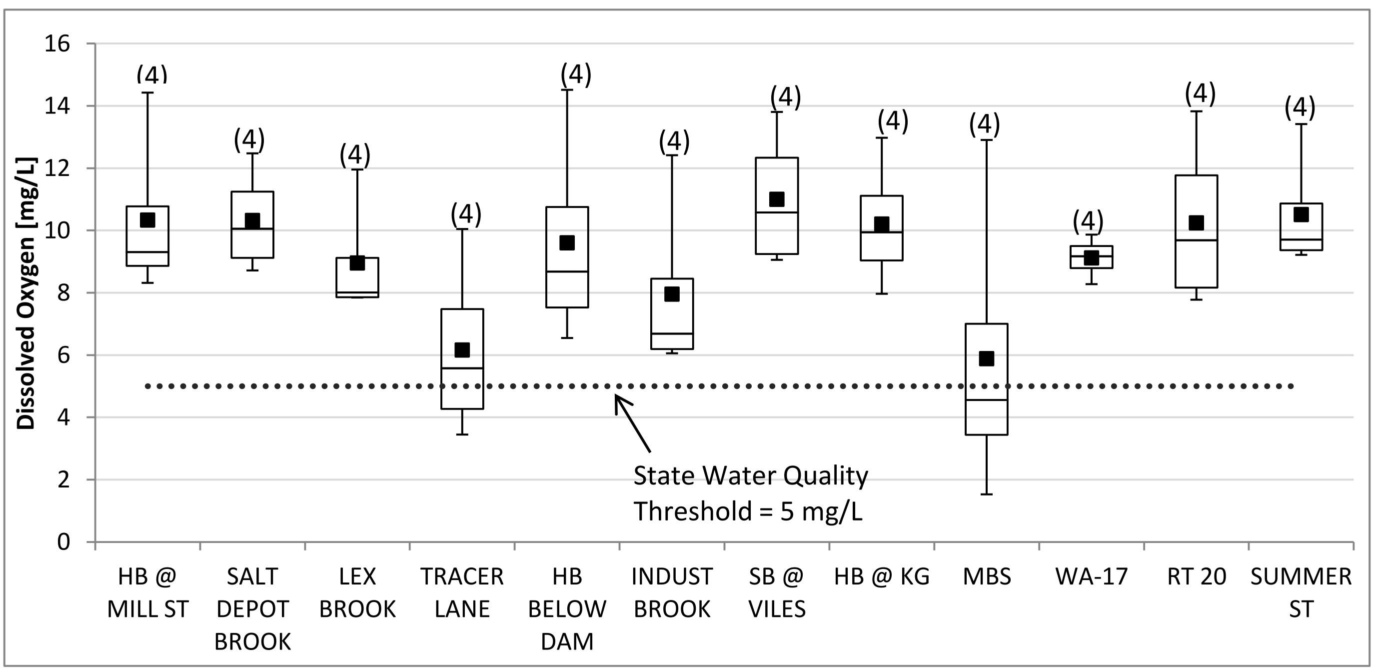


Figure 21: Primary Tributary Base flow Dissolved Oxygen (DO) Concentrations [mg/L], 2012

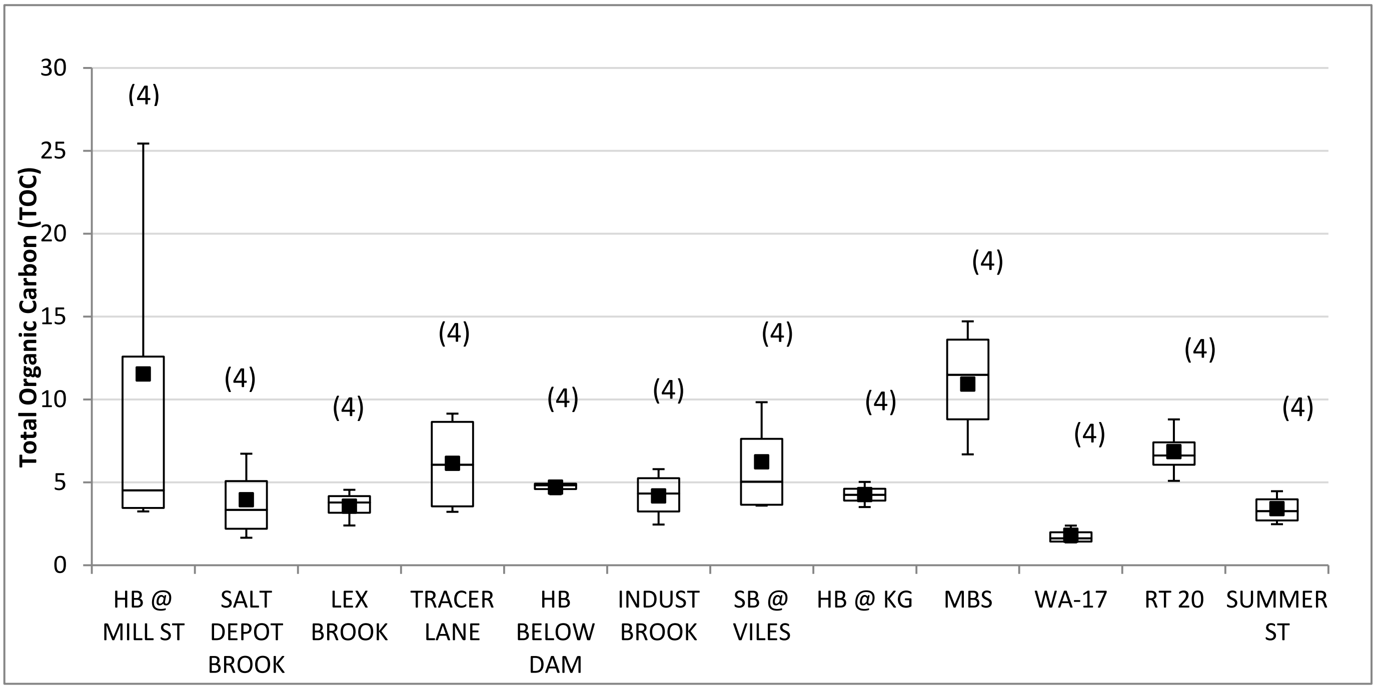


Figure 22: Primary Tributary Base flow Total Organic Carbon (TOC) Concentrations [mg/L], 2012

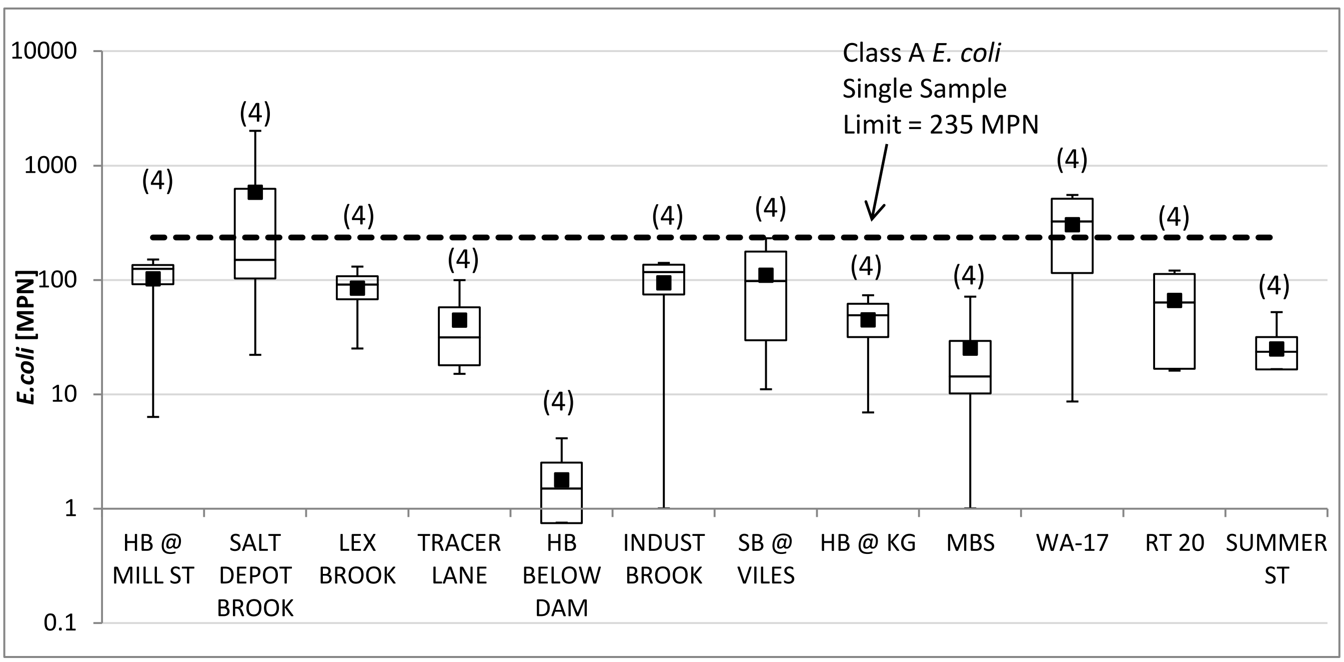


Figure 23: Primary Tributary Base flow E. coli [MPN], 2012 (Logarithmic Scale0

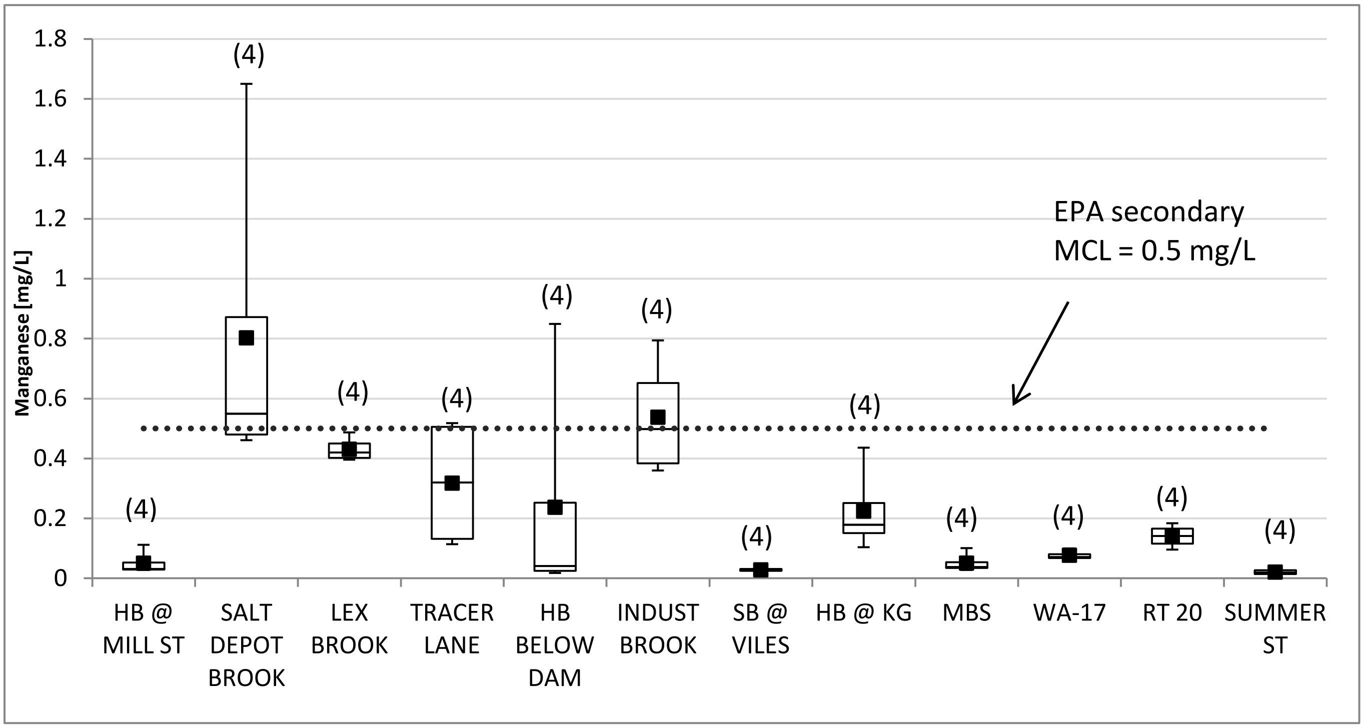


Figure 24: Primary Tributary Base flow Manganese Concentrations, [mg/L], 2012

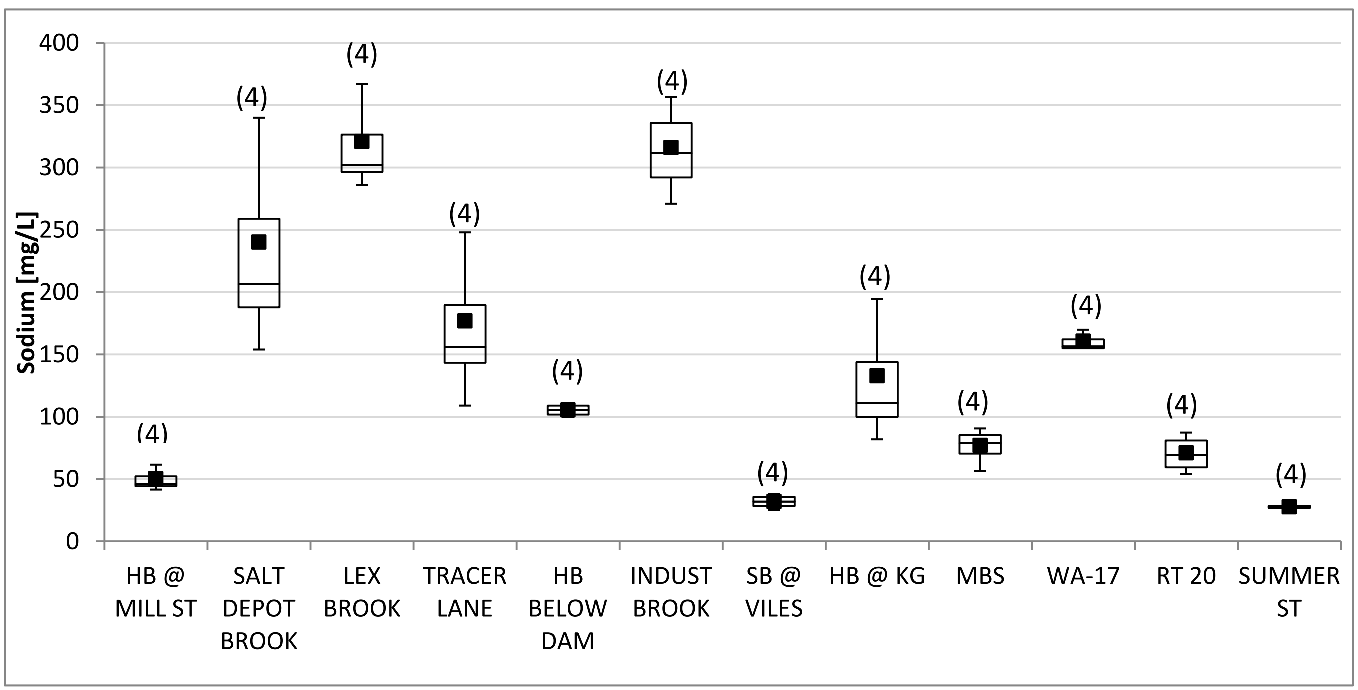


Figure 25: Primary Tributary Base flow Sodium Concentrations, [mg/L], 2012

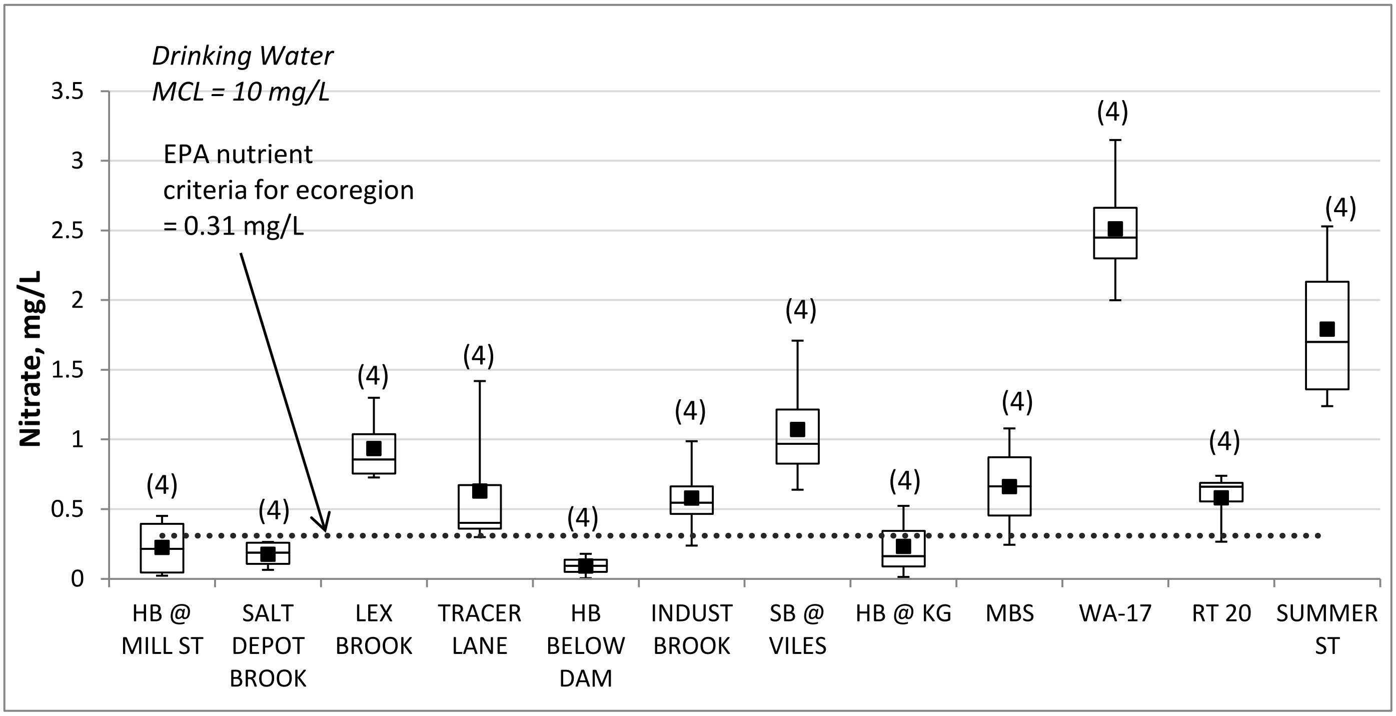


Figure 26: Primary Tributary Base flow Nitrate Concentrations, [mg/L], 2012

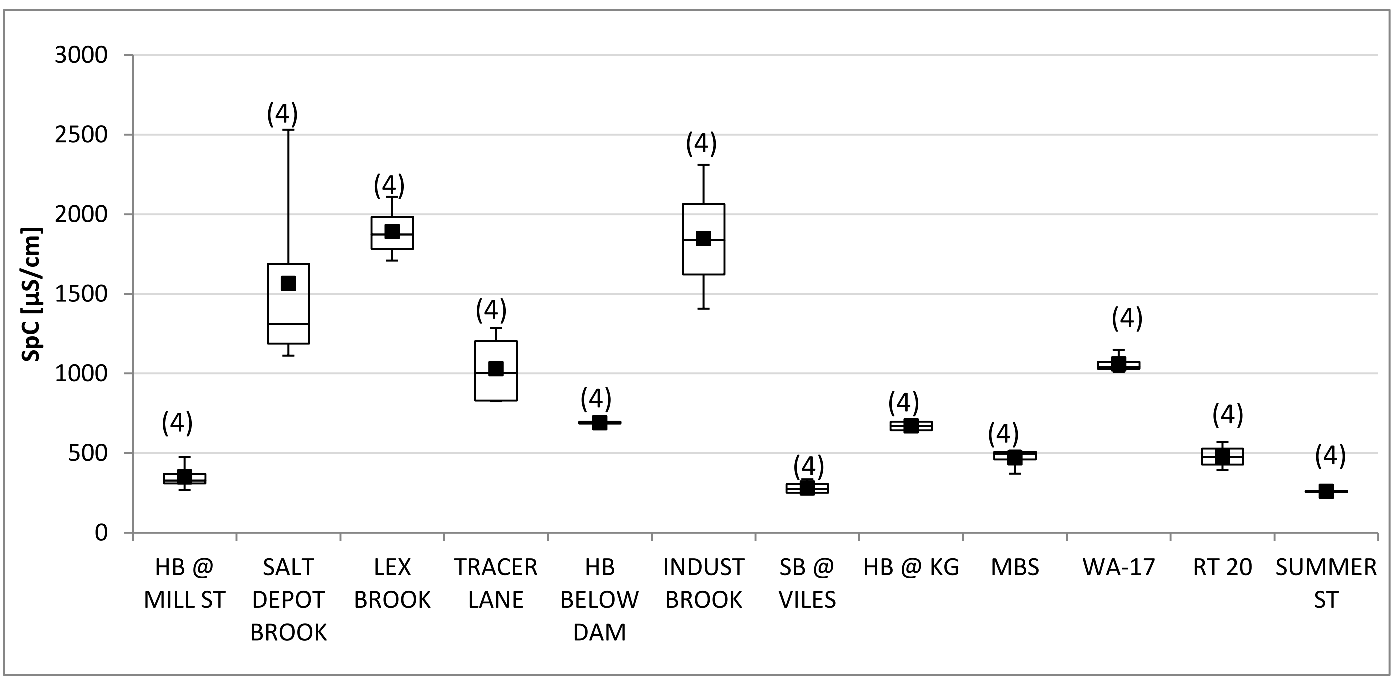


Figure 27: Primary Tributary Base flow Specific Conductance (SpC), [µS/cm], 2012

Figure 28: Primary Tributary Base flow Total Kjeldahl Nitrogen (TKN) Concentrations, [mg/L], 2012

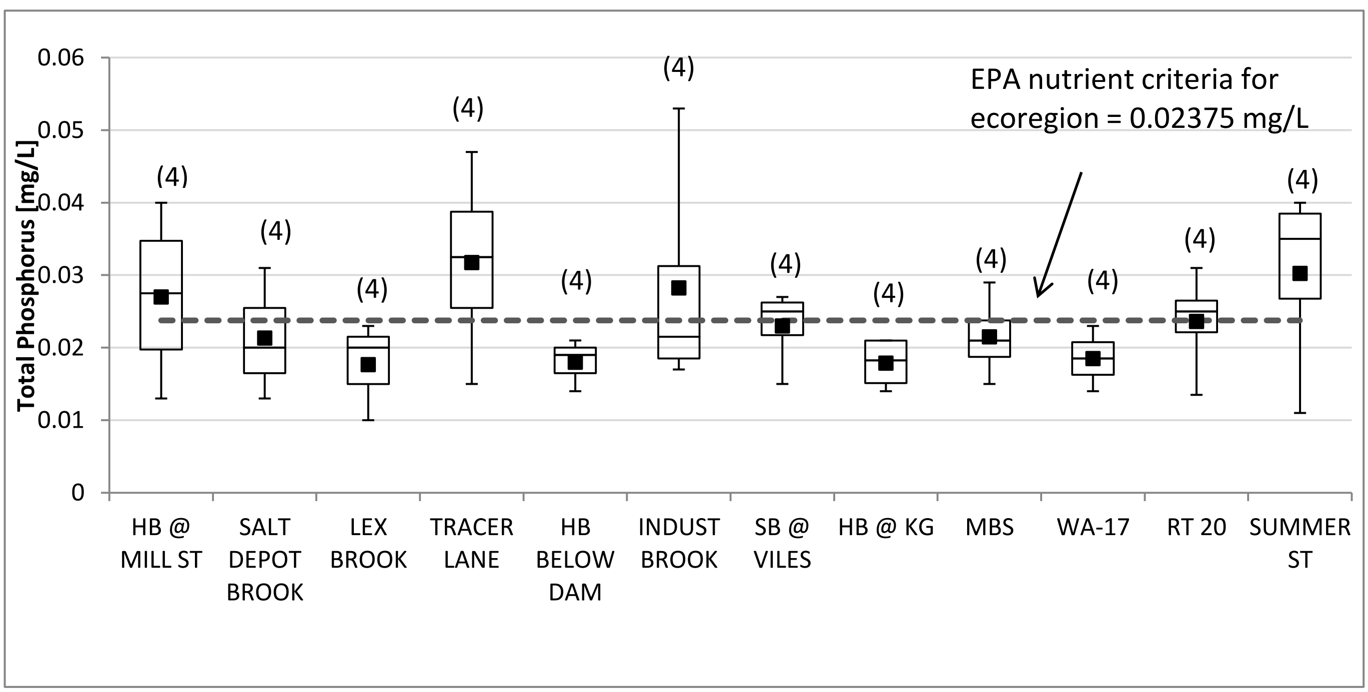


Figure 29: Primary Tributary Base flow Total Phosphorus (TP) Concentrations, [mg/L], 2012

Table 5: Primary Tributary Base flow Median Concentrations, 2012

	HB @ MILL ST	SALT DEPOT BROOK	LEX BROOK	TRACER LANE	HB BELOW DAM	INDUST BROOK	SB @ VILES	HB @ KG	MBS	WA-17	RT 20	SUMMER ST
Cl [mg/L]	74.85	**333**	**541**	**307.5**	188	**542**	57.55	182.75	126.25	**258**	110.5	35.1
DO [%sat]	9.3	10.05	8.015	5.58	8.68	6.68	10.575	9.945	**4.555**	9.17	9.69	9.71
E.Coli [MPN]	125	150	91	31.5	1.5	117	98	49	14.35	**325**	63.5	23.5
Mn [mg/L]	0.0315	**0.55**	0.4205	0.3195	0.041	**0.50**	0.029	0.18	0.038	0.072	0.142	0.02
Na [mg/L]	46.15	206.5	302	156	105.25	311.5	32	111	78.95	156.5	69.35	27.8
NO3 [mg/L]	0.2145	0.1885	**0.857**	**0.4015**	0.0925	**0.547**	**0.9695**	0.162	**0.6625**	**2.45**	**0.66**	**1.7**
SpC [µS/cm]	328.25	1311	1873.5	1003.7	691.1	1837	274	670.6	497	1040.5	476.5	259
TKN [mg/L]	1.2	0.62	ND	0.6	0.51	0.77	ND	ND	0.705	ND	0.5	ND
TOC [mg/L]	4.53	3.35	3.79	6.065	4.83	4.325	5.0525	4.255	11.5	1.625	6.63	3.275
TP [mg/L]	**0.0275**	0.02	0.02	**0.0325**	0.019	0.0215	**0.025**	0.01825	0.021	0.0185	**0.025**	**0.035**

ND : Not Detected
BOLD : Exceeds Massachusetts Water Quality Standard or 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 stormwater runoff. The small amount of water that flows to streams as runoff does not exacerbate erosion and is generally of high quality.

As the Cambridge source watershed is relatively developed, significant increases in constituent concentrations are observed in stream flows dominated by stormwater. Samples analyzed for nutrients, major ions, and selected metals were collected during one storm event during this reporting period for two USGS-recommended stations, LEX BROOK and WA-17. CWD event monitoring measures the worst case in-stream stormwater pollutant concentrations or the “first flush” of runoff into the stream. CWD targets storm events with greater than 0.5 inches of rain expected after 72 hours of no rainfall, which makes scheduling stormwater sampling events more difficult. Several USGS continuous monitoring stations have been outfitted to automatically sample storm events, eliminating scheduling conflicts. The USGS has complied and analyzed stormwater samples from 2005-2007 that is available here as in an interpretive report, *Water-quality conditions, and constituent loads and yields in the Cambridge drinking-water source area, Massachusetts, water years 2005–07*.

The recently published USGS interpretive report explains wet weather versus dry weather constituent contributions to the water supply and will help focus Watershed Division stormwater management programs. 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 number.

In addition to the stormwater sampling conducted by CWD in 2012, analysis was performed on wet weather monitoring sites using stormwater sampling results from the USGS and baseflow-stormflow estimations from 2012 (See *Water Balance* Section for more discussion on the baseflow-stormflow estimations). Annual yields were estimated for the baseflow and stormflow contributions using the mean concentration for each constituent from dry weather and wet weather sampling events. Annual yield estimations are provided in Figures 30-34. Averages taken from USGS were used for the estimations to supplement the wet weather sampling conducted in 2012 and to provide a more accurate representation of the stream concentrations. The results from the baseflow-stormflow yield estimations are provided in Figures 30-34. “Winter” storms (January-March) are separated from non-winter storms due to the dramatic differences in stormflow effects from winter to non-winter months.

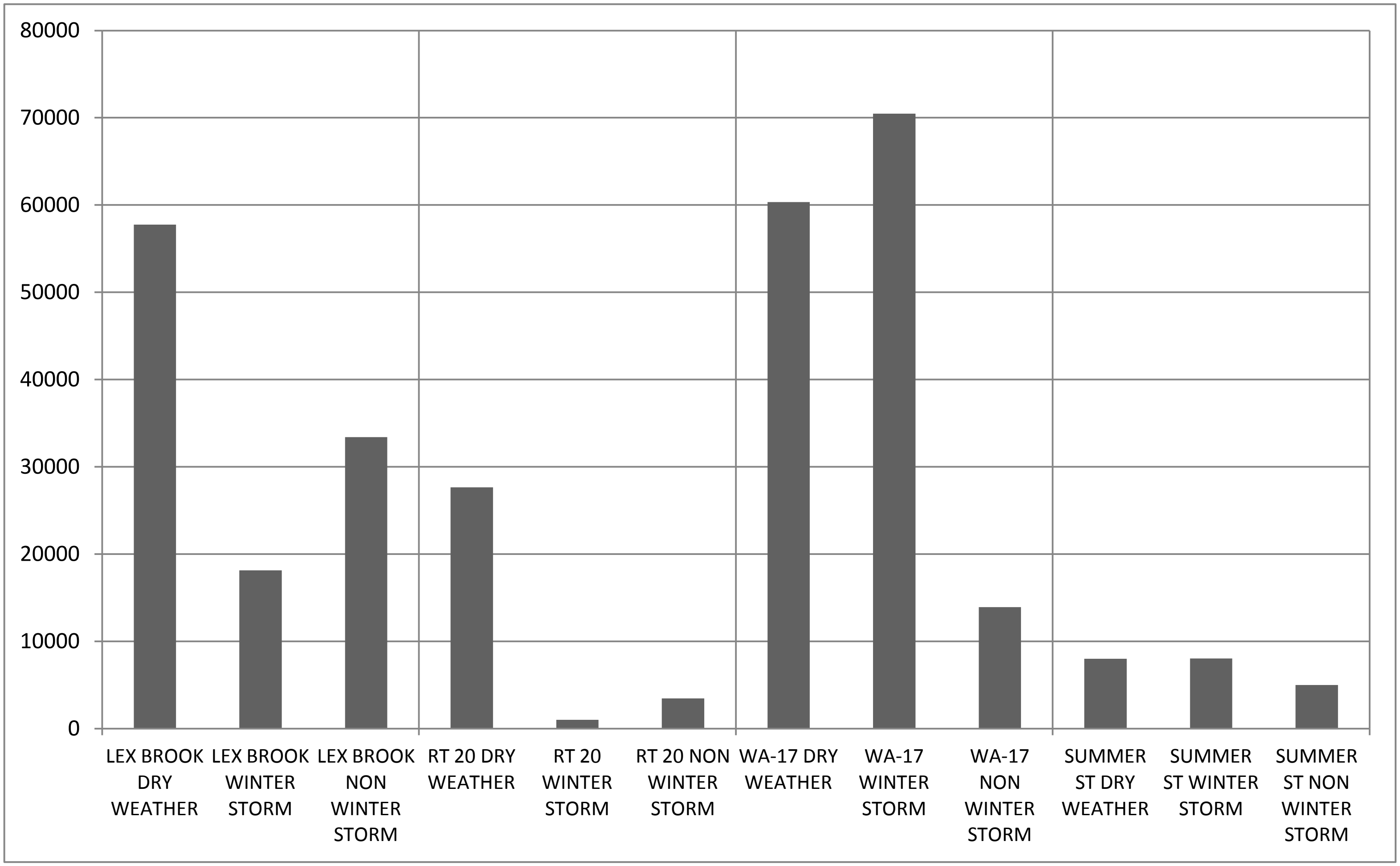


Figure 30: Annual Yield Estimation, Sodium [kg/km^2/yr]

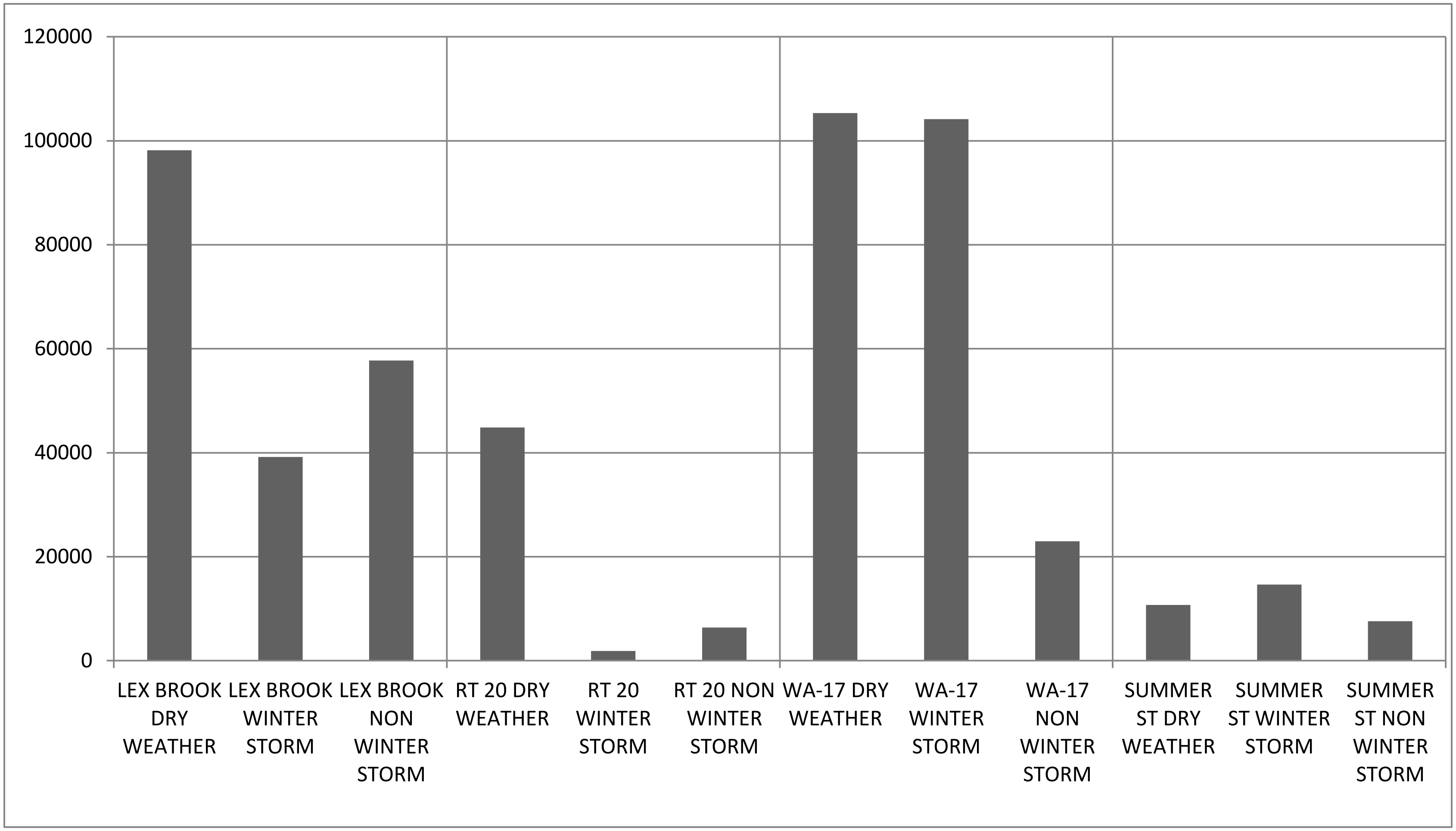


Figure 31: Annual Yield Estimation, Chloride [kg/km^2/yr]

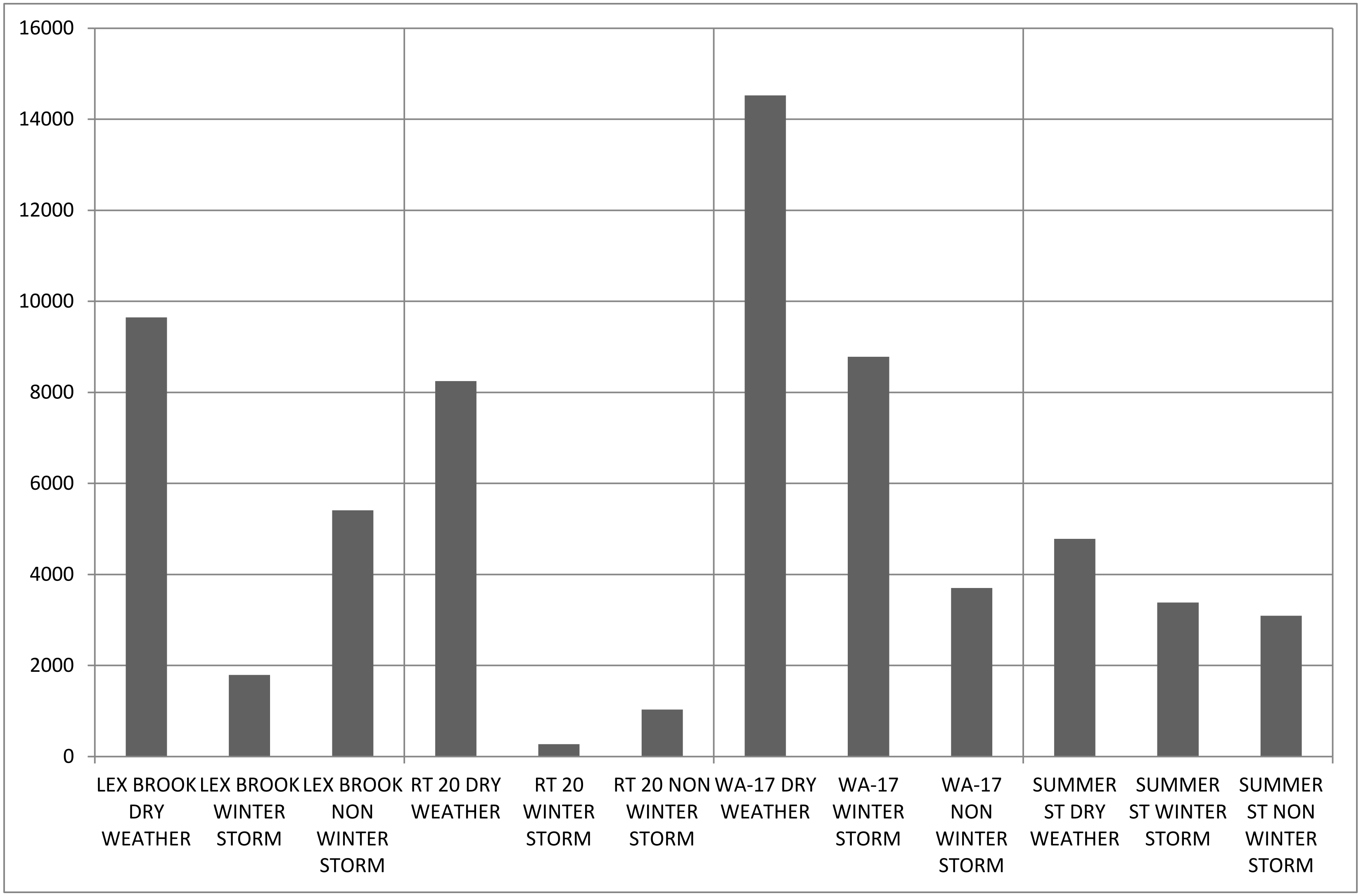


Figure 32: Annual Yield Estimation, Calcium [kg/km^2/yr]

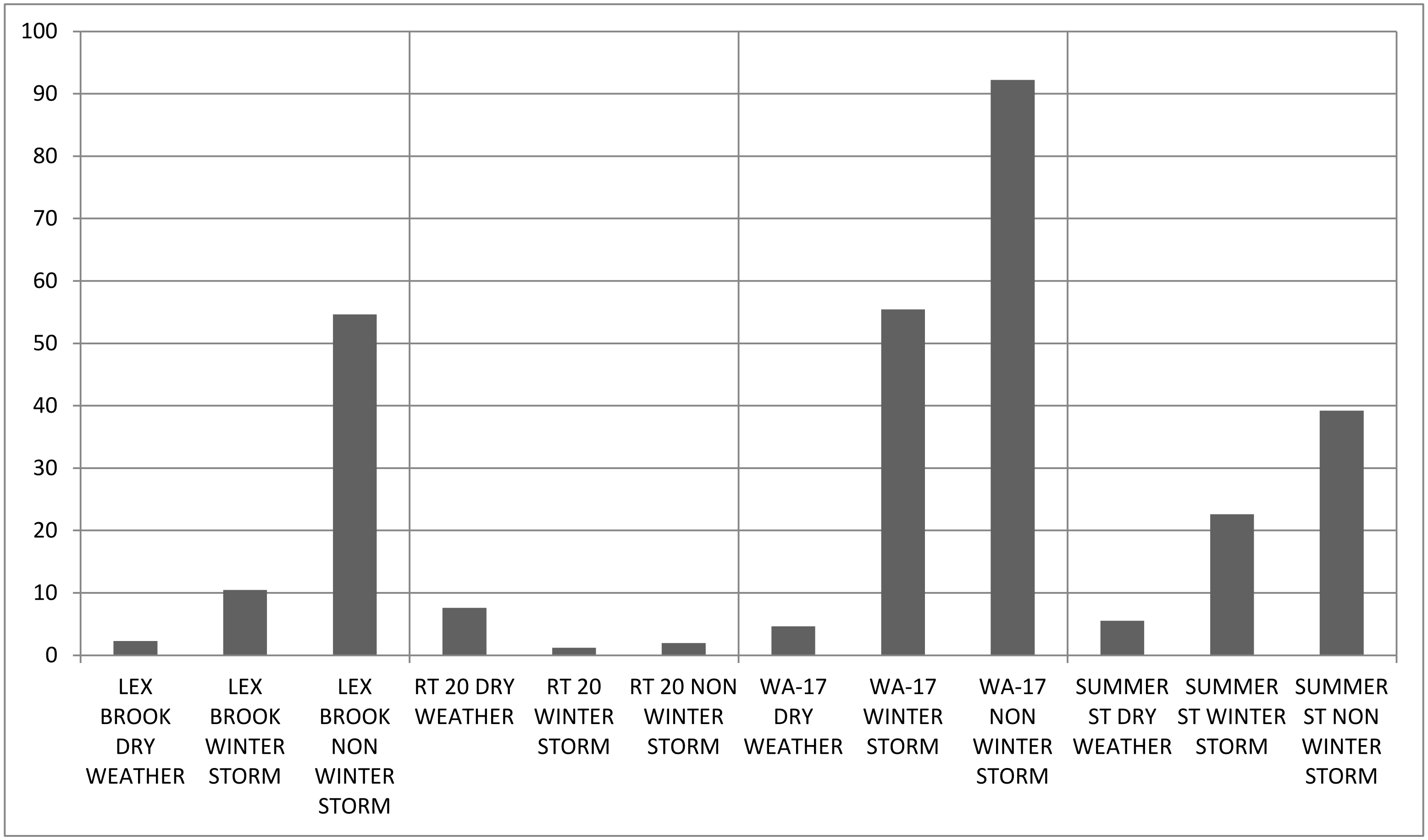
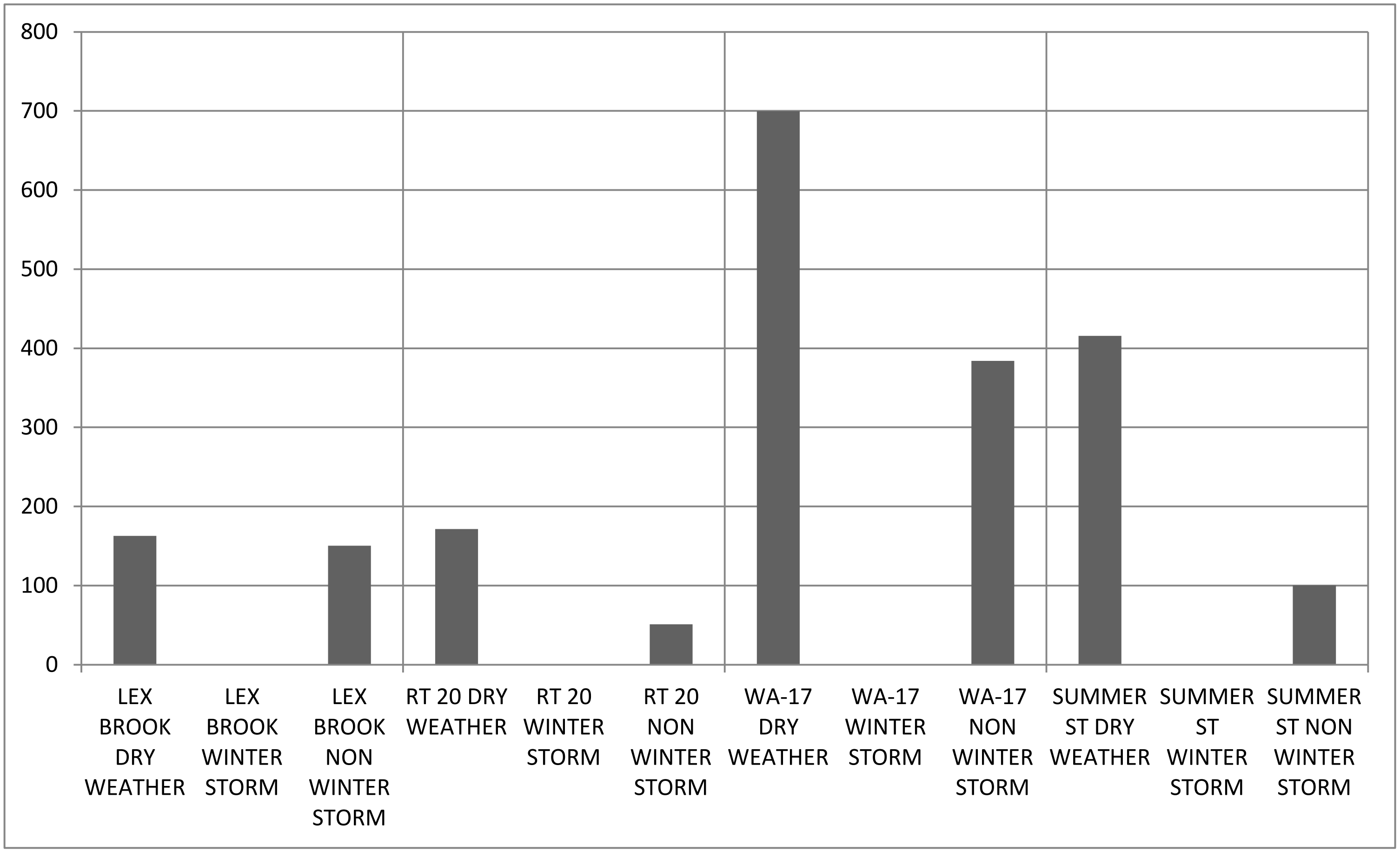


Figure 33: Annual Yield Estimation, Total Phosphorus [kg/km^2/yr]



*Stormflow data taken from CWD Databases

Figure 34: Annual Yield Estimation, Nitrate [kg/km^2/yr]

The most dramatic differences in stormflow from baseflow are apparent at the WA-17 and Lexington Brook sites for all parameters except nitrate. Stormflow contributions are much higher than baseflow, especially for the ions associated with deicing materials, sodium and chloride. The WA-17 monitoring station has much higher yields than all other stations, especially during stormflow. As evident in the hydrograph separation (Figure 49), WA-17 flows are mostly attributed to stormflow with little baseflow contributions. Since WA-17 was routed as a major highway outfall, these results reaffirm our knowledge and help prioritize WA-17 for stormwater improvements.

For the Route 20 and Summer Street stations, base flows contribute the highest yields for all parameters considered. This is the expected result from Summer Street, which receives its water from a relatively undeveloped subbasin. Route 20 is comprised of mostly baseflow (Figure 49), which explains the relatively high yields from baseflow compared to stormflow, despite the close proximity to highways.

Most of the total phosphorus loads is from stormflow. This is consistent with the findings from the 2005-2007 USGS report.

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 35). 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, as the ponds support primary contact recreation and are not considered to be part of the drinking water supply.

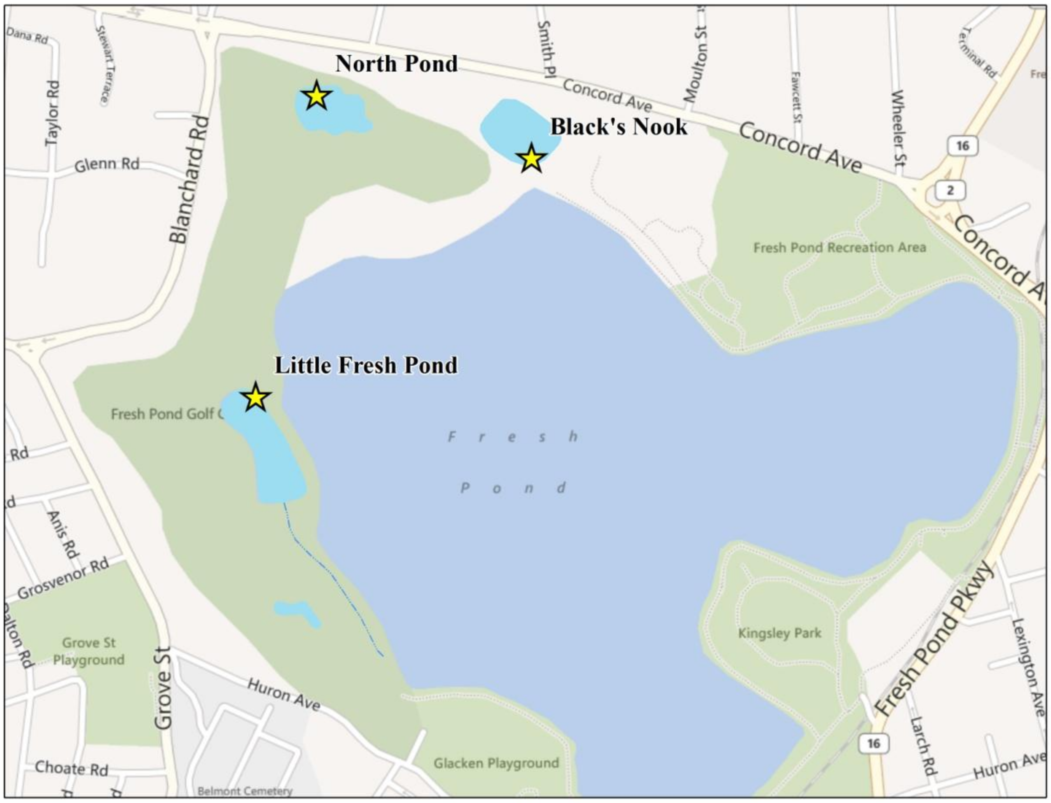


Figure 35: Fresh Pond Reservation Sampling Locations

During this period, reservation ponds were sampled three 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, Little Fresh Pond exceeded Class B water quality standards for pH on April 10th. Two dissolved oxygen measurements were lower than the 5 mg/L threshold at North Pond (October 4th

and November 11th); and one dissolved oxygen measurement was lower than the threshold at Black's Nook on October 4th. All other samples for all ponds met Class B standards for temperature, dissolved oxygen, and *E.coli.*

High phosphorus (Figure 36) and chlorophyll (Figure 37) 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 assumptions of good groundwater communication and also the influence of Fresh Pond water being periodically 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 (Figure 38).

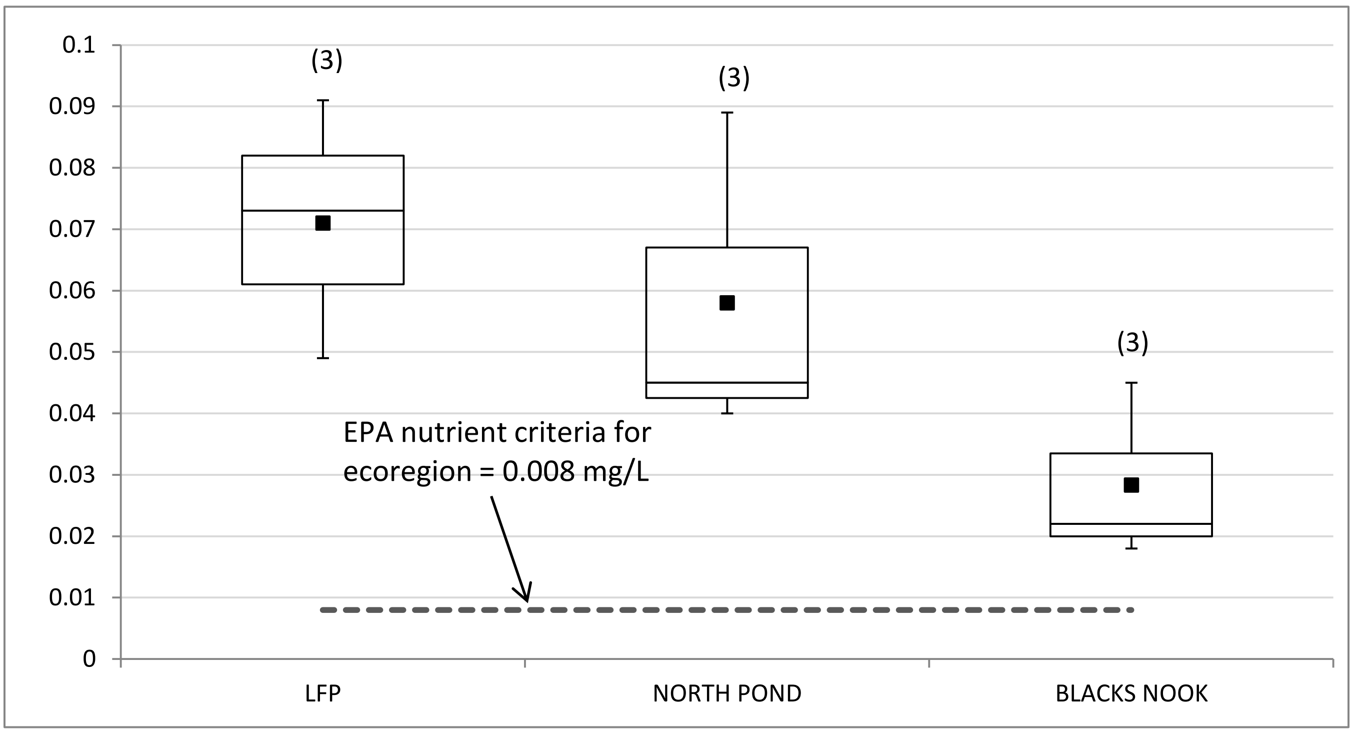


Figure 36: Fresh Pond Reservation Dry Weather Total Phosphorus [mg/L], 2012

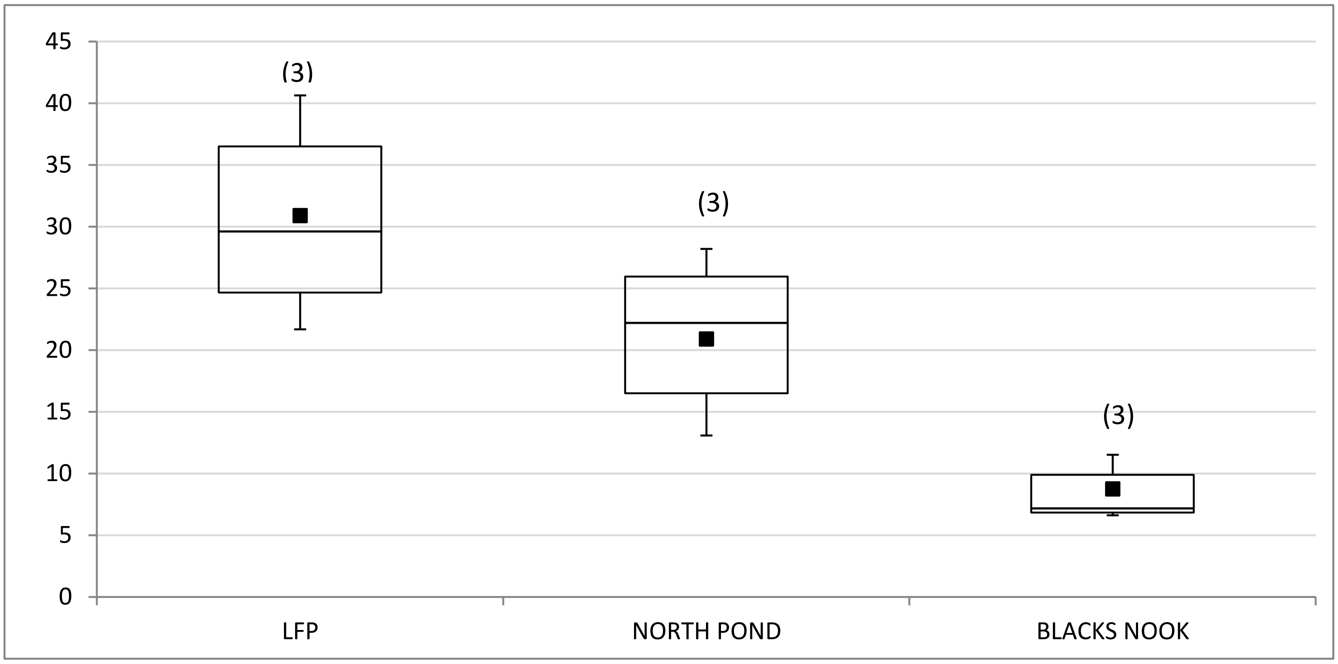


Figure 37: Fresh Pond Reservation Dry-Weather Chlorophyll-a [mg/m3], 2012

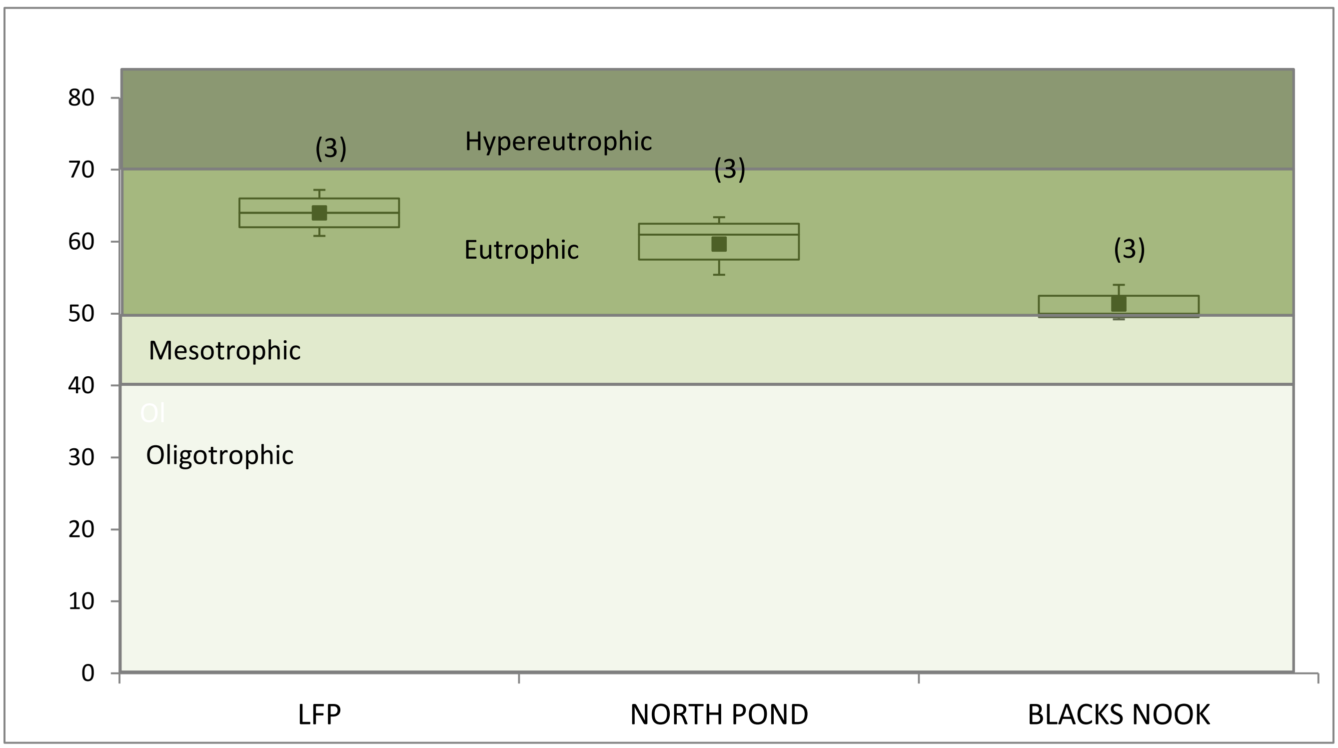


Figure 38: Fresh Pond Reservation Class B Waters Trophic State Index (TSI) from Chl-a, 2012

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 outfalls or other discharges whose sources were detected by routine or stormwater sampling and traced back upstream to their location. During this study period, continued sampling was conducted weekly at the Costco Drainage Canal, the site of a historic illicit sewage discharge into a detention basin in Waltham. An additional special water quality investigation was added at a salvage yard on Route 128 with noticeable negative stormwater impacts. The data for this site is currently under review and will not be discussed further at this time.

Costco Drainage Canal

Located downstream of a recently improved stormwater pond on Winter Street in Waltham, the Costco Drainage Canal 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, which 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.

Past 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 used to further rule out sewage sources. Bacteria results below do not yet show any clear significant trends of improvement from the recently completed pond project.

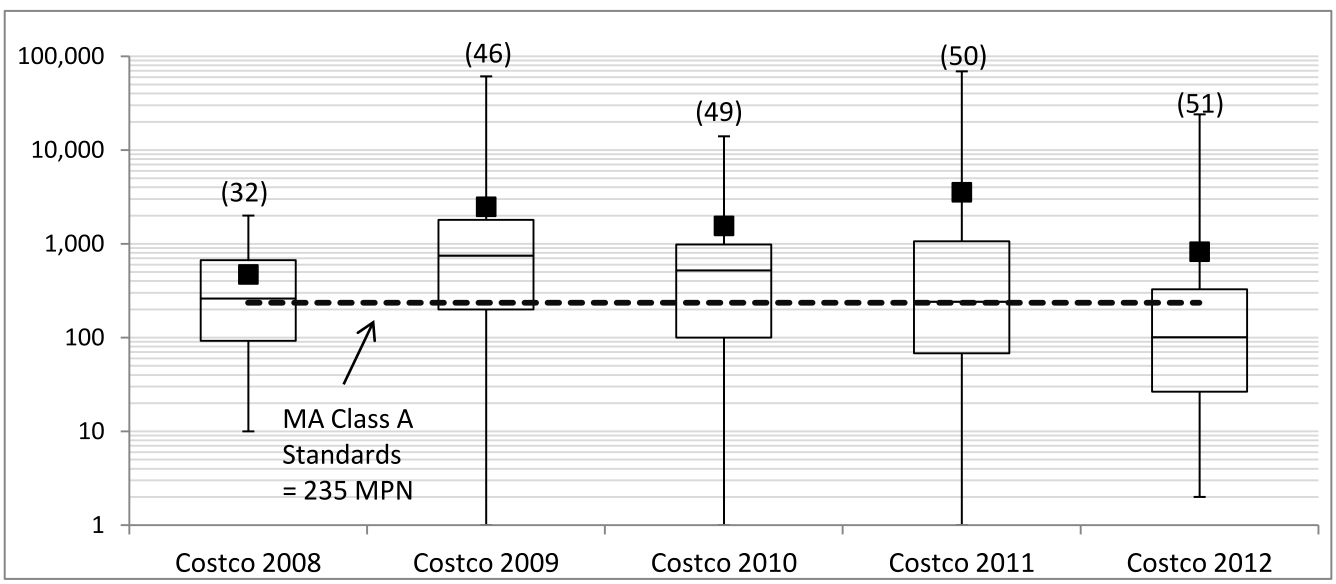


Figure 39: Weekly *E.coli* Results, Costco Drainage Ditch

Water Balance

Available Water

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. The annual outflow estimated from data obtained at the USGS monitoring station immediately downstream of Hobbs Brook in 2012 was 1.85 billion gallons (Table 6).

Between 2008 and 2012, at the USGS monitoring station immediately downstream of Hobbs Brook Reservoir, annual outflows ranged between 1.85 billion gallons (2012) to 4.89 billion gallons (2010), with a four year average of 3.10 billion gallons. The reservoir hydraulic detention time (defined as the time it would take for the reservoir to empty out if all inputs of water to the reservoir ceased) can be estimated using the total storage capacity of 2.52 billion gallons for 2010-2012 and 2.88 billion gallons for 2008-2009. The difference in storage capacity is due to the removal of spillway boards at the Hobbs Brook Dam in 2010. The hydraulic detention time was 16 months in 2012 and 11 months for the five year average.

Data records taken from the Hobbs Brook Dam precipitation gage (01104430) indicate that the Hobbs Brook and Stony Brook watersheds received an estimated 13 inches less of precipitation than 2011 (Table 7), resulting in less available water available for release to the Charles River. The high outflow in 2010 can be attributed to both the higher precipitation amount and to the March hurricane, in which very high flows were released from the Hobbs Brook Dam to sustain safe dam operating levels.

Table 6: 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
2012*	1850	2518	16

*provisional USGS data, subject to revision
total outflow = sum of avg. daily flows

Table 7: HB Below Dam (01104430) Precipitation Gage Annual Totals [in]

Year	2012*	2011	2010	2009	2008
Total Precipitation	43.8	57.04	53.51	40.53	62.73

*provisional USGS data, subject to revision

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 2.2 billion gallons in 2012 to 10.5 billion gallons in 2010 (Table 8). 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; 2012 flows were an exception due to the decreased amount of precipitation received by the watershed.

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. Charles River flows from Stony Brook are measured at a downstream USGS gaging station. Over the past five years, total output from Stony Brook Reservoir to the Fresh Pond ranged from 2.5 (2010) to 7.7 (2008) billion gallons. The total estimated detention time in Stony Brook Reservoir was between 11 and 26 days, indicating a high flushing rate.

Table 8: Stony Brook Reservoir Water Balance

Year	Stony to Charles (MG)	Stony to Fresh Pond (MG)	Storage Capacity (MG)	Estimated Detention Time (days)
2008	7729	7730	418	11
2009	6672	6672	418	11
2010	10521	2483	418	11
2011	7668	3167	418	15
2012*	2178	3398	418	26

*provisional USGS data, subject to revision

total outflow = sum of avg. daily flows

Total estimated output from Fresh Pond to the treatment plant (estimated from the total water produced by the plant) ranged from 4.71 to 4.89 billion gallons (Table 9). The five year average detention time is 3.79 months.

Table 9: 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
2012*	4749	1507	3.84

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

Baseflow Contribution Estimation

Estimating the baseflow and stormflow contributions from streams is a useful tool for guiding watershed protection decisions. The baseflow-stormflow hydrograph separations (Appendix D) were manually estimated in an Excel spreadsheet for all gaged streams using the sliding interval method, as developed by Pettyjohn and Henning in 1979. In this method, baseflow is estimated as the minimum streamflow recorded during the interval and assigned to the median day. The interval (2N*) is calculated as twice the duration of surface runoff (N) for the subbasin rounded to the nearest odd integer between 3 and 11. N is calculated using the equation

$$N = A^{0.2}$$

where A is the drainage area of the subbasin (in mi^2). The sliding method takes the lowest discharge from 0.5(2N*-1) days before and after and assigns it to the median day for that interval. For all gaged streams in the Cambridge watershed, the contributing subbasins are relatively small and yield intervals are three days. From this, the baseflow is estimated using an excel spreadsheet. The results from the baseflow estimations are provided in Table 10 and Figure 40. The hydrograph separation figures for all gaged streams are provided in Appendix D. As expected, Route 20 contributes the largest volume of water as it is downstream of all tributaries except for one unnamed tributary (Summer Street). Lexington Brook and WA-17 are comprised of more than 50% stormflow, and all other tributaries are between 20-30% stormflow based.

Table 10: Streamflow, Baseflow, and Stormflow Tributary Contribution Estimations [MG]

	SB@VILES	HB@ MILL ST	LEX BROOK	MBS	WA - 17	RT 20	SUMMER ST
STREAM	3031	534	138	577	327	6427	203
BASE	2441	377	47	462	131	5357	150
STORM	589	156	91	115	196	1070	53

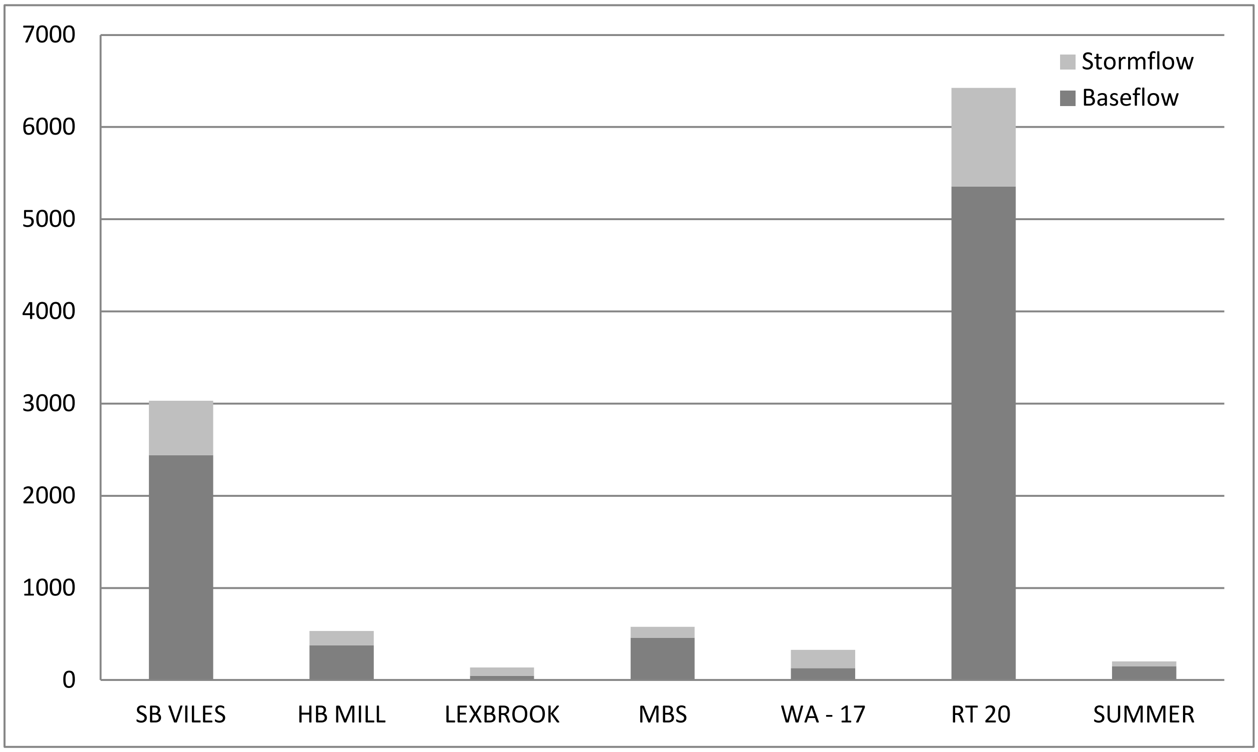


Figure 40: Gaged Streamflow Composition Estimations [MG], 2012

Future Recommendations

Schedule

The schedule proposed in the water quality monitoring program developed in cooperation with the USGS recommends a high amount of sampling events per site per year. Due to weather and staffing constraints, eight sampling events per primary site are unattainable and may be unnecessary. A more manageable goal of 4-6 sampling events per primary site should be targeted for future years. More frequent wet weather sampling should be targeted, however, may not be attainable with the strict weather conditions needed for a representative grab sample.

Calibrations

The Manta multiprobe was sent in for maintenance in December to determine the causes of the false dissolved oxygen measurements taken in 2012. The manufacturer found no issues with the probe and advised changes to the calibration method to ensure more accurate field results. Taking more time with the DO calibrations should help avoid inaccurate measurements.

References Cited

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.

Helsel, D.R. and R. M. Hirsch, 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. 522 pages.

Mitsch, W. J. & J. G. Gosselink, 1993. Wetlands (3rd edn). Van Nostrand Reinhold, New York. 171-173 p.

Osmond, D.L., D.E. Line, J.A. Gale, R.W. Gannon, C.B. Knott, K.A. Bartenhagen, M.H. Turner, S.W. Coffey, J. Spooner, J. Wells, J.C. Walker, L.L. Hargrove, M.A. Foster, P.D. Robillard, and D.W. Lehning. 1995. *WATERSHEDSS: **Water**, **S**oil and **H**ydro-**E**nvironmental **D**ecision **S**upport **S**ystem*, http://h2osparc.wq.ncsu.edu.

Pettyjohn, W.A., and Henning, Roger, 1979, Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio: Ohio State University Water Resources Center Project Completion Report Number 552, 323 p.

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. Geological Survey, WRIR 00-4263, Waldron, C., Bent, G.C., 2001, Factors Affecting Reservoir and Stream-Water Quality in the Cambridge, Massachusetts, Drinking-Water Source Area and Implications for Source-Water Protection.

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.

Benthic sediments— The surface layer and some sub-surface layers of sediment in contact with the bottom zone of a water body, such as a lake or ocean.

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.

Escherichia coli (*E.coli*) bacteria— Type of bacteria that is found in the human gastrointestinal tract. *E.coli* is commonly used as an indicator of fecal contamination in groundwater, as the result of a improper sewage connection or septic system failure.

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 deprivation of oxygen compared to how much is required by the system.

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.

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.

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 – Water Quality Monitoring Procedure and Schedule

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 11: Water Quality Monitoring Schedule

Primary Tributary Group 1 (5)	Sampling Dates
HB @ Mill St [1]	2/7
Salt Depot	6/19
Tracer Lane	9/18
SB @ Viles	11/6
MBS	

Frequency Target : 8 Events

[1] Route 20 and HB @ Mill St were swapped on 11/6 and 10/23

Primary Tributary Group 2 (5)	Sampling Dates
LexBrook	1/10
HB Below Dam	6/12
WA-17	8/21
Rt 20 [1]	10/23
Summer St	

Frequency Target : 8 Events

Primary Tributary and Reservoir Group (4)	Sampling Dates
Indust Brook	2/21
HB @ KG	7/10
HB @ Middle	9/25
HB @Upper	11/13

Frequency Target : 8 Events

Upcountry Reservoirs Group (6)	Sampling Dates
HB @ DH	5/31
HB @ DH _ m [2]	8/7
HB @ Intake	10/9
SB @ DH	11/20
SB @ DH _ m [2]	
Sb @ Intake	

Frequency Target : 8 Events

[2] Only during periods of thermal stratification

Fresh Pond Reservoir Group (4)	Sampling Dates
FP @ DH	3/15
FP @ DH_m [2]	7/3
FP @ COVE	9/11
FP @ INTAKE	12/4

Frequency Target : 8 Events

Fresh Pond Reservation Group (3)	Sampling Dates
LFP	4/10
BLACKS NOOK	10/4
NORTH POND	11/27

Frequency Target : 4 Events

Stormwater Sampling Group (6)	Sampling Dates
IndustBrook	8/28
RT 20	
Summer St	
Tracer Lane	
LexBrook	
WA-17	

Frequency Target : 4 Events

Parameters Measured	
Discharge	*E.Coli*
Temperature	Color
DO	Alkalinity
pH	Metals
Conductance	Ions
Turbidity	Secchi Depth*
Nutrients	Chlorophyll-*a**

*Reservoirs and Reservation Only

Appendix B – Water Quality Monitoring Results Median Instantaneous Yields

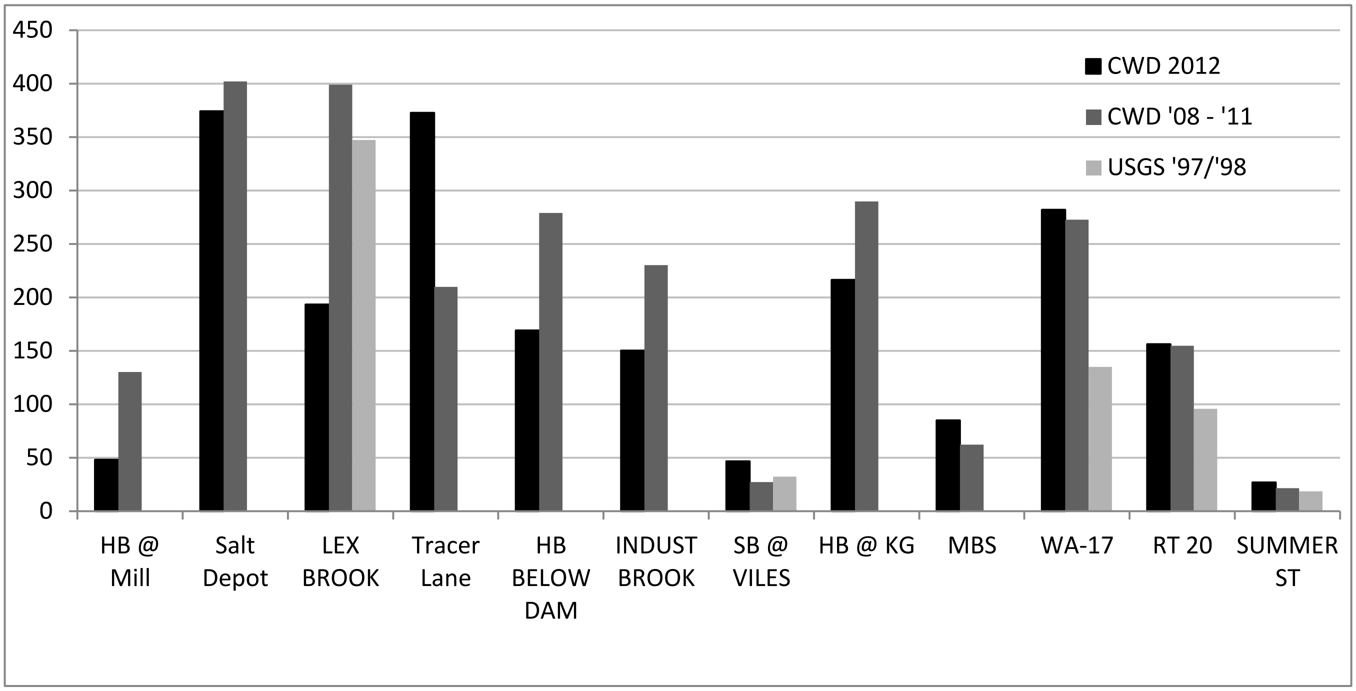


Figure 41: Primary Tributary Base flow Chloride Median Instantaneous Yields [kg/d/m2], 2012

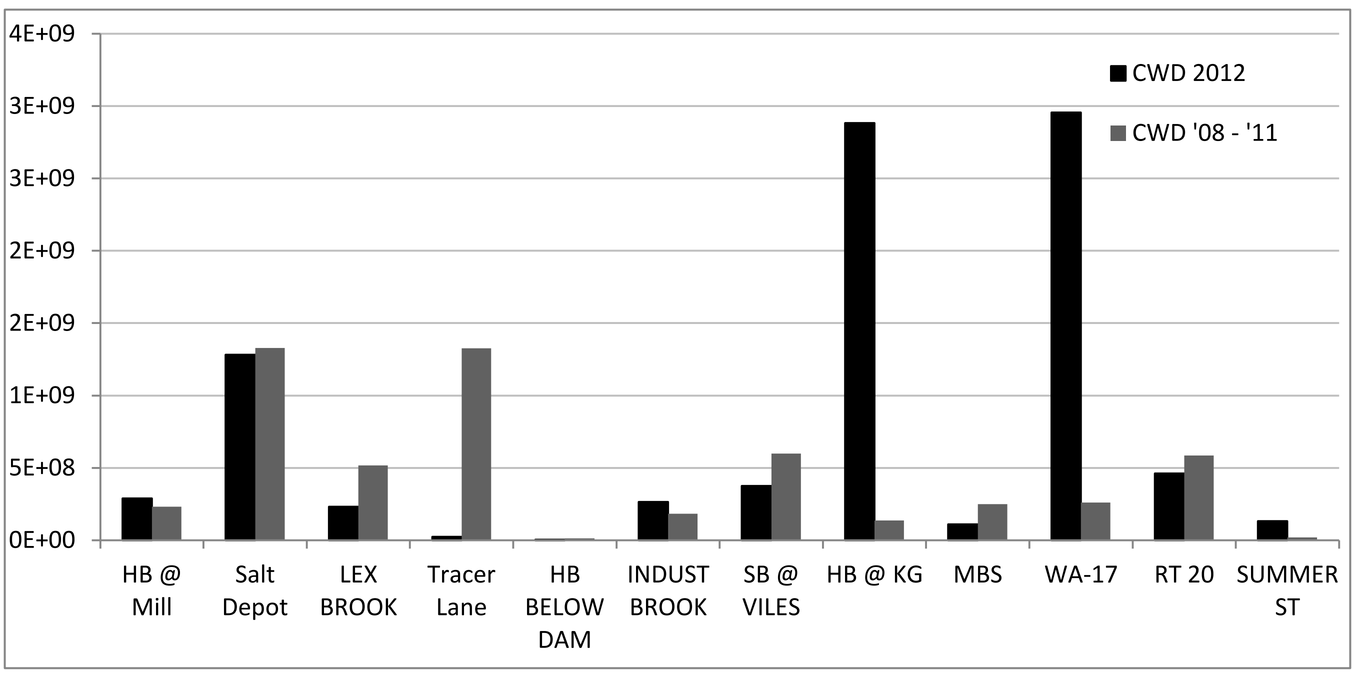


Figure 42: Primary Tributary Base flow *E.Coli* Median Instantaneous Yields [CFU/km2/d], 2012

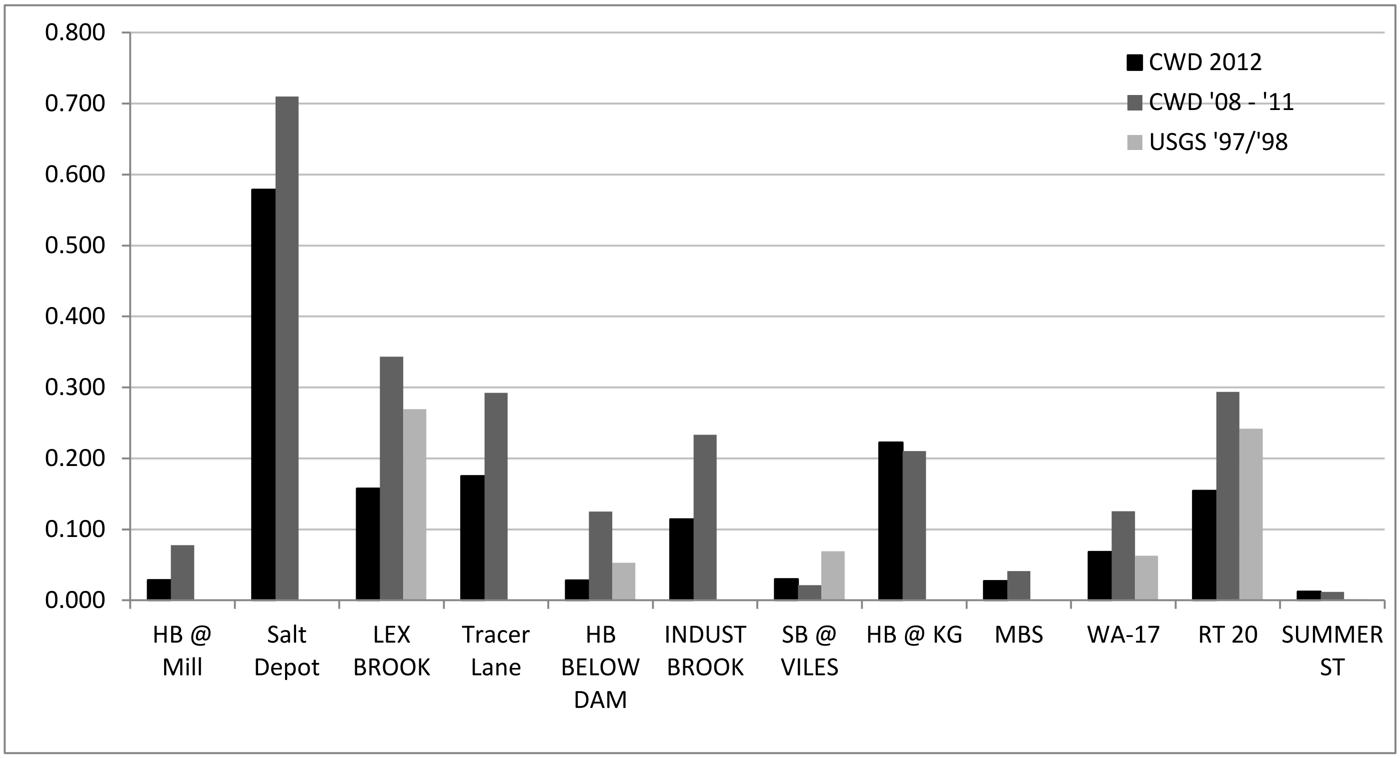


Figure 43: Primary Tributary Base flow Manganese Median Instantaneous Yields [kg/d/m^2], 2012

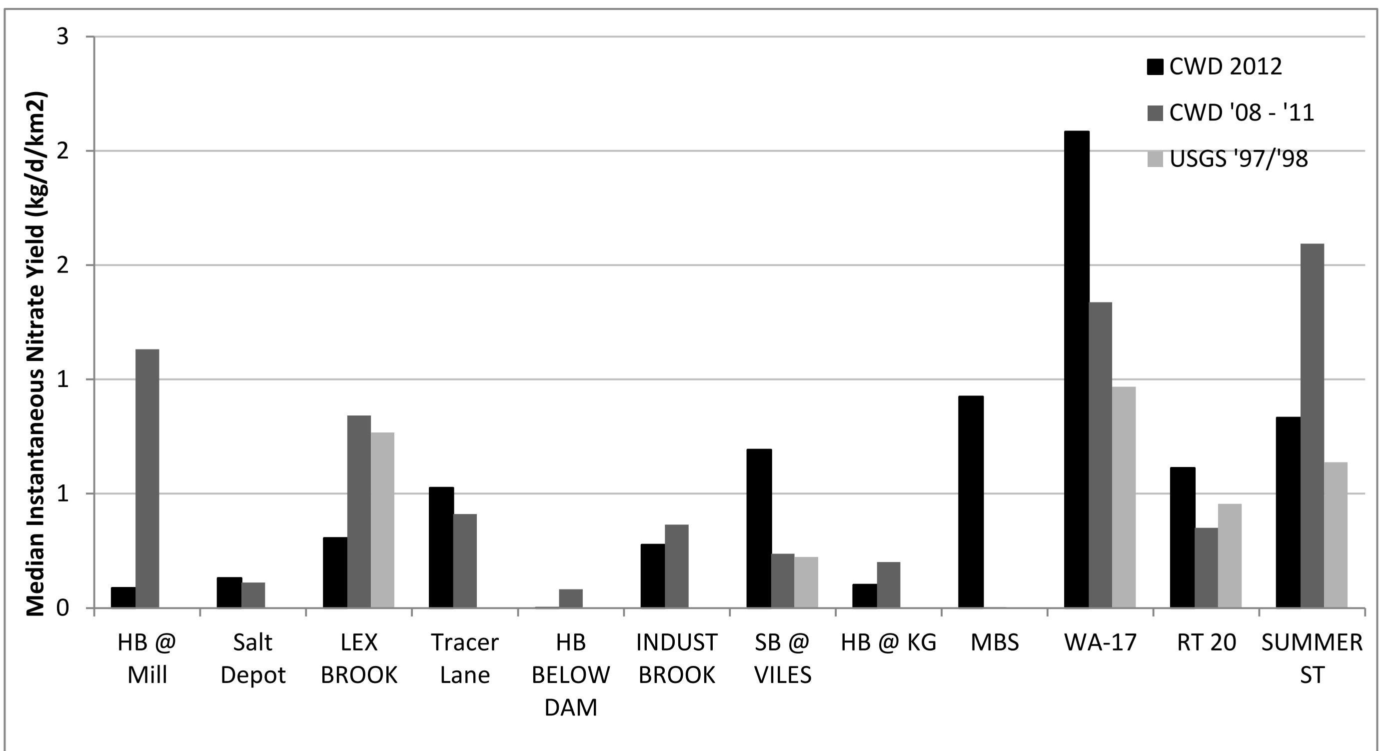


Figure 44: Primary Tributary Base flow Nitrate Median Instantaneous Yields [kg/d/m^2], 2012

Appendix C – Statistical Trend Analysis Method and Results

Statistical analysis was performed on time series data for each tributary site to determine the significance of trends in the concentrations of key parameters, using current and historic data sets compiled from CWD and various consultants. A variation of the Mann-Kendall test (as outlined in the USGS Statistical Methods Manual, Chapters 8 and 12) was used to test the significance of the trends. In this variation, the Pearson's r correlation coefficient was calculated from the ranks of the date-concentration data sets. Pearson's r on ranks was used as an alternative to Kendall's tau, which was unwieldy to compute using Excel for large data sets. The non-parametric approach was used instead of linear regression because normality of residuals is a requirement for hypothesis testing.

Trends were tested by calculating the Pearson's r correlation coefficient on the ranks of the data sets (also known as Spearman's rho). The ranks were calculated using excel in order of increasing time; the null hypothesis (no trend) was rejected when rho was significantly different from 0, as determined using the t-test. Spearman's rho was calculated using the equation

$$rho = \frac{\sum_{i=1}^{n}(Rx_i Ry_i) - n(\frac{n+1}{2})^2}{n(n^2-1)/12}$$

Where Rx_i is the rank of the dates and Ry_i is the rank of the concentrations. Since (n+1)/2 is the mean rank of both x and y, rho will be close to 0 when there is no trend in the ranks. To remove the effects that discharge may have on the parameters, the residuals from a LOWESS (Locally Weighted Scatterplot Smooth) of the concentrations was used to eliminate the effect. The LOWESS curve was calculated using the Excel add-on. P values were calculated using the TDIST excel function. A p-value < 0.05 was considered a significant trend and the null hypothesis (no trend) was rejected. P-values between 0.05 and 0.15 were considered weakly significant trends, and all others were considered to not be able to reject the null hypothesis (no trend). The direction of the trend (increase or decrease) was determined by the sign of the Pearson's r coefficient on ranks.

The results of the trend analysis are provided in Table 12.

Table 12: Primary Tributary Trend Results from LOWESS Smooth

	HB @ Mill St		Salt Depot		Lex Brook		Tracer Lane		HB Below		Industrial		SB @ Viles		HB @ KG		MBS		WA - 17		RT 20		Summer St	
Parameter	RT	p	RT	p	RT	p	RT	p	RT	p	RT	p	RT	p	RT	p	RT	p	RT	p	RT	p	RT	p
Na	0.33	0.02	-0.65	0.00	0.19	0.20	0.34	0.01	0.27	0.04	0.37	0.00	0.09	0.60	0.40	0.00	0.29	0.20	0.24	0.11	0.38	0.00	0.11	0.52
NO3/NO2	0.06	0.75	-0.05	0.74	-0.21	0.21	0.10	0.61	-0.27	0.13	-0.08	0.62	-0.11	0.55	-0.01	0.93	0.14	0.69	0.12	0.46	0.20	0.23	0.04	0.82
TKN	0.35	0.03	0.12	0.46	0.27	0.17	0.41	0.01	0.40	0.01	0.22	0.12	0.01	0.97	0.26	0.12	-0.21	0.41	0.04	0.85	0.23	0.15	-0.09	0.64
NH3	0.14	0.52	0.06	0.74	-0.10	0.61	0.20	0.26	0.12	0.60	0.11	0.48	-0.17	0.49	0.01	0.96	0.18	0.57	0.17	0.40	-0.12	0.55	0.30	0.26
SpC	0.14	0.32	0.24	0.09	0.07	0.63	0.23	0.09	0.15	0.27	0.28	0.03	-0.46	0.00	0.50	0.00	-0.42	0.04	0.14	0.32	0.36	0.00	0.03	0.86
Color	0.05	0.80	-0.04	0.84	0.24	0.15	-0.14	0.45	0.14	0.47	0.02	0.91	0.23	0.22	-0.12	0.51	0.18	0.45	0.04	0.83	0.12	0.46	0.01	0.95
Turb	0.11	0.59	-0.05	0.81	-0.17	0.39	0.29	0.11	-0.11	0.61	-0.03	0.82	-0.19	0.37	-0.08	0.65	-0.23	0.33	-0.26	0.17	-0.08	0.64	0.15	0.42
pH	0.09	0.51	0.30	0.04	0.15	0.30	-0.11	0.44	0.14	0.30	0.05	0.70	0.34	0.04	0.26	0.05	-0.12	0.59	0.19	0.19	0.18	0.17	0.19	0.25
Mn	0.00	1.00	0.19	0.28	0.13	0.46	0.43	0.01	0.09	0.56	0.16	0.30	-0.44	0.01	0.02	0.89	-0.64	0.01	-0.04	0.79	0.09	0.58	-0.16	0.39
Fecal	0.11	0.54	0.21	0.26	0.05	0.78	0.03	0.89	-0.14	0.48	0.00	0.98	-0.07	0.71	-0.21	0.25	-0.10	0.82	0.09	0.70	-0.20	0.28	-0.09	0.67
TP	0.08	0.63	-0.21	0.24	-0.05	0.77	0.09	0.61	0.18	0.40	-0.09	0.50	0.29	0.10	-0.05	0.76	0.18	0.47	0.14	0.48	0.02	0.91	0.28	0.09
Al	-0.14	0.45	-0.34	0.09	-0.29	0.14	0.07	0.73	-0.33	0.11	-0.04	0.83	-0.18	0.38	-0.18	0.35	-0.29	0.32	-0.06	0.79	0.00	0.99	-0.20	0.32

RT: Rank Transform

p: p-value

Appendix D – Hydrograph Separation Figures

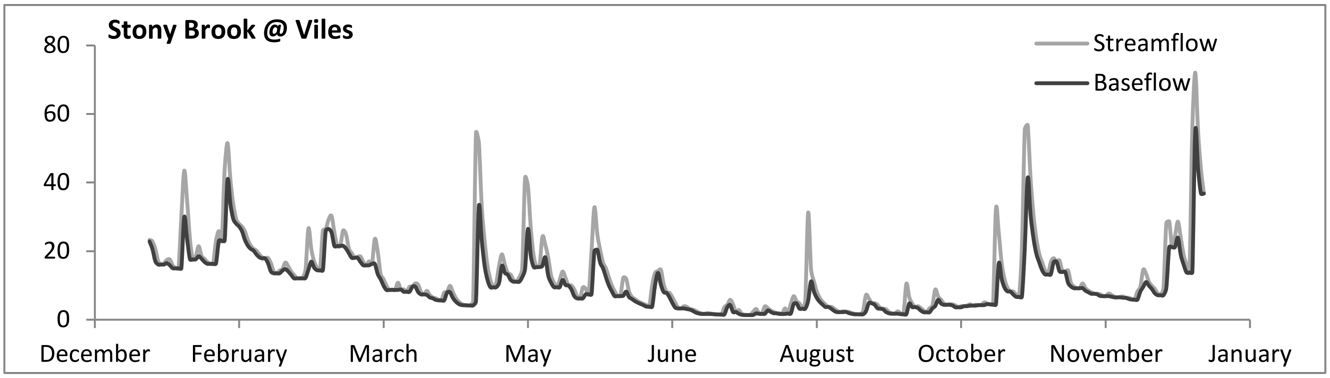


Figure 45 : Stony Brook @ Viles Hydrograph Baseflow – Stormflow Separation

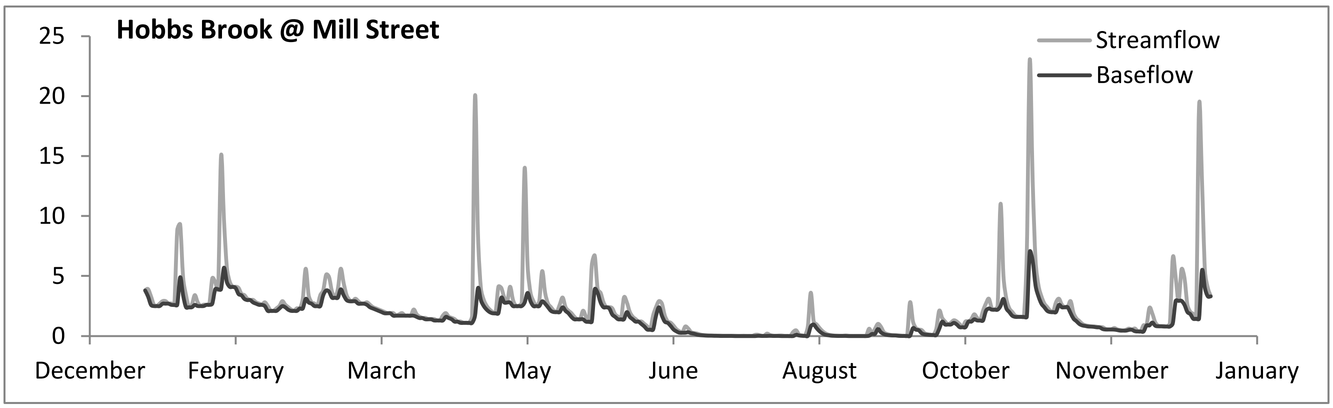


Figure 46: Hobbs Brook @ Mill Street Hydrograph Baseflow – Stormflow Separation

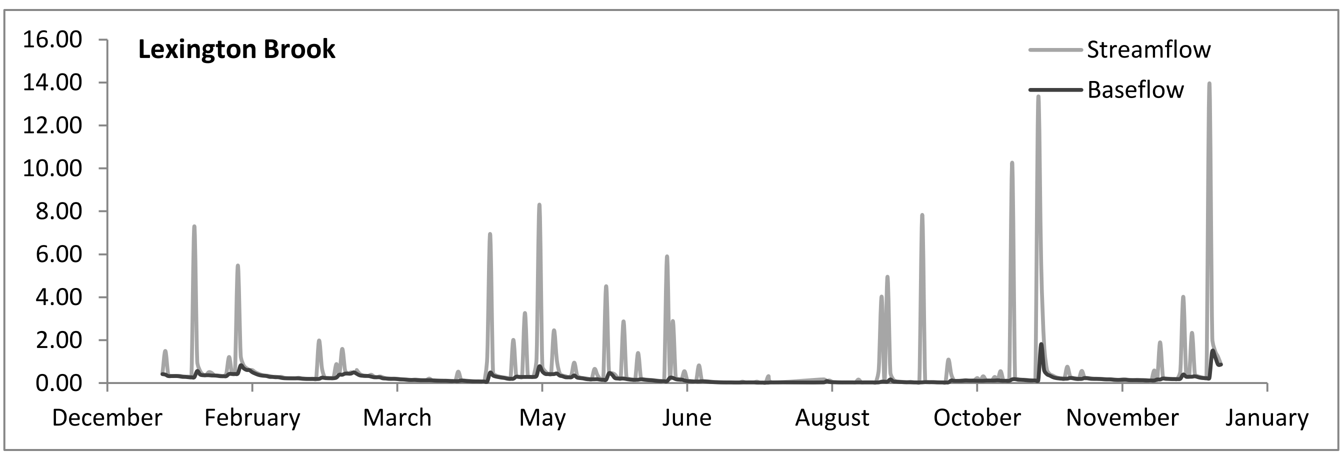


Figure 47: Lexington Brook Hydrograph Baseflow – Stormflow Separation

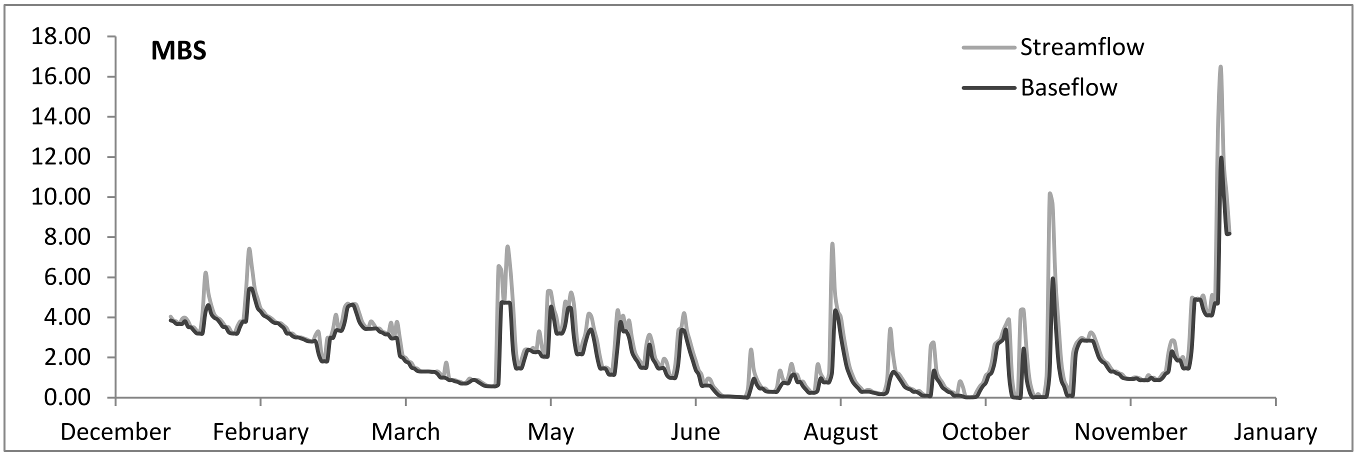


Figure 48: Mass Broken Stone Hydrograph Baseflow – Stormflow Separation

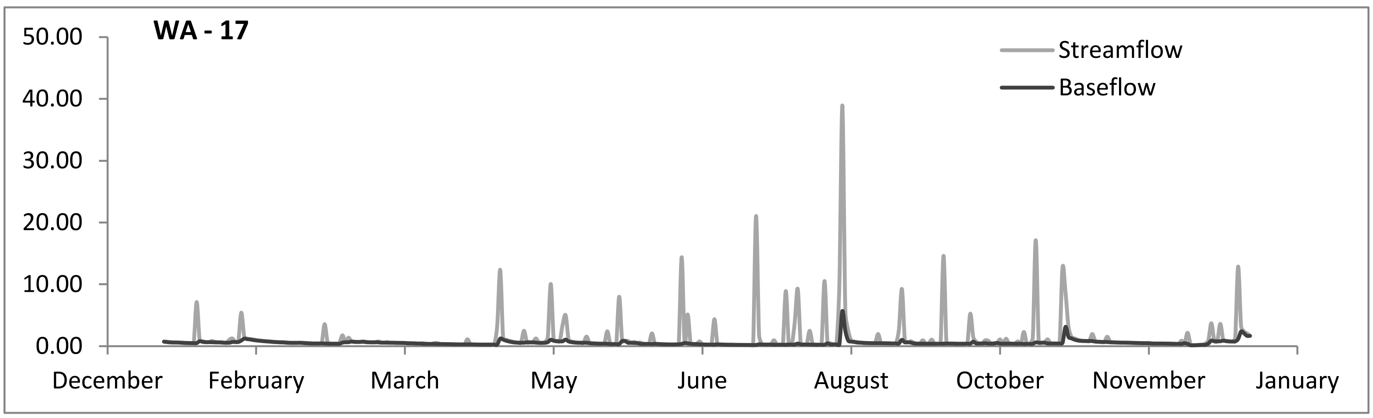


Figure 49: WA-17 Hydrograph Baseflow – Stormflow Separation

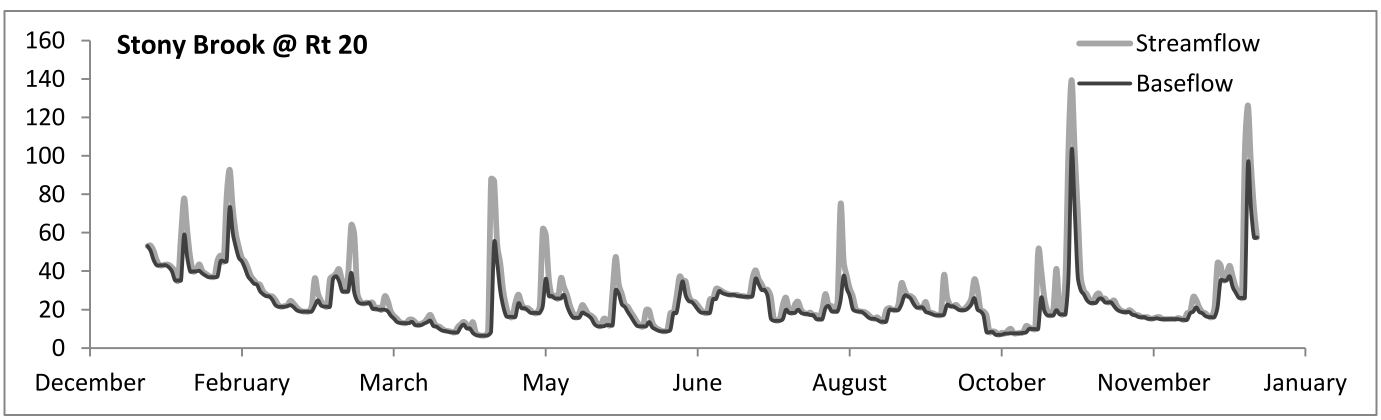


Figure 50: Stony Brook @ Route 20 Hydrograph Baseflow – Stormflow Separation

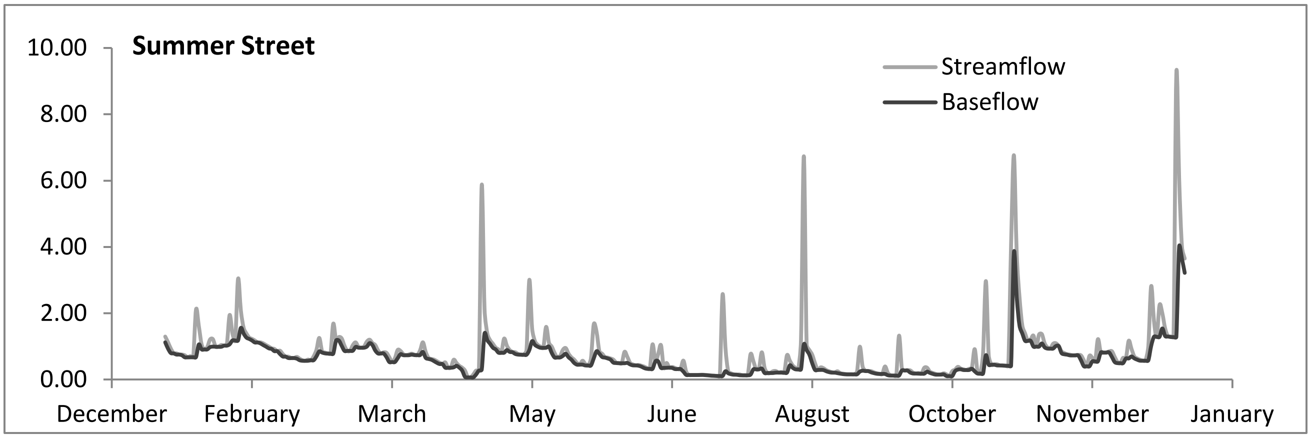


Figure 51: Summer Street Hydrograph Baseflow – Stormflow Separation

CWD 2012 Source Water Quality