City of Cambridge Water Department
2002-2003 Source Water Resources Assessment

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Table of Contents

Executive Summary

This report presents the results of an ongoing study conducted by the City of Cambridge, Massachusetts Water Department to assess reservoir and tributary-stream quality in the Cambridge drinking-water source area. It reports on the 2002/2003 sampling results and compares them to the 2000-2001 results.

Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs met Class "A" Surface Water Standards in Massachusetts for all parameters except for fecal coliform bacteria. Hobbs Brook Reservoir exceeded the State standard (20 cfu/100 ml) 12.5 percent of the sampling period; Stony Brook Reservoir exceeded this standard 21.4 percent of the sampling period; and Fresh Pond exceeded the standard 7 percent of the sampling period. All three reservoirs exhibited thermal and chemical stratification, despite artificial mixing by air hoses in Stony Brook and Fresh Pond Reservoirs.

Concentrations of sodium in the reservoirs were significantly higher (median concentration of approximately 70mg/L in Fresh Pond) than the amounts recommended by the U.S. environmental Protection agency for drinking-water sources (20mg/L). In the 2002/2003 sampling period, the Boston area experienced a relatively cold and wet winter with 77.7 inches of snow reported in the area, more than the previous 3 winters combined (National Weather Service). Urban runoff increases with precipitation and carries many of the ice-melting compounds, such as sodium and chloride, with it. Median sodium concentrations increased since the 2000/2001 study in all reservoirs except for Stony Brook Reservoir. The largest median sodium increase for this timeframe was observed in Fresh Pond Reservoir although of the three water bodies, it demonstrated the lowest sodium and chloride concentrations.

Long term, mean sodium levels in Fresh Pond have increased 93.5% since 1987. Sodium concentration increased 37.7% from 38.5 mg/l in 1987 to 53 mg/l in 1997. During the period when the plant was off-line (1998-2001), Fresh Pond received very little inflow from Stony Brook Reservoir, and sodium levels dropped back to 35 mg/l. The 2002-2003 level of 74.5 represents a 4.2% annual increase in sodium concentration.

Sodium levels in Hobbs Brook Reservoir show a similar trend. The 1985 Geotechnical Engineers, Inc. study determined a background level of 5 mg/l in the Hobbs Brook Reservoir watershed and a concentration of 43 mg/l in the reservoir itself. This has increased 203% to 130.5 mg/l (6.3% annually) in 2002-2003.

Consistent with previous studies, water quality in the reservoir system was generally lower in the upper basin of Hobbs Brook Reservoir, and improved as it flowed through the system via Stony Brook Reservoir in Weston to Fresh Pond, in Cambridge. The water quality during the 2002/2003 sampling period generally displayed higher levels of nutrients, major ions, and biological productivity, in the reservoirs than in the 2000/2001 study period.

Hobbs Brook and Stony Brook, the two principle streams draining the Cambridge drinking-water source area, differed in their relative contributions of many of the estimated constituent instantaneous yields (mg/km^2). The estimated instantaneous yield of fecal coliform bacteria was greater in Stony Brook at Kendal Green than in Hobbs Brook at Kendal Green. In the previous sampling period, Hobbs Brook had higher fecal coliform yields, however, during the 2002/2003 sampling period, Hobbs Brook experienced a significant decrease in fecal coliform yields. Fecal coliform yields at Stony Brook showed little change in both sampling periods.

In the previous sampling period, sodium yields at Hobbs Brook at Kendal Green were five times greater than sodium yields at Stony Brook at Kendal Green. In the 2002/2003 study, Stony Brook experienced a significant increase in sodium yields while sodium yields in Hobbs Brook decreased.

Tributaries that were identified in previous studies as problematic relative to their contributions of fecal coliform, manganese, sodium, nitrate, and phosphorous persisted throughout this study period. These tributaries, in particular were Salt Depot Brook (4410), Industrial Brook (4433), Tracer Lane (4420), and WA-17 (4455). Baseflow monitoring at these tributary sampling stations should continue in order to track long-term trends related to land use practices in these subbasins.

The mass balance for water in Hobbs Brook Reservoir indicated that the time required for complete flushing of the reservoir during the 2002/2003 study period were 7.5 months and 12 months respectively. The reservoir retained much of the sodium, chloride, nitrogen and phosphorus from the tributary streams and discharges from Routes 2 and 128. Waterfowl and precipitation were insignificant as sources of nitrogen to the reservoir but may have been important as sources of phosphorus. The estimated detention time of Stony Brook Reservoir was 12 days in 2002 and 7 days in 2003, with a total output to the Charles River at an estimated 20.5 billion gallons during the two-year study period. The detention time for Fresh Pond during this period was approximately 4 months and 3.4 months for 2002 and 2003 respectively.

For detailed analytical figures that describe the water quality data see Appendix A.

Purpose

The purpose of this report is to characterize the health of the source water for the City of Cambridge for the 24 month period ending in December 2003. The report uses data from the 2000-2001 Annual Report as a baseline for comparison with data collected during the reporting period. Obtaining long-term water quality information is essential in guiding watershed management practices. By understanding where certain weater 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 their watershed management practices and re-prioritize their efforts if necessary.

The following sections describe the results of the water quality analyses conducted in each tributary and reservoir and provides a comparison to the 2000-2001 Annual Report. For a detailed discussion on the methods and process overview of the water quality monitoring program, refer to Appendix B.

Introduction

This annual report describes the results of water-quality monitoring efforts during 2002-2003, as part of a long-term on-going study of the health and overall state of the City of Cambridge's drinking water supply. The water-quality monitoring program was designed by the U.S. Geological Survey (USGS), in cooperation with the Cambridge Water Department (CWD), and is based on several years of experience in water quality monitoring and the results of a 1998 assessment of reservoir and tributary-stream quality. The assessment, which was conducted jointly by the USGS and the CWD, included a detailed analysis of the drainage basin and the identification of subbasins within the drainage basin that are exporting disproportionate amounts of nonpoint pollutants from their subbasins to the reservoirs. This information then was used to help the design of the monitoring network which is now incorporated into CWD's long-term water quality monitoring program.

Figure 1: Study Area

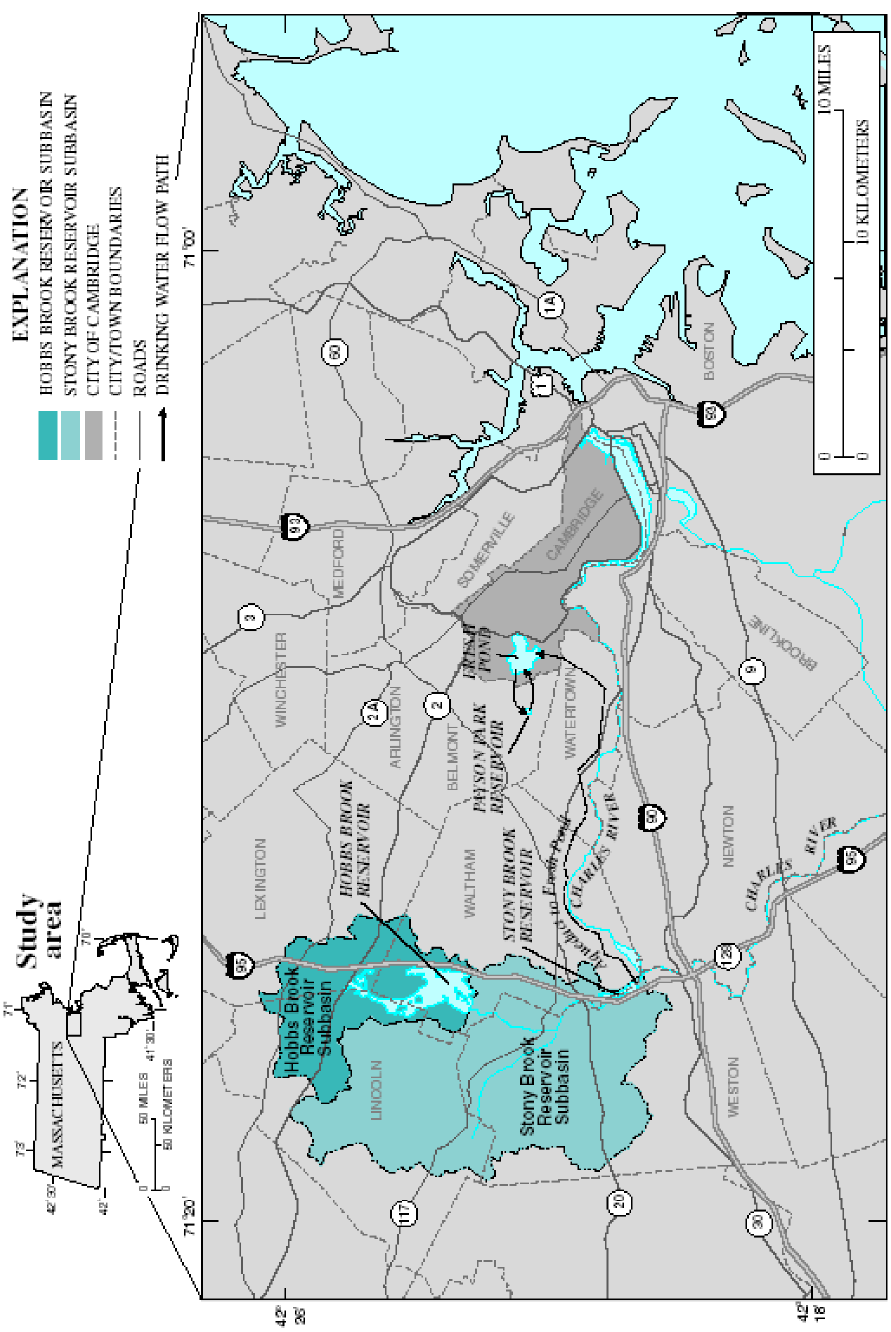
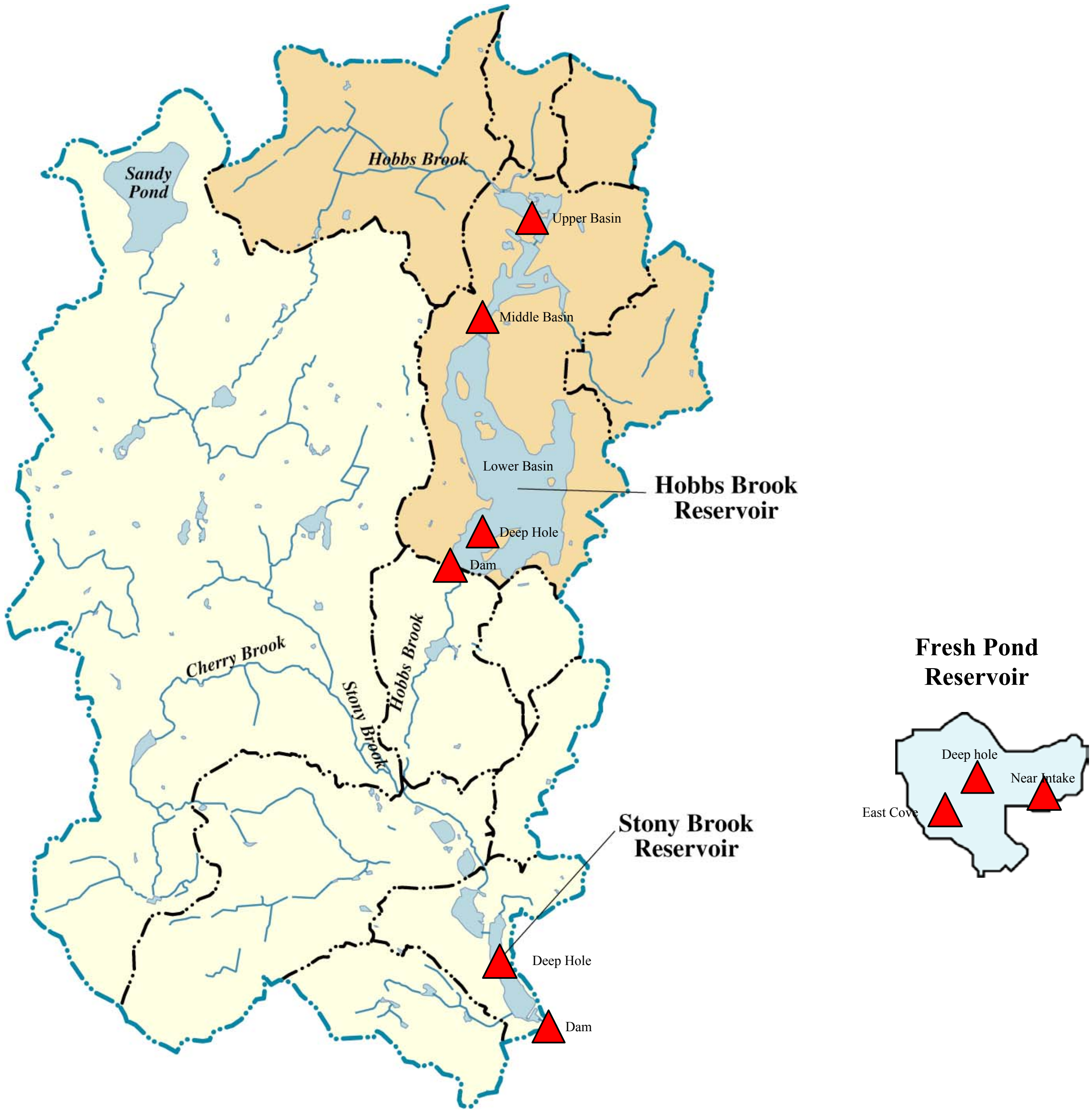


Figure 1. Location, extent, and components of the city of Cambridge drinking-water supply system, eastern Massachusetts.

Reservoir Water Quality

The following sections describe the physical, chemical, and biological changes observed in Hobbs Brook Reservoir, Stony Brook Reservoir, and Fresh Pond Reservoir over a two-year study period beginning in 2002.

Figure 2: Reservoir Sampling Stations



Hobbs Brook Reservoir

Hobbs Brook Reservoir is divided into three separate basins; the upper, middle, and lower basins were sampled 16 times during this study. Chlorophyll, nutrients, selected total metal samples and Secchi measurements were taken at the primary sampling station. Depth profiles of dissolved oxygen, pH, turbidity, temperature, and specific conductance, were made both at the primary sampling station, and at the secondary reservoir monitoring station where the gatehouse along Winter Street transfers water to Stony Brook Reservoir. Fecal coliform bacteria sampling was conducted during each visit to the secondary station.

A trophic state index (TSI – a numerical index indicating the degree of nutrient enrichment of a water body) for the lower basin was calculated from the chlorophyll-*a* concentrations and compared to the TSI values from the 2000-2001 Annual Report to determine general, long-term trends. Phytoplankton Chlorophyll-*a* concentrations, Secchi depth measurements, and overall calculated TSI for Hobbs Brook Reservoir is shown in Appendix-A, Figure 49 of this report. These water quality parameters are directly affected by nutrients in the water column and therefore provide good indicators of overall water quality.

The TSI for the upper and middle basins of Hobbs Brook Reservoir were less than that of the 2000/2001 study, while the lower basin's TSI value increased since that time. The upper basin of the reservoir was shown to be in the mesotrophic range during this study. The middle and lower basins were shown to be between the mesotrophic and the oligotrophic ranges. Appendix-A, Figure 49 depicts the trophic state of the reservoirs and the Class B waters in Fresh Pond Reservation.

The highest sodium and chloride concentrations measured in the reservoirs during this study period were in Hobbs Brook Reservoir, which is influenced by runoff from Route 2 and Interstate – 95. There was relatively little change in the sodium and chloride concentrations measured in the 2 studies. Compared to the 2000/2001 study, in Hobbs Brook Reservoir lower basin, the median sodium concentration rose from 121 mg/L to 124 mg/L and the median chloride concententraion rose from 200 mg/L to 225.9 mg/L.

In 2002, the water column at the deep hole in Hobbs Brook reservoir began to show signs of thermal and chemical stratification in May and was fully stratified by July, as shown in Appendix – A, Figures 4-9. By October, the water column was mixed with relatively uniform temperature and dissolved oxygen concentrations. In 2003, thermal and chemical stratification began in April. By July, Hobbs Brook was fully stratified and in October, the water column was mixed.

Stony Brook Reservoir

Water-column sampling at the deep hole in Stony Brook Reservoir began in March 2002 and continued through October 2003 on fourteen separate field visits. Chlorophyll, nutrient, and selected total metal samples as well as Secchi measurements were collected at the deep hole. Depth profiles of dissolved oxygen, pH, turbidity, temperature, and specific conductance, were made both at the deep hole, and at the gatehouse that transfers water to Fresh Pond Reservoir via the Stony Brook Conduit. Fecal coliform bacteria samples were also collected during each visit to the gatehouse.

Stony Brook Reservoir and its watershed exhibited lower sodium, chloride, and nutrient concentrations than those measured in Hobbs Brook Reservoir. There was relatively little change in the sodium and chloride concentrations measured in the 2 studies. Compared to the 2000/2001 study, in Stony Brook Reservoir, the median sodium concentration fell from 85 mg/L to 72 mg/L and the median chloride concentration fell from 150 mg/L to 139.25 mg/L (Appendix-A, Figure 25).

The Stony Brook Reservoir water column is artificially mixed with an aeration system, which experienced some operational difficulties during the study period but was operating during the entire duration of the study. In 2002, the water column at the deep hole in Stony Brook Reservoir began to show signs of stratification in April and was fully stratified by July. By October, the water column was mixed with relatively uniform temperature and dissolved oxygen concentrations. In 2003, the water column began to show signs of stratification in May and was fully stratified by July. By October, the water column was mixed and had relatively uniform temperature and dissolved oxygen concentrations.

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Fresh Pond Reservoir

Fresh Pond showed increases in some of the chemicals analyzed during the latter part of the previous water quality study. This observed phenomenon is largely attributable to the fact that Fresh Pond was isolated from the source water area while the treatment facility was under construction. This hydrologic isolation resulted in increased settling time and overall pristine water quality. Specific conductance values for example, generally increased throughout the 2000-2001 study period from 363 uS/cm in June, 2000 to 571 uS/cm in December, 2001. This can be attributed to influences from the up-stream source-water area during the winter of 2000-2001, and the fact that no water had been flowing into Fresh Pond from Stony Brook from 1998-to March of 2000 – resulting in low initial sodium concentrations (35 mg/L, April 17th, 2001 to 71.8 mg/L in April of 2003). During the 2002-2003 study period the trend of increased concentrations of analyzed chemicals continued as influences from the upstream, source-water area became more pronouced, then stabilized during normal operation of the supply.

Fresh Pond is artificially mixed with an aeration system. Isothermal conditions were observed during the summer months to a depth of approximately 35 feet at which point dissolved oxygen levels remained low (0.32 mg/L in late August, 2003) to just above the bottom of the reservoir at 50 feet. In 2002, the water column at the deep hole in Fresh Pond Reservoir began to show signs of stratification in April and was partially stratified by July. By October, the water column was mixed with relatively uniform temperature and dissolved oxygen concentrations. In 2003, the water column began to show signs of stratification in March and was partially stratified by July. Due to the operation of the aeration system, the water column at Fresh Pond never fully stratified. By October, the water column was mixed and had relatively uniform temperature and dissolved oxygen concentrations.

Generally, Fresh Pond had a lower chlorophyll concentration range and corresponding TSI value than that of the other two reservoirs, as shown in the TSI chart at the end of the water quality discussion of this report. This can be attributed to the fact that the reservoir also had relatively lower concentrations of nutrients than the other reservoirs in the system during the study period. The range of chlorophyll was much lower in Fresh Pond than that of the other two reservoirs.

Analytical results of samples collected in Fresh Pond were consistently low in concentrations of nutrients and selected total metals, with manganese, sodium, chloride being the most abundant of the constituents sampled with the greatest concentration measured in the 2000-2001 period being 160 mg/L and the same for the 2002-2003 period being 200 mg/L.

Over the two study periods there was a general increase in all measured constituents, resulting in overall greater biological productivity than the former study period as displayed in Appendix-A, Figure 24. As previously discussed, this general decrease in water quality is partially attributed to the influence of water from the source water area which was greater in the latter study period because of the City was operating its supply during all of this study period.

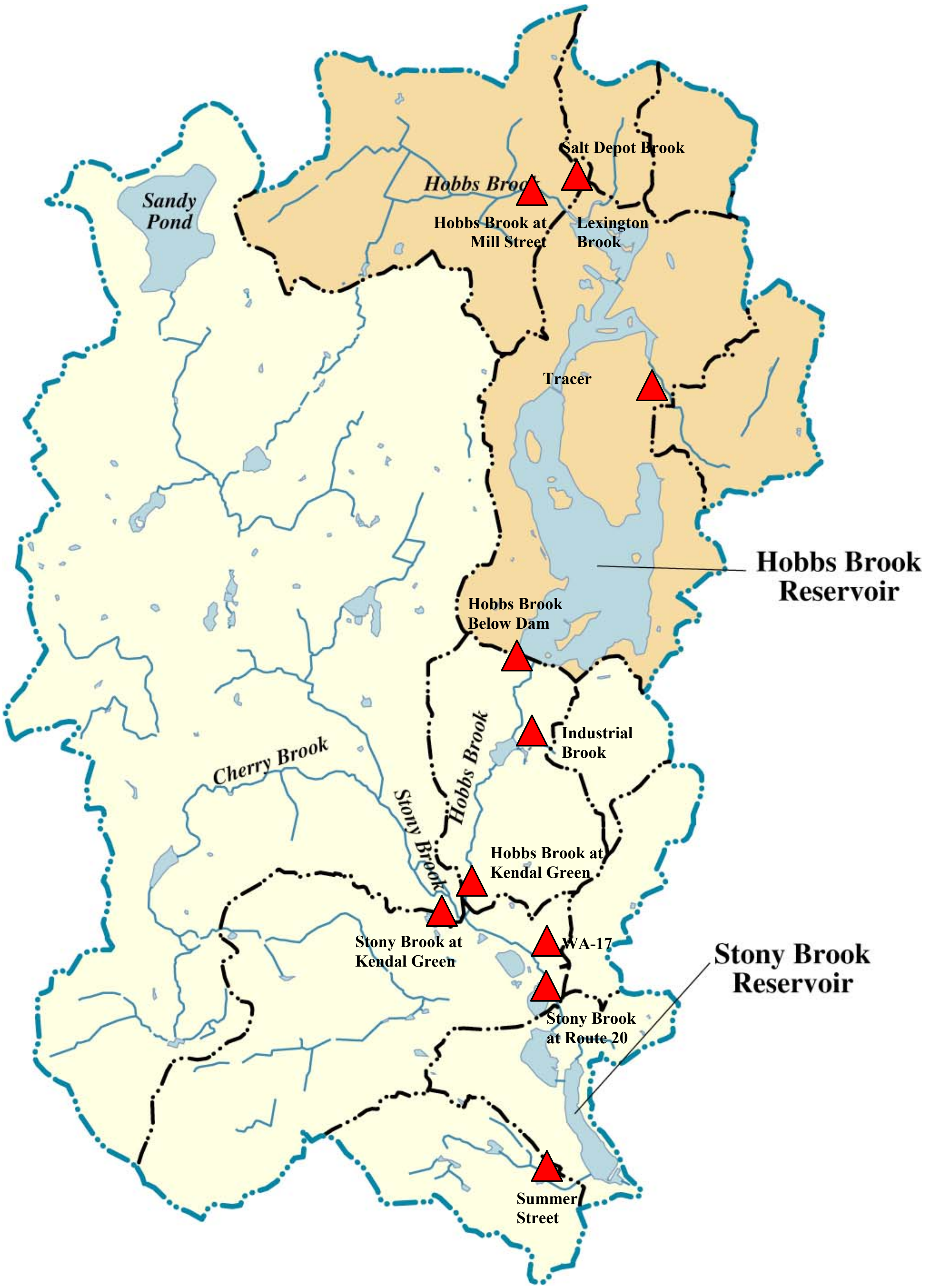
Tributary Water Quality

Sources of fecal coliform bacteria, dissolved sodium, dissolved chloride, nitrate nitrogen, total nitrogen, total phosphorus, dissolved iron, and dissolved manganese entering Hobbs Brook and Stony Brook Reservoirs were identified and constituent loads were quantified by calculating median instantaneous loads at key points in the drainage system over a one-year period. These load estimates then were normalized to the drainage areas of the subbasins resulting in instantaneous yields for each of the subbasins (defined by mg/km^2).

Discharge was measured at all tributary sampling stations either with current meters or based on measured stage-discharge relations. 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 2000 USGS report (Factors Affecting Reservoir and Stream Water Quality in the Cambridge, MA Drinking Water Source Area, USGS, Waldron, Marcus C., Bent, Gardner C, 1998).

All 11 primary tributary sampling sites (Figure 3) were sampled approximately every two months during the study period. Water samples for chemical analyses were collected at stream and reservoir sampling stations using clean-sampling protocols (Wilde and others, 1999) for all aspects of sample collection, preservation, and transport. Samples were collected either by the centroid dip technique or by combining volumes of water proportional to the amount of discharge at 10-12 equally spaced points along a stream cross section (Edwards and Glysson, 1999).

Figure 3: Primary Tributary Monitoring Stations



The following discussion highlights only the significant findings of tributary monitoring from north to south, throughout the watershed and provides a qualitative comparison of these findings with the 2001 Annual Report in order to observe any potential long-term trends in water quality. These findings relate to land use within each drainage area and implications for further study as well as watershed protection practices. Analyses results are displayed in the charts following this discussion.

Hobbs Brook at Mill Street (4405)

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 5.59 km^2, is by far the largest of the three. The subbasin is comprised of a large proportion of wetland and forested cover relative to the other tributaries in the basin.

Relative to the other tributary sampling stations, 4405 exhibited lower estimated yields (mg/km^2) of manganese, total phosphorus, total nitrogen, and sodium. Overall manganese, sodium, phosphorus, nitrogen and fecal coliform bacteria yields however, were slightly higher than those found in the 2000/2001 sampling period. Dissolved oxygen concentrations were shown to have slightly increased since 2000/2001, and the median concentration still remains above the State standard of 6 mg/L for Class-A water bodies.

Sodium yields, as with all tributaries sampled during this study, increased since the 2000/2001 study; this can possibly be attributed to the severity of the 2002/2003 winter and the application of de-icing compounds to the road surfaces. Compared to other stations, this station is not a major recipient of highway runoff, thus it displayed relatively low sodium concentrations, with the highest being 70 mg/L sampled in December 2003 (Appendix A, Figure 32). This is a significant increase from the previous study's high of 49 mg/L measured in March 2001.

Salt Depot Brook (4410)

This tributary has an estimated drainage area of 0.91 km^2 and by far had the highest yields of managanese and the second highest yields of fecal coliform of any of the tributary sampling stations. This station also had the third highest instantaneous sodium yields of the tributaries measured during this study. Instantaneous total nitrogen and phosphorus yields however, were relatively low compared to the other stations. Fecal coliform, total nitrogen, phosphorus, sodium, and manganese yields were all higher in the 2002/2003 study than they were in the 2000/2001 study (Appendix A, Figures 26-30).

High instantaneous sodium yields at this sampling station are consistent with upstream historical land uses of open salt storage piles associated with road de-icing operations. It is possible that over the years salt from these piles slowly migrated into the ground water and re-surfaces in the wetland that feeds this tributary. In addition, the percentage of floodplain alluvium in the subbasin is more than five times that of any other subbasin in the source area and this may account for the high median yields of phorsphorus and iron, since a high proportion of streamflow in the tributary enters as anoxic ground water rich in these constituents (USGS). Relatively high yeilds of fecal coliform bacteria may also be attributed to the wetland that contributes to this sampling station as wetlands typically provide habitat for an abundance of wildlife.

Lexington Brook (4415)

With a drainage area of 1.06 km^2, this station drains the second largest area in the subbasin and is fed by groundwater and direct discharges from State highway and road surfaces. An automated gaging station that continuously records temperature, stage, and specific conductance is located at this sampling station. 4415 measured by far the highest instantaneous sodium yields of any of the sampling stations as well as the second highest manganese yields. This station also saw a dramatic increase in sodium, manganese, nitrogen, and phosphorus yields from the previous study (Appendix A, Figures 26-30).

Tracer Lane (4420)

Unnamed Tributary 3 enters the middle basin of Hobbs Brook Reservoir and receives runoff from State Routes 2, 128, a commercial parking lot, and also drains a wetland area east of Route 128. Nitrate, sodium, manganese, and phosphorus all showed significant increases in the 2002/2003 study with only slight increases fecal coliform bacteria. All instantaneous yields measured, except for sodium, which was the second highest measured in the study, are comparable to the other sampling stations (Appendix A, Figures 26-30).

Hobbs Brook Below Dam (4430)

This station is directly downstream of the gatehouse that allows water to pass from Hobbs Brook Reservoir to Hobbs Brook continuing south to Stony Brook. Monitoring at this station in addition to taking open-water samples in the reservoir, provides futher information on the Reservoir water quality for which subsequent constituent loads and yields exiting the reservoir can be calculated and compared to the other subbasins in the system.

Because of dilution and attenuation in the reservoir, yields of most constituents were relatively low compared to other subbasins throughout the system. This station had the lowest yields of sodium, total nitrogen, manganese, and fecal coliform of any of the tribuatary monitoring stations. Hobbs Brook Below Dam also had the second lowest phosphorus yield of any of the stations. Compared to the 2000/2001 study, there were decreases in sodium, manganese, fecal coliform, and phosphorus in the 2002/2003 sampling period (Appendix A, Figures 26-30).

Industrial Brook (4433)

This station is on a small tributary that enters Hobbs Brook approximately 1km downstream from the dam (Figure 17). The subbasin drains a small forested wetland and has the greatest densities of commercial and industrial land use of any subbasin in the source area (USGS). This station saw an increase in sodium, total nitrogen, manganese, and fecal coliform during the 2002/2003 study. In comparison to the other stations, 4433 had similar yields of sodium, manganese, and fecal coliform. 4433 consistantly ranked around the middle of the group for each measurement. The only relatively low yields were for total nitrogen and phosphorus. Total nitrogen did, however, experience an increase since the previous study. Phosphorus, on the other hand, saw a significant decrease in 2002/2003 and is the only measurement taken for this station that followed that pattern (Appendix A, Figures 26-30).

Hobbs Brook at Kendal Green (4440)

Station 4440 is important because it integrates water and constituent loads from the entire Hobbs Brook subbasin. The station is located just upstream from the confluence of Hobbs Brook and Stony Brook and affords useful comparisons with monitoring data collected at the adjacent Stony Brook station.

This station exhibited decreases from the 2000/2001 study in fecal coliform bacteria and sodium. Instantaneous yields of both of these constituents ranked among the lowest in any of the tributary monitoring stations. Despite an increase in instantaneous yields of total nitrogen from the previous study, this parameter was relatively low compared to other tributary sampling stations. This station did see an increase in both manganese and phosphorus, which were comparable to those of the other tribuatary monitoring stations (Appendix A, Figures 26-30).

Stony Brook at Kendal Green (4390)

This station is located on Stony Brook just upstream from its confluence with Hobbs Brook. As such, water-quality data from the station integrates and represents conditions in a subbasin that comprises more than half of the total source-water area. Land use and land cover however, are appreciably different in the two integrator subbasins. The Stony Brook subbasin contains significantly less commercial and industrial land and a larger amount of low-density residential land use.

This station experienced an increase in sodium, total nitrogen, manganese, and phosphorus during the 2002/2003 sampling period. Dispite these increases, both sodium and manganese were relatively low compared to the other stations. Total nitrogen and phosphorus compared closely to values measured at the other tributary sampling stations. Stony Brook at Kendal Green experienced a slight decrease in instantaneous yields of fecal coliform bacteria compared to the 2000/2001 study, however, this station still ranks as having one of the highest fecal yields in any of the tributary monitoring stations.

WA-17 (4455)

This station discharges through a small wetland to Stony Brook approximately 0.7km upstream from Stony Brook Reservoir. The subbasin contains significant amounts of State and locally-maintained roads and commercial and industrial land use. Much of the lower part of the subbasin is paved and this part of the stream is routed through culverts that directly drain State Route 128 and the interchange connecting Routes 128 and 20.

This station saw a slight decrease in instantaneous yields of both managanese and fecal coliform. Both yields compared closely to the other sampling stations. Station 4455 the fourth highest sodium yield compared to the other stations. Similar to the 2000/2001 sampling period, this station had by far the highest total nitrogen yields in the 2002/2003 study. There was also a significant increase in manganese during the 2002/2003 samping period. In addition, this station experienced an increase in phosphorus, but was still relatively low compared to the other tributary monitoring stations (Appendix A, Figures 26-30).

Stony Brook at Route 20 (4460)

This station integrates the main part of the source area upstream from Stony Brook Reservoir. Most of the water that enters the Reservoir passes this station, thus it is one of the largest tributaries in the sampling network, contributing the highest volume of water to the reservoir. In both the 2000/2001 study and the 2002/2003 study, this station had the highest instantaneous yield of fecal coliform bacteria of any of the tribuatary monitoring stations. However, there was a significant decrease in fecal coliform yields in the 2002/2003 sampling period. Sodium, total nitrogen, manganese, and phosphorus all increased during this study. The increase in sodium was slight and this station still ranks as having one of the lowest sodium yields of the tributary stations measured. Both manganese and phosphorus compared closely to the other tributary monitoring stations. The instantaneous yields of total nitrogen were slightly higher and ranked as the fourth highest measured in the 2002/2003 sampling period.

Summer Street (4475)

This station is located on a small tributary in Weston that discharges directly into Stony Brook Reservoir near the intake at the Stony Brook Gatehouse. Land use in the subbasin differs from the others in that there is relatively little forest, no State-maintained roads, and no commercial or industrial development. The predominant land use in the subbasin is low density residential.

This station experienced increases in instantaneous yields of sodium, manganese, fecal coliform, total nitrogen, and phosphorus during the 2002/2003 sampling period. The largest increase observed was for total nitrogen, which ranks as the second highest measured during the 2002/2003 study. The increases of the other nutrients were less dramatic and the results were either slightly lower or comparable to the other sampling stations. Sodium yields slightly increased but remained low in comparison to the other stations. Managanese yields also slightly increased, yet remained the second lowest measured in the study. Fecal coliform and phosphorus yields were comparable to the other tribuatary monitoring stations (Appendix A, Figures 26-30).

Automated Monitoring

Automated water quality equipment is located at six tributary and reservoir locations throughout the source-water area. These stations measure stage, which is an indicator of stream flow, and specific conductance which is an indicator of sodium and chloride concentrations in the water. This report summarizes only currently available data from three of the stations. Figures 39 and 40 in Appendix A show the variable flow of water from Hobbs Brook Reservoir as adjustments were made to the sluice gate at this location. Maximum discharges for 2002 and 2003 were 26.8 million gallons a day (MG/D) or 43.3 cubic feet per second (cfs), and 23.8 MG/D (38.4 cfs) respectively. Peak discharges occurred in mid September in 2002 and mid October 2003. Minimum and Maximum specific conductance levels were 737.4 uS and 953.3 uS for 2002 and 660.00 uS and 1113.96 uS for 2003 respectively. Specific conductance peaks occurred in mid May of 2002 and late March of 2003, while troughs occurred in January for both years (Appendix A, Figures 39-40).

At the Stony Brook Reservoir gaging station located in the Stony Brook Gatehouse, maximum discharges to the Charles River in 2002 and 2003 were 55.41 MG/D (89.38 cfs) and 86 MG/D (138.88 cfs) respectively. Peak discharges in 2002 were observed in September, and for 2003 were observed in April. Specific conductivity measured at this location shows a peak in late August through October, with a steep drop-off in November. Minimum and maximum specific conductance values varied little during the study period with a high of approximately 850uS and a low of approximately 350uS (Appendix-A, Figures 41-42).

Automated data for Stony Brook unnamed tributary WA-17 located at the interchange of Routes 20 and I-95 (Appendix-A, Figures 43-44) shows sharp spikes in specific conductance during the winter months; maximum levels in 2002 and 2003 are 67127.09uS and 15850uS respectively, during periods of heavy winter runoff from treated road surfaces. Peak discharges in 2002 and 2003 are 3.4 MG/D (5.6 cfs) and 6.64 MG/D (10.72 cfs) respectively.

Wet Weather Monitoring

Samples analyzed for nutrients, major ions, and dissolved selected metals were collected during one to three storm events throughout the year at several monitoring stations that were identified in previous studies as recipient sites for urban runoff. Event sample collection was conducted in January, and October of 2002, and December of 2003. Instantaneous yields of several constituents that were sampled during these storms were compared to those collected during baseflow conditions. For almost all parameters analyzed, yields of measured constituents were much higher during storms. The two most extreme examples were fecal coliform bacteria and sodium (Appendix-A, Figures 36-38). However, nutrients and metals (e.g. sodium and manganese) are also mobilized during storms and enter the tributaries via surface water runoff from impervious, developed surface areas throughout the watershed. These data illustrate the importance of a detailed storm water monitoring program that will provide extensive characterization of how storms affect water quality and how watershed management practices should be directed in order to mitigate some of these storm water quality impacts.

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. Each of the ponds abuts the Cambridge Municipal Golf Course which is technically part of the Fresh Pond Reservation. These Ponds are considered to be an important component of the ecosystem that protects the water quality in Fresh Pond Reservoir. Under the Massachusetts State regulations, these ponds are considered to be Class B water bodies, thus that they are meant to support primary contact recreation, and are not considered to be direclty part of the drinking water supply. There are no surface water connections between Fresh Pond Reservoir and any of these ponds, however the potential exists for groundwater communication between them. Baseline data is collected in order to determine the existing conditions in each pond, how these conditions are changing over time, and how the ponds should be managed in the future in order to optimize the health of each ecosystem with the overall goal of protecting water quality in Fresh Pond Reservoir.

The same techniques that were applied to limnological monitoring of the reservoirs were also used for monitoring of these ponds, and the same analyses on water quality were conducted in order to begin the annual collection of baseline water quality data. These ponds however, are physically, chemically, and ecologically different from any of the reservoirs in the drinking water supply. The average depth in the ponds is approximately 6 feet. Water quality monitoring was conducted on May 15th, July 10th, August 5th, in 2002; and May 6th, July 23rd, September 8th, and October 16th in 2003.

Figures 45-48 in Appendix-A depict the range of constintuent concentrations measured in sample analysis from each pond on the Fresh Pond Reservation. Black's Nook showed the highest median concentration of fecal coliform bacteria of the three ponds analyzed, with North Pond showing the second highest. This may be a result of the habitat value of these two ponds above that of Little Fresh Pond. North Pond and Black's Nook in particular, are protected with surrounding trees and provide ideal aquatic habitat for mammals and birds. This may be the cause of relatively higher fecal concentration values.

Black's Nook also displayed the highest orthophosphate median concentration throughout the three ponds. Birds were identified in the 1998 USGS study as a potential source of orthophosphate in the watershed, thus Black's Nook, offering the most habitat of the three ponds, might attribute it's elevated nutrients to this. Past golf course practices may have also had an impact on water quality in the pond. Little Fresh Pond displayed the highest nitrate yields which may be attributed to the adjacent golf course – of the three ponds, Little Fresh is in the closest proximity to actively maintained turf grass. Little Fresh Pond also had the highest sodium concentrations of the three water bodies.

Little Fresh Pond also had the highest chlorophyll concentrations and associated TSI value, indicating that the greatest algal productivity of the three water bodies was observed in this pond. Black's Nook and North Pond, although had lower chlorophyll values, were choked with aquatic weeds during much of the growing season thus although sample results may not indicate an advanced eutrophic state in these ponds, they exhibit the typical over-production of biomass associated with the eutrophication process. Lower chlorophyll yields in Black's Nook and Little Fresh may be a result of other aquatic weeds blocking sunlight or temporarily up-taking nutrients available in the water column, limiting the growth of free-floating algae.

Figure 49 in Appendix-A displays the calculated trophic state indices for the drinking water supply and for the water bodies at Fresh Pond Reservation. The figure shows the apparent cascade effect that is inherent in the water supply, in which contaminants sequentially settle out of the water column before passing to the next reservoir resulting in low nutrient yields in Fresh Pond which allows the pond to remain oligotrophic, which is the desired biological state for a water supply.

With the exception of Stony Brook Reservoir, whose trophic state did not significantly change since the previous study, all other reservoirs displayed either a lower or higher trophic state value. Although the upper and middle basins of Hobbs Brook Reservoir portrayed a lower TSI value than the previous study, the lower basin of the reseroir, and Fresh Pond Reservoir both displayed a higher value indicating slightly more biological productivity than the previous years.

Special Water Quality Investigations

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

Illicit Discharge in Waltham

Data collected at the sewage discharge location were shared with the City of Waltham who responded with investigating the infrastructure in the immediate area. An ongoing effort is underway to rectify this situation, caused by a leaking municipal sewer line. Until this issue is completely resolved, sampling at this site for fecal coliform bacteria will continue (see Appendix-A, Table 2).

Water Balance Discussion

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 water supply management decisions.

Hobbs Brook Reservoir

The water balance determined for Hobbs Brook Reservoir during water years 2002 and 2003 can be considered a generalized approximation of the overall water availability. At the station immediately downstream of Hobbs Brook Reservoir, an approximate 1.59 billion gallons of outflow from the reservoir was measured in 2002. This volume is less than the estimated total storage capacity of the reservoir which is 2.497 billion gallons. The hydraulic detention time can be defined as the time it would take for the reservoir to empty out if all inputs of water to the reservoir ceased. Dividing the total estimated reservoir volume by the total estimated reservoir outflow produces a total estimated detention time of 0.63 year (just over 7.5 months) for 2002 (compared to 10 months for 2001). The total measured precipitation for this timeframe was 35.11 inches.

During the 2003 water year (October to September), the total volume of outflowing water from Hobbs Brook Reservoir was 2.4 billion gallons, roughly the equivalent of the estimated storage capacity for the reservoir, resulting in roughly a one-year retention time. This year brought a total of 46.77 inches of precipitation to this monitoring station, approximately 10 inches above the previous year's total.

Stony Brook Reservoir

Inputs to Stony Brook Reservoir were contributed mostly by its watershed and partially from the Hobbs Brook Reservoir. Outlfow from the Cambridge source water area to the Charles River was estimated using the gaging station located at the Stony Brook Gatehouse. The total outflow to the Charles for water year 2002 was 2.5 billion gallons (compared to 6.425 billion gallons for the previous year), significantly greater than the total estimated reservoir capacity of 255 million gallons. This can be attributed to the large watershed area that drains the relatively small Stony Brook Reservoir. In addition to the volume of water that passes through the overflow structure to the Charles River, the sluice gates to the gatehouse were opened to allow water into Fresh Pond in Cambridge, in order to meet demand for water in the City.

The best estimate of water sent to Cambridge from Stony Brook Reservoir is based on the annual water usage from the treatment plant which was 4.56 billion gallons for 2002. This should be added to the 2.5 billion gallons flowed to the Charles River in order to determine total output from the source water area. Based on these assumptions, total output from Stony Brook Reservoir is 7.06 billion gallons. Using this value, the total estimated detention time in Stony Brook Reservoir was 0.036 years, or approximately 12 days for 2002 (which is close to the estimated 10 days for the previous year). The total amount of precipitation measured at this station during water year 2002 was incomplete due to the construction of the station at this location during part of the study period.

During the 2003 period, a total estimated 7.6 billion gallons of water was discharged to the Charles River from Stony Brook Reservoir. In addition to this quantity, a total estimated 5.3 billion gallons was used by the treatment plant. Thus, a total estimated 12.9 billion gallons of water flowed from the watershed area during this period. With this estimated flow quantity, total estimated flushing time for Stony Brook Reservoir was approximately seven days. A total of 49.32 inches of precipitation fell at the Stony Brook monitoring station during the 2003 water year.

Fresh Pond

With 4.56 billion gallons as total estimated output from Fresh Pond to the treatment plant, the total estimated detention time of Fresh Pond was 0.33 years or close to four months for water year 2002 (compared to the estimated 6 months for the previous year, when the treatment plant was partially off-line). In 2003, the total estimated water used by the treatment plant was 5.3 billion gallons, thus the detention time during this period was an estimated 3.4 months.

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Glossary

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

Anoxic—The absence of oxygen; anaerobic.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Hypoxic—The near absence of oxygen.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix A – Analytical Figures

Thermal Profiles and Figures for Hobbs Brook Reservoir

Figure 4: Profile at the Deep Hole Hobbs Brook Reservoir on May 8, 2002

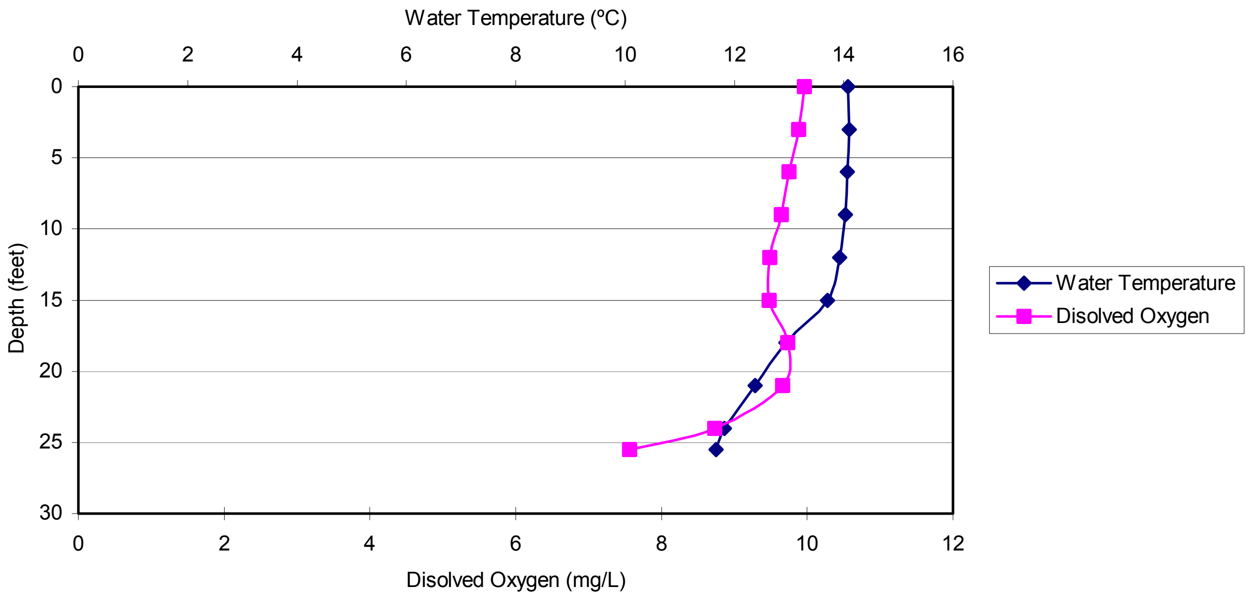


Figure 5: Profile at the Deep Hole in the Hobbs Brook Reservoir on July 17, 2002

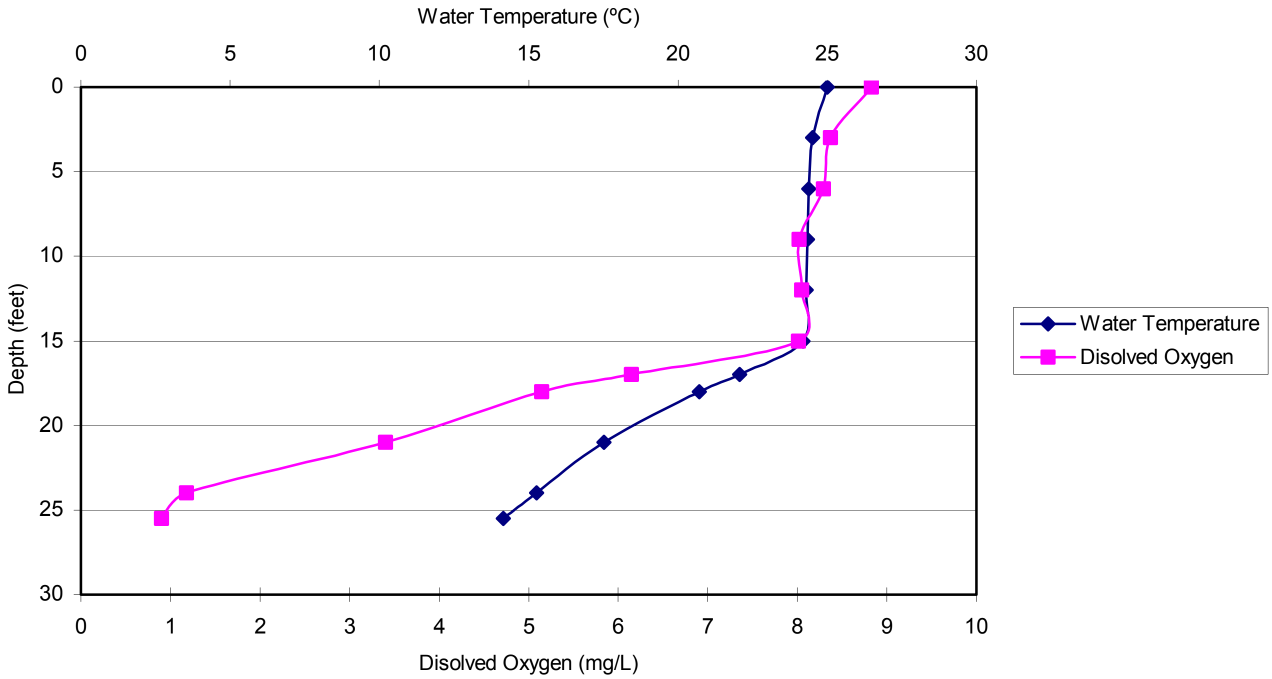


Figure 6: Profile at the Deep Hole in the Hobbs Brook Reservoir on October 2, 2002

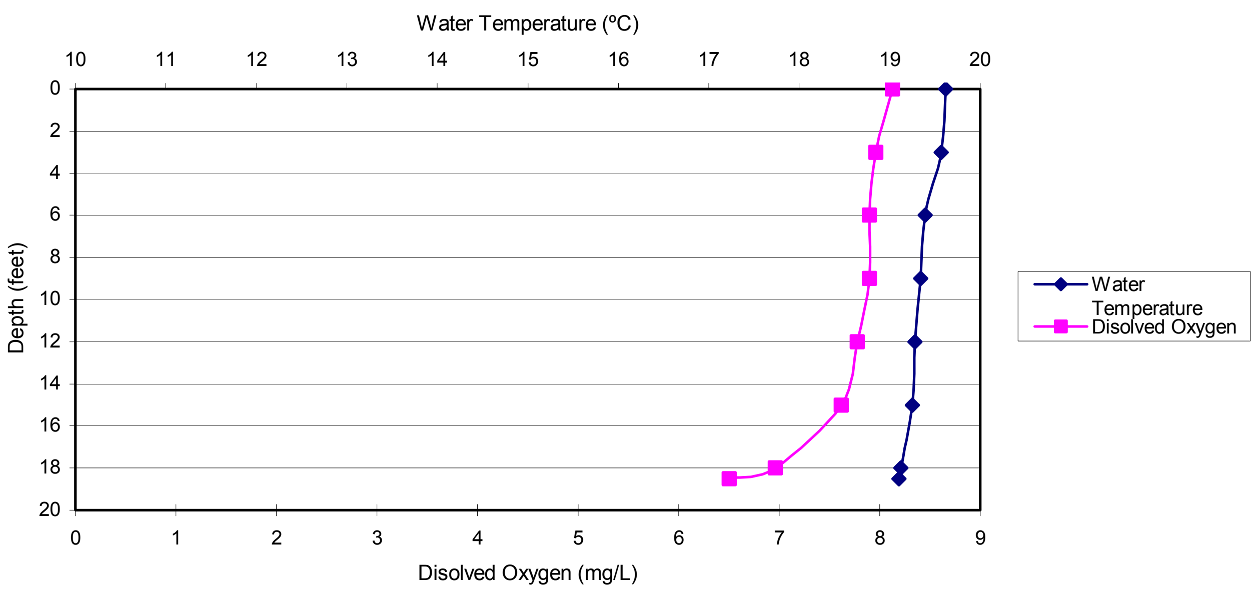


Figure 7: Profile at the Deep Hole in the Hobbs Brook Reservoir on April 30, 2003

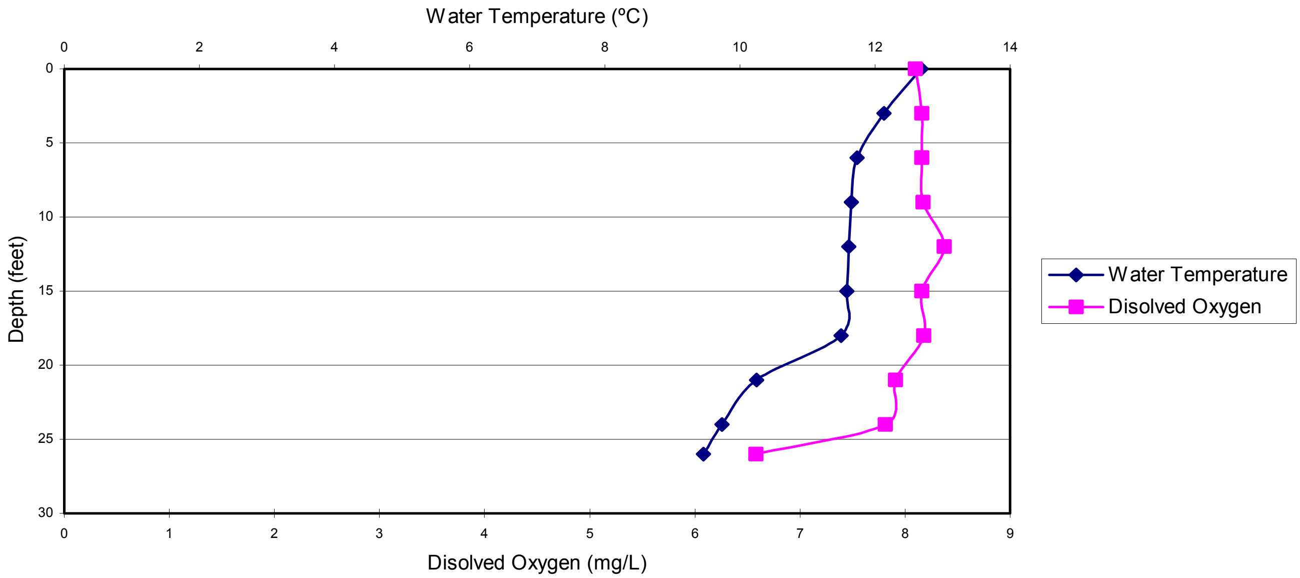


Figure 8: Profile at the Deep Hole in the Hobbs Brook Reservoir on July 10, 2003

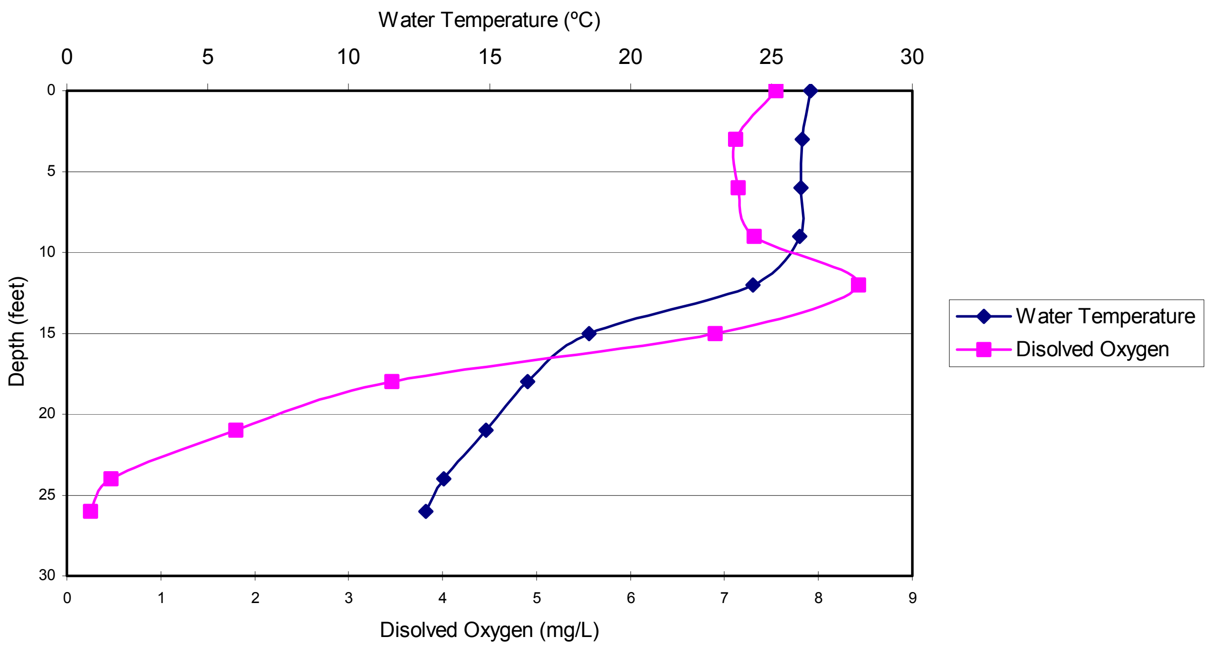


Figure 9: Profile at the Deep Hole in the Hobbs Brook Reservoir on October 9, 2003

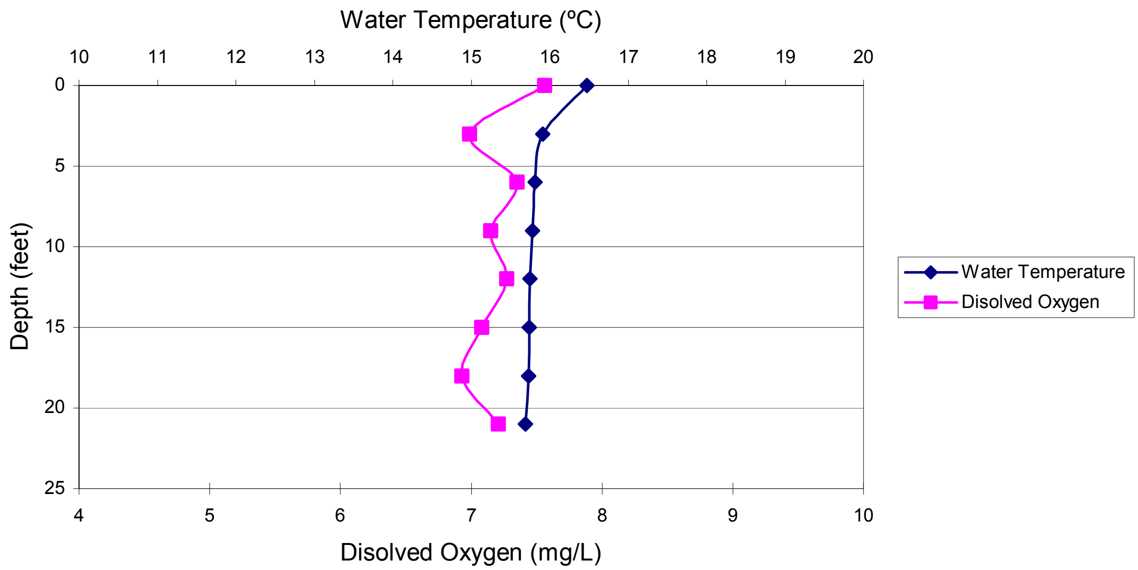
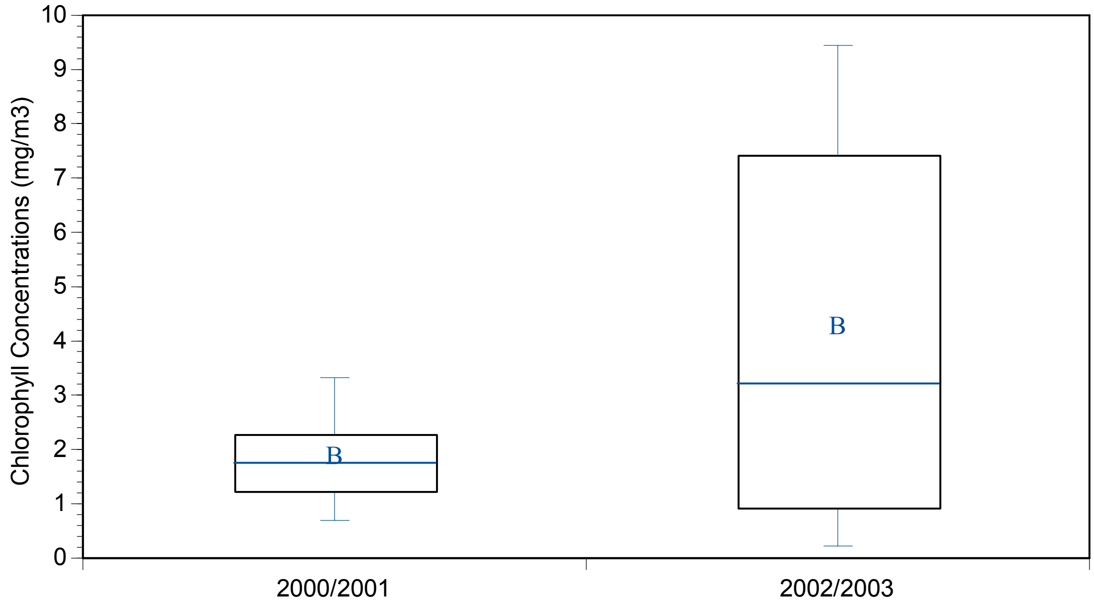
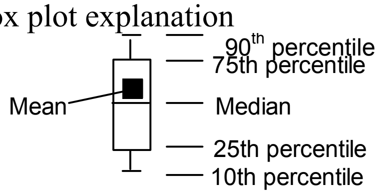


Figure 10: Chlorophyll Comparisons for Hobbs Brook Reservoir at Deep Hole for 2000/2001 and 2002/2003



Box plot explanation



Thermal Profiles and Figures for Stony Brook Reservoir

Figure 11: Profile at the Deep Hole in Stony Brook Reservoir on April 7, 2002

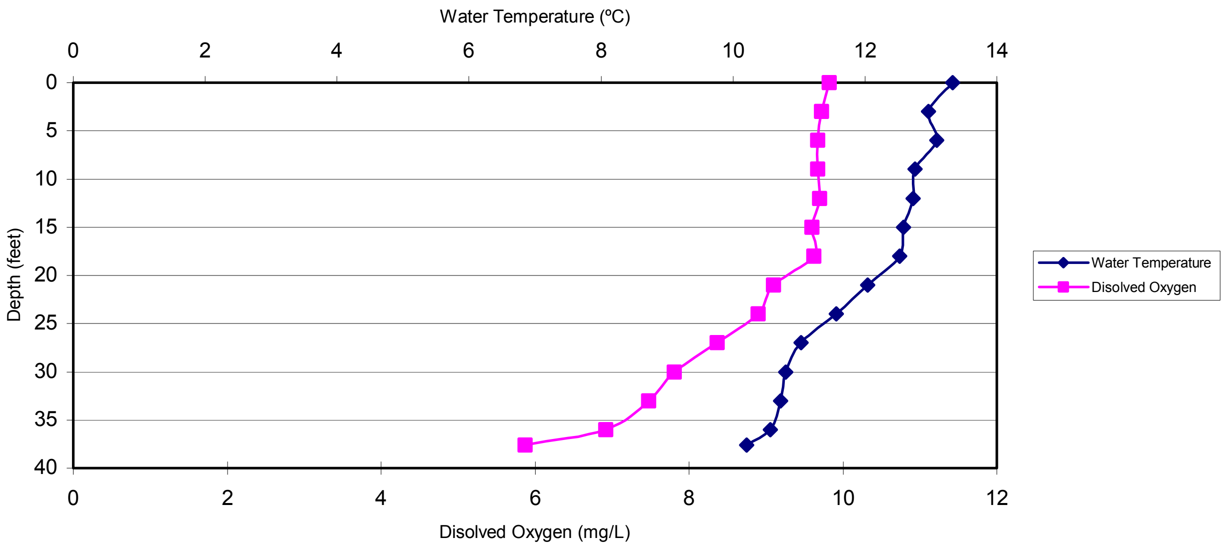


Figure 12: Profile at the Deep Hole in Stony Brook Reservoir on July 18, 2002

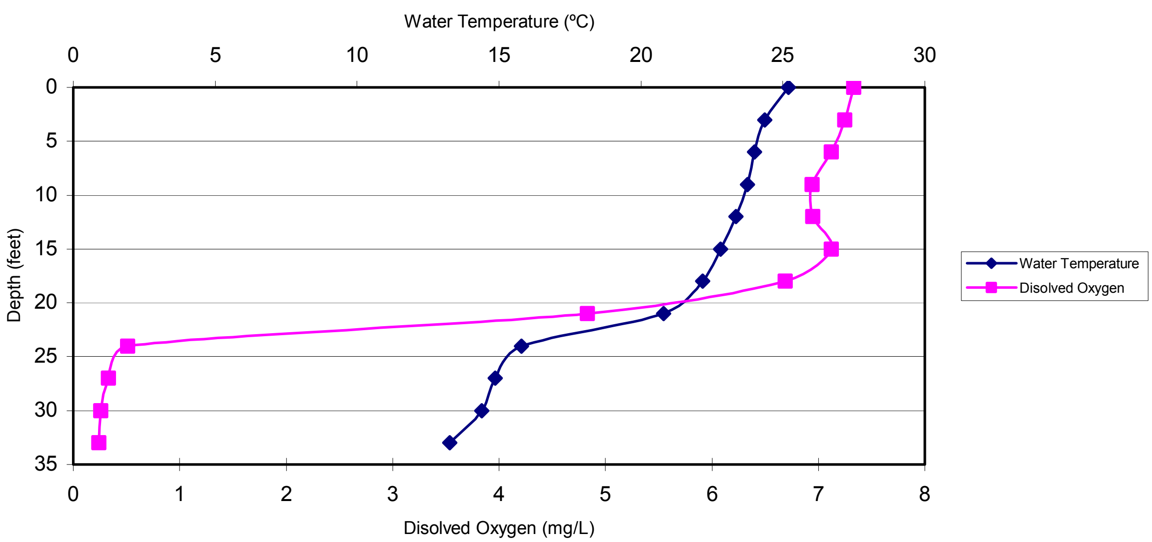


Figure 13: Profile at the Deep Hole in Stony Brook Reservoir on October 3, 2002

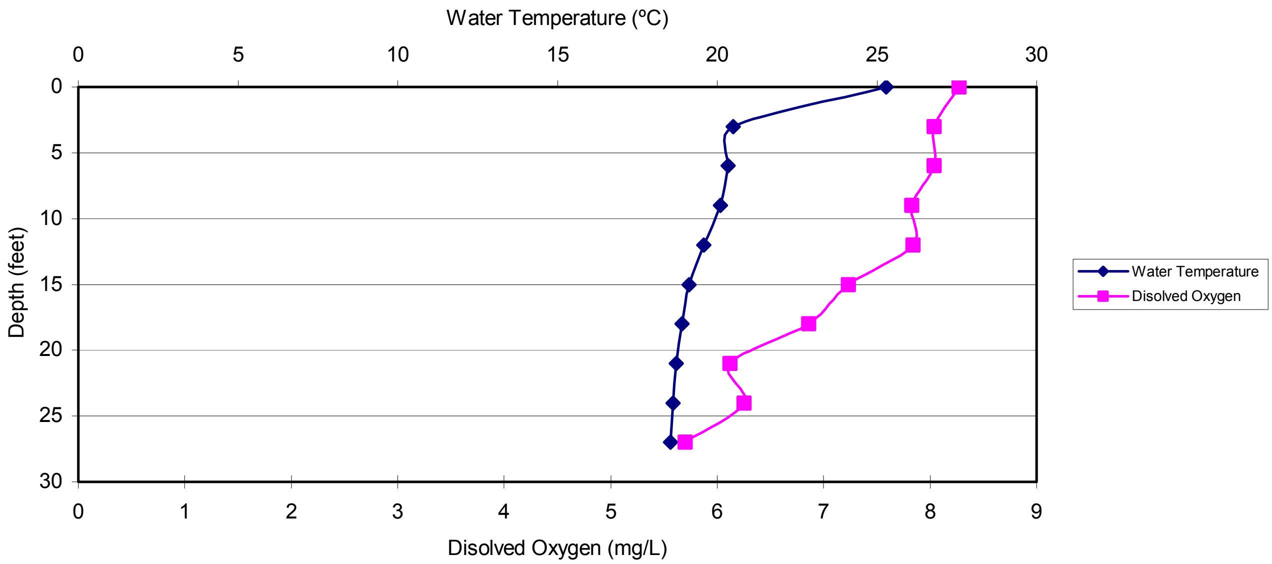


Figure 14: Profile at the Deep Hole in Stony Brook Reservoir on May 1, 2003

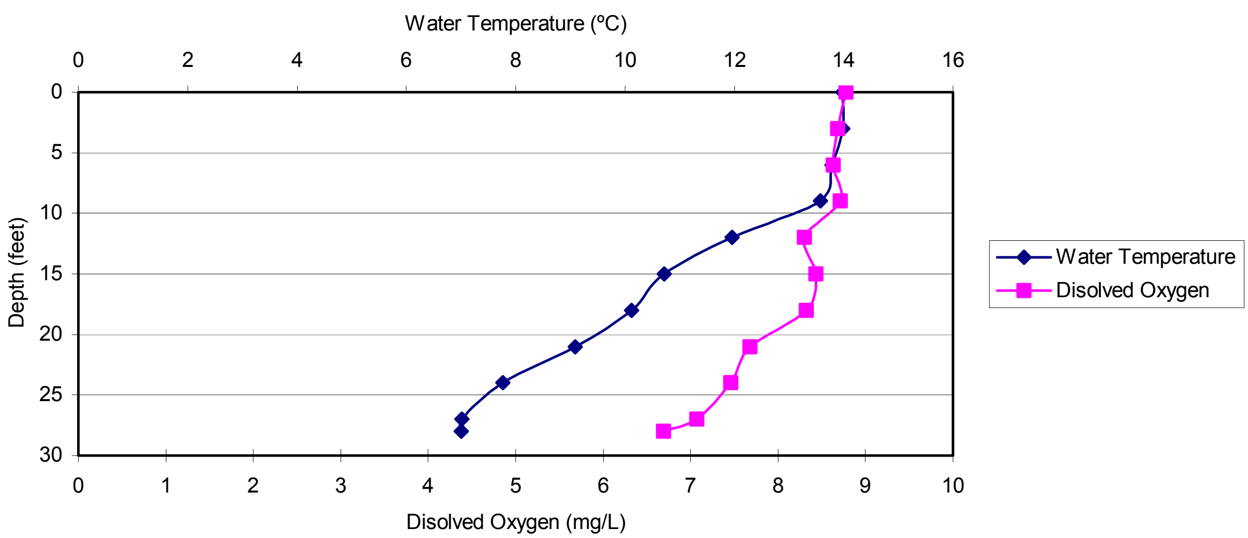


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Figure 15: Profile at the Deep Hole in Stony Brook Reservoir on July 8, 2003

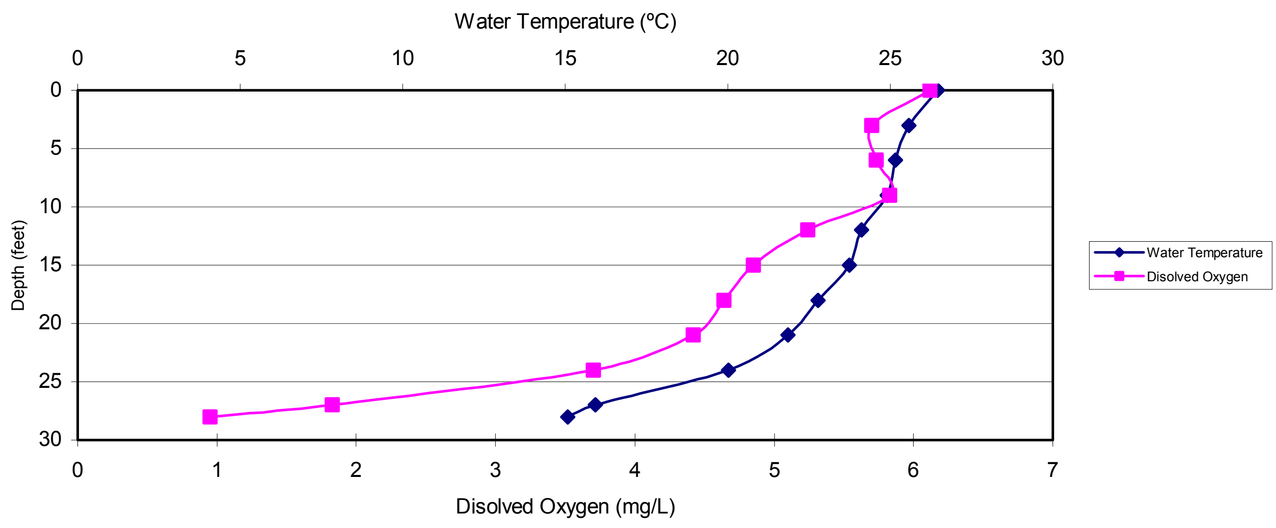


Figure 16: Profile at the Deep Hole in Stony Brook Reservoir on October 8, 2003

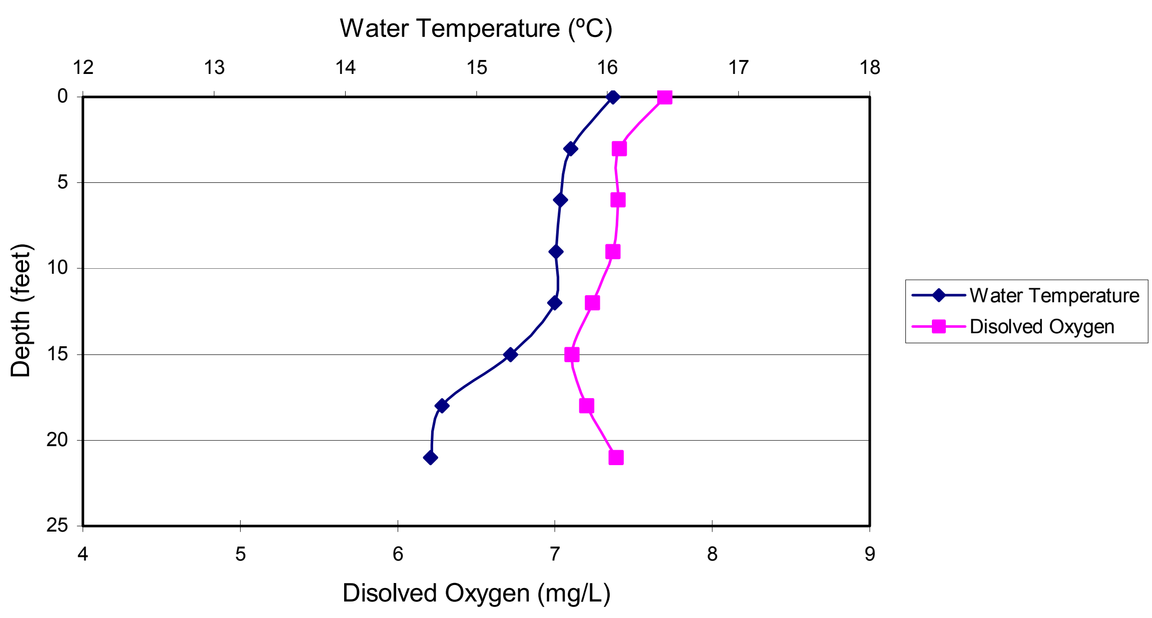
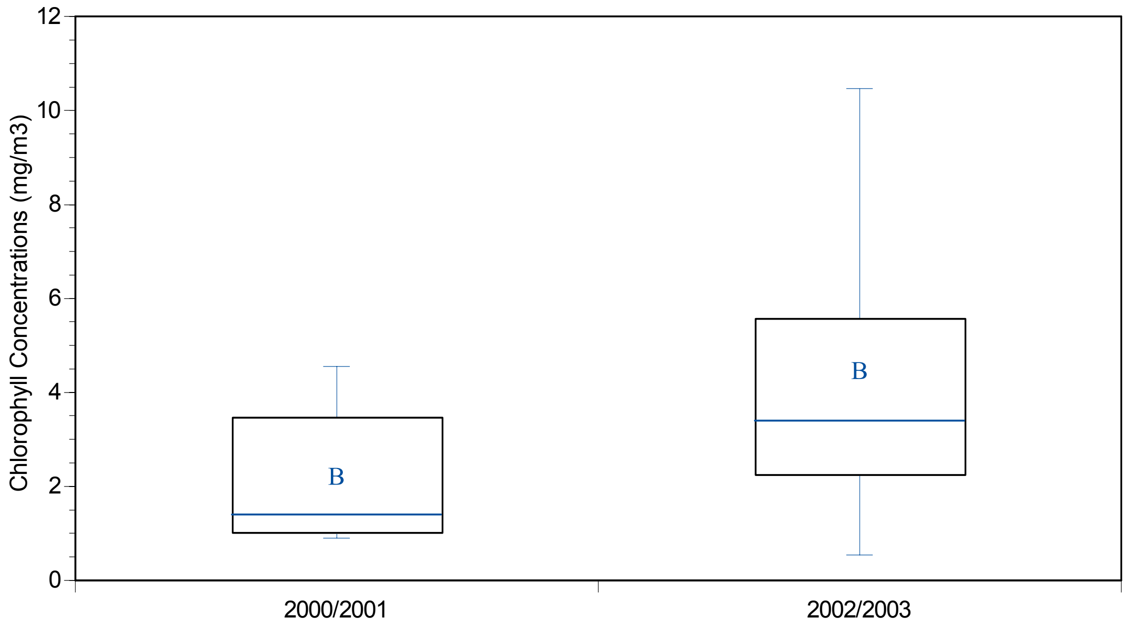


Figure 17: Chlorophyll Comparisons for Stony Brook Reservoir at Deep Hole for 2000/2001 and 2002/2003



Thermal Profiles and Figures for Fresh Pond Reservoir

Figure 18: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on April 23, 2002

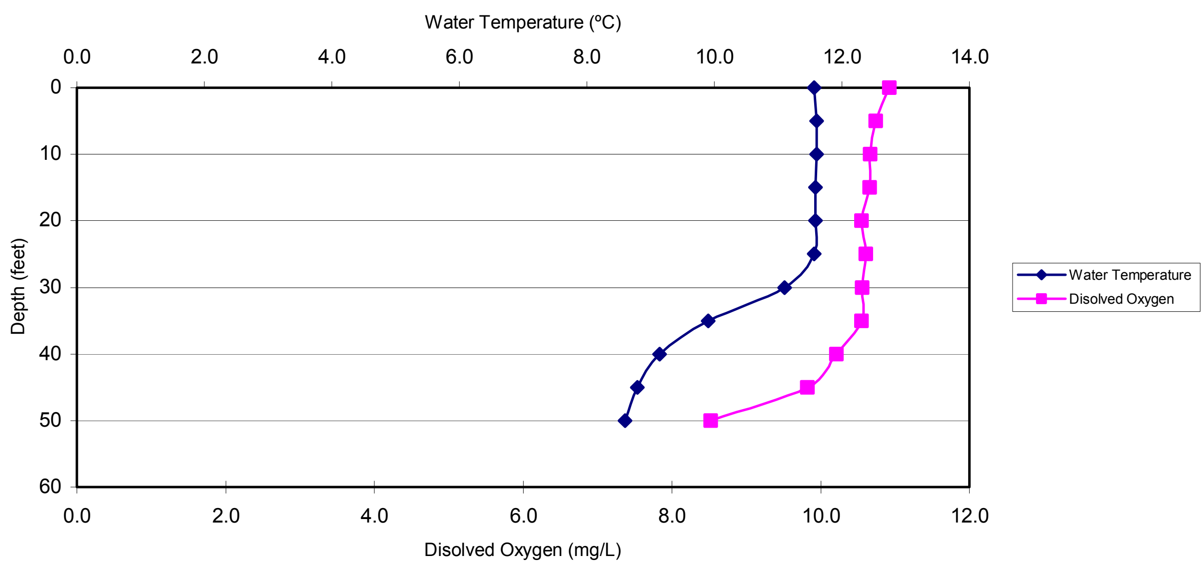


Figure 19: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on July 16, 2002

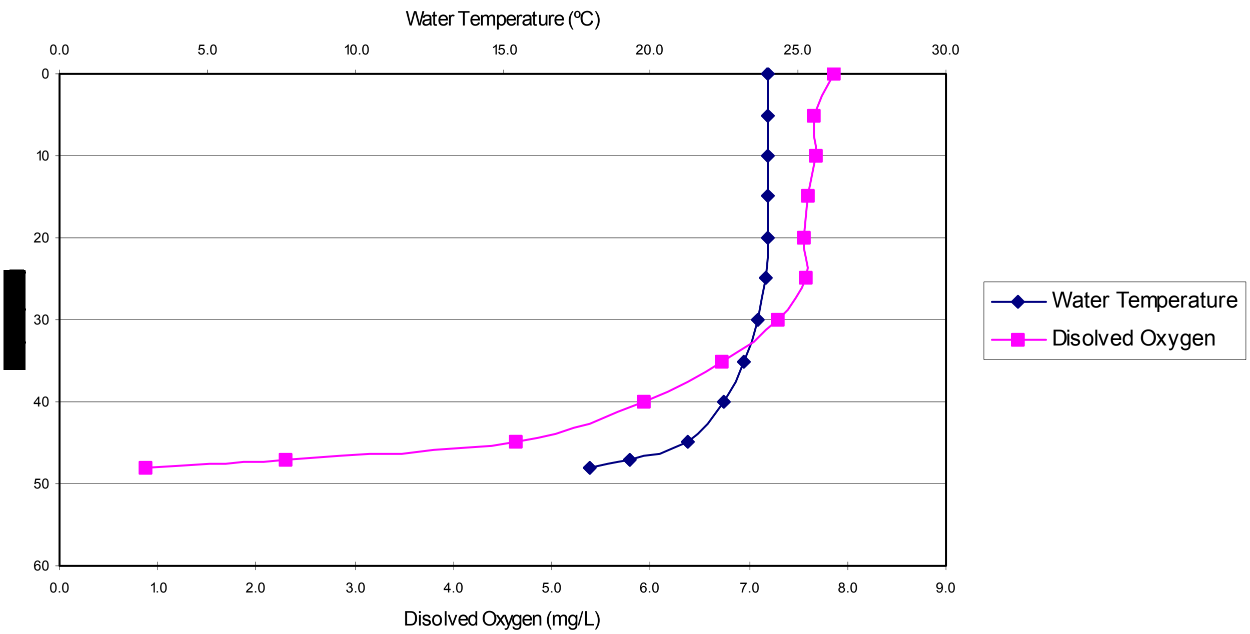


Figure 20: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on October 1, 2002

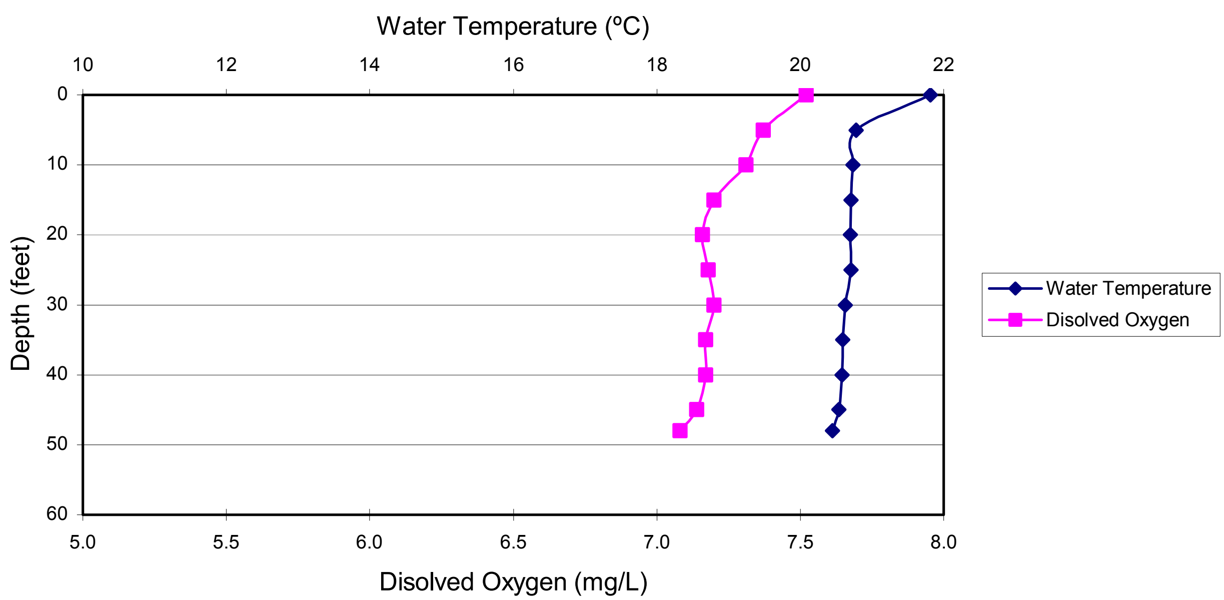


Figure 21: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on March 4, 2003

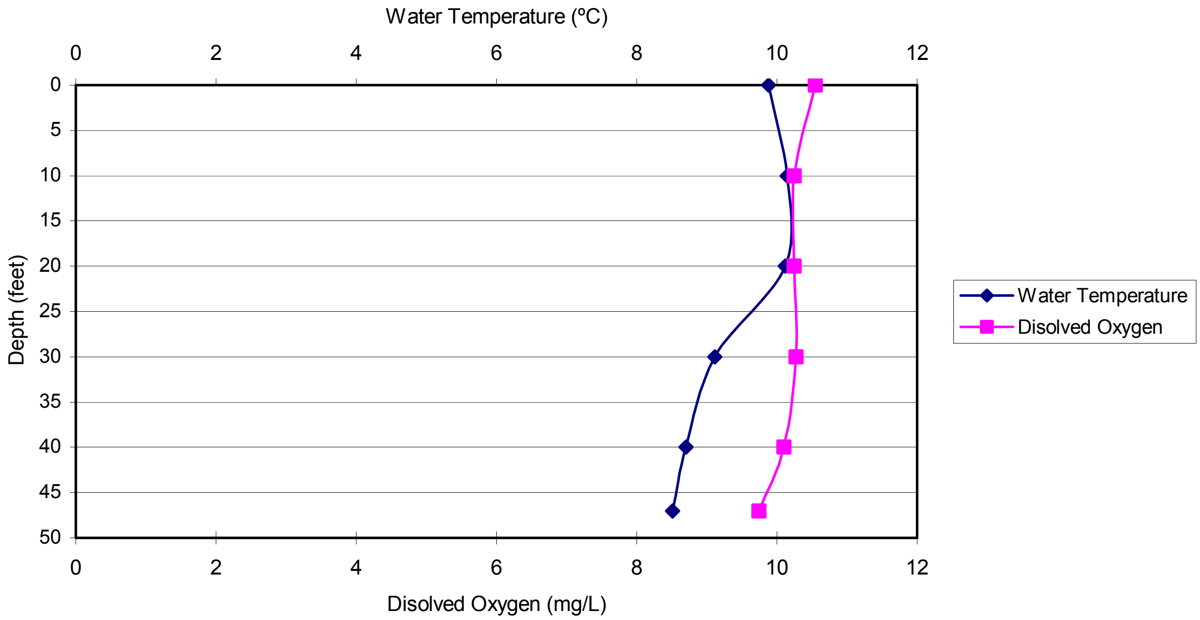


Figure 22: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on July 9, 2003

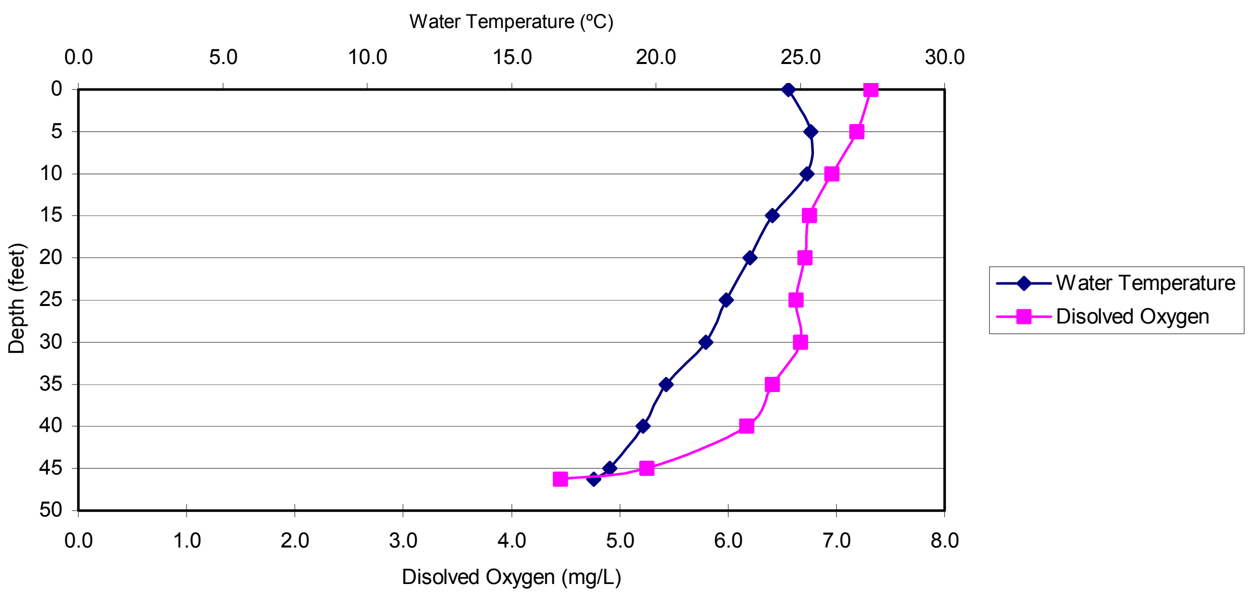


Figure 23: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on October 6, 2003

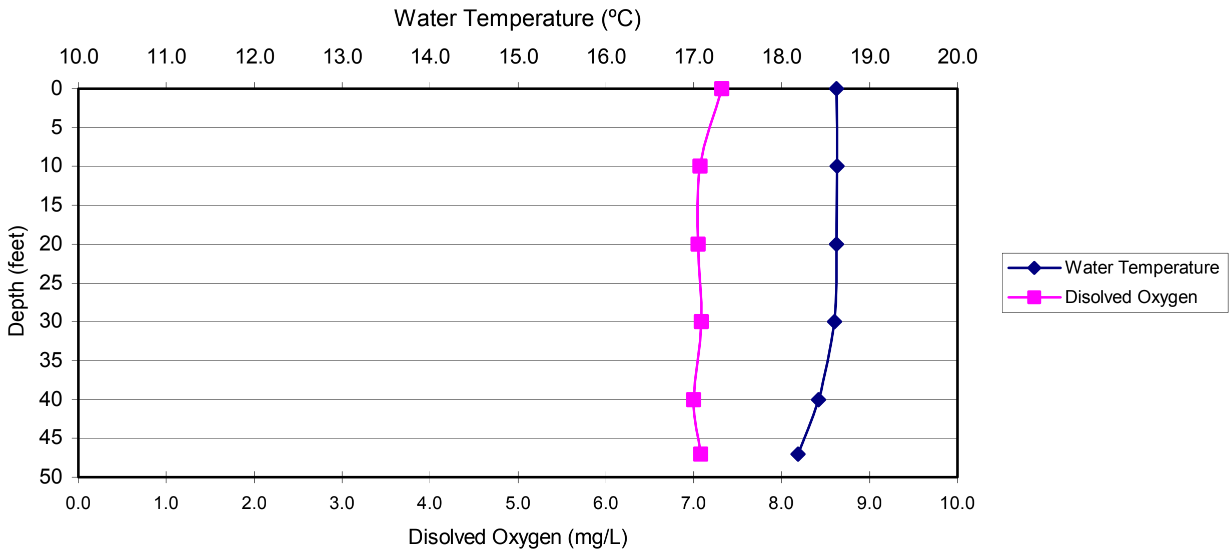
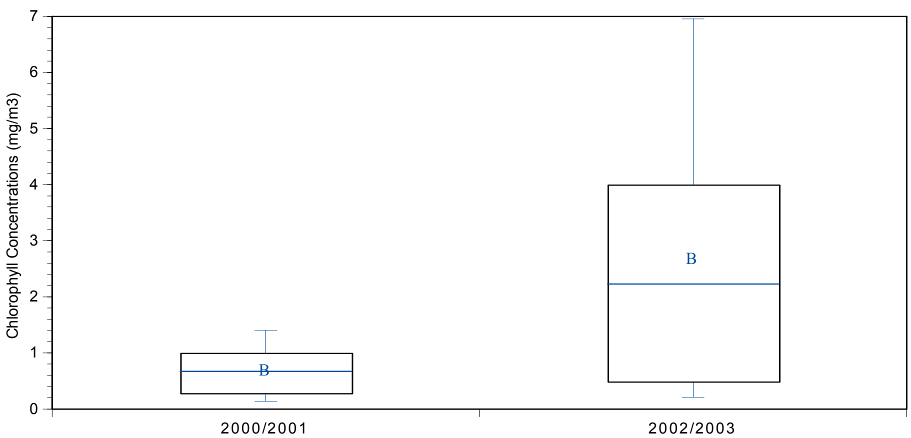


Figure 24: Chlorophyll Comparisons for Fresh Pond Reservoir at Deep Hole for 2000/2001 and 2002/2003



Box plot explanation

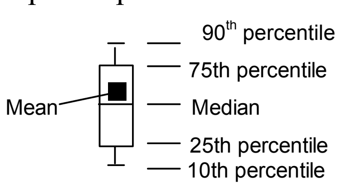
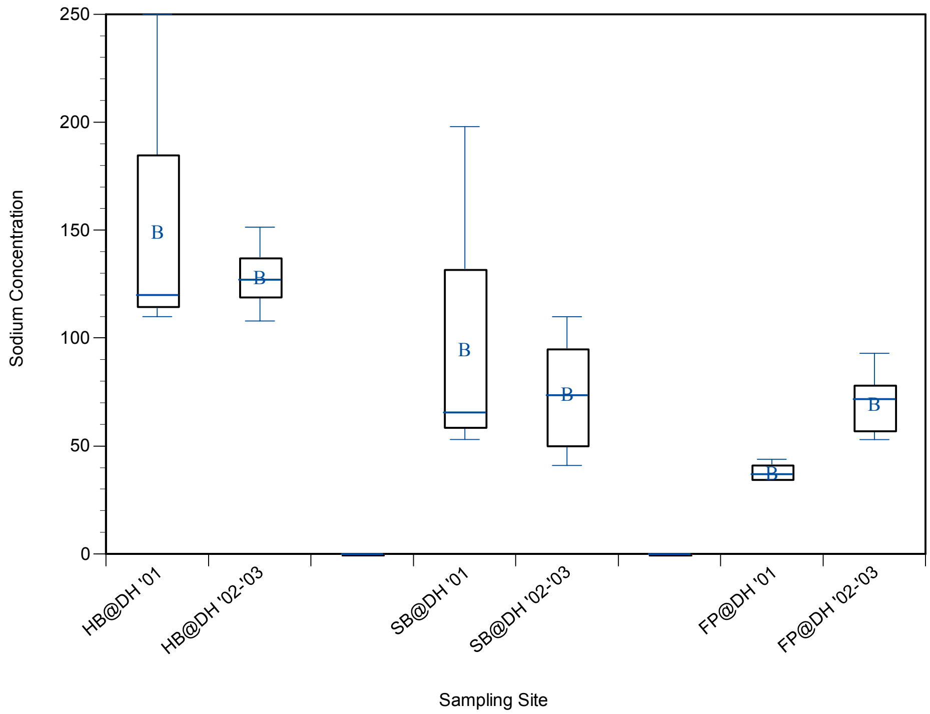
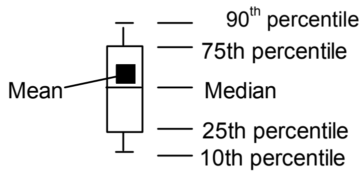


Figure 25: Sodium Concentration Comparisons for all Reservoirs



Box plot explanation



Tributary-Stream Chemistry Figures

Figure 26: Sodium Yield Comparison for 2000/2001 and 2002/2003

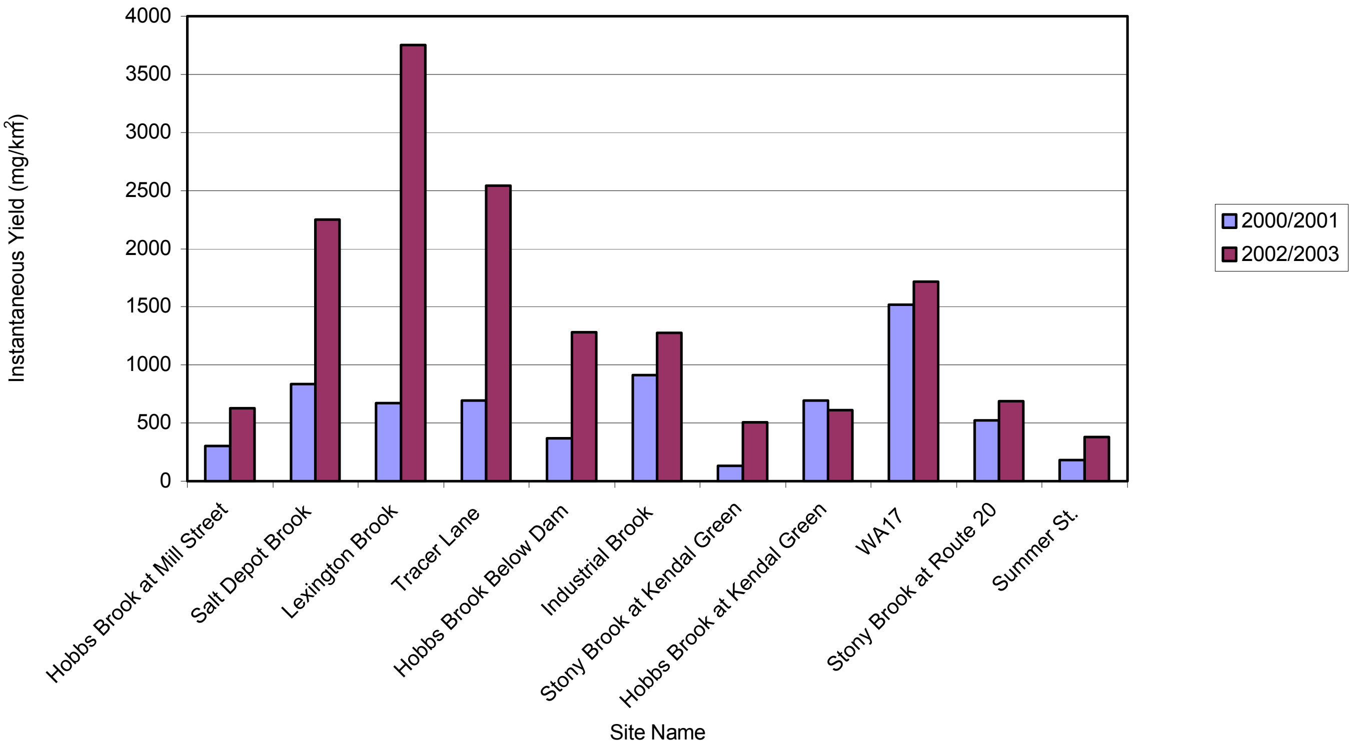


Figure 27: Total Nitrogen Yield Comparison for 2000/2001 and 2002/2003

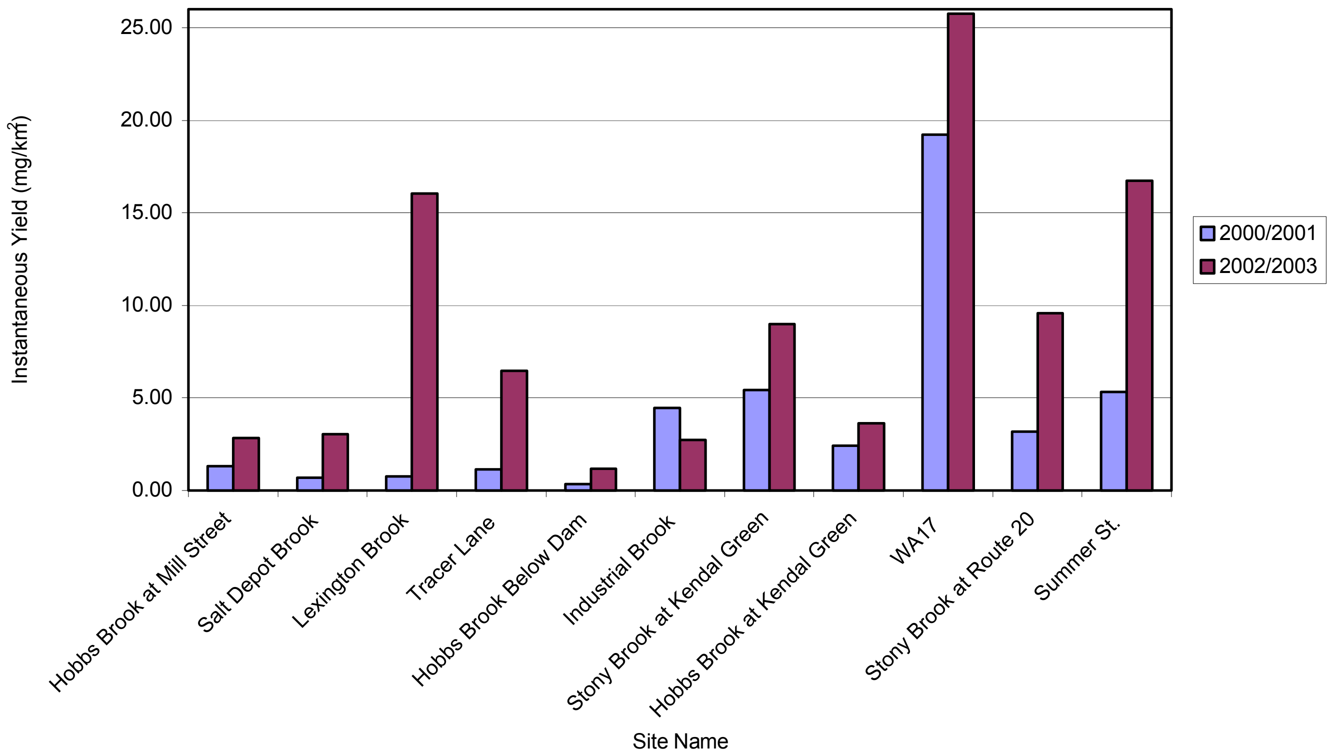


Figure 28: Manganese Yield Comparison for 2000/2001 and 2002/2003

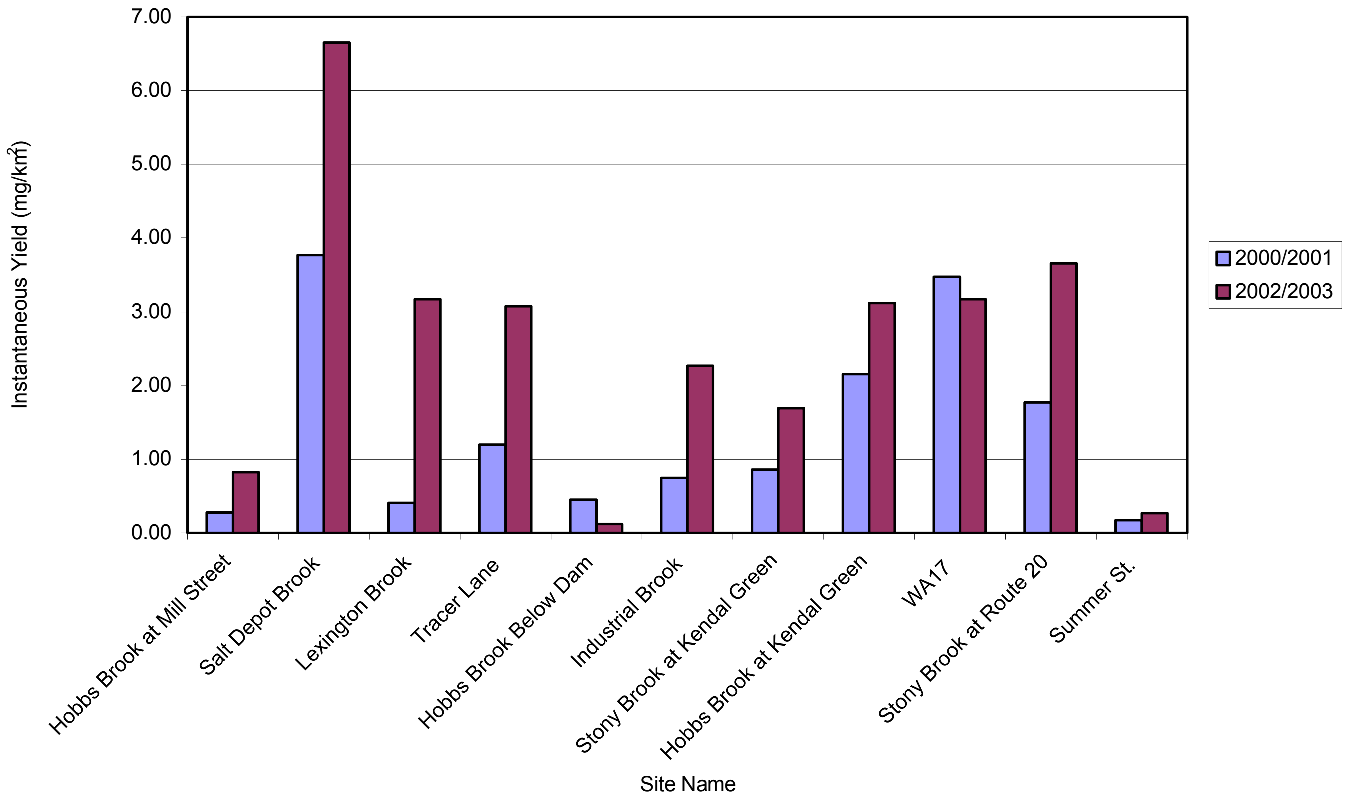


Figure 29: Fecal Coliform Yield Comparison for 2000/2001 and 2002/2003

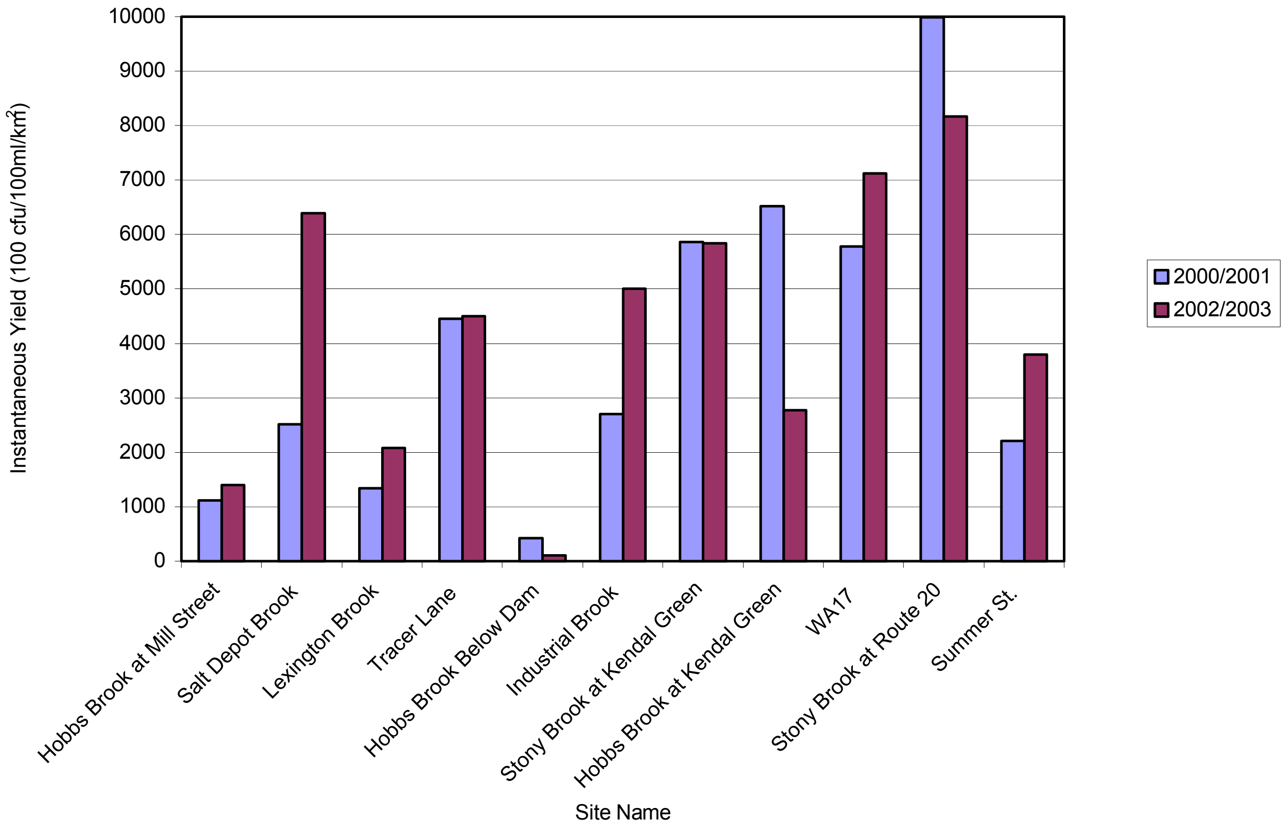
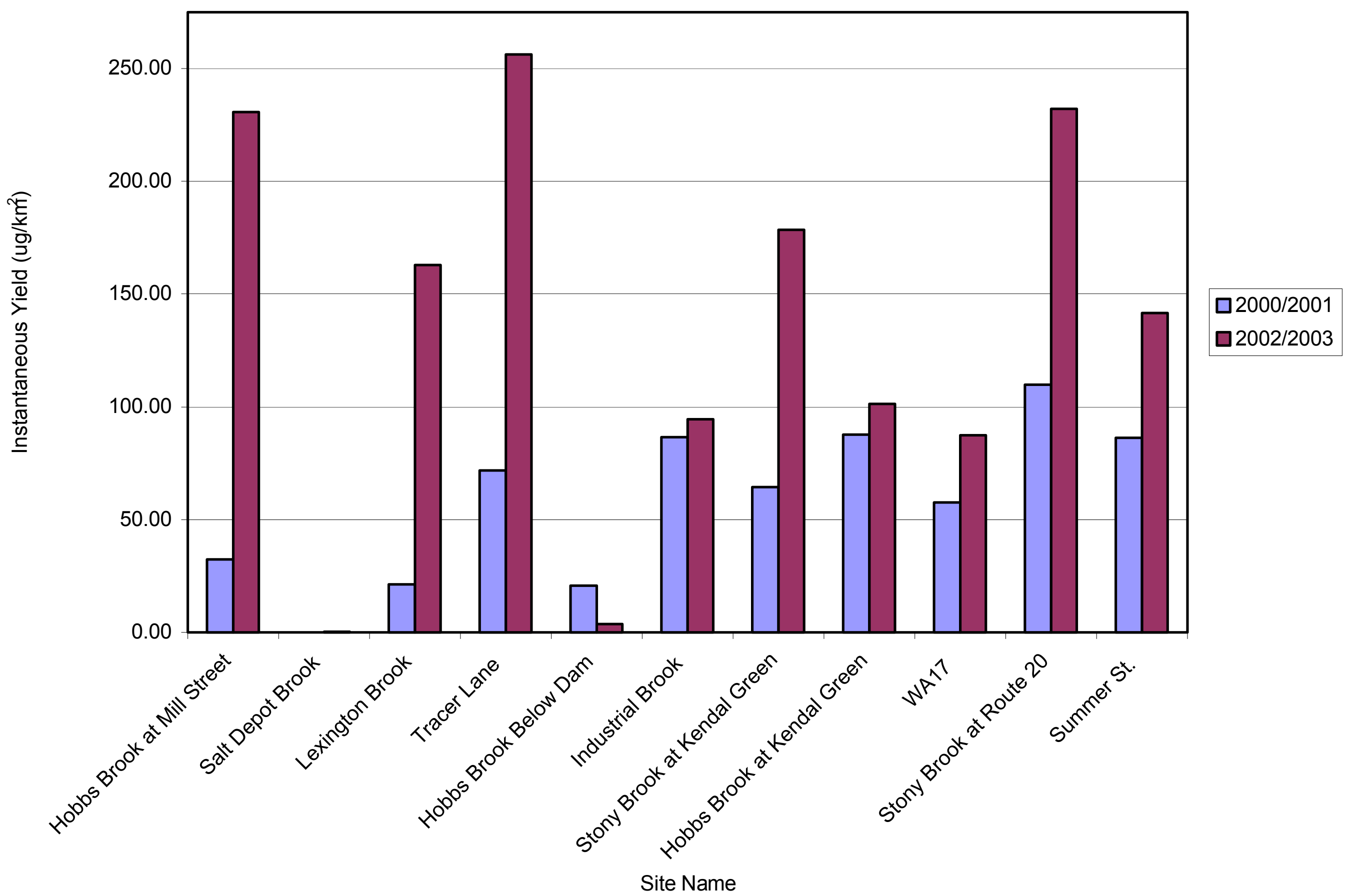


Figure 30: Phosphorus Yield Comparison for 2000/2001 and 2002/2003



Note: data for Salt Depot Brook is below the limits displayed on this chart

Figure 31 Fecal Coliform Bacteria Concentrations Comparisons

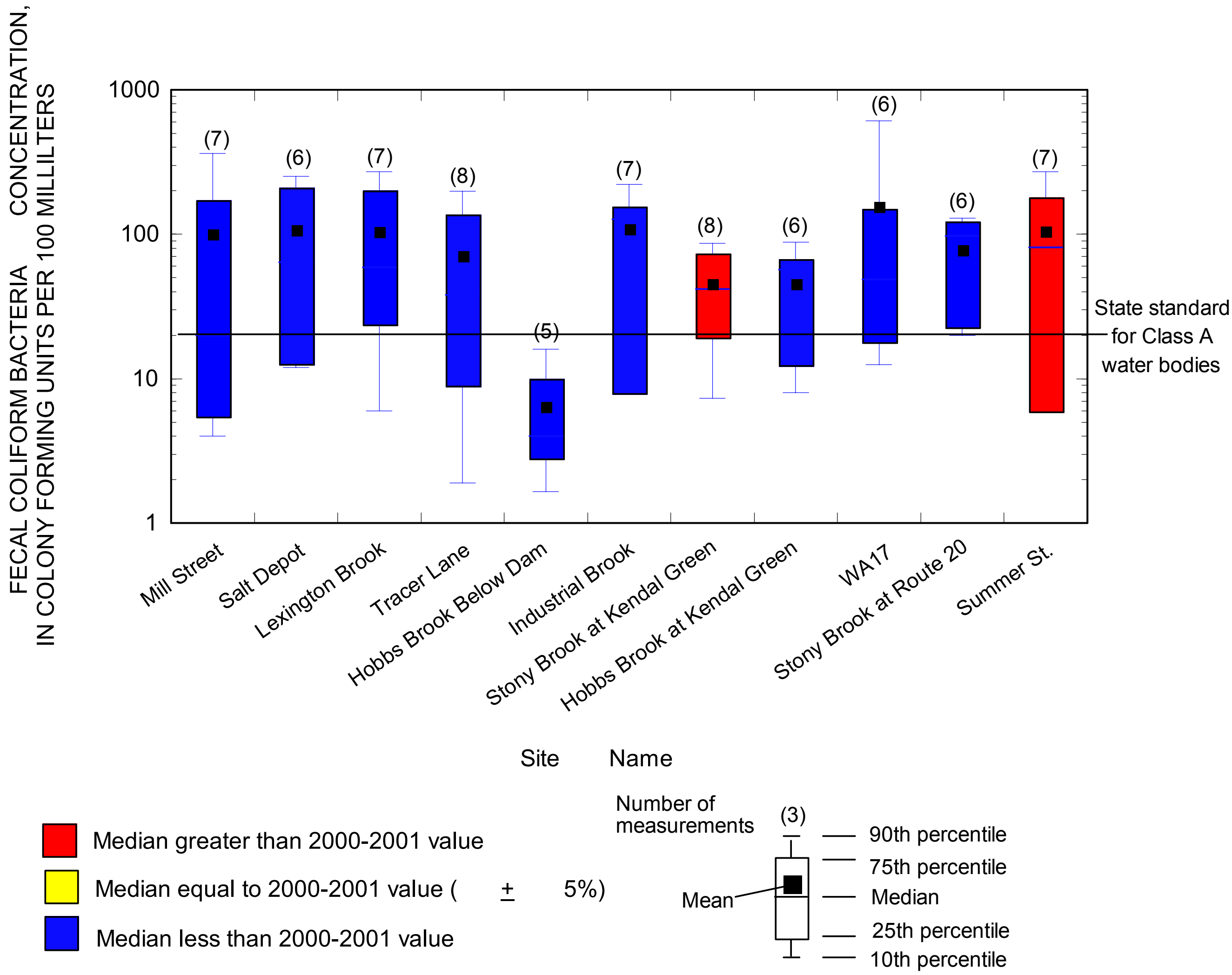


Figure 32 Sodium Concentrations Comparisons

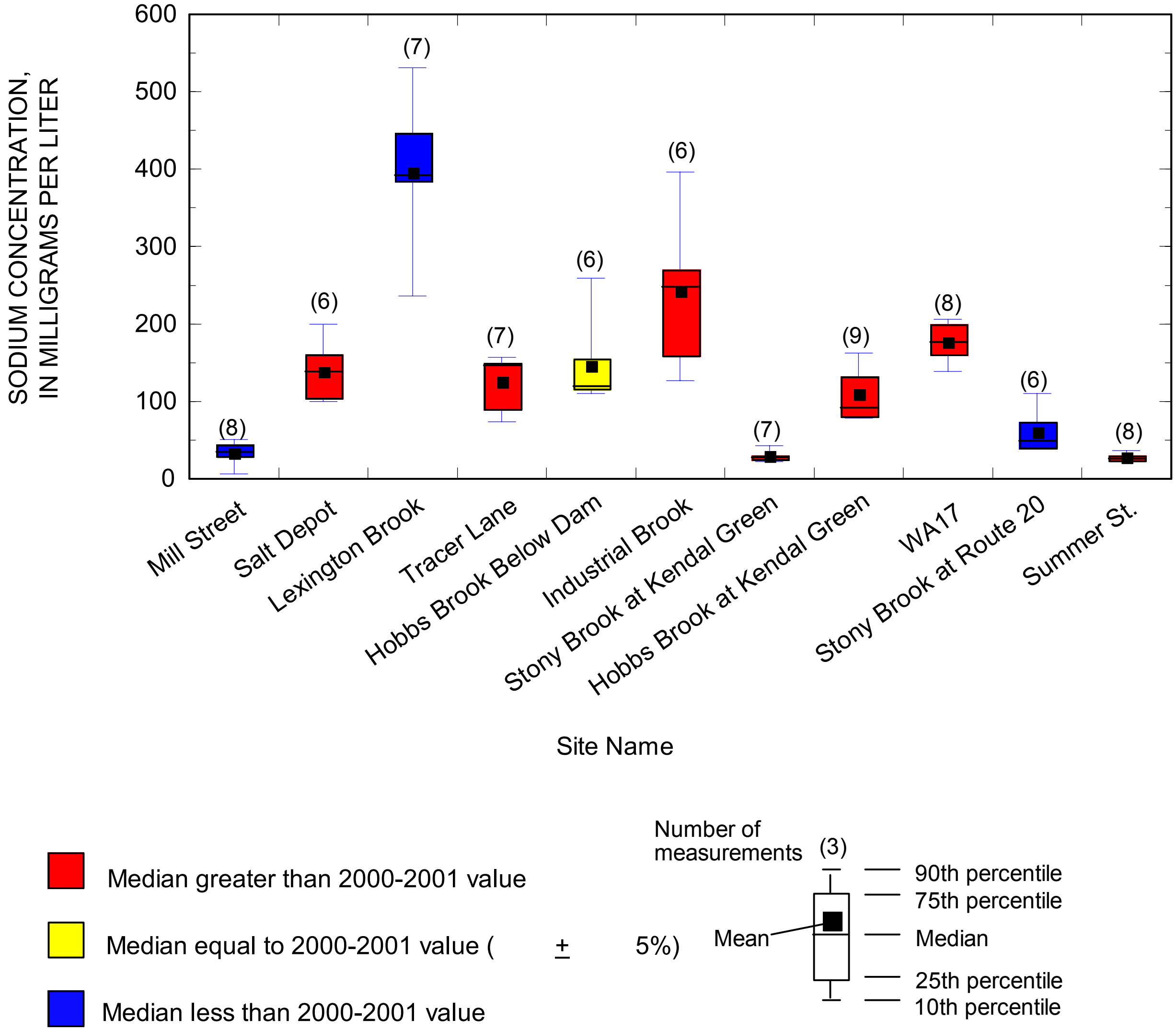


Figure 33 Manganese Concentration Comparisons

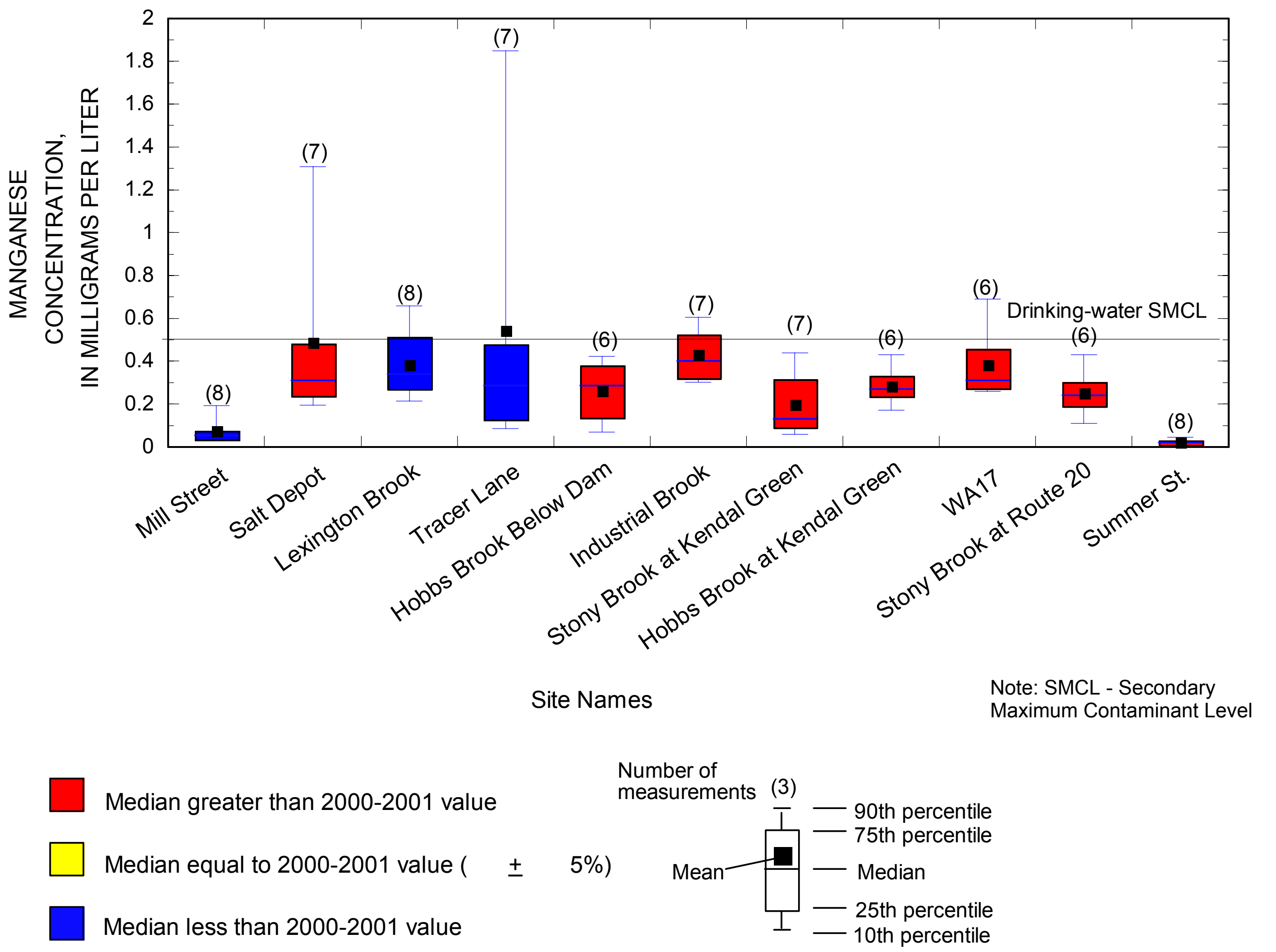


Figure 34 Nitrate Concentration Comparisons

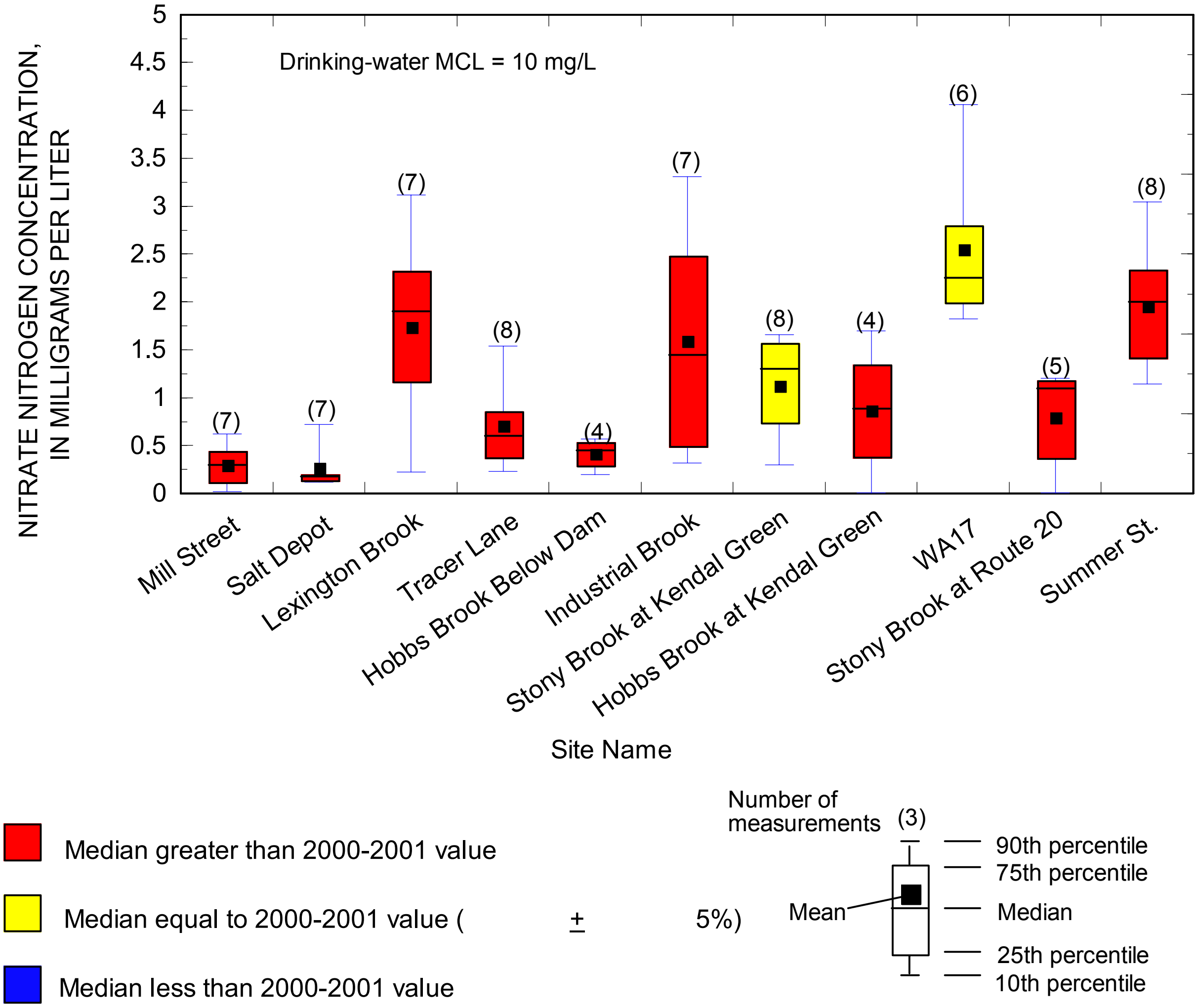
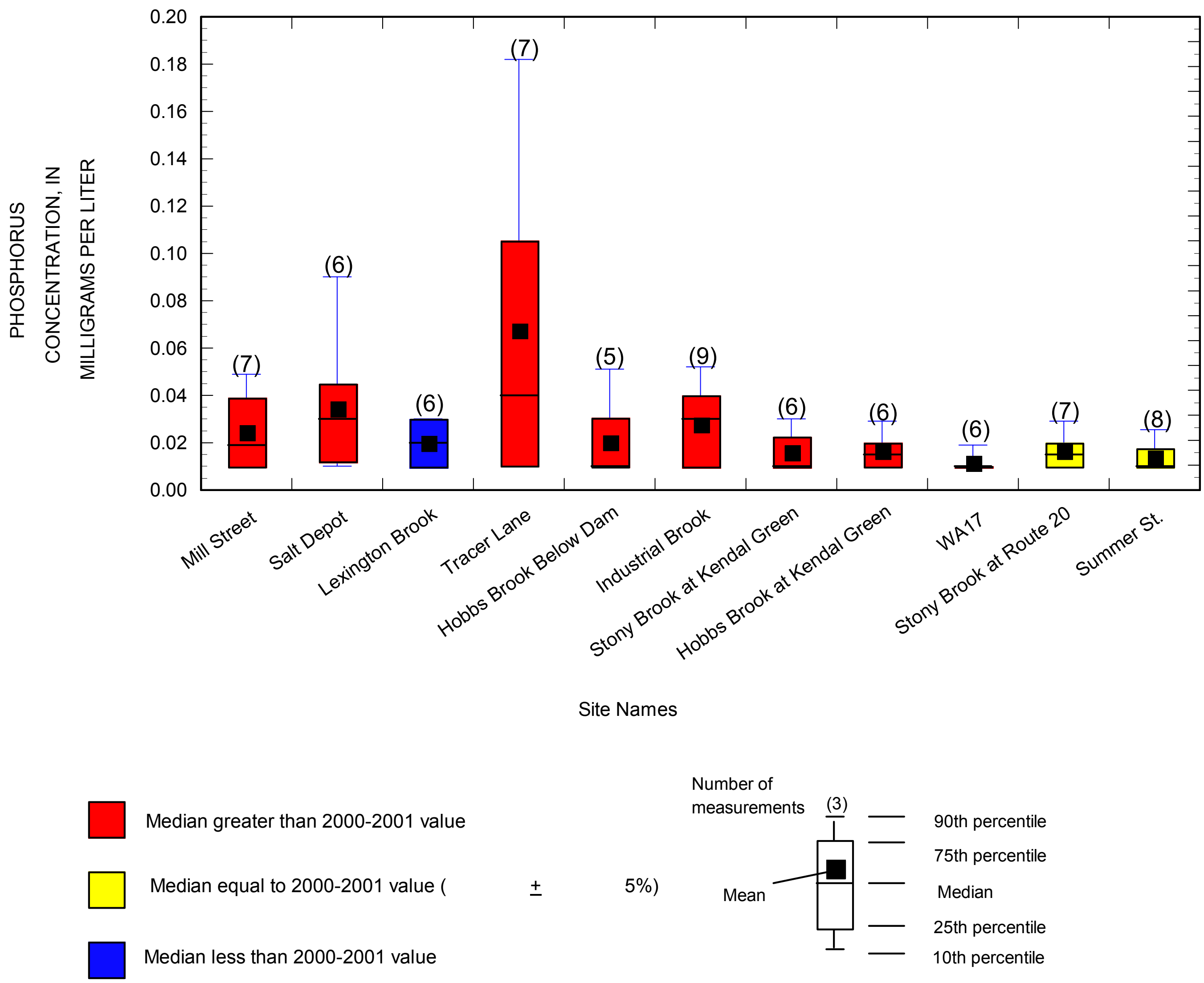


Figure 35 Phosphorus Concentrations Comparisons



Storm Water Quality Data

Figure 36: Fecal Coliform Storm Yields Comparison

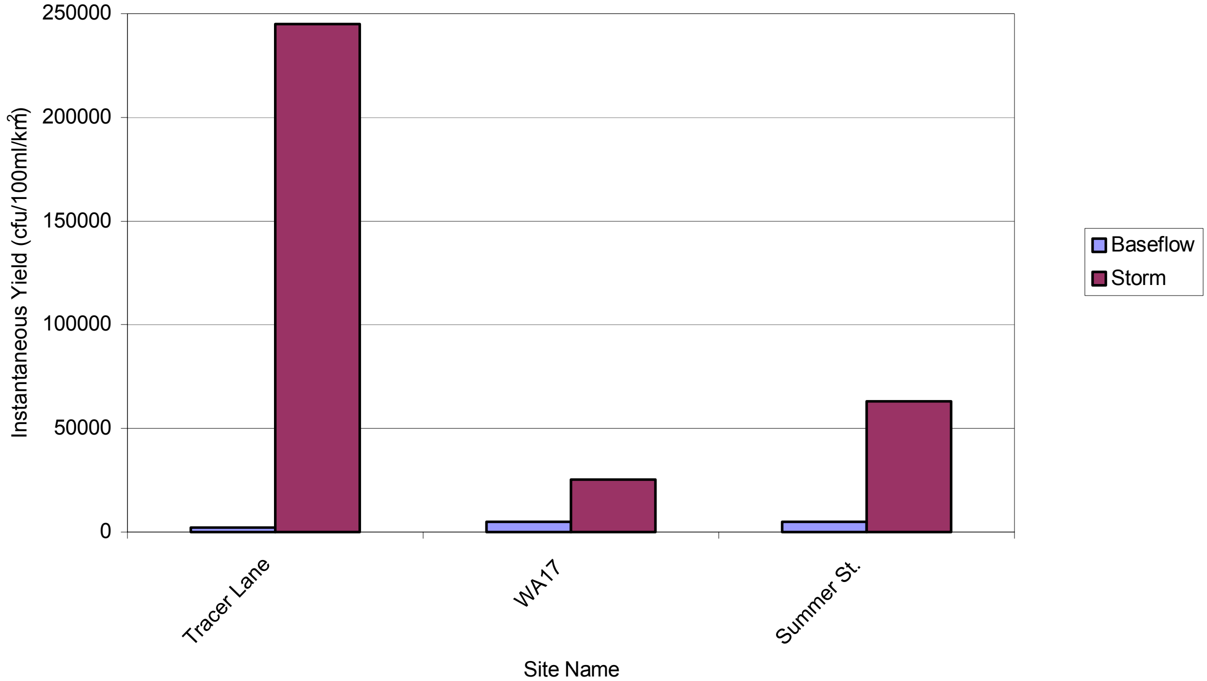


Figure 37: Manganese Storm Yields Comparison

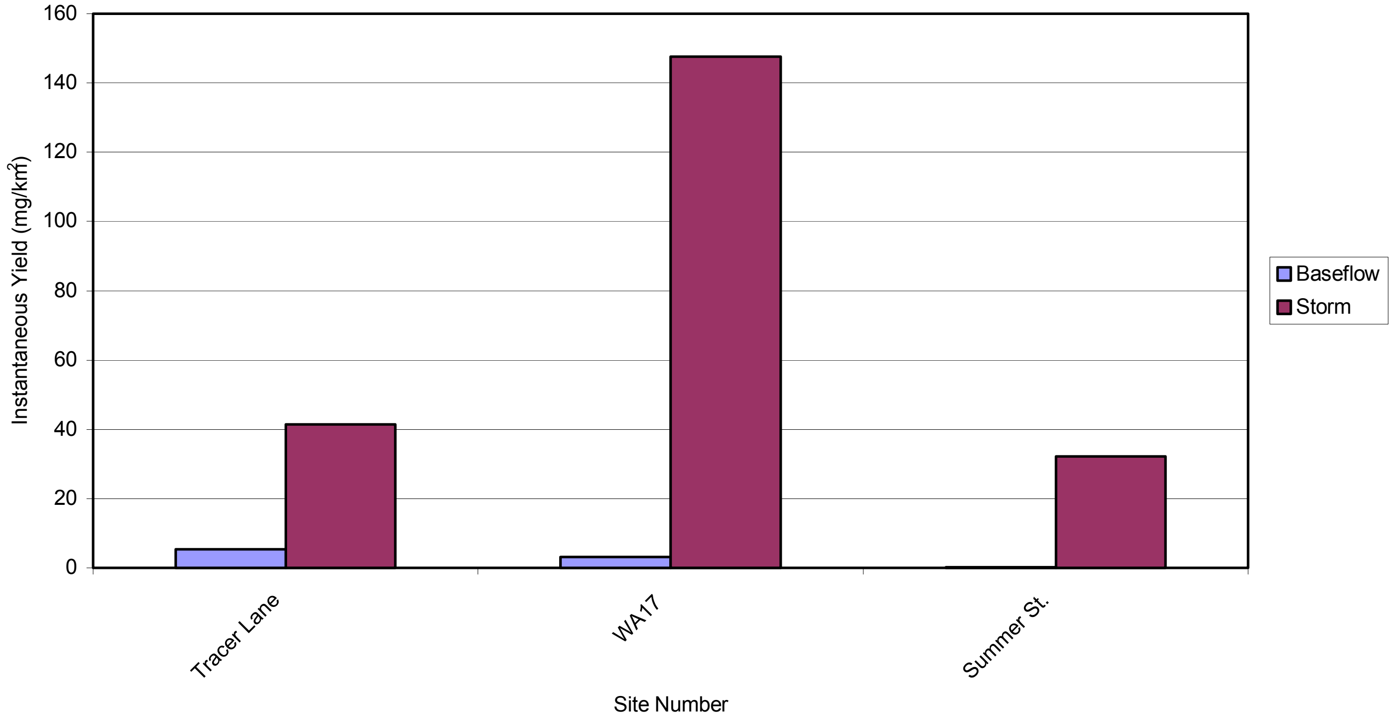


Figure 38: Sodium Storm Yields Comparison

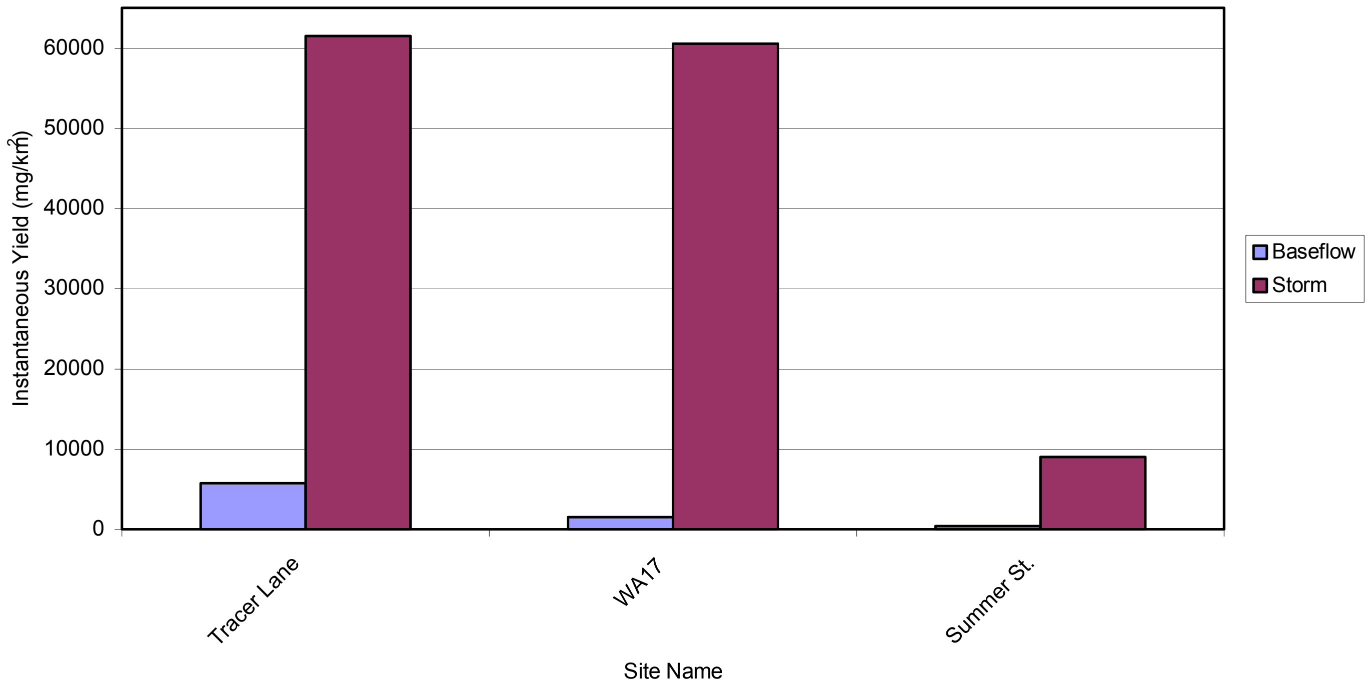


Table 1: Summary of Tributary Water Quality Data

	Sampling Station										
	4390	**4405**	**4410**	**4415**	**4420**	**4430**	**4433**	**4440**	**4455**	**4460**	**4475**
Subbasin Properties											
Fecal Coliform											
Baseflow:											
Concentration:											
Max	240	400	2100	900	380	40	400	88	660	150	280
Min	4	4	5	4	0	1.66	8	2	12	12	4
Median	42	30	64	42	38	16	140	45.5	95	61	36
Average	62	96	392.111	160.1	95	17.666	147.11	42.88	151	72.13	76.25
Load (kg/d)	156988.3	13189.97	9423.83	5398.6	9599.4	3531.67	7067.87	60648.92	8217.54	465392.3	8344.96
Yield (kg/km2/d)	5835.998	2259.564	10355.86	5093.02	5079.045	198.4085	6544.327	2769.357	6847.946	8164.777	3793.164
Storm:											
Concentration:											
Max	N/A	N/A	N/A	1400	N/A	N/A	2055	N/A	122	N/A	270
Min	N/A	N/A	N/A	44	N/A	N/A	86	N/A	80	N/A	92
Median	N/A	N/A	N/A	261	N/A	N/A	1800	N/A	96	N/A	181
Average	N/A	N/A	N/A	568.333	N/A	N/A	1313.67	N/A	99.33	N/A	181
Load (kg/d)	N/A	N/A	N/A	259902.9	N/A	N/A	107761.2	N/A	30310.3	N/A	138627
Yield (kg/km2/d)	N/A	N/A	N/A	245191.4	N/A	N/A	99778.85	N/A	25258.59	N/A	63012.27
Manganese											
Baseflow:											
Concentration:											
Max	0.46	0.24	1.4	0.68	2	1.75	0.62	0.45	0.69	0.43	0.05
Min	0.05	0.028	0.19	0.2	0.08	0.063	0.3	0.12	0.22	0.11	0.01
Median	0.16	0.063	0.35	0.345	0.26	0.2	0.4	0.27	0.31	0.24	0.02
Average	0.2	0.077	0.568	0.443	0.43	0.402	0.44	0.27	0.348	0.25	0.022
Load (kg/d)	45.61836	3.69	6.05	5.66	5.41	37.7	1.89	68.37	3.81	208.58	0.39
Yield (kg/km2/d)	1.69585	0.659569	6.65	5.34	2.864641	2.118011	1.746203	3.122089	3.171482	3.659226	0.176336
Storm:											
Concentration:											
Max	N/A	N/A	N/A	1.2	N/A	N/A	N/A	N/A	0.78	N/A	0.64
Min	N/A	N/A	N/A	0.6	N/A	N/A	N/A	N/A	0.11	N/A	0.07
Median	N/A	N/A	N/A	0.9	N/A	N/A	N/A	N/A	0.45	N/A	0.355
Average	N/A	N/A	N/A	0.9	N/A	N/A	N/A	N/A	0.45	N/A	0.355
Load (kg/d)	N/A	N/A	N/A	41.51	N/A	N/A	N/A	N/A	147.55	N/A	32.22
Yield (kg/km2/d)	N/A	N/A	N/A	39.16	N/A	N/A	N/A	N/A	122.9578	N/A	14.64644
Sodium											
Baseflow:											
Concentration:											
Max	48	70	200	540	280	259	410	170	208.5	110	38.5
Min	21.3	0.51	96.2	96.2	72	100	123	25	130	35	22
Median	28	43.15	139	390	147	121	260	92	191.6	61.4	27
Average	29.95	42.1	156.6	335.8	143.389	138.933	268.39	103.39	182.09	67.04	29.01111
Load (kg/d)	10796.35	2470.23	1575.55	3975.68	4800.12	22867.57	1221.32	9320.76	1823.6	39308.53	853.47
Yield (kg/km2/d)	401.3512	441.9016	1731.37	3750.64	2539.747	1284.695	1130.85	425.6054	1519.668	689.6234	387.9402
Storm:											
Concentration:											
Max	N/A	N/A	N/A	2000	N/A	N/A		N/A	400	N/A	85
Min	N/A	N/A	N/A	440	N/A	N/A		N/A	9.1	N/A	14
Median	N/A	N/A	N/A	1220	N/A	N/A		N/A	204.55	N/A	49.5
Average	N/A	N/A	N/A	1220	N/A	N/A		N/A	204.55	N/A	49.5
Load (kg/d)	N/A	N/A	N/A	65212.46	N/A	N/A		N/A	72623.27	N/A	9606.33
Yield (kg/km2/d)	N/A	N/A	N/A	61521.19	N/A	N/A		N/A	60519.39	N/A	9062.58

Table 1 Continued: Summary of Tributary Water Quality Data

	Sampling Station										
	4390	**4405**	**4410**	**4415**	**4420**	**4430**	**4433**	**4440**	**4455**	**4460**	**4475**
Subbasin Properties											
					Nitrogen						
Baseflow:											
Concentration:											
Max	1.67	0.66	0.78	3.3	1.7	0.57	3.4	1.7	4.2	1.2	3.2
Min	0.01	0.005	0.005	0.005	0.01	0.005	0.01	0.01	0.01	0.01	0.005
Median	0.91	0.23	0.16	1.8	0.43	0.3	0.8	0.62	2.4	0.5	1.5
Average	0.96	0.285	0.214	1.651	0.54	0.309	1.24	0.64	2.301	0.61	1.678
Load (kg/d)	255.494	19.26	2.14	11.21	12.18	30.19	2.94	92.01	22.2	544.96	36.87
Yield (kg/km2/d)	9.497918	3.44462	2.35	10.58	6.446192	1.696224	2.726803	4.201489	18.50031	9.560646	16.7584
Storm:											
Concentration:											
Max	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Min	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Median	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Load (kg/d)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Yield (kg/km2/d)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
					Phosphorus						
Baseflow:											
Concentration:											
Max	0.03	0.05	0.09	0.03	0.2	0.051	0.06	0.03	0.02	0.03	0.027
Min	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Median	0.02	0.02	0.025	0.01	0.04	0.01	0.03	0.01	0.01	0.01	0.01
Average	0.02	0.024111	0.034	0.017	0.061	0.015	0.03	0.02	0.011	0.02	0.014111
Load (kg/d)	4802.529	1289.55	0.37	195.39	676.77	119.29	101.94	3931.79	144.42	13231.02	387.94
Yield (kg/km2/d)	178.5327	230.6882	0.4	184.33	358.0802	6.701687	94.3893	179.5337	120.3464	232.1232	176.3364
Storm:											
Concentration:											
Max	N/A	N/A	N/A	0.26	N/A	N/A		N/A	0.39	N/A	0.17
Min	N/A	N/A	N/A	0.01	N/A	N/A		N/A	0.09	N/A	0.07
Median	N/A	N/A	N/A	0.135	N/A	N/A		N/A	0.24	N/A	0.12
Average	N/A	N/A	N/A	0.135	N/A	N/A		N/A	0.24	N/A	0.12
Load (kg/d)	N/A	N/A	N/A	8.17	N/A	N/A		N/A	76.03	N/A	9.11
Yield (kg/km2/d)	N/A	N/A	N/A	7.71	N/A	N/A		N/A	63.35494	N/A	4.142795

Automated Monitoring Hydrographs

Figure 39 Continuous monitoring record at Hobbs Brook Below Dam for 2002

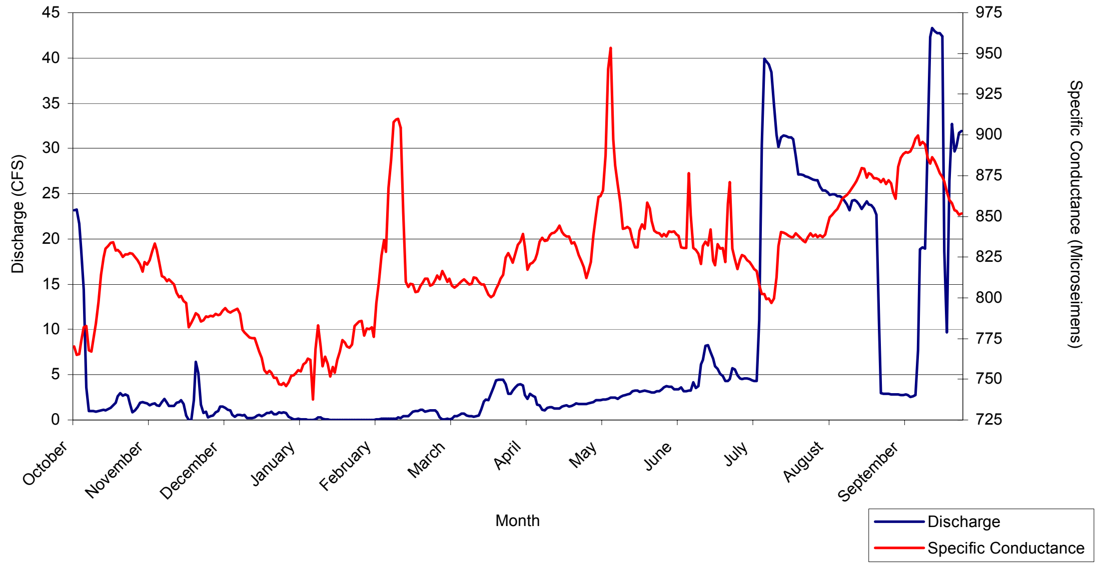


Figure 40 Continuous monitoring record at Hobbs Brook Below Dam for 2003

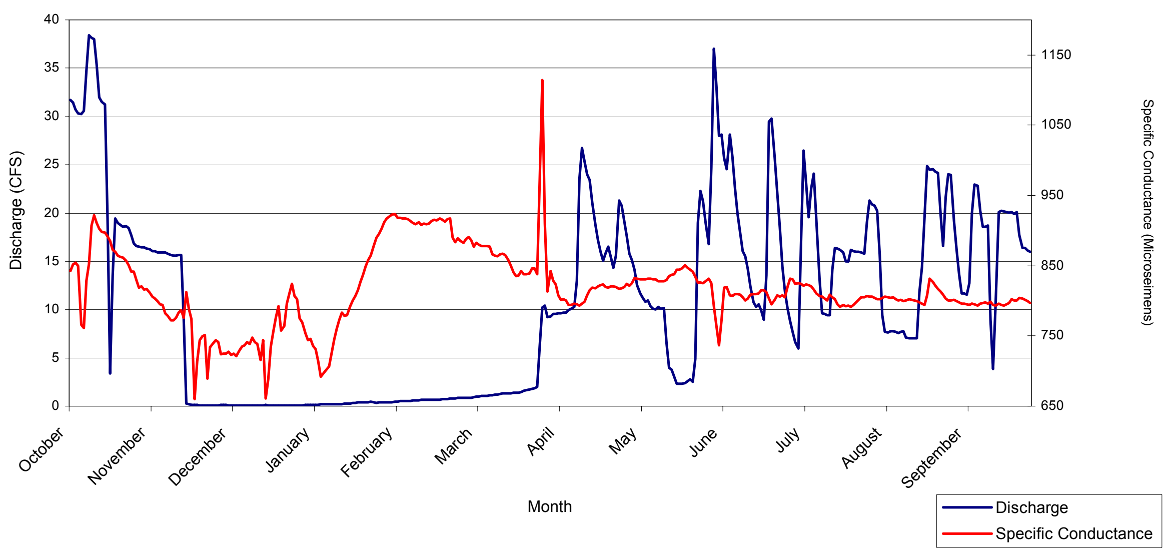


Figure 41 Continuous monitoring record at Stony Brook Reservoir Below Dam for 2002

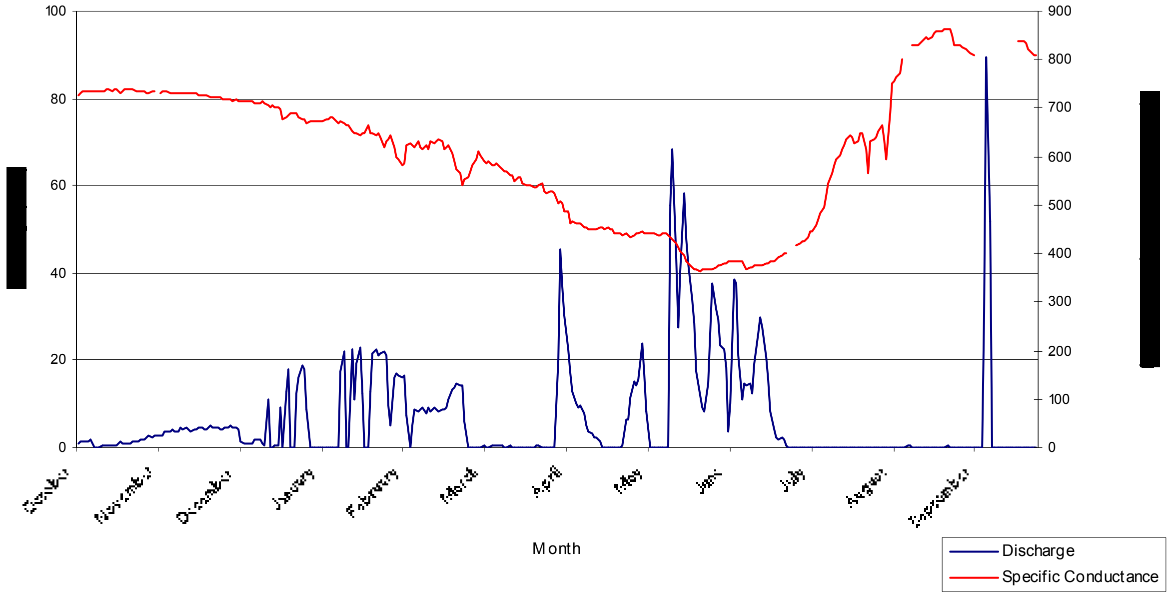


Figure 42 Continuous monitoring record at Stony Brook Reservoir Below Dam for 2003

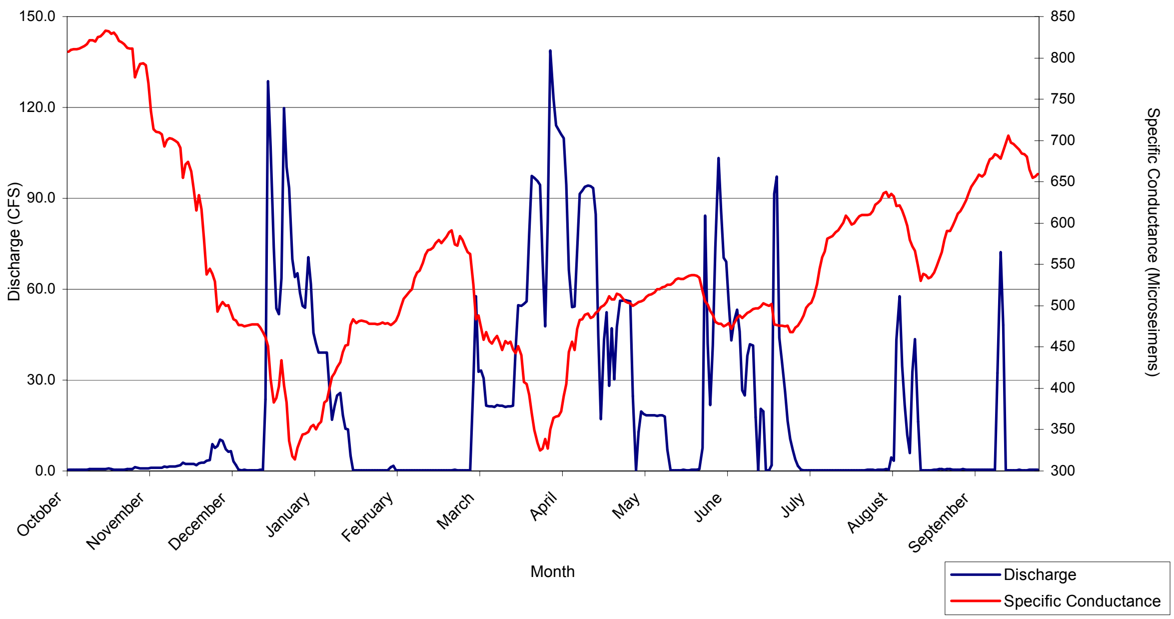


Figure 43 Continuous monitoring record at Stony Brook Unnamed Tributary WA-17 (station number 4455) for 2002

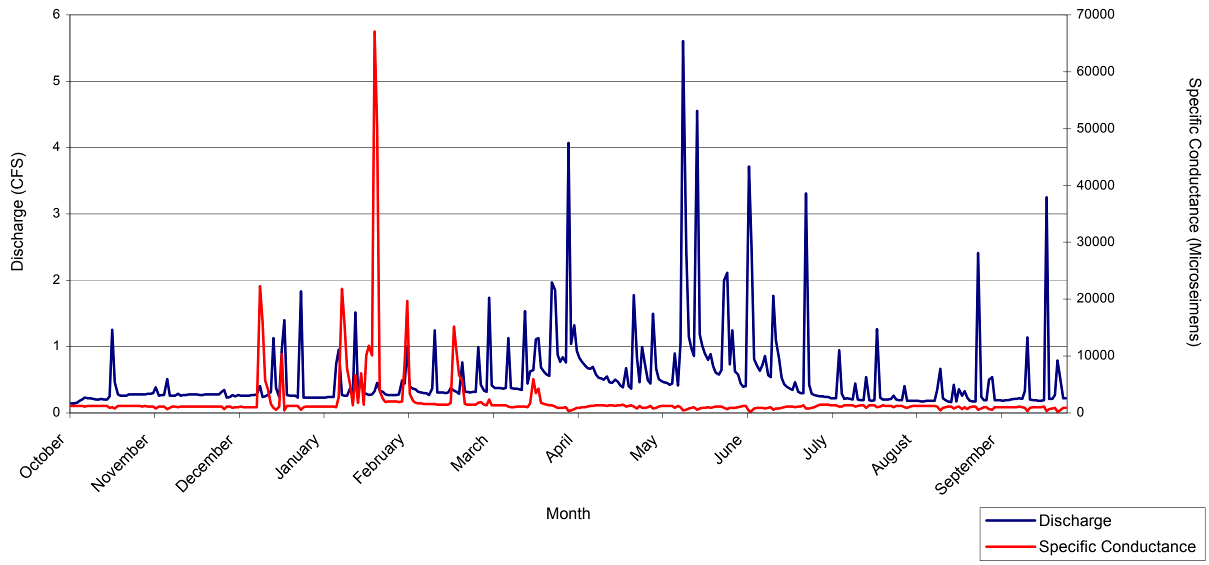
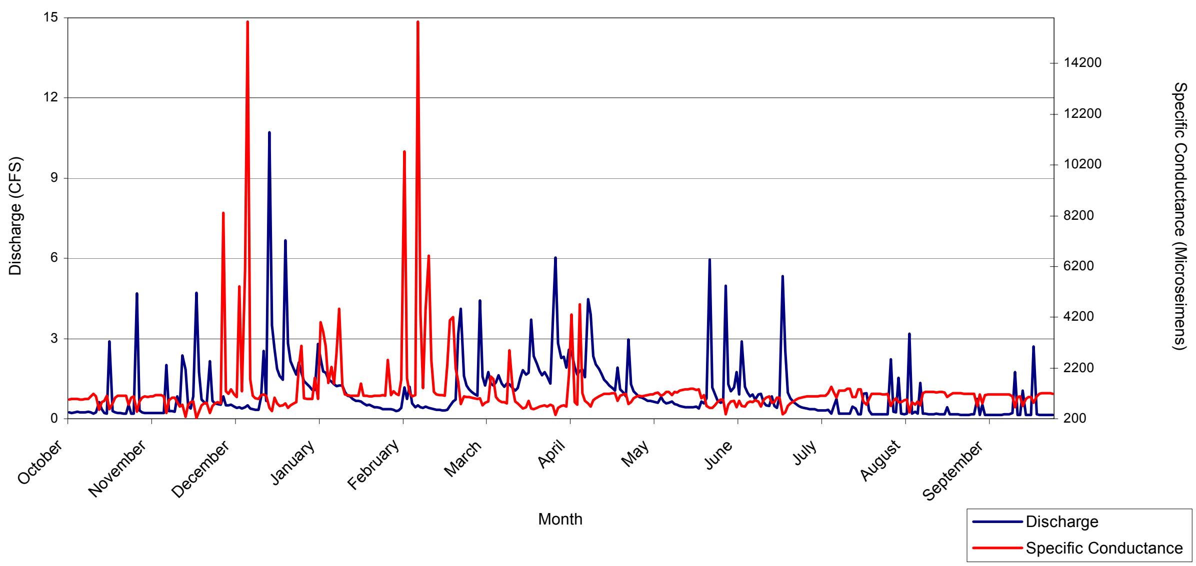


Figure 44 Continuous monitoring record at Stony Brook Unnamed Tributary WA-17 (station number 4455) for 2003



Analytical Figures for Class B Water Bodies on Fresh Pond Reservation

Figure 45: Fresh Pond Reservation Class B Waters – Orthophosphate Comparisons (2000/2001 in Blue, 2002/2003 in Red)

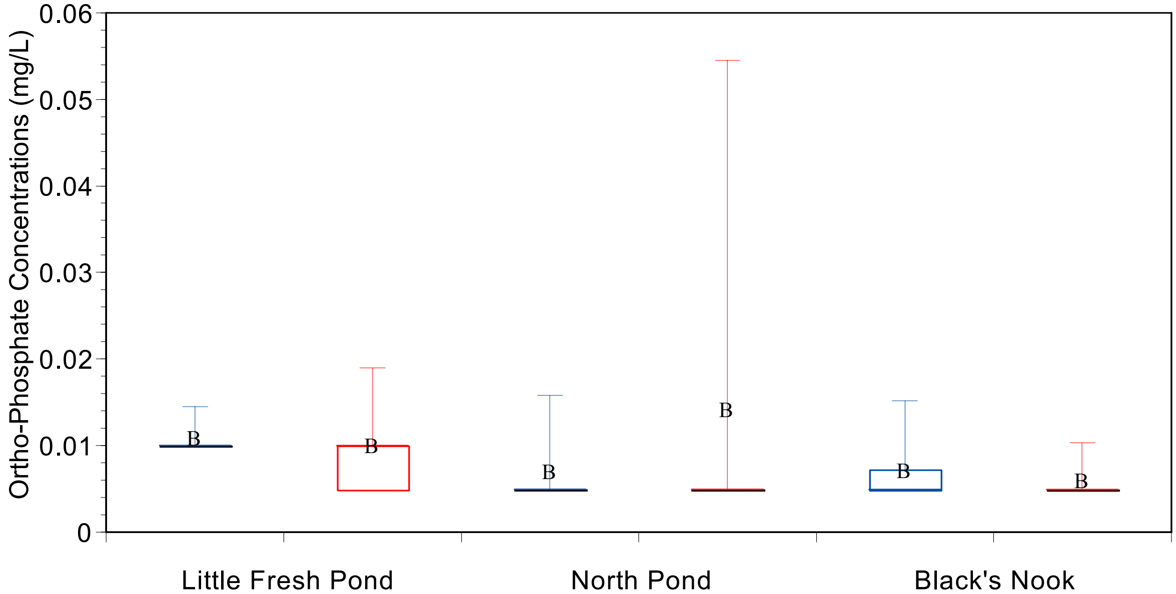


Figure 46: Fresh Pond Reservation Class B Waters – Nitrate Comparisons

(2000/2001 in Blue, 2002/2003 in Red)

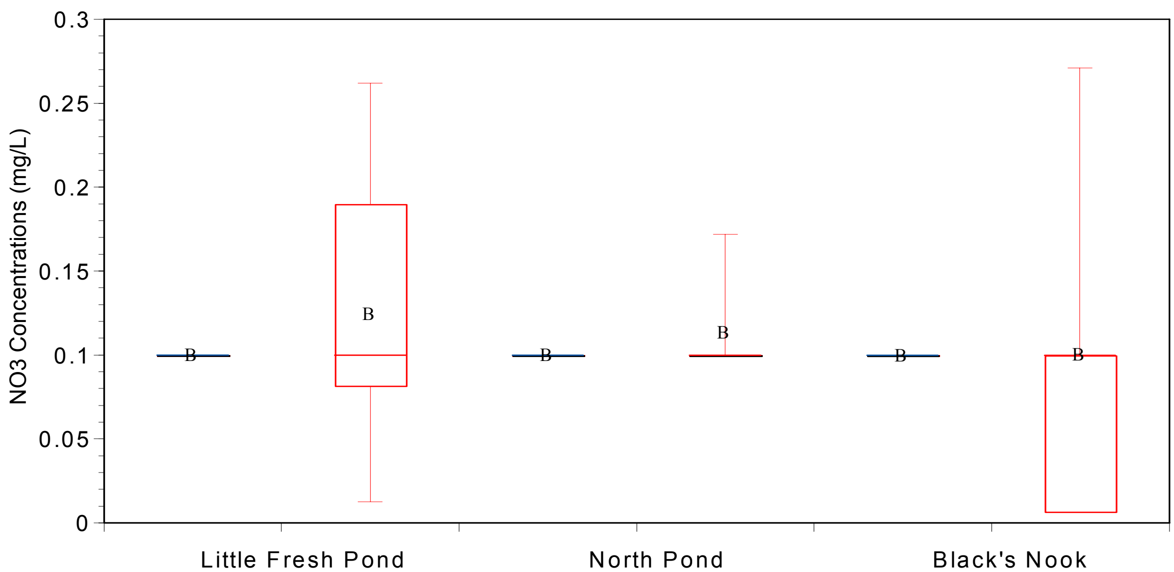


Figure 47: Fresh Pond Reservation Class B Waters – Sodium Comparisons
(2000/2001 in Blue, 2002/2003 in Red)

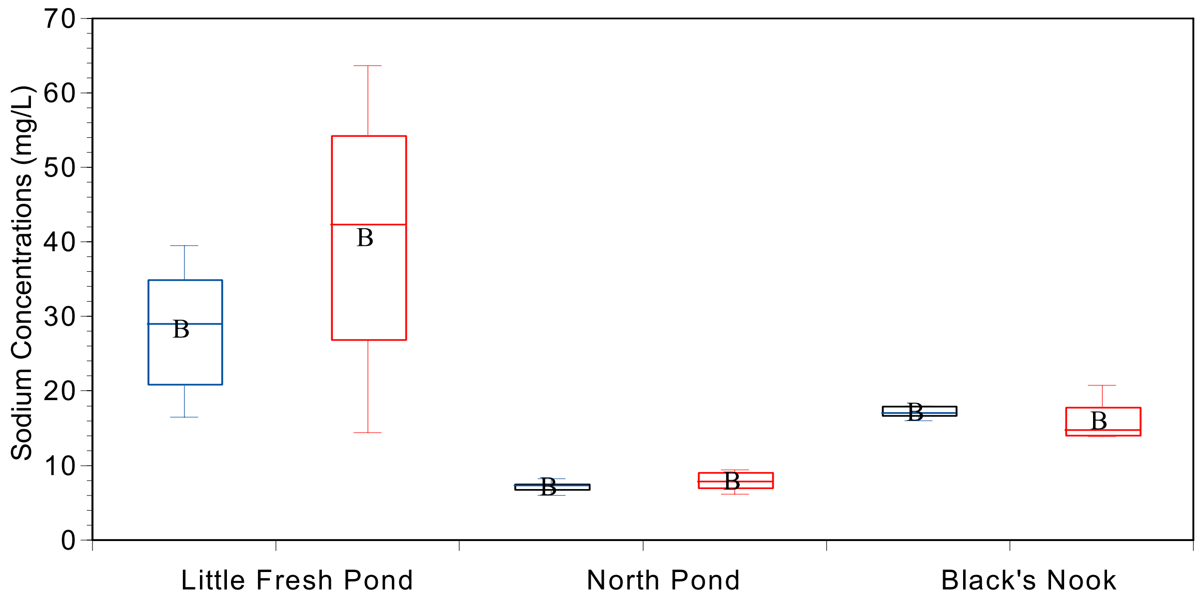
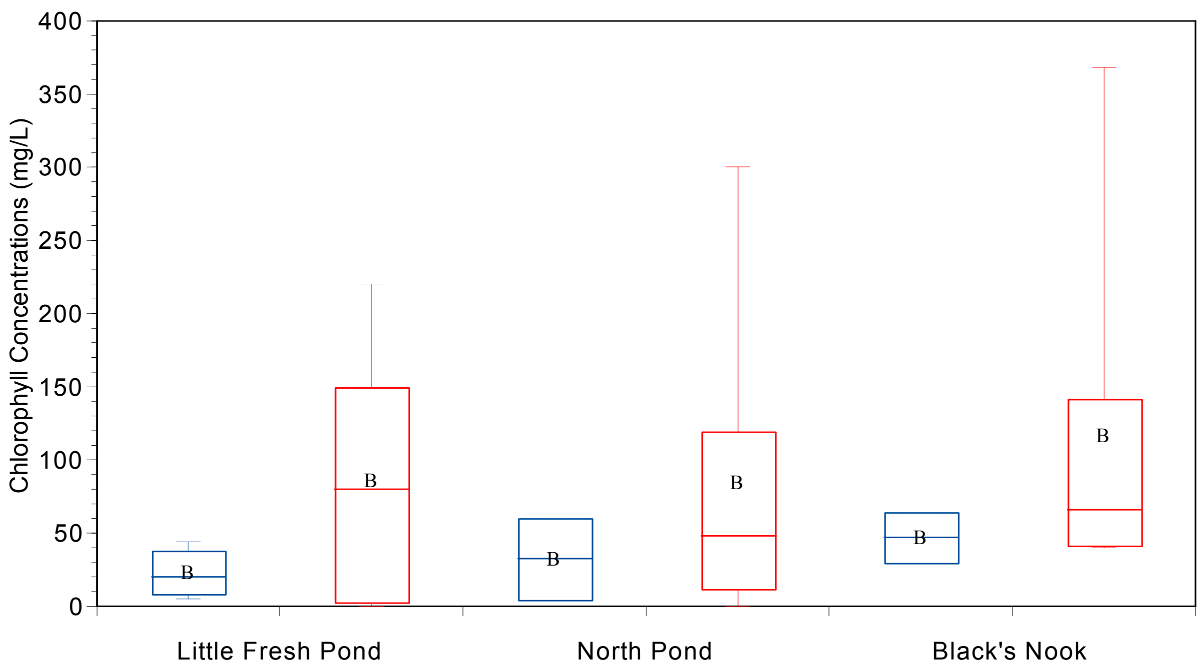
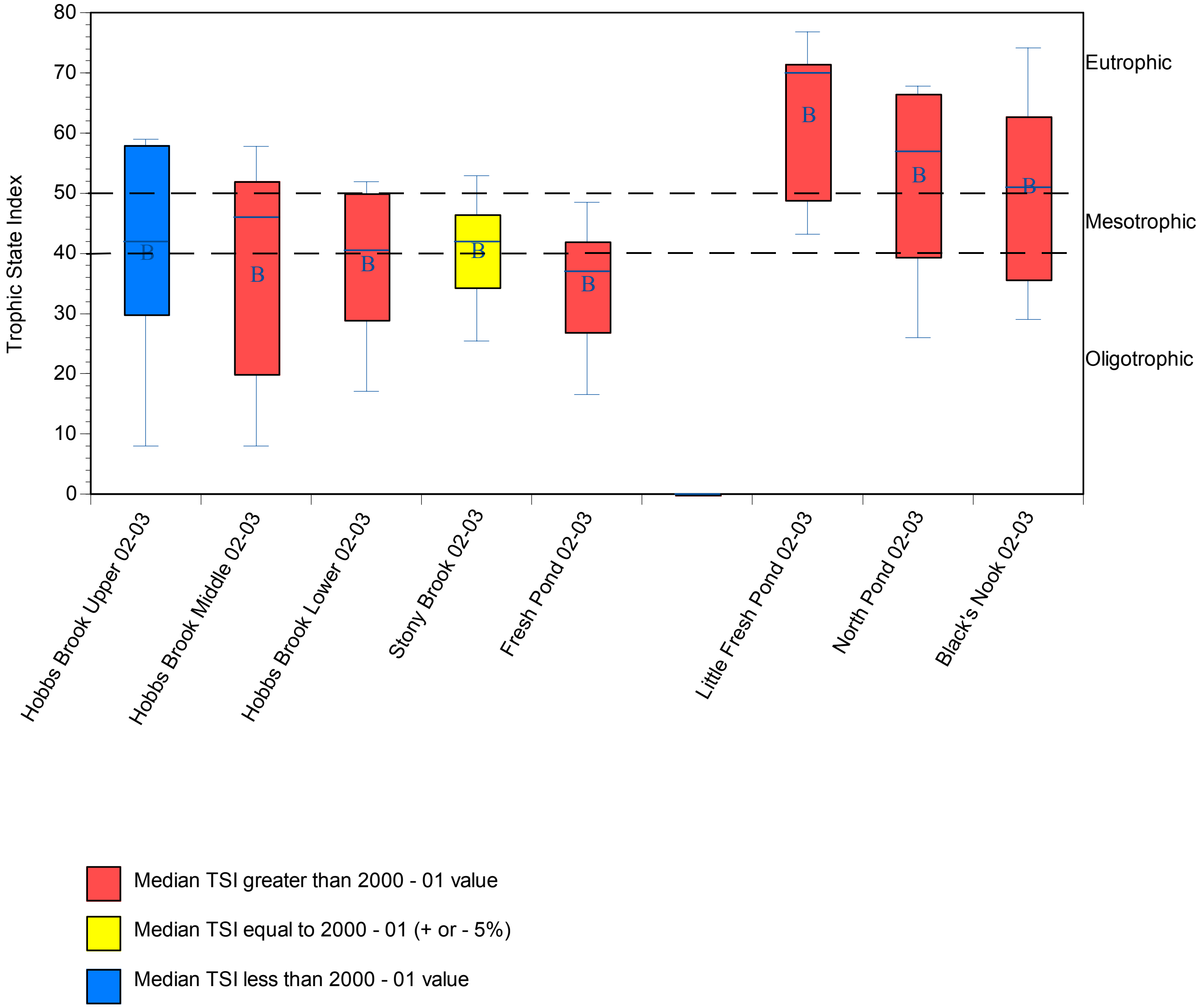


Figure 448: Fresh Pond Reservation Class B Waters - Chlorophyll Concentrations
(2000/2001 in Blue, 2002/2003 in Red)



Trophic State Index Box Chart Reservoirs and Class-B Waters

Figure 49: Surface Waters in Cambridge Source Water Area - Trophic State Index



Special Investigations Data

Table 2 - Data Table for Fecal Coliform Samples Collected at Costco drainage ditch in Waltham, MA

2002	(CFU/mgL)	2003	(CFU/mgL)
7-Feb	13300	23-Jan	590
19-Feb	4300	29-Jan	2100
21-Feb	0	19-Feb	60
26-Feb	5000	27-Feb	1200
14-Mar	8200	12-Mar	12200
20-Mar	1600	27-Mar	376
2-Apr	271	3-Apr	81
16-Apr	112	10-Apr	70
3-May	262	24-Apr	41
22-May	534	8-May	5
30-May	463	22-May	2500
13-Jun	336	29-May	800
24-Jun	1232	4-Jun	2200
2-Jul	1038	19-Jun	2500
11-Jul	284	17-Jul	272000
24-Jul	1480	24-Jul	8300
21-Aug	800	31-Jul	1300
28-Aug	240	14-Aug	500
3-Sep	400	5-Sep	TNTC
12-Sep	4	11-Sep	25000
18-Sep	1300	18-Sep	20
24-Sep	1130	2-Oct	4000
8-Oct	180	16-Oct	300
21-Oct	tntc	23-Oct	Lab Error
31-Oct	300	30-Oct	17000
6-Nov	300	6-Nov	400
13-Nov	600	13-Nov	300
5-Dec	40	20-Nov	1000
12-Dec	3500	3-Dec	900
19-Dec	8900		
Median	**534**	**Median**	**900**

Appendix B – Project Description

Monitoring Objectives

The process of designing a water-quality monitoring program begins with a clear definition of program goals and objectives (Reinelt and others, 1988). The goals then guide the entire process of program design and implementation. Ideally, the data obtained through monitoring provide an objective source of information needed to support management decisions. Specifically, an effective water-quality monitoring program will provide quantitative answers to the following questions (Intergovernmental Task Force on Monitoring Water Quality, 1995):

- What is the condition of the source water?
- Where, how, and why are water-quality conditions changing over time?
- What problems are related to source-water quality? Where are the problems occurring and what is causing them?
- Are programs to prevent or remediate problems working effectively?
- Are water-quality goals and standards being met?

The primary goal of the Cambridge drinking water source-area monitoring program is to ensure that water withdrawn from Fresh Pond for treatment is as free as possible from contaminants, thereby minimizing the costs of treatment. 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 effectiveness of programs to prevent or remediate problems;
- Ensure that all applicable water-quality goals, standards, and guidelines are being met; and
- Provide for rapid response to emerging problems.

Monitoring-Program Elements

The Cambridge source-area monitoring program consists of four major elements: (1) routine monitoring of reservoirs and tributary streams during dry weather, (2) event-based monitoring of streams, storm drains, and other outfalls during wet weather, (3) continuous recording of stage and selected water-quality characteristics at critical sites within the drainage basin, and (4) periodic monitoring of ground water in the vicinity of Fresh Pond.

Routine (Dry Weather) Surface-Water Monitoring

Dry-weather sampling is conducted at 3 primary and 6 secondary reservoir-monitoring stations, and at 11 primary and 5 secondary tributary-monitoring stations. The distinction between primary and secondary monitoring stations is based on the frequency of sampling and on the number of analyses performed on the samples.

The reservoir sampling schedule for this study (table A1) is based on the results of a USGS study which determined that monthly sampling was sufficient to characterize changes in reservoir water quality during the spring, summer, and early autumn months and that sampling every other month was sufficient during winter. At regular intervals (once each month from May through October and every other month from December through April), CWD staff measure Secchi disk transparency and depth profiles of specific conductance, pH, water temperature, turbidity, and dissolved oxygen concentration at both the primary and the secondary reservoir-monitoring stations.

Secchi disk transparency is a measure of the depth of penetration of sunlight in a reservoir. It is measured by lowering a small horizontal disk on a calibrated line and noting the depth at which it is no longer visible from the surface (Lind, 1974). In the Cambridge drinking-water source area, the Secchi disk transparency is related mainly to the abundance of phytoplankton algae in the upper mixed layers of the reservoirs which proliferate relative to nutrient abundance. Thus, Secchi depth readings provide a quick and inexpensive indicator of eutrophication problems. Water temperature, specific conductance, pH, turbidity, and dissolved oxygen concentration were measured *in-situ* with an electronic multiparameter water-quality monitoring system lowered on a cable. Depth profiles of these characteristics provide essential information on physical, chemical, and biological conditions in the reservoirs.

Reservoir Sampling Process Overview

At the three primary reservoir-monitoring stations only (fig. A1), water samples were pumped with a peristaltic pump through pre-cleaned Tygon tubing from three depths—6 ft below the surface, the depth of the thermocline (the point of maximum rate of change in water temperature with depth), and 2 to 6 ft above the bottom—when the water column was thermally stratified. Samples were dipped from below the surface of the pond when limnoligical conditions were isothermal. Water from each sampling depth was collected in accordance with clean-sampling protocols (Wilde and others, 1999) into Teflon bottles.

The samples were returned to the CWD laboratory and analyzed for color, alkalinity, and yields of major ions (sodium, calcium, chloride, and sulfate), nutrients (ammonia nitrogen, total Kjeldahl nitrogen, nitrate nitrogen, total phosphorus, and orthophosphate phosphorus), selected metals (aluminum, iron, and manganese), and phytoplankton chlorophyll-*a*, using standard methods (American Public Health Association and others, 1995). 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.

Color was measured spectrophotometrically on each sample and is primarily an indicator of the concentration of dissolved organic matter, which is abundant in source-area streams and reservoirs, and must be removed during treatment to prevent formation of organochlorine by-products. Alkalinity is a measure of the acid-neutralizing capacity of a water sample and is mainly dependent on the quantities of carbonate and bicarbonate ions. The most accurate indicator of the abundance of phytoplankton algae is the amount of particulate chlorophyll-*a* in the upper mixed layer of the reservoir. Changes in chlorophyll yields are indicative of changes in reservoir trophic state – the extent to which a water body is enriched with plant nutrients.

Nitrogen and phosphorus are plant nutrients that can, in sufficient quantities, cause algal blooms in the reservoirs and excessive growth of algae and higher plants in the streams. Ecologically significant forms of nitrogen include ammonia and nitrate nitrogen in runoff from areas that receive fertilizer applications and in wastewater discharges, and organic nitrogen produced by microbial processes. The concentration of organic nitrogen is determined by subtracting the concentration of ammonia nitrogen from that of total Kjeldahl nitrogen (TKN), therefore ammonia and TKN were analyzed in source water samples.

During each round of reservoir sampling, yields of fecal coliform bacteria were measured at the withdrawal points in all three reservoirs. The presence of fecal coliform bacteria in a water sample indicates that the water may have been contaminated with feces from humans or other warm-blooded animals. Such contamination can introduce disease- causing viruses and other potential pathogens.

Routine Tributary Monitoring Process Overview

Water entering the reservoirs is monitored at 11 primary and 5 secondary tributary-stream-monitoring stations (fig. A1). These stations represent streams that contribute water directly to the reservoirs and major tributaries, or integrate large areas of the drainage basin. Thus, the stations are important primary indicators of the condition of water likely to enter the reservoirs. Every 2 months, the CWD uses USGS methods (Rantz and others, 1982; Wilde and others, 1999) to measure stage and discharge and to assess water quality at each primary stream-monitoring station. The sampling frequency (table A1), in conjunction with continuous monitoring in each of the three reservoirs (see below), is sufficient to capture changes in water quality in time to prevent contamination problems at the water-treatment plant intake.

Specific conductance, pH, water temperature, turbidity, and dissolved oxygen concentration are measured on site and water samples are collected in accordance with clean-sampling protocols (Wilde and others, 1999) into 1-liter Teflon isokinetic samplers. Discharge-weighted, representative samples are collected from multiple vertical profiles distributed at equal distances along stream cross sections (Edwards and Glysson, 1999). The samples are then returned to the CWD laboratory for analysis of color, fecal coliform bacteria, alkalinity, total suspended solids, and yields of major ions, nutrients, and selected metals (table A1).

The five secondary stream-monitoring stations are monitored twice a year, usually during base flow and high flow. These stations are located higher up in the drainage basin on smaller tributaries or at points that discharge to the reservoirs predominantly during wet weather (fig. A1). The secondary stations are sampled biannually for the same constituents as the primary stations to provide indicators of potential changes in water quality or of base-flow conditions.

As with all samples collected during this study, each round of periodic sampling included quality-assurance samples (field and instrument blanks, duplicates, and sample splits) that represent about 10 percent of the total number of samples analyzed. Results from these analyses are out of the scope of this report, but were monitored throughout the field work component to insure that USGS quality control standards were consistently met.

Event-Based (Wet Weather) Surface-Water Monitoring

Storm-event sampling was conducted several times during this study at several sites, some of which are primary and secondary stream-monitoring stations and some of which are pipes and culverts that discharge to the reservoirs (fig. A1). 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. For this study, this goal was accomplished by manually collecting the first flush from, open tributaries, pipes, or culverts. The samples were analyzed for color, fecal coliform bacteria, alkalinity, total suspended solids, and yields of major ions, nutrients, and selected metals. These data were compared to results from routine, dry-weather monitoring in order to assess the effects of storms on introducing sediment and associated constitutent loads to the reservoirs. A detailed, multi-year stormwater study is propsoed beginning in 2002 which will provide an in-depth understanding of water quality during storm events that pass through the Cambridge Watershed.

Special Water Quality Investigations

The water quality monitoring program includes the investigation of specific point-source locations that contribute contaminants to the water supply. These locations are not tributary sampling stations, rather outfalls, or elicit discharges that enter tributaries, whose sources were detected by routine or stormwater sampling in the tributaries and traced back upstream to their specific location.

Continuous-Record Surface-Water Monitoring

Continuous (15 minute interval) monitoring is contucted at three primary tributary-monitoring stations and two secondary reservoir-monitoring stations. These stations are operated and maintained by the USGS and CWD for continuous measurement of stream and reservoir stage and temperature-corrected specific conductance. Precipitation also is monitored at two of the stations. Specific conductance, a measure of the ability of the water to conduct an electrical current, is an indicator of the yields of dissolved electrolytes in the water. The station at Hobbs Brook Reservoir and Stony Brook Reservoir also monitor stage and specific conductance of the discharges from the reservoirs. This information is uploaded on a real-time basis to the USGS internet site. The continuous stream-stage data are converted to discharge by the use of stage-discharge relations (Rantz and others, 1982) and the specific conductance records are converted to yields of sodium, calcium, and chloride in a similar fashion (Granato and Smith, 1999). Late in 2001, a more elaborate water quality monitoring system was installed at Stony Brook which measures pH, specific conductance, turbidity, temperature, and dissolved oxygen. Data from several additional continuous monitoring stations is anticipated to be accessible on the Internet by late 2002.

Data Management, Interpretation, Reporting, and Review

The monitoring and quality-assurance data were entered into a database, maintained by the CWD as part of this study, that enables the CWD analyze, track, and report changes in water quality efficiently. Monitoring was conducted by CWD staff with technical support from the USGS. USGS methods and protocols were used in the program so that results may be compared to baseline data collected by the USGS during water year 1998. This report was reviewed by a Technical Advisory Committee that includes members from the Cambridge academic community and a Watershed Advisory Committee composed of representatives from Cambridge, Waltham, Weston, Lexington, and Lincoln.

The CWD also conducts special investigations of water-quality-related problems and situations within the source area. Such investigations may include intensive monitoring at present water-quality-monitoring stations where increasing trends in contaminant loading have been noted, monitoring at locations where a known disturbance is taking place, and monitoring to assess the effectiveness of new management practices or infrastructure. These investigations frequently require analysis of a variety of constituents and water- quality related properties.

Table A-1 Water Quality Monitoring Schedule

Event Sites (3 times a year)

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

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

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

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