New York City Environmental Protection

2013 Watershed Water Quality Annual Report

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Emily Lloyd, Commissioner
Paul V. Rush, P.E., Deputy Commissioner
Bureau of Water Supply

Cover photo taken by Lori Froehlich, NYCDEP

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Acknowledgements

This report provides a summary of the scientific work conducted in 2013 to manage the water quality of the NYC water supply and to provide information for regulatory agencies and the general public. Commissioner of the Department of Environmental Protection, Ms. Emily Lloyd, provided oversight of the Department at the time this report was issued. Mr. Carter H. Strickland, Jr., Commissioner, and Mr. Paul Rush, P.E., Deputy Commissioner of the Bureau of Water Supply, provided guidance of the Department and the Bureau throughout 2013, with emphasis on operational excellence and compliance. Director of the Water Quality Directorate (WQD), Mr. Steven Schindler, continued to provide oversight and direction for WQD’s many activities. Dr. Lorraine Janus, Chief of Watershed Water Quality Science and Research (WWQSR), planned, coordinated production, and participated as an author of this report. Ms. Lori Emery, Chief of Watershed Water Quality Operations (WWQO), provided oversight of the watershed field and laboratory operations and quality assurance. WWQO staff were responsible for conducting water quality monitoring and developing the database presented here, while WWQSR staff were responsible for data analysis, interpretation, and report production.

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described objectives and DEP involvement in some important projects that enhance DEP's water quality management capabilities.

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Executive Summary

Watershed Monitoring

This report provides summary information about the 19 reservoirs, 3 controlled lakes, streams, and aqueducts that comprise the New York City drinking water system. It is an annual report that provides the public, regulators, and other stakeholders with a general overview of the City’s water resources and their condition during 2013. This report is complementary to the “New York City 2013 Drinking Water Supply and Quality Report,” which is distributed to consumers annually to provide information about the quality of the City’s tap water. Thus the two reports together document water quality from its source to the tap. DEP publications are accessible through the DEP website at http://www.nyc.gov/dep/.

Water quality samples were taken at the reservoirs, streams, and aqueducts throughout the watershed in order to: (1) demonstrate regulatory compliance, (2) guide operations to provide the highest quality drinking water to the City, (3) demonstrate the effectiveness of watershed protection measures, and (4) provide data for modeling predictions. In 2013, nearly 17,000 samples (resulting in approximately 214,000 analyses) were taken at 439 sites. In addition to these grab samples, continuous and robotic monitoring systems were in place to ensure well-informed operation of the system.

Water Quantity

The NYC Water Supply System is dependent on precipitation and subsequent runoff to supply the reservoirs in each of the three watersheds, Catskill, Delaware, and Croton. Overall, the total precipitation in the watershed for 2013 was 1,032 mm (40.6 inches), which was 117 mm (4.6 inches) below normal. However, the summer period (June-August) had above average precipitation, with a significant rainfall event in early June. Although overall precipitation in the watershed for the year was somewhat below the normal historical values, the annual runoff was generally near normal, i.e., between the 25th and 75th percentile ranking. The United States Geological Survey (USGS) also reported that New York State had near normal annual runoff for the 2013 water year (October 1, 2012-September 30, 2013), but was much above normal in the southeastern region of New York in June. Systemwide usable storage levels in the reservoir system began the year slightly higher than normal. Levels were near normal in late spring, but the summer storms brought levels back above normal, where they remained for much of the year until returning to near normal levels in late fall when year-end storms once again brought storage above normal going into 2014.

Water Quality

In 2013, turbidity levels were normal to below normal in most reservoirs of the New York City Water Supply System. Above normal levels at Schoharie and Neversink were attributed to lingering effects of storms from the last quarter of 2012 and to several localized large rain events in

2013. Schoharie also experienced large daily oscillations in turbidity (i.e., changes of up to 100 NTU) in its effluent water between July and September in 2013. DEP determined that the oscillations were the result of seiche activity acting on particles within the reservoir. Seiches (internal waves), generally caused by winds piling up surface water on one side of a reservoir, have been observed at Schoharie in the past. Turbid interflows from storms in June and sediments recently deposited in the vicinity of the Schoharie Intake chamber were the likely sources of the turbidity-causing particles.

Fecal coliform counts were normal to below normal at all reservoirs except Schoharie. Elevated counts at Schoharie were associated with rain events in June and August. All terminal reservoirs had fecal coliform counts that were well below the Surface Water Treatment Rule 10% threshold and met the criteria for non-restricted basins for both six-month assessment periods in 2013. Annual median total coliform counts were below normal at all reservoirs in 2013. However, total coliforms did exceed the assessment standards (Part 703) for at least one month in 6 of 17 non-terminal reservoirs.

Total phosphorus concentrations were generally normal to low in the Catskill and Delaware System reservoirs. Only West Branch was higher than usual, likely the result of its operational status in 2013. Most Croton System reservoirs were normal to below normal in 2013. Storm events in May and June and internal loading from anoxic sediments during summer months were probable factors for higher than usual concentrations observed at five Croton System reservoirs. The phosphorus-restricted calculations indicated that all basins associated with the Catskill/Delaware System (including West Branch and Kensico) and one basin in the Croton System (Boyd Corners) were non-restricted in 2013. Restricted basins included 13 of 14 Croton System reservoirs.

Trophic state indices (TSI) based on chlorophyll *a* were relatively low for Catskill reservoirs compared to their historical ranges. Turbidity was responsible for the decrease in TSI in Schoharie, while low nutrient concentrations resulted in lower TSI for the Ashokan basins. Most Delaware reservoirs were within normal limits in 2013, as was Kensico Reservoir. However, West Branch was borderline eutrophic due to its operational status in 2013. Most reservoirs of the Croton System were well below their historical medians, and New Croton, the terminal reservoir for the Croton System, achieved its lowest trophic status since 2003.

Additional reservoir analytes were evaluated against benchmarks in 2013. Most notably, as in 2012 all chloride samples in New Croton exceeded the Croton System benchmarks of the 40 mg L^{-1} single sample maximum standard and the annual mean standard of 30 mg L^{-1} in 2013. Likewise, all chloride samples in West Branch when compared to the Catskill/Delaware System standards exceeded the single sample maximum of 12.00 and annual mean standard of 8.00 mg L^{-1}.

Major input streams to the reservoirs were sampled at least monthly in 2013. The turbidity levels were generally near "normal" values, except for the Schoharie Creek inflow (S5I), which was somewhat elevated for the year (the second highest annual median in the last 10 years for Schoharie Creek). The annual median turbidities for the EOH inflows were all near or slightly below their historical values. In the Catskill/Delaware Systems, the 2013 median total phosphorus (TP) concentrations were generally near or slightly below their historical values, except for Rondout near Lowes Corners (RDOA), which was slightly above normal with the same annual TP median as 2012. The 2013 TP medians in the Croton System were varied, with the 2013 TP median at the inflow of East Branch at its highest value in the past 10 years. Cross River's 2013 TP value was slightly elevated above the normal historical values, and Hunter Creek, an inflow to New Croton, was slightly below its historical values. The 2013 median fecal coliform bacteria levels in Catskill/Delaware streams were generally near or somewhat below typical historical levels, except for Schoharie, which was at its highest annual median over the last 10 years. For the Croton Reservoir inflows, the annual fecal coliform levels were near normal for East Branch and the two inflows to Croton, while the inflow to Amawalk was somewhat below its typical annual median. Cross River was at its lowest fecal coliform value over the last 10 years, while the Boyd Corners inflow was at its highest value.

Additional analytes (alkalinity, sodium, chloride, total dissolved solids, sulfate, ammonia, and nitrate) measured at the major inputs and 28 smaller tributaries in 2013 were compared to benchmarks. With the exception of Kramer Brook in the Neversink basin, few exceedances were observed in the Catskill and Delaware streams. In the Croton System, sodium, chloride, and total dissolved solids benchmarks were frequently exceeded in most streams, likely because of the long-term use of road salt to maintain the relatively high road density of this area. Streams that exceeded benchmarks for nitrate and/or ammonia included Michael Brook in the Croton Falls basin, the Kisco River above New Croton Reservoir, and the Muscoot River above Amawalk Reservoir.

Water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages were also used to assess water quality in 2013. Assessments are made following protocols developed by the New York State Stream Biomonitoring Unit. In the Catskill System, 14 sites were non-impaired and five were slightly impaired, while in the Delaware System, five sites were non-impaired and five slightly impaired. Five impaired sites is a somewhat higher number than usual for the Delaware System. Most Catskill/Delaware sites were below their long-term means, which is also unusual. In the Croton System, one site (Stone Hill River, Site 142) was non-impaired, eight were slightly impaired, and two were moderately impaired. The high percentage of impaired sites is typical of the Croton System (e.g., 2008—84.6%, 2009—78.6%, 2010—100%, 2011—84.6%, 2012—100%).

Kensico Reservoir

Kensico Reservoir is the terminal reservoir for the City's Catskill/Delaware water supply. Because it is the last impoundment of Catskill/ Delaware water prior to entering the City's distribution system and is a key location prior to disinfection, monitoring is done at its highest frequency here. As an unfiltered surface water supply, New York City's Catskill/Delaware System must meet strict requirements for turbidity and fecal coliform concentrations set forth in the federal Surface Water Treatment Rule (SWTR). In 2013, four-hourly sampling of untreated (raw) water turbidity at site DEL18DT, the effluent keypoint for water leaving Kensico and moving toward the distribution system, had a maximum recorded value of 2.2 NTU. Only one sample from DEL18DT exceeded the 20 fecal coliform 100 mL^{-1} threshold in 2013. This occurred on September 13 following nearly three inches of rainfall. The 2013 water quality data also demonstrated that the Waterfowl Management Program continued to be instrumental in keeping coliform bacteria concentrations well below the limits set by the SWTR. Water quality from the influents to Kensico from the Catskill/Delaware System as well as from the stream inputs was generally good in 2013 with only one special investigation occurring due to a storm event. This happened in June 2013 when a series of three storm events totaling 6.01 inches of rain occurred within a nine-day period, which triggered additional storm event monitoring. Overall, the storm had little impact on the water leaving Kensico, with turbidity remaining less than 1.2 NTU and fecal coliforms not exceeding 7 coliforms 100mL^{-1}. Other activities at Kensico included biweekly inspections of the turbidity curtain located near the Catskill Effluent; a survey for bryozoans, that have the potential to cause clogging issues at the Catskill/Delaware UV plant; and forest restoration projects designed to improve aesthetics, safety, and soil stability following extensive wind damage caused by Hurricane Sandy in 2012. During 2013, DEP also continued a scientific collaboration with the Harvard School of Public Health. One project, "Modeling the Influence of Variable Tributary Inflow on Circulation and Contaminant Transport", provided insight into how a theoretical tracer, that mimics stream and stormwater, flows through Kensico, which may help to guide operations. Overall, water quality at Kensico during 2013 was excellent.

Pathogen Monitoring and Research

DEP collected 485 samples for protozoan analysis and 171 samples for human enteric virus (HEV) monitoring in 2013. Most samples were collected at keypoint locations and watershed streams, with additional samples collected at upstate reservoir effluents, Hillview Reservoir, and wastewater treatment plants (WWTPs). *Giardia* cysts continued to be detected at higher frequencies and concentrations in the watershed compared to *Cryptosporidium* oocysts. For the two-year period from January 1, 2012 to December 31, 2013, DEP source water continued to be well below the LT2 *Cryptosporidium* threshold for additional treatment at an unfiltered water supply (0.010 oocysts L^{-1}), with a mean of 0.0000 oocysts L^{-1} at the Delaware effluent site, and 0.0008 at the New Croton Reservoir effluent. For the second year in a row, no *Cryptosporidium* oocysts were detected leaving Kensico Reservoir at the Delaware effluent. The Delaware Aqueduct leaving Kensico Reservoir, however, did have more detections of *Giardia (*30) than those at the influent sites (Catskill influent 27 detections, Delaware influent 22 detections).This higher rate of detection is likely a result of the combination of input from the influents and additional *Giardia* contributions from the local Kensico watershed. Overall, protozoan concentrations leaving the upstate reservoirs and Kensico Reservoir were lower than levels at the stream sites that feed these reservoirs, suggesting a reduction as water passes through the system. There was one detection of *Giardia* cysts at a WWTP; however, there were no *Cryptosporidium* oocysts detected at any plants in 2013. As per the Hillview Administrative Order, DEP continued weekly protozoan monitoring at the Hillview Reservoir outflow (Site 3) through 2013, with 52 weekly samples collected. Of the 52 samples taken, there were 18 detections of *Giardia* and 2 detections of single *Cryptosporidium* oocysts.

Water Quality Modeling

DEP uses models to examine how changes in land use, population density, ecosystem processes and climate, as well as both watershed and reservoir management policies, affect the NYC drinking water supply. Changing conditions in the watersheds present both ongoing and new challenges that DEP must plan for and respond to in its mission to ensure the continued reliability and high quality of the NYC drinking water supply. DEP uses models to simulate and forecast changes in reservoir water quality related to watershed management, climate change, and short-term episodic events. Such simulations are critical for decision making, long-term planning, and management of the NYC watersheds and reservoir system.

Storm-generated turbidity in the NYC water supply watersheds—particularly in the Catskill System comprised of the Schoharie and Ashokan Reservoirs—is an important water quality issue that may constrain the operation of the NYC Water Supply. During 2013, there were three periods during which modeling analyses helped inform operational decisions. Simulations using the DEP Operations Support Tool (OST), and its component models, were used to understand the possible timing and magnitude of the expected peak turbidity in Ashokan Reservoir; the use of the Ashokan Release channel to mitigate the impacts of turbid inputs, and to predict optimal withdrawal from the Catskill and Delaware Systems needed to maintain acceptable turbidity in the Kensico Reservoir effluents.

Looking at a longer planning horizon, water quality modeling was used to evaluate the potential impact of climate change on water supply storage operation and water quality. The first phase of DEPs Climate Change Integrated Modeling Project (CCIMP) came to a close during 2013 with a workshop and evaluation by outside experts from the fields of hydrology, limnology, climate science, and civil engineering. The review was positive, and also led to a number of useful suggestions for future phases of the CCIMP. In particular it was recognized that future changes in the internal and external loading of dissolved organic carbon (DOC) to the reservoirs could result in water quality concerns associated with disinfection by-products (DBP). Following this recommendation, the water quality modeling group began a long-term evaluation of its modeling capabilities to simulate reservoir DOC and DBP formation potential, with the goal of eventually improving DEP’s ability to simulate DOC export from reservoir watersheds, DOC production within the reservoirs, and the transformation of DOC to DBP. During 2013, progress was also made in simulating the effects of climate change on reservoir thermal structure and phytoplankton community dynamics. Simulations suggest that warmer water temperature and longer and more stable thermal stratification could favor cyanobacteria under future climate conditions.

Further Research

DEP uses contracts and participates in research projects to extend its monitoring and data analysis capabilities where unique expertise may be required. In 2013, there were seven water quality-related contracts in place. They addressed bathymetry of the six Catskill/Delaware reservoirs, laboratory analysis of unusual compounds, microbial source tracking, and macroinvertebrate identification. The USGS provided operation and maintenance of stream gauges and monitoring of turbidity in Esopus Creek. A contract with the City University of New York has provided post-doctoral positions that have supported modeling work in climate data analysis, reservoir system modeling, watershed modeling, and forest ecosystem modeling. This contract led to improved modeling tools and future climate scenarios for modeling-based evaluations of climate change impacts. The Waterfowl Management Program contract (to keep coliform bacteria in check) requires staffing of up to 34 contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. Other contracts assisted in monitoring for the presence of potentially problematic organisms such as zebra mussels and bryozoans.

DEP participated in several Water Research Foundation (WRF) projects on water quality related to climate change impacts and assessments of vulnerability, dynamic reservoir operations, and algal bloom potential. Another project explored constituents of emerging concern (CECs). These projects give DEP an awareness and insight into potential future challenges to be considered in long-term planning.

1. Introduction to Watershed Monitoring

This report provides summary information about the watersheds, streams, and reservoirs that are the sources of New York City's drinking water. It is an annual report that provides the public, regulators, and other stakeholders with a general overview of the City's water resources, their condition during 2013, and compliance with regulatory standards. It also provides information on operations and the use of water quality models for management of the water supply. It is complementary to the New York City 2013 Drinking Water Supply and Quality Report (http://www.nyc.gov/html/dep/pdf/wsstate13.pdf), which is distributed to consumers annually to provide information about the quality of the City's tap water. Thus the two reports together document water quality from its source to the tap. More detailed reports on some of the topics described herein can be found in other DEP publications, accessible through the DEP website at http://www.nyc.gov/dep/.

Figure 1.1 The New York City Water Supply System.

The New York City Water Supply System (Figure 1.1) supplies drinking water to almost half the population of the State of New York, which includes over eight million people in New York City and one million people in upstate counties, plus millions of commuters and tourists. New York City's Catskill/Delaware System is one of the largest unfiltered surface water supplies in the world. The City's water is supplied from a network of 19 reservoirs and 3 controlled lakes that contain a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The total watershed area for the system is approximately 5,100 square kilometers (1,972 square miles), extending over 200 kilometers (125 miles) north and west of New York City. This resource is essential for the health and well-being of millions and must be monitored, managed, and protected for the future. The mission of the Bureau of Water Supply (BWS) is to reliably deliver a sufficient quantity of high quality drinking water to protect public health and the quality of life of the City of New York.

1.1 Water Quality Sampling

1.1.1 Grab Sampling

Water quality of the reservoirs, streams, and aqueducts is monitored throughout the watershed in order to demonstrate regulatory compliance, guide operations to provide the highest quality drinking water to the City, demonstrate the effectiveness of watershed protection measures, and provide data for modeling predictions. Much of these data are acquired via manual, or "grab sample", monitoring, in accordance with the Watershed Water Quality Monitoring Plan (DEP 2009). This document is DEP's comprehensive plan that describes what, when, where, and why water quality samples are taken throughout the watershed.

A summary of the number of grab samples and analyses that were processed in 2013 by the four upstate laboratories, and the number of sites that were sampled, is provided below in Table 1.1. The sampling effort for the distribution system is also listed for completeness; however, the discussion here is based on the results from samples taken throughout the upstate watershed.

Table 1.1: Number of grab samples collected, water quality analyses performed, and sites visited by DEP in 2013.

System/Laboratory	Number of samples	Number of analyses	Number of sites
Catskill/Kingston	3,361	63,684	125
Delaware/Grahamsville	3,951	45,904	116
East of Hudson/Kensico	8,435	96,190	131
East of Hudson/Brewster	1,189	8,205	67
Watershed	16,936	213,983	439
Distribution	30,938	354,048	1,000
Total	47,874	568,031	1,439

1.1.2 Robotic Monitoring

In addition to grab sampling, DEP collects a variety of data via automatic electronic devices through its Robotic Water Quality Monitoring Network (RoboMon). This program is a relatively new enhancement to DEP's monitoring capability and complements the continuous monitoring instrumentation at keypoints on the aqueducts. It was previously run under contract but has been operated by DEP since 2012. This new and growing network allows water quality to be monitored at high frequency in streams and reservoirs and allows DEP to make any operational changes as needed and without delay. The high-frequency monitoring data provided by the RoboMon also facilitates effective management of storm events, provides input to water quality models (e.g., the Operations Support Tool), offers insight into how substances travel through the reservoirs and aqueducts, and ensures timely communication of data to decision makers.

The RoboMon network employs two types of buoys, fixed-depth buoys and profiling buoys, the latter capable of moving sensors from the surface to the bottom in order to obtain measurements throughout the entire water column. Solar panels provide power to run the meters and data are either manually downloaded or transmitted via radio signals. At regular intervals, the DEP database in Kingston imports the latest data from each monitoring location, and these data are then internally viewable through a custom Web application. In some cases, near-real-time data are available within three minutes of the field reading. The Web application includes the ability to display data and comments as appropriate.

There were two fixed-depth buoys deployed on Kensico Reservoir in 2013, one near the Delaware Aqueduct intake and the other about midway between the Delaware Aqueduct intake and Malcolm Brook. Each buoy has three transmissometers suspended at 5, 10, and 15 meters in the water column to provide near-real-time estimates of turbidity. Data are recorded in 15-minute intervals and are used to determine trends in turbidity and assist with operational decisions at Delaware Shaft 18.

Four profiling buoys were deployed in 2013, as follows: two on the West Basin of Ashokan Reservoir, one on the East Basin of Ashokan Reservoir, and one on Kensico Reservoir. These buoys perform full water column profiles up to every six hours, with sensors measuring temperature, turbidity, and specific conductivity. Additionally, one West Basin buoy and the Kensico buoy are outfitted with meteorological stations.

Automated stream monitoring stations are located at Esopus Creek near Coldbrook in the Catskill System and in the Delaware System at Rondout Creek near Lowes Corners. These stations continuously monitor water temperature, specific conductivity, and turbidity. In September 2013, a third stream monitoring station was added on the Neversink River adjacent to the USGS gauge station to monitor turbidity and temperature only.

Due to the success of the RoboMon program, additional profiling buoys are being purchased for Rondout, Neversink, Schoharie, and Kensico Reservoirs, with deployment expected in the summer of 2014. In addition, DEP will deploy under-ice buoys specifically designed to monitor water quality during ice cover at Ashokan Reservoir. The under-ice buoys are tentatively scheduled for deployment at the end of 2014. Finally, enhancements to the existing RoboHut on the Neversink River and the buoy on Neversink Reservoir, as well as the installation of a new buoy on Cannonsville Reservoir, will provide additional data (chlorophyll *a* and colored dissolved organic matter (CDOM)) that it is hoped will improve DEP's reservoir carbon load estimates and ultimately improve DEP's understanding of the factors that influence disinfection by-product formation potential. These enhancements are expected to be installed in late 2014 or early 2015.

1.2 Operations in 2013 to Control Turbidity and Fecal Coliforms

Tropical Storm Sandy passed through the region in late October 2012, leaving a tremendous amount of wind damage in its wake. The storm made BWS aware that the shoreline adjacent to Delaware Aqueduct Shaft 18 could become a source of turbidity if strong winds emanated from easterly or northeasterly directions, as it did during Sandy. While DEP experienced no significant storms in 2013, weather forecasts occasionally predicted high winds from the east or northeast, and BWS proactively instituted operational changes to minimize any adverse impact. When weather forecasts predicted sustained easterly or northeasterly winds in excess of 15 mph, the mode at Delaware Aqueduct Shaft 18 was changed from direct reservoir-only withdrawal to “float” mode. Float mode operation brings water from West Branch Reservoir (via the Delaware Aqueduct Kensico By-pass Tunnel) directly to the downtake at Shaft 18 and minimizes the amount of water drawn from Kensico Reservoir. Float mode operation in anticipation of strong winds occurred 14 times in 2013. One additional instance of changing from reservoir to float mode occurred due to concerns regarding elevated fecal coliforms due to storm runoff into Kensico Reservoir.

In the Catskill System, the elevation of withdrawal at Ashokan Reservoir was adjusted throughout the year, as necessary, to draw the best quality water (i.e., low turbidity, low coliforms) from the reservoir and to meet operational needs. In the first six months of the year the best quality water was available in the surface waters of the reservoir’s East Basin. A blend of both East and West Basin waters was utilized from July through October. In November, water was transferred through the gatehouse from the West Basin to the East Basin to help equalize the basin elevations. In early December, diversion of water was solely from the West Basin, and by the end of that month diversion of water into the Catskill Aqueduct had returned to the east side at a low elevation of withdrawal. DEP also used the Ashokan Reservoir release works (which discharges water to lower Esopus Creek) as specified in the Interim Release Protocol for Ashokan Reservoir. Release waters are generally taken from the bottom of the West Basin, but elevation and basin can be changed when quality and volume conditions allow. The release of waters from the reservoir to the lower Esopus Creek occurred for spill mitigation in the early part of the year, and throughout the year as per the requirement for community releases.

In the Delaware System, selective withdrawal was also used to deliver the best quality water to the distribution system. In June, the elevation of withdrawal at Rondout Reservoir was changed from an upper withdrawal elevation to a lower level withdrawal to divert less turbid waters toward distribution. In September, the elevation of withdrawal at Cannonsville Reservoir was raised from the middle of the water column to the surface, again, to avoid more turbid waters further down in the water column.

The subsequent chapters of this report provide background information and present the analysis and interpretation of the data collected under the watershed monitoring plan. Water quantity (Chapter 2) is discussed first, because of its influence on operations and water quality. Next, water quality results are presented (Chapter 3), followed by a chapter on Kensico Reservoir (Chapter 4) that describes some programs unique to Kensico because of its importance as the site where “raw water” (i.e., untreated water just prior to distribution) is tested for compliance with fecal coliform bacteria and turbidity regulations. This is followed by a chapter specifically on pathogen monitoring (Chapter 5), which requires specialized collection techniques and is a prominent requirement for an unfiltered water supply. The modeling chapter (Chapter 6) describes how much of the information that DEP collects is integrated, how it is used to guide operations, and how it provides insight into possible future conditions. Finally, Chapter 7 is devoted to outlining the contracts and research projects that DEP uses to extend its monitoring and analysis capabilities where unique expertise may be required.

2. Water Quantity

2.1 The Source of New York City's Drinking Water

New York City's water is supplied by a system consisting of 19 reservoirs and 3 controlled lakes with a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The system's watershed drains approximately 5,100 square kilometers (1,972 square miles) (Figure 1.1). The system is dependent on precipitation (rainfall and snowmelt) and subsequent runoff to supply the reservoirs in each of three watershed systems, Catskill, Delaware, and Croton. The first two are located West of Hudson (WOH), while the Croton System is located East of Hudson (EOH). As the water drains from the watershed, it is carried via streams and rivers to the reservoirs. The water is then moved via a series of aqueducts to terminal reservoirs before it reaches the distribution system. The hydrologic inputs affect the nutrient and turbidity loads and the outputs affect the hydraulic residence time, both of which can influence the reservoirs' water quality.

2.2 2013 Watershed Precipitation

The average precipitation for each watershed was determined from daily readings collected from a network of precipitation gauges located in or near each watershed. The total monthly precipitation is the sum of the daily average precipitation values calculated for each reservoir watershed. The 2013 monthly precipitation total for each watershed is plotted along with the historical monthly average in Figure 2.1.

The total monthly precipitation figures show that in general precipitation was below normal for the first four months of 2013. May had near average precipitation in the Cannonsville, Neversink, Rondout, and Ashokan watersheds, and above average precipitation in Pepacton, Schoharie, and the Croton watersheds. June had above average precipitation in all watersheds, with well above average precipitation in Neversink, Rondout, Ashokan, and Croton. August also was above average in all watersheds except Croton, which was below average. Neversink, in particular, was well above average for August. September precipitation was below normal for all watersheds except Cannonsville, which was near normal. Likewise, in October precipitation was below normal in all watersheds except Rondout and Schoharie, which were near normal. Precipitation in November was again below normal in all watersheds. December had mixed results, ranging from near average in Cannonsville and Neversink to above average in Pepacton and Rondout, and below average in Schoharie, Ashokan, and Croton. Overall, the total average precipitation across the watershed for 2013 was 1032 mm (40.6 inches), which was 117 mm (4.6 inches) below normal.

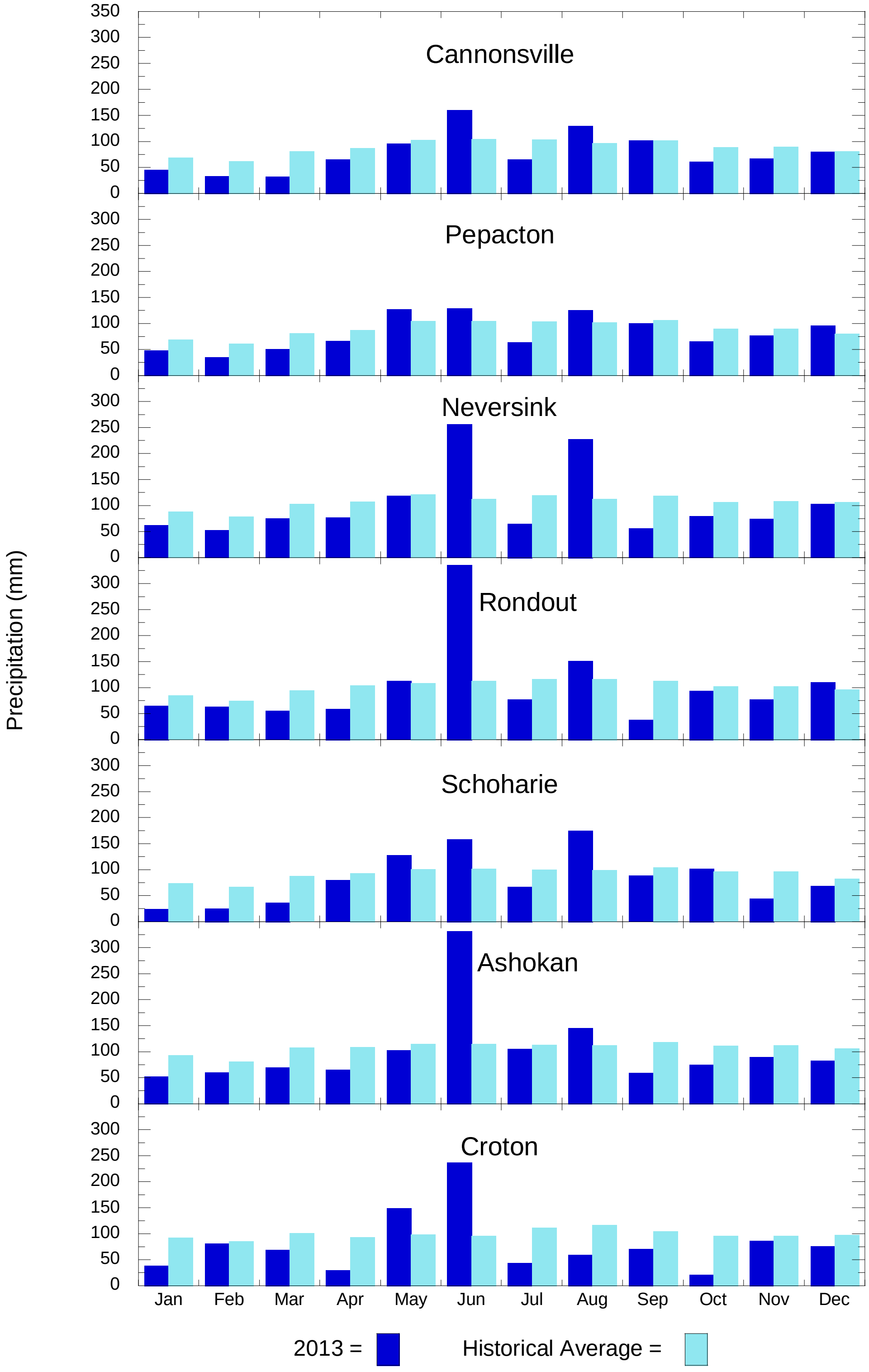


Figure 2.1 Monthly precipitation totals for New York City watersheds, 2013 and historical values.

The National Climatic Data Center's (NCDC) climatological rankings (http://www.ncdc.noaa.gov/temp-and-precip/climatological-rankings/) were queried to determine the 2013 rankings for New York. It should be noted that in March 2014 the NCDC transitioned from its traditional climate divisional dataset to a new divisional dataset, which is based on observations using a 5-km gridded approach. Also, new methodologies that use a grid-based calculation were instituted to compute temperature and precipitation values. While these changes will improve data coverage and quality, it will result in some differences with previously reported results. (See https://www.ncdc.noaa.gov/monitoring-references/dyk/climate-division-database-transition for additional information on this change.) In contrast to the precipitation in the NYC watersheds discussed above, overall precipitation for New York State was above normal in 2013 (26th wettest in the last 119 years). Winter precipitation (December 2012-February 2013) was above normal (33rd), while spring (March-May) and fall (September-November) totals were near normal, and the 2013 summer period (June-August) was one of the wettest years on record (4th wettest in the last 119 years). Also, the average temperature for 2013 was above normal for New York (23rd warmest over the past 119 years).

2.3 2013 Watershed Runoff

Runoff is defined as the portion of the total rainfall and snowmelt that flows from the ground surface to a stream channel or directly into a basin. The runoff from the watershed can be affected by meteorological factors such as type of precipitation (rain, snow, sleet), rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the drainage basin, direction of storm movement, antecedent precipitation and resulting soil moisture, and temperature. The physical characteristics of the watersheds also affect runoff. These include land use; vegetation; soil type; drainage area; basin shape; elevation; slope; topography; direction of orientation; drainage network patterns; and ponds, lakes, reservoirs, sinks, and other features of the basin which prevent or alter runoff. The annual runoff coefficient is a useful statistic to compare the runoff between watersheds. It is calculated by dividing the annual flow volume by the drainage basin area, yielding a depth that would cover the drainage area if all the runoff for the year were uniformly distributed over the basin. This statistic allows comparisons to be made of the hydrologic conditions in watersheds of varying sizes.

Selected USGS stations were used to characterize annual runoff in the different NYC watersheds (Figure 2.2). The annual runoff in 2013 was near normal for all sites (i.e., the 2013 values fell within the interquartile range of the historical values). The period of record for the WOH stations ranges from 50 years at the Esopus Creek Allaben station to 107 years at the Schoharie Creek Prattsville gauge. The EOH stations have an 18-year period of record, except for the Wappinger Creek site (85-year period of record). (Wappinger Creek is not located in the EOH System, but is included here because it is located in nearby Dutchess County, and its longer period of record is more comparable to those found in the WOH System.) New York State had near normal runoff (43rd out of the last 113 years) for the 2013 water year (October 1, 2012-September 30, 2013), as determined by the USGS (http://waterwatch.usgs.gov/index.php?r=ny&m=statesum). However, monthly average streamflow in the southeastern region of New York State was much above average in June.

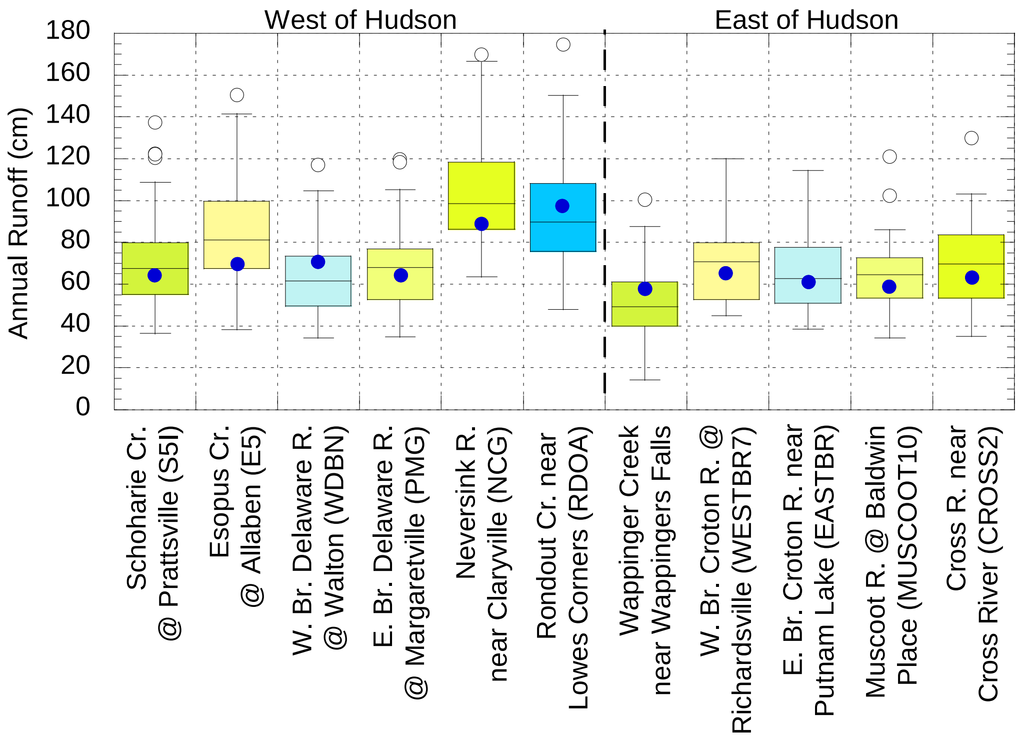


Figure 2.2 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds, with the values for 2013 displayed as a dot.

Figure 2.3 shows the 2013 mean daily discharge, along with the minimum, maximum, and median daily discharge for the period of record, for the same USGS stations that were used to characterize annual runoff. Overall, discharge was near normal for most of the year with the exception of elevated flows throughout the system in July. In the WOH streams most stations showed a spike in flows in early August. The West Branch and East Branch of the Delaware River also had elevated flows in September. For EOH stations, there were several spikes in flow observed throughout the year, in addition to the high flows in June. Flows in EOH were generally below normal in October and November until a late November storm caused EOH flows to return to near normal levels in December.

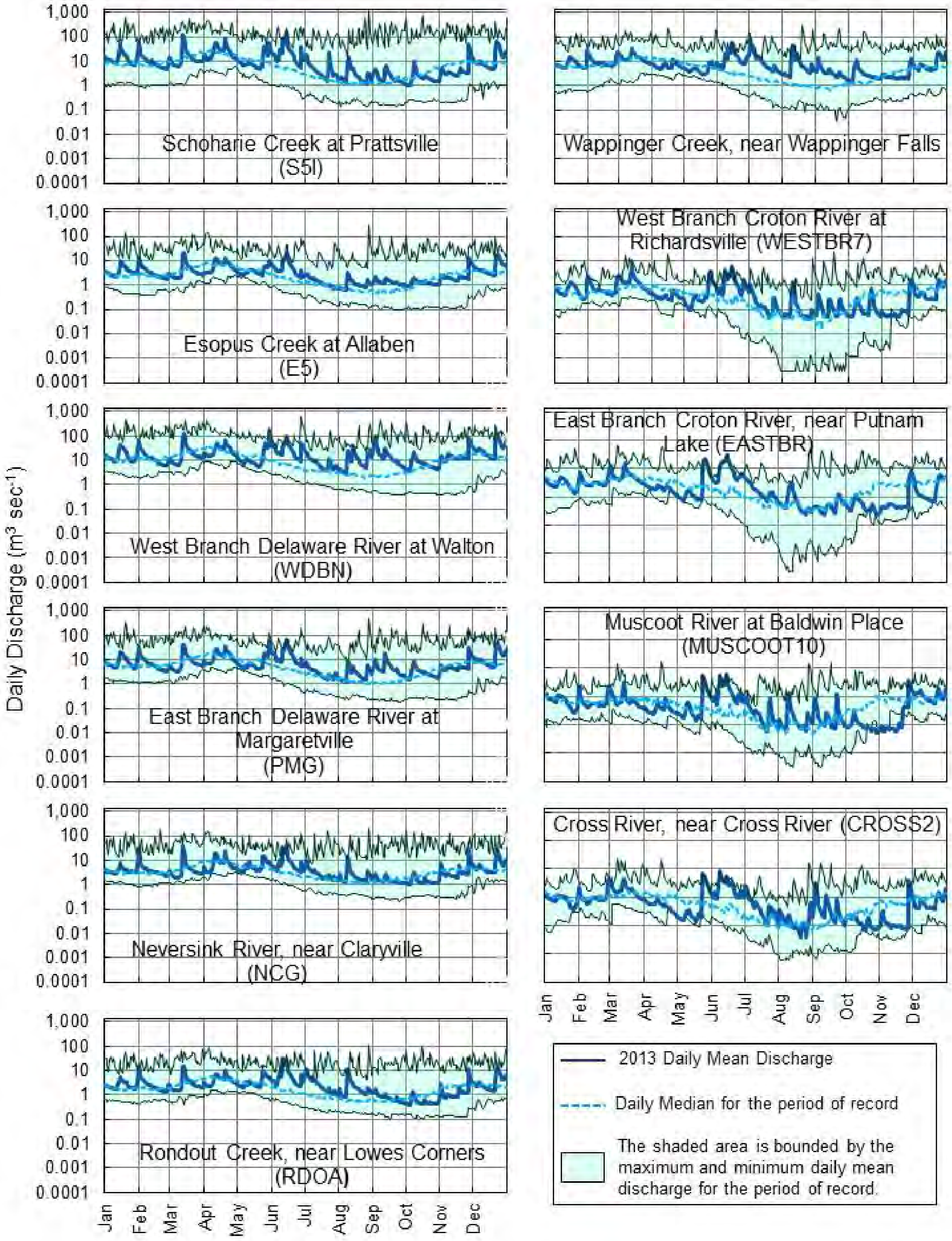


Figure 2.3 Daily mean discharge for 2013 at selected USGS stations.

2.4 Use of Rainfall Data in the Design of Stormwater Pollution Prevention Plans

DEP is responsible for regulatory oversight of land development activities in the watershed via the review and approval of applications submitted in accordance with Section 18-39 of the New York City Watershed Rules and Regulations (WR&R) (DEP 2010a). Section 18-39 established DEP's authority to regulate the management and treatment of stormwater runoff, created standards for the delineation and protection of watercourses, and codified prohibitions regarding the construction of impervious surfaces. This is the section under which Stormwater Pollution Prevention Plans (SWPPPs) are submitted, as well as applications for Individual Residential Stormwater Permits and Stream Crossing, Piping and Diversion Permits. Residential-, commercial-, institutional-, and transportation-related activities are among the land uses requiring DEP review under this section.

SWPPPs require specific hydrologic modeling and analyses of site runoff conditions prior to and after proposed construction and development activities. Stormwater computer models rely on historical records to size stormwater management practices and gauge a variety of runoff conditions and predict downstream impacts. These records include rainfall data to define the magnitude of a number of storm events, namely the 1-year, 10-year, and 100-year/24-hour events, and the 90% rainfall event (see Figures 2.4 through 2.7). The 1-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 100% chance of occurring in any given year, while the 10-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 10% chance of occurring in any given year. The 100-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 1% chance of occurring in any given year. Figures 2.4 through 2.7 are isohyetal maps that present estimates of these precipitation return periods for New York State. Where construction activities require DEP review and approval of an SWPPP in accordance with the WR&R, these maps are used in the design of stormwater management practices. They are available in Chapter 4 of the New York State Stormwater Management Design Manual (issued August 2010) or online at http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf.

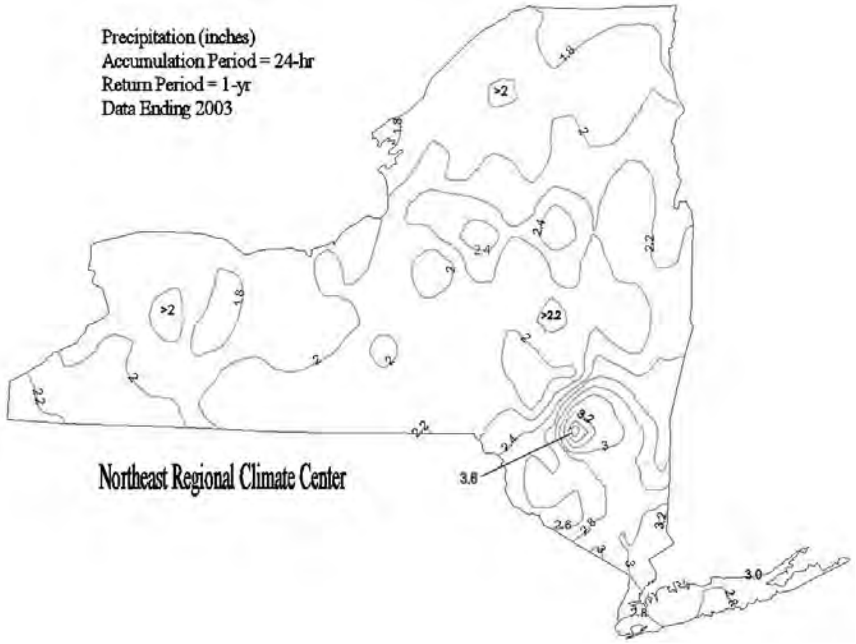


Figure 2.4 The 1-year, 24-hour storm for New York State, from the 2010 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

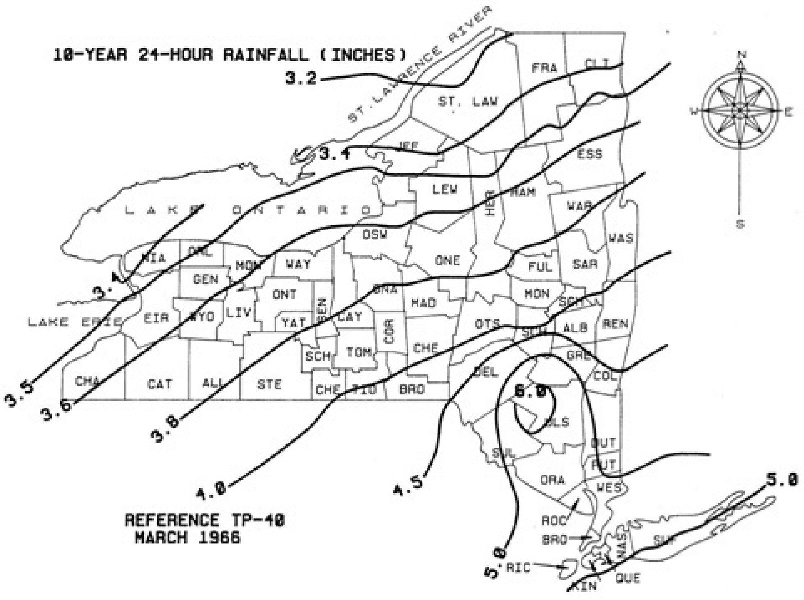


Figure 2.5 The 10-year, 24-hour storm for New York State, from the 2010 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

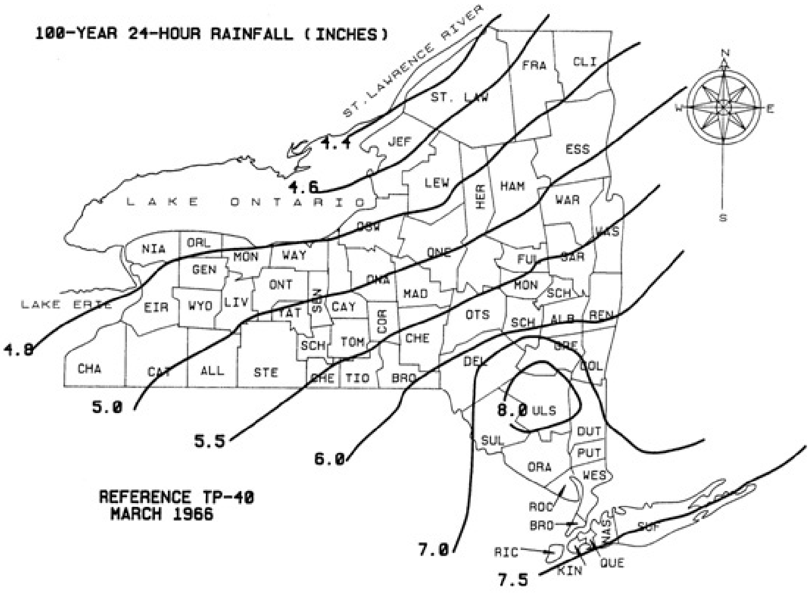


Figure 2.6 The 100-year, 24-hour storm for New York State, from the 2010 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

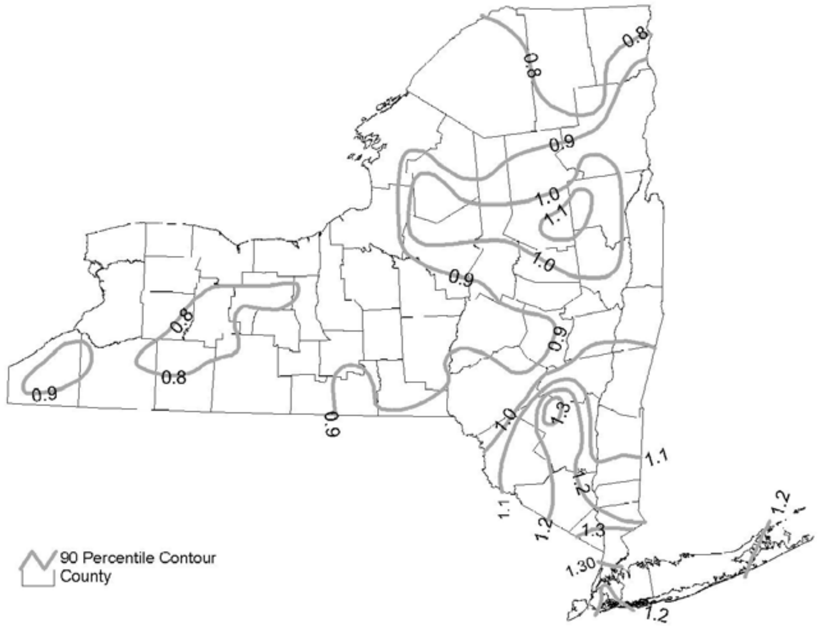


Figure 2.7 Ninety percent rainfall in New York State, from the 2010 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

2.5 Reservoir Usable Storage Capacity in 2013

Ongoing daily monitoring of reservoir storage allows DEP to compare the present systemwide storage against what is considered "normal" for any given day of the year. "Normal" systemwide usable storage levels were determined by calculating the average daily storage from 1991 to 2012. In 2013, system capacity was generally higher than historical levels (Figure 2.8). Due to rain events in late 2012, capacity in January and February 2013 was slightly higher than normal. In mid-March, systemwide rainstorms caused capacity to increase sharply, but it soon declined to below normal levels in the first half of April. Numerous small rain events in the second half of April and in early May soon restored capacity to slightly above normal levels. Storms in late May, followed by a very wet June, caused storage to exceed 100% for much of this period, delaying the normal summer-autumn decline for about a month. This decline was not as steep as usual due to some large localized rain events during the August-October period. Three large systemwide rain events, one in late November and two in mid-December, and one storm, local to the WOH basins in late December, caused capacity to increase 6% above normal going into 2014.

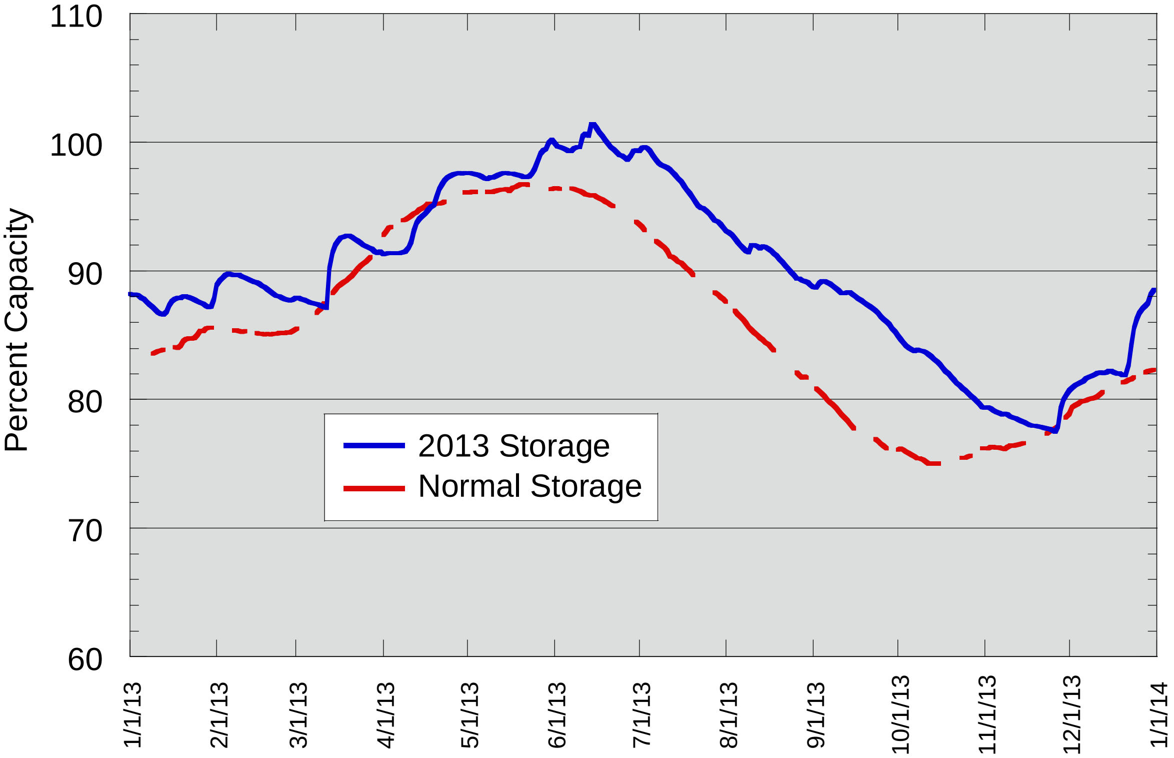


Figure 2.8 2013 systemwide usable storage compared to normal storage. Storage greater than 100% is possible when the reservoirs are spilling or when the water surface elevation is greater than the spillway elevation.

3. Water Quality

3.1 Reservoir Turbidity Patterns in 2013

Turbidity in reservoirs is comprised of both inorganic (e.g., clay, silt) and organic (e.g., plankton) particulates suspended in the water column. Turbidity may be derived from the watershed by erosional processes (storm runoff in particular) or generated within the reservoir itself (e.g., internal plankton development, sediment resuspension). In general, turbidity levels are highest in the Catskill reservoirs due to the occurrence of erodible lacustrine clay deposits found in these watersheds.

Turbidity in the Catskill System's Schoharie Reservoir was about 42% higher than normal (defined as the historical median) in 2013 (Figure 3.1). (An explanation of the boxplots used in this and other figures in this chapter is provided in Appendix A.) Spring turbidity levels were elevated due to numerous storm events during the last quarter of the previous year and a 1-inch rain event in March 2013. Additional turbidity-producing events occurred in 2013. The largest followed 2.7 inches of rain on October 31, which contributed to a nearly threefold increase in turbidity from October to November (3.5 to 10.0 NTU). In contrast, despite more rain events (especially in June), turbidity levels were normal to below normal in the east and west basins of Ashokan Reservoir. This is largely explained by below average rainfall from July to October and by the scarcity of large rain events from September-November. Note that the late October rain event which produced 2.7 inches in the Schoharie watershed only produced 1.1 inches in the Ashokan watershed.

In most of the Delaware System, large rain events were relatively rare after June, coinciding with lower than normal turbidity levels at Rondout, Pepacton, and Cannonsville Reservoirs. In contrast, Neversink Reservoir was about 45% higher than normal. Recovery in Neversink from a localized storm event in September 2012 was slow and interrupted by multiple storms in 2013, ranging from 1 to 3 inches of precipitation, in April, June, August, and October.

West Branch Reservoir, which receives inputs from both the Delaware and Croton Systems, had low turbidity levels in 2013 that fell within the normal historical range. West Branch was operated almost exclusively in "float" status, which minimized the amount of Delaware System water entering the basin. Rondout, Boyd Corners, and local West Branch streams contributed lower than normal turbidity inputs to West Branch Reservoir in 2013.

Turbidity at Kensico Reservoir, the terminal reservoir for the Catskill and Delaware Systems, was down slightly for the year, largely due to increased usage of the lower turbidity Delaware System in 2013.

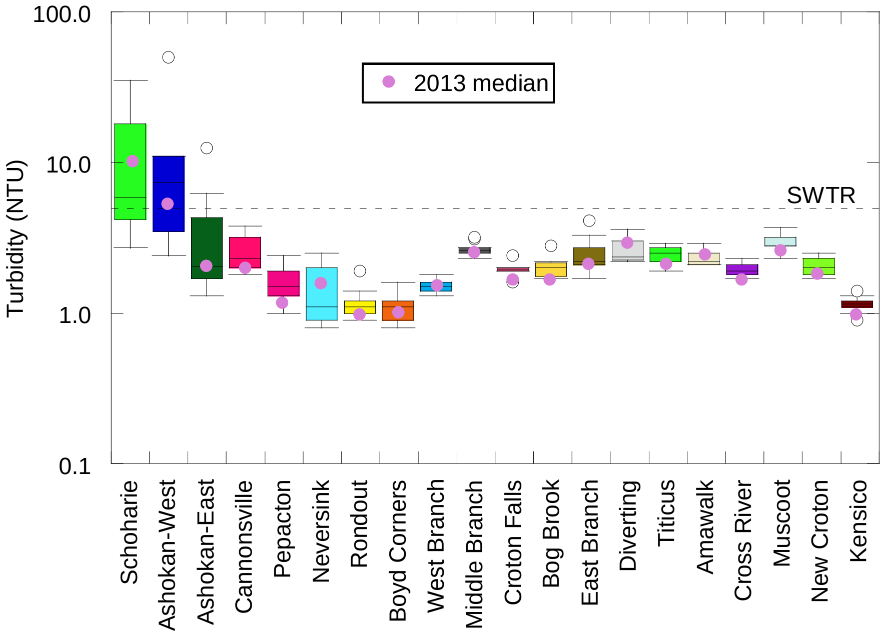


Figure 3.1 Annual median turbidity in NYC water supply reservoirs (2013 vs. 2003-2012). The dashed line at 5 NTU refers to the SWTR criterion that considers 2 consecutive days > 5NTU as a violation in source water reservoirs. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

Turbidity in the Croton System was generally normal to below normal in 2013 (reservoirs shown in Figure 3.1, controlled lakes in Table 3.1). Rainfall was well below average and large rain events were infrequent, except in June. Only Diverting and Amawalk Reservoirs and Kirk Lake were slightly above historical turbidity levels, with higher results at Diverting and Kirk Lake associated with algal blooms in September and October.

Table 3.1: Turbidity summary statistics for NYC controlled lakes (in NTU).

Lake	Median turbidity (2003-2012)	Median turbidity (2013)
Gilead	1.4	1.5
Gleneida	1.6	1.4
Kirk	3.8	4.4

3.1.1 Schoharie Reservoir Seiche and Turbidity Oscillations

Large daily oscillations in turbidity (i.e., changes of up to 100 NTU) were observed in the waters leaving Schoharie Reservoir via the Shandaken Tunnel Outlet between July and September 2013. A special investigation began in early August to assess the cause of this turbidity phenomenon. Water quality monitoring was conducted at the Schoharie Reservoir diversion and stream inputs, and numerous supplemental limnological surveys were performed at various times of the day and at additional reservoir locations (as indicated by the longitudinal and lateral transects in Figure 3.2). Twenty-three (23) supplementary samples and 3,620 in situ water quality measurements were made in addition to the routine sampling performed on Schoharie Reservoir during the month of August. Discrete depth and profiling water quality monitoring buoys were also deployed at the end of August near the intake to provide high frequency measurements of in situ reservoir turbidity.

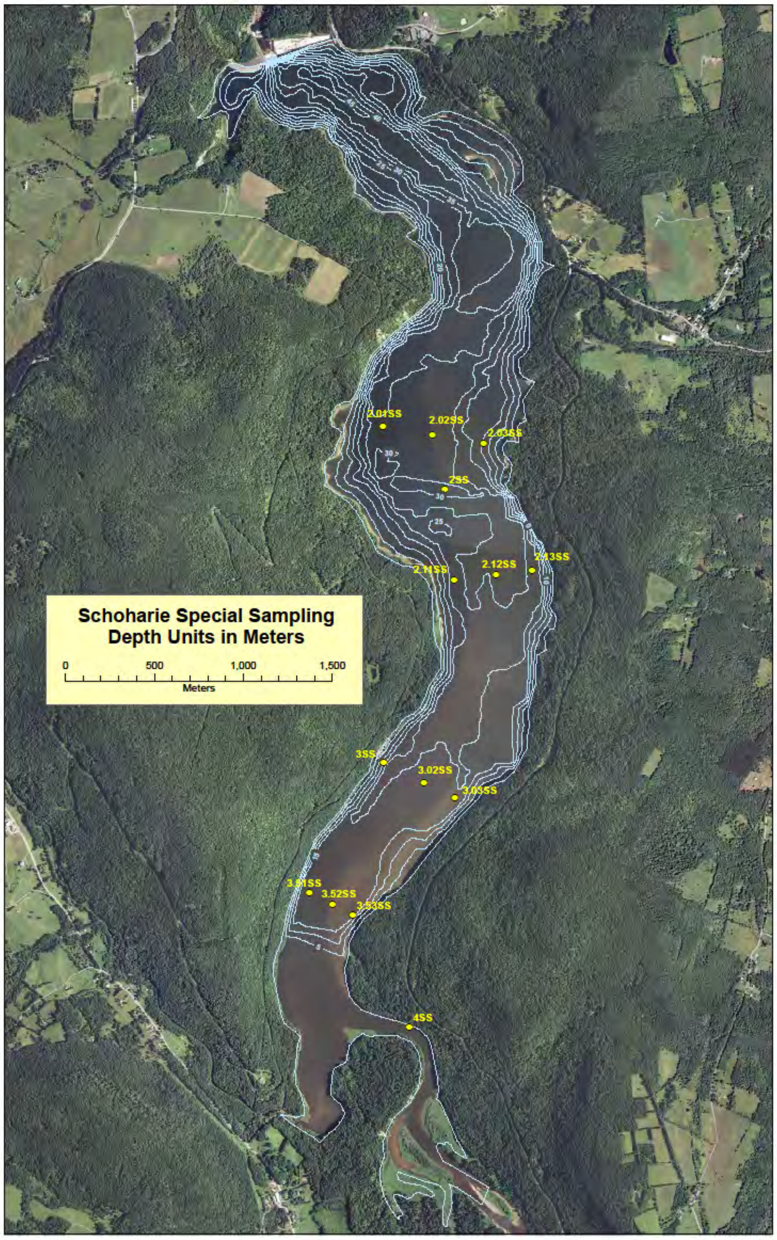


Figure 3.2 Sampling sites in Schoharie Reservoir used to track turbidity oscillations.

After a thorough field investigation, DEP determined that the oscillations in turbidity were the result of seiche activity within the reservoir. Seiches (internal waves) are generally caused by winds piling up surface waters on one side of a reservoir. This causes a depression of the reservoir's thermal structure and initiates a rocking motion of waters below the surface which is most evident near the reservoir's thermocline. In this particular event, turbidity originating from Schoharie watershed streams during storm events in June had entered the reservoir as an interflow and was located in the proximity of the thermocline. DEP observed a close relationship between turbidity and temperature in the diversion outflow as well as within the reservoir. It is likely that turbidity-causing particles, generated from the resuspension of sediments at the sediment-water interface, were also transported to the depth of the intake at the Schoharie Intake Chamber during these daily seiches, as well. Internal seiches, a natural phenomenon in lakes, have been observed in Schoharie Reservoir in previous years.

To further document and understand the oscillations in temperature and turbidity, DEP contracted with Upstate Freshwater Institute (UFI) to compare results of the CEQUAL-W2 water quality model predictions to the observed conditions (UFI 2014). The model performed well in simulating the in-reservoir temperature profiles and also predicted the observed periodicity of the seiche. A spectral analysis of the vertical movement of isotherms near the tunnel intake showed that the simulated dominant oscillation periods matched the periods observed in the withdrawal temperature time series. Although the timing of the oscillations in the temperature profiles was well predicted, the amplitude of the temperature oscillations in the withdrawal was somewhat under-predicted. This could have been due to uncertainty in the withdrawal algorithm that determines the water depths contained in the withdrawal; the complex features of the bathymetry in the vicinity of the intake, which affects the local flow dynamics that are not represented in the 2-D model framework; or potential errors in the wind speed input.

The model was also set up to simulate turbidity in the reservoir and in the withdrawal during the study period. Because of limited availability of measurements of turbidity in the Schoharie Creek input, a flow-turbidity relationship (Gannett Fleming & Hazen and Sawyer 2009) was used to estimate turbidity loading. Based on this relationship, it was determined that Schoharie Creek was not a significant source of turbidity during the summer months, except for the June event noted above. For the study period, the model predicted turbidities that were lower than the observed values in both the epilimnion and hypolimnion. The possible causes of model under-prediction of turbidity for the study include uncertainty in the estimates of loading from Schoharie Creek and absence in the model of a resuspension process driven by the seiche-induced horizontal currents. Further study and model improvements would be necessary to completely account for the turbidity oscillations observed during this time period.

3.2 Coliform-Restricted Basin Assessments in 2013

Coliform bacteria are used widely as indicators of potential pathogen contamination. To protect the City's water supply, the New York City Watershed Rules and Regulations (WR&R) (DEP 2010a) restrict potential sources of coliforms in the watershed area of threatened water bodies. These regulations require the City to perform an annual review of its reservoir water quality data to determine whether each reservoir and controlled lake meets the water quality standards set forth in Section 18-48(e) of the regulations.

Coliform-restricted determinations are governed by four sections of the regulations: Sections 18-48(a)(1), 18-48(c)(1), 18-48(d)(1), and 18-48(d)(2). Section 18-48(c)(1) applies to terminal reservoirs, which include Kensico, West Branch, New Croton, Ashokan, and Rondout Reservoirs. The coliform-restricted assessments of these reservoirs are based on compliance with federally-imposed limits on fecal coliforms collected from waters within 500 feet of the reservoir's aqueduct effluent chamber. Section 18-48(a)(1) applies to "non-terminal basins" and specifies that coliform-restricted assessments of these basins be based on compliance with NYS ambient water quality standard limits on total coliform bacteria (6 NYCRR Parts 701 and 703).

3.2.1 Terminal Basin Assessments

In 2013, assessments were made for all five NYC terminal reservoir basins. Currently, coliform-restricted assessments for terminal basins are made using data from a minimum of five samples each week over two consecutive six-month periods. If 10% or more of the samples measured have values greater than 20 fecal coliforms 100mL^{-1}, and the source of the coliforms is determined to be anthropogenic (Section 18-48(d)(2)), the associated basin is rated as a coliform-restricted basin. All terminal reservoirs in 2013 had fecal coliform counts that were well below the 10% threshold for both six-month assessment periods (Table 3.2).

Table 3.2: Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2013.

Reservoir	Effluent keypoint	Basin status for 2013
Kensico	DEL18DT	Non-restricted
New Croton	CROGH[1]	Non-restricted
Ashokan	EARCM[2]	Non-restricted
Rondout	RDRRCM[2]	Non-restricted
West Branch	CWB1.5	Non-restricted

[1] Data from sites CRO1B and CRO1T were also used for this analysis.

[2] Data from the elevation tap that corresponds to the level of withdrawal are included one day per week, and all other samples are collected at the specified effluent keypoint.

3.2.2 Non-terminal Basin Assessments

Section 18-48(a)(1) requires that non-terminal basins be assessed according to 6 NYCRR Part 703 for total coliforms. These New York State regulations are specific to the class of the reservoir. A minimum of five samples must be collected per month in each reservoir. Both the median value and more than 20% of the total coliform counts for a given month must exceed the values ascribed to the reservoir class to exceed the standard. Table 3.3 provides a summary of the coliform-restricted calculation results for the non-terminal reservoirs. Detailed results of monthly calculations are provided in Appendix B.

Table 3.3: Coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2013. TNTC = coliform plates too numerous to count.

Reservoir	Class[1]	Standard monthly median/>20% (total coliforms 100mL^{-1})	Number of months that exceeded the standard/ months of data	Number of months not evaluated due to TNTC data[2]
Amawalk	A	2400/5000	0/8	1
Bog Brook	AA	50/240	0/8	
Boyd Corners	AA	50/240	1/8	
Croton Falls	A/AA	50/240	1/8	
Cross River	A/AA	50/240	0/8	1
Diverting	AA	50/240	2/8	2
East Branch	AA	50/240	1/8	1
Lake Gilead	A	2400/5000	0/8	
Lake Gleneida	AA	50/240	0/8	
Kirk Lake	B	2400/5000	0/8	
Muscoot	A	2400/5000	0/8	
Middle Branch	A	2400/5000	0/8	
Titicus	AA	50/240	0/8	1
Pepacton	A/AA	50/240	0/8	
Neversink	AA	50/240	1/8	
Schoharie	AA	50/240	5/8	
Cannonsville	A/AA	50/240	0/9	

[1] The reservoir class for each water body is set forth in 6 NYCRR Chapter X, Subchapter B. For those reservoirs that have dual designations, the more stringent standard was applied.

[2] Determination of the monthly median or individual sample exceedance of the standard was not possible for TNTC samples. TNTC indicates that excessive numbers of other bacteria interfered with the determination of coliform types.

In 2013, 11 reservoirs and controlled lakes did not exceed the Part 703 standard for total coliforms during the sampling season (Table 3.3). Four reservoirs—Boyd Corners, Croton Falls, and East Branch in the Croton System, and Neversink in the Delaware System—exceeded the standard in a single month, while Diverting exceeded the standard in two out of eight months. Schoharie Reservoir exceeded the standard in five out of eight months, beginning at the time of a summer storm event in June and continuing for four successive months (Appendix B).

Total coliform bacteria originate from a variety of natural and anthropogenic (human-related) sources. However, Section 18-48(d)(1) indicates that the source of the total coliforms must be proven to be anthropogenic before a reservoir can receive coliform-restricted status. Since other microbial tests for identification of potential sources were not performed on these samples, the results in Table 3.3 represent only an initial assessment of total coliforms for the non-terminal basins in 2013. There were no other data indicating an anthropogenic source.

3.3 Reservoir Total and Fecal Coliform Patterns in 2013

Total coliform and fecal coliform bacteria are regulated at raw water intakes by the Surface Water Treatment Rule (USEPA 1989) at levels of 100 coliforms $100 mL^{-1}$ and 20 coliforms $100 mL^{-1}$, respectively. Both are important as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals; total coliforms include both fecal coliforms and other coliforms that typically originate in water, soil, and sediments.

Reservoir total coliform results are presented in Figure 3.3 and reservoir fecal coliform results in Figure 3.4. Coliform results for the controlled lakes of the Croton System are summarized in Table 3.4. Note that data used to construct the boxplots are annual 75th percentiles rather than medians. Using the 75th percentile makes it easier to discern differences among reservoirs, because a large percentage of coliform data are generally below the detection limit.

Historically, the highest total coliform counts occur in the Catskill System reservoirs (Figure 3.3). Because coliforms commonly adhere to soil particles, and soils are very susceptible to erosion in these watersheds, an equal volume of runoff tends to produce much higher coliform counts in the Catskill System reservoirs. In general, total coliform counts increase as temperatures warm, with peaks usually observed from July through October. In 2013, total coliform counts were slightly below normal in Schoharie, with low inputs occurring in spring and especially low counts in October and November. Total coliform counts were much lower in the Ashokan basins, perhaps related to relatively dry conditions during the July-October period (15.1 versus a normal 24.3 inches of rain). Large rain events (≥ 1.0 inch) were also infrequent during this period (4 versus a normal 7 events).

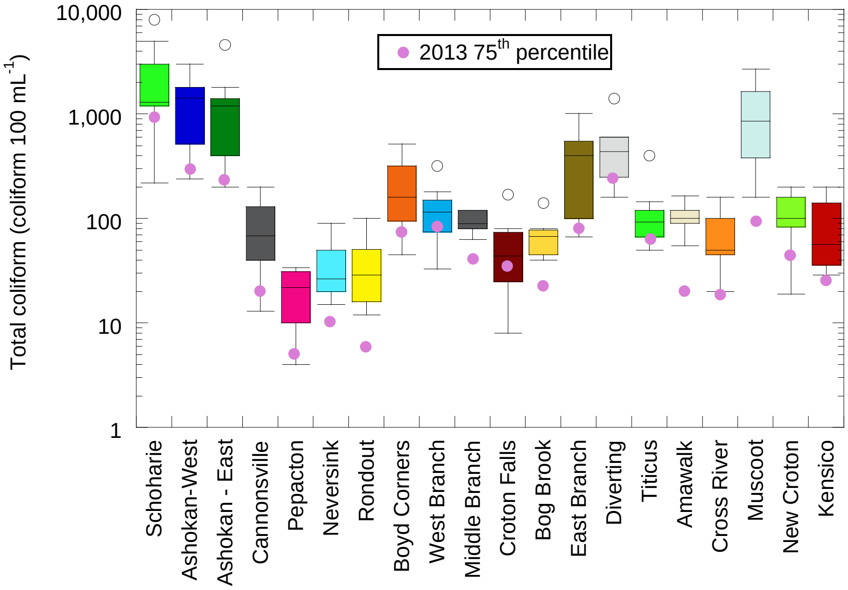


Figure 3.3 Annual 75th percentile of total coliforms in NYC water supply reservoirs (2013 vs. 2003-2012). In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

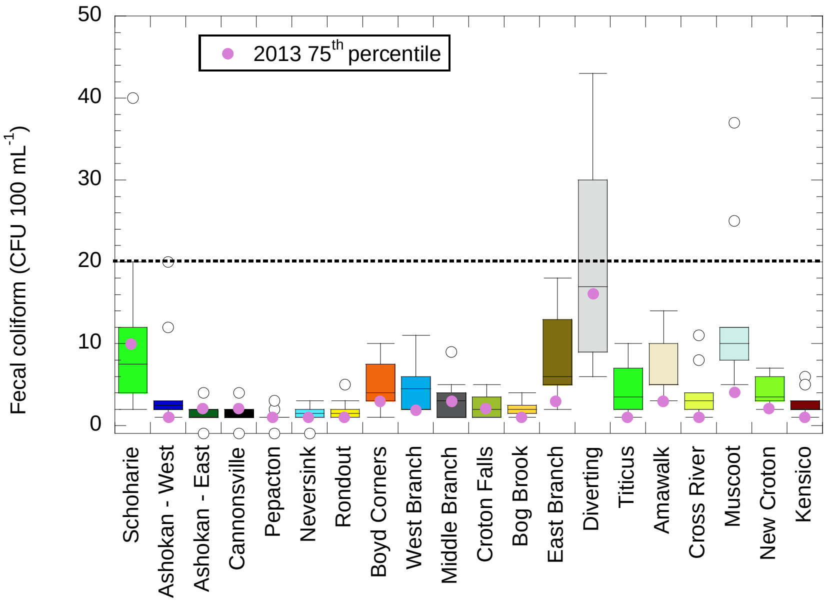


Figure 3.4 Annual 75th percentile of fecal coliforms in NYC water supply reservoirs (2013 vs. 2003-2012). The dashed line represents the SWTR standard for source waters as a reference. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

Table 3.4: Summary statistics for coliforms in NYC controlled lakes (coliforms 100mL^{-1}).

Lake	Historical total coliforms (75th percentile 2003-2012)	Current total coliforms (75th percentile 2013)	Historical fecal coliforms (75th percentile 2003-2012)	Current fecal coliforms (75th percentile 2013)
Gilead	40	16	4	1
Gleneida	24	9	1	0
Kirk	180	93	5	3

In the Delaware System, total coliform counts were well below historical levels in Cannonsville, Pepacton, Neversink, and Rondout, and slightly below normal in West Branch. The transport of total coliforms to the reservoirs was probably reduced by below average rainfall during the July-October period. Counts in Kensico Reservoir were low in 2013, reflecting the low inputs from Ashokan East and Rondout. Total coliform counts only became elevated in early July immediately following a large local rainfall event of 2.5 inches. However, this event was an outlier, as the July-October rainfall was much below normal (11.4 versus 20.9 inches) in the Kensico watershed during 2013.

Low total coliform counts were apparent in all Croton System reservoirs and controlled lakes in 2013, coinciding with low rainfall. Rainfall was almost 10 inches below normal (38.0 versus a normal 47.7 inches) and was especially low during the July-October period (7.7 versus a normal 18.8 inches). Elevated total coliforms are historically observed at Muscoot and Diverting Reservoirs (Figure 3.3) and Kirk Lake (Table 3.4).

Relative to historical data, fecal coliform patterns were very similar to those observed for total coliforms. Counts in most reservoirs were low (or low-normal) in 2013, coinciding with the generally low rainfall. Higher than normal counts were only observed at Schoharie. Elevated counts in June and August were associated with multiple large rain events (≥ 1 inch).

3.4 Phosphorus-Restricted Basin Assessments in 2013

The phosphorus-restricted basin status determination for 2013 is presented in Table 3.5 and was derived from two consecutive assessments (2008-2012 and 2009-2013) using the methodology described in Appendix C. Reservoirs and lakes with a geometric mean total phosphorus concentration that exceeds the benchmarks in the WR&R for both assessments are classified as restricted. Figure 3.5 graphically shows the phosphorus restriction status of the City’s reservoirs and controlled lakes, along with their 2013 geometric mean total phosphorus concentrations.

Table 3.5: Phosphorus-restricted reservoir basin status for 2013.

Reservoir	2008-2012 assessment (mean + S.E.)[1] (µg L^{-1})	2009-2013 assessment (mean + S.E.)[1] (µg L^{-1})	Phosphorus-restricted basin status[2]
Non-Source Waters (Delaware System)			
Cannonsville	15.3	15.6	Non-restricted
Pepacton	10.0	9.9	Non-restricted
Neversink	8.5	8.6	Non-restricted
Non-Source Waters (Catskill System)			
Schoharie	20.3	21.0	Non-restricted
Non-Source Waters (Croton System)			
Amawalk	20.5	21.4	Restricted
Bog Brook	27.2	27.0	Restricted
Boyd Corners	10.1	9.8	Non-restricted
Diverting	29.2	30.0	Restricted
East Branch	30.7	31.1	Restricted
Middle Branch	31.2	32.2	Restricted
Muscoot	29.4	29.8	Restricted
Titicus	25.0	25.7	Restricted
Lake Gleneida	28.4	27.3	Restricted
Lake Gilead	32.0	30.8	Restricted
Kirk Lake	33.2	32.1	Restricted
Source Waters (all systems)			
Ashokan-East	10.8	10.7	Non-restricted
Ashokan-West	18.3	18.4	Non-restricted
Cross River	16.7	16.9	Restricted
Croton Falls	17.7	19.9	Restricted
Kensico	6.8	6.8	Non-restricted
New Croton	17.3	17.6	Restricted
Rondout	8.1	8.2	Non-restricted
West Branch	10.7	11.5	Non-restricted

[1] Arithmetic mean of annual geometric mean total phosphorus concentration for 5-year period with S.E. (standard error of the mean) added to account for interannual variability.

[2] The WR&R standard for non-source waters is 20 µg L^{-1} and for source waters is 15 µg L^{-1}.

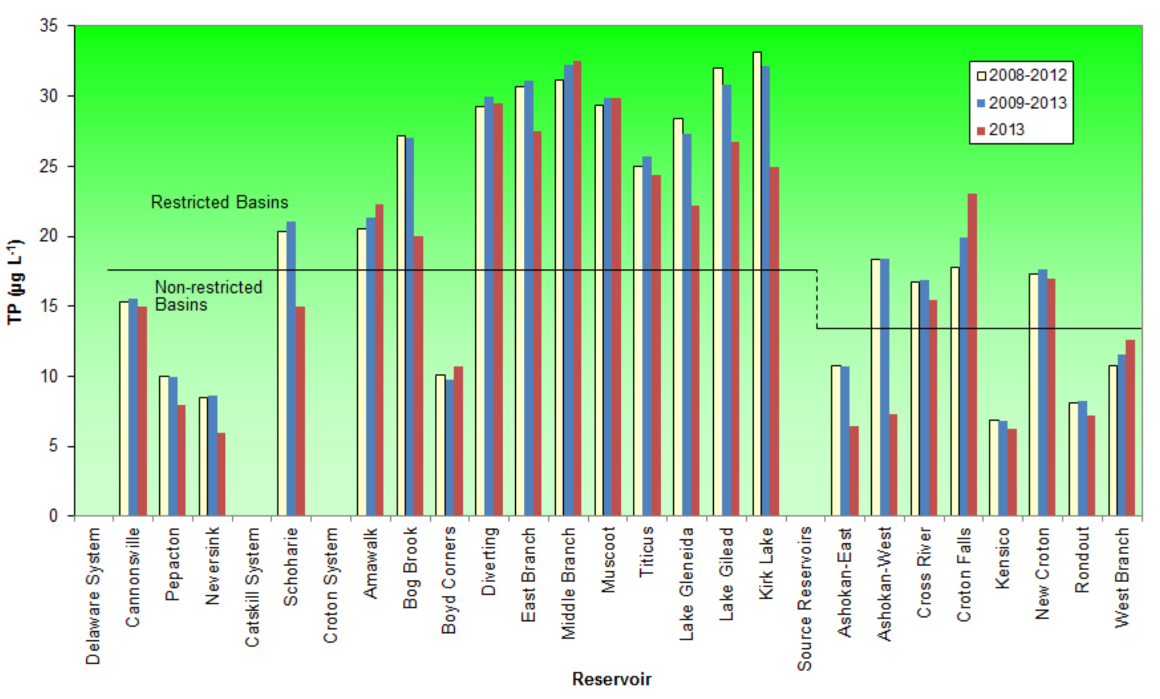


Figure 3.5 Phosphorus-restricted basin assessments, with the current year (2013) geometric mean phosphorus concentration displayed for comparison. The horizontal solid lines at 20µg L^{-1} and 15µg L^{-1} represent the WR&R standard for non-source waters and source waters, respectively.

Some notable features of the phosphorus-restricted basin status determinations in 2013 are:

- In the Catskill System, the annual geometric mean total phosphorus (TP) concentration for Ashokan Reservoir's West Basin declined from 10.2 µg L^{-1} in 2012 to 7.3 µg L^{-1} in 2013 (Appendix C). However, the five-year average used for the phosphorus-restricted basin status determination remained high due to the effects of Tropical Storms Irene and Lee in 2011, with a geometric mean concentration of 31 µg L^{-1}. The assessment for any five-year period that includes the anomalous high value for 2011 also incorporates the standard error of the mean to take interannual variability into consideration. The high value for 2011 did not result in eutrophication in the reservoir in 2011 or in subsequent years, and for this reason DEP exercised its best professional judgment and did not designate Ashokan Reservoir's West Basin as phosphorus restricted for 2013.
- The Catskill System's Schoharie Reservoir had a lower geometric mean TP concentration in 2013 (15.0 µg L^{-1}) than in the preceding year (20.0 µg L^{-1}), despite summer storm events that led to large oscillations in turbidity from July through September (see Section 3.1.1). The highest TP concentration of the season occurred following a storm event in June that was

accompanied by high turbidity. Both of the five-year assessments (2008-2012 and 2009-2013) reflect the impacts of tropical storms in 2011. The reservoir remained non-restricted based upon best professional judgment, since the five-year average was still largely influenced by the extreme storm events in 2011, and high turbidity reduced water clarity and limited algal productivity.

- The Delaware System reservoirs remained non-restricted. There was little change between the two evaluation periods (2008-2012 and 2009-2013), as shown in Table 3.5. There was a slight increase in the annual geometric mean TP concentration for Cannonsville from 12.4 µg L^{-1} in 2012 to 15.0 µg L^{-1} in 2013, and a decrease in Neversink from 9.7 µg L^{-1} in 2012 to 6.0 µg L^{-1} in 2013 (Appendix C).
- The phosphorus-restricted status of the Croton System reservoirs remained unchanged for 2013. All reservoirs in the Croton System were listed as “restricted” with the exception of Boyd Corners, which remained non-restricted, with a low value of 9.8 µg L^{-1} for the latest assessment period (Table 3.5).
- As in 2012, Cross River, Croton Falls, and New Croton remained in the “restricted” category. Kensico, Ashokan-East, Ashokan-West, Rondout, and West Branch Reservoirs were non-restricted. The annual geometric mean for all source water reservoirs decreased in 2013, with the exception of Croton Falls, which increased from 18.7 µg L^{-1} in 2012 to 23.0 µg L^{-1} (Appendix C).

3.5 Reservoir Total Phosphorus Patterns in 2013

Precipitation and runoff generated by precipitation are important mechanisms by which TP is transported from local watersheds into streams and reservoirs. Primary sources of TP include human and animal waste, fertilizer runoff, and internal loading from reservoir sediments during anoxic periods.

Annual TP concentrations in all Catskill and Delaware reservoirs ranged from low to normal in 2013 (Figure 3.6) although some seasonal increases were evident. In the Catskill System, Schoharie TP peaked in the spring following numerous storm events during the last quarter of the previous year and a 1-inch rain event in March 2013. Additional small increases followed rain events in June and August. TP concentrations in Ashokan Reservoir reached 11-year lows in both basins. Several factors may be important. Rainfall was low from July to October (15.1 versus a normal 24 inches) with few large storms (≥1.0 inch) occurring from September to November.

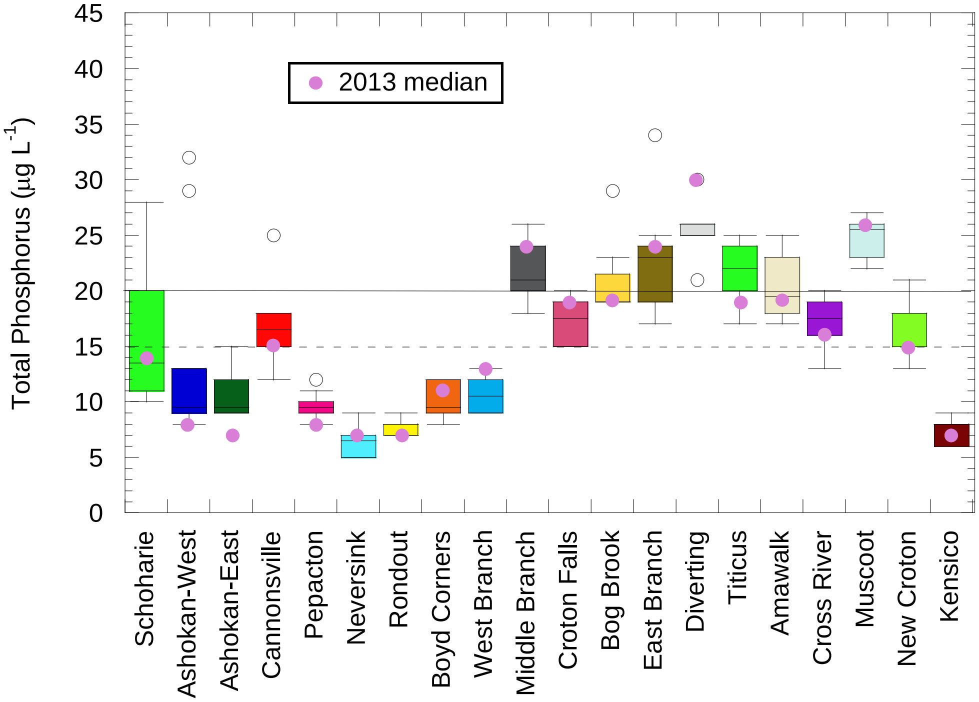


Figure 3.6 Annual median total phosphorus in NYC water supply reservoirs (2013 vs. 2003-2012). The horizontal dashed line at 15 µg L^{-1} refers to the NYC Total Maximum Daily Loads (TMDL) guidance value for source waters. The horizontal solid line at 20µg L^{-1} refers to the NYSDEC ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs). In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November. Note that although Kensico and New Croton are usually operated as source waters, these reservoirs can be by-passed so that any or all of the following can be operated as source waters: Rondout, Ashokan-East, Ashokan-West, and West Branch.

In the Delaware System, TP levels were below normal in Pepacton, Cannonsville, and Rondout. Rainfall was generally low during the July-October period, limiting transport of TP to these reservoirs. Rondout was well below normal all year except for July, when 6.8 inches of rain occurred within 10 days prior to sample collection. Neversink Reservoir was just slightly higher than normal (7 vs. 6.5 µg L^{-1}) in 2013. Recovery from the previous year's flooding event and an April rainfall event contributed to higher TP in the spring. Three large rain events (1.0, 2.3, and 1.9 inches) in mid-June were associated with a temporary TP increase of 5 to 7 µg L^{-1} by June 18. TP concentrations were normal to below normal for the remainder of the sampling season.

TP concentrations at West Branch in 2013 equaled the 11-year high for this reservoir in 2013. Lower inputs from Rondout and increased loading from local West Branch streams and, to a lesser extent, from the Boyd Corners release, is the best explanation for the increase.

TP concentrations in Kensico Reservoir, which receives water from Rondout, West Branch, and Ashokan, were equivalent to its historical median in 2013. Kensico, Rondout, and Ashokan-East median TP concentrations were similar, reflecting the influence of Rondout and Ashokan water (versus West Branch) diverted to Kensico in 2013.

Compared to the Catskill and Delaware Systems, the Croton watershed has a greater abundance of phosphorus sources: there are 60 wastewater treatment plants (WWTPs), numerous septic systems, and extensive paved surfaces scattered throughout the watershed. Because of this more extensive development as well as geologic differences, TP concentrations in the Croton System reservoirs (Figure 3.6) and controlled lakes (Table 3.6) are normally much higher than in the reservoirs of the Catskill and Delaware Systems. In 2013, most Croton reservoirs and controlled lakes were within historical levels, ranging from 11 to 30 $\mu g\ L^{-1}$. Higher than normal concentrations were observed at Boyd Corners, Middle Branch, Croton Falls, East Branch, and Diverting Reservoirs. Higher TP values in May and June could be explained by four large storm events that occurred between May 23 and June 13, producing 9.4 inches of rain. The rest of the year was fairly dry, suggesting that higher TP values in the summer may be related to internal loading from anoxic sediments or other sources. Higher values observed at Croton Falls may also be related to higher TP inputs from West Branch and Middle Branch Reservoirs, which lie upstream of Croton Falls.

Table 3.6: Total phosphorus summary statistics for NYC controlled lakes ($\mu g\ L^{-1}$).

Lake	Median total phosphorus (2003-2012)	Median total phosphorus (2013)
Gilead	20	17
Gleneida	18	14
Kirk	29	23

Efforts to reduce phosphorus loads in the Croton watershed are ongoing. Many WWTPs have been upgraded; others are at some intermittent stage of upgrade. Septic repair and pump out programs continue in Putnam and Westchester Counties, as well as the implementation of farm (usually equestrian based) BMPs.   In addition, stormwater remediation projects are ongoing in the Boyd Corners, West Branch, Croton Falls, and Cross River watersheds.

3.6 Terminal Reservoir Comparisons to Benchmarks in 2013

The NYC reservoirs and water supply system are subject to the federal SWTR standards, NYS ambient water quality standards, and DEP’s own guidelines. In this section, the results for 2013 water quality sampling including a variety of physical, biological, and chemical analytes for the terminal reservoirs, are evaluated by comparing the results to the water quality benchmarks listed in Table 3.7. These benchmarks are based on applicable federal, state, and DEP standards or guidelines, also listed in Table 3.7. Note that the standards in this table are not necessarily applicable to all individual samples and medians described herein (e.g., SWTR limits for turbidity and fecal coliforms apply only to the point of entry to the system). It should also be noted that different values apply to Croton reservoirs than to West of Hudson (WOH) reservoirs. Placing the data in the context of these benchmarks assists in understanding the robustness of the water system and water quality issues.

Table 3.7: Reservoir and controlled lake benchmarks.

Analyte	Basis[1]	Croton System Annual mean	Croton System Single sample maximum	Catskill/Delaware System Annual mean	Catskill/Delaware System Single sample maximum
Alkalinity (mg $CaCO_3$ L^{-1})	(a)	≥40.00		≥10.00	
Ammonia-N (mg L^{-1})	(a)	0.05	0.10	0.05	0.10
Dissolved chloride (mg L^{-1})	(a)	30.00	40.00	8.00	12.00
Chlorophyll *a* (mg L^{-1})	(a)	0.01	0.015	0.007	0.012
Color (Pt-Co units)	(b)		15		15
Dominant phytoplankton genus (SAU)	(c)		1000		1000
Fecal coliforms (coliforms 100 mL^{-1})	(d)		20		20
Nitrite+nitrate (mg L^{-1})	(a)	0.30	0.50	0.30	0.50
pH (units)	(b)		6.5-8.5		6.5-8.5
Phytoplankton (SAU)	(c)		2000		2000
Dissolved sodium (mg L^{-1})	(a)	15.00	20.00	3.00	16.00
Soluble reactive phosphorus (µg L^{-1})	(c)		15		15
Sulfate (mg L^{-1})	(a)	15.00	25.00	10.00	15.00
Total dissolved solids (mg L^{-1})[2]	(a)	150.00	175.00	40.00	50.00
Total organic carbon (mg L^{-1})[3]	(a)	6.00	7.00	3.00	4.00
Total dissolved phosphorus (µg L^{-1})	(c)		15		15
Total phosphorus (µg L^{-1})	(c)		15		15
Total suspended solids (mg L^{-1})	(a)	5.00	8.00	5.00	8.00
Turbidity (NTU)	(d)		5		5

[1] (a) WR&R (Appendix 18-B) – based on 1990 water quality results, (b) NYSDOH Drinking Water Secondary Standard, (c) DEP internal standard/goal, (d) USEPA filtration avoidance criteria established under the Surface Water Treatment Rule (USEPA 1989).

[2] Total dissolved solids was estimated by multiplying specific conductivity by 0.65 (van der Leeden 1990).

[3] Dissolved organic carbon was used in this analysis since total organic carbon is no longer analyzed

Comparison of reservoir water quality data for 2013 to these benchmarks is provided in Appendix D for all reservoirs and the controlled lakes. Data represent samples collected monthly from April to November for multiple reservoir and controlled lake sites and depths as part of the fixed-frequency water quality monitoring program.

Highlights of the benchmark comparisons for terminal reservoirs from 2013 are as follows. For the majority of samples, pH was circumneutral (6.5-8.5). Occurrences of pH exceeding 8.5 were associated with algal blooms, with a few occurrences in spring when diatoms were dominant, and the majority occurring in summer and early autumn. In New Croton Reservoir, pH exceeded the water quality benchmark of 8.5 for 12% of the samples. In the WOH reservoirs with lower alkalinities, samples outside the benchmark range for pH generally fell below 6.5, with 25% of Ashokan East Basin, 15% of Ashokan West Basin, and 16% of Rondout samples below the benchmark range. The pH values in Kensico were out of range for 14% of the samples and for West Branch, 5% of the samples.

As in 2012, all chloride samples in New Croton Reservoir exceeded the Croton System 40 mg L^{-1} single sample maximum standard and the annual mean standard of 30 mg L^{-1}. Likewise, all chloride samples in West Branch, when compared to the Catskill/Delaware System standards, exceeded the single sample maximum of 12.00 mg $L^{-1}$and the annual mean standard of 8.00 mg L^{-1}. Rondout, Ashokan East Basin, and Ashokan West Basin were below the limits for these standards, while Kensico was below the single sample maximum standard but slightly exceeded the annual mean standard of 8.00 mg L^{-1}, with a mean concentration of 8.6 mg L^{-1}. All chloride samples were well below the NYS ambient water quality standard limit of 250 mg L^{-1} (6 NYCRR Part 703).

Turbidity levels in Kensico and Rondout did not exceed the single sample maximum of 5 NTU in 2013, and only 2% of the samples exceeded the limit in West Branch. New Croton exceeded the standard for seven samples, representing 4% of fixed-frequency monitoring samples. Ashokan East Basin exceeded 5 NTU for 13% of the reservoir samples, in contrast to 42% in 2012. Ashokan West Basin exceeded 5 NTU for 64% of samples, a decline from 77% the preceding year.

The TP single sample maximum of 15 µg L^{-1} was not exceeded in Kensico and Rondout for samples collected in 2013. Both basins of Ashokan were markedly lower in 2013, with only one sample exceeding the benchmark in Ashokan East Basin, and two samples exceeding the benchmark in Ashokan West Basin. West Branch exceeded the benchmark for 31% of the samples, and New Croton exceeded the benchmark for 56%. In New Croton, 9% of the samples exceeded the single sample maximum for nitrate and 21% exceeded the single sample maximum for ammonia. In addition, New Croton’s annual mean ammonia concentration—0.09 mg L^{-1}—exceeded the ammonia benchmark of 0.05 mg L^{-1}. No other terminal reservoir exceeded the benchmark values for nitrate or ammonia except West Branch, which exceeded the ammonia benchmark for 5% of samples.

Phytoplankton counts were below the 2000 ASU benchmark in Kensico, West Branch, and both basins of Ashokan. Both in Rondout and New Croton, a single sample exceeded this benchmark, while two samples in each reservoir exceeded the 1000 ASU single sample maximum for the dominant genus. In New Croton and West Branch, chlorophyll *a* exceeded the single sample maximum for 11% and 19% of the samples, respectively, and only New Croton exceeded the annual mean benchmark of 0.010 mg L^{-1} (reported in Appendix D as 10.8 µg L^{-1}). Kensico exceeded the chlorophyll *a* single sample maximum for one sample, and did not exceed the annual mean. Rondout and both basins of Ashokan did not exceed chlorophyll *a* criteria.

Color in New Croton was above the benchmark of 15 units for 96% of the samples, while West Branch exceeded the color benchmark for 86% of fixed-frequency reservoir samples. Exceedances at other reservoirs ranged from 3% of samples in Rondout to 9% of samples in Ashokan East Basin.

Fecal coliform counts did not exceed the single sample maximum in Ashokan East Basin, and only one sample exceeded this level in Ashokan West Basin and West Branch. New Croton exceeded the single sample maximum of 20 coliforms 100mL^{-1} for 2% of samples, Rondout for 3% of samples, and Kensico for 6% of samples.

3.7 Reservoir Trophic Status in 2013

Trophic state indices (TSI) are commonly used to describe the productivity of lakes and reservoirs. Three trophic state categories—oligotrophic, mesotrophic, and eutrophic—are used to separate and describe water quality conditions. Oligotrophic waters are low in nutrients, low in algal growth, and tend to have high water clarity. Eutrophic waters, on the other hand, are high in nutrients, high in algal growth, and low in water clarity. Mesotrophic waters are intermediate. The indices developed by Carlson (1977, 1979) use commonly measured variables (i.e., chlorophyll *a*, TP, Secchi transparency) to delineate the trophic state of a body of water. TSI based on chlorophyll *a* concentration is calculated as:

$$\text{TSI} = 9.81 \times (\ln(\text{CHLA})) + 30.6$$

where CHLA is the concentration of chlorophyll *a*

The Carlson Trophic State Index ranges from approximately 0 to 100 (there are no upper or lower bounds), and is scaled so that values under 40 indicate oligotrophy, values between 40 and 50 indicate mesotrophy, and values greater than 50 indicate eutrophy. Trophic indices are generally calculated from data collected in the photic zone of the reservoir during the growing season (the DEP definition of "growing season" is May through October), when the relationship between the variables is most highly correlated. DEP water supply managers prefer reservoirs of a lower trophic state, because such reservoirs reduce the need for chemical treatments and produce better water quality at the tap; eutrophic waters, by contrast, may be aesthetically unpleasant from a taste and odor perspective.

Historical (2003-2012) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.7. The 2013 annual median TSI appears in the figure as a circle containing an “x”. Results for the East of Hudson (EOH) controlled lakes are provided in Table 3.8. This analysis indicates that all WOH reservoirs (including Kensico and West Branch) usually fall into the mesotrophic category. EOH reservoirs, on the other hand, tend to fall into the meso-eutrophic to eutrophic range, with only three—Boyd Corners and Lakes Gilead and Gleneida—usually in the mesotrophic range.

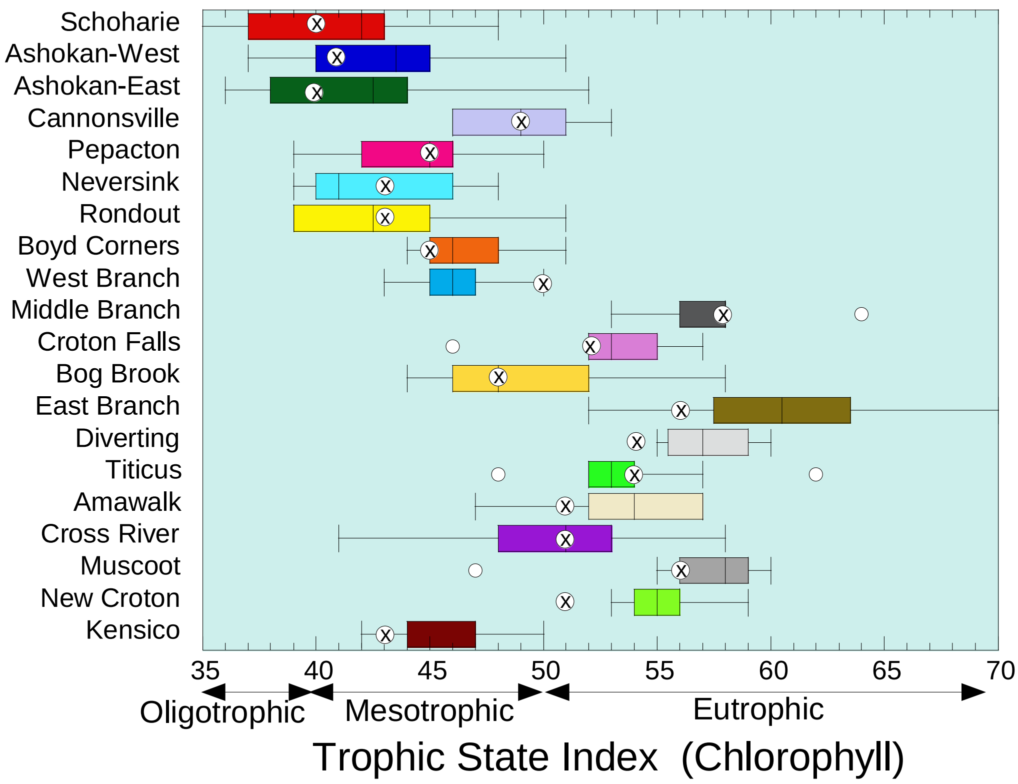


Figure 3.7 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2013 vs. 2003-2012). In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per month from May through October. TSI is based on Chlorophyll *a* concentration.

Table 3.8: Trophic State Index (TSI) summary statistics for NYC controlled lakes (NTU).

Lake	Median TSI (2003-2012)	Median TSI (2013)
Gilead	47	46
Gleneida	43	48
Kirk	56	61

In 2013, TSI was lower than normal in the Catskill reservoirs. In Schoharie, samples collected with high TP generally also had high turbidity, enough to reduce water clarity and limit algal productivity. Algal productivity is also controlled by the availability of nutrients (e.g., TP). In 2013, TP concentrations were extremely low in the Ashokan basins. Factors contributing to the low TP include low rainfall in the summer and fall.

TSI values in the Delaware reservoirs ranged from normal at Cannonsville and Pepacton to slightly elevated at Rondout and Neversink. Multiple large rain events (>1.0 inch) from late May to early July were associated with increased TP concentrations and algal productivity at various times during this period at Cannonsville, Neversink, and Rondout. Two additional large rain events in late August and early September preceded an algal bloom in Cannonsville in September. An additional localized rain event preceded increased algal productivity in October in Rondout and Neversink.

As was the case in 2012, West Branch Reservoir was borderline eutrophic in 2013. West Branch is usually mesotrophic because, in most years, the bulk of its water is from mesotrophic Rondout Reservoir. In 2012 and 2013, Rondout inputs were reduced, and West Branch was comprised of warmer, higher nutrient water from local streams, resulting in higher than normal productivity.

Kensico Reservoir, the terminal reservoir for the Catskill/Delaware System, is primarily a blend of Ashokan-East and Rondout water (and varying amounts from West Branch), with small contributions from local watershed streams. In 2013, Kensico's TSI fell between the TSIs of its major inputs and was well within historical levels.

In the Croton System, TSI was within historical levels for most reservoirs and Lake Gilead. Many reservoirs were well below their historical medians and New Croton, the terminal reservoir for the Croton System, had its lowest TSI since 2003. The low amount of rainfall in the region and the relative scarcity of large events after June resulted in lower nutrient loadings in 2013.

3.8 Water Quality in the Major Inflow Streams in 2013

The stream sites discussed in this section are listed in Table 3.9 and shown pictorially in Figure 3.8. These stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/Delaware reservoirs and five of the Croton reservoirs. This means they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds (except for New Croton, where the major inflow is from the Muscoot Reservoir release). Kisco River and Hunter Brook are tributaries to New Croton Reservoir and represent water quality conditions in the New Croton watershed.

Table 3.9: Site codes and site descriptions for the major inflow streams.

Site code	Site description
S5I	Schoharie Creek at Prattsville, above Schoharie Reservoir
E16I	Esopus Creek at Boiceville bridge, above Ashokan Reservoir
WDBN	West Branch Delaware River at Beerston, above Cannonsville Reservoir
PMSB	East Branch Delaware River below Margaretville WWTP, above Pepacton Reservoir
NCG	Neversink River near Claryville, above Neversink Reservoir
RDOA	Rondout Creek at Lowes Corners, above Rondout Reservoir
WESTBR7	West Branch Croton River, above Boyd Corners Reservoir
EASTBR	East Branch Croton River, above East Branch Reservoir
MUSCOOT10	Muscoot River, above Amawalk Reservoir
CROSS2	Cross River, above Cross River Reservoir
KISCO3	Kisco River, input to New Croton Reservoir
HUNTER1	Hunter Brook, input to New Croton Reservoir

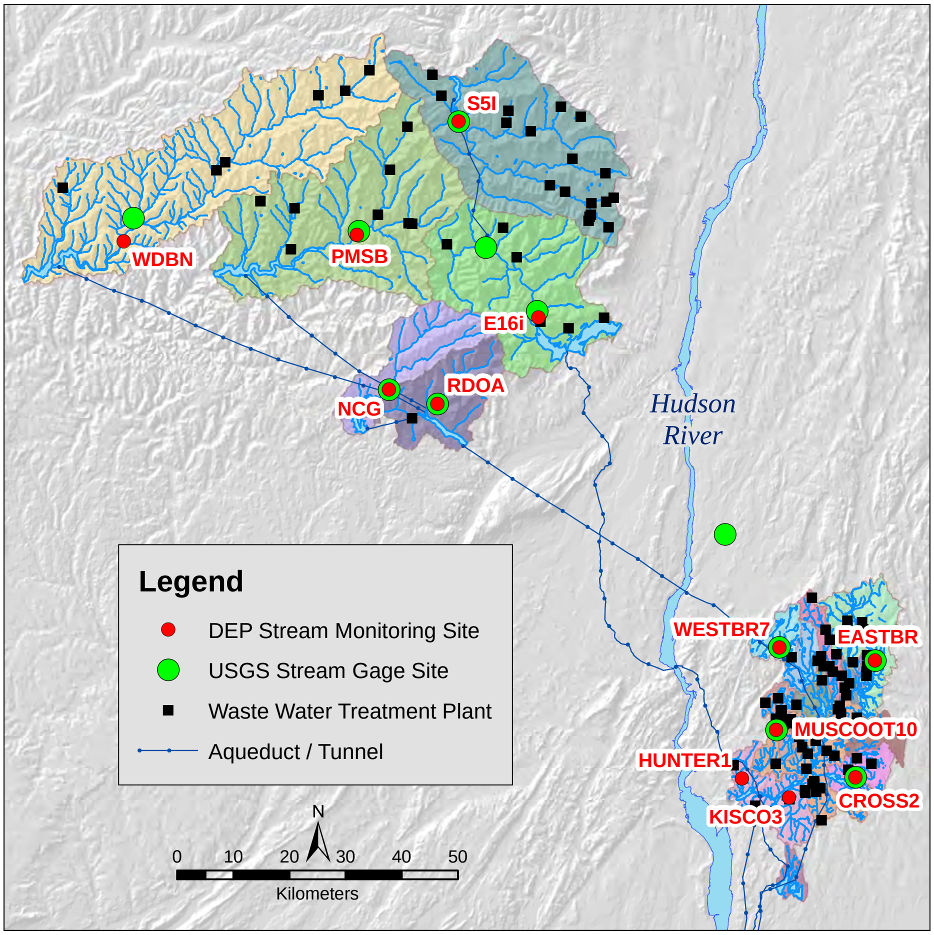


Figure 3.8 Locations of major inflow stream water quality sampling sites and USGS gauge stations used to calculate runoff values (see Section 2.3).

Water quality in these streams was assessed by examining those analytes considered to be the most important for the City's water supply. For streams, these are turbidity and fecal coliform bacteria (to maintain compliance with the SWTR), and TP (to control nutrients and eutrophication).

The 2013 results presented in Figure 3.9 are based on grab samples generally collected once a month, except that turbidity data were collected weekly at Esopus Creek at Boiceville bridge (E16I) and two or three times a month for most months at Rondout Creek near Lowes Corners (RDOA). The figure compares the 2013 median values against historical median annual values for the previous 10 years (2003-2012).

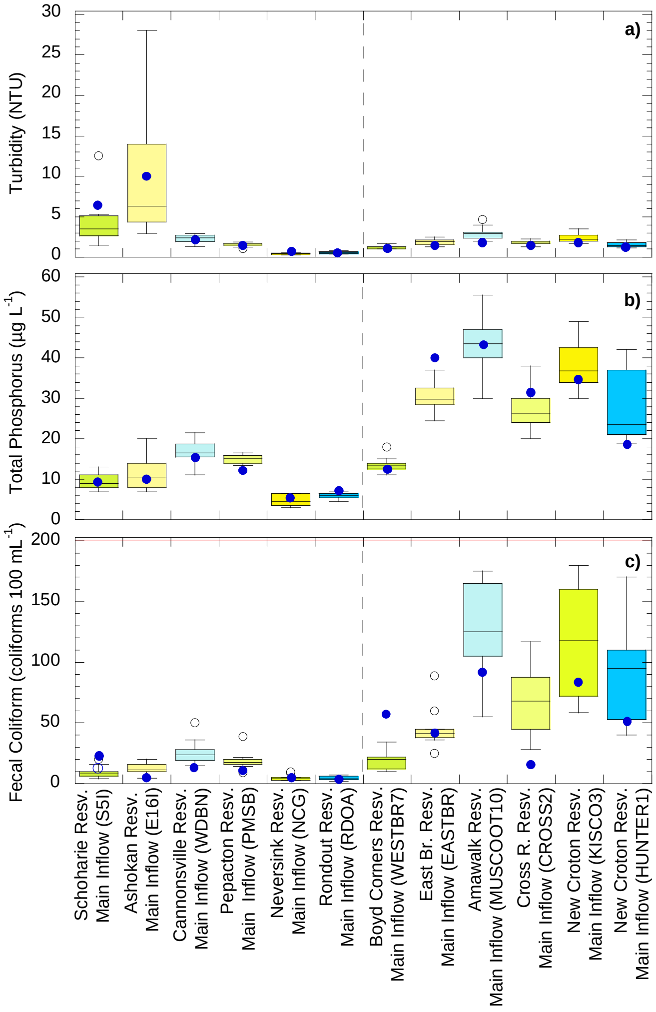


Figure 3.9 Boxplot of annual medians (2003-2012) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2013 displayed as a dot. The dotted line separates WOH streams (left) from EOH streams (right). The solid red line indicates the fecal coliform benchmark of 200 coliforms $100mL^{-1}$.

Turbidity

The turbidity levels for 2013 were generally near normal values, except for the Schoharie Creek inflow (S5I), which was somewhat elevated for the year (the second highest annual median in the last 10 years for Schoharie Creek). The annual median turbidities for the EOH inflows were all near or slightly below their historical values.

Total Phosphorus

In the Catskill/Delaware System, the 2013 median TP concentrations were generally near or slightly below their historical values, except for Rondout Creek near Lowes Corners (RDOA) which, with the same annual TP median as in 2012, was slightly above normal. The 2013 TP medians in the Croton System were varied, with the 2013 TP median at the inflow of East Branch Reservoir (East Branch Croton River) at its highest value in the past 10 years. Cross River's 2013 TP value was slightly elevated above its normal historical values, and Hunter Brook, an inflow to New Croton Reservoir, was slightly below its historical values.

Fecal Coliform Bacteria

The 2013 median fecal coliform bacteria levels in Catskill/Delaware streams were generally near or somewhat below typical historical levels, except for Schoharie Creek, which had its highest annual median in the last 10 years. For the Croton System, the annual fecal coliform levels were near normal for the East Branch Croton River, and below normal for the inflow to Amawalk (the Muscoot River) and the two inflows to New Croton, the Kisco River and Hunter Brook. Cross River was at its lowest fecal coliform value in the last 10 years, while the Boyd Corners inflow was at its highest value since 2003. A fecal coliform benchmark of 200 coliforms 100mL^{-1} is shown as a solid line in Figure 3.9. This benchmark relates to the NYSDEC water quality standard for fecal coliforms (expressed as a monthly geometric mean of five samples, the standard being <200 coliforms 100mL^{-1}) (6NYCRR §703.4b). The 2013 median values for all streams shown here lie below this value.

3.9 Stream Comparisons to Benchmarks in 2013

Selected water quality benchmarks have been established for reservoirs and reservoir stems (any watercourse segment which is tributary to a reservoir and lies within 500 feet or less of the reservoir) in the WR&R (DEP 2010a). In this section, the application of these benchmarks has been extended to 40 streams and reservoir releases in order to evaluate stream status in 2013 (as prescribed by the Watershed Water Quality Monitoring Plan (DEP 2009)). The benchmarks are provided in Table 3.10.

Table 3.10: Stream water quality benchmarks based on the WR&R, Appendix 18-B (DEP 2010a). These benchmarks are based on 1990 water quality results.

	Croton System		Catskill/Delaware System	
Analyte	Annual mean	Single sample maximum	Annual mean	Single sample maximum
Alkalinity (mg $CaCO_3$ L^{-1})	N/A	$\geq$40.00	N/A	$\geq$10.00
Ammonia-N (mg L^{-1})	0.1	0.2	0.05	0.25
Dissolved chloride (mg L^{-1})	35	100	10	50
Nitrite+nitrate (mg L^{-1})	0.35	1.5	0.4	1.5
Organic nitrogen[1]	0.5	1.5	0.5	1.5
Dissolved sodium (mg L^{-1})	15	20	5	10
Sulfate (mg L^{-1})	15	25	10	15
Total dissolved solids (mg L^{-1})[2]	150	175	40	50
Total organic carbon (mg L^{-1})[3]	9	25	9	25
Total suspended solids (mg L^{-1})	5	8	5	8

[1] Organic nitrogen is currently not analyzed.

[2] Total dissolved solids was estimated by multiplying specific conductivity by 0.65 (van der Leeden 1990).

[3] Dissolved organic carbon was used in this analysis since total organic carbon is no longer analyzed.

Comparison of stream results to these benchmarks is presented in Appendix E along with site descriptions, which appear next to the site codes. Note that the Catskill/Delaware System criteria are applied to the release from West Branch Reservoir (WESTBRR) since that release usually consists predominately of Delaware System water via Rondout Reservoir.

Alkalinity is a measure of water's ability to neutralize acids. Sufficient alkalinity ensures a stable pH in the 6.5 to 8.5 range and is a necessary condition for a healthy ecosystem. Monitoring alkalinity levels is also important to facilitate water treatment processes such as chemical coagulation, water softening, and corrosion control.

In the NYC water supply the lowest alkalinity levels typically occur in the winter and spring when acidic snowmelt reaches the streams. Streams of the Schoharie watershed always met the benchmark in 2013, while occasional excursions were observed in the Cannonsville and Pepacton watersheds. In the Pepacton watershed, values slightly below 10 mg L^{-1} occurred in March and April at Terry Clove (P-7) and at Fall Clove (P-8). During all winter and spring months at Mill Brook (P-60), values dipped below 10 mg L^{-1}, ranging from 7 to 9.1 mg L^{-1}. Excursions in the Cannonsville watershed only occurred in February, at Trout Creek (C-7) and Loomis Brook (C-8), where alkalinity reached a low of 9.5 mg L^{-1}. In contrast, values below 10 mg L^{-1} were common in the streams of the Ashokan, Rondout, and Neversink watersheds. Such low buffering capacity is typical of the surficial materials in this region of the Catskills. A benchmark of 40 mg L^{-1} is used for the Croton System streams, which reflects the much higher natural buffering capacity of this region. However, less buffering capacity does occur in the Boyd Corners and West Branch Reservoir watersheds. Alkalinity results from stream sites in those watersheds (i.e., GYPSYTRL1, HORSEPD12, WESTBR7 and BOYDR) were often below 40 mg L^{-1}, and lows from these streams ranged from 21.7 to 31.0 mg L^{-1}.

None of the Catskill or Delaware streams (including WESTBRR) exceeded the single sample chloride benchmark of 50 mg L^{-1} in 2013. However, the annual mean benchmark of 10 mg L^{-1} was exceeded in 7 of the 24 streams monitored in these two systems. The highest annual mean, 28.6 mg L^{-1}, occurred at Kramer Brook above Neversink Reservoir. In contrast, the two other monitored streams in the Neversink watershed, Aden Brook (NK4) and the Neversink River (NCG), averaged 4.4 and 3.2 mg L^{-1}, respectively. The Kramer Brook watershed is very small (<1 sq. mile), is bordered by a state highway, and contains pockets of development, all of which may contribute to the relatively high chloride levels. Other high annual means occurred at Bear Kill Creek (16.0 mg L^{-1}), a tributary to Schoharie Reservoir; at Trout Creek (12.8 mg L^{-1}), Loomis Brook (11.9 mg L^{-1}), and the West Branch of the Delaware River (11.1 mg L^{-1}), all tributaries to Cannonsville Reservoir; and at Chestnut Creek (14.6 mg L^{-1}), a tributary to Rondout Reservoir. The outflow from West Branch Reservoir (WESTBRR) increased from 10.5 mg L^{-1} in 2012 to 17.7 mg L^{-1} in 2013. The increase reflects the predominant “float” operational status of West Branch Reservoir in 2013. In float status, inputs to West Branch are reduced, resulting in much less Rondout water, which is relatively low in chloride, and greater inputs of local, higher chloride Croton water.

In the Croton System, the single sample chloride benchmark of 100 mg L^{-1} was commonly exceeded on the Muscoot River (MUSCOOT10) above Amawalk Reservoir, on Michael Brook (MIKE2) above Croton Falls Reservoir, and, on two occasions, at the Kisco River (KISCO3) above New Croton Reservoir. No other Croton stream exceeded 100 mg L^{-1} in 2013. However, 12 of the 16 monitored Croton streams did equal or exceed the annual mean benchmark of 35 mg L^{-1}. Means exceeding (or equaling) the benchmark ranged from 35.0 to 209.6 mg L^{-1}. The mean 2013 chloride concentration for all 16 Croton streams was 66.7 mg L^{-1}, a substantial increase from the 50.7 mg L^{-1} mean in 2012. By comparison, chloride was much lower in the Catskill and Delaware Systems, averaging 8.0 mg L^{-1} and 9.0 mg L^{-1}, respectively. Given the common occurrence of chloride and sodium, it is not surprising that sodium benchmarks were exceeded in much the same pattern as chloride. The primary source of sodium chloride is road salt. Secondary sources include septic system leachate, water softening brine waste, and wastewater treatment effluent.

Total dissolved solids (TDS) is a measure of the combined content of all inorganic and organic substances in the filtrate of a sample. Although TDS is not analyzed directly by DEP, it is commonly estimated in the water supply industry using specific conductivity measurements. Conversion factors for TDS relate to the water type (International Organization for Standardization 1985, Singh and Kalra 1975). For NYC waters, TDS was estimated by multiplying specific conductivity by 0.65 (van der Leeden 1990). In 2013, 15 of 24 Catskill/Delaware streams had at least one exceedance of the single sample maximum of 50 mg L^{-1}. Fourteen Catskill/Delaware streams also exceeded the annual mean benchmark of 40 mg L^{-1}. Most elevated TDS was associated with periods of low summer flow. Occasional winter excursions were correlated to high chloride concentrations. In the Croton System, 13 of 17 streams exceeded the annual benchmark of 150 mg L^{-1} and frequently exceeded the single sample maximum criterion of 175 mg L^{-1}.These excursions were correlated with elevated sodium and chloride concentrations.

When present in excess, nitrogen, especially in the bioavailable forms of nitrate and ammonia, is one of the important nutrients that can contribute to excessive algal growth in the reservoirs. The single sample nitrate benchmark of 1.5 mg L^{-1} was exceeded in one Croton stream, Michael Brook, located upstream of Croton Falls Reservoir. The benchmark was exceeded in 11 of 12 monthly samples and was especially high in August (5.4 mg L^{-1}), September (6.4 mg L^{-1}), October (7.7 mg L^{-1}), and November (10.4 mg L^{-1}). Four Croton streams equaled or exceeded the annual average benchmark of 0.35 mg L^{-1} for 2013: Horse Pound Brook at HORSEPD12, 0.35 mgL^{-1}; the Kisco River at KISCO3, 0.58 mg L^{-1}; the Muscoot River at MUSCOOT10, 0.56 mg L^{-1}; and Michael Brook at MIKE2, 3.97 mg L^{-1}. No streams from the Catskill/Delaware System exceeded the single sample nitrate benchmark of 1.5 mg L^{-1}. However, the average annual benchmark of 0.40 mg L^{-1} was exceeded in the West Branch of the Delaware River at WDBN, which averaged 0.52 mg L^{-1} for the year. Several streams that approached the benchmark included Kramer Brook at NK6, 0.38 mg L^{-1}; Fall Clove at P-8, 0.37 mg L^{-1}; and Chestnut Creek at RGB, 0.38 mg L^{-1}. The source of the nitrogen is unclear in some of these streams, but treatment plant input is a possible contributor to Michael Brook, Chestnut Creek, and the Kisco, Muscoot, and West Branch Delaware Rivers.

None of the true Catskill/Delaware System streams exceeded the ammonia single sample maximum of 0.20 mg L^{-1} in 2013. However, because West Branch Reservoir was operated mostly in float status in during the year, favoring local Croton inputs over water from Rondout Reservoir, its release (WESTBRR) exceeded the benchmark on three occasions. With the exception of Kramer Brook, almost all samples within the local Catskill/Delaware System were at or near the analytical detection limit of 0.02 mg L^{-1}. Ammonia results were elevated enough at Kramer Brook for it to exceed the mean annual ammonia benchmark of 0.05 mg L^{-1} by 0.01 mg L^{-1}. The annual average for the West Branch Reservoir release (WESTBRR), 0.11 mg L^{-1}, also exceeded the mean annual benchmark, reflecting its operational status in 2013. Two Croton System streams exceeded the ammonia single sample maximum of 0.2 mg L^{-1} in 2013. At the Titicus Reservoir release (TITICUSR) the single sample maximum was exceeded during the late summer and early autumn. The increase was associated with the release of ammonia from anoxic reservoir sediments brought about by the decomposition of summer algal blooms. The single sample maximum was also exceeded in February and March at Michael Brook. In this case, the source of the elevated ammonia may be related to the WWTP located upstream. In 2013, the mean annual benchmark of 0.10 mg L^{-1} was also exceeded at this stream. All other Croton streams were compliant with this benchmark in 2013.

Neither the single sample maximum (15.0 mg L^{-1}) nor the annual mean (10.0 mg L^{-1}) benchmarks for sulfate were surpassed in Catskill/Delaware streams in 2013. Most Croton stream results were below the Croton System single sample maximum of 25 mg L^{-1} and the annual average of 15 mg L^{-1}. The only exception was Michael Brook, where the single sample maximum was exceeded in two of four samples and the annual average was 23.3 mg L^{-1}. WWTPs are located upstream of these sampling locations and are the probable source of the excess sulfate.

Dissolved organic carbon (DOC) was used in this analysis instead of total organic carbon since the latter is not analyzed as part of DEP's watershed water quality monitoring program. Previous work has shown that DOC constitutes the majority of the organic carbon in stream and reservoir samples. The DOC benchmarks for a single sample (25 mg L^{-1}) and annual mean (9.0 mg L^{-1}) were not surpassed by any stream in 2013. The highest single sample DOC in the Catskill/Delaware System, 4.3 mg L^{-1}, occurred at Chestnut Creek in the Rondout watershed, while the annual mean Catskill/Delaware DOC ranged from 1.0 to 2.7 mg L^{-1}, well below the annual mean benchmark. Due to a greater percentage of wetlands in their watersheds, Croton streams typically have higher DOC concentrations than those in the Catskill/Delaware System; this is reflected in the 2013 annual means, which ranged from 2.4 to 4.7 mg L^{-1}. The highest single sample DOC was 6.9 mg L^{-1}, which occurred in the Muscoot River above Amawalk Reservoir (MUSCOOT10).

3.10 Stream Biomonitoring

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994. Assessments are made following protocols developed by the New York State Stream Biomonitoring Unit (SBU) (NYSDEC 2014.) In brief, five metrics, each a different measure of biological integrity, are calculated and averaged to produce a Biological Assessment Profile (BAP) score ranging from 0 to 10; these scores correspond to four levels of impairment (non-impaired, 7.5-10; slightly impaired, 5-7.5; moderately impaired, 2.5-5; severely impaired, 0-2.5). The five metrics used in the analysis are total taxa; Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa; Hilsenhoff Biotic Index, Percent Model Affinity; and, since 2012, Nutrient Biotic Index-Phosphorus (NBI-P).

In 2013, DEP sampled 38 sites in 25 streams throughout New York City's watershed, 19 in the Catskill System, 10 in Delaware, and 9 in Croton. (For site locations, see Appendix F.) Scores in Croton were generally lower than in Catskill and Delaware, which is consistent with previous years' results (see, e.g., DEP 2013a, 2013b, 2013c).

Catskill/Delaware Systems

In the Catskill System, 14 sites were non-impaired and 5 were slightly impaired, while in the Delaware System, 5 sites were non-impaired and 5 slightly impaired. Five impaired sites is a somewhat higher number than usual for the Delaware System. Most Catskill/Delaware sites were below their long-term means (Figure 3.10), which is also unusual. In both systems, low taxa counts were primarily responsible for the impaired results, although in Delaware, low NBI-P scores also contributed. While the lowest counts were recorded at the impaired sites, low counts were by no means restricted to those sites; both impaired and non-impaired sites were affected. In fact, of the 29 sites sampled in the Catskill/Delaware watersheds, 25 had counts below the historical (1994-2013) mean of 25.4, with the mean for all 29 sites (21.6) approaching the Croton mean (21.3) (Figure 3.11). Declines in total taxa at Catskill/Delaware sites first became apparent in the aftermath of Tropical Storms Irene and Lee in 2011 and have persisted since then. It is unknown whether this represents a continuing impact from these storms or some other form of disturbance.

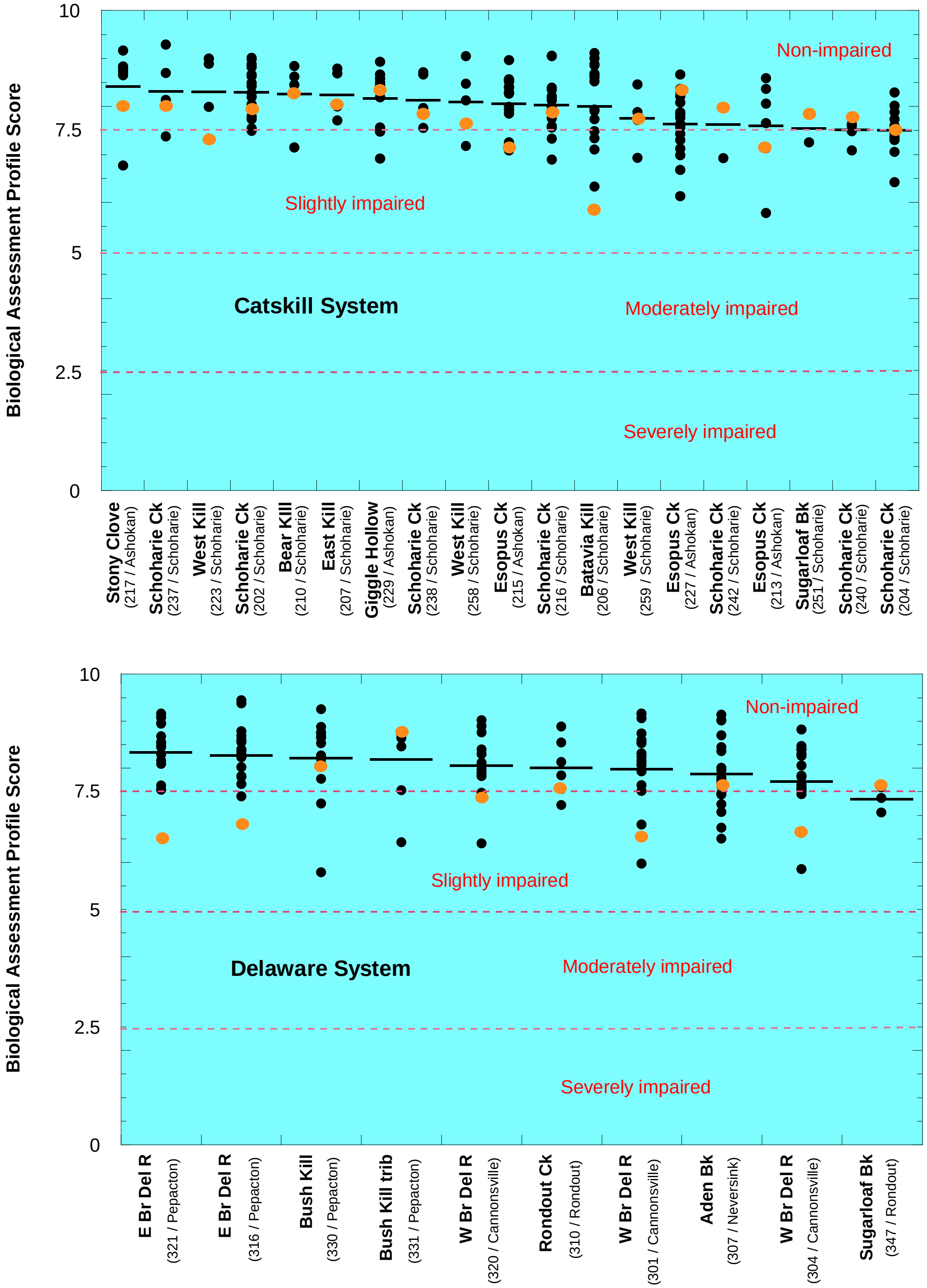


Figure 3.10 Biological Assessment Profile scores for Catskill/Delaware biomonitoring sites sampled in 2013, arranged by mean score (—) from highest to lowest. ● = 2013 score; ● = pre-2013 score. The site's number and watershed are indicated in parentheses following the site name.

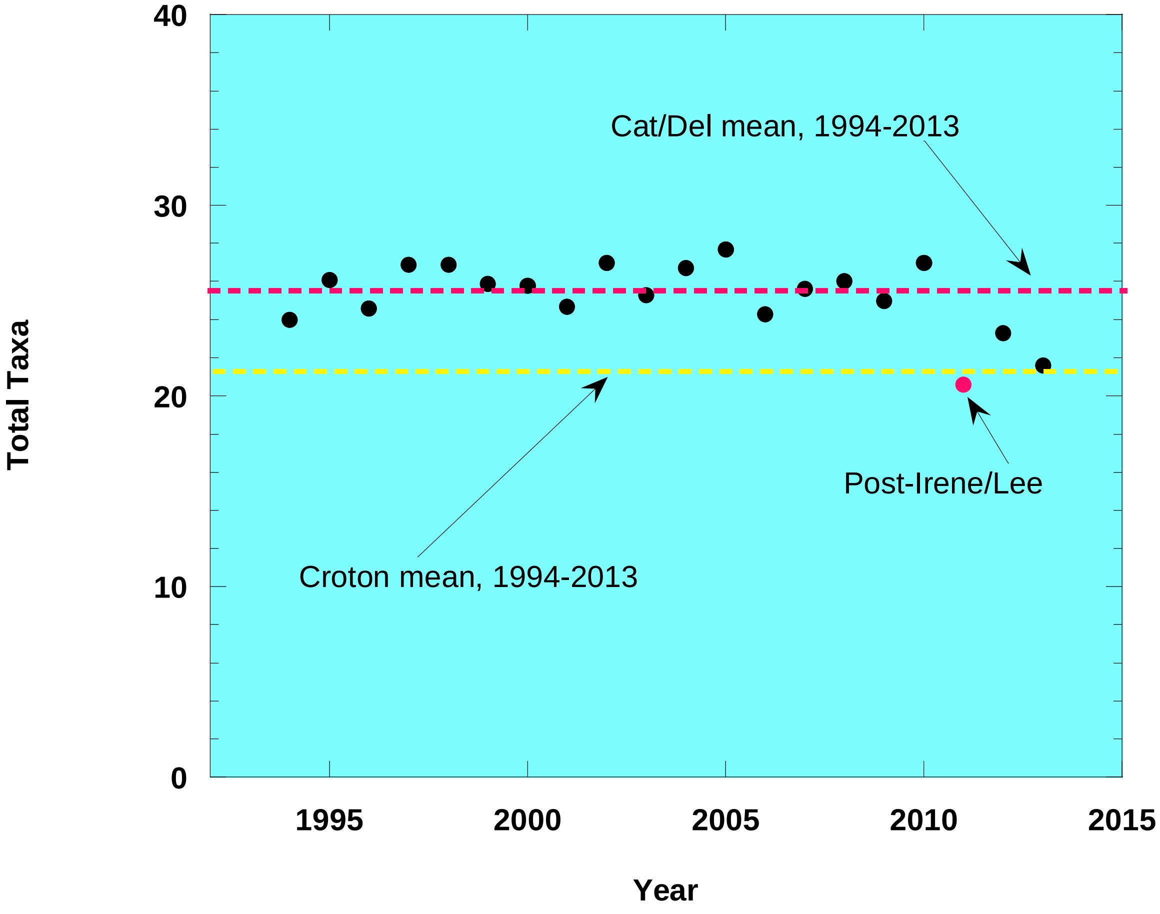


Figure 3.11 Mean annual total taxa counts for sites in the Catskill/Delaware watersheds, 1994-2013, compared to the overall Catskill/Delaware mean and the Croton mean for the same period. The red dot represents the mean for 2011, when many sites were severely impacted by Tropical Storms Irene and Lee.

Another possible consequence of the storms was the large spike in the percentage of hydropsychid caddisflies at most of the Catskill/Delaware sites sampled in 2012. (See DEP 2013a for details.) Those numbers dropped sharply in 2013, suggesting that, in this respect at least, the effect of the storms may be waning. At over half the sites sampled in 2012, hydropsychids constituted more than 30% of the macroinvertebrate community; in 2013, hydropsychid numbers had dropped at 70% of those sites, and had done so by an average of 23%. Overall, fewer than one-third of the sites sampled in 2013 had a hydropsychid percent composition exceeding 30% (Table 3.11).

Table 3.11: Biomonitoring sites in the Catskill/Delaware watersheds in 2012 and 2013 at which hydropsychid caddisflies constituted more than 30% of the macroinvertebrate community. Percentages in green mark sites in 2012 with more than 30% hydropsychids; percentages in red mark sites in 2013 with more than 30%. Total number of sites sampled in the Catskill/Delaware watersheds in 2012 = 32; total number sampled in 2013 = 29. ↓ indicates a decline from previous year's value. ns = not sampled.

Site number	Stream	2012 (%)	2013 (%)
202	Schoharie Creek at Hunter	35.3	36.8
204	Schoharie Creek at Prattsville	33.6	20.5 ↓
206	Batavia Kill	51.5	39.3 ↓
207	East Kill	ns	41.7
213	Esopus Creek at Boiceville	77.9	16.4 ↓
215	Esopus Creek at Allaben	39.4	32.7 ↓
216	Schoharie Creek at Lexington	44.5	26.9 ↓
217	Stony Clove	63.7	21.8 ↓
218	Beaver Kill	35.0	ns
227	Esopus Creek nr. Phoenicia	65.2	10.8 ↓
246	Bush Kill	33.6	ns
255	Esopus Creek nr. Mt. Tremper	43.0	ns
258	West Kill	38.7	23.6 ↓
259	West Kill	50.0	20.8 ↓
301	W. Br. Delaware R.	19.8	41.7
307	Aden Brook	47.2	27.8 ↓
310	Rondout Creek	44.2	37.3 ↓
316	E. Br. Del. R. nr. Margaretville	36.1	54
321	E. Br. Del. R. nr. Halcottsville	29.1	59.6
347	Sugarloaf Brook	37.4	36.8 ↓

Increases in hydropsychids has become a noticeable phenomenon in recent years, particularly at WOH sites. Hydropsychids are pollution tolerant, insensitive insects that often dominate disturbed streams, although the specific reason for their increased numbers at such sites is often unclear. Based on the communities representative of various forms of impact described in the SBU's Impact Source Determination (ISD) protocols (NYSDEC 2014), hydropsychids can dominate in streams affected by a wide variety of disturbance, including nonpoint nutrients and pesticides, municipal/industrial discharges, sewage effluent/animal waste, and impoundments. At some WOH sites, like those described above, the effects of the 2011 storms may be at least partly responsible for the rise in hydropsychid numbers, but at sites where increases occurred prior to 2011 the explanation presumably lies elsewhere, perhaps in the impacts identified by the ISD. Three such sites are located in the Catskill/Delaware watersheds and one in Croton, and at all of them, the increases appear to be playing a role in declining BAP scores. The affected sites, discussed below and in the Croton System section, are Sites 206, 301, 321, and 102.

At Site 206 on the Batavia Kill, the BAP score has been experiencing large declines since 2008, when it suffered a steep drop from the previous year's score of 8.30 to what was then a new low of 7.07. It has been falling ever since (Figure 3.12). This year, the score was 5.86, only slightly higher than last year's record low of 5.55. Overall, the average score from 2008-2013 (excluding the Irene/Lee-impacted year of 2011) was 6.35, considerably lower than the 8.17 average for prior years (1995-2007). The lower average also reflects a difference in assessment: 5 consecutive slightly impaired assessments from 2008 to 2013 versus 13 consecutive non-impaired assessments from 1995 to 2007. The drop in BAP has been driven by a sustained increase in hydropsychid numbers and a concomitant reduction in the number of mayflies, the effect of which has been to depress the Percent Model Affinity, total taxa, and HBI scores; this in turn is what has led to the lower BAP scores. While the 2011 storms may have influenced the results of the last three years, other factors must be involved, at the very least for the years preceding 2011. DEP plans to sample upstream on the Batavia Kill to see if it can locate a source of the disturbance that has caused these scores to decline so precipitously in recent years.

Figure 3.12 Biological Assessment Profile scores for Sites 102, 206, 301, and 321. The 2011 score at Site 206 has been omitted because of the low subsample count recorded that year.

At Site 301 on the West Branch Delaware River at Hobart, the 2013 slightly impaired BAP score of 6.54 reflects a trend that began in 2010, when scores first fell sharply from historical (1994-2009) levels (Figure 3.12). Prior to 2010, BAP scores at this site had ranged from 7.17 to 8.76, except for one year (1997) when the BAP dipped to 6.02. Two-thirds of the scores during this period exceeded 7.8, and the site was rated non-impaired 13 times. By contrast, in the last four years scores ranged from 6.54 to 6.72, resulting in a slightly impaired assessment in each of those years. High hydropsychid numbers were the primary drivers of the low scores in 2010, 2011, and 2013, as they were in 1997.

In every year from 1996 to 2006, Site 321 on the East Branch Delaware River near Halcottsville was rated non-impaired, with BAP scores never falling below 8. In 2007, however, the score dropped to 7.38, yielding a slightly impaired assessment for the first time ever. In four of the next six years, the highest score recorded was 7.70, and in 2013 the score fell to a new low of 6.52 (Figure 3.12). The source of this decline is unclear. In three of the seven years since 2007, spikes in hydropsychids were a major contributor (2007—48.5% hydropsychids, 7.55 BAP; 2009—44.6% hydropsychids, 7.63 BAP; 2013—59.6% hydropsychids, 6.52 BAP). As indicated above, however, the reason for these increases, two of which occurred before the tropical storms of 2011, remains elusive.

Croton System

In the Croton System, one site (Stone Hill River, Site 142) was non-impaired, eight were slightly impaired, and two were moderately impaired (Figure 3.13). The high percentage of impaired sites is typical of the Croton System (e.g., 2008—84.6%, 2009—78.6%, 2010—100%, 2011—84.6%, 2012—100%). At Site 112 on the Muscoot River, the 5.18 BAP score was one of the lowest recorded there since sampling began in 1996, just above the moderately/slightly impaired threshold of 5. This is the fourth year out of the last five that the site has experienced scores in this range. Low values for the new NBI-P metric, an indicator of phosphorus enrichment, appear to be at least partly responsible. In contrast, the mean BAP score for years preceding 2009 was 6.66.

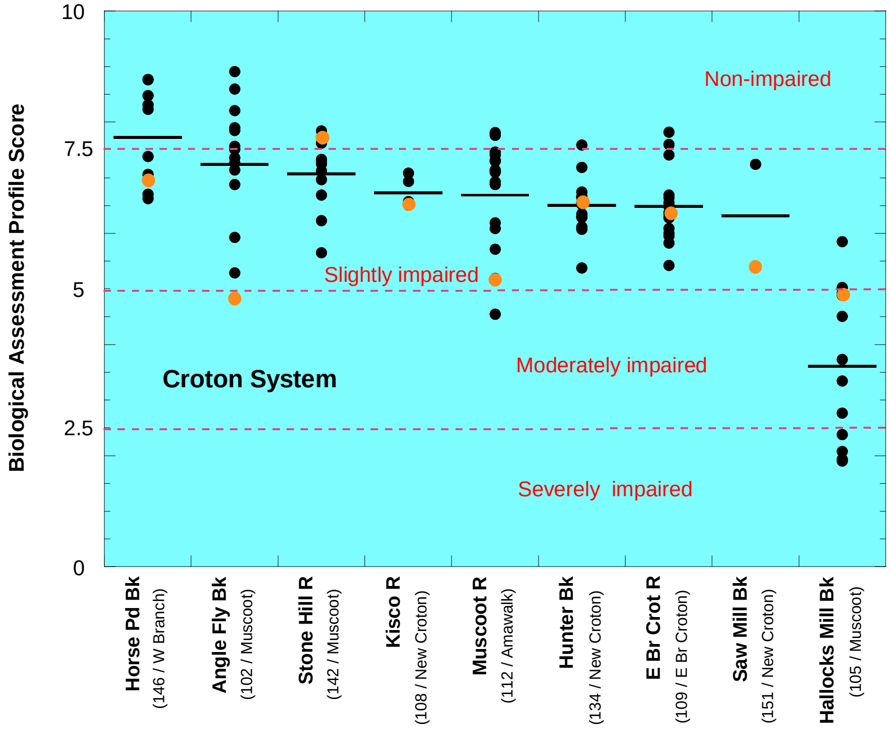


Figure 3.13 Biological Assessment Profile scores for Croton System biomonitoring sites sampled in 2013, arranged by mean score (—) from highest to lowest. 🟠 = 2013 score; ● = pre-2013 score. The site's number and watershed are indicated in parentheses following the site name.

The two moderately impaired assessments represent contrasting developments. Site 105 on Hallocks Mill Brook below the upgraded Yorktown Heights WWTP appears to have stabilized in the moderately to slightly impaired range, with a 2013 score of 4.89 and a mean BAP score in the years since the 2008 upgrade—4.96—that lies virtually on the moderately/slightly impaired boundary of 5. This compares to the seven years of prior sampling, when the 2.57 mean score fell almost exactly at the severely/moderately impaired threshold of 2.5. In effect, then, the site has improved by one full assessment category since the upgrade. Also noteworthy in 2013 was the relatively large number of mayflies belonging to the very sensitive genus *Isonychia*: 15 individuals altogether in the two subsamples drawn from the sample. Anglefly Brook (Site 102), on the other hand, continued to experience a decline that began in 2004 and has been accelerating since 2009 (Figure 3.12). The site was rated as non-impaired in every year of sampling but one from 1996 to 2003, but has been consistently assessed as impaired since then. From 2004 to 2012, it was rated slightly impaired, with gradually declining BAP scores that dipped below 6 for the first time in 2009. This year, the site received a new low score of 4.85, resulting in its first ever moderately impaired assessment, the second lowest possible. The principal driver of this decline has been the great increase in hydropsychid dominance—55.2% in 2008, 47.8% in 2009, 35.8% in 2011, 63.3% in 2012, and 72.9% in 2013, compared to an average 24.3% for the years 1994-2006. As at Site 206, the rise in hydropsychid numbers has been accompanied by a steady decline in mayflies, with not a single mayfly recorded in 2013. As has already been noted for the Catskill/Delaware sites, there is no ready explanation for these population fluctuations. DEP will sample at several sites upstream of Site 102 this year to see it if can isolate the source of the decline.

4. Kensico Reservoir

4.1 Kensico Reservoir Overview

Figure 4.1 Kensico Reservoir.

Kensico Reservoir (Figure 4.1), located in Westchester County, is the terminal reservoir for the City's Catskill/Delaware water supply. Because Kensico Reservoir is the last impoundment of Catskill/Delaware water prior to entering the City's distribution system, the protection of this reservoir is critically important to preventing water quality degradation and maintaining Filtration Avoidance. To further that goal, DEP conducts several ongoing water quality monitoring programs at aqueducts, local streams, and the reservoir. The routine sampling strategy for Kensico is documented in the 2009 Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009) and the sampling sites are shown in Figure 4.2. The plan prescribes monitoring to achieve compliance with all federal, state, and local regulations; enhance the capability to make current and future predictions of watershed conditions and reservoir water quality; and ensure delivery of the best water quality to consumers through ongoing surveillance. Because Kensico is the raw source water for the unfiltered Catskill/Delaware System, and is immediately upstream of disinfection, monitoring is done at its highest frequency here.

A summary of the samples that were collected at Kensico in 2013 is provided in Table 4.1. Because compliance with the Safe Drinking Water Act's Surface Water Treatment Rule (SWTR) (USEPA 1989) is of paramount importance to DEP for maintaining Filtration Avoidance, fecal coliforms and turbidity are focal points in the discussion of Kensico water quality. DEP's data continue to demonstrate that the Waterfowl Management Program has been instrumental in keeping coliform bacteria concentrations well below the limits set by the SWTR.

Only one special investigation (SI) was conducted on Kensico in 2013, to track and manage stormwater, and the results are discussed in Section 4.6. A detailed discussion of the protozoan pathogens *Cryptosporidium* and *Giardia*, and human enteric viruses, is provided in Chapter 5.

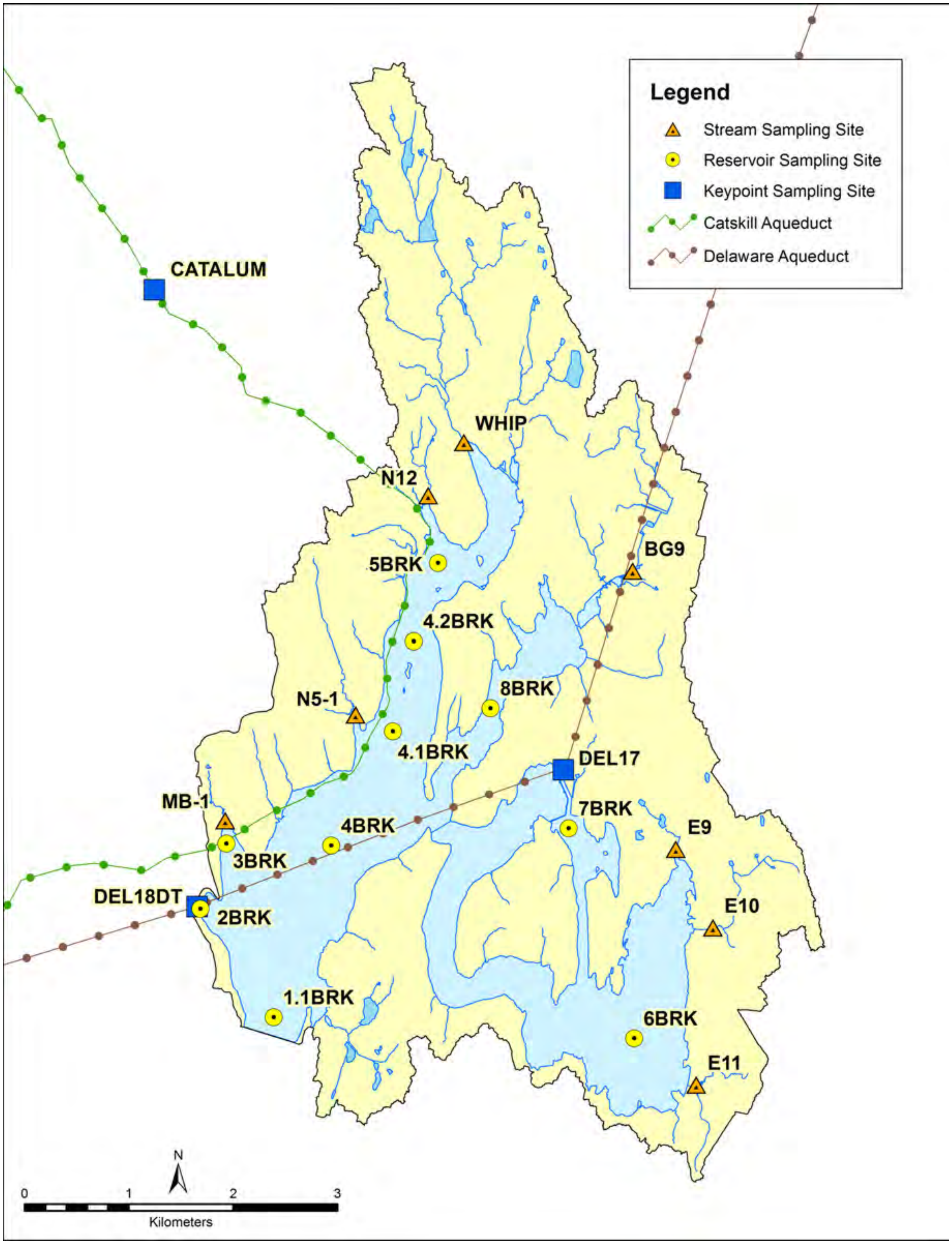


Figure 4.2 Kensico Reservoir, showing limnological and hydrological sampling sites, keypoints, and aqueducts. There is a meteorological station at DEL18.

Table 4.1: Summary of Kensico water quality samples collected in 2013.

Kensico sampling programs	Turbidity	Bacteria	*Giardia*/ *Cryptosporidium*	Virus	Nutrients	Other chemistry	Metals	Phyto-plankton
SWTR compliance	2,182	.	.	.	.	.	.	.
Keypoint effluent	365	368	52	51	12	417	4	156
Keypoint influent	522	522	103	103	106	625	8	106
Reservoir	859	577	.	.	199	577	24	105
Streams	105	96	97	.	72	169	.	.

4.2 Reservoir Raw Water Quality Compliance

DEP routinely conducts water quality compliance monitoring at the aqueduct keypoints at Kensico Reservoir. The CATALUM and DEL17 influent keypoints represent water entering Kensico Reservoir from the NYC upstate reservoirs via the Catskill and Delaware Aqueducts, respectively. The DEL18DT effluent keypoint represents Kensico Reservoir water entering the Delaware Aqueduct at a point just prior to disinfection; this water ultimately travels down to distribution. The CATALUM and DEL17 influent keypoints are monitored via grab samples for fecal coliforms (5 days per week), turbidity (5 days per week), and nutrients (monthly, except total phosphorus is collected weekly at CATALUM and DEL17 as one of the monitoring requirements of the CATIC and DEL17 SPDES permits, respectively). The information is used as an indicator of water quality entering Kensico Reservoir, which is in turn used to optimize operational strategies to provide the best possible quality of water leaving the reservoir. The DEL18DT effluent keypoint is monitored via daily grab samples for fecal coliforms (7 days per week), turbidity (every four hours, in accordance with SWTR regulations, and also at the time the fecal coliform samples are collected), and nutrients (monthly). The keypoint sites are also continuously monitored for temperature, pH, conductivity, and turbidity. The exceptional importance of the influent keypoints for optimal operations and the effluent keypoint as the source water compliance monitoring site warrants this high intensity monitoring.

For the fecal coliform counts measured at the Kensico influents from January 1 to December 31, 2013, medians of less than 1 fecal coliform 100mL^{-1} at both CATALUM and DEL17 were reported. The maximum fecal coliform counts were 5 fecal coliforms 100mL^{-1} at CATALUM (Figure 4.3) and 40 fecal coliforms 100mL^{-1} at DEL17 (Figure 4.4). These data demonstrate that the fecal coliform levels of the aqueducts flowing into Kensico were typically low. The median turbidity at CATALUM from January 1 to December 31, 2013 was 3.6 NTU, while at DEL17 it was 0.85 NTU. During this period, the maximum turbidity measurements were 7.0 NTU at CATALUM and 1.6 NTU at DEL17 (Figures 4.5 and 4.6).

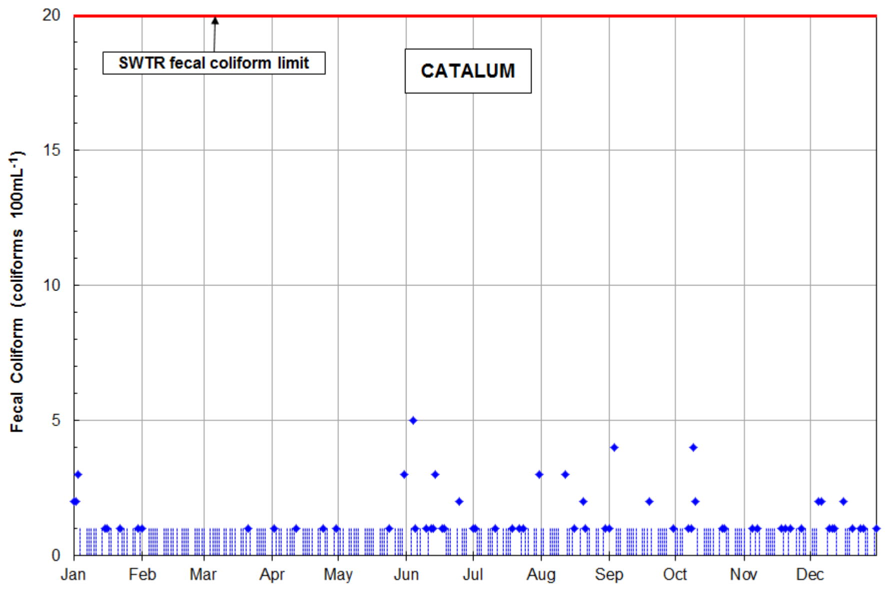


Figure 4.3 Five-day-per-week fecal coliform grab sample results at CATALUM, the Catskill Aqueduct Kensico influent. The "drop lines" along the x-axis indicate censored (below detection) values. Note that while the SWTR fecal coliform limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

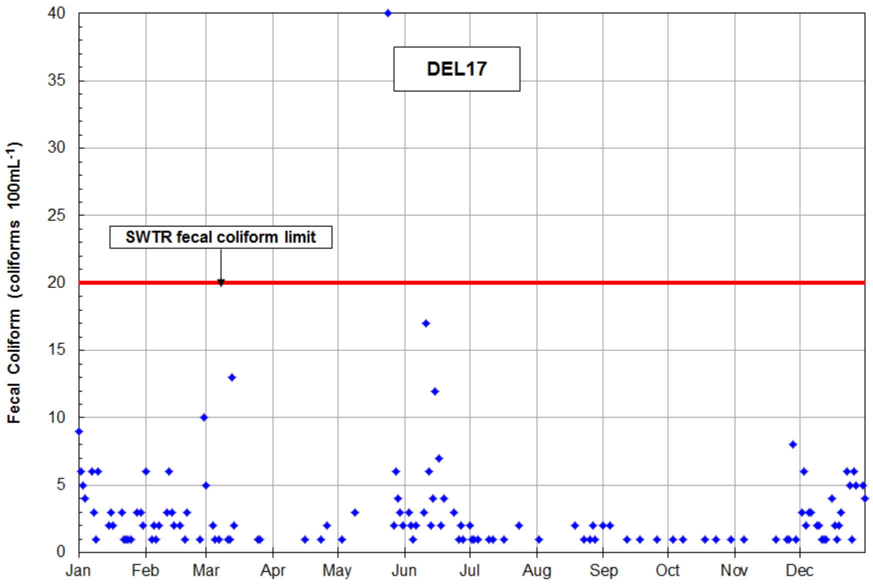


Figure 4.4 Five-day-per-week fecal coliform grab sample results at DEL17, the Delaware Aqueduct Kensico influent. The "drop lines" along the x-axis indicate censored (below detection) values. Note that while the SWTR fecal coliform limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

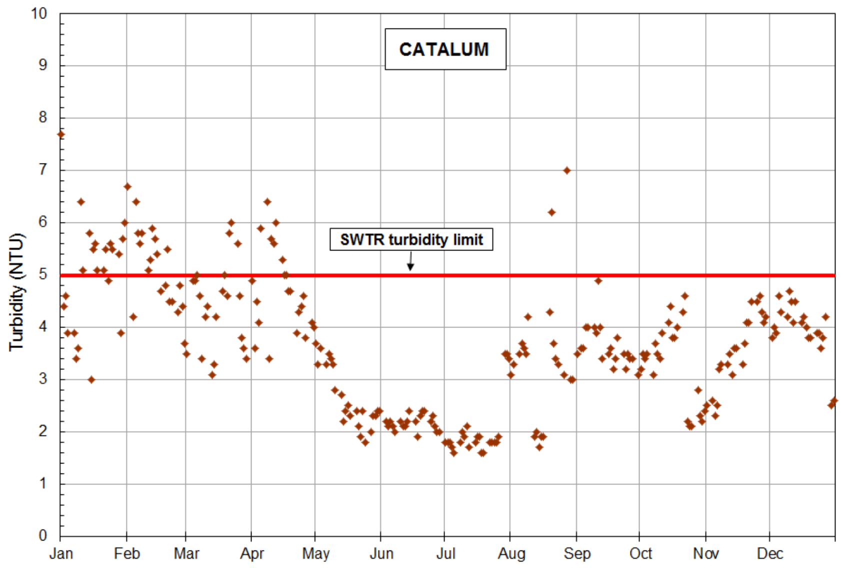


Figure 4.5 Five-day-per-week turbidity grab sample results at CATALUM, Kensico Reservoir's Catskill Aqueduct influent keypoint. Note that while the SWTR turbidity limit is indicated by a reference line, the influent keypoint is not subject to the SWTR.

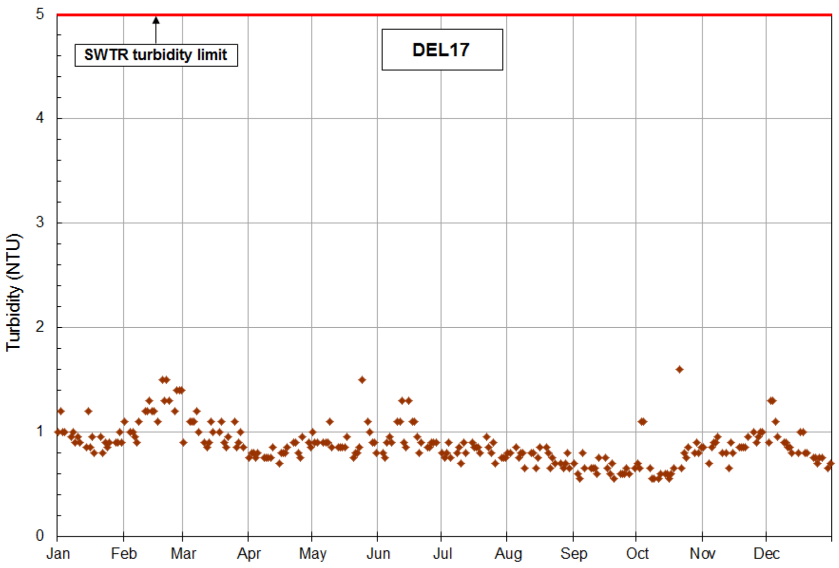


Figure 4.6 Five-day-per-week turbidity grab sample results at DEL17, Kensico Reservoir's Delaware Aqueduct influent keypoint. Note that while the SWTR turbidity limit is indicated by a reference line, the influent keypoint is not subject to the SWTR.

From January 1 to December 31, 2013 at the Kensico effluent (DEL18DT), the median fecal coliform count was 1 fecal coliform 100mL^{-1}. Only one sample exceeded the 20 fecal coliform 100 mL^{-1} threshold in 2013, when 34 coliforms 100mL^{-1} were reported on September 13 following nearly 3 inches of rainfall (Figure 4.7). Median turbidity from January 1 to December 31, 2013 was 1.0 NTU at DEL18DT and the maximum 4-hour turbidity measurement was 2.2 NTU (Figure 4.8).

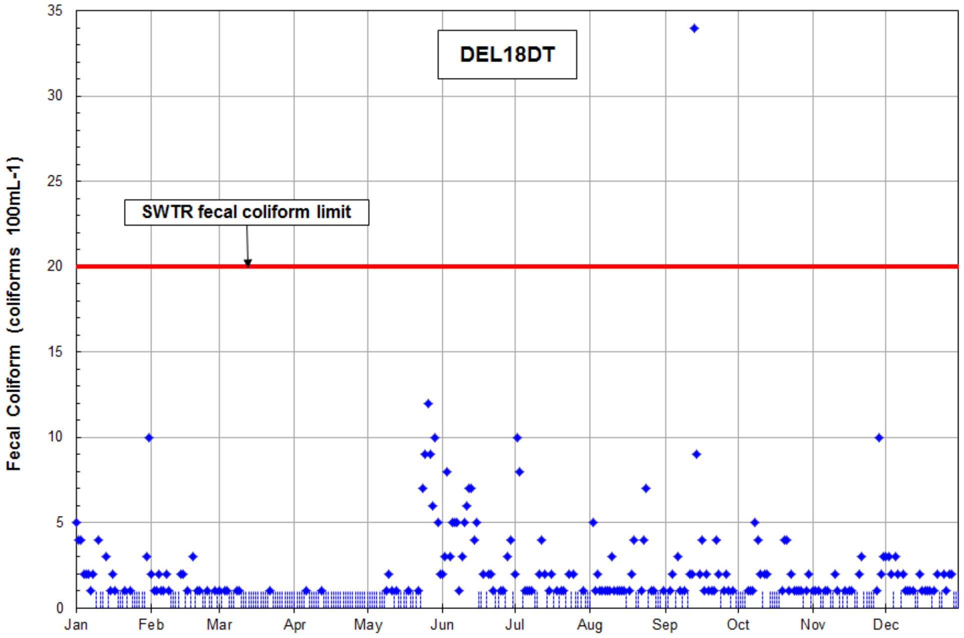


Figure 4.7 Seven-day-per-week fecal coliform grab sample results at Kensico Reservoir's Delaware Aqueduct effluent keypoint (DEL18DT). The "drop lines" along the x-axis indicate censored (below detection) values.

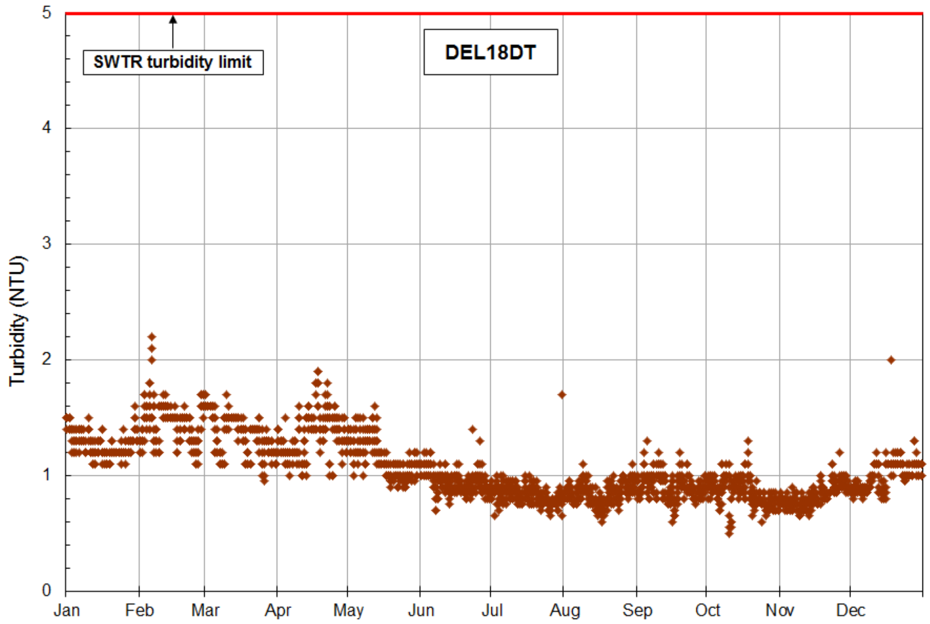


Figure 4.8 Four-hour turbidity and daily grab sample daily results at Kensico Reservoir's Delaware Aqueduct effluent keypoint (DEL18DT). The SWTR turbidity limit of 5 NTU is indicated by a reference line.

Overall, water quality in 2013 was excellent, with the source water at Kensico meeting the SWTR limits for both fecal coliforms and turbidity.

4.3 Reservoir Operations and Waterfowl Management

Migratory populations of waterbirds utilize NYC reservoirs as temporary staging areas and wintering grounds, and in doing so contribute to increases in fecal coliform loadings during the autumn and winter, primarily from direct fecal deposition in the reservoirs. These waterbirds generally roost nocturnally and occasionally forage and loaf diurnally on the reservoirs, although most foraging activity occurs away from the reservoirs. In the past, fecal samples collected and analyzed for fecal coliform bacteria concentrations from both Canada Geese (*Branta canadensis*) and Ring-billed Gulls (*Larus delawarensis*) revealed that fecal coliform concentrations are relatively high per gram of feces (Alderisio and DeLuca 1999). This is consistent with data from water samples collected over several years near waterbird roosting and loafing locations demonstrating that fecal coliform levels are correlated with waterbird populations at several NYC reservoirs (DEP 2002, 2003, 2004, 2005, 2006, 2007, 2008a, 2009, 2010b). Based on these data, DEP determined that waterbirds were the most important contributor to seasonal fecal coliform bacteria loads to Kensico and other terminal reservoirs (West Branch, Rondout, Ashokan), and that waterbirds can also lead to increased seasonal fecal coliform levels in other reservoirs from which water can be pumped into the Delaware Aqueduct (Croton Falls and Cross River).

In response to these data, which clearly demonstrate the relationship between waterbird population density and reservoir fecal coliform levels, DEP developed and implemented a Waterfowl Management Program (WMP) to reduce or eliminate the waterbird populations inhabiting the reservoir system (DEP 2002). The WMP has implemented standard bird management techniques at several NYC reservoirs that are approved by the United States Department of Agriculture's Animal and Plant Health Inspection Service's Wildlife Services, the United States Fish and Wildlife Service (USFWS), and the New York State Department of Environmental Conservation (NYSDEC). DEP has also acquired a depredation permit from the USFWS and NYSDEC to implement additional avian management techniques. Bird dispersal measures include non-lethal harassment by pyrotechnics, motorboats, airboats, propane cannons, and physical chasing; bird deterrence measures include waterbird reproductive management, shoreline fencing, bird netting, overhead bird deterrent wires, and meadow management. At Hillview Reservoir, additional wildlife management methods are employed, and continued to be used in 2013. They include lethal removal of resident Ruddy Ducks (*Oxyura jamaicensis*) and other migratory ducks through a United States Department of Agriculture contract, and the installation of a bird deterrent wire system installed along the reservoir dividing wall. In addition, mammals were trapped and removed in locations where animal feces (latrines or locations of repeated fecal eliminations by an animal) were identified. A federal wildlife depredation permit was also used to eliminate nesting Mallards where necessary. These efforts have led to continued reductions in local breeding opportunities around water intake structures, which in turn has led to reduced fecundity.

The SWTR (40 CFR 141.71(a)(1)) states that in no more than 10% of source water fecal coliform samples may counts exceed 20 fecal coliforms 100 mL^{-1} over the previous six-month period. Since the inception of the WMP, no such violation has occurred at Kensico Reservoir. The link between this success and the WMP is demonstrated by comparing source water fecal coliform levels before and after the implementation of the WMP (Figure 4.9). DEP will continue implementation of the WMP to help ensure delivery of high quality water to NYC consumers.

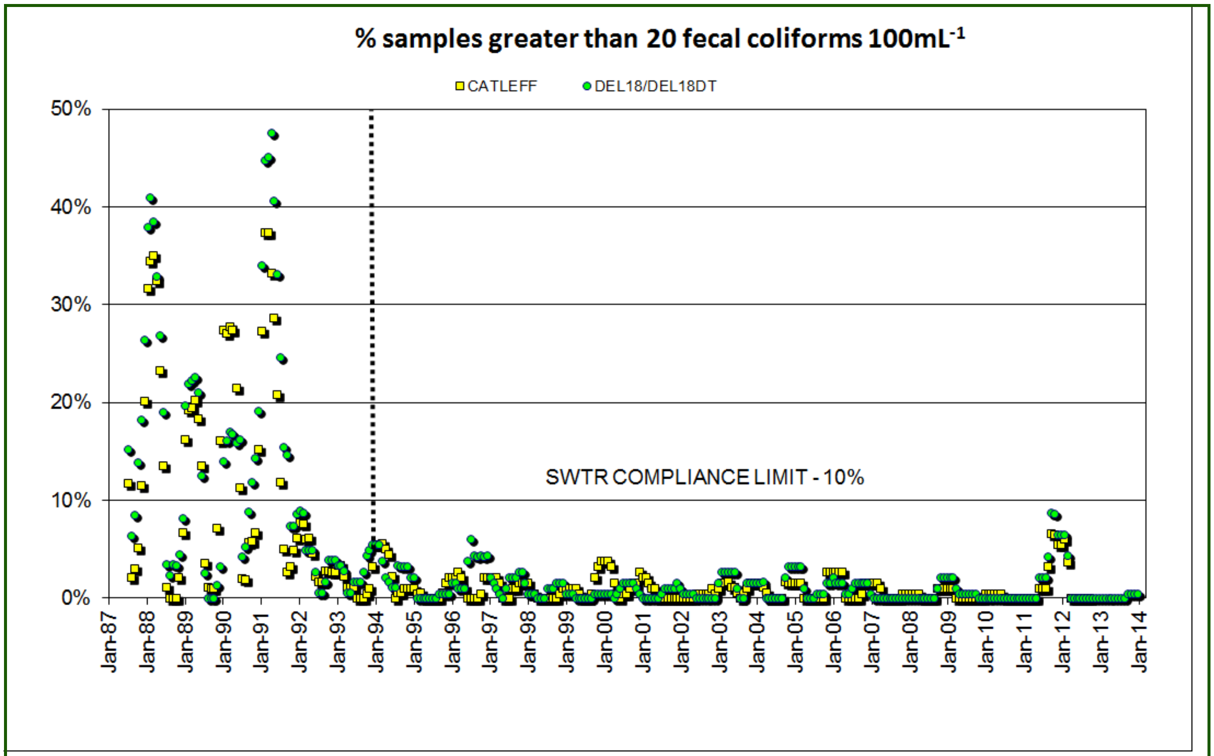


Figure 4.9 Percent of keypoint fecal coliform samples at Kensico Reservoir greater than 20 fecal coliforms 100mL^{-1} for the previous six-month period, 1987-2014. Note that the DEL18 site was relocated from the forebay (DEL18) to the downtake shaft (DEL18DT) commencing on August 20, 2012.

4.4 Kensico Streams and Turbidity Curtain Inspections

4.4.1 Kensico Stream Water Quality

DEP continues to monitor the hydrology of the Kensico watershed. Samples are collected at eight fixed sampling sites to quantify water quality at each of the perennial streams (BG9, E10, E11, E9, MB-1, N12, N5-1, WHIP) as shown in Figure 4.2. Routine sampling of these streams was conducted monthly in 2013. In addition to the routine program, special investigation samples were collected in response to a June 2013 storm (see Section 4.6).

Also in 2013, continuous flow measurements were maintained at six of the eight perennial Kensico tributaries. Stage height is recorded at 15-minute intervals and the flow is then calculated based on the appropriate flume, weir, or rating curve. Collection of flow data was suspended at the N12 tributary on February 12, 2012 and at the Whippoorwill Creek (WHIP) site on April 27, 2012. These suspensions were due to construction activities, and flow monitoring will resume once the construction activity is completed and the necessary flow monitoring equipment is re-installed.

Coliforms

The routine fecal coliform data for the period January 2013 through December 2013 are plotted in Figure 4.10. Boxplots are used to describe the distribution of the data, and to compare data between different sites. However, it should be noted that the Kensico fecal coliform data contain some censored values (i.e., nondetects, where the data are less than a detection limit), and so a Minitab® macro written by Dr. Dennis Helsel of Practical Stats® (http://www.practicalstats.com/nada/downloads.html) was used in the analysis to properly account for the censored data. A horizontal line is drawn at the maximum detection limit (Max Det. Limit) because only values above the maximum detection limit are known with certainty, while the distribution of values below the detection limit is uncertain. The maximum detection limit indicated on the plots is the maximum detection limit of multiple detection limits because coliform data may have various detection limits reported in the dataset, such as <1 or <10 coliforms 100mL^{-1}, depending on what dilution is used.

6 NYCRR Part 703 water quality standards for fecal coliforms have been used as a guideline against which to compare samples collected through DEP’s monthly fixed-frequency monitoring program. The fecal coliform standard for classes A, B, C, D is as follows: “The monthly geometric mean, from a minimum of five examinations, shall not exceed 200.” All Kensico streams had annual median values well below 200 fecal coliforms 100mL^{-1}. N12 had the highest median value at 55 fecal coliforms 100mL^{-1}, E11 had an annual median of 53 fecal coliforms 100mL^{-1}, and N5-1 had an annual median of 52 fecal coliforms 100mL^{-1}. Whippoorwill Creek (WHIP) had the lowest annual median of 18 fecal coliforms 100mL^{-1}. The maximum value for fecal coliforms during routine sample collection was 7,300 coliforms 100mL^{-1} at Malcolm Brook (MB-1) on June 4, following more than an inch of rain at Kensico on June 2-3. Highest fecal coliform values were generally observed when rain occurred on or just prior to the sampling date. 2013 descriptive statistics for fecal coliforms in all of the Kensico perennial streams are displayed in Table 4.2.

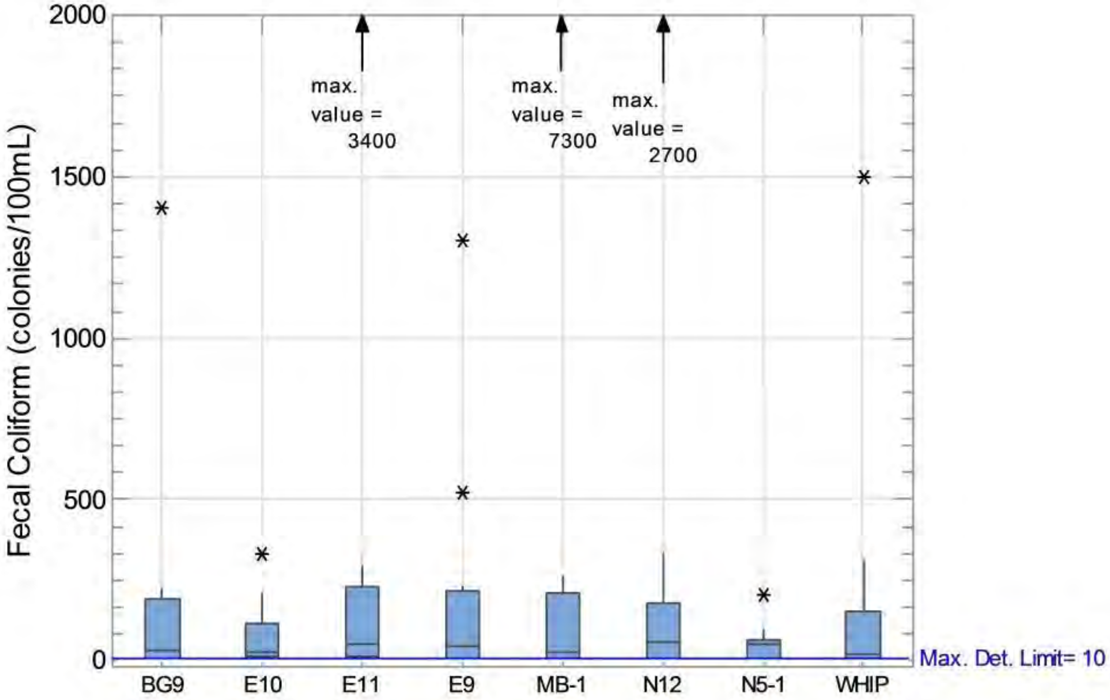


Figure 4.10 Fecal coliform plots for routine Kensico streams monitoring, January-December 2013.

Turbidity

The routine turbidity data for the period January 2013 through December 2013 are plotted in Figure 4.11. The median turbidity for all sites was less than 5 NTU. Turbidity values in 2013 were generally consistent with data from previous years, with the annual medians ranging from 0.75 NTU at WHIP to 4.8 NTU at N5-1. The maximum turbidity value recorded was 11 NTU at N12 on December 3, 2013, following more than three inches of rain in the Kensico watershed on November 26-27). 2013 descriptive statistics for turbidity in all of the Kensico perennial streams are displayed in Table 4.2.

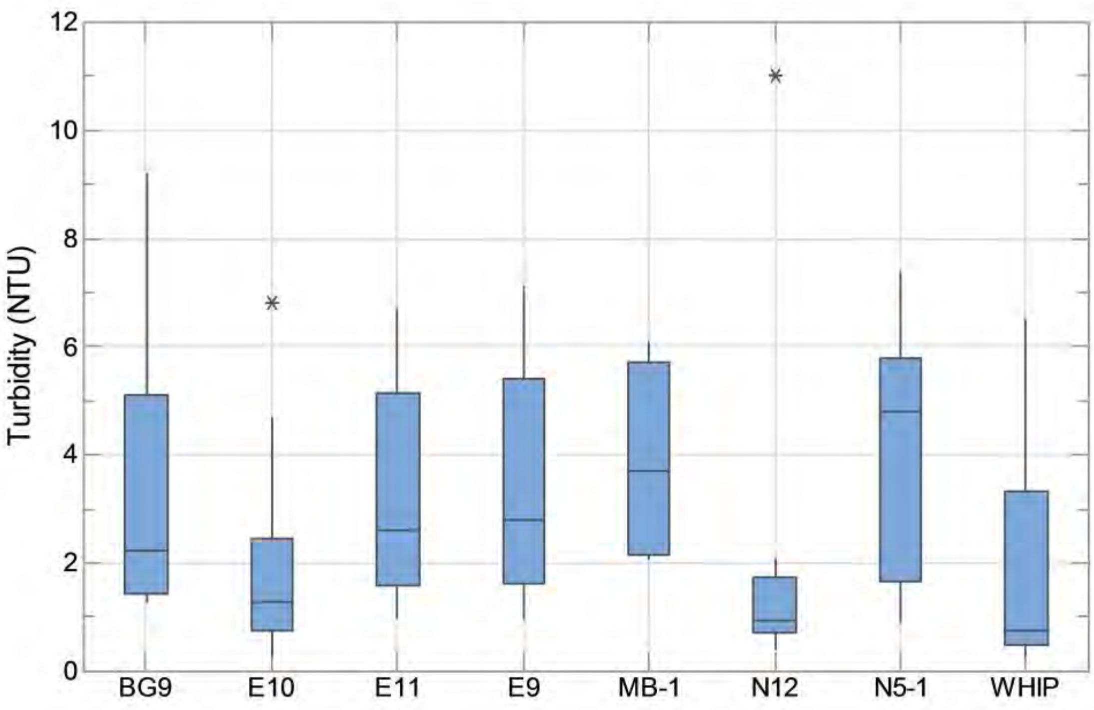


Figure 4.11 Turbidity plots for routine Kensico streams monitoring, January-December 2013.

Other Results

Stream Chemistry

In addition to the coliform bacteria, turbidity, and pathogen sampling, DEP monitors the eight perennial streams for temperature, dissolved oxygen, specific conductivity, and pH. Six of the eight streams are also monitored for alkalinity, chloride, dissolved organic carbon, total suspended solids, and nutrients. Monitoring for these analytes is an important component of the surveillance program. Descriptive statistics of the 2013 results for these analytes are displayed in Table 4.2. As previously discussed, on occasion environmental data may be reported only as below or above a certain detection limit due to methodological limitations. To address the uncertainty of censored values in the calculation of descriptive statistics, a Kaplan-Meier technique was used to calculate the quartile values when censored data were present.

Table 4.2: Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January-December 2013.

Analyte	Site	n	Minimum	25th percentile	Median	75th percentile	Maximum
Temperature (°C)	BG9	12	1.3	4.8	10.4	21.2	25.4
	E10	12	1.7	3.6	9.6	17.2	21.0
	E11	12	3.9	5.0	12.3	21.5	25.8
	E9	12	0.5	0.8	9.5	17.4	23.1
	MB-1	12	1.4	4.0	10.6	18.5	23.0
	N12	12	2.4	5.3	10.7	16.9	20.2
	N5-1	12	2.9	4.6	11.3	19.4	23.2
	WHIP	12	1.1	4.7	10.1	18.8	22.4
Dissolved oxygen (mg L^{-1})	BG9	12	2.7	5.7	8.9	12.9	16.0
	E10	12	8.0	8.6	10.1	13.9	17.0
	E11	12	2.0	5.2	8.4	12.2	15.9
	E9	12	3.8	5.0	6.7	10.8	12.1
	MB-1	11	7.1	8.2	9.8	13.6	13.9
	N12	11	8.6	9.4	12.7	14.8	42.2
	N5-1	11	7.8	9.1	10.4	12.8	23.6
	WHIP	11	8.4	9.3	11.3	14.5	14.9
Specific conductivity (µmhos cm^{-1})	BG9	12	351	607	692	922	1310
	E10	12	853	934	1025	1158	1430
	E11	12	298	403	444	490	580
	E9	12	449	518	588	629	731
	MB-1	12	411	549	610	803	1200
	N12	12	280	307	333	385	450
	N5-1	12	123	414	458	504	700
	WHIP	12	334	343	367	416	448
Chloride (mg L^{-1})	BG9	12	66.6	129.3	150.0	197.3	318.0
	E11	12	24.0	43.1	50.3	65.8	71.3
	MB-1	13	76.0	98.6	118.0	178.5	302.0
	N12	12	34.4	37.6	44.7	48.3	64.4
	N5-1	12	37.7	52.9	76.7	96.3	157.0
	WHIP	12	55.0	57.3	61.4	65.6	71.9
pH	BG9	12	6.55	7.10	7.24	7.45	7.59
	E10	12	7.02	7.46	7.58	7.70	7.80

Table 4.2: (Cont.) Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January-December 2013.

Analyte	Site	n	Minimum	25th percentile	Median	75th percentile	Maximum
	E11	12	7.14	7.22	7.34	7.55	7.83
	E9	12	6.54	6.81	6.93	7.05	7.52
	MB-1	11	6.86	6.98	7.23	7.35	7.42
	N12	11	7.34	7.38	7.58	7.83	8.34
	N5-1	11	6.97	7.28	7.38	7.51	7.60
	WHIP	11	7.12	7.47	7.62	7.75	7.90
Alkalinity (mg L^{-1} $CaCO_3$)	BG9	12	48.50	56.67	80.65	97.42	127.00
	E11	12	93.50	118.50	129.00	140.00	171.00
	MB-1	12	62.10	75.23	87.45	96.25	102.00
	N12	12	52.40	59.48	70.40	93.40	107.00
	N5-1	12	56.20	60.93	72.25	84.13	99.00
	WHIP	12	40.80	47.70	63.85	84.63	98.30
Dissolved organic carbon (mg L^{-1})	BG9	12	2.0	2.2	3.5	3.9	4.8
	E11	12	3.0	3.3	4.3	5.3	6.3
	MB-1	12	1.6	2.0	2.4	3.5	5.5
	N12	12	1.5	1.6	2.2	2.5	4.3
	N5-1	12	1.7	2.0	2.4	2.9	6.4
	WHIP	12	1.8	2.0	2.3	2.7	3.3
Total phosphorus (µg L^{-1})	BG9	12	11	14	38	55	109
	E11	12	13	16	25	41	51
	MB-1	12	15	18	35	53	62
	N12	12	11	12	21	34	58
	N5-1	12	19	37	53	85	127
	WHIP	12	9	12	15	27	39
Total nitrogen (mg L^{-1})	BG9	12	0.23	0.38	0.51	0.60	0.68
	E11	12	0.21	0.25	0.30	0.33	0.41
	MB-1	12	0.20	0.32	0.49	0.59	0.93
	N12	12	0.24	0.75	0.96	1.37	1.63
	N5-1	12	0.52	0.71	1.11	1.37	1.60
	WHIP	12	0.42	0.89	1.00	1.38	1.44
NH_3-N (mg L^{-1})	BG9	12	<0.02	0.02	0.03	0.06	0.10
	E11	12	<0.02	*	*	*	0.10
	MB-1	12	<0.02	*	0.04	0.08	0.11

Table 4.2: (Cont.) Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January-December 2013.

Analyte	Site	n	Minimum	25th percentile	Median	75th percentile	Maximum
	N12	12	<0.02	<0.02	<0.02	<0.02	<0.02
	N5-1	12	0.02	0.04	0.07	0.10	0.11
	WHIP	12	<0.02	<0.02	<0.02	<0.02	<0.02
NO_3+NO_2-N (mg L^{-1})	BG9	12	<0.02	0.16	0.24	0.43	0.57
	E11	12	<0.02	*	0.03	0.11	0.16
	MB-1	12	0.03	0.15	0.30	0.39	0.52
	N12	12	0.08	0.71	0.94	1.48	1.68
	N5-1	12	0.07	0.53	0.90	1.32	1.61
	WHIP	12	0.34	0.81	0.93	1.37	1.47
Total suspended solids (mg L^{-1})	BG9	12	<1.1	1.5	2.9	8.8	43.4
	E11	12	<1.0	*	2.2	6.3	8.8
	MB-1	12	1.1	1.3	3.7	6.0	8.9
	N12	12	<1.0	*	2.8	7.6	16.7
	N5-1	12	<1.0	*	5.1	7.4	9.2
	WHIP	12	<1.0	*	1.5	2.3	7.2
Total coliforms (coliforms 100mL^{-1})	BG9	11	<50	40	500	2700	9000
	E10	11	<50	160	360	4000	7300
	E11	11	<100	40	200	4400	10000
	E9	11	80	120	830	2300	5000
	MB-1	9	40	80	560	1900	2700
	N12	11	<50	120	300	3700	4700
	N5-1	10	<50	120	290	3300	5700
	WHIP	11	40	80	330	1000	7500
Fecal coliforms (coliforms 100mL^{-1})	BG9	12	<1	5	32	165	1400
	E10	12	<10	9	25	93	330
	E11	12	<10	5	53	215	3400
	E9	12	<1	12	45	195	1300
	MB-1	12	<1	8	25	190	7300
	N12	12	1	4	55	178	2700
	N5-1	11	<10	1	52	60	200
	WHIP	12	4	8	18	153	1500

Table 4.2: (Cont.) Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January-December 2013.

Analyte	Site	n	Minimum	25th percentile	Median	75th percentile	Maximum
Turbidity (NTU)	BG9	12	1.3	1.4	2.3	5.1	9.2
	E10	12	0.3	0.7	1.3	2.5	6.8
	E11	12	1.0	1.6	2.6	5.2	6.7
	E9	12	1.0	1.6	2.8	5.4	7.1
	MB-1	12	2.1	2.2	3.7	5.7	6.1
	N12	12	0.4	0.7	1.0	1.7	11.0
	N5-1	12	0.9	1.7	4.8	5.8	7.4
	WHIP	12	0.3	0.5	0.7	3.4	6.5

* Due to the number of censored values, percentiles were not estimated.

4.4.2 Turbidity Curtain Monitoring

A double turbidity curtain is maintained at the Catskill Upper Effluent Chamber cove in Kensico Reservoir to protect water entering into distribution from turbidity caused by the impacts of storm events on local streams. DEP conducts biweekly visual inspections of the turbidity curtain at the cove. Table 4.3 lists the dates and results of the turbidity curtain inspections carried out in 2013. When inspections indicate that maintenance is required, Bureau of Water Supply Systems Operations is notified and performs appropriate repairs or adjustments.

Table 4.3: Visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Date	Observations
1/2/2013	The curtain appears unchanged from 12/21/2012.
1/16/2013	Curtain appears intact and afloat as seen from shore.
1/30/2013	Curtain appears intact and afloat as seen from shore.
2/13/2013	Curtain appears intact and afloat as seen from shore.
2/27/2013	Curtain appears intact and afloat as seen from shore.
3/13/2013	Curtain appears intact and afloat as seen from shore.
3/27/2013	Curtain appears intact and afloat as seen from shore.
4/10/2013	Curtain appears intact and afloat as seen from shore.
4/24/2013	Curtain appears intact and afloat as seen from shore.
5/8/2013	Curtain appears intact and afloat as seen from shore.
5/22/2013	Curtain appears intact and afloat as seen from shore.
6/4/2013	Curtain appears intact and afloat as seen from shore.
6/19/2013	Curtain appears intact and afloat as seen from shore. Loose bird deterrent strip on yellow boom.
7/17/2013	Curtain appears intact and afloat as seen from shore.

Table 4.3: (Cont.)Visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Date	Observations
8/1/2013	Curtain appears intact and afloat as seen from shore.
8/14/2013	Curtain has one floating section. Hazmat checked, found the cause to be an air bubble and corrected the problem.
8/28/2013	Curtain appears intact and afloat as seen from shore.
9/11/2013	Curtain appears intact and afloat as seen from shore. A section appears at the surface.
9/25/2013	Curtain appears intact and afloat as seen from shore.
10/9/2013	Curtain appears intact and afloat as seen from shore.
10/24/2013	Curtain appears intact and afloat as seen from shore.
11/6/2013	Curtain appears intact and afloat as seen from shore.
11/20/2013	Curtain appears intact and afloat as seen from shore.
12/4/2013	Curtain appears intact and afloat as seen from shore.
12/19/2013	Curtains appear intact and afloat as seen from shore.

4.5 Catskill/Delaware Ultraviolet Disinfection Facility

When water destined for distribution leaves Kensico Reservoir, it is treated with chlorine and then flows to the Catskill/Delaware Ultraviolet (UV) Disinfection Facility for a second disinfection via ultraviolet light. The UV Disinfection Facility, which began treating Catskill/Delaware water in October 2012, is located on a NYC-owned 153-acre property in the Towns of Mount Pleasant and Greenburgh in Westchester County. The facility, the largest of its kind in the world, consists of 56 40-million-gallons-per-day UV disinfection units, and is currently designed to disinfect a maximum of 2.02 billion gallons of water per day.

Figure 4.12 Aerial photo of the Catskill/Delaware Ultraviolet Disinfection Facility, the largest of its kind in the world.

The UV Disinfection Facility was built in part to fulfill the requirements of the Long Term 2 Enhanced Surface Water Treatment Rule (USEPA 2006), which requires additional treatment for many water suppliers that use surface water sources. For unfiltered surface water sources, such as the Catskill/Delaware System, the rule requires two types of disinfection: chlorination and UV disinfection. Chlorination of Cat/Del water occurs before the water arrives at the UV Disinfection Facility, while UV disinfection occurs at the facility itself, when water flows under UV light. UV disinfection is an additional measure to protect against potentially harmful microbiological contaminants, such as *Cryptosporidium* and *Giardia*.

Although the U.S. Environmental Protection Agency now requires filtration of most surface drinking water, the federal government allows DEP to continue supplying unfiltered drinking water from the Catskill/Delaware watershed, as a result of NYC's $1.5 billion investment in watershed protection programs and its operation of the UV Disinfection Facility. This comprehensive and adaptive approach exempts NYC from building a mandated filtration plant estimated to cost $10 billion or more.

4.6 Kensico Research Projects

In addition to the routine monitoring, DEP also undertook several research projects and one special investigation related to Kensico in 2013, as described below.

Harvard School of Public Health Collaboration

During 2013, DEP collaborated with the Harvard School of Public Health (HSPH) on a project titled, "Modeling the Influence of Variable Tributary Inflow on Circulation and Contaminant Transport." In this project, numerical tracer experiments using the CE-QUAL-W2 model for Kensico Reservoir were conducted and analyzed to demonstrate the effects of thermal stratification, wind speed, and tributary inflow on the theoretical movement of a conservative tracer through Kensico Reservoir. The analysis provided insight into how substances move through the reservoir under different conditions of stratification and flow.

The inflows into Kensico Reservoir are dominated by the Catskill and Delaware Aqueducts. In general, the small tributary inputs to the reservoir have little impact, especially on the volume of water moving through the reservoir; however, the impact of these tributary flows on water quality is not well understood. To further analyze the potential influence of these local watershed flows, a conservative "numerical tracer" was incorporated into the model input of each tributary and the model was run to demonstrate how these tracers move through the reservoir during various storm event scenarios, wind events, seasons, and aqueduct flow rates. It is important to note that these experiments used a conservative tracer that does not settle or degrade. This allows analysis of potential transport dynamics within the reservoir but is not necessarily representative of the exact dynamics of any particular water quality constituent, which may also be reduced by these other processes.

The results of these experiments indicated that, under normal conditions, the numerical tracer contribution of the local tributaries to Kensico Reservoir withdrawal is negligible. However, under the maximum tested tributary flow rates (representing large storm event scenarios), there was some signal of the numerical tracer at the reservoir withdrawal. The timing and the magnitude of the tracer was highly dependent on a combination of factors, including the location and flow rate of the tributaries, whether or not the reservoir was stratified, and the wind conditions during and after the input event. Not surprisingly, the tributaries with the largest inflow tended to have the most dominant effect on withdrawal tracer concentration. In addition, water from tributaries closer to the withdrawal, especially those entering along the north-south arm of the reservoir, tended to reach the withdrawals sooner than the contributions from tributaries in the eastern portions of the reservoir. For the tributaries with the longer travel times, there was greater dispersion of the tracer and hence lower peak concentrations. Wind events can also play a large role in changing the tracer concentrations by causing the reservoir to lose stratification during the summer months. This results in a mixing of the epilimnion and hypolimnion and a change in the transport dynamics and the concentration of the tracer at the reservoir withdrawal.

Bryozoan Research

Bryozoans were identified in Kensico Reservoir as early as the late 1980s and early 1990s. The predominant species, *Pectinatella magnifica*, has been seen in coves throughout the reservoir, near the shoreline on branches and rocks, and at the Delaware outflow of the reservoir at Shaft 18. The presence of these organisms did not affect operations until the fall of 2012, shortly after the UV Disinfection Facility came on line. Bryozoan colonies were found downstream of Shaft 18 at the facility, and caused clogging issues at the 1" perforated plates located just prior to the UV lamps. The openings were manually cleared of the gelatinous colonies, but this was very labor intensive. A literature search was conducted and other water professionals were contacted to determine if there were other management or preventive measures available to control the growth and reproduction of these large colonial organisms. Control of organisms in a drinking water supply is particularly challenging because many control measures used for other applications are not an option for water that will be consumed.

In August 2013, BryoTechnologies LLC, Ohio, was hired to perform a shoreline survey of biofouling invertebrate organisms in Kensico Reservoir, with a focus on *Pectinatella*. This brief survey represented a snapshot of conditions for two days in August. In other seasons the mix of species might be slightly different, and changes can also be expected from year to year. The August survey revealed six species of bryozoans and one species of sponge. Of these, *P. magnifica* had already been identified as a nuisance at Kensico; another, *Paludicella articulata*, has been known to cause problems for public waterworks. A third bryozoan species, *Plumatella recluse*, is extremely rare and is now reported for the first time in New York State. Several additional bryozoan species may not have been seen during the survey. Most bryozoans at Kensico are considered to pose no danger to water quality, human health, or the outlet structures, but in large numbers may clog screens. *P. magnifica* remains the most abundant at the outlet works. *Paludicella articulata*, which has caused problems in other water bodies, could be a second problematic species, even though the population in Kensico is currently small and obscure. In 2014, DEP implemented a program to monitor the occurrence of bryozoans in Kensico Reservoir and to track their growth rate (via camera) on infrastructure at Shaft 18. The information obtained through this program will be used to evaluate the need, if any, for control measures in the future.

Kensico Storm Event Sampling

As outlined in the Kensico Storm Event Sampling Plan, the Kensico watershed is sampled more frequently than is provided for under the routine sampling strategy when a storm is predicted to deliver significant rainfall to the area. DEP performs intensified monitoring at stream, reservoir, and outflow locations for turbidity, conductivity, and fecal coliforms during these events. The main objectives of this additional monitoring are (1) arriving at an approximate timeline for any impacts that elevated microbial counts at the streams may have on the outflows of the reservoir, and (2) if elevated fecal coliforms are detected, determining whether the source is human or animal through the analysis of *Bacteroides*. *Bacteroides* analysis is a tool used in

Microbial Source Tracking (MST) and can help differentiate the source of fecal contamination. The origin of the fecal bacteria is of interest to determine possible public health risks and to minimize specific sources through targeted watershed protection projects.

Special Investigation Report: Kensico Reservoir Storm Events June 6-14, 2013.

From June 6 to June 14, 2013, a series of storm events occurred that met the criteria for triggering storm event monitoring at Kensico Reservoir. This Special Investigation was exceptional in that three storm events totaling 6.01 inches of rain occurred within a nine-day period (Figure 4.13). Analytes investigated were turbidity and fecal coliform, as well as *Bacteroides*. Data illustrate that there was a precipitous rise and fall of fecal coliform concentrations within the N5 stream (Figure 4.14); while samples taken at Malcolm Brook showed a more gradual rise and fall (Figure 4.15). This is normal due to the streams' differing landscapes, and has been demonstrated in the past. Changes in turbidity were minimal at the nearby limnological sampling sites, while some fecal coliform limnological data suggested possible influence from the streams or runoff. The reservoir effluent at DEL18DT had no turbidity issues as a result of the storms (<1.2NTU), and fecal coliform results did not exceed 7 coliforms 100mL^{-1}, with levels returning to <1 by June 16, 2013. All stream and reservoir samples tested were negative for human and bird markers, although a few stream samples did test positive for the ruminant source marker, indicating deer as a fecal source.

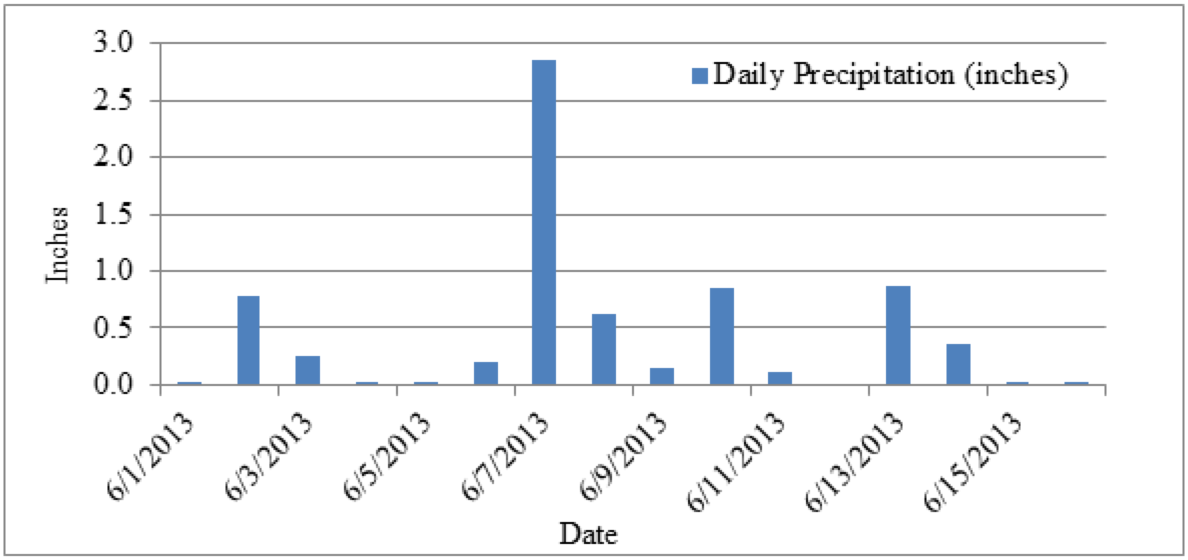


Figure 4.13 Daily precipitation amounts in the Kensico Reservoir area as measured by the meteorological station at Delaware Shaft 18 (June 1-16, 2013).

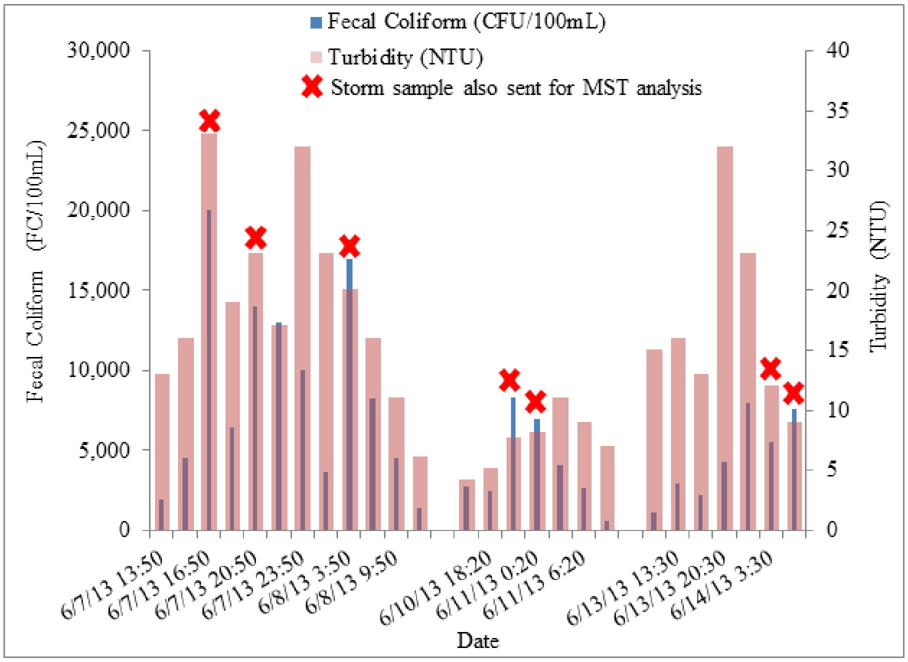


Figure 4.14 Fecal coliform and turbidity at N5-1 over the course of the three storm periods. N5-1 95th percentile 2002-2012 is 6,500 fecal coliforms $100ml^{-1}$.

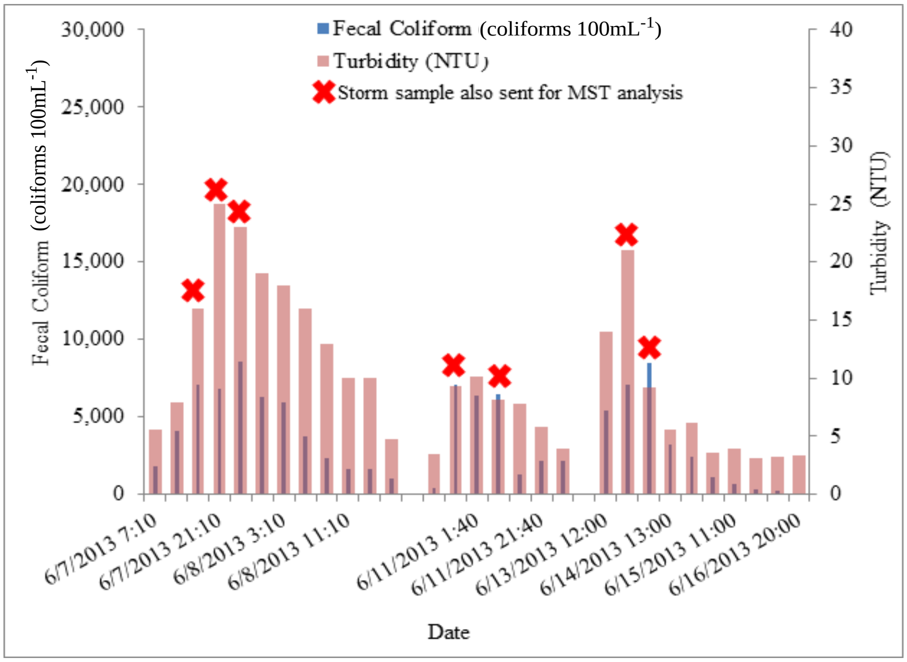


Figure 4.15 Fecal coliform and turbidity at MB-1 over the course of the three storm periods. MB-1 95th percentile 2002-2012 is 4,300 fecal coliforms $100mL^{-1}$.

Hurricane Sandy Forest Impact and Restoration

On October 29, 2012, Hurricane Sandy struck the New York coast and passed over the Kensico watershed, causing significant damage to City-owned forest land surrounding Kensico Reservoir. DEP undertook the Kensico Salvage Forest Management Project on approximately 50 damaged acres at four sites to remove storm debris, remove remaining trees destabilized by damage to adjacent trees, thin remaining portions of forest in affected areas to improve the ability to withstand extreme weather in the future, and restore forest cover on cleared sites as quickly as possible. The project was designed to help stabilize soils and restore water quality protection, reduce safety hazards, minimize the risk of forest fires, and improve aesthetics. Work began in March, 2013, and is expected to be complete by June 2015. A brief description of the work performed at each site follows.

Site 1, located off Nannyhagen Road in both North Castle and Mount Pleasant, was the largest of the four project sites, totaling approximately 27 acres of Norway spruce plantation. A significant portion of the site was completely blown down, and the remaining area suffered extensive damage. Work in this area consisted of removing all blown down trees, removing all Norway spruce still standing within 100 feet of public roads, and thinning the remaining patches of standing spruce more than 100 feet from the road. Removal of spruce within 100 feet of the road was necessary because the density of trees prior to the storm was such that remaining trees were extremely unstable and prone to further windthrow, and the average height of the trees was 100 feet. To minimize the spread of invasive species and pathogens within the newly cleared area, the project also removed obviously destabilized hardwoods that could have fallen into the road, all invasive Norway maple, and black birch infested with Nectria canker.

Subsequent to the tree removal work, remaining woody debris was chipped and spread on site to provide temporary stabilization. Stumps within 30 feet of the road edge that remained tipped up after tree removal were removed to improve aesthetics, and the cleared area was seeded with a native seed mix to provide permanent stabilization.

In the spring of 2015, the entire cleared area, approximately 11.5 acres, will be replanted with 3,600 trees and 2,480 shrubs of more than 40 different native species. The new plantings will be protected from deer browse with either an 8-foot-high exclusion fence or plastic tubes. The deer protection measures are expected to remain in place for five to eight years until the plantings are large and vigorous enough to withstand deer pressure.

Site 2, located off Route 120 in the Town of North Castle at the north end of the reservoir, was an approximately six-acre Norway spruce plantation. Most of the southeastern side of the plantation was blown down. The remainder showed less significant damage. Work in this area consisted of removing downed trees and thinning the remaining portion of the plantation to increase wind-firmness in the remaining forest. Because this site is not as visible as the others, remaining debris was left to decompose naturally. Also, because the area of complete blowdown was small, no replanting will be necessary.

Site 3, located off Route 120 in the Town of North Castle at the southern end of the reservoir near Rye Lake, was a 2.5-acre Norway spruce plantation. The plantation was thinned in 2006 and suffered only light damage in the storm. The project removed the few downed spruce, and lightly thinned the remaining stand to continue to improve wind-firmness and encourage species diversity. Because this area is heavily used by recreational boaters, the remaining debris was chipped and spread on-site. Since forest cover remains intact, no replanting is necessary at this location.

Site 4, located off West Lake Drive in Mount Pleasant on the southwestern side of the reservoir, was a nine-acre area of hardwood forest dominated by tulip poplar and a three-acre Norway spruce plantation. In the hardwood area, the project removed tulip poplar blown over or damaged by the storm. Because the site is not visible to the public, remaining debris was left on-site to decompose naturally. Since the site is still vegetated, no replanting is necessary at this time. In the spruce plantation, the project removed damaged and unstable trees. Since the site is highly visible, remaining debris was chipped and spread on-site. Due to the significant component of invasive Norway maple prior to the storm, the currently open areas will be replanted in the spring of 2015 to avoid spread of this invasive species. Three hundred trees of at least eight native species will be spread across the site, and will be temporarily protected with plastic tubes. The tubes will be in place for five to eight years, until the trees are large and strong enough to withstand deer pressure.

5. Pathogens

5.1 Introduction

DEP conducts compliance and surveillance monitoring for protozoan pathogens and human enteric viruses (HEV) throughout the 1,972-square-mile NYC Watershed. DEP staff collected and analyzed 485 samples for protozoan analysis during 2013, and 171 samples for HEV analysis. Source water samples (Kensico and New Croton keypoints) and watershed stream samples comprised the greatest portion of the 2013 protozoan sampling effort, each accounting for 34.6% of the sample load. Sampling at the Hillview Reservoir Catskill downtake, upstate reservoir effluents, and wastewater treatment plants (WWTPs) made up the remaining 30.7% (Figure 5.1).

In 2012, DEP made a series of modifications to the monitoring plan which continued into 2013. These modifications included a reduction in sampling sites and/or frequency required by the Croton Consent Decree (CCD), and the cessation of sampling at the Catskill outflow, the latter occasioned by the continued shutdown of the Catskill Aqueduct in 2013. (The shutdown began in September 2012, when the UV Disinfection Facility began operation.) Kensico outflow results are posted weekly on DEP's website (www.nyc.gov/html/dep/pdf/pathogen/path.pdf), and annually in this report.

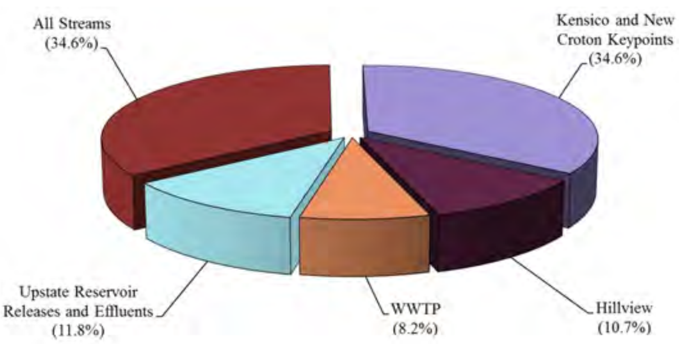


Figure 5.1 DEP protozoan sample type distribution for 2013. Data include both routine and enhanced monitoring samples.

5.2 Source Water Results

Catskill Aqueduct Inflow

In 2013, 1 sample out of 52 was positive for *Cryptosporidium* (1 oocyst $50L^{-1}$) at CATALUM (Catskill inflow to Kensico Reservoir) (Table 5.1). *Cryptosporidium* detections have been very infrequent in the last few years at this site, with only 2 detections (1 oocyst $50L^{-1}$ in each instance) in 209 weekly samples taken from January 2010 through December 2013. As mentioned, no samples were collected at the Catskill outflow of Kensico Reservoir this year.

Table 5.1: Summary of *Cryptosporidium*, *Giardia*, and HEV compliance monitoring data at the five DEP keypoints in 2013. ns = not sampled.

	Keypoint location	Number of positive samples	Mean[2]	Maximum
Cryptosporidium oocysts 50L^{-1}	CATALUM (n = 52)	1	0.02	1
	CATLEFF (n = 0)	ns	ns	ns
	DEL17 (n = 52)	6	0.12	1
	DEL18DT (n =52)	0	0.00	0
	CROGH[1] (n = 12)	0	0.00	0
Giardia cysts 50L^{-1}	CATALUM (n = 52)	27	0.88	5
	CATLEFF (n = 0)	ns	ns	ns
	DEL17 (n = 52)	22	0.88	8
	DEL18DT (n = 52)	30	1.06	5
	CROGH[1] (n = 12)	4	0.67	3
Human Enteric Virus 100L^{-1}	CATALUM (n = 52)	15	1.10	23.00
	CATLEFF (n = 0)	ns	ns	ns
	DEL17 (n = 52)	10	0.56	10.53
	DEL18DT (n = 52)	5	0.17	3.52
	CROGH[1] (n = 12)	3	1.75	18.8

[1] Includes alternate sites sampled to best represent effluents during “off-line” status.

[2] Samples not exactly equal to 50 L are calculated to per L concentrations and then re-calculated to 50 L for determination of means. Zero values are substituted for non-detect values when calculating means.

Giardia was detected in 22 out of 52 samples collected at CATALUM (51.9%), with a mean concentration of 0.88 cysts 50L^{-1} (Table 5.1). These figures represent an increase in the percent of detections and the mean from 2012 levels (15.1% and 0.17 cysts 50L^{-1}, respectively), but are lower than in some earlier years (Figure 5.2, Panel 1). The 2013 mean is very close to the historical mean (2001-2012) of 0.90 cysts 50L^{-1}.

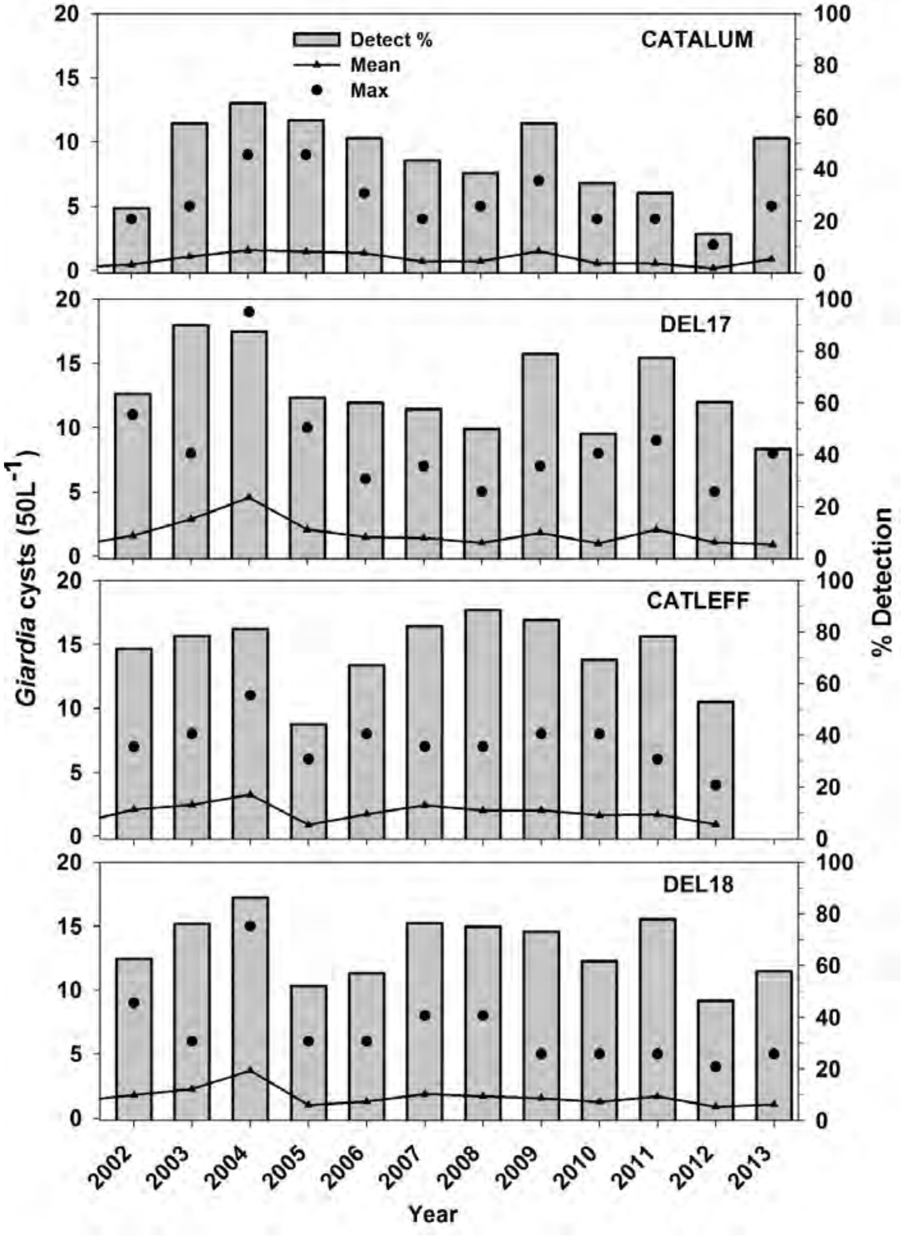


Figure 5.2 Annual percent detection of *Giardia*, mean concentration, and maximum result for the Kensico keypoint sites in each year from 2002 to 2013.

HEV detections at CATALUM increased from 10 detections (18.9%) in 2012 to 15 detections (28.8%) in 2013. The mean concentration of HEVs at CATALUM was higher in 2013 (1.10 MPN 100L^{-1}) than in 2012 (0.76 MPN 100L^{-1}); however, the mean concentration for 2013 at CATALUM was below the historical mean of 1.26 MPN 100L^{-1} for this site. The maximum concentration remained 23.00 MPN 100L^{-1}.

Delaware Aqueduct Inflow and Outflow

DEL17 (Delaware inflow to Kensico Reservoir) *Cryptosporidium* results were higher this year than in the previous four years, with 6 positive samples out of 52 (11.5%) and a mean concentration of 0.12 oocysts $50L^{-1}$ (Table 5.1). The previous four-year period had four fewer detections per year and annual means less than 0.08 oocysts $50L^{-1}$. The 2013 DEL17 results are similar to 2008 results (also 6 detections out of 52, and a mean of 0.15 oocysts $50L^{-1}$). For the second year in a row, no *Cryptosporidium* was detected at DEL18DT (Delaware outflow of Kensico Reservoir).

Giardia was detected in 22 out of the 52 samples collected at DEL17 (42.3%), with a mean concentration of 0.88 cysts $50L^{-1}$, matching the mean *Giardia* concentration for the Catskill inflow this year (Table 5.1). The G*iardia* detection at DEL18DT was slightly higher, with 30 samples positive (57.7%) and a mean concentration of 1.06 cysts $50L^{-1}$.

HEV mean and maximum concentration and detection frequency at DEL17 were 0.56 MPN $100L^{-1}$, 10.53 MPN $100L^{-1}$, and 10 positive samples (19.2%), respectively (Table 5.1). HEV results for DEL18DT were lower, with a mean concentration of 0.17 MPN $100L^{-1}$ and a maximum of 3.52 MPN $100L^{-1}$. DEL17 had twice as many HEV detections (10 detections, 19.2%) as DEL18DT, where 5 out of 52 samples were positive (9.6%).

New Croton Aqueduct

The 12-month protozoan sampling at the New Croton Reservoir outflow in 2013 resulted in no *Cryptosporidium* detections (Table 5.1). *Giardia*, on the other hand, had four positive samples (33.3%) and a mean concentration of 0.67 cysts $50L^{-1}$. HEV detection frequency and mean concentration at New Croton (3 samples positive (25.0%), mean of 1.75 MPN $100L^{-1}$) were similar to 2012's (33% positive, mean 2.00 MPN $100L^{-1}$).

As in prior years, *Giardia* was detected at all four keypoint sites in higher concentrations and occurred more frequently in winter and spring than in summer and fall (Figure 5.3), which is consistent with historical observations. While there may also be some seasonality associated with *Cryptosporidium* occurrence, there are too few oocysts detected in source water to provide statistical confidence in this hypothesis.

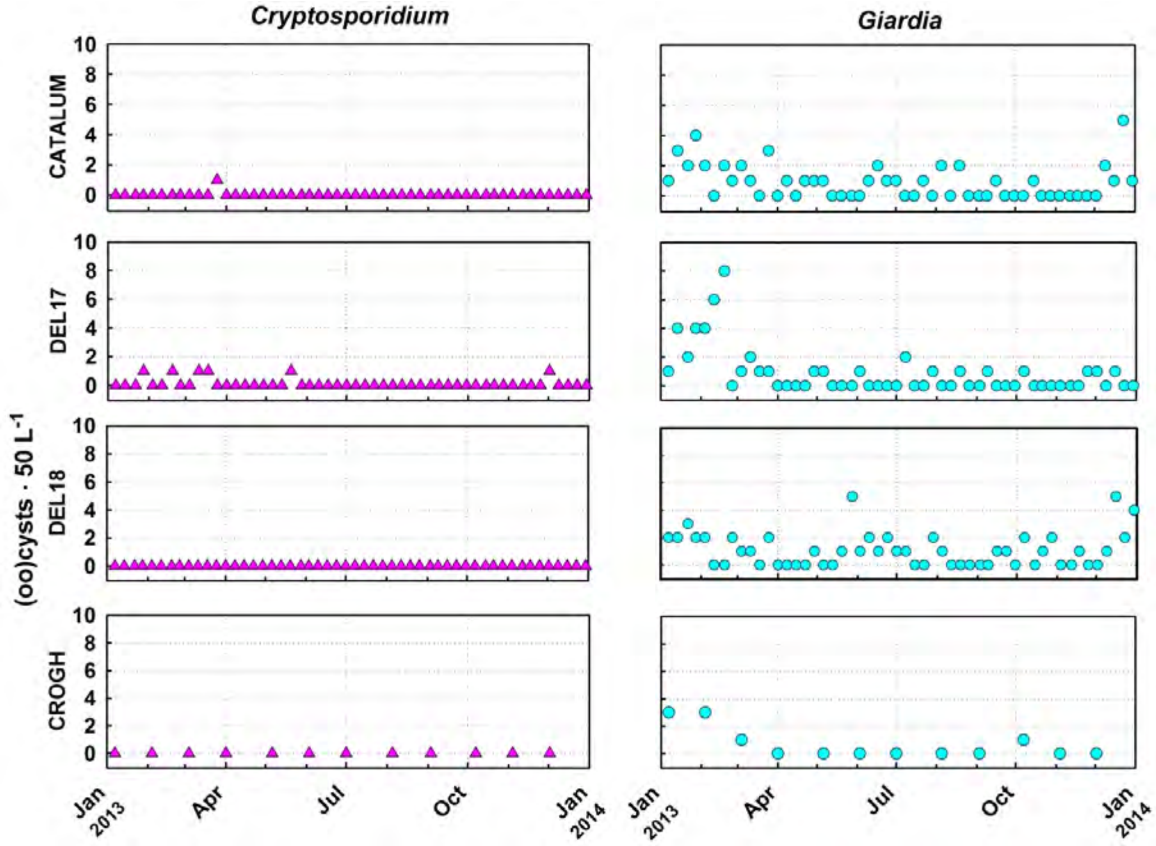


Figure 5.3 Routine weekly source water keypoint monitoring results for 2013.

5.2.1 2013 Source Water Compared to Historical Data

Water quality varies at the source water sites depending on several factors in their respective watersheds, such as storm water runoff, impacts from land use, effects of other ecological processes, and operational changes. Beginning in October 2001 and continuing until 2012, the five source water sites were sampled weekly for protozoans, using USEPA Method 1623HV. With this large data set, collected over several years, DEP has been able to document seasonal patterns and long-term changes in protozoan concentrations. Modifications to the frequency of monitoring at the New Croton Reservoir outflow (weekly to monthly), and the shutdown of the Catskill Aqueduct outflow from Kensico in 2012 (leaving the Delaware Aqueduct as the only outflow from Kensico Reservoir currently being sampled), make the comparison of summary statistics for 2013 with statistics from previous years more complex.

In 2013, there were 7 *Cryptosporidium* detections at the two Kensico inflow sites, which is more than in 2012 when there were 3 detections, each with 1 oocyst $50L^{-1}$. The greater number was particularly noticeable at the Delaware influent to Kensico Reservoir, which had 6 detections in 2013 (each with a low concentration of 1 oocyst $50L^{-1}$), compared to 1 detection in 2012

(1 oocyst $50L^{-1}$). Since 2010, with the exception of the 6 positive samples at DEL17 this year, oocyst detection and mean concentrations at the inflows have generally been lower at Kensico Reservoir than in previous years (Table 5.2). Oocyst detection has also been declining at the reservoir outflows in the past few years (Table 5.3). No oocysts were detected at either the Kensico or New Croton outflows in 2013, the first year no detections were reported at both effluent keypoints.

Table 5.2: Annual detection and mean oocyst concentration of *Cryptosporidium* at influent keypoints to Kensico Reservoir, 2002-2013.

	CATALUM			DEL17		
	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)
2002	6	11.5	0.17	8	15.4	0.15
2003	8	15.4	0.25	15	25.0	0.28
2004	10	19.2	0.29	11	19.6	0.20
2005	1	1.7	0.02	6	10.2	0.10
2006	3	5.8	0.06	3	6.0	0.06
2007	1	1.9	0.02	4	7.7	0.08
2008	7	13.5	0.13	6	11.5	0.15
2009	7	13.5	0.15	4	7.7	0.08
2010	1	1.9	0.04	1	1.9	0.02
2011	0	0.0	0.00	1	1.9	0.02
2012	0	0.0	0.00	1	1.9	0.02
2013	1	1.9	0.02	6	11.5	0.12

Table 5.3: Annual detection and mean oocyst concentration of *Cryptosporidium* at Kensico and New Croton Reservoir effluent keypoints. ns = not sampled.

	CATLEFF			DEL18			CROGH		
	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)
2002	21	29.2	0.35	18	25.0	0.31	13	20.0	0.28
2003	20	28.6	0.34	21	29.6	0.45	7	11.9	0.17
2004	20	27.0	0.38	25	34.7	0.36	28	40.0	0.51
2005	16	16.3	0.21	15	15.5	0.23	3	5.5	0.05
2006	8	12.5	0.13	7	10.8	0.12	7	13.5	0.13
2007	4	7.1	0.07	2	4.0	0.04	3	5.7	0.06
2008	10	19.2	0.23	1	1.9	0.02	8	14.3	0.21

Table 5.3: (Cont.)Annual detection and mean oocyst concentration of *Cryptosporidium* at Kensico and New Croton Reservoir effluent keypoints. ns = not sampled.

	CATLEFF			DEL18			CROGH		
	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)
2009	1	1.9	0.02	4	7.7	0.08	4	7.7	0.12
2010	3	5.8	0.06	1	1.9	0.02	5	9.6	0.10
2011	2	3.3	0.03	1	1.7	0.02	1	1.9	0.02
2012*	1	2.9	0.03	0	0.0	0.00	1	2.8	0.03
2013	ns	ns	ns	0	0.0	0.00	0	0.0	0.00

*Monitoring was discontinued at CATLEFF in September 2012.

Giardia detections at the source water sites in 2013 were similar to those seen historically. Concentrations of *Giardia* continued to be low for most of 2013 (mean of 0.47 cysts, April-November), and, as in the past, were higher during the cold weather months (mean of 1.85 cysts, January through March and December), continuing the seasonal pattern noted since 2001 (Figure 5.4).

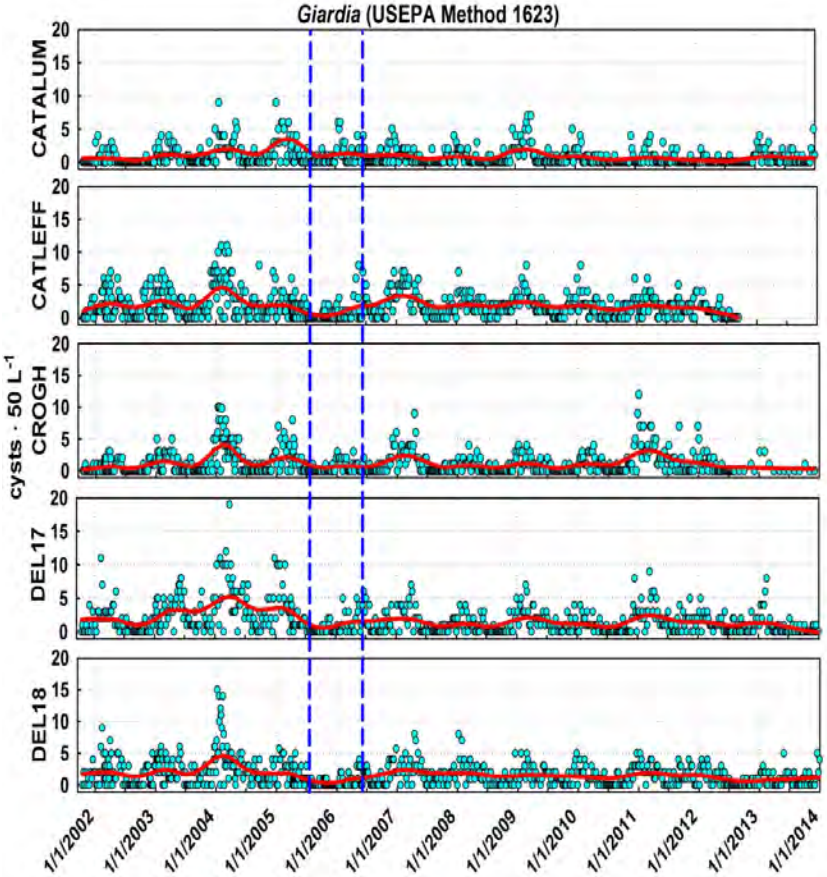


Figure 5.4 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2013. The area between the blue dotted lines indicates the period during which DEP temporarily switched to a different EPA-approved stain.

5.2.2 2013 Source Water Compared to Regulatory Levels

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA 2006) required that utilities conduct monthly source water monitoring for *Cryptosporidium* and report data from a two-year period, though a more frequent sampling schedule was permitted. The LT2 requires all unfiltered public water supplies to “provide at least 2-log (i.e., 99 percent) inactivation of *Cryptosporidium*.” If the average source water level exceeds 0.010 oocysts L^{-1} based on the LT2 monitoring, “the unfiltered system must provide at least 3-log (i.e., 99.9 percent) inactivation of *Cryptosporidium*.” The value is calculated based on the mean monthly results over the course of two years, and taking a mean of those monthly means. Results have been calculated here using data from the most recent two-year period (January 1, 2012-December 31, 2013), using all routine and non-routine samples (Table 5.4). As no samples were taken at the Catskill Aqueduct outflow of Kensico Reservoir in 2013, and the LT2 specifies a mean of a minimum of 24 monthly means to be averaged for two years, the calculation could not be done for the Catskill Aqueduct for the 2012-2013 period.

Table 5.4: Number and type of samples used to calculate the LT2 bin classification set from January 1, 2012 to December 31, 2013.

Aqueduct	Number of routine samples, 2012-2013	Number of non-routine samples, 2012-2013	Total n
Croton	48	0	48
Delaware	105	1	106

Mean levels of *Cryptosporidium* were quite low at the source water effluents for the 2012-2013 reporting period, with only one oocyst found in a sample taken at the Croton effluent in November 2012. Consequently, mean concentrations of *Cryptosporidium* at the source water effluents were far below the LT2 threshold level of 0.010 oocysts L^{-1}. Figure 5.5 displays NYC source water historical LT2 calculations, which have always remained below the threshold level. Mean concentrations have generally been declining over the past several years, reaching their lowest point during the past two years. With no *Cryptosporidium* detected at the Delaware effluent since February 2011, the Delaware effluent mean oocyst concentration was 0.0000 L^{-1} for 2012-2013. The Croton mean oocyst concentration was 0.0008 L^{-1} for the same period.

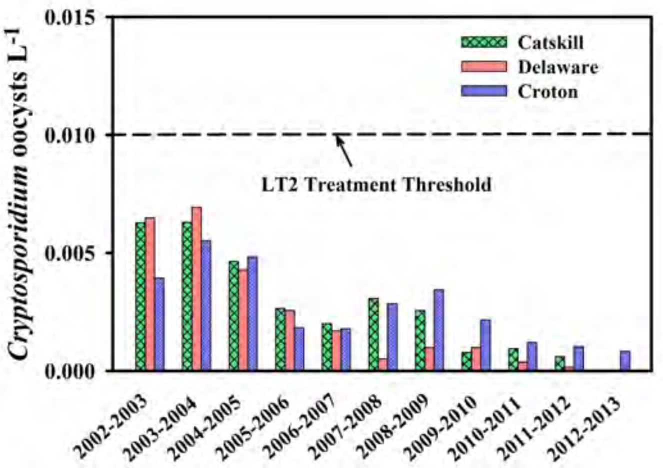


Figure 5.5 Four LT2 calculated means for *Cryptosporidium* since initiation of Method 1623 at DEP's three source waters (Croton, Catskill, and Delaware Aqueducts), 2002-2013. No mean was calculated for the Catskill Aqueduct for 2012-2013 as no samples were taken in 2013 due to aqueduct shut down.

5.3 Upstate Reservoir Effluents

Upstream of Kensico Reservoir, along the aqueduct system, are the Catskill and Delaware watersheds (collectively, the West of Hudson (WOH) watershed). These watersheds collect and store water in five upstate reservoirs which DEP monitors for protozoans to ensure the quality of water prior to its entering downstream reservoirs. Sampling is conducted at the effluents of these WOH reservoirs on a monthly basis (except for CATALUM, representing water from Ashokan

Reservoir, which is sampled weekly), and efforts are made to schedule the sampling during times of the month when the water is being conveyed to Kensico Reservoir. However, DEP does not always use water from all six WOH reservoirs every month, and in months when water is not so conveyed, no sampling is conducted. For this reason, two of the WOH reservoirs (Neversink and Pepacton) did not have samples collected for all 12 months of 2013.

Of 109 samples taken at the upstream reservoir outflows in 2013, 7 (6.4%) were positive for *Cryptosporidium* (Table 5.5), compared to 1 positive sample in 2012. Cannonsville's outflow had 3 positive samples in 2013 compared to no detections in 2012. Four reservoir outflows (Ashokan, Pepacton, Neversink, and Rondout) had one detection each in 2013. Concentrations of *Cryptosporidium* in positive samples remained low, with a maximum of 2 oocysts 50.1L^{-1} at the Cannonsville Reservoir outflow (WDTO) and 1 oocyst 50L^{-1}in the positive samples of the other outflows. For the second year in a row (2012 -2013) the outflow of Schoharie Reservoir had no *Cryptosporidium* detections.

Table 5.5: Summary of upstate reservoir effluent protozoan results in 2013.

		Cryptosporidium				*Giardia*			
Site	n	Mean (50L^{-1})	% Detects	Maximum (Liters sampled)	Maximum (L^{-1})	Mean (50L^{-1})	% Detects	Maximum (liters sampled)	Maximum (L^{-1})
Ashokan (CATALUM)	52	0.02	1.9%	1(50.0L)	0.02	0.88	51.9%	5 (50.0 L)	0.10
Neversink	10	0.10	10.0%	1 (50.0 L)	0.02	1.44	60.0%	6 (35.7 L)	0.17
Pepacton	11	0.09	9.1%	1 (50.0 L)	0.02	0.54	45.5%	2 (50.0 L)	0.04
Rondout	12	0.08	8.3%	1 (50.0 L)	0.02	0.92	50.0%	6 (50.0 L)	0.12
Schoharie	12	0.00	0.0%	0	0.00	7.75	100.0%	12 (45.8 L)	0.26
Cannonsville (WDTO)	12	0.33	25.0%	2 (50.1 L)	0.04	4.50	58.3%	31 (50.0 L)	0.62

Giardia was detected in 63 upstate reservoir outflow samples in 2013 (57.8%), compared to 50 (41.3%) in 2012. The overall mean concentration found for all six sites in 2013 (2.67 cysts 50L^{-1}) was very similar to the mean found in 2012 (2.14 cysts 50L^{-1}). On an individual site basis, there are some noteworthy points from the 2013 sampling. The Ashokan mean concentration rose from 0.17 cysts 50L^{-1} in 2012 to 0.88 cysts 50L^{-1} in 2013, with an increase in the percentage of detections from 15.1% to 51.9%. The maximum concentration at this site changed from 2 cysts 50L^{-1} in 2012, to 5 cysts 50L^{-1} in 2013. The Schoharie Reservoir mean concentration rose by 71% from 2012 to 2013 (4.53 to 7.75 cysts 50L^{-1}, respectively). In Cannonsville, a maximum concentration of 31 cysts 50L^{-1} was found at the outflow in December 2013 (Figure 5.6). This is the highest concentration seen at the site since July 2005, when 79 cysts 50L^{-1} was recorded. The sample was possibly affected by precipitation (over 1.5 inches) in the seven days prior to sampling.

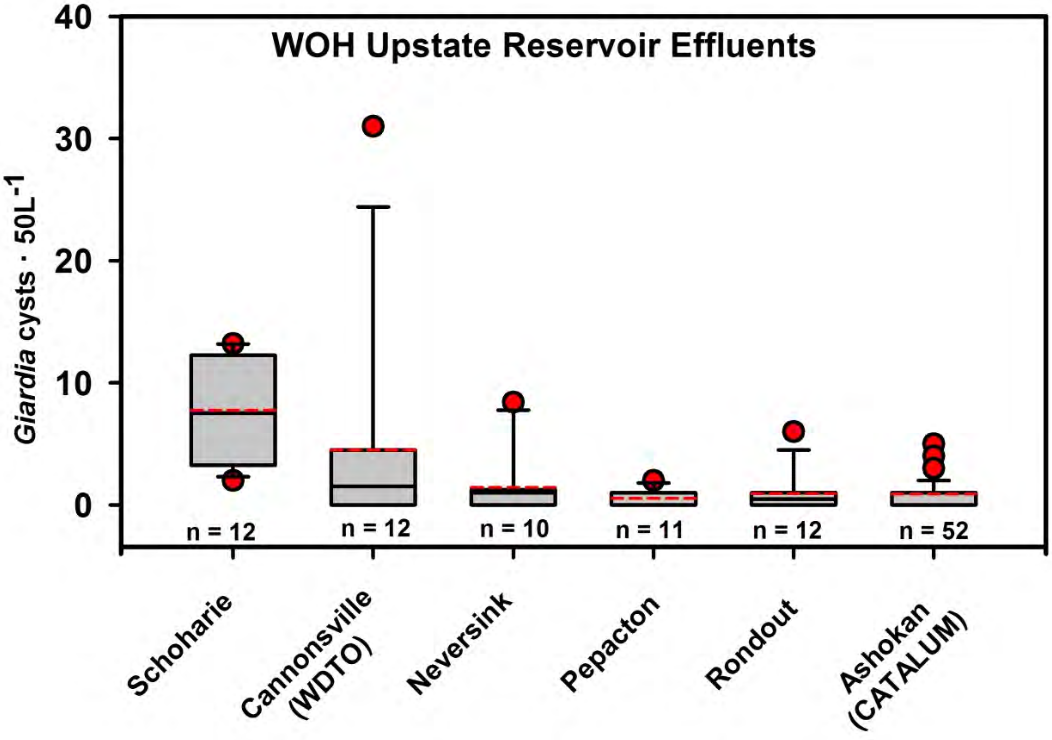


Figure 5.6 *Giardia* distribution among WOH and EOH basins for 2013 (--- mean, __ median, ● outliers).

5.4 Watershed Streams

The 2009 Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009) prescribes protozoan monitoring at 18 streams in the NYC watershed. This includes 8 stream sites in the WOH watershed, 8 in the Kensico watershed, and 2 in the Croton watershed, each to be monitored monthly. In 2012, as a result of modifications to the WWQMP, sampling frequency at four of the streams in the WOH watershed was reduced to every other month and, owing to a change to the CCD, monitoring at the two Croton watershed streams was discontinued. The eight Kensico perennial stream sites, the three stream sites in the WOH watershed which are being monitored for upstream source identification, and one additional WOH site, were sampled monthly in 2013. A total of 168 samples was collected in 2013, 72 in the WOH watershed and 96 at Kensico perennial streams.

West of Hudson Streams

Four of the eight WOH streams were monitored every other month (CDG1, S4, S5i, and WDBN) in 2013 while S7i and PROXG were monitored monthly (Figure 5.7). As part of an effort to determine if point sources could be identified upstream of sites with the highest mean protozoan concentrations, new upstream sites on the Manorkill were sampled. Two sites upstream of S7i (S7iB and S7iD3 (Figure 5.8)) were also sampled monthly in 2013, with monitoring for all three sites scheduled on the same day.

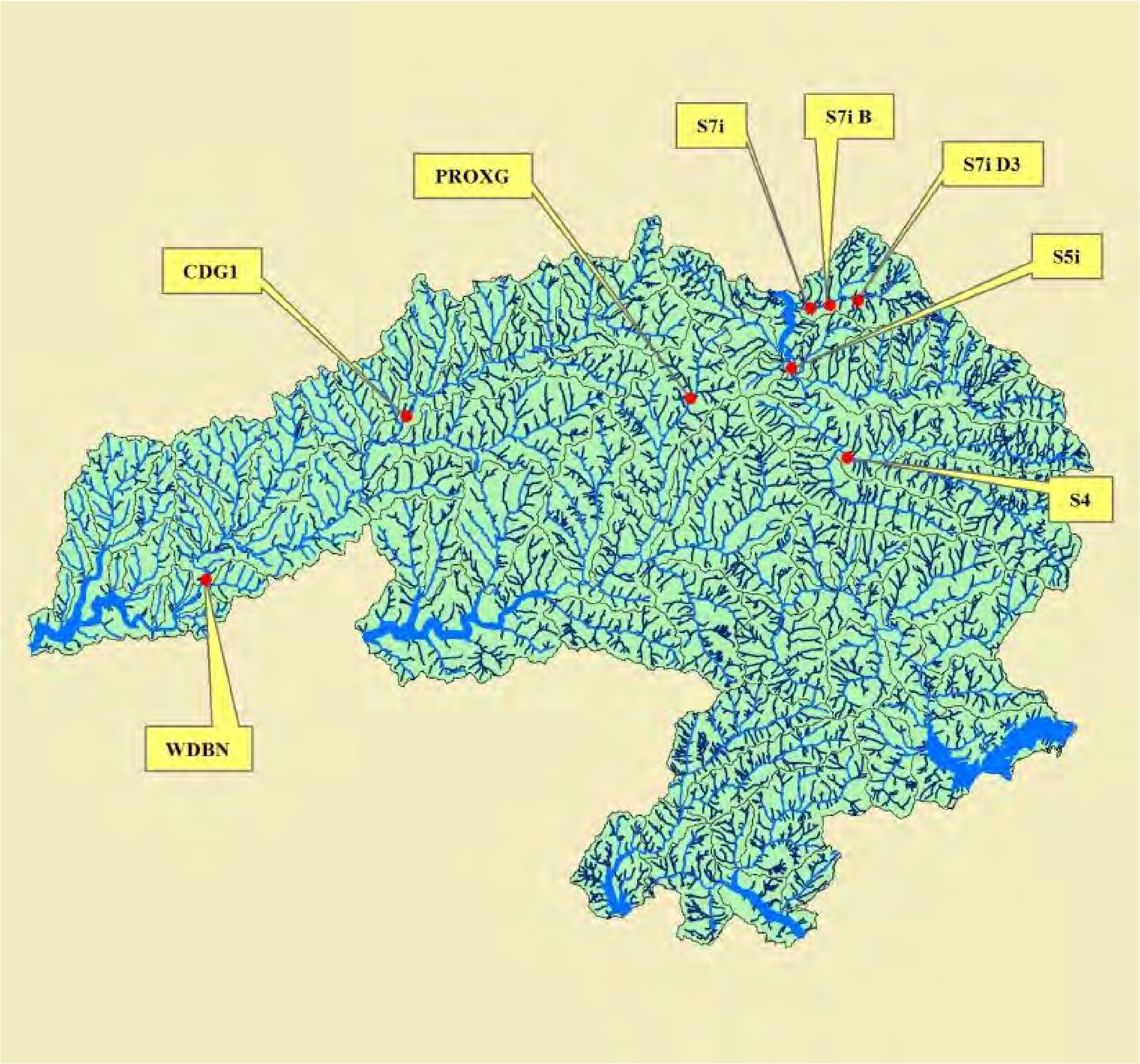


Figure 5.7 WOH stream sites sampled in 2013.

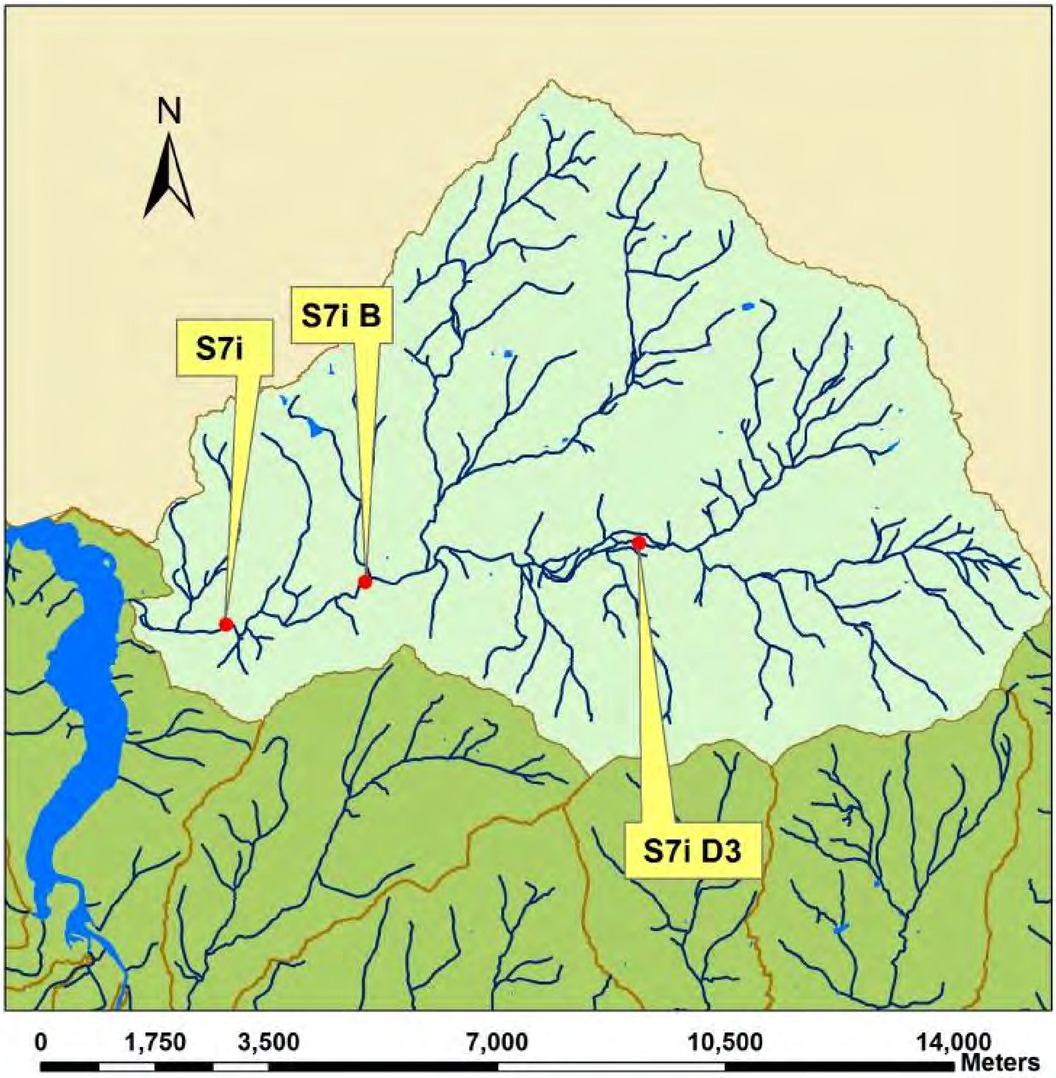


Figure 5.8 The Manorkill sub-basin in the Schoharie watershed, depicting pathogen monitoring sites sampled in 2013.

Cryptosporidium detections were frequent in WOH watershed stream samples in 2013, with a 34.7% detection rate (25 positives from 72 samples) compared to a 17.7% detection rate in 2012. Concentrations were generally low, with 23 of the 25 positive samples having 3 oocysts $50L^{-1}$ or less. The maximum concentration of 7 oocysts $50L^{-1}$ was found at PROXG (Table 5.6), pushing its annual mean concentration up to 1.92 oocysts $50L^{-1}$, higher than the 2012 mean of 0.36 oocysts $50L^{-1}$, and the highest annual mean concentration at this site since 2004.

Table 5.6: Summary of watershed stream protozoan results for WOH sites in 2013.

Site	n	*Cryptosporidium* Mean ($50L^{-1}$)	*Cryptosporidium* Maximum (Liters sampled)	*Cryptosporidium* Maximum (L^{-1})	*Giardia* Mean ($50L^{-1}$)	*Giardia* Maximum (Liters sampled)	*Giardia* Maximum (L^{-1})
CDG1	6	0.67	3	0.06	63.40	189	3.78
PROXG	12	1.92	7	0.14	95.31	299	5.98
S4	6	0.00	0	0	23.81	52	1.04
S5i	6	0.67	3	0.06	45.42	145	2.90
S7i	12	0.58	2	0.04	24.80	69	1.38
S7iB	12	0.58	3	0.06	25.07	119	2.38
S7iD3	12	0.08	1	0.02	2.08	12	0.24
WDBN	6	0.67	2	0.04	11.50	23	0.46

As in the past, *Giardia* was found far more frequently than *Cryptosporidium* [68 of 72 samples (94.4%) positive] and at much higher concentrations (Table 5.6). *Giardia* was found in all the samples taken in seven of the eight streams in 2013, the exception being the upstream site along the Manorkill (S7iD3). Two of the eight streams (CDG1 and PROXG) showed increases in annual mean concentration of more than 50% compared to 2012 means (63.40 and 95.31 cysts $50L^{-1}$ versus 40.94 and 38.42 cysts $50L^{-1}$). PROXG's results were consistently higher for the latter half of 2013, with all six samples over 95 cysts $50L^{-1}$, and an average of 162.18 cysts $50L^{-1}$ for the period. Sites S4 and S7i both showed reductions of 50% or more in annual mean concentration from 2012 levels (23.81 and 24.80 cysts $50L^{-1}$ versus 65.58 and 51.33 cysts $50L^{-1}$).

For the last four years, DEP has been comparing protozoan concentrations found at S7i and S7iB with upstream sites to narrow down the relative location of potential sources of cysts. In 2013, both downstream sites had the same *Cryptosporidium* mean concentration (0.58 oocysts $50L^{-1}$), while the upstream site (S7iD3) had a much lower mean of 0.08 oocysts $50L^{-1}$(Table 5.6). *Giardia* results for the two downstream sites ranged from 3 to 199 cysts $50L^{-1}$ and both sites had a mean concentration of approximately 25 cysts $50L^{-1}$ (24.80 and 25.07 cysts $50L^{-1}$ at S7i and S7iB, respectively.) S7iD3, on the other hand, had a lower annual mean concentration of 2.08 cysts $50L^{-1}$ despite concurrent sampling. DEP will continue to look for a source downstream of the S7iD3 site, and investigate pond outflows in 2014.

East of Hudson (EOH) Streams

In 2013, eight perennial streams in the Kensico Reservoir watershed were sampled monthly for protozoans. Kensico streams overall showed a *Cryptosporidium* detection rate of 17.7%. with annual mean concentrations below 1.00 oocysts $50L^{-1}$ at each stream, except for E9. The mean concentration at E9 was 1.32 oocysts $50L^{-1}$; this site also had the highest individual sample result at the Kensico streams of 7 oocysts $50L^{-1}$ (Table 5.7). With the exception of E9, these *Cryptosporidium* results are similar to those found at Kensico Reservoir streams in the prior three years (2010-2012), when annual mean concentrations at each site did not exceed 0.85 oocysts $50L^{-1}$.

Overall *Giardia* occurrence at Kensico streams was almost 70% in 2013, very similar to the detection rate in 2012 (75%), while mean concentrations ranged from1.92 to 14.91 cysts $50L^{-1}$. However, the pooled mean for all sites (the mean of all the sample concentrations (96 in total) for all eight sites) dropped in 2013 to 6.23 cysts $50L^{-1}$ from 12.51 cysts $50L^{-1}$ in 2012. This overall decrease in the pooled mean was heavily affected by much lower results at site E9. In 2012, E9 had a mean of 54.73 cysts $50L^{-1}$ and a maximum result of 240 cysts $34.8L^{-1}$, whereas 2013 had a mean of 9.86 cysts $50L^{-1}$ and a maximum of 43 cysts $50L^{-1}$ (Table 5.7).

Table 5.7: Summary of watershed stream protozoan results for EOH sites in 2013.

		Cryptosporidium			*Giardia*		
Site	n	Mean ($50L^{-1}$)	Maximum (Liters sampled)	Maximum (L^{-1})	Mean ($50L^{-1}$)	Maximum (Liters sampled)	Maximum (L^{-1})
BG9	12	0.23	1 (29.3 L)	0.03	7.70	32 (39.4 L)	0.81
E10	12	0.08	1 (50.0 L)	0.02	1.92	6 (50.0 L)	0.12
E11	12	0.25	2 (50.0 L)	0.04	14.91	54 (50.0 L)	1.57
E9	12	1.32	7 (50.0 L)	0.14	9.86	43 (50.0 L)	0.86
MB-1	12	0.00	0	0	2.24	7 (45.8 L)	0.18
N12	12	0.00	0	0	4.25	12 (50.0 L)	0.24
N5-1	12	0.10	1 (41.9 L)	0.02	1.96	6 (44.2 L)	0.14
WHIP	12	0.62	2 (41.7 L)	0.05	6.97	44 (50.0 L)	0.88

5.5 Wastewater Treatment Plants

In 2013, DEP monitored 10 WWTP effluents (8 WOH and 2 EOH) quarterly for *Cryptosporidium* and *Giardia*. No *Cryptosporidium* detections, and only one *Giardia* detection, were reported from these 40 samples. The positive sample—a 50L filtered sample containing 2 *Giardia* cysts—was collected from the Hunter WWTP effluent on January 22, 2013. Operators at the Hunter plant report that the plant was running properly on that day, with a daily flow of 0.137 MGD and no operational issues. However, it should be noted that this sample was taken a day after the Martin Luther King, Jr. holiday weekend, a busy time for the ski resorts in the area.

5.6 Hillview Monitoring

After an assessment of data collected from 2006 to 2008, and as part of the Hillview Administrative Order, a routine sampling program for *Giardia* and *Cryptosporidium* was developed for the Catskill outflow from Hillview Reservoir at Site 3. Weekly monitoring began at Hillview Site 3 in August 2011. In 2013, 52 samples were collected from Site 3, with two samples positive for *Cryptosporidium* (3.8%) and 18 samples positive for *Giardia* (34.6%) (Table 5.8). In 2012, there were no *Cryptosporidium* detections at Site 3, and *Giardia* percent detection was very similar, at 31.5%.

Table 5.8: Summary of Hillview Site 3 monitoring results in 2013.

	Cryptosporidium	*Giardia*
n	52	52
Detections	2	18
% Detections	3.8	34.6
Mean ($50L^{-1}$)	0.04	0.58
Maximum ($50L^{-1}$)	1.00	4.00

6. Modeling for Watershed Management

6.1 Overview of DEP Modeling System

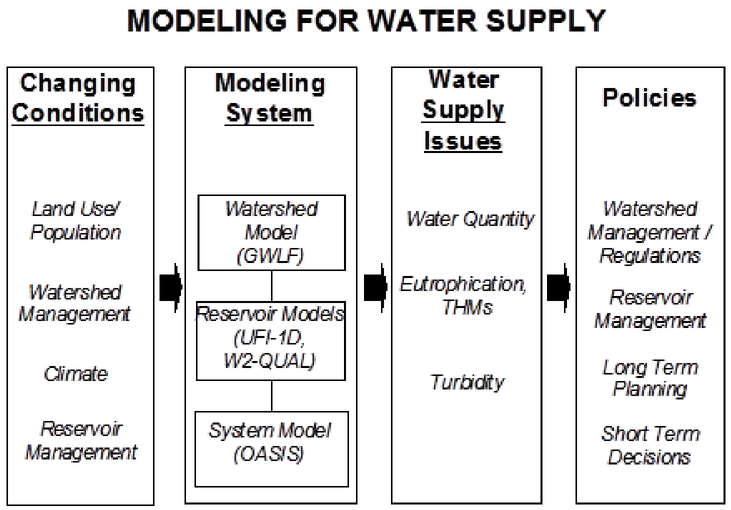


Figure 6.1 Use of models for the NYC Water Supply.

DEP uses models to examine how changes in land use, population density, ecosystem processes, and climate, as well as both watershed and reservoir management policies, affect the NYC Water Supply (Figure 6.1). Changing conditions in the watersheds present both ongoing and new challenges that DEP must plan for and respond to in its mission to ensure the continued reliability and high quality of the NYC Water Supply. Changing patterns of land use and population in the watersheds influence nutrient loadings, which can increase eutrophication and organic carbon disinfection by-product (DBP) precursors in the reservoirs. Changes in stream channel erosion related to climate and to urbanization may exacerbate turbidity in the water supply system. Climate change and changes in watershed ecosystem functions may impact both the future quantity and quality of water in the upstate reservoir system. Understanding the effects of changing conditions is critical for decision making, long-term planning, and management of the NYC watersheds and reservoir system.

The DEP modeling system consists of a series of linked models that simulate the transport of water and dissolved and suspended materials within the watersheds and reservoirs that comprise the upstate (Catskill and Delaware) water supply system. Watershed models are used to simulate the amount and seasonal variability of water, sediment, and nutrients transported from the land surface to the reservoirs. The Generalized Watershed Loading Function (GWLF) model is widely applied across the entire West of Hudson (WOH) watershed region. The modeling group is also developing more physically-based model applications for agricultural watersheds using the Soil Water Assessment Tool (SWAT) and for forested watersheds using the RHESSys model. Reservoir models (including the UFI-1D and the CE-QUAL-W2 models) simulate hydrothermal structure and hydrodynamics of the reservoirs and the nutrient and sediment distribution within the reservoir body and at aqueduct outlets. The water supply system model (OASIS) simulates the operation of the multiple reservoirs that comprise the water supply system, including the storage of water within the reservoirs and the transfer of water between them. The modeling system is used to explore how the water supply system and its components may behave in response to changes in land use, population, climate, ecosystem disturbances, watershed/reservoir management, and system operations.

Major water supply issues that the modeling system is used to address include turbidity in the Catskill System, eutrophication in the Delaware System, and water quantity in the entire system to meet NYC demand. Simulations are performed during and in the aftermath of storm events to provide guidance for operating the reservoir system in response to elevated turbidity levels, particularly in the Catskill System. The models have been used to examine alternative operational changes in Schoharie and Ashokan Reservoirs to mitigate the impacts of elevated turbidity and limit the use of alum treatment. The effects of changing land use and watershed management on nutrient loading and eutrophication in Delaware System reservoirs (Cannonsville and Pepacton) have been analyzed using linked watershed and reservoir models. A project to investigate the use of models to evaluate organic carbon and DBP precursors in the water supply watersheds and reservoir system has been initiated. The effects of climate change on the water supply are currently under investigation using the modeling system.

6.2 Modeling Applications to Support Reservoir Operations Decisions

Storm-generated turbidity in the NYC Watershed—particularly in the Catskill System (consisting of Schoharie and Ashokan Reservoirs and their respective watersheds)—is an important water quality issue that constrains the operation of the NYC Water Supply. When turbidity events occur or other operational limitations exist, water system reservoirs are carefully managed to control turbidity at keypoints where regulatory limits must be maintained. In extreme cases alum treatment may be applied to reduce turbidity in Kensico Reservoir. Such treatment is costly and has environmental implications, and every effort is made to avoid alum treatment by careful operation of the reservoir system.

An integral component of controlling turbidity in the Catskill System involves the development and use of the Operations Support Tool (OST). OST combines reservoir water quality and water system models, near-real-time data describing flows and water quality, and meteorological and streamflow forecasts to test effective operational strategies to both control turbidity levels and continue to reliably meet water demands. The modeling backbone of the OST includes a version of the CE-QUAL-W2 reservoir model developed specifically to simulate turbidity in the Catskill System reservoirs, coupled to the OASIS model, a water system model used to simulate reservoir system volumes and flows. The combined modeling system simulates the relationship and feedback between reservoir turbidity levels and reservoir operations. The OST can be used to evaluate water system operational strategies in order to gain an understanding of the effects of these decisions on future water system quantity and quality.

A “position analysis” strategy is followed for OST model runs. Under this strategy, the current initial conditions of the reservoir and watershed are used as the starting point for the model. For analysis of Ashokan Reservoir, the model is run for a forecast period which is typically three months. Separate forecast traces are simulated using the flows, derived turbidity loads, and meteorological inputs from the historical record for the same three-month period during the years 1948-2004. For Kensico, a similar position analysis approach is used, except that aqueduct input flows and turbidities are fixed at differing levels to evaluate the sensitivity of effluent turbidity to variations in input conditions. This helps to determine the optimal ratios of Catskill System and Delaware system inputs to the reservoir, given the turbidity levels in each system. The results of the positional analysis are typically a range of potential outcomes based on the potential variability in near-term future meteorology, flows, and turbidity.

During 2013, there were three periods during which modeling analyses helped to inform operational decisions. In January 2013, OST was used to understand the possible timing and magnitude of the expected peak turbidity in Ashokan Reservoir due to upcoming spring runoff events. This was of particular importance, as more Catskill water was going to be needed during the spring due to a drawdown of Rondout Reservoir. After a rain and snowmelt event in mid-March, a Kensico Reservoir sensitivity simulation was run to continue to ensure that Kensico effluents would meet turbidity standards. Finally, in April 2013, OST was used once more to ascertain the water quality benefits versus the storage drawdown trade-offs of using the Ashokan release channel to reduce the impact of West Basin to East Basin movement of water and turbidity in Ashokan Reservoir.

A typical analysis for Kensico Reservoir occurred in March 2013. The Catskill Aqueduct turbidity increased to about 6-7 NTU due to a spring snowmelt/rain event. Snowpack in the Esopus Creek watershed was about normal for mid-late March, and spring events were expected to begin to impact the watershed in the upcoming weeks. At the time, Kensico Reservoir turbidity generally ranged from 1.3 to1.7 NTU, with somewhat higher turbidity greater than 3 NTU near the Catskill influent.

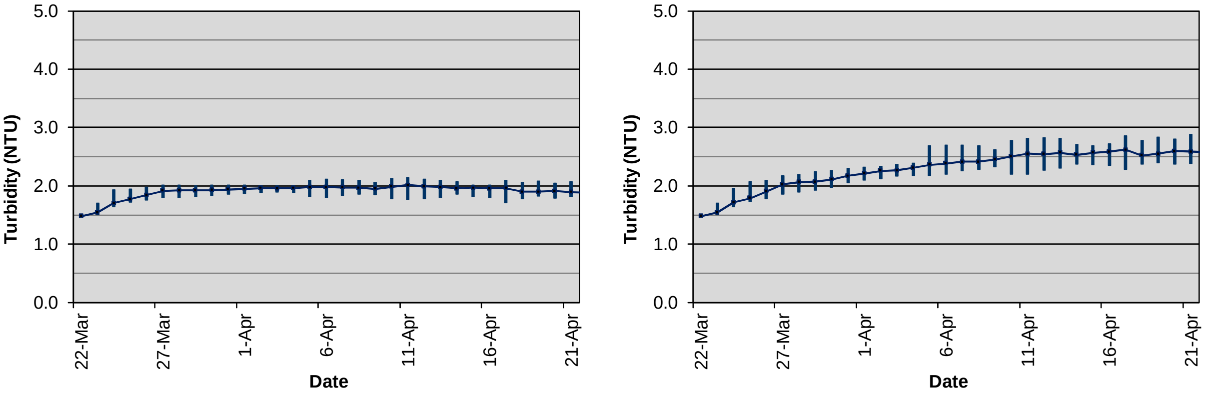
Sensitivity simulations for Kensico Reservoir were performed using the position analysis framework, with meteorological forcings and aqueduct input water temperatures for the years 1987-2004 (18 traces) representing historical variability in the model forcings. The simulations were run for a 30-day forecast period from March 22-April 21. Initial conditions for in-reservoir turbidity and temperature were based on a limnological survey conducted on March 19 and information from an automated buoy profile in Kensico Reservoir. For all runs the input turbidity from the Delaware Aqueduct was set to 1.0 NTU based on conditions at the time. To test various combinations of inflow and turbidity input from the Catskill Aqueduct to Kensico Reservoir, flows were set to 300, 400, and 500 MGD and input turbidities were set to 6, 8, and 10 NTU. Delaware

Aqueduct inflows were set to balance the Catskill Aqueduct flows so that total inflow to the reservoir equaled 1,100 MGD. Each of the simulations assumed that these inputs and outputs were constant for the 30-day forecast period.

Figure 6.2 shows the results of a subset of the simulations covering the 300 and 500 MGD flow rates and the 6 and 10 NTU influent turbidities from the Catskill Aqueduct. A sustained Catskill Aqueduct turbidity of 6 NTU, at a flow of 300 MGD, produced Kensico effluent turbidity levels of 1.8-2.1 NTU once steady state conditions are reached at the reservoir effluents following flow of turbidity through the reservoir (Figure 6.2a). Variation between traces, as indicated by the vertical bars, is due to climate variability between simulations, which leads to variations in inflow aqueduct influent temperatures and reservoir thermal stratification. A sustained input of 10 NTU water at the same flow rate resulted in somewhat higher effluent turbidity of 2.4-2.9 NTU (Figure 6.2b). At the 500 MGD flow, sustained 6 NTU Catskill influent into Kensico produced effluent turbidity ranging from 2.3-2.7 NTU, while sustained 10 NTU influent resulted in an effluent turbidity range of 3.3-4.1 NTU (Figure 6.2c,d). These results indicated the appropriate flows at various Catskill turbidity inputs that would be necessary to maintain acceptable Kensico effluent turbidity even in the event of an increase in Ashokan withdrawal turbidity were to 10 NTU.

(a) Catskill influent: 300 MGD; 6 NTU

(b) Catskill influent: 300 MGD;10 NTU



(c) Catskill influent: 500 MGD; 6 NTU

(d) Catskill influent: 500 MGD; 10 NTU

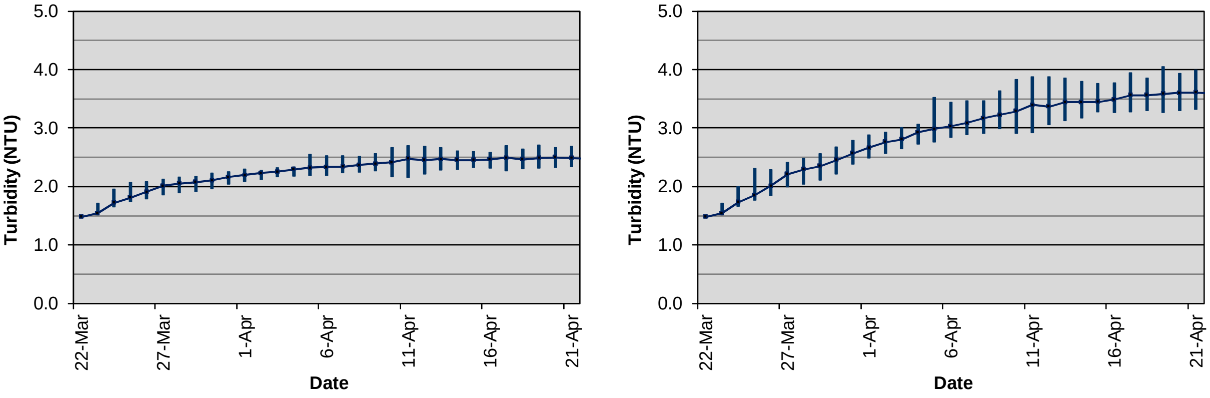


Figure 6.2 Selected turbidity forecasts of Kensico Reservoir effluent turbidity with constant input from the Catskill Aqueduct of (a) 6 NTU at 300 MGD, (b) 10 NTU at 300 MGD, (c) 6 NTU at 500 MGD, and (d) 10 NTU at 500 MGD. Forecasts were made on March 22 for a period of one month into the future. The line on the graph shows the median of the 18 traces from the position analysis; the vertical bars show the range of turbidity for all traces.

6.3 Climate Change Integrated Modeling Project

The Climate Change Integrated Modeling Project (CCIMP) has the goal to evaluate the effects of future climate change on the quantity and quality of water in the NYC water supply. The project is an element of DEP's Climate Change Action Plan released in 2008. The CCIMP is designed to address issues of concern to NYC including: quantity of water in the entire water supply; turbidity in the Catskill System of reservoirs, including Kensico; and eutrophication in Delaware System reservoirs. In the first phase of the project an initial estimate of climate change impacts was made using available GCM data sets and DEP's suite of watershed, reservoir and system operation models.

CCIMP Phase I overview

During 2013, the first phase of the CCIMP was brought to a close with the holding of a review workshop in September and the subsequent publication and distribution of a report detailing Phase I activities and an expert panel review. (The report is available online at the DEP website: http://www.nyc.gov/html/dep/html/about_dep/climate_resiliency.shtml.) Phase I focused on water quantity in the West of Hudson (WOH) watershed, turbidity in Schoharie Reservoir, and eutrophication in Cannonsville Reservoir.

Some of the general findings of Phase I were:

- The timing of the spring snowmelt was predicted to shift from a distinct peak in late March and April to a more consistent distribution throughout the winter and autumn. This shift is a function of increased temperatures, which will cause less precipitation to fall as snow and faster melting of the snowpack that does develop. The consequent shift in streamflow drives many of the findings obtained from application of the water system and reservoir water quality models.
- Greater winter streamflow will cause the WOH reservoirs to fill earlier in the year, and for spill from the reservoirs to increase during the winter. The increased winter spill will come at the cost of lost storage in the spring snowpack.
- For the WOH watershed, it appears that drought will be less prevalent, because the GCM simulations used in the study predict increased precipitation throughout the year, which compensates for lost snow storage and increased evapotranspiration due to higher temperatures.
- The shifting seasonal pattern in streamflow will similarly affect the turbidity loads into Schoharie Reservoir, which in turn will impact Schoharie withdrawals, resulting in increased turbidity in the autumn and winter and decreased turbidity in the spring.
- The nutrient loads to Cannonsville Reservoir will also exhibit shifts similar to the streamflow shifts noted above. However, despite increased nutrient loads during the winter and autumn, the response of the phytoplankton will be small, presumably due to unfavorable growth conditions at this time of the year. The thermal structure of the reservoir will be impacted by the higher temperatures of the future climate, with thermal stratification beginning earlier in the spring and lasting longer into the autumn.

Phase II of the CCIMP will improve and expand upon the analyses of Phase I. During Phase II, DEP will be making use of a more extensive set of GCM data, utilizing improved downscaling methods to develop a wider variety of future climate scenarios, implementing use of updated watershed, reservoir, and water system models as they are developed, and expanding the analysis to other WOH watersheds and reservoirs.

CCIMP analysis of Cannonsville Reservoir thermal structure, phytoplankton growth, and eutrophication

An important factor in phytoplankton growth is the length of time that a reservoir is thermally stratified. Under future climate conditions, with generally warmer temperatures, the reservoirs are expected to be stratified for a longer period of time, and have more stable stratification and warmer water temperatures. As part of the CCIMP, DEP investigated the effects of this changing physical environment on Cannonsville Reservoir phytoplankton populations.

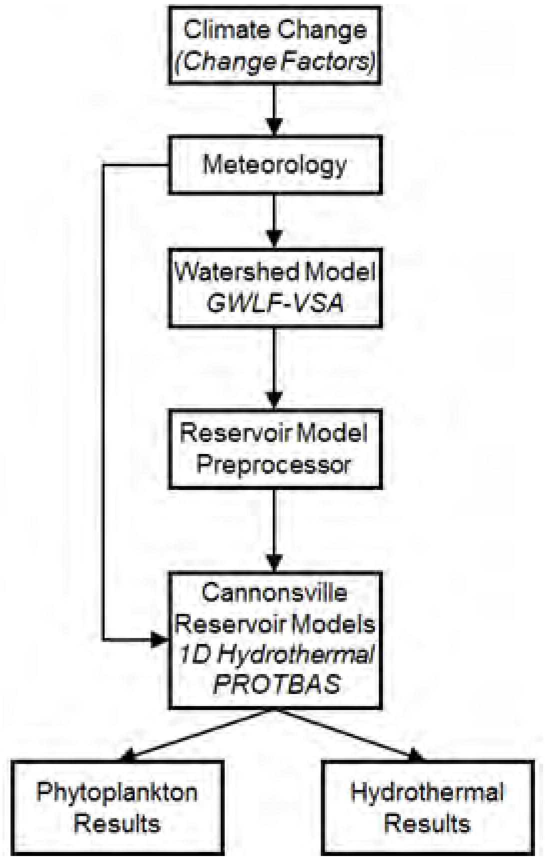


Figure 6.3 Schematic diagram depicting use of DEP modeling system for climate change-related simulations to analyze eutrophication in Cannonsville Reservoir.

For Phase I of the CCIMP, DEP used integrated modeling tools to investigate the potential changes to reservoir thermal structure as well as the potential changes in total phytoplankton biomass growth and the phytoplankton functional groups in Cannonsville Reservoir. These investigations were facilitated by applying the suite of DEP's watershed and reservoir water quality models in an integrated way (Figure 6.3). For the analysis, projected climate change was represented by future time series of meteorology which were developed using a change factor methodology (Anandhi et al. 2011a). This method produced a number of future climate scenarios which served as inputs to watershed and reservoir model simulations. These representations of future climate were used as input to the DEP watershed model, GWLF-VSA (Schniederman et al. 2002, 2007), to simulate flows and nutrient loads. These were then used to specify future stream inflows, water temperatures, and constituent loads that were input to the reservoir models. For thermal structure and eutrophication in Cannonsville Reservoir, a one-dimensional hydrothermal reservoir model (Owens 1998) was used along with the PROTBAS model (Markensten and Pierson 2007), which has been adapted for DEP's Cannonsville Reservoir. In addition to the GWLF-derived inputs, meteorological parameters from the climate scenarios were also input to the reservoir model. Variations in these meteorological parameters affect the reservoir water temperature and pattern of thermal stratification.

Figure 6.4 shows the range of climate change inputs for temperature and the resulting changes in monthly average flows and dissolved phosphorus loads into the reservoir. As reported above, all climate change scenarios consistently predicted increased temperature throughout the year. This results in an increase in fall and early winter streamflow, as more precipitation falls as rain rather than snow during the early winter. In addition, there is a slight reduction in the traditional spring peak runoff and the less snowpack in the watershed.

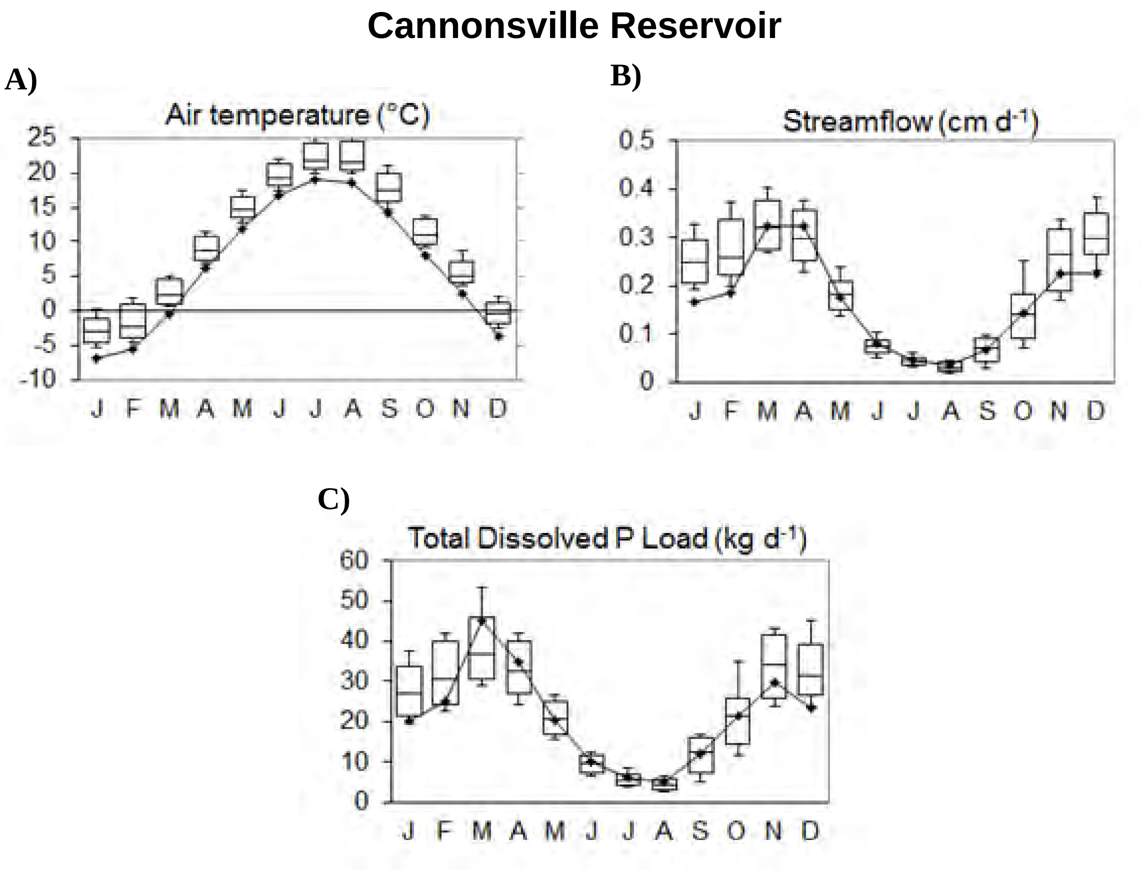


Figure 6.4 Seasonal patterns in mean monthly air temperature driving the GWLF watershed model, and GWLF simulated stream discharge and dissolved phosphorus loads for Cannonsville Reservoir. Effects of future climate change can be seen by comparing the historical mean patterns, plotted as a line, with the range of mean monthly values associated with future scenarios, shown as boxplots.

Figures 6.5 and 6.6 present comparisons of reservoir thermal conditions simulated using the Cannonsville 1D hydrothermal model (Figure 6.3) for present day (baseline) conditions. These conditions were simulated to occur using model meteorological data derived from three separate global climate models (GCMs) under the IPCC A2 scenario for the future period 2081-2100. The A2 scenario describes the greatest continued growth in atmospheric CO_2 and therefore also results in the greatest levels of future warming. The isopleths in Figure 6.5 are constructed using daily average water temperature profiles associated with the baseline historical period and the combined data from the three GCM scenarios representing the A2 future conditions. Likewise, in Figure 6.6, annual variations in the timing of stratification are based on each year of the baseline data set and the mean of the yearly estimates associated with the three different GCM simulations. Figure 6.5 shows the overall seasonal variation of water temperature; comparison of the two figures shows the predicted increase in future mixed layer depth and surface temperatures in the future scenario compared to the baseline period. On average, surface water temperature was simulated to increase by 1.8 ^{o}C and the bottom water temperature by 0.8 ^{o}C.

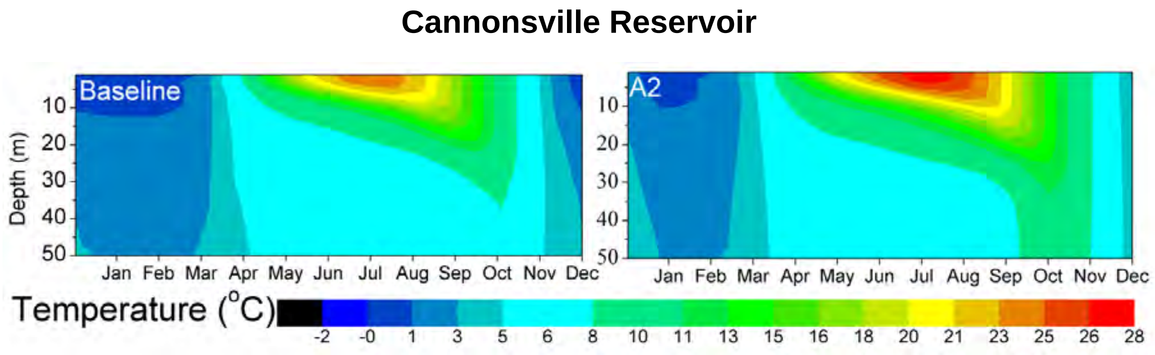


Figure 6.5 Mean annual isopleths of simulated temperature under baseline conditions and A2 emission scenario for Cannonsville Reservoir. Profiles from which these isopleths were calculated are the mean daily profiles of all baseline scenario years and the combined means of all A2 scenarios associated with the CGCM3, ECHAM and GISS model simulations for the 2081-2100 time period.

Figure 6.6 shows the Julian Day of onset and loss of thermal stratification simulated by the reservoir model for 39 future years, under baseline meteorology conditions versus future A2 emission scenario climate conditions. The simulations indicated that, on average, the onset of stratification is expected to occur about two to three weeks earlier in the spring under the future climate scenarios. The loss of stratification is not affected as strongly and, on average, is simulated to occur four days later in the fall. Overall, this translates to a stratification period that is on average 23 days longer under future scenario conditions than baseline conditions. Thus, the future scenario was simulated to have warming water temperatures, a longer stratification period, greater vertical temperature gradients, and more stable thermal stratification.

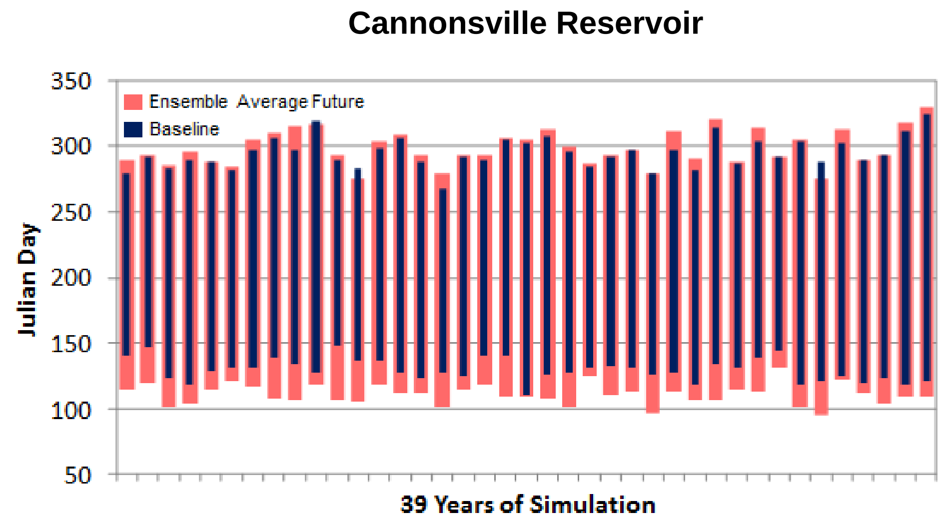


Figure 6.6 Interannual variation in the onset, loss, and duration of thermal stratification in Cannonsville Reservoir for baseline conditions (blue bars) and future scenario ensemble average conditions (red bars). The bottom of each bar shows the day of onset of stratification, the top of each bar shows the day of loss of stratification, and the length of each bar shows the duration of stratification.

When considering the potential impacts of climate change on Cannonsville Reservoir trophic status, two potential drivers of change in phytoplankton community biomass and composition must be taken into account: changes in the amount and seasonality of nutrient loading to the reservoir, and changes to the reservoir thermal and mixing regime. To understand the impacts of each of these factors, the simulated climate effects were separated into three separate runs: (1) those including all climate change effects, including both hydrothermal changes to the reservoir and flow and nutrient loading changes; (2) those including only changes in the flows and nutrient loads to the reservoir; and (3) those including only effects of changes in the reservoir hydrothermal structure (as discussed above). These three simulations made it possible to separate the changes in thermal structure from changes in flow and nutrient load timing.

The results of the simulations of the three scenarios are shown in Figure 6.7. When examining the total effect of climate change on both watershed and reservoir hydrothermal processes (Figure 6.7a), it is clear that in most months there is a modest (10-15%) increase phytoplankton biomass expressed as reservoir chlorophyll concentration. More striking are the results of the simulations that attempt to separate the effects of the future changes in reservoir loading from future changes in reservoir thermal structure and mixing (Figure 6.7b and c). These suggest that despite an overall increase in future levels of nutrient loading, these effects on their own have virtually no effect on the seasonal patterns of chlorophyll concentration, and in fact actually lead to a slight decrease in chlorophyll concentration during thermally stratified conditions in May-October (Figure 6.7b). The reason for this is that shifts in the seasonality of nutrient loading result in greater amounts of nutrient loading in the late fall to winter, when conditions are not favorable for phytoplankton growth (Pierson et al. 2013). Pierson et al. further hypothesized that in the time between nutrient input and favorable growth conditions, nutrient bioavailability could decrease, and nutrients could be lost from the reservoir in spills and releases.

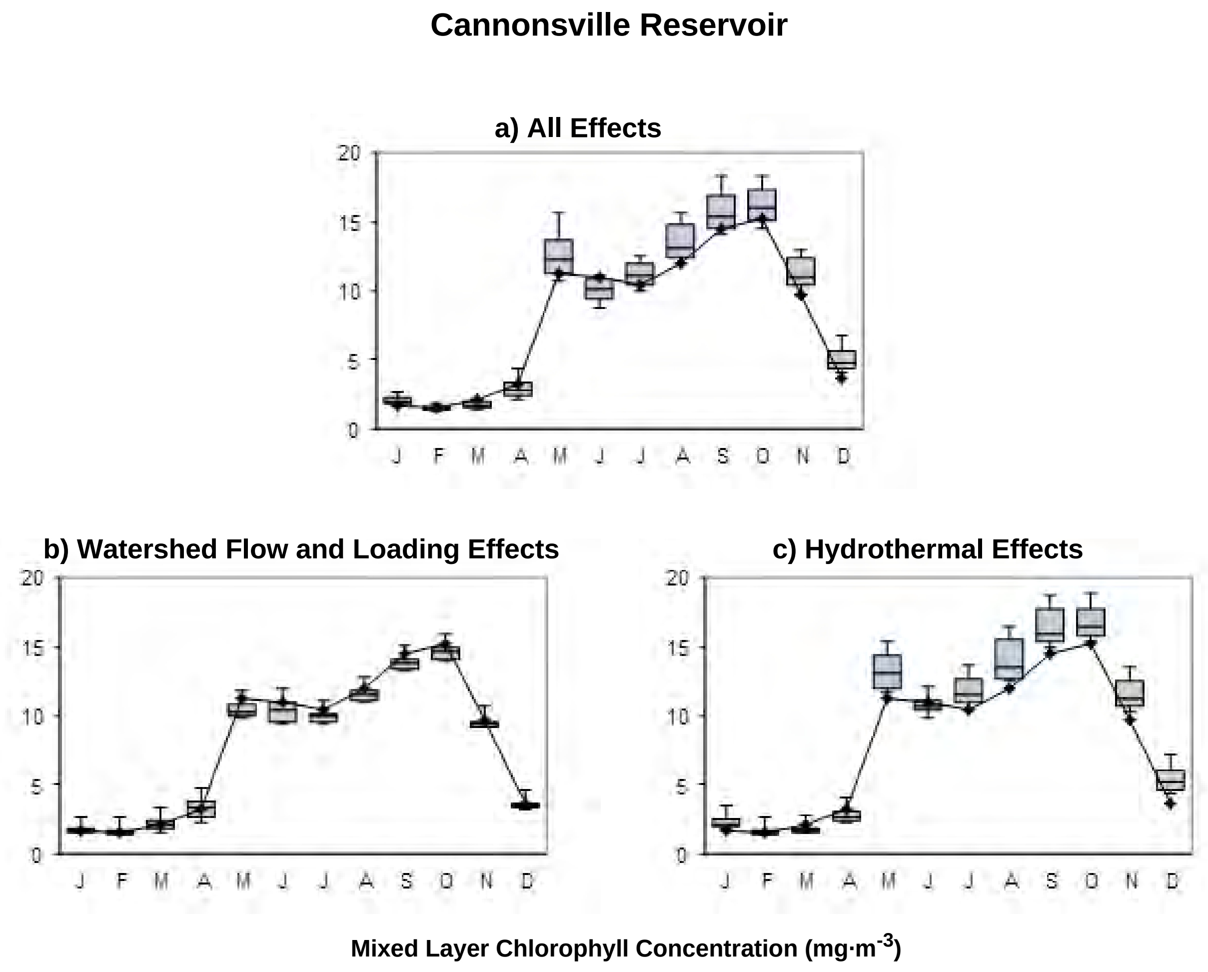


Figure 6.7 Average seasonal patterns of monthly mean mixed layer chlorophyll concentration for Cannonsville Reservoir under three future scenarios of watershed and hydrothermal conditions. Solid line shows the results with the model driven by historical conditions, box plots show the range from future scenarios. The boxplots in (a) show the range in future conditions when both watershed and hydrothermal effects are allowed to impact the phytoplankton, while (b) and (c) show the separate effects of watershed and hydrothermal effects.

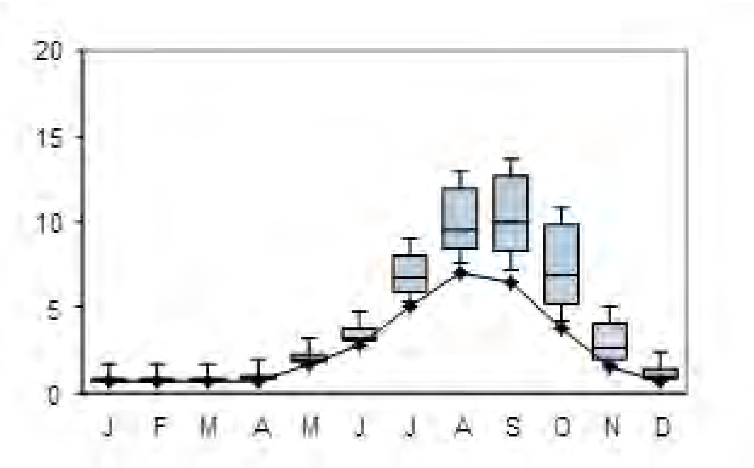
It is very important to note that this finding—that future changes in watershed nutrient loading may have little effect on in-reservoir phytoplankton growth—takes no account of potential increases in the frequency and intensity of growing season storms due to climate change. This is because the methodology used in this study to generate future climate scenarios does not account well for future changes in extreme events, even though watershed nutrient loading caused by extreme events during the growing season may have a marked effect on phytoplankton growth. Accounting for extreme events is an important goal of continuing climate change studies.

Simulations which allowed future climate conditions to affect only reservoir thermal structure (Figure 6.7c) show that it is largely these effects that account for future increases in reservoir chlorophyll concentration. Hydrothermal effects enhance phytoplankton growth due to the positive effect of the warmer water temperatures on the simulated rate of growth, as well as stratification's effect on phytoplankton light exposure (Huisman et al. 2004). This result illustrates that the interaction between nutrient loading and variability in the physical environment moderates nutrient impacts on phytoplankton biomass. In fact, both the negative effects associated with changes in the seasonality of hydrology and nutrient loading and the positive effects associated with changes in thermal structure are illustrated by these simulations.

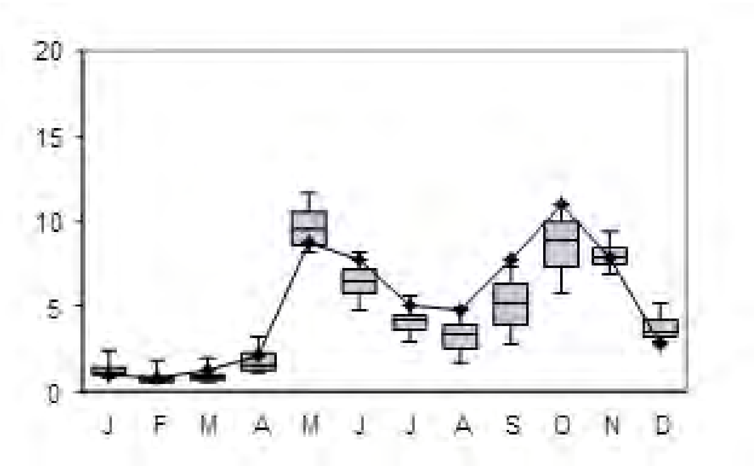
The UFI-PROTBAS model simulates the biomass of eight functional phytoplankton groups which have different growth characteristics and successional strategies (Reynolds et al. 2001, DEP 2008b). The seasonal variations in total biomass shown in Figure 6.7 are obtained by summing the biomass of all these groups. In Figure 6.8, the seasonal variations in the biomass of diatoms and cyanobacteria, the two major groups dominating the phytoplankton biomass, are plotted. The increased phytoplankton chlorophyll under future conditions was simulated to be the consequence of a successional change which favors the growth of cyanobacteria at the expense of diatoms. This simulated change is consistent with the physiology and ecology of these phytoplankton functional groups. Cyanobacteria are expected to dominate future climate conditions and warmer water temperatures (Paul 2008; Paerl and Huisman 2008, 2009; Kosten et al. 2012), since their maximum rate of growth generally occurs at higher temperatures than other phytoplankton groups (Reynolds 2006). The stronger and longer stratification period also gives an advantage to cyanobacteria, which are more buoyant and can migrate to the upper water column during periods of intermittent stratification, thus gaining a competitive advantage from greater light exposure; diatoms, on the other hand, generally have no upward motility and a relatively high sinking rate. (Reynolds and Walsby 1975, Huisman et al. 2004, Jöhnk et al. 2008).

Cannonsville Reservoir

(a) Cyanobacteria



(b) Diatoms



Mixed Layer Chlorophyll Concentration (mg·m^{-3})

Figure 6.8 Average seasonal patterns of monthly mean mixed layer chlorophyll concentration associated with (a) cyanobacteria and (b) diatoms in Cannonsville Reservoir.

6.4 DOC/DBP Workshop

One outcome of a recent review of the CCIMP was a recommendation to develop a long-term modeling effort that would allow climate effects on reservoir dissolved organic carbon (DOC) and DBP formation potential to be simulated. As a first step in this process, it was recommended that DEP convene a workshop to develop a strategy to for DOC/DBP modeling. This was deemed important because New York City's water supply is largely untreated and chlorination of DOC in the water can produce DBPs, which, as a result of recent regulatory changes, are now more stringently controlled in the water distribution system.

The goals of the workshop were to:

1. Consider the processes that need to be included in models of DOC and DBP formation potential in the water supply reservoirs.
2. Discuss how best to collect the data that can be used to both test and calibrate DOC/DBP models and inform water supply operations in near real time.

These two tasks could ultimately support an expansion of the capability of the OST and allow information on DBP formation potential, as measured by proxy indicators, to influence short-term operational forecasts. Additionally, the simulated effects of climate change on long-term trends in DBP formation potential might have implications for long-term future reservoir operation policy.

The workshop brought together experts with knowledge in three different areas: watershed hydrology and water quality, limnology, and DOC/DBP formation potential chemistry and monitoring. To begin the workshop, an overview of the DOC and DBP data that have already been collected by DEP was presented. Also presented was an overview of the watershed and reservoir models used by DEP that can simulate DOC, and which can potentially be further improved and linked to simulations of DBPs.

DEP proposed that Cannonsville and Neversink Reservoirs and their associated watersheds be designated as DOC/DBP study sites. As such, they will be the test sites for watershed and reservoir modeling and be subject to enhanced monitoring to support the long-term modeling effort. These sites were chosen for a number of reasons:

- They are both headwater reservoirs and have similar reservoir DOC concentrations.
- Cannonsville is the most eutrophic reservoir and Neversink is the most oligotrophic reservoir in the WOH watershed. The Cannonsville watershed has the most agricultural land in the WOH watershed, while Neversink is nearly completely forested. This suggests that Cannonsville may have a relatively greater amount of autochthonous DOC, while Neversink may receive a greater proportion of its DOC from allochthonous sources.
- Eutrophication modeling efforts have been largely focused on Cannonsville Reservoir in the past and, as a consequence, the reservoir model that could be used for DOC/DBP has been well tested in this reservoir.
- Monitoring infrastructure that could support the DOC/DBP modeling effort is either established or in the planning stage for these two reservoirs. This includes automated stream monitoring (including autosampling) and reservoir buoys to monitor phytoplankton and DOC (using proxy indicators).

In the remainder of the workshop, group discussions focused on identifying the key sources of DOC, the key processes that would be expected to regulate the transport of DOC to the reservoirs, the production of DOC in the reservoirs, DBP formation potential in reservoir water, and proxy measurements that could be used to monitor DOC and DBP formation potential. Following this, discussion focused on modeling the sources and processes, and monitoring that will be needed both to develop and calibrate models and to provide indicators of reservoir DOC/DBP levels in near real time. Additional workshops are planned for the future as part of DEP's continuing efforts on the CCIMP.

7. Further Research

The analytical, monitoring, and research activities of DEP are supported through a variety of contracts, and through participation in research projects conducted by the Water Research Foundation (WRF). Participation with external groups is an efficient way for DEP to bring specialized expertise into the work of the Water Quality Directorate (WQD) and to remain aware of the most recent developments in the water supply industry, such as evaluating the risks associated with climate change. The ongoing contracts and projects in which WQD is involved are described in the two sections below.

7.1 Contracts Managed by the Water Quality Directorate in 2013

In 2013, the WQD managed seven water quality-related contracts to enhance its ability to monitor and model the watershed. The contracts supported surveillance, model development, and management goals. A brief description of each contract is provided below.

7.1.1 Bathymetric Surveys of the Six West of Hudson Reservoirs

This contract with the United States Geological Survey (USGS) provides for bathymetric surveys of the six West of Hudson reservoirs. The spatial data and information delivered under this contract will help DEP, as manager of the reservoirs, to more accurately regulate storage in the reservoirs and to improve water-quality models used in reservoir management. The following data products for each reservoir will be delivered to DEP: the original survey point data, corrected for water surface elevation at the time of survey; a TIN (Triangulated Irregular Network) three dimensional surface of the reservoir bottom; 2-foot contours of reservoir depth; and updated stage-area-capacity tables in 0.01-foot increments. The bathymetric surface and tabular data are used in water quality modeling applications, the stage-capacity tables are used to determine current and available reservoir storage, and the three dimensional TIN and contours are used in GIS mapping applications. These products will update lower resolution bathymetric data acquired in the late 1990s. The contract was registered in August 2013. During the latter part of 2013, USGS staff attended required environmental health and safety training, configured and tested survey equipment, and completed final survey planning. The Ashokan-West reservoir basin was surveyed in September, and approximately half of Rondout Reservoir was surveyed in November, before weather conditions precluded further fieldwork. Review and processing of data for these basins was begun. Surveys of the remaining reservoirs will be conducted throughout 2014 and 2015. Final data deliverables for each reservoir will be received approximately four months after field data collection for that reservoir is completed.

7.1.2 Laboratory Analytical Support

Under this contract, Eurofins Eaton Analytical, Inc. conducts various analyses for which DEP's laboratories are not certified. The contract is managed by DEP's Distribution Water Quality Laboratory.

In 2013, contracted analyses included: volatile organic carbon (VOC) and semivolatile organic carbon (SVOC) analyses on selected aqueduct samples; total Kjeldahl nitrogen analyses on wastewater samples; trace metals, cyanide, fluoride, and New York State Sanitary Code Part 5 organics analyses of DEP facility drinking water samples; and additional organics analyses (e.g., Diesel Range Organics (DRO)) on special investigation (SI) samples.

Other laboratories used for contracted analyses in 2013 included:

- H2M Laboratories (formerly known as ECOTEST Laboratories). Pepacton **spill event** samples collected at the keypoint or elevation tap were sent to the laboratory for DRO analysis on a bi-weekly basis from January through May. The collections for DRO were discontinued after May due to the continued lack of detections.
- Source Molecular Laboratories. Samples from storm events occurring at Kensico Reservoir in June 2013 were sent to this laboratory for **microbial source tracking** analysis. The results are discussed further in Section 4.6.
- Watershed Assessment Associates. Samples of **benthic macroinvertebrates** collected in Croton, Catskill, and Delaware System streams were sent to the laboratory for identification to levels that meet the taxonomic targets set forth in the New York State Stream Biomonitoring Unit's Standard Operating Procedure. The results were used to calculate metrics and Biological Assessment Profile scores for each stream, as reported in Section 3.10.

7.1.3 Water Quality Operation and Maintenance and Assessment for the Hydrological Monitoring Network

DEP contracted with the USGS for a project titled, "Water Quality Operation and Maintenance for the Hydrological Monitoring Network." Under this agreement, the USGS measures stage and discharge at 57 stream gauges throughout the Croton, Catskill, and Delaware watersheds, and turbidity at 2 gauges (see below). The operation and maintenance of the gauges involves: (1) retrieving the stage, water temperature, and/or turbidity data; measuring stream flow; and/or collecting sediment samples at specified gauges, (2) ensuring the integrity of the data, (3) maintaining the automatic equipment used to collect the data, (4) preparing selected data for real-time distribution over the Internet, (5) analyzing stage, water temperature, turbidity, and stream flow data, and (6) preparing an annual summary report. The data support DEP's development of multi-tiered water quality models, which is a requirement of the 2007 Filtration Avoidance Determination (FAD) (USEPA 2014). The data also support the following FAD-mandated programs: Land Acquisition, the Watershed Agricultural Program, the Watershed Forestry Program, the Stream Management Program, the Wetlands Protection Program, and Catskill Turbidity Control.

In 2013, as an enhancement to the agreement, DEP contracted with the USGS to install, operate, and maintain a new gauge on Esopus Creek near Lomontville to measure streamflow and turbidity. In addition, the USGS will install, operate, and maintain turbidity equipment at the existing gauge at Mt. Marion, also on Esopus Creek.

7.1.4 Turbidity and Suspended Sediment Monitoring in the Upper Esopus Creek Watershed

This contract with the USGS involved retrofitting the five existing USGS streamflow gauges in the Esopus Creek watershed to automatically monitor turbidity at high (15-minute) frequency. The project ended in 2013 after three years of data had been collected. A final report was issued which (1) used the data to rank Esopus Creek sub-basins by the magnitude of annual sediment export, and (2) developed turbidity versus flow and suspended sediment versus flow relationships for the studied sub-basins. All data collected by the project were transferred to the DEP water quality modeling group.

7.1.5 CUNY Post-Doctoral Support

This contract provides the City University of New York (CUNY) with the funding needed to hire seven post-doctoral research associates (post docs) who are jointly advised by CUNY faculty, external faculty advisors, and DEP scientists. The post docs are stationed in Kingston, New York, working with the DEP modeling group on a day-to-day basis. The positions are for an initial two-year period, with the possibility of an additional two-year extension. This project was originally scheduled to end in 2013, but has been extended until August 2014 to ensure that all of the hired post docs have a chance to use their full four-year term of employment.

The post docs funded under the contract have supported the modeling group’s work in:

- Climate data analysis
- Reservoir system modeling
- Reservoir turbidity modeling
- Reservoir eutrophication modeling
- Watershed nutrient modeling
- Watershed sediment erosion and transport modeling
- Forest ecosystem modeling

The contract has been very successful, leading to the development and testing of improved modeling tools; new and improved data sets, including future climate scenarios used by the Climate Change Integrated Modeling Project; and modeling-based evaluations of climate change impacts. To date, 20 peer reviewed publications have resulted from the project (Anandhi et al. 2011b, Anandhi et al. 2011c, Matonse et al. 2011, Pradhanang et al. 2011, Zion et al. 2011, Huang and Pierson 2012, Klug et al. 2012, Matonse et al. 2012, Mukundan et al. 2012, Samal et al. 2012, Anandhi et al. 2013, Matonse and Frei 2013, Mukundan et al. 2013a, Mukundan et al. 2013b, Pierson et al. 2013, Pradhanang et al. 2013a, Pradhanang et al. 2013b, Samal et al. 2013, Schneiderman et al. 2013, Pradhanang et al. 2014). The sections of this report describing modeling based evaluation, model development and data analysis benefited from the work of these post-doctoral scientists.

7.1.6 Waterfowl Management

The Waterfowl Management Program (WMP) was developed in response to seasonal elevations of fecal coliform bacteria first identified at Kensico Reservoir from the late 1980s to the early 1990s. In 1993, DEP demonstrated a direct relationship between the waterfowl populations present and the concentrations of fecal coliforms in reservoirs, and this highly effective management program was developed based on this scientific finding. A contract was first let in 1995 to a private environmental consulting firm and has been re-bid every three to four years since to help meet the requirements of the federal Surface Water Treatment Rule for fecal coliform bacteria (USEPA 1989). The current WMP contract, with Henningson Durham & Richardson, requires staffing of up to 34 contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. It is intended to run through September 17, 2014.

7.1.7 Zebra Mussel Monitoring

DEP has been monitoring all 19 New York City reservoirs for the presence of zebra mussel larvae (veligers) and the settlement of mature zebra mussels since the early 1990s, via contract with a series of laboratories that have professional experience in identifying zebra mussels. All East of Hudson reservoirs are monitored on a monthly basis between May and October, while West of Hudson reservoirs are monitored in July and October of each year. The contract laboratory analyzes the samples and provides a monthly report to the project manager indicating whether or not zebra mussels have been detected. To date, no infestations have been found.

7.1.8 Bryozoan Monitoring

BryoTechnologies LLC, Ohio, was hired to perform a shoreline survey in August 2013 of biofouling invertebrate organisms in Kensico Reservoir, with a focus on *Pectinatella*. This brief survey represented a snapshot of conditions for two days in August. In other seasons the mix of species might be slightly different, and changes can also be expected from year to year. The August survey revealed six species of bryozoans and one species of sponge. One bryozoan, *Pectinatella magnifica*, has already been identified as a nuisance at the Kensico UV plant screens.

7.2 Water Research Foundation Project Participation by WQD in 2013

In 2013, two upper management personnel participated on WRF Advisory Councils. Mr. Paul Rush, P.E., is currently serving on the Focus Area Council (for a term that runs from 2012 to 2015) and Mr. Steven Schindler is serving on the Technical Advisory Council for Contaminants of Emerging Concern (CECs) in Drinking Water (for a term that runs from 2012 to 2017). As Council members, they serve an important role in identifying key needs of the water industry and guiding decisions on what areas of research to fund.

The WQD participated in the following WRF projects in 2013. The project abstracts can be found on the WRF website, http://www.waterrf.org.

WRF Project 4222 – Reservoir Operations and Maintenance Strategies

The WRF Project 4222—Reservoir Operations and Maintenance Strategies—will identify, compile, and describe (1) leading practices for lake and reservoir oxygenation/circulation techniques, (2) the use of rapid, or near-real-time, sensors and traditional water quality monitoring tools, and (3) the range of water quality models that are being used to guide operational decisions. The first of three state-of-the-industry reports was published in 2013. The objective of this report, titled “Water Quality Modeling to Aid Water Supply Reservoir Management”, was to provide, in a format comprehensible to water supply managers, background information on available models from literature and experience learned by the use of models in the water supply industry. Research partner: United Kingdom Water Industry Research.

WRF Project 4262 – Vulnerability Assessment and Risk Management Tools for Climate Change: Assessing Potential Impacts and Identifying Adaptation Options

The WRF Project 4262—Vulnerability Assessment and Risk Management Tools for Climate Change—was completed in 2013 and the final report, titled “A Framework for Assessing Climate Change Vulnerability and Defining Robust Risk Management Strategies for Water Utilities”, has been published by the WRF. Project collaborators included researchers from Stockholm Environment Institute, Rand Corporation, Hydrologics, Hazen and Sawyer, DEP, and the National Center for Atmospheric Research (NCAR). The project focused on the use of a quantitative, iterative, analytical framework called Robust Decision Making (RDM) to assess water supply systems’ vulnerability to climate change. Guidelines for application of RDM were provided by means of examples in two pilot studies, Colorado Springs Utilities and the New York City Water Supply. RDM was demonstrated to be an efficient tool for testing the sensitivity of water supply systems to climate change, and may prove useful in future studies of the effects of climate change on the NYC Water Supply. DEP provided data as a participating utility, and DEP modeling staff provided modeling support for the project.

WRF Project 4306 – Dynamic Reservoir Operations: Managing for Climate Variability and Change

The WRF Project 4306—Dynamic Reservoir Operations: Managing for Climate Variability and Change—was completed in 2013 and the final report has been published by the WRF. The project focused on the use of Dynamic Reservoir Operations (DRO) to improve system reliability, resilience, and performance under challenging climate conditions. DRO are operating rules that change based on properties of the present state of the system, such as storage levels, current inflow, and/or forecasted conditions. The project included a literature review; creation of a DRO development guide with step-by-step guidelines for developing effective rules; and case studies that included the Washington, D.C., Metropolitan Area, New York City, and the City of Calgary. The NYC case study focused on the use of dynamic hydrologic forecast-based rules. An assessment of the incremental effect of increasingly sophisticated forecasting techniques on performance measures under historical and climate-adjusted hydrology showed a substantial benefit from the use of forecasts. The DRO guide and case studies provide valuable guidance for application of DRO in future studies of the effects of climate change on the NYC Water Supply. DEP provided data as a participating utility, and DEP modeling staff provided modeling support for the project.

WRF Project 4382 – Impact of Climate Change on the Ecology of Algal Blooms

The WRF Project 4382—Impact of Climate Change on the Ecology of Algal Blooms—is nearing completion and a final draft is under review. The goal of this research was to determine how cyanobacterial risk may change with climate change. Different lakes may have different sensitivity to cyanobacteria and climate change, which may be a function of latitude, nutrient loading, and lake size. Further objectives were to determine the factors leading to cyanobacterial blooms, determine if these factors are common across all lake types and latitude, and predict how cyanobacteria risk may change using predictive coupled climate-hydrodynamic-biogeochemical models. This project will deliver five products for use by the water industry to predict and respond to the impacts of climate change on cyanobacteria:

1. A literature review of the key drivers of cyanobacterial blooms and how these are likely to vary with anticipated climate change scenarios.
2. An analysis of water bodies from North America, New Zealand, Europe, and Australia that span a range of latitudes, represent a range of lake sizes, and have different nutrient status.
3. A generalized model of lake/reservoir sensitivity to cyanobacteria and climate change.
4. Quantification of the possible risk, in terms of cyanobacterial biomass, that could be expected with climate and nutrient loading scenarios, documented in a table that uses correlations between biomass and the major threats from cyanobacteria: toxins, taste and odors, organic carbon.
5. Fact sheets that build on existing fact sheets, alert levels frameworks, and monitoring plans; a user friendly, web-based tool linked to a smart-phone application.

Ultimately, this research showed that an increase in cyanobacterial blooms is not inevitable with climate change. Reducing nutrients can offset increased algal primary production caused by temperature increases. Humans have committed to a significant increase in temperature and will take decades to achieve targeted reductions in greenhouse gases. As this is a global problem requiring a global response, water utilities and communities by themselves can do little to alter increasing temperatures. On the other hand, because nutrient control can occur at a local scale, communities have the power to control cyanobacteria locally, and thus maintain water quality for healthy human populations. DEP provided support for this project as a member of the Project Advisory Committee.

WRF Project 4387 – Development of a Water Utility Primer on EDCs/PPCPs for Public Outreach

The goal of WRF Project 4387—Development of a Water Utility Primer on EDCs/PPCPs for Public Outreach—is to distill and synthesize current information on endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs) into a primer, with supporting citations and communication materials, which drinking water utilities can use to inform and communicate with non-technical audiences. The primer will be a centralized up to date data source that can provide a landmark for future summaries of EDCs and PPCPs in water, as well as a reference source for further information. DEP provided support for this project as a member of the Project Advisory Committee.

WRF Project 4494 – Evaluation of current and alternative strategies for managing CECs in Water

The WRF Project 4494—Evaluation of current and alternative strategies for managing CECs in Water—will provide research that will aggregate and evaluate CEC management plans which have been employed or are being considered in North America, Europe, and Australia. Strengths and weaknesses of each approach will be identified, considering a holistic water approach that takes into account environmental and public health considerations. Alternative approaches that combine the best features of existing approaches will be considered as well. CEC management strategies will be prioritized to evaluate the costs and benefits of selected approaches in the form of a triple bottom line analysis. The research project consists of several expert workshops, including one already held in Europe to identify strategies being used or considered abroad, as well as workshops in the U.S. focusing on strategies in North America. Workshops will also develop alternative holistic management strategies and identify tools for the triple bottom line analyses. DEP is part of a WRF PAC that will provide project review and advice on WRF Project 4494.

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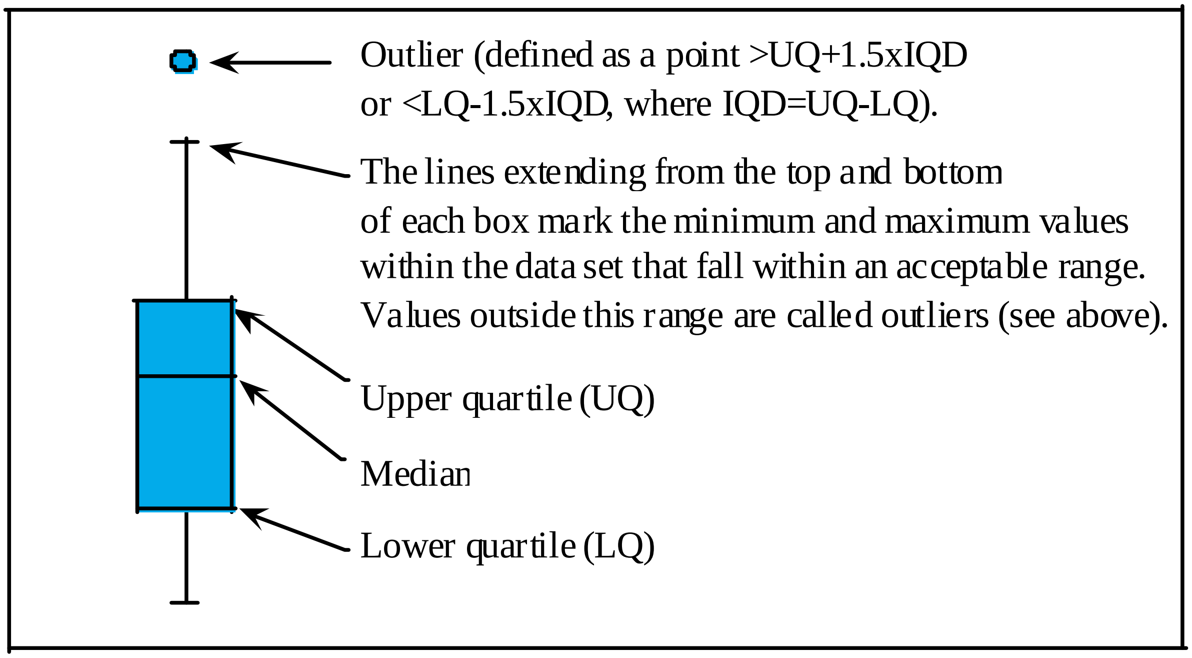
Appendix A. Key to Boxplots and Summary of Non-Detect Statistics Used in Data Analysis



Outlier (defined as a point >UQ+1.5xIQD or <LQ-1.5xIQD, where IQD=UQ-LQ).

The lines extending from the top and bottom of each box mark the minimum and maximum values within the data set that fall within an acceptable range. Values outside this range are called outliers (see above).

Upper quartile (UQ)

Median

Lower quartile (LQ)

Water quality data are often left-censored in that many analytical results occur below the instrument's detection limit. Substituting some value for the detection limit results, and then using parametric measures such as means and standard deviations, will often produce erroneous estimates. In this report we used the nonparametric Kaplan-Meier (K-M) method, described in Helsel (2005), to estimate summary statistics for analytes where left-censoring occurred (e.g., fecal and total coliforms, ammonia, nitrate, suspended solids). If a particular site had no censored values for a constituent, the summary statistics reported are the traditional mean and percentiles, not K-M estimates.

Appendix B. Monthly Coliform-Restricted Calculations for Total Coliform Counts on Non-Terminal Reservoirs

Appendix Table 1: Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20% of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (median, value not >20% of samples)	Collection date	n	Median total coliforms[2] (coliforms $100mL^{-1}$)	Percentage greater than standard
Amawalk	A (2400, 5000)	Apr-13	5	<20	0
Amawalk		May-13	5	25	0
Amawalk		Jun-13	5	110	0
Amawalk		Jul-13	5	<10	0
Amawalk		Aug-13	5	TNTC	0
Amawalk		Sep-13	5	<200	0
Amawalk		Oct-13	5	<50	0
Amawalk		Nov-13	5	<20	0
Bog Brook	AA (50, 240)	Apr-13	5	9	0
Bog Brook		May-13	5	110	20
Bog Brook		Jun-13	5	14	0
Bog Brook		Jul-13	5	<50	0
Bog Brook		Aug-13	5	<200	20
Bog Brook		Sep-13	5	<200	0
Bog Brook		Oct-13	5	<100	0
Bog Brook		Nov-13	5	<50	0
Boyd Corners	AA (50, 240)	Apr-13	6	<10	0
Boyd Corners		May-13	7	48	0
Boyd Corners		Jun-13	7	18	0
Boyd Corners		Jul-13	6	100	17
Boyd Corners		Aug-13	7	33	0
Boyd Corners		Sep-13	7	130	43
Boyd Corners		Oct-13	6	13	0
Boyd Corners		Nov-13	6	8	0
Croton Falls	A/AA (50, 240)	Apr-13	8	4	0
Croton Falls		May-13	8	8	0
Croton Falls		Jun-13	7	10	0
Croton Falls		Jul-13	8	9	0
Croton Falls		Aug-13	8	33	0
Croton Falls		Sep-13	8	250	50
Croton Falls		Oct-13	8	40	13
Croton Falls		Nov-13	8	17	0
Cross River	A/AA (50, 240)	Apr-13	6	5	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20% of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (median, value not >20% of samples)	Collection date	n	Median total coliforms[2] (coliforms $100mL^{-1}$)	Percentage greater than standard
Cross River		May-13	6	14	0
Cross River		Jun-13	6	100	0
Cross River		Jul-13	6	17	0
Cross River		Aug-13	6	<20	0
Cross River		Sep-13	6	33	0
Cross River		Oct-13	6	TNTC	17
Cross River		Nov-13	6	8	0
Diverting	AA (50, 240)	Apr-13	5	45	0
Diverting		May-13	5	130	40
Diverting		Jun-13	5	100	20
Diverting		Jul-13	5	TNTC	40
Diverting		Aug-13	5	83	20
Diverting		Sep-13	5	420	60
Diverting		Oct-13	5	40	0
Diverting		Nov-13	5	TNTC	0
East Branch	AA (50, 240)	Apr-13	6	<10	0
East Branch		May-13	6	350	67
East Branch		Jun-13	6	14	0
East Branch		Jul-13	6	TNTC	0
East Branch		Aug-13	6	<50	0
East Branch		Sep-13	5	80	0
East Branch		Oct-13	5	14	0
East Branch		Nov-13	5	<20	0
Lake Gilead	A (2400, 5000)	Apr-13	5	<5	0
Lake Gilead		May-13	5	5	0
Lake Gilead		Jun-13	5	27	0
Lake Gilead		Jul-13	5	<10	0
Lake Gilead		Aug-13	5	9	0
Lake Gilead		Sep-13	5	<100	0
Lake Gilead		Oct-13	5	<20	0
Lake Gilead		Nov-13	5	4	0
Lake Gleneida	AA (50, 240)	Apr-13	5	<5	0
Lake Gleneida		May-13	5	<5	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20% of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (median, value not >20% of samples)	Collection date	n	Median total coliforms[2] (coliforms 100mL^{-1})	Percentage greater than standard
Lake Gleneida		Jun-13	5	18	0
Lake Gleneida		Jul-13	5	<10	0
Lake Gleneida		Aug-13	5	<10	0
Lake Gleneida		Sep-13	5	<100	0
Lake Gleneida		Oct-13	5	<20	0
Lake Gleneida		Nov-13	5	4	0
Kirk Lake	B (2400, 5000)	Apr-13	5	10	0
Kirk Lake		May-13	5	29	0
Kirk Lake		Jun-13	5	27	0
Kirk Lake		Jul-13	5	27	0
Kirk Lake		Aug-13	5	100	0
Kirk Lake		Sep-13	5	750	0
Kirk Lake		Oct-13	5	<100	0
Kirk Lake		Nov-13	5	43	0
Muscoot	A (2400, 5000)	Apr-13	7	<10	0
Muscoot		May-13	7	25	0
Muscoot		Jun-13	6	130	0
Muscoot		Jul-13	5	170	0
Muscoot		Aug-13	6	1300	0
Muscoot		Sep-13	6	<100	0
Muscoot		Oct-13	7	73	0
Muscoot		Nov-13	6	36	0
Middle Branch	A (2400, 5000)	Apr-13	5	<10	0
Middle Branch		May-13	5	8	0
Middle Branch		Jun-13	5	25	0
Middle Branch		Jul-13	5	<50	0
Middle Branch		Aug-13	5	<200	0
Middle Branch		Sep-13	5	120	0
Middle Branch		Oct-13	5	40	0
Middle Branch		Nov-13	5	17	0
Titicus	AA (50, 240)	Apr-13	5	<10	0
Titicus		May-13	5	17	0
Titicus		Jun-13	5	75	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20% of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (median, value not >20% of samples)	Collection date	n	Median total coliforms[2] (coliforms 100mL^{-1})	Percentage greater than standard
Titicus		Jul-13	5	17	0
Titicus		Aug-13	5	TNTC	40
Titicus		Sep-13	5	<200	0
Titicus		Oct-13	5	33	0
Titicus		Nov-13	5	14	0
Pepacton	A/AA (50, 240)	Apr-13	16	1	0
Pepacton		May-13	16	4	0
Pepacton		Jun-13	16	8	0
Pepacton		Jul-13	16	<10	0
Pepacton		Aug-13	15	2	0
Pepacton		Sep-13	15	10	0
Pepacton		Oct-13	14	2	0
Pepacton		Nov-13	14	5	0
Neversink	AA (50, 240)	Apr-13	13	1	0
Neversink		May-13	13	<1	0
Neversink		Jun-13	13	20	0
Neversink		Jul-13	13	4	0
Neversink		Aug-13	12	15	0
Neversink		Sep-13	12	5	0
Neversink		Oct-13	11	4	0
Neversink		Nov-13	11	8	0
Schoharie	AA (50, 240)	Apr-13	11	42	0
Schoharie		May-13	11	20	0
Schoharie		Jun-13	12	450	50
Schoharie		Jul-13	11	1600	100
Schoharie		Aug-13	11	700	100
Schoharie		Sep-13	11	1600	100
Schoharie		Oct-13	11	200	45
Schoharie		Nov-13	11	27	0
Cannonsville	A/AA (50, 240)	Apr -13	15	1	0
Cannonsville		May-13	15	4	0
Cannonsville		Jun-13	15	4	0
Cannonsville		Jul-13	15	20	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20% of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (median, value not >20% of samples)	Collection date	n	Median total coliforms[2] (coliforms $100mL^{-1}$)	Percentage greater than standard
Cannonsville		Aug-13	15	3	20
Cannonsville		Sep-13	14	100	14
Cannonsville		Oct-13	14	10	0
Cannonsville		Nov-13	13	20	8
Cannonsville		Dec-13	9	260	44

[1] The reservoir class is defined by 6 NYCRR Chapter X, Subchapter B. For those reservoirs that have dual designations, the more stringent standard was applied.

[2] The median could not be estimated for samples determined to be “Too Numerous To Count” (TNTC).

Appendix C. Phosphorus-Restricted Basin Assessment Methodology

A phosphorus-restricted basin is defined in the New York City Watershed Regulations, amended April 4, 2010, as “(i) the drainage basin of a source water reservoir in which the phosphorus load to the reservoir results in the phosphorus concentration in the reservoir exceeding 15 micrograms per liter, or (ii) the drainage basin of a reservoir other than a source water reservoir or of a controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus concentration in the reservoir or controlled lake exceeding 20 micrograms per liter in both instances as determined by the Department pursuant to its annual review conducted under §18-48 (e) of Subchapter D” (DEP 2010). The phosphorus-restricted designation prohibits new or expanded wastewater treatment plants with surface discharges in the reservoir basin. The list of phosphorus-restricted basins is updated annually in the Watershed Water Quality Annual Report.

A summary of the methodology used in the phosphorus-restricted analysis will be given here; the complete description can be found in A Methodology for Determining Phosphorus Restricted Basins (DEP 1997). The data utilized in the analysis are from the routine limnological monitoring of the reservoirs during the growing season, which is defined as May 1 through October 31. Any recorded concentration below the analytical limit of detection is set equal to half the detection limit to conform to earlier analyses following the prescribed methodology. The detection limit for DEP measurements of total phosphorus is assessed each year by the DEP laboratories, and typically ranges between 2 and 5 $\mu g\ L^{-1}$. The phosphorus concentration data for the reservoirs approach a lognormal distribution; therefore, a geometric mean is used to characterize the annual phosphorus concentrations. Appendix Table 2 provides the annual geometric mean for the past six years.

The five most recent annual geometric means are averaged arithmetically, and this average constitutes one assessment. This “running average” method weights each year equally, reducing the effects of unusual hydrological events or phosphorus loading, while maintaining an accurate assessment of the current conditions in the reservoir. Should any reservoir have less than three surveys during a growing season, the annual average may or may not be representative of the reservoir, and the data for the undersampled year are removed from the analysis. In addition, each five-year assessment must incorporate at least three years of data.

To provide some statistical assurance that the five-year arithmetic mean is representative of a basin’s phosphorus status, given the interannual variability, the five-year mean plus the standard error of the five-year mean is compared to the NYS guidance value of 20 $\mu g\ L^{-1}$ (15 $\mu g\ L^{-1}$ for potential source waters). A basin is considered **unrestricted** if the five-year mean plus standard error is below the guidance value of 20 $\mu g\ L^{-1}$ (15 $\mu g\ L^{-1}$ for potential source waters). A basin is considered phosphorus **restricted** if the five-year mean plus standard error is equal to or greater than 20 µg L^{-1} (15 µg L^{-1} for potential source waters), unless the Department, using its best professional judgment, determines that the phosphorus-restricted designation is due to an unusual and unpredictable event unlikely to occur in the future. A reservoir basin designation, as phosphorus restricted or unrestricted, may change through time based on the outcome of this annual assessment. However, a basin must have two consecutive assessments (i.e., two years in a row) that result in the new designation in order to officially change the designation.

Appendix Table 2: Geometric mean total phosphorus data utilized in the phosphorus-restricted assessments. All reservoir samples taken during the growing season (May 1 through October 31) are used.

Reservoir	2008 µg L^{-1}	2009 µg L^{-1}	2010 µg L^{-1}	2011 µg L^{-1}	2012 µg L^{-1}	2013 µg L^{-1}
Non-Source Waters (Delaware System)						
Cannonsville	13.5	14.0	16.4	16.3	12.4	15.0
Pepacton	8.2	7.6	9.9	11.9	8.4	7.9
Neversink	4.7	5.9	6.5	10.2	9.7	6.0
Non-Source Waters (Catskill System)						
Schoharie	9.5	11.2	13.4	29.4	20.0	15.0
Non-Source Waters (Croton System)						
Amawalk	17.9	19.4	20.5	18.3	22.3	22.3
Bog Brook	21.5	22.8	31.1	23.6	27.9	20.0
Boyd Corners	11.6	8.6	8.4	8.7	10.1	10.7
Diverting	22.7	*	29.1	31.1	26.8	29.5
East Branch	21.6	26.1	33.8	32.3	28.5	27.5
Middle Branch	27.9	22.4	25.5	29.8	37.6	32.5
Muscoot	27.6	24.9	28.7	28.8	31.5	29.9
Titicus	17.5	20.8	26.4	26.9	24.4	24.4
Lake Gleneida	*	22.7	25.9	31.9	25.1	22.2
Lake Gilead	*	36.0	30.1	28.9	16.4	26.7
Kirk Lake	*	31.4	27.6	33.1	34.6	24.9
Source Waters (all systems)						
Ashokan-West	7.2	8.6	12.9	31.0	10.2	7.3
Ashokan-East	7.6	9.5	9.8	13.5	8.4	6.4
Cross River	13.8	13.8	15.4	18.7	17.0	15.4
Croton Falls	14.4	14.7	13.3	20.6	18.7	23.0

Appendix Table 2: (Continued) Geometric mean total phosphorus data utilized in the phosphorus-restricted assessments. All reservoir samples taken during the growing season (May 1 through October 31) are used.

Reservoir	2008 µg L^{-1}	2009 µg L^{-1}	2010 µg L^{-1}	2011 µg L^{-1}	2012 µg L^{-1}	2013 µg L^{-1}
Kensico	6.4	5.8	6.6	7.5	6.4	6.2
New Croton	15.5	14.4	15.7	18.2	18.7	17.0
Rondout	6.1	8.1	8.0	8.9	7.2	7.2
West Branch	9.2	9.6	9.4	11.1	11.8	12.6

* Indicates less than three successful surveys during the growing season (May-October).

Appendix D. Comparison of Reservoir Water Quality Results to Benchmarks

Appendix Table 3: Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean^1
Kensico Reservoir						
Alkalinity (mg CaCO$_3$ L^{-1})		24			>10	13
Chloride (mg L^{-1})	12	24	0	0	8	8.6
Chlorophyll *a* (µg L^{-1})	12	64	1	2	7	3.8
Color (Pt-Co units)	15	199	8	4	na	na
Dissolved organic carbon (mg L^{-1})^2	4.0	199	0	0	3	1.7
Fecal coliforms (coliforms 100 mL^{-1})	20	199	11	6	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	199	0	0	0.3	0.17*
pH (units)	6.5-8.5	199	28	14	na	na
Sodium, undig., filt. (mg L^{-1})	16	22	22	100	3	5.3
Soluble reactive phosphorus (µg L^{-1})	15	200	0	0	na	na
Sulfate (mg L^{-1})	15	24	0	0	10	4.9
Total ammonia-N (mg L^{-1})	0.10	200	0	0	0.05	0.02*
Total dissolved phosphorus (µg L^{-1})	15	199	0	0	na	na
Total dissolved solids (mg L^{-1})^3	50	199	30	15	40	46
Total phosphorus (µg L^{-1})	15	199	0	0	na	na
Total phytoplankton (ASU)	2000	96	0	0	na	na
Primary genus (ASU)	1000	96	0	0	na	na
Secondary genus (ASU)	1000	96	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	80	0	0	5	1.2*
Turbidity (NTU)	5	199	0	0	na	na
Amawalk Reservoir						
Alkalinity (mg CaCO$_3$ L^{-1})		9			>40	87
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (µg L^{-1})	15	16	2	13	10	9.2
Color (Pt-Co units)	15	40	40	100	na	na
Dissolved organic carbon (mg L^{-1})^2	7.0	0			6	

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Fecal coliforms (coliforms 100 mL^{-1})	20	40	2	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	7	18	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	40	40	100	150	312
Total phosphorus (µg L^{-1})	15	43	35	81	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	0	0	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.6
Turbidity (NTU)	5	40	2	5	na	na
Bog Brook Reservoir						
Alkalinity (mg CaCO$_3$ L^{-1})		6			>40	78
Chloride (mg L^{-1})	40	6	6	100	30	46.7
Chlorophyll *a* (µg L^{-1})	15	8	1	13	10	7.5
Color (Pt-Co units)	15	18	16	89	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	18	0	0	6	3.7
Fecal coliforms (coliforms 100 mL^{-1})	20	40	1	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	18	0	0	0.3	0.02*
pH (units)	6.5-8.5	40	4	10	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	25.1
Soluble reactive phosphorus (µg L^{-1})	15	18	0	0	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	7.6

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total ammonia-N (mg L^{-1})	0.10	18	4	22	0.05	0.08*
Total dissolved phosphorus (µg L^{-1})	15	18	1	6	na	na
Total dissolved solids (mg L^{-1})[3]	175	18	18	100	150	209
Total phosphorus (µg L^{-1})	15	18	15	83	na	na
Total phytoplankton (ASU)	2000	8	0	0	na	na
Primary genus (ASU)	1000	8	0	0	na	na
Secondary genus (ASU)	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	2.2
Turbidity (NTU)	5	18	0	0	na	na
Boyd Corners Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		8			>40	36
Chloride (mg L^{-1})	40	8	0	0	30	32.7
Chlorophyll *a* (µg L^{-1})	15	8	0	0	10	4.1
Color (Pt-Co units)	15	21	21	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	21	0	0	6	3.4
Fecal coliforms (coliforms 100 mL^{-1})	20	52	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	21	0	0	0.3	0.06*
pH (units)	6.5-8.5	52	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	8	8	100	15	20.6
Soluble reactive phosphorus (µg L^{-1})	15	21	0	0	na	na
Sulfate (mg L^{-1})	25	8	0	0	15	6.7
Total ammonia-N (mg L^{-1})	0.10	21	1	5	0.05	0.03*
Total dissolved phosphorus (µg L^{-1})	15	21	1	5	na	na
Total dissolved solids (mg L^{-1})[3]	175	21	0	0	150	126
Total phosphorus (µg L^{-1})	15	21	1	5	na	na
Total phytoplankton (ASU)	2000	8	0	0	na	na
Primary genus (ASU)	1000	8	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Secondary genus (ASU)	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	8	0	0	5	1.2*
Turbidity (NTU)	5	21	0	0	na	na
Croton Falls Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		18			>40	73
Chloride (mg L^{-1})	40	18	18	100	30	60.9
Chlorophyll *a* (µg L^{-1})	15	21	6	29	10	16
Color (Pt-Co units)	15	64	62	97	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	64	0	0	6	3.5
Fecal coliforms (coliforms 100 mL^{-1})	20	63	2	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	8	13	0.3	0.23*
pH (units)	6.5-8.5	48	9	19	na	na
Sodium, undig., filt. (mg L^{-1})	20	18	18	100	15	35.2
Soluble reactive phosphorus (µg L^{-1})	15	65	1	2	na	na
Sulfate (mg L^{-1})	25	18	0	0	15	9.7
Total ammonia-N (mg L^{-1})	0.10	60	6	10	0.05	0.06*
Total dissolved phosphorus (µg L^{-1})	15	64	3	5	na	na
Total dissolved solids (mg L^{-1})[3]	175	64	64	100	150	266
Total phosphorus (µg L^{-1})	15	64	56	88	na	na
Total phytoplankton (ASU)	2000	24	6	25	na	na
Primary genus (ASU)	1000	24	8	33	na	na
Secondary genus (ASU)	1000	24	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.4*
Turbidity (NTU)	5	64	15	23	na	na
Cross River Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		9			>40	50
Chloride (mg L^{-1})	40	9	0	0	30	31.1

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Chlorophyll *a* (µg L^{-1})	15	16	1	6	10	8.6
Color (Pt-Co units)	15	48	47	98	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	48	0	0	6	3.4
Fecal coliforms (coliforms 100 mL^{-1})	20	48	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	48	0	0	0.3	0.07*
pH (units)	6.5-8.5	48	10	21	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	17.3
Soluble reactive phosphorus (µg L^{-1})	15	48	0	0	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	8.2
Total ammonia-N (mg L^{-1})	0.10	48	9	19	0.05	0.06*
Total dissolved phosphorus (µg L^{-1})	15	48	1	2	na	na
Total dissolved solids (mg L^{-1})[3]	175	48	0	0	150	140
Total phosphorus (µg L^{-1})	15	48	31	65	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	0	0	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.3
Turbidity (NTU)	5	48	1	2	na	na
Diverting Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		6			>40	86
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (µg L^{-1})	15	16	6	38	10	11.9
Color (Pt-Co units)	15	24	24	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliforms 100 mL^{-1})	20	40	8	20	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	37	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	24	22	92	150	218
Total phosphorus (µg L^{-1})	15	24	24	100	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	0	0	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	3.1
Turbidity (NTU)	5	24	1	4	na	na
East Branch Reservoir						
Alkalinity (mg CaCO$_3$ L^{-1})		8			>40	88
Chloride (mg L^{-1})	40	8	4	50	30	40.9
Chlorophyll *a* (µg L^{-1})	15	8	2	25	10	14
Color (Pt-Co units)	15	22	21	95	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	22	0	0	6	4.2
Fecal coliforms (coliforms 100 mL^{-1})	20	45	4	9	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	22	0	0	0.3	0.03*
pH (units)	6.5-8.5	45	2	4	na	na
Sodium, undig., filt. (mg L^{-1})	20	7	7	100	15	24.3
Soluble reactive phosphorus (µg L^{-1})	15	22	0	0	na	na
Sulfate (mg L^{-1})	25	8	0	0	15	7.6
Total ammonia-N (mg L^{-1})	0.10	22	2	9	0.05	0.04*
Total dissolved phosphorus (µg L^{-1})	15	22	3	14	na	na
Total dissolved solids (mg L^{-1})[3]	175	22	19	86	150	202

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total phosphorus (µg L^{-1})	15	22	21	95	na	na
Total phytoplankton (ASU)	2000	8	0	0	na	na
Primary genus (ASU)	1000	8	1	13	na	na
Secondary genus (ASU)	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	8	0	0	5	2.6
Turbidity (NTU)	5	22	0	0	na	na
Lake Gilead						
Alkalinity (mg $CaCO_3$ L^{-1})		9			>40	44
Chloride (mg L^{-1})	40	9	9	100	30	43.5
Chlorophyll *a* (µg L^{-1})	15	3	0	0	10	6.7
Color (Pt-Co units)	15	9	2	22	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	3
Fecal coliforms (coliforms 100 mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	0.02*
pH (units)	6.5-8.5	10	1	10	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	43.2
Soluble reactive phosphorus (µg L^{-1})	15	9	3	33	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7.4
Total ammonia-N (mg L^{-1})	0.10	9	3	33	0.05	0.26*
Total dissolved phosphorus (µg L^{-1})	15	9	3	33	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	0	0	150	161
Total phosphorus (µg L^{-1})	15	9	6	67	na	na
Total phytoplankton (ASU)	2000	3	0	0	na	na
Primary genus (ASU)	1000	3	0	0	na	na
Secondary genus (ASU)	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.6*
Turbidity (NTU)	5	9	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Lake Gleneida						
Alkalinity (mg $CaCO_3$ L^{-1})		9			>40	69
Chloride (mg L^{-1})	40	9	9	100	30	98.8
Chlorophyll *a* (µg L^{-1})	15	3	0	0	10	6.5
Color (Pt-Co units)	15	9	2	22	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	2.9
Fecal coliforms (coliforms 100 mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	
pH (units)	6.5-8.5	10	1	10	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	32.9
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7
Total ammonia-N (mg L^{-1})	0.10	9	2	22	0.05	0.15*
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	9	100	150	309
Total phosphorus (µg L^{-1})	15	9	4	44	na	na
Total phytoplankton (ASU)	2000	3	0	0	na	na
Primary genus (ASU)	1000	3	0	0	na	na
Secondary genus (ASU)	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.7*
Turbidity (NTU)	5	9	0	0	na	na
Kirk Lake						
Alkalinity (mg $CaCO_3$ L^{-1})		3			>40	62
Chloride (mg L^{-1})	40	3	3	100	30	61.1
Chlorophyll *a* (µg L^{-1})	15	3	2	67	10	18.4
Color (Pt-Co units)	15	3	2	67	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	3	0	0	6	4.5

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Fecal coliforms (coliforms 100 mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	3	0	0	0.3	0.02*
pH (units)	6.5-8.5	10	2	20	na	na
Sodium, undig., filt. (mg L^{-1})	20	3	3	100	15	32.8
Soluble reactive phosphorus (µg L^{-1})	15	3	0	0	na	na
Sulfate (mg L^{-1})	25	3	0	0	15	8.7
Total ammonia-N (mg L^{-1})	0.10	3	1	33	0.05	0.13*
Total dissolved phosphorus (µg L^{-1})	15	3	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	223
Total phosphorus (µg L^{-1})	15	3	3	100	na	na
Total phytoplankton (ASU)	2000	3	1	33	na	na
Primary genus (ASU)	1000	3	1	33	na	na
Secondary genus (ASU)	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	3	0	0	5	4.4*
Turbidity (NTU)	5	3	1	33	na	na
Muscoot Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		6			>40	88
Chloride (mg L^{-1})	40	6	6	100	30	67.9
Chlorophyll *a* (µg L^{-1})	15	25	9	36	10	14.8
Color (Pt-Co units)	15	50	50	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	50	0	0	6	3.8
Fecal coliforms (coliforms 100 mL^{-1})	20	50	3	6	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	50	6	12	0.3	0.21*
pH (units)	6.5-8.5	50	2	4	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	37.6
Soluble reactive phosphorus (µg L^{-1})	15	50	2	4	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	8.9

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total ammonia-N (mg L^{-1})	0.10	50	11	22	0.05	0.16*
Total dissolved phosphorus (μg L^{-1})	15	50	3	6	na	na
Total dissolved solids (mg L^{-1})[3]	175	50	50	100	150	256
Total phosphorus (μg L^{-1})	15	50	50	100	na	na
Total phytoplankton (ASU)	2000	29	2	7	na	na
Primary genus (ASU)	1000	29	0	0	na	na
Secondary genus (ASU)	1000	29	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	4.7
Turbidity (NTU)	5	50	6	12	na	na
Middle Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		12			>40	67
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (μg L^{-1})	15	16	10	63	10	15.7
Color (Pt-Co units)	15	40	40	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliforms 100 mL^{-1})	20	40	2	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	3	8	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (μg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (μg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	40	40	100	150	271
Total phosphorus (μg L^{-1})	15	40	40	100	na	na
Total phytoplankton (ASU)	2000	16	1	6	na	na
Primary genus (ASU)	1000	16	2	13	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	10	0	0	5	3*
Turbidity (NTU)	5	40	4	10	na	na
New Croton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		30			>40	73
Chloride (mg L^{-1})	40	30	30	100	30	63.6
Chlorophyll *a* (µg L^{-1})	15	56	6	11	10	10.8
Color (Pt-Co units)	15	167	161	96	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	167	0	0	6	3.3
Fecal coliforms (coliforms 100 mL^{-1})	20	167	4	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	167	15	9	0.3	0.21*
pH (units)	6.5-8.5	154	18	12	na	na
Sodium, undig., filt. (mg L^{-1})	20	30	30	100	15	36.2
Soluble reactive phosphorus (µg L^{-1})	15	169	3	2	na	na
Sulfate (mg L^{-1})	25	30	0	0	15	10.3
Total ammonia-N (mg L^{-1})	0.10	166	35	21	0.05	0.09*
Total dissolved phosphorus (µg L^{-1})	15	173	12	7	na	na
Total dissolved solids (mg L^{-1})[3]	175	167	167	100	150	242
Total phosphorus (µg L^{-1})	15	167	93	56	na	na
Total phytoplankton (ASU)	2000	64	1	2	na	na
Primary genus (ASU)	1000	64	2	3	na	na
Secondary genus (ASU)	1000	64	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	77	0	0	5	1.6*
Turbidity (NTU)	5	167	7	4	na	na
Titicus Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		9			>40	77
Chloride (mg L^{-1})	40	0			30	

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Chlorophyll *a* (µg L^{-1})	15	16	2	13	10	10
Color (Pt-Co units)	15	34	34	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliforms 100 mL^{-1})	20	39	1	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	5	13	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	34	25	74	150	181
Total phosphorus (µg L^{-1})	15	34	29	85	na	na
Total phytoplankton (ASU)	2000	16	1	6	na	na
Primary genus (ASU)	1000	16	1	6	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.1*
Turbidity (NTU)	5	34	5	15	na	na
West Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		13			>10	28
Chloride (mg L^{-1})	12	13	13	100	8	21.9
Chlorophyll *a* (µg L^{-1})	12	32	6	19	7	9.3
Color (Pt-Co units)	15	65	56	86	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	65	0	0	3	2.5
Fecal coliforms (coliforms 100 mL^{-1})	20	65	1	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	65	0	0	0.3	0.04*
pH (units)	6.5-8.5	65	3	5	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Sodium, undig., filt. (mg L^{-1})	16	13	13	100	3	13.7
Soluble reactive phosphorus (µg L^{-1})	15	65	0	0	na	na
Sulfate (mg L^{-1})	15	13	0	0	10	6
Total ammonia-N (mg L^{-1})	0.10	65	3	5	0.05	0.03*
Total dissolved phosphorus (µg L^{-1})	15	65	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	65	65	100	40	88
Total phosphorus (µg L^{-1})	15	65	20	31	na	na
Total phytoplankton (ASU)	2000	42	0	0	na	na
Primary genus (ASU)	1000	42	1	2	na	na
Secondary genus (ASU)	1000	42	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	7	0	0	5	1.6*
Turbidity (NTU)	5	65	1	2	na	na
Ashokan East Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		9			>10	13
Chloride (mg L^{-1})	12	9	0	0	8	5.2
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	2.7
Color (Pt-Co units)	15	64	6	9	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	64	0	0	3	1.5
Fecal coliforms (coliforms 100 mL^{-1})	20	64	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	0	0	0.3	0.07*
pH (units)	6.5-8.5	64	16	25	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	3.5
Soluble reactive phosphorus (µg L^{-1})	15	64	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.10	64	0	0	0.05	0.02*
Total dissolved phosphorus (µg L^{-1})	15	64	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	64	0	0	40	35

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total phosphorus (µg L^{-1})	15	64	1	2	na	na
Total phytoplankton (ASU)	2000	43	0	0	na	na
Primary genus (ASU)	1000	43	0	0	na	na
Secondary genus (ASU)	1000	43	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	64	0	0	5	2.2*
Turbidity (NTU)	5	64	8	13	na	na
Ashokan West Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		12			>10	13
Chloride (mg L^{-1})	12	12	0	0	8	5.8
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	2.8
Color (Pt-Co units)	15	78	11	14	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	78	0	0	3	1.4
Fecal coliforms (coliforms 100 mL^{-1})	20	78	3	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	78	0	0	0.3	0.17*
pH (units)	6.5-8.5	78	12	15	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	3.7
Soluble reactive phosphorus (µg L^{-1})	15	78	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.7
Total ammonia-N (mg L^{-1})	0.10	78	0	0	0.05	0.02*
Total dissolved phosphorus (µg L^{-1})	15	78	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	78	0	0	40	36
Total phosphorus (µg L^{-1})	15	78	2	3	na	na
Total phytoplankton (ASU)	2000	41	0	0	na	na
Primary genus (ASU)	1000	41	0	0	na	na
Secondary genus (ASU)	1000	41	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	78	5	6	5	4*
Turbidity (NTU)	5	78	50	64	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Pepacton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		20			>10	14
Chloride (mg L^{-1})	12	20	0	0	8	6.3
Chlorophyll *a* (µg L^{-1})	12	40	1	3	7	4
Color (Pt-Co units)	15	122	9	7	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	122	0	0	3	1.6
Fecal coliforms (coliforms 100 mL^{-1})	20	122	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	121	0	0	0.3	0.15*
pH (units)	6.5-8.5	121	27	22	na	na
Sodium, undig., filt. (mg L^{-1})	16	21	21	100	3	4.1
Soluble reactive phosphorus (µg L^{-1})	15	121	1	1	na	na
Sulfate (mg L^{-1})	15	20	0	0	10	4.4
Total ammonia-N (mg L^{-1})	0.10	122	0	0	0.05	0.02*
Total dissolved phosphorus (µg L^{-1})	15	122	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	122	0	0	40	41
Total phosphorus (µg L^{-1})	15	122	12	10	na	na
Total phytoplankton (ASU)	2000	60	1	2	na	na
Primary genus (ASU)	1000	60	2	3	na	na
Secondary genus (ASU)	1000	60	1	2	na	na
Total suspended solids (mg L^{-1})	8.0	60	0	0	5	1.2*
Turbidity (NTU)	5	122	1	1	na	na
Neversink Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		11			>10	3
Chloride (mg L^{-1})	12	11	0	0	8	3
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	3.1
Color (Pt-Co units)	15	98	46	47	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	74	0	0	3	1.9

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Fecal coliforms (coliforms 100 mL^{-1})	20	98	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	74	0	0	0.3	0.18*
pH (units)	6.5-8.5	98	70	71	na	na
Sodium, undig., filt. (mg L^{-1})	16	11	0	0	3	1.9
Soluble reactive phosphorus (µg L^{-1})	15	74	0	0	na	na
Sulfate (mg L^{-1})	15	11	0	0	10	3.1
Total ammonia-N (mg L^{-1})	0.10	74	0	0	0.05	0.02*
Total dissolved phosphorus (µg L^{-1})	15	74	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	98	0	0	40	19
Total phosphorus (µg L^{-1})	15	74	0	0	na	na
Total phytoplankton (ASU)	2000	48	0	0	na	na
Primary genus (ASU)	1000	48	1	2	na	na
Secondary genus (ASU)	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	24	0	0	5	1.5*
Turbidity (NTU)	5	98	4	4	na	na
Rondout Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		12			>10	11
Chloride (mg L^{-1})	12	12	0	0	8	6.9
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	4
Color (Pt-Co units)	15	80	2	3	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.8
Fecal coliforms (coliforms 100 mL^{-1})	20	80	3	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	56	0	0	0.3	0.2*
pH (units)	6.5-8.5	80	13	16	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	4.4
Soluble reactive phosphorus (µg L^{-1})	15	56	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	4.5

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total ammonia-N (mg L^{-1})	0.10	57	0	0	0.05	0.02*
Total dissolved phosphorus (µg L^{-1})	15	56	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	80	0	0	40	39
Total phosphorus (µg L^{-1})	15	80	0	0	na	na
Total phytoplankton (ASU)	2000	47	1	2	na	na
Primary genus (ASU)	1000	47	2	4	na	na
Secondary genus (ASU)	1000	47	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	32	0	0	5	1.1*
Turbidity (NTU)	5	80	0	0	na	na
Schoharie Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		9			>10	19
Chloride (mg L^{-1})	12	9	0	0	8	7.7
Chlorophyll *a* (µg L^{-1})	12	30	0	0	7	2.3
Color (Pt-Co units)	15	73	45	62	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	89	0	0	3	2
Fecal coliforms (coliforms 100 mL^{-1})	20	89	18	20	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	65	0	0	0.3	0.15*
pH (units)	6.5-8.5	78	2	3	na	na
Sodium, undig., filt. (mg L^{-1})	16	6	6	100	3	5.2
Soluble reactive phosphorus (µg L^{-1})	15	65	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.10	65	1	2	0.05	0.02*
Total dissolved phosphorus (µg L^{-1})	15	65	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	89	37	42	40	49
Total phosphorus (µg L^{-1})	15	89	44	49	na	na
Total phytoplankton (ASU)	2000	48	0	0	na	na
Primary genus (ASU)	1000	48	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Secondary genus (ASU)	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	89	25	28	5	8.2
Turbidity (NTU)	5	89	70	79	na	na
Cannonsville Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})		17			>10	17
Chloride (mg L^{-1})	12	17	0	0	8	10.3
Chlorophyll *a* (µg L^{-1})	12	40	8	20	7	8
Color (Pt-Co units)	15	116	49	42	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	115	0	0	3	2
Fecal coliforms (coliforms 100 mL^{-1})	20	116	11	9	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	116	9	8	0.3	0.29*
pH (units)	6.5-8.5	116	22	19	na	na
Sodium, undig., filt. (mg L^{-1})	16	17	17	100	3	7
Soluble reactive phosphorus (µg L^{-1})	15	116	0	0	na	na
Sulfate (mg L^{-1})	15	17	0	0	10	5.3
Total ammonia-N (mg L^{-1})	0.10	116	1	1	0.05	0.03*
Total dissolved phosphorus (µg L^{-1})	15	116	3	3	na	na
Total dissolved solids (mg L^{-1})[3]	50	116	114	98	40	57
Total phosphorus (µg L^{-1})	15	115	65	57	na	na
Total phytoplankton (ASU)	2000	55	4	7	na	na
Primary genus (ASU)	1000	55	7	13	na	na
Secondary genus (ASU)	1000	55	2	4	na	na
Total suspended solids (mg L^{-1})	8.0	47	0	0	5	2.1*
Turbidity (NTU)	5	116	12	10	na	na

[1] Due to the occurrence of nondetects, means designated by * were estimated using the Kaplan-Meier Method as described in Helsel (2005). All other means are arithmetic means.

[2] Dissolved organic carbon replaced total organic carbon in 2000. In New York City reservoirs, the dissolved portion comprises the majority of the total organic carbon.

[3] Total dissolved solids estimated from specific conductivity according to the USGS in van der Leeden et al. (1990).

Appendix E. Comparison of Stream Water Quality Results to Benchmarks

Appendix Table 4. Comparison of stream water quality results to benchmarks.
na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
E10I (Bushkill inflow to Ashokan)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	9	75	na	8.0
Chloride (mg L^{-1})	50	12	0	0	10	2.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	0.8
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.11
Sulfate (mg L^{-1})	15	4	0	0	10	3.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	23
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.7
E16I (Esopus Creek at Coldbrook)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	11	0	0	na	16.2
Chloride (mg L^{-1})	50	12	0	0	10	6.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.18
Sulfate (mg L^{-1})	15	4	0	0	10	3.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	4	33	40	43
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.3
E5 (Esopus Creek at Allaben)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	7	58	na	11.1
Chloride (mg L^{-1})	50	12	0	0	10	4.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.16
Sulfate (mg L^{-1})	15	4	0	0	10	3.7
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	1	8	40	32
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.8
S5I (Schoharie Creek at Prattsville)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	19.3
Chloride (mg L^{-1})	50	12	0	0	10	9.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.6

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks.
na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.21
Sulfate (mg L^{-1})	15	3	0	0	10	4.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	7	58	40	55
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.5
S6I (Bear Kill at Hardenburgh Falls)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	11	0	0	na	26.6
Chloride (mg L^{-1})	50	11	0	0	10	16.0
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	2.5
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.27
Sulfate (mg L^{-1})	15	3	0	0	10	5.8
Total ammonia-N (mg L^{-1})	0.20	11	0	0	0.05	0.03
Total dissolved solids (mg L^{-1})[2]	50	11	11	100	40	81
Dissolved sodium (mg L^{-1})	10	3	3	100	5	11.4
S7I (Manor Kill)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	25.9
Chloride (mg L^{-1})	50	12	0	0	10	7.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.16
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	9	75	40	60
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.3
SRR2CM (Schoharie Reservoir Diversion)[3]						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	18.0
Chloride (mg L^{-1})	50	12	0	0	10	8.9
Dissolved organic carbon (mg L^{-1})	25	52	0	0	9	2.0
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.23
Sulfate (mg L^{-1})	15	4	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean^1
Total dissolved solids (mg L^{-1})^2	50	52	33	59	40	52
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.2
C-7 (Trout Creek above Cannonsville Reservoir)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	1	8	na	15.7
Chloride (mg L^{-1})	50	12	0	0	10	12.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.29
Sulfate (mg L^{-1})	15	4	0	0	10	6.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})^2	50	12	10	83	40	61
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.1
C-8 (Loomis Brook above Cannonsville Reservoir)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	1	8	na	14.6
Chloride (mg L^{-1})	50	12	0	0	10	11.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.24
Sulfate (mg L^{-1})	15	4	0	0	10	5.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})^2	50	12	8	67	40	57
Dissolved sodium (mg L^{-1})	10	4	0	0	5	7.5
WDBN (West Branch Delaware River at Beerston Bridge)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	0	0	na	18.6
Chloride (mg L^{-1})	50	12	0	0	10	11.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.52
Sulfate (mg L^{-1})	15	4	0	0	10	6.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})^2	50	12	7	58	40	61
Dissolved sodium (mg L^{-1})	10	4	1	25	5	9.0
NCG (Neversink Reservoir near Claryville)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	12	100	na	3.7

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Chloride (mg L^{-1})	50	12	0	0	10	3.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.2
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.24
Sulfate (mg L^{-1})	15	4	0	0	10	3.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	20
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.9
NK4 (Aden Brook above Neversink Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	11	92	na	6.2
Chloride (mg L^{-1})	50	12	0	0	10	4.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.18
Sulfate (mg L^{-1})	15	4	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	27
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.2
NK6 (Kramer Brook above Neversink Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	6	50	na	9.7
Chloride (mg L^{-1})	50	12	0	0	10	28.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.7
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.38
Sulfate (mg L^{-1})	15	5	0	0	10	5.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.06
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	89
Dissolved sodium (mg L^{-1})	10	4	4	100	5	16.7
P-13 (Tremper Kill above Pepacton Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	16.7
Chloride (mg L^{-1})	50	12	0	0	10	8.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.32
Sulfate (mg L^{-1})	15	4	0	0	10	5.1

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	6	50	40	52
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.1
P-21 (Platte Kill at Dunraven)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	0	0	na	17.0
Chloride (mg L^{-1})	50	12	0	0	10	6.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.27
Sulfate (mg L^{-1})	15	4	0	0	10	4.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	4	33	40	47
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.3
P-60 (Mill Brook near Dunraven)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	6	50	na	10.3
Chloride (mg L^{-1})	50	12	0	0	10	1.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.28
Sulfate (mg L^{-1})	15	4	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	26
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.1
P-7 (Terry Clove above Pepacton Reservoir)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	2	17	na	14.1
Chloride (mg L^{-1})	50	12	0	0	10	1.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.35
Sulfate (mg L^{-1})	15	4	0	0	10	5.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	32
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.4
P-8 (Fall Clove above Pepacton Reservoir)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	2	17	na	13.5

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks.
na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Chloride (mg L^{-1})	50	12	0	0	10	2.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.37
Sulfate (mg L^{-1})	15	4	0	0	10	5.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	35
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.0
PMSB (East Branch Delaware River near Margaretville)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	17.7
Chloride (mg L^{-1})	50	12	0	0	10	9.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.34
Sulfate (mg L^{-1})	15	4	0	0	10	4.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	8	67	40	54
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.6
RD1 (Sugarloaf Brook near Lowes Corners)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	12	100	na	5.0
Chloride (mg L^{-1})	50	12	0	0	10	5.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.2
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.14
Sulfate (mg L^{-1})	15	4	0	0	10	4.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	29
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.2
RD4 (Sawkill Brook near Yagerville)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	12	100	na	4.8
Chloride (mg L^{-1})	50	12	0	0	10	5.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.7
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.07
Sulfate (mg L^{-1})	15	4	0	0	10	5.0

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	29
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.5
RDOA (Rondout Creek near Lowes Corners)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	12	100	na	3.9
Chloride (mg L^{-1})	50	12	0	0	10	3.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.18
Sulfate (mg L^{-1})	15	4	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	21
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.1
RGB (Chestnut Creek below Grahamsville STP)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	8	67	na	8.4
Chloride (mg L^{-1})	50	12	0	0	10	14.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.7
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.37
Sulfate (mg L^{-1})	15	4	0	0	10	5.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	8	67	40	55
Dissolved sodium (mg L^{-1})	10	4	1	25	5	10.2
AMAWALKR (Amawalk Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	82.6
Chloride (mg L^{-1})	100	12	0	0	35	89.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.18
Sulfate (mg L^{-1})	25	4	0	0	15	10.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.06
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	312
Dissolved sodium (mg L^{-1})	20	4	4	100	15	49.7
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	84.3

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Chloride (mg L^{-1})	100	12	0	0	35	44.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.10
Sulfate (mg L^{-1})	25	4	0	0	15	9.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.04
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	212
Dissolved sodium (mg L^{-1})	20	4	4	100	15	25.9
BOYDR (Boyd Corners Release) [3]						
Alkalinity (mg CaCO$_3$ L^{-1})	≥40.0	11	11	100	na	35.6
Chloride (mg L^{-1})	100	11	0	0	35	31.6
Dissolved organic carbon (mg L^{-1})	25	31	0	0	9	3.5
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.35	0.10
Sulfate (mg L^{-1})	25	4	0	0	15	7.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.03
Total dissolved solids (mg L^{-1})[2]	175	28	0	0	150	125
Dissolved sodium (mg L^{-1})	20	4	3	75	15	19.8
CROFALLSR (Croton Falls Reservoir Release)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥40.0	9	0	0	na	71.7
Chloride (mg L^{-1})	100	9	0	0	35	64.4
Dissolved organic carbon (mg L^{-1})	25	9	0	0	9	3.2
Nitrate+nitrite-N (mg L^{-1})	1.5	9	0	0	0.35	0.19
Sulfate (mg L^{-1})	25	3	0	0	15	10.5
Total ammonia-N (mg L^{-1})	0.20	9	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	9	9	100	150	242
Dissolved sodium (mg L^{-1})	20	3	3	100	15	37.1
CROSS2 (Cross River near Cross River Reservoir)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥40.0	12	0	0	na	59.3
Chloride (mg L^{-1})	100	12	0	0	35	35.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.16
Sulfate (mg L^{-1})	25	4	0	0	15	8.5

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.03
Total dissolved solids (mg L^{-1})[2]	175	12	2	17	150	165
Dissolved sodium (mg L^{-1})	20	4	1	25	15	19.0
CROSSRVR (Cross River Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	8	0	0	na	49.2
Chloride (mg L^{-1})	100	8	0	0	35	31.1
Dissolved organic carbon (mg L^{-1})	25	8	0	0	9	3.2
Nitrate+nitrite-N (mg L^{-1})	1.5	8	0	0	0.35	0.12
Sulfate (mg L^{-1})	25	3	0	0	15	8.6
Total ammonia-N (mg L^{-1})	0.20	8	0	0	0.10	0.04
Total dissolved solids (mg L^{-1})[2]	175	8	0	0	150	145
Dissolved sodium (mg L^{-1})	20	3	0	0	15	17.0
DIVERTR (Diverting Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	84.3
Chloride (mg L^{-1})	100	12	0	0	35	50.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.7
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.17
Sulfate (mg L^{-1})	25	4	0	0	15	8.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.06
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	226
Dissolved sodium (mg L^{-1})	20	4	4	100	15	29.5
EASTBR (East Branch Croton River above East Branch Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	100.2
Chloride (mg L^{-1})	100	12	0	0	35	38.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.08
Sulfate (mg L^{-1})	25	4	0	0	15	8.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	9	75	150	219
Dissolved sodium (mg L^{-1})	20	4	4	100	15	25.2

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks.
na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
GYPSYTRL1 (Gypsy Trail Brook)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	10	83	na	31.8
Chloride (mg L^{-1})	100	12	0	0	35	24.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.0
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.03
Sulfate (mg L^{-1})	25	4	0	0	15	6.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	103
Dissolved sodium (mg L^{-1})	20	4	1	25	15	18.9
HORSEPD12 (Horse Pound Brook)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	4	33	na	45.6
Chloride (mg L^{-1})	100	12	0	0	35	39.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.35
Sulfate (mg L^{-1})	25	4	0	0	15	8.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.03
Total dissolved solids (mg L^{-1})[2]	175	12	1	8	150	158
Dissolved sodium (mg L^{-1})	20	4	4	100	15	23.5
KISCO3 (Kisco River above New Croton Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	84.2
Chloride (mg L^{-1})	100	12	2	17	35	139.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.2
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.58
Sulfate (mg L^{-1})	25	4	0	0	15	12.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.04
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	347
Dissolved sodium (mg L^{-1})	20	4	4	100	15	38.7
LONGPD1 (Long Pond outflow above West Branch Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	58.2
Chloride (mg L^{-1})	100	12	0	0	35	65.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.20

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
Sulfate (mg L^{-1})	25	4	0	0	15	8.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	239
Dissolved sodium (mg L^{-1})	20	4	4	100	15	39.7
MIKE2 (Michael Brook)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥40.0	12	0	0	na	93.1
Chloride (mg L^{-1})	100	12	12	100	35	209.6
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	3.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	11	92	0.35	3.97
Sulfate (mg L^{-1})	25	4	2	50	15	23.3
Total ammonia-N (mg L^{-1})	0.20	12	2	17	0.10	0.12
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	549
Dissolved sodium (mg L^{-1})	20	4	4	100	15	110.2
MUSCOOT10 (Muscoot River above Amawalk Reservoir)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥40.0	12	0	0	na	92.4
Chloride (mg L^{-1})	100	12	8	67	35	126.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.56
Sulfate (mg L^{-1})	25	4	0	0	15	13.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.04
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	409
Dissolved sodium (mg L^{-1})	20	4	4	100	15	72.9
TITICUSR (Titicus Reservoir Release)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥40.0	12	0	0	na	75.8
Chloride (mg L^{-1})	100	12	0	0	35	35.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.16
Sulfate (mg L^{-1})	25	4	0	0	15	9.3
Total ammonia-N (mg L^{-1})	0.20	12	3	25	0.10	0.08
Total dissolved solids (mg L^{-1})[2]	175	12	11	92	150	186
Dissolved sodium (mg L^{-1})	20	4	1	25	15	19.4

Appendix Table 4. (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

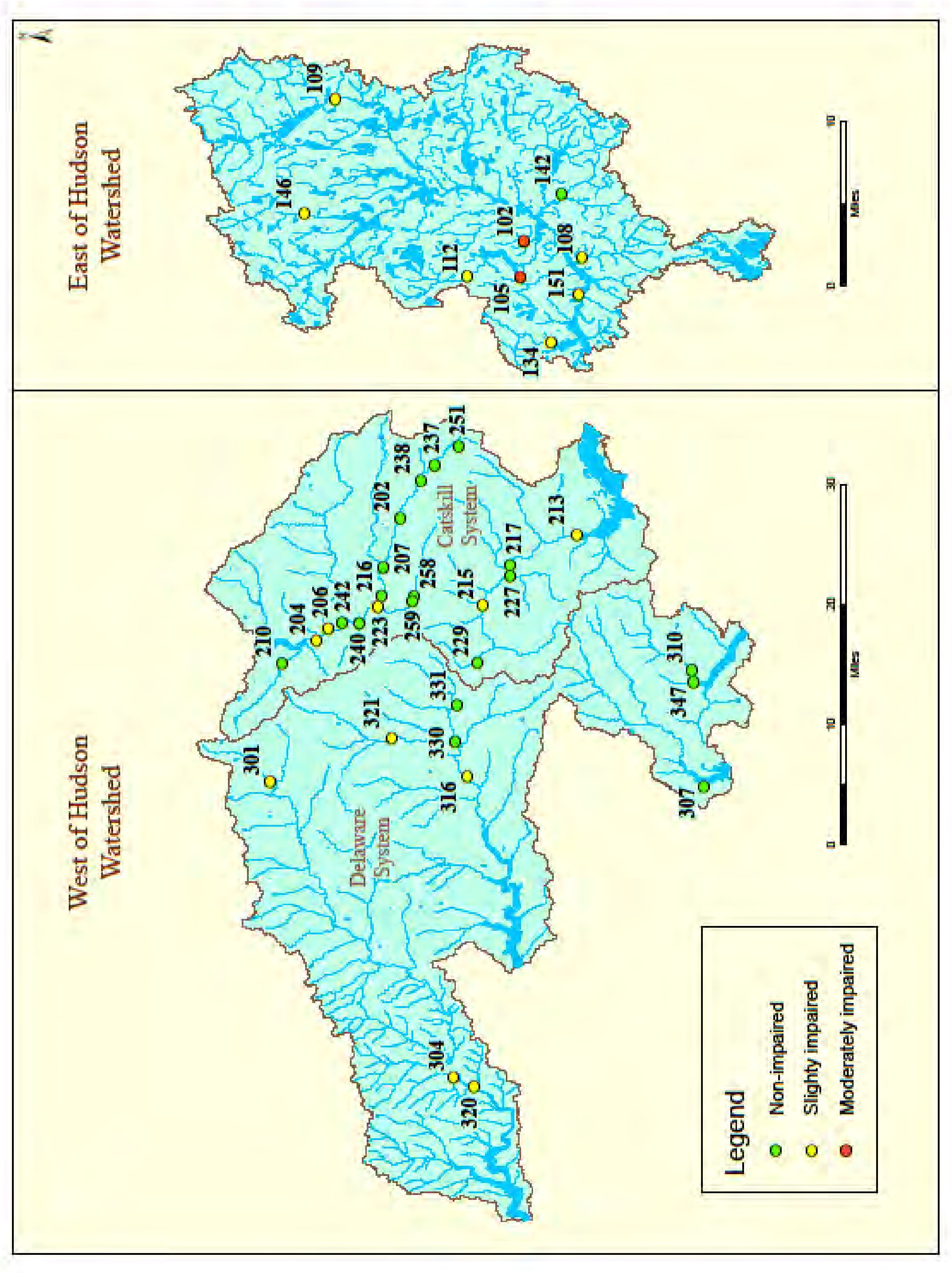
Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2013 Mean[1]
WESTBR7 (West Branch Croton River above Boyd Corners Reservoir)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥40.0	12	8	67	na	34.8
Chloride (mg L^{-1})	100	12	0	0	35	29.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.7
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.04
Sulfate (mg L^{-1})	25	4	0	0	15	5.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	117
Dissolved sodium (mg L^{-1})	20	4	2	50	15	20.0
WESTBRR (West Branch Reservoir Release)						
Alkalinity (mg CaCO$_3$ L^{-1})	≥10.0	12	0	0	na	26.5
Chloride (mg L^{-1})	50	12	0	0	10	17.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.3
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.08
Sulfate (mg L^{-1})	15	4	0	0	10	5.4
Total ammonia-N (mg L^{-1})	0.20	12	3	25	0.05	0.11
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	81
Dissolved sodium (mg L^{-1})	10	4	3	75	5	10.8

[1] Underlined means indicate that at least one result was measured at the detection limit. For these cases, means were estimated using the Kaplan-Meier method as described in Helsel (2005). In cases where the number of non-detects was greater than 50% of total n, the detection limit (identified as <) is reported in place of the mean. The arithmetic mean is reported for the remainder.

[2] Total dissolved solids estimated from specific conductivity according to the USGS in van der Leeden et al. (1990).

[3] In 2013, SRR2CM and BOYDR were sampled at higher frequencies for dissolved organic carbon and total dissolved solids. SRR2CM was sampled approximately weekly for the entire year while BOYDR was sampled monthly from January to June and weekly thereafter.

Appendix F. Biomonitoring Sampling Sites



Appendix Figure 1. Biomonitoring sampling sites.