New York City Environmental Protection

2015 Watershed Water Quality Annual Report

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Bureau of Water Supply

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List of Acronyms

BEPA	Bureau of Environmental Planning and Analysis
BMP	Best Management Practice
CATALUM	Catskill Alum Chamber
CATIC	Catskill Influent Chamber
CATLEFF	Catskill Lower Effluent Chamber
CATUEC	Catskill Upper Effluent Chamber
CFU	Colony Forming Units
CUNY-RF	City University of New York Research Foundation
DBP	Disinfection Byproducts
DEL17	Delaware Aqueduct Shaft Building 17
DEL18	Delaware Aqueduct Shaft Building 18
DEC	New York State Department of Environmental Conservation
DEP	New York City Department of Environmental Protection
DMR	Discharge Monitoring Report
DOH	New York State Department of Health
DOT	Department of Transportation
DRO	Diesel Range Organics
EOH	East of Hudson
EPA	United States Environmental Protection Agency
FAD	Filtration Avoidance Determination
GLEON	Global Lake Ecological Observatory Network
HEV	Human Enteric Virus
IMR	Inter-Municipal Agreement
MPN	Most Probable Number
MST	Microbial Source Tracking
NTU	Nephelometric Turbidity Units
NYC	New York City
RHESSys	Regional Hydro-Ecologic Simulation System
SEQR	State Environmental Quality Review
SPDES	State Pollution Discharge Elimination System

SVOC	Semivolatile Organic Compound
SWAT	Soil Water Assessment Tool
SWTR	Surface Water Treatment Rule
TSI	Trophic State Index
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compound
WMP	Waterfowl Management Program
WOH	West of Hudson
WQD	Water Quality Directorate
WRF	Water Research Foundation
WUCA	Water Utility Climate Alliance
WWQMP	Watershed Water Quality Monitoring Plan
WWQO	Watershed Water Quality Operations
WWQSR	Water Quality Science and Research
WWTP	Wastewater Treatment Plants

Acknowledgements

This report provides a summary of the scientific work conducted in 2015 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 throughout 2015. Mr. Paul Rush, P.E., provided guidance for the Bureau of Water Supply, and Mr. Steven Schindler, Director of Water Quality, continued to provide oversight and direction for the many activities of the Water Quality Directorate (WQD). Dr. Lorraine Janus, Chief of Water Quality Science and Research (WQSR), directed production of this report and her Division was responsible for the data analysis, interpretation, and report production. Ms. Lori Emery, Chief of Watershed Water Quality Operations (WWQO), provided oversight of Watershed Field Operations, Laboratory Operations, and Quality Assurance. WWQO was responsible for conducting water quality monitoring, conducting the laboratory analysis, and developing the database that forms the basis of this report.

Chapter 1 *Introduction* was co-authored by Dr. Lorraine Janus, Mr. James Mayfield, Section Chief of Program Evaluation and Planning, Mr. Andrew Bader and Mr. Charles Olson, Deputy Chiefs of WWQO. Mr. Bader provided the sections on Robotic Monitoring; both Mr. Bader and and Mr. Olson wrote the section on Operations. Chapter 2 on *Water Quantity*, was written by Mr. Mayfield, and Mr. Alec Fu of Strategic Services was most helpful in providing the rainfall and operations data presented in this chapter. Chapter 3 on *Water Quality,* was written by Dr. Karen Moore and Mr. Rich Van Dreason with contributions from Mr. James Mayfield on streams, Ms. Kerri Alderisio on stream biomonitoring and Dave Quentin on Special Investigations. Chapter 4 about *Kensico Reservoir* was composed by Mr. Dave Van Valkenburg, Mr. Chris Nadareski, Mr. Kurt Gabel, and Ms. Kerri Alderisio. Chapter 5 on *Pathogens* was authored by Ms. Kerri Alderisio, Chief of Watershed Impacts and Pathogen Assessment, with assistance from Mr. Christian Pace. Chapter 6 *Modeling* was written by Mr. Emmet Owens, P.E., Section Chief of Modeling, Dr. Rakesh Gelda, and Mr. Jordan Gass. This chapter describes ongoing model development and applications conducted by the Modeling Section. Finally, Chapter 7 presents *Further Research*, which supplements the capabilities of WQD through contracts and participation in scientific organizations. The chapter was coordinated by Dr. Lorraine Janus with contributions from Mr. Andrew Bader, Ms. Kerri Alderisio, Mr. James Mayfield, Mr. Emmet Owens, P.E., Mr. Chris Nadareski, Ms. Sharon Neuman, Mr. Jordan Gass, Mr. James Alair, Ms. Anne Seeley, Mr. Rich Van Dreason, and Dr. Karen Moore. Other essential database expertise was provided by Ms. Kelly Seelbach of WWQO. Mr. Jordan Gass and Mr. Don Kent were responsible for bringing the chapters of the report together as a single document and polishing the format to make it suitable for printing and posting. Major authors mentioned above edited and proofread chapters of the report to produce the final document for review by the Director and Deputy Commissioner. Everyone involved in this report takes pride in their work and they are to be commended for their dedication.

Notably, the production of this report required the scientific expertise and cooperation of many more staff members in the Water Quality Directorate than those named above. All deserve special recognition and thanks for their willing participation in the many facets of the work to operate the largest unfiltered water supply in the nation. This report would not exist without the extensive field work, laboratory analysis, scientific interpretation, and administrative work needed to keep the watershed programs of the Directorate operating. Therefore, thanks are due to all field and laboratory staff who collected and analyzed the thousands of samples required for the watershed monitoring programs; the administrative, computing, health and safety, and quality assurance staff who support them; and the scientific staff responsible for planning, interpreting, and documenting the results of our collective work. Although we could not name everyone, thanks go to all those who contributed directly and indirectly to this report.

Executive Summary

Chapter 1 Introduction

The New York City Water Supply System 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. This report provides summary information about the water quality of 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 detailed description of the City's water resources, their condition during 2015, and compliance with regulatory standards. Field sampling and robotic (continuous) monitoring equipment are employed at 470 sites throughout the watershed to measure an array of water quality analytes at various frequencies. These data provide information for operational changes, for use in water quality models, and for watershed protection policies. Overall, the report illustrates how DEP maintains high quality source water.

Chapter 2 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 2015 was 1,056 mm (41.6 inches), which was 91 mm (3.6 inches) below normal. Reflecting the below normal precipitation in the watershed for the year, the annual runoff was also below normal for all WOH and EOH sites. The United States Geological Survey (USGS) also reported that New York State had somewhat below normal annual runoff for the 2015 water year (October 1, 2014-September 30, 2015). Although the system-wide useable storage level was well below normal at the start of 2015, snowmelt in April and a wet June brought the capacity to above 100% and storage remained above normal for most of the year. Also, the most recent 1-year, 10-year, and 100-year, 24-hour rainfall events, and the 90% rainfall event maps for New York are presented and are also available in Chapter 4 of the New York State Stormwater Management Design Manual.

Chapter 3 Water Quality

In 2015, with the exception of Cannonsville Reservoir, turbidity levels were at or below long-term median levels throughout the Catskill, Delaware, and Croton Systems. The best explanation for the low turbidity was the low rainfall amounts observed throughout most of the NYC water supply watersheds. Only the Cannonsville basin was above average for the year (45.4 inches versus a historic 44.9 inches) while annual rain deficits of 5.7 and 10.9 inches occurred in the remaining Catskill/Delaware and Croton System watersheds, respectively.

Annual total phosphorus concentrations in 2015 ranged from normal to below normal median values in all parts of the system. The Croton System generally has higher concentrations, and more sources of phosphorus than the rest of the watershed, but in 2015 levels were generally below their historical ranges, with reductions attributed to low rainfall and to continuing efforts to reduce phosphorus through stormwater and wastewater nutrient mitigation strategies. The phosphorus-restricted basin calculations indicated that all nine basins associated with the Catskill/Delaware System (including West Branch and Kensico) and four basins in the Croton System (Boyd's Corners, Amawalk, Bog Brook and Titicus) were non-restricted in 2015. Restricted basins included 10 of 14 Croton System reservoirs and controlled lakes. Note that only Boyd's Corners Reservoir was considered non-restricted in 2014.

Total and fecal coliform levels were generally within historical ranges throughout the NYC Water Supply System in 2015. Reservoir trophic state was generally low compared to historic levels throughout the NYC water supply system. West Branch Reservoir improved significantly compared to 2014, in part due to receiving a large diversion of Rondout water during much of April.

Additional reservoir and stream analytes were evaluated against benchmarks in 2015. As in 2014, all streams, reservoirs and controlled lakes in the Croton System exceeded the Croton System annual mean chloride benchmarks of 30.00 mg L^{-1} for reservoirs and 35.00 mg L^{-1} for streams. Single sample benchmarks were frequently exceeded as well. Likewise, all chloride samples in West Branch when compared to the Catskill/Delaware System benchmarks exceeded the single sample maximum of 12.00 mg L^{-1} and annual mean standard of 8.00 mg L^{-1}. All chloride levels were well below the health standard of 250 mg L^{-1}.

Water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages were also used to assess water quality in 2015. Assessments are made following protocols developed by the New York State Stream Biomonitoring Unit. For the East of Hudson sites, nine sites were slightly impaired and two were moderately impaired in the Croton System, and one site was slightly impaired and one site moderately impaired in the Kensico basin. The high percentage of impaired sites is typical of the Croton System. In the Catskill System, eight sites were non-impaired and four were slightly impaired, while in the Delaware System, seven sites were non-impaired and five slightly impaired. Contrary to recent years, high numbers of *hydropsychid* caddisflies (>30%) were not present at most of the impaired sites. Only one site East of Hudson (Angle Fly 102) and one site West of Hudson (Batavia Kill 206) had percentages over 30% in 2015.

Supplemental (non-required) monitoring for metals and a large number of semivolatile and volatile organic compounds were conducted at important keypoint locations throughout the water supply system. None of the monitored semivolatile or volatile compounds were detected in 2015. Most metal results were well below state and federal benchmarks. Benchmarks related to aesthetic concerns (e.g., taste, staining) were occasionally exceeded for iron, manganese, and aluminum at locations well upstream of the distribution system.

Several special investigations were conducted in 2015. A sewage spill occurred near Croton Falls Reservoir on April 29. Follow-up sampling in the reservoir showed no adverse effects. A small plane crashed into Titicus Reservoir on November 19. Post-crash water quality samples periodically collected from the reservoir release and analyzed for a variety of synthetic organic compounds (e.g. diesel range organics (DRO)) did not indicate contamination. The presence of oil-like sheens, first observed in 2012 on Pepacton Reservoir and in April 2015 on Schoharie Reservoir, necessitated that DRO samples be monitored at these reservoirs in 2015. The source of the DRO compounds was removed from Schoharie Reservoir and follow up sampling indicated that water quality was no longer impacted by the end of August. However, despite remediation efforts, low level DRO detections were observed at Pepacton in 2015 and that situation will continue to be monitored closely in 2016.

Chapter 4 Kensico Reservoir

Kensico Reservoir is the terminal reservoir for the unfiltered Catskill/Delaware water supply and is the last impoundment prior to entering the City's distribution system. The City's high frequency monitoring ensures that ever effort is taken, at this key location to meet strict requirements for turbidity and fecal coliform concentrations set forth in the federal Surface Water Treatment Rule (SWTR). Monitoring of the water discharged from Kensico takes place at DEL18DT where only one turbidity grab (four-hour and routine) sample exceeded 2.0 NTU, less than half the SWTR turbidity limit, and none of the fecal coliform results exceeded the 20 fecal coliform $100mL^{-1}$ threshold in 2015. The Waterfowl Management Program continues to be instrumental in keeping coliform bacteria concentrations well below the limits set by the SWTR. Routine inspections of the turbidity curtains near the Catskill Upper Effluent Chamber cove continued to show that they were intact. Overall, water quality from Kensico continued to be excellent during 2015.

In addition to DEP's routine monitoring, three special investigations were conducted in the Kensico Watershed and video monitoring for Bryozoans continued at the Delaware Shaft 18 sluice gates. The special investigations included a brush fire along Kensico Reservoir, a September storm event in the Catskill Upper Effluent Chamber cove, and follow-up sampling investigation to high *Cryptosporidium* and *Giardia* oocysts results at stream sites in December. No water quality impacts were detected after comparing pre- and post-fire brush fire sample results. For the September storm event, a localized temporary increase in fecal coliform was detected and was followed up with *Bacteroides* sampling. The microbial source tracking (MST) follow up sampling suggested that the most likely source was wildlife with a possible trace of human source. The December oocyst follow-up investigation continued to show higher levels of oocyst and MST sampling resulted in *Cryptosporidium* being associated with wildlife. The 2015 Bryozoan inspections showed similar growth patterns to last year. Operational changes were made midsummer and resulted in the death all of the colonies that fell to the bottom where they were found by divers in September. Potential future work could include investigating whether flow changes can be used to control Bryozoan populations.

Chapter 5 Pathogen Monitoring and Research

DEP collected 601 samples for protozoan (*Cryptosporidium* and *Giardia*) analysis and 134 samples for human enteric virus (HEV) monitoring in 2015. 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). On April 6, 2015, DEP changed methods for protozoan analysis from Method 1623 to Method 1623.1 with EasyStain to improve both recovery and the ability to genotype samples after slide processing. This change is coincident with a shift in results for the remainder of the year. The shift in data was both an increased detection of *Cryptosporidium* oocysts and a decreased detection of *Giardia* cysts throughout the watershed and is believed to be a result of the method change and not a change of prevalence in the environment. Additional data with the new method will be needed to confirm this effect of method change.

For the two-year period from January 1, 2014 to December 31, 2015, DEP source water continued to be well below the Long Term 2 Enhanced Surface Water Treatment Rule *Cryptosporidium* threshold for additional treatment at an unfiltered water supply (0.010 oocysts L^{-1}), with a mean of 0.0028 oocysts L^{-1} at the Delaware outflow. In May of 2015, the sampling site for NYC's Croton filtered water supply came on line. With less than one year of data (n=35), the mean of the monthly means at 1CR21 was 0.0000 (indicating non-detection). 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 were three detections of *Giardia* cysts at WWTPs this year and one detection of a *Cryptosporidium* oocyst. As per the Hillview Administrative Order, DEP continued weekly protozoan monitoring at the Hillview Reservoir outflow (Site 3) through 2015, with 52 routine samples collected, and many more collected for method studies. Of the 52 samples, there were five samples positive for *Giardia* and six samples positive for *Cryptosporidium,* as mentioned, likely a reflection of the method change.

Chapter 6 Water Quality Modeling

The general goal of the water quality modeling program is to develop and apply quantitative tools, supporting data, and data analysis in order to evaluate effects of land use change, watershed management, reservoir operations, ecosystem health, and climate change on water supply quantity and quality. The quantitative tools include models that simulate future climate conditions in the watersheds of the water supply reservoirs (weather generators), terrestrial/watershed models that simulate the quantity and quality of runoff from the watersheds entering the reservoirs, reservoir models that simulate mixing, fate and transport of water, heat and pollutants within the reservoirs themselves, and operations models that consider alternative operations of DEP's system of reservoirs in the delivery of high quality water in sufficient quantities to meet demand.

These models were used in a variety of applications during 2015. DEP's reservoir turbidity model was used to evaluate the impact of runoff events on turbidity in Kensico Reservoir. This model was also used to evaluate the impact of the planned 2022 shutdown of the Rondout-West Branch Tunnel on turbidity in Kensico. The turbidity model was also used to evaluate the impact of the potential sustained drawdown of Cannonsville Reservoir on turbidity conditions in Rondout Reservoir. A major new modeling initiative at DEP is the development of watershed and reservoir models to predict the origins, fate and transport of the organic compounds that are precursors of disinfection byproducts (DBPs). Research was conducted in 2015 on the development of stochastic weather generators for the watersheds of the West of Hudson reservoirs. These models generate synthetic time series of weather variables such as precipitation and air temperature that have statistical properties which closely resemble observations, but contain extreme events that may not be captured in historical weather records. Also in 2015, DEP made significant progress in the initial application and testing of two terrestrial/watershed models, these being the Soil Water Assessment Tool (SWAT), and the Regional Hydro-Ecologic Simulation System (RHESSys). These two models were each applied to smaller watersheds in 2015, and will be applied to entire reservoir watersheds in the future. DEP continued to develop and organize data to support model development, testing, and applications in 2015. These data include GIS, meteorology, hydrology, and stream, reservoir and aqueduct water quality. DEP continued its collaboration with various outside groups in activities associated with the modeling program.

Chapter 7 Further Research

The analytical, monitoring, and research activities of DEP are supported through a variety of contracts, participation in research projects conducted by the Water Research Foundation (WRF), and interactions with national and international groups such as the Water Utility Climate Alliance (WUCA) and the Global Lake Ecological Observatory Network (GLEON). 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. In 2015, the WQD managed several water quality-related contracts to enhance its ability to monitor and model the watershed. These included four contracts for laboratory analyses, hydrological monitoring by United States Geological Survey (USGS), modeling support through CUNY Research Foundation (CUNY-RF), waterfowl management, zebra mussel monitoring, bathymetric surveys by USGS, and WISKI Software Support. DEP participated in 10 WRF projects as both Project Advisory Committee members and as Participating Utilities. WQD and the Bureau of Environmental Planning and Analysis (BEPA) staff participate with the other members of the Water Utility Climate Alliance (WUCA), a consortium of 10 water utilities across the nation interested in planning for climate change. In addition, DEP participated in the international organization Global Lake Ecological Observatory Network (GLEON), with the objectives of adopting software tools developed by GLEON scientists, to display and analyze the high-frequency data generated by DEP's Robotic Monitoring project and to contribute to projects with other scientists. DEP contributed data to four GLEON projects exploring temperature changes related to global weather patterns, salt and iron concentrations trends over several decades, and the ecological impact of changes in the timing of spring runoff. These projects allow DEP to see source water quality in a global context and it allows us to plan for the future.

1. Introduction

1.1. Water Quality Monitoring of the Watershed

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 detailed description of the City's water resources, their condition during 2015, 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 2015 Drinking Water Supply and Quality Report (http://www.nyc.gov/html/dep/pdf/wsstate15.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. As a summary document, topics are not described in depth, but more detailed reports on some of the topics can be found in other DEP publications posted on the DEP website at http://www.nyc.gov/dep/.

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 three controlled lakes that contain a total storage capacity of approximately two 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

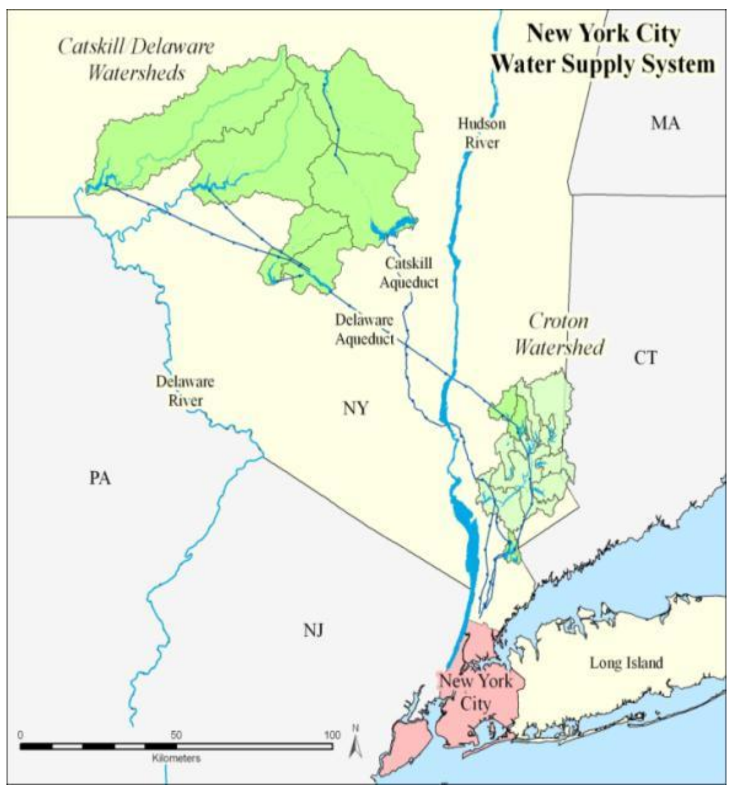


Figure 1.1 The New York City Water Supply System.

deliver a sufficient quantity of high quality drinking water to protect public health and the quality of life of the City of New York. In order to gather and process the information needed to meet these goals, there is an ongoing program of sample collection (by grab samples and continuously recording (robotic monitoring) equipment), data display and analysis, modeling runs, and operational responses to changing conditions. DEP supplements the work of the Water Quality Directorate through contracts and interactions with other organizations, as discussed in the last chapter on 'Further Research'. Monitoring of the vast watershed is accomplished by Watershed Water Quality Operations based at three upstate locations in Grahamsville, Kingston, and Hawthorne, NY. (The Kensico and Brewster laboratories were consolidated and moved to a new, modern laboratory facility in Hawthorne in August-September, 2015.) The results of these activities are presented here to provide an overview of watershed water quality in 2015 and how high quality source water is maintained.

1.1.1. Grab Sample Monitoring

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. Sampling is specified in the Watershed Water Quality Monitoring Plan (WWQMP; DEP 2016). This document is DEP's comprehensive plan that describes why, what, when, and where water quality samples are taken throughout the watershed. Thus the sampling effort is tailored to the needs of the Department.

A summary of the number of grab samples and analyses that were processed in 2015 by the three upstate laboratories, and the number of sites that were sampled, is provided below in Table 1.1. The samples included in the table were collected from streams, reservoirs, reservoir releases, wastewater treatment plants (WWTP's), and keypoints (i.e., water supply intakes and aqueduct sites) as described in the 2016 WWQMP. Samples taken as the result of special investigations are also included. The sample numbers for the City's distribution system are also listed for completeness; however, this report only discusses results from watershed samples.

Table 1.1 Number of grab samples collected, water quality analyses performed, and sites visited by WQD in 2015.

System/Laboratory	Number of Samples	Number of Analyses	Number of Sites
Catskill/Kingston	3,027	62,896	136
Delaware/Grahamsville	3,719	41,552	135
EOH/Hawthorne	8,711	89345	199
Watershed	15,457	193,793	470
Distribution	31,700	383,200	>1,000[2]
Total	**47,157**	**576,993**	**1,470**

[1] Catskill/Kingston totals include samples analyzed by the Pathogen Laboratory.
[2] Approximate number

1.1.2. Robotic Monitoring

In 2012, the Robotic Water Quality Monitoring Network (RoboMon) became part of WQD's routine operation, rather than run by contract. Continuous monitoring data obtained by the network are critical for ensuring effective water supply management during storm events, providing early warning of water quality conditions, and for forming a basis for management actions that guide the operation of the water supply system. It also provides data essential for model development.

When acquired in 2012, the RoboMon network was focused on data collection for turbidity management. It consisted of four profiling buoys located on the West Basin of Ashokan Reservoir (Sites 1.4 and 3.1), the East Basin of Ashokan Reservoir (Site 4.2), and on Kensico Reservoir (Site 4.1). Two fixed-depth buoys were also deployed on Kensico Reservoir, near the water supply intake (Delaware Shaft 18) and approximately midway between the intake and the turbidity curtain which mitigates impacts from Malcolm Brook. Each buoy had three transmissometers suspended at 5, 10, and 15 meters to provide near-real-time estimates of turbidity. Data were used to develop reservoir models, determine trends in turbidity and assist with operational decisions at Delaware Shaft 18.

In 2014, four reservoir water column profiling buoys were added at Rondout (Site 1), Neversink (Site 1.5), Schoharie (Site 3), and Kensico (Site 4) Reservoirs. These buoys performed full water column profiles every six hours with sensors measuring temperature, turbidity, and specific conductivity. Additionally, the Ashokan-West Basin (Site 1.4) buoy and the Kensico (Site 4.1) buoy were outfitted with meteorological stations.

In 2015, the RoboMon program objective was expanded (beyond tracking turbidity) in an effort to develop reservoir carbon budgets to ultimately improve DEP's understanding of the factors that influence disinfection by-product formation potential. An additional reservoir profiling buoy was added on Cannonsville Reservoir (Site 4), with probes for chlorophyll, phycocyanin (blue-green algae), dissolved oxygen, and colored dissolved organic matter. The

Neversink Reservoir (Site 1.5) buoy was also upgraded with similar probes as part of this program expansion.

To monitor water quality conditions during times of ice cover, two under-ice buoys were deployed at the end of 2014 to monitor Ashokan Reservoir during the winter of 2015. These were fixed depth buoys located in front of the gatehouse in each basin with turbidity sensors positioned at two depths at approximate elevations of 555 feet and 515 feet.

Seven automated stream monitoring stations (RoboHuts) are maintained year-round in addition to the reservoir buoy network. Two RoboHuts located at Esopus Creek near Coldbrook and at Rondout Creek near Lowes Corners continuously monitor water temperature, specific conductivity, and turbidity. Five additional stream monitoring stations (including one on the Neversink River, one on the West Branch Delaware River, and three in the Stony Clove/Warner Creek watershed) continuously monitor for turbidity and temperature only.

Each robotic monitoring location contains data logging and communications equipment. At regular intervals each day, the most recent data are uploaded to a database at the DEP Kingston Facility and can be viewed on the DEP intranet. In some cases, near-real-time data were available. Divisional Standard Operating Procedure QUAL5000D describes the program's data management and quality control procedures. In 2015, the RoboMon program yielded over 1.6 million measurements at 20 sites (Table 1.2).

Table 1.2 Summary of RoboMon Project for 2015.

System/Field Section	Number of Measurements	Number of Sites
Catskill/Kingston	676,850	10
Delaware/Grahamsville	617,704	6
EOH/Hawthorne	322,653	4
Total	**1,617,207**	**20**

In 2015, RoboMon buoys were also deployed temporarily for Special Investigation work as follows:

- Cannonsville Reservoir Dam area to monitor potential changes in stream turbidity downstream of the dam due to a bore hole test (no issues were found).
- Rondout Reservoir mid-basin to determine how turbid discharges from Cannonsville Reservoir (unrelated to above) were impacting the reservoir.
- Schoharie Reservoir mid-basin to enhance monitoring of an internal seiche.

1.1.3. Operations in 2015

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 (e.g., lowering the West Basin to accept more runoff during large storm events). From February to April water was diverted from the middle elevations of Ashokan's West Basin in anticipation of spring snow-melt. Following the annual runoff event, a switch was made to the East Basin where turbidity was lowest. In the summer months water quality was acceptable in the West Basin and a change was made to move colder water from the bottom of the West Basin to Kensico to help alleviate total coliform levels in distribution. A drop of about 10°C was observed in the water leaving Ashokan following this change. In late August, a decision was made to go back to the East Basin to bring in less turbid water. For the month of September water was taken from the bottom depths of the East Basin. In October, DEP returned to a middle draw on the East Basin which was maintained until the end of the year.

In the Delaware System, selective withdrawal was implemented at two of the four reservoirs in 2015. From January through August water was drawn from a middle depth at Rondout. In August, the elevation of withdrawal was changed to the bottom and Kensico was placed in float mode in order to directly move cold water to Hillview Reservoir to reduce total coliform growth rates in the distribution system. A modest drop in temperature (2°C) was noted after this change in withdrawal elevation. The draw was kept at the lowest intake through December. At Cannonsville Reservoir, water was taken from the middle depth until April. In April the elevation of withdrawal was moved to the surface to avoid elevated turbidity from spring storm runoff. By July the turbidity levels had subsided and the draw was moved back to the middle depths to avoid the higher phytoplankton concentrations at the surface, to maximize diversions and releases out of the basin, and to draw down the reservoir during repairs to bore holes below the Cannonsville Dam. Overall, water quality was very good throughout the year in the Delaware System and few changes were needed to deliver the best quality water to the distribution system.

At Kensico Reservoir, when weather forecasts predict sustained easterly or northeasterly winds in excess of 15 mph, the mode at Delaware Aqueduct Shaft 18 is often changed from a reservoir-only withdrawal to "float" mode due to the potential for wave action to resuspend adjacent shoreline sediments. Float mode operation brings water from Rondout Reservoir via the Delaware Aqueduct directly to the forebay at Delaware Aqueduct Shaft 18. Since the bypass tunnel cannot fully meet demand with Rondout Reservoir water, the balance of water is drawn from Kensico Reservoir in much lesser amounts than would occur during reservoir mode operation. Float operation in anticipation of strong winds occurred only three times in 2015. Kensico Reservoir was also put in float mode from August 1 to August 4 to move cold water to Hillview Reservoir to reduce total coliform growth rates in the distribution system.

The Croton Water Filtration Plant began delivery of water into distribution on May 7, 2015. The plant uses treatment processes involving coagulation, dissolved air floatation, filtration, and disinfection. During coagulation, chemicals are added to untreated water, causing any natural particulates to coalesce into become larger particles called floc. Most of the floc floats to the top and is skimmed off and any that remains is removed by filtration. The water is disinfected with chlorine and UV light. The treatment process helps to reduce color levels, the risk of microbiological contamination, and disinfection by-products, and it ensures compliance with water quality regulatory standards. Raw water withdrawal from New Croton Reservoir typically occurs from the lower intake (site CRO1B) of the Cornell Dam, but in response to increases in turbidity and color, a change to the upper intake (site CRO1T) occurred for 12 days in October, 2015.

2. Water Quantity

2.1. The Source of New York City's Drinking Water

The New York City Water Supply System is dependent on precipitation (rainfall and snowmelt) and subsequent runoff to supply the reservoirs. 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 and tunnels 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. 2015 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 2015 monthly precipitation total for each watershed is plotted along with the historical monthly average (Figure 2.1).

The total monthly precipitation figures show that precipitation was generally near normal to somewhat below normal for the first five months of 2015. June had above average precipitation in all watersheds. July had below average precipitation in all watersheds except Cannonsville, which was above normal, while in August all watersheds, except Croton, were near normal or slightly below normal, while Croton was well below normal. Precipitation for September was near normal, except for Rondout and Ashokan, which were well above normal. Ashokan recorded 148 mm (5.84 inches) of rain on Sept. 12 and another 185 mm (7.27 inches) on September 29, while Rondout recorded 107 mm (4.63 inches) and 118 mm (4.2 inches) on those two dates, respectively. The remainder of the year was near normal or somewhat below normal except for Croton in October and November, which were well below normal. Overall, the total precipitation across the watershed for 2015 was 1,056 mm (41.6 inches), which was 91 mm (3.6 inches) below normal.

The National Climatic Data Center's (NCDC) climatological rankings (http://www.ncdc.noaa.gov/temp-and-precip/climatological-rankings/) were queried to determine the 2015 rankings for New York. Overall total precipitation for New York State was 7.62 mm (0.3 inches) above normal in 2015 (55th wettest in the last 121 years). However in Climate Division 5, which includes the EOH reservoirs, precipitation was 76.20 mm (3.00 inches) below normal. Also, the average temperature for 2015 was 0.7°C (1.2°F) above normal (23rd warmest in the last 121 years) for New York.

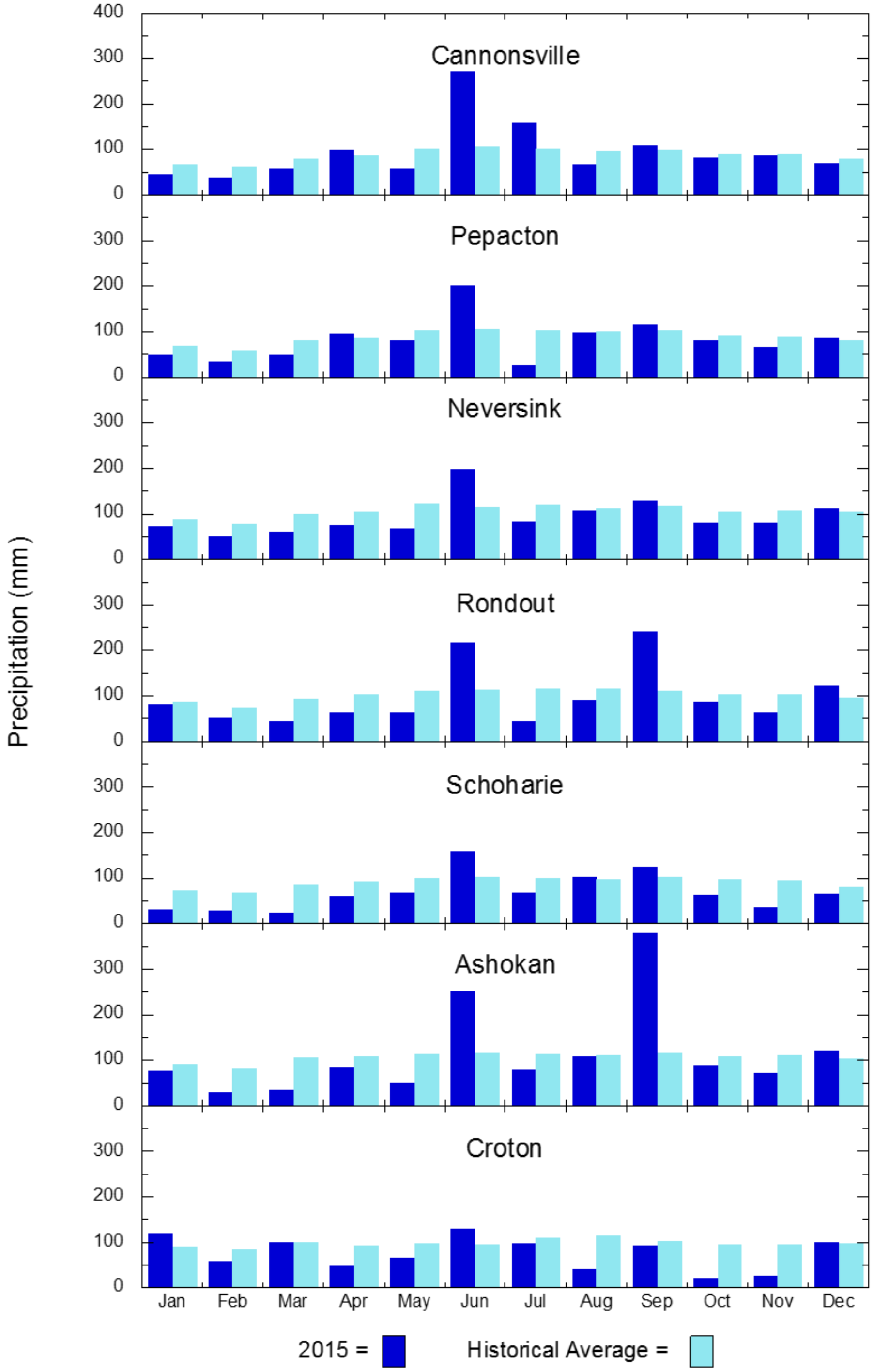


Figure 2.1 Monthly precipitation totals for New York City watersheds, 2015 and historical values.

2.3. 2015 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, watershed orientation and drainage network pattern and occurrence and area of ponds, lakes, reservoirs, sinks, and other features of the basin which store 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 (Figure 3.7) were used to characterize annual runoff in the different NYC watersheds (Figure 2.2). The period of record for the WOH stations ranges from 52 years at the Esopus Creek Allaben station to 109 years at the Schoharie Creek Prattsville gauge. The EOH stations have a twenty year period of record, except for the Wappinger Creek site (87-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.) The annual runoff in 2015 was below normal for all sites, both EOH and WOH, ranging from the lowest on record at West Branch and the East Branch of the Croton River to the 42nd percentile at the Neversink River. New York State had somewhat below normal runoff (34th lowest out of the last 115 years) for the 2015 water year (October 1, 2014-September 30, 2015), as determined by the USGS (http://waterwatch.usgs.gov/index.php?r=ny&m=statesum).

Figure 2.3 shows the 2015 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. For the WOH sites, flows were generally below the historical median for the first five months of the year except for a peak in April. Flows were then above normal for part of June and July and near normal for the remainder for the year with occasional spikes from storms. In EOH the year began with flows at near normal levels, but were below the historical median in February and part of March. From mid-March into July the flows were generally near normal. EOH flows were then below normal for the remainder of the year except for occasional spikes from storm events.

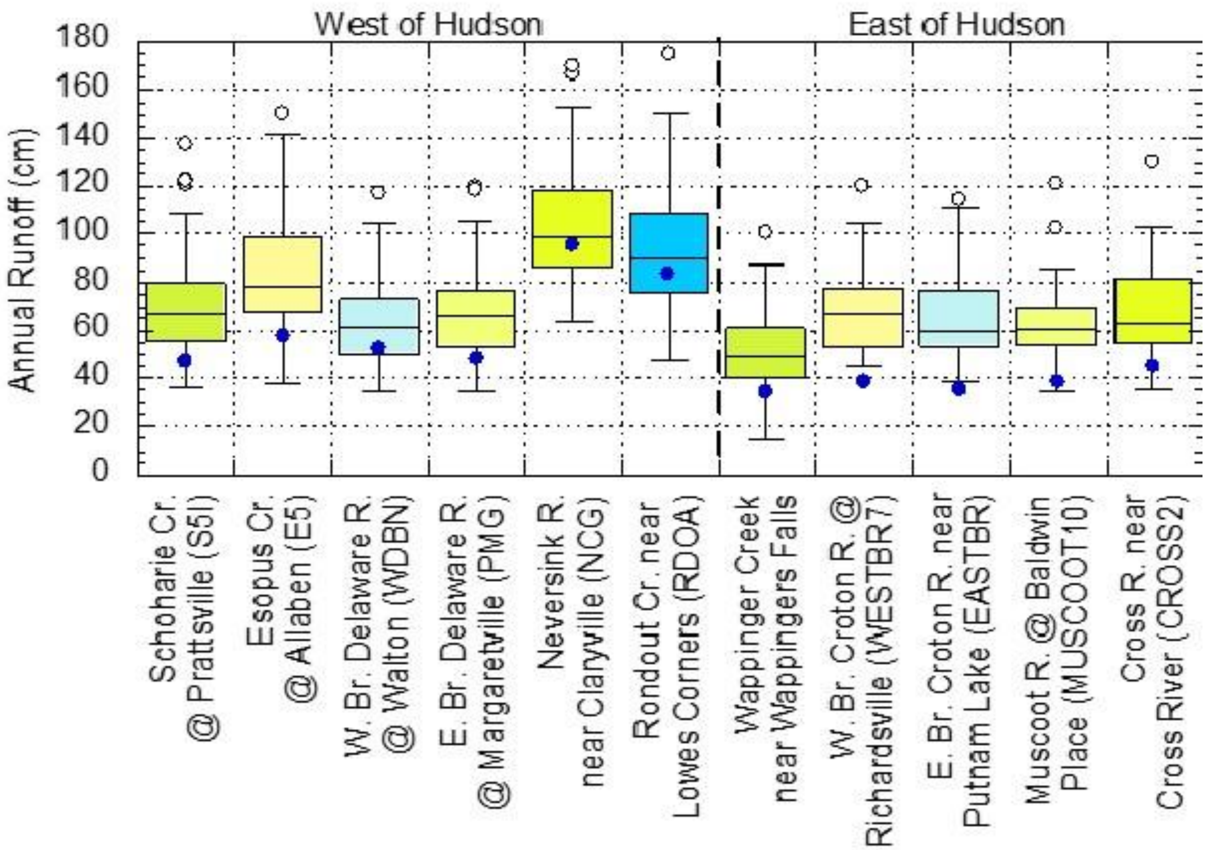


Figure 2.2 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds, with the values for 2015 displayed as a solid dot. The open circles indicate outliers (see appendix A for a key to the boxplot).

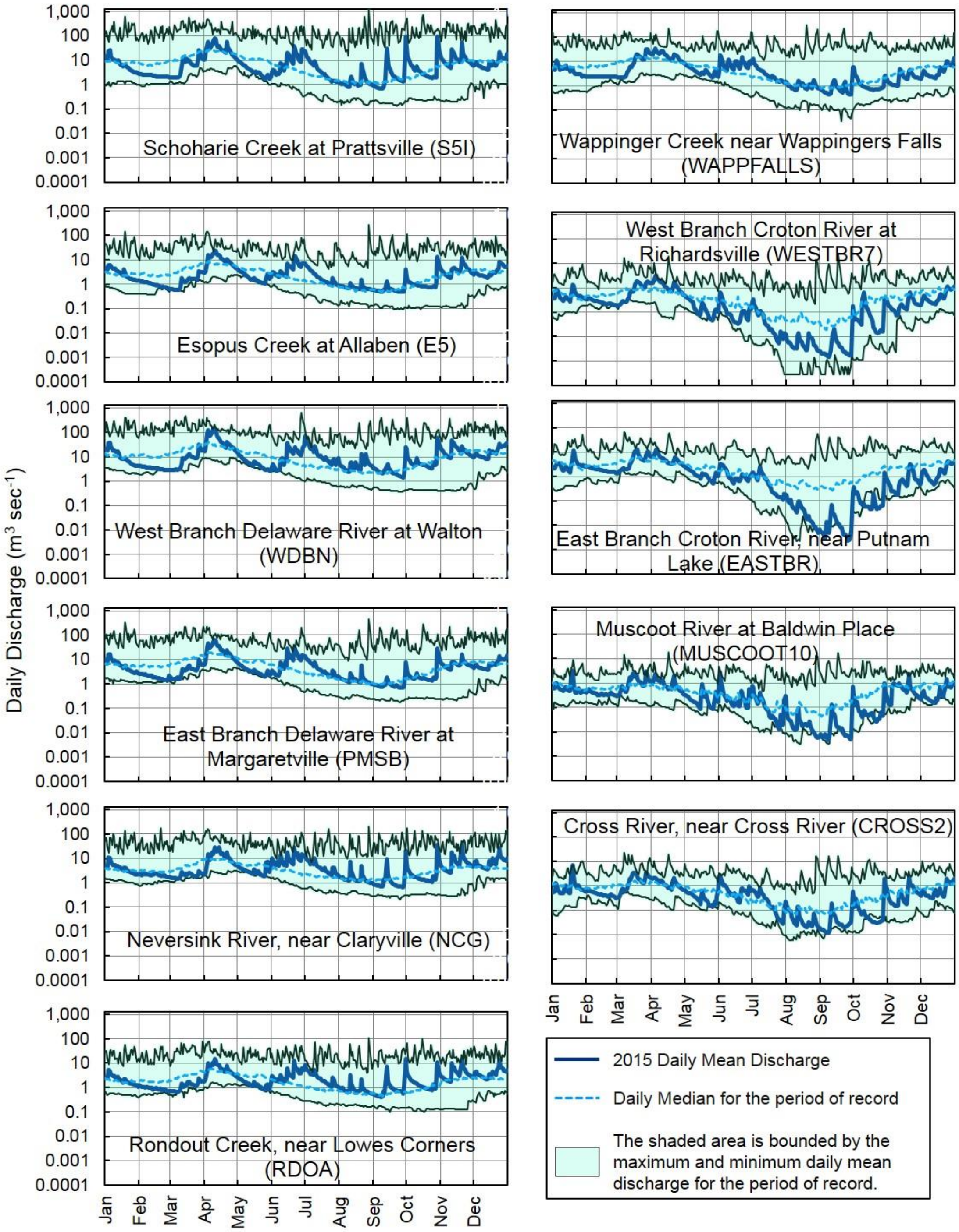


Figure 2.3 Daily mean discharge for 2015 at selected USGS stations.Daily data from Oct. 1-Dec. 31, 2015 are provisional and subject to revision until they have received final approval from the USGS.

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 2010). 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, 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 one-year, ten-year, and one hundred-year, 24-hour events, and the 90% 24-hour rainfall event (see Figures 2.4 through 2.7). The one-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 ten-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 one hundred-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 1% chance of occurring in any given year. The 90% storm indicates the rainfall total that is greater than or equal for 90% of all events of 24-hour duration. Figures 2.4 through 2.7 are isohyetal maps that present estimates of these four rainfall depths for New York State. Where construction activities require DEP review and approval of an SWPPP in accordance with the WR&R, these maps may be used in the design of stormwater management practices. They are available in Chapter 4 of the New York State Stormwater Management Design Manual (updated January 2015) ("Design Manual") or at http://www.dec.ny.gov/docs/water_pdf/swdm2015chptr04.pdf. Alternatively, as precipitation data are updated, designers may use the most recent rainfall frequency values developed by acceptable sources as noted in the Design Manual.

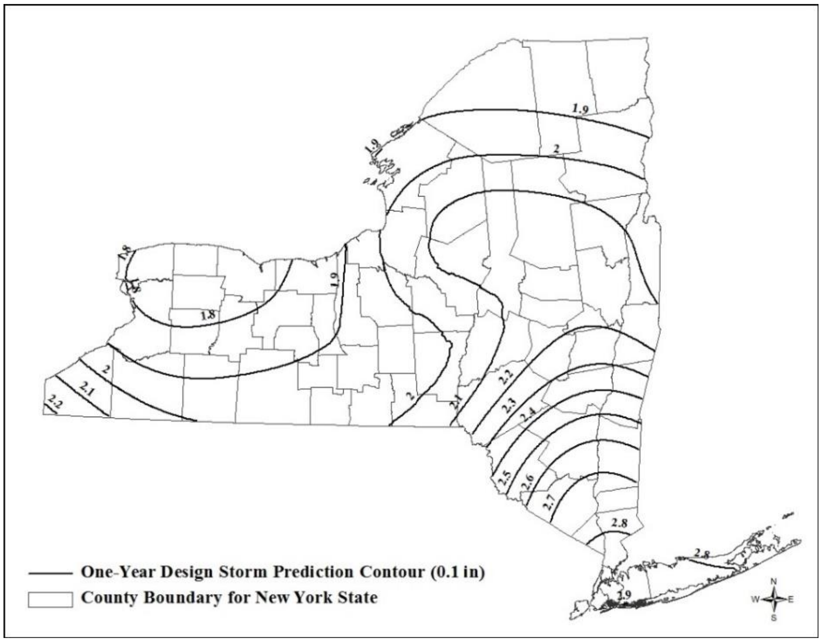


Figure 2.4 The one-year, 24-hour design storm in New York State, from the 2015 Stormwater Management Design Manual.

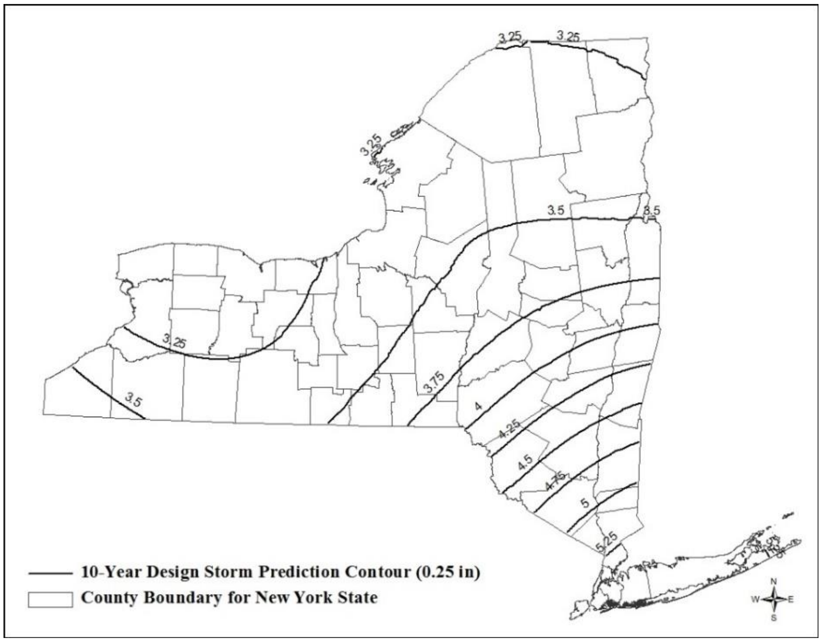


Figure 2.5 The ten-year, 24-hour design storm for New York State, from the 2015 Stormwater Management Design Manual.

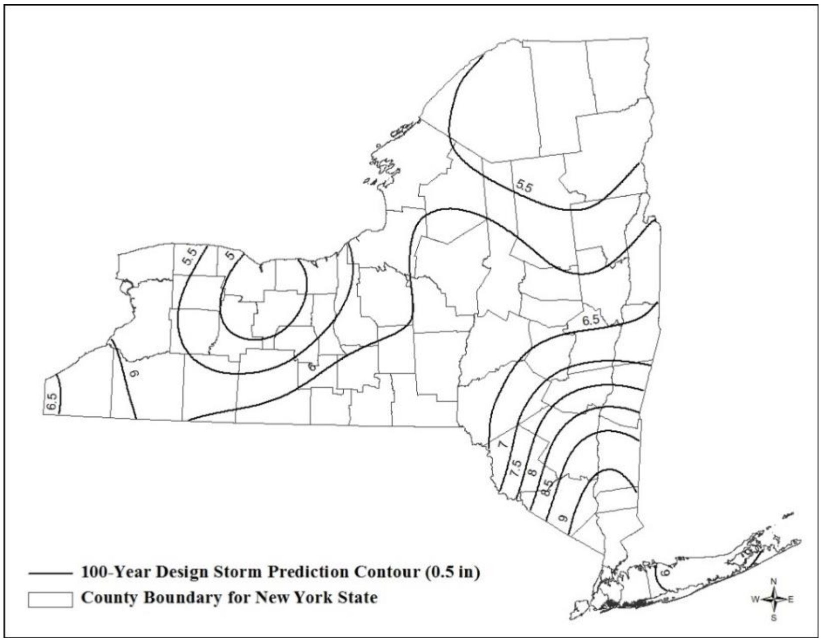


Figure 2.6 The one hundred-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual.

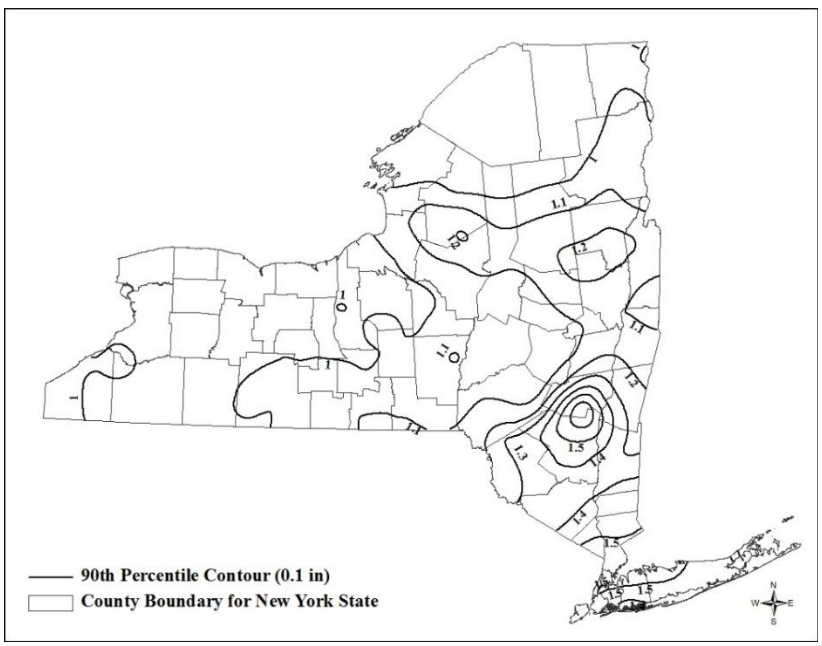


Figure 2.7 90th percentile, 24-hour rainfall for New York State, from the 2015 Stormwater Management Design Manual.

2.5. Reservoir Usable Storage Capacity in 2015

Ongoing daily monitoring of reservoir storage allows DEP to compare the present system-wide storage (including Kensico Reservoir) against what is considered “normal” for any given day of the year (Figure 2.8). “Normal” system-wide usable storage (i.e. capacity) levels were determined by calculating the average daily storage from 1991 to 2014. An absence of melting events due to consistent cold temperatures caused system capacity to decline well below normal during the winter of 2014-15. However, melting of the large snowpack in early April quickly filled the system to 98% capacity before May 1. June was extremely wet in the Catskill/Delaware system and capacity exceeded 100% by early July. As usual capacity declined throughout the summer, but still remained above normal until November when it briefly dipped to 75%. Capacity increased at an above normal rate for the remainder of the year due to above average rainfall in the Catskill/Delaware system during the November-December period.

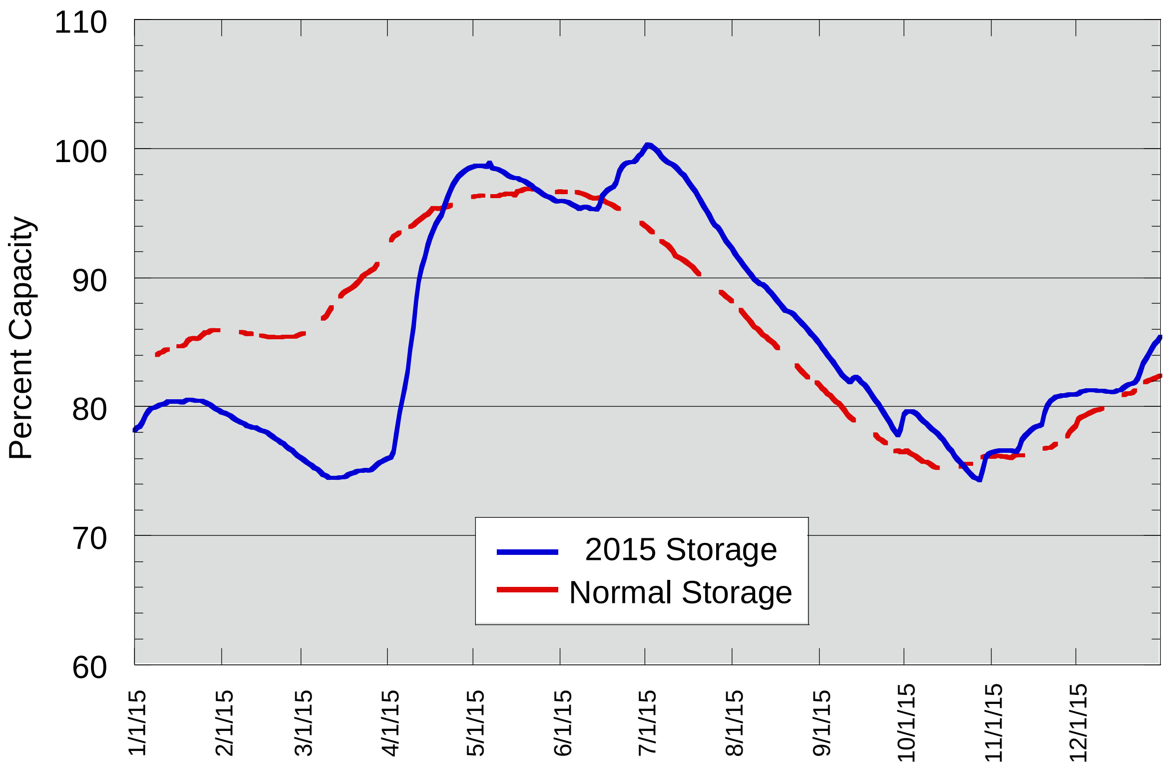


Figure 2.8 2015 System-wide usable storage compared to normal storage. Storage greater than 100% is possible when the reservoirs are spilling or when the water surface elevation is greater than the spillway elevation.

3. Water Quality

3.1. Monitoring Overview

Water quality samples are collected from streams, reservoirs, and aqueduct locations throughout the NYC water supply (Appendix A, Figures 1-7). Routine stream samples used in this report are collected on a fixed frequency, typically monthly schedule. Unless otherwise indicated, reservoir samples are obtained from multiple sites and multiple depths, at routine sampling frequencies once per month from April through November. Aqueduct keypoint samples are collected year round at frequencies that vary from daily to weekly. Note that although Kensico Reservoir is usually operated as a source water, the reservoir can be by-passed so that any or all of the following reservoirs can be operated as source waters: Rondout, Ashokan-East Basin, Ashokan-West Basin, and West Branch Reservoirs. When operating as a source, water from these reservoirs would be regulated by the Surface Water Treatment Rule (SWTR).

3.2. Reservoir Turbidity Patterns in 2015

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 easily erodible lacustrine clay deposits found in these watersheds.

With the exception of Cannonsville Reservoir, 2015 turbidity levels in the Catskill/Delaware System reservoirs were close to or well below their respective historic 25th percentile levels (Figure 3.1). (An explanation of the boxplots used in this and other figures in this chapter is provided in Appendix B.)

The best explanation for the low turbidity was the low rainfall amounts observed throughout most of the NYC water supply watersheds in 2015 (Figure 2.1). Only the Cannonsville Basin was above average for the year (45.4 inches versus a historic 44.9 inches) with June being particularly wet (10.7 inches). However, rain events in August, November and especially in April produced the highest turbidity levels in Cannonsville during the year. The other Catskill/Delaware basins were well below average with 2015 annual deficits averaging 5.7 inches. Three large rain events, especially significant in the Ashokan-West Basin, did occur on September 12 (5.8 inches), September 29 (7.3 inches) and on October 28 (2.9 inches), but turbidity remained relatively low, with median turbidities ranging from 9-12 NTU, in the reservoir during the September-November period.

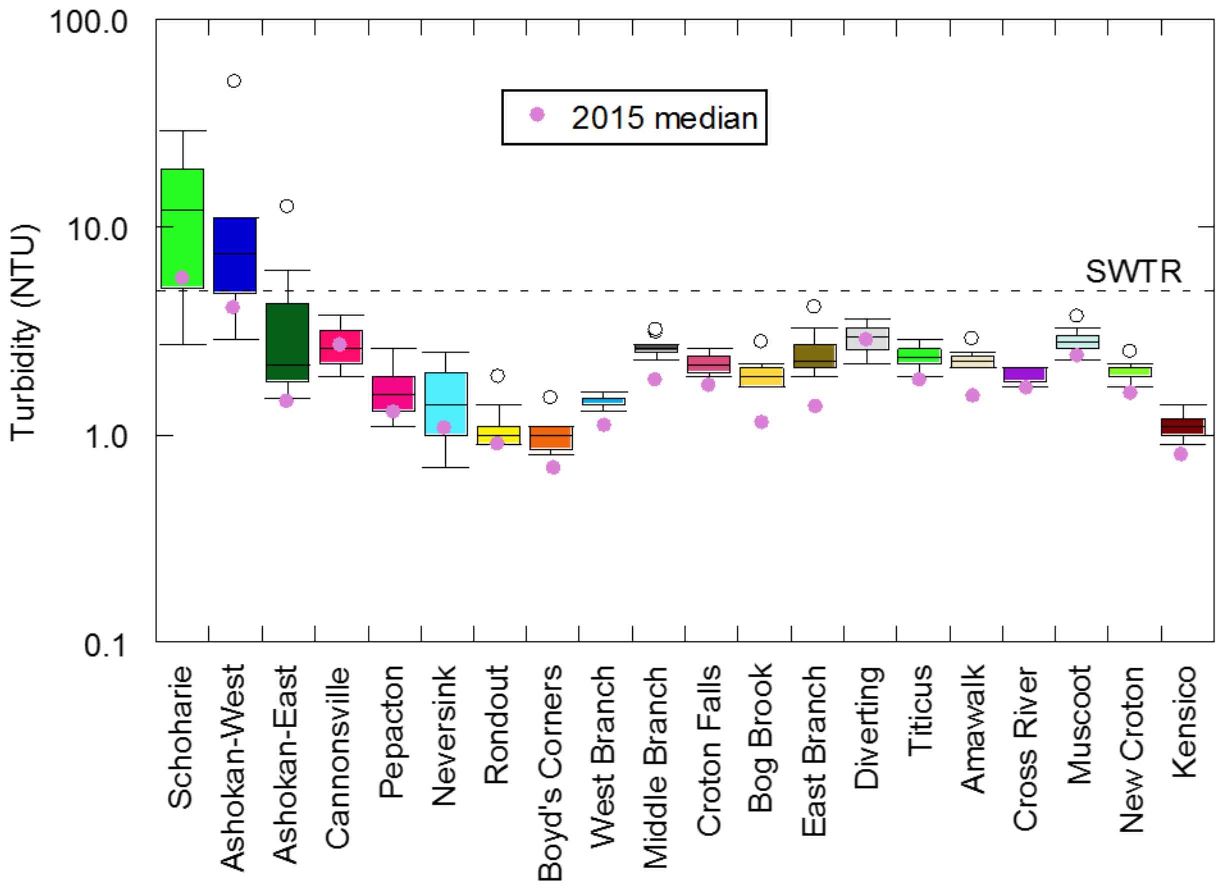


Figure 3.1 Annual median turbidity in NYC water supply reservoirs (2015 vs. 2005-2014) with the 2015 values displayed as a solid dot. The dashed line represents the standard for source waters as a reference.

West Branch Reservoir, which receives inputs from both the Delaware and Croton Systems, also had low turbidity levels in 2015. Low turbidity water transfers from Rondout and low turbidity inputs (due to both low concentration and flow) from local Croton streams resulted in an annual median turbidity of 1.1 NTU for West Branch in 2015. The slightly higher historic turbidity of West Branch Reservoir compared to its main inputs, Rondout Reservoir and Boyd's Corners Reservoir, is largely due to higher summer-fall turbidity associated with anoxic conditions in the hypolimnion of West Branch. Turbidity at Kensico Reservoir, the terminal reservoir for the Catskill and Delaware Systems, was expectedly low given the high clarity of water received from both systems in 2015.

Similar to the Catskill/Delaware Systems, turbidity in the Croton System was generally normal to well below normal in 2015 (reservoirs shown in Figure 3.1, controlled lakes in Table 3.1). The low turbidity is probably related to the lack of runoff events in the Croton region in 2015. Annual rainfall in the region was 10.9 inches less than the average rainfall from the previous 10-year period.

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

Lake	Median Turbidity (2005-14)	Median Turbidity (2015)
Gilead	1.6	1.2
Gleneida	1.5	1.6
Kirk	4.3	4.2

3.3. Coliform-Restricted Basin Assessments in 2015

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 2010) 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 basins to decide which, if any, should be given "coliform-restricted" determinations.

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 basins" which include Kensico, West Branch, New Croton, Ashokan, and Rondout Reservoirs. The coliform-restricted assessments of these basins 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).

3.3.1. Terminal Basin Assessments

In 2015, 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 > 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 had fecal coliform counts that were well below the 10% threshold and met the criteria for non-restricted basins for both six-month assessment periods in 2015 (Table 3.2).

Table 3.2 Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2015.

Reservoir basin	Effluent keypoint	2015 assessment
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.

3.3.2. Non-Terminal Assessments

Section 18-48(a)(1) requires that non-terminal basins be assessed according to 6 NYCRR Part 703 for total coliform. 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 basin. If both the median value and more than 20% of the total coliform counts for a given month exceed the values ascribed to the reservoir class then the reservoir class standard has been exceeded and the non-terminal reservoir should be restricted. Table 3.3 provides a summary of the coliform-restricted calculation results for the non-terminal reservoirs. In 2015, there were few exceedances of the Part 703 standard for total coliform during the sampling season (Table 3.3). These occurred in May in Boyds Corners and Diverting Reservoirs, with most of the occurrences in summer months (July–August) in Croton Falls, Cross River, Diverting, Cannonsville, Pepacton, Neversink, and Schoharie Reservoirs. There were a few exceedances in the fall period (September–November) for Croton Falls, Cannonsville, and Schoharie Reservoirs and Lake Gleneida. Detailed results of monthly calculations are provided in Appendix C.

Total coliform bacteria originate from a variety of natural and anthropogenic (human-related) sources. However, Section 18-48(d)(1) states 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 2015. There were no other data indicating an anthropogenic source.

Table 3.3 Coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2015.

Reservoir	**Class[1]**	**Standard Monthly Median / >20% (Total coliforms 100 mL^{-1})**	**Months that exceeded the standard /months of data**	**Months not evaluated due to TNTC data[2]**
Amawalk	A	2400/5000	0/8	1
Bog Brook	AA	50/240	0/8	1
Boyd's Corners	AA	50/240	1/5	0
Croton Falls	A/AA	50/240	3/8	0
Cross River	A/AA	50/240	2/8	0
Diverting	AA	50/240	3/8	0
East Branch	AA	50/240	0/8	0
Lake Gilead	A	2400/5000	0/8	0
Lake Gleneida	AA	50/240	1/8	0
Kirk Lake	B	2400/5000	0/7	1
Muscoot	A	2400/5000	0/8	0
Middle Branch	A	2400/5000	0/8	0
Titicus	AA	50/240	0/8	0
Cannonsville	A/AA	50/240	2/8	1
Pepacton	A/AA	50/240	2/8	0
Neversink	AA	50/240	1/9	1
Schoharie	AA	50/240	3/9	1

[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 higher standard was applied.
[2]Determination of the monthly median or individual sample exceedance of the standard was not possible for TNTC (too numerous to count) samples.

3.4. Reservoir Total and Fecal Coliform Patterns in 2015

Total coliform and fecal coliform bacteria are regulated by the Surface Water Treatment Rule (SWTR) at raw water intakes with regulatory levels of 100 coliform 100mL^{-1} and 20 coliform 100mL^{-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 fecal coliform results are presented in Figure 3.2 and reservoir total coliform results in Figure 3.3. 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 is easier to discern differences among reservoirs because a large percentage of coliform data are generally below the detection limit.

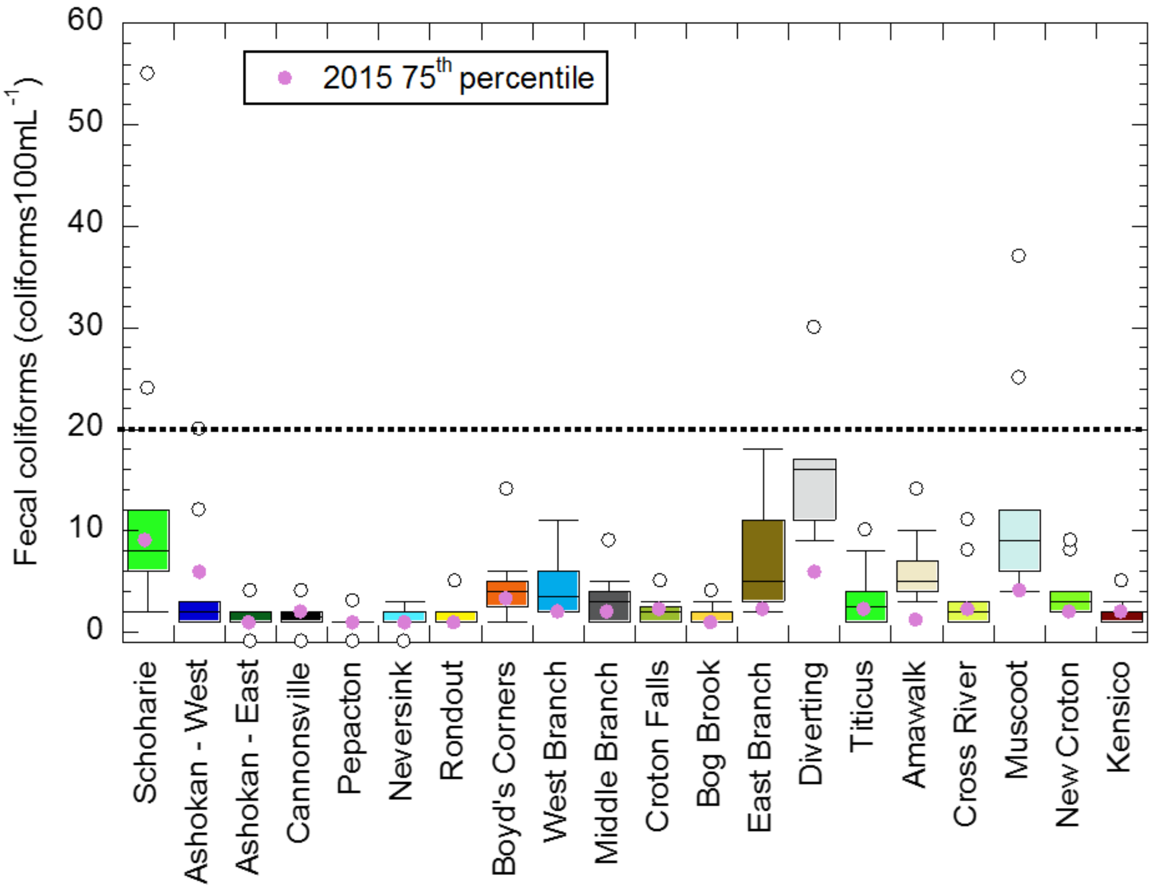


Figure 3.2 Annual 75th percentile of fecal coliforms in NYC water supply reservoirs (2015 vs. 2005-2014) with the 2015 values displayed as a solid dot. The dashed line represents the SWTR standard for source waters as a reference.

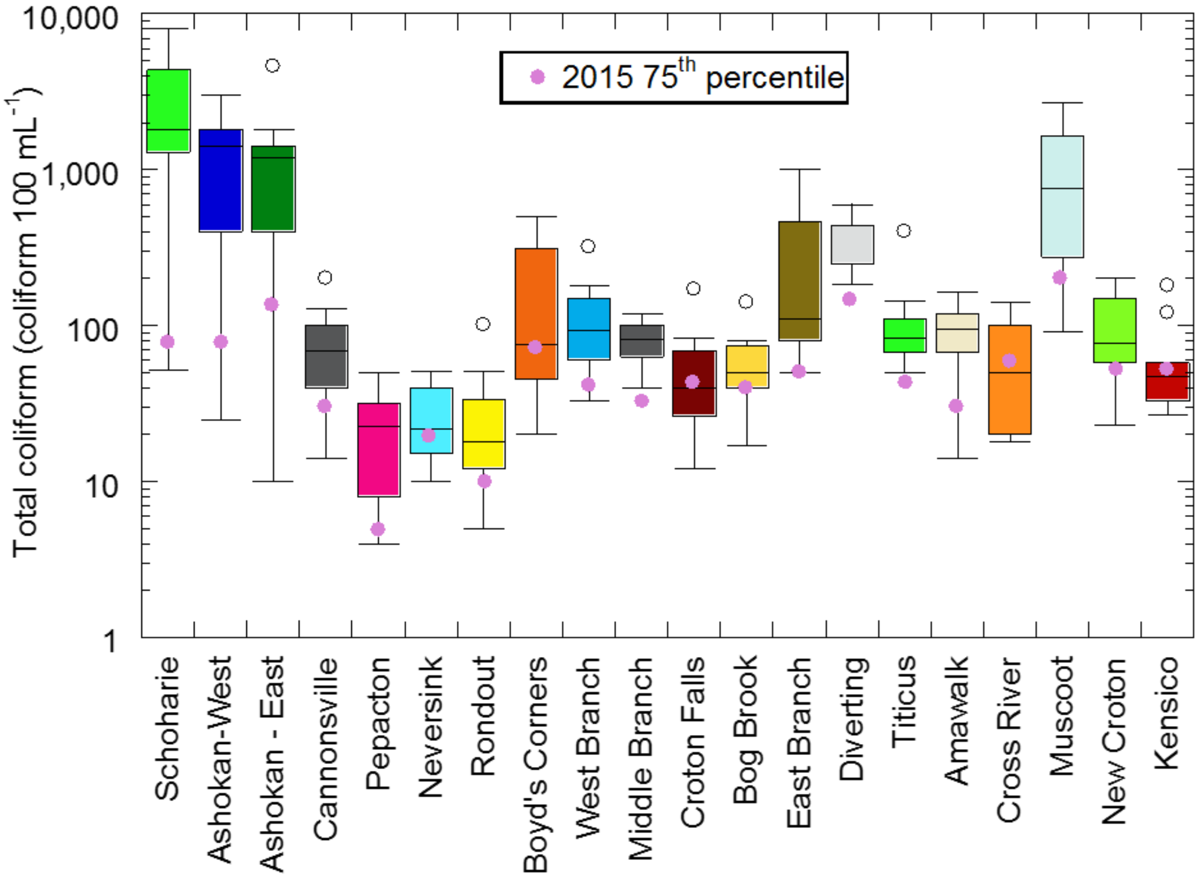


Figure 3.3 Annual 75th percentile of total coliforms in NYC water supply reservoirs (2015 vs. 2005-2014) with the 2015 values displayed as a solid dot.

With the exception of fecal coliform levels at Ashokan-West Basin and to a lesser extent at Schoharie and Cannonsville, fecal and total coliform counts throughout the water supply were low (or low-to-normal) in 2015 coinciding with the generally low rainfall. That being said, the exceptions noted for 2015 fecal coliform levels at Ashokan-West Basin, Schoharie and Cannonsville appear to be related to large rain events in September and October and in the case of Cannonsville, multiple storms in June. Historically, the highest total coliform levels 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 levels in the Catskill System reservoirs. However, in 2015, Catskill total coliform counts were 9 to 23 times lower than historical levels and consistent with levels typically observed for the rest of the water supply system. The large rain events in September and October did not produce much turbidity suggesting that transport of total coliforms via entrained soil particles was not important in 2015.

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

Lake	Historical total coliforms (75^{th} percentile 2005-14)	Current total coliforms (75^{th} percentile 2015)	Historical fecal coliforms (75^{th} percentile 2005-14)	Current fecal coliforms (75^{th} percentile 2015)
Gilead	21	4	2	<1
Gleneida	20	1	1	<1
Kirk	150	40	3	2

3.5. Phosphorus-Restricted Basin Assessments in 2015

The phosphorus-restricted basin status determination for 2015 is presented in Table 3.5 and was derived from two consecutive assessments (2010-2014 and 2011-2015) using the methodology described in Appendix D. Reservoirs and lakes with a total phosphorus concentration geometric mean that exceeds the benchmarks in the New York City Watershed Rules and Regulations (DEP 2010) for both assessments are classified as restricted. Figure 3.4 graphically shows the phosphorus restriction status of the City's reservoirs and controlled lakes along with their 2015 geometric mean total phosphorus concentrations.

Table 3.5 Phosphorus-restricted reservoir basins for 2015.

Reservoir basin	2010-2014 Assessment (mean + S.E.)[1] (µg L^{-1})	2011-2015 Assessment (mean + S.E.)[1] (µg L^{-1})	Phosphorus restricted status[2]
Non-Source Waters (Delaware System)			
Cannonsville	15.5	15.0	Non-restricted
Pepacton	10.0	9.8	Non-restricted
Neversink	8.5	8.5	Non-restricted
Non-Source Waters (Catskill System)			
Schoharie	22.4	22.2	Non-restricted
Non-Source Waters (Croton System)			
Amawalk	21.4	21.2	Restricted
Bog Brook	26.3	23.3	Restricted
Boyd's Corners	9.8	9.9	Non-restricted
Diverting	29.8	29.4	Restricted
East Branch	31.0	28.6	Restricted
Middle Branch	34.3	34.4	Restricted
Muscoot	30.1	30.0	Restricted
Titicus	25.8	25.2	Restricted
Lake Gleneida	27.0	29.7	Restricted
Lake Gilead	29.8	29.1	Restricted
Kirk Lake	32.8	33.3	Restricted
Source Waters (all systems)			
Ashokan-East	10.3	10.0	Non-restricted
Ashokan-West	18.2	17.5	Non-restricted
Cross River	17.5	17.5	Restricted
Croton Falls	20.7	21.1	Restricted
Kensico	6.8	7.0	Non-restricted
New Croton	17.7	17.8	Restricted
Rondout	8.0	8.0	Non-restricted
West Branch	11.7	11.9	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}.

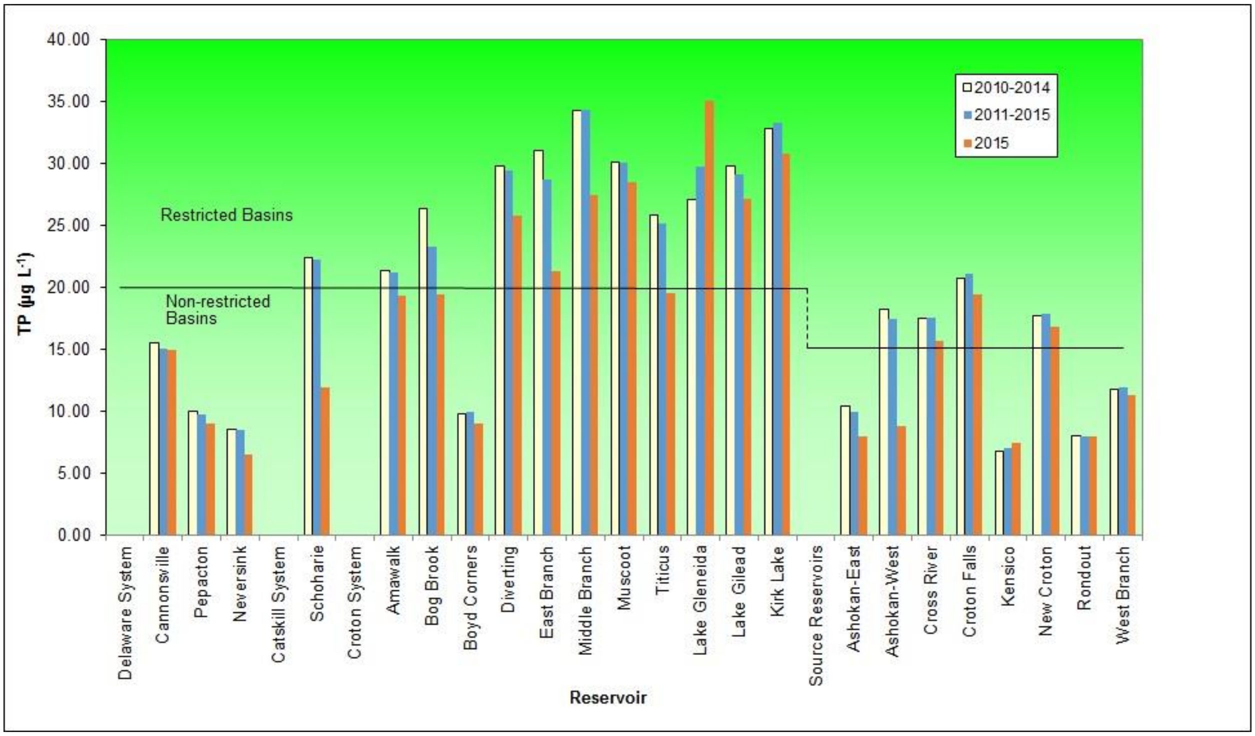


Figure 3.4 Phosphorus-restricted basin assessments, with the current year (2015) geometric mean phosphorus concentration displayed for comparison. The horizontal solid lines at 20 µg L^{-1} and 15 µg L^{-1} represent the WR&R standard for non-source and source waters, respectively.

Some notable features of the phosphorus-restricted basin status determinations in 2015 include:

• The Delaware System reservoirs remained non-restricted with respect to total phosphorus (TP). There was little change between the two evaluation periods (2010-2014 and 2011-2015) as shown in Table 3.5.

• In the Catskill System, the five-year average for the period of 2011-2015 was still affected by the influx of phosphorus associated with Tropical Storms Irene and Lee in 2011, and Schoharie Reservoir and Ashokan-West Basin remained above the phosphorus benchmarks of 20 and 15 µg L^{-1}, respectively. Both Schoharie and Ashokan-West Basin were classified as non-restricted based on professional judgment due to low algal productivity. Carlson's Trophic State Index (TSI) values were calculated from chlorophyll a concentrations (see Section 3.8) and the TSI values were generally low. Both basins fell at or near the mesotrophic range (TSI of 40-50); median TSI values were 42.5 and 39.0 for Schoharie and Ashokan-West Basin, respectively. Median turbidity was 5.8 NTU in Schoharie and 4.1 NTU for Ashokan-West Basin in 2015. Phytoplankton response was light-limited due to higher turbidity in these reservoirs, and supplemental data (chlorophyll, turbidity, and Secchi transparency) support the determination of "non-restricted" TP status for Schoharie and Ashokan-West Basin.

• The Croton System reservoirs remained unchanged in terms of their phosphorus-restricted status for 2015. All reservoirs in the Croton system are listed as "restricted" with the exception of Boyd's Corners, which remained non-restricted, with a low value of 9.9 µg L^{-1} for the latest assessment period and 9.8 µg L^{-1} for the previous assessment period (Table 3.5).

• Source water reservoirs have a limit of 15 µg L^{-1} and as in the preceding assessment period, Kensico, Ashokan-East Basin, Rondout, and West Branch Reservoirs were non-restricted for the current assessment period (Table 3.5). As noted previously Ashokan-West Basin was not designated as phosphorus restricted for the current assessment due to low algal productivity that was light-limited rather than nutrient-limited.

3.6. Reservoir Total Phosphorus Patterns in 2015

Precipitation, and runoff generated by precipitation, are important mechanisms by which total phosphorus (TP), often bound to soil particles, 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.

Due to generally below average precipitation annual TP concentrations in all Catskill and Delaware reservoirs ranged from low to near the long-term median in 2015 (Figure 3.5). Even Cannonsville Reservoir, which was the only reservoir to experience above average rainfall in 2015, had relatively low TP compared to the past 10 years. These results may provide evidence that agricultural BMPs were successful at containing TP on the farms, although declining domesticated animal populations in the watersheds could also be a factor.

The annual TP concentration at West Branch Reservoir was the same as its 10-year historical median. Note that West Branch TP is typically higher than TP from its primary inputs; Rondout Reservoir and Boyd's Corners Reservoir. The higher TP in West Branch is mainly due to the release of phosphorus from anoxic sediments within the reservoir. Local small stream inputs are an additional source but their influence was probably greatly reduced in 2015 due to low rainfall. The two local streams for which we have data together had a median TP of 20 µg L^{-1} in 2015.

The annual TP concentration in Kensico Reservoir was equivalent to its historical median in 2015 (7µg L^{-1}), a result of the low TP concentrations of its primary inputs: Rondout Reservoir, and the East Basin of Ashokan Reservoir.

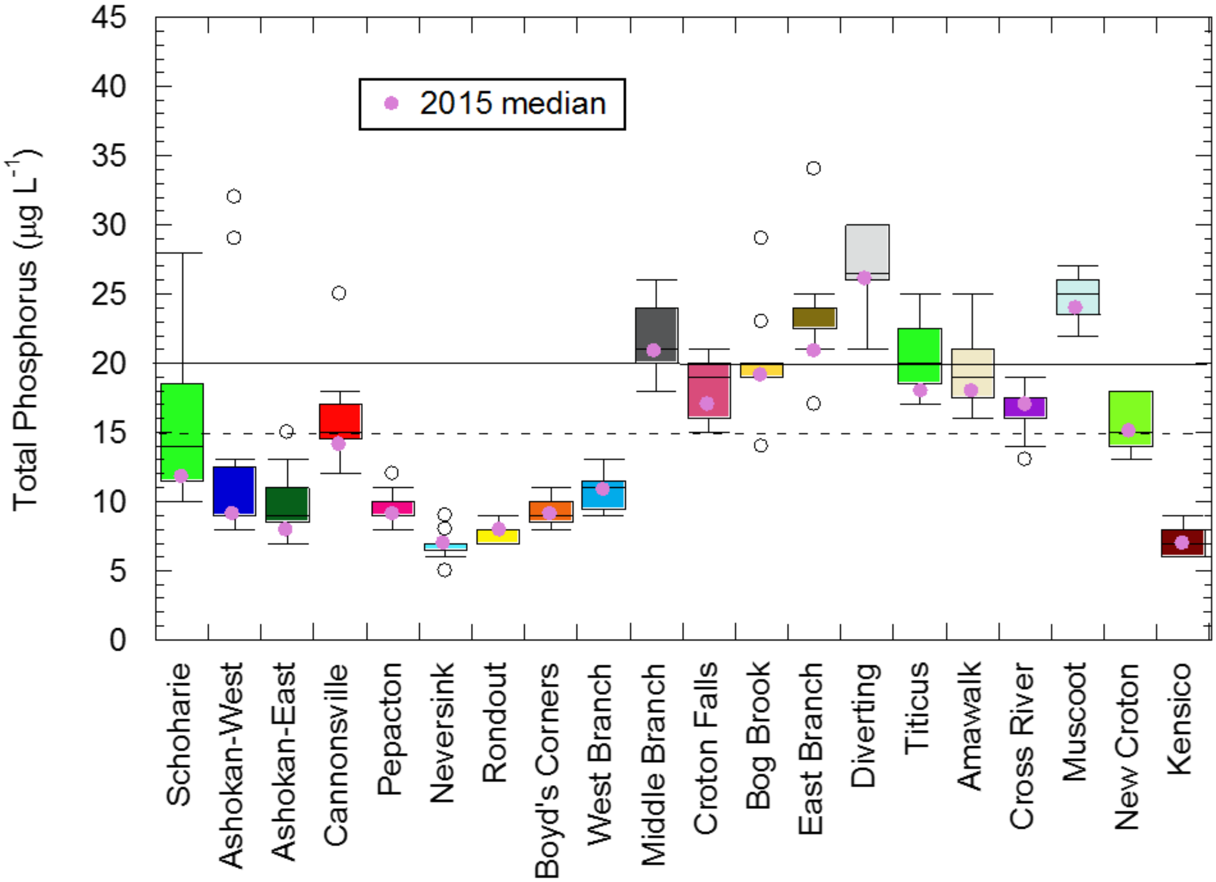


Figure 3.5 Annual median total phosphorus in NYC water supply reservoirs (2015 vs. 2005-2014) with the 2015 values displayed as a solid dot. The horizontal dashed line at 15 µg L^{-1} refers to the NYC Total Maximum Daily Loads (TMDL) guidance value for source waters. The horizontal solid line at 20 µg L^{-1} refers to the NYSDEC ambient water quality guidance value appropriate for reservoirs other than source waters.

Compared to the Catskill and Delaware watersheds, the Croton watershed has a greater abundance of phosphorus sources; there are 60 wastewater treatment plants, 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 3.5) and controlled lakes (Table 3.6) are much higher than in the reservoirs of the Catskill and Delaware Systems. In 2015, most Croton reservoirs were on the low side of historical levels, ranging from 9 to 26 µg L^{-1}. Higher than normal concentrations were only observed at the controlled lakes: Kirk, Gleneida and Gilead. Kirk Lake is extremely shallow (approx. 7 m deep) and observed choppy conditions during two of the three sample collections may have stirred up particulate phosphorus from the bottom. Low oxygen concentrations in May and an algal bloom in October may be additional factors. Elevated TP as well as dissolved phosphorus in mid-depth and bottom samples at Gilead and Gleneida was associated with anoxic conditions in July and October suggesting release of phosphorus from bottom sediments.

Efforts to reduce phosphorus loads in the Croton watershed are ongoing. Many WWTPs have been upgraded, while 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's Corners, West Branch, Croton Falls and Cross River watersheds. These efforts, together with below average rainfall during the year, are likely responsible for the relatively low TP concentrations observed in much of the Croton System in 2015.

Table 3.6 Total phosphorus summary statistics for NYC controlled lakes (µg L^{-1}).

Lake	**Median Total Phosphorus (2005-14)**	**Median Total Phosphorus (2015)**
Gilead	20	23
Gleneida	16	22
Kirk	27	42

3.7. Terminal Reservoir Comparisons to Benchmarks in 2015

The New York City 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 2015 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 System 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.

Comparison of reservoir water quality data for 2015 to the benchmark values (Table 3.7) is provided in Appendix E for all reservoirs. 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 2015 include:

For the majority of reservoir samples, pH was circumneutral (6.5-8.5). Occurrences of pH exceeding 8.5 were associated with algal blooms. The pH values in Kensico were out of range for 37% of the samples, while 25% of West Branch samples exceeded the benchmark. In New Croton Reservoir, pH exceeded the water quality benchmark of 8.5 for 17% of the samples. In the WOH reservoirs, with lower alkalinities, samples outside the benchmark range for pH generally fell below 6.5, with a few samples exceeding a pH of 8.5. These samples exceeding a pH value of 8.5 were associated with seasonal increases in algal growth. Samples out of range included 27% of Ashokan-East Basin, 15% of Ashokan-West Basin, and 32% of Rondout samples.

As in 2014, all of the 2015 chloride samples in New Croton exceeded the Croton System benchmarks of the 40 mg L^{-1} single sample maximum standard and the annual mean benchmark of 30 mg L^{-1}. All 2015 West Branch chloride samples exceeded the benchmarks when compared to the Catskill/Delaware System standards, with 100% of the samples exceeding the single sample maximum of 12.0, and the mean of 23.9 exceeding the annual mean standard of 8.0 mg L^{-1}. In contrast to 2014, when Rondout, Pepacton, Neversink, Ashokan-East Basin, and Ashokan-West Basin were below the limits for these benchmarks, there were exceedances of the mean for all West of Hudson reservoirs except Neversink. Kensico exceeded both the single sample maximum and annual mean benchmarks. All chloride samples were well below the health secondary standard of 250 mg L^{-1}.

Turbidity levels in Kensico, Rondout, and West Branch did not exceed the single sample maximum of 5 NTU in 2015. Ashokan-East Basin exceeded 5 NTU for 6% of the routine monitoring samples, a decline from 22% in the previous year. Ashokan-West Basin exceeded 5 NTU for 30% of the reservoir samples, a decline from 47% in 2014. Turbidity in Cannonsville Reservoir was higher than usual due to the intentional drawdown of the reservoir that commenced in July, and the single sample maximum was exceeded for 25% of the samples for the season.

The TP concentration for the single sample maximum of 15 µg L^{-1} was not exceeded in Rondout, while only one sample exceeded the benchmark for Kensico. Ashokan-West Basin surpassed the benchmark on four occasions (same as in 2014) while Ashokan-East Basin had three excursions compared to six in 2014. West Branch exceeded the benchmark for 19% of the samples, a slight increase from 16% in the previous year, and New Croton exceeded the benchmark for 52% of samples in 2014, an increase from 48% of the samples in 2014. Many excursions at New Croton occurred during the summer when phosphorus was solubilized from anoxic sediments or soon after turnover in the fall. Excursions could also be linked to upstream sources such as the Muscoot Reservoir and the Kisco River. Nitrate samples exceeded the single sample maximum in New Croton for 20% of the samples, and also exceeded the ammonia benchmark for both the single sample maximum (20% of samples) and annual mean concentration (0.11 as compared with 0.05 mg L^{-1}). No other terminal reservoir exceeded the benchmark values for nitrate or ammonia, with the exception of West Branch, which exceeded the ammonia benchmark for two samples, representing 3% of the samples collected in 2015.

Phytoplankton counts did not exceed the 2000 ASU mL^{-1} benchmark in Kensico, West Branch, Rondout, Ashokan-West Basin and Ashokan-East Basin in 2015. For New Croton Reservoir, a single sample exceeded both the single sample maximum of 2000 ASU mL^{-1} and the 1000 ASU mL^{-1} sample maximum for the dominant genus. In New Croton Reservoir, chlorophyll a exceeded the single sample maximum for a single sample, representing 2% of the samples collected. None of the terminal reservoirs exceeded their annual mean benchmarks. Color in all terminal reservoirs was above the benchmark of 15 units in 2015. New Croton had the highest number of exceedances (92% of the samples exceeded the single sample maximum), while Ashokan-East Basin had the least (1 sample representing 2% of samples collected). West Branch ranked second in the number of exceedances for color, with 54% of the samples exceeding the single sample maximum.

Fecal coliform counts did not exceed the single sample maximum in Rondout and West Branch in 2015. One sample in New Croton and Ashokan-East Basin exceeded the single sample maximum of 20 fecal coliforms 100mL^{-1}, 3 samples exceeded the benchmark (2% of samples collected) in Kensico, and 2 samples exceeded the benchmark (3% of samples collected) in Ashokan-West Basin in 2015.

Table 3.7 Reservoir and controlled lake benchmarks as listed in the WRR (DEP 2010a).

Analyte	Basis[1]	Croton System		Catskill/Delaware System	
		Annual Mean	Single Sample Maximum	Annual Mean	Single Sample Maximum
Alkalinity (mg L^{-1})	(a)	≥40.00		≥40.00	
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)	0.010	0.015	0.007	0.012
Color (Pt-Co units)	(b)		15		15
Dominant genus (ASU mL^{-1})	(c)		1000		1000
Fecal coliform (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 (ASU mL^{-1})	(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) NYSDOH Drinking Water Primary Standard.
[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

3.8. Reservoir Trophic Status in 2015

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) use commonly measured variables (i.e., chlorophyll a, TP, and Secchi transparency) to delineate the trophic state of a body of water. TSI based on chlorophyll a concentration is calculated as:

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

where CHLA is the concentration of chlorophyll *a* in $\mu g\ L^{-1}$.

The Carlson TSI 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 state 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 generally produce better water quality at the tap; eutrophic waters, by contrast, may be aesthetically unpleasant from a taste and odor perspective.

Historical (2005-2014) annual median TSI based on chlorophyll a concentration is presented in boxplots for all reservoirs in Figure 3.6. The 2015 annual median TSI appears in the figure as a circle containing an "x". Results for the East of Hudson controlled lakes are provided in Table 3.8. This analysis generally indicates that all West of Hudson reservoirs (including Kensico and West Branch) and only three East of Hudson reservoirs (Boyd's Corners, Gilead and Gleneida) usually fall into the mesotrophic category. The remaining East of Hudson reservoirs tend to fall into the meso-eutrophic to eutrophic range.

In 2015, algal productivity was low to normal in all Catskill-Delaware system reservoirs. For the most part, the TSI for all reservoirs were consistently low throughout the year. However, Cannonsville did experience a temporary TSI increase in August-September. This increase occurred when the reservoir elevation was very low due to low rainfall totals in August and because of water removal in mid-to-late July to repair bore holes below the dam.

Due in part to West Branch Reservoir operation in recent years, which resulted in a greater proportion of warmer, more nutrient rich water entering West Branch from local streams, this reservoir became mildly eutrophic in the 2012-2014 period. In 2015 a significant improvement in trophic state was observed for West Branch. Two factors were probably responsible for the improvement; first, a large infusion of cold, low nutrient Rondout water was diverted to West Branch through much of April and second, low rainfall in 2015 which resulted in greatly diminished summer-fall flows to West Branch from its warmer, more nutrient-rich local streams.

Kensico Reservoir, the terminal reservoir for the Catskill-Delaware System, is primarily a blend of Ashokan-East Basin and Rondout water with varying amounts from West Branch, and small contributions from local Kensico watershed streams. The diversion of lower than average productivity water from Ashokan, Rondout and West Branch culminated in an oligotrophic rating for Kensico in 2015.

In contrast to 2014, TSI was lower in most reservoirs and controlled lakes of the Croton System in 2015 (Figure 3.6, Table 3.8). One factor contributing to the low productivity was the relatively low phosphorus levels observed in 2015 (Figure 3.5). The low nutrient levels may, in part, be due to reduced transport to streams as rainfall was exceptionally low in 2015. Rain was about 10 inches below average for the year and was especially scarce in August (1.6 in.) and October (0.9 in.).

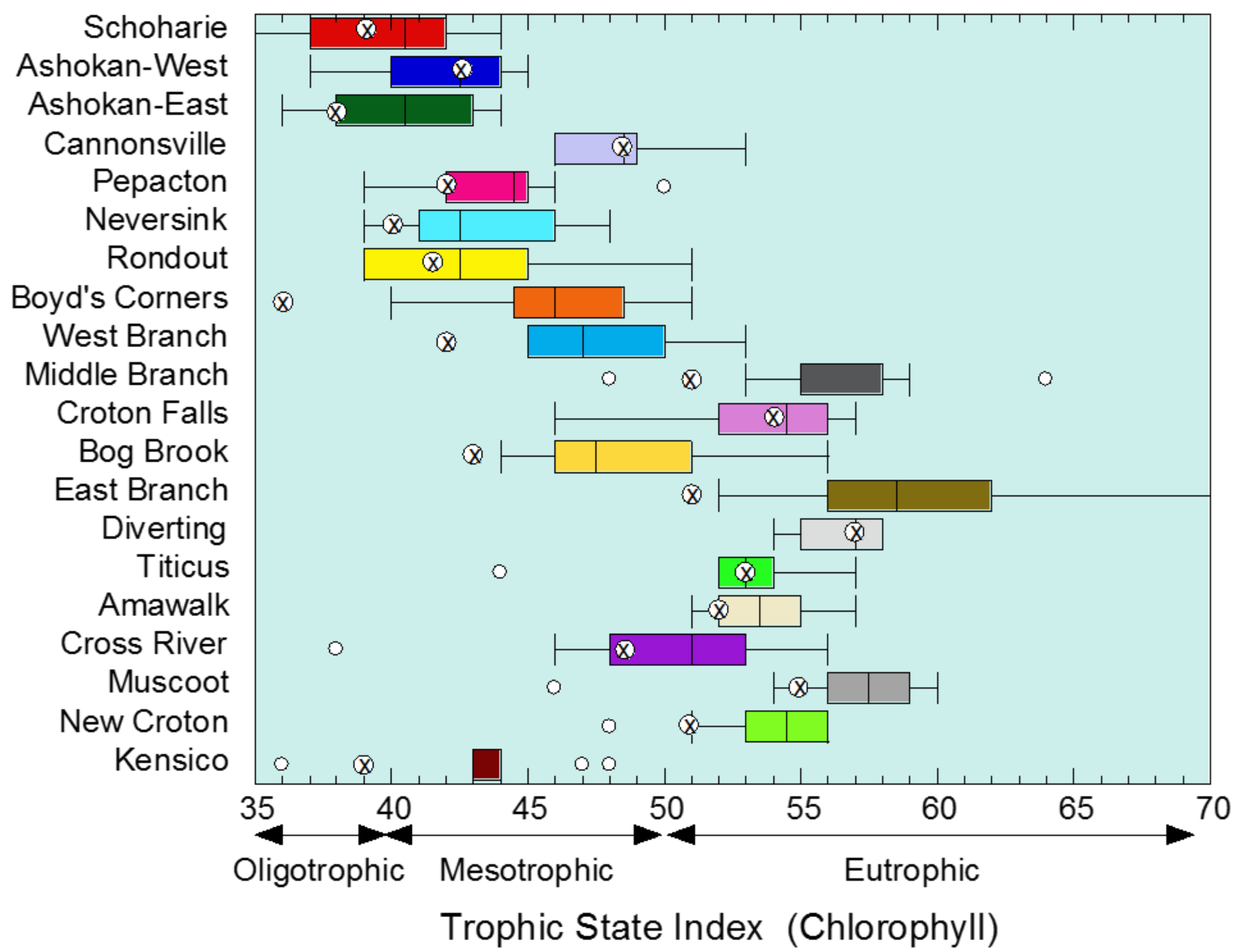


Figure 3.6 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2015 vs. 2005-2014) with the 2015 values displayed as a circled x. In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per month from May through October. TSI is based on Chlorophyll a concentration.

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

Lake	Median TSI (2005-14)	Median TSI (2015)
Gilead	47	42
Gleneida	43	42
Kirk	57	59

3.9. Water Quality in the Major Inflow Streams in 2015

The stream sites discussed in this section are listed in Table 3.9, with locations shown in Figure 3.7. 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 six of the Croton reservoirs. In other words, 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. The exception is New Croton Reservoir, whose major inflow is from the Muscoot Reservoir release; the 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's 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

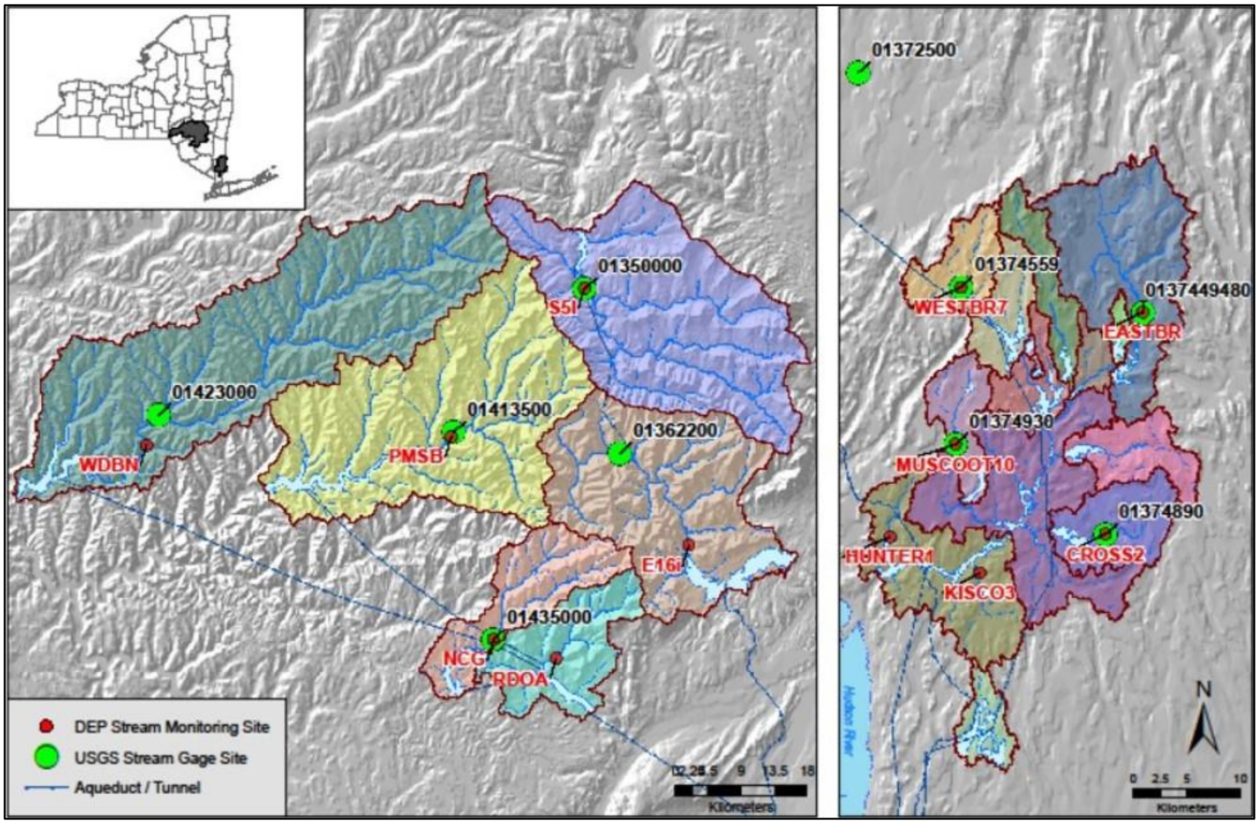


Figure 3.7 Locations of major inflow stream water quality sampling sites and USGS gage stations used to calculate runoff values (see Section 2.4).

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 2015 results presented in Figure 3.8 are based on grab samples generally collected once a month, except that turbidity data were collected weekly at Esopus Creek just downstream of the Boiceville bridge (E16I) and three or four times a month at Rondout Creek near Lowes Corners (RDOA) and the Neversink River near Claryville (NCG). Figure 3.8 compares the 2015 median values against historical median annual values for the previous 10 years (2005-2014).

Turbidity

The turbidity levels for 2015 were generally within the range of the annual medians observed over the previous ten years (2005-2014). The 2015 annual median turbidities at West Branch Croton River (WESTBR7), Muscoot River (MUSCOOT10), and Cross River (CROSS2) were the lowest median in the last 10 years, while East Branch Croton River (EASTBR) had the highest.

Total Phosphorus

In the WOH streams, the 2015 median TP concentrations were generally near their normal historical values based on the previous ten years (2005-2014), except for the Cannonsville Reservoir inflow (WDBN), which had its lowest annual median, while the Neversink inflow (NCG) had its highest annual median over the last ten years. The 2015 TP medians in the Croton System were also within the range of the last ten annual medians, except the Kisco River (KISCO3) which had its lowest annual median compared to the 2005-2014 data, while the East Branch Croton River (EASTBR) had the highest annual TP median compared to its previous ten annual medians.

Fecal Coliform Bacteria

The fecal coliform bacteria levels for 2015 were generally near or somewhat below the annual medians observed over the previous ten years (2005-2014). The 2015 annual medians at West Branch Delaware River at Beerston (WDBN), East Branch Delaware River below Margaretville WWTP (PMSB) and Rondout Creek at Lowes Corners were the lowest annual median in the last 10 years, while the annual medians at East Branch Croton River (EASTBR), Muscoot River (MUSCOOT10), Cross River (CROSS2), and Kisco River (KISCO3) were the second lowest annual median recorded at those sites since 2005.

A fecal coliform benchmark of 200 coliforms $100mL^{-1}$ is shown as a solid line in Figure 3.8c. 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 2015 median values for all streams shown here lie well below this value. Elevated fecal coliform counts were generally associated with rain storms.

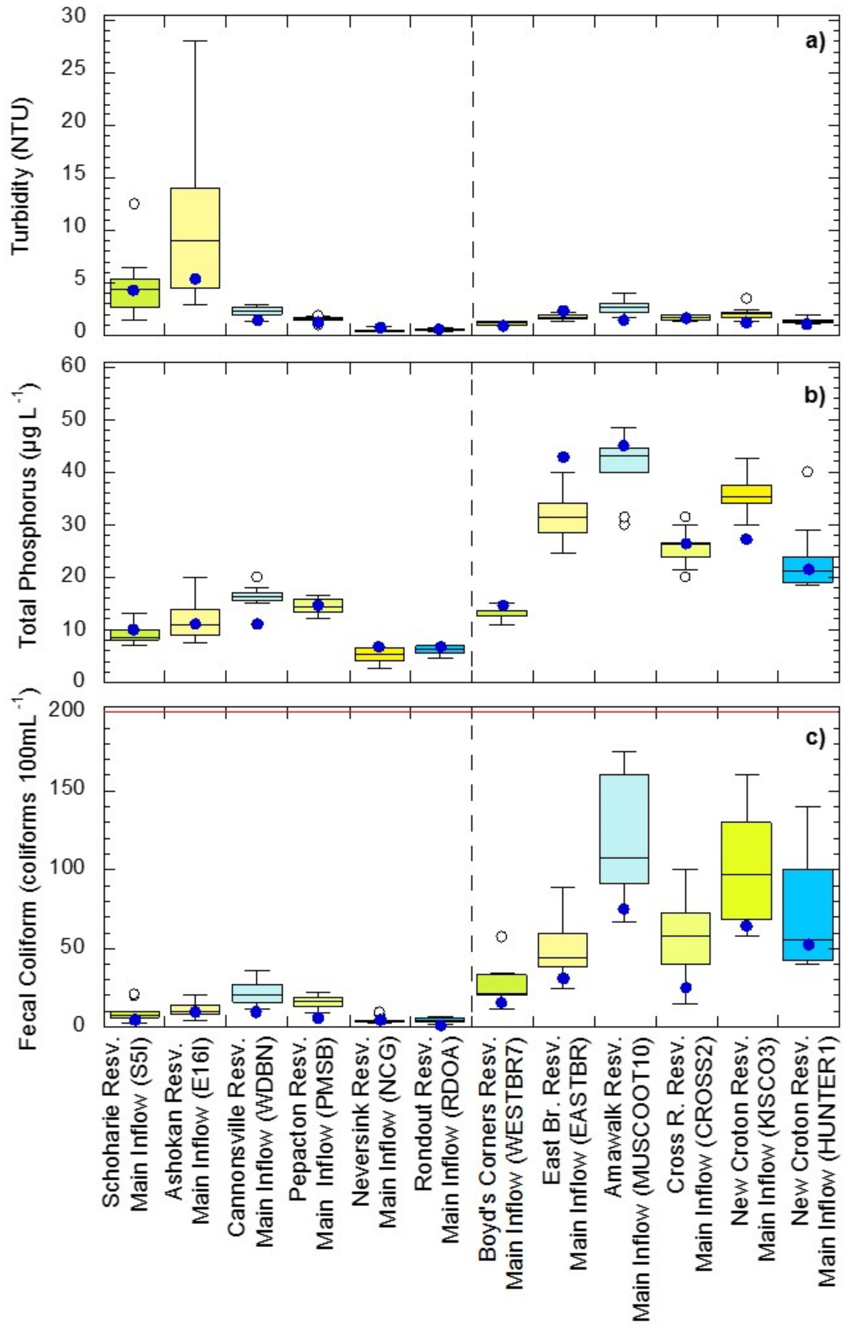


Figure 3.8 Boxplot of annual medians (2005-2014) for a) turbidity, b) total phosphorus, and c) fecal coliform for selected stream (reservoir inflow) sites, with the 2015 values displayed as a solid dot. The dotted line separates WOH streams (left) from EOH streams (right). The solid red line indicates the fecal coliform benchmark of 200 coliforms $100mL^{-1}$.

3.10. Stream Comparisons to Benchmarks in 2015

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 2010). In this section, the application of these benchmarks has been extended to 40 streams and reservoir releases in order to evaluate stream status in 2015 (DEP 2016). The benchmarks are provided in Table 3.10.

Table 3.10 Stream water quality benchmarks as listed in the WR&R (Appendix 18-B) (DEP 2010). The benchmarks are based on 1990 water quality results.

	Croton System		**Catskill/Delaware Systems**	
	Annual Mean	**Single Sample Maximum**	**Annual Mean**	**Single Sample Maximum**
Alkalinity (mg $CaCO_3 L^{-1}$)	N/A	≥40.00	N/A	≥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	5	8	5	8

[1] Organic nitrogen is currently not analyzed.
[2] Total dissolved solids are estimated by multiplying specific conductivity by 0.65 (van der Leeden et al. 1990).
[3] Dissolved organic carbon was used in this analysis since TOC is no longer analyzed.

Comparison of stream results to these benchmarks is presented in Appendix F 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 is dominated by Delaware System water via Rondout Reservoir.

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

Watersheds of the Catskill and Delaware Systems vary in their capacity to neutralize acids. Low buffering capacity is typical of the surficial materials in the Ashokan, Rondout and Neversink watersheds and excursions below the alkalinity benchmark of 10 mg L^{-1} were common much of the year in most streams from these watersheds. In contrast, only occasional excursions below 10 mg L^{-1} were observed in streams of the Cannonsville, Pepacton, and Schoharie basins. These excursions occurred in the December-April period and were likely caused by acidic inputs from melting snow. A benchmark of 40 mg L^{-1} is used for the Croton System streams that reflects the much higher natural buffering capacity of this region. However, less buffering capacity does occur in the Boyd's Corners and West Branch Reservoir watersheds with stream sites GYPSYTRL1, HORSEPD12, WESTBR7 and BOYDR often below 40 mg L^{-1} in 2015 with average alkalinities ranging from 32.5 to 43.7 mg L^{-1}. Single excursions, associated with snowmelt, also occurred at sites CROSS1 and LONGPD1. At Michael Brook (MIKE2), a single excursion of 31.7 mg L^{-1} occurred on August 11 which is much lower than this streams historic summertime alkalinity of 102 mg L^{-1}. Flow and calcium levels were normal suggesting that the low result is an analytical error.

The single sample Catskill/Delaware chloride benchmark of 50 mg L^{-1} was exceeded once on Bear Creek (S6I), a tributary of Schoharie Reservoir, and on three occasions at Kramer Brook, a tributary of Neversink Reservoir. However, the annual mean benchmark of 10 mg L^{-1} was exceeded in 12 of the 24 streams monitored in the Catskill/Delaware System with the highest mean, 43.9 mg L^{-1}, occurring at Kramer Brook. In contrast, in 2015, the two other monitored streams in the Neversink watershed, Aden Brook (NK4) and the Neversink River (NCG), averaged 4.5 and 3.9 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 (28.9 mg L^{-1}), a tributary to Schoharie Reservoir; at Trout Creek (17.1 mg L^{-1}), Loomis Brook (16.9 mg L^{-1}), and the West Branch of the Delaware River (14.0 mg L^{-1}), all tributaries to Cannonsville Reservoir; and at Chestnut Creek (19.2 mg L^{-1}), a tributary to Rondout Reservoir. As was the case in 2014, three Pepacton streams: Tremper Kill (P-13), Platte Kill (P-21) and the East Branch of the Delaware River (PMSB) exceeded the average benchmark in 2015. Chloride was especially high (19.2 mg L^{-1}) at PMSB reflecting both higher road salt usage associated with the long, cold winter and the concentration effect of low flow conditions in late summer. Average annual chloride was also high (22.1 mg L^{-1}) at the outflow from West Branch Reservoir (WESTBRR). West Branch was predominantly operated in "float" mode in 2015. In float mode, less Rondout water is diverted into West Branch resulting in a higher percentage of local "chloride-rich" stream water in the blend of waters that comprise West Branch.

In the Croton System, the single sample chloride benchmark of 100 mg L^{-1} was commonly exceeded in the Muscoot River (MUSCOOT10) above Amawalk Reservoir, the release from Amawalk (AMAWALKR), Michael Brook (MIKE2) above Croton Falls Reservoir, the Long Pond outflow above West Branch Reservoir (LONGPD1), and in the Kisco River (KISCO3) above New Croton Reservoir. Occasional excursions occurred at the Diverting release (DIVERTR) and Horse Pound Brook (HORSEPD12), a tributary to West Branch Reservoir. In addition to the single sample excursions, the annual mean benchmark of 35 mg L^{-1} was exceeded in all 16 monitored Croton streams. Means exceeding the benchmark ranged from 42.7 mg L^{-1} at the Cross River Reservoir release (CROSSRVVC) to 217.0 mg L^{-1} at Michael Brook (MIKE2). The mean 2015 chloride for all 16 Croton streams was 90.7 mg L^{-1}, a substantial increase from the 72.0 mg L^{-1} mean reported in 2014. By comparison, chloride was much lower in the Catskill/Delaware Systems in 2015, with both averaging 12.5 mg L^{-1}. Road salt is the primary source of chloride in these systems, while secondary sources include septic system leachate, water softening brine waste, and wastewater treatment plant effluent. The much greater chloride concentrations in the Croton System are due to higher road and population densities in these watersheds. Given the common co-occurrence of chloride and sodium, it was not surprising that sodium benchmarks were exceeded in much the same pattern as chloride (Appendix F).

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 measurements of specific conductivity. Conversion factors used to compute TDS from specific conductivity relate to the water type (International Organization for Standardization 1985, Singh and Kalra 1975). For NYC waters, specific conductivity was used to estimate TDS by multiplying specific conductivity by 0.65 (van der Leeden et al. 1990).

In 2015, 15 of 24 Catskill/Delaware streams had at least one exceedance of the TDS single sample maximum of 50 mg L^{-1}. Fourteen Catskill/Delaware streams also exceeded the TDS annual mean benchmark of 40 mg L^{-1}. Nearly all exceedances were associated with elevated chloride concentrations (Figure 3.9).

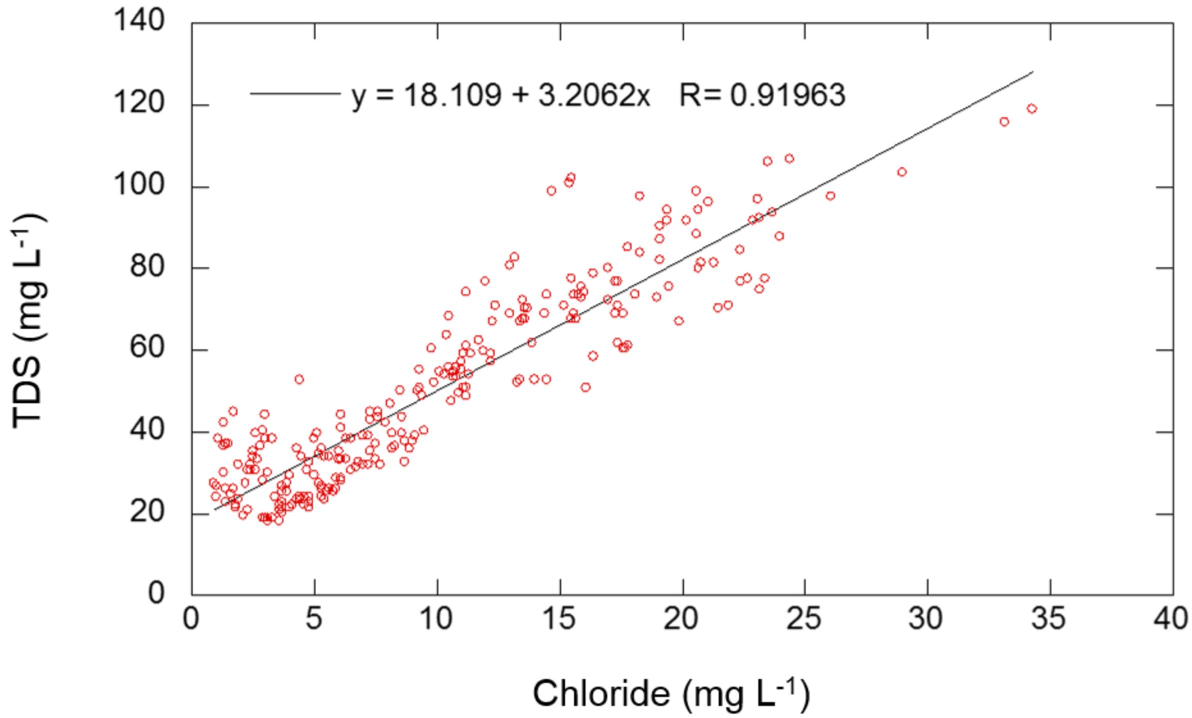


Figure 3.9 TDS versus chloride for Catskill/Delaware System streams in 2015.

In addition to winter, TDS (and chloride) levels were often high in the summer and fall, presumably due to greater contributions from salt-impacted groundwater during low flow conditions. Only streams with very low average chloride concentrations (<7.2 mg L^{-1}) consistently met both TDS benchmarks. TDS excursions in the Croton streams were also associated with elevated chloride concentrations (Figure 3.10).

In the Croton System only BOYDR (Boyd's Corners release) and WESTBR7 (above Boyd's Corners Reservoir) met both the annual benchmark of 150 mg L^{-1} and the single sample maximum criterion of 175 mg L^{-1}. As with the Catskill/Delaware streams, these Croton streams and reservoir releases had relatively low chloride concentrations.

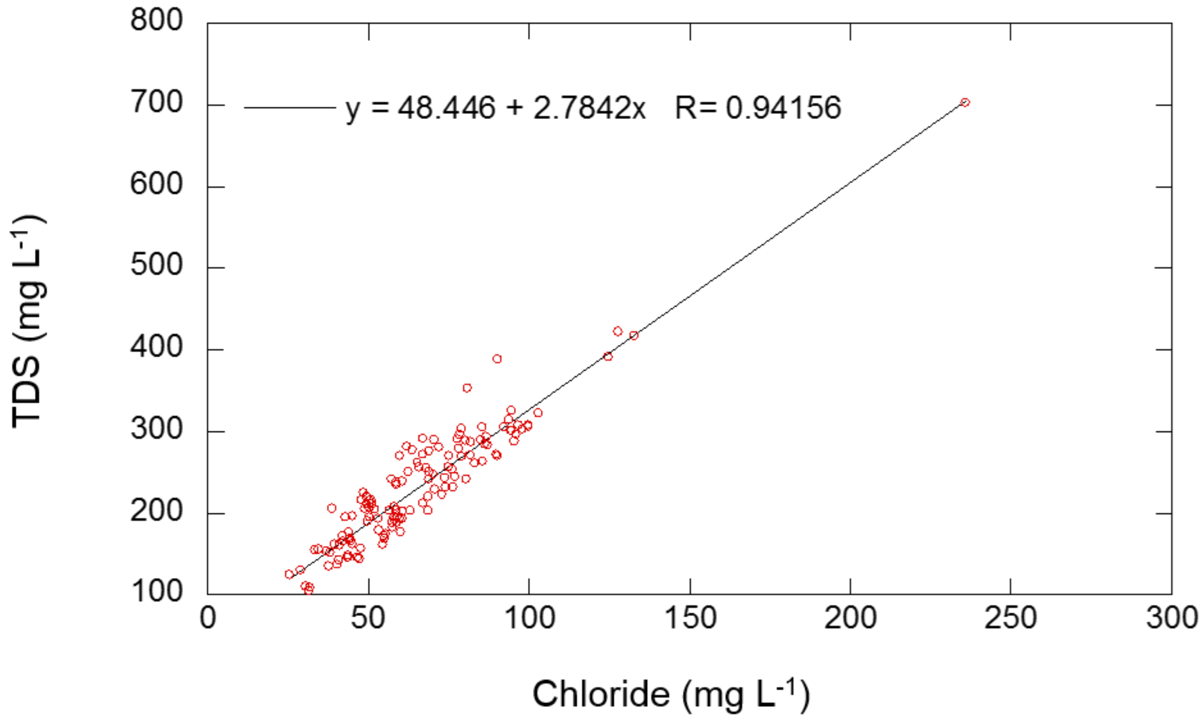


Figure 3.10 TDS versus chloride for Croton System streams in 2015.

Nitrogen (and phosphorus) concentrations in the reservoirs have been decreasing with the implementation of watershed protection programs. However, some localized high values were observed. The single sample nitrate benchmark of 1.5 mg L^{-1} was exceeded in one Croton stream, Michael Brook upstream of Croton Falls Reservoir. The benchmark was exceeded in 9 of 12 monthly samples and was especially high in September (13.5 mg L^{-1}) and October (9.4 mg L^{-1}). Four Croton streams and one reservoir release equaled or exceeded the annual average benchmark of 0.35 mg L^{-1} for 2015: Horse Pound Brook at HORSEPD12 (0.39 mg L^{-1}), the Kisco River at KISCO3 (0.66 mg L), the Muscoot River at MUSCOOT10 (0.46 mg L), Michael Brook at MIKE2 (3.56 mg L^{-1}), and the Croton Falls release at CROFALLSVC (0.38 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 (0.55 mg L^{-1}), Bear Creek at S6I (0.48 mg L^{-1}), Kramer Brook at NK6 (0.71 mg L^{-1}), Fall Clove at P-8 (0.43 mg L^{-1}), and in the East Branch of the Delaware River at PMSB (0.57 mg L^{-1}). The source of the nitrogen is unclear.

None of the true Catskill/Delaware System streams exceeded the ammonia single sample maximum of 0.25 mg L^{-1} or the mean annual benchmark of 0.05 mg L^{-1} in 2015. However, the mean annual benchmark was equaled in the release from West Branch Reservoir (WESTBRR), a mixture of Croton and Delaware System waters. Higher concentrations were observed from July to September (ranging from 0.09 to 0.12 mgL^{-1}) due to low oxygen conditions in the reservoirs hypolimnion and the subsequent release of ammonia from the reservoir sediments. Two Croton System streams exceeded the ammonia single sample maximum in 2015. The reservoir release from Titicus (TITICUSR) exceeded it twice reaching 0.29 mg L^{-1} in October and again in November. As was the case for WESTBRR, the increase was associated with the release of ammonia from anoxic reservoir sediments in late summer. The single sample maximum was also exceeded in February at Michael Brook. The source of the elevated ammonia (0.34 mgL^{-1}) was not clear but may be related to the wastewater treatment plant located upstream. Due to late season anoxia in Titicus Reservoir, the mean annual benchmark of 0.10 mg L^{-1} was exceeded (by 0.01 mg L^{-1}) at the reservoir release in 2015. All other Croton streams were compliant with the annual benchmark.

Neither the single sample maximum (15 mg L^{-1}) nor the annual mean (10.0 mg L^{-1}) benchmarks for sulfate were surpassed in the Catskill/Delaware streams in 2015. With the exception of the East Branch of the Croton River (EASTBR) all Croton stream results were below the Croton System single sample maximum of 25 mg L^{-1} and most were below the annual average of 15 mg L^{-1}. Exceptions for the annual average occurred at the East Branch of the Croton River, Michael Brook and at the Kisco River (KISCO3), with annual averages of 18.9 mg L^{-1}, 21.8 mg L^{-1} and 15.3 mg L^{-1}, respectively. The average for EASTBR is questionable however, and is driven by one high result of 51.9 mg L^{-1}. Historically (2006 – 2015), sulfate at EASTBR ranged from 4.3 to 18.4 mg L^{-1} and averaged 10.1 mg L^{-1}. The Michael Brook and Kisco River watersheds are relatively populous and since sulfate is a common ingredient in personal care products (ex. soaps, shampoos and toothpaste) and mineral supplements, the likely source of the excess sulfate is anthropogenic. Note that EPA does not consider sulfate to be a health risk and has only established a secondary maximum contaminant level of 250 mg L^{-1} as a benchmark for aesthetic consideration (i.e. salty taste).

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 single sample (25 mg L^{-1}) and annual mean (9.0 mg L^{-1}) were not surpassed by any stream in 2015. The highest single sample DOC in the Catskill/Delaware System, 5.7 mg L^{-1}, occurred at Sawkill Brook (RD4) in the Rondout watershed, while the annual mean Catskill/Delaware DOC ranged from 0.9 to 2.6 mg L^{-1}, well below the annual mean benchmark. Due to a greater percentage of wetlands in their watersheds, Croton streams typically had higher DOC concentrations than those in the Catskill/Delaware watersheds; this is reflected in the 2015 annual means, which ranged from 2.6 to 5.1 mg L^{-1}. The highest single sample DOC was 6.9 mg L^{-1}, which occurred at Gypsy Trail Brook (GYPSYTRL1), a tributary to West Branch Reservoir.

3.11. 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 0-10; 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 (HBI), Percent Model Affinity (PMA); and, since 2012, Nutrient Biotic Index-Phosphorus (NBI-P).

In 2015, DEP collected 37 samples from 37 stations in 21 streams throughout New York City's watershed, 11 in Croton System, 2 in Kensico, 12 in Catskill, and 12 in Delaware (for site locations, see Appendix G). Six of the 37 samples were analyzed twice allowing for 43 results, and mean values of replicates are used when data are presented in figures in this section. Scores in Croton were again generally lower than in Catskill and Delaware, which is consistent with previous years' results (see, e.g., DEP 2013a, 2013b, 2014).

East of Hudson - Croton and Kensico Systems

In the Croton System, 11 samples were collected in 2015 and 4 of them were analyzed twice, as replicates, culminating in 15 results. Sites with replicates are represented by mean values for presentation and BAP rating. Nine of the 11 sites were slightly impaired and 2 were moderately impaired (Figure 3.11). The high percentage of impaired sites this year (100%) is typical of the Croton System (e.g., 2010—100%, 2011—84.6%, 2012—100%, 2013—90.0%, 2014—86.7%).

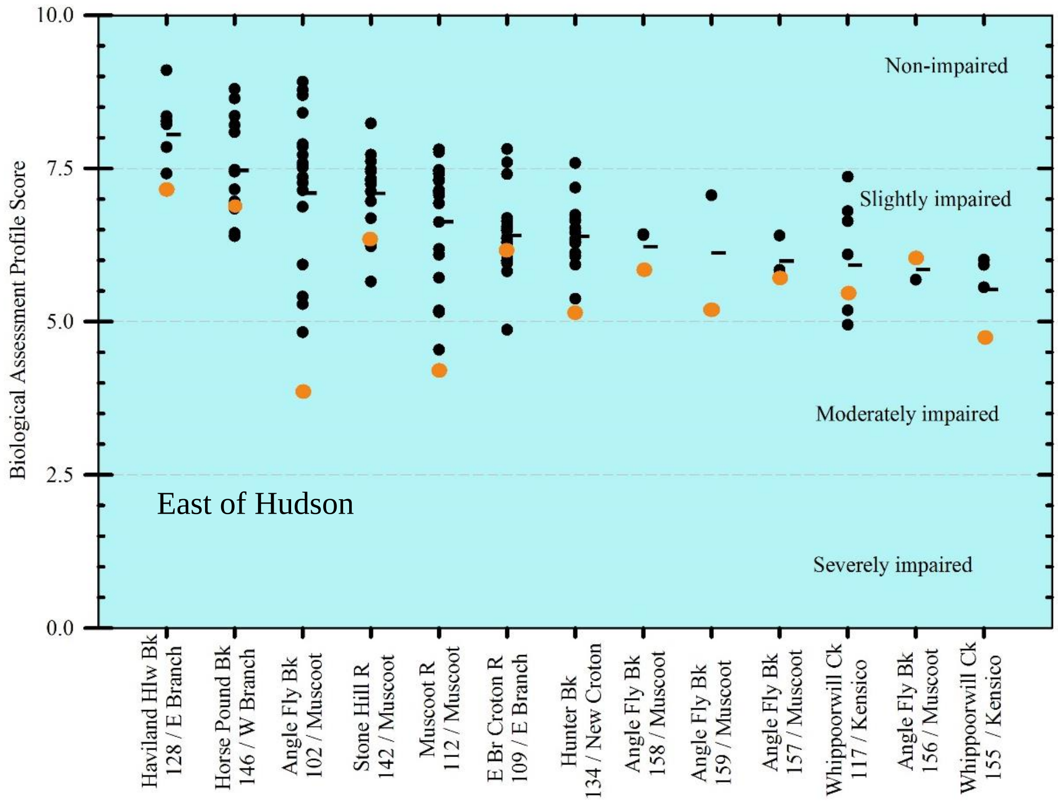


Figure 3.11 Biological Assessment Profile scores for East of Hudson biomonitoring sites sampled in 2015, arranged by mean score from highest to lowest. Horizontal bars represent the mean score, orange dots the 2015 score, and black dots the pre-2015 score. The site's number and watershed are indicated following the site name.

At Site 146 on Horse Pound Brook, the 2015 6.89 BAP score was slightly higher than last year (6.45 – which was the lowest recorded since sampling began there in 2004), and although only barely, it is the fourth consecutive year the score has fallen below 7. This is a site which from 2005 to 2009 consistently scored above 8, making it one of the highest scoring streams East of Hudson. The proximate cause of the drop in scores is usually a reduced number of taxa. No issues relating to development in the stream's watershed or to wastewater treatment plant discharges have been identified, nor have changes in water chemistry been noted. DEP will continue to monitor this stream, perhaps the slight increase this year is a sign of improvement.

The assessment at Anglefly Brook (Site 102) returned to a moderately impaired rating (3.86) in 2015 after having improved to slightly impaired in 2014. In fact, this is the lowest score for this site for the period of record. Even in 2014, the site continued to display the low metric values that have produced impaired assessments there since 2004, after years of being one of the highest rated sites in the East of Hudson System (Figure 3.12).

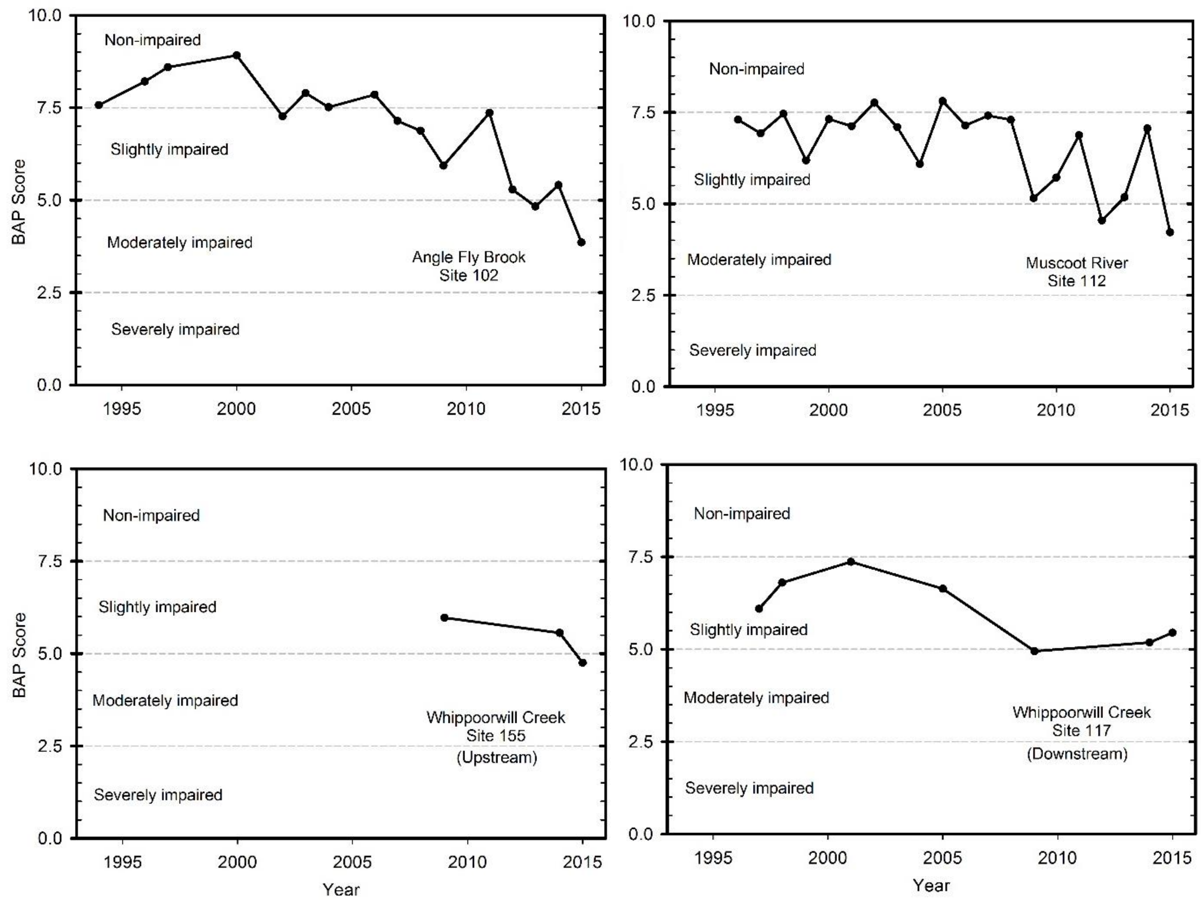


Figure 3.12 1994-2015 BAP scores for the Angle Fly, Muscoot and upstream Whippoorwill sites ranked moderately impaired in 2015, and the downstream Whippoorwill site showing a slightly improved rating this year.

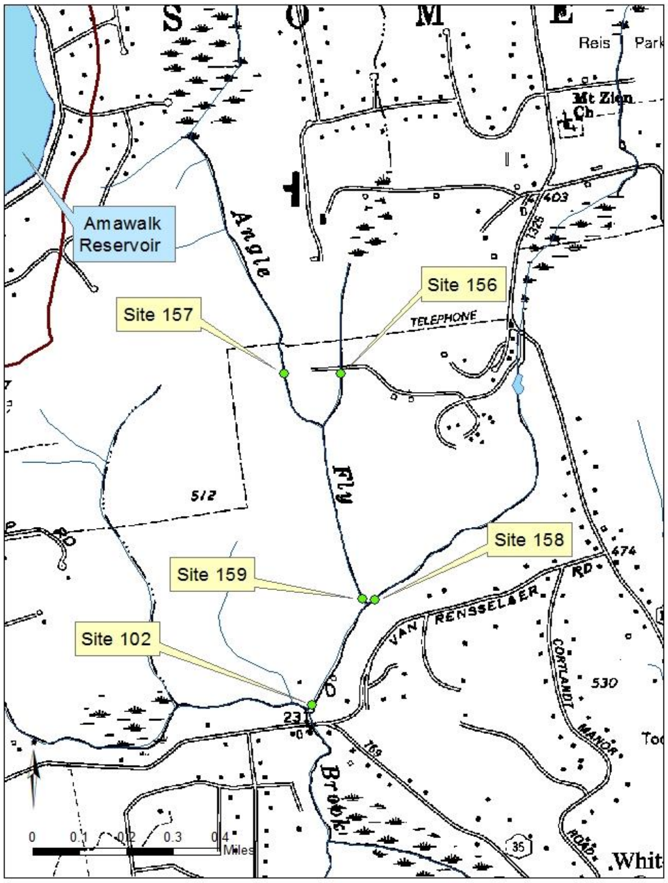


Figure 3.13 Angle Fly Brook biomonitoring sites.

As in past years, high numbers of *hydropsychid* caddisflies likely contributed to the poor outcome at Site 102. DEP sampled several sites upstream of Site 102 (and these samples were analyzed twice) in an effort to isolate the source of the problem: two headwaters about 0.8 miles upstream (Sites 156 and 157), and the mainstem (Site 159) and a major tributary (Site 158), both about one-quarter mile upstream (Figure 3.13). The result was a BAP range of 5.18-6.02, all slightly impaired. *Hydropsychids* were present at these upstream sites (replicate range of 5.77-13.73% abundance, and values generally decreased while moving downstream) but none approached the 45.8% *hydropsychid* presence at Site 102 (Table 3.11). DEP will resample all four upstream sites again to determine if the numbers of *hydropsychids* observed there in 2015 provide a true estimate of abundance in those reaches.

Table 3.11 Percent *hydropsychid* abundance at 2015 Anglefly Brook biomonitoring sites.

Site No.	Percent *Hydropsychidae*
102	45.79
156	7.03[1]
157	7.47[1]
158	8.95[1]
159	9.75[1]

[1]Mean of two replicates.

The other moderately impaired site for the NYC watershed in 2015 was also in the Croton System – Muscoot River (112) (Figure 3.11). Site 112 returned to a moderate impairment rating this year (BAP 4.22) after rating slightly impaired last year. DEP will continue to sample at this site as well to monitor trends in the BAP scores.

In the Kensico basin, two sites were sampled on Whippoorwill Creek in 2015 (Sites 117 and 155). These were sampled (and analyzed twice) to evaluate the impact to the stream's macroinvertebrate community of a streambank stabilization project completed in 2012. Site 155 is located above the affected reach, Site 117 below. A report (Rosenfeld 2015) concluded that the project had little or no effect on the downstream community. It cautioned, however, that because of limited data and the likelihood that community composition at the downstream site will change as it continues to recover from the disturbance caused by the blowdown from Hurricane Sandy, additional sampling would be needed to obtain a clearer picture. DEP resampled both sites in 2015 and the BAP scores indicate a higher rating below the stabilization area. The site above the project area (155) was rated as moderately impaired (BAP 4.75) this year, while the rating below the stabilization (117) was only slightly impaired (BAP 5.45) (Figure 3.11). These sites will be resampled in 2016, as this may be an indication that the streambank stabilization or recovery from Hurricane Sandy is improving conditions downstream for the benthic community.

In summary, the three moderately impaired assessments for the East of Hudson sites, and the NYC watershed as a whole, occurred at a site on Anglefly Brook (102), a site on the Muscoot River (112) and the upstream site of the Whippoorwill Creek project area (155). All of the BAP scores for these sites were lower than they have been in the past – Site 102, 3.86; Site 112, 4.22; and Site 155, 4.75. Notably, the *hydropsychid* caddisflies made up 45.79% of the population at the Anglefly Brook 102 site, which was the highest percentage of *hydropsychids* in all samples collected in 2015, and may have contributed to the lower rating.

West of Hudson - Catskill/Delaware System

In the Catskill System, 8 sites were non-impaired and 4 were slightly impaired, while in the Delaware System, 7 sites were non-impaired and 5 slightly impaired (Figure 3.14). Contrary to last year when high numbers of *hydropsychid* caddisflies (>30%) were present at two-thirds of the impaired sites and nearly half overall, this year only one site (Batavia Kill 206) had >30% *hydropsychids* present. Dominance by a single group of organisms tends to depress the total taxa and PMA metrics, resulting in lower BAP scores, but this does not appear to have been a wide-spread factor for 2015. Note, however, that low taxa numbers, another development of recent years (DEP 2014), were not restricted to sites with high *hydropsychid* abundance or to impaired streams.

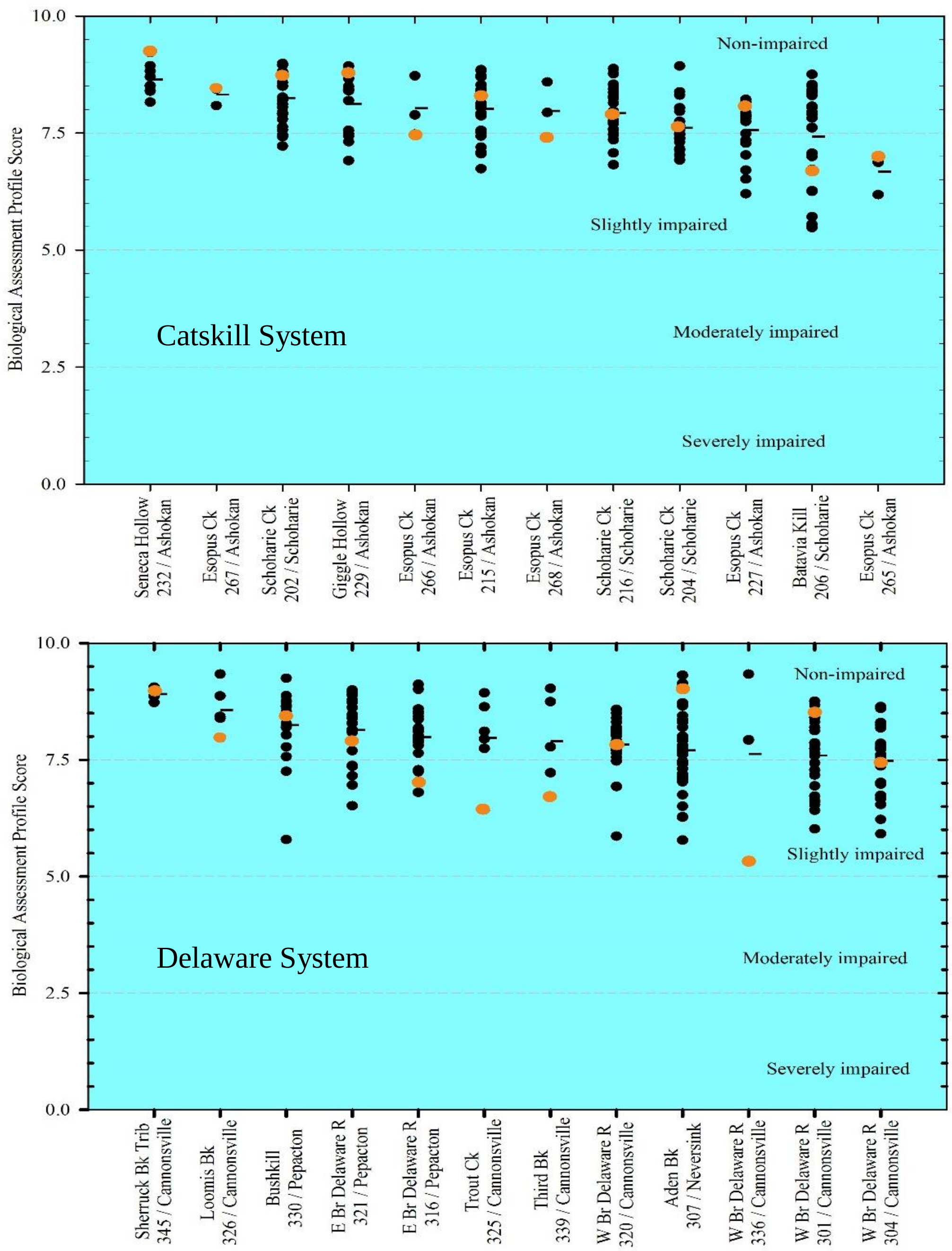


Figure 3.14 Biological Assessment Profile scores for West of Hudson biomonitoring sites sampled in 2015, arranged by mean score from highest to lowest. Horizontal bars represent the mean score, orange dots the 2015 score, and black dots the pre-2015 score. The site's number and watershed are indicated following the site name.

The four slightly impaired sites in the Catskill System were Site 206 on the Batavia Kill, and Sites 265, 266 and 268 on the Esopus Creek. The dominance of *hydropsychid* caddisflies at Site 206 was still present in 2015 (Table 3.12), however, it decreased to 33% compared to 57% reported last year (DEP 2014). This is the seventh consecutive slightly impaired assessment for this formerly non-impaired site, although the BAP score did increase to above 6 this year (6.72). The source of impairment, however, remains unidentified.

The Esopus Creek samples (265, 266 and 268) resulted in BAP scores of 6.97, 7.48 and 7.39, respectively, two of which are relatively close to the 7.5 measurement for a non-impaired rating. Interestingly, the Esopus Creek site with the highest BAP (266) was also the site with the highest *hydropsychid* percentage for this group of three samples (16.67%) which reiterates that the percentage of this caddisfly does not alone drive the BAP scores (Table 3.12).

Table 3.12 Total Taxa, Percent Model Affinity (PMA), Nutrient Biotic Index-Phosphorus (NBI-P), Biological Assessment Profile (BAP) and Percent *Hydropsychidae* for 2015 slightly impaired sites in the Catskill/Delaware watershed.

Site No.	**Total Taxa**	**PMA**	**NBI-P**	**BAP**	**Percent *Hydropsychidae***
			Catskill		
206	19	55	6.02	6.72	33.33
265	21	72	6.23	6.97	4.9
266	25	55	4.89	7.48	16.67
268	25	61	5.41	7.39	9.8
			Delaware		
304	25	72	6.20	7.47	17.54
316	20	59	5.18	7.04	24
325	23	52	6.04	6.43	8.85
336	23	48	7.04	5.32	1.92
339	23	66	5.81	6.71	6.7

Of the slightly impaired sites in the Delaware System (Sites 304, 316, 325, 336 and 339) BAP scores ranged between 5.32 and 7.47 for 2015. Only two of the sites (304 and 316) experienced moderate numbers of *hydropsychids* at 17. 54 and 24% abundance, while others were all less than 10% this year (Table 3.12).

In summary, the percent *Hydropsychidae* decreased considerably compared to last year. Most percentages were in the single digits this year, whereas double digits were more common in 2014. Moreover, the sites in the Catskill and Delaware regions with the highest hydropsychid percentages in 2015 decreased considerably (Site 206 decreased from 57% to 33% and Site 316 decreased from 50% to 24%). DEP will continue to monitor these sites to track any future developments.

3.12. Supplemental Contaminant Monitoring

DEP monitors a large number of volatile and semi-volatile organic compounds (including the herbicide glyphosate) in the upstate watersheds to supplement the required distribution system monitoring for these compounds. The list of compounds is provided in Appendix H and the sites sampled are provided below in Table 3.13. These supplemental samples were collected by DEP personnel in October and shipped to a contract lab for analysis. No detections were observed in 2015 for any of the compounds monitored.

Table 3.13 Sampling sites for VOC and SVOC monitoring.

Site Code	Site Description	Reason for Site Selection
	East of Hudson	
CROGH	Croton Gate House	Croton Aqueduct intake
DEL10	Delaware Shaft 10	Delaware intake on West Branch
DEL18DT	Delaware Shaft 18	Delaware intake on Kensico
	West of Hudson	
EARCM	Ashokan Intake	Represents Ashokan water
NRR2CM	Neversink Intake	Represents Neversink water
PRR2CM	Pepacton Intake	Represents Pepacton water
SRR2CM	Schoharie Intake monitoring site	Schoharie water entering Esopus
RDRRCM	Rondout Intake	Represents Rondout water
WDTO	West Delaware Tunnel Outlet	Represents Cannonsville water

Note: In the event that one of these diversions is off at the collection time, the sample is drawn from the upstream reservoir elevation tap that corresponds to the tunnel intake depth as if that reservoir were on-line.

3.13. Metals Monitoring

If metals are detected at unusual concentrations, supplemental (non-required) sampling of the Catskill, Delaware and East of Hudson Systems is conducted to better determine more specific contaminant source(s). The following metals (total concentrations in all cases) were analyzed on a quarterly basis: Silver (Ag), Aluminum (Al), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb), Antimony (Sb), Selenium (Se), Thallium (Tl) and Zinc (Zn). These metals are monitored at the keypoint sites listed in Table 3.14.

Table 3.14 Keypoint sampling sites for trace and other metal occurrence monitoring.

Reservoir Basin	Site(s)
	Catskill System
Ashokan	EARCM[1]
Schoharie	SRR2CM[1]
	Delaware System
Cannonsville	WDTO[1]
Pepacton	PRR2CM[1]
Neversink	NRR2CM[1]
Rondout	RDRR2CM[1]
	East of Hudson
Kensico	CATALUM, DEL17, DEL18DT, DEL19LAB
Croton	CROGH, CROGH1CM[2], CROGHC, CRO9
West Branch	DEL9, DEL10, CWB1.5

[1]Elevation tap samples will be collected when the reservoir is offline.
[2] Only sampled when blending of Croton waters occurs.

Data are reviewed on an annual basis and compared to the Health (Water Source) standard as stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and the USEPA National Primary and Secondary Drinking Water Standards. Selected metals standards are presented in Table 3.15 and Table 3.16.

Table 3.15 USEPA National Primary and Secondary Drinking Water Quality Standards.

Analyte	**Primary Standard ($\mu g\ L^{-1}$)**	**Secondary Standard ($\mu g\ L^{-1}$)**
Silver (Ag)		100
Aluminum (Al)		50-200
Arsenic (As)	10	
Barium (Ba)	2000	
Beryllium (Be)	4	
Cadmium (Cd)	5	
Chromium (Cr)	100	
Copper (Cu)	1300	1000
Iron (Fe)		300

Table 3.15 USEPA National Primary and Secondary Drinking Water Quality Standards.

Analyte	Primary Standard ($\mu g\ L^{-1}$)	Secondary Standard ($\mu g\ L^{-1}$)
Mercury (Hg)	2	
Manganese (Mn)		50
Nickel (Ni)		
Lead (Pb)	15	
Antimony (Sb)	6	
Selenium (Se)	50	
Thallium (Tl)	0.5	
Zinc (Zn)		5000

Table 3.16 Water quality standards for metals from Part 703.5.

Analyte	Primary Standard ($\mu g\ L^{-1}$)	Secondary Standard ($\mu g\ L^{-1}$)
Silver (Ag)	H(WS)	50
Arsenic (As)	H(WS)	50
Barium (Ba)	H(WS)	1000
Cadmium (Cd)	H(WS)	5
Chromium (Cr)	H(WS)	50
Copper (Cu)	H(WS)	200
Mercury (Hg)	H(WS)	0.7
Manganese (Mn)	H(WS)	300
Nickel (Ni)	H(WS)	100
Lead (Pb)	H(WS)	50
Antimony (Sb)	H(WS)	3
Selenium (Se)	H(WS)	10

In 2015, most metal sample results were well below state and federal benchmarks. Selenium, antimony, arsenic, beryllium, cadmium, lead, silver and thallium were not detected above the detection limit of 1 $\mu g\ L^{-1}$ for any sample. Chromium, zinc and mercury were not detected above their detection limits of 5, 10 and 0.06 $\mu g\ L^{-1}$, respectively. Three samples analyzed for nickel were measured just above the detection limit of 1 $\mu g\ L^{-1}$, ranging from 1.2 to 1.6 $\mu g\ L^{-1}$. All were collected at the Croton Lake gatehouse (CROGH). Barium ranged from 8.1

to 46.1 µg L^{-1}, while copper ranged from <1.0 (25 of 54 samples were at this detection limit) to 15.7 µg L^{-1}. The four highest copper results occurred at the Pepacton Reservoir keypoint PRR2CM, ranging from 8.8 to 15.7 µg L^{-1}, but it should be noted that the plumbing for the Pepacton sample tap contains a mix of copper and PVC pipe while the other Delaware keypoint taps are mainly plumbed with PVC pipe. Note that these detected nickel, barium, and copper results were all well below their respective benchmarks. However, benchmarks, were exceeded by three metals: iron, aluminum, and manganese. The iron benchmark of 300 µg L^{-1} was exceeded twice (331 and 413 µg L^{-1}) at SRR2CM, the diversion from Schoharie Reservoir. The manganese benchmark of 50 µg L^{-1} was equaled or exceeded on eleven occasions, while the aluminum benchmark of 50 µg L^{-1} was exceeded in four samples. Manganese excursions ranged from 50 to 198 µg L^{-1} µg L^{-1}. Aluminum excursions all occurred at SRR2CM and ranged from 103 to 429 µg L^{-1}. Note that these iron, aluminum and manganese excursions may pose aesthetic concerns (e.g., taste, staining) but are not considered a risk to health. Moreover, most of these excursions occurred well upstream of the NYC distribution system. Samples from Catskill/Delaware system sites in closest proximity to distribution, DEL18DT and DEL19LAB, were well below the benchmarks, ranging from <10 to 17.1 µg L^{-1} for aluminum, <3.0 to 47.0 µg L^{-1} for iron, and 0.01 to 18.0 µg L^{-1} for manganese. The Croton keypoint closest to the distribution system, CROGH, was also below benchmarks, ranging from <10 to 10 µg L^{-1} for aluminum and from 56 to 78 µg L^{-1} for iron. However, the benchmark for manganese was exceeded in all four quarterly samples, with concentrations ranging from 57 to 67 µg L^{-1}.

3.14. Special Investigations

There were seven special investigations conducted during 2015. All of these special investigations had the potential to compromise drinking water quality in different respects. The four discussed in this section include one each within the Croton Falls, Titicus, Pepacton and Schoharie watersheds. The remaining three special investigations occurred within the Kensico watershed and are discussed in Chapter 4.

Sewage Spill near Croton Falls Reservoir - April 29, 2015

A sewage spill occurred near the Croton Falls Reservoir on April 29, 2015. The cause of the spill was a malfunctioning sewage pump station. EOH field personnel sampled the next day (April 30) at two sites along the stream, and at one site at a culvert within the reservoir that goes underneath Stoneleigh Avenue. Samples were taken for fecal and total coliform analyses among other analytes. Results from the samples indicated very high levels of both total and fecal coliform bacteria at the stream site interfacing with the reservoir, and the culvert site. Routine sampling conducted the next week at nearby reservoir sampling sites indicated that both coliform concentrations and other analyte concentrations had returned to pre-spill conditions. It was concluded that the sewage spill did not adversely affect Croton Falls Reservoir drinking water quality.

Plane Crash into Titicus Reservoir - November 19, 2015

During the evening of November 19, 2015 DEP Police received news of a potential plane accident in the vicinity of the Titicus Reservoir. An investigation the next day revealed that a small single-engine aircraft had crashed into the reservoir. Samples were taken periodically at the Titicus Release during the months of November and December to determine if any anthropogenic substances associated with the plane crash reached the release. Samples were taken for Purgeable/Volatile Organic Compounds (POCs/VOCs), Diesel Range Organics (DROs), and Semivolatile Compounds (SVOCs), as well as more conventional analytes. None of the synthetic organic compounds were detected over the course of sampling. Wet chemistry and fecal coliform results did not indicate contamination associated with the plane crash.

Diesel Range Organics Monitoring at Pepacton Reservoir Effluent Keypoint PRR2CM

A submerged oil tank was discovered in 2012 at the bottom of Pepacton Reservoir, approximately 100 yards from the intake chamber. Although the site was remediated in 2012, residual oil sheens have been occasionally observed in the vicinity. In response, effluent from Pepacton Reservoir that discharges into Rondout Reservoir at the East Delaware Tunnel Outlet (PRR2CM) has been sampled monthly for Diesel Range Organics (DRO). In this case, DRO refers to petroleum hydrocarbon mixtures composed of compounds with carbon numbers ranging from C10-C44. This range includes diesel range organic compounds C10-C28 as well as higher molecular weight compounds C29-C44. The wider range was chosen so that a greater number of hydrocarbon products could be monitored. In addition to DRO samples, the remediation site was inspected weekly by observing it from the East Delaware Intake Chamber during routine keypoint sample collections. Closer inspections occured monthly during routine reservoir limnology surveys when the reservoir was ice-free. Surveillance monitoring will continue until visual inspections indicate no sheen on the reservoir for 6 months and laboratory results do not indicate the presents of hydrocarbons.

In 2015, 12 monthly keypoint samples were collected and no positive results for DRO were confirmed. DRO was reported as "not detected" in 7 samples (detection limits ranged from 100 to 250 µg L^{-1}) and in three other samples the presence of DRO could not be determined due to failed quality control samples. Samples collected in January and July were initially reported as having DRO values near the detection limit. Upon further review of analytical instrument data by the contract laboratory it was determined that the results were not an indication of DRO in the sample.

Weekly visual inspections from the East Delaware Intake Chamber did not identify the presence of a hydrocarbon-like sheen near the chamber in 2015. However, a sheen was observed on the reservoir in April, August, September and October at the site of the remediated submerged oil tank. WWQO will continue to collect monthly keypoint samples for DRO and perform visual inspections into 2016.

Investigation of Oil Sheen at Schoharie Reservoir

Bureau of Water Supply (BWS) Operations staff noticed an oily sheen in the vicinity of Shandaken Tunnel Intake Chamber (STIC) on April 6, 2015 at approximately 2:30 pm. The diversion from Schoharie Reservoir was quickly shutdown, regulators notified and an oil absorbent boom was installed around the reservoir intake chamber. A sample collected from surface sheen was found to contain diesel range organics (DRO) at a concentration of 25 mg L^{-1}. To further protect Ashokan Reservoir (connected to Schoharie Reservoir via tunnel) an additional boom was installed at the Shandaken Tunnel Outlet (STO) on April 8. On April 9, a monitoring plan was developed and provided to the regulators. The plan called for daily visual inspections near the STIC and the STO as well as periodic sampling for DRO, and semivolatile and volatile organic compounds at SRR1CM, the elevation tap representative of water leaving Schoharie, and at SRR2CM, representative of Schoharie water entering Esopus Creek and eventually Ashokan Reservoir. Note that semivolatile and volatile organic compounds were only sampled once and replaced with oil and grease compounds, which were considered more emblematic of the observed contamination. With booms in place, and no indication that Schoharie water was impacted at its withdrawal elevation, the Schoharie tunnel was reactivated on April 10. Although the sources of contamination could not be removed until the week of July 29-August 4, the daily visual inspections and weekly water quality monitoring indicated no contamination occurred in water diverted from Schoharie Reservoir and demonstrated the effectiveness of surface booming.

4. Kensico Reservoir

4.1. Kensico Reservoir Overview

Kensico Reservoir, located in Westchester County, is the terminal reservoir for the City's raw source water from the Catskill/Delaware water supply and is the last impoundment of unfiltered Catskill/Delaware water prior to treatment and delivery to the City's distribution system. Protection of this reservoir is critically important to prevent water quality degradation and to maintain Filtration Avoidance. To ensure this goal is met, DEP has a routine water quality monitoring strategy for Kensico aqueducts, streams, and the reservoir that is documented in the Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2016). The sampling site locations are shown in Figure 4.1. 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 high frequency surveillance.

Table 4.1 shows a summary of all the water quality samples collected within the Kensico watershed during 2015. Compliance with the Safe Drinking Water Act's Surface Water Treatment Rule (SWTR) (USEPA 1989) is of paramount importance to DEP to maintain Filtration Avoidance. The results of this monitoring illustrate the excellent quality of water leaving Kensico Reservoir during 2015. Additionally, DEP's data continues to demonstrate that the Waterfowl Management Program has been instrumental in keeping coliform bacteria concentrations well below the limits set by the SWTR.

Table 4.1 Summary of Kensico Watershed water quality samples collected in 2015.

Kensico sampling program	**Turbidity**	**Bacteria**	***Giardia/ Crypto-sporidium***	**Virus**	**Nutrients**	**Other chemistry**	**Metals**	**Phyto-plankton**
SWTR Turbidity compliance	2177							
Keypoint effluent	362	365	56	40	12	419	4	159
Keypoint influent	519	525	104	80	102	623	10	104
Reservoir	814	433			211	659	24	116
Stream	131	125	99		72	210		

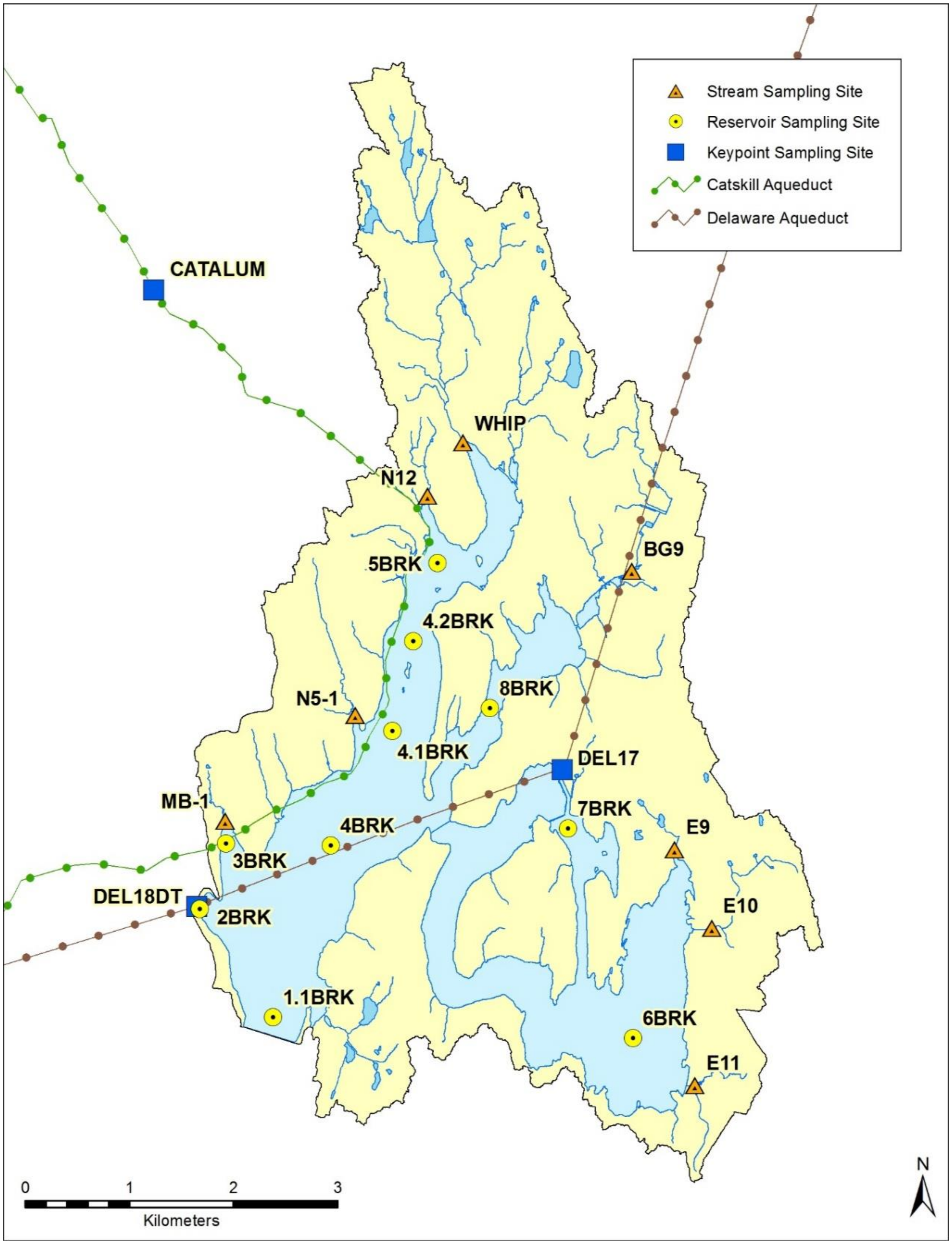


Figure 4.1 Kensico Reservoir, showing limnological and hydrological sampling sites, keypoints, and aqueducts. There is a meteorological station at Delaware Shaft 18.

4.2. Reservoir Raw Water Quality Compliance

DEP routinely conducts water quality compliance monitoring at the Kensico Reservoir aqueduct keypoints. The CATALUM and DEL17 influent keypoints represent water entering Kensico Reservoir from the NYC upstate reservoirs via the Catskill and Delaware Aqueducts, respectively. The monitoring requirements for CATALUM and DEL17 were defined by the CATIC and DEL17 SPDES permits, 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. Table 4.2 outlines the grab sample monitoring that took place at the three aqueduct keypoint locations during 2015. The analytes for all three keypoints are used as an indicator of water quality entering and discharging from Kensico Reservoir, which is in turn used to optimize operational strategies to provide the best possible quality of water leaving the reservoir. In addition to the routine grab sample monitoring, these three sites were 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.

Table 4.2 Water Quality Compliance Monitoring for Kensico Reservoir Aqueduct Keypoints via routine grab samples for 2015.

Site	Coliform, Fecal and Total, Turbidity, Specific Conductivity, Scent, , and Apparent Color	Field pH and Temperature	Turbidity (SWTR)	Phytoplankton	UV-254	TP	DOC&TDN	Alkalinity, Ammonia, Chlorophyll a, NOx, Orthophosphate, TDP, TN, Total Suspended Solids	Anions (SO4, Cl), Major Metals (Ca, K, Na, Mg), Trace Metals, Fe, Mn, Hg
CATALUM	5D	5D		W		W	M	M	Q
DEL17	5D	5D		W	W	W	W	M	Q
DEL18DT	7D	7D	4H	3D	W	M	W	M	Q

4H – Sampled every four hours
7D – Sampled seven days per week
5D – Sampled five days per week.
3D – Sampled three times per week
W – Sampled Weekly
M – Sampled Monthly
Q – Sampled Quarterly

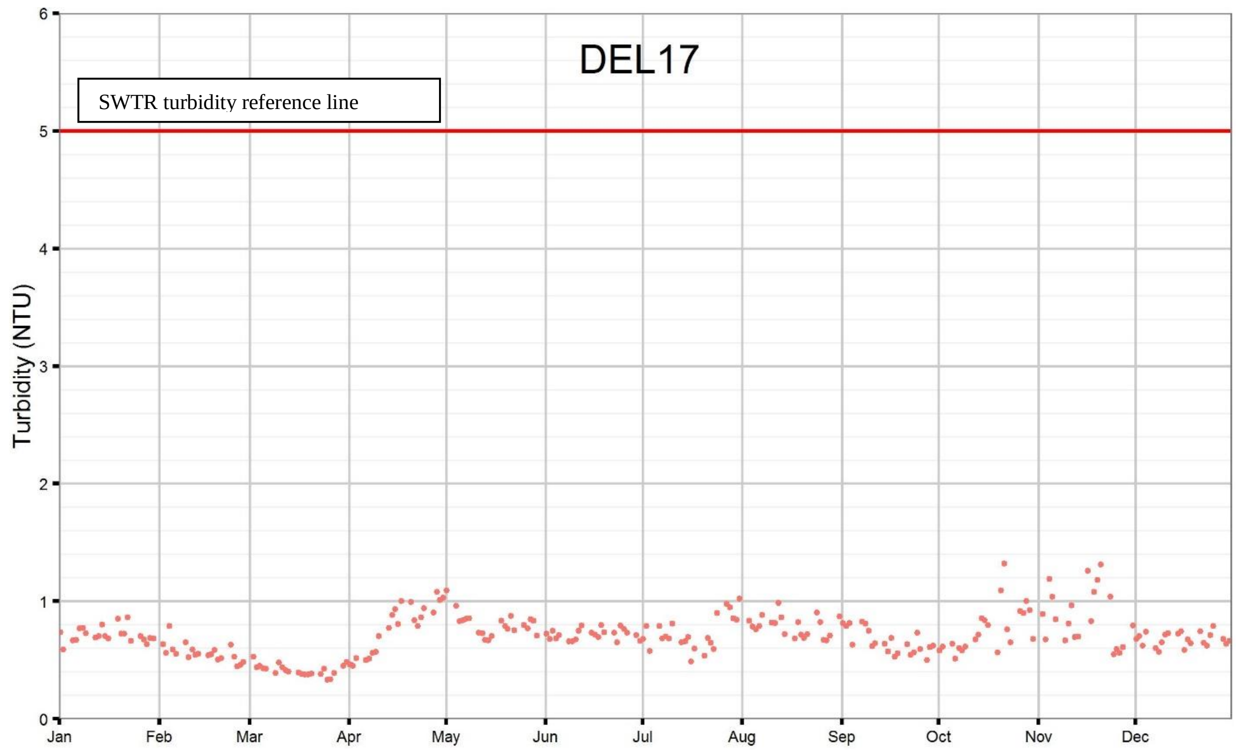
Table 4.3 shows the Kensico Reservoir influent and effluent samples collected during the 2015 calendar year and all of the sites continued to have medians of less than 1 fecal coliform $100mL^{-1}$. Single sample maximum value were less than the 2014 maximum at CATALUM and similar to the 2014 single sample maximum value at DEL17 and DEL18DT. For turbidity, both influents and the effluent showed a decrease in the median and single sample maximum values from 2014 to 2015. These decreases can be attributed to a relatively quiet year with regard to intense rainfall and runoff events during 2015.

Table 4.3 Kensico Keypoint Fecal Coliform and Turbidity Results from January 1, 2015 to December 31, 2015.

Analyte	Kensico Sampling Location	Median	Single Sample Maximum
Fecal Coliform (Coliform 100mL^{-1})	CATALUM	< 1	10
	DEL17	< 1	21
	DEL18DT	< 1	10
Turbidity (NTU)	CATALUM	2.2	3.9
	DEL17	0.7	1.3
	DEL18DT	0.8	2.1

The routine grab sample analytical results at CATALUM, DEL17, and DEL18DT for the 2015 turbidity and fecal coliform results can be seen in Figure 4.2, Figure 4.3, and Figure 4.4. For the two influent sites, DEL17 and CATALUM, the SWTR limit line is shown as a reference line only because the influent sites are not subject to the SWTR. Additionally, the fecal coliform plots contain “drop lines” along the x axis to indicate that the result is censored (below detection) values. The length of the “drop lines” goes up to the top of the censored range. A “drop line” that goes to 1 indicates that the result was less than 1.

For the 2015 calendar year there were no large storm events impacting the influent keypoints or effluent keypoints of Kensico Reservoir. Short term increases in turbidity or fecal coliform can be attributed to changes in reservoir operations and/or rainfall/runoff events, as seen in June and September at CATALUM with slight increases in turbidity and fecal coliforms in months with above average rainfall at Ashokan. Overall, water quality in 2015 was excellent, with the source water at Kensico meeting the SWTR limits for both fecal coliform and turbidity.



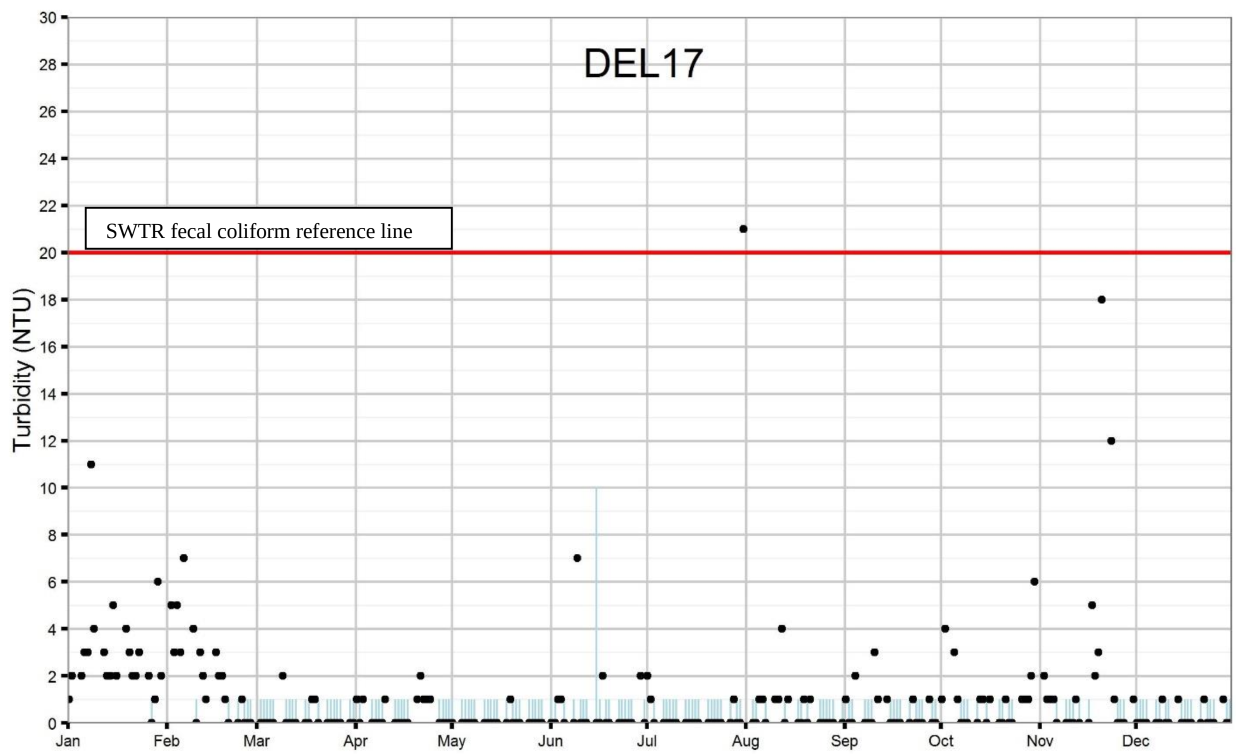
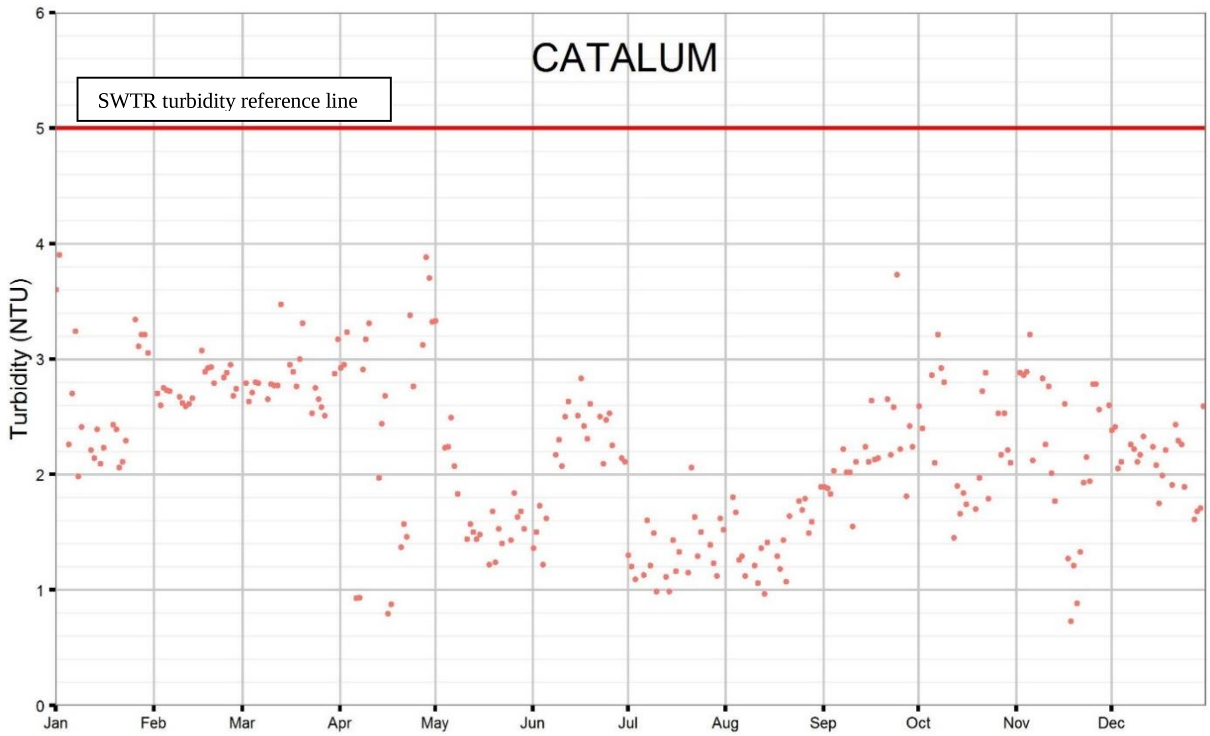


Figure 4.2 Five-day-per-week Turbidity and Fecal Coliform grab samples at DEL17.



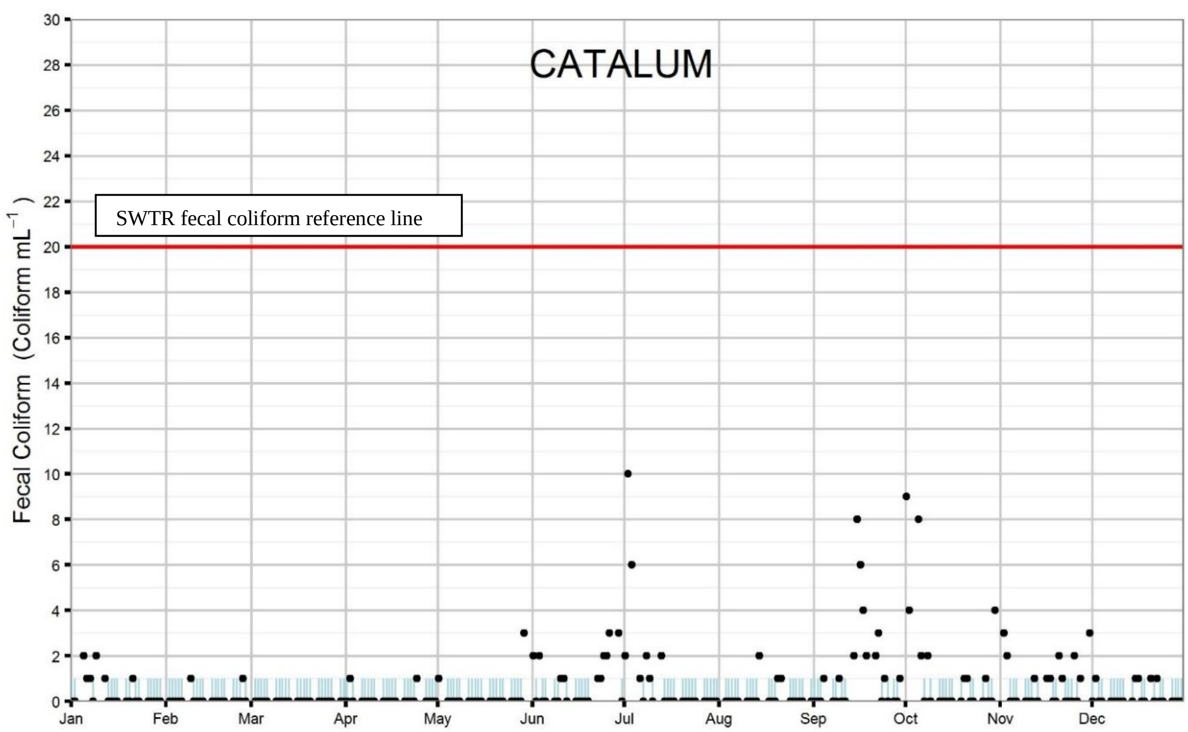


Figure 4.3 Five-day-per-week Turbidity and Fecal Coliform grab samples at CATALUM.

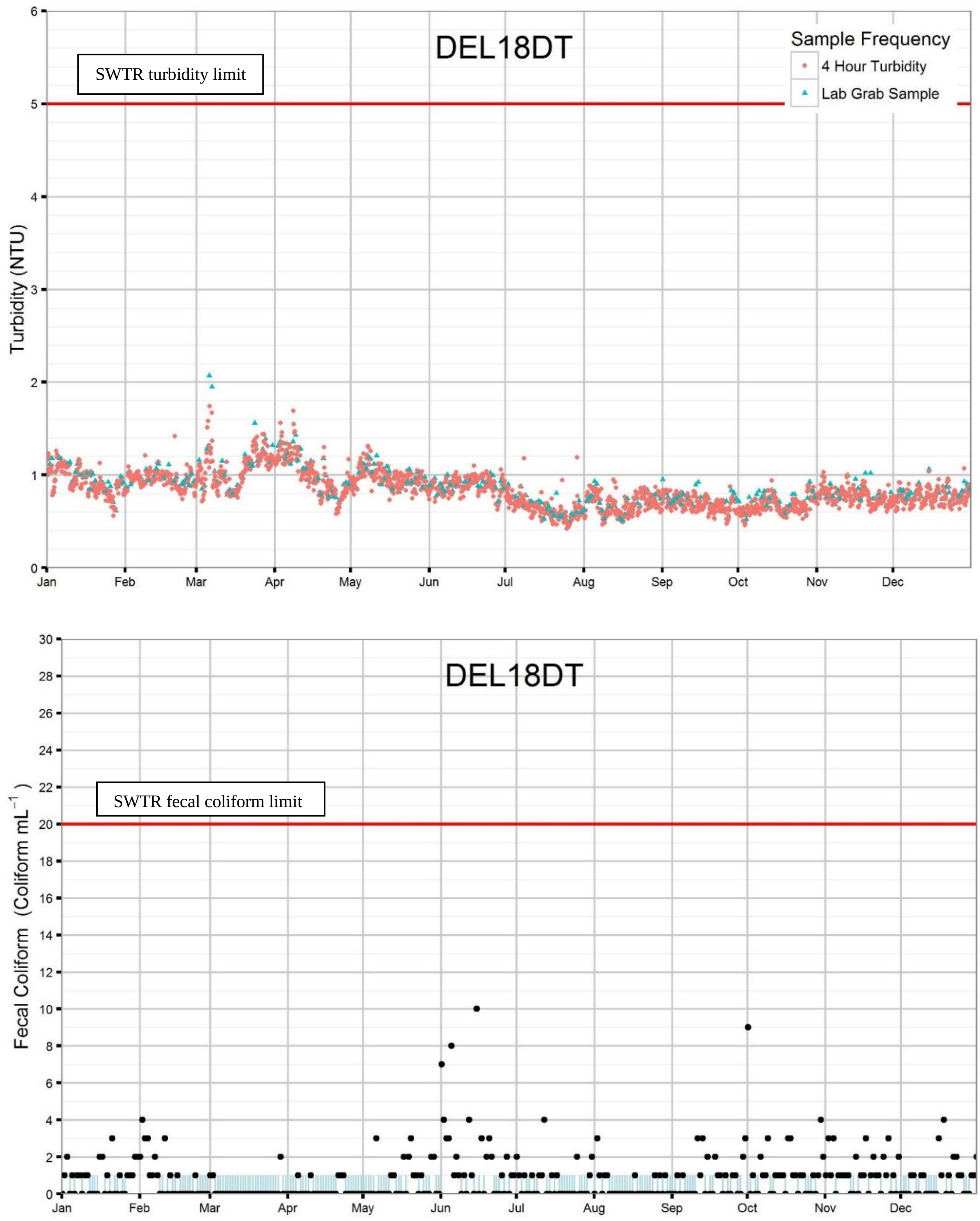


Figure 4.4 Seven-day-per-week Turbidity and Fecal Coliform grab samples at DEL18DT.

4.3. Kensico Watershed Monitoring and Turbidity Curtain Inspections

4.3.1. Kensico Watershed Monitoring

DEP continues to conduct a fixed-frequency monitoring program of streams and the reservoir of the Kensico watershed. Routine samples were collected from eight perennial streams and 10 locations within the Kensico reservoir as shown in Figure 4.1. Continuous flow measurements continue to be made at eight of the Kensico perennial streams. Flows for WHIP and BG9 are determined via a rating curve. Flows at E11, E10, MB-1, and N5-1 are determined via a V - notch weir. Flows at N12 and E9 are determined via an H - flume.

Table 4.4 2015 Summary statistics for Kensico Reservoir streams.

Site/Analyte	Number samples	Minimum	Median[1]	Mean[1]	Maximum
E11 (Stream E11)					
Total suspended solids (mg L^{-1})	12	<1	<u>2.0</u>	<u>3.0</u>	8.2
Specific Conductance (µmhos cm^{-1})	12	289	477	451	635
Chloride (mg L^{-1})	12	23.8	66.2	64.7	107.0
Dissolved organic carbon (mg L^{-1})	12	2.8	4.4	4.6	7.4
Alkalinity (mg L^{-1})	12	85.3	118.0	116.7	138.0
Total phosphorus (µg L^{-1})	12	11	28	32	67
Total nitrogen (mg L^{-1})	12	0.22	0.32	0.33	0.45
Nitrate+Nitrite-N (mg L^{-1})	12	<0.02	<u>0.031</u>	<u>0.065</u>	0.240
Total ammonia-N (mg L^{-1})	12	<0.02	<u>0.01</u>	<u>0.02</u>	0.05
Fecal coliforms (coliform 100mL^{-1})	11	2	11	44	170
E9 (Stream E9)					
Specific Conductance (µmhos cm^{-1})	10	459	795	770	953
Fecal coliforms (coliform 100mL^{-1})	9	3	14	79	510
MB-1 (Malcolm Brook)					
Total suspended solids (mg L^{-1})	12	<1	<u>2.3</u>	<u>2.9</u>	6.8
Specific Conductance (µmhos cm^{-1})	12	444	712	763	1280
Chloride (mg L^{-1})	12	93.6	148.5	177.4	332.0
Dissolved organic carbon (mg L^{-1})	12	1.7	2.5	3.0	6.2
Alkalinity (mg L^{-1})	12	58.3	79.7	77.9	99.0
Total phosphorus (µg L^{-1})	12	5	34	36	75

Table 4.4 2015 Summary statistics for Kensico Reservoir streams.

Site/Analyte	Number samples	Minimum	Median[1]	Mean[1]	Maximum
Total nitrogen (mg L^{-1})	12	0.32	0.54	0.54	0.77
Nitrate+Nitrite-N (mg L^{-1})	12	0.080	0.315	0.323	0.580
Total ammonia-N (mg L^{-1})	12	<0.02	0.04	0.05	0.09
Fecal coliforms (coliform 100mL^{-1})	11	1	88	244	1100
N12 (Stream N12)					
Total suspended solids (mg L^{-1})	12	<1	0.4	2.0	12.4
Specific Conductance (µmhos cm^{-1})	12	319	376	440	902
Chloride (mg L^{-1})	12	39.1	60.1	77.3	229.0
Dissolved organic carbon (mg L^{-1})	12	1.7	2.2	2.5	4.2
Alkalinity (mg L^{-1})	12	48.6	74.5	71.4	102.0
Total phosphorus (µg L^{-1})	12	10	25	23	40
Total nitrogen (mg L^{-1})	12	0.43	0.87	0.90	1.42
Nitrate+Nitrite-N (mg L^{-1})	12	0.280	0.715	0.768	1.350
Total ammonia-N (mg L^{-1})	12	<0.02	<0.02	<0.02	<0.02
Fecal coliforms (coliform 100mL^{-1})	12	3	71	157	580
N5-1 (Stream N5-1)					
Total suspended solids (mg L^{-1})	12	<1	1.3	1.9	7.6
Specific Conductance (µmhos cm^{-1})	12	308	513	609	1720
Chloride (mg L^{-1})	12	47.7	90.0	125.0	491.0
Dissolved organic carbon (mg L^{-1})	12	1.5	2.6	2.9	6.8
Alkalinity (mg L^{-1})	12	60.1	80.5	80.8	110.0
Total phosphorus (µg L^{-1})	12	21	53	56	117
Total nitrogen (mg L^{-1})	12	0.57	1.21	1.21	2.12
Nitrate+Nitrite-N (mg L^{-1})	12	0.110	0.875	0.896	1.390
Total ammonia-N (mg L^{-1})	12	<0.02	0.08	0.08	0.18
Fecal coliforms (coliform 100mL^{-1})	11	<3	36	60	190
WHIP (Whippoorwill Creek)					
Total suspended solids (mg L^{-1})	12	<1	2.3	3.4	11.8
Specific Conductance (µmhos cm^{-1})	12	371	473	463	538
Chloride (mg L^{-1})	12	68.8	95.1	90.7	106.0
Dissolved organic carbon (mg L^{-1})	12	1.9	2.4	2.6	4.0
Alkalinity (mg L^{-1})	12	40.4	58.0	60.9	89.0

Table 4.4 2015 Summary statistics for Kensico Reservoir streams.

Site/Analyte	Number samples	Minimum	Median[1]	Mean[1]	Maximum
Total phosphorus (µg L^{-1})	12	10	17	22	49
Total nitrogen (mg L^{-1})	12	0.62	0.97	1.01	1.40
Nitrate+Nitrite-N (mg L^{-1})	12	0.370	0.865	0.858	1.280
Total ammonia-N (mg L^{-1})	12	<0.02	0.01	0.02	0.05
Fecal coliforms (coliform $100mL^{-1}$)	12	1	18	81	350

[1] Summary statistics for data containing nondetects was estimated using the robust ROS technique recommended in Helsel (2005) using an R program developed for U.S. Environmental Protection Agency (Bolks et al 2014). These estimates are underlined using two lines. In cases where >80% of data is censored the mean and median cannot be estimated and here we report the detection limit prefixed by <. Results with no underlining indicate that the estimates were made using the standard median and mean.

4.3.2. Turbidity Curtain Inspection

The three turbidity curtains maintained around the Catskill Upper Effluent Chamber cove in Kensico Reservoir protect water entering into distribution from the impacts of storm events by local streams. DEP conducts at least a monthly visual inspection of the turbidity curtains from fixed shore locations around the cove. Table 4.5 lists the dates and results of the turbidity curtain inspections carried out in 2015. When inspections indicate that maintenance is required, Bureau of Water Supply Systems Operations is notified and Operations will perform the appropriate repairs or adjustments. The Catskill Upper Effluent Chamber has been offline since September 2012 because there is insufficient head to deliver water to the Catskill/Delaware UV Plant.

Table 4.5 Visual inspections of the Kensico Reservoir turbidity curtains.

Date	Observations
01/14/15	Curtains appear intact and afloat as seen from shore.
01/29/15	Curtains appear intact and afloat as seen from shore.
02/11/15	Curtains appear intact and afloat as seen from shore.
02/25/15	Curtains appear intact and afloat as seen from shore.
03/25/15	Curtains appear intact and afloat as seen from shore.
04/09/15	Curtains appear intact and afloat as seen from shore.
04/22/15	Curtains appear afloat. Abrasion possible on DEL18 point curtain (underwater portion)
05/06/15	Curtains appear intact and afloat as seen from shore.

Table 4.5 Visual inspections of the Kensico Reservoir turbidity curtains.

Date	**Observations**
06/03/15	A portion of the DEL18 point boom is on shore; the rest of the turbidity curtains appear intact and afloat as seen from shore.
06/17/15	Curtains appear intact and afloat as seen from shore.
07/01/15	Curtains appear intact and afloat as seen from shore.
07/29/15	Curtains appear intact and afloat as seen from shore.
08/12/15	Curtains appear intact and afloat as seen from shore.
08/26/15	Curtains appear intact and afloat as seen from shore.
09/10/15	Curtains appear intact and afloat as seen from shore.
09/23/15	Curtains appear intact and afloat as seen from shore.
10/08/15	Curtains appear intact and afloat as seen from shore.
10/21/15	Turbidity curtains Del 18 Cove, UEC Cove & MB Cove appeared in good order.
11/04/15	Curtains appear intact and afloat as seen from shore.
11/19/15	Curtains appear intact and afloat as seen from shore.
12/16/15	Curtains appear intact and afloat as seen from shore.

4.4. 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 correspond to waterbird populations at several NYC reservoirs (DEP 2002). As waterbird counts increased during the avian migratory and wintering periods fecal coliform bacteria levels also increased. Upon implementation of the avian dispersal measures both waterbird counts and fecal coliform levels declined allowing DEP to maintain compliance with the federal Surface Water Treatment Rule (SWTR).

Historic water quality monitoring data collected at the two main water influent and effluent facilities at Kensico demonstrated that higher levels of fecal coliform bacteria were leaving the reservoir than what was contributed through aqueducts from the upstate reservoirs (DEP 1992). It was apparent at that time that a local source of fecal coliform bacteria was impacting Kensico. Based on these data, DEP determined that waterbirds were the most important contributor to seasonal fecal coliform bacteria loads to Kensico as waterbirds can also lead to increased seasonal fecal coliform levels.

The Waterfowl Management Program (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 (USDA), and in part under permit by the United States Fish and Wildlife Service (USFWS) and the New York State Department of Environmental Conservation (NYSDEC). DEP maintains an annual depredation permit from the USFWS and NYSDEC to manage avian and mammalian populations for water quality improvements.

Avian management techniques include non-lethal dispersal actions by use of 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.

The Surface Water Treatment Rule (40 CFR 141.71(a)(1)) states that no more than 10% of source water samples can have counts that exceed 20 fecal coliforms $100mL^{-1}$ 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 4.5). DEP will continue implementation of the WMP to help ensure delivery of high quality water to NYC consumers.

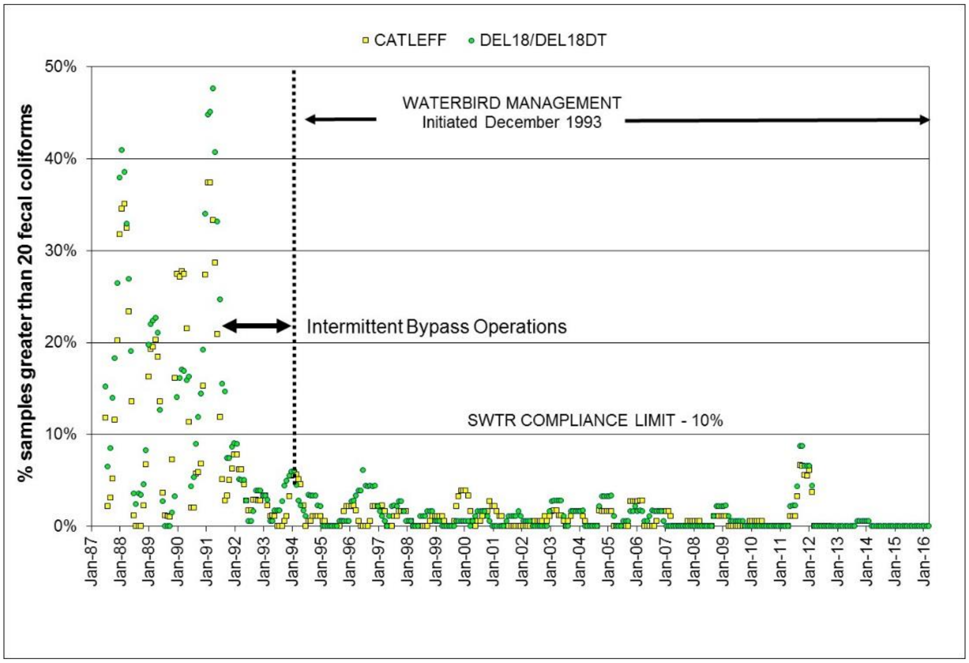


Figure 4.5 Percent of keypoint fecal coliform samples at Kensico Reservoir greater than 20 fecal coliforms $100mL^{-1}$ for the previous six-month period, 1987-2015. The vertical dashed line indicates the year in which the WMP was implemented.

4.5. Kensico Research Projects and Special Investigations

4.5.1. Bryozoans

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. Control of these organisms in a drinking water supply is particularly challenging because many control measures used for other applications are not an option for drinking water.

DEP staff initially began monitoring the development of bryozoan colonies in the Delaware Shaft 18 sluice gates from April 2014 through September of 2014. The monitoring procedure utilized lowering an underwater video camera on a long set of poles down into the sluice gates (upstream of the traveling screens) and high definition (HD) video recordings were created to document the conditions in each of the five gates. Video monitoring predominantly focused on the access ladder and adjacent wall areas. Since no colonies were observed in April, nor most of May 2014, the 2015 monitoring was not started until June 3 and continued through

September. During 2015, video monitoring was conducted approximately every two to three weeks, for a total six visits with video observations. Notes on water quality parameters (temperature, turbidity, etc.) and operational conditions (flow rate) were also taken at the time of the visits.

Numerous still frame shots documenting the temporal growth of colonies were collected from the videos, usually on specific ladder rungs. As it had occurred the previous year, *Cristatella mucedo* appeared earlier in the season than *Pectinatella magnifica*, and it resided at lower depths as it prefers cooler water than *Pectinatella*. *C. mucedo* was present in June, while *P. magnifica* did not appear until July. Similarly, *C. mucedo* began to die and peel off the walls in mid-August; whereas *P. magnifica* survived until late September.

Notably, in August, an oily substance was detected on the video poles in the sluice gate #5 area. The area was closed down the same day and it was later determined to have been caused by a leak of lubricant that was subsequently cleaned by the operators. When we returned for the September survey, flow through the sluiceway had been stopped for approximately one month (and was still off). Interestingly, September video observations of this closed area showed that all of the colonies that had been in sluice gate 5 were no longer on the walls or the ladder. It was hypothesized that due to either the lack of flow (no nutrients being delivered to the filter feeder) or the oily substance (a pollutant to the filter feeder), that the organisms died and sank to the bottom of the chamber. This was confirmed at the end of the season when divers entered the area and found numerous gelatinous masses in a pile at the bottom of the chamber – the colonies had died. This observation may help DEP manage this organism if the flow through the various gates can be altered during the course of the growing season to possibly limit growth.

The photo progression shown below illustrates how quickly the *P. magnifica* colonies develop during the later summer months (Figure 4.6) and compares two years of photos from the same location. As can be observed, the colonial growth rate appears to be very similar in 2015 compared to similar dates in 2014. Moreover, observations included identifying the growth of some of the colonies in the same exact location as the previous year (ie, The right side of rung 12 in both 2014 and 2015). Perhaps this information can also aid DEP in managing the growth of these organisms if areas of previous growth can be cleaned thoroughly at the end of the season. Many large colonies (more than 40 colonies larger than 8 inches in diameter) were present by late September when divers were contracted to remove them. The largest of these *P. magnifica* colonies had grown to several feet wide. Monitoring will continue in 2016.

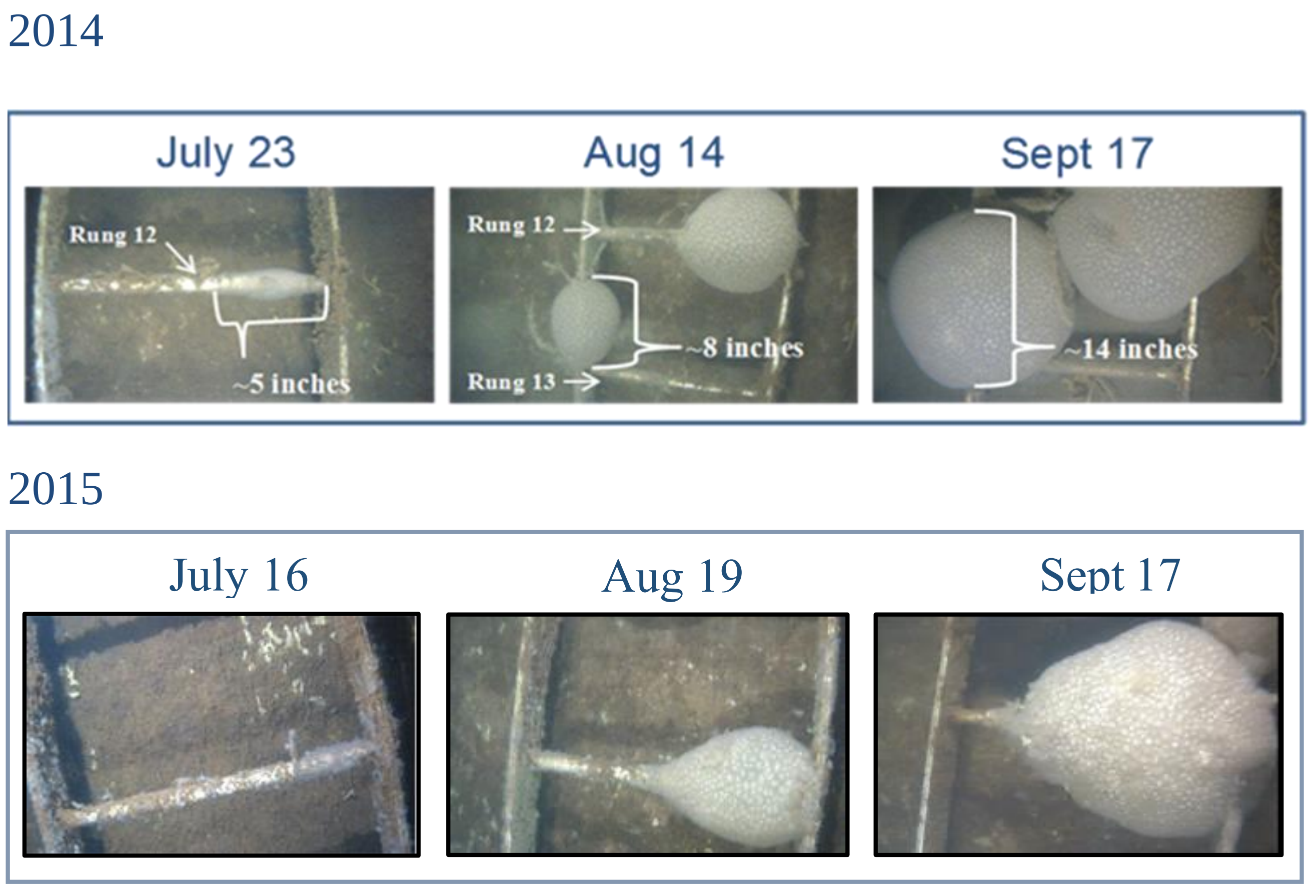


Figure 4.6 Photographs showing progression of *P. magnifica* colony growth on ladder rungs 12 and 13 at Delaware Shaft 18 in Sluice Gate 3 for 2014 and 2015. For scale, each of the ladder rungs are about 12 inches across.

4.5.2. Special Investigations

There were three special investigations within the Kensico watershed conducted during 2015. All of these special investigations had the potential to compromise drinking water quality in different respects. A brief summary of each investigation and the results are stated below in chronological order.

Brush Fire along Kensico Reservoir – April 16, 2015

A brush fire along and on the hill above the shoreline of the Kensico Reservoir in the vicinity of the Rye Lake Bridge was investigated. The brush fire occurred during the evening of April 16, 2015. The area impacted was approximately 4.5 acres in size. Samples were taken for conductivity, turbidity, temperature, pH, ammonia, total dissolved nitrogen, dissolved organic carbon, total organic carbon, nitrate/nitrite, total phosphorus, total dissolved phosphorus, soluble reactive phosphorus and UV-254. Sample results from a sampling run performed 10 days before the brushfire indicated no appreciable change of analytical results compared to the day after the brushfire. It was concluded that the brushfire did not impact Kensico Reservoir drinking water quality.

Storm Event Kensico Reservoir - September 29-30, 2015

The only Kensico storm event sampled for the year was on September 29-30, 2015, when approximately 1.91 inches of rainfall fell at Kensico Reservoir. Analytes investigated were turbidity, fecal coliforms and conductivity, as well as samples for microbial source tracking (MST). As is usual during an event in this area, there was a sharp increase in streamflow for Malcolm Brook and N5, with Malcolm Brook having a gradual decline and N5 having a more erratic decline. Fecal coliform concentrations spiked high within the Malcolm Brook and N5 streams during the beginning of the storm event with a maximum concentration of 47,000 fecal coliforms $100mL^{-1}$ on September 30**.** Change in turbidity was minimal at the nearby limnological sampling sites, while some fecal coliform limnological data suggested possible influence from the streams or direct runoff. The reservoir effluent at DEL18DT had no turbidity issues as a result of these storms (≤0.85 NTU), and fecal coliform results did not exceed 9 fecal coliforms $100mL^{-1}$, with levels returning to <1 by October 2. MST data indicated trace levels of human *Bacteroides* markers in three out of four stream samples tested, and moderate concentrations of *Bacteroides* with ruminant markers in the two samples tested for that marker. These results suggest that wildlife were the most likely source of fecal contamination in these sub-basins with trace levels of a possible human source.

N12 Pathogen Sampling - December 1, 2015

A pathogen sample collected from Kensico Reservoir tributary N12 on December 1, 2015 returned 16 *Cryptosporidium* oocysts and 13 *Giardia* cysts. These oocyst counts exceeded the 95th percentile for N-12. Other analytes investigated were streamflow, temperature, specific conductivity and turbidity. Follow up sampling on December 15 found 25 *Cryptosporidium* oocysts and 17 *Giardia* cysts. Routine sampling on December 28 included *Cryptosporidium*, *Giardia*, fecal coliform, temperature, pH, turbidity, and conductivity. Results for *Cryptosporidium* and *Giardia* showed increased concentrations of *Cryptosporidium* in samples upstream from the reservoir and variable concentrations of *Giardia*. Additional samples were collected for microbial source tracking and resulted in *Cryptosporidium* types associated with wildlife – not human sources.

5. Pathogen Monitoring and Research

5.1. Introduction

Cryptosporidium, *Giardia*, and human enteric viruses (HEV) are monitored throughout the 1,972-square-mile NYC Watershed by DEP as part of compliance and surveillance monitoring. DEP staff collected 601 protozoan (*Cryptosporidium* and *Giardia*) samples in 2015. Of these, 597 samples were analyzed, 81 of which were analyzed as part of protozoan special studies and are discussed elsewhere in this report. The remaining 516 samples will be discussed here. Samples taken at source water keypoints (Kensico and New Croton) made up the largest portion (36.8%) of the sampling effort (Figure 5.1), with watershed streams composing the next largest component (29.6%). The remaining 33.6% are comprised of samples collected at the Hillview downtake, upstate reservoir releases and the wastewater treatment plants. Samples collected for protozoan analysis were analyzed by Method 1623HV until April 6, 2015, when DEP changed to Method 1623.1 with EasyStain. Additionally, 134 HEV samples were collected and analyzed in 2015. All virus samples were analyzed by DEP according to the Information Collection Rule (ICR) Manual (USEPA 1996).

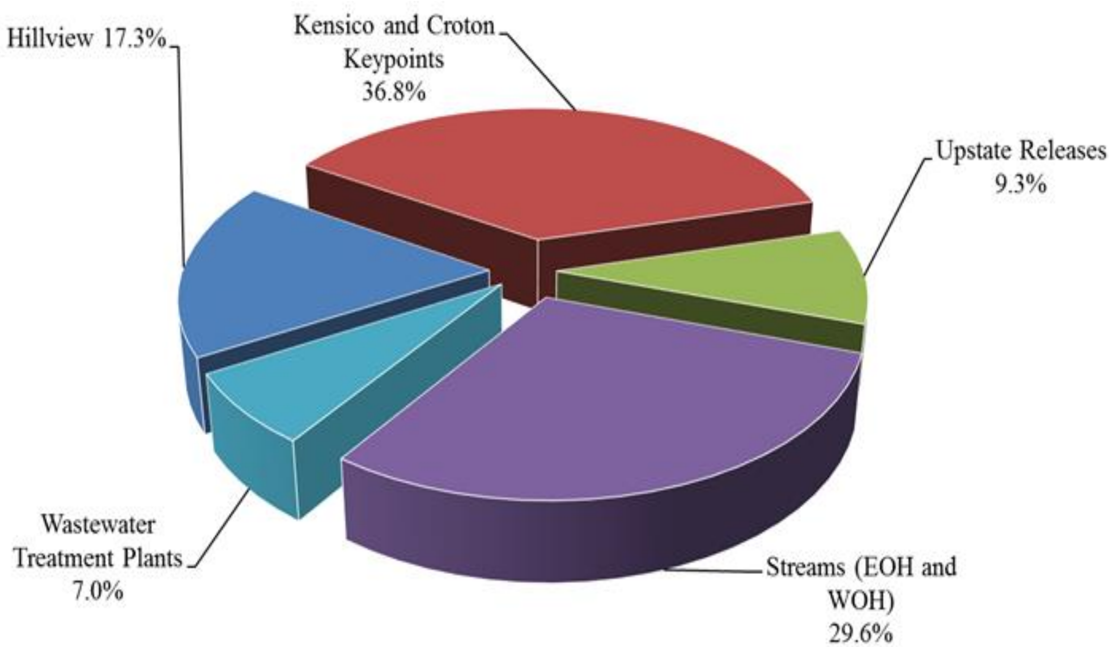


Figure 5.1 DEP protozoan sample collection type distribution for 2015.

The Catskill Aqueduct south of Kensico Reservoir remained shut down throughout 2015. HEV sampling frequency at Kensico Reservoir keypoint sites was reduced from weekly to monthly beginning in mid-September 2015, with prior approval granted by the New York State Department of Health. Kensico outflow results are posted weekly on DEP's website (www.nyc.gov/html/dep/pdf/pathogen/path.pdf), and reported annually in this report.

5.1.1. Protozoan Method Change in 2015

On April 6, 2015, DEP changed methods for protozoan analysis from Method 1623 to Method 1623.1 with EasyStain to improve both recovery and the ability to genotype samples after slide processing. This change is coincident with a shift in results for the remainder of the year. The shift in data is both an increased detection of *Cryptosporidium* oocysts and a decreased detection of *Giardia* cysts throughout the watershed; however, additional data with the new method will be needed to confirm this effect of method change.

The major difference between Method 1623 and 1623.1 is the addition of sodium hexametaphosphate (HMP) to improve recovery in the elution step of the procedure which is most effective with difficult matrices. This change alone, as approved by EPA in the method validation, often leads to improved recovery of organisms. EasyStain, optimized for use with Method 1623/ 1623.1, is highly specific (IgG1) to reduce cross reactivity with background material and improve slide reading accuracy. The specificity is targeted to *G. duodenalis* (formerly *G. lamblia*), the type most associated with human illness. The previous stain, also approved by EPA, is pan-specific, and therefore reacts with all *Giardia* species, as well as background material on the slides sometimes causing interference. This difference in specificity would result in a decline in the detection of cysts, especially in locations where animals or other sources are contributing *Giardia* species less associated with human illness. In a 2007 study, with side-by–side samples, DEP demonstrated a statistically significant decrease in the detection of *Giardia* cysts when using EasyStain resulting in a 45% detection rate, compared to 82% with the previous stain (Alderisio, et. al, 2008). Moreover, EasyStain, when used without fixing buffer, allows for greater success with genotyping organisms from the slides after analysis.

In summary, the information known about the use of Method 1623.1 and EasyStain combined with previous research performed by DEP provided the motivation for DEP to change methods – to improve the ability to recover protozoa from water samples and improve the success rate of genotyping positive samples. The decline of *Giardia* detection was expected since EasyStain does not target all species of *Giardia*, yet the previous stain did detect all species. As a result, the increased detection of *Cryptosporidium* and the decreased detection of *Giardia* noted here in the 2015 data are believed to be due to the method changes and not due to an increase or decrease of these organisms in the environment.

5.2. Source Water Results

Catskill Aqueduct Inflow

There were six detections of *Cryptosporidium* in 52 weekly samples collected at the Catskill Aqueduct inflow to Kensico Reservoir (CATALUM) in 2015 (Table 5.1). There were two detections in 2014 (n=51), and a total of four detections in the five year period from 2010-2014 (n=260). The mean annual *Cryptosporidium* concentration increased from 0.04 oocysts $50L^{-1}$ in 2014, to 0.15 oocysts in 2015.

In 52 weekly samples at the CATALUM inflow, nine were positive (17.3%) for *Giardia* in 2015 (Figure 5.2), compared to 33.3% positive in 2014. The mean *Giardia* concentration for 2015 was 0.50 cysts $50L^{-1}$, compared to 1.12 cysts in 2014. The 2015 *Giardia* annual mean is one of the lowest observed at this site in the last 14 years, the exceptions being 2002 and 2012 (0.46 and 0.17 cysts $50L^{-1}$, respectively) (Figure 5.2). HEV were detected in 11 of 40 (27.5%) samples taken at CATALUM in 2015, similar to the 35.3% positive in 2014 (n=51). Mean HEV concentration, as determined by the "most probable number" (MPN) method, was 0.72 MPN $100L^{-1}$ for 2015, which was lower than the 2014 mean (1.20 MPN $100L^{-1}$). However, as stated previously, virus sampling at keypoints was reduced from weekly to monthly beginning in September of 2015, creating an uneven distribution of sample size across the year. This unevenness makes it more difficult to compare the current year's summary statistics with those from past years, especially considering the potential for seasonality in HEV results.

Table 5.1 Summary of *Cryptosporidium*, *Giardia*, and HEV compliance monitoring data at the five DEP keypoints for 2015. NS = not sampled.

	Keypoint Location	**Number of Positive Samples**	**Mean[2]**	**Maximum**
Cryptosporidium oocysts $50L^{-1}$	CATALUM (n=52)	6	0.15	2
	DEL17 (n= 52)	5	0.12	2
	DEL18DT (n=52)	8	0.17	2
	CROGH[1] (n= 12)	1	0.08	1
	1CR21 (n= 12)	0	0.00	0
Giardia cysts $50L^{-1}$	CATALUM (n=52)	9	0.50	11
	DEL17 (n=52)	19	1.08	7
	DEL18DT (n=52)	19	0.85	8
	CROGH[1] (n=12)	2	0.25	2
	1CR21 (n=12)	0	0.00	0

Table 5.1 Summary of *Cryptosporidium*, *Giardia*, and HEV compliance monitoring data at the five DEP keypoints for 2015. NS = not sampled.

	Keypoint Location	Number of Positive Samples	Mean[2]	Maximum
Human Enteric Virus $100L^{-1}$ (HEV)	CATALUM (n=40)	11	0.72	4.90
	DEL17 (n= 40)	7	0.25	2.23
	DEL18DT (n=40)	3	0.08	1.07
	CROGH[1] (n= 12)	5	1.76	7.94
	1CR21 (n= 0)	NS	NS	NS

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

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

Delaware Aqueduct Inflow and Outflow

Kensico Reservoir's Delaware inflow (DEL17) had a higher *Cryptosporidium* detection rate in 2015 (5 in 52 samples, 9.6%) than in 2014 (1 in 52 samples, 1.9%). The prior year (2013), exhibited a similar detection rate to 2015, with 6 positives in 52 samples, and the same mean annual concentration of 0.12 oocysts $50L^{-1}$. *Cryptosporidium* detections at the Delaware outflow from Kensico Reservoir (DEL18DT) were also higher in 2015 (8 in 52 samples, 15.4%) compared to 2014 (4 in 54 samples, 7.4%). This was the highest detection rate at the Delaware outflow since 2005 (15 in 97 samples, 15.5%). The mean annual concentration for DEL18DT was also higher in 2015 (0.17 oocysts $50L^{-1}$) when compared to the preceding nine years 2006-2014 (each year <0.13 oocysts $50L^{-1}$).

Similar to the Catskill inflow, *Giardia* detections were lower at the DEL17 inflow in 2015 (19 in 52 samples, 36.5%) compared to 2014 (31 in 52 samples, 59.6%). Mean *Giardia* concentrations were also lower in 2015 compared to 2014 (1.08 and 1.61 oocysts $50L^{-1}$, respectively). As in 2014, the DEL18DT outflow had the same number of detections as the DEL17 inflow in 2015, although DEL18DT had a lower mean *Giardia* concentration in 2015 (0.85 oocysts $50L^{-1}$) compared to 2014 (1.43 oocysts $50L^{-1}$). The *Giardia* detection rate and mean annual concentration for DEL18DT are the lowest observed since Method 1623HV began at DEP (Figure 5.2).

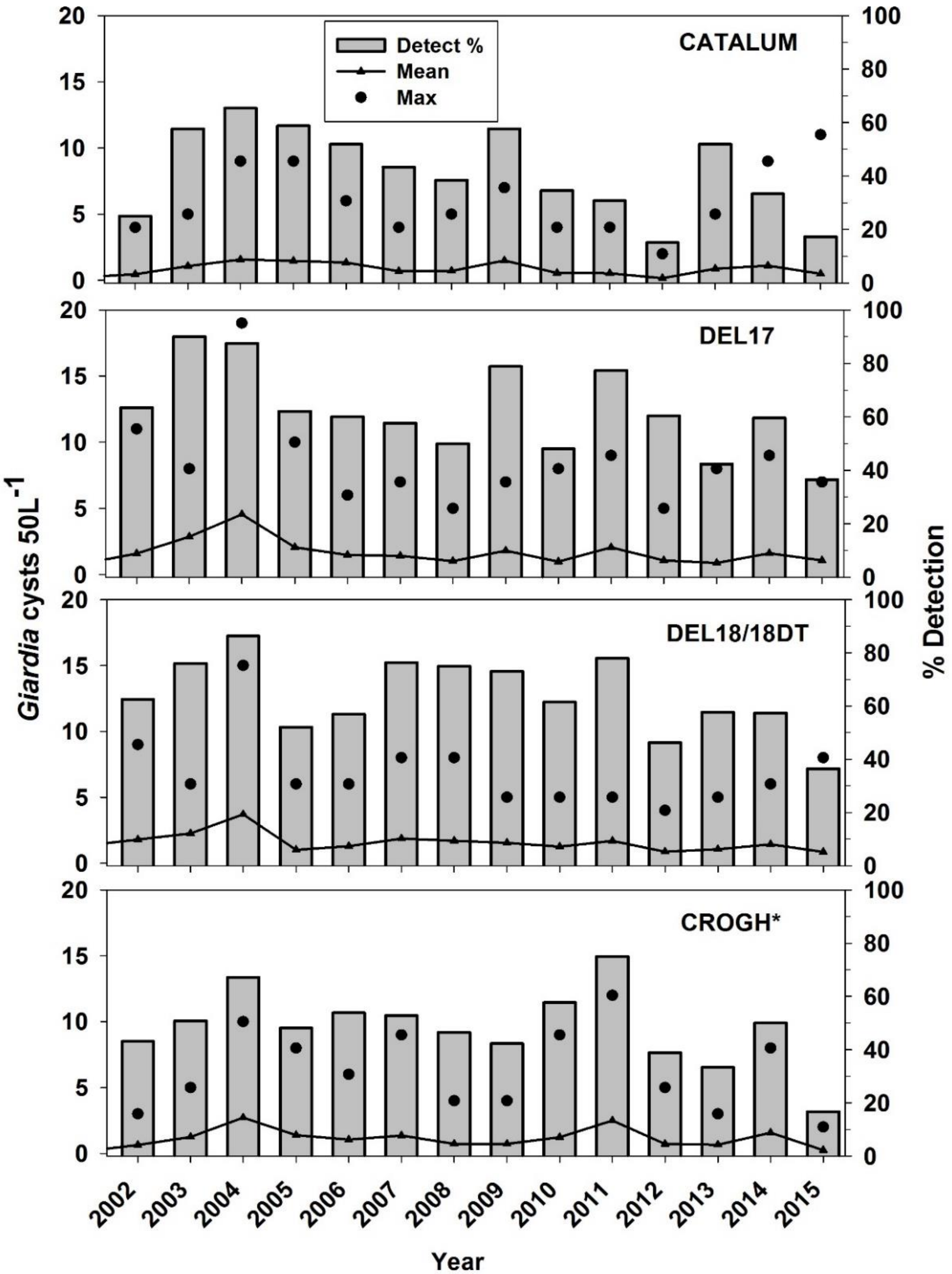


Figure 5.2 *Giardia* annual percent detection, mean concentration, and maximum result for the keypoint sites during each year from 2002 to 2015. Alternate sites may be sampled to best represent the Croton Reservoir effluent in the event the reservoir was not online.

HEV were detected in 7 out of 40 samples (17.5%) at DEL17, similar to 2014 when 8 out 52 samples (15.4%) were positive for HEV. The mean HEV concentration in 2015 was 0.25 MPN $100L^{-1}$, which is within this site's historical range for the ICR Method (0.08 - 1.41 MPN $100L^{-1}$ from 2004 to 2014) and similar to the 2014 mean of 0.33 MPN $100L^{-1}$. DEL18DT had a lower HEV detection rate in 2015 (3 out of 40 samples, 7.5%) compared to 2014 (7 out of 52 samples, 13.5%). The HEV annual mean concentration at DEL18DT was 0.08 MPN $100L^{-1}$ in 2015, compared to those found in the previous two years (0.17 and 0.19 MPN $100L^{-1}$ for 2013 and 2014, respectively).

New Croton Aqueduct

Cryptosporidium was found in one sample at the Croton Reservoir effluent site in 2015 (1 in 12 samples) and at a very low concentration (1 oocyst $50L^{-1}$). This has been the only *Cryptosporidium* detection at the Croton Reservoir effluent site in the past three years (2013-2015, n=38). In May 2015, with the startup of the Croton Filtration Plant (CFP), DEP began analyzing weekly samples for protozoans at an additional Croton Aqueduct site, which would now be the source water location for the Croton supply prior to filtration. The new Croton source water site is named 1CR21 and is located at the effluent of Jerome Park Reservoir. A total of 35 samples were collected at 1CR21 in 2015, and all were negative for *Cryptosporidium*.

Giardia was found in two of the 12 monthly samples (February and December) taken at the Croton reservoir outflow in 2015 (2.00 and 1.00 oocyst $50L^{-1}$, respectively). This is the lowest percent positive (16.7%) and the lowest mean annual concentration (0.25 oocyst $50L^{-1}$) at this site since Method 1623HV began in October 2001 (Figure 5.2). There were no *Giardia* detected in the 35 weekly samples taken at 1CR21 in 2015.

HEV were detected in five of the 12 monthly samples (41.7%) at the Croton Reservoir outflow, with a mean annual concentration of 1.76 MPN $100L^{-1}$. This detection rate was higher than the two previous years (2013, 25.0% and 2014, 16.7%) which included monthly HEV sampling. However, due to the relatively low concentration of HEV in 2015 samples (maximum result of 7.94 MPN $100L^{-1}$), the mean concentration was quite similar to that found in 2013 (1.75 MPN $100L^{-1}$). HEV sampling is not required at the 1CR21 location.

Giardia continues to be detected more frequently and at higher concentrations during winter and spring months compared to summer and fall (Figure 5.3), as has been seen in results from past years. It should be noted that in 2015, the higher *Giardia* concentrations seem to decrease immediately after the change to Method 1623.1 with EasyStain; however, there is normally a seasonal decline of *Giardia* cysts at this time each year. Multiple years of analysis with Method 1623.1 and EasyStain will better demonstrate a difference, if one exists.

As described above in the introduction, it is important to note that the increase in *Cryptosporidium* and decrease in *Giardia* observed in 2015, are believed to be a result of the method change, and not an increase or decrease of these organisms in the environment.

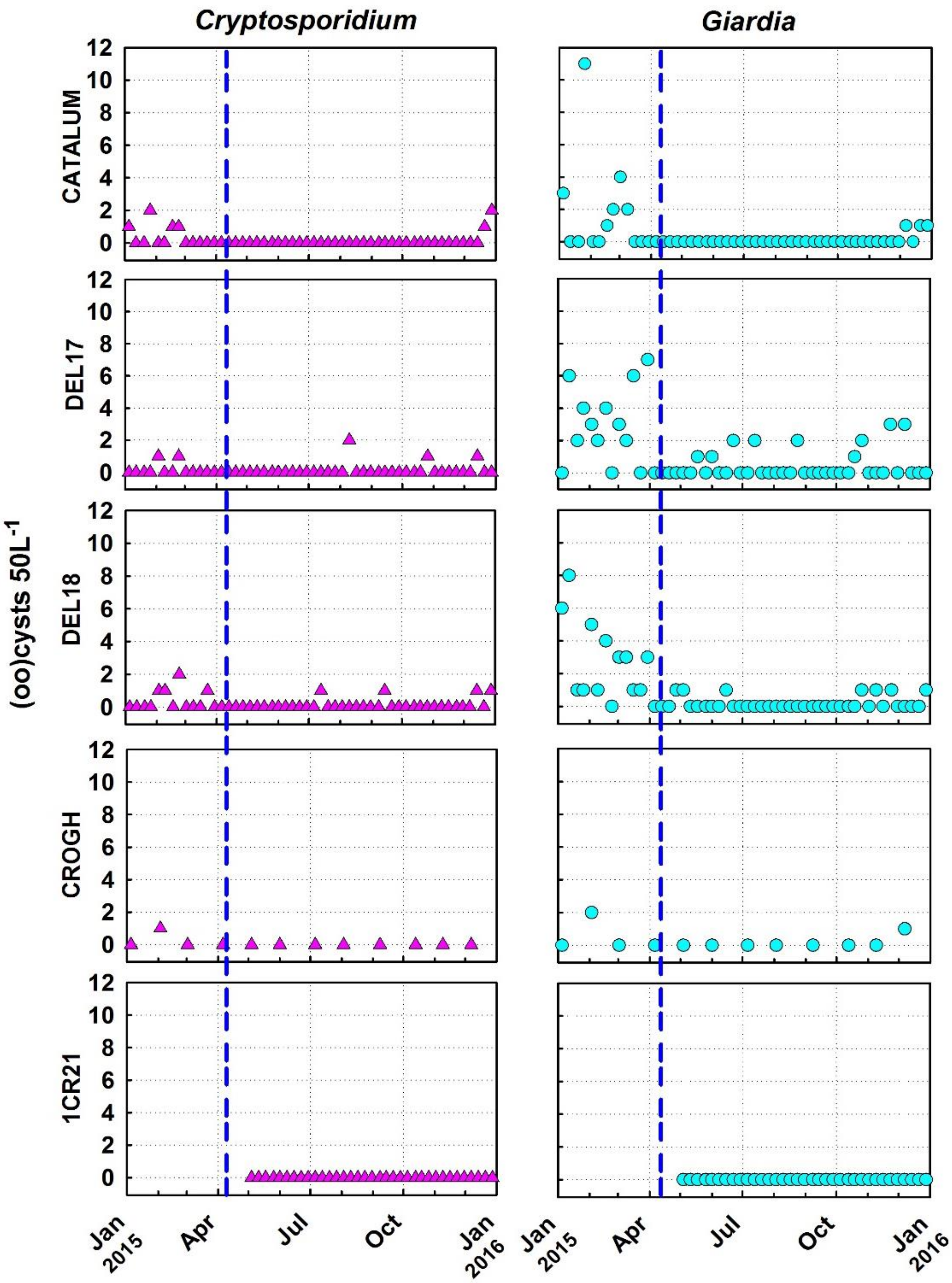


Figure 5.3 Routine weekly source water keypoint monitoring results for 2015. The dashed vertical blue line denotes the change from Method 1623HV to Method 1623.1 with EasyStain.

5.2.1. 2015 Source Water Compared to Historical Data

Water quality at the different source water sites can vary due to the many influences in the respective watersheds (stormwater runoff, impacts from landuse, operational changes, etc.), Beginning in October 2001, source water sites were sampled weekly for protozoans and analyzed using Method 1623HV. A few changes have occurred since 2001 including; the change in frequency of monitoring at the New Croton outflow from weekly to monthly (August 2012), the shutdown of the Catskill Aqueduct outflow from Kensico Reservoir (September 2012), a change in the analytical Method 1623HV to Method 1623.1 with EasyStain (April 2015), and the addition of sampling at the Jerome Park Reservoir outflow (1CR21) with the Croton Filtration Plant startup (May 2015). Each change has added some complexity when comparing the current year's data to the historical dataset (with the exception of 1CR21, which has no historical data).

In 2015, there were 11 samples positive for *Cryptosporidium* at the two Kensico Reservoir inflows (CATALUM and DEL17) compared to 8 positives at the outflow (Table 5.2 and Table 5.3). Each of these three sites had 4 more samples with detections of oocysts than were found in 2014. There are prior years with a similar number of detections (2013 for DEL17, 2009 for CATALUM, and 2006 for DEL18DT) but for the most part, detection of oocysts has been lower in the recent past. The number of samples with *Cryptosporidium* detections at Croton Reservoir's outflow remained low for the fifth straight year, with only three positive samples from 2011-2015 (n=126) and a maximum concentration of 1 oocyst $50L^{-1}$. However, the rate of detection was higher than the past several years since samples were collected less often. Again, it was expected that we might see an increase in detection/concentration at the keypoint sites with the method change this year.

Table 5.2 Annual detection and mean oocyst concentration of *Cryptosporidium* at inflow keypoints to Kensico Reservoir 2002-2015.

Site	CATALUM			DEL17		
Year	**Detects**	**% Detects**	**Mean ($50L^{-1}$)**	**Detects**	**% Detects**	**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

Table 5.2 Annual detection and mean oocyst concentration of *Cryptosporidium* at inflow keypoints to Kensico Reservoir 2002-2015.

Site	CATALUM			DEL17		
Year	Detects	% Detects	Mean ($50L^{-1}$)	Detects	% Detects	Mean ($50L^{-1}$)
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
2014	2	3.9	0.04	1	1.9	0.02
2015	6	11.6	0.15	5	9.7	0.12

Table 5.3 Annual detection and mean concentration of *Cryptosporidium* at Kensico and New Croton Reservoir outflow keypoints 2002-2015.

Site	DEL18DT			CROGH		
Year	Detects	% Detects	Mean ($50L^{-1}$)	Detects	% Detects	Mean ($50L^{-1}$)
2002	18	25.0	0.31	13	20.0	0.28
2003	21	29.6	0.45	7	11.9	0.17
2004	25	34.7	0.36	28	40.0	0.51
2005	15	15.5	0.23	3	5.5	0.05
2006	7	10.8	0.12	7	13.5	0.13
2007	2	4.0	0.04	3	5.7	0.06
2008	1	1.9	0.02	8	14.3	0.21
2009	4	7.7	0.08	4	7.7	0.12
2010	1	1.9	0.02	5	9.6	0.10
2011	1	1.7	0.02	1	1.9	0.02
2012[1]	0	0.0	0.00	1	2.8	0.03
2013	0	0.0	0.00	0	0.0	0.00
2014	4	7.4	0.11	0	0.0	0.00
2015	8	15.4	0.17	1	8.3	0.08

[1]Monitoring at CROGH was modified from weekly to monthly in August 2012.

Giardia concentrations at the three Kensico keypoints and New Croton Reservoir outflow were low in 2015, with two of the sites (DEL18DT and CROGH) reporting the lowest mean annual concentrations since 2002, or earlier. While DEL17 did not result in a new low for mean annual concentration in 2015, it did have the lowest number of detections (19 positives out of 52 samples) with the lowest percent detection (36.5%) compared to historical data. Seasonal variation in *Giardia* results can be discerned for all four keypoints sampled in 2015, however, this seasonality is less apparent in the locally weighted regression (LOWESS) smoothed line for the Croton outflow data (Figure 5.4). This is due in part to the reduction in sampling frequency in 2012. The LOWESS uses uniformly specified proportions of the dataset to determine regressions, with no mechanism to adapt to the change in sample frequency.

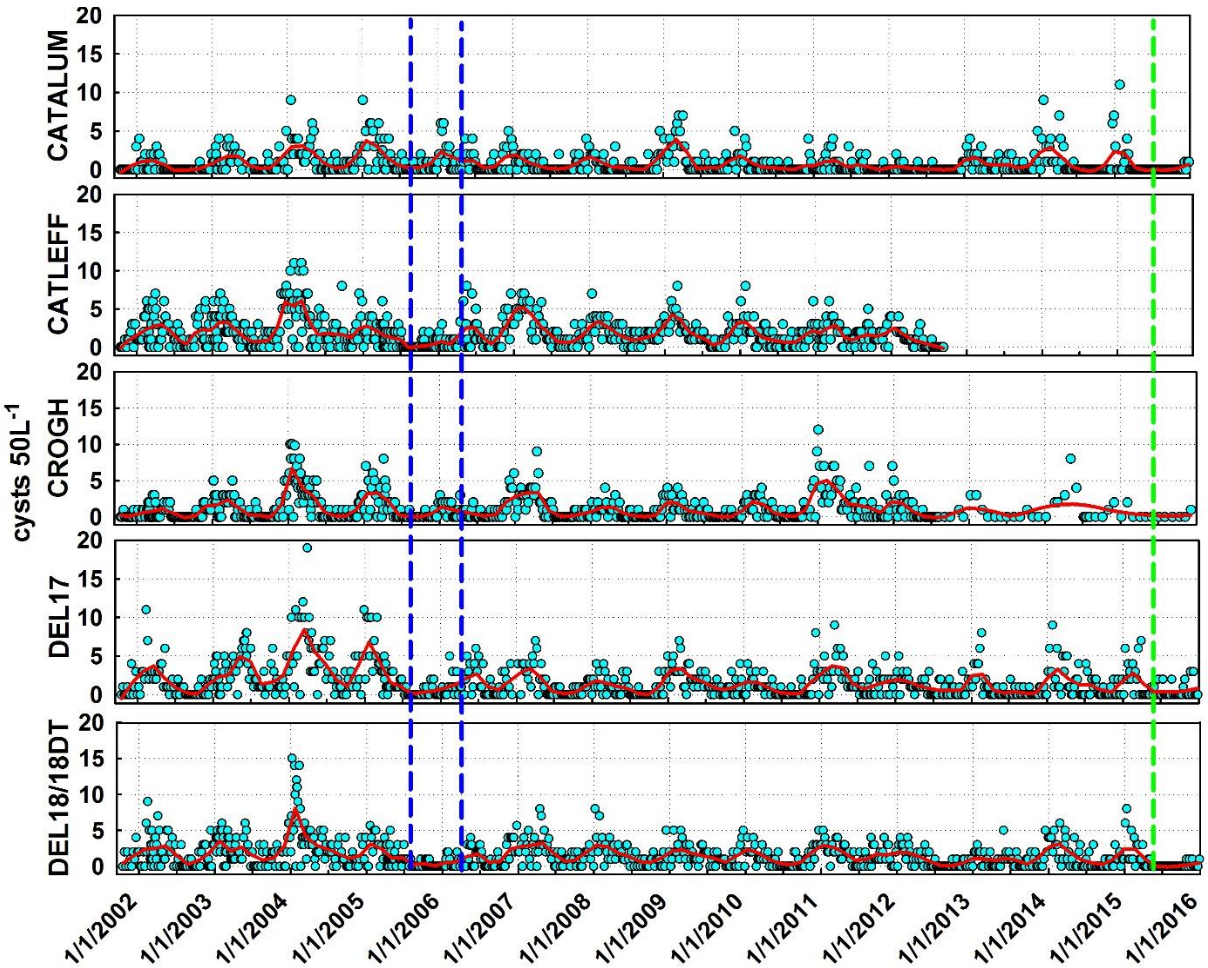


Figure 5.4 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed – 0.05) from October 15, 2001 to December 31, 2015. The area between the blue dotted lines indicates the period during which DEP temporarily switched to EasyStain. The green dotted line indicates the change from Method 1623HV to Method 1623.1 with EasyStain.

As 2015 was the first year for protozoan sample collection at the Croton System's Jerome Park Reservoir outflow (1CR21), no comparison with historical data is possible.

5.2.2. 2015 Source Water Compared to Regulatory Levels

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA 2006) requires utilities to conduct monthly source water monitoring for *Cryptosporidium* and report data from two, two-year periods, though a more frequent sampling schedule is 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 concentration exceeds 0.01 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*." For filtered supplies, the average needs to be below 0.075 oocysts L^{-1} to remain in Bin 1. The average source water *Cryptosporidium* concentration is calculated by taking a mean of the monthly *Cryptosporidium* mean concentrations at the source water outflows over the course of two, 2-year periods. While 2015 is not a reporting year under the LT2 (reporting is due in 2017), results have been calculated here using data from the most recent two-year period (January 1, 2014-December 31, 2015) using all analyzed routine and non-routine samples (Table 5.4).

Table 5.4 Number and type of samples used to calculate the LT2 values from January 1, 2014 to December 31, 2015.

Site	Number of routine samples 2014 - 2015	Number of non-routine samples 2014 - 2015	Total n
New Croton (CROGH)	24	2	26
New Croton (1CR21)	35	0	35
Delaware (DEL18DT)	104	2	106

Unfiltered Supply

The Catskill/ Delaware System is NYC's unfiltered water supply. The 2014 to 2015 mean of monthly means for *Cryptosporidium* was 0.0028 oocysts L^{-1} for the Delaware outflow, well below the LT2 threshold level of 0.01 oocysts L^{-1} for unfiltered systems (Figure 5.5). These results are consistent with NYC source water historical LT2 calculations which have always remained below the threshold levels. With the exception of the last two years' calculated values for the Delaware effluent, the monthly means have generally been declining since 2009. As DEP has switched to a new method for protozoan analysis, which was expected to recover more *Cryptosporidium* from samples, at least some of the increase in the last year is likely attributed to the new method.

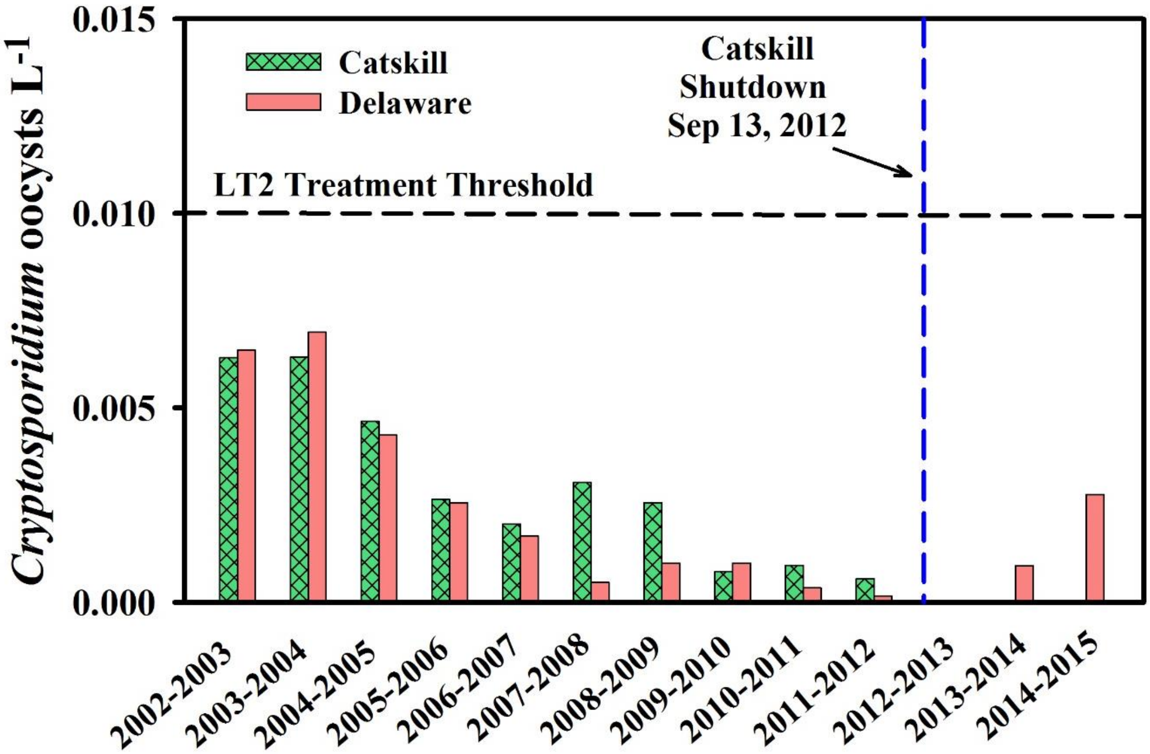


Figure 5.5 *Cryptosporidium* means using LT2 calculation method since initiation of Method 1623HV (1623.1 with EasyStain since April 2015) at the Delaware Aqueduct 2002-2015 and the Catskill Aqueduct 2002-2012. No means were reported for the Catskill Aqueduct for the last three 2-year spans as no samples were collected during these years due to aqueduct shutdown.

Filtered Supply

The Croton System is the source of NYC's filtered water supply. With less than a year of weekly results (n=35), this system had a calculated mean of monthly means of 0.0000 oocysts L^{-1}, as all results were negative. The filtered system bin threshold value is 0.075 oocysts L^{-1}. While the CROGH source water was not used for City service in the last several years (due to construction of the filtration plant), the LT2 calculations can be used for perspective. The 2014 to 2015 mean of monthly means for *Cryptosporidium* at CROGH was 0.0008 oocysts L^{-1}, also well below the LT2 threshold level of 0.01 oocysts L^{-1} for an unfiltered system (Figure 5.6).

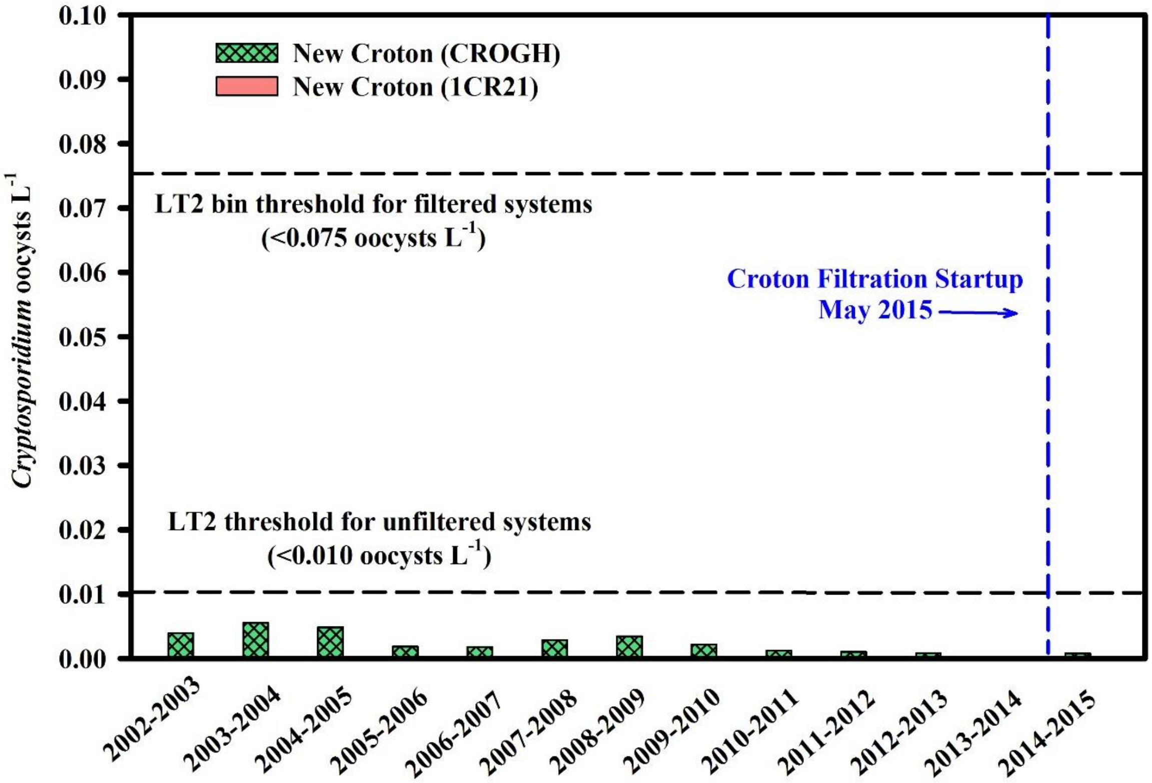


Figure 5.6 *Cryptosporidium* means using LT2 calculation method since initiation of Method 1623HV (1623.1 with EasyStain since April 2015) at the Croton aqueduct keypoint sites 2002-2015.

5.3. Upstate Reservoir Effluents

The Catskill and Delaware Aqueducts bring water to Kensico Reservoir from the West of Hudson (WOH) watershed. The WOH watershed consists of six main reservoirs; Ashokan and Schoharie in the Catskill System, and Cannonsville, Neversink, Pepacton, and Rondout in the Delaware System. The outflow of these reservoirs is sampled monthly for protozoans to ensure high quality water prior to entering downstream reservoirs. One exception, is Ashokan Reservoir, as the water leaving this reservoir is monitored weekly for protozoans just upstream of Kensico Reservoir at the Catskill Aqueduct Aluminum Sulfate Plant (CATALUM). Monthly sampling is not required for a reservoir when water from that basin is not being delivered to a downstream reservoir for eventual consumption. For this reason, three of the WOH reservoirs (Cannonsville, Neversink, and Pepacton) do not have samples for all 12 months of 2015.

Out of 104 samples collected at upstate reservoir outflows, 14 samples (13.5%) were positive for *Cryptosporidium*. This is twice as many as were found in each of the two previous years (7 detections each in 2014 and 2013). The Ashokan outflow (CATALUM) had the largest change in number of detections, with 4 more in 2015 (6 out of 52 samples) than in 2014 (2 out of 51 samples). Schoharie had the highest percent detection of oocysts out of these sites (33.3%), with Cannonsville only slightly lower (28.6%) (Table 5.5). However, only 7 monthly samples were taken at Cannonsville, as this water was infrequently diverted to Rondout Reservoir in 2015. Pepacton and Neversink outflows had one detection each for the third and fourth year in a row, respectively. Rondout Reservoir's outflow had no *Cryptosporidium* detections in 2015 and only 1 detection in the last 7 years (2009 to 2015).

Table 5.5 Summary of 2015 protozoan results for upstate reservoir outflows.

		Cryptosporidium				***Giardia***			
Site	**n**	**Mean ($50L^{-1}$)**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**	**Mean ($50L^{-1}$)**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**
Schoharie	12	0.59	33.3%	3 (48.6L)	0.06	5.55	50.0%	17 (25.0L)	0.68
Ashokan (CATALUM)	52	0.15	11.6%	2 (50.0L)	0.04	0.50	17.3%	11 (50.0L)	0.22
Cannonsville	7	0.57	28.6%	3(50.1L)	0.06	4.98	57.1%	20 (50.1L)	0.40
Pepacton	11	0.06	9.1%	1(50.8L)	0.02	1.32	18.2%	2 (45.3L)	0.04
Neversink	10	0.10	10.0%	1 (50.1L)	0.02	0.20	20.0%	1 (50.1L)	0.02
Rondout	12	0.00	0.0%	0	0.00	1.16	41.7%	4 (50.8L)	0.10

Out of the 104 protozoan samples collected at upstate reservoir outflow sites, 28 (27.0%) were positive for *Giardia*, compared with 51 positive samples out of 108 (47.2%) in 2014. Of the six sample sites, Schoharie Reservoir exhibited the largest decrease in detection rate (90.9% in 2014 down to 50.0% in 2015) and a drop in the annual mean concentration from 21.53 cysts $50L^{-1}$ in 2014, to 5.55 cysts $50L^{-1}$. The outflow from Cannonsville was the only site which showed a possible increase in mean annual concentration (3.00 to 4.98 cysts $50L^{-1}$). However, it should be noted that this site was not sampled during several months of the summer and fall (June, August, September, October, and November), so there was an uneven proportion of sampling in the winter and spring, when *Giardia* is known to occur more frequently and at higher concentrations. Additionally, the analytical method used during the first three months of 2015 (Method 1623HV) was believed to have higher recovery of environmental *Giardia* than the method used for the latter nine months of the year (Method 1623.1 with EasyStain). As previously explained, the method change helps to explain the overall lower detection rate of *Giardia* at upstate reservoir outflows in 2015.

5.4. Watershed Streams and WWTPs

Routine monitoring of protozoans was conducted at 16 stream sites in the watersheds in 2015. Eight stream sites in the WOH watershed were selected as part of an objective aimed at determining upstream sources of protozoans, and the eight perennial tributaries to Kensico Reservoir (EOH) were identified for continued monthly sampling. A total of 168 stream samples were collected and analyzed in 2015, 69 from the WOH watershed and 99 from the Kensico perennial streams.

Forty samples were taken at WWTPs in 2015, with four samples positive for protozoans. A discussion of WOH and EOH WWTPs results will follow the stream results discussion for each watershed.

West of Hudson Streams

Four of the eight WOH streams monitored during 2015 (Figure 5.7) were sampled monthly (PROXG, S7i, S7iB, and S7iDPond3) and the remaining four (CDG1, S4, S5i, and WDBN) were sampled bimonthly. *Cryptosporidium* oocysts were detected in a greater percentage of the WOH stream samples (50.7%) in 2015 when compared to 2013 and 2014 (34.7 and 37.9%, respectively). Both sites along the West Branch of the Delaware River (CDG1 and WDBN) had mean annual *Cryptosporidium* concentrations >2.00 oocysts $50L^{-1}$ and a high percentage of detections (5 detects out of 6 samples, 83.3%) at both sites (Table 5.6). In 2015, CDG1 and WDBN each had three samples with *Cryptosporidium* concentrations over their historical dataset's 95^{th} percentile (3.85 and 3.00 oocysts $50L^{-1}$, respectively).

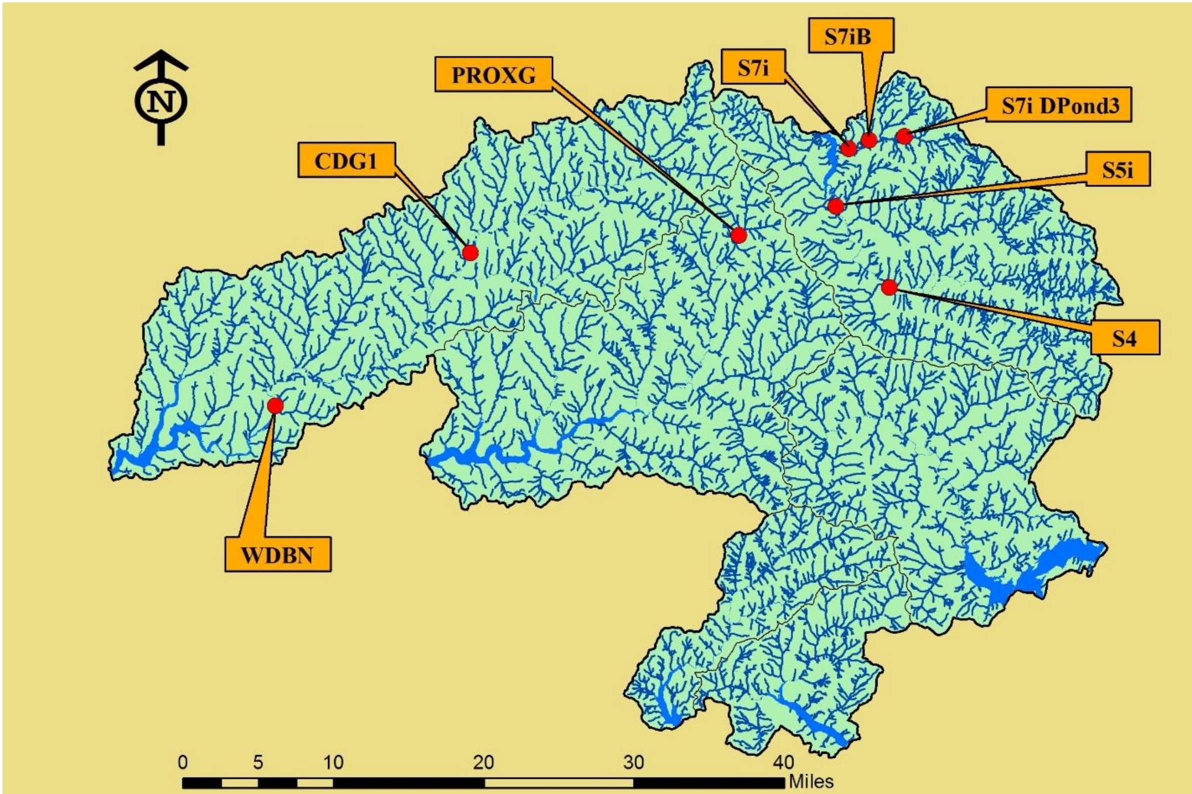


Figure 5.7 WOH stream sites monitored for protozoans in 2015.

Giardia cysts were detected in 61 of the 69 samples (88.4%) taken at WOH streams in 2015. In the NYC Watershed, *Giardia* is, on average, found more frequently and at higher concentration than *Cryptosporidium*. This pattern holds true in most years and at most sites in the watershed, but is most evident in the WOH streams where the difference between mean cyst and oocyst concentrations at each site can be greater than two orders of magnitude (Table 5.6). For the third year in a row, the East Branch Delaware River site at Roxbury (PROXG) had the highest mean annual *Giardia* concentration (2013: 95.31, 2014: 214.33, and 2015: 147.68 cysts $50L^{-1}$). The sample with the highest *Giardia* concentration in 2015 (893 cysts in 43.9L) was found at PROXG in February. The January and March samples at PROXG also had elevated *Giardia* results (277 and 434 cysts per volume sampled, respectively), both exceeding the historical 95^{th} percentile for this site (262.75 cysts $50L^{-1}$).

Table 5.6 Summary of WOH stream protozoan results for 2015.

Site	n	*Cryptosporidium*				*Giardia*			
		Mean ($50L^{-1}$)	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**	**Mean ($50L^{-1}$)**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**
CDG1	6	4.00	83.3%	8 (35.9L)	0.22	66.91	100.0%	171 (50.1L)	3.41
PROXG	12	1.24	66.7%	5 (50.L)	0.10	147.68	91.7%	893 (43.9L)	20.34
S4	6	0.15	16.7%	1 (54.7L)	0.02	42.67	100.0%	212 (54.7L)	3.88
S5	6	0.85	50.0%	2 (49.7L)	0.02	31.12	100.0%	48 (50.1L)	0.98
S7i	11	0.63	45.5%	3 (50.4L)	0.06	97.71	90.9%	576 (50.1L)	11.50
S7iB	11	0.91	45.5%	4 (49.9L)	0.08	23.83	81.8%	204 (50.2L)	4.06
S7iDPond3	11	0.27	27.3%	1 (50.0L)	0.02	1.55	63.6%	5 (50.1L)	0.10
WDBN	6	2.97	83.3%	8 (51.1L)	0.16	33.99	100.0%	75 (50.1L)	1.50

The investigation upstream of S7i (Manorkill influent to Schoharie Reservoir) continued in 2015, with two upstream sites (S7iB and S7iDPond3) in order to help narrow down the location of where the *Giardia* were originating in the sub-basin (Figure 5.8). The three sites were sampled immediately one after another on the same day of each month, however, one set of monthly samples could not be collected in January 2015 when the stream sites were frozen. Results from the upstream sites were, on average, much lower than those from the downstream site (S7i), especially at the site farthest upstream (S7iDPond3) (Table 5.6). S7iDPond3 was a new site in 2014 and had been showing very high results late in 2014, indicating it could be a potential source for *Giardia* cysts found downstream. Considering the intermittent frequency and general sporadic nature of high counts at sites in this sub-basin, DEP has decided to discontinue the upstream investigation along the Manorkill, with the conclusion that most sources are likely in the area between sites S7iD2 and S7iD3, and are likely wildlife. As a consequence, resources will be shifted to begin an investigation upstream of site PROXG to focus on the origin of those *Giardia*.

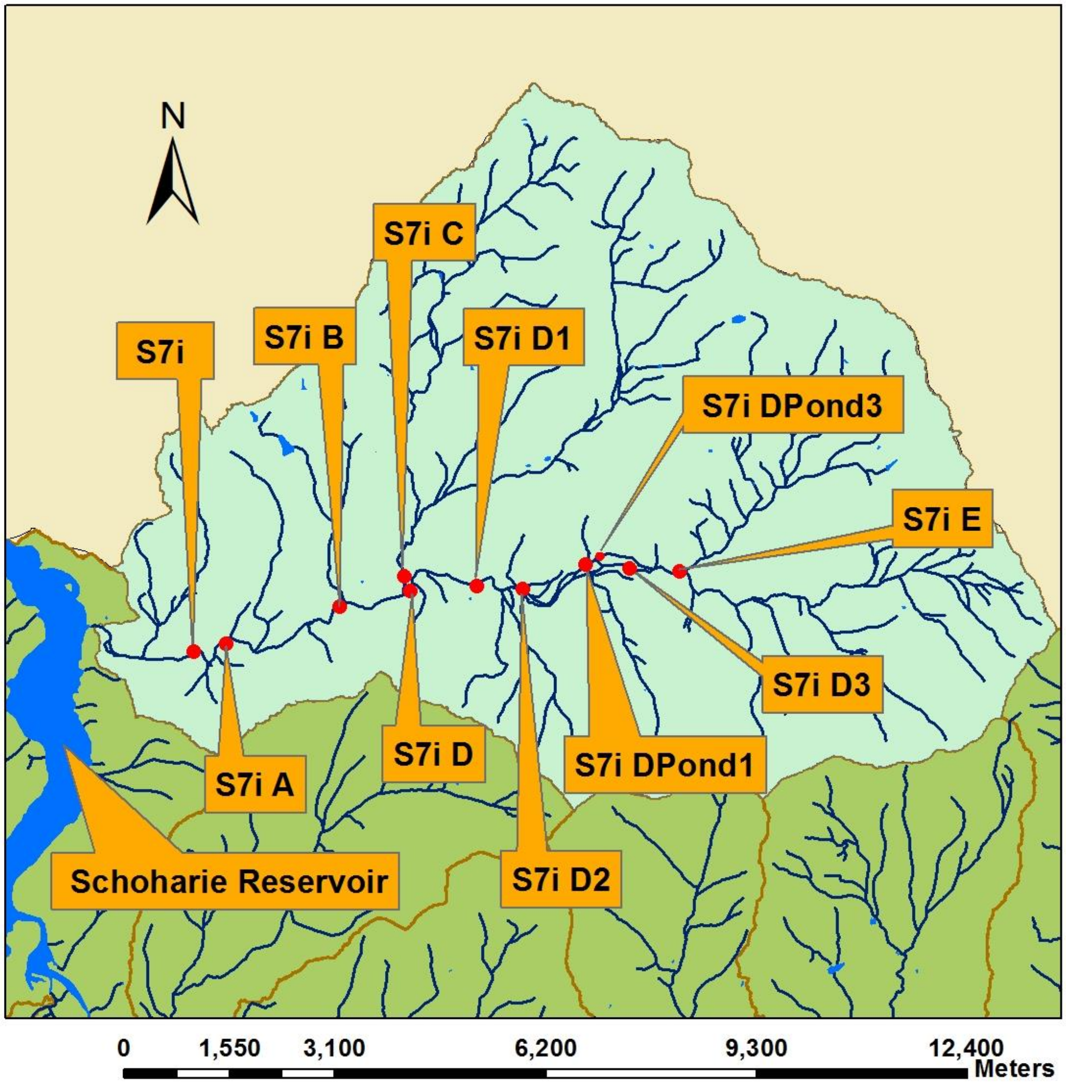


Figure 5.8 The Manorkill sub-basin in the Schoharie watershed, including all sites monitored for protozoans from 2010 to 2015.

West of Hudson WWTPs

The eight WOH WWTPs were sampled quarterly in 2015 (n=32) with 4 protozoan detections (12.5%) at two different plants (Windham and Hunter Highlands).

The first positive sample was found in February 2015 at Windham, where a single *Giardia* cyst was found in a 51L sample (Table 5.7). There were no recorded turbidity spikes, filtration process or chemical addition malfunctions, and no mechanical or process abnormalities on that day. A sludge press run was conducted that day which sends an extra 90 gallons per minute (GPM) to the equalization tank. A daily turbidity report obtained for that day, includes

24 hourly samples with a maximum of 0.26 NTU, well under this plant's SPDES instantaneous limit of 5.0 NTU and below the 0.5 NTU limit for 95% of samples.

Table 5.7 Protozoan detections at WOH WWTPs in 2015.

Date	Site	Plant	Sample Volume (L)	*Cryptosporidium* Result	*Giardia* Result
2/18/2015	Windham WTP	Windham	51.0	0	1
5/20/2015	Windham WTP	Windham	50.0	1	0
5/20/2015	Hunter Highlands BD	Hunter Highlands	50.4	0	1
12/1/2015	Hunter Highlands BD	Hunter Highlands	50.0	0	26

The second and third detections both occurred on May 20, at Windham and Hunter Highlands (1.00 *Cryptosporidium* oocyst $50.0L^{-1}$ and 1.00 *Giardia* cyst $50L^{-1}$, respectively). Neither plant recorded any mechanical or process abnormalities, nor were there any turbidity excursions before, during or after the samples were taken. Plant flows were lower compared with those from the same period last year due the moderate drought in the Catskill region, and there were no other impacts to plant operation or effluent water quality parameters.

The fourth detection in 2015 was a sample taken on December 1, and protozoan analysis found 26 *Giardia* cysts $50L^{-1}$. This sample was taken soon after the continuous backwash, upflow dual (CBUD) sand filter unit was put back online after air lancing (cleaning procedure utilizing pressurized air). Typically, the filter is set to recirculate following an air lance operation for long enough to ensure proper particulate removal. How long the filters were allowed to recirculate before sampling is not known. When the new plant operators performed an air lance in March 2016, it was discovered that a large portion of the surface area of the bottom of both filter units was saturated with solids and coagulant. The operators broke up this bound layer with sodium hypochlorite and physical force, and were successful in restoring the filters to full capacity. In the future, water quality sampling will be conducted in such a way as to avoid sampling during periods of plant maintenance activity.

East of Hudson Streams

Protozoan monitoring at the Kensico perennial streams was conducted monthly in 2015, with three exceptions. In August 2015, no sample could be taken at E9 as there was insufficient flow at the stream site, a very common occurrence at this site in the late summer. At the same site in September 2015, a representative sample of the stream flow could not be taken because Kensico Reservoir's elevation was so high that a backwater condition was created at the site.

The third exception to monthly sampling was when two additional samples were taken at N12 in December 2015, in response to a high *Cryptosporidium* result.

Cryptosporidium oocysts were detected in 24 out of 94 routine samples (25.5%) at Kensico perennial streams in 2015, which was more than twice as many as in 2014's routine samples (11 out of 95 samples or 11.6%). Site N12 had the highest mean annual concentration (1.58 oocysts $50L^{-1}$) and the highest individual routine sample result (16.00 oocysts $50L^{-1}$) (Table 5.8). This elevated result from December 1, 2015 exceeded this site's historical 95th percentile (3.00 oocysts $50L^{-1}$) leading to an investigation with additional protozoan sampling at the site and upstream. Results of this follow-up sampling can be found in the Special Investigation section of this report. *Cryptosporidium* results at the other seven perennial streams were generally within historical ranges, with the exception of the November E11 sample result of 13.00 cysts $50L^{-1}$ which exceeded the 95th percentile for this site.

Table 5.8 Summary of routine Kensico perennial stream protozoan results for 2015.

		Cryptosporidium				***Giardia***			
Site	**n**	**Mean ($50L^{-1}$)**	**% Detects**	**Max ($50L^{-1}$)**	**Max (L^{-1})**	**Mean ($50L^{-1}$)**	**% Detects**	**Max ($50L^{-1}$)**	**Max (L^{-1})**
BG9	12	0.17	16.7%	1	0.02	1.81	33.3%	18	0.36
E10	12	0.50	33.3%	3	0.06	0.25	16.7%	2	0.04
E11	12	1.42	25.0%	13	0.26	2.42	33.3%	12 (46.0L)	0.26
E9	10	0.84	50.0%	3	0.06	17.70	60.0%	91	1.82
MB-1	12	0.08	8.3%	1	0.02	0.30	16.7%	2	0.04
N12	12	1.58	33.3%	16	0.32	2.58	41.7%	13	0.26
N5-1	12	0	0.0%	0	0.00	8.08	41.7%	89	1.78
WHIP	12	0.50	41.7%	2	0.04	0.92	33.3%	4	0.08

The *Giardia* detection rate was 34.0% for routine samples at Kensico perennial streams in 2015, considerably less than in the prior three years (2012: 75.0%; 2013: 69.8%; and 2014: 74.0%). Six of the sites (BG9, E10, E11, E9, MB-1, and WHIP) exhibited annual mean concentrations less than half of those found in 2014 (E10 less than one-tenth) and for five sites (BG9, E10, E11, MB-1, and WHIP) annual mean concentrations were the lowest since Method 1623HV began in 2002. As noted earlier, the change to Method 1623.1 with EasyStain likely had an effect on these concentrations. The two highest *Giardia* results were, however, found after the method change. Both taken on October 6, the E9 sample had 91 cysts $50L^{-1}$, and the N5-1 sample had 89 cysts $50L^{-1}$. The N5-1 sample did exceed the historical dataset's 95th percentile, but results returned to decreased levels in the November and December samples (5.00 and 0.00 cyst $50L^{-1}$, respectively).

East of Hudson WWTPs

Two EOH WWTPs, Carmel and Mahopac, were sampled quarterly (n=8) and all samples collected were negative for *Cryptosporidium* and *Giardia*.

5.5. Hillview Monitoring

Hillview Reservoir has been monitored for *Giardia* and *Cryptosporidium* at Site 3 as part of the Hillview Administrative Order since August 2011. In 2015, 52 weekly, 50L samples were collected and two supplemental samples were collected to investigate low matrix spike recovery. As explained above in section 5.1, and as has been observed throughout the previous sections of this report, an increase in *Cryptosporidium* occurrence after the April method change was possible, and can be observed for Hillview in Figure 5.9. Although the difference at the time of the earlier studies with EasyStain was not statistically significant for *Cryptosporidium*, 2015 data supports the likelihood of increased detection of oocysts using 1623.1 and EasyStain (Figure 5.9). The previous work with EasyStain indicated the opposite effect on *Giardia*, showing a significant decrease in detection of cysts, which held true at Hillview as well (Figure 5.10).

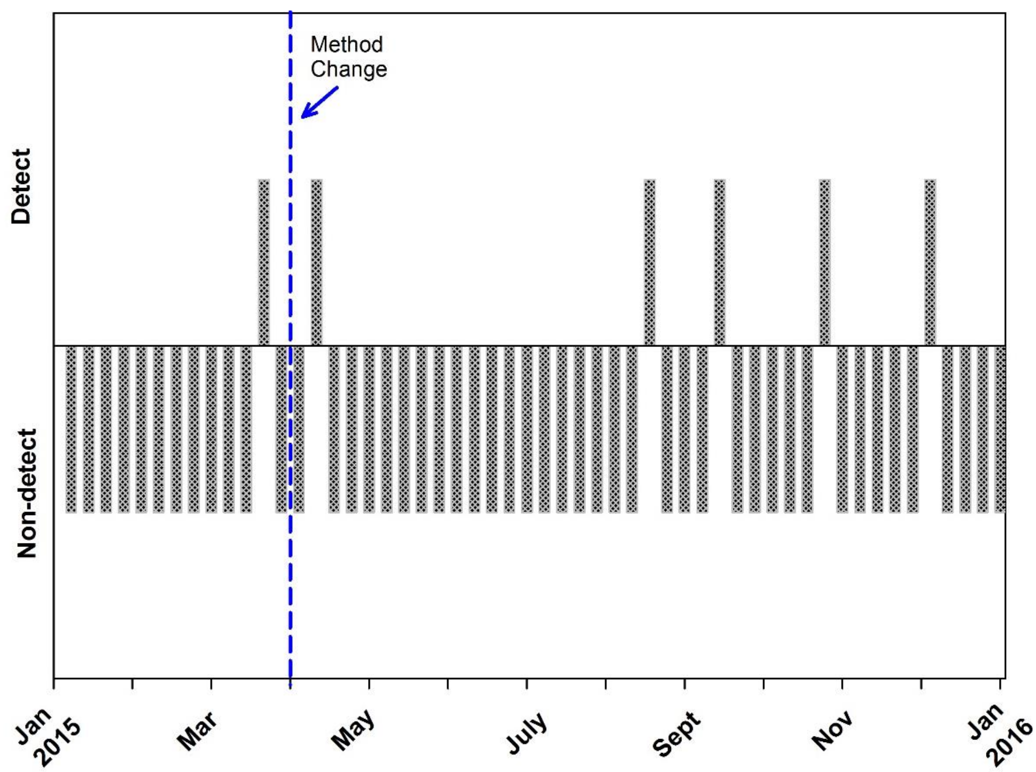


Figure 5.9 *Cryptosporidium* oocyst detections at Hillview Site 3 in 2015. The vertical blue dashed line indicates the change in analysis methods.

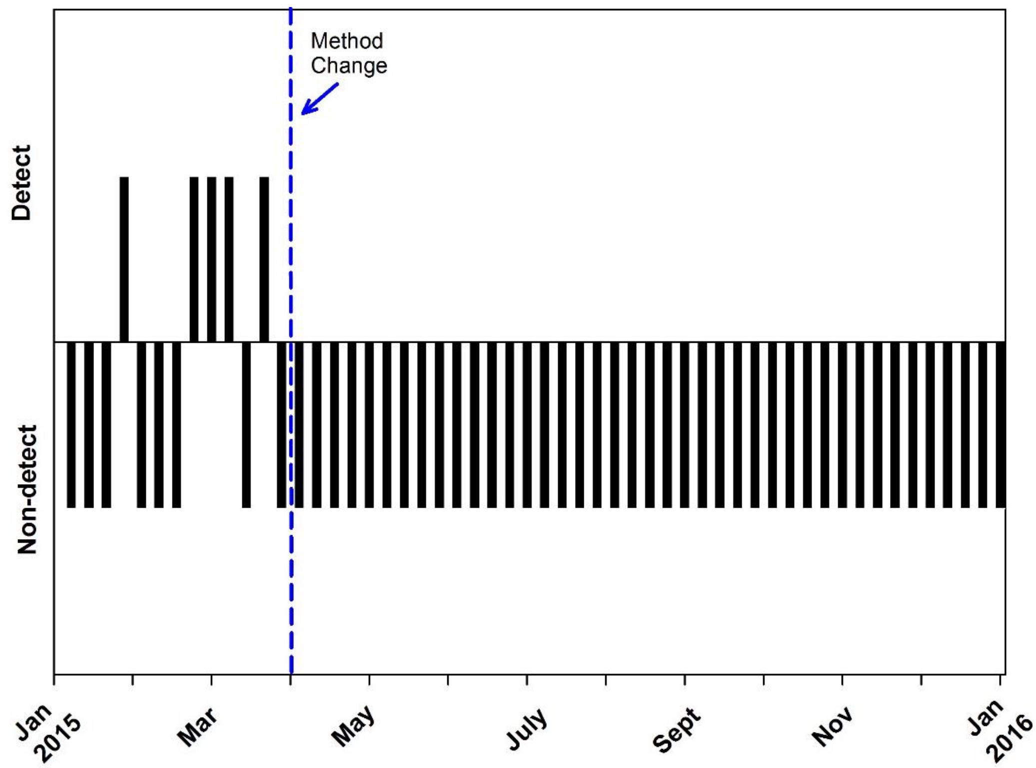


Figure 5.10 *Giardia* cyst detection at Hillview Site 3 in 2015. The vertical blue dashed line indicates the change in analysis methods.

As the previous figures indicate, results at Hillview for both protozoans were interesting in 2015. *Cryptosporidium* was detected 11.1% of the time and the annual mean concentration was 0.11 oocysts $50L^{-1}$ (all detections were a single oocyst) (Table 5.9). The *Giardia* detection rate for the 50L samples was 9.3%, and the annual mean concentration was 0.13 cysts $50L^{-1}$. These results differ compared to previous years, in that *Cryptosporidium* detections have increased and *Giardia* detections have decreased (Table 5.10). This change in detection is believed to be attributed to the method change, and not an increase in *Cryptosporidium*, nor a decrease in *Giardia*, in the environment.

Table 5.9 Hillview Site 3 monitoring results summary for 2015.

	Cryptosporidium	*Giardia*
n	54	54
Detects	6	5
% Detects	11.1%	9.3%
Mean ($50L^{-1}$)	0.11	0.13
Maximum ($50L^{-1}$)	2.00	1.00

Table 5.10 Hillview Site 3 protozoan detections from 2011 to 2015.

	Cryptosporidium		*Giardia*	
Year	**Detects**	**% Detect**	**Detects**	**% Detect**
2011[1]	0	0.0%	4	18.2%
2012	0	0.0%	17	31.5%
2013	2	3.8%	18	34.6%
2014	2	3.7%	19	35.2%
2015	6	11.1%	5	9.3%

[1]Sampling began in August of 2011.

As part of research studies at Hillview Reservoir, extra sampling and analysis was performed. In order to improve matrix spike recovery, 44 samples were collected as five 10L filter samples (instead of a single-50L filter). In addition, 30 samples were collected for infectivity analysis utilizing a Cell Culture-Immunofluorescent Assay (CC-IFA) method. Summaries of this work are provided in Section 7.1.2.

The overall *Cryptosporidium* detection rate and mean concentration resulting from the 44, five-10L filter method in 2015 (11.4% detection rate and 0.11 oocysts $50L^{-1}$) were quite similar when compared to those resulting from the single 50L filter method (9.1% detection rate and 0.09 oocysts $50L^{-1}$) (Table 5.11). Out of the 44 samples, 5 were positive for oocysts using the five-50L filter method and 4 were positive with the single 50L method, with no significant difference between these two methods for oocyst recovery.

Table 5.11 *Cryptosporidium* and *Giardia* results from Hillview Site 3 comparing the five-10L filter results to a single filter at 50 liters, 2015.

	Five-10L Filters		**One-50L Filter**	
	Cryptosporidium	***Giardia***	***Cryptosporidium***	***Giardia***
2015 n	44	44	44	44
Detects	5	10	4	2
% Detect	11.4%	22.7%	9.1%	4.5%
Mean	0.11	0.68	0.09	0.07
Max	1.00	6.00	1.00	2.00

Giardia was found more frequently and with higher mean concentration by the five-10L filter method (22.7% detection rate and 0.68 cysts $50L^{-1}$) as compared to the single 50L filter method (4.5% detection rate and 0.07 cysts $50L^{-1}$). *Giardia* maxima were higher with the five-10L filter method as well (6 cysts maxima compared to 2 cysts $50L^{-1}$). Of the 44 samples, 10 were positive for *Giardia* using the five-10L filters, while only 2 were positive using the single filter. This suggests a distinct improvement in the recovery of cysts using the five-10 liter filter method during this year. Additional variations of this method were investigated during the course of the study including the use of sodium hexametaphosphate, a milk coating on the filter, and heat dissociation (Kuhne and McDonald, 2015).

6. Water Quality Modeling

6.1. Overview and Summary

The Water Quality Modeling Program protects and improves water quality by developing and applying quantitative tools that relate climate, natural and anthropogenic conditions in watersheds, fate and transport processes in reservoirs, water demand and water supply system operation to the quality of drinking water. These models allow DEP to evaluate and forecast the impact of reservoir operations, watershed protection programs, climate change, and supply system infrastructure on water quantity and quality, including turbidity, eutrophication, and disinfection byproduct precursors.

A report titled "Multi-Tiered Water Quality Modeling Program, Annual Status Report" was completed on March 31, 2016, which gives a detailed description of activities and accomplishments in the water quality modeling program in 2015. Submission of a Water Quality Modeling Annual Report is a requirement of the current Filtration Avoidance Determination (FAD). Here, Table 6.1 gives a summary of the major modeling activities during 2015. Readers are referred to the Annual Modeling Report for additional details.

Table 6.1 Summary of 2015 Water Quality Modeling Projects.

Title	Objective(s)	Features	Conclusions	Status
Use of models for support of reservoir operation decisions	Apply reservoir turbidity model to guide operations in order to minimize turbidity impacts	- one model run to guide operations in anticipation of a snowmelt/runoff event (3/26/2015) - other simulations made to evaluate alternatives for Rondout West Branch tunnel shutdown (planned for 2022)	No significant impact occurred as a result of the snowmelt/runoff event	Ongoing
Development of stochastic weather generators to evaluate climate change and extreme events	- develop alternative models to generate synthetic time series of precipitation - compare alternative modeling approaches - extend to other weather variables (air temperature, solar radiation)	compared a variety of weather generators, including five parametric models, one resampling model, and a 2nd order polynomial curve fitting model	Best models were skewed normal, mixed exponential, and k-nearest neighbor resampling	Ongoing
Application of Soil Water Assessment Tool (SWAT) to Town Brook watershed	- develop enhancements to SWAT to simulate saturation-excess runoff - test Enhanced model for Town Brook watershed	Observations used for model calibration: -outflow hydrographs from Town Brook Watershed -area of watershed with saturated soil	Enhanced model gave improved predictions of outflow and saturated area	Ongoing

Table 6.1 Summary of 2015 Water Quality Modeling Projects.

Title	Objective(s)	Features	Conclusions	Status
Application of General Lake Model (GLM) to Cannonsville and Neversink Reservoirs	- compile input data for application of hydrothermal component of GLM to Cannonsville and Neversink - compare predictions and observations of water column and withdrawal temperatures	Observations used for model calibration: -water column temperature at deep water site -temperature of reservoir withdrawal	Model performed well in simulation of water column temperature; further work needed on withdrawal temperature	Ongoing
Development of a Probabilistic Turbidity model for Rondout Reservoir	Extend existing two-dimensional turbidity model for Rondout to generate short-term forecast accounting for uncertainty due to weather and stream inflow	-uses the same type of probabilistic streamflow forecasting that is used in Operations Support Tool	Software has successfully generated forecasts	Completed
Simulation of the Impact of Drawdown of Cannonsville Reservoir on Turbidity in Rondout Reservoir	A rapid drawdown of Cannonsville Reservoir was initiated in July 2015, was planned to continue to Sept.; evaluate impact on turbidity in Rondout Reservoir	-empirical turbidity-drawdown relationship developed for Cannonsville -used OST prediction of Delaware system operation during drawdown	Model predicted no significant impact of drawdown on Rondout; actual drawdown was halted in late July	Completed
Ecohydrologic Modeling using RHESSys	Apply and test the ecohydrologic model RHESSys for watersheds in the Neversink basin	Begin with smaller Biscuit Brook and Shelter Creek Watersheds; then move to	Initial testing of runoff predictions has been promising	Ongoing

Table 6.1 Summary of 2015 Water Quality Modeling Projects.

Title	Objective(s)	Features	Conclusions	Status
		entire Neversink River watershed		
Data Analysis to Support Modeling	Data analysis tasks, the results of which were then used in modeling	-historical water balance calculations performed for Delaware System reservoirs -historical residence time calculated for Catskill/Delaware System reservoirs	Simple reservoir water balance that lumps evaporation, direct precipitation, and groundwater into ungaged flow performs well	Will be updated annually
Model Data Acquisition and Organization	Provide watershed, reservoir, and supply system characteristics and data for use in modeling	-a variety of GIS data used for watershed modeling -new bathymetric surveys of reservoirs are underway -Water Quality Modeling Program is developing modeling database	GIS data continually being enhanced and updated; West of Hudson reservoir bathymetric surveys complete, East of Hudson to start 2017	Ongoing

7. Further Research

The analytical, monitoring, and research activities of DEP are supported through a variety of contracts, participation in research projects conducted by the Water Research Foundation (WRF), and interactions with national and international groups such as the Water Utility Climate Alliance (WUCA) and the Global Lake Ecological Observatory Network (GLEON). Participation with external groups is an efficient way for DEP to bring specialized expertise into the work of the Directorate and to remain aware of the most recent developments in the water supply industry. The on-going contracts and projects in which WQD is involved are described below.

7.1. Contracts Managed by the Water Quality Directorate (WQD) in 2015

In 2015, 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. Laboratory Analytical Support

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

In 2015, contracted analyses included: algal toxins on aqueduct and reservoir samples, volatile organic carbon (VOC), semivolatile organic carbon (SVOC) and glyphosate analyses on selected aqueduct samples; total Kjeldahl nitrogen, MBAS, TDS, Hg (low level), cyanide, purgeable organics, and base/neutrals and acids analyses on wastewater samples; and additional organics analyses (e.g., SVOCs/VOCs and Diesel Range Organics (DRO) on special investigation (SI) samples (e.g., DEL18 sluice gate and Titicus Reservoir airplane crash).

Other laboratories used for contracted analyses in 2015 included:

- **York Analytical Laboratories** - Pepacton Reservoir post-mediation event samples collected at the keypoints or elevation taps were sent to this contract laboratory for DRO analysis on a monthly basis from January through December.

- **Source Molecular Laboratories** - As part of the Shokan Community Septic System special investigation program, routine and storm event samples, which had elevated fecal coliform levels, were sent out sent to this laboratory for microbial source tracking analysis (June 2015).

- **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 here.

7.1.2. *Cryptosporidium* Infectivity Analysis for Hillview; University of Texas Public Health Laboratory Contract

The current method DEP uses for determining the presence of *Cryptosporidium* in water (US EPA Method 1623.1 with EasyStain) does not determine viability, infectivity or the genotype of the oocysts observed within samples. The oocysts are conservatively counted and recorded. This, however, may lead to an overestimation of risk to public health since oocysts counted may be dead, non-infectious, or not a genotype associated with human illness.

As a follow up to the 2014 research, and in the interest of exploring the possibility of determining the infectivity of oocysts from water samples, an additional spiking study was designed to determine if cell-culture immunofluorescent assay (CC-IFA) would be an effective tool in New York City's water matrix. The difference this year was that C. hominis was used as the spike material rather than *C. parvum*. Samples collected from the outlet of Hillview Reservoir were spiked with 100 viable flow sorted *C. hominis* oocysts, in addition to other samples spiked with low doses of 25 and 10 oocysts. Samples were pre-processed at the DEP Laboratory and then cell culture analysis was performed at the University of Texas Public Health Laboratory.

C. hominis recovery from the Hillview sample matrix using CC-IFA compared favorably with the control samples, indicating that the matrix does not appear to have a detrimental effect on recovery at the 100 and low level oocyst dosing. Round 1 testing of 100 oocysts was performed at the end of the recommended timeframe for oocyst infectivity and results from those two trials were not consistent. As a result, Round 2 of testing, with three trials, was performed and it was conducted shortly after receiving the oocysts. Hillview matrix results (52.8% mean recovery of infectious oocysts, n=9) were quite comparable with the *C. hominis* infectivity control (55.4% infectivity, n=3). Low dose testing (10 and 25 oocysts) was similar to control samples as well. At the 25 oocyst dose, the infection and trip control samples were positive 8/10 and 9/10 times, respectively, and the matrix samples were positive 7/10 times. At the 10 oocyst dose, the infection and trip control samples were positive 9/20 and 10/20 times, respectively, and the matrix samples were positive 8/20 times. Variability is expected at such low doses and minor differences in these data are not considered statistically significant. Overall, CC-IFA infectivity testing of both *C. parvum* and *C. hominis* in the Hillview sample matrix has indicated no significant difference from the control samples, and the ability to detect low levels of oocysts from the samples.

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

DEP contracted with the United States Geological Survey (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 gages throughout the Croton, Catskill, and Delaware watersheds along with turbidity at two gages and water temperature at four gages. 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 monitoring 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.

7.1.4. CUNY Postdoctoral Modeling Support

This contract between DEP and the City University of New York-Research Foundation (CUNY-RF) provides modeling support for the WQD and allows us to pursue research that will lead to model improvement. In August of 2014, a new four-year contract was registered. It provides for four post-doctoral research associates who are jointly advised by CUNY faculty, external faculty advisors, and DEP scientists. The post-doctoral associates are stationed in Kingston, New York and work with the Water Quality Modeling Section staff on a day-to-day basis. The positions are for an initial two year period, with the possibility of an additional two year extension.

The areas of research that the associates pursue are:

- Climate data analysis
- Watershed nutrient modeling
- Forest ecosystem modeling
- Reservoir eutrophication modeling

Three of four post-doctoral scientists were hired in 2014 with an additional research associate to cover the forest ecosystem modeling hired in 2015. This 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 (DEP 2013), and modeling based evaluations of climate change impacts. In 2015, several peer-reviewed publications (listed below) have resulted from the CUNY-RF contracts. The sections of this report describing modeling-based evaluation, model development, and data analysis have benefited greatly from the work of our post-doctoral scientists.

Mukundan, R., D.C. Pierson, E.M. Schneiderman, and M.S. Zion, 2015. Using detailed monitoring data to simulate spatial sediment loading in a watershed. Environmental Monitoring and Assessment 187:532, DOI 10.1007/s 10611-015-4751-8.

Pierson, D.C., N.R. Samal, H. Markensten and E.M. Owens, 2015. Simulating the effects of climate change on phytoplankton in a New York City Water Supply Reservoir. ASLO Aquatic Science Meeting, Granada Spain

Samal, N.R., K.D. Jöhnk, D.C. Pierson, M. Leppäranta, H. Yao, B.R. Hargreaves, T. Kratz, S. Sharma, A. Laas, D. Hamilton, R. Adrian, J. Rusak, D. Oezkundakci, C. Williamson, D. Vachon, B. Denfeld, G. Kirillin, K. Czajkowski and L. Camarero, 2015. Long term changes in ice seasons of twenty-one geographically distributed freshwater lakes: Modeling Simulations and Observations, ASLO Aquatic Science Meeting, Granada Spain.

7.1.5. 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 identified a direct relationship between the waterfowl populations present and the concentrations of fecal coliforms in Kensico Reservoir. Subsequently, a 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 (WMP-16), with Henningson, Durham & Richardson, requires staffing of up to 25 contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. It is intended to run through July 30, 2018.

7.1.6. Zebra Mussel Monitoring

DEP has been monitoring all 19 New York City reservoirs for the presence of zebra mussel (*Dreissena polymorpha*) larvae (veligers), as well as settlement of juvenile and mature zebra mussels. This monitoring began in 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 (due to lower calcium levels and less chance of colonization). The current lab, Shaw Environmental Inc., examines integrated (0-5m) pump and plankton net samples to monitor for veligers, as well as solid substrate and bridal veil substrates to monitor for juveniles and adults. 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.

7.1.7. Bathymetric Surveys of the Reservoirs

Under an inter-governmental agreement with United States Geological Survey (USGS), bathymetric surveying work was completed during the summer of 2015 for the two West of Hudson reservoirs: Cannonsville and Pepacton. With the completion of these surveys, fieldwork for all six West of Hudson reservoirs has been completed, with subsequent data processing occurring and data delivery in 2016. Final data deliverables for each reservoir will include raw and corrected survey points, a derived topographic surface of the reservoir bottom from those points, 2-foot contours of reservoir depth derived from the topographic surface, and a stage-area-volume table in 0.01-foot increments.

A separate inter-governmental agreement with the USGS was initiated in 2015 to survey the bathymetry of the 13 reservoirs east of the Hudson River and three controlled lakes. This project will result in data comparable in methodology and accuracy to the West of Hudson surveys. The contract is expected to be finalized in 2016, with fieldwork to be completed by 2019, and final data delivery due by 2020. The spatial data and information delivered under these contracts will help DEP to more accurately regulate storage in the reservoirs and to improve water-quality models used in reservoir management.

7.1.8. WISKI Software Support

DEP has continued to expand and enhance usage of the WISKI software to collect and view fixed point as well as continuous on-line data in an effort to provide a management tool that tracks water from rainfall in the watershed, through the streams and reservoirs, and into the distribution systems that supply drinking water to New York City. To date, data are collected from keypoints on the aqueducts, stream monitoring locations from both USGS and DEP sites, as well as sites throughout the distribution system. Ongoing work will bring additional data from weather stations connected to the New York City Harbor Buoy Networks and from shaft buildings in the Delaware District. In the future (summer of 2016), the software will be updated from WISKI 7.1 to 7.4. Additionally, the Contamination Warning System Dashboard will be updated from Adobe Flexviewer software to HTML5 and ESRI GIS ARC Portal with enhanced data from BWS StarLIMS software, 311 Hansen, and WISKI. The data collected by this system is used for tracking water balances and modeling.

7.2. Water Research Foundation (WRF) Project Participation by WQD

WQD participated in several WRF projects as members of Project Advisory Committees (PACs) in 2015. Participation is one of the ways DEP staff are able to remain aware of new methods and developing areas of research. It also provides a mechanism for interaction with national experts on topics of interest to DEP.

7.2.1. WRF Project 4589: Evaluation of Scientific Literature on Increased Turbidity Associated with the Risk of Gastrointestinal (GI) Illness

The objective of this project is to better inform key stakeholders on the current state of knowledge regarding whether there is a relationship between turbidity and the risk of gastrointestinal (GI) illness due to consumption of drinking water that meets U.S. drinking water standards. The specific objectives were: (1) identify and select relevant studies focusing on GI illness and turbidity, (2) critically evaluate these studies with respect to data and methodologies used and conclusions reached, (3) prepare a comprehensive summary based on the evaluation of literature, and (4) conduct a facilitated expert workshop to discuss the summary paper and integrate relevant findings from the workshop participants. The final report is expected to be published in 2016. A. Seeley is on the PAC for this project.

7.2.2. WRF Project 4590: Wildfire Impacts on Drinking Water Treatment Process Performance: Development of Evaluation Protocols and Management Practices

The objective of this project is to expand the knowledge base regarding the effects of wildfire on drinking water quality, treatment, plant performance, and operations. Specifically, this project will address three important components: (1) assess the impact that a wildfire has on source water quality within a recently-impacted watershed, (2) develop and apply a lab-based approach to simulate the effects of a wildfire on water quality and treatability, and (3) evaluate the implications of a wildfire for full-scale operation and design. To date all soil and forest litter samples have been collected and processed. Laboratory results are expected to be completed by the end of summer 2016 and the final report is expected to be published in 2017. R. Van Dreason is on the PAC for this project.

7.2.3. WRF Project 4664: Customer Messaging on Plumbing Systems Issues

The objective of this project is to develop customer communication messages on the risk of opportunistic pathogens in plumbing systems (a.k.a., premise plumbing) and how to minimize risk. This is a new project in which DEP has expressed interest as a participating utility.

7.2.4. WRF Project 4663: Upgrading Workforce Skills to Meet Demands of an Intelligent Water Network

The objective of this project is to prepare utilities for the workforce changes anticipated as they implement increased automation and smart water technologies. It should examine changing job requirements for the workforce of the future, as well as various means of attracting and training both new and existing workers to fill these more skilled positions. L. Emery is on the PAC for this project.

7.2.5. WRF Project 4616: Hospital Discharge Practices and Contaminants of Emerging Concern in Water

This project will investigate hospital discharge practices in order to better understand the loading of contaminants of emerging concern (CECs) discharged from hospitals, what actions hospitals are taking to mitigate or reduce that loading, if any, and what actions are feasible beyond what's already being done. It will also investigate what regulations exist regarding such discharge practices and how they are communicated. S. Neuman is a PAC member for this project.

7.2.6. WRF Project 4595: Water Quality and Economic Benefits of Forested Watershed Protection

The objectives of the workshop were 1) Through information exchange, enhance understanding of challenges and opportunities for implementing and financing forested watershed protection, 2) Identify existing roadblocks and explore best practices and ideas/approaches that could overcome barriers and allow for significant measurable progress, 3) Identify research objectives to address critical roadblocks, 4) Develop and prioritize specific project concepts that will support these objectives and overcome barriers to accelerate forested watershed protection. J. Schwartz of WPP participated in a two-day workshop which was held on August 5 and 6, 2015 at the San Francisco Public Utilities Commission.

7.2.7. WRF Project 4568: Evaluation of Innovative Reflectance Based UV for Enhance Disinfection and Enhanced Oxidation

This is a Technology Research Project to evaluate effectiveness of UV treatment via a pilot at the East Bay MUD treatment facility. The objective is a test of the potential to offer effective treatment with lower energy use. DEP is a co-founder of this project and C. Glaser is a member of the PAC.

7.2.8. WRF Project 4386: Decision support program for reducing Endocrine Disrupting Contaminants (EDCs) and Pharmaceuticals Products (PPCPs) in Drinking Water

The objective of this project is to develop a computerized decision support system to guide water and wastewater utilities in determining the most cost effective measures for reducing consumer exposure to endocrine disrupting compounds, pharmaceuticals, and personal care products (EDCs/PPCPs) in drinking water. C. Glaser participated in the PAC for this project.

7.2.9. WRF Project 4382: Impact of Climate Change on the Ecology of Algal Blooms

The goal of this research is to determine how cyanobacterial and other algal risk may change with climate change. Algal blooms can cause serious deterioration of drinking water quality by producing compounds that can cause taste and odor problems, are liver and nerve toxins, and form disinfection by-products. In order to monitor, manage, predict, and prevent algal blooms, the ecological relationships that lead to their development must be understood. Different lakes may have different sensitivity to algal blooms and climate change, which may be a function of latitude, nutrient loading and lake size. Further objectives are to determine the factors leading to blooms, determine if these factors are common across all lake types and latitude, and to predict how cyanobacterial risk may change using predictive coupled climate-hydrodynamic-biogeochemical models. Eventually, such information may be incorporated into the water quality models of the OST that will guide DEP’s operation of the water supply. L. Janus wrote the project proposal and participated as a PAC member for this project.

7.2.10. WRF Project 4551: Terminology for Improved Communication Regarding CECs

Media reports about contaminants of emerging concern (CECs) tend to portray the risk as very high (by use of alarmist phrases such as “toilet to tap” and “cocaine found in drinking water”) in contrast to more neutral scientific articles or utility outreach materials and websites. Problematically, the media information sources are probably what consumers find most easily when they use search engines to learn more about an issue. Part of the work requested by the RFP should be to demonstrate how to improve utility webpages to make their coverage of this issue more discoverable (i.e., highly ranked) by search engines like Google, including live website testing. This would enable the public to find information from reliable and trusted sources. DEP submitted a letter of support for another organization pursuing this project.

7.2.11. WRF Conservation Workshop

This workshop was devoted to discussion of tools and strategies used for conservation, conservation implementation, and highlighting case studies of successful public communication and education campaigns. The conservation workshops were intended to assist DEP's upstate customers, particularly with the planned outage of the Catskill Aqueduct (to support the later planned outage of the Delaware Aqueduct). Two workshops were held, in April 2014, and November 2015 in Tarrytown, NY. There were 43 participants from nearly 20 utilities who attended in addition to DEC participation from the Water Withdrawal Team (B. Tarrier and E. Schmitt). W. Richardson participated in the workshops. All materials are available to view at: http://collab.waterrf.org/Workshops/NYC-LeakMgt-2015/default.aspx.

7.3. Water Utility Climate Alliance: Piloting Utility Modeling Applications

WQSR and Bureau of Environmental Planning and Analysis (BEPA) staff participate with the other members of the Water Utility Climate Alliance (WUCA), a consortium of ten water utilities across the nation interested in planning for climate change. These utilities develop projects and share costs of conducting such projects. Conference calls are held on a monthly basis to discuss the administrative and research progress identified by WUCA. DEP benefits from this information exchange between utilities by keeping current with climate change information and its application for long-term planning in the context of water supply.

In 2015, DEP contributed to the Piloting Utility Modeling Applications (PUMA) effort by documenting our modeling work as a case study for a white paper entitled: Actionable Science in Practice: Co-Producing Climate Change Information for Water Utility Vulnerability Assessments. This paper, with lead author Jason M. Vogel for the Water Utility Climate Alliance, was published in 2015. The PUMA project featured four water utilities (New York, Tampa Bay, Seattle, and Portland) who worked in collaboration with local climate science consortiums to hand-pick or develop locally appropriate tools, projections, and approaches to understand the impact of climate change on drinking water supplies. These utilities pursued customized approaches based on specific utility needs and learned important lessons in conducting assessments that may be of interest to the wider adaptation community. In addition, these projects attempted to create a “climate services” environment in which utility managers worked collaboratively and iteratively with climate scientists to understand both utility concerns and the ability or limitations of today's climate science to respond to those concerns. These broader lessons that cut across the pilot projects are presented in a closing chapter entitled “Conclusions for an Applied Research Agenda for Climate Services.”

7.4. Global Lake Ecological Observatory Network

WQSR began participation in GLEON, an international organization, in 2014 with the objective of learning readily available software tools, developed by GLEON scientists, to display and analyze the high-frequency data generated by DEP's RoboMon project. The RoboMon project has proved invaluable to DEP for water quality management and the program is currently in a growth phase. It is therefore necessary to find efficient ways to display and use the high-frequency data generated by this equipment, in which we have considerable investment. The software and expertise available through GLEON has greatly accelerated our ability to make use of the data generated by our robotic monitoring equipment and has opened many project participation and publication opportunities described below.

WQSR has remained active in GLEON through participation in the GLEON17 meeting in Chuncheon, South Korea in October, 2015. The meeting featured a range of topics that were generally built around the use of robotic buoys and sensors for monitoring water quality in lakes and reservoirs. Much of the time at GLEON meetings is spent in small group workshops. DEP staff participated in workshops in three areas, the first being data assimilation –the routine annual use of monitoring data in the testing and validation of water quality models. The sessions described procedures and software that can be used for this purpose. At DEP, all of our water quality models have been validated using a subset of the observations from our monitoring program. We can gain greater credibility for our models if we, on an annual basis, undertake model validation, using observations from the previous year of monitoring, as a routine, annual program. The second area was use of GLEON data analysis software. GLEON members have developed a number of software tools that allow for processing and analysis of monitoring data, particularly from buoys. Two packages that were discussed are Lake Analyzer and Lake Metabolizer. Lastly, workshops were held on the GLEON-supported model GLM/AED. This is an open-source lake and reservoir model that is maintained and supported by GLEON. DEP is currently applying this model to Cannonsville and Neversink Reservoirs, with the goal of simulating organic carbon and the precursors of disinfection byproducts. DEP staff prepared and presented two posters based on modeling work conducted in 2015. The titles of these posters were "Use of Robotic Water Quality Monitoring and Modeling to Forecast Turbidity Impacts During Drawdown of Cannonsville Reservoir", and "Dissolved Oxygen and Phytoplankton Seasonality in New York City Reservoirs of Contrasting Trophic State". Through GLEON, WQSR staff has established professional relationships with lake and reservoir scientists from around the world.

Several collaborations have developed from DEP's participation in annual meetings convened by GLEON in 2015 and prior years. GLEON scientists meet yearly to develop ideas and tools to analyze data from an array of lake and reservoir sensors deployed around the globe to address local issues for individual aquatic ecosystems. Additionally, this network of collaborators work to document changes in lake and reservoir ecosystems that occur in response to different environmental conditions and stressors. The overall mission of GLEON is to "understand, predict, and communicate the role and response of lakes in a changing global environment." This is done in part by sharing and interpreting high-frequency sensor data and other water quality and environmental data. DEP contributed data to four collaborative GLEON research projects in 2015.

7.4.1. Temperature Sentinels in Northeastern North America (NENA): In-depth Study of Lake Thermal Responses and Teleconnections in Northeastern North America

The primary intent of this study is to examine subsurface water temperature profiles from lakes and reservoirs across the northeastern region of North America to determine how water temperature responds to regional-scale climatic drivers and teleconnections. To accomplish this, the researchers will examine a set of lakes and reservoirs with long-term, high resolution temperature profile data and a larger set of NENA lakes and reservoirs with temperature profiles from a single annual profile. Historical water temperature data for Cannonsville, Pepacton, Neversink, and Rondout reservoirs at the deepest sites at the time of peak thermal stratification were formatted and shared with the project lead scientist, Dr. David Richardson, State University of New York (SUNY) at New Paltz for use in this GLEON-sponsored study.

7.4.2. GLEON Fellowship SALT Project

A study of increasing salinization of lakes and reservoirs was conducted as part of the GLEON Fellowship Program in 2015. The Fellowship Program trains cohorts of graduate students to explore the information contained in large data sets, work in diverse international teams, and communicate their findings to a broad range of audiences. DEP contributed data for a modeling analysis of global trends and drivers of lake and reservoir salinity to assess ecological impacts. Data included specific conductivity, chloride, sulfate, and sodium concentrations for the period of 1987 to 2014 for ten reservoirs, including Cannonsville, Pepacton, Neversink, Schoharie, Boyd's Corners, Cross River, Croton Falls, Middle Branch, New Croton, and Kensico. The work was carried out in connection with the Cary Institute of Ecosystem Studies in Millbrook, New York. The lead investigator was Dr. Hilary Dugan, a post-doctoral scientist at the University of Wisconsin–Madison.

7.4.3. Iron Concentration Trends Around the Globe

This project is an analysis of how iron concentrations in freshwaters around the world have changed over the past 20 years. Data analysis is being performed by Caroline Björnerås, a doctoral candidate at Lund University, Sweden, under the supervision of Dr. Emma Kritzberg from Lund University and Dr. Gesa Weyhenmeyer, Uppsala University, Sweden. Data contributed by DEP in 2015 included iron, total organic carbon, dissolved organic carbon, water color, pH, sulfate, silica, dissolved oxygen, water temperature, and aluminum for two sites on New Croton Reservoir for the period of 1994-2009.

7.4.4. Effects of Climate Change on Spring-Winter Runoff and Lake Productivity

The Climate Sentinels working group in GLEON is looking at the effects of ongoing changes in the seasonality of winter – spring streamflow on lake productivity. The initial hypothesis is: Changes in the timing of spring runoff, with more runoff occurring in the winter and early spring, will lead to reduced productivity and phytoplankton biomass during the summer stratified period. The foundation for this expectation is based on our current understanding that nutrients delivered to a lake during colder, deeply mixed, and possibly ice covered conditions, could be less effective at stimulating phytoplankton growth. To test the hypothesis we are assembling data from a large variety of lakes that meet the following minimal requirements:

- In a geographic location where snow accumulation and melt significantly impact the seasonality of stream discharge.
- A lake or reservoir with data from 1990 or earlier and continuing to present. There should be multiple samples per year that cover at least the period of thermal stratification.
- Measurements of chlorophyll profiles during thermal stratification and/or measurements of hypolimnetic oxygen at the onset and just before the loss of thermal stratification.
- Stream discharge measurements of a major inflow to the lake starting in 1990 or earlier, or measurements from a nearby stream or river than can be used to provide an index of lake inflow.

Dr. Don Pierson, currently at Uppsala University, Sweden, is taking the lead with DEP data contributed to the project.

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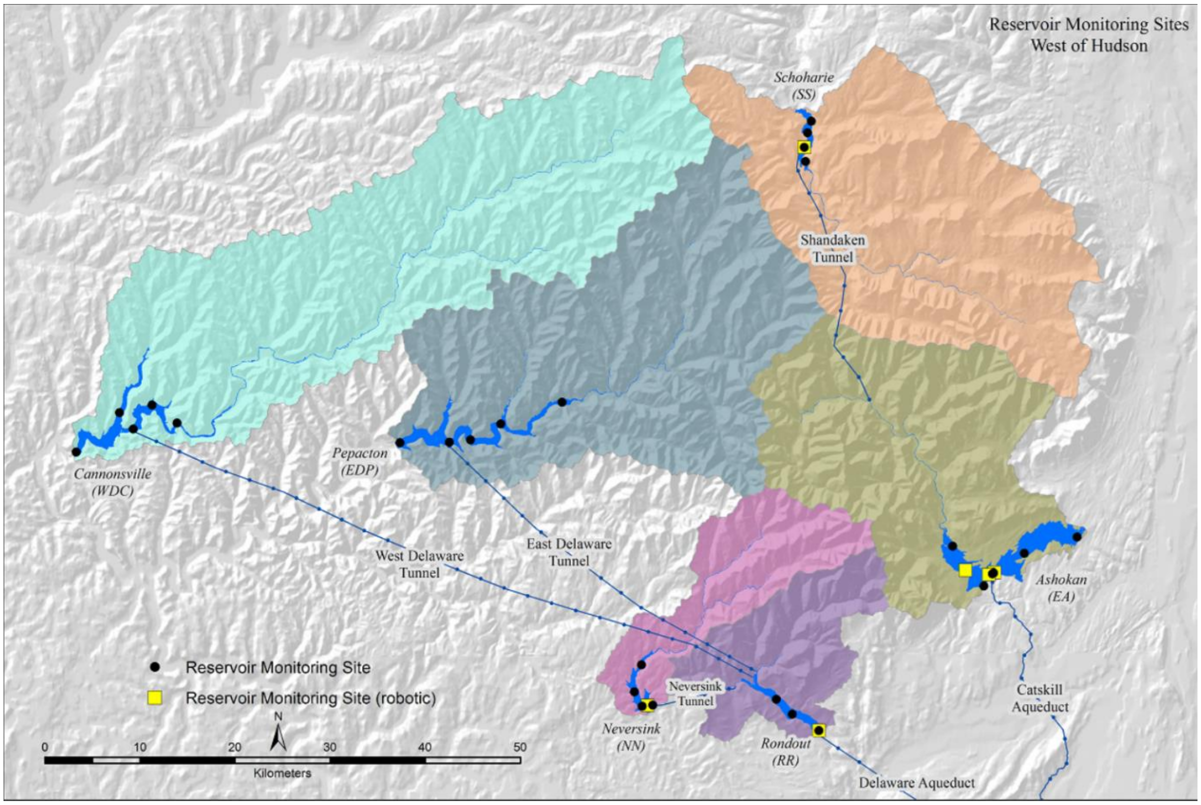
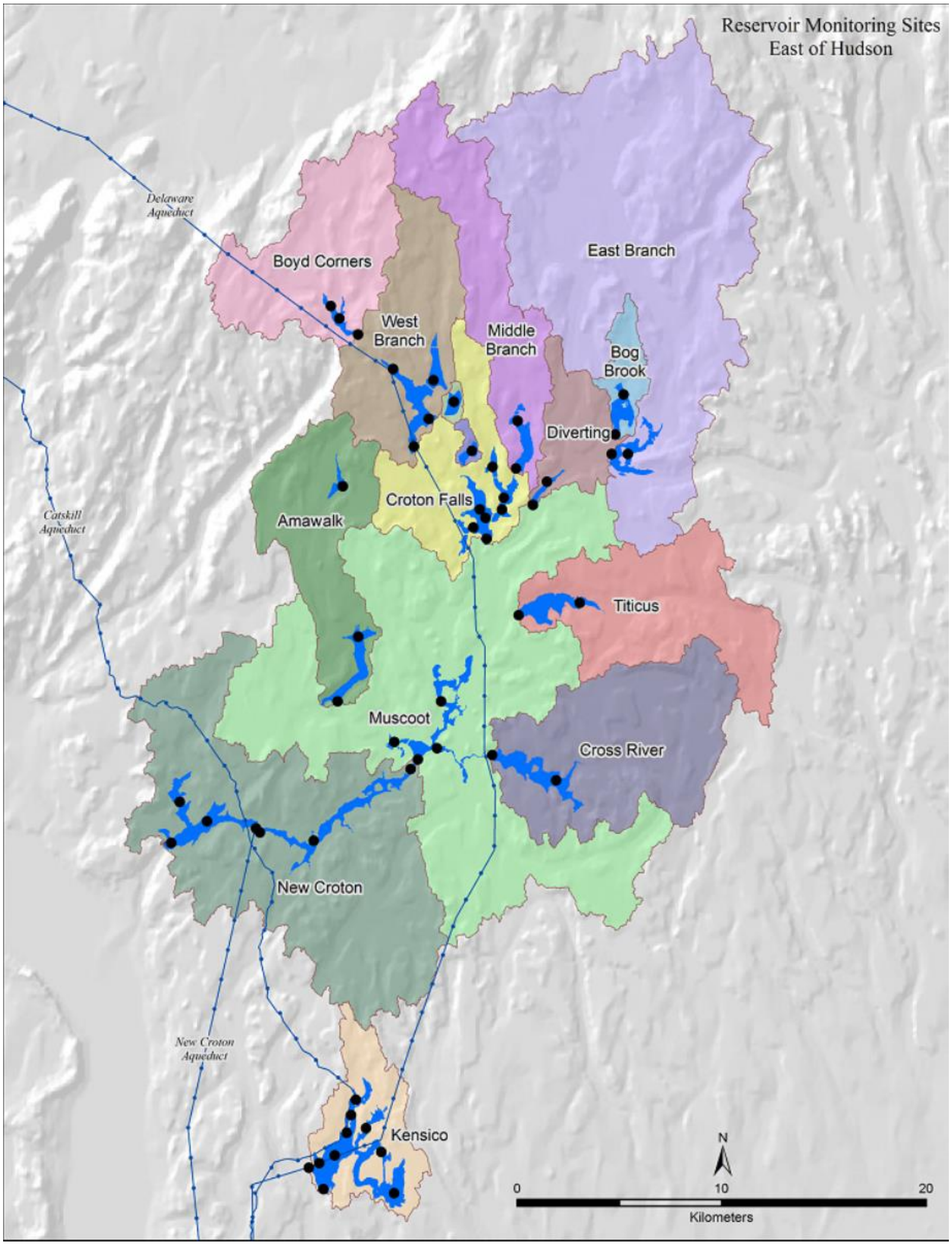
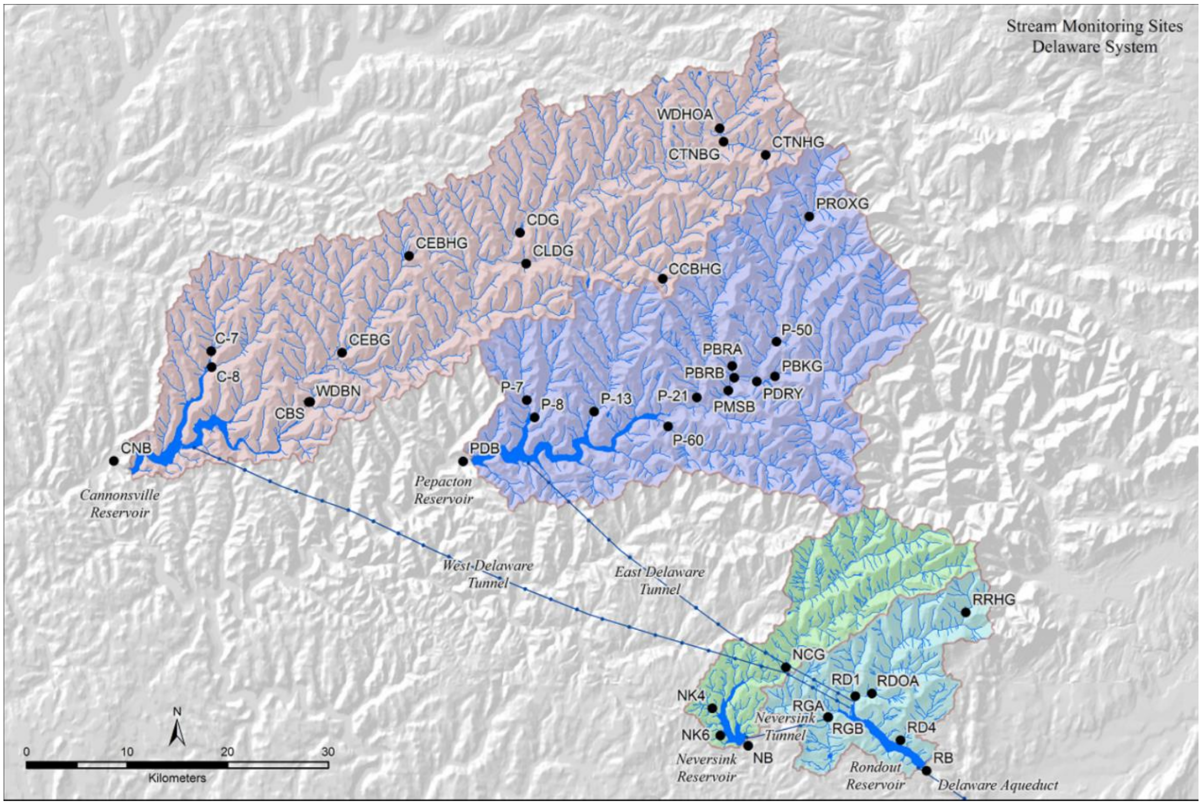
Appendix A. Sampling Locations



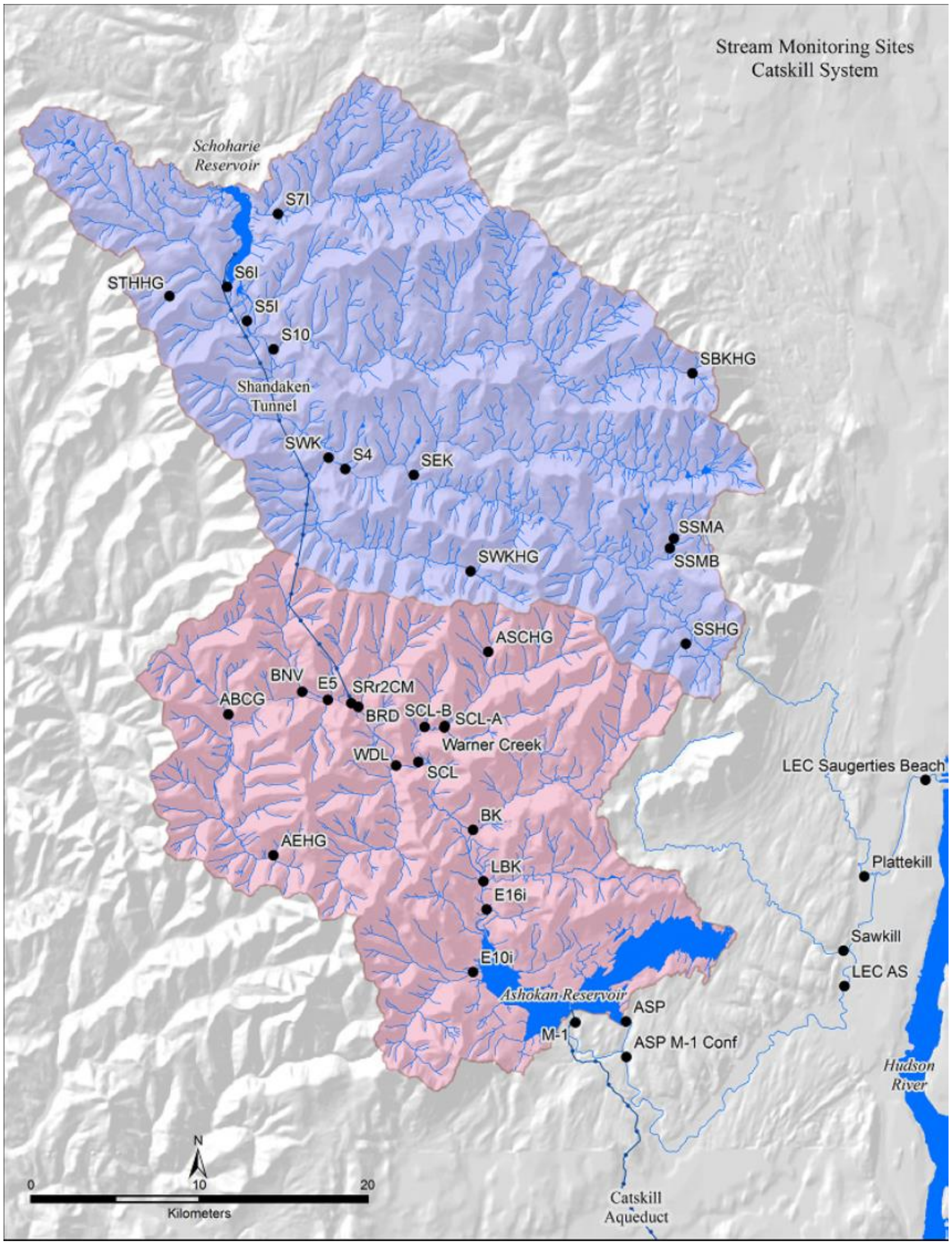
Appendix Figure 1 WOH reservoir monitoring sites (see 2016 WWQMP for detailed maps).



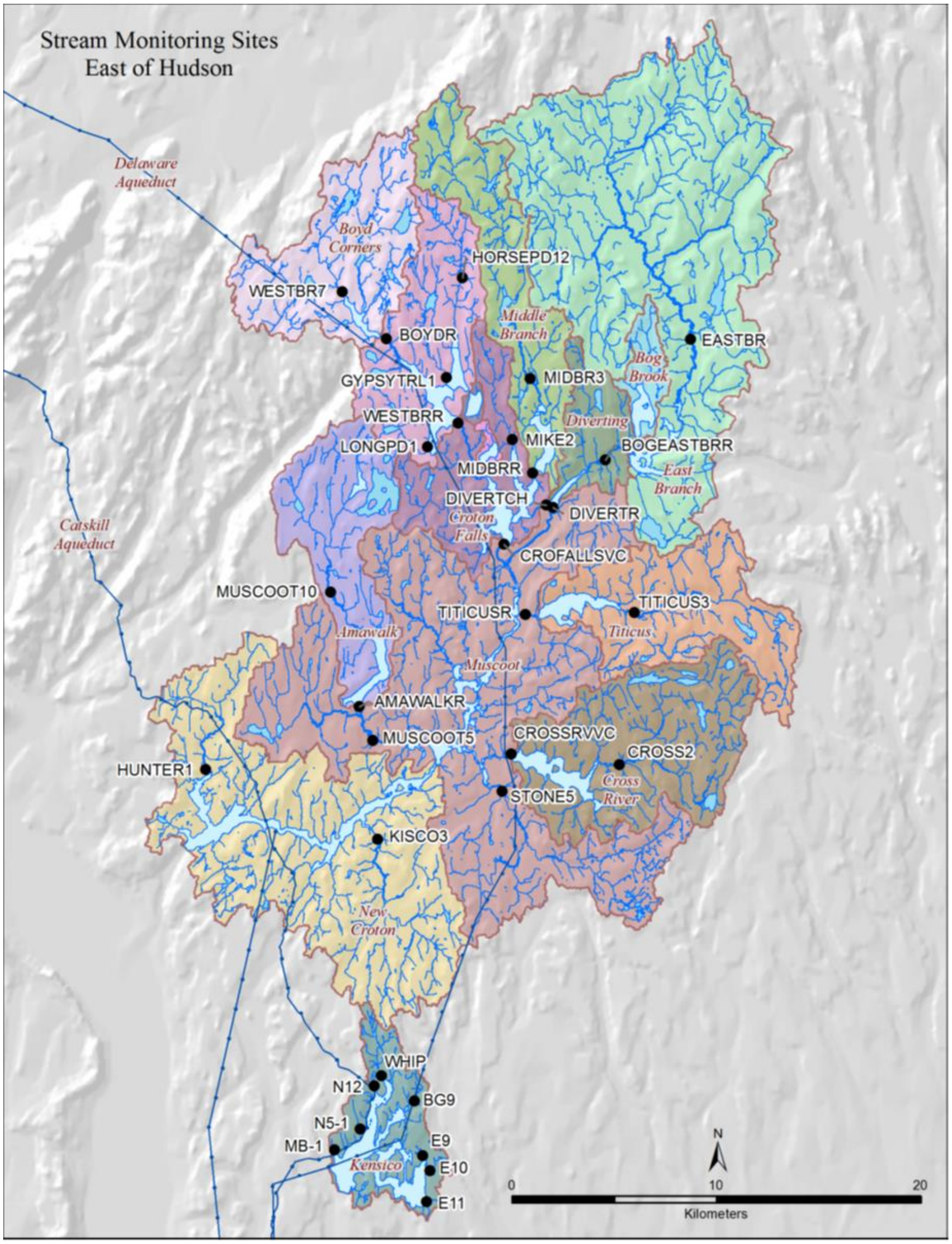
Appendix Figure 2 EOH reservoir monitoring sites (see 2016 WWQMP for detailed maps).



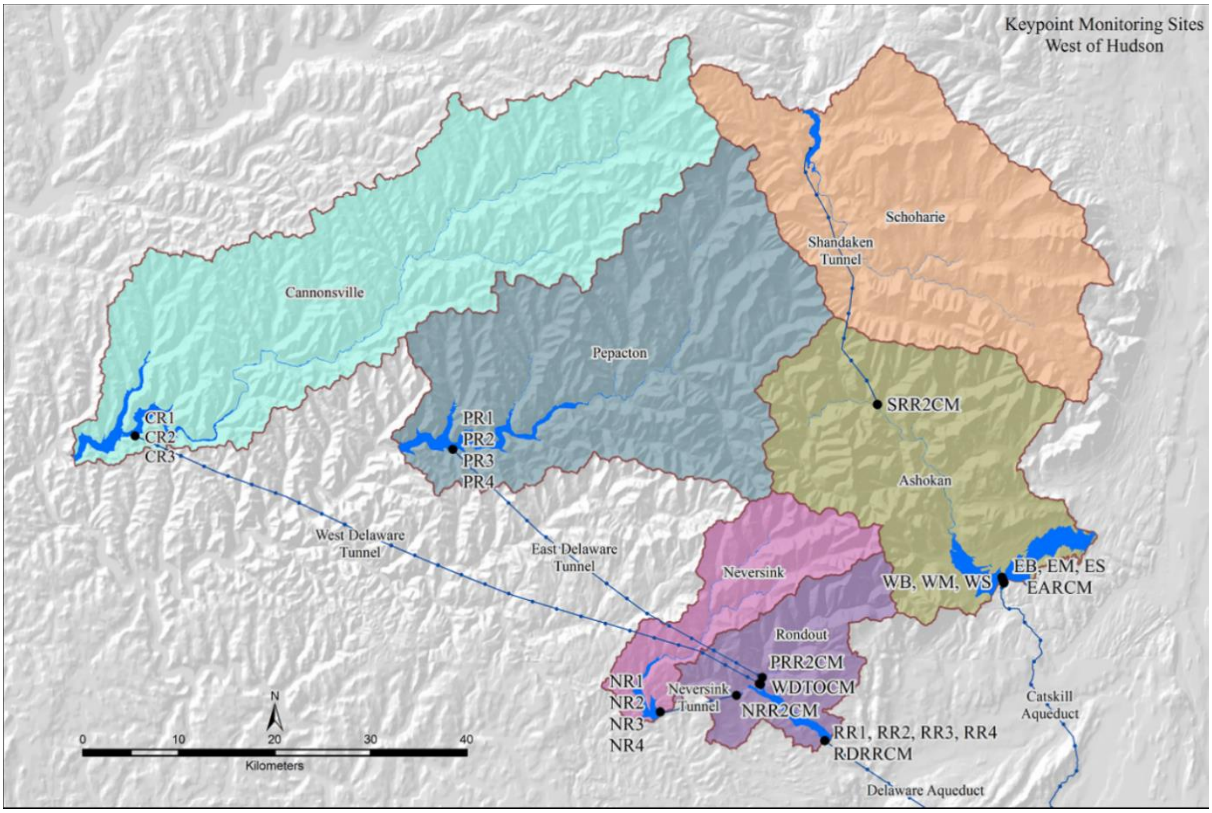
Appendix Figure 3 Delaware System stream monitoring sites (see 2016 WWQMP for detailed maps).



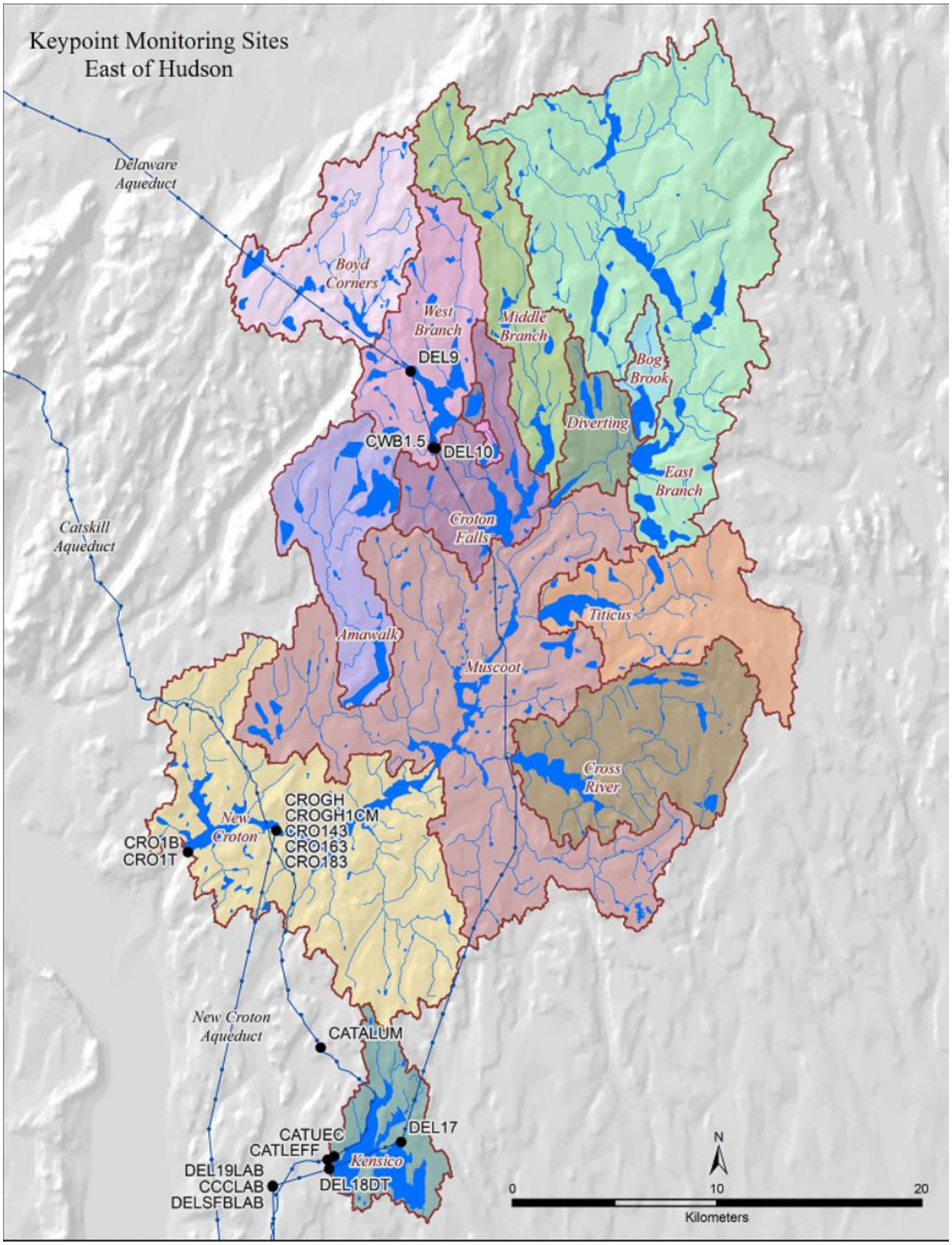
Appendix Figure 4 Catskill System stream monitoring sites (see 2016 WWQMP for detailed maps).



Appendix Figure 5 EOH stream monitoring sites (see 2016 WWQMP for detailed maps).

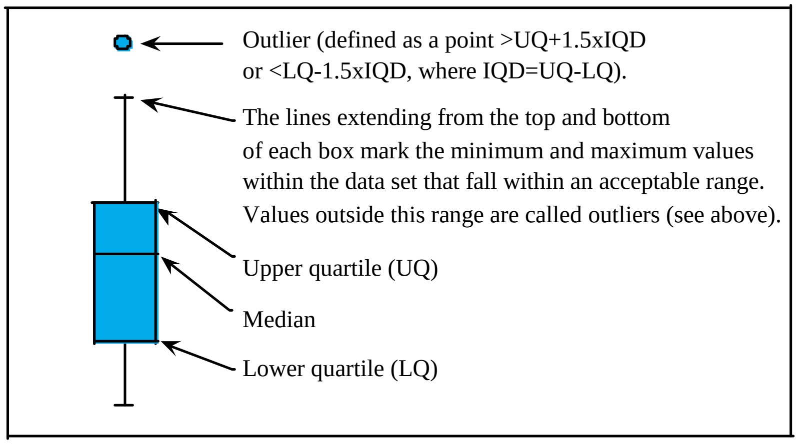


Appendix Figure 6 WOH aqueduct keypoint monitoring sites (see 2016 WWQMP for detailed maps).



Appendix Figure 7 EOH aqueduct keypoint monitoring sites (see 2016 WWQMP for detailed maps).

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



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 methods 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.

Appendix C. Monthly Coliform-Restricted Calculations used for Non-Terminal Reservoirs

Appendix Table 1 Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6NYCRR 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.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (coliform $100ml^{-1}$)	Percentage > Standards
Amawalk	A (2400, 5000)	Apr-15	5	2	0
Amawalk		May-15	5	10	0
Amawalk		Jun-15	5	TNTC	0
Amawalk		Jul-15	5	<50	0
Amawalk		Aug-15	4	<5 samples/month	0
Amawalk		Sep-15	5	86	0
Amawalk		Oct-15	5	8	0
Amawalk		Nov-15	5	5	0
Bog Brook	AA (50, 240)	Apr-15	6	4	0
Bog Brook		May-15	6	4	0
Bog Brook		Jun-15	6	20	0
Bog Brook		Jul-15	6	TNTC	0
Bog Brook		Aug-15	6	40	0
Bog Brook		Sep-15	5	<50	0
Bog Brook		Oct-15	5	5	0
Bog Brook		Nov-15	5	90	0
Boyd’s Corners	AA (50, 240)	Apr-15	7	3	0
Boyd’s Corners		May-15	7	1100	57
Boyd’s Corners		Jun-15	7	36	0
Boyd’s Corners		Jul-15	6	18	0
Boyd’s Corners		Aug-15	7	50	0
Boyd’s Corners		Sep-15	0	Site inaccessible	NA
Boyd’s Corners		Oct-15	0	Site inaccessible	NA
Boyd’s Corners		Nov-15	0	Site inaccessible	NA
Croton Falls	A/AA (50, 240)	Apr-15	8	4	0

Appendix Table 1 Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6NYCRR 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.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (coliform 100ml^{-1})	Percentage > Standards
Croton Falls		May-15	8	<5	0
Croton Falls		Jun-15	8	16	0
Croton Falls		Jul-15	8	200	37
Croton Falls		Aug-15	8	33	0
Croton Falls		Sep-15	6	29	25
Croton Falls		Oct-15	8	43	12
Croton Falls		Nov-15	8	29	0
Cross River	A/AA (50, 240)	Apr-15	6	9	0
Cross River		May-15	6	2	0
Cross River		Jun-15	6	52	17
Cross River		Jul-15	6	240	50
Cross River		Aug-15	6	55	0
Cross River		Sep-15	6	17	0
Cross River		Oct-15	6	58	0
Cross River		Nov-15	6	8	0
Diverting	AA (50, 240)	Apr-15	5	8	0
Diverting		May-15	5	220	40
Diverting		Jun-15	5	400	80
Diverting		Jul-15	5	83	20
Diverting		Aug-15	5	8	0
Diverting		Sep-15	5	100	0
Diverting		Oct-15	5	120	0
Diverting		Nov-15	5	110	0
East Branch	AA (50, 240)	Apr-15	6	24	0
East Branch		May-15	6	30	0
East Branch		Jun-15	6	52	0
East Branch		Jul-15	6	30	0
East Branch		Aug-15	6	160	0
East Branch		Sep-15	6	<50	0
East Branch		Oct-15	6	8	0

Appendix Table 1 Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6NYCRR 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.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (coliform $100ml^{-1}$)	Percentage > Standards
East Branch		Nov-15	6	80	0
Lake Gilead	A (2400, 5000)	Apr-15	5	<1	0
Lake Gilead		May-15	5	<2	0
Lake Gilead		Jun-15	5	<5	0
Lake Gilead		Jul-15	5	20	0
Lake Gilead		Aug-15	5	<20	0
Lake Gilead		Sep-15	5	<20	0
Lake Gilead		Oct-15	5	<10	0
Lake Gilead		Nov-15	5	<5	0
Lake Gleneida	AA (50, 240)	Apr-15	5	<1	0
Lake Gleneida		May-15	5	<2	0
Lake Gleneida		Jun-15	5	<5	0
Lake Gleneida		Jul-15	5	<500	0
Lake Gleneida		Aug-15	5	<330	0
Lake Gleneida		Sep-15	5	<330	20
Lake Gleneida		Oct-15	5	18	0
Lake Gleneida		Nov-15	5	<10	0
Kirk Lake	B (2400, 5000)	Apr-15	5	28	0
Kirk Lake		May-15	5	<20	0
Kirk Lake		Jun-15	5	TNTC	0
Kirk Lake		Jul-15	5	<50	0
Kirk Lake		Aug-15	5	<100	0
Kirk Lake		Sep-15	5	83	0
Kirk Lake		Oct-15	5	<50	0
Kirk Lake		Nov-15	0	Site inaccessible	NA
Muscoot	A (2400, 5000)	Apr-15	7	10	0
Muscoot		May-15	7	18	0
Muscoot		Jun-15	7	100	0
Muscoot		Jul-15	6	200	0
Muscoot		Aug-15	7	170	0
Muscoot		Sep-15	7	83	0

Appendix Table 1 Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6NYCRR 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.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (coliform $100ml^{-1}$)	Percentage > Standards
Muscoot		Oct-15	7	67	0
Muscoot		Nov-15	7	33	0
Middle Branch	A (2400, 5000)	Apr-15	5	<2	0
Middle Branch		May-15	5	13	0
Middle Branch		Jun-15	5	18	0
Middle Branch		Jul-15	5	17	0
Middle Branch		Aug-15	5	150	0
Middle Branch		Sep-15	5	<10	0
Middle Branch		Oct-15	5	12	0
Middle Branch		Nov-15	5	32	0
Titicus	AA (50, 240)	Apr-15	5	2	0
Titicus		May-15	5	7	0
Titicus		Jun-15	5	12	0
Titicus		Jul-15	5	<100	0
Titicus		Aug-15	4	<5 samples/month	0
Titicus		Sep-15	5	40	0
Titicus		Oct-15	5	33	0
Titicus		Nov-15	5	43	0
Cannonsville	A/AA (50, 240)	Apr-15	15	4	0
Cannonsville		May-15	15	10	0
Cannonsville		Jun-15	15	TNTC	0
Cannonsville		Jul-15	15	50	13
Cannonsville		Aug-15	14	40	0
Cannonsville		Sep-15	13	10	0
Cannonsville		Oct-15	12	7	0
Cannonsville		Nov-15	12	50	8
Pepacton	A/AA (50, 240)	Apr-15	15	1	0
Pepacton		May-15	16	2	0
Pepacton		Jun-15	16	10	6
Pepacton		Jul-15	15	10	0

Appendix Table 1 Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6NYCRR 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.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (coliform $100ml^{-1}$)	Percentage > Standards
Pepacton		Aug-15	15	4	7
Pepacton		Sep-15	15	4	0
Pepacton		Oct-15	14	2	0
Pepacton		Nov-15	14	4	0
Neversink	AA (50, 240)	Apr-15	13	TNTC	0
Neversink		May-15	13	4	0
Neversink		Jun-15	13	6	0
Neversink		Jul-15	13	4	8
Neversink		Aug-15	12	40	0
Neversink		Sep-15	12	5	0
Neversink		Oct-15	11	5	0
Neversink		Nov-15	11	8	0
Neversink		Dec-15	10	2	0
Schoharie	AA (50, 240)	Apr-15	11	16	0
Schoharie		May-15	11	TNTC	0
Schoharie		Jun-15	11	50	18
Schoharie		Jul-15	12	40	8
Schoharie		Aug-15	11	7	0
Schoharie		Sep-15	11	100	18
Schoharie		Oct-15	11	100	0
Schoharie		Nov-15	11	40	0
Schoharie		Dec-15	12	13	0

Notes: The reservoir class is defined by 6 NYCRR Chapter X, Subchapter B. For those reservoirs that have dual designations, the higher standard was applied. The median could not be estimated for samples determined to be Too Numerous To Count (TNTC).

Appendix D. 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 2-5 µg L^{-1}. The phosphorus concentration data for the reservoirs approaches 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 under-sampled 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 µg L^{-1} (15 µg 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 µg L^{-1} (15 µg 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 Basin	2010 µg L^{-1}	2011 µg L^{-1}	2012 µg L^{-1}	2013 µg L^{-1}	2014 µg L^{-1}	2015 µg L^{-1}
Non-Source Waters (Delaware System)						
Cannonsville Reservoir	16.4	16.3	12.4	15.0	13.1	14.9
Pepacton Reservoir	9.9	11.9	8.4	7.9	7.8	9.0
Neversink Reservoir	6.5	10.2	9.7	6.0	6.2	6.5
Non-Source Waters (Catskill System)						
Schoharie Reservoir	13.4	29.4	20.0	15.0	15.3	11.9
Non-Source Waters (Croton System)						
Amawalk Reservoir	20.5	18.3	22.3	22.3	19.4	19.3
Bog Brook Reservoir	31.1	23.6	27.9	20.0	14.4	19.4
Boyd's Corners Reservoir	8.4	8.7	10.1	10.7	9.0	9.0
Diverting Reservoir	29.1	31.1	26.8	29.5	29.1	25.8
East Branch Reservoir	33.8	32.3	28.5	27.5	24.2	21.3
Middle Branch Reservoir	25.5	29.8	37.6	32.5	35.3	27.4
Muscoot Reservoir	28.7	28.8	31.5	29.9	28.7	28.5
Titicus Reservoir	26.4	26.9	24.4	24.4	24.8	19.5
Lake Gleneida	25.9	31.9	25.1	22.2	19.8	35.0
Lake Gilead	30.1	28.9	16.4	26.7	32.8	27.1
Kirk Lake	27.6	33.1	34.6	24.9	32.8	30.8
Source Waters (all systems)						
Ashokan-West Basin	12.9	31.0	10.2	7.3	8.1	8.8
Ashokan-East Basin	9.8	13.5	8.4	6.4	7.5	7.9
Cross River Reservoir	15.4	18.7	17.0	15.4	17.6	15.7
Croton Falls Reservoir	13.3	20.6	18.7	23.0	19.9	19.4
Kensico Reservoir	6.6	7.5	6.4	6.2	5.7	7.4
New Croton Reservoir	15.7	18.2	18.7	17.0	16.0	16.8
Rondout Reservoir	8.0	8.9	7.2	7.2	6.6	7.9
West Branch Reservoir	9.4	11.1	11.8	12.6	11.2	11.3

Appendix E. Comparison of Reservoir Water Quality Results to Benchmark

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
East of Hudson Reservoirs						
Kensico Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	24			>10	14
Chloride (mg L^{-1})	12	24	18	75	8	13.3
Chlorophyll a (µg L^{-1})	12	64	0	0	7	3.0
Color (Pt-Co units)	15	199	14	7	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	199	0	0	3	1.7
Fecal coliforms (coliform 100mL^{-1})	20	199	3	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	199	0	0	0.3	0.19
pH (units)	6.5-8.5	199	74	37	na	na
Sodium, undig., filt. (mg L^{-1})	16	24	24	100	3	7.6
Soluble reactive phosphorus (µg L^{-1})	15	200	0	0	na	na
Sulfate (mg L^{-1})	15	24	1	4	10	5.1
Total ammonia-N (mg L^{-1})	0.10	199	0	0	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	200	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	198	160	81	40	57
Total phosphorus (µg L^{-1})	15	199	1	1	na	na
Total phytoplankton (ASU mL^{-1})	2000	96	0	0	na	na
Primary genus (ASU mL^{-1})	1000	96	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	96	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	80	0	0	5	0.7
Turbidity (NTU)	5	199	0	0	na	na
Amawalk Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	80
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	15	1	7	10	8.2
Color (Pt-Co units)	15	36	34	94	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform 100mL^{-1})	20	39	0	0	na	na

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

Analyte	**Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2015 Mean** [1]
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	39	4	10	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	32	32	100	150	386
Total phosphorus (µg L^{-1})	15	36	29	81	na	na
Total phytoplankton (ASU mL^{-1})	2000	15	2	13	na	na
Primary genus (ASU mL^{-1})	1000	15	2	13	na	na
Secondary genus (ASU mL^{-1})	1000	15	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	1.6
Turbidity (NTU)	5	36	1	3	na	na
Bog Brook Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	7			>40	73
Chloride (mg L^{-1})	40	7	7	100	30	64.8
Chlorophyll a (µg L^{-1})	15	8	1	13	10	6.4
Color (Pt-Co units)	15	20	15	75	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	20	0	0	6	3.4
Fecal coliforms (coliform $100mL^{-1}$)	20	45	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	20	0	0	0.3	0.07
pH (units)	6.5-8.5	39	4	10	na	na
Sodium, undig., filt. (mg L^{-1})	20	7	7	100	15	33.1
Soluble reactive phosphorus (µg L^{-1})	15	20	0	0	na	na
Sulfate (mg L^{-1})	25	7	0	0	15	8.6
Total ammonia-N (mg L^{-1})	0.10	20	3	15	0.05	0.04
Total dissolved phosphorus (µg L^{-1})	15	20	1	5	na	na
Total dissolved solids (mg L^{-1})[3]	175	20	20	100	150	241
Total phosphorus (µg L^{-1})	15	20	16	80	na	na
Total phytoplankton (ASU mL^{-1})	2000	8	0	0	na	na
Primary genus (ASU mL^{-1})	1000	8	0	0	na	na

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

Analyte	**Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2015 Mean [1]**
Secondary genus (ASU mL^{-1})	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	7	0	0	5	2.4
Turbidity (NTU)	5	20	2	10	na	na
Boyd's Corners Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	5			>40	31
Chloride (mg L^{-1})	40	5	5	100	30	55.4
Chlorophyll a (µg L^{-1})	15	5	0	0	10	2.4
Color (Pt-Co units)	15	13	12	92	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	13	0	0	6	2.6
Fecal coliforms (coliform 100mL^{-1})	20	34	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	13	0	0	0.3	<u>0.08</u>
pH (units)	6.5-8.5	34	5	15	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	31.2
Soluble reactive phosphorus (µg L^{-1})	15	13	0	0	na	na
Sulfate (mg L^{-1})	25	5(4)[4]	1(0)[4]	20(0)[4]	15	37.1(6.9)[4]
Total ammonia-N (mg L^{-1})	0.10	13	0	0	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	13	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	13	3	23	150	170
Total phosphorus (µg L^{-1})	15	13	0	0	na	na
Total phytoplankton (ASU mL^{-1})	2000	5	0	0	na	na
Primary genus (ASU mL^{-1})	1000	5	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	5	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	5	0	0	5	1.8
Turbidity (NTU)	5	13	0	0	na	na
Croton Falls Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18			>40	65
Chloride (mg L^{-1})	40	18	18	100	30	92.0
Chlorophyll a (µg L^{-1})	15	23	6	26	10	20.4
Color (Pt-Co units)	15	64	62	97	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	64	0	0	6	3.4
Fecal coliforms (coliform 100mL^{-1})	20	63	2	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	13	20	0.3	<u>0.31</u>
pH (units)	6.5-8.5	64	13	20	na	na

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

Analyte	**Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2015 Mean [1]**
Sodium, undig., filt. (mg L^{-1})	20	18	18	100	15	49.1
Soluble reactive phosphorus (µg L^{-1})	15	64	0	0	na	na
Sulfate (mg L^{-1})	25	18	0	0	15	9.7
Total ammonia-N (mg L^{-1})	0.10	64	15	23	0.05	<u>0.09</u>
Total dissolved phosphorus (µg L^{-1})	15	65	5	8	na	na
Total dissolved solids (mg L^{-1})[3]	175	64	64	100	150	331
Total phosphorus (µg L^{-1})	15	63	44	70	na	na
Total phytoplankton (ASU mL^{-1})	2000	24	4	17	na	na
Primary genus (ASU mL^{-1})	1000	24	4	17	na	na
Secondary genus (ASU mL^{-1})	1000	24	1	4	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.8
Turbidity (NTU)	5	64	13	20	na	na
Cross River Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	47
Chloride (mg L^{-1})	40	9	9	100	30	44.6
Chlorophyll a (µg L^{-1})	15	16	0	0	10	5.6
Color (Pt-Co units)	15	48	43	90	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	48	0	0	6	3.3
Fecal coliforms (coliform $100mL^{-1}$)	20	48	1	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	48	0	0	0.3	<u>0.13</u>
pH (units)	6.5-8.5	42	18	43	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	22.8
Soluble reactive phosphorus (µg L^{-1})	15	48	1	2	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	8.5
Total ammonia-N (mg L^{-1})	0.10	48	8	17	0.05	<u>0.06</u>
Total dissolved phosphorus (µg L^{-1})	15	48	3	6	na	na
Total dissolved solids (mg L^{-1})[3]	175	48	18	38	150	172
Total phosphorus (µg L^{-1})	15	48	30	63	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	0	0	na	na
Primary genus (ASU mL^{-1})	1000	16	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.2

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Turbidity (NTU)	5	48	5	10	na	na
Diverting Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	81
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	6	38	10	11.7
Color (Pt-Co units)	15	32	32	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform $100mL^{-1}$)	20	40	3	8	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	1	3	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	32	32	100	150	289
Total phosphorus (µg L^{-1})	15	32	30	94	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	1	6	na	na
Primary genus (ASU mL^{-1})	1000	16	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	3.5
Turbidity (NTU)	5	32	3	9	na	na
East Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	80
Chloride (mg L^{-1})	40	9	9	100	30	63.5
Chlorophyll a (µg L^{-1})	15	8	0	0	10	7.3
Color (Pt-Co units)	15	23	22	96	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	23	0	0	6	3.5
Fecal coliforms (coliform $100mL^{-1}$)	20	48	2	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	23	0	0	0.3	0.10
pH (units)	6.5-8.5	42	3	7	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	32.0
Soluble reactive phosphorus (µg L^{-1})	15	23	1	4	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Sulfate (mg L^{-1})	25	9	0	0	15	10.5
Total ammonia-N (mg L^{-1})	0.10	23	4	17	0.05	0.06
Total dissolved phosphorus (µg L^{-1})	15	23	1	4	na	na
Total dissolved solids (mg L^{-1})[3]	175	23	23	100	150	249
Total phosphorus (µg L^{-1})	15	23	17	74	na	na
Total phytoplankton (ASU mL^{-1})	2000	8	0	0	na	na
Primary genus (ASU mL^{-1})	1000	8	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.3
Turbidity (NTU)	5	23	1	4	na	na
Lake Gilead						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	45
Chloride (mg L^{-1})	40	9	9	100	30	51.6
Chlorophyll a (µg L^{-1})	15	3	0	0	10	3.1
Color (Pt-Co units)	15	9	5	56	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	3.2
Fecal coliforms (coliform 100mL^{-1})	20	40	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	15	4	27	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	27.7
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7.6
Total ammonia-N (mg L^{-1})	0.10	9	1	11	0.05	0.05
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	5	56	150	181
Total phosphorus (µg L^{-1})	15	9	7	78	na	na
Total phytoplankton (ASU mL^{-1})	2000	3	0	0	na	na
Primary genus (ASU mL^{-1})	1000	3	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.3
Turbidity (NTU)	5	9	0	0	na	na
Lake Gleneida						

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

Analyte	**Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2015 Mean [1]**
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	70
Chloride (mg L^{-1})	40	9	9	100	30	109.7
Chlorophyll a (µg L^{-1})	15	3	0	0	10	3.0
Color (Pt-Co units)	15	9	4	44	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	2.9
Fecal coliforms (coliform $100mL^{-1}$)	20	40	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	15	7	47	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	59.5
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9(8)[5]	1(0)[5]	11(0)[5]	15	13.2(6.1)[5]
Total ammonia-N (mg L^{-1})	0.10	9	2	22	0.05	0.16
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	9	100	150	335
Total phosphorus (µg L^{-1})	15	9	7	78	na	na
Total phytoplankton (ASU mL^{-1})	2000	3	0	0	na	na
Primary genus (ASU mL^{-1})	1000	3	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.6
Turbidity (NTU)	5	9	2	22	na	na
Kirk Lake						
Alkalinity (mg $CaCO_3$ L^{-1})	na	5			>40	62
Chloride (mg L^{-1})	40	5	5	100	30	100.7
Chlorophyll a (µg L^{-1})	15	3	2	67	10	19.3
Color (Pt-Co units)	15	5	5	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	5	0	0	6	4.2
Fecal coliforms (coliform $100mL^{-1}$)	20	35	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	5	0	0	0.3	<0.02
pH (units)	6.5-8.5	15	2	13	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	49.7
Soluble reactive phosphorus (µg L^{-1})	15	5	0	0	na	na
Sulfate (mg L^{-1})	25	5	0	0	15	8.6
Total ammonia-N (mg L^{-1})	0.10	5	4	80	0.05	0.27

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	5	1	20	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	175	5	5	100	150	313
Total phosphorus ($\mu g\ L^{-1}$)	15	5	4	80	na	na
Total phytoplankton (ASU mL^{-1})	2000	3	2	67	na	na
Primary genus (ASU mL^{-1})	1000	3	1	33	na	na
Secondary genus (ASU mL^{-1})	1000	3	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	5	1	20	5	4.8
Turbidity (NTU)	5	5	2	40	na	na
Muscoot Reservoir						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	6			>40	78
Chloride ($mg\ L^{-1}$)	40	6	6	100	30	104.5
Chlorophyll a ($\mu g\ L^{-1}$)	15	32	11	34	10	18.8
Color (Pt-Co units)	15	55	55	100	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	7.0	55	0	0	6	3.8
Fecal coliforms (coliform $100mL^{-1}$)	20	55	1	2	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	55	6	11	0.3	<u>0.26</u>
pH (units)	6.5-8.5	48	4	8	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	20	6	6	100	15	55.2
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	55	1	2	na	na
Sulfate ($mg\ L^{-1}$)	25	6	0	0	15	10.0
Total ammonia-N ($mg\ L^{-1}$)	0.10	55	17	31	0.05	<u>0.14</u>
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	55	6	11	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	175	55	55	100	150	328
Total phosphorus ($\mu g\ L^{-1}$)	15	55	54	98	na	na
Total phytoplankton (ASU mL^{-1})	2000	32	3	9	na	na
Primary genus (ASU mL^{-1})	1000	32	4	13	na	na
Secondary genus (ASU mL^{-1})	1000	32	1	3	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	6	0	0	5	2.6
Turbidity (NTU)	5	55	8	15	na	na
Middle Branch Reservoir						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	9			>40	64
Chloride ($mg\ L^{-1}$)	40	0			30	

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Chlorophyll a (µg L^{-1})	15	16	1	6	10	8.6
Color (Pt-Co units)	15	40	39	98	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform $100mL^{-1}$)	20	40	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	12	30	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	386
Total phosphorus (µg L^{-1})	15	40	29	73	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	0	0	na	na
Primary genus (ASU mL^{-1})	1000	16	1	6	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	1	11	5	3.3
Turbidity (NTU)	5	40	9	23	na	na
New Croton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	30			>40	67
Chloride (mg L^{-1})	40	30	30	100	30	95.3
Chlorophyll a (µg L^{-1})	15	55	1	2	10	7.6
Color (Pt-Co units)	15	168	154	92	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	168	0	0	6	3.2
Fecal coliforms (coliform $100mL^{-1}$)	20	168	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	168	34	20	0.3	<u>0.24</u>
pH (units)	6.5-8.5	139	23	17	na	na
Sodium, undig., filt. (mg L^{-1})	20	30	30	100	15	50.2
Soluble reactive phosphorus (µg L^{-1})	15	168	4	2	na	na
Sulfate (mg L^{-1})	25	30	0	0	15	10.0
Total ammonia-N (mg L^{-1})	0.10	168	33	20	0.05	<u>0.11</u>
Total dissolved phosphorus (µg L^{-1})	15	168	13	8	na	na
Total dissolved solids (mg L^{-1})[3]	175	168	168	100	150	303

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

Analyte	**Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2015 Mean [1]**
Total phosphorus (µg L^{-1})	15	168	88	52	na	na
Total phytoplankton (ASU mL^{-1})	2000	64	1	2	na	na
Primary genus (ASU mL^{-1})	1000	64	1	2	na	na
Secondary genus (ASU mL^{-1})	1000	64	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	56	0	0	5	1.4
Turbidity (NTU)	5	168	11	7	na	na
Titicus Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	71
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	2	13	10	9.3
Color (Pt-Co units)	15	37	36	97	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform 100mL^{-1})	20	39	1	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	39	11	28	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	33	32	97	150	202
Total phosphorus (µg L^{-1})	15	37	29	78	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	0	0	na	na
Primary genus (ASU mL^{-1})	1000	16	2	13	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	1.9
Turbidity (NTU)	5	37	3	8	na	na
West Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	15			>10	21
Chloride (mg L^{-1})	12	13	13	100	8	23.9
Chlorophyll a (µg L^{-1})	12	32	0	0	7	4.8
Color (Pt-Co units)	15	72	39	54	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Dissolved organic carbon (mg L^{-1})[2]	4.0	72	0	0	3	2.0
Fecal coliforms (coliform 100mL^{-1})	20	72	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	72	0	0	0.3	<u>0.12</u>
pH (units)	6.5-8.5	72	18	25	na	na
Sodium, undig., filt. (mg L^{-1})	16	14	14	100	3	14.5
Soluble reactive phosphorus (µg L^{-1})	15	72	0	0	na	na
Sulfate (mg L^{-1})	15	13	0	0	10	5.3
Total ammonia-N (mg L^{-1})	0.10	72	2	3	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	72	2	3	na	na
Total dissolved solids (mg L^{-1})[3]	50	72	72	100	40	84
Total phosphorus (µg L^{-1})	15	72	14	19	na	na
Total phytoplankton (ASU mL^{-1})	2000	43	0	0	na	na
Primary genus (ASU mL^{-1})	1000	43	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	43	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.7
Turbidity (NTU)	5	72	0	0	na	na
West of Hudson Reservoirs						
Ashokan-East Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	13
Chloride (mg L^{-1})	12	9	0	0	8	9.1
Chlorophyll a (µg L^{-1})	12	24	0	0	7	2.3
Color (Pt-Co units)	15	64	1	2	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	64	0	0	3	1.6
Fecal coliforms (coliform 100mL^{-1})	20	64	1	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	0	0	0.3	<u>0.09</u>
pH (units)	6.5-8.5	64	17	27	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	5.5
Soluble reactive phosphorus (µg L^{-1})	15	64	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	3.5
Total ammonia-N (mg L^{-1})	0.10	64	0	0	0.05	<u>0.02</u>
Total dissolved phosphorus (µg L^{-1})	15	64	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	64	0	0	40	45
Total phosphorus (µg L^{-1})	15	64	3	5	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Total phytoplankton (ASU mL^{-1})	2000	40	0	0	na	na
Primary genus (ASU mL^{-1})	1000	40	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	40	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	64	0	0	5	1.8
Turbidity (NTU)	5	64	6	9	na	na
Ashokan-West Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	12
Chloride (mg L^{-1})	12	12	0	0	8	9.8
Chlorophyll a (µg L^{-1})	12	23	0	0	7	2.9
Color (Pt-Co units)	15	74	9	12	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	74	0	0	3	1.7
Fecal coliforms (coliform $100mL^{-1}$)	20	74	2	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	74	0	0	0.3	<u>0.22</u>
pH (units)	6.5-8.5	73	11	15	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	5.8
Soluble reactive phosphorus (µg L^{-1})	15	74	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.5
Total ammonia-N (mg L^{-1})	0.10	74	0	0	0.05	<u>0.01</u>
Total dissolved phosphorus (µg L^{-1})	15	74	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	74	4	5	40	47
Total phosphorus (µg L^{-1})	15	74	4	5	na	na
Total phytoplankton (ASU mL^{-1})	2000	39	0	0	na	na
Primary genus (ASU mL^{-1})	1000	39	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	39	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	74	5	7	5	3.5
Turbidity (NTU)	5	74	30	41	na	na
Pepacton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	21			>10	13
Chloride (mg L^{-1})	12	21	0	0	8	9.2
Chlorophyll a (µg L^{-1})	12	40	1	3	7	4.0
Color (Pt-Co units)	15	120	24	20	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	120	0	0	3	1.4

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

Analyte	**Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2015 Mean** [1]
Fecal coliforms (coliform $100mL^{-1}$)	20	120	2	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	120	0	0	0.3	<u>0.21</u>
pH (units)	6.5-8.5	110	32	29	na	na
Sodium, undig., filt. (mg L^{-1})	16	21	21	100	3	5.3
Soluble reactive phosphorus (µg L^{-1})	15	120	0	0	na	na
Sulfate (mg L^{-1})	15	21	0	0	10	3.9
Total ammonia-N (mg L^{-1})	0.10	120	0	0	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	120	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	121	11	9	40	47
Total phosphorus (µg L^{-1})	15	120	13	11	na	na
Total phytoplankton (ASU mL^{-1})	2000	58	1	2	na	na
Primary genus (ASU mL^{-1})	1000	58	5	9	na	na
Secondary genus (ASU mL^{-1})	1000	58	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	51	0	0	5	<u>0.9</u>
Turbidity (NTU)	5	120	7	6	na	na
Neversink Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	11			>10	3
Chloride (mg L^{-1})	12	11	0	0	8	4.6
Chlorophyll a (µg L^{-1})	12	24	0	0	7	2.5
Color (Pt-Co units)	15	98	4	4	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	74	0	0	3	1.7
Fecal coliforms (coliform $100mL^{-1}$)	20	98	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	74	0	0	0.3	<u>0.20</u>
pH (units)	6.5-8.5	97	64	66	na	na
Sodium, undig., filt. (mg L^{-1})	16	11	0	0	3	2.6
Soluble reactive phosphorus (µg L^{-1})	15	74	0	0	na	na
Sulfate (mg L^{-1})	15	11	0	0	10	2.9
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	22
Total phosphorus (µg L^{-1})	15	74	2	3	na	na
Total phytoplankton (ASU mL^{-1})	2000	47	0	0	na	na
Primary genus (ASU mL^{-1})	1000	47	2	4	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Secondary genus (ASU mL^{-1})	1000	47	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	24	0	0	5	0.8
Turbidity (NTU)	5	98	0	0	na	na
Rondout Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	10
Chloride (mg L^{-1})	12	12	0	0	8	9.7
Chlorophyll a (µg L^{-1})	12	24	0	0	7	3.2
Color (Pt-Co units)	15	80	9	11	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.6
Fecal coliforms (coliform $100mL^{-1}$)	20	80	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	56	0	0	0.3	0.26
pH (units)	6.5-8.5	76	24	32	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	5.8
Soluble reactive phosphorus (µg L^{-1})	15	56	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.7
Total ammonia-N (mg L^{-1})	0.10	56	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	1	1	40	45
Total phosphorus (µg L^{-1})	15	80	0	0	na	na
Total phytoplankton (ASU mL^{-1})	2000	48	0	0	na	na
Primary genus (ASU mL^{-1})	1000	48	1	2	na	na
Secondary genus (ASU mL^{-1})	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	28	0	0	5	0.8
Turbidity (NTU)	5	80	0	0	na	na
Schoharie Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	16
Chloride (mg L^{-1})	12	9	1	11	8	11.4
Chlorophyll a (µg L^{-1})	12	32	0	0	7	2.4
Color (Pt-Co units)	15	87	47	54	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	89	0	0	3	2.3
Fecal coliforms (coliform $100mL^{-1}$)	20	89	14	16	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	65	0	0	0.3	0.17

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
pH (units)	6.5-8.5	78	13	17	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	6.8
Soluble reactive phosphorus (µg L^{-1})	15	65	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	3.7
Total ammonia-N (mg L^{-1})	0.10	65	1	2	0.05	<u>0.01</u>
Total dissolved phosphorus (µg L^{-1})	15	65	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	89	83	93	40	56
Total phosphorus (µg L^{-1})	15	89	26	29	na	na
Total phytoplankton (ASU mL^{-1})	2000	48	1	2	na	na
Primary genus (ASU mL^{-1})	1000	48	2	4	na	na
Secondary genus (ASU mL^{-1})	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	89	7	8	5	4.9
Turbidity (NTU)	5	89	58	65	na	na
Cannonsville Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	17			>10	17
Chloride (mg L^{-1})	12	22	22	100	8	14.5
Chlorophyll a (µg L^{-1})	12	40	4	10	7	6.3
Color (Pt-Co units)	15	111	66	59	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	111	0	0	3	1.8
Fecal coliforms (coliform $100mL^{-1}$)	20	111	5	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	111	33	30	0.3	<u>0.34</u>
pH (units)	6.5-8.5	110	37	34	na	na
Sodium, undig., filt. (mg L^{-1})	16	17	17	100	3	8.8
Soluble reactive phosphorus (µg L^{-1})	15	111	0	0	na	na
Sulfate (mg L^{-1})	15	22	0	0	10	4.9
Total ammonia-N (mg L^{-1})	0.10	117	3	3	0.05	<u>0.03</u>
Total dissolved phosphorus (µg L^{-1})	15	111	12	11	na	na
Total dissolved solids (mg L^{-1})[3]	50	104	102	98	40	64
Total phosphorus (µg L^{-1})	15	111	53	48	na	na
Total phytoplankton (ASU mL^{-1})	2000	57	2	4	na	na
Primary genus (ASU mL^{-1})	1000	54	3	6	na	na
Secondary genus (ASU mL^{-1})	1000	54	1	2	na	na
Total suspended solids (mg L^{-1})	8.0	48	5	10	5	2.8

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean [1]
Turbidity (NTU)	5	111	25	23	na	na

[1] Means were estimated using recommended techniques according to Helsel (2005). For 100% uncensored data the arithmetic mean is reported. For <50% censored data the mean is estimated using the Kaplan-Meier Method. These estimates are underlined with one line. For 50-80% censored data the robust ROS method was used. These estimates are underlined using two lines. In cases where >80% of data is censored the mean cannot be estimated and here we report the detection limit preceded by <.

[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).

[4] First number is the calculated result using all data. Number in parenthesis is the calculated result after removal of one outlier and is considered more representative. In this case the outlier was 158 mg L^{-1} well outside the historic (2005-2015) range of 5.0 to 10.7 mg L^{-1}.

[5] First number is the calculated result using all data. Number in parenthesis is the calculated result after removal of one outlier and is considered more representative. In this case the outlier was 70.2 mg L^{-1} well outside the historic (2005-2015) range of 3.4 to 9.4 mg L^{-1}.

Appendix F. 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	2015 Mean[1]
Ashokan Watershed						
E10I (Bushkill inflow to Ashokan)						
Alkalinity (mg L^{-1})	≥10.0	12	10	83	na	7.6
Chloride (mg L^{-1})	50	12	0	0	10	4.5
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	0.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.12</u>
Sulfate (mg L^{-1})	15	4	0	0	10	3.5
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	11	0	0	40	28
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.8
E16I (Esopus Brook at Coldbrook)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	15.2
Chloride (mg L^{-1})	50	12	0	0	10	10.1
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	0.20
Sulfate (mg L^{-1})	15	0			10	
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	5	42	40	51
Dissolved sodium (mg L^{-1})	10	0			5	
E5 (Esopus Creek at Allaben)						
Alkalinity (mg L^{-1})	≥10.0	12	8	67	na	10.7
Chloride (mg L^{-1})	50	13	0	0	10	5.7
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.21</u>
Sulfate (mg L^{-1})	15	5	0	0	10	3.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	11	3	27	40	36
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.2

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	2015 Mean[1]
Schoharie Watershed						
S5I (Schoharie Creek at Prattsville)						
Alkalinity (mg L^{-1})	≥10.0	10	1	10	na	21.0
Chloride (mg L^{-1})	50	10	0	0	10	15.5
Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	1.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	10	0	0	0.40	0.17
Sulfate (mg L^{-1})	15	3	0	0	10	4.4
Total ammonia-N (mg L^{-1})	0.25	10	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	10	8	80	40	71
Dissolved sodium (mg L^{-1})	10	3	1	33	5	9.6
S6I (Bear Creek at Hardenburgh Falls)						
Alkalinity (mg L^{-1})	≥10.0	11	0	0	na	32.0
Chloride (mg L^{-1})	50	11	1	9	10	28.9
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	2.6
Nitrate+Nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.48
Sulfate (mg L^{-1})	15	4	0	0	10	6.8
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	11	11	100	40	119
Dissolved sodium (mg L^{-1})	10	4	4	100	5	16.7
S7I (Manor Kill)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	31.1
Chloride (mg L^{-1})	50	12	0	0	10	12.6
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	0.15
Sulfate (mg L^{-1})	15	4	0	0	10	5.3
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	11	92	40	77
Dissolved sodium (mg L^{-1})	10	4	0	0	5	7.7

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	2015 Mean[1]
SRR2CM (Schoharie Reservoir Diversion) [3]						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	16.3
Chloride (mg L^{-1})	50	12	0	0	10	10.6
Dissolved organic carbon (mg L^{-1})	25	53	0	0	9	2.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.22
Sulfate (mg L^{-1})	15	4	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	≤0.02
Total dissolved solid (mg L^{-1})[2]	50	48	43	90	40	59
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.6
Cannonsville Watershed						
C-7 (Trout Creek above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	16.0
Chloride (mg L^{-1})	50	12	0	0	10	17.1
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	0.33
Sulfate (mg L^{-1})	15	4	0	0	10	5.4
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	≤0.02
Total dissolved solid (mg L^{-1})[2]	50	12	12	100	40	71
Dissolved sodium (mg L^{-1})	10	4	2	50	5	10.0
C-8 (Loomis Brook above Cannonsville Reservoir						
Alkalinity (mg L^{-1})	≥10.0	11	2	18	na	15.7
Chloride (mg L^{-1})	50	12	0	0	10	16.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.30
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	12	100	40	70
Dissolved sodium (mg L^{-1})	10	4	1	25	5	9.6
WDBN (West Branch Delaware River at Beerston Bridge)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	19.6
Chloride (mg L^{-1})	50	12	0	0	10	14.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.2

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	2015 Mean[1]
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.55
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	7	58	40	69
Dissolved sodium (mg L^{-1})	10	4	2	50	5	9.0
Neversink Watershed						
NCG (Neversink Reservoir near Claryville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	3.6
Chloride (mg L^{-1})	50	13	0	0	10	3.9
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	0.22
Sulfate (mg L^{-1})	15	5	0	0	10	3.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	21
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.4
NK4 (Aden Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	10	83	na	7.8
Chloride (mg L^{-1})	50	13	0	0	10	4.5
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	0.18
Sulfate (mg L^{-1})	15	5	0	0	10	3.7
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	29
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.6
NK6 (Kramer Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	10	83	na	8.6
Chloride (mg L^{-1})	50	12	3	25	10	43.9
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	0.71
Sulfate (mg L^{-1})	15	4	0	0	10	5.1

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	2015 Mean[1]
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	0.02
Total dissolved solid (mg L^{-1})[2]	50	12	12	100	40	122
Dissolved sodium (mg L^{-1})	10	4	4	100	5	25.6
Pepacton Watershed						
P-13 (Tremper Kill above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	17.9
Chloride (mg L^{-1})	50	12	0	0	10	14.6
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	0.33
Sulfate (mg L^{-1})	15	4	0	0	10	4.6
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	9	75	40	66
Dissolved sodium (mg L^{-1})	10	4	0	0	5	8.2
P-21 (Platte Kill at Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	19.3
Chloride (mg L^{-1})	50	12	0	0	10	12.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.24
Sulfate (mg L^{-1})	15	4	0	0	10	4.4
Total Ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	8	67	40	62
Dissolved sodium (mg L^{-1})	10	4	1	25	5	7.7
P-60 (Mill Brook near Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	4	33	na	12.1
Chloride (mg L^{-1})	50	12	0	0	10	2.6
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	0.25
Sulfate (mg L^{-1})	15	4	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	30
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.5

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	2015 Mean[1]
P-7 (Terry Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	15.0
Chloride (mg L^{-1})	50	12	0	0	10	1.4
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	0.38
Sulfate (mg L^{-1})	15	4	0	0	10	4.6
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	34
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.5
P-8 (Fall Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	13.9
Chloride (mg L^{-1})	50	12	0	0	10	3.0
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	0.43
Sulfate (mg L^{-1})	15	4	0	0	10	4.7
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	36
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.2
PMSB (East Branch Delaware River near Margaretville)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	20.0
Chloride (mg L^{-1})	50	12	0	0	10	19.2
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	0.57
Sulfate (mg L^{-1})	15	4	0	0	10	4.7
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	12	100	40	80
Dissolved sodium (mg L^{-1})	10	4	2	50	5	10.7

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	2015 Mean[1]
Rondout Reservoir						
RD1 (Sugarloaf Brook near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	4.8
Chloride (mg L^{-1})	50	12	0	0	10	7.2
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	<u>0.17</u>
Sulfate (mg L^{-1})	15	4	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	31
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.0
RD4 (Sawkill Brook near Yagerville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	5.2
Chloride (mg L^{-1})	50	12	0	0	10	7.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.10</u>
Sulfate (mg L^{-1})	15	4	0	0	10	4.8
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	33
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.3
RDOA (Rondout Creek near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	3.8
Chloride (mg L^{-1})	50	13	0	0	10	4.4
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	0.17
Sulfate (mg L^{-1})	15	5	0	0	10	3.5
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	0	0	40	23
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.7
RGB (Chestnut Creek below Grahamsville STP)						
Alkalinity (mg L^{-1})	≥10.0	12	10	83	na	8.4
Chloride (mg L^{-1})	50	13	0	0	10	19.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.1

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	2015 Mean[1]
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.35
Sulfate (mg L^{-1})	15	5	0	0	10	4.8
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solid (mg L^{-1})[2]	50	12	12	100	40	66
Dissolved sodium (mg L^{-1})	10	4	3	75	5	12.1
East of Hudson						
AMAWALKR (Amawalk Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	78.0
Chloride (mg L^{-1})	100	12	12	100	35	120.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.25</u>
Sulfate (mg L^{-1})	25	4	0	0	15	10.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.07</u>
Total dissolved solid (mg L^{-1})[2]	175	11	11	100	150	375
Dissolved sodium (mg L^{-1})	20	4	4	100	15	64.3
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	79.3
Chloride (mg L^{-1})	100	12	0	0	35	69.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.16
Sulfate (mg L^{-1})	25	4	0	0	15	9.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.05</u>
Total dissolved solid (mg L^{-1})[2]	175	12	12	100	150	264
Dissolved sodium (mg L^{-1})	20	4	4	100	15	34.4
BOYDR (Boyd's Corners Release)[3]						
Alkalinity (mg L^{-1})	≥40.0	12	12	100	na	34.0
Chloride (mg L^{-1})	100	12	0	0	35	52.9
Dissolved organic carbon (mg L^{-1})	25	52	0	0	9	3.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.11</u>
Sulfate (mg L^{-1})	25	5	0	0	15	6.9

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	2015 Mean[1]
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.03
Total dissolved solid (mg L^{-1})[2]	175	48	20	42	150	169
Dissolved sodium (mg L^{-1})	20	4	4	100	15	29.4
CROFALLSVC (Croton Falls Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	65.0
Chloride (mg L^{-1})	100	12	0	0	35	90.3
Dissolved organic carbon (mg L^{-1})	25	52	0	0	9	3.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.38
Sulfate (mg L^{-1})	25	5	0	0	15	10.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.05
Total dissolved solid (mg L^{-1})[2]	175	48	45	94	150	285
Dissolved sodium (mg L^{-1})	20	4	4	100	15	48.5
CROSS2 (Cross River near Cross River Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	1	8	na	54.9
Chloride (mg L^{-1})	100	12	0	0	35	51.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.20
Sulfate (mg L^{-1})	25	3	0	0	15	10.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solid (mg L^{-1})[2]	175	11	9	82	150	199
Dissolved sodium (mg L^{-1})	20	4	4	100	15	25.0
CROSSRVVC (Cross River Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	9	0	0	na	46.9
Chloride (mg L^{-1})	100	9	0	0	35	42.7
Dissolved organic carbon (mg L^{-1})	25	40	0	0	9	3.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	9	0	0	0.35	0.23
Sulfate (mg L^{-1})	25	4	0	0	15	8.7
Total ammonia-N (mg L^{-1})	0.20	9	0	0	0.10	0.07
Total dissolved solid (mg L^{-1})[2]	175	36	7	19	150	177
Dissolved sodium (mg L^{-1})	20	3	3	100	15	22.2

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	2015 Mean[1]
DIVERTR (Diverting Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	77.5
Chloride (mg L^{-1})	100	12	2	17	35	88.1
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	0.25
Sulfate (mg L^{-1})	25	4	0	0	15	9.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.06</u>
Total dissolved solid (mg L^{-1})[2]	175	12	12	100	150	303
Dissolved sodium (mg L^{-1})	20	4	4	100	15	41.6
EASTBR (East Branch Croton River above East Branch River)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	85.1
Chloride (mg L^{-1})	100	12	0	0	35	65.0
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	<u>0.10</u>
Sulfate (mg L^{-1})	25	4	1	25	15	18.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.03</u>
Total dissolved solid (mg L^{-1})[2]	175	12	11	92	150	271
Dissolved sodium (mg L^{-1})	20	4	4	100	15	34.6
GYPSYTRL1 (Gypsy Trail Brook in West Branch Watershed)						
Alkalinity (mg L^{-1})	≥40.0	10	7	70	na	32.5
Chloride (mg L^{-1})	100	10	0	0	35	48.9
Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	4.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	10	0	0	0.35	<u>0.06</u>
Sulfate (mg L^{-1})	25	4	0	0	15	7.5
Total ammonia-N (mg L^{-1})	0.20	10	0	0	0.10	<0.02
Total dissolved solid (mg L^{-1})[2]	175	10	4	40	150	160
Dissolved sodium (mg L^{-1})	20	4	4	100	15	27.0
HORSEPD12 (Horse Pound Brook in West Branch Watershed)						
Alkalinity (mg L^{-1})	≥40.0	12	3	25	na	43.7
Chloride (mg L^{-1})	100	12	1	8	35	65.7

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	2015 Mean[1]
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.6
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.39
Sulfate (mg L^{-1})	25	4	0	0	15	10.7
Total Ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.01
Total dissolved solid (mg L^{-1})[2]	175	12	10	83	150	215
Dissolved sodium (mg L^{-1})	20	4	4	100	15	35.2
KISCO3 (Kisco River above New Croton Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	81.4
Chloride (mg L^{-1})	100	12	12	100	35	157.0
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	0.66
Sulfate (mg L^{-1})	25	4	0	0	15	15.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.03
Total dissolved solid (mg L^{-1})[2]	175	11	11	100	150	472
Dissolved sodium (mg L^{-1})	20	4	4	100	15	80.7
LONGPD1 (Long Pond outflow above West Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	1	8	na	58.6
Chloride (mg L^{-1})	100	12	6	50	35	114.4
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	0.25
Sulfate (mg L^{-1})	25	4	0	0	15	9.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.01
Total dissolved solid (mg L^{-1})[2]	175	12	12	100	150	340
Dissolved sodium (mg L^{-1})	20	4	4	100	15	51.7
MIKE2 (Michael Brook in Croton Falls Watershed)						
Alkalinity (mg L^{-1})	≥40.0	12	1	8	na	83.3
Chloride (mg L^{-1})	100	12	11	92	35	217.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	9	75	0.35	4.41
Sulfate (mg L^{-1})	25	4	1	25	15	21.8

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	2015 Mean[1]
Total ammonia-N (mg L^{-1})	0.20	12	1	8	0.10	0.05
Total dissolved solid (mg L^{-1})[2]	175	12	12	100	150	619
Dissolved sodium (mg L^{-1})	20	4	4	100	15	121.3
MUSCOOT10 (Muscoot River above Amawalk Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	89.7
Chloride (mg L^{-1})	100	12	12	100	35	165.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	5.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.46
Sulfate (mg L^{-1})	25	4	0	0	15	9.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.07
Total dissolved solid (mg L^{-1})[2]	175	12	12	100	150	485
Dissolved sodium (mg L^{-1})	20	4	4	100	15	81.0
TITICUSR (Titicus Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	69.4
Chloride (mg L^{-1})	100	12	0	0	35	48.0
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	0.19
Sulfate (mg L^{-1})	25	4	0	0	15	8.0
Total ammonia-N (mg L^{-1})	0.20	12	2	17	0.10	0.11
Total dissolved solid (mg L^{-1})[2]	175	12	11	92	150	206
Dissolved sodium (mg L^{-1})	20	4	4	100	15	25.1
WESTBR7 (West Branch Croton River above Boyd's Corners Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	6	50	na	43.5
Chloride (mg L^{-1})	100	12	0	0	35	52.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.10
Sulfate (mg L^{-1})	25	4	0	0	15	6.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solid (mg L^{-1})[2]	175	12	7	58	150	182
Dissolved sodium (mg L^{-1})	20	4	4	100	15	29.5

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

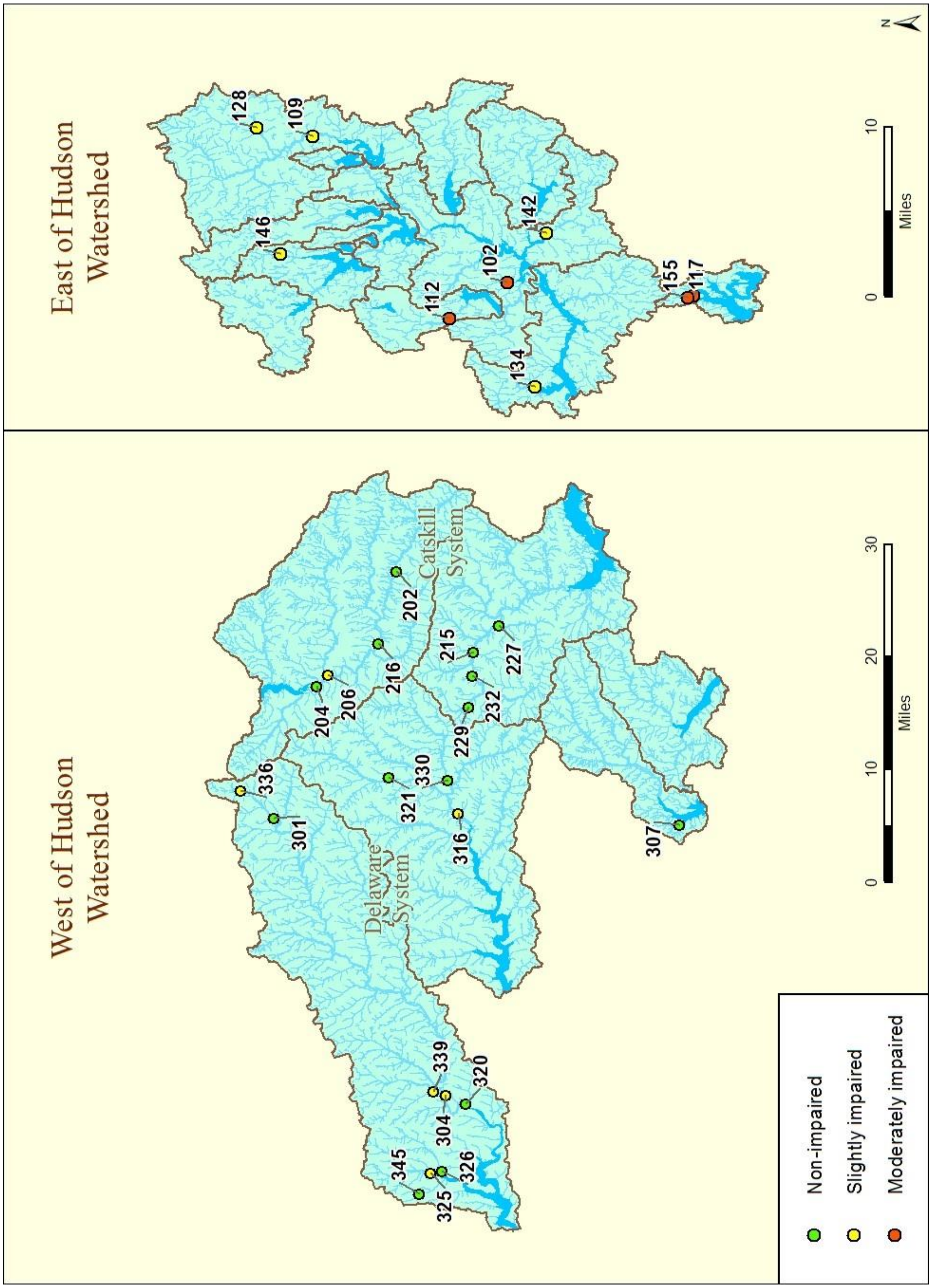
Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2015 Mean[1]
WESTBRR (West Branch Reservoir Release)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	19.9
Chloride (mg L^{-1})	50	12	0	0	10	22.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.13</u>
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<u>0.05</u>
Total dissolved solid (mg L^{-1})[2]	50	12	12	100	40	84
Dissolved sodium (mg L^{-1})	10	4	3	75	5	12.0

[1] Means were estimated using recommended techniques according to Helsel (2005). For 100% uncensored data the arithmetic mean is reported. For <50% censored data the mean is estimated using the Kaplan-Meier Method. These estimates are underlined with one line. For 50-80% censored data the robust ROS method was used. These estimates are underlined using two lines. In cases where >80% of data is censored the mean cannot be estimated and here we report the detection limit preceded by <.

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

[3] Note: In 2015, CROFALLSVC, CROSSRVVC, SRR2CM and BOYDR were sampled weekly 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 G. Biomonitoring Sampling Sites



Appendix H. Semi Volatile and Volatile Organic Compounds

EPA 525.2 – Semi-volatiles

2,4-Dinitrotoluene, 2,6-Dinitrotoluene, 4,4-DDD, 4,4-DDE, 4,4-DDT, Acenaphthene, Acenaphthylene, Acetochlor, Alachlor, Aldrin, Alpha-BHC, alpha-Chlordane, Anthracene, Atrazine, Benz(a)Anthracene, Benzo(a)pyrene, Benzo(b)Fluoranthene, Benzo(g,h,i)Perylene, Benzo(k)Fluoranthene, Beta-BHC, Bromacil, Butachlor, Butylbenzylphthalate, Caffeine, Chlorobenzilate, Chloroneb, Chlorothalonil(Draconil,Bravo), Chlorpyrifos (Dursban), Chrysene, Delta-BHC, Di-(2-Ethylhexyl)adipate, Di(2-Ethylhexyl)phthalate, Diazinon, Dibenz(a,h)Anthracene, Dichlorvos (DDVP), Dieldrin, Diethylphthalate, Dimethoate, Dimethylphthalate, Di-n-Butylphthalate, Di-N-octylphthalate, Endosulfan I (Alpha), Endosulfan II (Beta), Endosulfan Sulfate, Endrin, Endrin Aldehyde, EPTC, Fluoranthene, Fluorene, gamma-Chlordane, Heptachlor, Heptachlor Epoxide (isomer B), Hexachlorobenzene, Hexachlorocyclopentadiene, Indeno(1,2,3,c,d)Pyrene, Isophorone, Lindane, Malathion, Methoxychlor, Metolachlor, Metribuzin, Molinate, Naphthalene, Parathion, Pendimethalin, Pentachlorophenol, Permethrin (mixed isomers), Phenanthrene, Propachlor, Pyrene, Simazine, Terbacil, Terbuthylazine, Thiobencarb, trans-Nonachlor, Trifluralin, 1,3-Dimethyl-2-nitrobenzene, Acenaphthene-d10, Chrysene-d12, Perylene-d12, Phenanthrene-d10, Triphenylphosphate

EPA 524.2 - Volatile Organics

1,1,1,2-Tetrachloroethane, 1,1,1-Trichloroethane, 1,1,2,2-Tetrachloroethane, 1,1,2-Trichloroethane, 1,1-Dichloroethane, 1,1-Dichloroethylene, 1,1-Dichloropropene, 1,2,3-Trichlorobenzene, 1,2,3-Trichloropropane, 1,2,4-Trichlorobenzene, 1,2,4-Trimethylbenzene, 1,2-Dichloroethane, 1,2-Dichloropropane, 1,3,5-Trimethylbenzene, 1,3-Dichloropropane, 2,2-Dichloropropane, 2-Butanone (MEK), 4-Methyl-2-Pentanone (MIBK), Benzene, Bromobenzene, Bromochloromethane, Bromodichloromethane, Bromoethane, Bromoform, Bromomethane (Methyl Bromide), Carbon disulfide, Carbon Tetrachloride, Chlorobenzene, Chlorodibromomethane, Chloroethane, Chloroform (Trichloromethane), Chloromethane(Methyl Chloride), cis^{-1},2-Dichloroethylene, cis^{-1},3-Dichloropropene, Dibromomethane, Dichlorodifluoromethane, Dichloromethane, Di-isopropyl ether, Ethyl benzene, Hexachlorobutadiene, Isopropylbenzene, m,p-Xylenes, m-Dichlorobenzene (1,3-DCB), Methyl Tert-butyl ether (MTBE), Naphthalene, n-Butylbenzene, n-Propylbenzene, o-Chlorotoluene, o-Dichlorobenzene (1,2-DCB), o-Xylene, p-Chlorotoluene, p-Dichlorobenzene (1,4-DCB), p-Isopropyltoluene, sec-Butylbenzene, Styrene, tert-amyl Methyl Ether, tert-Butyl Ethyl Ether, tert-Butylbenzene, Tetrachloroethylene (PCE), Toluene, Total 1,3-Dichloropropene, Total THM, Total xylenes, trans^{-1},2-Dichloroethylene, trans^{-1},3-Dichloropropene, Trichloroethylene (TCE), Trichlorofluoromethane, Trichlorotrifluoroethane(Freon 113), Vinyl chloride (VC), 1,2-Dichloroethane-d4 4-Bromofluorobenzene, Toluene-d8

Herbicides

glyphosate