NYC Department of Environmental Protection

2016 Watershed Water Quality Annual Report

July 2017

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Bureau of Water Supply

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List of Acronyms

BEPA	Bureau of Environmental Planning and Analysis
CATALUM	Catskill Alum Chamber
CATLEFF	Catskill Lower Effluent Chamber
CATUEC	Catskill Upper Effluent Chamber
CUNY-RF	City University of New York Research Foundation
DBP	Disinfection Byproducts
DBPFP	Disinfection Byproduct formation potential
DEL17	Delaware Aqueduct Shaft Building 17
DEL18	Delaware Aqueduct Shaft Building 18
DEP	New York City Department of Environmental Protection
DRO	Diesel Range Organics
EOH	East of Hudson
FAD	Filtration Avoidance Determination
fDOM	Fluorescent Dissolved Organic Matter
GLEON	Global Lake Ecological Observatory Network
HEV	Human Enteric Virus
IAR	Inactivation Ratio
MPN	Most Probable Number
MST	Microbial Source Tracking
NTU	Nephelometric Turbidity Units
NYC	New York City
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
RHESSys	Regional Hydro-Ecologic Simulation System
SPDES	State Pollutant 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
WR&R	New York City Watershed Rules and Regulations
WUCA	Water Utility Climate Alliance
WWQMP	Watershed Water Quality Monitoring Plan
WWQO	Watershed Water Quality Operations
WQSR	Water Quality Science and Research
WWTP	Wastewater Treatment Plant

Acknowledgements

This report provides a summary of the scientific work conducted in 2016 to manage the water quality of the New York City water supply and to provide information for regulatory agencies and the general public. Acting Commissioner of the Department of Environmental Protection, Mr. Vincent Sapienza, P.E., provided oversight of the Department throughout 2016. Mr. Paul Rush, P.E., Deputy Commissioner, 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, Watershed Laboratory Operations, Wildlife Studies, and Systems Support. WWQO also manages 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, Deputy Chief for West of Hudson Water Quality Operations; and Mr. Dale Borchert, Deputy Chief for East of Hudson Water Quality Operations. Mr. Bader and Mr. Borchert provided the information on Robotic Monitoring and Operations, respectively. Chapter 2 on Water Quantity was written by Mr. Mayfield, Mr. Rich Van Dreason, and Mr. Matthew Giannetta with Mr. Alec Fu of Reservoir Operations 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, Mr. Don Kent on stream biomonitoring, and Mr. Dave Quentin with contributions from Mr. Tracy Lawrence, Ms. Kirsten Askildsen and Mr. Andrew Bader on Special Investigations. Chapter 4 about Kensico Reservoir was written 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, Section 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 the 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, Dr. Karen Moore, Ms. Aspa Capetenakis, and Ms. Carla Glaser. Other essential database expertise was provided by Mr. Brian O'Malley, Section Chief of Data Management. Most maps in the report were created by Mr. Jordan Gass. Mr. Jim Mayfield was 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. The cover photograph of the Ashokan Reservoir was taken by Mr. John Staby. 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 approximately half the population of the State of New York, which includes over 8.5 million people in New York City (NYC) 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 general overview of the City's water resources, their condition during 2016, and compliance with regulatory standards. Field sampling, along with early warning and robotic monitoring equipment, are employed at 461 sites throughout the watershed to measure an array of water quality analytes at various frequencies. This data provides scientific information to guide system operations, for use in water quality models, and for watershed protection policies. Overall, the report illustrates how DEP uses constant surveillance and scientific understanding to protect and maintain high quality source water for the NYC water supply.

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 2016 was 35.8 inches (910 mm), which was 9.3 inches (236 mm) below normal. Reflecting the below normal precipitation in the watershed for the year, the annual runoff was also well below normal for all WOH and EOH sites. The United States Geological Survey (USGS) also reported that New York State had well below normal annual runoff (100th lowest out of the last 116 years) for the USGS 2016 water year (October 1, 2015-September 30, 2016).

The system-wide useable storage level for the reservoirs was somewhat above normal at the start of 2016 and generally remained above normal through May. Typical declines in storage were then observed through the end of August. Unusually dry conditions prevailed for the rest of the year, which led the Delaware River Basin Commission (DRBC) to declare a drought watch for the entire Delaware River basin on November 23 based on the combined storage of Cannonsville, Pepacton, and Neversink Reservoirs. The drought watch was lifted January 18, 2017.

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

Similar to the previous year, 2016 turbidity levels in the Catskill/Delaware System reservoirs were close to or well below their respective historic 25th percentile levels. Turbidity in the Croton System was generally at or below historical levels as well. Low turbidity levels coincided with low rainfall amounts observed throughout all of the NYC water supply watersheds in 2016.

Total and fecal coliform levels were generally low as compared with historical ranges in both watershed streams and reservoirs in 2016. Reservoir trophic state was generally low with some exceptions. In 2016, the trophic state index (TSI) increased in two Croton System reservoirs: Boyd's Corners and Diverting. Among the factors related to the increase were warm summer temperatures, reservoir drawdown, and a summer storm. Trophic state continued to improve in West Branch Reservoir, attributed to a large diversion of Rondout water during July and reduced rainfall and runoff in summer and fall that diminished the influence of local streams.

Total phosphorus (TP) levels in most Catskill/Delaware and Croton System reservoirs and streams in 2016 were higher than historical levels. Reasons for the increase are not clear since there were few runoff events in 2016. Therefore, turbidity was low and consequently there was minimal transport of particulate phosphorus to streams and reservoirs. Drought could be a contributing factor to the observed increase.

Despite the increase in TP, trophic state indices (TSI) were quite low for most reservoirs in 2016, indicating the observed increases in TP did not result in an increase in algal productivity. Also, despite these increases, there were no changes in phosphorus-restricted status from the previous assessment period. DEP will continue to monitor TP concentrations to determine if the 2016 increase is a trend and further investigate possible causes.

Evaluation of additional reservoir and stream analytes in 2016 included chloride. As in previous years, all streams, reservoirs, and controlled lakes in the Croton System exceeded the Croton System annual mean chloride benchmarks of 30 mg L^{-1} for reservoirs and 35 mg L^{-1} for streams. Fewer exceedances of the single sample concentration benchmark of 12.0 mg L^{-1} for the Catskill/Delaware System benchmarks occurred in 2016, and all exceedances of chloride benchmark values for chloride were well below the health standard of 250 mg L^{-1}.

Water quality assessments of watershed streams, based on resident benthic macroinvertebrate assemblages, continued in 2016. Assessments follow protocols developed by the New York State Stream Biomonitoring Unit. Of the 13 Croton System sites assessed in 2016, six were considered moderately impaired, six were slightly impaired, and one was non-impaired. The high percentage of impaired sites is typical of the Croton System. Of the 14 sites assessed in the Catskill System in 2016, four were considered slightly impaired and 10 sites ranked as non-impaired. Of the 15 Delaware System sites assessed in 2016, five were slightly impaired and 10 sites ranked as non-impaired.

Surveillance monitoring for metals; a large number of semivolatile and volatile organic compounds; and the herbicide Glyphosate continued at several keypoint locations throughout the water supply system. Most metal sample results were well below state and federal benchmarks.

Exceedances of benchmark values occurred for iron, aluminum, and manganese. While they may potentially cause aesthetic concerns (e.g., taste, staining), they were not at levels considered to be a risk to health and occurred well upstream of the NYC distribution system. There were no detections of the monitored semivolatile or volatile compounds or Glyphosate in 2016.

Monitoring for Diesel Range Organics (DRO) at the Pepacton Reservoir effluent (PRR2CM) continued in 2016 as follow-up to the 2012 remediation of an oil tank from the bottom of the reservoir near the intake. Collection of 12 monthly keypoint samples for DRO analysis yielded no detections for DRO. Weekly visual inspections from the East Delaware Intake Chamber did not identify the presence of a hydrocarbon-like sheen. Consequently, the investigation was completed and monthly DRO monitoring at the Pepacton Reservoir effluent keypoint ceased after December 2016. Visual inspections will continue during 2017 monthly Pepacton Reservoir surveys (April – November). Additional DRO monitoring occurred at the Schoharie Tunnel Outlet keypoint (SRR2CM) in response to an incident in December 2016 when a tugboat working on the Gilboa Dam project capsized in the Schoharie Reservoir. DRO results indicated that booms deployed on the reservoir and at the tunnel intake had successfully contained the petroleum product.

In 2016, there were six special investigations outside of the Kensico basin. There were two separate investigations of potential leaks from the Catskill Aqueduct, with one in Yonkers in May and a second in Garrison in August. The leak in Yonkers was not from the Catskill Aqueduct, while the leak in Garrison was likely from the aqueduct based on an evaluation of water chemistry. Further investigations of the leak in Garrison will be conducted when operations allow.

Monitoring for algal toxins continued in 2016, with samples submitted for a comprehensive suite of algal toxins. In 2016, algal toxins were not detected at keypoint sites. However, algal toxins were detected in six reservoirs. Microcystin was present at levels barely above the detection limit in New Croton and Boyd’s Corners reservoirs and elevated levels were found in surface samples from blooms in remote areas of Croton Falls and Cannonsville reservoirs. Anatoxin-a was detected at low levels in East Branch and Diverting reservoirs.

Another special investigation into water quality impacts conducted at the Peekamoose Blue Hole area of the upper Rondout Creek in 2016 included several physical, chemical, and biological parameters. DEP conducted weekly plus holiday weekend monitoring at two sites directly above and below the Blue Hole area to determine if the activities of recreational visitors affected water quality. Sampling results indicated there were no exceedances of NYSDEC or DEP water quality standards.

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 every 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 was high (4.3 NTU), and this occurred on June 25 when biofilm was observed in the sample line. All samples were below the SWTR turbidity limit, and none of the fecal coliform results exceeded the 20 fecal coliform $100mL^{-1}$ threshold in 2016. 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 they were intact. Overall, water quality from Kensico continued to be excellent during 2016.

In addition to DEP's routine monitoring, four special investigations were conducted in the Kensico watershed and video monitoring for Bryozoans continued at the Delaware Shaft 18 sluice gates. The four special investigations were in response to storm events monitored in the Malcom Brook and Stream N5-1 watersheds. For each of the storm events, there were temporary increases in turbidity and fecal coliforms at the stream sites, but there were no turbidity or fecal coliform issues at DEL18DT. Microbial source tracking (MST) with Bacteroidales was submitted for analysis with each of the four storm events. For N5-1, there were detects for human markers at trace levels for each of the storm events, while there were no detections of human markers for MB-1. The 2016 Bryozoan inspections showed similar growth patterns to the previous two years. Operational changes were made again in midsummer and resulted in decreased colonies at the sluice gate where flow had been shut down. Monitoring will continue during 2017 and a summary report of findings will be produced by the end of 2017.

Chapter 5 Pathogen Monitoring and Research

DEP collected 582 samples for protozoan analysis and 48 samples for human enteric virus (HEV) monitoring in 2016. Most samples were collected at source water keypoint locations and watershed streams. Additional samples were collected at Hillview Reservoir, upstate reservoir effluents, and wastewater treatment plants (WWTPs). As a reminder, on April 6, 2015, DEP changed methods for protozoan analysis from Method 1623 to Method 1623.1 with EasyStain to improve *Cryptosporidium* recovery as well as the ability to genotype samples after slide processing, making 2016 the first full year of the new method. In many cases, this method change has been coincident with a shift in data that suggests an increased detection of *Cryptosporidium* oocysts and, at times, a decreased detection of *Giardia* cysts. These fluctuations may be a result of the method change and not a variation of prevalence in the environment. Additional data with the new method will be needed to confirm the method change as a cause of the potential shift in the data.

For the two-year period from January 1, 2015, to December 31, 2016, DEP source water results continued to be below the Long Term 2 Enhanced Surface Water Treatment Rule (LT2) *Cryptosporidium* threshold for additional treatment at both the filtered and unfiltered water supplies. The Catskill/Delaware system was below the LT2 unfiltered water supply threshold (0.010 oocysts L^{-1}), with a mean of 0.0028 oocysts L^{-1} at the Delaware outflow. This happens to be the same LT2 value as that calculated for the 2014-2015 period. Although only 19 months were sampled at 1CR21 during this two-year period due to the Croton System being off-line, a value was calculated and the Croton System result was below the filtered system bin threshold (0.075 oocysts L^{-1}) with a mean of 0.0541 oocysts L^{-1}. This result is higher than all of the historical values and was mostly driven by one result of 241 oocysts detected in December.

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 two samples positive for *Giardia* cysts at WWTPs this year, and two positive for *Cryptosporidium* oocysts as well. As per the Hillview Administrative Order, DEP continued weekly protozoan monitoring at the Hillview Reservoir outflow (Site 3) through 2016, with 53 routine samples collected (one resample), and many more collected for method studies. Of the 53, there were 6 samples positive for *Giardia* and 4 samples positive for *Cryptosporidium*, possibly related to method changes.

Chapter 6 Water Quality Modeling

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; and 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.

In 2016, the major activities of the Water Quality Modeling Program included the following: (i) application of the Operations Support Tool (OST) and the Rondout Reservoir Position Analysis (RondoutPA) models to provide guidance to DEP regarding the operation of the water supply system in response to events or episodes of elevated turbidity; (ii) development of a stochastic weather generator (SWG) for the City's West of Hudson (WOH) watersheds; (iii) application of the multi-tiered models, the Generalized Watershed Loading Function (GWLF), to predict future streamflows; (iv) testing and application of the Soil and Water Assessment Tool (SWAT) to the Town Brook (Cannonsville Reservoir basin); (v) a preliminary setup of the Regional Hydro-Ecologic Simulation System (RHESSys) model to two watersheds (Biscuit Brook and Shelter Creek) in the watershed of Neversink Reservoir; and (vi) development and testing of a turbidity model based on CE-QUAL-W2 for Neversink Reservoir. A detailed description of these activities and other accomplishments is provided in a FAD-deliverable report titled "Multi-Tiered Water Quality Modeling Program, Annual Status Report" (completed March 2017).

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 Directorate and to remain aware of the most recent developments in the water supply industry. In 2016, the WQD managed several water quality-related contracts to enhance its ability to monitor and model the watershed. These included eight different contract types, such as those for laboratory analyses, hydrological monitoring by United States Geological Survey (USGS), modeling support through CUNY-RF, waterfowl management, zebra mussel monitoring, bathymetric surveys by USGS, WISKI Software Support, and *Cryptosporidium* infectivity analyses. DEP participated in nine WRF projects as both project advisory committee members and as participating utilities. WQSR 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 ten water utilities across the nation with interest in planning for climate change. In addition, DEP participated in the international 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 six GLEON projects: an exploration of temperature changes related to global weather patterns; an examination of salt and iron concentration trends over several decades; the **LA**ke multi-scaled **G**e**OS**patial and temporal database (LAGOS); a survey of ecological threats; an analysis of the relationship between oxygen and chlorophyll, and investigate long-term oxygen profile trends. These projects allow DEP to see source water quality in a global context and provide insight that may be used 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 2016, and compliance with regulatory standards. It also provides an overview of operations and the use of water quality models for management of the water supply. It is complementary to the New York City 2016 Drinking Water Supply and Quality Report (http://www.nyc.gov/html/dep/pdf/wsstate16.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 on the DEP website at http://www.nyc.gov/html/dep/html/home/home.shtml .

The New York City Water Supply System (Figure 1.1) provides drinking water to almost half the state's population, which includes over 8.5 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 deliver a sufficient quantity of high

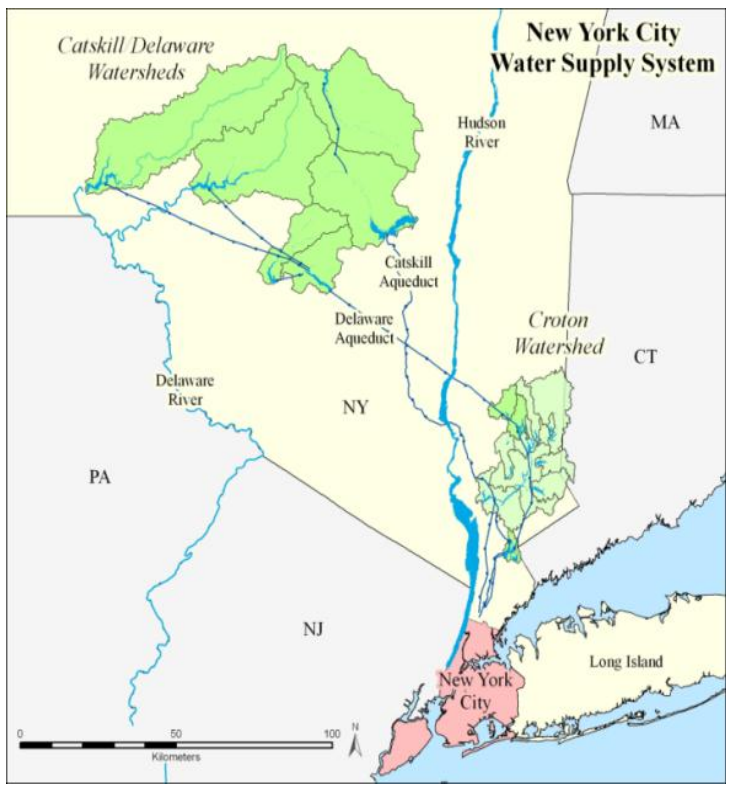


Figure 1.1 The New York City Water Supply System.

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 water quality data collection (by grab samples and by early warning and robotic monitoring equipment), data display and analysis, modeling runs, and operational responses to changing conditions. Monitoring of the vast watershed is accomplished by Watershed Water Quality Operations based at three upstate locations in Grahamsville, Kingston, and Hawthorne, NY. The data generated by field and laboratory activities are presented here to provide an overview of watershed water quality in 2016 and to show how high quality source water is reliably maintained through constant vigilance. DEP supplements the work of the Water Quality Directorate through contracts and interactions with other organizations as discussed in Chapter 7 Further Research.

1.1.1. Grab Sample Monitoring

Water quality of the reservoirs, streams, and aqueduct keypoints is monitored throughout the watershed for several purposes. Results are used to demonstrate regulatory compliance, to guide operations to provide the highest quality drinking water to the City, to demonstrate the effectiveness of watershed protection measures, and to provide data for modeling applications. Sampling is specified in the Watershed Water Quality Monitoring Plan (WWQMP; DEP 2016a). 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 carefully tailored to meet DEP's needs.

A summary of the number of grab samples and analyses that were processed in 2016 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 (WWTPs), and keypoints (i.e., water supply intakes and aqueduct sites) as described in the 2016 WWQMP. Samples taken as the result of special investigations (SIs) 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.) The number of analyses conducted by DEP's watershed laboratories increased (by about 39,000) in 2016 due to an increase in requests for free residential lead test kits by drinking water customers in the City. Analyses of the free residential lead test kits were performed at the DEP Kingston Laboratory.

In addition to grab sampling, a great deal of data is generated by continuous monitoring equipment at keypoints on the aqueducts, and by dataloggers at stream sites. Robotic monitoring is deployed at reservoirs as described below.

Table 1.1 Summary of grab samples collected, water quality analyses performed, and sites visited by WQD in 2016.

System	Number of Samples	Number of Analyses	Number of Sites
Watershed	15,200	231,700	461
Distribution	36,300	407,500	~1,000
Total	51,500	639,200	1,460

1.1.2. Robotic Monitoring (RoboMon) Network

DEP's RoboMon network provides near real-time (NRT) data that are essential for water quality modeling and for guiding water supply operations. The data are of particular importance when conditions are changing rapidly and operational responses may be required. In addition to surveillance, these data are used by water supply modelers to run computational tools such as the Operational Support Tool (OST), reservoir models, and terrestrial models. The data generated by the RoboMon network have proven to be invaluable for protection of the water supply, particularly during storm events, special investigations, and construction of water supply infrastructure projects that potentially affect water quality. These activities contribute to the safety and reliability of the water supply.

The Robotic Water Quality Monitoring Network (RoboMon) began in 2012 with four reservoir sites (i.e., three at Ashokan and one at Kensico). The network has continued to grow over the past four years to its current configuration of 20 sites (Figure 1.2) located in both reservoirs and streams. There has also been enhancement of the sites with additional sensors to obtain data essential for model development.

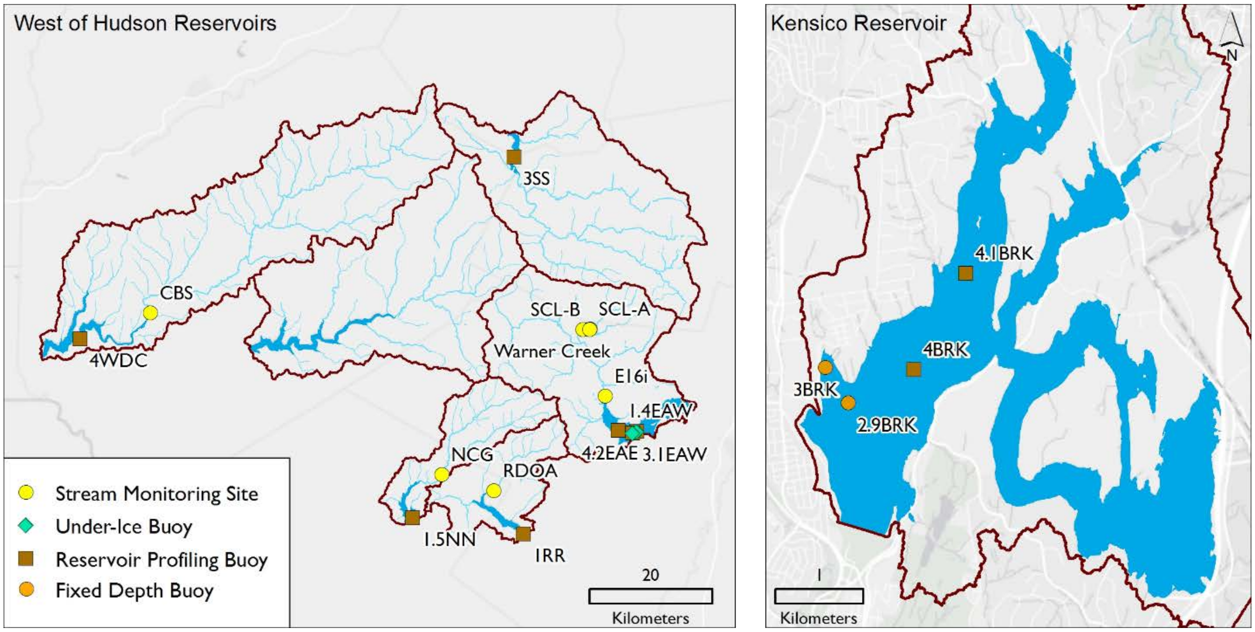


Figure 1.2 Robotic Monitoring sites and types in the Catskill and Delaware Systems in 2016.

There are three types of site installations that comprise the RoboMon network: i) profiling buoys in reservoirs, ii) fixed-depth sensors in reservoirs, including under-ice buoys, as discussed below, and iii) sensors in streams. Profiling buoys record and transmit full water column profiles for reservoir sites every six hours. These buoys are typically equipped with sensors that measure temperature, turbidity, and specific conductivity. Additionally, meteorological stations are located on the Ashokan West Basin (Site 1.4) buoy and the Kensico (Site 4.1) buoy. Fixed-depth buoys record turbidity and have transmissometers or turbidity sensors which are suspended in the water column at specific depths (e.g., 5, 10, and 15 meters) to provide near-real-time data that are recorded in 15-minute intervals. Stream sensors typically record temperature and turbidity at 15-minute intervals.

Each site is designed to contribute data for specific objectives. In an effort to develop reservoir carbon budgets to ultimately improve DEP's understanding of disinfection by-product formation potential (DBPFP), probes for chlorophyll, phycocyanin (a blue-green algae pigment), dissolved oxygen, and fluorescent dissolved organic matter (fDOM) were added at Cannonsville and Neversink Reservoir buoys in 2015.

To monitor water quality conditions during times of ice-over, two under-ice buoys were deployed on Ashokan Reservoir in the winter of 2015 and 2016. These consisted of fixed depth buoys located in front of the East and West Basin gatehouses with turbidity sensors positioned at two depths, approximate elevations of 555 feet and 515 feet.

Recent refinements include the replacement of transmissometers in 2015 on one of the fixed-depth buoys at Kensico Reservoir (site 2.9BRK) with Forest Technology Systems (FTS) turbidity sensors to provide a better estimate of turbidity with less maintenance and calibration effort. In 2016, further refinements to the buoy network were made by deploying a profiling buoy at Schoharie Reservoir (Site 1.5SS) to monitor seiche activity in this reservoir.

Operation of the network is not without its challenges. Due to near-drought conditions in 2016, the storage level of the Schoharie Reservoir dropped to 7.5% of capacity. Both of the profiling buoys deployed at Schoharie became stranded in the reservoir until partial refill. While the Site 3 (near intake) buoy sustained damage, the Site 1.5 (mid-basin) buoy was retrieved unscathed except for some lost data.

In addition to the reservoir buoy network, there are seven automated stream monitoring stations (RoboHuts) operated and maintained year-round. Two RoboHuts located at Esopus Creek near Coldbrook and at Rondout Creek near Lowes Corners monitor water temperature, specific conductivity, and turbidity at 15-minute intervals and have been in operation since 2012. Five additional stream monitoring stations—one on the Neversink River (installed in 2014), one on the West Branch Delaware River (developed in 2011), and three in the Stony Clove/Warner Creek watershed (deployed in 2011)—continuously monitor for turbidity and temperature only.

In 2016, the Rondout Creek multiparameter YSI sonde was removed and replaced with a FTS turbidity sensor to reduce labor and maintenance costs. As a result of this sensor change, specific conductivity was discontinued because the FTS sensor only measures turbidity and temperature. Preparations are underway for a similar replacement at the Esopus Creek site. Specific conductivity was not required from these RoboMon sites to meet the data objectives for this specific program. The three RoboMon storm event sites at Stony Clove and Warner Creek watersheds were dismantled in July (as the project had ended), and one of two new monitoring sites were established in the Schoharie watershed near Red Falls on the Batavia Kill. Preparations were made to add fluorescent dissolved organic matter (fDOM) sensors to the West Branch Delaware River and the Neversink River multiparameter sondes as part of a DBPFP special investigation study.

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 made viewable on the DEP intranet through a custom Web application. In some cases, near-real-time data are available within three minutes of the field measurement being taken. A standard operating procedure was developed for the program’s data management and quality control procedures. The Robotic Monitoring program yielded approximately 1.5 million measurements in 2016 at 20 sites (Table 1.2).

Table 1.2 Summary of Robotic Monitoring measurements in 2016.

System/Field Section	Number of Measurements	Number of Sites
Catskill/Kingston	456,480	10
Delaware/Grahamsville	651,080	6
EOH/Hawthorne	369,040	4
Total	1,476,600	20

1.1.3. Early Warning Remote Monitoring (EWRM)

Aqueduct "keypoint" monitoring is conducted as a means of keeping a "finger on the pulse" of the water supply with respect to the major water flowing through the system and into distribution. Monitoring at these sites is conducted through the use of daily or weekly grab sampling (noted previously) and continuous automated monitoring equipment. The automated equipment at these keypoint sites are operated and maintained by the Early Warning Remote Monitoring (EWRM) group. The automated monitoring that is conducted is specific to each site (Table 1.3). These sites have some of the highest frequencies of sampling conducted by DEP, the purpose of which is to maintain a high degree of reliability in the quality of water entering the distribution system. In addition to sites used for operational decisions, keypoint monitoring includes compliance sites for the Surface Water Treatment Rule (SWTR) and are of utmost importance for operation of the system to maintain the status of filtration avoidance.

Data from DEL18DT and DEL19LAB sites are required for daily inactivation ratio (IAR) compliance reporting. DELSFBLAB is used as an alternate site for DEL19LAB site. Chlorine monitoring is conducted in compliance with EPA Method 334. CROGH data are of utmost importance to process control at the Croton Filtration plant.

In addition to the parameters outlined in Table 1.3, Intelligent Automated Biological Systems (iABS) using fish are installed at DEL18DT and CROGH sites for rapid detection of water quality changes and contamination events. The purchase of a new fish biological monitoring system, the ToxProtect 64 is currently in progress. The new system is anticipated to reduce the number of false alarms and maintenance expenditures.

In 2016, Watershed Water Quality Operations (WWQO) began expanding the EWRM program to include three sites at the newly constructed Cat/Del Interconnect at Shaft 4 (CDIS4). Analytes include temperature, pH, specific conductivity (SpCond), turbidity (Turb), and chlorine residual.

In 2017, we anticipate finalizing the site work begun at CDIS4. We also plan to add continuous monitoring of turbidity to Rondout's four elevation taps. Finally we will install new

S::CAN spectrolyser analyzer capability at two sites (WDTOCM and NRR2CM) in association with a DBP study underway.

Table 1.3 Site List for Watershed Water Quality Operations (WWQO) Early Warning Remote Monitoring (EWRM).

Site	Location	System	Water Type	Parameters
SRR1CM	Schoharie Intake Chamber	Catskill	Raw	Turb, pH, Temp, SpCond
SRR2CM	Shandaken Tunnel Outlet	Catskill	Raw	Turb, pH, Temp, SpCond
EARCM	Catskill Aqueduct	Catskill	Raw	Turb, pH, Temp, SpCond,
M-1	Ashokan Release Channel	Catskill	Raw	Turb
AEAP	Esopus Creek Upstream STO	Catskill	Raw	Turb
RDRRCM	Delaware Aqueduct (REC)	Delaware	Raw	Turb, pH, Temp, SpCond
NNR2CM	Neversink Tunnel Outlet	Delaware	Raw	Turb, pH, Temp, SpCond
PRR2CM	East Delaware Tunnel Outlet	Delaware	Raw	Turb, pH, Temp, SpCond
WDTOCM	West Delaware Tunnel Outlet	Delaware	Raw	Turb, pH, Temp, SpCond
RR1 - RR4	Active Elevation Taps All taps	Delaware Delaware	Raw Raw	Turb, pH, Temp, SpCond Temp, Turb
CDIS4-DEL	Cat/Del Interconnect at Shaft 4 (Catskill)	Catskill	Raw	Turb, pH, Temp,
CDIS4-CAT	Cat/Del Interconnect at Shaft 4 (Delaware)	Delaware	Raw	Turb, pH, Temp,
CDIS4-Combined	Cat/Del Interconnect at Shaft 4 (Catskill)	Catskill	Raw	Turb, pH, Temp, SpCond,
CWB1.5	Croton West Branch Reservoir	Delaware	Raw	Pump
DEL9	Delaware Shaft 9	Delaware	Raw	Turb, pH, Temp, SpCond, TCR, Dechlor, DO
DEL10	Delaware Shaft 10	Delaware	Raw	Turb, pH, Temp, SpCond, Elev

Table 1.3 Site List for Watershed Water Quality Operations (WWQO) Early Warning Remote Monitoring (EWRM).

Site	Location	System	Water Type	Parameters
DEL17	Delaware Shaft 17	Delaware	Raw	Turb, pH, Temp, SpCond, TCR, Dechlor, DO
DEL18DT	Delaware Shaft 18 Downtake	Cat/Del	Raw	Turb, pH, Temp, SpCond, Flow, Elev
DEL19	Delaware Shaft 19	Cat/Del	Pre-Treated	Turb, pH, Temp, SpCond, FCR, F
DEL19LAB	Delaware Shaft 19 Lab	Cat/Del	Pre-Treated	Turb, pH, Temp, SpCond, FCR, F
DELSFB	Delaware South Forebay	Cat/Del	Pre-Treated	Turb, pH, Temp, SpCond, FCR, F
DELSFBLAB	Delaware South Forebay Lab	Cat/Del	Pre-Treated	Turb, pH, Temp, SpCond, FCR, F
CCC	Catskill Connection Chamber	Cat/Del	Pre-Treated	Turb, pH, Temp, SpCond, FCR, F
CCCLAB	Catskill Connection Chamber Lab	Cat/Del	Pre-Treated	Turb, pH, Temp, SpCond, FCR, F
CROFALLSVC	Croton Falls Valve Chamber	Croton	Raw	Turb
CROSSRVVC	Cross River Valve Chamber	Croton	Raw	Turb
CATALUM	Catskill Alum Plant	Catskill	Raw	Turb
CATIC	Catskill Influent Chamber	Catskill	Raw	pH, Temp
CROGH	CLGH Raw Water	Croton	Raw	Turb, pH, Temp, SpCond
Catskill_Flow_Total	CDUV Catskill Flow	Cat/Del	Pre-Treated	Flow
CDUV_TOTAL_FLOW	CDUV Total Flow	Cat/Del	Pre-Treated	Flow
Del_Aqueduct_Total	CDUV Delaware Total Flow	Cat/Del	Pre-Treated	Flow

1.2. Operations in 2016 to Control Turbidity and Fecal Coliforms

In the Catskill System, the elevation and location (i.e., East and/or West Basin) of withdrawal at Ashokan Reservoir was adjusted throughout the year 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 create a void to accept more runoff during large storm events). The Catskill System started off the year diverting water from the mid-depths of the East Basin. Since water quality in the West Basin was very good, a switch to the West Basin was made in early January and stayed in this configuration until March. In late February, the Ashokan watershed experienced a significant storm event (>3inches precipitation) on top of snow. This resulted in substantial stream runoff flowing into the reservoir's West Basin. The turbidity-laden inflow prompted a switch in the draft over to the East Basin in March. By early June, however, good water quality was again available in the West Basin, and a switch was made back to that basin. In early August, water was withdrawn from both East and West Basins to offset declining water quality in the West Basin. The elevation of the withdrawal point on the East Basin was adjusted to take water lower in the water column where the best quality could be found. In October, a change was made back to an East Basin only draw, and the elevation of withdrawal was raised back to mid-depths. The diversion from the East Basin continued until the end of the year.

In the Delaware System, water quality was very good throughout the year and no operational changes were needed to deliver the best quality water to the distribution system. The chambers at all Delaware System reservoirs were configured for diversion through the mid- or lower-level intakes, and no elevation changes were needed at any of the reservoirs in 2016.

At Kensico Reservoir, when weather forecasts predict sustained easterly or northeasterly winds in excess of 15 mph, the operating mode at Delaware Aqueduct Shaft 18 is often changed from "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 downtake at Delaware Aqueduct Shaft 18. Since float mode at Kensico Reservoir cannot fully meet demand, water from Rondout Reservoir is supplemented by water drawn from Kensico Reservoir as needed, but in much lesser amounts than would occur during "reservoir mode" operation. This proactive measure minimizes turbidity that would otherwise enter the distribution system. Float operation in anticipation of strong winds occurred five times for all or part of 16 days in 2016.

The Croton Water Filtration Plant operated for the most of the year producing 21 to 236 million gallons per day (MGD), but was off-line from August 25 to October 20 for two reasons. First, there was ample and higher quality water available in the Catskill/Delaware System. Secondly, DEP wanted to shut down the filtration plant to modify chemical piping in the plant's chlorine system and to rework some of its electrical systems.

2. Water Quantity

2.1. Introduction

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. 2016 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 2016 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 below normal to somewhat below normal for the first six months of 2016, except for February, which was above normal for all watersheds. July had above average precipitation in all watersheds, but only slightly above in the Croton watershed, while Ashokan received 4.5 inches (114.3 mm) of rain on July 8. August was mixed with some watersheds receiving slightly greater than average precipitation, e.g., Cannonsville, Pepacton, and Ashokan, while Rondout and Schoharie were somewhat below normal, and Croton was well below normal. During September and October, precipitation was below historical averages in all basins except Cannonsville, which was near normal. In particular, Neversink, Rondout, Ashokan, Schoharie, and Croton were far below normal in September. November precipitation values were mixed and all watersheds were somewhat below normal in December. However, rain during the last week of November and first week of December provided enough runoff to begin to refill the reservoirs. Overall, the total precipitation across the watershed for 2016 was 35.8 inches (910 mm), which was 9.3 inches (236 mm) below normal (1991-2015).

The National Climatic Data Center's (NCDC) climatological rankings (http://www.ncdc.noaa.gov/temp-and-precip/climatological-rankings/) were queried to determine the 2016 rankings for New York. Overall total precipitation for New York State was 2.12 inches (53.85 mm) below normal in 2016 (32nd driest in the last 122 years). However in Climate Division 5, which includes the EOH reservoirs, precipitation was 6.27 inches (159.26 mm) below normal, while in Climate Division 2, which includes the WOH reservoirs, precipitation was 2.6 inches (66.04 mm) below normal. Also, the average temperature for 2016 was 3.2°F (1.8°C) above normal (3rd warmest in the last 122 years) for New York.

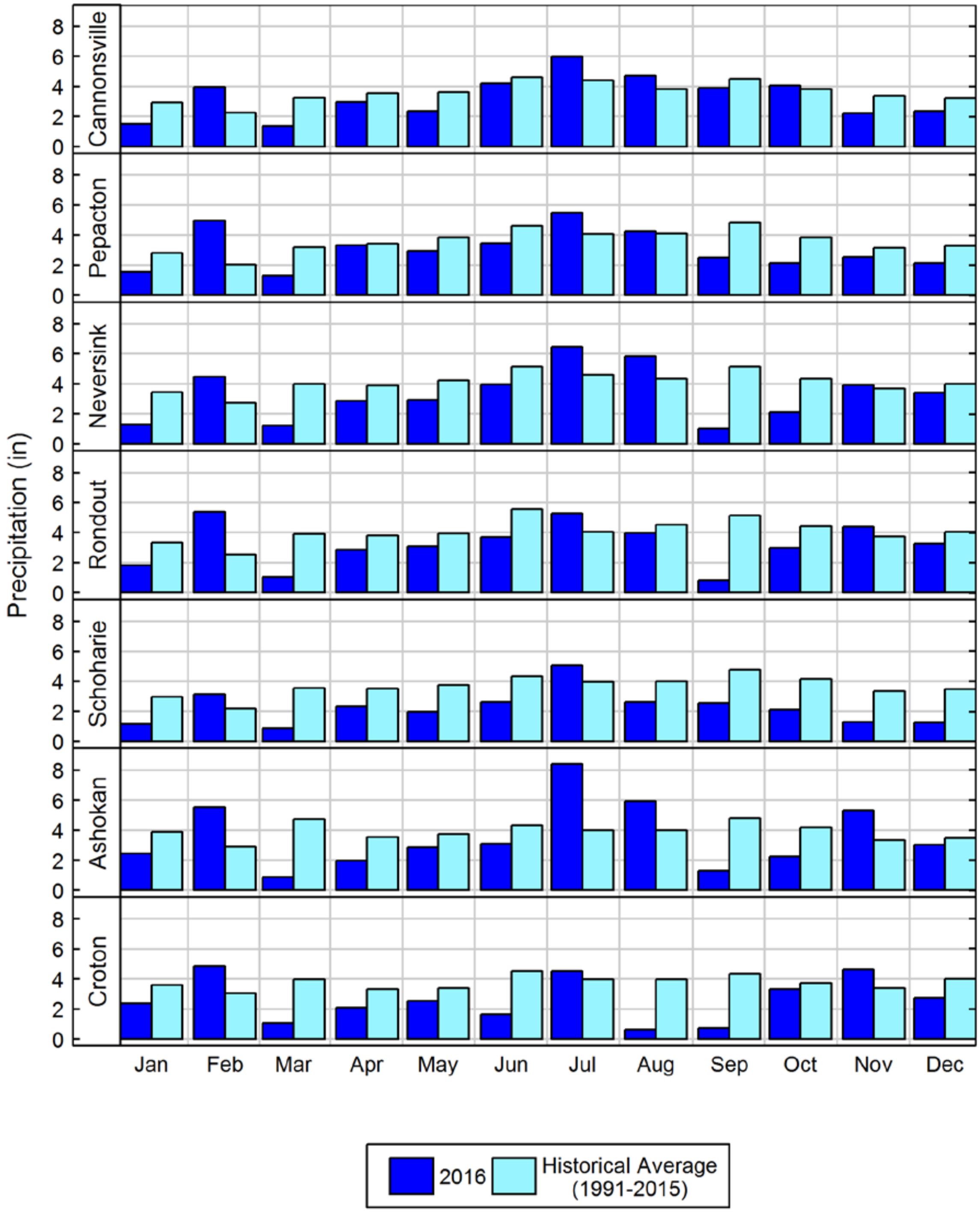


Figure 2.1 Monthly precipitation totals for New York City watersheds, 2016 and historical values.

2.3. 2016 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 a watershed can be affected by meteorological factors such as type of precipitation (rain, snow, and 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 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 53 years at the Esopus Creek Allaben station to 110 years at the Schoharie Creek Prattsville gage. The EOH stations have a 21-year period of record, except for the Wappinger Creek site (88-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 2016 was below normal for all sites, both EOH and WOH, ranging from the lowest on record at Muscoot River at Baldwin Place and the East Branch Croton River near Putnam Lake, and second lowest at Rondout Creek near Lowes Corners (79-year period of record) and Schoharie Creek at Prattsville (110-year period of record). It was the lowest annual runoff in the last twenty years at six of the sites, second lowest at four sites, and the third lowest at one site. Overall, the state had well below normal runoff (100th lowest out of the last 116 years) for the 2016 water year (October 1, 2015-September 30, 2016), as determined by the USGS (http://waterwatch.usgs.gov/index.php?r=ny&m=statesum).

Figure 2.3 shows the 2016 mean daily discharge, along with the minimum, maximum, and median daily discharge for the period of record, for the same USGS stations used to characterize annual runoff. In most cases, mean daily flows were somewhat below normal from March through most of the year with occasional spikes from storms. Flows in the fall were well below normal, even reaching the minimum mean daily flows recorded for some of the EOH sites. At most sites, flows rebounded to near normal at year’s end.

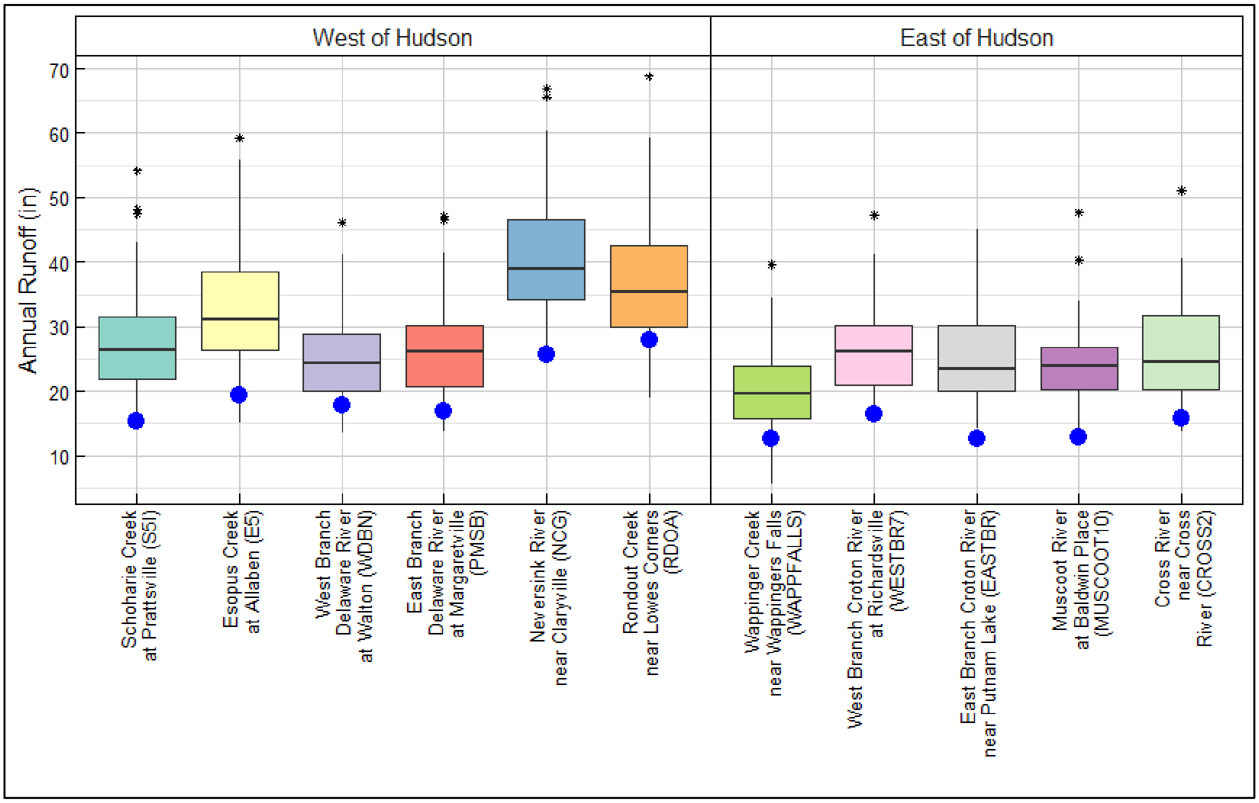


Figure 2.2 Historical annual runoff as boxplots for the WOH and EOH watersheds, with the values for 2016 displayed as a solid blue dot. The asterisks indicate outliers (see Appendix B for a key to the boxplot).

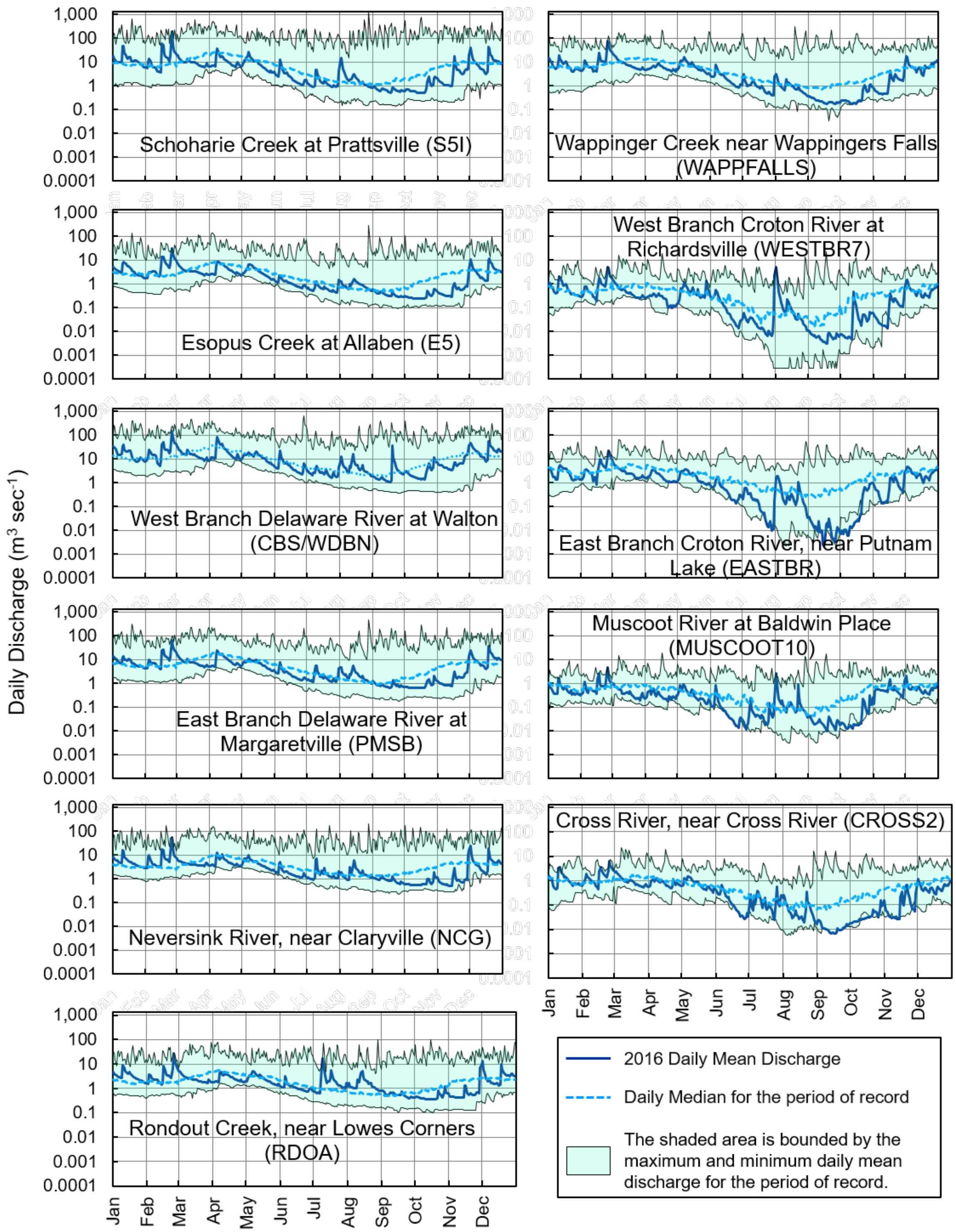


Figure 2.3 Daily mean discharge for 2016 at selected USGS stations. Daily data from October 1-December 31, 2016 are provisional and subject to revision until they have received final approval from the USGS.

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 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, evaluate 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, 10-year, and 100-year, 24-hour events, and the 90% 24-hour rainfall event (Figure 2.4 through Figure 2.7). The one-year, 24-hour storm gives the rainfall depth with a 24-hour duration that statistically has a 100% chance of being equaled or exceeded in any given year. The ten-year, 24-hour storm specifies the rainfall depth with a 24-hour duration that statistically has a 10% chance of being equaled or exceeded in any given year. The 100-year, 24-hour storm is the rainfall depth with a 24-hour duration that statistically has a 1% chance of being equaled or exceeded in any given year. The 90% storm indicates the rainfall depth that is equaled or exceeded during 90% of all events of 24-hour duration. Figure 2.4 through Figure 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.

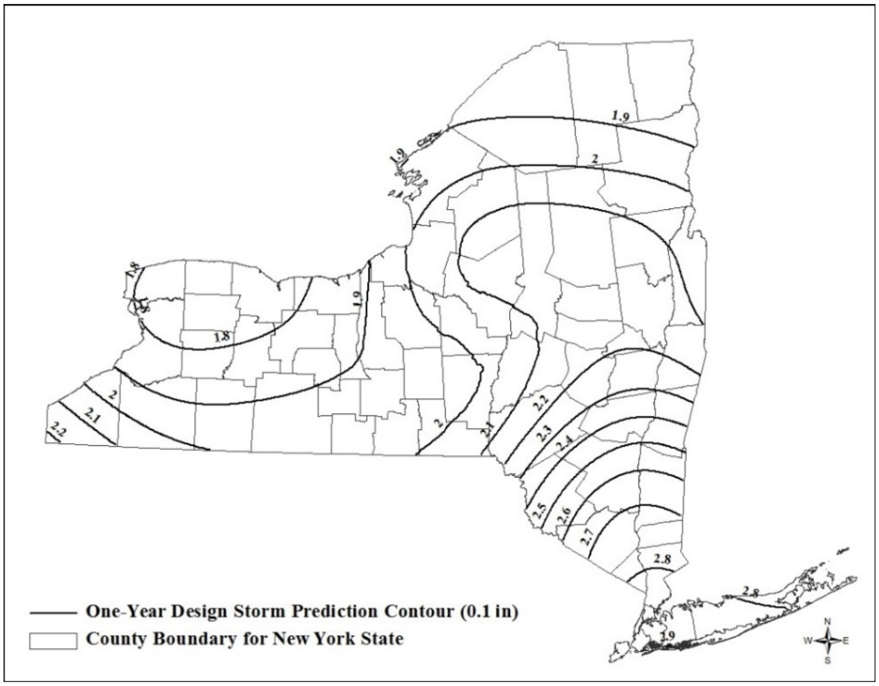


Figure 2.4 The one-year, 24-hour design storm in New York State, from the 2015 Stormwater Management Design Manual.

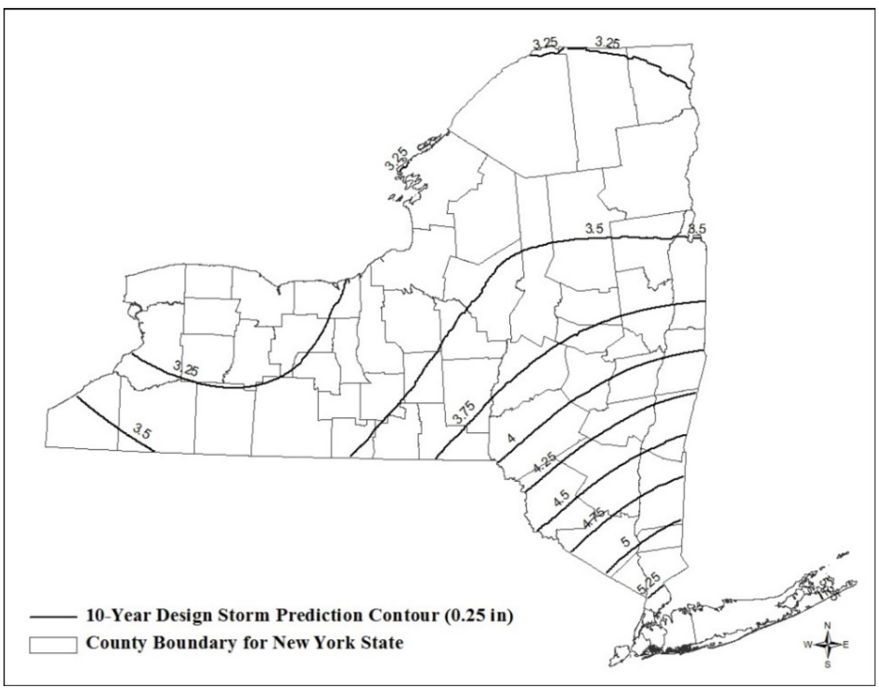


Figure 2.5 The 10-year, 24-hour design storm for New York State, from the 2015 Stormwater Management Design Manual.

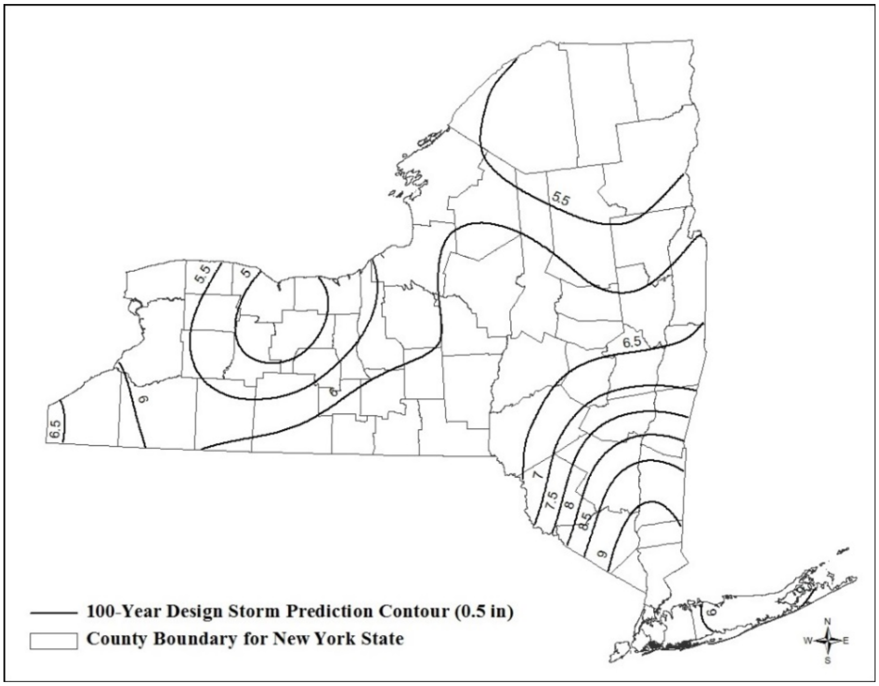


Figure 2.6 The 100-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual.

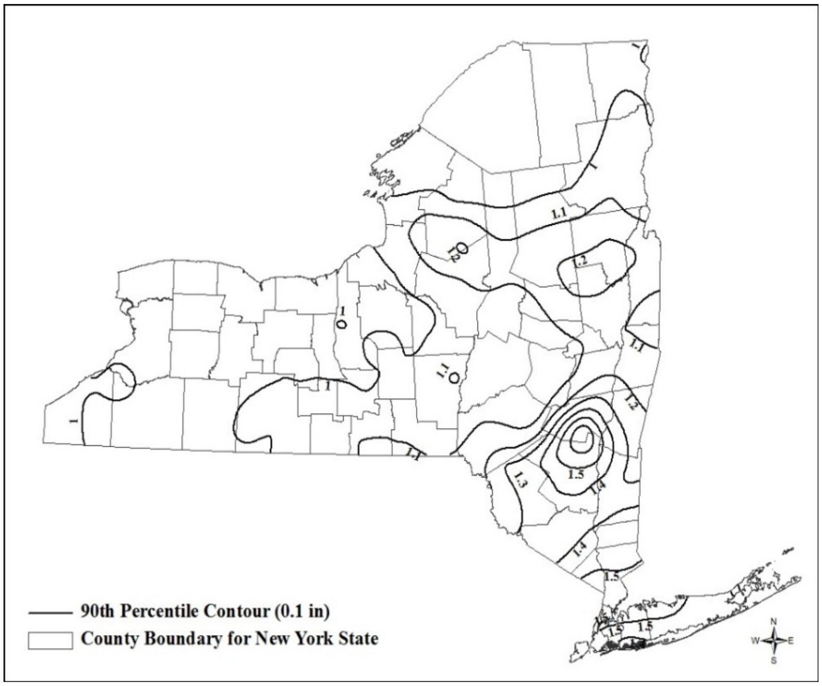


Figure 2.7 90^{th} percentile, 24-hour rainfall for New York State, from the 2015 Stormwater Management Design Manual.

2.5. Reservoir Usable Storage Capacity in 2016

Ongoing daily monitoring of reservoir storage allows DEP to compare the systemwide storage in 2016 (including Kensico Reservoir) against average historical values for 1991-2015 for any given day of the year (Figure 2.8). Numerous widespread small rain events in December 2015 allowed system capacity to exceed normal levels early in 2016. Wet weather in February culminating in a large widespread runoff event in late February pushed levels to 96% capacity in early March. Numerous small rain events in early April and May caused system capacity to mostly exceed the historical average levels though the end of May 2016. Typical declines in storage were then observed through the end of August. Unusually dry conditions prevailed for the rest of the year resulting in storage capacities 16 to 18% lower than the historical average in November and December.

It should be noted that the decline in the combined storage of Cannonsville, Pepacton, and Neversink reservoirs led the Delaware River Basin Commission (DRBC) to declare a drought watch for the entire Delaware River basin on November 23. The drought watch was lifted January 18, 2017, as the reservoir storage levels increased, although not to historical average levels.

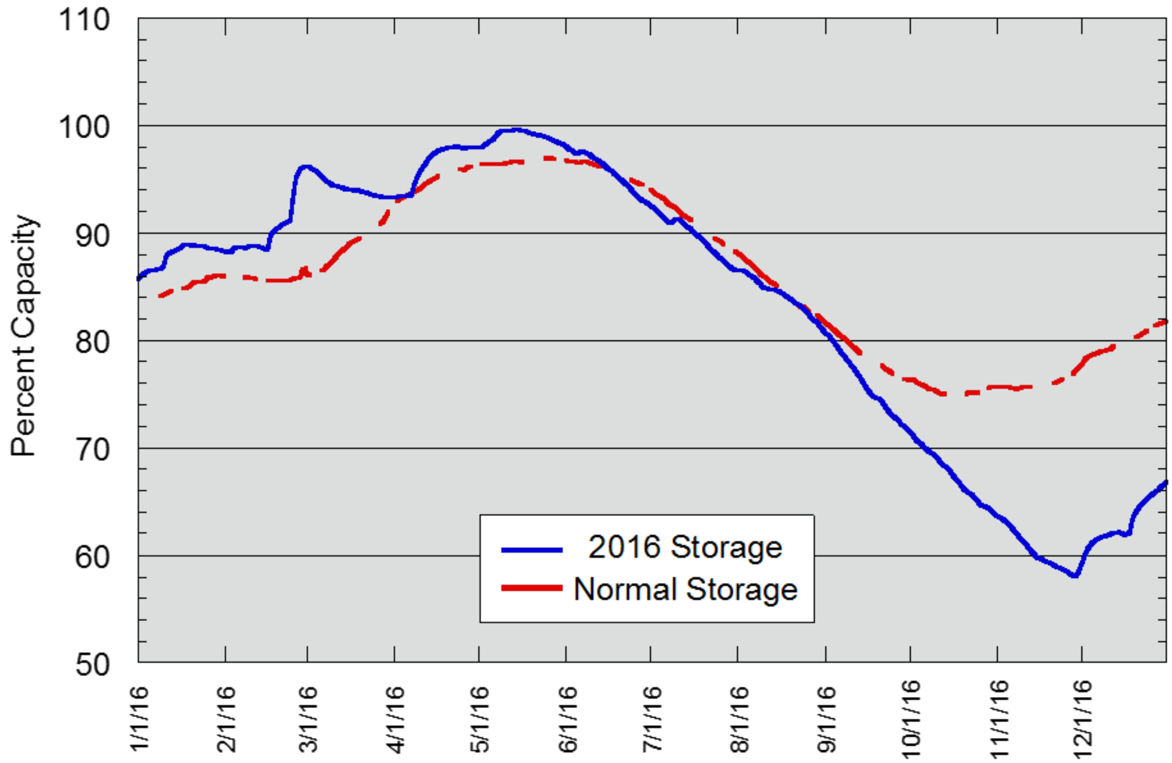


Figure 2.8 Systemwide usable storage in 2016 compared to the average historical value (1991-2015.) Storage greater than 100% occurs when the water surface elevation is greater than the spillway elevation, so that reservoirs are spilling.

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 with routine sampling frequencies of 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 bypassed 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 2016

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.

Similar to the previous year, 2016 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 low turbidity levels coincide with low rainfall amounts observed throughout all of the NYC water supply watersheds in 2016 (Figure 2.1). Annual rainfall sums were down 9-39% compared to historic totals in the Catskill/Delaware System.

Since 2012, approximately 2 kilometers of stream restoration sediment and turbidity reduction projects (STRPs) have been completed in the Stony Clove Creek watershed, which may account in part for the low turbidity in 2016. Previous research found that the Stony Clove Creek watershed produced the largest suspended sediment loads of any Esopus Creek tributaries, accounting for 30 to 57 percent of the annual suspended sediment load for the period 2010-2012 (McHale and Siemion 2014). Subsequent research shows that the STRPs have been effective at reducing turbidity and suspended sediment for the range of flows between the period of STRP construction in 2012 to 2015 (Siemion et al. 2016). Note that Schoharie Reservoir was sampled only from April to August. After August, the reservoir was inaccessible due to low water conditions. To ensure a fair comparison to the 2016 data, the historic Schoharie boxplot in Figure 3.1 was constructed using data from April to August.

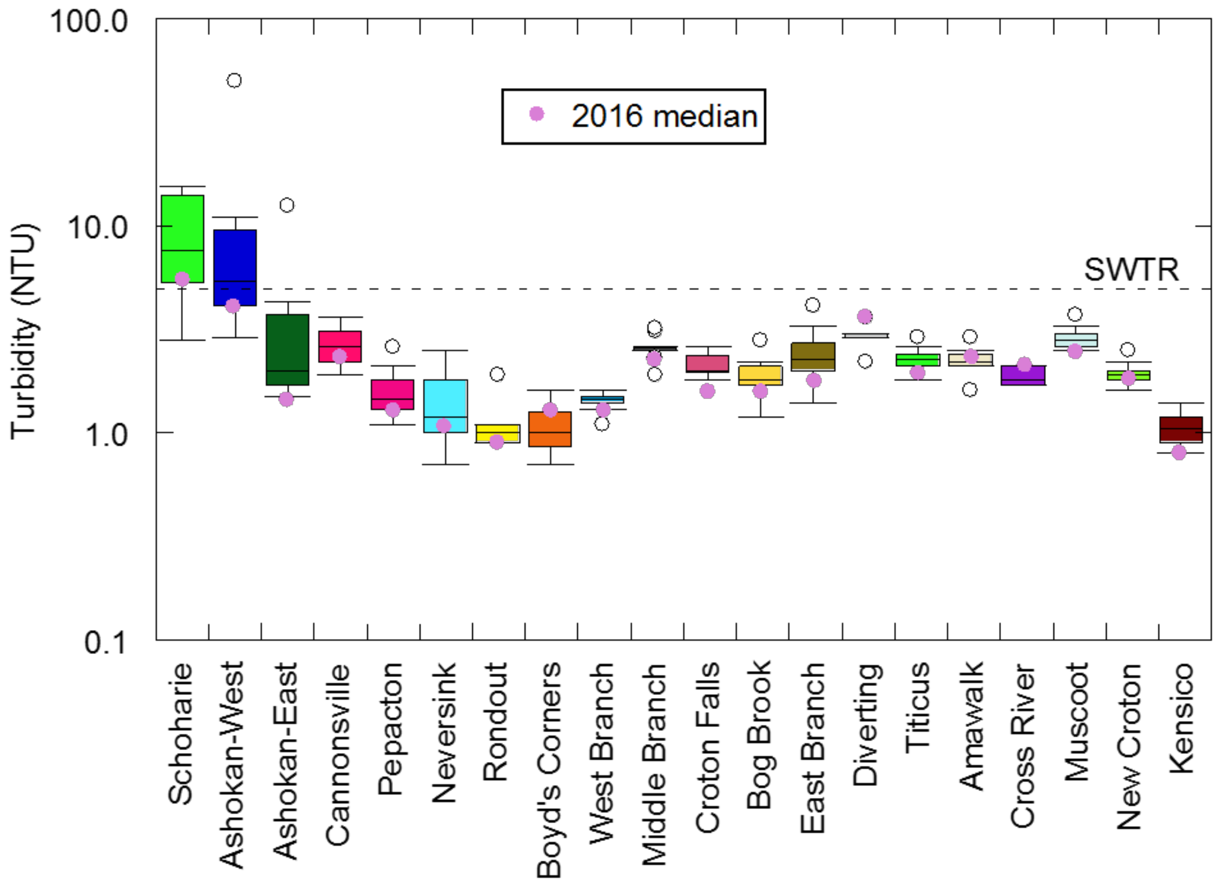


Figure 3.1 Annual median turbidity in NYC water supply reservoirs (2016 vs. 2006-2015) with the 2016 values displayed as a solid dot. The dashed line represents the standard for source waters as a reference.

West Branch Reservoir, which receives inputs from both the Delaware and Croton Systems, also had low turbidity levels in 2016. 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 1.3 NTU for West Branch in 2016. 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 low oxygen conditions in the hypolimnion of West Branch. Within Kensico Reservoir, the terminal reservoir for the Catskill and Delaware Systems, turbidity was low corresponding to the high clarity of water received from both systems in 2016.

Similar to the Catskill/Delaware Systems, turbidity in the Croton System was generally normal to well below normal in 2016 (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 2016. Annual rainfall in the region was 14.1 inches less (31% below average) than the average rainfall from the previous 25-year period with August and September being particularly dry (Figure 2.8).

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

Lake	Median Turbidity (2006-15)	Median Turbidity (2016)
Gilead	1.6	1.1
Gleneida	1.6	1.2
Kirk	4.3	4.3

3.3. Coliform-Restricted Basin Assessments in 2016

Coliform bacteria are used widely as indicators of potential pathogen contamination. To protect the City's water supply, the City's WR&R restrict potential sources of coliform bacteria 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

Coliform-restricted assessments were made for five terminal basins using 2016 fecal coliform data from a minimum of five samples each week over two consecutive six-month periods. If 10% or more of the coliform 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 below the 10% threshold and met the criteria for non-restricted basins for both six-month assessment periods in 2016 (Table 3.2).

Table 3.2 Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2016.

Reservoir basin	Effluent keypoint	2016 assessment
Kensico	DEL18DT[1]	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 corresponding alternate site used when the sample could not be collected at the primary site listed.
[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) of the WR&R 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 per month are required in each basin to be included in the assessment. 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 is designated as restricted. Table 3.3 provides a summary of the 2016 coliform-restricted calculation results for the non-terminal reservoirs. In 2016, there were few exceedances of the Part 703 standard for total coliform during the sampling season. These occurred most frequently in Diverting Reservoir (April, June, October, and November), in the summer months (June, August) in East Branch Reservoir, and in September in Croton Falls and Titicus Reservoirs. For the remaining 13 reservoirs and controlled lakes evaluated, there were no exceedances of the standards for total coliform. Appendix C includes the details for coliform monthly medians and the percentage of values exceeding the relevant standard.

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 2016. There were no other data indicating an anthropogenic source for 2016.

Table 3.3 Coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2016.

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	0
Bog Brook	AA	50/240	0/8	0
Boyd's Corners	AA	50/240	0/8	0
Croton Falls	A/AA	50/240	1/8	0
Cross River	A/AA	50/240	0/8	0
Diverting	AA	50/240	4/8	0
East Branch	AA	50/240	2/8	0
Lake Gilead	A	2400/5000	0/8	0
Lake Gleneida	AA	50/240	0/8	0
Kirk Lake	B	2400/5000	0/7	0
Muscoot	A	2400/5000	0/8	1
Middle Branch	A	2400/5000	0/8	0
Titicus	AA	50/240	1/8	0
Cannonsville	A/AA	50/240	0/8	1
Pepacton	A/AA	50/240	0/8	0
Neversink	AA	50/240	0/9	0
Schoharie	AA	50/240	0/4	0

[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 2016

Total coliform and fecal coliform bacteria are regulated by the Surface Water Treatment Rule (SWTR) at raw water intakes with regulatory levels of 100 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 while 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 based on the distribution of the annual 75th percentiles. The center line in the boxplot represents the median of the 75th percentile values rather than the 50th percentile or median of annual values. 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.

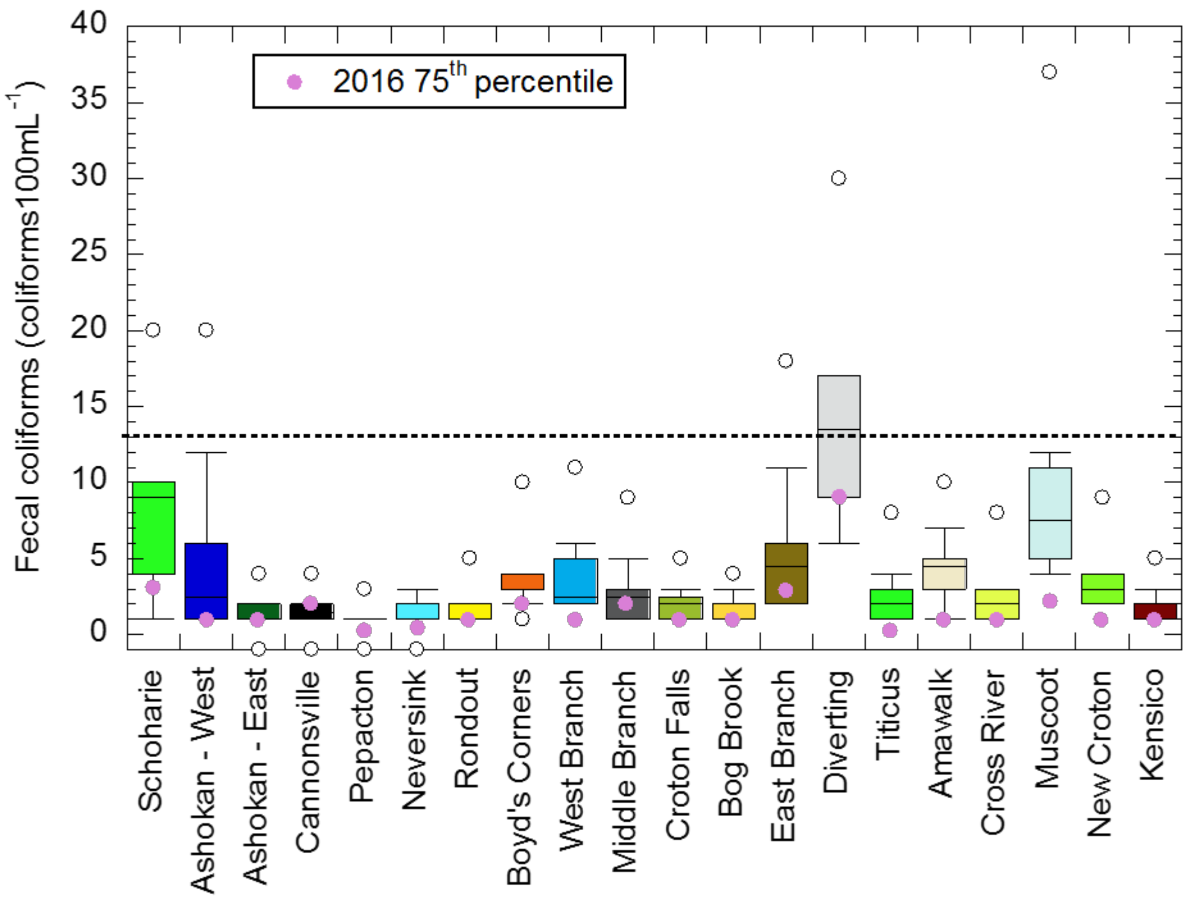


Figure 3.2 Annual 75th percentile of fecal coliforms in NYC water supply reservoirs (2016 vs. 2006-2015) with the 2016 values displayed as a solid dot. The dashed line represents the SWTR standard for source waters as a reference.

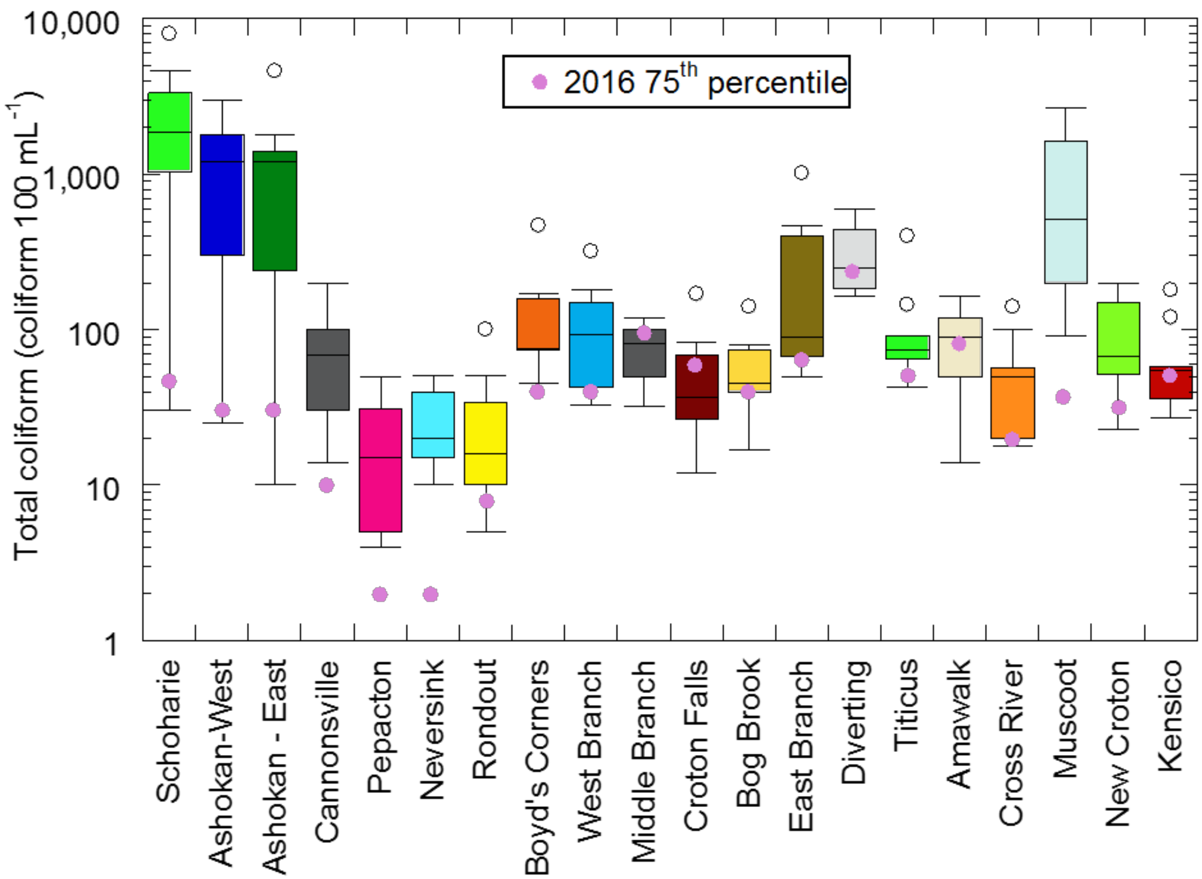


Figure 3.3 Annual 75th percentile of total coliforms in NYC water supply reservoirs (2016 vs. 2006-2015) with the 2016 75th percentile values displayed as a solid dot.

Fecal and total coliform counts throughout the water supply were low (or low-to-normal) in 2016 coinciding with the generally low rainfall. 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 2016, Catskill total coliform counts were over 50 times lower than historical levels and consistent with levels typically observed for the rest of the water supply system.

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

Lake	Historical total coliforms (75th percentile 2006-15)	Current total coliforms (75th percentile 2016)	Historical fecal coliforms (75th percentile 2006-15)	Current fecal coliforms (75th percentile 2016)
Gilead	16	9	2	<1
Gleneida	15	21	1	<1
Kirk	125	67	3	3

3.5. Phosphorus-Restricted Basin Assessments in 2016

The phosphorus-restricted basin status determination for 2016 is presented in Table 3.5. Basin status is determined from two consecutive assessments (2011-2015 and 2012-2016) using the methodology described in Appendix D. Reservoirs and lakes with a geometric mean total phosphorus (TP) concentration that exceeds the benchmarks in the WR&R for both assessments are classified as restricted.

Figure 3.4 graphically shows the phosphorus-restricted status of the City's reservoirs for the five-year assessment period compared with the previous assessment period. Geometric means for individual years that contributed to the assessments are shown in Appendix D. For 2016, with few exceptions, the geometric mean TP concentration was above the geometric mean concentration in 2015 (Appendix D). The exceptions were Lake Gleneida, Kirk Lake, and Croton Falls Reservoir, with geometric means of 27.0, 27.3, and 18.0 µg L^{-1}, respectively. All other reservoirs experienced increases in TP, with geometric mean TP ranging from 7.6 µg L^{-1} (Kensico) to 37.4 µg L^{-1} (Diverting). However, despite these increases in the annual geometric mean TP concentration, there were no changes in phosphorus-restricted status from the previous assessment period. For the 2012-2016 assessment period, for which the impacts of Hurricane Irene and Lee (2011) are no longer included, Ashokan West and Schoharie Reservoirs were improving over the course of the five-year period. Access was limited to Schoharie Reservoir in 2016 due to low reservoir levels, with no samples collected in September and October to contribute to the assessment.

In summary, none of the Delaware or Catskill Systems were phosphorus-restricted. All of the reservoirs in the Croton System were phosphorus-restricted, with the exception of Boyd's Corners Reservoir. Among the source water reservoirs and potential Catskill/Delaware reservoirs, New Croton, Cross River, and Croton Falls Reservoirs were restricted. West Branch Reservoir was non-restricted, reflecting the influence of Delaware System water on its water quality status.

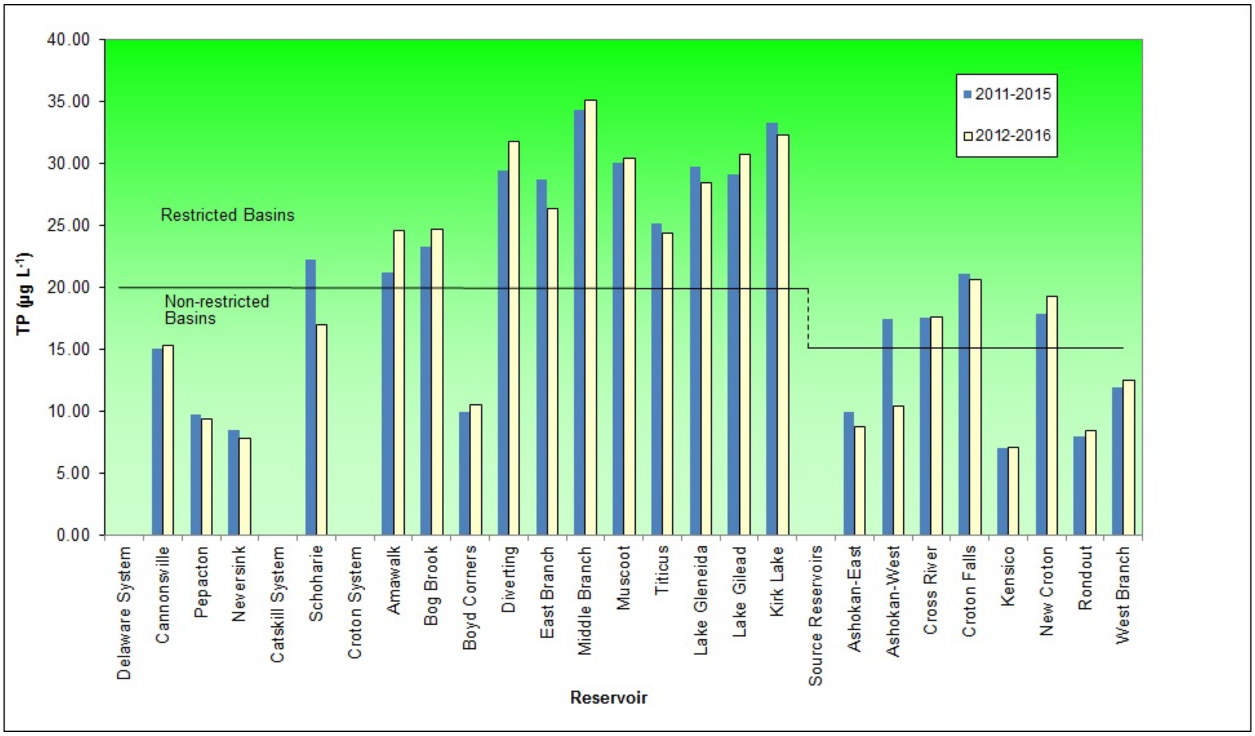


Figure 3.4 Phosphorus-restricted basin assessments. The horizontal solid lines at 20 µg L^{-1} and 15 µg L^{-1} represent the WR&R standard for non-source and source waters, respectively.

Table 3.5 Phosphorus-restricted reservoir basins for 2016.

Reservoir basin	2011-2015 Assessment[1] (µg L^{-1})	2012-2016 Assessment[1] (µg L^{-1})	Phosphorus restricted status[2]
Non-Source Waters (Delaware System)			
Cannonsville	15.0	15.3	Non-restricted
Pepacton	9.8	9.3	Non-restricted
Neversink	8.5	7.8	Non-restricted
Non-Source Waters (Catskill System)			
Schoharie	22.2	16.9	Non-restricted
Non-Source Waters (Croton System)			
Amawalk	21.2	24.5	Restricted
Bog Brook	23.3	24.7	Restricted
Boyd Corners	9.9	10.5	Non-restricted
Diverting	29.4	31.8	Restricted
East Branch	28.6	26.3	Restricted
Middle Branch	34.4	35.1	Restricted
Muscoot	30.0	30.4	Restricted
Titicus	25.2	24.3	Restricted
Lake Gleneida	29.7	28.4	Restricted
Lake Gilead	29.1	30.7	Restricted
Kirk Lake	33.3	32.2	Restricted
Source Waters (all systems)			
Ashokan-East	10.0	8.8	Non-restricted
Ashokan-West	17.5	10.4	Non-restricted
Cross River	17.5	17.6	Restricted
Croton Falls	21.1	20.7	Restricted
Kensico	7.0	7.0	Non-restricted
New Croton	17.8	19.2	Restricted
Rondout	8.0	8.4	Non-restricted
West Branch	11.9	12.5	Non-restricted

[1]Arithmetic mean of annual geometric mean total phosphorus concentration for 5-year period with S.E. (standard error of the mean) added to account for interannual variability.
[2]The WR&R standard for non-source waters is 20 µg L^{-1} and for source waters is 15 µg L^{-1}.

3.6. Reservoir Total Phosphorus Patterns in 2016

In 2016, TP levels in most Catskill/Delaware and Croton System reservoirs (Figure 3.5, Table 3.6) and streams (Figure 3.8b) were near or exceeded their highest levels since 2006. Additional analysis (not shown) indicated phosphorus was high throughout the year in most reservoirs. Reasons for the increase are not clear as runoff events were uncommon in 2016 (Figure 2.2 and Figure 2.3), resulting in generally low turbidity (Figure 3.1), and suggests minimal transport of particulate phosphorus to streams and reservoirs. Drought could be a contributing factor to the observed increase. Note that despite the increase in TP, trophic state indices (TSI) were quite low for most reservoirs in 2016 (Figure 3.6), indicating that the observed increases in TP did not result in an increase in algal productivity. Also, despite these increases, there were no changes in phosphorus-restricted status from the previous assessment period (see sec. 3.5). DEP will continue to monitor TP concentrations to determine if this is a trend or an anomaly and will further investigate possible causes for the 2016 increase.

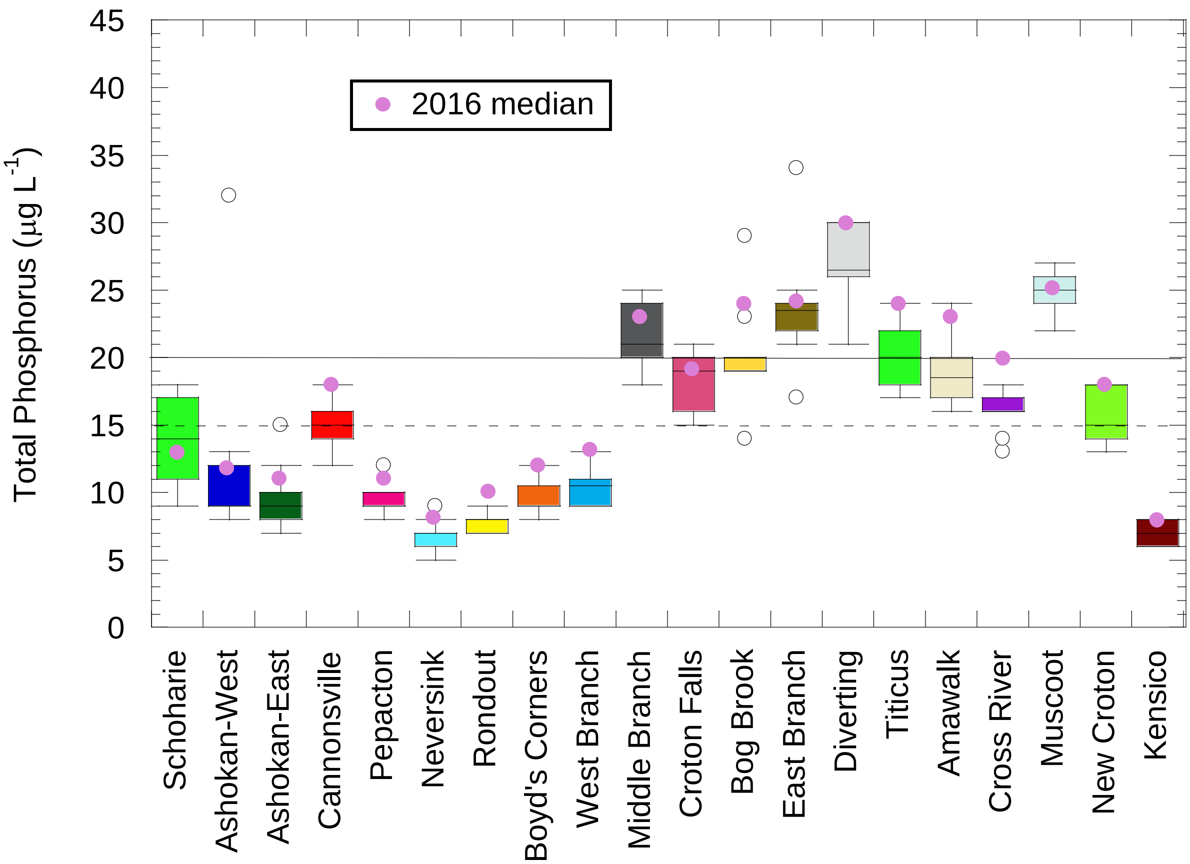


Figure 3.5 Annual median total phosphorus in NYC water supply reservoirs (2016 vs. 2006-2015) with the 2016 75th percentile values displayed as a solid dot.The horizontal dashed line at 15 µg L^{-1} refers to the NYC Total Maximum Daily Load (TMDL) guidance value for source waters. The horizontal solid line at 20 µg L^{-1} refers to the NYSDEC ambient water quality guidance value for reservoirs other than source waters.

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

Lake	Median Total Phosphorus (2006-15)	Median Total Phosphorus (2016)
Gilead	20	33
Gleneida	17	18
Kirk	29	29

3.7. Terminal Reservoir Comparisons to Benchmarks in 2016

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 2016 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. 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) and different values apply to Croton reservoirs than to WOH reservoirs. Placing the data in the context of these benchmarks assists in understanding the robustness of the water system and helps in identifying water quality issues.

Appendix E presents comparisons of 2016 reservoir sample results to the benchmark values (Table 3.7). 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 2016 include:

pH

For the majority of reservoir samples, pH was circumneutral (6.5-8.5) in 2016. Kensico and West of Hudson reservoirs with lower alkalinities had occurrences of pH below 6.5, with 22% of Ashokan East and 11% of Kensico samples below this range. Occurrences of pH exceeding 8.5 are generally associated with algal blooms. There were fewer exceedances for pH in Kensico, West Branch, and Rondout Reservoirs in 2016 as compared with the previous year. In New Croton Reservoir, the number of pH exceedances declined from 17% in 2015 to 11% in 2016, despite reported algal blooms. All New Croton exceedances were above pH 8.5, which may reflect algal blooms in surface samples during July, August, and September.

Phytoplankton

Phytoplankton counts did not exceed sample maximum of 2000 ASU mL^{-1} for Total Phytoplankton in the terminal reservoirs in 2016. This does not mean that blooms did not occur, and some of the evidence was from visual observations where phytoplankton counts were well below the benchmark value. Four NYC reservoirs and one controlled lake were included on the NYSDEC Harmful Algal Blooms (HABs) Program notification page (NYSDEC 2016) (http://www.dec.ny.gov/docs/water_pdf/habsextentsummary.pdf). Reservoirs listed on the NYSDEC HABs list for 2016 included Croton Falls, Muscoot, and New Croton Reservoirs as having a "suspicious bloom" based on visual observation and/or digital photographs. Cannonsville Reservoir and Kirk Lake were listed as having confirmed blooms. NYSDEC categorizes confirmed blooms for water sampling results with confirmed cyanobacteria that may produce toxins or other harmful compounds. Based on DEP's routine monthly monitoring, New Croton Reservoir had one sample that exceeded the single sample maximum of 2000 ASU mL^{-1} and two samples above the Primary Genus 1000 ASU mL^{-1} sample maximum. Phytoplankton samples are collected at a discrete depth of 3 m and algal blooms at the reservoir surface may be underrepresented as a consequence. However, some surface samples were collected as part of screening for algal toxins in 2016 (see section 3.12.4).

Chlorophyll a, Color, and Dissolved Organic Carbon

Chlorophyll *a* concentration is another measure of algal biomass. In 2016, one sample exceeded the single sample maximum for West Branch and none of the terminal reservoirs exceeded the annual mean benchmark values for chlorophyll *a*. Color is an indicator of organic matter both from in reservoir and watershed sources. In 2016, New Croton and West Branch exceeded the single sample maximum value of 15 units for 88% and 65% of the samples, respectively. Color in the Croton system is high due in part to the relatively high percentage of wetlands. The highest color values occurred in hypolimnetic (bottom) samples during summer when anoxic sediments release iron and manganese, resulting in discoloration. By contrast, Kensico Reservoir had few exceedances for color, reflecting the characteristics of Catskill/Delaware water. There were no exceedances of the benchmark values for dissolved organic carbon (DOC). New Croton and West Branch Reservoirs had the highest annual means of 3.3 and 2.3 mg L^{-1}, respectively, reflecting Croton watershed characteristics with a higher percentage of wetlands.

Chloride

All samples collected in 2016 from New Croton and West Branch Reservoirs exceeded their corresponding single sample maximum, as was the case in 2015. Additionally, the annual mean chloride concentrations for both reservoirs were over three times higher than their benchmark values of 30 mg L^{-1} and 8 mg L^{-1}, respectively. However, there was a slight decrease in the annual mean value for New Croton Reservoir from the previous year that dropped from 95.3 mg L^{-1} to 91.5 mg L^{-1}. All chloride samples were well below the health secondary standard of 250 mg L^{-1}. There was a notable reduction in the number of samples exceeding the single sample maximum for Kensico Reservoir. In 2015, 75% of the samples exceeded the single sample benchmark value of 12 mg L^{-1}, while in 2016 there were no exceedances. The annual mean of 10.8 mg L^{-1} for Kensico exceeded the benchmark value, but was lower than the mean of 13.3 mg L^{-1} for the preceding year. Ashokan East, Ashokan West, and Rondout Reservoirs had no exceedances of the single sample maximum and their annual means were at or slightly above the benchmark value of 8 mg L^{-1}. For all terminal reservoirs, chloride concentrations were generally lower and reflected drier conditions with fewer winter storms, less snow cover, and, consequently, reduced application of road salt in 2016.

Turbidity

Turbidity levels in Kensico Reservoir had no exceedances of the single sample maximum of 5 NTU in 2016. The highest number of values exceeding the benchmark of 5 NTU for Ashokan West was 33% of monthly reservoir monitoring samples, while 9% of the Ashokan East samples exceeded the benchmark. Few samples exceeded 5 NTU in the other terminal reservoirs: New Croton had 6%, Rondout had 5%, and West Branch had 3% of samples exceeded 5 NTU.

Nutrients

The highest number of exceedances of the 15-µg L^{-1} benchmark TP concentration for terminal reservoirs was in New Croton Reservoir where 84% of the samples exceeded the single sample benchmark. High values in the hypolimnion in the late summer to fall are indicative of phosphorus release from reservoir sediments. There are also high values at Site 8 near the inflow from Muscoot Reservoir, where 100% of the samples exceed the benchmark value of 20 µg L^{-1} for non-terminal reservoirs (Appendix E). West Branch exceeded the TP benchmark for 25% of the samples, an increase from 19% in 2015. Ashokan West exceeded the TP benchmark for 25% of the samples, and Ashokan East exceeded it for 19% of the samples. While Rondout had no exceedances for TP in 2015, 9% of the samples exceeded the benchmark in 2016. For nitrate, only New Croton Reservoir had a few exceedances of the single sample maximum of 0.5 mg L^{-1} (five samples representing 3% of routine samples analyzed). New Croton also exceeded the ammonia benchmark for both the single sample maximum (25% of samples) and annual mean concentration (0.12 as compared with 0.05 mg L^{-1}). Kensico and West Branch exceeded the single sample maximum for one sample and Ashokan East had three samples that exceeded the benchmark.

Fecal Coliform Bacteria

Fecal coliform counts did not exceed the single sample maximum in Kensico, New Croton, and West Branch Reservoirs in 2016. One sample (2% of samples collected) in Ashokan East exceeded the single sample maximum of 20 fecal coliforms 100mL^{-1}, while four samples in West Branch, four samples in Ashokan West, and five samples in Rondout exceeded the benchmark representing 6% of the routine samples.

Table 3.7 Reservoir and controlled lake benchmarks as listed in the WR&R (DEP 2010).

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 not routinely analyzed at all sites.

3.8. Reservoir Trophic Status in 2016

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 x (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 oligotrophic conditions, values between 40 and 50 indicate mesotrophic conditions, and values greater than 50 indicate eutrophic conditions. 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 (2006-2015) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.6. 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/lakes (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 2016, algal productivity was low to normal (within the 2006-2015 historical range) in most Catskill/Delaware System reservoirs. Higher productivity in Schoharie Reservoir was associated with warmer spring temperatures and higher than normal clarity due to fewer rain events.

In 2015, a significant improvement in trophic state was observed for West Branch Reservoir, which continued through 2016. Two factors were probably responsible for the improvement in 2016: a large infusion of cold, low nutrient Rondout water was diverted to West Branch through much of July and diminished summer to fall seasonal 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 water transferred through the Ashokan-East Basin and Rondout 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 resulted in an oligotrophic rating for Kensico in 2016.

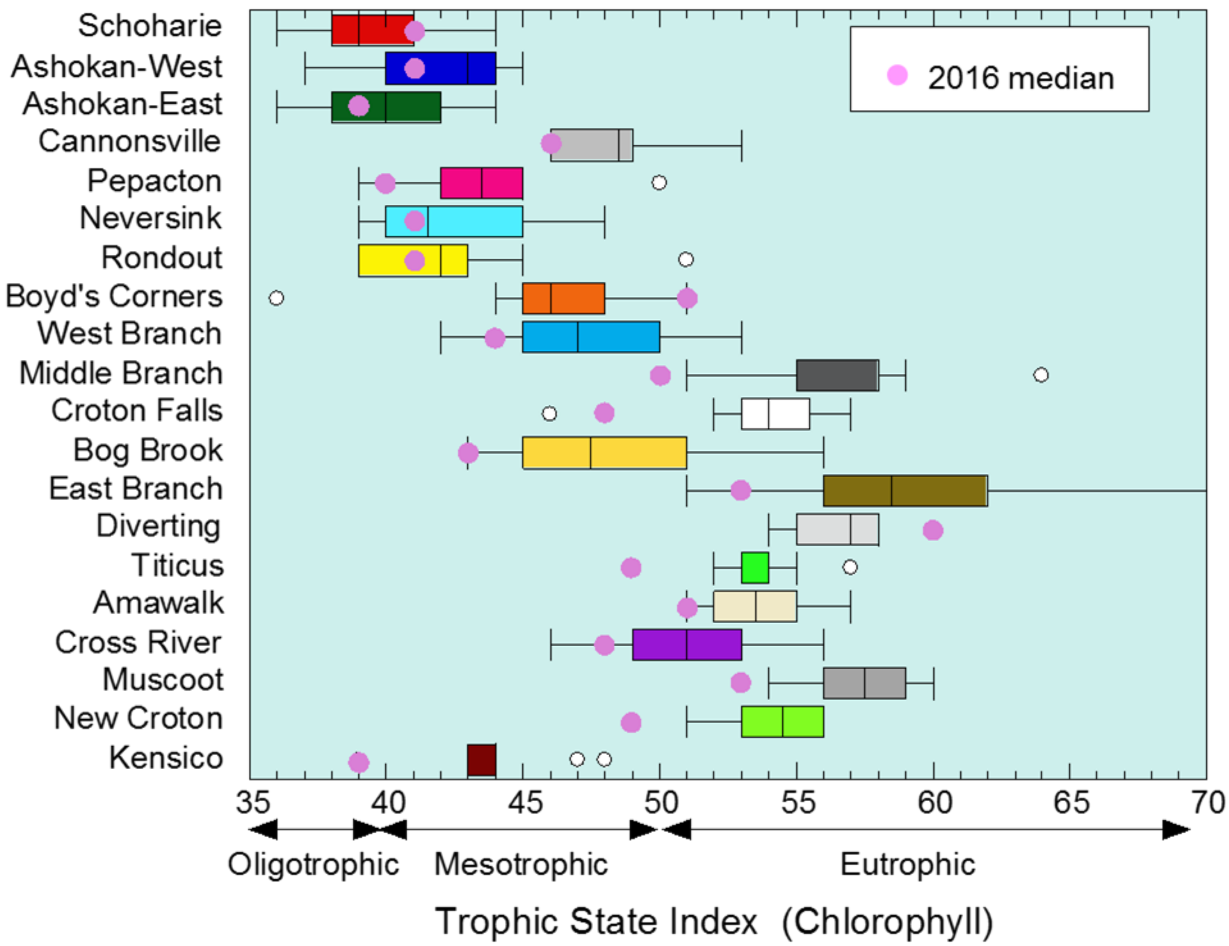


Figure 3.6 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2016 vs. 2006-2015). In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per month from May through October. TSI is based on Chlorophyll a concentration.

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

Lake	Median TSI (2006-2015)	Median TSI (2016)
Gilead	47	43
Gleneida	43	42
Kirk	58	60

Similar to 2015, TSI was lower in most reservoirs and controlled lakes of the Croton System in 2016 (Figure 3.6, Table 3.8). Reasons for the low values are not clear since phosphorus levels were quite high throughout the Croton System in 2016 (Figure 3.5) as was water clarity (Figure 3.1). The highest phosphorus concentrations were found to occur in the bottom waters, so perhaps these nutrients were less available for utilization by algae located higher up in the water column. In 2016, TSI increased in two Croton System reservoirs: Boyd's Corners and Diverting. TSI in Boyd's Corners increased 15 TSI units to 51 in 2016 while Diverting increased about 3 TSI units above the 2015 results. The significant increase at Boyd's Corners coincides with very warm summer water temperatures (exacerbated by drawdown).

3.9. Water Quality in the Major Inflow Streams in 2016

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. In 2016, the site on the West Branch Delaware River at Beerston was moved about 500 feet downstream from its previous site (site code WDBN). This change took effect on June 1, 2016. WDBN was consolidated to the location of the long-term storm event monitoring and automated stream monitoring station (site code CBS) and provides better year-round access.

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/CBS	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

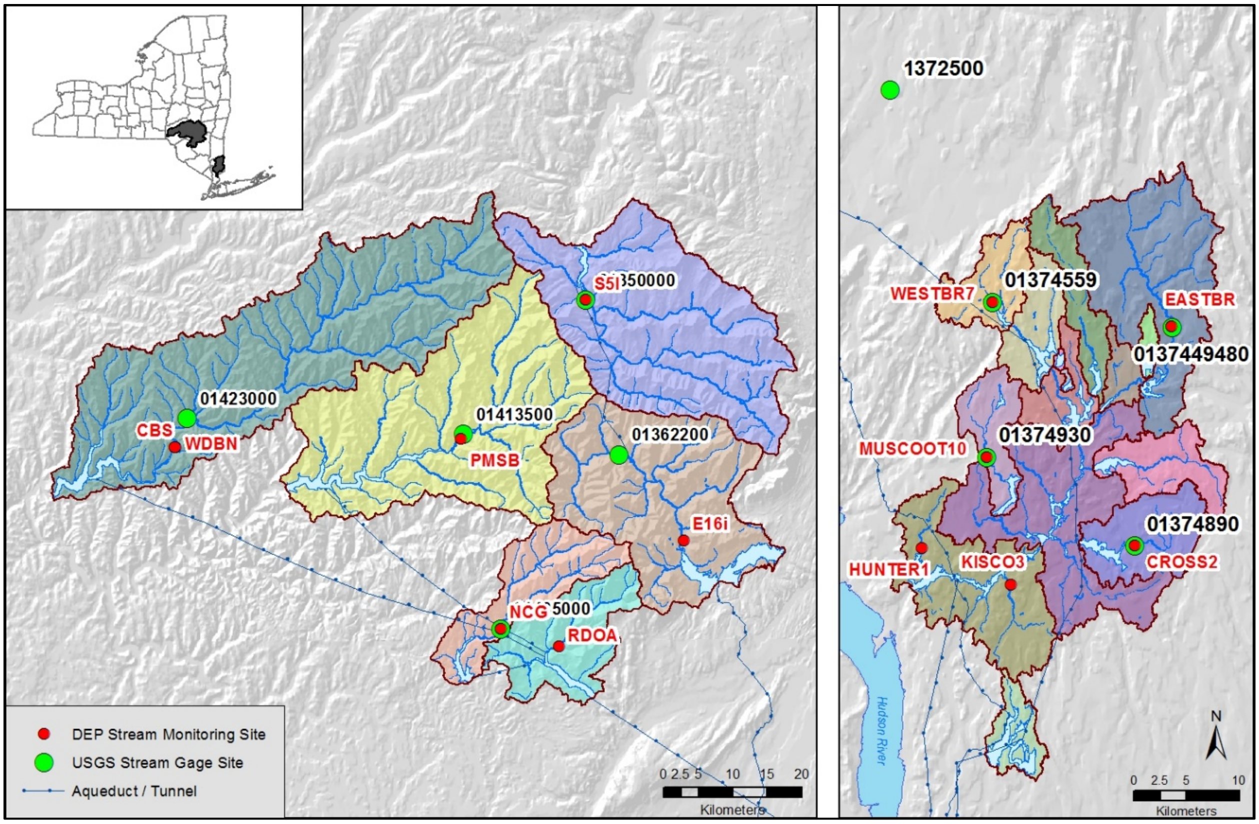


Figure 3.7 Locations of major inflow stream water quality sampling sites and USGS gage stations used to calculate runoff values (see Section 2.4).

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 2016 results presented in Figure 3.8 are based on grab samples generally collected once a month. Exceptions include collection of turbidity data weekly at Esopus Creek just downstream of the Boiceville bridge (E16I) and at the Neversink River near Claryville (NCG), and three or four times a month at Rondout Creek near Lowes Corners (RDOA) and the West Branch Delaware River at Beerston, (CBS). Also, total phosphorus was collected weekly at NCG and three or four times a month at CBS. Figure 3.8 compares the 2016 median values against historical median annual values for the previous 10 years (2006-2015).

Turbidity

The turbidity levels for 2016 were generally within the range of the annual medians observed over the previous ten years (2006-2015) (Figure 3.8a). The 2016 annual median turbidities at two New Croton inflows, Hunter Brook (HUNTER1) and Kisco River (KISCO3) were the lowest medians in the last 10 years, while West Branch Delaware River (WDBN/CBS) had the highest.

Total Phosphorus

In general, the 2016 median TP concentrations were higher than their normal historical values based on the previous ten years (2006-2015) (Figure 3.8b). Six of the inflows (East Branch of the Delaware River (PMSB), Neversink, (NCG), Rondout (RDOA), West Branch of the Croton River (WESTBR7), (East Branch (EASTBR), and Amawalk River (MUSCOOT10)) had their highest median compared to the last ten years, while four (Esopus Creek (E16I), West Branch of the Delaware River (WDBN/CBS), Cross River (CROSS2), and Kisco River (KISCO3)) had their second highest TP median.

Fecal Coliform Bacteria

The fecal coliform bacteria levels for 2016 were generally near or somewhat below the annual medians observed over the past ten years (2006-2015). The 2016 annual medians at HUNTER10 and Amawalk River (MUSCOOT10) were their lowest compared to the last 10 years, while the annual medians at East Branch Delaware River (PMSB) had its highest annual median recorded since 2006.

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 2016 median values for all streams shown here lie well below this value. There were only eight individual samples with greater than or equal to 200 coliforms $100mL^{-1}$ and those were all at EOH sites. These elevated fecal coliform counts were mostly associated with rain events.

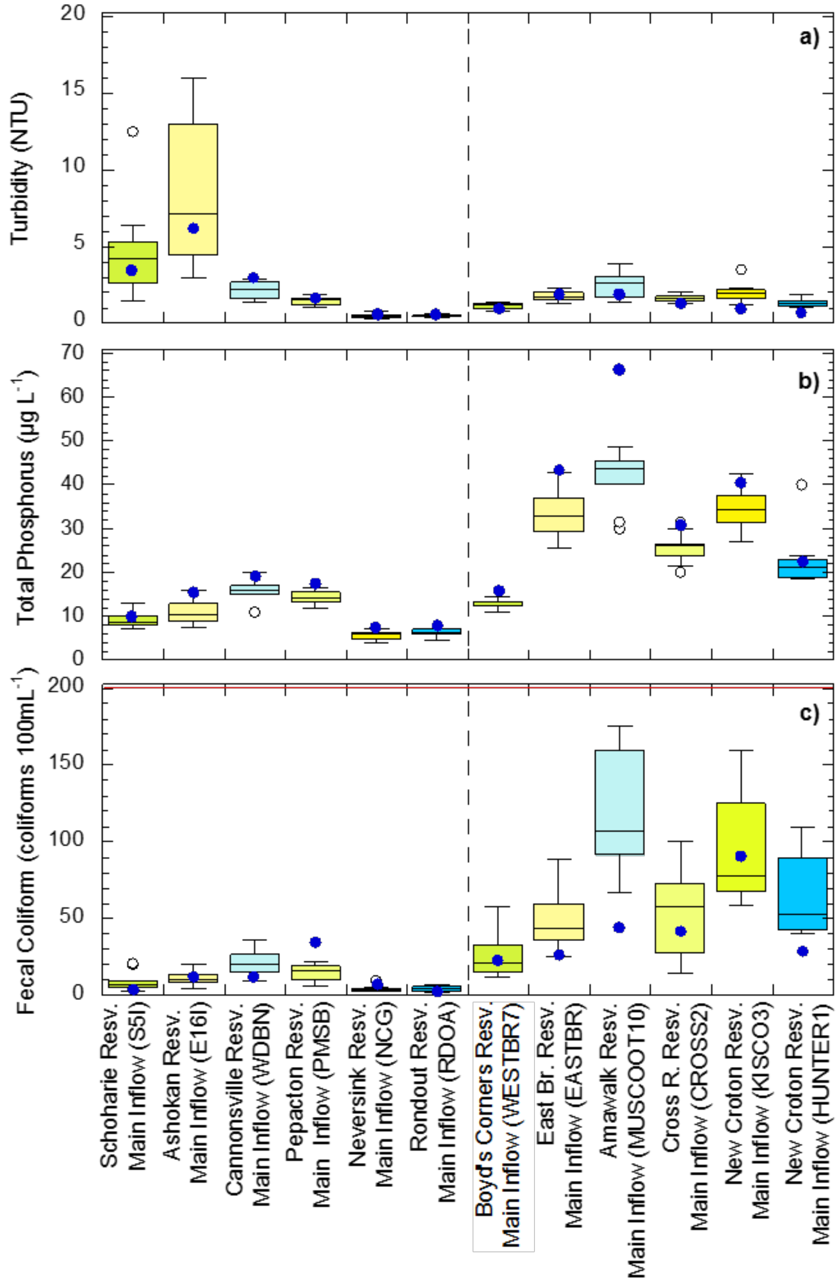


Figure 3.8 Boxplot of annual medians (2006-2015) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the 2016 values displayed as a solid dot. The dotted line separates WOH streams (left) from EOH streams (right). The solid red line indicates the fecal coliform benchmark of 200 coliforms $100mL^{-1}$.

3.10. Stream Comparisons to Benchmarks in 2016

Selected water quality benchmarks have been established for reservoirs and reservoir stems (any watercourse segment which is a tributary to a reservoir and lies within 500 feet of the full 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 2016 (DEP 2016a). The benchmarks are provided in Table 3.10.

Table 3.10 Stream water quality benchmarks as listed in the WR&R (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 $CaCO_3L^{-1}$)	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 not routinely analyzed at all sites.

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 affected by Delaware System water. Below is a discussion of selected sites and analytes.

Alkalinity

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/Delaware System 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 naturally acidic rain and melting snow moving over frozen or semi-frozen ground into the streams. 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} with average alkalinities ranging from 33.6 to 45.8 mg L^{-1}.

Chloride

The Catskill/Delaware System 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, 45.1 mg L^{-1}, occurring at site NK6 on Kramer Brook in the Neversink watershed. The single sample Catskill/Delaware chloride benchmark of 50 mg L^{-1} was exceeded twice at site S6I on the Bear Kill, and on four occasions at site NK6. In contrast to Kramer Brook, chloride concentrations in two additional monitored streams in the Neversink watershed, Aden Brook (NK4) and the Neversink River (NCG), were quite low, averaging 4.4 and 3.8 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 Catskill/Delaware System streams with high annual means included Bear Kill at S6I (28.4 mg L^{-1}); Trout Creek at C-7 (14.1 mg L^{-1}), Loomis Brook at C-8 (13.4 mg L^{-1}), and the West Branch of the Delaware River at WDBN/CBS (14.1 mg L^{-1}), all tributaries to Cannonsville Reservoir; Chestnut Creek at RGB (17.8 mg L^{-1}), a tributary to Rondout Reservoir. Two Pepacton streams: Tremper Kill at P-13 and the East Branch of the Delaware River at PMSB exceeded the average benchmark in 2016. In general, higher chloride concentrations correlate with the percentage of impervious surfaces (e.g., roads, parking lots) in the watersheds. Average annual chloride was also high (20.7 mg L^{-1}) at the outflow from West Branch Reservoir release (WESTBRR). In 2016, less Rondout water was diverted into West Branch during the spring and early summer resulting in a higher percentage of local stream water of higher chloride content in the blend of waters that comprise West Branch.

The Croton System annual mean benchmark of 35 mg L^{-1} was exceeded at in all 16 monitored Croton streams. Annual means exceeding the benchmark ranged from 43.5 mg L^{-1} in Cross River at CROSS2 to 204.8 mg L^{-1} in Michael Brook at MIKE2. The mean 2016 chloride concentration for all 16 Croton streams was 88.9 mg L^{-1}, substantially higher than the streams of the Catskill/Delaware System which together averaged 11.3 mg L^{-1}. The single sample chloride benchmark is 100 mg L^{-1} for streams of the Croton System. This benchmark was commonly exceeded on the Muscoot River at MUSCOOT10, at the Amawalk Reservoir Release at AMAWALKR, on Michael Brook at MIKE2, and on the Kisco River at site KISCO3. Occasional excursions occurred on the Long Pond outflow at LONGPD1, and Gypsy Trail Brook at site GYPSYTRL1. 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

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 2016, 14 of 24 Catskill/Delaware streams had at least one exceedance of the TDS single sample maximum of 50 mg L^{-1}. These same streams also exceeded the TDS annual mean benchmark of 40 mg L^{-1}. All excursions of the single sample maximum were associated with chloride concentrations that exceeded 7.4 mg L^{-1} (Figure 3.9).

TDS (and chloride) levels were not only high in winter but were often high in the summer and fall, presumably due to the concentration effect of low flow conditions and to greater contributions from salt-impacted groundwater. Only streams with very low average chloride concentrations (approx. 7 mg L^{-1}) consistently met both TDS benchmarks.

TDS excursions in the Croton streams were also associated with elevated chloride concentrations (Figure 3.10). No streams in the Croton System met the annual benchmark of 150 mg L^{-1} or consistently met the single sample maximum criterion of 175 mg L^{-1}.

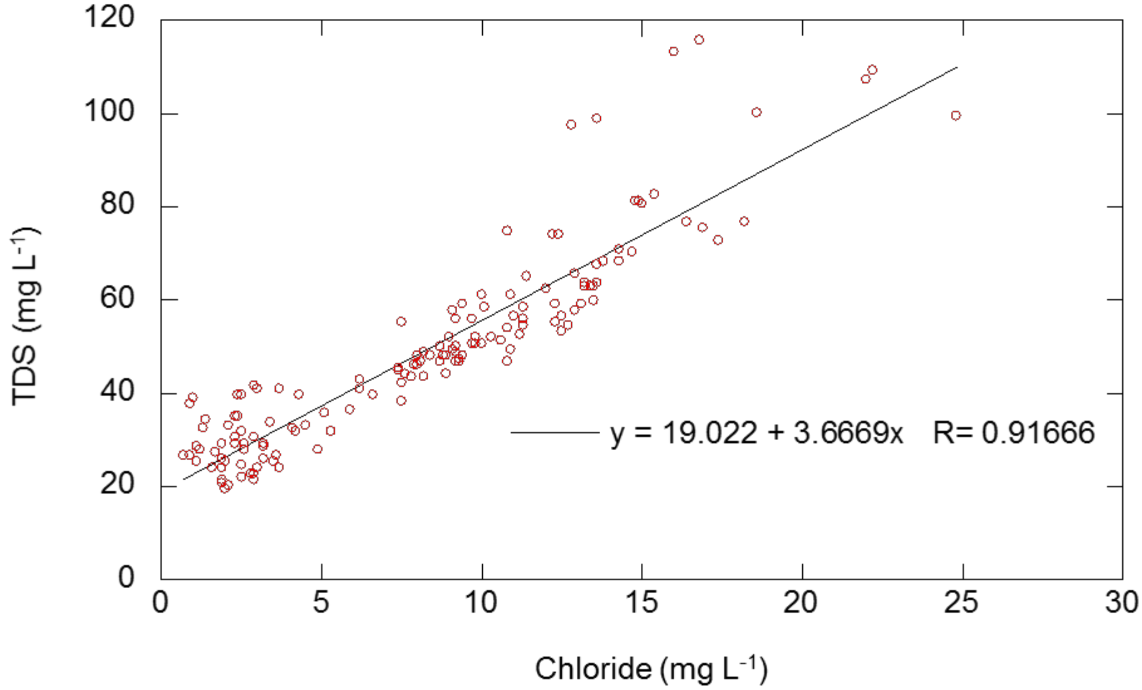


Figure 3.9 Total Dissolved Solids (TDS) versus chloride for Catskill/Delaware System streams in 2016.

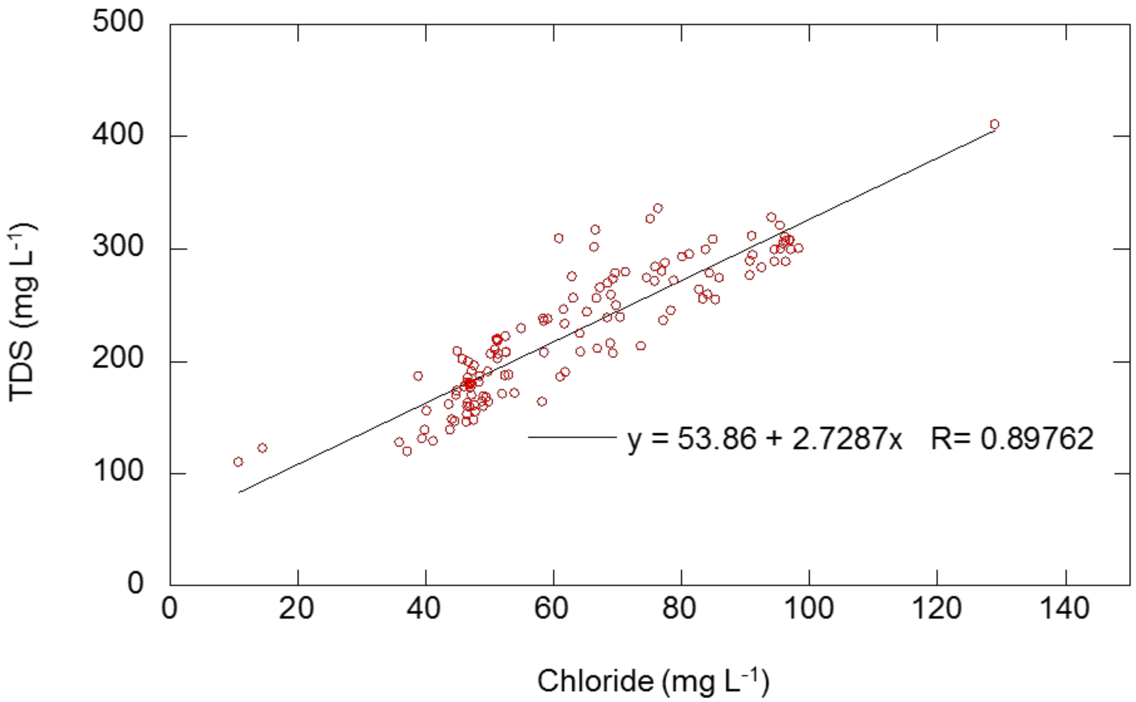


Figure 3.10 Total Dissolved Solids (TDS) versus chloride for Croton System streams in 2016.

Nitrogen

Nitrogen results were generally in compliance with benchmarks in the Catskill/Delaware System in 2016. Only the Bear Kill at S6I exceeded the single sample nitrate benchmark of 1.5 mg L^{-1}, with excursions of 1.6 mg L^{-1} in September and 2.8 mg L^{-1} in October. The average annual benchmark of 0.40 mg L^{-1} was also exceeded in the Bear Kill at S6I (0.79 mg L^{-1}) as well as in the West Branch of the Delaware River at WDBN/CBS (0.50 mg L^{-1}), and in Kramer Brook at NK6 (0.72 mg L^{-1}). One likely source for nitrate in the Bear Kill and Delaware River watersheds include fertilizers associated with the relatively high agricultural activity in these basins. Wastewater treatment plants that discharge to these streams maybe another source. The source of excess nitrogen in the Kramer Brook watershed is unclear.

Two Croton streams exceeded the annual average benchmark of 0.35 mg L^{-1} for 2016: the Kisco River at KISCO3 (0.65 mg L^{-1}) and Michael Brook at MIKE2 (3.05 mg L^{-1}). The single sample nitrate benchmark of 1.5 mg L^{-1} was also exceeded at Michael Brook in 7 of 12 monthly samples and was especially high in July (9.0 mg L^{-1}) and December (5.0 mg L^{-1}).

None of the 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 2016. Three Croton System streams exceeded the ammonia single sample maximum of 0.20 mg L^{-1} in 2016. The Titicus Reservoir Release at TITICUSR exceeded it three times: reaching 0.25 mg L^{-1} in September, 0.28 mg L^{-1} in October, and 0.26 mg L^{-1} in November. The Cross River at CROSS2 exceeded the benchmark three times: 0.20 mg L^{-1} in September, 0.32 mg L^{-1} in October, and 0.56 mg L^{-1} in November. Other exceedances: the Croton Falls release (CROFALSSVC) was 0.24 mg L^{-1} in October and the Muscoot River at MUSCOOT10 reached 0.24 mg L^{-1} in May. With the exception of the Muscoot River, all high ammonia results were associated with the release of ammonia from anoxic reservoir sediments in late summer.

Sulfate

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 2016. The highest mean sulfate, 7.2 mg L^{-1}, and the highest single sample, 10.4 mg L^{-1}, occurred at the Bear Kill at S6I. The collective average for the Catskill/Delaware streams was 4.5 mg L^{-1}. With the exception of the East Branch of the Croton River at 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 to the annual average benchmark occurred at EASTBR and MIKE2, with annual averages of 20.5 mg L^{-1}, and 19.3 mg L^{-1}, respectively. The average for EASTBR is driven by one high result of 38.4 mg L^{-1} that occurred on November 2 following a rain event after two months of very low flow (Figure 2.3). Watersheds with extensive wetlands, like the East Branch of the Croton River, oxidize stored sulfur to sulfate when the water table is lowered which is then flushed out by subsequent rain events (Kerr et al. 2012). Wetlands are not extensive in the Michael Brook watershed and sulfate was consistently high throughout the year ranging from 16.8-22.9 mg L^{-1}. Here the likely sulfate source is anthropogenic. The Michael Brook watershed is relatively populous and sulfate is a common ingredient in personal care products (e.g., soaps, shampoos, and toothpaste) and mineral supplements. Note that USEPA 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

Dissolved organic carbon (DOC) was used in this analysis instead of total organic carbon since the latter is not routinely analyzed as part of DEP's monitoring program. Previous work has shown that DOC constitutes the majority of the organic carbon in stream and reservoir samples. The DOC single sample benchmarks of 25 mg L^{-1} and annual mean of 9.0 mg L^{-1} were not surpassed by any stream in the Catskill/Delaware and Croton Systems in 2016. In the Catskill/Delaware System, the highest single sample DOC result occurred at Platte Kill at P-21 (6.0 mg L^{-1}) in the Pepacton watershed while the annual mean DOC in the Catskill/Delaware System ranged from 0.6 to 2.6 mg L^{-1}; well below the annual mean benchmark. In the Croton System, DOC is generally higher than the Catskill/Delaware System (although still well below benchmarks) due to a higher occurrence of wetlands in the Croton watersheds. Mean DOC ranged from 3.0 to 6.2 mg L^{-1} in 2016, and the highest single sample DOC was 14.3 mg L^{-1}. DOC concentrations were high in most streams during the last quarter of 2016, the result of DOC buildup during the extremely dry late summer and subsequent flushing out after fall rain events.

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 metrics used in the analysis are total number of taxa (SPP or species richness); total Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) taxa (EPT richness); Hilsenhoff Biotic Index for taxa tolerance to organic pollution (HBI), Percent Model Affinity (PMA); and, since 2012, Nutrient Biotic Index-Phosphorus (NBI-P).

In 2016, DEP collected samples from 42 stations in 31 streams throughout New York City's watershed. Thirteen sites were assessed on 11 streams in the Croton System, 14 sites were assessed on 8 streams in the Catskill System, and 15 sites were assessed on 12 streams in the Delaware System (Appendix G). Some samples were analyzed twice as replicates. The mean values of those replicates are used when data are presented in figures in this section. Scores in the Croton watershed were again generally lower than the Catskill/Delaware watershed, which is consistent with previous years' results (see, e.g., DEP 2013a, 2013b, 2014, 2015, 2016b).

East of Hudson – Croton System

Of the 13 Croton System sites assessed in 2016, six were considered moderately impaired (with scores for sites 109 and 131 dropping at or just below the slightly impaired BAP threshold of 5.0), six were considered slightly impaired, and one was considered non-impaired (Figure 3.11). While 11 of the sites had BAP scores lower than their respective period of record means, two of the sites scored higher than their period of record means. Additionally, five of the sites scored higher than during the previous sampling year (sites 102, 133, 134, 146, and 158) and two sites stayed relatively unchanged with a BAP score decreases of less than 0.5 (sites 101 and 142).

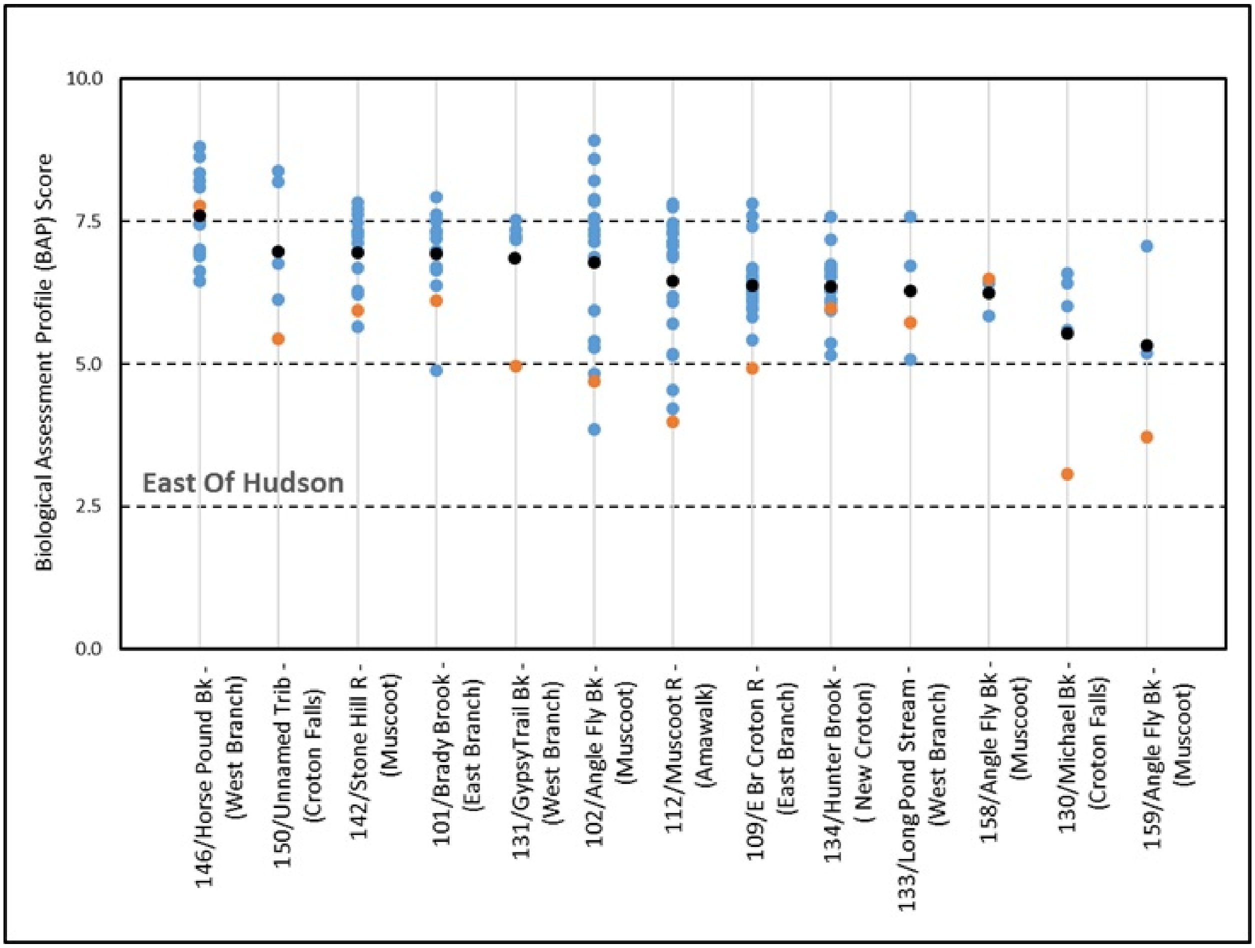


Figure 3.11 Biological Assessment Profile scores for East of Hudson biomonitoring sites sampled in 2016, arranged by mean score from highest to lowest. Black dots represent the mean score, orange dots the 2016 score, and blue dots the pre-2016 score. Watershed is indicated in parentheses.

Site 146 on Horse Pound Brook saw a second consecutive year with an increased BAP score. After four years of BAP scores below 7.5, the 2016 BAP score of 7.7 brought it above its period of record mean and back into non-impaired status (Figure 3.12). This is a site which from 2005 to 2009 consistently scored above 7.5, making it one of the highest scoring streams East of Hudson. 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. While the increased BAP score is encouraging, the DEP will monitor this West Branch Reservoir watershed stream again in 2017.

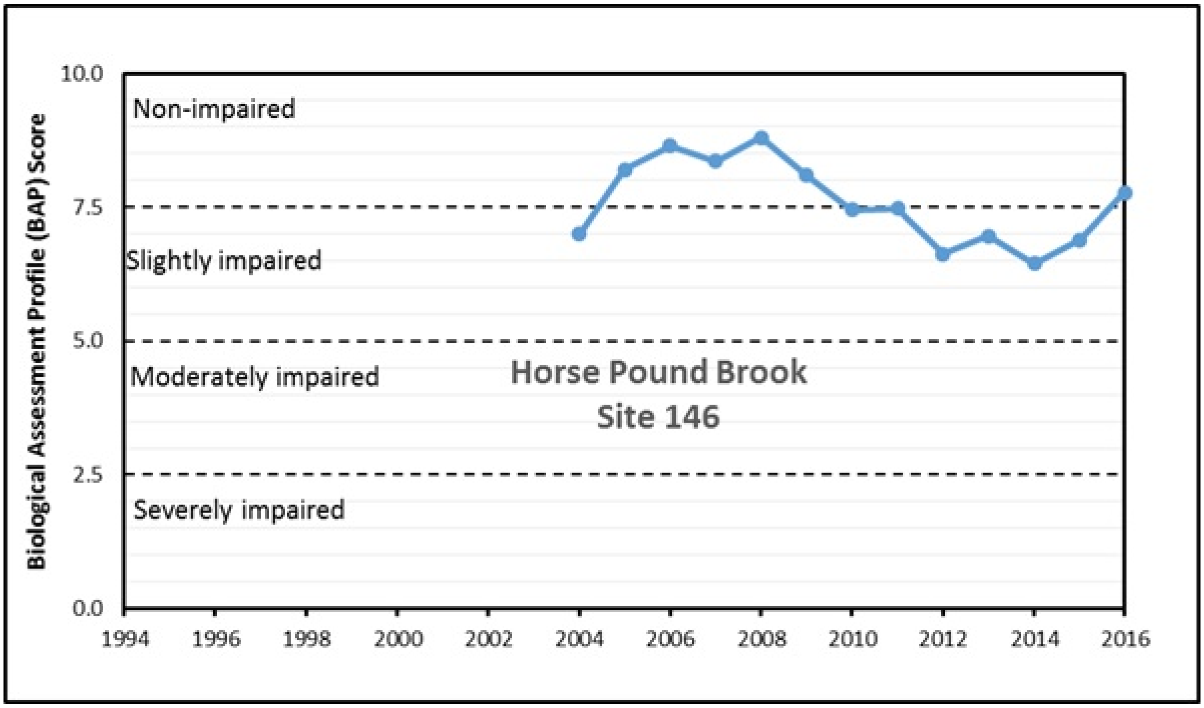


Figure 3.12 2004 - 2016 Biological Assessment Profile scores for the Site 146 on Horse Pound Brook showing its return to non-impaired BAP rating.

The assessment at site 102 on Angle Fly Brook (Figure 3.13) showed an increased BAP score of 4.69, which nearly brought the site back to slightly impaired status after last year's decline to 3.96, the lowest score for this site for the period of record.

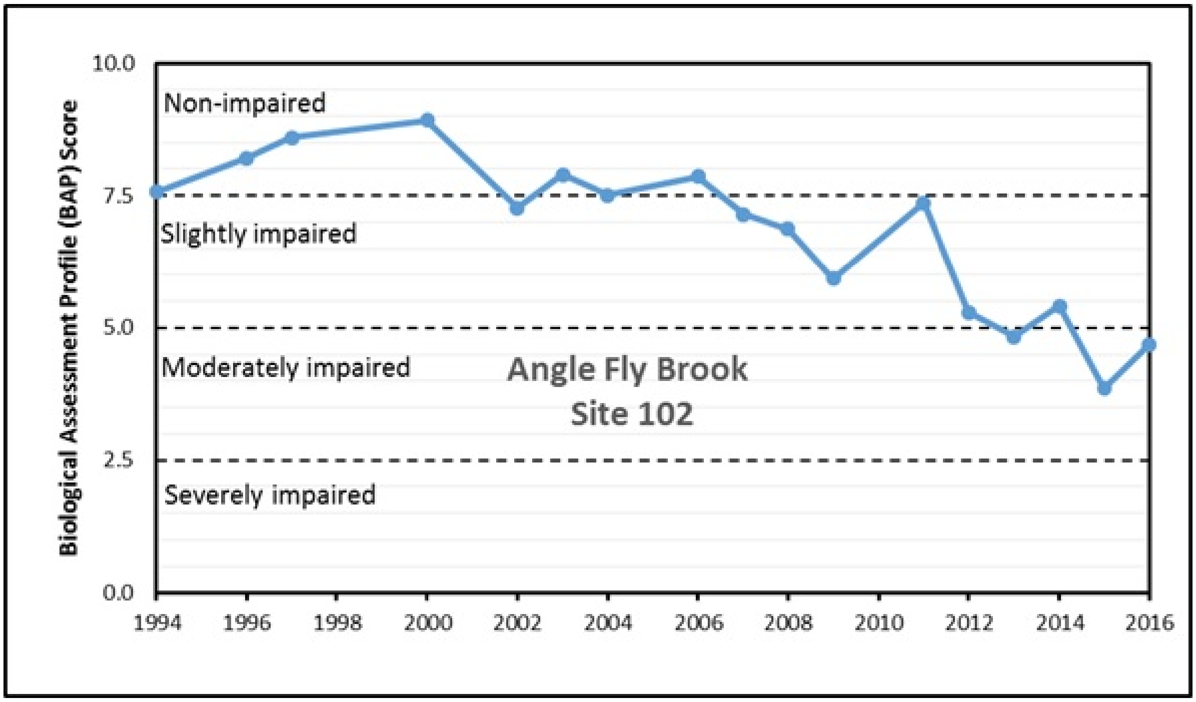


Figure 3.13 1994-2016 Biological Assessment Profile scores for Site 102 on Angle Fly Brook showing a slightly improved rating this year.

DEP sampled two sites upstream of Site 102 on Angle Fly Brook in an effort to isolate the source of the downward trend shown in previous years: Site 159 on Angle Fly Brook (mainstem) and Site 158 on a major Angle Fly Brook tributary are both about one-quarter mile upstream (Figure 3.14). The result was a BAP score range of 3.72 or moderately impaired at Site 159 (the second lowest 2016 BAP score) to 6.50 or slightly impaired at Site 158 (a value above the site's period record mean). All three sites exhibited a high percentage of hydropsychid, a type of caddisfly, relative to their total EPT taxa but their respective EPT values all fell inside of the slightly impaired range of 6 to 10 (Table 3.11). While the increased 2016 BAP score at Site 102 is promising, it follows a drop from 2014 to 2015. It is possible that there may be some impacts originating from upstream of site 159. As such, the DEP will continue to monitor this Muscoot Reservoir watershed site in 2017.

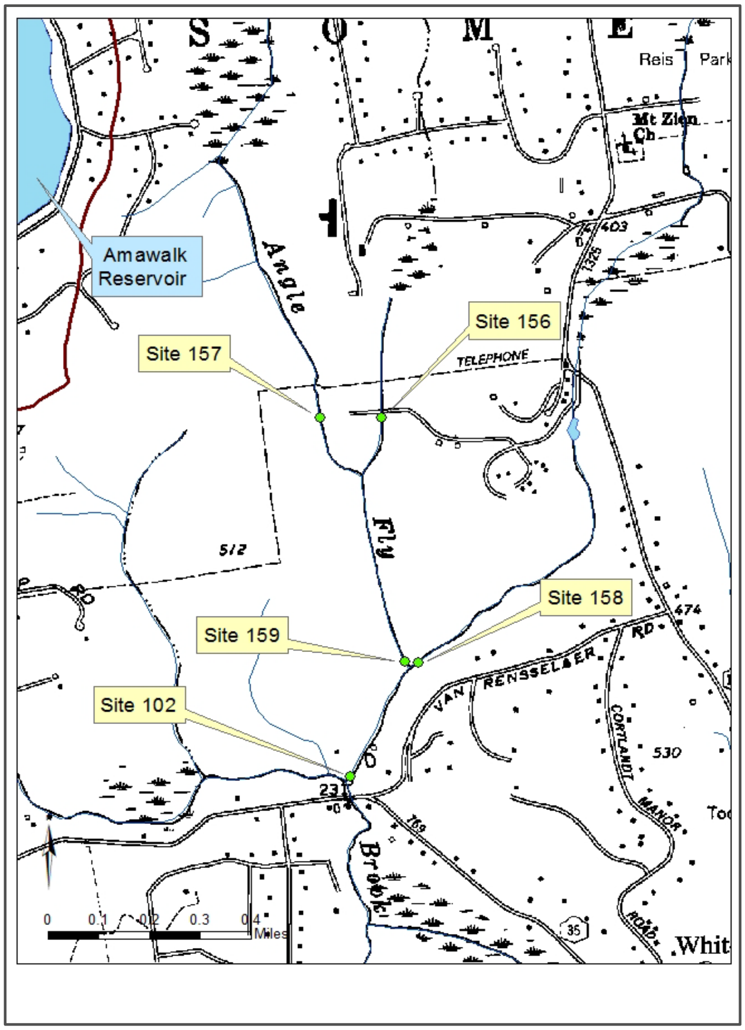


Figure 3.14 Angle Fly Brook biomonitoring sites

Table 3.11 Percent hydropsychid/EPT abundance at 2016 Angle Fly Brook biomonitoring sites.

Site No.	Percent Hydropsychidae
102	86.1
158	66.7
159	28.6

Again, in 2016 all moderately impaired sites for the NYC watershed were located within the Croton System. In addition to sites 102 and 159 on Angle Fly Brook, the other moderately impaired sites of note are sites 112 and 130 (Figure 3.11). Site 112 on Muscoot River in the Amawalk Reservoir watershed dropped slightly from a BAP score of 4.22 in 2015 to 3.99 in 2016. Site 130 on Michael Brook in the Croton Falls Reservoir watershed, which has only been sampled three other years (2000, 2005 and 2010), had its lowest BAP score of 3.06. The underlying causes for the low score at site 130 may be related to low flows and/or an increase in nutrient load as suggested by an NBI-P value of 7.9. The DEP will continue to sample at these sites as well to monitor trends in the BAP scores.

West of Hudson - Catskill/Delaware System

Of the 14 Catskill System sites assessed in 2016, four were considered slightly impaired with the remaining 10 considered non-impaired (Figure 3.15). While four of the 14 sites had BAP scores lower than their respective period of record annual means, 10 of the sites scored higher than their period of record means. Additionally, nine of the sites scored higher than during the previous sampling year (sites 204, 206, 213, 217, 218, 224,227, 229, and 254) and four sites stayed relatively unchanged with BAP score decreases of less than 0.5 (202, 215, 246, and 255).

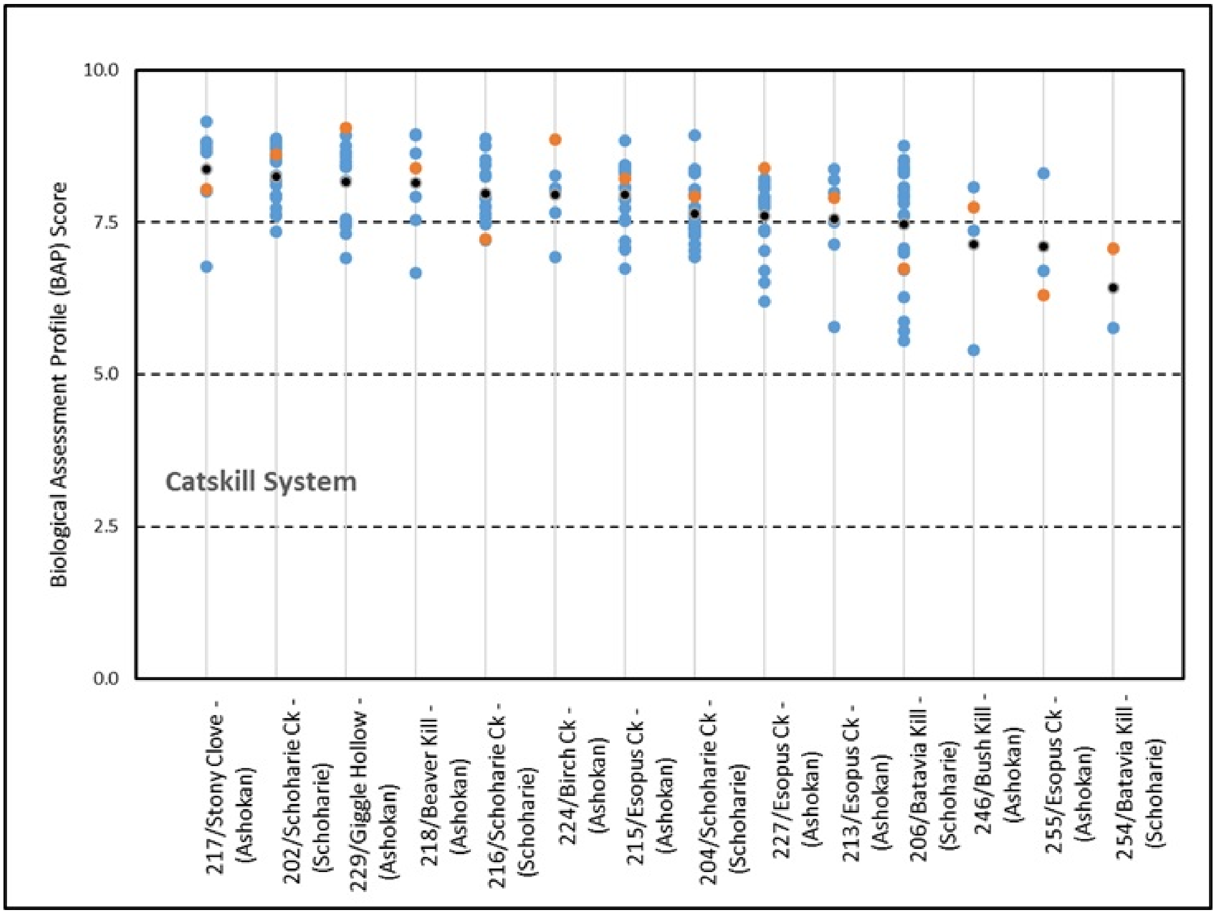


Figure 3.15 Biological Assessment Profile scores for the Catskill System biomonitoring sites sampled in 2016, arranged by mean score from highest to lowest. Black dots represent the mean score, orange dots the 2016 score, and blue dots the pre-2016 score. Watershed is indicated in parentheses.

Of the 15 Delaware System sites assessed in 2016, five were considered slightly impaired (sites 316 and 321 scores were very close to the non-impaired BAP threshold of 7.5) with the remaining 10 considered non-impaired (Figure 3.16). While eight of the 15 sites had BAP scores lower than their respective period of record annual means, seven of the sites scored higher than their period of record means. Additionally, four of the sites scored higher than during the previous sampling year (sites 316, 320, 330, and 341) and three sites stayed relatively unchanged with BAP score decreases of less than 0.5 (321, 323, and 331).

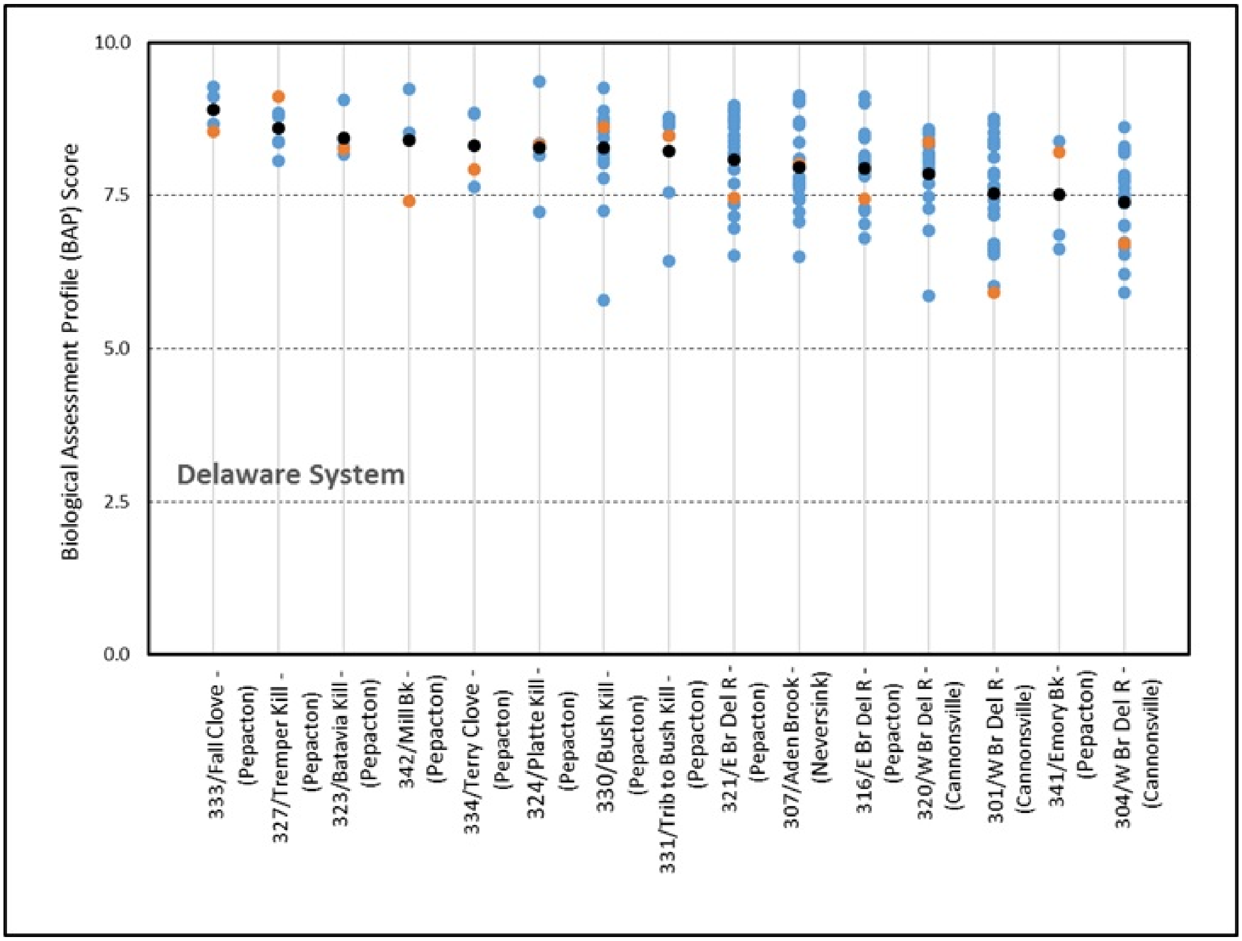


Figure 3.16 Biological Assessment Profile scores for the Delaware System biomonitoring sites sampled in 2016, arranged by mean score from highest to lowest. Black dots represent the mean score, orange dots the 2016 score, and blue dots the pre-2016 score. Watershed is indicated in parentheses.

While all sites in both the Catskill and Delaware systems are well within the slightly to non-impaired range, it is worth noting that Site 301 on the West Branch of the Delaware River dropped to its lowest recorded BAP score (Figure 3.17). However, the NBI-P (nutrient biotic-phosphorus) value for Site 301 improved significantly from 2015 to 2016, suggesting the cause for the drop in BAP score is not from an increase in nutrient loading (Table 3.12). All other parameters, used to calculate the BAP score remained relatively unchanged except for SPP (species richness) and PMA (model affinity). Additionally, Site 301 had the highest hydropsychid percentage (69.5%) of all Delaware System sites. The proximate cause of the drop in SPP and PMA is unclear. Given that 2016 was a dry year (see section 2.2), it is possible Site

301 was impacted to a greater degree than the other sites. Nevertheless, DEP will continue to monitor this stream, and its watershed to try to identify any controllable disturbances.

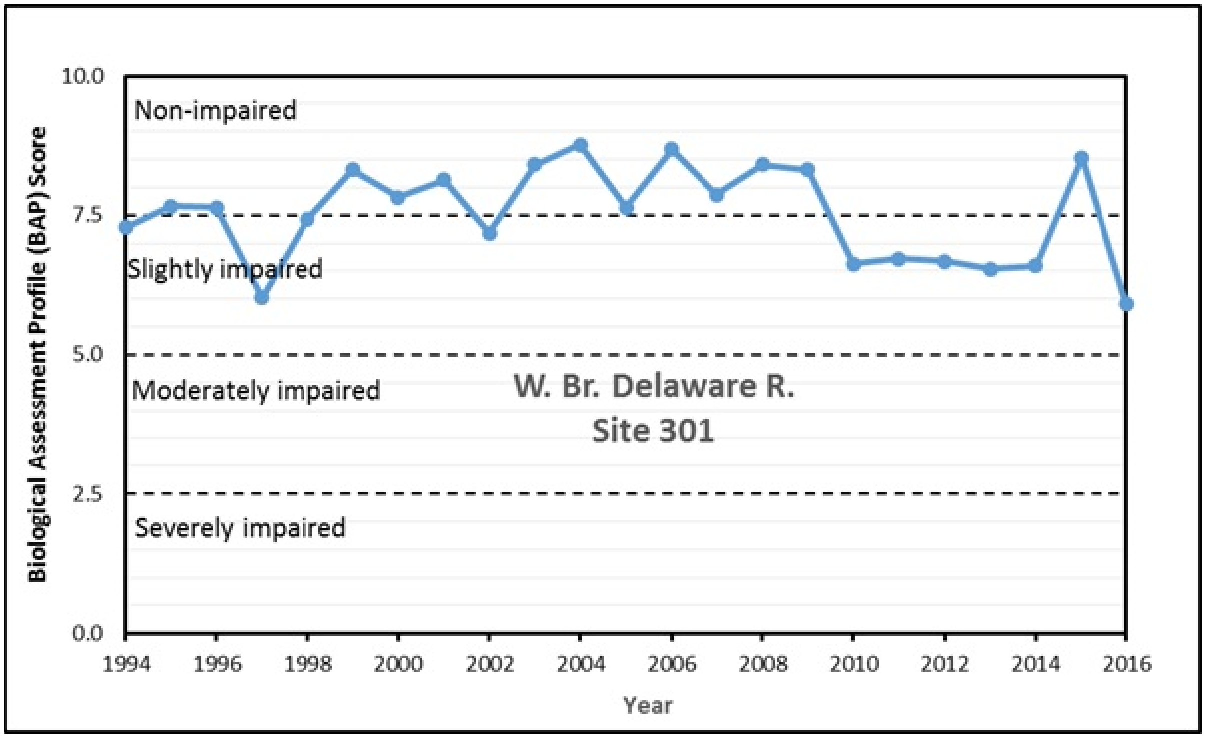


Figure 3.17 1994-2016 Biological Assessment Profile scores for Site 301 on West Branch Delaware River.

Table 3.12 2015 and 2016 parameter values used to calculate the BAP score for Site 301 on the West Branch Delaware River.

Year	SPP	EPT	HBI	PMA	NBI-P	BAP
2015	10	10	7.3	8.5	6.9	8.53
2016	7.4	9	7.6	3.2	2.5	5.91

3.12. Supplemental Contaminant Monitoring

3.12.1. Volatile (VOC) and Semivolatile Organic (SVOC) Compounds

DEP monitors a large number of volatile and semivolatile organic compounds and glyphosate in the upstate watersheds annually 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 2016 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
WDTOCM	West Delaware Tunnel Outlet	Represents Cannonsville water

In the event that one of these diversions is off-line 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.

3.12.2. 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. The site was remediated in 2012 but 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). DRO in this case 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 occurred monthly during routine reservoir limnology surveys when the reservoir was ice-free.

In 2016, 12 monthly keypoint samples were collected for DRO analysis and all results were non-detect for DROs. Weekly visual inspections from the East Delaware Intake Chamber did not identify the presence of a hydrocarbon-like sheen in 2016. Visual inspection made during monthly Pepacton Reservoir surveys (April – November) at the site of remediated submerged oil tank also did not identify the presence of a hydrocarbon-like sheen in 2016. Since no sheen was observed on the reservoir in 2016, monthly DRO monitoring at the Pepacton Reservoir effluent keypoint will be discontinued after December 2016. Visual inspections will still continue to be made during 2017 monthly Pepacton Reservoir surveys (April – November).

3.12.3. 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 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
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	Type	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 2016, most metal sample results were well below state and federal benchmarks. Selenium, antimony, beryllium, cadmium, silver, and thallium were not detected above the detection limit of 1.0 µg L^{-1} for any sample. Likewise, mercury was not detected above its detection limit of 0.06 µg L^{-1}. A single arsenic detection of 1.3 µg L^{-1} occurred on November 14 at SRR2CM, the diversion from Schoharie Reservoir, but was below the USEPA primary standard of 10 µg L^{-1}. One sample was detected for chromium on November 11 at WDTOCM, the outflow from Cannonsville Reservoir. The detected value was 6.1 µg L^{-1}, well below the NYSDEC standard of 50 µg L^{-1}. Lead was also detected on one occasion on May 10 at DEL9, the influent to or bypass above West Branch Reservoir. The detected value, 1.3 µg L^{-1}, was below the USEPA action level of 15 µg L^{-1}. One zinc detection of 105 µg L^{-1} was detected at DEL9 on May 10 with additional zinc detections of 11.1 µg L^{-1} and 15.6 µg L^{-1} occurring at DEL19LAB, the Delaware Aqueduct treated supply sampled at Shaft 19. Nickel was detected at CROGH, the untreated effluent from Croton Reservoir selective withdrawal blend, on February 9 (1.0 µg L^{-1}) and on August 9 (1.3 µg L^{-1}). Nickel was also detected at DEL9 (1.9 µg L^{-1}) on May 10 and at WDTOCM (3.1 µg L^{-1}) on November 7. Barium was detected in all samples ranging from 6.3 to 51.4 µg L^{-1}, while copper ranged from less than the detection limit (1.0 µg L^{-1}) at 29 of 56 samples to 23.2 µg L^{-1}. Note that these detected zinc, nickel, barium, and copper results were all well below their respective benchmarks.

However, iron, aluminum, and manganese did exceed benchmarks in 2016. The iron benchmark of 300 µg L^{-1} was exceeded once (522 µg L^{-1}) at SRR2CM, the diversion from Schoharie Reservoir. The manganese benchmark of 50 µg L^{-1} was exceeded on eleven occasions, while the aluminum benchmark of 50 µg L^{-1} was exceeded in seven samples. Manganese excursions ranged from 54 to 205 µg L^{-1}. Aluminum excursions occurred in one sample each at NRR2CM (55.4 µg L^{-1}), CATALUM (66.9 µg L^{-1}), WDTOCM (72.9 µg L^{-1}), and DEL9 (134 µg L^{-1}), and on three occasions at SRR2CM (105, 164 and 454 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 site in closest proximity to distribution, DEL18DT, was well below the benchmarks, ranging from <10 to 23.8 µg L^{-1} for aluminum, <3.0 to 39.0 µg L^{-1} for iron, and 10 to 18.0 µg L^{-1} for manganese. Note that < designates the analytical detection limit. The Croton keypoint closest to the distribution system, CROGH, was also below benchmarks, ranging to <10 µg L^{-1} for aluminum and from 51 to167 µg L^{-1} for iron. However, the benchmark for manganese was exceeded in three of four quarterly samples, with concentrations ranging from 79 to 205 µg L^{-1}.

3.13. Special Investigations

There were a total of ten special investigations conducted throughout the watershed during 2016, four of which were in the Kensico basin (see 4.5.2). All of these special investigations had the potential to compromise drinking water quality in different respects.

3.13.1. Catskill Aqueduct Leak Investigation – May 20, 2016

Two samples were obtained from a groundwater upwelling site along the Catskill Aqueduct within the vicinity of 25 Gramatan Drive, Yonkers, NY. The goal of sampling was to determine whether the water leakage originated from the nearby Catskill Aqueduct or a City of Yonkers water main located in the vicinity of the aqueduct leakage upwelling site. The presence of water treatment chemicals indicated that the source was a treated surface water supply. Orthophosphate concentrations corroborated that the Catskill Aqueduct was not the source since orthophosphate is not added to the aqueduct water until it reaches Hillview Reservoir downstream of Yonkers. The City of Yonkers adds orthophosphate to the water as it enters its distribution system, pointing to the Yonkers water supply as the likely source of the leak.

3.13.2. Catskill Aqueduct Leak Investigation – August 23, 2016

Three samples were obtained from a surface water site along the Catskill Aqueduct within the vicinity of 18 Belle Lane, Garrison, NY. The goal of sampling was to determine whether water occurring within the 18 Belle Lane residence was from a leak originating from the Catskill Aqueduct or from an ambient source of water. Nearly identical levels of turbidity, conductivity, temperature, and a rich algae count were found when a sample taken near the affected residence was compared with a sample from the nearby Catskill Aqueduct, suggesting that the water found at the residence was likely from the Catskill Aqueduct. Further investigations will be conducted when operations allow.

3.13.3. Mahopac WWTP Pathogen Investigation – November 15, 2016

A routine quarterly protozoan sample was collected from the effluent tank of the Mahopac WWTP. Results yielded 967 *Giardia* cysts and 2 *Cryptosporidium* oocysts in a 50L filtered sample. Plant operators reported that the plant was operating properly and water quality parameters were at acceptable levels; however, there were 1.35 inches of heavy rain between 11/14/16 and 11/15/16. Follow-up samples collected on 11/22/16 and 12/27/16 were negative for both *Giardia* and *Cryptosporidium*. Molecular testing of the original sample for *Giardia* DNA was negative but was positive for *Cryptosporidium*. *Cryptosporidium* genotyping results indicated an association with a rodent source. Analysis of a sample scraped from the effluent tank wall was negative for protozoa and positive for filamentous algae common to WWTPs. The most likely conclusion, based on the process of elimination, is that either surface runoff from the rainstorm washed fecal material directly into the tank from the surrounding concrete pad or wildlife got into the tank contaminating the original sample.

3.13.4. Diesel Range Organics Monitoring at Schoharie Tunnel Outlet Keypoint (SRR2CM)

In December 2016, a tugboat working on the Gilboa Dam project capsized in the Schoharie Reservoir. The vessel reportedly had a 1,000 gallon fuel tank and a petroleum sheen was observed. A boom was installed to contain the product and an additional boom was placed in front of the Shandaken Tunnel Intake as a precautionary measure. Surface samples were collected that day from inside the boomed area and then outside of the boom at 10 and 150 feet away. A reservoir sample was also collected at the intake chamber and a keypoint sample was collected at the end of the Shandaken Tunnel at the portal. Diesel Range Organic (DRO) analysis indicated that the boom had successfully contained the petroleum product and the investigation was closed.

3.13.5. Algal Toxins

In June 2015, the U.S. Environmental Protection Agency (USEPA) issued 10-day health advisory values for the algal toxins, microcystins and cylindrospermopsin, in drinking water. Algal blooms (particularly cyanobacteria) in rivers, lakes, and bays sometimes produce harmful toxins. Because utilities often use these water bodies as sources of drinking water, USEPA has determined algal toxin levels in tap water that are protective of human health based on the best available science. USEPA has also made recommendations on how utilities can monitor and treat drinking water for algal toxins and notify the public if drinking water exceeds protective levels. Although NYC's reservoir system generally has low phytoplankton levels, some reservoirs occasionally do experience cyanobacterial blooms at certain times of the year. This baseline monitoring is intended to investigate whether anatoxin, microcystin, and cylindrospermopsin are present at critical keypoint and reservoir sampling locations during peak algae season. In 2015, WWQO conducted the baseline sampling of keypoint and reservoir locations and no detections of these three compounds were found. Special Investigation sampling, where surface sampling of visible reservoir surface blooms was conducted, did result in detections of microcystin and anatoxin. In 2016, this study continued. Samples were submitted for an algal toxin suite that includes anatoxin-a, cylindrospermopsin, microcystin-LA, microcystin-LF, microcystin-LR, microcystin-LY, microcystin-RR, microcystin-YR, and nodularin.

In 2016, algal toxins were found in six upstate watershed reservoirs but none were detected at keypoint sites. Two reservoirs (New Croton and Boyd’s Corners) had total microcystin present, but at levels barely above the limit of detection (0.11 µg/L). Anatoxin-a was detected at low levels (0.16 µg/L) in two reservoirs (East Branch and Diverting). Two outlying reservoirs (Croton Falls and Cannonsville) had elevated levels of microcystin in samples from surface blooms in remote areas of each reservoir.

3.13.6. Peekamoose, Blue Hole Monitoring

In the warmer months, the Peekamoose Blue Hole area of the upper Rondout Creek receives many recreational visitors on the weekends. People come to swim and picnic. There is limited space and parking. There are limited bathroom facilities, garbage receptacles, and officially established picnicking areas. Human waste and garbage left behind may be the result of an inadequate number of sanitary and trash facilities. The influx of visitors has increased over the last few years largely due to the location’s popularity on social media. The NYSDEC, which governs the land, established access restrictions, parking restrictions, and other posted regulations (e.g., no picnicking, swimming only) in 2016.

DEP conducted weekly monitoring at two sites directly above and below the Blue Hole area in 2016 in an attempt to determine if the activities of recreational visitors impacted water quality. Weekly monitoring was conducted May 23-September 4. Once per month samples were collected on a weekend to correspond with the time when visitor use was highest. Several physical, chemical, and biological parameters were measured both in situ and by collecting samples for laboratory analysis.

The 2016 sampling results indicated there were no exceedances of NYSDEC or DEP water quality standards due to the recreational use of the Peekamoose Blue Hole. The Wilcoxon signed-rank test was used to evaluate these data to determine if there was a significant difference between the above and below sample sites at the 95% confidence level of the measured water quality parameters. The Wilcoxon signed-rank test indicated that there is little to no difference in water quality parameters between the above and below sample sites. Due to these finding, no additional monitoring of the Blue Hole area is planned.

4. Kensico Reservoir

4.1. Kensico Reservoir Overview

Kensico Reservoir 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 2016a). 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 summarizes all of the water quality samples collected within the Kensico watershed during 2016. 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. Fecal coliform and turbidity are focal points when discussing Kensico water quality. The results of this monitoring are representative of the excellent quality of water leaving Kensico Reservoir during 2016. 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 2016.

Kensico sampling programs	**Turbidity**	**Bacteria**	***Giardia/ Crypto-sporidium***	**Virus**	**Other chemistry**	**Phyto-plankton**
SWTR Turbidity compliance	2,196					
Keypoint effluent	366	365	61	12	429	164
Keypoint influent	521	522	104	24	628	115
Reservoir	807	412			753	133
Streams	165	162	101		271	

NYC Environmental Protection

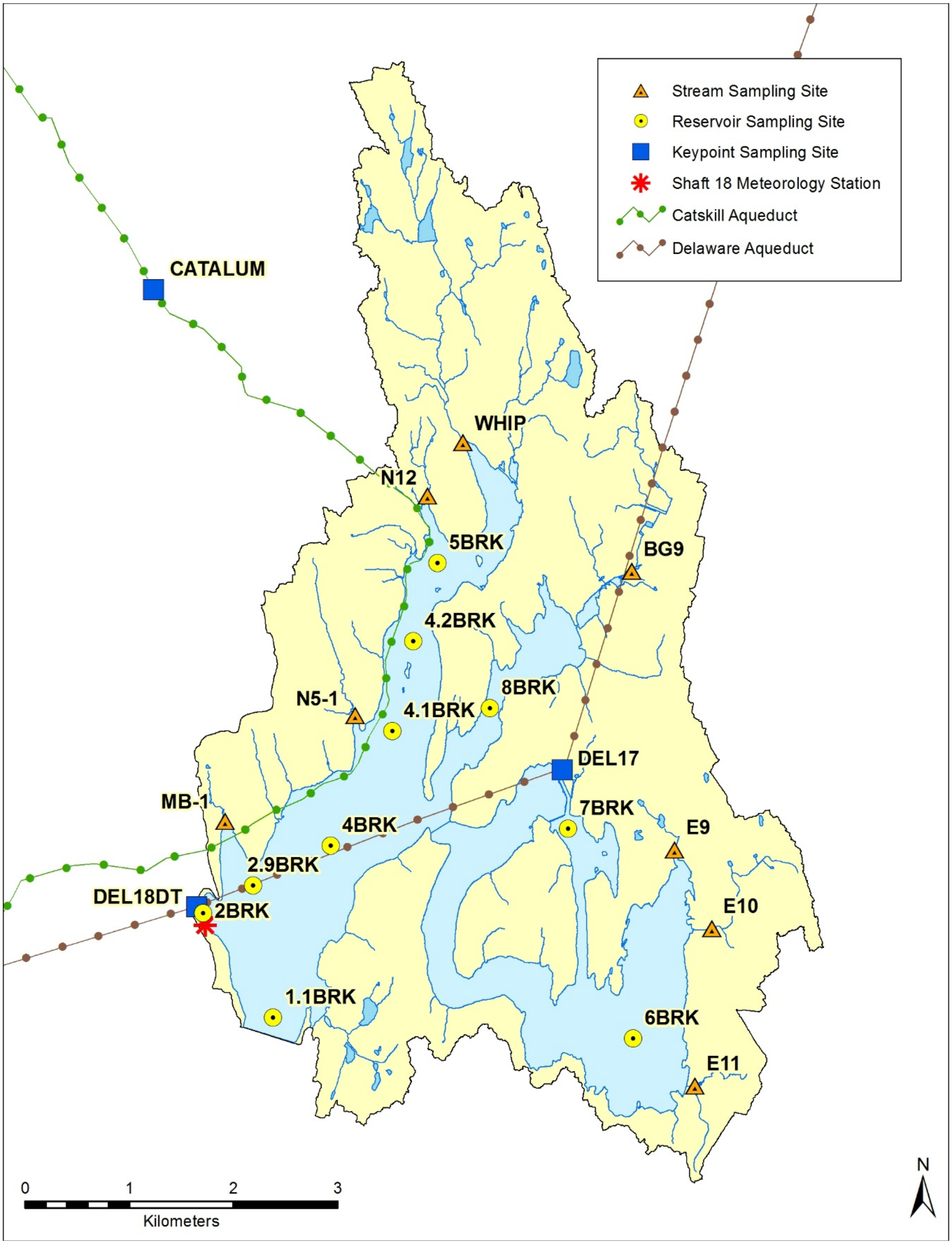


Figure 4.1 Kensico Reservoir, showing limnological, hydrological, and keypoint sampling sites, meteorology stations, and aqueducts.

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 Catskill Influent Chamber and Delaware Aqueduct (DEL17) SPDES permits, NY-026-4652 and NY-026-8224 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 three active aqueduct keypoint locations during 2016. The analytes for all three keypoints are used as an indicator of water quality entering and discharging from Kensico Reservoir, which is 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. The other effluent keypoint, Catskill Lower Effluent Chamber (CATLEFF), has been offline since September 2012 due to insufficient hydraulic head to deliver water to the Catskill/Delaware UV plant.

Table 4.2 Water quality compliance monitoring for Kensico Reservoir aqueduct keypoints via routine grab samples for 2016.

Site	**Coliform, Fecal and Total, Turbidity, Specific Conductivity, Scent, and Apparent Color**	**Field pH and Temperature**	**Turbidity (SWTR)**	**Phytoplankton**	**UV254**	**TP**	**DOC**	**Alkalinity, Ammonia, Chlorophyll *a*, NOx, TDN 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
3D – Sampled three times per week
M – Sampled Monthly
7D – Sampled seven days per week
W – Sampled Weekly
Q – Sampled Quarterly
5D – Sampled five days per week.
SDPES permit monitoring requirements are in bold.

Table 4.3 shows the Kensico Reservoir influent and effluent turbidity and fecal coliform samples collected during the 2016 calendar year. All of the sites continued to have median values less than 1 fecal coliform 100mL^{-1} with the single sample maximum similar to 2015. For turbidity, all of the sites had similar median values with the single sample maximum higher in 2016 as compared to the previous year. At DEL18DT, one turbidity value was greater than twice any other value for the year, remaining below the SWTR turbidity limit, and was suspected to have been contaminated by biofilm from the sample line. The corresponding continuous monitoring result and operator grab sample were 1.15 and 1.34 NTU, respectively.

Table 4.3 Kensico keypoint fecal coliform and turbidity results from January 1, 2016 to December 31, 2016.

Analyte	Kensico Sampling Location	Median	Single Sample Maximum
Fecal Coliform (coliform 100mL^{-1})	CATALUM	< 1	21
	DEL17	< 1	9
	DEL18DT	< 1	5
Turbidity (NTU)	CATALUM	1.9	6.4
	DEL17	0.8	1.8
	DEL18DT	0.8	4.3[1]

[1]Result possibly affected by biofilm in sample line.

The routine grab sample analytical results at CATALUM, DEL17, and DEL18DT for the 2016 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 only as a reference line 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.

During 2016, there were no large storm events affecting the influent or effluent keypoints of Kensico Reservoir. Short term increases in turbidity or fecal coliforms can be attributed to changes in reservoir operations and/or rainfall/runoff events, as seen in February and October at CATALUM with slight increases in turbidity and fecal coliforms in months with above average rainfall at Ashokan. Water quality in 2016 was excellent overall, with the source water at Kensico meeting the SWTR limits for both fecal coliform and turbidity.

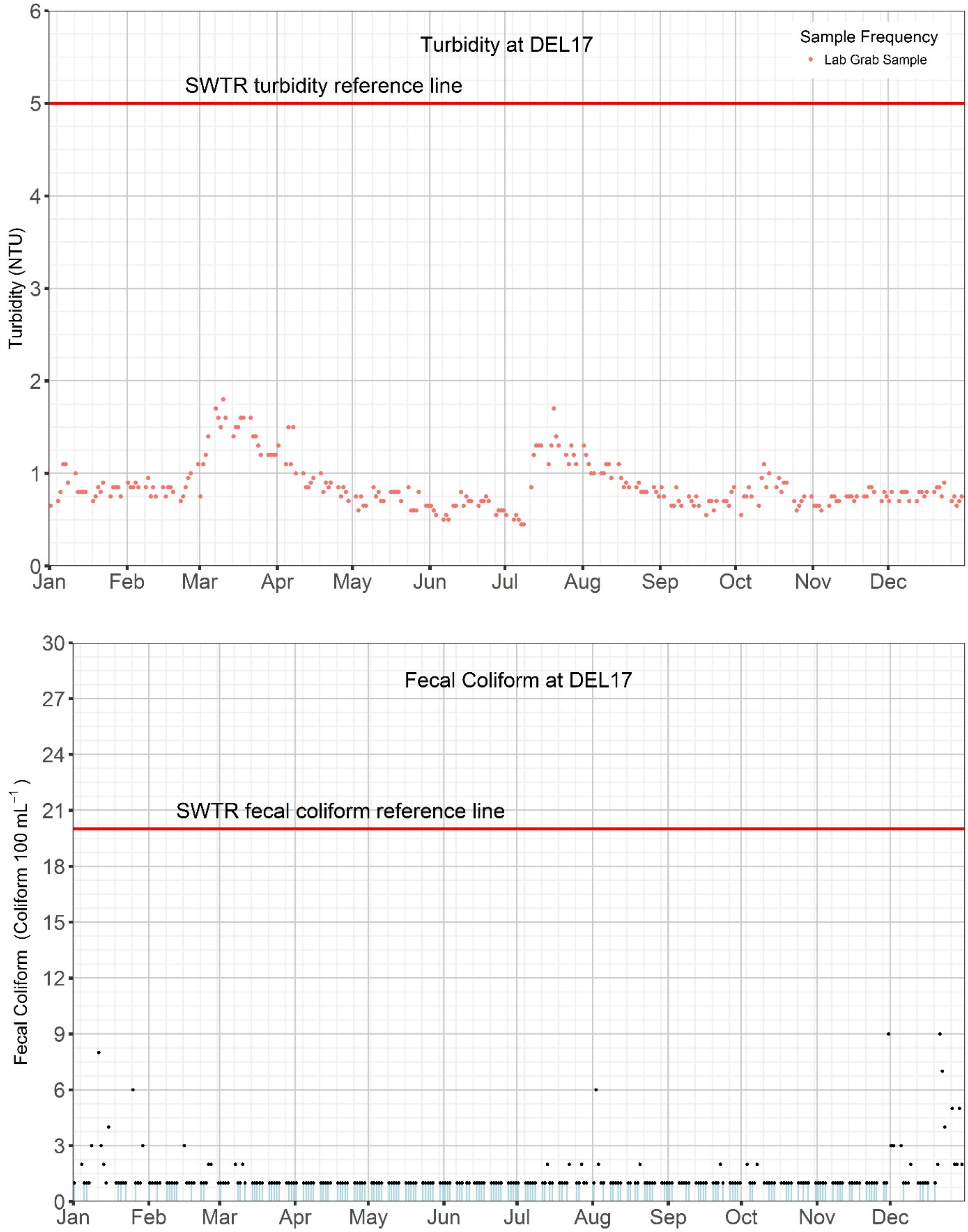
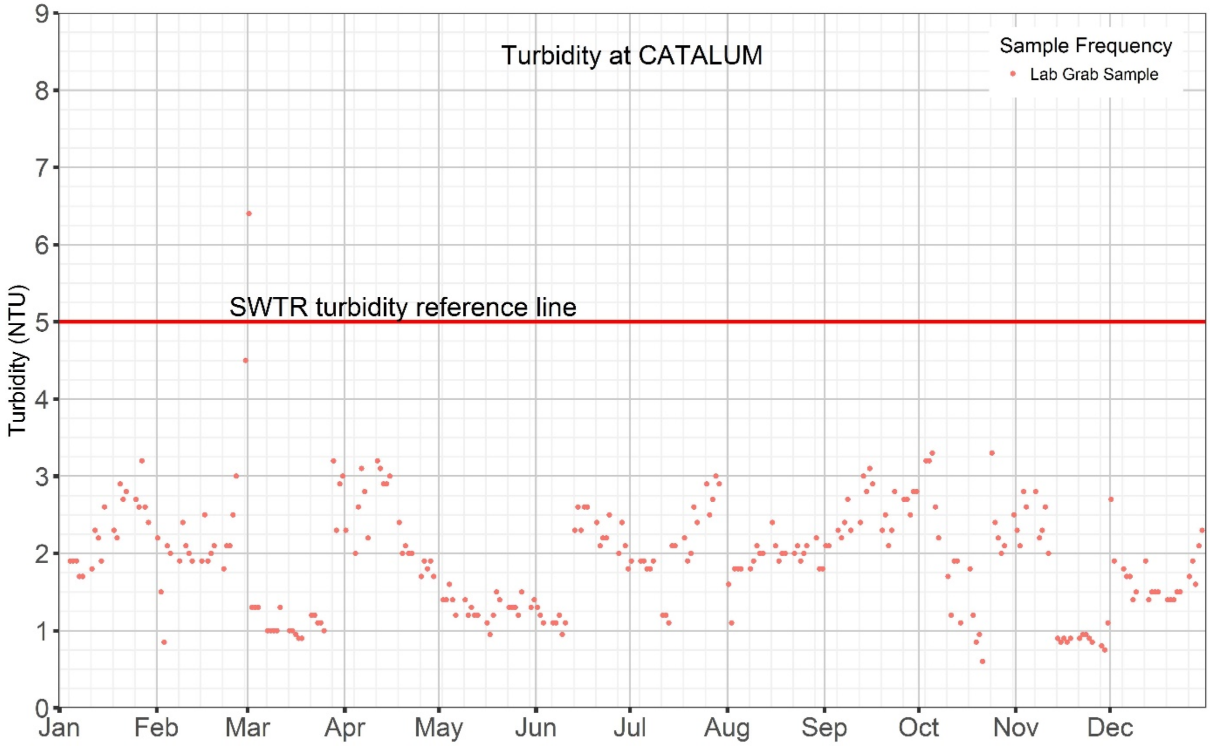


Figure 4.2 Five-day-per-week turbidity and fecal coliform grab samples at DEL17.



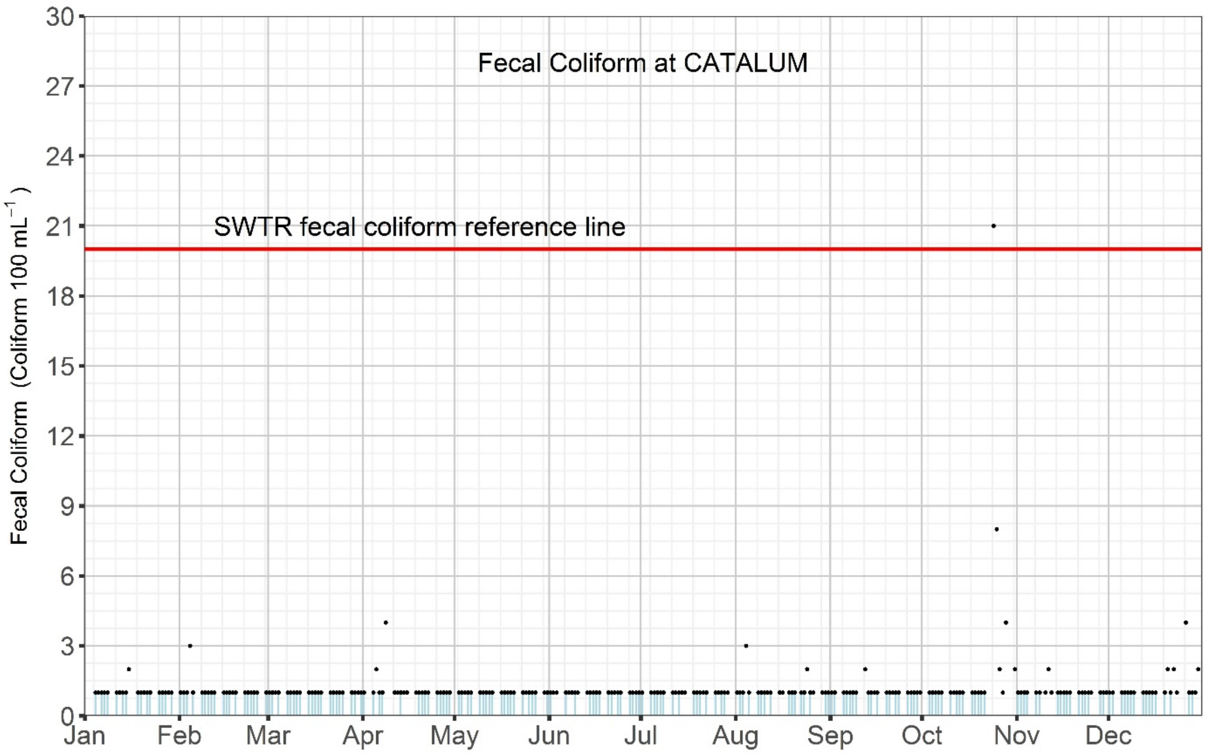


Figure 4.3 Five-day-per-week turbidity and fecal coliform grab samples at CATALUM.

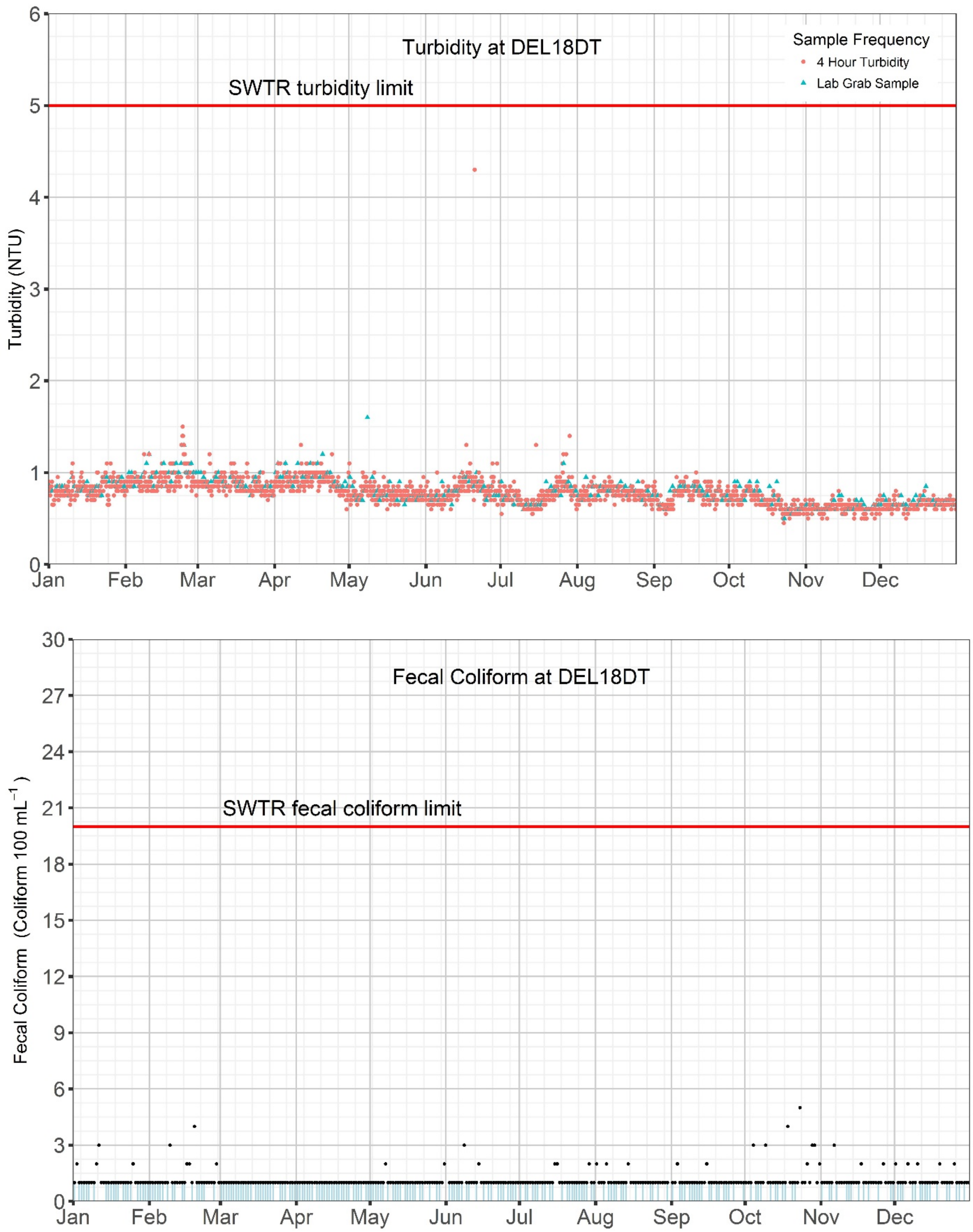


Figure 4.4 Seven-day-per-week turbidity and fecal coliform grab samples at DEL18DT.

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 stream and reservoir sites in the Kensico watershed. Routine samples were collected from eight perennial streams and 10 locations within Kensico Reservoir as shown in Figure 4.1. Continuous flow measurements continued at eight of the Kensico perennial streams. Flows for WHIP (Whippoorwill Creek) and BG9 (Bear Gutter) are determined via a rating curve. Flows at E11 (Stream E11), E10 (Stream E10), MB-1 (Malcolm Brook), and N5-1 (Stream N5-1) are determined via a V-notch weir. Flows at N12 (Stream N12) and E9 (Stream E9) are determined via an H-flume. Summary statistics are presented in Table 4.4.

Table 4.4 2016 summary statistics for Kensico watershed streams.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum	Note
NH3-N (mg L^{-1})	BG9	12	<0.02	0.02	0.03	0.06	0.14	KM
	E11	12	<0.02	<0.02	<0.02	<0.02	0.03	>80%
	MB-1	12	<0.02	<0.02	0.02	0.03	0.11	KM
	N12	12	<0.02	<0.02	<0.02	<0.02	<0.02	>80%
	N5-1	12	<0.02	<0.02	0.03	0.08	0.16	KM
	WHIP	12	<0.02	<0.02	<0.02	<0.02	0.02	>80%
NO3+NO2-N (mg L^{-1})	BG9	12	0.08	0.12	0.14	0.33	0.60	
	E11	12	<0.02	<0.02	0.05	0.10	0.18	KM
	MB-1	12	0.10	0.23	0.27	0.43	0.74	
	N12	12	0.36	0.50	0.56	0.96	1.55	
	N5-1	12	0.34	0.69	0.82	1.14	1.87	
	WHIP	12	0.41	0.50	0.58	1.06	1.42	
Total Nitrogen (mg L^{-1})	BG9	12	0.36	0.42	0.49	0.51	0.66	
	E11	12	0.25	0.28	0.31	0.35	0.46	
	MB-1	12	0.35	0.46	0.54	0.56	0.77	
	N12	12	0.52	0.67	0.74	0.99	1.53	
	N5-1	12	0.73	1.01	1.13	1.37	1.84	
	WHIP	12	0.60	0.71	0.77	1.19	1.40	
Total Phosphorus (µg L^{-1})	BG9	12	13	19	29	65	99	
	E11	12	12	26	30	48	88	
	MB-1	12	23	32	45	67	78	
	N12	12	17	28	56	66	71	
	N5-1	12	29	51	75	95	160	

Table 4.4 2016 summary statistics for Kensico watershed streams.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum	Note
	WHIP	12	10	18	23	39	44	
Alkalinity (mg L^{-1})	BG9	12	47.3	62.6	66.1	86.7	115.0	
	E11	12	93.0	101.8	121.0	136.5	149.0	
	MB-1	12	50.4	70.9	73.7	77.6	86.1	
	N12	12	49.1	58.8	64.9	84.4	110.0	
	N5-1	12	55.8	61.5	74.0	84.1	104.0	
	WHIP	12	41.3	49.4	57.5	74.2	98.7	
Chloride (mg L^{-1})	BG9	12	125.0	148.0	165.0	197.3	343.0	
	E11	12	26.2	44.9	55.4	62.8	99.6	
	MB-1	12	101.0	123.8	139.0	159.5	261.0	
	N12	12	42.0	46.1	51.6	58.4	62.7	
	N5-1	12	41.4	57.5	74.1	89.0	172.0	
	WHIP	12	67.4	82.8	85.7	92.2	97.2	
Dissolved Organic Carbon (mg L^{-1})	BG9	12	2.0	3.2	3.9	4.4	5.4	
	E11	12	3.4	4.1	5.2	5.6	6.4	
	MB-1	12	2.2	2.6	3.6	4.5	5.3	
	N12	12	1.8	2.4	2.6	4.2	4.8	
	N5-1	12	2.1	2.8	3.8	4.5	5.5	
	WHIP	12	1.8	2.2	3.1	3.8	5.3	
TSS (mg L^{-1})	BG9	12	<1.0	<1.0	2.0	4.8	23.9	KM
	E11	12	<1.0	1.0	1.5	6.4	18.0	KM
	MB-1	12	<1.0	1.5	3.9	4.7	12.6	KM
	N12	12	<1.0	<1.0	<1.0	1.2	29.1	ROS
	N5-1	12	<1.0	1.4	5.3	8.2	22.6	KM
	WHIP	12	<1.0	<1.0	1.6	3.4	11.0	KM
Specific Conductivity (µmhos cm^{-1})	BG9	12	554	647	734	843	1370	
	E10	12	422	933	1200	1330	1440	
	E11	12	334	365	422	483	652	
	E9	12	630	674	735	855	928	
	MB-1	12	478	558	643	727	1060	
	N12	12	273	317	350	391	482	
	N5-1	12	279	364	430	511	772	
	WHIP	12	341	424	454	481	528	

Table 4.4 2016 summary statistics for Kensico watershed streams.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum	Note
Turbidity (NTU)	BG9	12	0.8	1.6	2.7	4.1	5.2	
	E10	12	0.5	0.9	1.2	1.6	8.8	
	E11	12	0.9	1.6	4.6	5.1	12.0	
	E9	12	0.7	0.9	1.8	5.9	20.0	
	MB-1	12	1.4	2.6	3.1	4.7	8.9	
	N12	12	0.3	0.5	0.6	1.2	2.4	
	N5-1	12	0.5	2.8	3.4	4.8	13.0	
	WHIP	12	0.3	0.6	0.7	1.4	11.0	
Fecal Coliform (coliforms $100mL^{-1}$)	BG9	12	<50	13	17	200	1200	KM
	E10	11	<2	14	42	160	640	KM
	E11	10	<2	<2	54	400	880	KM
	E9	12	<2	8	75	880	27000	KM
	MB-1	11	<10	23	100	1500	9400	KM
	N12	11	<2	5	67	260	9500	KM
	N5-1	11	<10	25	56	350	5000	KM
	WHIP	12	<2	8	25	80	1500	KM
Total Coliform (coliforms $100mL^{-1}$)	BG9	12	<500	91	460	2300	5700	KM
	E10	12	45	298	2500	6275	17000	
	E11	11	91	235	2900	4500	12000	
	E9	12	45	255	2000	4925	33000	
	MB-1	12	80	458	1200	8775	33000	
	N12	12	<200	160	1300	8000	38000	KM
	N5-1	12	<200	270	1300	10000	27000	KM
	WHIP	12	71	278	670	6275	12000	
Dissolved Oxygen (mg L^{-1})	BG9	12	2.5	4.3	8.1	11.5	12.7	
	E10	12	7.5	7.8	11.4	13.5	17.2	
	E11	12	0.7	5.2	9.0	11.6	19.6	
	E9	12	2.8	5.0	6.6	8.4	10.3	
	MB-1	12	6.7	8.1	10.5	12.4	13.7	
	N12	12	9.0	10.6	11.3	12.3	16.5	
	N5-1	12	5.2	8.1	10.3	11.9	12.6	
	WHIP	12	8.3	10.1	10.7	12.9	15.7	
pH	BG9	12	6.63	7.13	7.22	7.31	7.41	

Table 4.4 2016 summary statistics for Kensico watershed streams.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum	Note
	E10	12	7.40	7.57	7.67	7.72	7.95	
	E11	12	7.16	7.33	7.43	7.51	7.94	
	E9	12	6.47	6.63	6.72	6.87	6.99	
	MB-1	12	6.74	6.99	7.12	7.20	7.43	
	N12	12	7.34	7.70	7.80	7.90	8.34	
	N5-1	12	7.15	7.43	7.49	7.55	7.71	
	WHIP	12	7.18	7.67	7.76	7.92	8.13	
Temperature (°C)	BG9	13	2.4	4.7	10.3	21.1	24.0	
	E10	12	0.0	6.3	9.7	19.7	21.0	
	E11	13	2.6	5.1	10.0	19.9	23.5	
	E9	12	0.3	1.9	7.4	17.7	20.4	
	MB-1	12	3.3	4.9	10.3	19.5	21.1	
	N12	12	-0.5	7.2	9.6	17.8	19.3	
	N5-1	12	0.3	5.6	10.6	19.2	21.9	
	WHIP	12	-0.4	6.0	9.9	19.9	22.1	

Summary statistics for data containing nondetects was estimated using techniques recommended in Helsel (2005) using an R program developed for U.S. Environmental Protection Agency (Bolks et al. 2014). The Note column indicates which analysis method was used to determine the statistics when there were censored data. KM indicates Kaplan-Meier, ROS indicates robust ROS, and >80% indicates that greater than 80 % of the data are censored and statistics cannot be estimated, so the detection limit, preceded by "<", is reported.

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. Figure 4.5 lists the dates and results of the turbidity curtain inspections carried out in 2016. When inspections indicate that maintenance is required, Bureau of Water Supply Systems Operations is notified and Operations staff perform the appropriate repairs or adjustments.

Table 4.5 Visual inspections of the Kensico Reservoir turbidity curtains.

Date	Observations
01/13/16	Curtains appear intact and afloat as seen from shore.
01/28/16	Curtains appear intact and afloat as seen from shore.
02/11/16	Curtains appear intact and afloat as seen from shore.
02/23/16	Curtains appear intact and afloat as seen from shore.
03/09/16	Curtains appear intact and afloat as seen from shore.
03/24/16	Curtains appear intact and afloat as seen from shore.
04/06/16	The curtain appears intact and floating as seen from shore, except that a part of the boom on the Point is washed ashore.
04/20/16	The curtain appears intact and floating as seen from shore, except that a part of the boom on the Point is washed ashore.
05/04/16	The turbidity curtains on the DEL18 cove point and at the CATUEC are attached firmly to the anchor points and are afloat. The turbidity curtain outside Malcolm Brook appears largely intact and afloat, however there is one section of yellow curtain that potentially has come untethered.
05/18/16	Curtains appear intact and afloat as seen from shore.
06/15/16	Curtains appear intact and afloat as seen from shore.
06/29/16	Curtains appear intact and afloat as seen from shore.
07/13/16	Curtains appear intact and afloat as seen from shore.
07/27/16	Curtains appear intact and afloat as seen from shore. DEL18 boom and curtain appear separated.
08/12/16	Curtains appear intact and afloat as seen from shore. DEL18 boom and curtain appear separated.
08/24/16	Curtains appear intact and afloat as seen from shore.
09/07/16	Curtains appear intact and afloat as seen from shore.
09/21/16	Curtains appear intact and afloat as seen from shore.
10/05/16	Curtains appear intact and afloat as seen from shore.
10/20/16	Curtains appear intact and afloat as seen from shore.
11/02/16	Curtains appear intact and afloat as seen from shore.
12/01/16	Curtains appear intact and afloat as seen from shore.
12/14/16	Curtains appear intact and afloat as seen from shore.
12/28/16	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 can 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, avian 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 then 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.

The Waterfowl Management Program (WMP) has implemented standard bird management techniques at several NYC reservoirs that are approved by the U.S. Department of Agriculture’s Animal and Plant Health Inspection Service’s Wildlife Services (USDA), and in part under permit by the U.S. Fish and Wildlife Service (USFWS) and the New York State Department of Environmental Conservation (NYSDEC). DEP maintains annual depredation permits 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, active nest removals of terrestrial avian species, remote-control boats, and physical chasing; bird deterrence measures include waterbird reproductive management, shoreline fencing, bird netting, overhead bird deterrent wires, and meadow management. In addition, in advance of storm events that are expected to yield excessive precipitation levels, pre-storm wildlife sanitary surveys are conducted adjacent to the Delaware Shaft 18 Effluent Facility and along stream corridors entering Kensico Reservoir near the source water intake. All wildlife fecal excrement (mostly mammalian) collected during these surveys is identified to species and disposed of in advance of the storms to prevent the feces from being washed into the reservoir.

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.

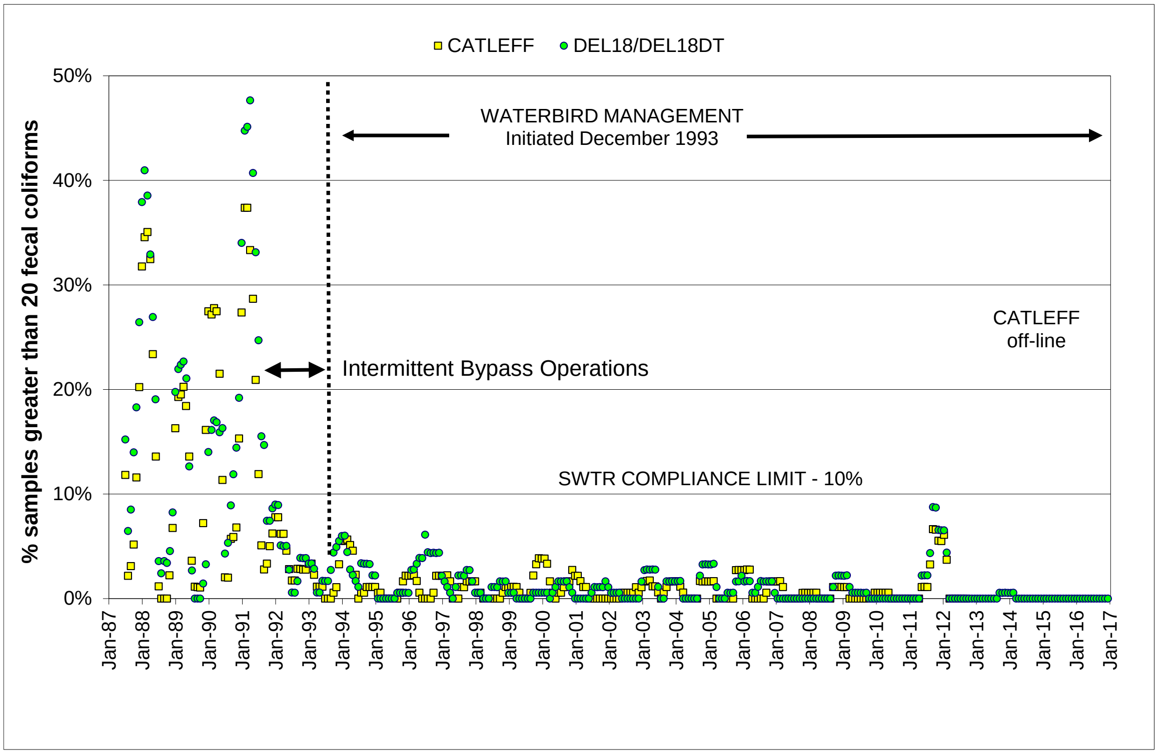


Figure 4.5 Percent of keypoint fecal coliform samples at Kensico Reservoir greater than 20 fecal coliforms $100mL^{-1}$ for the previous six-month period, 1987-2016. The vertical dashed line indicates the year in which the WMP was implemented.

4.5. Kensico Research Projects and Special Investigations

4.5.1. Bryozoans

Background

Bryozoans have been observed in Kensico Reservoir by DEP staff for decades. As early as the late 1980s and early 1990s the most obvious bryozoan, due to its large, gelatinous, spherical shape, was identified as *Pectinatella magnifica. Pectinatella* has been seen in coves throughout the reservoir, near the shoreline on branches and rocks, in the narrowed channel by the Rye Lake Bridge, and at the Delaware outflow of the reservoir at Shaft 18. Moreover, it has been observed in numerous other reservoirs throughout the watershed. The presence of these organisms was inconsequential until the fall of 2012, shortly after the UV Disinfection Facility came on line. Bryozoan colonies were found downstream of Shaft 18 at the UV 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.

Monitoring

DEP staff began monitoring bryozoan colonies in the sluice gates at Delaware Shaft 18 using an underwater video camera from April through September of 2014. Since no colonies were observed in April 2014, nor most of May, the 2015 monitoring began in June. For 2016, monitoring started on June 15 and continued approximately every few weeks until the last survey on September 21. A total of five surveys with video observations were completed in 2016. The process of monitoring included the lowering of 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. Notes on water quality parameters (temperature, turbidity, etc.) and operational conditions (flow rate) were also taken at the time of the visits. Video monitoring predominantly focused on the access ladder and adjacent wall area in each sluiceway.

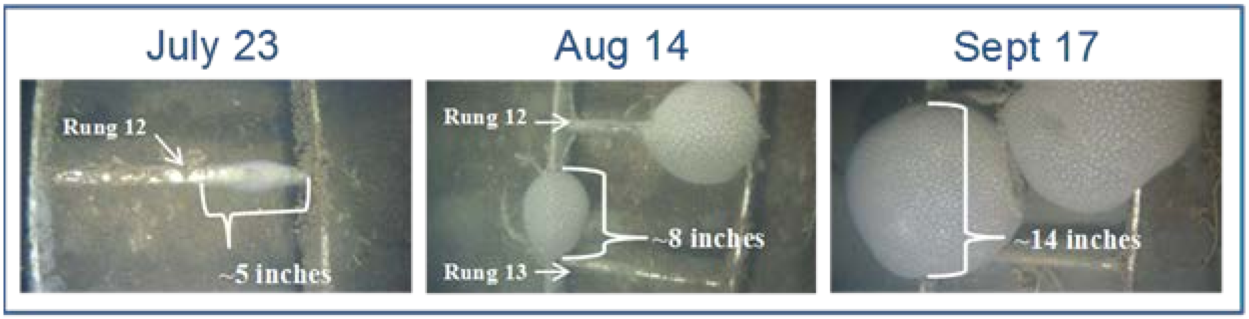
Results

Numerous still-frame shots documenting the temporal growth of colonies were collected from the videos, usually on specific ladder rungs. As has occurred in the previous two years, *Cristatella mucedo* appeared earlier in the season than *Pectinatella magnifica*, and it resided at lower depths since it prefers cooler water than *Pectinatella*. *C. mucedo* was present in June, while *P. magnifica* did not appear until the July 14 survey. Similarly, *C. mucedo* began to die and peel off the walls in mid-August; whereas *P. magnifica* survived until late September.

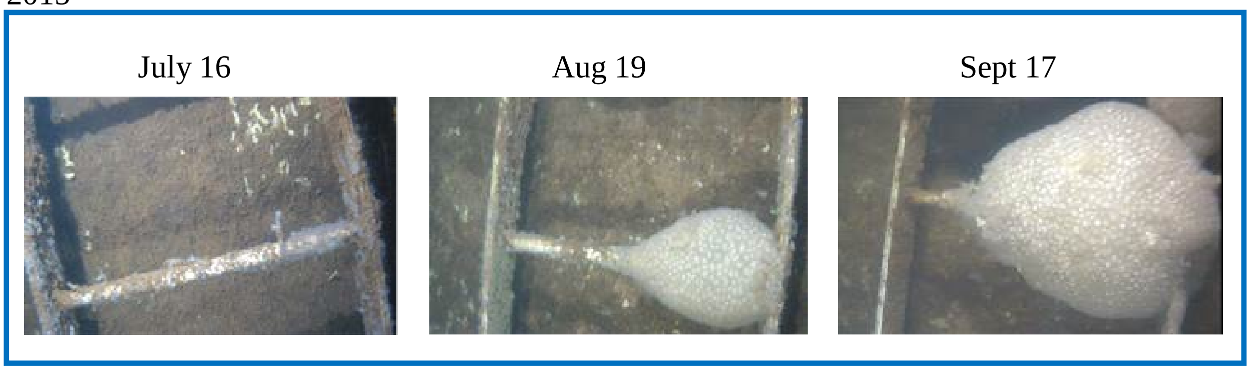
Not unlike when sluice gate 5 was closed in 2015, there was a shutdown of sluice gate 2 in 2016 that yielded similar observations of decreased colonies. Sluice gate 2 was shut down on July 6 and remained closed throughout the remaining bryozoan monitoring survey period. As had been noted in sluice gate 5 in the previous year, sluice gate 2 had a reduction of growth and no additional growth of either bryozoan throughout the season after shutdown. It is apparent that these colonies cannot thrive without a minimum level of flow to sustain growth. 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 in Figure 4.6 illustrates how quickly the *P. magnifica* colonies develop during the later summer months and compares three years of photos on the same ladder rung (#12) for 2014, 2015, and 2016. The colonial growth rate appears to be very similar in 2016 compared to approximately the same three dates in 2014 and 2015. Details related to the location on the rung are interesting as well, and may provide guidance for more thorough cleaning of areas where colonies have regrown. Many large colonies (more than 60 colonies larger than 12 inches in diameter on the ladder and walls) were present by late September when divers were contracted to remove them and, as in the past, sluice gate 3 was the most populated. The largest of the *P. magnifica* colonies had grown to several feet wide. Monitoring will continue and a summary report of findings will be produced by the end of 2017.

2014



2015



2016

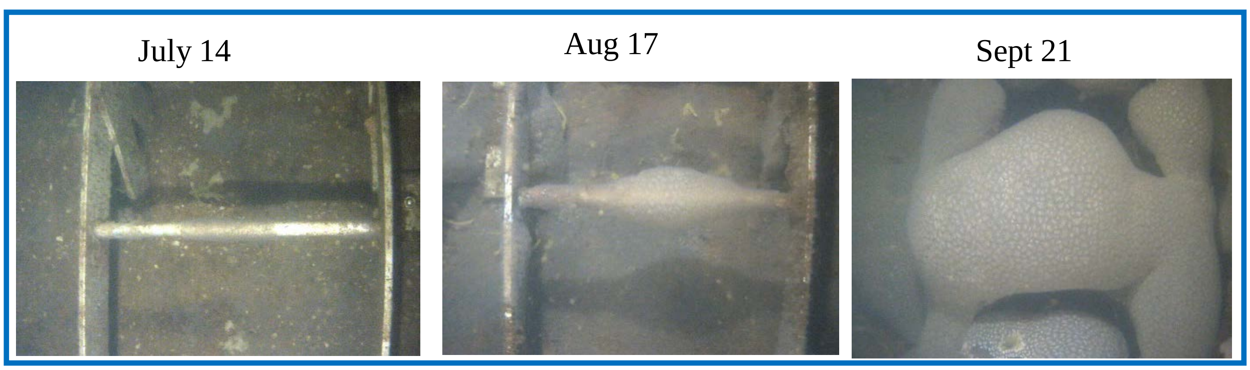


Figure 4.6 Photographs showing progression of *P. magnifica* colony growth on ladder rungs 12 and 13 at Delaware Shaft 18 in Sluice Gate 3 for 2014 to 2016. For scale, each of the ladder rungs are about 12 inches across.

4.5.2. Special Investigations within the Watershed

There were four special investigations conducted during 2016 in the Kensico watershed. All of these special investigations involved stream storm sampling at Malcolm Brook and/or N5 tributaries. A brief summary of each investigation and the events follow in chronological order.

Storm Event Kensico Reservoir – June 5–6, 2016

A storm event occurred that resulted in approximately 0.87 inches of rain, triggering storm event monitoring at Kensico Reservoir tributary N5. This event occurred over a period of approximately 48 hours. Analytes investigated were turbidity, fecal coliforms, and conductivity, as well as Microbial Source Tracking (MST). There was a sharp increase of flow as indicated in the hydrograph for N5-1 and an accompanying dramatic increase in turbidity at the onset of the storm event**.** Fecal coliform concentrations mirrored this initial high turbidity concentration, gradually decreasing over time**.** The reservoir effluent at DEL18DT had no turbidity issues as a result of this storm (≤ 1.5 NTU), and fecal coliform results did not exceed 3 fecal coliforms 100mL^{-1} at the reservoir outflow. MST with Bacteroidales detected human markers at trace levels in two of the four N5-1 storm samples analyzed, occurring at the peak and descending limb of the hydrograph. Both samples were also positive for at least one additional human marker during supplemental analysis.

Storm Event Kensico Reservoir – October 21 – 22, 2016

A storm event occurred that resulted in approximately 1.72 inches of rain, triggering storm event monitoring at Kensico Reservoir tributaries N5 and Malcom Brook. Analytes investigated were turbidity, fecal coliforms, and conductivity, as well as MST. Data indicate a sharp increase of flow for both streams followed by more a gradual decline. Fecal coliform concentrations spiked just before the peak in flow at N5-1 (maximum concentration of 42,000 fecal coliforms 100mL^{-1}). MB-1 displayed a lower maximum (11,000 fecal coliforms 100mL^{-1}) and a more gradual increase in fecal coliform during the storm event. As the stream returned to base flow, both turbidity and fecal coliforms at both streams declined but remained elevated in the remaining storm event samples**.** The reservoir effluent at DEL18DT had no turbidity issues as a result of this storm (≤0.90 NTU) and fecal coliform results rose to just 5 fecal coliforms 100mL^{-1} on October 23, after which levels dropped and remained under 4 fecal coliforms 100mL^{-1} for the rest of October. MST with Bacteroidales detected human markers at trace levels in one of the four N5-1 storm samples analyzed, occurring at approximately peak stormflow. Neither of the two MB-1 samples were positive for human markers.

Storm Event Kensico Reservoir – November 15–16, 2016

A storm event occurred that resulted in approximately 1.56 inches of rain, triggering storm event monitoring at Kensico Reservoir tributary N5. Analytes investigated were turbidity, fecal coliforms, and conductivity as well as MST. Flow data from N5-1 show there was a sharp increase in flow on November 15 up to about 4.2 CFS, remaining relatively high overnight and then descending over the next two days. Fecal coliform and turbidity results peaked along with flow, although only at moderately elevated levels (2,000 fecal coliforms $100mL^{-1}$ and 20 NTU, respectively). The reservoir outflow at DEL18DT had no turbidity issues as a result of this event (≤0.75 NTU), and fecal coliform results did not exceed 2 fecal coliforms $100mL^{-1}$ for 10 days after the storm. MST with Bacteroidales detected human markers at trace levels in two out of the four N5-1 storm samples analyzed, occurring at the peak and descending limb of the hydrograph.

Storm Event Kensico Reservoir – November 29–December 1, 2016

A storm event occurred that resulted in over 2 inches of rain and met the criteria for triggering storm event monitoring at Kensico Reservoir tributaries N5 and Malcolm Brook. This event occurred over a period of 48 hours with an approximate precipitation amount totaling 2.46 inches. Analytes investigated were turbidity, fecal coliforms, and conductivity, as well as MST. Hydrographs indicate there were two distinct periods of rain along with two peaks in discharge for both streams, with a higher flow in the second peak. Turbidity and fecal coliform concentrations generally followed the rise and fall of flow, but only fecal coliforms spiked higher during the second peak. Changes in turbidity and fecal coliforms were minimal at the nearby limnological sampling sites, with limnological fecal coliform data suggesting little influence from stream runoff. The reservoir outflow at DEL18DT had no turbidity issues as a result of this storm (≤0.75NTU), and fecal coliform results did not exceed 2 fecal coliforms $100mL^{-1}$, with levels returning to <1 fecal coliforms $100mL^{-1}$ by December 2, 2016. MST detected human markers at trace levels in two of the five N5-1 storm samples analyzed, occurring after the peak of the first flush and on the descending limb of the second peak flow of this two-part storm. None of the four MB-1 samples analyzed were positive for human markers.

5. Pathogen Monitoring and Research

5.1. Introduction

Each year *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 collected 582 protozoan samples in 2016, of which 576 samples were analyzed. Additional samples (for method studies, etc.) accounted for 30 of these analyses, while the remaining 546 samples are discussed here. Samples collected from Kensico, New Croton and Jerome Park Reservoirs made up the largest portion of the sampling effort (39.9%, Figure 5.1), with watershed streams composing the second largest component (31.9%). Samples collected at the Hillview downtake, upstate reservoir releases, and the wastewater treatment plants combined to make up the remaining 28.2%. Samples collected for protozoan analysis were analyzed by Method 1623.1 with EasyStain. In addition to protozoan sampling, DEP collected 48 HEV samples in 2016. All virus samples were analyzed by DEP using a modified version of the Information Collection Rule (ICR) Manual Method (USEPA 1996).

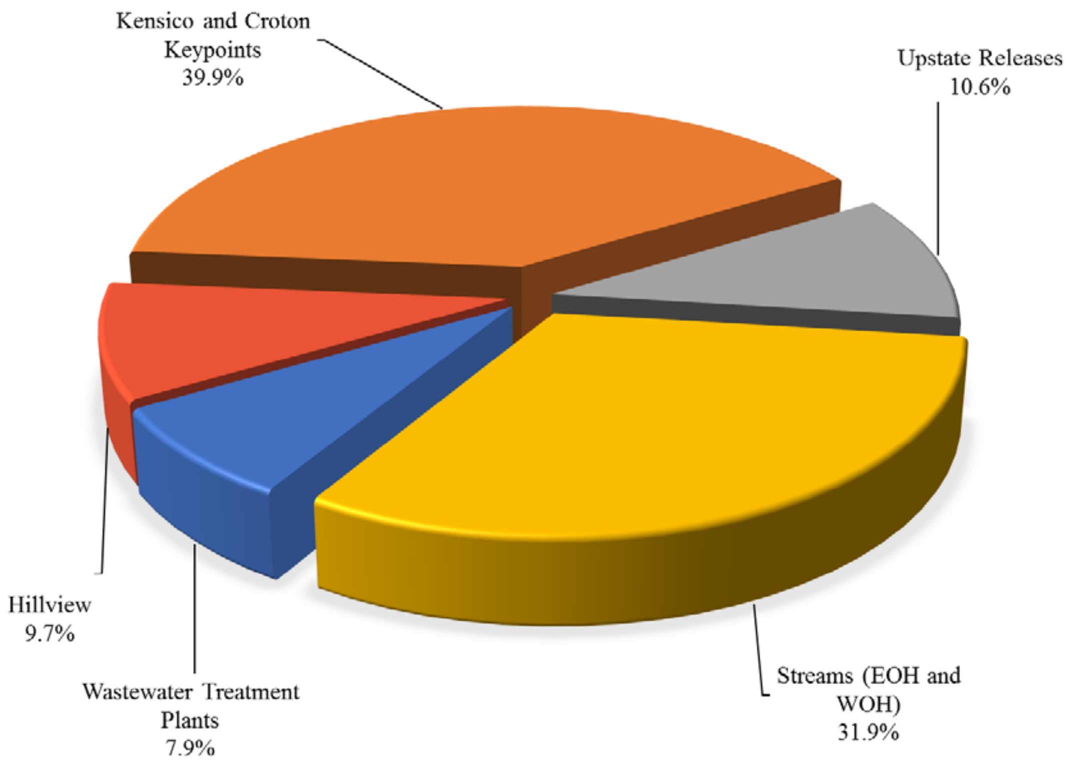


Figure 5.1 DEP protozoan sample collection type distribution for 2016.

As with most years, there are often notable changes or operational facts worth mentioning. The Catskill Aqueduct south of Kensico Reservoir remained shut down throughout 2016. Virus sampling frequency at the 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. Additionally, sample collection frequency for the outflow of New Croton Reservoir (CROGH) was changed from monthly to quarterly after October 2016, while protozoan samples continue to be collected weekly at the Jerome Park Reservoir outflow for Croton source water. 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.

5.2. Source Water Results

Catskill Aqueduct Inflow

There were seven samples out of 52 (13.5%) with detection of *Cryptosporidium* at the Catskill Aqueduct inflow to Kensico Reservoir (CATALUM) in 2016 (Table 5.1), similar to the 6 detections found in 2015. The mean annual *Cryptosporidium* concentration was 0.17 oocysts $50L^{-1}$ in 2016, compared to 0.15 oocysts $50L^{-1}$ in 2015.

There were 17 samples out of 52 (32.7%) positive for *Giardia* in 2016, compared to nine samples (7.3%) positive in 2015. The mean *Giardia* concentration for 2016 was 0.83 cysts $50L^{-1}$, compared to 0.50 cysts in 2015. The 2016 *Giardia* annual mean is very close to the historical average (0.89 cysts $50L^{-1}$) for CATALUM (October 2001 – December 2015).

HEV were detected at CATALUM in three of the 12 samples (25.0%) in 2016, similar to the 27.5% positive in 2015 (n=40). Mean HEV concentration for 2016 was 0.38 MPN $100L^{-1}$, which is lower than both the 2014 and 2015 means (1.20 and 0.72 MPN $100L^{-1}$, respectively). As mentioned in last year's report, the monitoring frequency for virus sampling at keypoints was reduced from weekly to monthly beginning in September of 2015, which can make it more difficult to compare data with historical averages.

Table 5.1 Summary of *Cryptosporidium*, *Giardia*, and HEV compliance monitoring data at the five DEP keypoints for 2016.

	Keypoint Location	Number of Positive Samples	Mean[2]	Maximum
Cryptosporidium oocysts 50L^{-1}	CATALUM (n=52)	7	0.17	2
	DEL17 (n= 52)	6	0.17	3
	DEL18DT (n=52)	4	0.10	2
	CROGH[1] (n= 12)	0	0.00	0
	1CR21 (n= 45)	9	5.64	241
Giardia cysts 50L^{-1}	CATALUM (n=52)	17	0.83	9
	DEL17 (n=52)	20	1.06	6
	DEL18DT (n=52)	20	0.73	5
	CROGH[1] (n=12)	2	0.17	1
	1CR21 (n=45)	22	1.11	11
Human Enteric Virus 100L^{-1} (HEV)	CATALUM (n=12)	3	0.38	2.24
	DEL17 (n= 12)	2	0.60	5.04
	DEL18DT (n=12)	1	0.18	2.16
	CROGH[1] (n= 10)	3	0.33	1.19
	1CR21 (n= 0)	NS[3]	NS[3]	NS[3]

[1]Includes alternate sites sampled to best represent outflow 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.
[3]NS = not sampled.

Delaware Aqueduct Inflow and Outflow

Cryptosporidium detections at Kensico Reservoir's Delaware inflow (DEL17) were similar in 2016 (six in 52 samples, 11.5%) to 2015 (five in 52 samples, 9.6%). The mean annual concentration of 0.17 oocysts 50L^{-1} for 2016 was the highest since 2004 (0.20 oocysts 50L^{-1}) (Figure 5.2). *Cryptosporidium* detections at the Delaware outflow from Kensico Reservoir (DEL18DT) were lower in 2016 (four in 52 samples, 8.2%) compared to 2015 (eight in 52 samples, 15.4%), but quite similar to the number of detects found in 2014 (four in 54 samples, 7.4%). The mean annual concentration for DEL18DT in 2016 (0.10 oocysts 50L^{-1}) was also similar to 2014 (0.11 oocysts 50L^{-1}).

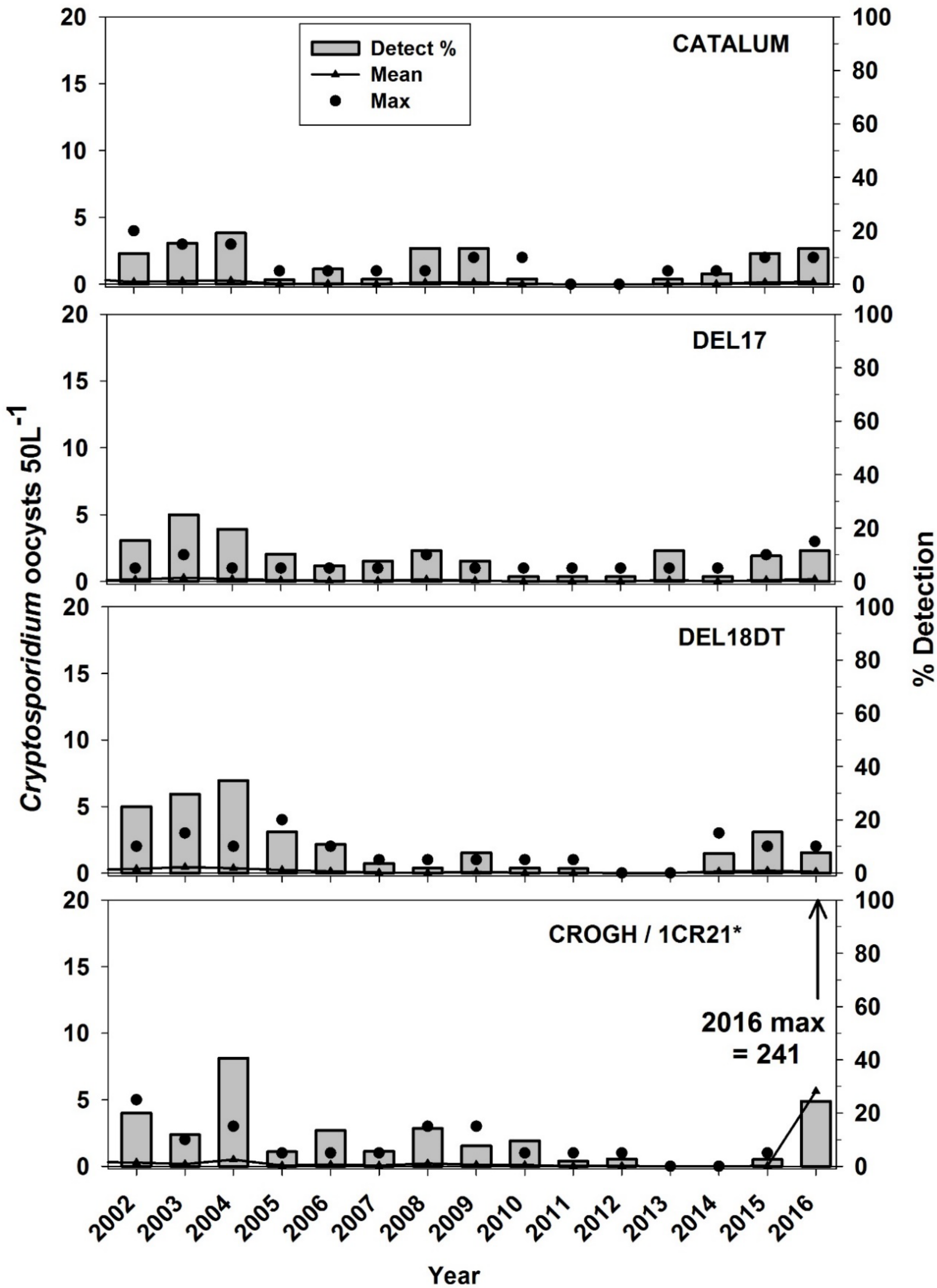


Figure 5.2 *Cryptosporidium* annual percent detection, mean concentration, and maximum result for the keypoint sites during each year from 2002 to 2016. *1CR21 (the outflow of Jerome Park Reservoir) became the Croton System source water site in May 2015.

The number of *Giardia* detections at DEL17 in 2016 (20 in 52 samples, 38.5%) was similar to 2015 (19 in 52 samples, 36.5%), however this was a decrease from previous years when detections had averaged 62.5% (October 2001- December 2014). Likewise, mean *Giardia* concentrations were similar in 2015 and 2016 (1.61 and 1.08 oocysts $50L^{-1}$, respectively), but lower than the historical mean (1.82 oocysts $50L^{-1}$, October 2001 – December 2014). For the third consecutive year, samples collected in 2016 from DEL18DT resulted in the same number of detections as DEL17. Moreover, with 20 detections in 2016 (38.5%), it was similar to detections in 2015 at DEL18DT (19 detections). This site had a slightly lower mean *Giardia* concentration in 2016 (0.73 oocysts $50L^{-1}$) compared to 2015 (0.85 oocysts $50L^{-1}$), which had been the lowest observed since DEP began using Method 1623HV in 2001 (Figure 5.3).

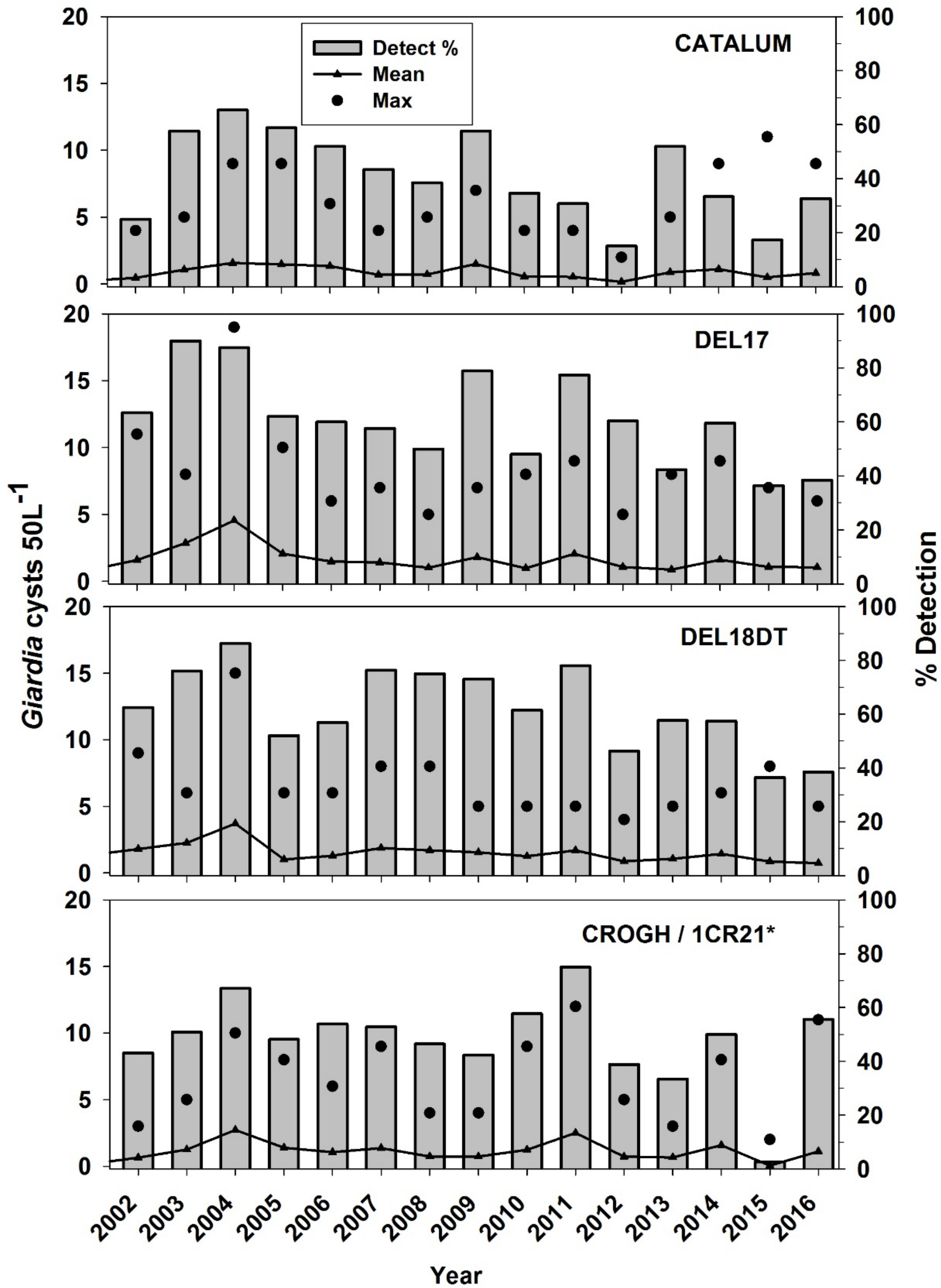


Figure 5.3 *Giardia* annual percent detection, mean concentration, and maximum result for the keypoint sites during each year from 2002 to 2016. *1CR21 (the outflow of Jerome Park Reservoir) became the Croton System source water site in May 2015.

HEV were detected in two out of 12 samples (16.7%) at DEL17, similar to 2015 when seven out 40 samples (17.5%) were positive for HEV. The mean HEV concentration for DEL17 in 2016 was 0.60 MPN $100L^{-1}$, which is within this site's historical range for the ICR Method (0.08 - 1.14MPN $100L^{-1}$ from 2004 to 2015) but higher than the 2015 mean of 0.25 MPN $100L^{-1}$. DEL18DT had a similar HEV detection rate in 2016 (one out of 12 samples, 8.3%) compared to 2015 (3 out of 40 samples, 7.5%). The annual mean concentration for HEV at DEL18DT was 0.18 MPN $100L^{-1}$ in 2016, within the range of the mean for the previous two years (0.19 and 0.08 MPN $100L^{-1}$ for 2014 and 2015, respectively).

Croton System

This year marked the first full year that the outflow of Jerome Park Reservoir (1CR21) was considered the source water for the Croton System since filtration began in May of 2015. Weekly protozoan monitoring continued at 1CR21, with the exception of when the system was off-line, and a total of 45 samples were collected and analyzed in 2016.

Jerome Park Reservoir

There were nine detections of *Cryptosporidium* out of 45 samples (20%) this year, compared to zero out of 35 at this site in 2015. On December 19, one of these positive samples had 241 oocysts $50L^{-1}$. A follow up sample was collected two days later on December 21, which was negative for *Cryptosporidium*, along with the next weekly sample on December 27. Genotyping of the December 19 *Cryptosporidium* positive slide was consistent with the deer mouse genotype that we have seen previously in the watershed (W1). The DNA segments studied from the oocysts on the slide were in 100% agreement with the target genome of the Cryptosporidium sp. deer mouse genotype W1. The hsp70 sequence was a novel type but also suggested a rodent source. On December 21, an additional sample was collected for microbial source tracking analysis. This sample was only tested for the presence of a gull fecal marker and was positive; however, as a reminder, the corresponding duplicate sample on this day was negative for *Cryptosporidium*. The source of the 241 oocysts was likely a rodent source since the identification confidence was so high and the testing was done on the same 241 organisms actually recovered from the slide. Gulls had been reported in the area, so the detection of a fecal marker is not unexpected; but there is no direct data to link gulls to the *Cryptosporidium* recovered on December 19. Five off-line samples were also collected from 1CR21 in 2016 when the system was shut down. However, since not representative, those results are not included in these analyses.

Giardia was detected in 22 out of the 45 (48.9%) samples collected at 1CR21 in 2016, compared to zero detections from May through December 2015. The year 2016 was the first year with winter and spring data from this location. The mean concentration for *Giardia* at 1CR21 in 2016 was 1.11 cyst $50L^{-1}$.

New Croton Reservoir

Monthly protozoan monitoring continued at the New Croton Reservoir outflow (CROGH) through October 2016, with two additional samples taken in February. No *Cryptosporidium* was detected in any of these samples in 2016. There has only been one *Cryptosporidium* detection at CROGH in the past four years (2013-2016, n=50). The monitoring frequency for this site was reduced from monthly to quarterly in the autumn, so the October sample was the last to be taken at CROGH in 2016.

Giardia was detected in two of the 12 samples collected at CROGH in 2016 (1.00 cyst $50L^{-1}$, both in February). These results are similar to 2015, with the lowest percent positive (16.7%) and the lowest mean annual concentration (0.17 oocyst $50L^{-1}$) at this site since Method 1623HV began in October 2001 (Figure 5.3).

HEV were detected in three of the 10 monthly samples (30.0%) at CROGGH, with a mean annual concentration of 1.76 MPN $100L^{-1}$. This detection rate was bracketed by the two previous years (2014, 16.7% and 2015, 41.7%) which included monthly HEV sampling. However, due to the relatively low concentration of HEV in 2015 samples (maximum result of 1.19 MPN $100L^{-1}$), the mean concentration for 2016 (0.18 MPN $100L^{-1}$) was lower than most previous years. The routine virus sampling frequency was also changed from monthly to quarterly in October 2016. As a note, HEV sampling is not required at the 1CR21 location.

In general, *Giardia* continues to be detected more frequently and at higher concentrations during winter and spring months compared to summer and fall (Figure 5.4), as has been seen in results from previous years. It is important to note that the increase in *Cryptosporidium* and decrease in *Giardia* which began in 2015, and continued in 2016 at some sites, are believed to possibly be a result of the analytical change to Method 1623.1 with EasyStain and not an increase or decrease of these organisms in the environment. Additional years of data will be valuable in determining the possibility of an overall shift in the data.

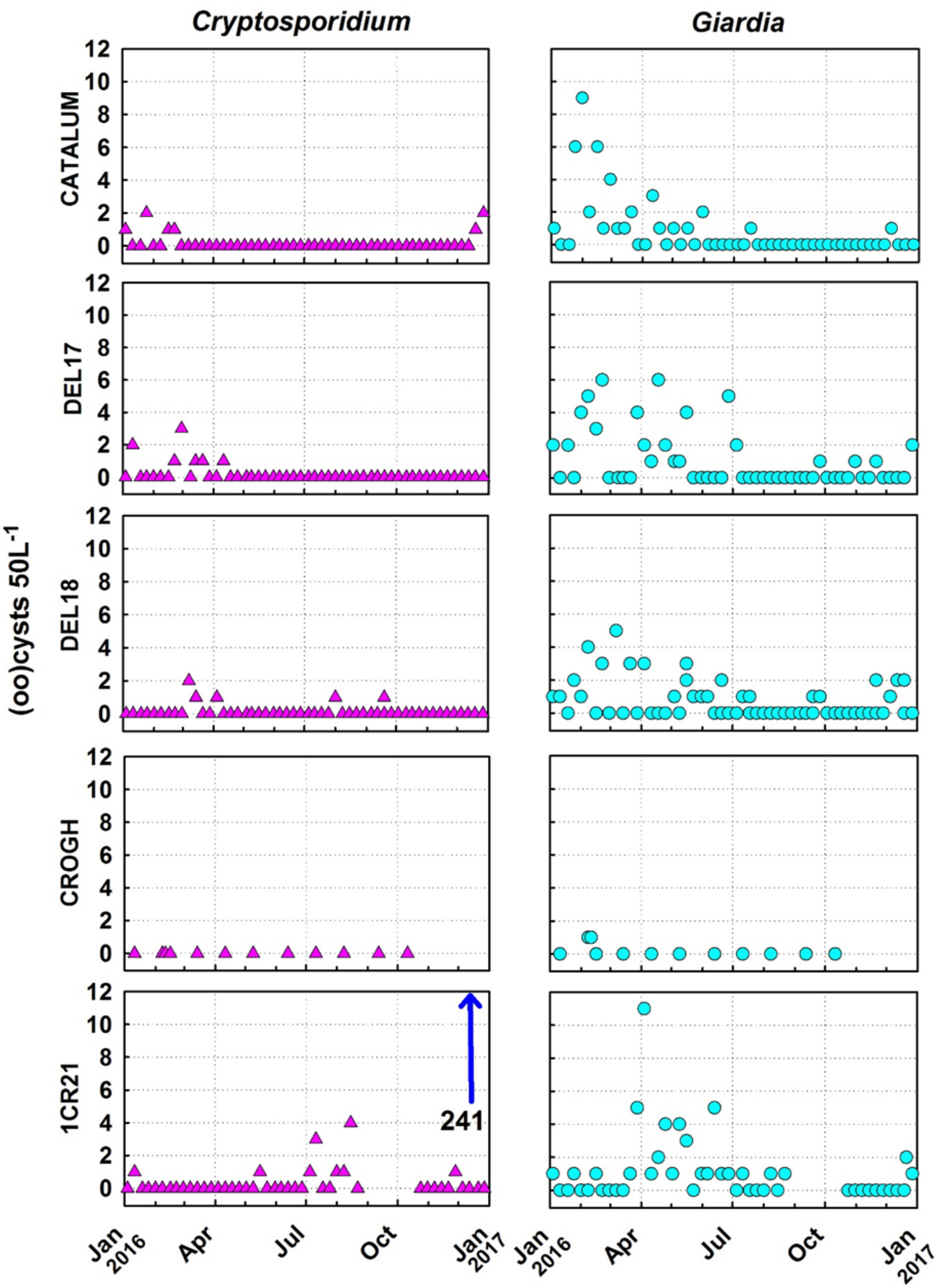


Figure 5.4 Weekly routine source water keypoint protozoan monitoring results for 2016.

5.2.1. 2016 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 land use, 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, such as the change in frequency of monitoring at the New Croton Reservoir outflow from weekly to monthly (August 2012) and then monthly to quarterly (October 2016), 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 modification has added a layer of complexity when comparing the current year's data to the historical dataset.

Cryptosporidium

In 2016, there were 13 samples positive (out of 104 pooled samples, 12.5%) for *Cryptosporidium* at the two Kensico Reservoir inflows (CATALUM and DEL17) compared to four positives at the outflow (n=52, 7.7%) (Table 5.2 and Table 5.3). There were more detects of oocysts at the Kensico inflows in 2016 than in the previous seven years. The mean *Cryptosporidium* concentration for both of the inflow sites in 2016 was 0.17 oocysts $50L^{-1}$. The highest mean concentration for either inflow site since 2004 was observed in 2016. Again, it was anticipated that we might see an increase in oocyst detection/concentration at some sites with the method change implemented in 2015. Conversely, *Cryptosporidium* detections at the Kensico Reservoir outflow were lower in 2016 than in 2015 (Table 5.3); however, not unlike some detection levels seen in the past.

There were nine samples positive for *Cryptosporidium* at the 1CR21 source water site in 2016, with a maximum concentration of 241 oocysts $50L^{-1}$. This single, very high, positive result greatly influenced the mean (5.64 oocysts $50L^{-1}$). Interestingly, there were no *Cryptosporidium* detections at the New Croton Reservoir outflow (CROGH) in 2016. This is the third year out of the last four with no detections at this site, and only three detections in the last six years (n=138) with a maximum concentration of 1 oocyst $50L^{-1}$.

Table 5.2 Annual sample detection and mean oocyst concentration of *Cryptosporidium* at inflow keypoints to Kensico Reservoir 2002-2016.

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
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
2016	7	13.5	0.17	6	11.5	0.17

Table 5.3 Annual sample detection and mean concentration of *Cryptosporidium* at Kensico and New Croton Reservoir source water outflows 2002-2016.

Site	DEL18DT			CROGH / 1CR21		
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[2]	8	15.4	0.17	1	2.6	0.03
2016[2]	4	7.7	0.10	9	20.0	5.64

[1]Monitoring at CROGH was modified from weekly to monthly in August 2012.
[2]The source water sampling site for the Croton System changed from CROGH to 1CR21 on May 4, 2015.

Giardia

Giardia concentrations at the three Kensico keypoints and the New Croton Reservoir outflow were low in 2016, with two of the sites (DEL18DT and CROGH) reporting the lowest mean annual concentrations since 2002 for the second year in a row. DEL17 had one more detection in 2016 than in 2015, which had the lowest number of detections (19 positives out of 52 samples) with the lowest percent detection (36.5%) compared to historical data. CATALUM had a higher detection rate in 2016 (32.7%, n=52) than 2015 (17.3%, n=52), but still lower than the historical average of 41.2% (2002-2015, n=733). Seasonal variation in *Giardia* results can be discerned for all four keypoints (Figure 5.5), however, this seasonality is less apparent in the locally weighted regression (LOWESS) smoothed line for the New Croton outflow data due in part to the reduction in sampling frequency from weekly to monthly 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.

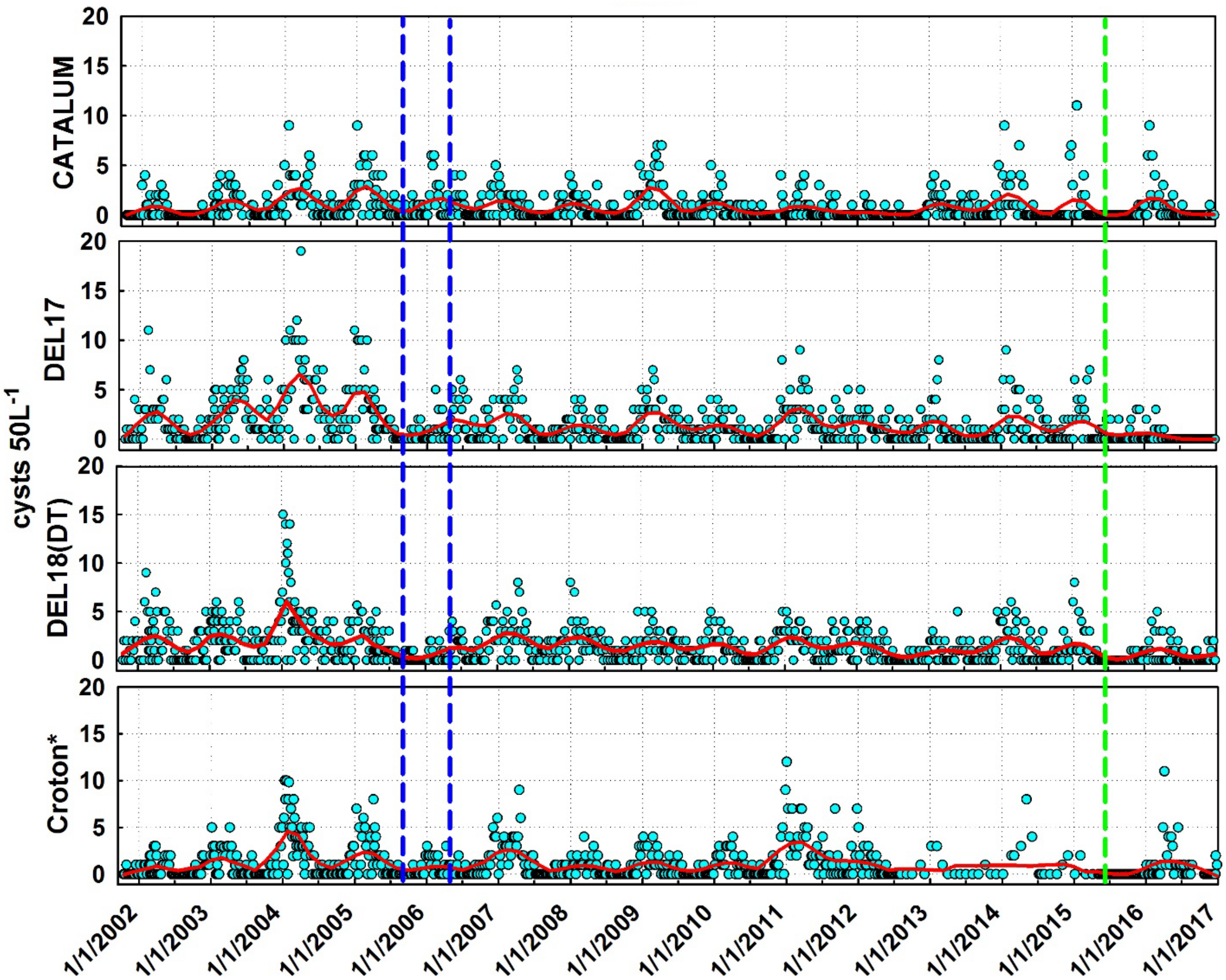


Figure 5.5 Weekly routine source water keypoint results for *Giardia* (circles), and LOWESS 5% smoothed regression (red curved line) from October 15, 2001 to December 31, 2016. The area between the blue dashed lines indicates the period during which DEP temporarily switched to EasyStain. The green dashed line indicates the change from Method 1623HV to Method 1623.1 with EasyStain. *The Croton System's source water sampling location changed from CROGH to 1CR21 on May 4, 2015.

Protozoan monitoring began in May of 2015 at the Jerome Park Reservoir outflow (1CR21), so 2016 is the first full year for protozoan sample collection. No *Cryptosporidium* or *Giardi*a were detected at this site in 2015. However, considering the seasonal nature of protozoan detections at the keypoint sites, it is not surprising that an increase might be observed when monitoring was conducted through the winter and spring of 2016. The elevated result of 241 oocysts $50L^{-1}$ in December of 2016 was well above the historical record for this or any other DEP keypoint site. The highest *Cryptosporidium* result found in a routine keypoint sample prior to this instance, was 19 oocysts $50L^{-1}$ at the Delaware inflow to Kensico Reservoir (DEL17) in March 2004. Subsequent sampling results, two days and one week after the December detections, were negative for *Cryptosporidium*.

5.2.2. 2016 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 2-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, which is the category that defines needing no additional treatment. 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. The year 2016 falls within the reporting period of the second round of the LT2 (April 2015 – March 2017). However, since this report only covers through 2016, results have been calculated here using data from the two most recent complete calendar years (January 1, 2015-December 31, 2016) 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, 2015 to December 31, 2016.

Site	Number of routine samples 2015-2016	Number of non-routine samples 2015-2016	Total n
New Croton (CROGH)	22	2	24
New Croton (1CR21)	79	1	80
Delaware (DEL18DT)	104	0	104

Unfiltered Supply

The Catskill/ Delaware System is NYC's unfiltered water supply. The 2015 to 2016 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 5.6). 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 outflow, the monthly means have generally been declining since 2009. As DEP has switched to a new method for protozoan analysis, which was predicted to possibly recover more *Cryptosporidium* from samples, at least some of the increase in the last year may be attributed to the new method.

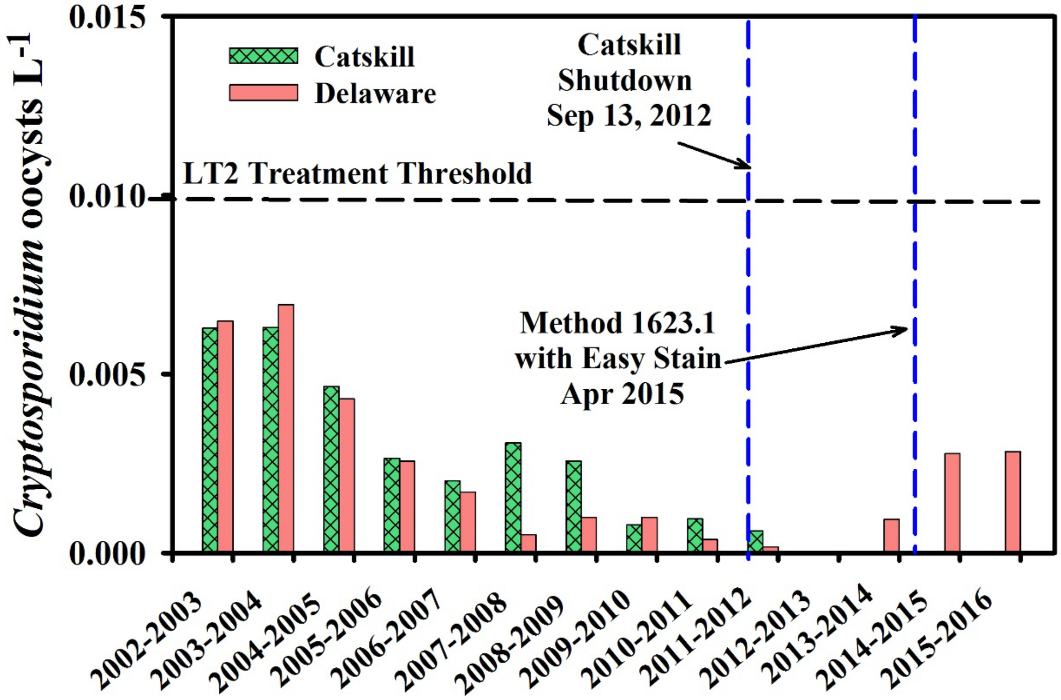


Figure 5.6 *Cryptosporidium* means using LT2 calculation method since initiation of Method 1623HV (1623.1 with EasyStain since April 2015) at the Delaware Aqueduct 2002-2016 and the Catskill Aqueduct 2002-2012. No means are reported for the Catskill Aqueduct for the last three 2-year spans as no samples were collected during these years due to aqueduct shutdown.

Filtered Supply

The Croton System is the source of NYC's filtered water supply. The source water site since filtration began in May 2015 is 1CR21, prior to which the sampled source water site was the outflow of New Croton Reservoir (CROGH). With less than two years of weekly results (n=80), 19 monthly means were averaged for a calculation of 0.0541 oocysts L^{-1} which is below the filtered system bin threshold value of 0.075 oocysts L^{-1} (Figure 5.7). The 2015 to 2016 mean of monthly means (22 months, n=24) for *Cryptosporidium* at CROGH was 0.0009 oocysts L^{-1}. This is very similar to the 2014-2015 mean of monthly means (0.0008 oocysts L^{-1}) and well below the LT2 threshold level of 0.01 oocysts L^{-1} for unfiltered systems.

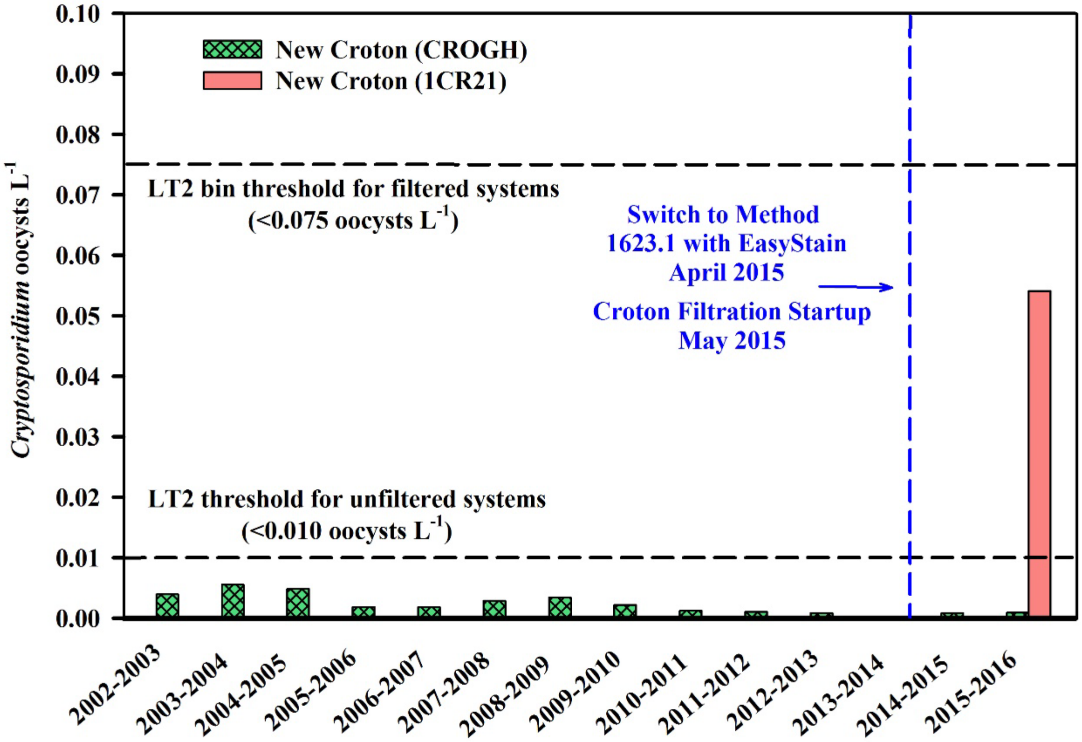


Figure 5.7 *Cryptosporidium* means using LT2 calculation method since initiation of Method 1623HV (1623.1 with EasyStain since April 2015) at the Croton System source water sites 2002-2016.

5.3. Upstate Reservoir Outflows

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 in two systems; Ashokan and Schoharie in the Catskill System, and Cannonsville, Neversink, Pepacton, and Rondout in the Delaware System. The outflow of each reservoirs is sampled monthly for protozoans to ensure high quality water prior to entering downstream reservoirs. In addition, the water leaving Ashokan Reservoir is monitored weekly for protozoans just upstream of Kensico Reservoir at the Pleasantville Alum Plant (CATALUM). Monthly sampling may be performed, but 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, two of the WOH reservoirs (Neversink and Pepacton) do not have samples for all 12 months of 2016.

From the 108 samples collected at WOH reservoir outflows in 2016, 10 samples (9.3%) were positive for *Cryptosporidium*, which were predominantly from the Ashokan outflow (7 of the 10). Overall, this is fewer than had been seen in 2015 (14 positives out of 104 samples), and just a few more than were found in each of the two previous years (7 detections each in 2014 and 2013). CATALUM had the highest detection rate of oocysts of all the WOH reservoir outflow sites in 2016 (13.5%), and compared to the 2015 rate (11.5%) (Table 5.5). For the fifth year in a row, Neversink had one *Cryptosporidium* detection (1 oocyst $50L^{-1}$). Rondout Reservoir's outflow also had one *Cryptosporidium* detection in 2016, for a combined total of 2 detections in the last 8 years (2009 to 2016). Both were 1 oocyst $50L^{-1}$. Neither Pepacton nor Cannonsville outflows had *Cryptosporidium* detections in 2016.

Table 5.5 Summary of 2016 protozoan results for upstate reservoir outflows.

		Cryptosporidium				***Giardia***			
Site	**n**	**Mean[1] ($50L^{-1}$)**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**	**Mean ($50L^{-1}$)**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**
Schoharie	12	0.33	8.3%	5 (50.0L)	0.08	3.17	41.7%	21 (50.0L)	0.42
Ashokan (CATALUM)	52	0.17	13.5%	2 (50.0L)	0.04	0.83	32.7%	9 (50.0L)	0.18
Cannonsville	12	0.00	0.0%	0	0.00	1.50	41.7%	9 (50.1L)	0.18
Pepacton	11	0.00	0.0%	0	0.00	0.20	9.1%	2 (45.3L)	0.04
Neversink	9	0.11	11.1%	1 (50.2L)	0.02	0.85	33.3%	3 (50.0L)	0.06
Rondout	12	0.08	8.3%	1 (50.1L)	0.02	0.42	16.7%	4 (50.1L)	0.08

[1]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.

In 2016, there were 33 *Giardia* detections (30.6%) out of the 108 samples collected at upstate reservoir outflow sites, compared with 28 positive samples out of 104 (27.0%) in 2015. Schoharie and Cannonsville Reservoir outflows had the highest detection rate for *Giardia* (41.7%, 5 out of 12 samples). These two sites also had the highest detection rates in 2015 (50.0% and 57.1%, respectively). Schoharie also had the highest mean annual *Giardia* concentration in 2016 (3.17 cysts $50L^{-1}$) and in 2015 (5.55 cysts $50L^{-1}$). These annual means are relatively low compared to the historical mean of 10.68 cysts $50L^{-1}$ (2002-2015) for the Schoharie outflow. *Giardia* concentrations were low in samples from the other five WOH reservoir outflows with no samples greater than 10 cysts $50L^{-1}$, and annual means at or below 1.50 cysts $50L^{-1}$. As previously explained, the method change may be a factor in the overall lower detection rate and concentration of *Giardia* at upstate reservoir outflows in 2016.

In East of Hudson (EOH), as part of a two-week pre-activation startup sampling program (prior to being able to pump Cross River Reservoir water into the Delaware Aqueduct), two protozoan samples were collected at the Cross River Pump Station (CROSSRVVC) on November 21 and 28. Both were negative for *Cryptosporidium* and *Giardia*. Also, annual HEV samples were collected at the Cross River and Croton Falls Pumping Stations on February 9. Both of these samples were negative for HEVs.

5.4. Watershed Streams and WWTPs

Routine monitoring of protozoans was conducted at 16 stream sites in the WOH and EOH watersheds in 2016. Eight stream sites in the WOH watershed were selected as part of an objective aimed at determining upstream sources of protozoans – four were sampled monthly and four were sampled bi-monthly. Monthly sampling continued at the eight perennial tributaries to Kensico Reservoir (EOH). Additionally, three sites above stream N12 were sampled as part of a special investigation. A total of 174 stream samples were collected and analyzed in 2016, 69 from the WOH watershed and 105 from the Kensico perennial streams.

In 2016, 43 samples were taken at WWTPs, with three 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 2016 were sampled monthly (PROXG, PROXG-1, PROXG-2, and S7i) and the remaining four (CDG1, S4, S5i, and CBS (formerly WDBN)) were sampled bimonthly (Figure 5.8). Two of these sites were new in May of 2016, both upstream of PROXG (Figure 5.9). In June of 2016, the monitoring location for the West Branch Delaware River at Beerston was moved from site WDBN (120 feet upstream of the Beerston Bridge) to site CBS (about 400 feet downstream of the bridge). CBS is approximately 750 feet downstream from the tributary Beers Brook and the added distance allows for a better mixed streamflow between West Branch Delaware and Beers Brook. This site modification consolidates routine and storm event monitoring and also provides for year-round access to the stream.

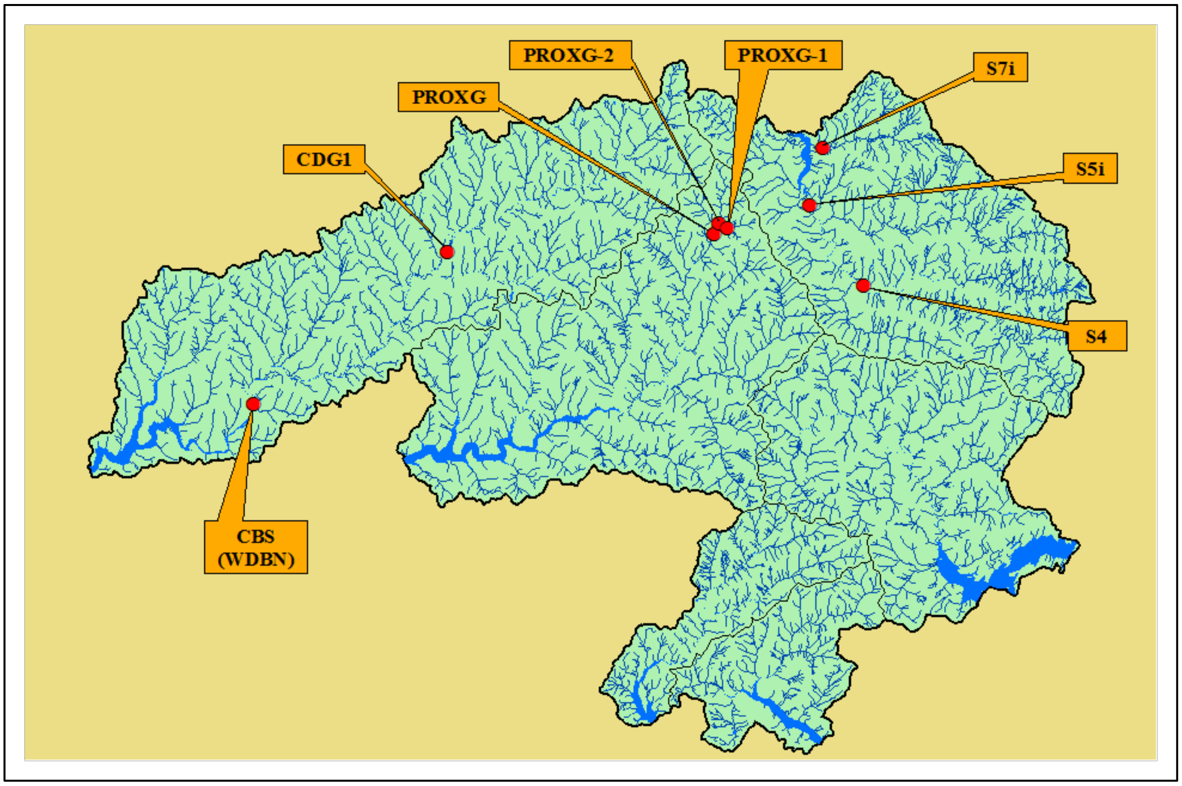


Figure 5.8 WOH stream sites monitored for protozoans in 2016.

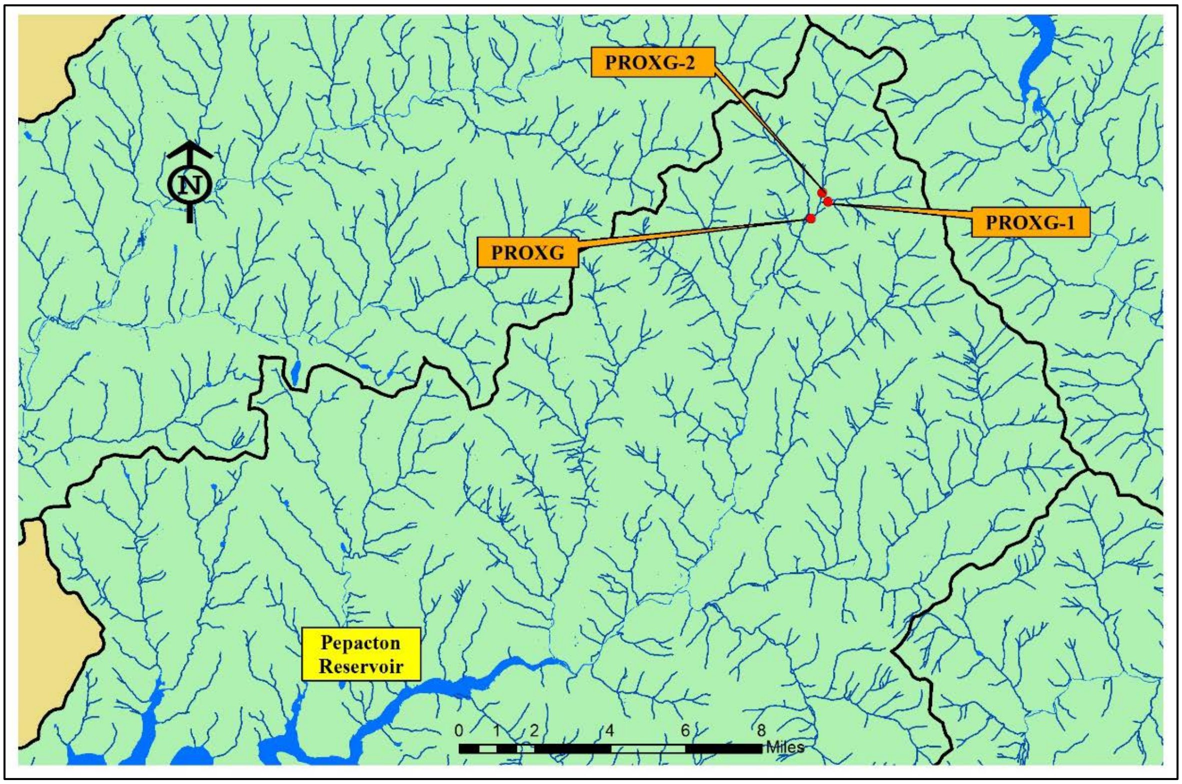


Figure 5.9 New stream sites monitored upstream of PROXG for protozoans in 2016.

Cryptosporidium oocysts were detected in 32 of the 69 WOH stream samples (46.4%) in 2016, similar to 2014 and 2015 (37.9% and 50.7%, respectively). Of the 69 samples, 46 were between 47 and 53 liters due to the occasional clogging of filters during sampling. While the goal for sampling is to filter 50 liters, the method allows for a minimum of 10 liters for an acceptable sample. In order to normalize the data, results are presented in several different ways: mean of all results calculated to a 50L volume, percent detection, maximum count per actual sampled volume, and maximum value per liter (Table 5.6). All WOH stream sites had calculated mean annual *Cryptosporidium* concentrations <2.00 oocysts 50L^{-1} in 2016 (Table 5.6) with CDG1, PROXG and CBS claiming the top three annual means. Five of the eight sites had detections of oocysts in 50% or more of their samples. CDG1 had the highest maxima per actual liters sampled (5 oocysts 50L^{-1}) in May, while PROXG had one sample in September that resulted in 2 oocysts in 11 liters, which translated to the highest per liter result for the year.

Table 5.6 Summary of WOH stream protozoan results for 2016.

		Cryptosporidium				*Giardia*			
Site	**n**	**Mean[1] (50L^{-1})**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**	**Mean (50L^{-1})**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**
CDG1	8	1.54	50.0%	5 (50.0L)	0.10	37.6	87.5%	152 (50.0L)	3.04
PROXG	12	1.65	58.3%	3 (50.3L)	0.18	8.24	83.3%	28 (50.2L)	0.56
PROXG-1	8	0.64	50.0%	1 (23.9L)	0.04	1.54	62.5%	10 (50.0L)	0.20
PROXG-2	8	0.69	37.5%	3 (50.0L)	0.06	2.33	75.0%	8 (38.8L)	0.21
S4	7	0.86	28.6%	4 (50.1L)	0.08	173	100%	409 (36.2L)	11.3
S5	7	1.08	57.1%	3 (50.0L)	0.06	76.3	85.7%	112 (50.0L)	3.51
S7i	12	0.42	25.0%	2 (50.1L)	0.04	116	100%	547 (50.1L)	10.9
WDBN/ CBS	7	0.86	71.4%	2 (50.1L)	0.04	9.57	100%	22 (50.0L)	0.44

[1]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.

Giardia cysts were detected in 60 of the 69 samples (87.0%) taken at WOH streams in 2016. In the NYC Watershed, *Giardia* is generally 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). Site S4 was found to have the highest calculated annual *Giardia* mean (173 cysts 50L^{-1}), among the highest percent detections (100%) and the highest maxima per liter (11.3 cysts L^{-1} in November). The October sample from S7i had the highest count of cysts in actual volume sampled in 2016 (547 cysts in 50.1L). S4 in particular had the largest increase in annual *Giardia* mean, from 42.7 cysts $50L^{-1}$ in 2015, to 173 cysts $50L^{-1}$ in 2016. During the same period, the annual mean at PROXG had the largest decline in annual mean, from 148 cysts $50L^{-1}$ to 8.24 cysts $50L^{-1}$.

With the conclusion of the investigation upstream of S7i in December of 2015, DEP selected PROXG as the new focus site to sample upstream for source identification (Table 5.7). This site had the highest *Giardia* concentration averaged over the two-year period from 2014 to 2015 (181 oocysts $50L^{-1}$) and the highest historical mean (2002-2015, 119 cysts $50L^{-1}$). Two new sites were selected upstream (PROXG-1 and PROXG-2) and monthly monitoring began in May 2016 (Figure 5.9). Protozoan results from the three sites have been low compared to the above mentioned historical means for PROXG (all results < 30 cysts $50L^{-1}$; Table 5.6); however, the decline in *Giardia* at this location is coincident with the implementation of the new analytical method using 1623.1 and EasyStain. Not all *Giardia* spp. are detected with EasyStain (ex. *G. muris*) and it is believed that the decline is likely related to the type of *Giardia* in this area not being detected with this new stain. Monitoring will continue at these sites through 2017, at which point the data and selected sites will be re-evaluated.

West of Hudson WWTPs

The eight WOH WWTPs were sampled quarterly in 2016 (n=32) with 2 protozoan detections (6.3%) at two different plants (Hunter and Windham). The first detection at a WWTP in 2016 was in a sample taken on January 25 at the Hunter WWTP (Table 5.7). The sample had 1 *Cryptosporidium* oocyst $50L^{-1}$. The Hunter plant staff reported no abnormal conditions around the time of the sample collection and there were no turbidity values above 0.1 NTU for days before and after the collection. As a note, there have been previous detections at the Hunter plant effluent around the time of the Martin Luther King, Jr. holiday weekend when there is likely increased patronage at the ski resort.

Table 5.7 Protozoan detections at WOH WWTPs in 2016.

Date	Site	Plant	Sample Volume (L)	*Cryptosporidium* Result	*Giardia* Result
1/25/2016	Hunter WTP	Hunter	50.0	1	0
8/23/2016	Windham WTP	Windham	49.9	0	1

The second detection occurred on August 23, at Windham (1 *Giardia* cyst $49.9L^{-1}$). Operators at the plant indicated there were no mechanical or process abnormalities observed which could have led to the detection. Flow rate, pumping, and chemical dosage were all operating within normal parameters. The daily turbidity report for that day indicated a maximum effluent turbidity of 0.29 NTU.

East of Hudson Streams

The Kensico perennial streams were monitored at least monthly for protozoans in 2016. In addition to 96 routinely scheduled samples, five additional samples were taken at routine sites, as well as four at new upstream locations, as a follow-up to elevated results, for a total of 105 samples at the eight streams this year.

Cryptosporidium oocysts were detected in 45 out of 96 samples (46.9%) at Kensico perennial stream sites in 2016. This was almost twice as many as found in 2015 (24 out of 94 samples, 25.5%) and just over four times as many as in 2014 (11 out of 95 samples, 11.6%). As in 2015, N12 had the highest calculated mean concentration (5.75 oocysts $50L^{-1}$) as well as the highest count per actual volume sampled (43.0 oocysts $50L^{-1}$) and maximum result per liter (0.86) (Table 5.8). As was true WOH, five of the eight EOH sites resulted in 50% or more detection of oocysts in 2016. Annual *Cryptosporidium* means calculated for all the perennial streams were higher than those seen in 2015. Moreover, seven of the eight streams had means which more than doubled from 2015 to 2016 (all except E11) (Figure 5.10). It is possible the change in stain in 2015 may account for this increase in detection of oocysts; however, more years of testing are needed to determine if this is a true shift in the data.

Table 5.8 Summary of routine Kensico perennial stream protozoan results for 2016.

Site	n	*Cryptosporidium* Mean[1] ($50L^{-1}$)	*Cryptosporidium* % Detects	*Cryptosporidium* Max ($50L^{-1}$)	*Cryptosporidium* Max (L^{-1})	*Giardia* Mean ($50L^{-1}$)	*Giardia* % Detects	*Giardia* Max ($50L^{-1}$)	*Giardia* Max (L^{-1})
BG9	12	0.92	33.3%	7	0.14	0.08	16.7%	4	0.08
E10	12	1.59	50.0%	12	0.24	1.59	50.0%	6	0.12
E11	12	2.09	50.0%	10 (40.0L)	0.25	3.02	50.0%	18	0.36
E9	12	1.79	58.3%	4	0.08	11.1	75.0%	51 (50.3L)	1.01
MB-1	12	1.05	16.7%	5 (34.0L)	0.15	17.7	75.0%	34 (19.1L)	1.78
N12	12	5.75	50.0%	43	0.86	16.4	91.7%	130	2.60
N5-1	12	2.87	50.0%	19	0.38	7.62	75.0%	21	0.55
WHIP	12	1.25	49.5%	4	0.08	4.50	64.4%	23	0.46

[1]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.

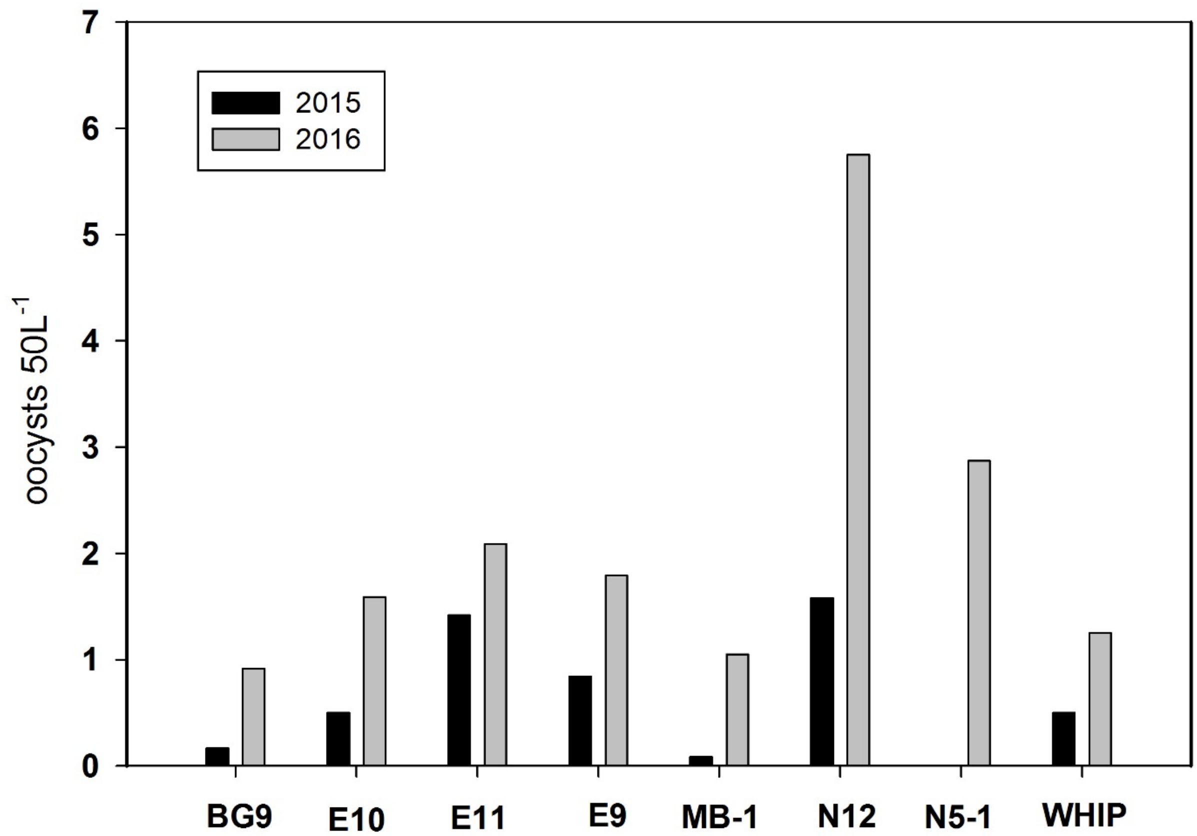


Figure 5.10 Annual mean *Cryptosporidium* concentrations for routine samples taken at the eight Kensico streams in 2015 and 2016.

The *Giardia* detection rate was 63.5% for routine samples at Kensico perennial streams in 2016, similar to that seen in prior years (2012: 75.0%; 2013: 69.8%; and 2014: 74.0%), but higher than the 34.0% rate in 2015. Five sites (E10, E11, MB-1, N12 and WHIP) exhibited increases in annual mean concentrations compared to 2015. Most notably, the 2016 mean for MB-1 (17.7 cysts $50L^{-1}$) was similar to the historical mean for this site (2002-2015, 13.6 cysts $50L^{-1}$) but significantly higher than the 2015 mean (0.25 cysts $50L^{-1}$). While the percent detection of *Giardia* at some of these sites appears to have decreased since the method change, more data, over several years, are necessary to support this hypothesis. Changes observed may be due to the potentially selective nature of EasyStain, and that not all *Giardia* in the watershed originate from the same source.

Additional Samples

An elevated *Cryptosporidium* result at N12 on January 6 (43.0 oocysts $50L^{-1}$) exceeded this site's historical 95th percentile (3.00 oocysts $50L^{-1}$). A sample collected at an upstream location on the same day had a similar result ("N12above-3"; 41.0 oocysts $50L^{-1}$) and additional testing was performed. Microbial Source Tracking (MST) analysis was completed on the sample, using Bacteroidales as a target organism. It was negative for the detection of the human marker, suggesting an animal source. Results at N12 were back to normal in February and remained low until August and September, when results became slightly elevated with 7 oocysts $50L^{-1}$ for each of these routine monthly samples. Follow-up samples (6 and 14 days later in August), and one upstream sample, all had only 1 or 2 oocysts $50L^{-1}$. Both the August and September oocysts were sent to a contract laboratory for genotyping analysis and the 18S amplicons indicated non-specific animal-associated genotypes. *Cryptosporidium* results at N12 were zero for the remainder of the year.

Results from two samples taken on November 1 at E11 and N5-1 (5.00 oocysts $34.3L^{-1}$ and 4.00 oocysts $50L^{-1}$, respectively) slightly exceeded the 95th percentile for those sites (4.00 and 3.70 oocysts $50L^{-1}$, respectively). As a precaution, follow-up samples were collected at both sites on November 14, and results were similarly boarder line for additional sampling (2.99 and 4.00 oocysts $50L^{-1}$, respectively). December sampling for both streams resulted in zero oocysts and no further investigation was performed.

East of Hudson WWTPs

Two EOH WWTPs, Carmel and Mahopac, were sampled quarterly in 2016, with some additional sampling done as a follow-up for a *Cryptosporidium* positive at the Mahopac plant (n=11). All 2016 samples from Carmel STP were negative for *Cryptosporidium* and *Giardia*. The conditions surrounding the positive sample at Mahopac and the subsequent special investigation are described below.

On November 15, during heavy rain, a protozoan sample was taken at Mahopac WWTP, with a result of 967 *Giardia* cysts and 2 *Cryptosporidium* oocysts $50L^{-1}$. Operations staff determined that the microfiltration turbidity did not exceed 0.06 NTU the entire week. Even during the rain event and the days after, the facility did not encounter any issues with sand filtration or microfiltration. Operators did not observe any issues with process operations during this time period and the facility was considered to be functioning under normal operations. As a note, monthly fecal coliform results from the November 1 and December 6 samples were both <1 FC $100ml^{-1}$.

The microscopy slide with 967 cysts and 2 oocysts was sent to a contract laboratory (University of Texas Public Health Laboratory) for molecular analysis. While the *Giardia* cysts were in abundance and at a much higher concentration than *Cryptosporidium*, no *Giardia* DNA was recovered, which is fairly unusual but can happen depending on environmental conditions. However, molecular analysis was also performed for *Cryptosporidium* and the DNA was recovered. The results of the *Cryptosporidium* DNA analysis was a genotype associated with rodents. A follow-up sample was taken on November 22 and those results came back negative for *Giardia* and *Cryptosporidium*. On December 5, research staff met with WWTP operators on site to try to determine potential sources of contamination. The UV treatment area and effluent contact tanks were open to possible animal intrusion and had the potential for storm runoff to contaminate the final tank during precipitation events. It was also suggested that biofilm on the contact tank walls could be harboring (oo)cysts which might then dislodge during sampling. On December 27, two additional samples were taken; one following standard field filtration procedures, and a second sample was taken from the walls and bottom of the tank to remove biofilm and re-suspend settled materials. Both of these samples were negative for *Giardia* and *Cryptosporidium.*

Although unusual to have so many *Giardia* negative for DNA, it may have been destroyed by the UV treatment at the plant (if contamination was prior to the UV treatment), or perhaps just destroyed in the environment since it is known that cysts are not as resilient as oocysts. One may infer from the *Cryptosporidium* typing that the source of the *Giardia* may also have been from a rodent source; however, that is not conclusive. Plant operations are not believed to have been a factor as operators report the plant was operating normally even during the rain event. Scraping and analysis of biofilm from the wall of the effluent tank ruled out the biofilm as a source of both protozoans. The most likely conclusion, based on the process of elimination, is that either surface runoff from the rain washed fecal material directly into the tank, or wildlife, in this case likely a rodent, got into the tank contaminating the original sample.

5.5. Hillview Monitoring

Giardia and *Cryptosporidium* have been routinely monitored weekly at Hillview Reservoir Site 3 since August 2011 as part of the Hillview Administrative Order. In 2016, 53 samples were collected and analyzed using the routine method, including an extra sample collected in May. In addition, 17 supplemental samples were collected for method improvement studies. As explained in previous editions of this annual report, a decrease in *Giardia* cysts and a potential increase in *Cryptosporidium* detections and concentrations after the April 2015 method change may be occurring. Although changing stains during the pilot study did not demonstrate a significant difference in *Cryptosporidium* detection, 2015-2016 data supports the likelihood of increased detection of oocysts using 1623.1 and EasyStain. More data will be needed over the next few years to increase confidence in any changes in the database.

As a note, an additional method change (within the guidelines of Method 1623.1) was implemented for Hillvew Site 3 samples in 2016. The method allows analysts to use a heat dissociation process as an alternative to the acid dissociation to improve matrix recovery. Once the heat dissociation was applied and demonstrated improved *Giardia* recovery from the Hillview matrix, the heat dissociation became part of the routine method at this site as of March 14, 2016 (Figure 5.11 and Figure 5.12).

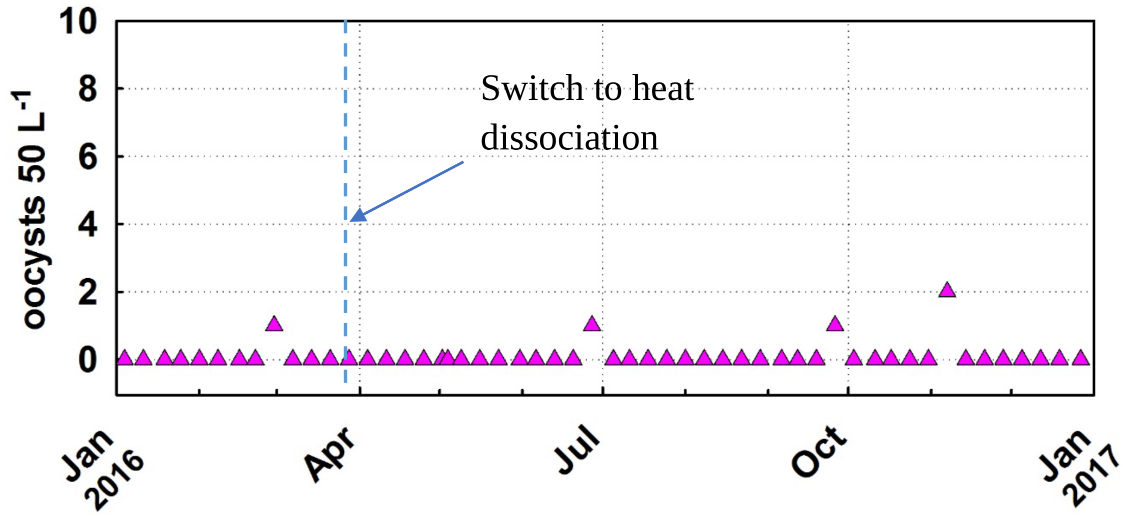


Figure 5.11 *Cryptosporidium* oocyst concentrations for routine samples at Hillview Site 3 in 2016.

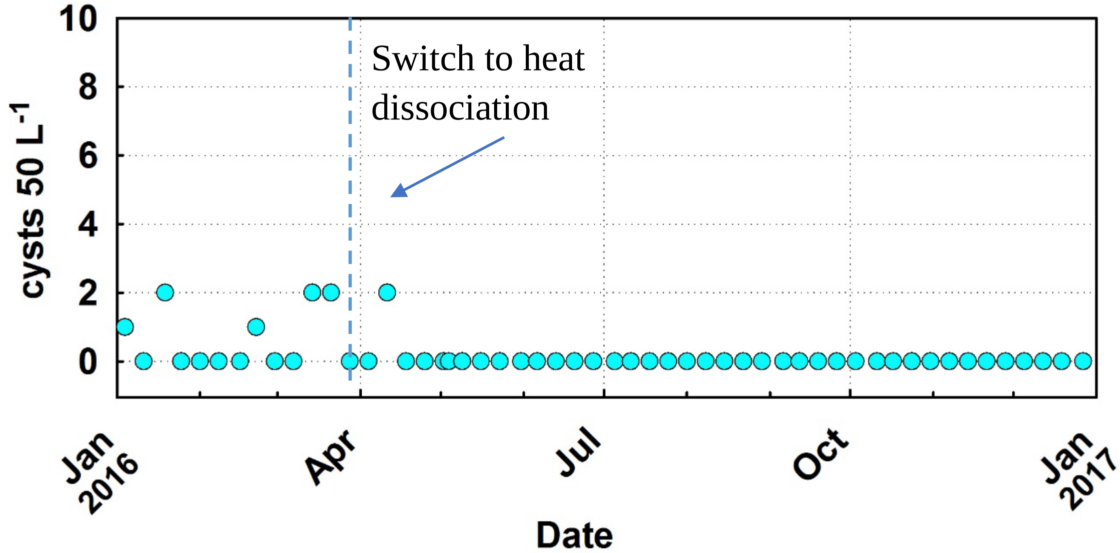


Figure 5.12 *Giardia* cyst concentrations for routine samples at Hillview Site 3 in 2016.

Cryptosporidium was detected in 7.5% of samples and the annual mean concentration was 0.09 oocysts 50L^{-1} (Table 5.9). The *Cryptosporidium* detection rates in 2016 were again higher than those observed before implementation of 1623.1 and EasyStain method change in April of 2015 (Table 5.10) and the *Giardia* detection was again lower than before the method change. The *Giardia* detection rate was 11.3%, and the annual mean concentration was 0.19

cysts $50L^{-1}$. Again, additional years of data are needed to be confident about the cause of this change in detection. However, 2016 data support the preliminary conclusion that it is likely the April 2015 method change that is making a difference, and not an increase in *Cryptosporidium*, nor a decrease in *Giardia,* in the environment.

Table 5.9 Hillview Site 3 protozoan monitoring results summary for 2016.

	***Cryptosporidium* oocysts**	***Giardia* cysts**
n	53	53
Number of Detects	4	6
% Detects	7.5%	11.3%
Mean ($50L^{-1}$)	0.09	0.19
Maximum ($50L^{-1}$)	2.00	2.00

Table 5.10 Hillview Site 3 protozoan detections from 2011 to 2016.

	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%
2016	4	7.5%	6	11.3%

[1]Sampling began in August of 2011.
Dashed line indicates method change, April 6, 2015.

As part of research studies at Hillview Reservoir, extra sampling and analyses were performed. In order to improve matrix spike recovery, nine samples were collected as five-10L filter samples (instead of a single-50L filter) and those results are discussed here. In addition, three samples were analyzed with a heat dissociation step alongside the routine samples (run with acid dissociation) to help improve matrix recovery and five samples were collected for infectivity analysis utilizing a Cell Culture-Immunofluorescent Assay (CC-IFA) method - Summaries of the infectivity analysis are provided in Chapter 7 (see sec. 7.1.8).

Filter Volume Comparison

The *Cryptosporidium* detection rate and mean concentration for the nine, five-10L filter method samples taken early in 2016 (22.2% detection rate and 0.44 oocysts $50L^{-1}$) were two and four times higher than those resulting from the single 50L filter method, respectively (11.1% detection rate and 0.11 oocysts 50L^{-1}) (Table 5.11). Out of the nine samples, two were positive for oocysts using the five-50L filter method and one was positive with the single 50L method. While this should not be seen as a significant difference, it should also be noted that the five-10L filter method found 3 oocyst 50L^{-1} compared to just 1 oocyst 50L^{-1}in the paired sample for that day.

Table 5.11 *Cryptosporidium* and *Giardia* results from Hillview Site 3 comparing the five-10L filter results to a single filter at 50 liters, 2016.

	Five-10L Filters		**One-50L Filter (Acid Diss)**	
	Cryptosporidium	***Giardia***	***Cryptosporidium***	***Giardia***
n	9	9	9	9
Detects	2	5	1	3
% Detect	22.2%	55.5%	11.1%	33.3%
Mean	0.44	0.89	0.11	0.44
Max	3.00	3.00	1.00	2.00

Giardia was also found more frequently and with higher mean concentration by the five-10L filter method (55.5% detection rate and 0.89 cysts 50L^{-1}) as compared to the single 50L filter method (33.3% detection rate and 0.44 cysts 50L^{-1}). *Giardia* maxima were higher with the five-10L filter method as well (3 cysts maxima compared to 2 cysts 50L^{-1}). Of the nine paired samples, five were positive for *Giardia* using the five-10L filters, while three were positive using the single filter. This data, along with data collected in previous years, suggests an improvement in the recovery of cysts using the five-10 liter filter method (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.

The problem of episodic increases in turbidity in the water supply has been studied in a comprehensive manner in the past and has led to validated, predictive watershed and reservoir water quality models. In 2016, two such models — the Operations Support Tool (OST) and the Rondout Reservoir Position Analysis (RondoutPA) — were applied to provide guidance to DEP regarding the operation of the water supply system in response to events of elevated turbidity.

The Bureau of Water Supply's (BWS's) Climate Change Integrated Modeling Project (CCIMP) encompasses an effort to develop and apply a suite or multi-tiered group of models to study the impact of climate change on the water supply. Phase I of the CCIMP concluded in 2013 with a number of "first-cut" or screening level modeling analyses. In 2016, progress continued on Phase II of the CCIMP, which involves the study of climate impacts using more sophisticated, realistic, and complex modeling approaches and tools. A stochastic weather generator (SWG) has been developed for the City's West of Hudson (WOH) watersheds. This weather model allows prediction of a long, synthetic time series of weather conditions (such as precipitation and air temperature), the statistics of which closely match observed conditions, but which also include infrequently occurring events (e.g., floods and droughts) that have not been captured in monitoring. In 2016, the first multi-tiered application of the SWG was completed by using numerous weather time series generated by the SWG as input to the Generalized Watershed Loading Function (GWLF) model to predict streamflow.

In addition to more realistic climate predictions, Phase II of the CCIMP will also utilize more realistic and complex watershed models. The Soil and Water Assessment Tool (SWAT) has been applied and tested for the Town Brook watershed within the larger Cannonsville Reservoir watershed. The particular version of SWAT was developed by DEP staff in order to allow mechanistic simulation of saturation-excess runoff, a component not considered in the standard version of SWAT. Setup of the Regional Hydro-Ecologic Simulation System (RHESSys) model to two watersheds (Biscuit Brook and Shelter Creek) in the watershed of Neversink Reservoir began in 2016. More work needs to be done in 2017 before it can be applied.

The water quality modeling group has begun to extend the application of the two-dimensional model CE-QUAL-W2, including the turbidity sub-model, to Neversink Reservoir then to be followed by Cannonsville and Pepacton. As in past applications to Schoharie, Ashokan, Rondout, and Kensico Reservoirs, CE-QUAL-W2 was able to accurately capture the response of Neversink Reservoir to episodes of elevated turbidity loading from surface runoff. Supporting work that was completed in 2016 includes the development of empirical temperature and turbidity models for the Neversink River inflow to Neversink Reservoir.

Other modeling work conducted in 2016 includes (i) the use of the quantile regression approach to investigate the uncertainty in predictions of turbidity for selected streams entering West of Hudson reservoirs, (ii) the testing and application of the watershed model GWLF to watersheds in the East of Hudson (EOH) system of reservoirs, (iii) continuation of the development of database and data analysis tools to support modeling work, and (iv) contract management of the field work and data analysis for the West of Hudson bathymetry project.

The water quality modeling group continues to be involved with outside groups including the Water Utility Climate Alliance (WUCA). The interaction among post-doctoral researchers employed by the City University of New York (CUNY), university faculty advisors, and DEP staff (all supported by DEP funding) continues to be a major source of ideas, modeling software, modeling products, reports, and publications. The current four-year contract between the Research Foundation of CUNY and DEP continues until August 2018.

On March 31, 2017, NYCDEP completed a report titled "Multi-Tiered Water Quality Modeling Program, Annual Status Report." This report gives a detailed description of activities and accomplishments in the Water Quality Modeling Program in 2016. Submission of a Water Quality Modeling Annual Report is a requirement of the current Filtration Avoidance Determination (FAD). A summary of major water quality modeling activities during 2016 is given in Table 6.1. For additional details, readers are referred to the annual Modeling report (http://www.nyc.gov/html/dep/pdf/reports/fad_5.2_multi-tiered_water_quality_modeling_program_-_annual_report_03-17.pdf).

Table 6.1 Summary of 2016 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 meet water supply and minimize turbidity impacts	Rondout Position Analysis model used for six events during 2016: April 7, June 6, July 11, November 2, December 5 and 22	No significant impact occurred as a result of these events	Ongoing
Development of stochastic weather generators to predict time series of future precipitation and air temperature	Evaluate alternative models to simulate current and predict future time series of precipitation, air temperature Future time series should contain infrequently occurring (extreme) events not captured in historic data	Compared a variety of weather generators, including 5 parametric models, 1 resampling model, and a 2nd order polynomial curve fitting model	Recommended models: skewed normal, mixed exponential, combined with 1st-order Markov chain	Ongoing
Use of General Watershed Loading Function (GWLF) to predict streamflow based on stochastic weather generator	Predict streamflow for Esopus Cr. at Coldbrook using weather time series from stochastic generator. Compare statistics of predicted streamflow to observations	Results are presented on sensitivity surface, a first step toward “bottom-up” evaluation of climate change	Seasonal pattern in streamflow captured over range of flows; long time series required to capture extreme events	Ongoing
Development of modified Soil Water Assessment Tool (SWAT); testing at Town Brook watershed	Description of enhancements leading to modified model SWAT-HS Test runoff prediction in Town Brook watershed	Observations used for model testing: -outflow hydrographs from Town Br. watershed -area of watershed with saturated soil	Enhanced model gave improved predictions of outflow and saturated area	Ongoing

Table 6.1 Summary of 2016 Water Quality Modeling Projects.

Evaluation of watershed characteristics controlling dissolved organic carbon (DOC) in Neversink watershed	Characteristics considered for effect on DOC levels: topography, vegetation density, soil properties, hydrologic flow partition	DOC concentration is correlated with slope; not correlated with soil or vegetation DOC concentration positively correlated with streamflow	-Organic matter transported largely by surface and shallow subsurface flow -DOC export appears to be transport-limited, not source-limited	Ongoing
Application of the Regional Hydro-Ecologic Simulation System (RHESSys) to simulate streamflow, nitrate and DOC in two Neversink watersheds	Calibration and validation of RHESSys for Biscuit Br. and Shelter Cr. watersheds, for runoff quantity and quality	Streamflow accurate for monthly-yearly time scale Nitrate concentration over-predicted in summer Seasonal variation in DOC not simulated well	Testing indicates more accurate model inputs for soil depth and leaf area index are required to improve predictions	Ongoing
Evaluation of impact of forest harvesting on Neversink watershed streamflow	Compare observed streamflow from Shelter Cr. (where harvesting occurred) to Biscuit Br. (no harvesting)	Used paired watershed approach, using observed streamflow from same time interval for both watersheds	-Harvesting increased monthly, annual flows - Flows then decreased during forest recovery, but not to pre-harvest levels	Ongoing
Preliminary testing of a turbidity model for Neversink Reservoir	Apply and test CE-QUAL-W2 turbidity model for Neversink, as previously done for Schoharie, Ashokan, Rondout, Kensico	Compared model predictions of water column and withdrawal turbidity to observations for 2012-2016	-Generally good prediction of temperature and turbidity -Further testing required	Ongoing

Table 6.1 Summary of 2016 Water Quality Modeling Projects.

Streamflow simulation for East of Hudson watersheds	EOH streamflows needed to: -make system-wide simulations using Operations Support Tool (OST) -evaluate the impact of climate change on EOH streamflows	GWLF model applied to 5 watersheds for which observed streamflows were available	Accuracy of simulated streamflows was good	Ongoing
Use of Parameter-elevation Relationships on Independent Slopes Model (PRISM) precipitation data to drive hydrologic models for West of Hudson watersheds	Evaluate the accuracy of hydrologic model (GWLF) predictions using PRISM data as input	Study motivated in part by the steady decline in number of precipitation stations in WOH watersheds in recent years	Streamflow simulations using PRISM inputs were comparable or better for 9 of 10 WOH streams	Ongoing
Estimating predictive uncertainty in turbidity-flow relationships for streams	Apply quantile regression procedure to analysis of historical turbidity-streamflow data	Empirical regression models are the primary basis for predicting turbidity of stream inflows to reservoirs	Preliminary quantile regression analysis completed for Esopus Cr. at Coldbrook	Ongoing
Data analyses to support modeling activities	These analyses required as a part of application of turbidity model to Neversink Reservoir	Includes: -weather data analysis -empirical predictors for temperature of stream inflow and reservoir release -empirical model for stream inflow turbidity	Analyses completed, allowing testing of the model for Neversink Reservoir to proceed	Completed

Table 6.1 Summary of 2016 Water Quality Modeling Projects.

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 for all reservoirs and controlled lakes -Water Quality Modeling Program is developing modeling database	GIS data continually being enhanced and updated; WOH bathymetric surveys complete, EOH ready to start in 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 Observation 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 in 2016

In 2016, the WQD managed eight 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 Contracts

Eurofins Eaton Analytical Inc. (EEA): EEA conducts various analyses to support DEP's laboratories monitoring efforts. In 2016, EEA analyses for DEP included algal toxins on aqueduct and reservoir samples; total and volatile solids on some aqueduct 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., Shandaken Tunnel Outlet). The contract is managed by DEP's Distribution Water Quality Operations Laboratory.

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, as well as routine samples and storm events which had elevated fecal coliform levels, samples were sent to this laboratory for microbial source tracking analysis.

Watershed Assessment Associates: Samples of benthic macroinvertebrates collected in Croton, Catskill, and Delaware System streams were sent to this 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. 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 58 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 gages involves (1) retrieving the stage, water temperature, and/or turbidity data; measuring stream flow; and/or collecting sediment samples at specified gages, (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 revised 2007 Filtration Avoidance Determination (FAD) (NYSDOH 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.

7.1.3. CUNY Postdoctoral Support

Work continued on the four-year water quality modeling support contract between DEP and the City University of New York-Research Foundation (CUNY-RF) in 2016. This contract provides support for the Water Quality Directorate in the analysis and use of water quality data, development of new models, enhancement of existing models, and application of models for water quality management and water system operation. The contract supports four post-doctoral researchers who work full-time in the NYCDEP Water Quality Modeling office in Kingston, and four associated faculty advisors.

The topics that are the focus of work by the researchers and associated faculty advisors are the following:

- Climate data analysis and modeling
- Watershed runoff and nutrient modeling
- Ecohydrologic modeling of forested watersheds
- Reservoir modeling of organic carbon, precursors of disinfection byproducts, and eutrophication

Two of the four post-doctoral positions were open for a time in 2016 but all positions were filled by the end of the year. 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, and modeling based evaluations of climate change impacts. In 2016, two peer-reviewed publications and eight conference presentations were made by the post-doctoral researchers, faculty advisors, and DEP staff.

7.1.4. 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 with an option to renew under the same terms for an additional two years through July 30, 2020.

7.1.5. 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. 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, CB&I Environmental & Infrastructure, 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.

7.1.6. Bathymetric Surveys of Reservoirs

Under an inter-governmental agreement with United States Geological Survey (USGS), bathymetric surveying work was conducted on the six WOH reservoirs from 2013-2015. The USGS employed a single-beam echosounder to survey evenly spaced transects across each reservoir, with an average spacing between transects of between 100-150 meters. Additional, more closely spaced overlapping transects were completed near reservoir spillways and intakes to improve local data quality in those areas. In 2016, final data deliverables for each reservoir were submitted by USGS, including 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 draft report was submitted for review and comment by DEP.

A separate inter-governmental agreement with the USGS was initiated in 2015 to survey the bathymetry of the 13 EOH reservoirs and three controlled lakes. The contract is expected to be finalized in early 2017, with fieldwork to be conducted in 2017-2018, and final data delivery due by 2020. The EOH reservoirs will be surveyed using a multibeam echosounder, which will improve accuracy throughout the reservoir with better coverage than transect-based surveys. 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.

7.1.7. WISKI Software Support Contract

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. By the beginning of June 2017, the software update from WISKI 7.1 to 7.4 will be completed. 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 IPS, and WISKI. The data collected by this system is used for tracking water balances and for modeling.

7.1.8. *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 (USEPA 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 last year's research, and in the continued 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 identification of *C. hominis* in New York City's water matrix. Both *C. parvum* and *C. hominis* spiking has been done previously by DEP; however, the first stock of *C. hominis* was believed to have some issues based on the quality control results from those initial tests. Samples collected from the outlet of Hillview Reservoir were spiked with a new stock of 100 viable flow sorted *C. hominis* oocysts, in addition to other samples spiked with low doses of 10, 5, and 3 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, and low level oocyst recovery was very good as well. Overall, CC-IFA infectivity testing of both *C. parvum* and *C. hominis* in the Hillview sample matrix has indicated comparability to control samples and the ability to detect low levels of oocysts. Data are still undergoing analysis at the time of this report.

7.2. Water Research Foundation Project Participation by WQD in 2016

7.2.1. WRF Project 4386: Decision support program for reducing Endocrine Disrupting Contaminants (EDCs) and Pharmaceutical 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. WRF & Arcadis are in the process of setting up the online tool to be publicly accessible. The online tool and user’s manual are the final products for this project. C. Glaser is a member of the Project Advisory Committee (PAC) for this project.

7.2.2. WRF Project 4422 – Online NOM Characterization: Advanced Techniques for Monitoring Changes in NOM and Controlling DBPs under Dynamic Weather Conditions

The objective of this project was to evaluate the effectiveness of online monitoring tools and response systems that can be used to detect subtle changes in the character and amount of NOM and its effect on disinfection byproduct (DBP) formation potential. The specific objectives were (1) evaluate advanced online instrumentation technology based on UV spectral derivatives, (2) evaluate specific excitation/emission matrix (EEM) pairings from 3-D fluorescence monitoring, (3) develop correlations between online units for analysis of NOM characterization, and (4) determine effectiveness of online instrumentation technology to predict changes in DBP formation potential of NOM in real-time as part of an Operations Support Tool. This was a tailored collaboration funded in 2011 and DEP was a participating utility. The final report was published in January 2016.

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

This project began June 30, 2014. The objective of the project was to evaluate the NeoTech Aqua Solutions, Inc. (NeoTech) reflectance-based UV technology to determine the effectiveness and energy efficiency (energy use per volume of treated water) on the inactivation of microorganisms. Additionally, a specific comparison of the energy efficiency observed with the NeoTech reactor as compared to the existing UV system at the EBMUD Walnut Creek Water Treatment Plant (WTP) that hosted the biodosimetric testing, and other available UV systems was done. This is relevant to DEP because the City operates a large UV plant and any advances in technology, or reduction in energy usage would be something for the agency to consider. C. Glaser, is a member of the PAC for this project.

7.2.4. 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 or not there is a relationship between low level turbidity and risk of gastrointestinal (GI) illness due to consumption of drinking water that meets U.S. drinking water standards. The specific objectives were to (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 was published in September 2016. A. Seeley was a member of the PAC for this project.

7.2.5. 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 (e.g., disinfection by-products and turbidity) and treatability, and (3) evaluate the implications of a wildfire for full-scale operation and design of treatment systems. To date all soil and forest litter samples have been collected, processed, and analyzed. The final report is expected to be published in 2017. R. Van Dreason is a member of the PAC for this project.

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

This project began January 1, 2016. The research team is conducting a literature review to evaluate the current regulatory status for controlling discharges of Contaminants of Emerging Concern (CECs) in hospital wastewater, the wastewater treatment technologies currently employed in healthcare facilities, and best available technologies for managing CECs in hospital wastewater. In addition, the research team continues its effort to increase the number of responses to their survey from WWTPs and hospitals. A time extension was requested in order to obtain additional data. S. Neuman is a member of the PAC for this project.

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

This project began in February of 2016. 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. The project was awarded to American Water and the focus of the project will be water utilities in North America. The final product is a report that will contain a state of the industry review, proposed worker profiles, identification of workforce gaps, and proposed solutions to workforce gaps. L. Emery is a member of the PAC for this project.

7.2.8. WRF Project 4664: Customer Messaging on Plumbing Systems

The objective of this project, which began in July 2016, is to develop messages for the water community to communicate with different audiences about the potential risks of opportunistic pathogens in plumbing systems — specifically, the development of a basic messaging system for the assessment, prevention, and treatment of *Legionella* in building water systems. The goal is to draft messages for utilities to share depending on the target audience (i.e., single family residential, multifamily residential, commercial, retail, industrial, institutional, healthcare, hospitality, etc.). To date, DEP completed and provided comments to a preliminary utility survey which was used to develop the final survey for the focus groups and participated in a two-day workshop to discuss the outcomes of the surveys and to provide comments to the draft messages for utilities. Consultants are currently summarizing the findings from the workshop. The final project will not be a traditional written report. Instead, the final product will include materials that different stakeholders can use and recommendations for key messages to communicate to specific groups. A. Capetenakis is a member of the PAC for this project.

7.2.9. WRF Project 4713 Full Lead Service Line Replacement Guidance

An RFP was issued for this project in 2016, and submissions were due May 17, 2017. The objective is to evaluate strategies to reduce lead exposure after conducting full lead service line replacements. The City is currently only responsible for the replacement of lead service lines at City-owned properties, but long term revisions to the Lead and Copper Rule may change the requirements. Additionally, DEP is interested in being proactive when it comes to protecting customers from at-the-tap lead exposure, and is investigating options to mitigate lead exposure, including possibly subsidizing and/or offering loans for lead service line replacement. C. Glaser is a member of the PAC for this project.

7.3. Water Utility Climate Alliance (WUCA): Piloting Utility Modeling Applications (PUMA)

DEP continued its participation in the Water Utility Climate Alliance (WUCA) in 2016. WUCA is a consortium of ten large public water utilities in the United States: Central Arizona Project, Denver Water, Metropolitan District of Southern California, Portland (OR) Water Bureau, San Diego County Water Authority, San Francisco Public Utilities Commission, Seattle Public Utilities, Southern Nevada Water Authority, Tampa Bay Water, and NYCDEP. WUCA members supply water to roughly 43 million people in the United States. WUCA was formed in 2007 and has the goal of enhancing climate change research and improving water management decision-making to ensure water utilities will be positioned to respond to climate change and protect our water supplies. The group provides leadership and collaboration on climate change issues. These utilities develop projects and share costs of conducting such projects. Conference calls are held regularly to discuss current activities and future projects. DEP benefits from this information exchange among utilities by keeping current with climate change information and evaluation and in long-term planning in the context of water supply. Alan Cohn, Ph.D., of the Bureau of Environmental Planning and Analysis (BEPA) and staff from Water Quality Science and Research participate in WUCA activities. In addition, Allan Frei, Ph.D., Chair, Professor, and Deputy Director of CUNY Institute for Sustainable Cities and a contractor to DEP on climate modeling, is also involved in WUCA activities on behalf of DEP.

Five of the 10 WUCA utilities, including DEP, participated in the Piloting Utility Modeling Applications (PUMA) initiative. This project reviewed how these utilities use water quality modeling to evaluate climate impacts. The two-year PUMA project was completed in 2015. In May 2016, Alan Cohn and Allan Frei attended a WUCA meeting in Boulder, CO. The main purpose of this meeting was to bring the PUMA project to a formal end and to discuss the results and conclusions from that project. DEP's contribution to PUMA focused on climate, water quantity, and water quality evaluations that had been completed prior to 2015. This work focused on the West of Hudson reservoirs: eutrophication in Cannonsville Reservoir, and turbidity in the Catskill System reservoirs. Following are some general conclusions from the Boulder meeting:

- Climate evaluations are an ongoing process, and are not a one-time analysis.
- The uncertainty in climate change predictions increases as projections are made farther into the future.
- The accuracy of climate models is steadily improving.
- Relative to the other WUCA utilities, DEP is performing much of our climate analyses in-house, rather than by contracts and consultants.

DEP plans to remain an active participant in WUCA in the coming years.

7.4. Global Lake Ecological Observation Network (GLEON)

The overall mission of GLEON is to "understand, predict, and communicate the role and response of lakes in a changing global environment." GLEON fosters the sharing of ideas and tools for interpreting high-frequency sensor data and other water quality and environmental data. Several collaborations have developed from DEP's participation in annual meetings convened by GLEON. In 2016, the annual meeting held in Gaming, Austria provided an opportunity to follow up on existing projects and discuss potential future collaborations. In most cases, projects initiated at these meetings take some time to realize. One project that culminated in 2016 with publication of a review paper that included two DEP co-authors was a review of the use of automatic high frequency monitoring (AHFM) in lakes and reservoirs with specific recommendations on the use of AHFM technology to support management (Marcé et al. 2016).

A highlight of DEP's participation in GLEON in 2016 was completion of a formal application for site membership with Cannonsville and Neversink Reservoirs featured as primary sites for collaborative research. Some additional highlights for 2016 follow. Only projects that have accomplished major milestones are included.

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

The primary intent of this study was 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. During 2016, a manuscript titled *Trends in lake surface and deep water temperature and stratification in northeastern North America (1975-2012)* was drafted to address the following research questions: 1) Has the lake thermal structure in NENA lakes changed in recent decades? 2) Is the change in below surface temperature as great as surface temperature changes through time? 3) Have certain types of lakes that differ in geomorphology or limnology changed more than other lakes and, if so, what types of lakes have shown the strongest changes or trends in lake thermal structure? 4) In this region, are lake temperatures changing more rapidly than air temperature or than surface temperature in lakes around the world? Lead investigators are David Richardson, Ph.D., of the State University of New York (SUNY) – New Paltz and Stephanie Melles, Ph.D., of Ryerson University, Ontario, Canada. DEP contributed data from four reservoirs to this study of 231 lakes and reservoirs.

7.4.2. Salting Our Waters: Global Trends in Chloride

In 2015, DEP contributed long-term chloride data from 10 reservoirs to a study of 529 lakes and reservoirs in the GLEON graduate fellowship "SALT" project. At the 2016 annual GLEON meeting, Hilary Dugan, Ph.D., and colleagues presented a poster on the lessons learned from this large collaborative project. The project resulted in a synthesis of data that identified the northeastern United States as a “salinization hotspot” and found that impervious surface was the best predictor of chloride trend. DEP data will be included in a paper titled: *Long-term chloride concentrations in North American and European freshwater lakes* (Dugan et al., submitted) that was completed in 2016 and accepted for publication in 2017 in *Nature Research Scientific Data*, an open-access journal that published descriptions of scientifically valuable datasets and research that promotes sharing and reuse of scientific data.

7.4.3. LAGOS Database

The ***LA****ke multi-scaled* ***G****e****OS****patial & temporal database* is a multi-scale spatial/temporal database of lake chemistry and landscape characteristics for over 49,000 lakes in a 17-state area in the northeast and midwest United States. This initiative led by Pat Soranno, Ph.D., of Michigan State University, along with colleagues who are part of the Cross-Scale Interactions (CSI) Limnology research consortium, has built the LAGOS database, one of the largest-known spatially explicit lake water chemistry and landscape databases that will be available to researchers for years to come. DEP joined over 80 other collaborators to provide data for this effort described in a 2015 publication (Soranno et al. 2015) on methods for building this large integrated database. The corresponding database was finalized in 2016.

7.4.4. State of the Lakes Survey

The Reservoir and Lake Management Working Group developed a survey about ecological threats and management of lakes and reservoirs studied by GLEON members. The goal was to understand the current state of lakes and reservoirs around the globe and characterize the management structures in place to address ecological threats (e.g., harmful algal blooms, invasive species, and climate change). In 2016, DEP contributed a survey response for two reservoirs that are specified GLEON sites: Cannonsville and Neversink. Since managers and stakeholders were a small proportion of the GLEON survey respondents, expansion of the survey in October 2016 through the North American Lake Management Society allowed further exploration of the perceptions of lake managers and stakeholders regarding threats to freshwaters.

7.4.5. A Comparison of Dissolved Oxygen (DO) and Chlorophyll Fluorescence Maxima across Lake Types and Seasons

There is a presumption that chlorophyll and DO peaks in vertical lake and reservoir profiles should align, but this is often not the case. A GLEON project to investigate the conditions under which chlorophyll and DO maxima are decoupled and exploration of the processes that drive this decoupling started with data gathering. DEP contributed buoy profile data from 2016 for Cannonsville and Neversink Reservoirs to the project that will continue in the upcoming year. Studies of this type contribute to GLM/AED model development.

7.4.6. Long-term Dissolved Oxygen (DO) Concentrations in Lakes and Reservoirs

This project focuses on using long-term dissolved oxygen profiles to identify trends in dissolved oxygen at different depths, both for lakes with different watershed features and in lakes of different trophic status. Project goals include exploring the response of dissolved oxygen concentrations to changing temperatures and examining how temperature and productivity interact to influence dissolved oxygen. DEP contributed data to this project initiated in 2016 by GLEON's Climate Sentinels Working Group.

References

Alderisio, K. A. and N. DeLuca. 1999. Seasonal Enumeration of Fecal Coliform Bacteria from the Feces of Ring-Billed Gulls (*Larus delawarensis*) and Canada Geese (*Branta canadensis*). Appl. Environ Microbiol. 65: 5628-5630.

Bolks, A., A. DeWire, and J.B. Harcum. 2014. Baseline assessment of left-censored environmental data using R. Tech Notes 10, June 2014. Developed for U.S. Environmental Protection Agency by Tetra Tech, Inc., Fairfax, VA, 28 p. Available online at www.bae.ncsu.edu/programs/extension/wqg/319monitoring/tech_notes.htm (accessed 07/19/2016).

Carlson, R. E. 1977. A trophic state index for lakes. Limnology and Ocenaography 22:361-369.

DEP 1992. New York City Department of Environmental Protection. 1992. Kensico Watershed Study 1991-92. Drinking Water Quality Control and Sources Divisions, Valhalla, NY.

DEP. 1997. A Methodology for Determining Phosphorus-Restricted Basins. Valhalla, NY.

DEP. 2002. Continued Implementation of Final Waterfowl Management Plan. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2010. New York City Watershed Rules and Regulations. 1997, amended April 4, 2010. Rules and Regulations for the Protection from Contamination, Degradation, and Pollution of the New York City Water Supply and its Sources. RCNY Title 15, Chapter 18. http://www.nyc.gov/html/dep/pdf/recrules/regulations.pdf (accessed 6/9/17).

DEP. 2013a. 2011 Watershed Water Quality Annual Report, revised January 2013. Valhalla, NY. 144 p.

DEP. 2013b. 2012 Watershed Water Quality Annual Report. Valhalla, NY. 156 p.

DEP. 2014. 2013 Watershed Water Quality Annual Report. Valhalla, NY. 168 p.

DEP. 2015. 2014 Watershed Water Quality Annual Report. Valhalla, NY. 165 p.

DEP. 2016a. Watershed Water Quality Monitoring Plan. Directorate of Water Quality (issued October 2008, first revision, second revision May 2009, revised May 2016). Valhalla, NY. 264 p. http://www.nyc.gov/html/dep/pdf/water/2016-wwqmp.pdf (accessed 06/9/17).

DEP. 2016b. 2015 Watershed Water Quality Annual Report. Valhalla, NY. 171 p.

Dugan, H., J. Summers, N. Skaff, F. Krivak-Tetley, J. Doubek, S. Burke, S. Bartlett, L. Arvola, H. Jarjanazi, J. Korponai, A. Kleeberg, G. Monet, D. Monteith, K. Moore, M. Rogora, P. Hanson, and K. Weathers. (submitted). Long-term chloride concentrations in North American and European freshwater lakes. Nature Research Scientific Data (http://www.nature.com/sdata/).

Helsel D. R. 2005. Nondetects and Data Analysis. John Wiley & Sons, New York.

International Organization for Standardization. 1985. Water quality—determination of electrical conductivity. Geneva, 1985 (ISO 7888:1985).

Kerr, J. G., M. C. Eimers, I. F. Creed, M. B. Adams, F. Beall, D. Burns, J. L. Campbell, S. F. Christopher, T. A. Clair, F. Courchesne, L. Duchesne, I. Fernandez, D. Houle, D. S. Jeffries, G. E. Likens, M. J. Mitchell, J. Shanley, and H. Yao. 2012. The effect of seasonal drying on sulfate dynamics in streams across southeastern Canada and the northeastern USA. Biogeochemisty 111:393-409.

Kuhne, W. and L. McDonald. 2015. Improving Matrix Spike Recoveries for the Analysis of *Cryptosporidium* and *Giardia* in Treated Potable Water. AWWA, Water Quality Technology Conference, Nov. 15-19, Salt Lake City, Utah.

Marcé R, G. George P. Buscarinu, M. Deidda, J. Dunalska, E. de Eyto, G. Flaim, H-P. Grossart, V. Istvanovics, M. Lenhardt E. Moreno-Ostos, B. Obrador, I. Ostrovsky, D.C. Pierson, J. Potužak, S. Poikane, K. Rinke, S. Rodríguez-Mozaz, P.A. Staehr, K. Šumberová, G. Waajen, G.A. Weyhenmeyer, K.C. Weathers, M. Zion, B.W. Ibelings, and E. Jennings. 2016. Automatic high frequency monitoring for improved lake and reservoir management. Environmental Science and Technology 50: 10780-10794.

McHale, M.R. and J. Siemion. 2014. Turbidity and suspended sediment in the upper Esopus Creek watershed, Ulster County, New York: U.S. Geological Survey Scientific Investigation Report 2014-5200, 42 p. http://dx/doi.org/10.3133/sir20145200.

NYSDEC [New York State Department of Environmental Conservation]. 2014. Standard Operating Procedure: Biological Monitoring of Surface Waters in New York State. Albany, NY. 171 p.

NYSDEC [New York State Department of Environmental Conservation]. 2016. DEC HABs program archive summary 2012 – 2016. http://www.dec.ny.gov/docs/water_pdf/habsextentsummary.pdf (accessed 6/26/2017).

NYSDOH [New York State Department of Health]. 2014. New York City Filtration Avoidance Determination. Final Revised 2007 FAD. 99 p.

https://www.health.ny.gov/environmental/water/drinking/nycfad/docs/final_revised_2007_fad_may_2014.pdf (accessed 7/25/17.

Siemion, Jason, M. R. McHale, and W. D. Davis. 2016, Suspended-sediment and turbidity responses to sediment and turbidity reduction projects in the Beaver Kill, Stony Clove Creek, and Warner Creek, Watersheds, New York, 2010–14: U.S. Geological Survey Scientific Investigations Report 2016–5157, 28 p. https://doi.org/10.3133/sir20165157.

Singh, T. and Y. P. Kalra. 1975. Specific conductance method for in situ estimation of total dissolved solids. Journal of the American Water Works Association, 1975, 67(2):99.

Soranno, P.A., E.G. Bissell, K.S. Cheruvelil, S.T. Christel, S.M. Collins, C.E. Fergus, C.T. Filstrup, J-F. Lapierre, N.R. Lottig, S.K. Oliver, C.E. Scott, N.J. Smith, S. Stopyak, S. Yuan, M.T. Bemigan, J.A. Downing, C. Gries, E.N. Henry, N.K. Skaff, E.H. Stanley, C.A. Stow, P-N. Tan, T. Wagner and K.E. Webster. 2015. Building a multi-scaled geospatial temporal ecology database from disparate data sources: fostering open science and data reuse. GigaScience 4: 28. (DOI: 10.1186/s13742-015-0067-4).

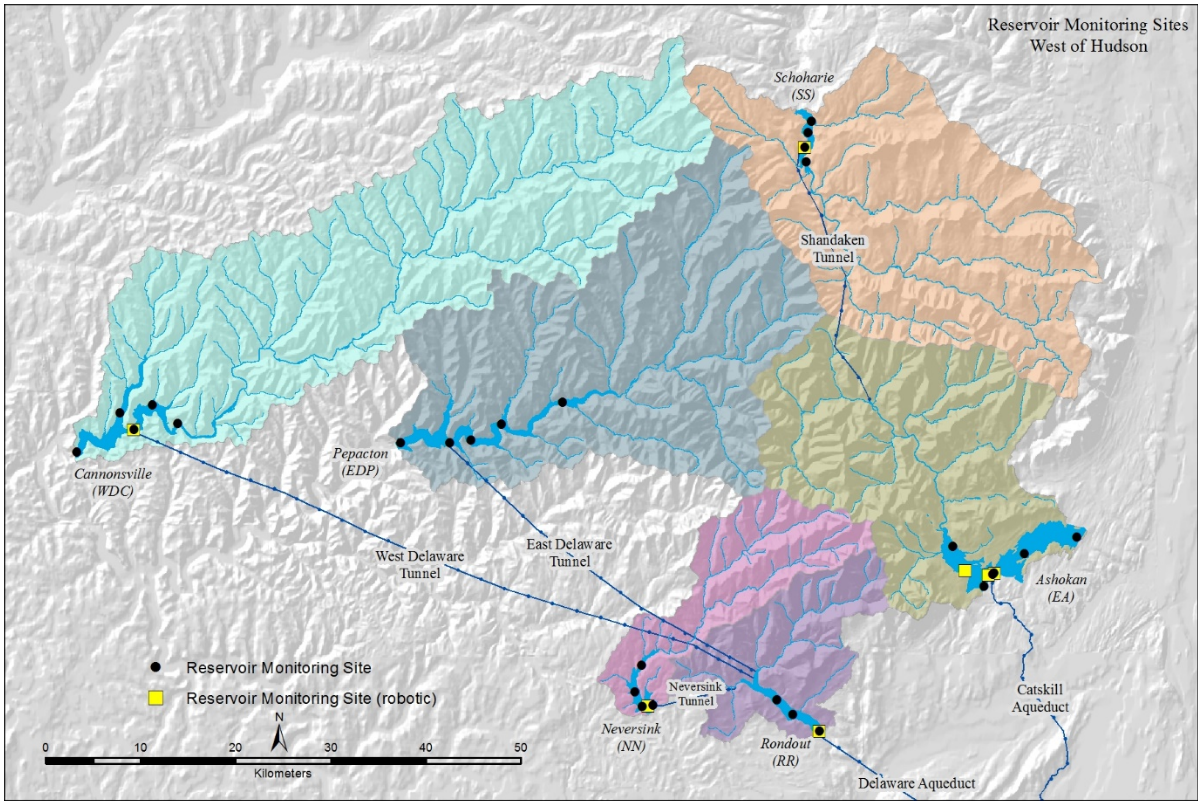
USEPA [United States Environmental Protection Agency]. 1989. Drinking Water: National Primary Drinking Water Regulations; Filtration, Disinfection; Turbidity, *Giardia lamblia*, Viruses, Legionella, and Heterotrophic Bacteria; Final Rule. 54 Fed. Reg. 27486. June 29, 1989. WH-FRL-3607-7. Washington, D.C.

USEPA [United States Environmental Protection Agency]. 1996. ICR Laboratory Microbial Manual. EPA 600/R-95/178. Office of Research and Development. Washington, DC. Government Printing Office.

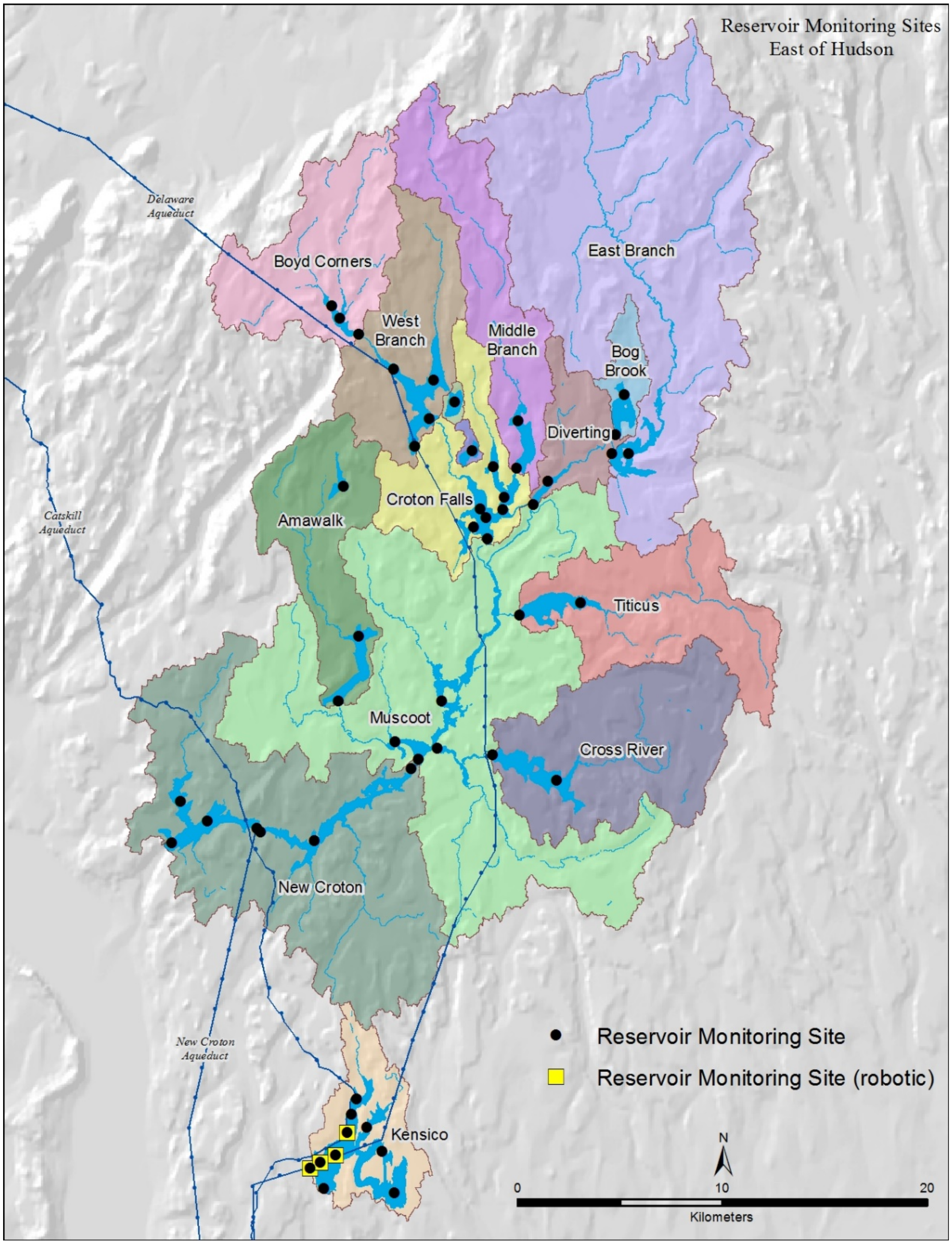
USEPA [United States Environmental Protection Agency]. 2006. Long Term 2 Enhanced Surface Water Treatment Rule. EPAHQ-2002-0039. Washington, D.C. http://www.federalregister.gov/a/06-4 (accessed 7/11/17).

van der Leeden, F., F. L. Troise, and D. K. Todd. 1990. The Water Encyclopedia, 2nd Edition. Chelsea, MI: Lewis Publishers.

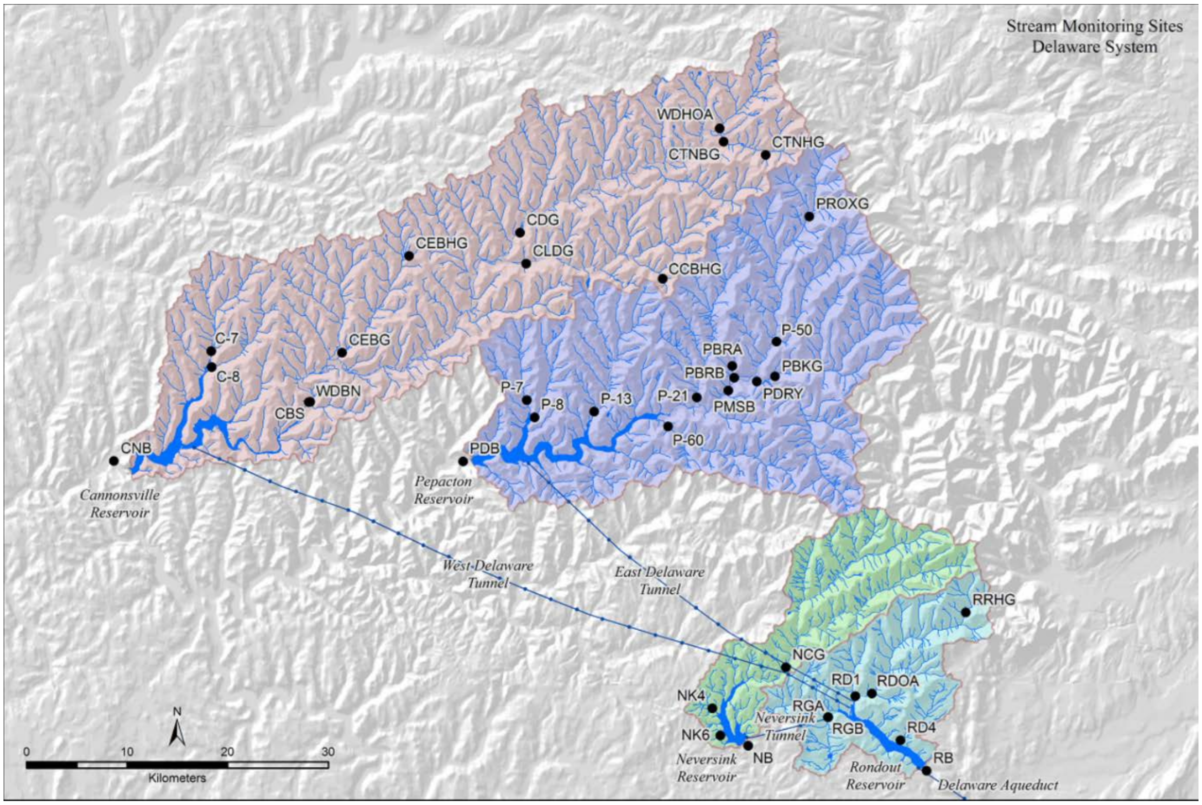
Appendix A. Sampling Locations



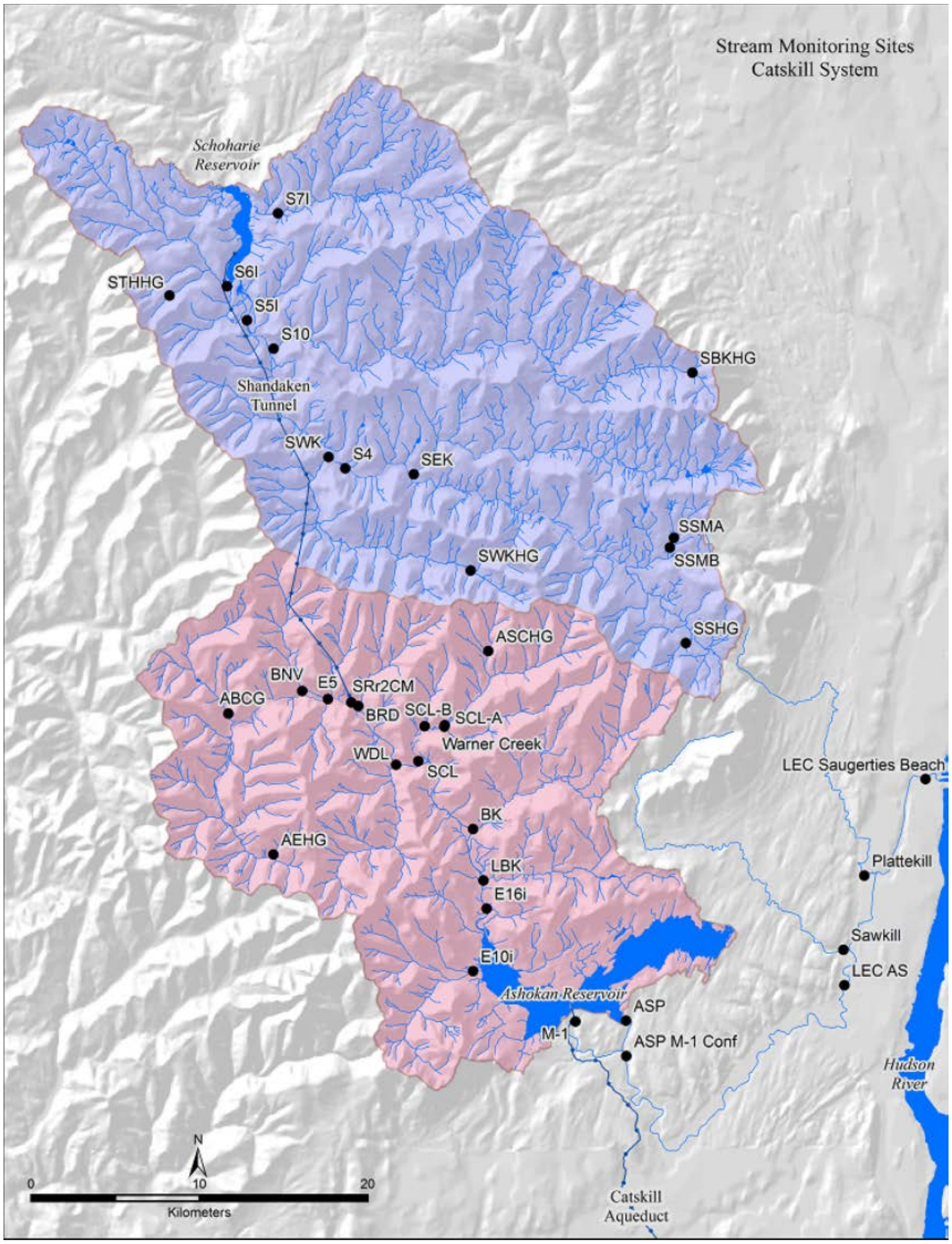
Appendix Figure 1 WOH reservoir monitoring sites (see 2016 WWQMP (DEP 2016a) for detailed maps).



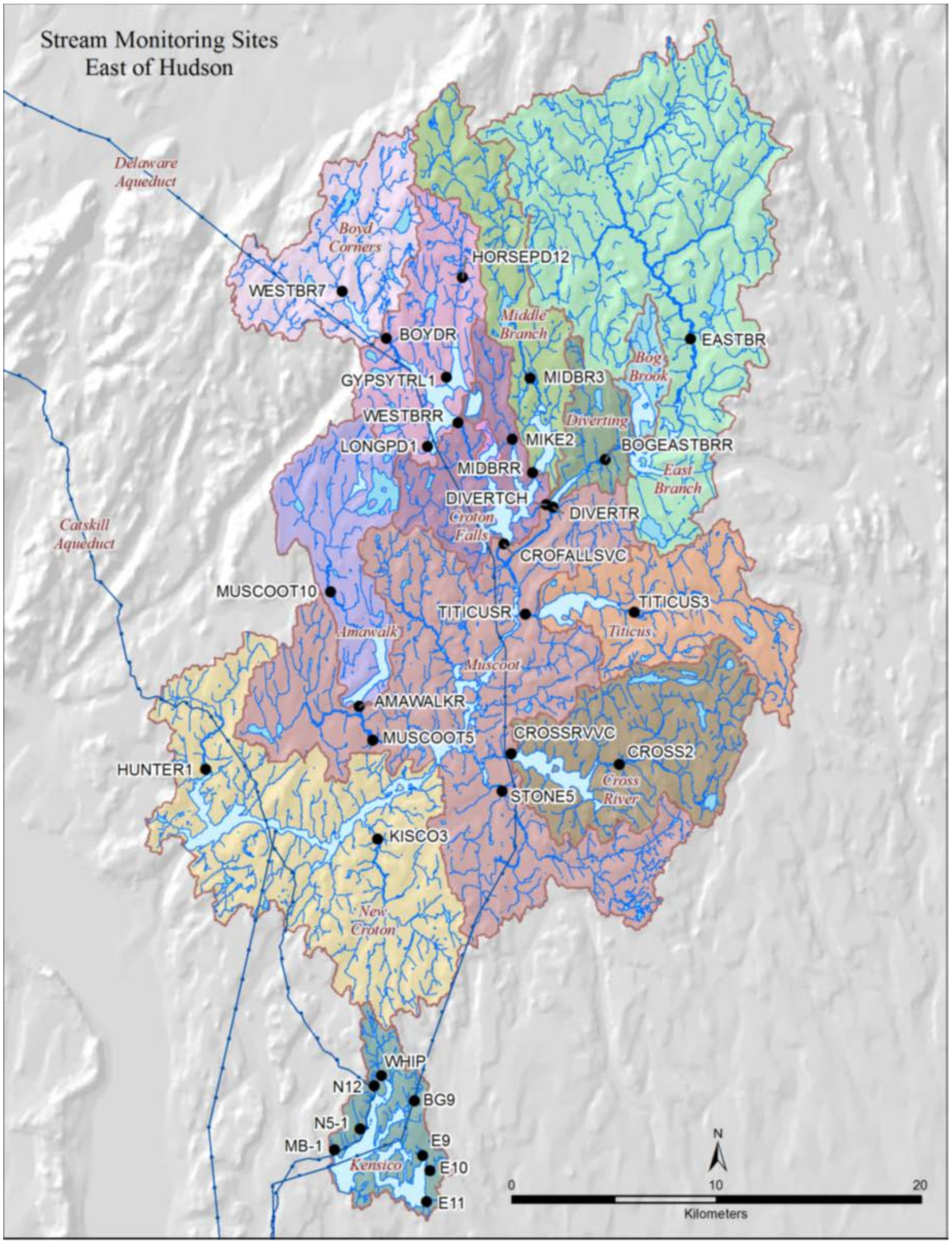
Appendix Figure 2 EOH reservoir monitoring sites (see 2016 WWQMP (DEP 2016a) for detailed maps).



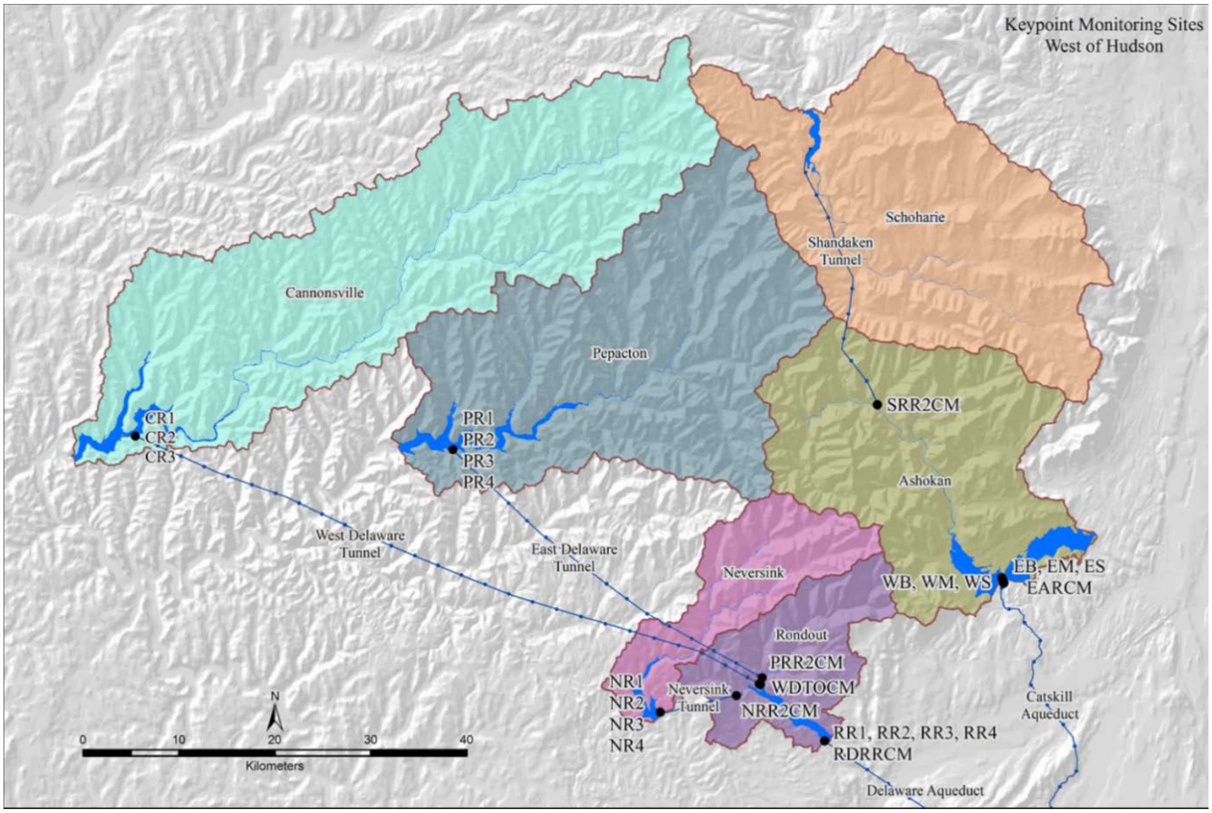
Appendix Figure 3 Delaware System stream monitoring sites (see 2016 WWQMP (DEP 2016a) for detailed maps).



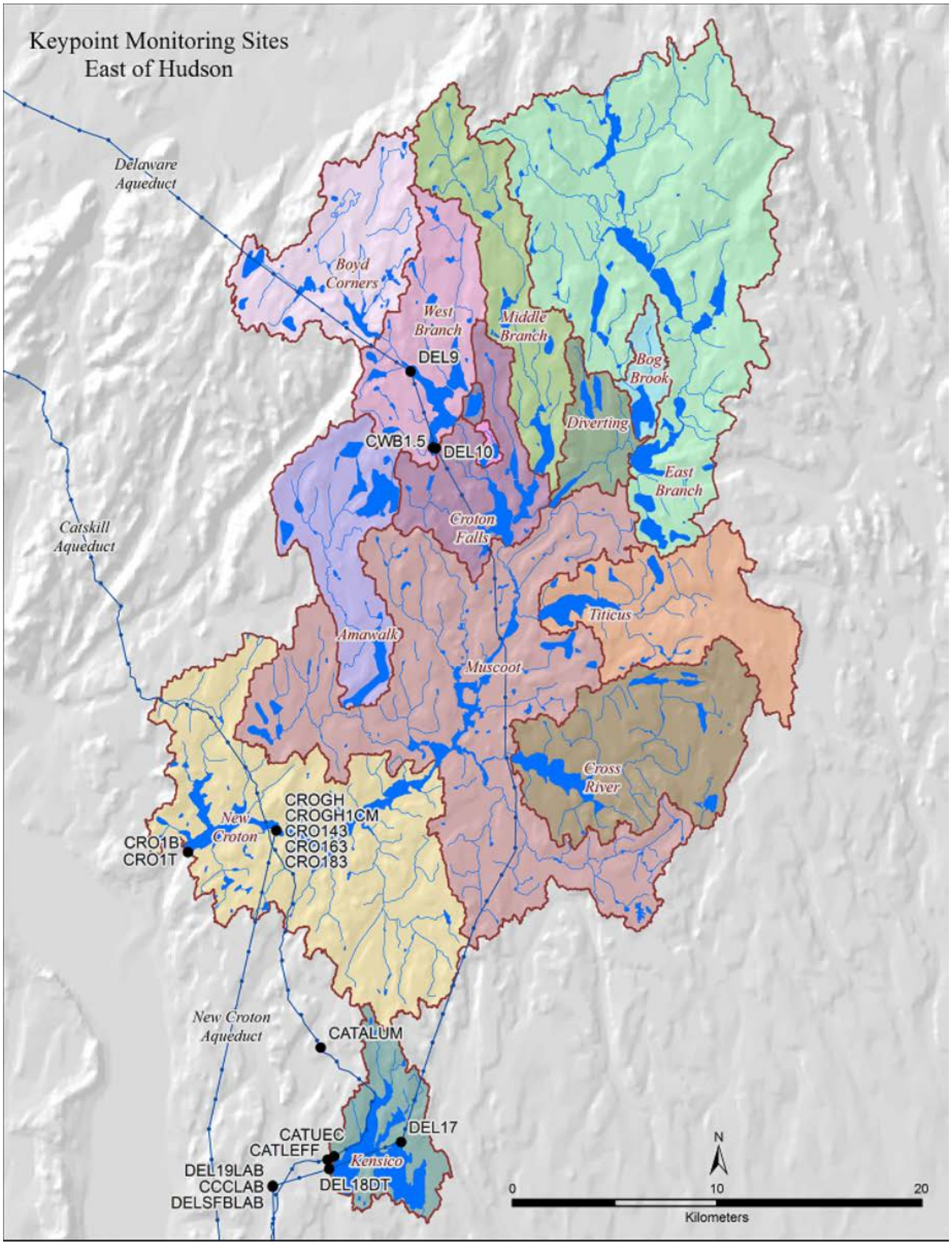
Appendix Figure 4 Catskill System stream monitoring sites (see 2016 WWQMP (DEP 2016a) for detailed maps).



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

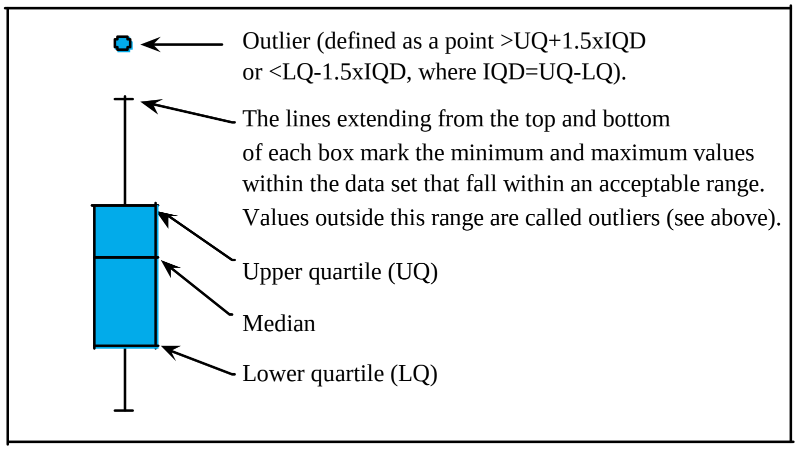


Appendix Figure 6 WOH aqueduct keypoint monitoring sites (see 2016 WWQMP (DEP 2016a) for detailed maps).



Appendix Figure 7 EOH aqueduct keypoint monitoring sites (see 2016 WWQMP (DEP 2016a) 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.

Reservoir	Class & Standard (Median, Value not > 20% of samples)	Collection Month	N	Median Total Coliform (coliforms 100 mL^{-1})	Percentage > Standard
Amawalk	A (2400, 5000)	Apr-16	5	20	0
Amawalk		May-16	5	41	0
Amawalk		Jun-16	5	10	0
Amawalk		Jul-16	5	100	0
Amawalk		Aug-16	5	33	0
Amawalk		Sep-16	5	<100	0
Amawalk		Oct-16	5	14	0
Amawalk		Nov-16	5	<20	0
Bog Brook	AA (50, 240)	Apr-16	6	5	0
Bog Brook		May-16	5	23	0
Bog Brook		Jun-16	5	5	0
Bog Brook		Jul-16	5	<200	20
Bog Brook		Aug-16	5	83	20
Bog Brook		Sep-16	5	130	20
Bog Brook		Oct-16	5	33	0
Bog Brook		Nov-16	5	42	0
Boyd's Corners	AA (50, 240)	Apr-16	7	7	0
Boyd's Corners		May-16	7	16	0
Boyd's Corners		Jun-16	6	17	0
Boyd's Corners		Jul-16	6	40	0
Boyd's Corners		Aug-16	7	92	14
Boyd's Corners		Sep-16	6	83	0
Boyd's Corners		Oct-16	6	36	0
Boyd's Corners		Nov-16	6	17	0
Croton Falls	A/AA (50, 240)	Apr-16	8	<10	0
Croton Falls		May-16	8	10	0
Croton Falls		Jun-16	8	40	0
Croton Falls		Jul-16	8	36	0
Croton Falls		Aug-16	8	<100	0
Croton Falls		Sep-16	8	83	25
Croton Falls		Oct-16	8	40	25
Croton Falls		Nov-16	7	43	0

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

Reservoir	Class & Standard (Median, Value not > 20% of samples)	Collection Date	N	Median Total Coliform (coliforms 100 mL $^{-1}$)	Percentage > Standard
Cross River	A/AA (50, 240)	Apr-16	6	10	0
Cross River		May-16	6	20	0
Cross River		Jun-16	6	33	0
Cross River		Jul-16	6	17	0
Cross River		Aug-16	6	17	0
Cross River		Sep-16	6	<20	0
Cross River		Oct-16	6	<20	0
Cross River		Nov-16	6	17	0
Diverting	AA (50, 240)	Apr-16	5	160	20
Diverting		May-16	5	84	0
Diverting		Jun-16	5	220	40
Diverting		Jul-16	5	30	0
Diverting		Aug-16	5	100	25
Diverting		Sep-16	5	<50	0
Diverting		Oct-16	5	320	80
Diverting		Nov-16	5	200	40
East Branch	AA (50, 240)	Apr-16	6	3	0
East Branch		May-16	6	28	0
East Branch		Jun-16	5	900	60
East Branch		Jul-16	5	36	0
East Branch		Aug-16	6	170	33
East Branch		Sep-16	5	67	0
East Branch		Oct-16	5	<50	0
East Branch		Nov-16	5	50	0
Lake Gilead	A (2400, 5000)	Apr-16	5	1	0
Lake Gilead		May-16	5	<5	0
Lake Gilead		Jun-16	5	5	0
Lake Gilead		Jul-16	5	2	0
Lake Gilead		Aug-16	5	<20	0
Lake Gilead		Sep-16	5	9	0
Lake Gilead		Oct-16	5	20	0
Lake Gilead		Nov-16	5	8	0
Lake Gleneida	AA (50, 240)	Apr-16	5	<2	0
Lake Gleneida		May-16	5	<5	0
Lake Gleneida		Jun-16	5	<10	0
Lake Gleneida		Jul-16	5	160	20
Lake Gleneida		Aug-16	5	24	0
Lake Gleneida		Sep-16	5	48	20
Lake Gleneida		Oct-16	5	14	0
Lake Gleneida		Nov-16	5	8	0

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

Reservoir	Class & Standard (Median, Value not > 20% of samples)	Collection Date	N	Median Total Coliform (coliforms 100 mL $^{-1}$)	Percentage > Standard
Kirk Lake	B (2400, 5000)	Apr-16	5	3	0
Kirk Lake		May-16	5	36	0
Kirk Lake		Jun-16	5	<50	0
Kirk Lake		Jul-16	5	250	0
Kirk Lake		Aug-16	5	36	0
Kirk Lake		Sep-16	5	36	0
Kirk Lake		Oct-16	5	67	0
Kirk Lake		Nov-16	0	Site inaccessible	NA
Muscoot	A (2400, 5000)	Apr-16	7	10	0
Muscoot		May-16	7	36	0
Muscoot		Jun-16	7	TNTC	0
Muscoot		Jul-16	7	18	0
Muscoot		Aug-16	7	<200	0
Muscoot		Sep-16	7	67	0
Muscoot		Oct-16	7	83	0
Muscoot		Nov-16	7	17	0
Middle Branch	A (2400, 5000)	Apr-16	5	84	0
Middle Branch		May-16	5	56	0
Middle Branch		Jun-16	5	64	0
Middle Branch		Jul-16	5	<5	0
Middle Branch		Aug-16	5	20	0
Middle Branch		Sep-16	5	<50	0
Middle Branch		Oct-16	5	50	0
Middle Branch		Nov-16	5	58	0
Titicus	AA (50, 240)	Apr-16	5	2	0
Titicus		May-16	5	7	0
Titicus		Jun-16	5	24	0
Titicus		Jul-16	5	<100	0
Titicus		Aug-16	5	<20	20
Titicus		Sep-16	5	320	60
Titicus		Oct-16	5	29	0
Titicus		Nov-16	5	<20	0
Cannonsville	A/AA (50, 240)	Apr-16	15	8	0
Cannonsville		May-16	15	<4	0
Cannonsville		Jun-16	15	8	10
Cannonsville		Jul-16	14	10	0
Cannonsville		Aug-16	14	TNTC	0
Cannonsville		Sep-16	12	<20	0
Cannonsville		Oct-16	11	<20	0
Cannonsville		Nov-16	4	<5 samples/month	0

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

Reservoir	Class & Standard (Median, Value not > 20% of samples)	Collection Date	N	Median Total Coliform (coliforms 100 mL $^{-1}$)	Percentage > Standard
Pepacton	A/AA (50, 240)	Apr-16	16	1	0
Pepacton		May-16	16	1	0
Pepacton		Jun-16	15	<4	0
Pepacton		Jul-16	15	<10	0
Pepacton		Aug-16	15	4	0
Pepacton		Sep-16	14	4	0
Pepacton		Oct-16	14	2	0
Pepacton		Nov-16	12	2	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. 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. 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 to change the designation.

Appendix Table 2 Geometric Mean Total Phosphorus Data used in the Phosphorus Restricted Assessments based on reservoir samples taken during the growing season (May 1 - Oct. 31).

Reservoir Basin	2011 $\mu g\ L^{-1}$	2012 $\mu g\ L^{-1}$	2013 $\mu g\ L^{-1}$	2014 $\mu g\ L^{-1}$	2015 $\mu g\ L^{-1}$	2016 $\mu g\ L^{-1}$
Non-Source Waters (Delaware System)						
Cannonsville Reservoir	16.3	12.4	15.0	13.1	14.9	17.0
Pepacton Reservoir	11.9	8.4	7.9	7.8	9.0	10.8
Neversink Reservoir	10.2	9.7	6.0	6.2	6.5	8.0
Non-Source Waters (Catskill System)						
Schoharie Reservoir	29.4	20.0	15.0	15.3	11.9	12.5
Non-Source Waters (Croton System)						
Amawalk Reservoir	18.3	22.3	22.3	19.4	19.3	29.8
Bog Brook Reservoir	23.6	27.9	20.0	14.4	19.4	28.4
Boyd’s Corners Reservoir	8.7	10.1	10.7	9.0	9.0	11.3
Diverting Reservoir	31.1	26.8	29.5	29.1	25.8	37.4
East Branch Reservoir	32.3	28.5	27.5	24.2	21.3	23.5
Middle Branch Reservoir	29.8	37.6	32.5	35.3	27.4	34.1
Muscoot Reservoir	28.8	31.5	29.9	28.7	28.5	30.6
Titicus Reservoir	26.9	24.4	24.4	24.8	19.5	23.7
Lake Gleneida	31.9	25.1	22.2	19.8	35.0	27.0
Lake Gilead	28.9	16.4	26.7	32.8	27.1	34.6
Kirk Lake	33.1	34.6	24.9	32.8	30.8	27.3
Source Waters (all systems)						
Ashokan-West Basin	31.0	10.2	7.3	8.1	8.8	12.6
Ashokan-East Basin	13.5	8.4	6.4	7.5	7.9	10.3
Cross River Reservoir	18.7	17.0	15.4	17.6	15.7	19.0
Croton Falls Reservoir	20.6	18.7	23.0	19.9	19.4	18.0
Kensico Reservoir	7.5	6.4	6.2	5.7	7.4	7.6
New Croton Reservoir	18.2	18.7	17.0	16.0	16.8	22.1
Rondout Reservoir	8.9	7.2	7.2	6.6	7.9	10.0
West Branch Reservoir	11.1	11.8	12.6	11.2	11.3	13.4

Appendix E. Comparison of Reservoir Water Quality Results to Benchmarks

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Croton System						
Amawalk Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>40	77
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	1	6	10	8.4
Color (Pt-Co units)	15	38	36	95	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	35	4	11	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	38	38	100	150	400
Total phosphorus (µg L^{-1})	15	38	37	97	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	2.1
Turbidity (NTU)	5	38	2	5	na	na
Bog Brook Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6	na	na	>40	73
Chloride (mg L^{-1})	40	6	6	100	30	68.9
Chlorophyll a (µg L^{-1})	15	8	1	13	10	6.3
Color (Pt-Co units)	15	18	14	78	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	18	0	0	6	3.8
Fecal coliforms (coliform $100mL^{-1}$)	20	41	1	2	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	17	0	0	0.3	<0.02
pH (units)	6.5-8.5	27	5	19	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	35.2
Soluble reactive phosphorus (µg L^{-1})	15	17	1	6	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	11.0
Total ammonia-N (mg L^{-1})	0.10	18	3	17	0.05	0.07
Total dissolved phosphorus (µg L^{-1})	15	18	3	17	na	na
Total dissolved solids (mg L^{-1})[3]	175	18	18	100	150	261
Total phosphorus (µg L^{-1})	15	18	15	83	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	6	0	0	5	1.9
Turbidity (NTU)	5	18	2	11	na	na
Boyd's Corners Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	8	na	na	>40	35
Chloride (mg L^{-1})	40	8	8	100	30	48.2
Chlorophyll a (µg L^{-1})	15	7	0	0	10	6.2
Color (Pt-Co units)	15	19	19	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	19	0	0	6	4.0
Fecal coliforms (coliform $100mL^{-1}$)	20	51	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	19	0	0	0.3	0.03
pH (units)	6.5-8.5	32	1	3	na	na
Sodium, undig., filt. (mg L^{-1})	20	8	8	100	15	27.3
Soluble reactive phosphorus (µg L^{-1})	15	19	0	0	na	na
Sulfate (mg L^{-1})	25	8	0	0	15	7.2
Total ammonia-N (mg L^{-1})	0.10	19	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	19	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	19	0	0	150	162
Total phosphorus (µg L^{-1})	15	19	5	26	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	8	0	0	5	1.6
Turbidity (NTU)	5	19	0	0	na	na
Cross River Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>40	50

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	**Benchmark Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2016 Mean [1]**
Chloride (mg L^{-1})	40	9	9	100	30	47.1
Chlorophyll a (µg L^{-1})	15	16	1	6	10	7.3
Color (Pt-Co units)	15	48	42	88	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	48	0	0	6	3.5
Fecal coliforms (coliform 100mL^{-1})	20	48	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	48	0	0	0.3	<u>0.02</u>
pH (units)	6.5-8.5	48	4	8	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	23.5
Soluble reactive phosphorus (µg L^{-1})	15	48	0	0	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	8.5
Total ammonia-N (mg L^{-1})	0.10	48	14	29	0.05	0.10
Total dissolved phosphorus (µg L^{-1})	15	48	1	2	na	na
Total dissolved solids (mg L^{-1})[3]	175	48	42	88	150	180
Total phosphorus (µg L^{-1})	15	48	41	85	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	2.3
Turbidity (NTU)	5	48	6	13	na	na
Croton Falls Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18	na	na	>40	63
Chloride (mg L^{-1})	40	18	18	100	30	96.0
Chlorophyll a (µg L^{-1})	15	24	5	21	10	11.2
Color (Pt-Co units)	15	64	54	84	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	64	0	0	6	3.5
Fecal coliforms (coliform 100mL^{-1})	20	63	1	2	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	64	10	16	0.3	<u>0.28</u>
pH (units)	6.5-8.5	48	13	27	na	na
Sodium, undig., filt. (mg L^{-1})	20	18	18	100	15	50.8
Soluble reactive phosphorus (µg L^{-1})	15	64	0	0	na	na
Sulfate (mg L^{-1})	25	18	0	0	15	12.4
Total ammonia-N (mg L^{-1})	0.10	63	11	17	0.05	<u>0.05</u>
Total dissolved phosphorus (µg L^{-1})	15	63	2	3	na	na
Total dissolved solids (mg L^{-1})[3]	175	64	64	100	150	350
Total phosphorus (µg L^{-1})	15	64	44	69	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Total phytoplankton (ASU mL^{-1})	2000	24	3	13	na	na
Primary genus (ASU mL^{-1})	1000	24	3	13	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	1.9
Turbidity (NTU)	5	64	9	14	na	na
Diverting Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6	na	na	>40	86
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	9	56	10	17.8
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	39	1	3	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	35	0	0	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	292
Total phosphorus (µg L^{-1})	15	32	32	100	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	6	38	na	na
Primary genus (ASU mL^{-1})	1000	16	6	38	na	na
Secondary genus (ASU mL^{-1})	1000	16	1	6	na	na
Total suspended solids (mg L^{-1})	8.0	6	2	33	5	10.5
Turbidity (NTU)	5	32	7	22	na	na
East Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>40	83
Chloride (mg L^{-1})	40	9	9	100	30	64.7
Chlorophyll a (µg L^{-1})	15	8	3	38	10	10.8
Color (Pt-Co units)	15	23	22	96	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	23	0	0	6	4.2
Fecal coliforms (coliform $100mL^{-1}$)	20	43	2	5	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	23	0	0	0.3	0.01
pH (units)	6.5-8.5	30	3	10	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	**Benchmark Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2016 Mean [1]**
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	31.8
Soluble reactive phosphorus (µg L^{-1})	15	23	0	0	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	11.7
Total ammonia-N (mg L^{-1})	0.10	23	6	26	0.05	0.06
Total dissolved phosphorus (µg L^{-1})	15	23	3	13	na	na
Total dissolved solids (mg L^{-1})[3]	175	23	23	100	150	261
Total phosphorus (µg L^{-1})	15	23	23	100	na	na
Total phytoplankton (ASU mL^{-1})	2000	8	0	0	na	na
Primary genus (ASU mL^{-1})	1000	8	1	13	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	3.1
Turbidity (NTU)	5	23	1	4	na	na
Kirk Lake						
Alkalinity (mg $CaCO_3$ L^{-1})	na	3	na	na	>40	61
Chloride (mg L^{-1})	40	3	3	100	30	98.8
Chlorophyll a (µg L^{-1})	15	3	2	67	10	16.7
Color (Pt-Co units)	15	3	3	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	3	0	0	6	4.8
Fecal coliforms (coliform 100mL^{-1})	20	35	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	3	0	0	0.3	0.05
pH (units)	6.5-8.5	15	3	20	na	na
Sodium, undig., filt. (mg L^{-1})	20	3	3	100	15	47.1
Soluble reactive phosphorus (µg L^{-1})	15	3	0	0	na	na
Sulfate (mg L^{-1})	25	3	0	0	15	9.0
Total ammonia-N (mg L^{-1})	0.10	3	1	33	0.05	0.16
Total dissolved phosphorus (µg L^{-1})	15	3	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	306
Total phosphorus (µg L^{-1})	15	3	3	100	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	3	0	0	5	4.1
Turbidity (NTU)	5	3	1	33	na	na
Lake Gilead						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>40	45

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Chloride (mg L^{-1})	40	9	9	100	30	54.6
Chlorophyll a (µg L^{-1})	15	3	0	0	10	3.3
Color (Pt-Co units)	15	9	5	56	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	3.4
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	2	13	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	29.0
Soluble reactive phosphorus (µg L^{-1})	15	9	3	33	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7.4
Total ammonia-N (mg L^{-1})	0.10	9	3	33	0.05	<u>0.13</u>
Total dissolved phosphorus (µg L^{-1})	15	9	3	33	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	9	100	150	189
Total phosphorus (µg L^{-1})	15	9	8	89	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	1.7
Turbidity (NTU)	5	9	0	0	na	na
Lake Gleneida						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>40	68
Chloride (mg L^{-1})	40	9	9	100	30	110.7
Chlorophyll a (µg L^{-1})	15	3	0	0	10	2.9
Color (Pt-Co units)	15	9	3	33	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	3.1
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	3	20	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	60.1
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	6.2
Total ammonia-N (mg L^{-1})	0.10	9	2	22	0.05	<u>0.14</u>
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	11	11	100	150	334
Total phosphorus (µg L^{-1})	15	9	6	67	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
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	1.9
Turbidity (NTU)	5	9	0	0	na	na
Middle Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>40	66
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	2	13	10	8.5
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	35	3	9	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	389
Total phosphorus (µg L^{-1})	15	40	40	100	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	1	11	5	3.2
Turbidity (NTU)	5	40	6	15	na	na
Muscoot Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6	na	na	>40	81
Chloride (mg L^{-1})	40	6	6	100	30	96.2
Chlorophyll a (µg L^{-1})	15	32	8	25	10	14.7
Color (Pt-Co units)	15	56	55	98	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	56	0	0	6	3.9
Fecal coliforms (coliform $100mL^{-1}$)	20	56	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	56	5	9	0.3	0.19
pH (units)	6.5-8.5	49	3	6	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	47.6
Soluble reactive phosphorus (µg L^{-1})	15	56	3	5	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	9.8
Total ammonia-N (mg L^{-1})	0.10	56	13	23	0.05	0.16
Total dissolved phosphorus (µg L^{-1})	15	56	4	7	na	na
Total dissolved solids (mg L^{-1})[3]	175	56	56	100	150	321
Total phosphorus (µg L^{-1})	15	56	56	100	na	na
Total phytoplankton (ASU mL^{-1})	2000	32	1	3	na	na
Primary genus (ASU mL^{-1})	1000	32	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	32	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	3.7
Turbidity (NTU)	5	56	10	18	na	na
New Croton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	33	na	na	>40	68
Chloride (mg L^{-1})	40	33	33	100	30	91.5
Chlorophyll a (µg L^{-1})	15	58	4	7	10	7.9
Color (Pt-Co units)	15	171	151	88	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	171	0	0	6	3.3
Fecal coliforms (coliform $100mL^{-1}$)	20	170	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	171	5	3	0.3	0.15
pH (units)	6.5-8.5	150	16	11	na	na
Sodium, undig., filt. (mg L^{-1})	20	33	33	100	15	46.1
Soluble reactive phosphorus (µg L^{-1})	15	171	10	6	na	na
Sulfate (mg L^{-1})	25	33	0	0	15	11.2
Total ammonia-N (mg L^{-1})	0.10	171	42	25	0.05	0.12
Total dissolved phosphorus (µg L^{-1})	15	171	25	15	na	na
Total dissolved solids (mg L^{-1})[3]	175	171	171	100	150	300
Total phosphorus (µg L^{-1})	15	171	144	84	na	na
Total phytoplankton (ASU mL^{-1})	2000	66	1	2	na	na
Primary genus (ASU mL^{-1})	1000	66	2	3	na	na
Secondary genus (ASU mL^{-1})	1000	66	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	58	0	0	5	1.7
Turbidity (NTU)	5	171	11	6	na	na
Titicus Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>40	71

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	1	6	10	7.3
Color (Pt-Co units)	15	37	34	92	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	35	3	9	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	37	37	100	150	219
Total phosphorus (µg L^{-1})	15	37	34	92	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	1.9
Turbidity (NTU)	5	37	1	3	na	na
Catskill System						
Ashokan East Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9	na	na	>10	13
Chloride (mg L^{-1})	12	9	0	0	8	8.5
Chlorophyll a (µg L^{-1})	12	24	0	0	7	2.7
Color (Pt-Co units)	15	64	3	5	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	64	0	0	3	1.7
Fecal coliforms (coliform 100mL^{-1})	20	64	1	2	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	64	0	0	0.3	<0.02
pH (units)	6.5-8.5	64	14	22	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	5.3
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	3	5	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	64	3	5	na	na
Total dissolved solids (mg L^{-1})[3]	50	64	2	3	40	43

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Total phosphorus (µg L^{-1})	15	64	12	19	na	na
Total phytoplankton (ASU mL^{-1})	2000	38	0	0	na	na
Primary genus (ASU mL^{-1})	1000	38	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	38	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	64	3	5	5	2.6
Turbidity (NTU)	5	64	6	9	na	na
Ashokan West Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12	na	na	>10	14
Chloride (mg L^{-1})	12	12	0	0	8	8.0
Chlorophyll a (µg L^{-1})	12	24	0	0	7	2.9
Color (Pt-Co units)	15	72	4	6	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	73	0	0	3	1.6
Fecal coliforms (coliform 100mL^{-1})	20	72	4	6	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	73	0	0	0.3	<u>0.10</u>
pH (units)	6.5-8.5	72	2	3	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	5.1
Soluble reactive phosphorus (µg L^{-1})	15	73	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.6
Total ammonia-N (mg L^{-1})	0.10	73	0	0	0.05	<u>0.01</u>
Total dissolved phosphorus (µg L^{-1})	15	73	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	73	20	27	40	44
Total phosphorus (µg L^{-1})	15	73	18	25	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	72	9	13	5	4.6
Turbidity (NTU)	5	73	24	33	na	na
Schoharie Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6	na	na	>10	17
Chloride (mg L^{-1})	12	6	0	0	8	10.0
Chlorophyll a (µg L^{-1})	12	20	0	0	7	2.6
Color (Pt-Co units)	15	56	27	48	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.9
Fecal coliforms (coliform 100mL^{-1})	20	56	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	41	0	0	0.3	<u>0.12</u>

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	**Benchmark Single sample maximum (SSM)**	**Number samples**	**Number exceeding SSM**	**Percent exceeding SSM**	**Annual Mean Standard**	**2016 Mean [1]**
pH (units)	6.5-8.5	56	4	7	na	na
Sodium, undig., filt. (mg L^{-1})	16	6	6	100	3	6.5
Soluble reactive phosphorus (µg L^{-1})	15	41	0	0	na	na
Sulfate (mg L^{-1})	15	6	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.10	41	0	0	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	41	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	56	36	64	40	54
Total phosphorus (µg L^{-1})	15	56	21	38	na	na
Total phytoplankton (ASU mL^{-1})	2000	30	0	0	na	na
Primary genus (ASU mL^{-1})	1000	30	4	13	na	na
Secondary genus (ASU mL^{-1})	1000	30	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	56	2	4	5	3.6
Turbidity (NTU)	5	56	35	63	na	na
Delaware System						
Cannonsville Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12	na	na	>10	17
Chloride (mg L^{-1})	12	12	5	42	8	12.3
Chlorophyll a (µg L^{-1})	12	37	3	8	7	7.4
Color (Pt-Co units)	15	100	19	19	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	100	0	0	3	1.8
Fecal coliforms (coliform $100mL^{-1}$)	20	100	6	6	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	100	0	0	0.3	0.26
pH (units)	6.5-8.5	100	11	11	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	8.2
Soluble reactive phosphorus (µg L^{-1})	15	100	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	5.0
Total ammonia-N (mg L^{-1})	0.10	101	1	1	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	101	2	2	na	na
Total dissolved solids (mg L^{-1})[3]	50	100	97	97	40	64
Total phosphorus (µg L^{-1})	15	100	71	71	na	na
Total phytoplankton (ASU mL^{-1})	2000	52	2	4	na	na
Primary genus (ASU mL^{-1})	1000	52	5	10	na	na
Secondary genus (ASU mL^{-1})	1000	52	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	46	3	7	5	2.7
Turbidity (NTU)	5	99	9	9	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Neversink Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	10	na	na	>10	4
Chloride (mg L^{-1})	12	10	0	0	8	3.9
Chlorophyll a (µg L^{-1})	12	24	0	0	7	3.2
Color (Pt-Co units)	15	94	8	9	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	69	0	0	3	1.6
Fecal coliforms (coliform $100mL^{-1}$)	20	94	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	70	0	0	0.3	<u>0.12</u>
pH (units)	6.5-8.5	94	55	59	na	na
Sodium, undig., filt. (mg L^{-1})	16	10	0	0	3	2.3
Soluble reactive phosphorus (µg L^{-1})	15	70	0	0	na	na
Sulfate (mg L^{-1})	15	10	0	0	10	2.9
Total ammonia-N (mg L^{-1})	0.10	70	0	0	0.05	<u>0.01</u>
Total dissolved phosphorus (µg L^{-1})	15	70	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	94	0	0	40	21
Total phosphorus (µg L^{-1})	15	70	1	1	na	na
Total phytoplankton (ASU mL^{-1})	2000	48	0	0	na	na
Primary genus (ASU mL^{-1})	1000	48	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	24	0	0	5	<u>0.9</u>
Turbidity (NTU)	5	94	0	0	na	na
Pepacton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	20	na	na	>10	14
Chloride (mg L^{-1})	12	20	0	0	8	8.9
Chlorophyll a (µg L^{-1})	12	38	0	0	7	2.8
Color (Pt-Co units)	15	117	2	2	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	117	1	1	3	1.6
Fecal coliforms (coliform $100mL^{-1}$)	20	117	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	117	0	0	0.3	<u>0.11</u>
pH (units)	6.5-8.5	117	8	7	na	na
Sodium, undig., filt. (mg L^{-1})	16	20	20	100	3	5.4
Soluble reactive phosphorus (µg L^{-1})	15	117	0	0	na	na
Sulfate (mg L^{-1})	15	20	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.10	117	0	0	0.05	<u>0.01</u>
Total dissolved phosphorus (µg L^{-1})	15	117	0	0	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Total dissolved solids (mg L^{-1})[3]	50	117	23	20	40	48
Total phosphorus (µg L^{-1})	15	117	20	17	na	na
Total phytoplankton (ASU mL^{-1})	2000	55	0	0	na	na
Primary genus (ASU mL^{-1})	1000	55	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	55	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	55	0	0	5	0.9
Turbidity (NTU)	5	117	4	3	na	na
Rondout Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12	na	na	>10	11
Chloride (mg L^{-1})	12	12	0	0	8	8.8
Chlorophyll a (µg L^{-1})	12	24	0	0	7	3.4
Color (Pt-Co units)	15	80	2	3	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.7
Fecal coliforms (coliform 100mL^{-1})	20	80	5	6	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	56	0	0	0.3	0.15
pH (units)	6.5-8.5	80	10	13	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	5.4
Soluble reactive phosphorus (µg L^{-1})	15	56	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	4.0
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	7	9	40	44
Total phosphorus (µg L^{-1})	15	80	7	9	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	32	0	0	5	0.9
Turbidity (NTU)	5	80	4	5	na	na
West Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	15	na	na	>10	20
Chloride (mg L^{-1})	12	15	15	100	8	24.6
Chlorophyll a (µg L^{-1})	12	32	1	3	7	5.0
Color (Pt-Co units)	15	71	46	65	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	71	0	0	3	2.3
Fecal coliforms (coliform 100mL^{-1})	20	71	0	0	na	na

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Nitrate+Nitrite-N (mg L^{-1})	0.5	71	0	0	0.3	<u>0.04</u>
pH (units)	6.5-8.5	62	2	3	na	na
Sodium, undig., filt. (mg L^{-1})	16	15	15	100	3	13.3
Soluble reactive phosphorus (µg L^{-1})	15	71	0	0	na	na
Sulfate (mg L^{-1})	15	15	0	0	10	5.7
Total ammonia-N (mg L^{-1})	0.10	71	1	1	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	71	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	71	71	100	40	91
Total phosphorus (µg L^{-1})	15	71	18	25	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	71	2	3	na	na
Terminal Reservoir for Catskill/Delaware System						
Kensico Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	24	na	na	>10	13
Chloride (mg L^{-1})	12	24	0	0	8	10.8
Chlorophyll a (µg L^{-1})	12	64	0	0	7	2.7
Color (Pt-Co units)	15	200	11	6	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	200	0	0	3	1.7
Fecal coliforms (coliform 100mL^{-1})	20	199	0	0	na	na
Nitrate+Nitrite-N (mg L^{-1})	0.5	200	0	0	0.3	<u>0.11</u>
pH (units)	6.5-8.5	178	19	11	na	na
Sodium, undig., filt. (mg L^{-1})	16	24	24	100	3	6.4
Soluble reactive phosphorus (µg L^{-1})	15	200	0	0	na	na
Sulfate (mg L^{-1})	15	24	0	0	10	4.2
Total ammonia-N (mg L^{-1})	0.10	200	1	1	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	200	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	200	74	37	40	50
Total phosphorus (µg L^{-1})	15	200	1	1	na	na
Total phytoplankton (ASU mL^{-1})	2000	96	0	0	na	na
Primary genus (ASU mL^{-1})	1000	96	1	1	na	na
Secondary genus (ASU mL^{-1})	1000	96	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	70	0	0	5	<u>0.9</u>

Appendix Table 3 Comparison of reservoir water quality results to benchmarks.

Reservoir/Analyte	Benchmark Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean [1]
Turbidity (NTU)	5	200	0	0	na	na

na = not applicable.

[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).

Environmental Protection

Appendix F. Comparison of Stream Water Quality Results to Benchmarks

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
Ashokan Watershed						
E10I (Bushkill at West Shokan)						
Alkalinity (mg L^{-1})	≥10.0	12	8	67	na	8.4
Chloride (mg L^{-1})	50	12	0	0	10	3.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	<u>0.9</u>
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.07</u>
Sulfate (mg L^{-1})	15	4	0	0	10	3.6
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	13	0	0	40	26
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.5
E16I (Esopus Brook at Coldbrook)						
Alkalinity (mg L^{-1})	≥10.0	13	0	0	na	20.1
Chloride (mg L^{-1})	50	13	0	0	10	10.7
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	13	0	0	0.40	<u>0.14</u>
Sulfate (mg L^{-1})	15	2	0	0	10	4.5
Total ammonia-N (mg L^{-1})	0.25	13	0	0	0.05	<u>0.01</u>
Total dissolved solids (mg L^{-1})[2]	50	14	8	57	40	59
Dissolved sodium (mg L^{-1})	10	2	0	0	5	8.3
E5 (Esopus Creek at Allaben)						
Alkalinity (mg L^{-1})	≥10.0	12	6	50	na	14.5
Chloride (mg L^{-1})	50	12	0	0	10	6.7
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	<u>0.15</u>
Sulfate (mg L^{-1})	15	4	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	13	5	38	40	43
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.9

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
Schoharie Watershed						
S5I (Schoharie Creek at Prattsville)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	22.5
Chloride (mg L^{-1})	50	12	0	0	10	12.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.16</u>
Sulfate (mg L^{-1})	15	4	0	0	10	4.3
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.04</u>
Total dissolved solids (mg L^{-1})[2]	50	13	10	77	40	69
Dissolved sodium (mg L^{-1})	10	4	1	25	5	7.8
S6I (Bear Creek at Hardenburgh Falls)						
Alkalinity (mg L^{-1})	≥10.0	11	0	0	na	31.4
Chloride (mg L^{-1})	50	12	2	17	10	28.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.6
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	2	17	0.40	0.79
Sulfate (mg L^{-1})	15	4	0	0	10	7.2
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	124
Dissolved sodium (mg L^{-1})	10	4	3	75	5	16.0
S7I (Manor Kill)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	30.6
Chloride (mg L^{-1})	50	12	0	0	10	11.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.06</u>
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 solids (mg L^{-1})[2]	50	12	9	75	40	74
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.4

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
SRR2CM (Schoharie Reservoir Diversion) [3]						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	19.9
Chloride (mg L^{-1})	50	12	0	0	10	11.8
Dissolved organic carbon (mg L^{-1})	25	52	0	0	9	1.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.18
Sulfate (mg L^{-1})	15	4	0	0	10	4.5
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	248	169	68	40	65
Dissolved sodium (mg L^{-1})	10	5	1	20	5	9.6
Cannonsville Watershed						
C-7 (Trout Creek above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	17.5
Chloride (mg L^{-1})	50	12	0	0	10	14.1
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	0.26
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 solids (mg L^{-1})[2]	50	12	12	100	40	66
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.9
C-8 (Loomis Brook above Cannonsville Reservoir						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	16.5
Chloride (mg L^{-1})	50	12	0	0	10	13.4
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	0.25
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 solids (mg L^{-1})[2]	50	12	11	92	40	63
Dissolved sodium (mg L^{-1})	10	4	1	25	5	9.1

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
WDBN (West Branch Delaware River at Beerston Bridge)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	21.7
Chloride (mg L^{-1})	50	12	0	0	10	14.1
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	0.50
Sulfate (mg L^{-1})	15	4	0	0	10	5.4
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	13	12	92	40	76
Dissolved sodium (mg L^{-1})	10	4	1	25	5	9.7
Neversink Watershed						
NCG (Neversink River near Claryville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	3.8
Chloride (mg L^{-1})	50	12	0	0	10	3.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	<u>1.0</u>
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.17
Sulfate (mg L^{-1})	15	4	0	0	10	3.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	21
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.3
NK4 (Aden Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	8	67	na	8.5
Chloride (mg L^{-1})	50	12	0	0	10	4.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	<u>1.1</u>
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.16</u>
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 solids (mg L^{-1})[2]	50	13	0	0	40	31
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.4

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
NK6 (Kramer Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	10	83	na	8.5
Chloride (mg L^{-1})	50	11	4	36	10	45.1
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	0.72
Sulfate (mg L^{-1})	15	4	0	0	10	5.4
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	121
Dissolved sodium (mg L^{-1})	10	4	4	100	5	22.8
Pepacton Watershed						
P-13 (Tremper Kill above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	18.6
Chloride (mg L^{-1})	50	12	0	0	10	11.5
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	0.26
Sulfate (mg L^{-1})	15	4	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	13	9	69	40	61
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.8
P-21 (Platte Kill at Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	18.9
Chloride (mg L^{-1})	50	12	0	0	10	8.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.20</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	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	13	7	54	40	56
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.7

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
P-60 (Mill Brook near Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	6	50	na	12.2
Chloride (mg L^{-1})	50	13	0	0	10	2.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	13	0	0	0.40	0.19
Sulfate (mg L^{-1})	15	4	0	0	10	3.6
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	13	0	0	40	31
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.5
P-7 (Terry Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	14.3
Chloride (mg L^{-1})	50	12	0	0	10	1.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.33
Sulfate (mg L^{-1})	15	4	0	0	10	4.2
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	13	0	0	40	33
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	14.4
Chloride (mg L^{-1})	50	12	0	0	10	2.6
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	0.30
Sulfate (mg L^{-1})	15	4	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	13	0	0	40	37
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.8

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
PMSB (East Branch Delaware River near Margaretville)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	20.5
Chloride (mg L^{-1})	50	12	0	0	10	14.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.34
Sulfate (mg L^{-1})	15	4	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	50	13	11	85	40	72
Dissolved sodium (mg L^{-1})	10	4	1	25	5	7.8
Rondout Reservoir						
RD1 (Sugarloaf Brook near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	5.3
Chloride (mg L^{-1})	50	12	0	0	10	6.8
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>0.11</u>
Sulfate (mg L^{-1})	15	4	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	31
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.9
RD4 (Sawkill Brook near Yagerville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	5.5
Chloride (mg L^{-1})	50	12	0	0	10	6.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	<u>0.07</u>
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 solids (mg L^{-1})[2]	50	12	0	0	40	31
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.8

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
RDOA (Rondout Creek near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	4.0
Chloride (mg L^{-1})	50	12	0	0	10	3.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	26	0	0	0.40	<u>0.11</u>
Sulfate (mg L^{-1})	15	4	0	0	10	3.6
Total ammonia-N (mg L^{-1})	0.25	26	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	51	0	0	40	22
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.4
RGB (Chestnut Creek below Grahamsville STP)						
Alkalinity (mg L^{-1})	≥10.0	12	7	58	na	9.5
Chloride (mg L^{-1})	50	12	0	0	10	17.8
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	0.37
Sulfate (mg L^{-1})	15	4	0	0	10	4.9
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	10	83	40	64
Dissolved sodium (mg L^{-1})	10	4	2	50	5	11.2

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
East of Hudson						
AMAWALKR (Amawalk Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	77.3
Chloride (mg L^{-1})	100	12	12	100	35	129.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.16</u>
Sulfate (mg L^{-1})	25	4	0	0	15	11.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.09</u>
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	392
Dissolved sodium (mg L^{-1})	20	4	4	100	15	67.1
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	78.8
Chloride (mg L^{-1})	100	12	1	8	35	78.1
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	0.13
Sulfate (mg L^{-1})	25	4	0	0	15	13.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.05</u>
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	285
Dissolved sodium (mg L^{-1})	20	4	4	100	15	38.5
BOYDR (Boyd's Corners Release) [3]						
Alkalinity (mg L^{-1})	≥40.0	12	11	92	na	33.6
Chloride (mg L^{-1})	100	12	0	0	35	49.1
Dissolved organic carbon (mg L^{-1})	25	52	0	0	9	4.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.08</u>
Sulfate (mg L^{-1})	25	4	0	0	15	12.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.04</u>
Total dissolved solids (mg L^{-1})[2]	175	52	2	4	150	164
Dissolved sodium (mg L^{-1})	20	4	4	100	15	27.3

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
CROFALLSVC (Croton Falls Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	10	0	0	na	60.0
Chloride (mg L^{-1})	100	10	0	0	35	93.5
Dissolved organic carbon (mg L^{-1})	25	45	0	0	9	3.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	10	0	0	0.35	0.26
Sulfate (mg L^{-1})	25	3	0	0	15	11.1
Total ammonia-N (mg L^{-1})	0.20	10	1	10	0.10	0.07
Total dissolved solids (mg L^{-1})[2]	175	45	45	100	150	297
Dissolved sodium (mg L^{-1})	20	3	3	100	15	47.7
CROSS2 (Cross River above Cross River Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	1	8	na	55.9
Chloride (mg L^{-1})	100	12	0	0	35	43.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.13
Sulfate (mg L^{-1})	25	4	0	0	15	9.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	8	67	150	179
Dissolved sodium (mg L^{-1})	20	4	3	75	15	23.5
CROSSRVVC (Cross River Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	11	0	0	na	49.1
Chloride (mg L^{-1})	100	11	0	0	35	46.9
Dissolved organic carbon (mg L^{-1})	25	47	0	0	9	3.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	11	0	0	0.35	0.06
Sulfate (mg L^{-1})	25	4	0	0	15	8.3
Total ammonia-N (mg L^{-1})	0.20	11	3	27	0.10	0.16
Total dissolved solids (mg L^{-1})[2]	175	55	47	85	150	179
Dissolved sodium (mg L^{-1})	20	4	4	100	15	23.5

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
DIVERTR (Diverting Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	77.0
Chloride (mg L^{-1})	100	12	0	0	35	80.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.19
Sulfate (mg L^{-1})	25	4	0	0	15	13.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.04
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	290
Dissolved sodium (mg L^{-1})	20	4	4	100	15	41.5
EASTBR (East Branch Croton River above East Branch River)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	93.9
Chloride (mg L^{-1})	100	12	0	0	35	62.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	5.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.05
Sulfate (mg L^{-1})	25	4	1	25	15	20.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.01
Total dissolved solids (mg L^{-1})[2]	175	13	13	100	150	275
Dissolved sodium (mg L^{-1})	20	4	4	100	15	30.9
GYPSYTRL1 (Gypsy Trail Brook above West Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	9	75	na	33.2
Chloride (mg L^{-1})	100	12	2	17	35	60.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.07
Sulfate (mg L^{-1})	25	4	0	0	15	7.7
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	13	5	38	150	187
Dissolved sodium (mg L^{-1})	20	4	3	75	15	24.2

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
HORSEPD12 (Horse Pound Brook above West Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	5	42	na	45.8
Chloride (mg L^{-1})	100	12	0	0	35	70.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.29
Sulfate (mg L^{-1})	25	4	0	0	15	8.7
Total Ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	13	13	100	150	227
Dissolved sodium (mg L^{-1})	20	4	4	100	15	33.8
KISCO3 (Kisco River above New Croton Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	1	8	na	86.4
Chloride (mg L^{-1})	100	12	12	100	35	138.0
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	0.65
Sulfate (mg L^{-1})	25	4	0	0	15	14.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	427
Dissolved sodium (mg L^{-1})	20	4	4	100	15	64.1
LONGPD1 (Long Pond outflow above West Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	58.8
Chloride (mg L^{-1})	100	12	4	33	35	107.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.18
Sulfate (mg L^{-1})	25	4	0	0	15	12.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	13	13	100	150	326
Dissolved sodium (mg L^{-1})	20	4	4	100	15	47.6

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
MIKE2 (Michael Brook above Croton Falls Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	85.6
Chloride (mg L^{-1})	100	12	12	100	35	204.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	7	58	0.35	3.05
Sulfate (mg L^{-1})	25	4	0	0	15	19.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.02</u>
Total dissolved solids (mg L^{-1})[2]	175	13	13	100	150	593
Dissolved sodium (mg L^{-1})	20	4	4	100	15	105.9
MUSCOOT10 (Muscoot River above Amawalk Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	86.2
Chloride (mg L^{-1})	100	12	11	92	35	155.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	6.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.31</u>
Sulfate (mg L^{-1})	25	4	0	0	15	10.9
Total ammonia-N (mg L^{-1})	0.20	12	1	8	0.10	<u>0.05</u>
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	461
Dissolved sodium (mg L^{-1})	20	4	4	100	15	69.6
TITICUSR (Titicus Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	72.0
Chloride (mg L^{-1})	100	12	0	0	35	52.1
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	0.17
Sulfate (mg L^{-1})	25	4	0	0	15	8.7
Total ammonia-N (mg L^{-1})	0.20	12	3	25	0.10	<u>0.10</u>
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	216
Dissolved sodium (mg L^{-1})	20	4	4	100	15	25.0

Appendix Table 4 Comparison of stream water quality results to benchmarks.

Site/Analyte	Single Sample Maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2016 Mean[1]
WESTBR7 (West Branch Croton River above Boyd's Corners Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	5	42	na	42.2
Chloride (mg L^{-1})	100	12	0	0	35	45.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	5.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.04
Sulfate (mg L^{-1})	25	4	0	0	15	6.7
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.01
Total dissolved solids (mg L^{-1})[2]	175	12	3	25	150	164
Dissolved sodium (mg L^{-1})	20	4	4	100	15	26.5
WESTBRR (West Branch Reservoir Release)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	18.5
Chloride (mg L^{-1})	50	12	0	0	10	20.7
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	0.05
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	80
Dissolved sodium (mg L^{-1})	10	4	2	50	5	10.9

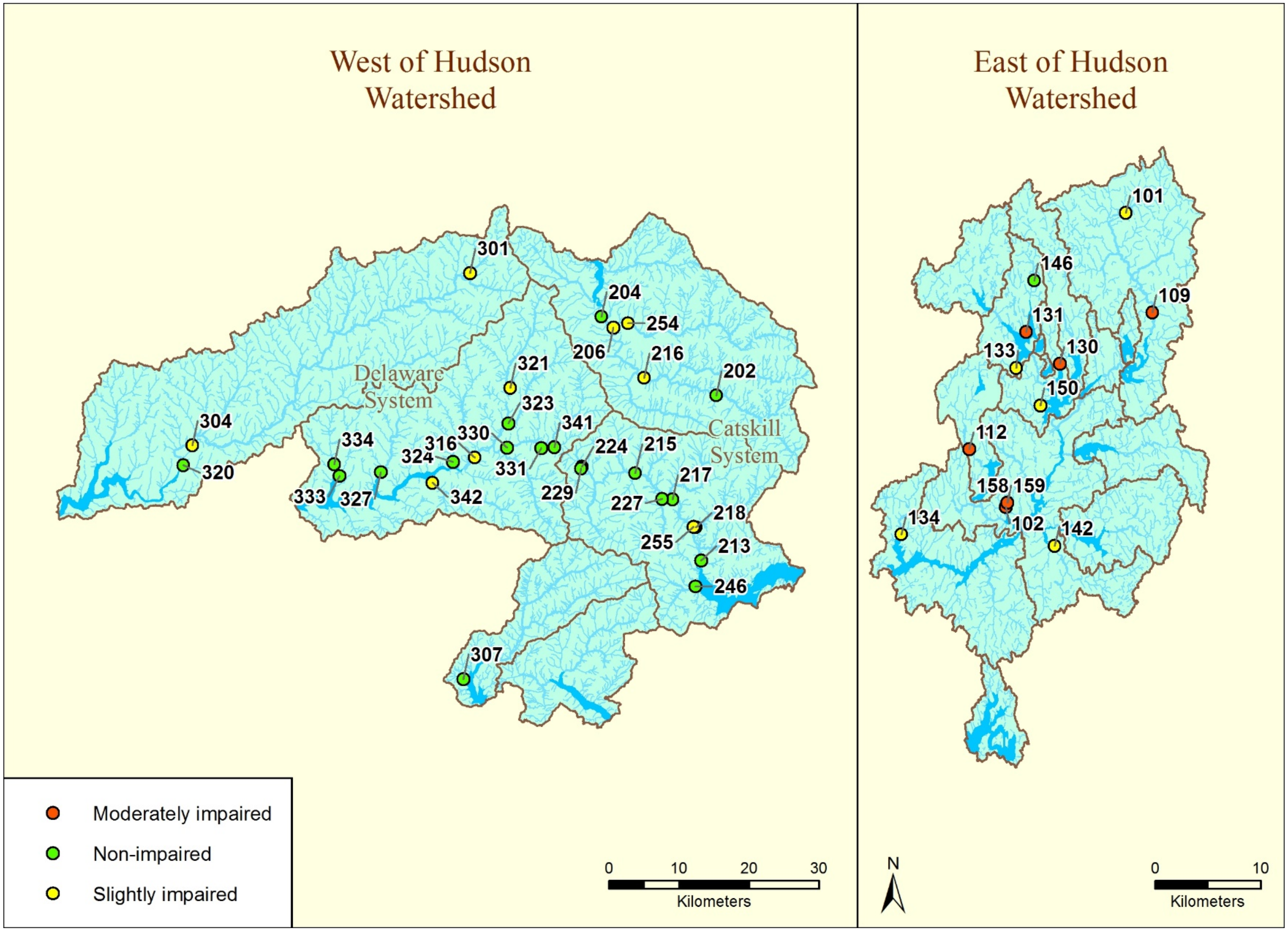
na = not applicable.

[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. Semivolatile and Volatile Organic Compounds

EPA 525.2 – Semivolatiles

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

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), 2,4 DDD, 2,4 DDE, 2,4-DDT

Herbicides

Glyphosate