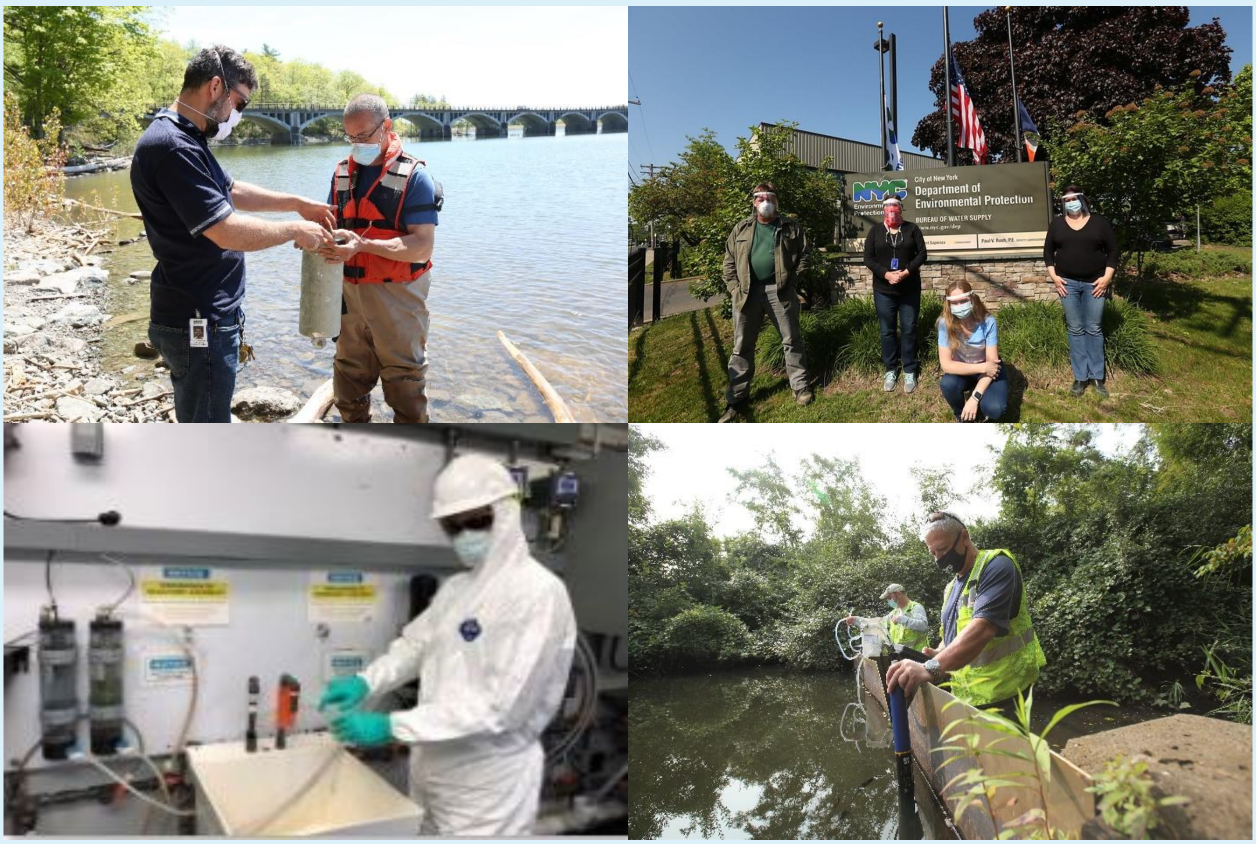
NYC Department of Environmental Protection

2020 Watershed Water Quality Annual Report

July 2021



NYC Environmental Protection

Vincent Sapienza, P.E., Commissioner
Paul V. Rush, P.E., Deputy Commissioner
Bureau of Water Supply

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List of Acronyms

AEAP	Esopus Creek above Portal for Shandaken Tunnel
BAP	Biological Assessment Profile
BEPA	Bureau of Environmental Planning and Analysis
BMP	Best Management Practice
BWS	Bureau of Water Supply
CATALUM	Catskill Alum Chamber Sampling Location
CATUEC	Catskill Upper Effluent Chamber
CCCLAB	Catskill Aqueduct Connection Chamber just prior to lower Catskill Aqueduct piped to a sample tap in the UV Plant Laboratory
CFR	Code of Federal Regulations
cfs	cubic feet per second
CROGH	New Croton Reservoir Gatehouse; elevation 213 feet above sea level
CUNY-RF	City University of New York Research Foundation
DBP	Disinfection Byproducts
DBPfp	Disinfection Byproduct formation potential
DEL17	Delaware Aqueduct Shaft Building 17 Sampling Location
DEL18DT	Delaware Aqueduct Shaft Building 18 Sampling Location
DEL19LAB	Shaft 19 Uptake Building piped to a sample tap in the UV Plant Laboratory
DELSFBLAB	South Forebay just prior to DEL19 Downtake piped to a sample tap in the UV Plant Laboratory
DEP	New York City Department of Environmental Protection
DOC	Dissolved Organic Carbon
DRO	Diesel Range Organics
EARCM	Ashokan Reservoir effluent collected at Ashokan Reservoir pump house
EOH	East of Hudson
EWRM	Early Warning Remote Monitoring
FAD	Filtration Avoidance Determination
fDOM	Fluorescent Dissolved Organic Matter
GLEON	Global Lake Ecological Observatory Network
GWLF	Generalized Watershed Loading Function
HEV	Human Enteric Virus
IAR	Inactivation Ratio
LT2	Long Term 2 Enhanced Surface Water Treatment Rule
$\mu g\ L^{-1}$	microgram per liter
$\mu mhos\ cm^{-1}$	micromhos per centimeter
$mg\ L^{-1}$	milligram per liter
MIB	2-methylisoborneol
MPN	Most Probable Number

MST	Microbial Source Tracking
NASEM	National Academies of Sciences, Engineering, and Medicine
ND	Non-detect
nm	Nanometers
NR2	Neversink Reservoir Elevation Tap 2; elevation 1350 feet above sea level
NRT	Near real-time
NTU	Nephelometric Turbidity Units
NYC	New York City
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
Obs	Observations
OGP	Operational Guidance Plan
OST	Operational Support Tool
PR2	East Delaware Intake Chamber Tap 2; 1186 feet above sea level
ROS	Regression on order statistics
Shaft 17	Delaware Aqueduct Shaft Building 17
Shaft 18	Delaware Aqueduct Shaft Building 18
SPDES	State Pollutant Discharge Elimination System
SRR2CM	Schoharie Reservoir Release, Shandaken tunnel outlet into Esopus Creek.
SSM	Single sample maximum
STRP	Sediment and Turbidity Reduction Project
SVOC	Semivolatile Organic Compound
SWAT	Soil Water Assessment Tool
SWTR	Surface Water Treatment Rule
TMDL	Total Maximum Daily Load
TNTC	too numerous to count
TP	Total Phosphorus
TSI	Trophic State Index
USEPA	United States Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
UV	ultraviolet
VOC	Volatile Organic Compound
UV_{254}	Absorbance reading at 254 nm
WISKI	Water Information Systems KISTERS
WMP	Waterfowl Management Program
WOH	West of Hudson
WPP	Watershed Protection Programs
WQD	Water Quality Directorate
WQSR	Water Quality Science and Research

WR&R	New York City Watershed Rules and Regulations
WRF	Water Research Foundation
WUCA	Water Utility Climate Alliance
WWQMP	Watershed Water Quality Monitoring Plan
WWQO	Watershed Water Quality Operations
WWTP	Wastewater Treatment Plant

Acknowledgements

This report provides a summary of the scientific work conducted in 2020 to manage the water quality of the New York City water supply and to provide information for regulatory agencies and the general public. This was a particularly challenging year as the COVID-19 pandemic required DEP to make many adaptations while continuing to fulfill our mission. New York City Department of Environmental Protection (DEP) Commissioner Vincent Sapienza, P.E., provided oversight of the department throughout 2020. Paul Rush, P.E., Deputy Commissioner, and Mr. Steven Schindler, Director of Water Quality, who retired from DEP in December 2020, continued to provide direction for the many activities of the Water Quality Directorate (WQD). Dr. Lorraine Janus, Chief of Water Quality Science and Research (WQSR), who retired in January 2021, and her division were responsible for the data analysis, interpretation, and report production. Mr. Andrew Bader, Chief of Watershed Water Quality Operations (WWQO), provided oversight of Watershed Field Operations, Watershed Laboratory Operations, and Systems Support, the divisions that provided the bulk of data which form the basis of this report.

Chapter 1 Introduction was co-authored by Mr. James Mayfield, Section Chief, Program Evaluation and Planning; Mr. James Broderick, Deputy Chief, WQ Systems Support; Ms. Meredith Mathewson, Deputy Chief, East of Hudson Field Operations; and Mr. David Robinson, Deputy Chief, East of Hudson Laboratory Operations. Chapter 2 Water Quantity was written by James Mayfield and Mr. Rich Van Dreason. Mr. Ken DeRose, Section Chief for Data Management in Water System Operations provided the operations and rainfall data presented in this chapter. Chapter 3 Water Quality was written by Dr. Karen Moore and Mr. Rich Van Dreason with contributions from Mr. James Mayfield on streams. The descriptions of Special Investigations were authored by Ms. Meredith Mathewson, Mr. David Robinson; Mr. Kurt Gabel, Deputy Chief, West of Hudson Field Operations, and Mr. Michael Spada. Chapter 4 Kensico Reservoir was written by Mr. Dave Van Valkenburg, Mr. Chris Nadareski, Mr. Christian Pace, and Ms. Kerri Alderisio, Section Chief, Watershed Impacts and Pathogen Assessment, with contributions for Special Investigations from Ms. Meredith Mathewson and Ms. Allison Dewan. Chapter 5 Pathogens was co-authored by Mr. Christian Pace and Ms. Kerri Alderisio. Chapter 6 Water Quality Modeling was written by Mr. Emmet Owens, P.E., Section Chief of Water Quality Modeling, Dr. Rakesh Gelda, Dr. Rajith Mukundan, and Mr. Jordan Gass. This chapter describes ongoing model development and applications conducted by the Modeling Section. Chapter 7 Further Research describes how WQD supplements its capabilities through contracts and participation in scientific organizations. The chapter was coordinated by Mr. James Mayfield with contributions from Mr. David Robinson, Ms. Lisa McDonald, Ms. Kerri Alderisio, Mr. Emmet Owens, P.E., Mr. Chris Nadareski, Mr. Jordan Gass, Mr. James Alair, Ms. Jennifer Farmwald, and Dr. Karen Moore. Other essential database expertise was provided by Mr. Brian O’Malley, Section Chief, Data Management. Maps were created by Mr.

Jordan Gass. Mr. Dave Van Valkenburg authored Appendices. Mr. James Mayfield, Dr. Karen Moore, Mr. Dave Van Valkenburg, Mr. Rich VanDreason, Kerri Alderisio, and Chris Pace were responsible for bringing the chapters together as a single document and polishing the format to produce the final document. Mr. Michael Risinit, BWS Reporting and Publications Assistant, provided edits for the entire document, and Ms. Kristen Rendler, Ms. Meredith Mathewson, Mr. Kurt Gabel provided the cover photo.

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 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. Although we could not name them all, thanks go to all those who contributed directly and indirectly to this report.

The 2020 Watershed Water Quality Annual Report is dedicated to Steven C. Schindler. Steve began his career in 1987 as an Assistant Chemist at the Grahamsville Laboratory, and held several positions of increasing responsibility for the Bureau of Water Supply before becoming the Director of Water Quality in 2003. In his career that spanned nearly 34 years, Steve was an exceptional scientist and public servant who led the teams that conducted millions of water quality tests annually both in New York City and the upstate watershed. In 2020, Steve was a recipient of the Sloan Public Service Award for his outstanding commitment and service to the City of New York. Steve retired from DEP in December of 2020 and began the next phase of his life spending time with family and friends, and continuing his passion for swimming, biking and running events. We thank Steve for over three decades of leadership and service at DEP.

Executive Summary

Chapter 1 Introduction

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 a detailed description of the City's water resources, their condition during 2020, and compliance with regulatory standards. It is complementary to the New York City 2020 Drinking Water Supply and Quality Report (Download the 2020 Drinking Water Supply & Quality Report), which is distributed to consumers annually to provide information about the quality of the City's tap water. Thus, the two reports together document water quality from its source to the tap. In 2020 it was necessary to reduce some components of the Watershed Water Quality Monitoring Plan (DEP 2018) during the COVID-19 outbreak while maintaining the critical components of the plan. The impact of the reductions will be noted at various points throughout the report.

The New York City Water Supply System 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. The City's water is supplied from a network of 19 reservoirs and three controlled lakes that contain a total storage capacity of approximately 2 billion cubic meters (570 billion gallons). A summary of the number of sites, samples, and analyses that were processed in 2019 by the three upstate laboratories is provided. Grab sampling, robotic monitoring, and an early warning system are all employed. These data are used to guide system operations to provide high quality drinking water to the City.

Chapter 2 Water Quantity

The National Climatic Data Center's (NCDC) climatological rankings determined the 2020 rankings for New York. Overall total precipitation for New York State in 2020 was 39.23 inches (996 mm), which was 1.06 inches (27 mm) below the 20th-century mean (1901-2000) and the forty-seventh driest year in the last 126 years (1895-2020). Overall, New York State had fairly normal runoff for the 2020 water year (October 1, 2019-September 30, 2020), ranking as the 54th highest annual runoff (55.37 percentile) out of the last 120 years) as determined by the USGS (http://waterwatch.usgs.gov/index.php?r=ny&m=statesum). The statewide average temperature for New York State in 2020 was 47.8 degrees Fahrenheit (8.8 degrees Celsius), which was 3.3 degrees Fahrenheit (1.9 degrees Celsius) above the 20th-century mean and the third warmest in the last 126 (1895-2020) years for New York. In New York's Climate Division 2, which includes the West of Hudson (WOH) reservoirs, the 2020 precipitation total was 1.29 inches (33 mm) above the 20th-century mean. In New York's Climate Division 5, which includes the East of Hudson (EOH) reservoirs, precipitation was 2.69 inches (68 mm) below the 20th-century mean. Usable storage capacity of the water supply was at or above normal storage except for June through August and for October through most of December, when capacity was down about 6% below normal levels because of dry conditions. However, a rain-on-snow event in late December caused widespread flooding allowing system capacity to exceed normal levels by 10 % by the end of the year.

Chapter 3 Water Quality

In 2020, turbidity levels in the Catskill/Delaware System reservoirs and in all monitored Croton System reservoirs were close to their median historic levels or well below the 10-year median in the case of Schoharie Reservoir and the east and west basins of Ashokan Reservoir. Runoff was generally low in 2020, although two large rain events exceeding 3 inches did occur in the Catskill/Delaware System in August and September, but monthly reservoir surveys did not reflect a corresponding increase in turbidity.

In the Croton System no rain events exceeded 2 inches and only three exceeded 1 inch, so for reservoirs sampled, turbidity remained near the historic median. Reservoir surveys throughout the system were concluded before a December storm, so data do not reflect the impact of this storm. Streams were generally well within range of the 10-year median turbidity values, although a few higher values were related to storm events.

The 2020 median fecal coliform counts were below historic median 75th percentile levels in all of the Catskill/Delaware reservoirs, including West Branch and Kensico. Dry conditions probably helped keep fecal coliform counts low to normal (near the historic median) in most of the Croton System reservoirs. Higher counts at New Croton Reservoir were likely related to rainfall events that occurred within seven days prior to sampling in September. All terminal reservoir basins remained "non-restricted" for coliform-restricted assessments in 2020. For non-terminal reservoir coliform-restricted evaluations in 2020, there was a significant reduction in sampling and few exceedances for the total coliform standard for the seven reservoirs evaluated. Of the major inflow stream samples collected in 2020, none had a result greater than or equal to 200 coliforms 100mL^{-1}. Total coliform counts at Kensico, the terminal reservoir for the Catskill/Delaware System, were close to their historic median 75th percentile, as were all monitored reservoirs of the Croton System.

In 2020, there were no changes in phosphorus-restricted status as compared to the previous five-year assessment period. Among the source water reservoirs and potential source water (i.e., terminal) reservoirs, New Croton, Cross River, and Croton Falls reservoirs were classified as phosphorus-restricted. West Branch Reservoir was non-restricted, reflecting the influence of Delaware System water on its water quality status. When comparing total phosphorus (TP) sample results for the single sample maximum benchmark value of 15 µg L^{-1}, Cannonsville Reservoir had the highest number of exceedances in the Delaware System. There were few exceedances in the remainder of the WOH reservoirs, West Branch and Kensico. Of the Croton System reservoirs sampled in 2020, Cross River and Croton Falls had the highest number of exceedances of the benchmark value for TP. Total phosphorus in streams was generally near or below historical monthly values, with a few elevated concentrations in samples collected during storm events.

Trophic state indices (TSI) are used to describe algal productivity of lakes and reservoirs. In 2020, TSI was elevated in Schoharie Reservoir and in the Ashokan West Basin, while the Ashokan East Basin had its lowest annual median since 2011. TSI trends in the Delaware System Reservoirs varied, with Cannonsville comparable to its historic annual median and Pepacton slightly lower than the historic annual median. Neversink and Rondout were both higher than their historic annual median TSI values. The TSI for West Branch Reservoir was lower than the historical median, which may be reflective of lower surface water temperatures resulting from increased cold-water inputs from Rondout in 2020. Kensico Reservoir TSI was elevated in 2020 compared to its historic median TSI.

Evaluation of additional reservoir and stream analytes in 2020 included chloride and other analytes that are compared to benchmark values set in the NYC Watershed Rules and Regulations. Chloride increases have been generally correlated with road density. In 2020, all Delaware System reservoirs slightly exceeded the annual mean value of 8 mg L^{-1} but only Cannonsville exceeded the single sample maximum value. For Catskill/Delaware System streams, 11 of 23 streams exceeded the annual mean of 10 mg L^{-1} although there were no exceedances of the 50 mg L^{-1} single sample maximum benchmark value. Of the Croton System reservoirs sampled in 2020, Croton Falls had the highest number of samples that exceeded the single sample maximum of 40 mg L^{-1} and annual mean benchmark of 30 mg L^{-1}. West Branch Reservoir slightly exceeded the annual mean benchmark chloride value of 8 mg L^{-1} and 44% of the 9 samples collected exceeded the single sample maximum. Croton System streams exceeded the annual mean of 35 mg L^{-1} in 15 of 16 streams. Half of the 16 samples collected in Kensico Reservoir exceeded the single sample maximum value and slightly exceeded the annual mean value. All chloride samples were well below the health secondary standard of 250 mg L^{-1}.

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994. However, in 2020 no biomonitoring was conducted due to sampling reductions during the COVID-19 pandemic.

In 2020, zebra mussel sampling was restricted to veligers in Lake Mahopac (outside of the NYC water supply system but the source of detections in 2018); veligers and colonization substrate in the Muscoot River; and only veligers at the confluence with Amawalk Reservoir. WOH reservoirs were not monitored in 2020.

No veligers or settled adults were found in samples from the Muscoot River and its confluence with the Amawalk Reservoir in 2020. Veligers were found only in Lake Mahopac, and adults have only been found in Lake Mahopac and the Muscoot River up to about 1 kilometer downstream of Lake Mahopac. Data suggests that downstream movement of veligers from infested Lake Mahopac is dependent on the elevation of the lake and its spill status.

Routine annual surveillance monitoring for metals, a wide range of semivolatile and volatile organic compounds, and the herbicide glyphosate continued at several keypoint locations with some reductions in sampling due to the COVID-19 pandemic. Most metal sample results were well below state and federal benchmarks. Arsenic, lead, antimony, beryllium, cadmium, silver, and selenium were not detected above the detection limit of 1.0 µg L^{-1} for any sample. Zinc, mercury, and chromium samples were all below their detection limits. Nickel was detected on one occasion each at CRO1T and CRO1B with concentrations ranging from 1.0 to 1.1 µg L^{-1}. All results were well below the NYSDEC regulation of 100 µg L^{-1}. Additionally, all detected barium, copper, and iron results were well below their respective benchmarks.

Benchmarks for manganese and aluminum were occasionally surpassed in 2020. The manganese benchmark of 50 µg L^{-1} was exceeded on five occasions, while the aluminum benchmark of 50 µg L^{-1} was exceeded in eight samples well upstream of the distribution system. Iron, aluminum, and manganese exceedances may pose aesthetic concerns (e.g., taste, staining), but are not considered a health risk. Moreover, most of these excursions occurred well upstream of the NYC distribution system.

There were 15 water quality special investigations conducted throughout the system in 2020. Five of these occurred in the Kensico basin and are reported in Chapter 4, and seven are reported in Chapter 3. The ten special investigations conducted outside of the Kensico basin consisted of monitoring the impacts of Tropical Storm Fay; sampling to evaluate cold water banking in Schoharie Reservoir; evaluation of Croton System taste and odor issues; follow-up on a fuel spill in the Titicus Reservoir basin that occurred in 2019; sampling for Croton Falls Pumping Station operation; suspected aqueduct leaks (four separate examinations); continuation of a pilot study begun in 2018 to determine the effectiveness of using an ultrasonic platform in preventing and mitigating algal blooms; continuation of a research project in the Neversink and Cannonsville watersheds to evaluate potential proxy measurements for DBP precursors to support water supply operations and water quality modeling efforts; DEP joined scores of utilities nationwide to monitor levels of the COVID-19 virus that causes COVID-19 in untreated wastewater; and providing laboratory analytical support for metals sample analysis.

Chapter 4 Kensico Reservoir

Kensico Reservoir is the terminal reservoir for the unfiltered Catskill/Delaware water supply. Monitoring of the water outflow from Kensico takes place at DEL18DT. The City's high frequency monitoring ensures that every effort is taken at this keypoint location to meet strict requirements for turbidity and fecal coliform concentrations set forth in the federal Surface Water Treatment Rule (SWTR). During 2020, all DEL18DT turbidity results were less than the SWTR 5 NTU limit and only two of 365 DEL18DT fecal coliform results exceeded the SWTR 20 fecal coliforms $100mL^{-1}$ limit, which meant DEP continued to meet the SWTR turbidity and fecal coliform limits. The Waterfowl Management Program continues to be instrumental in keeping coliform bacteria concentrations well below the limits set by the SWTR. Routine inspections through March of the turbidity curtains near the Catskill Upper Effluent Chamber cove continued to show the turbidity curtains were intact. These inspections were suspended for the rest of 2020 due to the COVID-19 pandemic. Overall, water quality from Kensico continued to be excellent during 2020.

In addition to DEP's routine monitoring, there were six special investigations/projects conducted in the Kensico watershed and limited video monitoring for Bryozoans at the Delaware Shaft 18 sluice gates due to the COVID-19 pandemic.

There were two Kensico tributary special investigations this year, one involved a milky-white substance observed by a contractor on stream N5, and the other a potential septic issue from a stormwater catch basin system within the Whippoorwill Creek watershed. The N5 sampling resulted in normal turbidity and fecal coliform measurements and indicated no potential impact to the reservoir. The stormwater catch basins along Whippoorwill Creek resulted in fecal coliform concentrations two orders of magnitude greater than the local stream and were positive for Bacteroidales human markers used for microbial source tracking. Follow-up monitoring and the use of forward looking infrared technology to detect failing septic systems are planned for 2021.

The remaining special investigations/projects were Kensico Shoreline Stabilization, Catskill Water Supply Alum Treatment, Delaware Shaft 18 Supply Conduit repair, and Shaft 18 bryozoan video monitoring. Results from the Kensico shoreline study indicated no turbidity impact to the Shaft 18 outflow from efforts to repair the nearby shoreline. Results from the Catskill Water Supply Alum Treatment demonstrated the effectiveness of keeping turbidity levels below 1.5 NTU immediately after the CAT-RR shutdown for maintenance and removal of biofilm from the Catskill Aqueduct. The Delaware Shaft 18 Supply Conduit repair demonstrated that analytes of interest were not detectable after completing a repair made to Shaft 18 conduit 8. Video monitoring surveys of the sluiceways at Shaft 18 were not able to be conducted this summer due to COVID-19 reductions. Water Quality and Water Treatment Operations collaborated using historical colonial growth data to estimate which sluice gates should be closed. A video survey conducted in September confirmed the success of the collaboration demonstrating minimal growth due to reduced flow, and no occlusion downstream was reported.

Chapter 5 Pathogen Monitoring and Research

DEP collected 399 samples for protozoan analysis and 39 samples for *Cryptosporidium* infectivity testing in 2020. Normally, most of the samples collected in a given year are from watershed streams. However, due to COVID-19 monitoring reductions, most 2020 samples were collected at Kensico and New Croton reservoir outflows (38.3%) and the outflows of the CDUV plant and Hillview Reservoir (26.1%). Additional samples were collected at watershed streams, upstate reservoir effluents, and wastewater treatment plants (WWTPs) at a reduced frequency.

As a reminder, a method variation - replacing acid dissociation with heat dissociation - was implemented by DEP in August 2017. Therefore, fluctuations in the annual sample data compared to historical data may be a result of a method change and not a difference in prevalence in the environment. DEP continues to analyze data gathered using the method variation to identify any potential shift in the data.

For the two-year period from January 1, 2019, to December 31, 2020, DEP Catskill/Delaware source water results continued to be below the Long Term 2 Enhanced Surface Water Treatment Rule (LT2) *Cryptosporidium* threshold for additional treatment. The Catskill/Delaware system was below the LT2 unfiltered water supply threshold (0.010 oocysts L^{-1}), with a mean of 0.0011 oocysts L^{-1} at the Delaware outflow – which is slightly lower, but similar to, the LT2 means of the past few years. Since the LT2 monitoring is complete, and the frequency of sample collection at New Croton Reservoir has been reduced to quarterly, assessments of the Croton data for comparison to LT2 thresholds for DEP's filtered system are no longer conducted due to the small sample size.

As historical data have established, protozoan concentrations leaving the upstate reservoirs and Kensico Reservoir were lower than levels at the stream sites that feed these reservoirs, albeit less stream samples were collected in 2020 compared to the past. Elevated *Giardia* concentrations at Rondout Reservoir continued from fall 2019 into spring 2020, but not to the extent of the previous year. Cyst concentrations declined in the summer and increased again in November 2020, but only to normal seasonal levels. There was one sample positive for *Giardia* cysts at WWTPs this year, and no samples were positive for *Cryptosporidium* – however, it should be noted that the WWTPs were only sampled once during 2020 (in the first quarter) due to COVID-19 monitoring reductions. As per the Hillview Consent Decree and Judgement, DEP continued weekly protozoan monitoring at the Hillview Reservoir outflow (Site 3) through 2020, with 52 routine samples collected. Of the 52, there were 17 samples positive for *Giardia* (five less detections than 2019) and two samples positive for *Cryptosporidium* (the same as 2019). All 39 Hillview samples tested for infectious *Cryptosporidium* by cell-culture immunofluorescent assay were negative.

Chapter 6 Water Quality Modeling

The staff of the Water Quality Modeling section is involved in the development, testing, validation, and application of climate, watershed/terrestrial, reservoir, and water system operation models. To support this modeling work, the staff compiles, analyzes, and organizes data from a variety of sources. Following testing and validation, models are used to identify the processes that are important to production, fate, and transport of pollutants of concern within the watersheds, reservoirs and water supply system. The models are applied to evaluate the impacts of climate change, to evaluate components of DEP's watershed protection program, and to provide guidance regarding the operation of the water supply system.

In 2020, the Soil and Water Assessment Tool (SWAT-HS) model was applied to evaluate watershed protection programs in the Cannonsville watershed. This model had earlier been validated in reproducing historical streamflows and stream phosphorus concentrations in the West Branch Delaware River. Watershed protection program components that were evaluated and quantified included nutrient management on agricultural lands, winter cover cropping, riparian forest buffers, and septic systems. Model predictions of 1990s watershed conditions with that of 2010s representing current watershed conditions, subject to same hydro-climatic conditions show that nonpoint source contributions of dissolved phosphorus have decreased by about 35%.

Substantial progress was made in 2020 on a new modeling approach based on SWAT-HS to more fully represent uncertainty in model predictions. The work conducted in 2020 was based on SWAT-HS predictions for streamflow in each of the six WOH watersheds. This work uses the statistical approach of Bayesian model averaging. The effect of uncertainty in the 14 model coefficients or parameters that are used in streamflow predictions was considered and quantified. The analysis of uncertainty in the streamflow predictions for 2001 through 2018 indicated a high level of reliability of the simulation results.

Progress continued in 2020 on the application, testing and validation of the W2 reservoir turbidity model to Cannonsville and Pepacton reservoirs. The validated models performed well in simulating the observed historical conditions including temperature and turbidity in the water column of the reservoirs, and in the diversion for water supply. The Water Quality Modeling section continued to apply the W2 and Operations Support Tool (OST) models to guide short-term reservoir operations decisions, and in long-term planning for operations.

We continued to develop and apply models to evaluate the impacts of future climate change on the water supply system. Properly adjusted climate projections from 20 CMIP5 (Coupled Model Intercomparison Project Version 5) global climate models were used to compute climate indices including extreme weather indicators such as number of frost days, summer days, heat waves, and cold spells. Two greenhouse gases emission scenarios were considered. The same climate projections were also used to drive the GWLF hydrologic model and identify potential changes in the hydrologic components of the watershed, e.g., snowfall, snowpack, and annual peak flow in Esopus Creek. We also continued work on the development of climate change indices for the water supply watersheds. This work compiles meteorological, streamflow and stream water quality, snowpack, reservoir storage, operations, and water quality data to identify trends over the years of data collection.

Progress continued in 2020 on the development of a fate and transport model for UV_{254} in reservoirs. This modeling effort was based on the one-dimensional reservoir model UFILS4. The hydrothermal component of this model was validated for conditions in Neversink Reservoir for 2016 through 2020. A simplified UV_{254} model based on the assumption that in-reservoir sources and sinks of UV_{254} could be neglected, was applied and tested. As in the earlier work on Cannonsville Reservoir, it was concluded that in-reservoir production and loss were important and need to be included in the model.

On October 29, 2020, the Water Quality Modeling section held its annual meeting with state and federal regulatory agencies to describe progress in water quality modeling. Also during 2020, section staff and post-doctoral support scientists authored peer-reviewed papers and made presentations at remotely held professional meetings.

Chapter 7 Further Research

The analytical, monitoring, and research activities of DEP are supported through a variety of contracts, participation in 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). In 2020, DEP managed five contracts for laboratory services and five for other support services, including bathymetric surveys and operation of a stream gage network by the USGS, modeling support by City University of New York (CUNY), waterfowl management, and software support for Water Information System KISTERS (WISKI) software. DEP participated in eleven Water Research Foundation projects. These projects provide insight into pathogens, emerging contaminants, and corrosivity of source water that can interact with distribution system features and may have operational implications. In 2019, DEP continued as one of 12 members of the Water Utility Climate Alliance (WUCA) where use of models to evaluate the impact of climate change was shared. DEP's participation in the Global Lake Ecological Observatory Network (GLEON) also continued. A study on the effects of climate on dissolved oxygen concentrations (DO) in lakes and reservoirs around the globe was initiated in 2016 and DEP contributed Cannonsville and Neversink reservoir temperature, DO, nutrient, and chlorophyll data and expertise. In 2020 the journal Nature accepted a manuscript from this project that was published in June 2021. A second GLEON project "Before the Pipe: Monitoring and Modeling DBP Precursors in Drinking Water Sources" with a goal of identifying important questions and research gaps on disinfection byproduct (DBP) precursors and water supply concerns was put on hold in 2020 due to restricted library access during the global pandemic and is expected to resume in 2021. Participation with external groups is an efficient way for DEP to bring specialized expertise into the work of the Water Quality Directorate and to remain aware of the most recent developments in the water supply industry.

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 2020, 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 2020 Drinking Water Supply and Quality Report (https://www1.nyc.gov/assets/dep/downloads/pdf/water/drinking-water/drinking-water-supply-quality-report/2020-drinking-water-supply-quality-report.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. The COVID-19 global pandemic presented challenges in 2020 which required adjustments to the sampling schedules as discussed below, but throughout the pandemic DEP scientists and engineers continued to work to ensure the high-quality of New York City's drinking water supply.

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 2 billion cubic meters (570 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 deliver a reliable and sufficient quantity of high

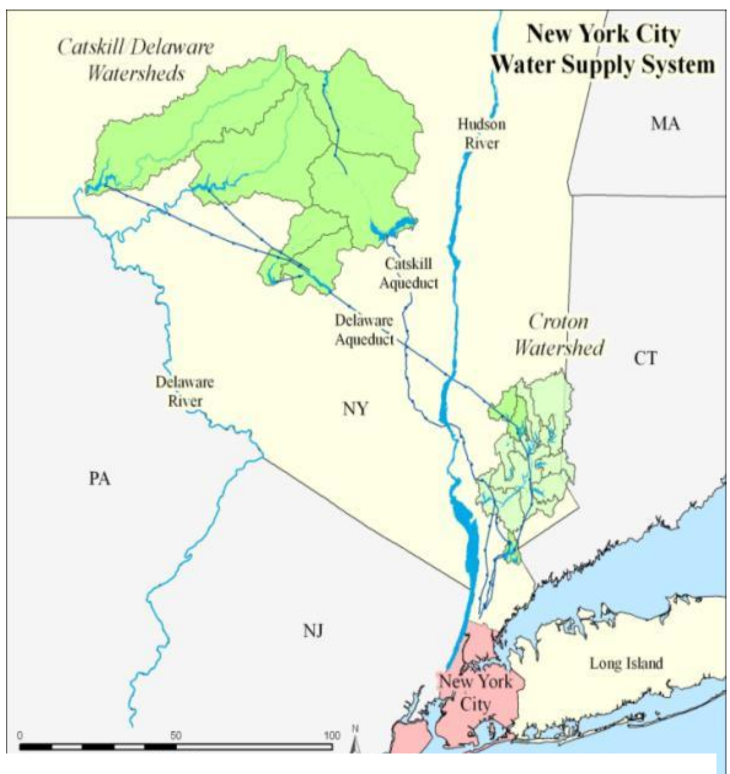


Figure 1.1 The New York City water supply system.

quality drinking water to protect public health and the quality of life for the City of New York. To gather and process the information needed to meet these goals, there is an ongoing program of water quality monitoring and modeling. Monitoring of the watershed is accomplished by Watershed Water Quality Operations based primarily at three upstate New York locations: Grahamsville, Kingston, and Hawthorne. Manual and automated monitoring systems are used for database development. The Water Quality Science and Research Division uses these data to perform data and modeling analyses. The results of these activities guide operational responses to changing water quality conditions of the reservoirs. The information generated by field, laboratory, and data analysis activities are presented here to provide an overview of watershed water quality in 2020, and to show how high quality source water is reliably maintained through constant vigilance and operational changes. In addition to the work of the Water Quality Directorate, DEP extends its capabilities through contracts and interactions with other organizations (see Chapter 7, Further Research).

1.1.1. Grab Sample Monitoring

Water quality of the reservoirs, streams, and aqueduct keypoints is monitored throughout the watershed to meet several objectives. Results are used for several purposes: to ensure regulatory compliance, to guide operations, to demonstrate the effectiveness of watershed protection measures, and to provide data for modeling applications. The Watershed Water Quality Monitoring Plan (WWQMP; DEP 2018) is DEP's comprehensive plan that describes why, what, when, and where water quality samples are taken throughout the watershed. The sampling effort is carefully tailored to meet specific objectives of DEP.

In 2020, BWS needed to reduce some components of the WWQMP (DEP 2018) during the COVID-19 outbreak to meet the mayor's directive to provide only essential services while maintaining the critical components of the monitoring plan. DEP proposed a set of temporary reductions in watershed surveillance sampling and NYSDOH agreed these temporary changes would not impact DEP's ability to maintain compliance with the terms of the 2017 Filtration Avoidance Determination and other required sampling (NYSDOH 2017). The plan consisted of phases. As conditions improved, some of the monitoring was resumed while extensions were granted to keep the remaining reductions in place. The impact of the reductions will be noted throughout this report.

A summary of the number of sites, samples, and analyses that were processed in 2020 by the three upstate laboratories 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, reservoir elevation taps, and aqueduct sites) as described in the WWQMP (DEP 2018). Samples taken as the result of special investigations (SIs) and from the free residential lead test kits, performed at the DEP Kingston Laboratory, are also included. The sample numbers for the City's distribution system are listed simply to demonstrate the comprehensive sampling from source to tap; however, this report is devoted to discussion of results from watershed samples that relate to untreated source water.

Table 1.1 Summary of grab samples collected, water quality analyses performed, and sites visited by WQD in 2020.

System	Number of Samples	Number of Analyses	Number of Sites
Watershed	12,300	166,800	445
Distribution	31,300	363,200	~1,000
Total	43,600	530,000	~1,445

In addition to grab sampling, data are recorded by continuous monitoring equipment at keypoints on the aqueducts, by data loggers at stream sites, and by robotic monitoring buoys deployed at reservoirs as described in the sections that follow.

1.1.2. Robotic Monitoring (RoboMon) Network

DEP's Robotic Monitoring (RoboMon) network provides high frequency, near real-time (NRT) data that are essential for guiding water supply operations and to support water quality modeling. The data are of particular importance when water quality conditions are changing rapidly and operational responses may be required. In addition to water quality surveillance, these data are used to run the Operations Support Tool (OST), reservoir models, and watershed models. The data generated by the RoboMon network have proven to be invaluable for the protection of the water supply (particularly during storm events), during water quality special investigations, and during the construction phase of water supply infrastructure projects that can potentially affect water quality. In 2020, approximately two million measurements were recorded from more than 20 sites. These automated water quality monitoring systems contribute significantly to help manage the water supply for the continuous reliable delivery of high quality drinking water.

The RoboMon network began in 2012 with four reservoir monitoring buoys (three at Ashokan and one at Kensico). The network has continued to grow to its current configuration (Figure 1.2) with sites located in both reservoirs and streams. There has also been enhancements to some monitoring sites to provide additional parameters essential for model development.

Each site is designed to contribute data for specific objectives. To develop reservoir carbon models to ultimately improve DEP's understanding of disinfection by-product formation potential (DBPfp), sensors for chlorophyll, phycocyanin (a blue-green algae pigment), dissolved oxygen, and fluorescent dissolved organic matter (fDOM) were added to the Cannonsville and Neversink reservoir monitoring buoys in 2015. In addition, fDOM probes were installed in 2017 at two stream monitoring huts to record data for the main inflows to Cannonsville and Neversink reservoirs.

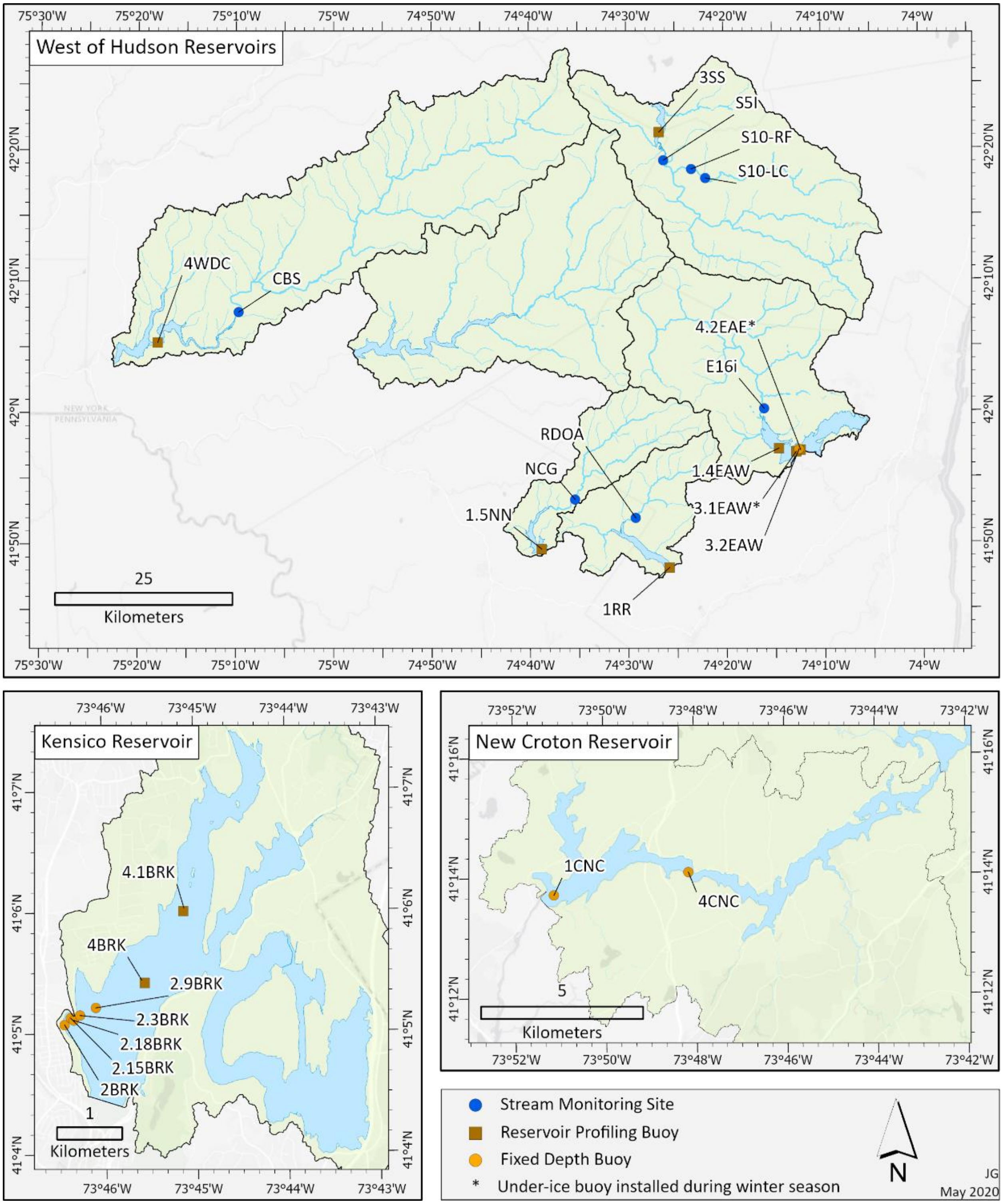


Figure 1.2 Robotic monitoring sites and types in the Catskill and Delaware Systems in 2020.

Two profiling buoys were deployed in New Croton Reservoir in 2019 to assist in making operational decisions for the best water quality. These buoys include sensors for pH, dissolved oxygen, specific conductivity, chlorophyll, and phycocyanin.

To monitor water quality conditions during times of ice-over, two under-ice buoys are deployed on Ashokan Reservoir. The buoys are typically installed in December and removed in April. These units measure turbidity with sensors positioned at two discrete depths at approximately 5 and 15 meters below the water surface. The units were placed in front of the east and west basin gatehouses.

In addition to the reservoir buoy network, there are seven automated stream monitoring stations (RoboHuts) operated and maintained year-round. Two RoboHuts continuously monitor water temperature, specific conductivity, and turbidity at 15-minute intervals. One is located at Esopus Creek, near Coldbrook (installed 2012) and the other station is located on Schoharie Creek near Prattsville (installed 2017). Five additional stream monitoring stations—Rondout Creek, near Lowes Corners (installed 2012), Neversink River (installed 2014), West Branch Delaware River (installed 2011) and two sites on the Batavia Kill in the Schoharie watershed (installed 2016 and 2017)—continuously monitor for turbidity and temperature only.

Changes in the robotic monitoring program during 2020 include the following:

- In late December 2020, two of the three fixed depth buoys deployed in Kensico Reservoir to monitor construction activities near the intake at Shaft 18 were relocated to monitor a new construction area in same location. These buoys provide turbidity data at 15-minute intervals. Sensors are deployed on these buoys at two specific depths, generally one in the middle of the water column and one at about 1m off the bottom of the reservoir.

- The under-ice monitoring systems deployed on Ashokan Reservoir were upgraded to a new style of winter buoy in 2020. The former equipment was made up of multiple custom-made underwater canisters housing instrumentation and batteries, as well as a stick buoy outfitted with an antenna. This system became difficult to service and repair. The new style buoy is a narrow profile rugged float which contains all of the instrumentation, communications, and power in a sealed compartment. These new systems proved to be extremely effective through the winter of 2020-2021 and survived thick ice cover.

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. These data can be viewed on the DEP intranet through a custom web application. In some cases, data are available within three minutes of the field measurement being collected. A standard operating procedure was developed to guide the program's data management and quality control procedures.

Due to the pandemic, some of the profiling buoy deployments in the EOH watershed were delayed in 2020. Deployment of the profiling buoys on Kensico Reservoir were delayed until early April, whereas buoy placements on New Croton were delayed until July.

In the Catskill System, the Ashokan Reservoir site 1.4EAW buoy platform became compromised and the equipment was removed from the reservoir at the end of October. Ashokan Reservoir site 4.2EAE also had some technical difficulties which resulted in some data loss. Capital orders were prepared in fiscal year 2020 for the planned replacement and upgrading of the original four profiling buoys deployed in 2012.

1.1.3. Early Warning Remote Monitoring

The Early Warning Remote Monitoring (EWRM) team operates a network of real-time, continuous, water quality monitoring stations at strategic locations known as keypoints. These include aqueduct shafts, pumping stations, treatment facilities, and an Esopus Creek station. Instrumentation and sensors vary by site (Appendix A) and typical parameters include turbidity, temperature, pH, conductivity, free and/or total chlorine residual, chlorine dioxide, fluoride residual, dissolved oxygen, elevation and flow. The EWRM team follows a quality assurance program to ensure stations operate continuously and generate defensible data. The data are used by BWS staff to help guide the operation of the water supply.

Keypoint monitoring also includes sites needed for regulatory compliance. The Surface Water Treatment Rule (SWTR) requires calculation of the inactivation ratio (IAR) for pathogens and viruses. The daily IAR report utilizes data from the sites DEL18DT and DEL19LAB (or its alternate site DELSFBLAB). Fluoride residual is monitored at sites DEL19LAB and CCCLAB for compliance with treatment targets and limits. The Shandaken Portal (SRR2CM) and the upstream sampling station (AEAP) are both monitored for compliance with SPDES permits. For the Croton System, data collected from the Croton Gatehouse (CROGH) and the five potential withdrawal taps are of utmost importance to process control at the Croton Water Filtration Plant. EWRM is also preparing for the future application of chlorine dioxide in the Catskill and Croton systems, as well as, being involved in the planning stages for continuous manganese measurement in the Croton System.

In addition to the instrumentation and parameters listed above, ToxProtect 64 fish biomonitoring systems continued to be operated at DEL18DT and CROGH sites in 2020. This system provides for the rapid detection of water quality impairments, including contamination events not detectable by the standard array of continuous monitoring instruments. This system has few false alarms—all caused by excessive bioaccumulation—which we have learned can be mitigated with maintenance that varies seasonally. In 2020, repairs to the collocated autosamplers and communications were made.

Other 2020 enhancements completed by the EWRM team include the following:

- Rebuilding a pH and temperature monitoring station with wireless telemetry at the Catskill influent weir to support alum treatment readiness.

- Extending the sample line piping to a lower height in Shaft 4. The previous sample tap was seven feet up the wall, which meant that we could only sample during high flow rates. Designing a sample tap that extended to the bottom of the aqueduct wall required extra EHS training, aqueduct entry, design, procurement and installation, which all had to occur during the Catskill Aqueduct Rehabilitation and Repair (CAT-RR) shutdown 3. This was a highly collaborative effort that worked very well.
- The portable sample station at the Schoharie Tunnel Intake Chamber continues to be of great benefit during the reconstruction of that facility.
- Following two pump tubing failures, the pump tube replacement timing has been shortened, thus reducing the likelihood of sampling failure at the Shandaken Portal.
- The 2020 Christmas Eve storm changed the stream channel of the Esopus Creek at Allaben. The sampling equipment was destroyed and required complete replacement.
- Upgrades were made to prepare the EARCM station for chlorine dioxide treatment of the Catskill Aqueduct, in addition to creating a new sample testing station (EARRAW) with motive water pumps for the treatment system.

1.2. Operations in 2020 to Control Turbidity and Fecal Coliforms

In 2020, Water Quality staff continued to utilize the "Water Quality Index," to assist in routine operations to provide the best quality water to Kensico Reservoir, which then flows into the distribution system. To review, the calculation uses the most recent data available for turbidity, fecal coliform, UV_{254}, and phytoplankton to calculate an index number for each of the nine reservoirs in the Catskill and Delaware systems so they can be ranked according to their water quality status. Normally the four parameters are given equal weight in the index number, but the index report can be adjusted as water quality concerns change throughout the year. For example, after a storm event the report could be modified to give turbidity a greater weight in the calculation. The Water Quality Index report is issued weekly to those involved in making operational decisions about reservoir diversions.

In 2020, monitoring for the potential formation of disinfection by-products (DBPfp) continued to help guide selective withdrawal in order to deliver the highest quality water to the distribution system. UV_{254} (absorbance at 254 nm) and dissolved organic carbon (DOC) are used as surrogate measurements for DBPfp as they are indicators of aromatic organic compounds found in natural organic matter. Each of these parameters continued to be monitored weekly at the reservoir effluents and intake elevation taps and these data helped guide decision making when selecting which reservoirs to utilize. This is most useful in the Delaware System, where there can be significant differences in DBPfp between the three headwater reservoirs. Utilizing reservoirs with lower UV_{254} and DOC can help minimize DBP formation in the distribution system.

In the Catskill System, the elevation and location (east and/or west basin) of withdrawal at Ashokan Reservoir can be adjusted as needed throughout the year to divert the best quality water from the reservoir. These changes are also made to meet operational needs (e.g., lowering the west basin to create a void to accept more runoff during large storm events). In 2020, the main water quality component driving operational changes was turbidity, as DBPfp surrogates were relatively low throughout the year.

In January 2020, the Catskill Aqueduct was shut down for the CAT-RR project. By the end of January, the flow was increased to 585 MGD drawing from the east basin and the aqueduct was back in operation. The flow was adjusted to balance the basins. During April and May, there were three more aqueduct shutdowns for repair. By the middle of June, the Ashokan diversion was switched to draw from the west basin. The Ashokan release channel was used during May to help with water quality and for spill mitigation. In October, Ashokan turbidity levels reached 5 NTU. As a result, the Ashokan diversion was switched from a west draw to an east/west basin blend until November. There was one more shutdown in support of the CAT-RR project in December. This shutdown continued through the end of the year.

In the Delaware System, intake chambers at the four reservoirs were configured for diversion through the mid- or upper-level intakes. Elevation withdrawal changes only occurred at the Rondout Effluent Chamber and Pepacton Intake Chamber during the year. On March 3, the elevation intake at the Rondout Effluent Chamber was lowered from the surface draw (RR4) to mid-depth draw (RR3). This allowed for continual water quality monitoring during stop shutter and leaf gate cleaning work being performed during that timeframe. This mid-depth elevation draw remained throughout the year. On December 31, following a winter rainstorm and snowmelt event, the elevation draw at the Pepacton Intake Chamber was raised from the mid depth (PR2) to a surface draw (PR4) to provide lower turbidity water. The DBPfp surrogates UV_{254} and DOC, with UV_{254} being the main driver, helped guide decisions on selecting diversions into Rondout from the three upstream reservoirs.

Weather forecasts at Kensico Reservoir are watched closely to minimize the potential for elevated turbidity caused by wind and wave action from entering the intake. If sustained easterly or northeasterly winds in excess of 15 mph are predicted, the operating mode at Delaware Aqueduct Shaft 18 is often changed from a reservoir-only withdrawal to a float or bypass mode withdrawal. This proactive change is made due to the potential for wave action to resuspend shoreline sediments adjacent to the intake. Float mode operation uses the Delaware bypass tunnel, which brings water from the Delaware Aqueduct directly to the downtake at Delaware Aqueduct Shaft 18, supplemented by water drawn from Kensico Reservoir. This operational change minimizes turbidity from Kensico Reservoir that could otherwise enter the Delaware Aqueduct Shaft 18 intake. Float operation in anticipation of strong winds occurred 10 times (for all or part of 27 days) in 2020. The Kensico Shoreline Stabilization Project is expected to substantially reduce sediment resuspension and thus reduce the turbidity risk that they pose.

Water Treatment Operations (WTO) staff at the Croton Water Filtration Plan performed extensive testing of granulated activated carbon (GAC) treatment during 2020. This enhanced treatment is intended to help mitigate taste and odor problems seen previously in the Croton water supply. Following the commissioning of the plant, Croton water began flowing into distribution October 27th. The plant remained on-line through the remainder of the year. In addition, WTO staff developed a Water Quality Index for selecting the optimal intake location from the New Croton Reservoir. This new index is very similar to the index utilized for the Delaware and Catskill reservoirs. Parameters of interest for the Croton index are iron and manganese, pH, phycocyanin, scent, total organic carbon, UV_{254} absorbance, and geosmin/ 2-methylisoborneol (MIB).

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 and outputs affect turbidity, nutrient loads, and water residence times, which are primary factors that influence reservoir water quality.

2.2. 2020 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 2020 monthly precipitation total for each watershed is plotted along with the historical monthly average (1990-2019) (Figure 2.1).

The total monthly precipitation (Figure 2.1) shows that precipitation was less than the previous 30-year historical average (1990-2019) for January, and generally near or somewhat higher than the historical average for February and March, except precipitation in the Croton watershed was below average in March. All watersheds, except Cannonsville, had above average precipitation in April while Cannonsville was near normal. From May through July, precipitation was generally below normal with a few exceptions of near or slightly above normal. August brought above average rainfall to all but the Croton watershed, which was near normal. During September and October precipitation was again generally below normal with a few exceptions of near or slightly above normal totals. In November and December the monthly precipitation totals were generally above normal with a few exceptions of near normal totals. One 2020 December weather event of note was a rain-on-snow event that occurred when a large rainstorm on December 24-25 (two to three inches were reported in all watersheds) fell on the snowpack from a large snowstorm that happened the previous week. The runoff from this event yielded the largest flows of the year in all watersheds (see Figure 2.3).

The National Climatic Data Center's (NCDC) climatological rankings (https://www.ncdc.noaa.gov/cag/) were queried to determine the 2020 rankings for New York. Overall total precipitation for New York State in 2020 was 39.23 inches (996 mm), which was 1.06 inches (27 mm) below the 20th-century mean (1901-2000) and the forty-seventh driest year in the last 126 years (1895-2020). In New York's Climate Division 2, which includes the WOH reservoirs, the 2020 precipitation total was 1.29 inches (33 mm) above the 20th-century mean. In New York's Climate Division 5, which includes the EOH reservoirs, precipitation was 2.69 inches (68 mm) below the 20th-century mean. Also, the statewide average temperature for New

York State in 2020 was 47.8 degrees Fahrenheit (8.8 degrees Celsius), which was 3.3 degrees Fahrenheit (1.9 degrees Celsius) above the 20th-century mean and the third warmest in the last 126 (1895-2020) years for New York.

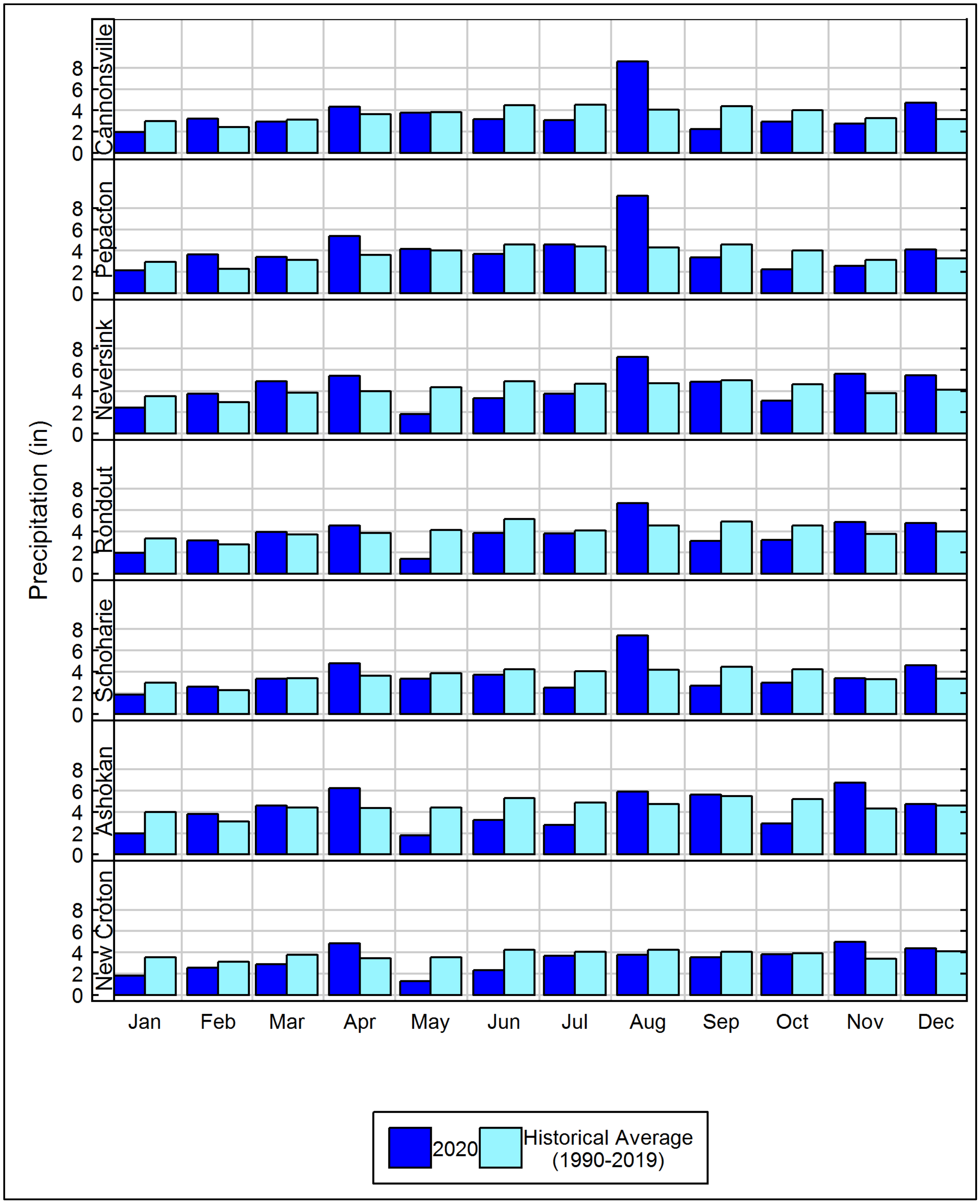


Figure 2.1 Monthly precipitation totals for New York City watersheds, 2020 and historical values (1990-2019).

2.3. 2020 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), intensity, amount, duration, spatial distribution 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, drainage network pattern, and occurrence and area of ponds, lakes, reservoirs, sinks, and other features of the basin that 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 of the hydrologic conditions in watersheds of varying sizes.

Selected United States Geological Survey (USGS) stations (Figure 3.7) were used to characterize runoff in the different NYC water supply watersheds (Figure 2.2). The time period with a complete record to calculate annual statistics for the WOH USGS stations ranges from 57 years at the Esopus Creek Allaben station to 114 years at the Schoharie Creek Prattsville station. The EOH USGS stations have a 25-year period of record, except for the Wappinger Creek site (92-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. Figure 2.2 shows the 2020 monthly runoff for each of the stations and a boxplot of the historical (1990-2020 for WOH and 1995-2020 for EOH) runoff for the site and month. The 2020 runoff values reflect the precipitation patterns. The monthly runoff values are mostly between the 25th and 75th percentiles with December showing elevated exceptions, especially at the WOH sites. Overall, New York State had fairly normal runoff for the 2020 water year (October 1, 2019-September 30, 2020), ranking as the 54th highest annual runoff (55.37 percentile) out of the last 120 years) as determined by the USGS (http://waterwatch.usgs.gov/index.php?r=ny&m=statesum). Daily flow/runoff data from October 1-December 31, 2020 are provisional and subject to revision until final approval from the USGS.

Figure 2.3 shows the 2020 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. The patterns again reflect the precipitation patterns and show the peak flow occurring in December as a result of the storms and resulting runoff.

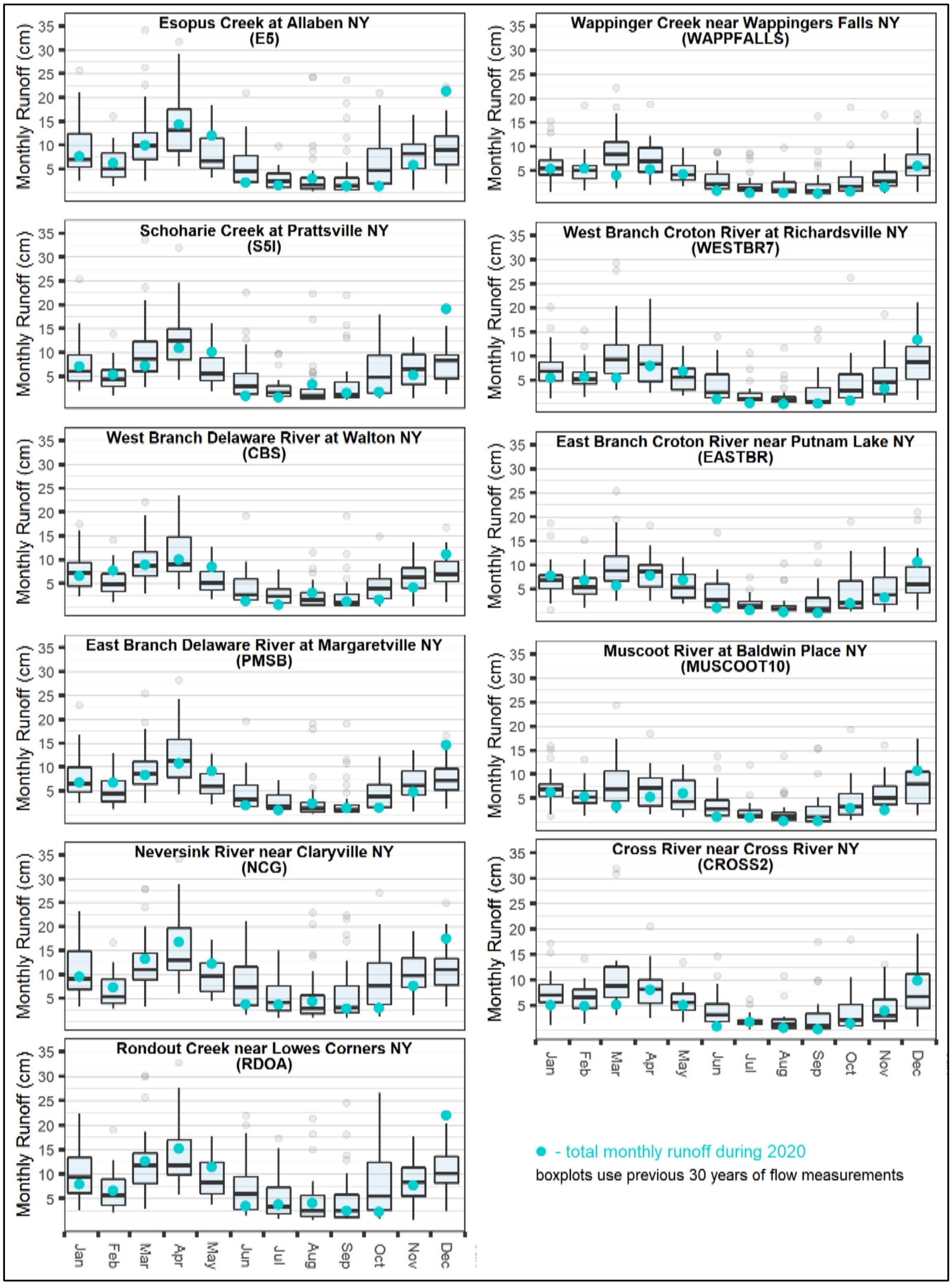


Figure 2.2 Historical monthly runoff vs. 2020 monthly runoff with the historical data (1990-2020 for WOH and 1995-2020 for EOH) displayed as boxplots and the values for 2020 displayed as a solid blue dot. The gray circles indicate outliers (see Appendix C for a key to the boxplot).

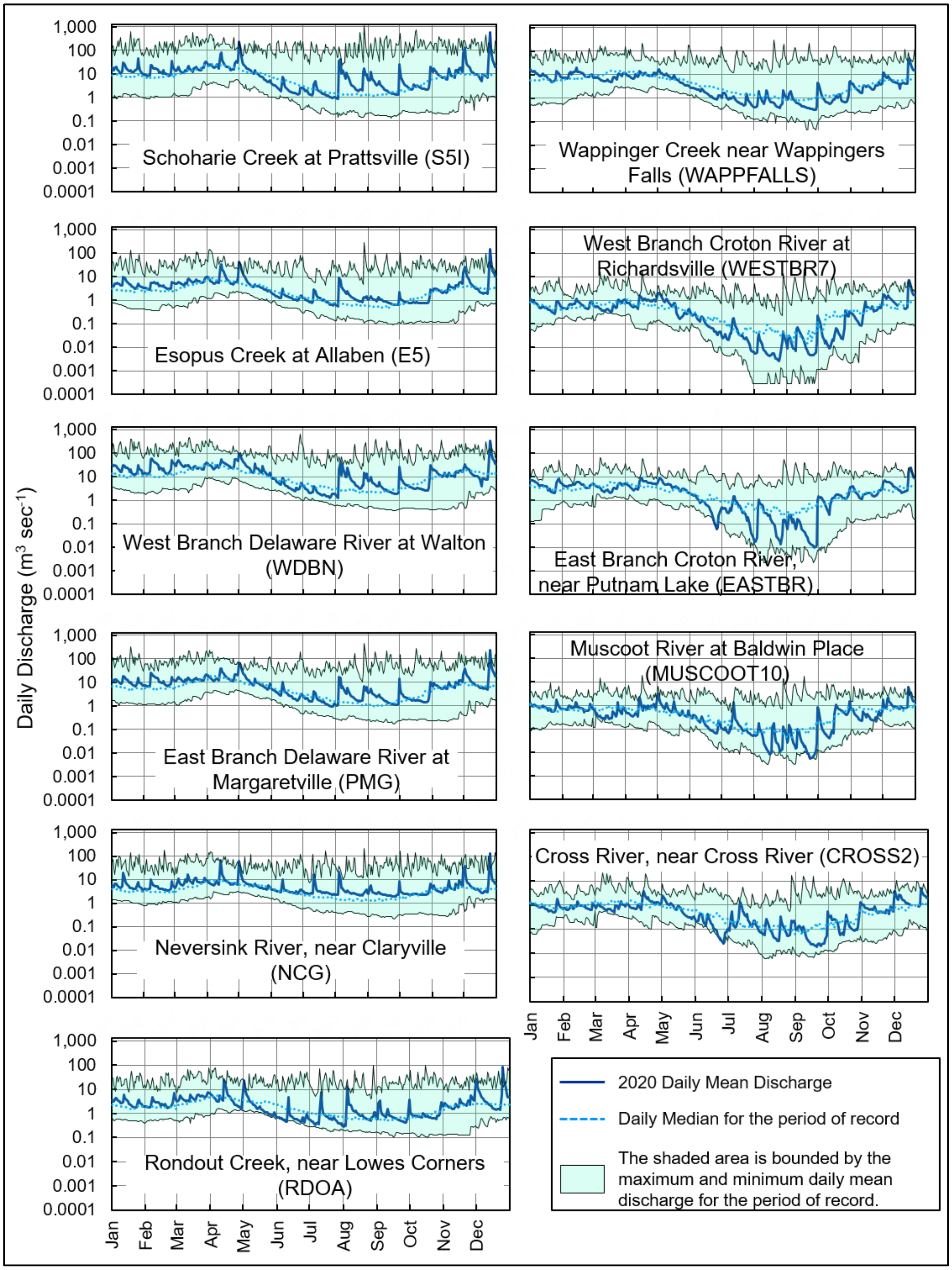


Figure 2.3 Daily mean discharge for 2020 at selected USGS stations.

2.4. Reservoir Usable Storage Capacity in 2020

Ongoing daily monitoring of reservoir storage allows DEP to compare the system wide storage in 2020 (including Kensico Reservoir) against average historical values for 1991-2019 for any given day of the year (Figure 2.4). Storage capacity fluctuated between 90% and 100% through mid-May, generally 5% above normal capacity. Beginning in mid-June capacity was 2-5% below normal through the end of July but rainfall in August and September restored the system to normal levels. In October, November, and much of December dry conditions prevailed causing capacity to decline to levels approximately 5% below normal. However, a rain-on-snow event in late December caused widespread flooding allowing system capacity to exceed normal levels by 10 % by the end of the year.

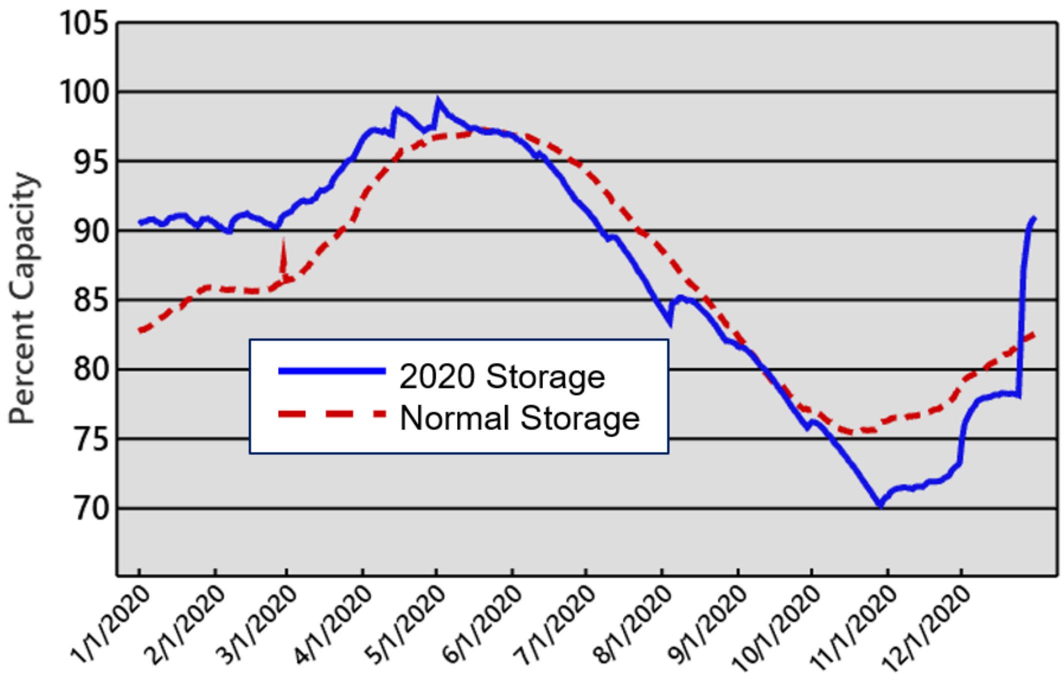


Figure 2.4 System wide usable storage in 2020 compared to the average historical value (1991-2019). Storage greater than 100% occurs when the water surface elevation is greater than the spillway elevation and reservoirs are spilling.

3. Water Quality

3.1. Monitoring Overview

Water quality samples are collected from designated sites (Appendix B) at streams, reservoirs, and aqueduct locations throughout the NYC water supply. Routine stream samples used in this report are collected on a fixed frequency, typically monthly schedule according to DEP's watershed water quality monitoring plan (DEP 2018). However, due to the 2020 COVID-19 pandemic, sample reductions are noted with reported results and summaries. Unless otherwise indicated, reservoir samples are obtained from multiple sites and multiple depths with routine sampling frequencies of once per month. In previous reports, the sample period is from April through November. In 2020, Catskill/Delaware System reservoirs including West Branch, Kensico and most EOH FAD basins (West Branch, Croton Falls and Cross River) were sampled from June through November. EOH FAD basin Boyd Corners was sampled from June through August. EOH non-FAD basins were not sampled in 2020 with the exception of New Croton Reservoir, the terminal basin of the Croton System. New Croton was only sampled at sites 1, 3, and 4 in June, August, September, October, and November. Only a limited number of analytes were collected including fecal and total coliform bacteria, turbidity, color, dissolved organic carbon, and phytoplankton samples along with field profile measurements of pH, dissolved oxygen, specific conductance, and temperature. Total and dissolved nutrients, chlorophyll, alkalinity, and chlorides were not sampled at New Croton in 2020.

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, and West Branch. When operating as a source, water from these reservoirs is regulated by the SWTR.

3.2. Reservoir Turbidity Patterns in 2020

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 erosion (storm runoff in particular) or generated within the reservoir itself (e.g., plankton, sediment resuspension). In general, turbidity levels are highest in the Catskill reservoirs (Schoharie and Ashokan) due to the occurrence of easily erodible lacustrine clay deposits found in these watersheds.

In 2020, turbidity levels in the Catskill/Delaware System reservoirs and in all monitored Croton System reservoirs were close to their median historic levels or well below in the case of Schoharie Reservoir and the east and west basins of Ashokan (Figure 3.1). (A key to boxplots is provided in Appendix C). Runoff was elevated in May at the primary inflows in the Catskill/Delaware System (Figure 2.2) but turbidity levels did not increase significantly according to approximately daily turbidity results collected at reservoir keypoints. With the exception of August, and to a lesser extent, September, runoff was generally below historic values through November. Although two large rain events exceeding 3 inches did occur in the Catskill/Delaware System in August and September, the data collected from the monthly reservoir surveys did not show a significant increase in turbidity. Monthly runoff was low throughout the Croton System in 2020 with no rain events exceeding 2 inches and only three exceeding 1 inch. The effects of a large rain-on-snow event in late December is not reflected in Figure 3.1 because it occurred after all December reservoir samples were collected.

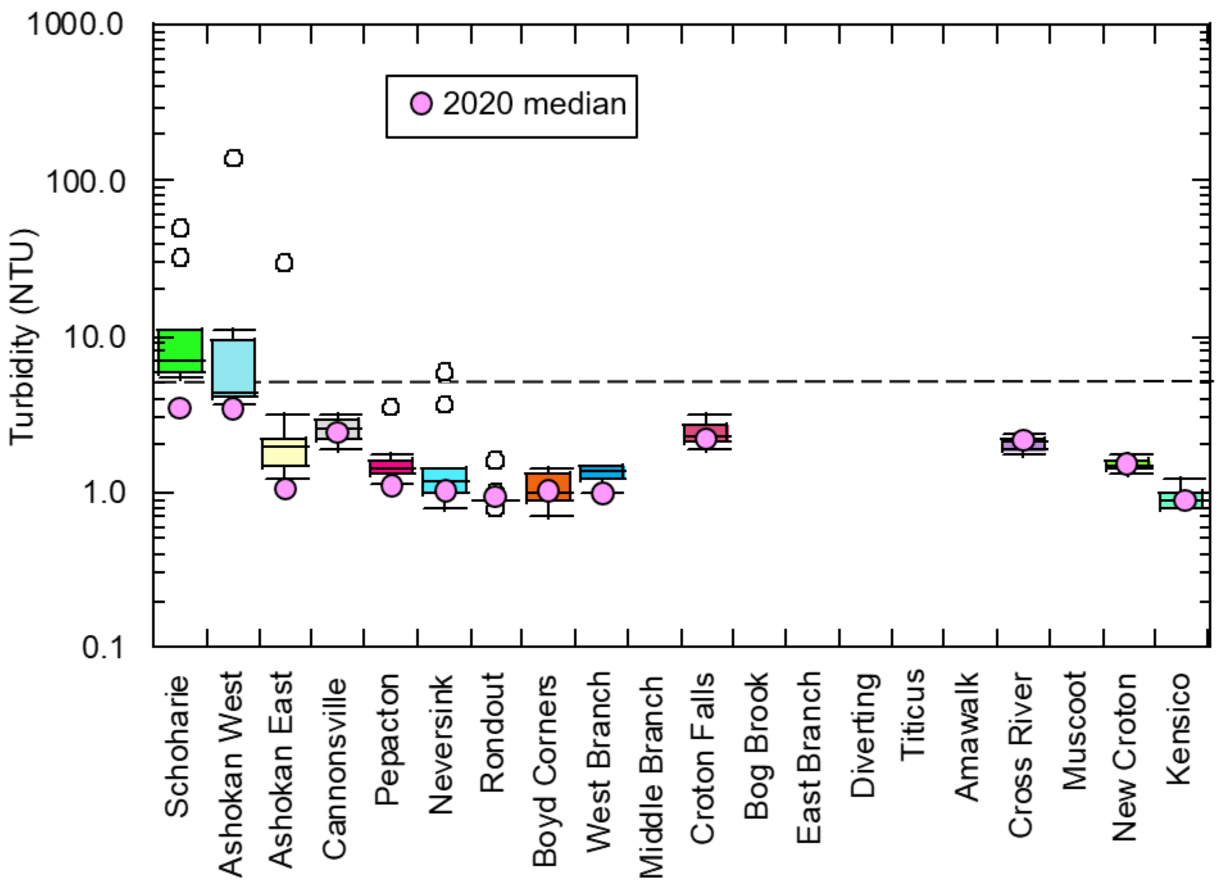


Figure 3.1 Annual median turbidity in NYC water supply reservoirs (2020 vs. 2010-2019), with the 2020 values displayed as a solid dot and outliers as open circles. The dashed line represents the SWTR standard for source water as a reference.

3.3. Coliform-Restricted Basin Assessments in 2020

Coliform bacteria serve as indicators of potential pathogen contamination. To protect the City's water supply, the New York City Watershed Rules and Regulations (WR&R) limit potential sources of coliform bacteria in the watershed area of water bodies classified as restricted. These regulations require the City to perform an annual review of its reservoir basins to make "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 that include Kensico, West Branch, New Croton, Ashokan, and Rondout reservoirs. The coliform-restricted assessments of these basins conform to 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 New York State ambient water quality standard limits on total coliform bacteria (6 NYCRR Parts 701 and 703).

3.3.1. Terminal Basin Assessments

Table 3.1 provides coliform-restricted assessments for the five terminal reservoir basins. The results are based on 2020 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 basin is classified 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 2020.

Table 3.1 Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2020.

Reservoir basin	Effluent keypoint	2020 assessment
Kensico	DEL18DT	Non-restricted
New Croton	CROGH[1]	Non-restricted
Ashokan	EARCM[2]	Non-restricted
Rondout	RDRRCM[2]	Non-restricted
West Branch	CWB1.5	Non-restricted

[1]Data from the 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 Basin 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 results exceed the reservoir class standard and the non-terminal reservoir is designated as restricted. Table 3.2 provides a summary of the 2020 coliform-restricted calculation results for the non-terminal reservoirs and Appendix D includes the details for coliform monthly medians and the percentage of values exceeding the relevant standard.

In 2020, there was a significant reduction in sampling and few exceedances for the Part 703 total coliform standard for the seven reservoirs evaluated (Table 3.2). The highest number of exceedances occurred in Cannonsville Reservoir for three out of five months sampled. Cross River, Croton Falls, and Neversink did not exceed the standard for the months sampled.

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. No other data were collected that could definitively indicate an anthropogenic source.

Table 3.2 Coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2020.

Reservoir	Class[1]	Standard: Monthly Median / >20% (Total coliforms 100 mL[1])	Months that exceeded the standard /months of data
Boyd Corners	AA	50/240	1/3
Cross River	A/AA	50/240	0/6
Croton Falls	A/AA	50/240	0/6
Cannonsville	A/AA	50/240	3/5
Pepacton	A/AA	50/240	1/6
Neversink	AA	50/240	0/6
Schoharie	AA	50/240	2/6

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.

3.4. Reservoir Fecal and Total Coliform Patterns in 2020

Total coliform and fecal coliform bacteria 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. According to the Filtration Avoidance Criteria of the Surface Water Treatment Rule (SWTR), fecal coliform concentrations must be ≤ 20 fecal coliforms $100mL^{-1}$ or total coliform concentrations must be ≤ 100 total coliforms $100mL^{-1}$ in at least 90% of the measurements from the last 6 months. The rule only applies to source waters at the keypoint immediately prior to the first point of disinfectant application and so does not apply overall to other samples from the reservoirs and controlled lakes of the NYC water supply. Nonetheless, lines at 20 fecal coliforms $100mL^{-1}$ and 100 total coliforms $100mL^{-1}$ are provided on the plots in this section as a point of reference. Also, note that data used to construct the boxplots are based on the distribution of the annual 75th percentiles. The centerline 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. If a calculated annual 75th percentile results in a censored value or zero, it was estimated using the robust regression on statistics method (ROS) of Helsel and Cohn (1988).

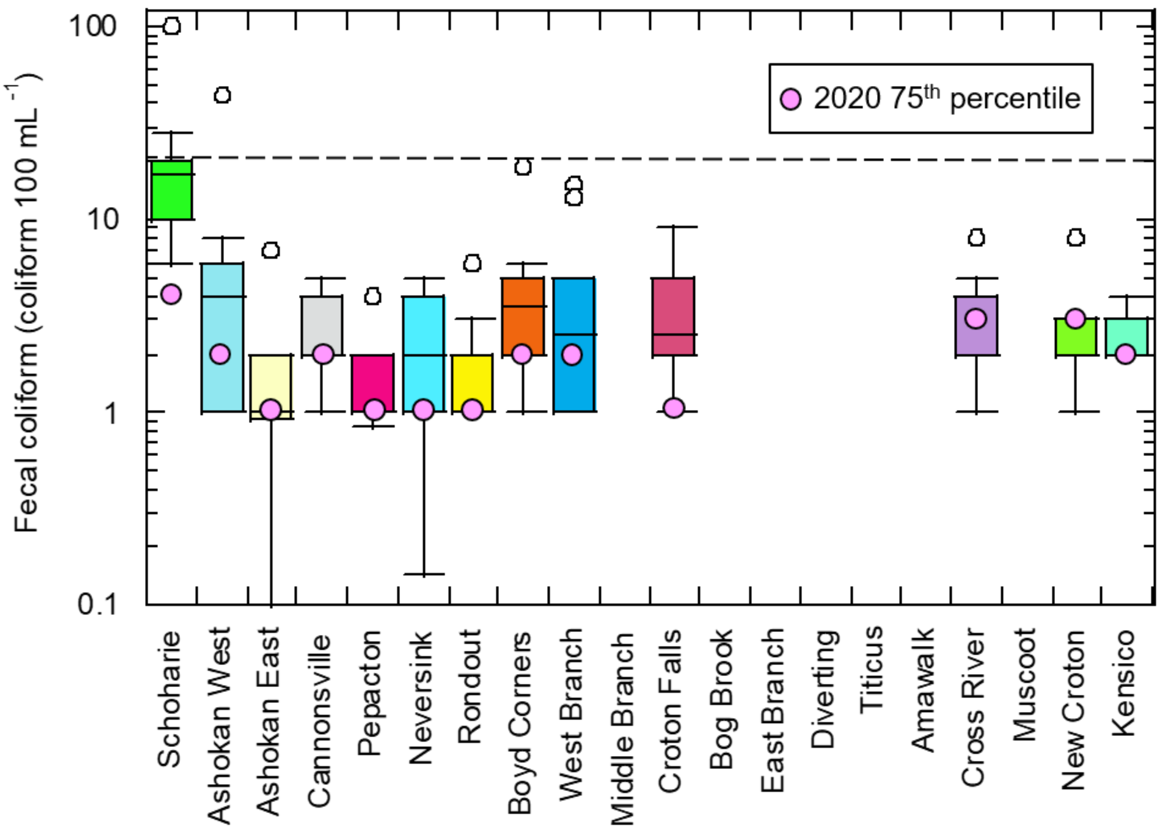


Figure 3.2 Annual 75th percentile of fecal coliforms in NYC water supply reservoirs (2020 vs. 2010-2019), with the 2020 values displayed as a solid dot and outliers as open circles. The dashed line represents the SWTR standard for source water as a reference.

In 2020, fecal coliform counts were below historic median 75th percentile levels in all of the Catskill/Delaware reservoirs, including West Branch and Kensico (Figure 3.2). The generally low runoff in 2020 is the likely explanation for the low fecal coliform counts. Rain events that did occur often did not occur in close proximity to sampling surveys. Fecal coliforms introduced via these rain events were likely reduced by natural processes such as predation, die-off, photolysis, and sedimentation before samples were collected in the monthly reservoir surveys. Dry conditions probably helped keep fecal coliform counts low to normal (near historic median) in most of the Croton System reservoirs. Higher counts at New Croton Reservoir were likely related to rainfall events that occurred within seven days prior to sampling in September (1.95 inches) and October (1.74 inches).

Similar to 2018 and 2019, total coliform counts were lower than normal in the Catskill System reservoirs but were higher than normal in all Delaware System reservoirs, especially Cannonsville (Figure 3.3). The elevated total coliform counts were probably introduced to the reservoirs via elevated runoff in August and September, which coincided with elevated daily keypoint results from Cannonsville and Neversink starting in August, and from Pepacton in September. Diversions to Rondout from Pepacton in August and September and higher than normal diversions from Cannonsville in these months likely explain the higher total coliform counts observed at Rondout. Although West Branch Reservoir receives most of its water from Rondout, historically it tends to have higher total coliform counts then Rondout suggesting that local sources such as the release from Boyd Corners and local streams may be important. Annual

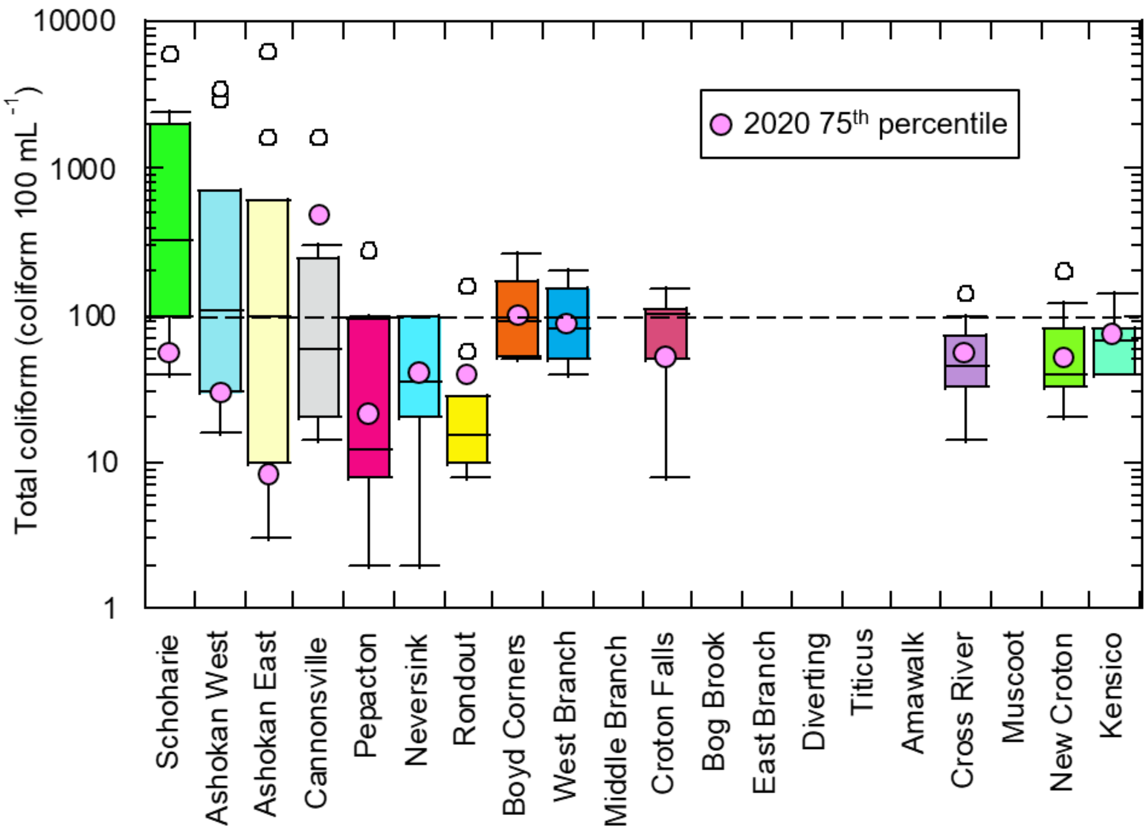


Figure 3.3 Annual 75th percentile of total coliforms in NYC water supply reservoirs (2020 vs. 2010-2019), with the 2020 75th percentile values displayed as a solid dot and outliers as open circles. The dashed line represents the SWTR standard for source water as a reference.

total coliform counts at Kensico, the terminal reservoir for the Catskill/Delaware System, were close to their historic median 75th percentile as were all monitored reservoirs of the Croton System.

3.5. Phosphorus-Restricted Basin Assessments in 2020

The phosphorus-restricted basin status determination for 2020 is presented in Figure 3.4 and Table 3.3. Status is determined from two consecutive assessments (2015-2019 and 2016-2020) using the methodology described in Appendix E. 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. For eight reservoirs and three controlled lakes the calculation for the most recent assessment period is based on four years (2016-2020) due to sampling reductions in 2020.

There were no changes in phosphorus-restricted status from the classifications presented in 2019. All West of Hudson reservoirs and three East of Hudson reservoirs retained their non-restricted classification (Table 3.3). Figure 3.4 graphically shows the phosphorus-restricted basin status of the City's reservoirs and controlled lakes. Geometric means for individual years that contributed to the assessments are shown in Appendix E. For 2020, annual geometric mean phosphorus concentrations in the Delaware system declined from the previous year in Cannonsville, with a decrease of 1.3 $\mu g\ L^{-1}$, and in Pepacton, with a decrease of 0.4 $\mu g\ L^{-1}$. Neversink increased slightly from 6.5 $\mu g\ L^{-1}$ in 2019 to 6.8 $\mu g\ L^{-1}$, whereas Rondout decreased by 0.5 $\mu g\ L^{-1}$ (Appendix E). Schoharie Reservoir in the Catskill system declined from 12.3 $\mu g\ L^{-1}$ in 2019 to 9.9 $\mu g\ L^{-1}$ in 2020. Ashokan West Basin remain the same as the previous year and Ashokan East Basin declined slightly in 2020. The majority of the Croton System reservoirs were not sampled in 2020, with the exception of Boyd Corners, which decreased by 0.3 $\mu g\ L^{-1}$ in 2020 (Appendix E). Among the source water reservoirs and potential source water (i.e., terminal) reservoirs, New Croton, Cross River, and Croton Falls reservoirs were classified as phosphorus-restricted. West Branch Reservoir was non-restricted, reflecting the influence of Delaware System water on its water quality status.

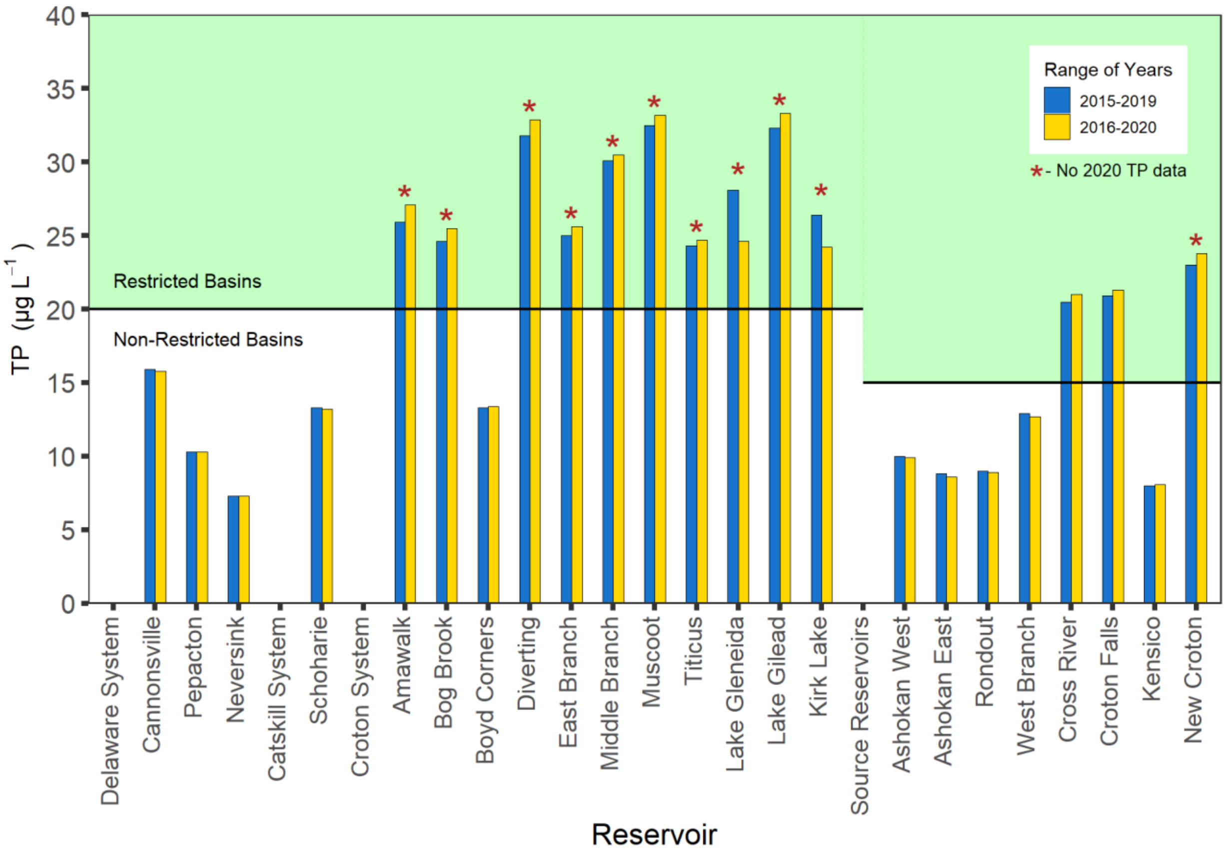


Figure 3.4 Phosphorus-restricted basin assessments. The horizontal solid lines at 20 µg L^{-1} and 15 µg L^{-1} represent the trophic guidance value for non-source and source waters, respectively.

Table 3.3 Phosphorus-restricted basin status for 2020.

Reservoir basin	2015-2019 Assessment[1] (µg L^{-1})	2016-2020 Assessment[1, 2] (µg L^{-1})	Phosphorus restricted status[3]
Non-Source Waters (Delaware System)			
Cannonsville	15.9	15.8	Non-restricted
Pepacton	10.3	10.3	Non-restricted
Neversink	7.3	7.3	Non-restricted
Non-Source Waters (Catskill System)			
Schoharie	13.3	13.3	Non-restricted
Non-Source Waters (Croton System)			
Amawalk	25.9	27.4	Restricted
Bog Brook	24.6	25.9	Restricted
Boyd Corners	13.3	13.4	Non-restricted
Diverting	31.8	33.2	Restricted
East Branch	25.0	25.7	Restricted
Middle Branch	30.1	30.9	Restricted
Muscoot	32.5	33.3	Restricted
Titicus	24.3	24.8	Restricted
Lake Gleneida	28.1	24.9	Restricted
Lake Gilead	32.3	33.7	Restricted
Kirk Lake	26.4	24.4	Restricted
Source Waters (all systems)			
Ashokan East	8.8	8.7	Non-restricted
Ashokan West	10.0	9.9	Non-restricted
Cross River	20.5	21.0	Restricted
Croton Falls	20.9	21.5	Restricted
Kensico	8.0	8.1	Non-restricted
New Croton	23.0	24.0	Restricted
Rondout	9.0	8.9	Non-restricted
West Branch	12.9	12.7	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] Reservoirs and lakes with sample reductions in 2020 were based on the calculation of a 4-year value (2016-2019).
[3]The guidance value 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 2020

Total phosphorous (TP) levels in the Catskill/Delaware reservoirs, including West Branch and Kensico, were generally within their historic ranges (Figure 3.5). In the Croton System, only Cross River Reservoir showed a notable increase in 2020. Chlorophyll levels were elevated in August and September at Cross River and subsequent senescence and decomposition of the algae likely explains some particularly high phosphorus concentrations in bottom samples in September, October, and November.

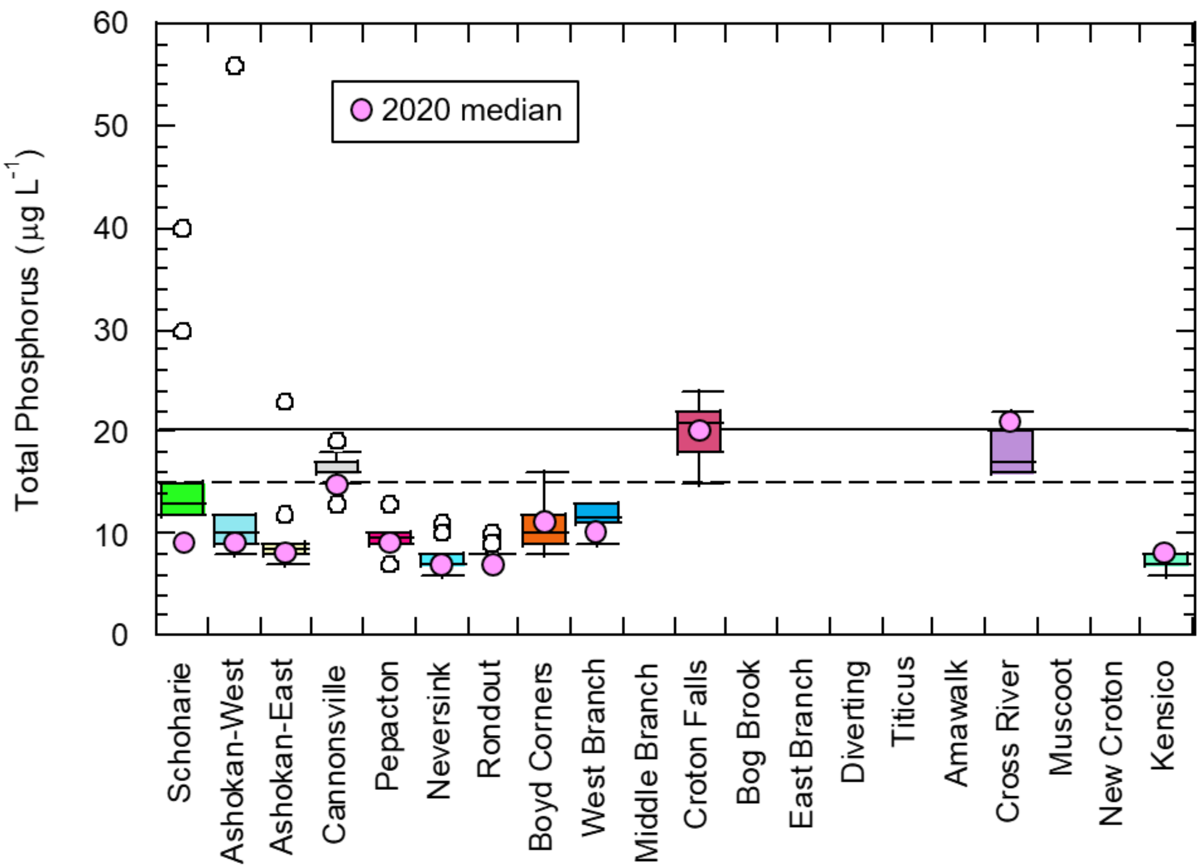


Figure 3.5 Annual median total phosphorus in NYC water supply reservoirs (2020 vs. 2010-2019), with the 2020 median values displayed as a solid dot and outliers as open circles. The horizontal dashed line at 15 $\mu g\ L^{-1}$ refers to the NYC Total Maximum Daily Load (TMDL) guidance value for source waters. The horizontal solid line at 20 $\mu g\ L^{-1}$ refers to the NYSDEC ambient water quality guidance value for reservoirs other than source waters.

3.7. Reservoir Comparisons to Benchmarks in 2020

The New York City reservoirs and water supply system are subject to the federal SWTR standards, New York State ambient water quality standards, and DEP's own guidelines. In this section, the results for 2020 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 3.4. 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 source water point of entry to the system) and different values apply to Croton reservoirs than to Catskill/Delaware System 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.

Comparisons of 2020 reservoir sample results to benchmark values are provided in Appendix F. Data represent samples collected monthly on a reduced sampling schedule as noted 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 2020 include the following:

pH

In 2020, reservoir samples were generally in the circumneutral pH range (6.5-8.5). In the Croton System, all exceedances were from values above pH 8.5, with the exception of West Branch Reservoir. In West Branch, all samples outside the circumneutral range were below pH 6.5, with the exception of one sample that was above pH 8.5, a reflection of water transferred from the Delaware System. The number of high values exceeding a pH of 8.5 was greatest in Croton Falls Reservoir, an indication of algal blooms.

All pH values outside the circumneutral range for Kensico were below a pH of 6.5, reflecting the influence of water transferred from West of Hudson reservoirs. The majority of pH values for all West of Hudson reservoirs, with lower alkalinities than Croton System reservoirs, were below a pH of 6.5, with some exceptions when algal blooms elevated pH. The pH exceeded 8.5 during summer phytoplankton blooms, particularly in Cannonsville Reservoir where all exceedances were in samples collected at 3 meters. The greatest number of pH values below 6.5 were in Neversink Reservoir, with 67% of all samples below this benchmark.

Table 3.4 Reservoir and controlled lake benchmarks as listed in the WR&R (DEP 2019).

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		≥10.00	
Ammonia-N (mg L^{-1})	(a)	0.05	0.10	0.05	0.10
Dissolved chloride (mg L^{-1})	(a)	30.00	40.00	8.00	12.00
Chlorophyll *a* (mg L^{-1})	(a)	0.010	0.015	0.007	0.012
Color (Pt-Co units)	(b)		15		15
Dominant genus (ASU mL^{-1})	(c)		1000		1000
Fecal coliform (coliforms $100mL^{-1}$)	(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.

Phytoplankton

Phytoplankton sampling was reduced in 2020 and 10 EOH reservoirs were not sampled. Of the 13 water bodies assessed (Appendix F), counts exceeded the single sample maximum of 2,000 ASU mL^{-1} for total phytoplankton for eight out of 23 samples collected in Croton Falls Reservoir. In 2020, there were a total of five NYSDEC Harmful Algal Blooms (HABs) Program notifications (NYSDEC 2020) (2020 Archived HABs Notices (ny.gov)). NYSDEC categorizes confirmed blooms for water sampling results as those with confirmed presence of cyanobacteria that may produce toxins or other harmful compounds. Cannonsville Reservoir had three reported blooms between July 31 and October 14; Croton Falls, had one bloom reported on August 18; and Kirk Lake had one reported bloom on November 20.

Chlorophyll a, Color, and Dissolved Organic Carbon

Chlorophyll *a* concentration is a surrogate measure of algal biomass. In 2020, eight Croton System reservoirs and three controlled lakes were not sampled for chlorophyll *a*. Boyd Corners had no exceedances of the benchmark value among the few samples collected, West Branch had a single exceedance, and Cross River had two exceedances. Croton Falls had the highest number of exceedances of the chlorophyll *a* benchmark value with 57% of samples exceeding the single sample maximum and both Cross River and Croton Falls slightly exceeded the annual mean standard (11.5 and 33.8 µg L^{-1}, respectively).

Color is an indicator of organic matter both from reservoir and watershed sources. For reservoir samples in 2020, only New Croton was evaluated for color. The majority of samples collected (91%) exceeded the 15 Pt-Co unit color benchmark value for single sample maximum.

There was a single exceedance of the annual mean standard for dissolved organic carbon (DOC) in Ashokan West Basin in 2020. Due to sample reductions in 2020, DOC was not sampled in eight reservoirs and three controlled lakes.

Chloride

In 2020, all Delaware System reservoirs slightly exceeded the annual mean value of 8 mg L^{-1} but only Cannonsville exceeded the single sample maximum value (91% of samples collected). Of the Croton System reservoirs and three controlled lakes sampled in 2020, Croton Falls had the highest number of samples that exceeded the single sample maximum of 40 mg L^{-1} (100%) and annual mean benchmark of 30 mg L^{-1} (67.5 mg L^{-1}). West Branch Reservoir slightly exceeded the annual mean benchmark chloride value of 8 mg L^{-1} (12.6 mg L^{-1}) and 44% of the nine samples collected exceeded the single sample maximum. Half of the 16 samples collected in Kensico Reservoir exceeded the single sample maximum value and slightly exceeded the annual mean value. All chloride samples were well below the health secondary standard of 250 mg L^{-1}.

Turbidity

Among the Catskill reservoirs, Schoharie had the highest number of single sample maximum exceedances of the 5 NTU benchmark value for turbidity (19%) and Ashokan West Basin had the second highest number (14%). For the Delaware System reservoirs, Cannonsville had the highest number of exceedances (17%), Pepacton had few exceedances (4%), and both Neversink and Rondout had no exceedances of the single sample benchmark value. For the Croton System, Croton Falls had the highest number of turbidity exceedances (27%). There were no exceedances of the 5 NTU turbidity value in West Branch and Kensico reservoirs in 2020.

Among the Catskill reservoirs, Schoharie had the highest number of single sample maximum exceedances of the 5 NTU benchmark value for turbidity (19%) and Ashokan West Basin had the second highest number (14%). For the Delaware System reservoirs, Cannonsville had the highest number of exceedances (17%), Pepacton had few exceedances (4%), and both Neversink and Rondout no exceedances of the single sample benchmark value. For the Croton System, Croton Falls had the highest number of turbidity exceedances (27%). There were no exceedances of the 5 NTU turbidity value in West Branch and Kensico reservoirs in 2020.

Nutrients

In 2020 for the Delaware System, Cannonsville had the greatest number of single sample maximum exceedances (48%), Pepacton had fewer exceedances (8%), and Neversink and Rondout had no exceedances of the benchmark value of 15 µg L^{-1} for total phosphorus (TP). For the Catskill System, Schoharie and Ashokan West Basin had few exceedances (6% and 4%, respectively). In the Croton System, TP exceedances of the 15 µg L^{-1} benchmark were highest in Cross River (78%), followed by Croton Falls (69%). New Croton was not sampled in 2020 due to reductions in the monitoring program. West Branch with influences from the local watershed and the Delaware System had few exceedances (13%). Kensico Reservoir had two samples (2%) that exceeded the benchmark value for TP.

There were no exceedances for nitrate/nitrite for the 11 reservoirs sampled in the entire system in 2020, with the exception of Croton Falls, where three out of 48 samples (6%) exceeded the single sample maximum of 0.5 mg L^{-1}. None of the reservoirs sampled in 2020 exceeded the annual mean benchmark for nitrate/nitrite of 0.30 mg L^{-1}.

Fecal Coliform Bacteria

In 2020, fecal coliform bacteria were low in reservoirs throughout the system for the 13 reservoirs sampled. Fecal coliform counts exceeded the single sample maximum of 20 fecal coliforms $100mL^{-1}$ for one sample in Ashokan West Basin, Ashokan East Basin, and Croton Falls, representing 2% of samples collected. Cannonsville was the only reservoir in the Delaware system with an exceedance of the fecal coliform benchmark value with 2 out of 65 samples (3%) and Schoharie Reservoir in the Catskill System had two samples that exceeded the benchmark (3%).

3.8. Reservoir Trophic Status in 2020

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

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

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

The Carlson TSI ranges from approximately 0 to 100 (there are no upper or lower bounds), and is scaled so that values under 40 indicate oligotrophic conditions, values between 40 and 50 indicate mesotrophic conditions, and values greater than 50 indicate eutrophic conditions. A low trophic state is desirable because such reservoirs produce better water quality at the tap. Trophic state indices are generally calculated from data collected in the photic zone of the reservoir during the growing season (May through October). In 2020, COVID-19 protocols prevented personnel from collecting May and June samples at Catskill/Delaware System reservoirs, including West Branch and Kensico, and in East of Hudson reservoirs, Croton Falls and Cross River. East of Hudson basin Boyd Corners was only sampled in June, July and, August. Because of COVID-19, chlorophyll samples were not collected from non-FAD East of Hudson reservoirs in 2020.

Historical (2010-2019) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.6. This analysis generally indicates that all West of Hudson reservoirs (including Kensico and West Branch) and East of Hudson reservoir Boyd Corners usually fall into the mesotrophic category. East of Hudson reservoirs, Croton Falls and Cross River tend to fall into the meso-eutrophic to eutrophic range. Comparisons to historic data were made using only the months collected from each reservoir in 2020.

In 2020, TSI was elevated in Schoharie Reservoir and in the west basin of Ashokan while the East Basin was at its lowest annual median since 2011. The elevated TSI at Schoharie and the west basin of Ashokan is likely explained by high surface water clarity and warm surface water temperatures that were observed throughout the growing season. The East Basin is typically lower than the West Basin due to senescence and sedimentation of algal particles and sedimentation of phosphorus as water moves through the West Basin to the east. TSI trends in the Delaware System reservoirs varied. Cannonsville was equivalent its historic annual median, Pepacton was slightly lower with Neversink and Rondout both elevated compared to their respective historic annual median TSI's. The higher TSI at Neversink and Rondout may be explained by higher than normal surface water temperatures throughout the year and by longer annual residence times in 2020 compared to their average historic annual residence times. West Branch Reservoir TSI was lower than normal perhaps due to unusually low surface water temperatures resulting from increased cold-water inputs from Rondout in 2020. Kensico Reservoir TSI was elevated in 2020 compared to its historic median TSI. Diversions from upstream reservoirs, increased residence time, slightly higher phosphorus levels and warmer surface water temperatures are possible factors that could explain the increase.

Croton System chlorophyll samples were only collected from Cross River and Croton Falls reservoirs in 2020. Warm surface water temperatures and elevated phosphorus likely contributed to the productivity increase observed at Cross River. Similar temperature, phosphorus, and TSI levels were observed at Cross River and Croton Falls although this TSI result for Croton Falls is a marked improvement compared to historic data.

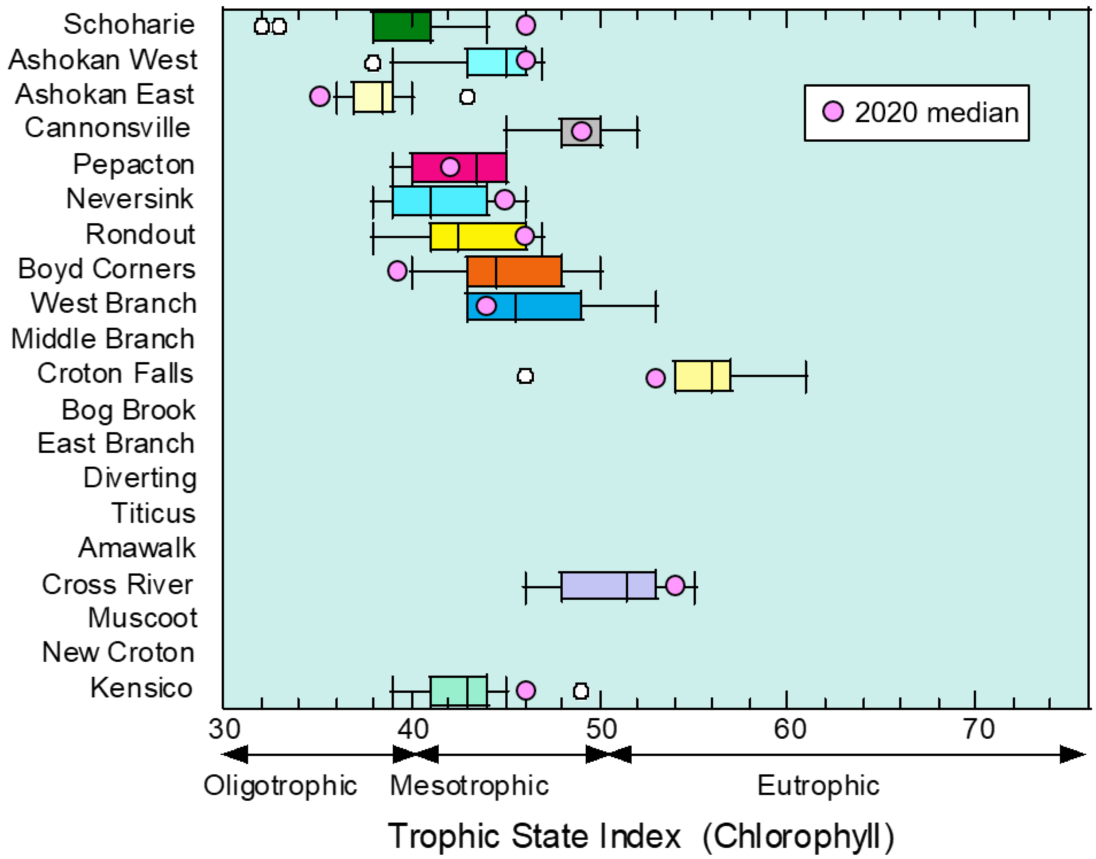


Figure 3.6 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2020 vs. 2010-2019), with the median displayed as a solid dot and outliers as open circles. In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per month from June through October. TSI is based on chlorophyll *a* concentration.

3.9. Water Quality in the Major Inflow Streams in 2020

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 immediately upstream from the six Catskill/Delaware System reservoirs and five of the Croton reservoirs. They represent the bulk of the water entering the reservoirs from their respective watershed. The exception is New Croton Reservoir, whose major inflow is from the Muscoot Reservoir release. Kisco River and Hunter Brook are tributaries to New Croton Reservoir and represent water quality conditions in the New Croton watershed.

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 2020 results presented here are based on routine grab samples generally collected once a month, but also include additional samples from locations (Esopus Creek at Boiceville, West Branch Delaware River at Beerston, and Neversink River near Claryville) where ongoing studies include fixed frequency samples that would be comparable to the routine samples and increase the number of samples for the year. As noted elsewhere in this report, there were reductions in the 2020 water quality monitoring programs during the COVID-19. The figures in this section show the 2020 results with a boxplot of historical (2010-2019) monthly values for comparison.

Table 3.5 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
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 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

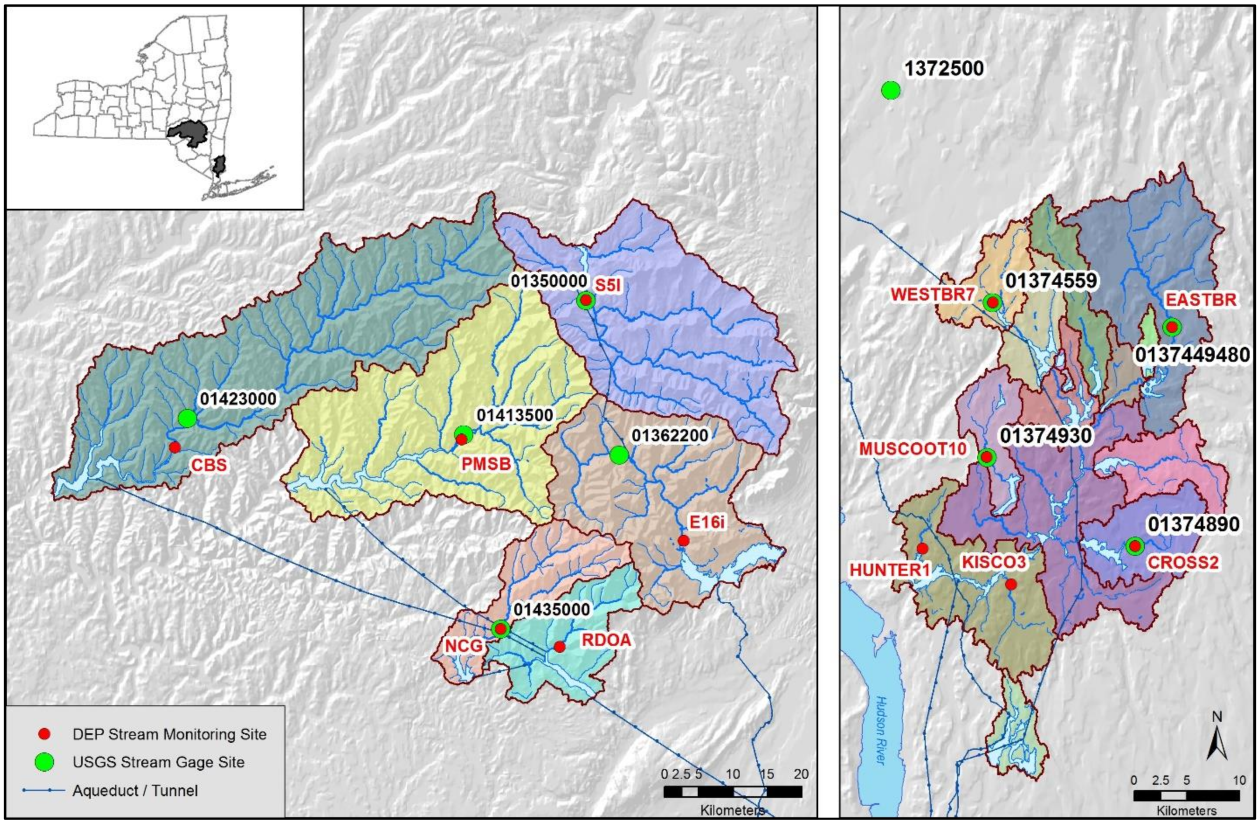


Figure 3.7 Locations of major inflow stream water quality sampling sites and USGS gage stations used to calculate runoff values (see Section 2.3).

Turbidity

The turbidity values for 2020 were generally within the range of the annual medians observed over the previous 10 years (2010-2019) (Figure 3.8) with the Esopus Creek at Boiceville (E16I) being well below the median for most of the year. A few elevated turbidity results were observed which were generally related to storms. For example, Esopus Creek had a turbidity value of 36 NTU on April 14 after about 2.8 inches of rain fell on the previous two days and a value of 55 NTU on December 29 after the December 24-25 rain-on-snow event. Schoharie Creek at Prattsville (S5I) had a value of 60 NTU on September 30 after about 1.8 inches of rain the previous two days.

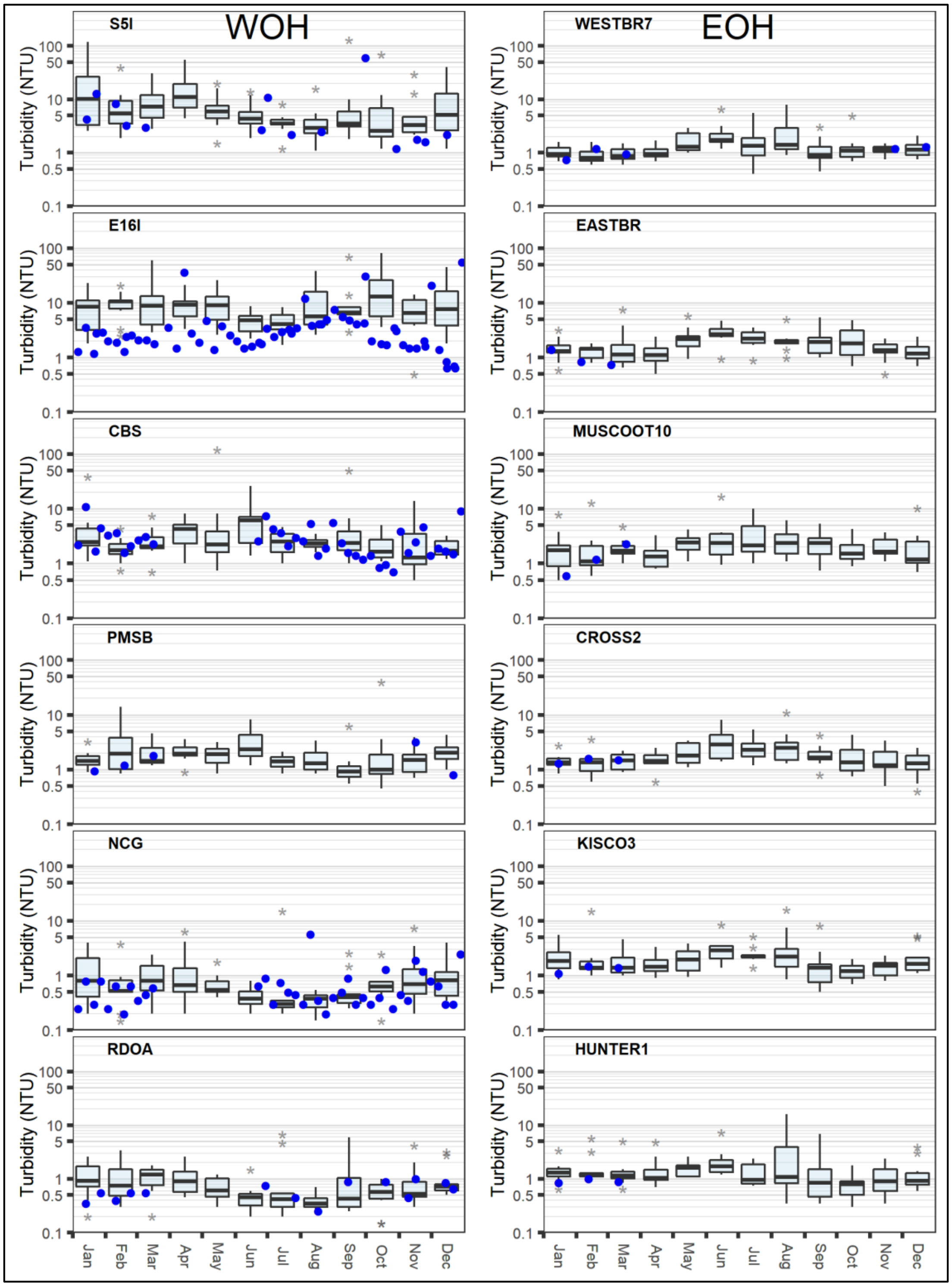


Figure 3.8 2020 turbidity values from routine stream samples with a monthly boxplot of the historic (2010-2019) routine monthly samples. Note the y-axis is a log scale.

Total Phosphorus

The 2020 total phosphorus concentrations (Figure 3.9) were generally near or below the historical monthly values. The Schoharie Creek (S5I) and Esopus Creek (E16I) were generally near or at the lowest monthly concentrations compared to the last ten years. The other streams showed fairly typical concentrations compared to the historical data with a few elevated sample related to storms.

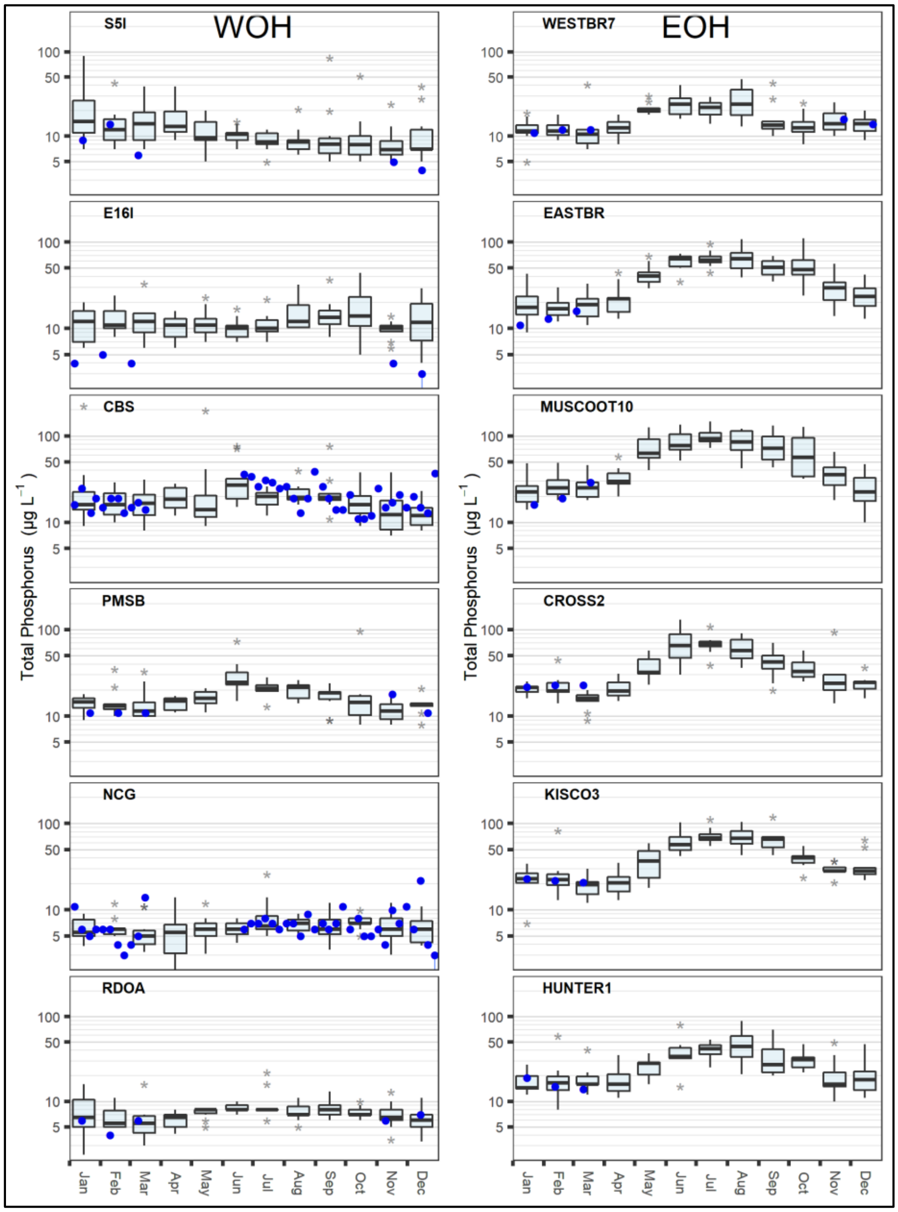


Figure 3.9 2020 total phosphorus values from routine stream samples with a monthly boxplot of the historic (2010-2019) routine monthly samples. Note the y-axis is a log scale.

Fecal Coliform Bacteria

The 2020 fecal coliform bacteria results for the main inflow streams (Figure 3.10) exhibited fairly typical results when compared to the historic monthly data. On occasions when a 2020 sample result exceeded the historic values, it was generally due to the sample being collected after a precipitation event. For example, Schoharie Creek at Prattsville (S5I) had 0.39 inches of rain two days before the 21 fecal coliforms $100mL^{-1}$ result was reported. When the East Branch Delaware River (PMSB) had 46 fecal coliforms $100mL^{-1}$ on February 18, 0.34 inches of precipitation fell that day. A fecal coliform benchmark of 200 coliforms $100mL^{-1}$ relates to the NYSDEC water quality standard for fecal coliforms (which is a monthly geometric mean of five samples) (6NYCRR §703.4b). Of the major inflow stream samples collected in 2020, none had a result greater than or equal to 200 coliforms $100mL^{-1}$.

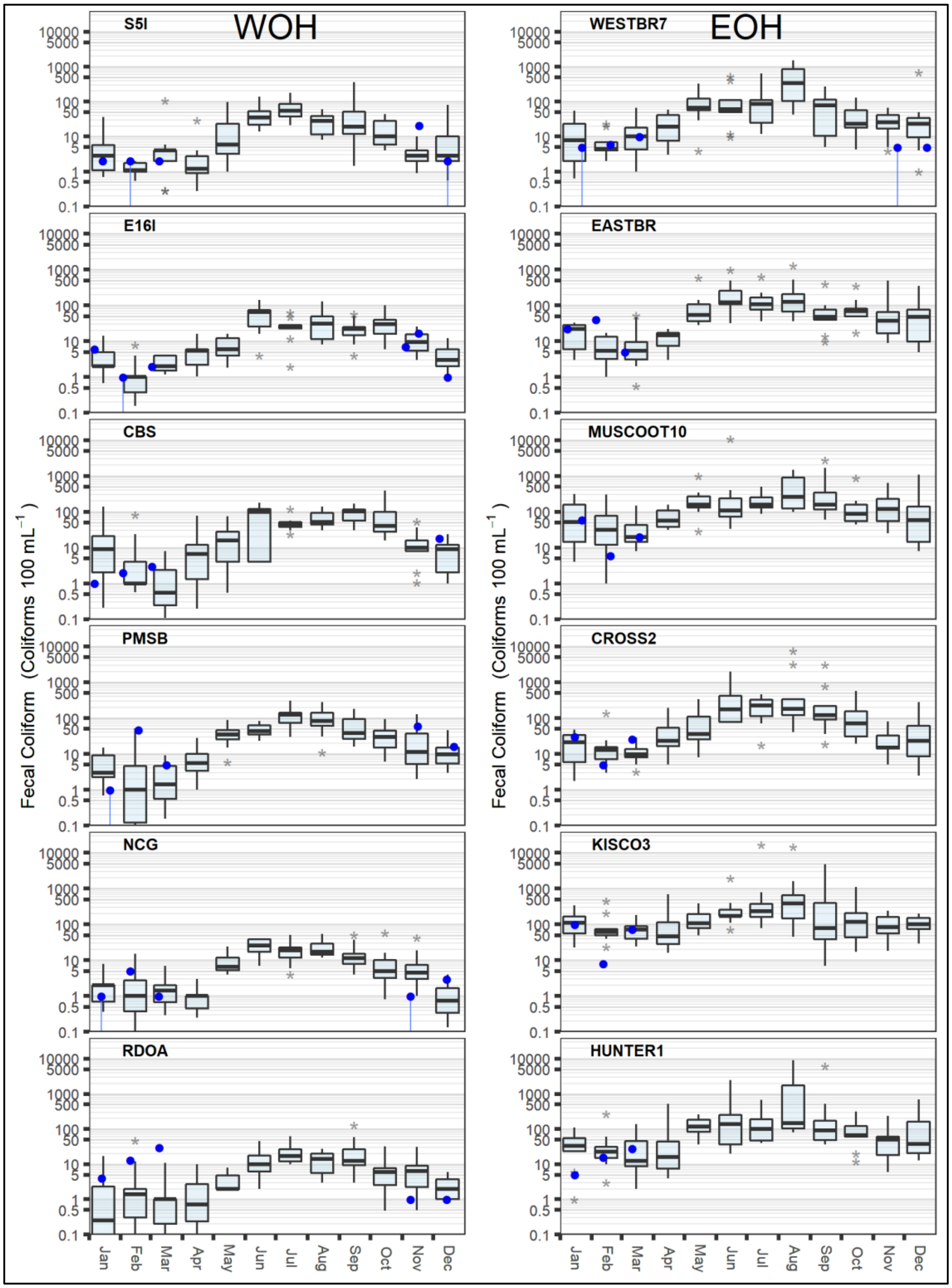


Figure 3.10 2020 fecal coliform values from routine stream samples with a monthly boxplot of the historic (2010-2019) routine monthly samples. Note the y-axis is a log scale.

3.10. Stream Comparisons to Benchmarks in 2020

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 2019b). In this section, the application of these benchmarks has been extended to 40 streams and reservoir releases to evaluate stream status in 2020 (DEP 2019). The benchmarks are provided in Table 3.10.

Table 3.6 Stream water quality benchmarks as listed in the WR&R (DEP 2019). The benchmarks are based on 1990 water quality results.

	Croton System		**Catskill/Delaware Systems**	
	Annual Mean	**Single Sample Maximum**	**Annual Mean**	**Single Sample Maximum**
Alkalinity (mg $CaCO_3 L^{-1}$)	N/A	>40.00	N/A	>10.00
Ammonia-N (mg L^{-1})	0.1	0.2	0.05	0.25
Dissolved chloride (mg L^{-1})	35	100	10	50
Nitrite+Nitrate (mg L^{-1})	0.35	1.5	0.4	1.5
Organic Nitrogen [1]	0.5	1.5	0.5	1.5
Dissolved sodium (mg L^{-1})	15	20	5	10
Sulfate (mg L^{-1})	15	25	10	15
Total dissolved solids (mg L^{-1})[2]	150	175	40	50
Total organic carbon (mg L^{-1})[3]	9	25	9	25
Total suspended solids	5	8	5	8

[1] Organic nitrogen is not analyzed currently.
[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 G 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. Please note that sampling in 2020 was limited due to COVID-19 safety protocols so 2020 results will not necessarily be comparable to past years.

Alkalinity

Alkalinity is a measure of water's ability to neutralize acids and is largely controlled by the abundance of carbonate rocks/surficial materials 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 single sample benchmark of 10 mg L^{-1} were common much of the year in most streams from these watersheds. Higher buffering capacity is generally observed in the Cannonsville, Pepacton, and Schoharie watersheds. As a result, no excursions below 10 mg L^{-1} were observed in Cannonsville and Schoharie streams and only one excursion was observed for Pepacton streams in 2020. A benchmark of 40 mg L^{-1} is used for the Croton System streams; the higher benchmark reflects the much higher natural buffering capacity of this region. However, less buffering capacity does occur in the Boyd Corners and West Branch watersheds with stream sites GYPSYTRL1, HORSEPD12, WESTBR7, and BOYDR often below 40 mg L^{-1}, with mean alkalinities ranging from 25.9 to 39.4 mg L^{-1} in 2020.

Chloride

The Catskill/Delaware System annual mean benchmark of 10 mg L^{-1} was met or exceeded in 11 of the 23 streams monitored in the Catskill/Delaware System with the highest mean, 32.7 mg L^{-1}, occurring at site NK6 on Kramer Brook in the Neversink watershed. 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 4.0 and 3.8 mg L^{-1}, respectively. The Kramer Brook watershed is very small (<1 square mile), is bordered by a state highway and contains pockets of development, all of which contribute to the relatively high chloride levels. The single sample Catskill/Delaware chloride benchmark of 50 mg L^{-1} was not exceeded in 2020 although this observation is based on much fewer samples compared to past years.

Other Catskill/Delaware System streams with high annual mean chloride included Bear Kill at S6I (22.0 mg L^{-1}), Schoharie Creek at S5I (12.5 mg L^{-1}) , and Manor Kill at S7I (10.0 mg L^{-1}), all located within the Schoharie watershed; Trout Creek at C-7 (14.8 mg L^{-1}), Loomis Brook at C-8 (14.6 mg L^{-1}), and the West Branch of the Delaware River at CBS (11.6 mg L^{-1}), all tributaries to Cannonsville Reservoir; and Chestnut Creek at RGB (15.8 mg L^{-1}), a tributary to Rondout Reservoir. Two Pepacton streams, Tremper Kill at P-13 (10.0 mg L^{-1}) and the East Branch of the Delaware River at PMSB (10.3 mg L^{-1}), exceeded or equaled the average annual benchmark in 2020. Average annual chloride was also elevated (12.5 mg L^{-1}) at the outflow from the West Branch Reservoir release (WESTBRR). In general, higher chloride concentrations correlate with the percentage of impervious surfaces (e.g., roads, parking lots) in the watersheds (Mayfield and Van Dreason 2019).

The Croton System annual mean chloride benchmark of 35 mg L^{-1} was exceeded in 15 of 16 monitored Croton streams. Only the release from Boyd Corners Reservoir at BOYDR was below the annual mean benchmark with a mean concentration of 25.6 mg L^{-1} in 2020. Annual means exceeding the benchmark ranged from 37.2 mg L^{-1} in the West Branch of the Croton River at WESTBR7 to 183.2 mg L^{-1} in Michael Brook at MIKE2. The mean 2020 chloride concentration for all 16 Croton streams was 67.8 mg L^{-1}, substantially higher than the streams of the Catskill/Delaware System, which together averaged 9.8 mg L^{-1}. The single sample chloride benchmark is 100 mg L^{-1} for streams of the Croton System. In 2020, this benchmark was commonly exceeded on the Muscoot River at MUSCOOT10, at the Amawalk Reservoir Release at AMAWALKR, and on Michael Brook at MIKE2. Historically, additional streams occasionally exceeded the benchmark and likely did in 2020. However, since COVID-19 protocols resulted in fewer samples collected, we were unable to quantify exceedances as fully as years past. 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 G).

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 2020, 13 of 23 Catskill/Delaware streams had at least one value greater than 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 approximately11.5 mg L^{-1} (Figure 3.11).

TDS excursions in the Croton streams were also strongly associated with elevated chloride concentrations with chloride accounting for about 98 percent of the variation in TDS (Figure 3.12). In 2020, Gypsy Trail Brook (GYPSYTRL1), the West Branch of the Croton River (WESTBR7) and the release from Boyd Corners Reservoir (BOYDR) were the only streams in the Croton System that were below the annual benchmark of 150 mg L^{-1}. These streams and the reservoir release from Cross River Reservoir were also below the single sample maximum criterion of 175 mg L^{-1}.

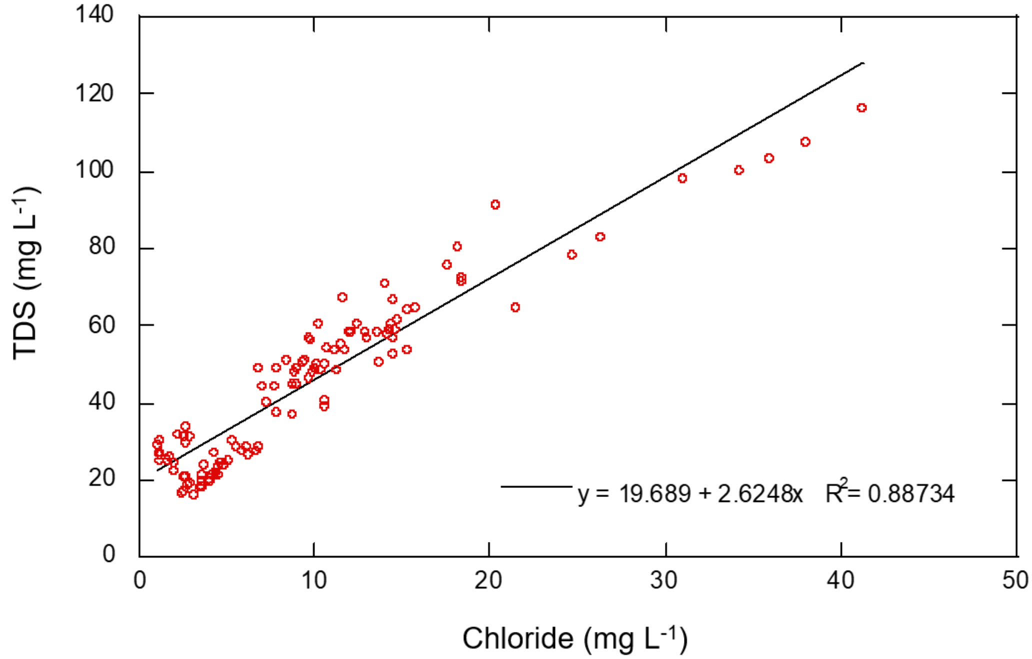


Figure 3.11 Total Dissolved Solids (TDS) versus chloride for Catskill/Delaware System streams in 2020.

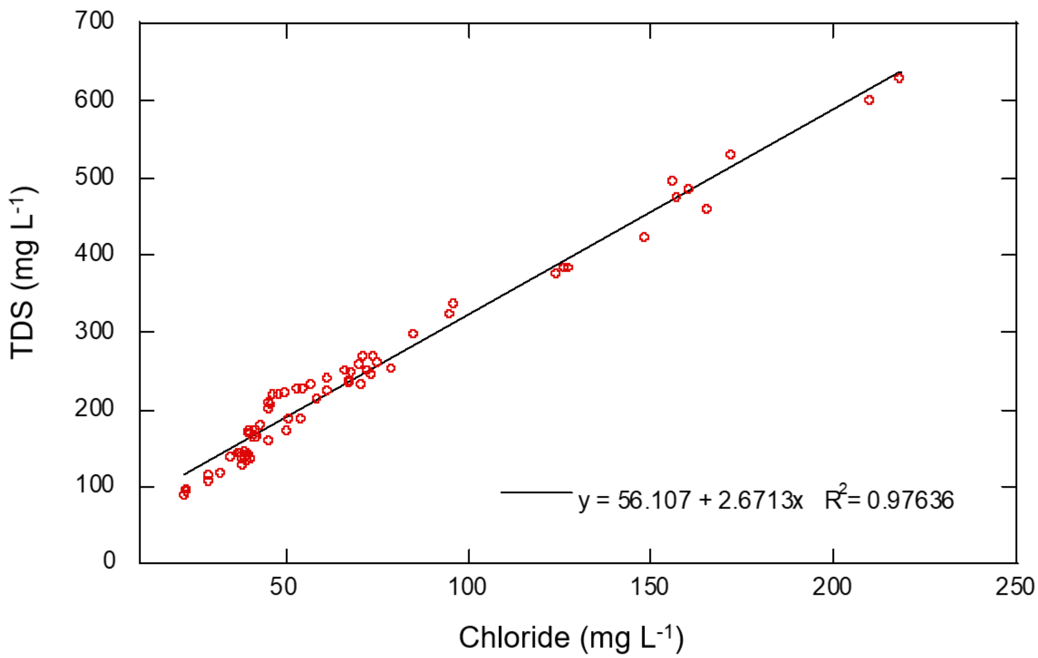


Figure 3.12 Total Dissolved Solids (TDS) versus chloride for Croton System streams in 2020.

Nitrogen

Nitrogen results were generally in compliance with benchmarks in the Catskill/Delaware System in 2020. No stream exceeded the single sample nitrate benchmark of 1.5 mg L^{-1}. The mean annual benchmark of 0.40 mg L^{-1} was exceeded in three streams: the West Branch of the Delaware River at CBS (0.58 mg L^{-1}), Fall Clove at P-8 (0.44 mg L^{-1}), and at Kramer Brook at NK6 (0.45 mg L^{-1}). Likely sources for nitrate are fertilizers associated with the relatively high agricultural activity in these basins, and wastewater treatment plants that discharge to the West Branch of the Delaware River.

Four Croton streams exceeded the annual average benchmark of 0.35 mg L^{-1} for 2020: the Kisco River at KISCO3 (0.76 mg L^{-1}), the Muscoot River at MUSCOOT10 (0.73 mg L^{-1}), Horse Pound Brook at HORSEPD12 (0.46 mg L^{-1}), and Michael Brook at MIKE2 (3.31 mg L^{-1}). The single sample nitrate benchmark of 1.5 mg L^{-1} was also exceeded at Michael Brook in four of five monthly samples. Concentrations ranged from 1.44 mg L^{-1} in November to 5.47 mg L^{-1} in December.

All ammonia results complied with the single sample ammonia benchmark of 0.25 mg L^{-1} and the mean ammonia annual benchmark of 0.05 mg L^{-1} in the Catskill/Delaware System in 2020. One Croton System stream exceeded the ammonia single sample maximum of 0.20 mg L^{-1} in 2020. The Cross River release (CROSS2RVVC) exceeded the benchmark each month from September to December with concentrations ranging from 0.22 to 0.61 mg L^{-1}. These elevated ammonia results were associated with the release of ammonia from upstream anoxic reservoir sediments in late summer/autumn.

Sulfate

Neither the single sample maximum (15 mg L^{-1}) nor the annual mean (10.0 mg L^{-1}) benchmarks for sulfate were exceeded in the Catskill/Delaware streams in 2020. The collective average for the Catskill/Delaware streams was 3.9 mg L^{-1}. Croton stream results were all below the Croton System single sample maximum of 25 mg L^{-1} in 2020. However, Michael Brook (MIKE2) exceeded the annual mean benchmark of 15 mg L^{-1} with an average of 18.4 mg L^{-1}. Concentrations were 19.8 mg L^{-1} in February and 16.9 mg L^{-1} in November, the only months sampled in 2020. The Michael Brook watershed has relatively high population density 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 the DEP monitoring program. Previous work has shown that DOC constitutes the majority of the organic carbon in stream and reservoir samples. The DOC single sample benchmark of 25 mg L^{-1} and annual mean benchmark of 9.0 mg L^{-1} were not surpassed by any stream in the Catskill/Delaware or Croton systems in 2020. In the Catskill/Delaware System, the highest single sample DOC result was 3.5 mg L^{-1}, which occurred at the Bear Kill (S6I), located in the Schoharie watershed. The annual mean DOC in the Catskill/Delaware System ranged from 0.9 to 2.2 mg L^{-1}; well below the annual mean benchmark. DOC is generally higher in the Croton System compared to the Catskill/Delaware System (although still well below benchmarks) due to a higher occurrence of wetlands in the Croton watersheds. Mean DOC in the Croton System ranged from 2.6 to 5.5 mg L^{-1} in 2020, and the highest single sample DOC, 7.9 mg L^{-1}, occurred at the West Branch of the Croton River (WESTBR7).

3.11. 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 zebra mussels. This monitoring began in the early 1990s, via contract with a series of laboratories that had professional experience in identifying zebra mussels. In 2018, this work was moved in-house. This program changed dramatically for 2020, with the COVID-19 pandemic necessitating funding and sampling reductions. In 2020, zebra mussel sampling was restricted to veligers in Lake Mahopac (outside of the NYC water supply system but the source of detections in 2018); veligers and colonization substrate in the Muscoot River; and only veligers at the confluence with Amawalk Reservoir. West of Hudson reservoirs were not monitored in 2020. In 2020, no veligers or settled adults were found in samples from the Muscoot River and its confluence with the Amawalk Reservoir. Veligers were found only in Lake Mahopac, and adults have only been found in Lake Mahopac and the Muscoot River up to about 1 km downstream of Lake Mahopac. Data suggests that downstream movement of veligers from infested Lake Mahopac is dependent on the elevation of the lake and its spill status. We have found no veligers outside of Lake Mahopac in years when the lake is not spilling (since early May 2019) during the zebra mussels' reproductive season (May-September).

3.12. Stream Biomonitoring

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994. However, in 2020 no biomonitoring was conducted due to sampling reductions during the COVID-19 pandemic.

3.13. Supplemental Contaminant Monitoring

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

To supplement required distribution system monitoring, DEP collects one sample at key sites throughout the upstate watersheds each October to test for a large number of volatile and semivolatile organic compounds as well as the herbicide glyphosate. The list of compounds is provided in Appendix I and the sites sampled are provided below in Table 3.7. Because Neversink Reservoir was off-line at the time of sampling, reservoir elevation tap NR2 was sampled in place of its keypoint NRR2CM. No samples were collected from East of Hudson sites due to COVID-19 related sample reductions. All West of Hudson samples were shipped to a contract lab for analysis. In 2020, no detections were observed in West of Hudson key sites for any of the compounds monitored. Note that results for the compound pentachlorophenol were not available because the contract lab no longer includes this compound as part of EPA 525.2 but rather as part of EPA 515.4.

Table 3.7 Sampling sites for VOC, SVOC, and glyphosate 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.

3.13.2. Metals Monitoring

Supplemental, noncompliance sampling of the Catskill, Delaware, and East of Hudson systems is conducted in order to determine background concentrations for a variety of metals. The following metals (total concentrations in all cases) are typically 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 3.8. In 2020, sampling was reduced as per COVID-19 protocols.

Instead of the normal four samples, the following sites were sampled three times: CATALUM, CWB1.5, DEL9, DEL10, DEL17, DEL18DT, and DEL19LAB. Sampling occurred in February, September, and November. The Croton System was also tested in these months but at three different sites: CROGH and at elevation taps CRO1B and CRO1T. The Catskill and Delaware systems were only sampled once in February at the following sites: CR2 (elevation tap alternate for WDTCOCM), NR2 (elevation tap alternate for NRR2CM), EARCM, PRR2CM, RDRRCM, and SRR2CM.

Table 3.8 Keypoint sampling sites for trace and other metal occurrence monitoring.

Reservoir Basin	Site(s)
West of Hudson	
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
New 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 USEPA National Primary and Secondary Drinking Water Standards (Table 3.9) and the New York State Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 (Table 3.10).

Table 3.9 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)	2,000	
Beryllium (Be)	4	
Cadmium (Cd)	5	
Chromium (Cr)	100	
Copper (Cu)	1,300	1,000
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)		5,000

Table 3.10 Water quality standards for metals from NYSDEC Title 6 regulations.

Analyte	Type	Standard ($\mu g\ L^{-1}$)
Silver (Ag)	H(WS)	50
Arsenic (As)	H(WS)	50
Barium (Ba)	H(WS)	1,000
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 2020, most metal sample results were well below state and federal benchmarks. Arsenic, lead, antimony, beryllium, cadmium, silver, and selenium were not detected above the detection limit of 1.0 µg L^{-1} for any sample. In February, thallium was detected above its detection limit of 1.0 µg L^{-1} at sites EARCM (1.5 µg L^{-1}) and SRR2CM (2.2 µg L^{-1}). These results are considered anomalies that may have come from contamination during sampling or processing. Zinc, mercury, and chromium results were all below their detection limits of 10 µg L^{-1}, 0.10 µg L^{-1} and 5 µg L^{-1}, respectively.

Nickel was detected on one occasion each at CRO1T and CRO1B with concentrations ranging from 1.0 to 1.1 µg L^{-1}. All results were well below the NYSDEC regulation (Title 6, Chapter X, Part 703.5) of 100 µg L^{-1}. Barium was detected in all 30 samples, ranging from 7.1 µg L^{-1} at EARCM to 33.8 µg L^{-1} at CRO1T. Copper exceeded its detection limit of 1.0 µg L^{-1} in 13 of 30 samples. Concentrations ranged from 1.0 µg L^{-1} at CWB1.5 and DEL18DT to 13 µg L^{-1} at CR2. Iron was detected in 22 of 30 samples with concentrations ranging from 32 to 120µg L^{-1}. All detected barium, copper, and iron results were well below their respective benchmarks.

Benchmarks for manganese and aluminum were occasionally surpassed in 2020. The manganese benchmark of 50 µg L^{-1} was exceeded on five occasions, while the aluminum benchmark of 50 µg L^{-1} was surpassed in eight samples. Manganese exceedances occurred at CATALUM (76 µg L^{-1} and 95 µg L^{-1}), NR2 (64 µg L^{-1}), CROIT (68 µg L^{-1}), and CROGH (70 µg L^{-1}). Aluminum exceedances occurred in one sample at SRR2CM (107 µg L^{-1}). Note that these iron, aluminum, and manganese exceedances 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 the Catskill/Delaware System site in closest proximity to distribution, DEL19LAB, were below the benchmarks, ranging from 10.7 to 20.5 µg L^{-1} for aluminum, <30 to 35 µg L^{-1} for iron, and 16 to 24 µg L^{-1} for manganese (the "<" designates the analytical detection limit). The Croton keypoint, CROGH (or CRO1T or CRO1B), was also below most benchmarks, ranging from <10 to 21.9 µg L^{-1} for aluminum and from 81 to 93 µg L^{-1} for iron. However, the benchmark for manganese was exceeded in two samples, with concentrations of 68 and 70 µg L^{-1}.

3.14. Special Studies

There were 12 special studies conducted throughout the watershed during 2020. Among these, five investigations occurred in the Kensico basin and are reported in Chapter 4. Studies were initiated when a water quality concern was raised or to better understand monitoring and management alternatives.

3.14.1. Tropical Storm Fay Impacts

In early July 2020, Tropical Storm Fay took aim at the upstate watershed. Terminal reservoirs Ashokan and Rondout were impacted by this large precipitation event and Watershed Water Quality Operations management requested additional sample collection on both reservoirs for turbidity. On the scheduled routine limnology survey on July 13, a YSI EXO field sonde was outfitted with a turbidity probe to collect profile data at the six routine survey sites in Ashokan. This probe is not part of the routine instrument setup for limnology studies. Turbidity readings were collected at 1-meter intervals through the water column at each site. The data were used to inform management of the extent of the turbidity levels in both basins of Ashokan Reservoir to help guide operational decisions. On Rondout, the Rondout Effluent Chamber keypoint sites were sampled for turbidity and fecal coliforms over the weekend immediately following the event. Further, a limnology survey was conducted to collect samples for turbidity and fecal coliform bacteria analysis at three sites on July 13. No further investigation was warranted on either reservoir.

3.14.2. Schoharie Reservoir Cold Water Bank Assessment

The Schoharie Reservoir diversion is regulated by a SPDES permit that specifies the acceptable temperature range of the water released to the Esopus creek at the Shandaken Tunnel Outlet. The permit also requires that a special temperature profile survey of Schoharie Reservoir be completed by June 15 each year to measure the amount of cold water banked at deeper depths and outlying locations in the reservoir. The NYSDEC contacted the BWS Operations division to request additional temperature profiles in the months of May and July, bracketing the SPDES required sampling event. On May 21, temperature profiles were collected at four sites on Schoharie Reservoir at half-meter intervals. These same four sites were surveyed again on July 21 at the same half meter profile intervals. These data were sent to BWS Operations who then contacted the NYSDEC. It was recommended that if this additional sampling were to be requested in the future, that this additional Schoharie Reservoir survey work be added to WWQO’s routine monitoring program as an addendum to the Watershed Water Quality Monitoring Plan.

3.14.3. Croton System Taste and Odor Event

Due to issues with taste and odor at the Croton Water Filtration Plant (CFP) in 2019, more sampling was requested in 2020. Some of the additional sampling was to support the plant in adjusting its water treatment operations and to support the installation and testing of a new GAC treatment unit.

The additional sample collection for commissioning of plant B, supporting GAC installation and adjusting plant operations took place from June 11 to July 29, 2020. There were some issues on startup, including some clogging at the plant. Requested reservoir sampling was weekly and included Geosmin/MIB, total and dissolved Fe/Mn, phytoplankton, total and dissolved organic carbon, turbidity, scent, temperature, pH, specific conductivity, and dissolved oxygen. Similar monitoring was also done at the New Croton Reservoir intake sample taps on a weekly basis. During this time, a suspected algae bloom was also sampled on New Croton Reservoir.

Sample collection started again on September 4, 2020, for the same analytes and frequencies to support the commissioning of plant A and to prepare for use of the CFP during the upcoming Catskill Aqueduct shutdown. This taste and odor support sampling continued thru the end of 2020 and continues into 2021.

In 2020, the elevation in Geosmin/MIB concentrations were detected in the late autumn/early winter period and was similar to observations made in 2019 (see Figure 3.13).

Extra sampling has continued into 2021 to track taste and odor analytes over time.

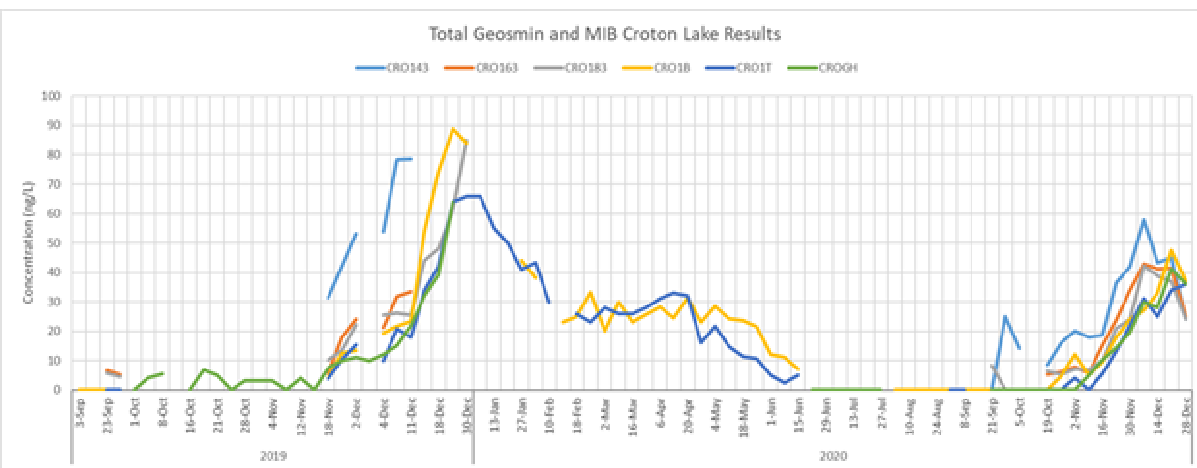


Figure 3.13 Total Geosmin and MIB concentrations for Croton Lake, 2020.

3.14.4. Continued Monitoring of Titicus Fuel Spill

On February 19, 2019, the EOH/Hawthorne Field unit responded to a special investigation at Titicus Reservoir, located on Titicus Road (i.e., County Route 116). A tanker truck rolled over, spilling dyed diesel and gasoline adjacent to Titicus Reservoir. The fuel spill was monitored throughout the clean-up, which lasted from February 19, 2019, through July 2020. Throughout 2020, weekly sampling took place at the Titicus Dam Release (TITICUSR).

Analyses included: gasoline range organics (GRO), diesel range organics (DRO) and scent. The GRO/DRO samples were sent to contract labs, York Analytical Laboratory and Eurofins Eaton Laboratory, for analysis. Scent was analyzed at the DEP Hawthorne Laboratory. In 2020, sampling took place from January 6, 2020, through March 16, 2020, and stopped temporarily due to water quality monitoring reductions that were put in place as a result of the COVID-19 pandemic. The weekly surveys were reinstated on June 23, 2020 and the site was sampled through July 29, 2020. All 2020 GRO sample results were reported as non-detects. For DRO, there were three samples where results were above the detection limit: January 13, 2020 (0.119 mg L^{-1}), March 2, 2020 (0.127 mg L^{-1}), and March 16, 2020 (12.8 mg L^{-1}), with all other results below detection. All DRO samples with detections, however, had the following analytical qualifier associated with it: "GC-DRO did not display a fuel pattern. Contains several discreet peaks." The samples were, therefore, considered not a result of the spill and non-threatening to the water supply. The scent (scent intensity and character) analysis results ranged from 2 to 3 E (earthy), 2 to 3 M (musty), and 3 Mm (moldy) throughout the sample period. A scent intensity of 2 indicates that the scent may be detected by an average consumer, but only if attention were called to it. A scent intensity of 3 is a scent that would be readily detected and might cause the water to be regarded with disfavor.

3.14.5. Croton Falls Pump Station Monitoring

As a continuation of the Catskill Aqueduct Repair and Rehabilitation project, the Catskill Aqueduct was taken out of service for about 10 weeks from November 10, 2019, to January 23, 2020. This scheduled shutdown was for the removal of biofilm from the interior of the aqueduct and removal of accumulated alum floc and sediments from the tail end of the aqueduct. To compensate for the loss of Catskill water during this time, the Croton Falls Pump Station was operated between November 11, 2019, and January 22, 2020.

A second round of pump station operations began on February 3, 2020. This was to help balance the reservoirs during rehabilitation of the Rondout Effluent Chamber, during which time flow from the chamber was reduced to about half its normal capacity. The Croton Falls Pump Station was operated intermittently until February 9, 2020, and was not used again in 2020.

Sampling during these times included weekly limnology sampling on Croton Falls Reservoir, weekly pathogen sampling, and daily grab sampling at the valve chamber tap at Croton Falls and some additional sampling at wastewater treatment plants surrounding the Croton Falls Reservoir.

At all times the water quality of the water delivered by the Croton Falls pump station to the Delaware Aqueduct met the SWTR requirements of an unfiltered system.

3.14.6. Aqueduct Leak Monitoring

In 2020, the WWQO WOH field unit received several requests from BEDC and BWS Operations to investigate potential aqueduct leaks in the watershed. The first investigation was on March 27 at the St. Elmo Siphon on the Catskill Aqueduct in Wallkill, NY. Water quality samples were collected and analyzed for phytoplankton, pH, turbidity, scent, and specific conductivity at five sites at or near the reported surface expression. Sample results were compared to the same analyses from samples collected at the head of the Catskill Aqueduct at site EARCM. These results were not conclusive in determining the source of the expression and additional sampling was recommended during the next aqueduct shutdown later that year. There was some indication that leaking aqueduct water may be the source but further investigation was needed to confirm.

The Catskill aqueduct was shut down in April 2020 and was due to come back online in early May. WWQO received a request from BWS Operations for follow-up sampling during this shutdown just before the expected return to service. On May 5, a second round of samples were collected at the same five siphon area sites as with the previous investigation on March 27. During this shutdown, the interconnection at CDIS4 was online so the Catskill Aqueduct was receiving water from the Delaware Aqueduct. Data collected at the special investigation sites were compared to results from samples collected at the head of the Delaware Aqueduct at site RDRRCM instead of the Catskill EARCM site sampled in the previous investigation. In this follow-up to the first investigation, the results again were inconclusive and the recommendation was that further study should be focused on the next shutdown in 2021 when CDIS4 would not be operating. This will provide an opportunity to monitor the potential leak when the Catskill Aqueduct is dewatered.

The second suspected leak site investigation was in the Delaware System at the East Delaware Tunnel Outlet facility (EDTO) where a seep was observed running down a wall inside of the building. WWQO staff responded to the request from Grahamsville Operations to investigate the seep and the work was done on several dates in May 2020. Water quality samples were collected and analyzed for temperature, pH, lab specific conductance, field specific conductance, turbidity, coliforms (total and fecal), and phytoplankton on May 8, 11, and 14 at two sites inside the EDTO building. Results were compared to samples collected at the tail of the East Delaware Tunnel at Pepacton Reservoir site PRR2CM. Analysis of the results were not explicitly indicative of an aqueduct leak. It was noted that the presence of seepage coincided with a multi-day precipitation event during that time. WWQO recommended that the EDTO facility seep be monitored and resampled as needed should the seep reappear.

The third aqueduct leak investigation was performed at the Hudson River Drainage Chamber at Catskill Aqueduct Shaft 9 on August 12 and 13. A request for sampling was received from BEDC in early August and sampling was conducted over two days in cooperation with onsite BEDC contractors. There are several manholes proximate to the shaft building as well as an interior seep which is located in a confined space. The BEDC contractors provided specific conductance data from their instruments at two manholes, one confined space location, and at a shoreline location at the nearby Hudson River. They also collected samples for phytoplankton analysis from the confined space seep. Phytoplankton samples were collected by DEP from the manhole sites and at the Hudson River site. All measurements were repeated on May 13 due to some sample interference on May 12. Data were compared to measurements obtained at the beginning of the aqueduct at site EARCM. The comparison indicated that Catskill Aqueduct water is leaking into the manholes surrounding Shaft 9. No further sampling was recommended.

The fourth location for suspected aqueduct leakage was at the Poor Farm Arch on the Catskill Aqueduct in New Paltz and again the request came from BEDC. The requested analytes were temperature, pH, specific conductance, and phytoplankton for two sample locations and the investigation was conducted on November 17. Results were compared to the same analytes collected at the head of the aqueduct at site EARCM. The specific conductance values at the surface expression and at EARCM were similar therefore it was concluded that the Catskill Aqueduct is leaking at this location.

3.14.7. DBP Formation Potential in Watershed Sources

BWS is conducting research in the Neversink and Cannonsville watersheds to evaluate potential proxy measurements for DBP precursors to support water supply operations and water quality modeling efforts. Samples from major stream inputs, along with reservoirs and reservoir diversions, are being analyzed for total trihalomethane formation potential, haloacetic acid formation potential and potential proxy analytes. The proxy analytes include total and dissolved organic carbon, UV_{254}, fluorescent dissolved organic matter, S::CAN multi-spectral absorbance, chlorophyll a and phycocyanin.

The study, which includes a combination of laboratory, field and robotic monitoring, will assist BWS in developing a water quality index and models to optimize the quality of water being delivered to the City.

3.14.8. Ultrasonic Algae Control

Widespread regional and national concern over increased harmful algal blooms has prompted additional research into monitoring and mitigation approaches. Although there are many treatment alternatives available, non-chemical treatment options of algal blooms are specifically attractive for water supply operations.

The 2020 deployment of the ultrasonic platform on Croton Falls Reservoir was conducted as a continuation of a 2018 pilot study to determine the effectiveness of this technology in preventing and mitigating algal blooms. Equipment malfunctions during 2018 and 2019 warranted a third study season to effectively evaluate the technology. As was observed in 2018 and 2019, there was no significant difference in water quality at the control or treatment sites in terms of chemical or biological parameters. Algal production at the testing site has proven to be beyond the control capability of this particular ultrasonic buoy platform.

While this technology remains of interest to the DEP, no further study will be undertaken in Croton Falls. DEP will evaluate other locations that may be of interest and will request appropriate permits as needed based on study locations.

3.14.9. Wastewater Based Epidemiology: SARS CoV-2 Monitoring

In August 2020, DEP's Bureau of Wastewater Treatment (BWT) joined scores of utilities nationwide to monitor levels of the virus that causes COVID-19 in untreated wastewater. With significant help from our academic partners at CUNY and NYU, the Newtown Creek Wastewater Resource Recovery Facility microbiology lab set up monitoring procedures in a very short timeframe using a testing method that looks at viral RNA. This was a significant achievement, as it represents the implementation of the very first molecular biology method in this laboratory. To date, the Newtown Creek microbiology lab has analyzed hundreds of samples from DEP WWTPs, as well as from Westchester County, Plattsburgh, NY, and BWS upstate. Since August 2020, DEP has reported data on the City’s 14 WWTPs to the NYCDOHMH for their public health monitoring, and has participated in several national initiatives on the important area of wastewater-based epidemiology (e.g., Association of Public Health Laboratories’ guidance documents for laboratories getting started on wastewater-based epidemiology for SARS-CoV-2RNA).

3.14.10. Upstate Laboratory Analytical Support for Metals Analysis

Distribution Water Quality Operations (DWQO) was conducting a study in preparation for the Lead and Copper Rule revisions. Profile samples were collected at select homes, most with lead service lines, under varying temperatures and phosphate doses to see if there was an increase in effectiveness of corrosion control (through increased phosphate application). The Kingston Metals lab analyzed approximately 200 samples toward this effort and provided DWQO the results through LIMS. The study results will help to determine if a City-wide increase in phosphate dose is beneficial.

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. Protection of this reservoir is critically important to prevent water quality degradation and to maintain the Filtration Avoidance Determination. 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 2018). These sampling site locations are shown in Figure 4.1. The WWQMP 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 the approximate number of water quality samples collected within the Kensico watershed during 2020. Human Enteric Virus sampling ceased in 2019 after consultation with the New York State Department of Health (NYSDOH). There are no plans to resume this sampling program in the future. All Kensico Reservoir aqueduct compliance monitoring was achieved throughout the COVID-19 pandemic except at CATALUM when the aqueduct was shut down for maintenance during the beginning and end of 2020. All other sample collection and analysis was significantly reduced for 2020 after consultation with the NYSDOH.

Table 4.1 Summary of Kensico watershed water quality samples collected in 2020.

Kensico sampling programs	Turbidity	Bacteria	*Giardia/ Crypto-sporidium*	Phyto-plankton	Other Analyses
SWTR Turbidity compliance	2192				
Keypoint effluent	366	366	52	135	2202
Keypoint influent	494	472	97	97	3064
Reservoir	543	269		69	1862
Streams	57	58	58		747

Compliance with the Safe Drinking Water Act Surface Water Treatment Rule (SWTR) (USEPA 1989) is of paramount importance to DEP to maintain the Filtration Avoidance Determination. Fecal coliforms and turbidity are often focal points when discussing Kensico water quality. Fecal coliform and turbidity results during 2020 consistently exceeded compliance requirements for water leaving Kensico Reservoir. The predominantly low 2020 fecal coliform results are in large part due to the ongoing success of the Waterfowl Management Program discussed in Section 4.4.1 in greater detail.

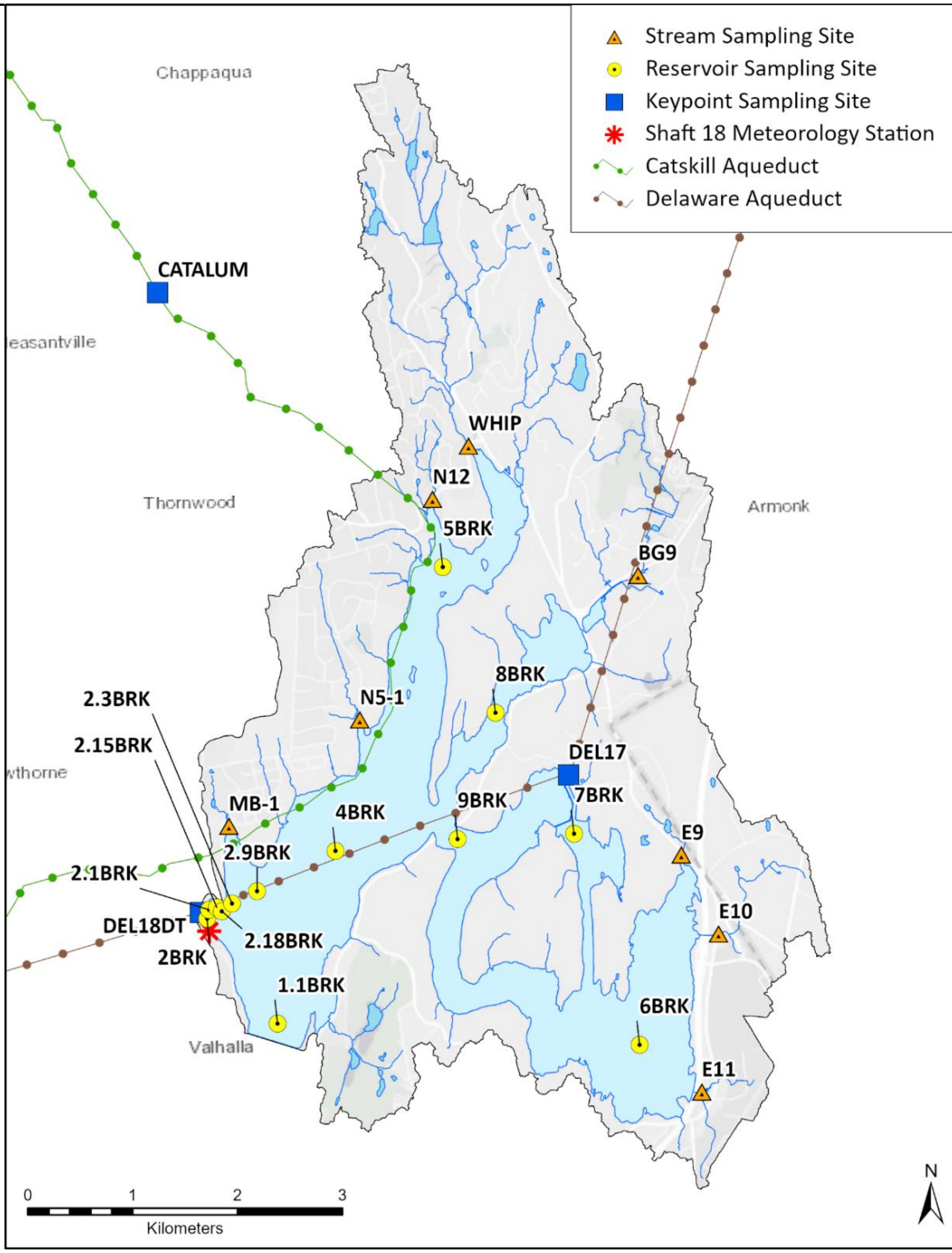


Figure 4.1 Kensico Reservoir showing limnological, hydrological, and keypoint sampling sites, meteorology stations, and aqueducts.

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 upstate reservoirs of the Catskill/Delaware System via the Catskill and Delaware Aqueducts, respectively. The monitoring for CATALUM and DEL17 include requirements 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 Shaft Building 18 at a point just prior to disinfection; this water ultimately travels down to distribution. Table 4.2 outlines the routine grab sample monitoring that occurred at three aqueduct keypoint locations for most of 2020. The COVID-19 pandemic resulted in reduced monitoring during April and May 2020.

Analytical results from all three keypoint locations are used as an indicator of water quality entering and discharging from Kensico Reservoir and utilized to optimize operational strategies providing the best possible water quality leaving the reservoir. Operational strategies are enhanced by the continuous monitoring instrumentation for temperature, pH, conductivity, and turbidity at all three locations in near-real time.

Table 4.2 Water quality monitoring for Kensico Reservoir aqueduct keypoints via routine grab samples for 2020.

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

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

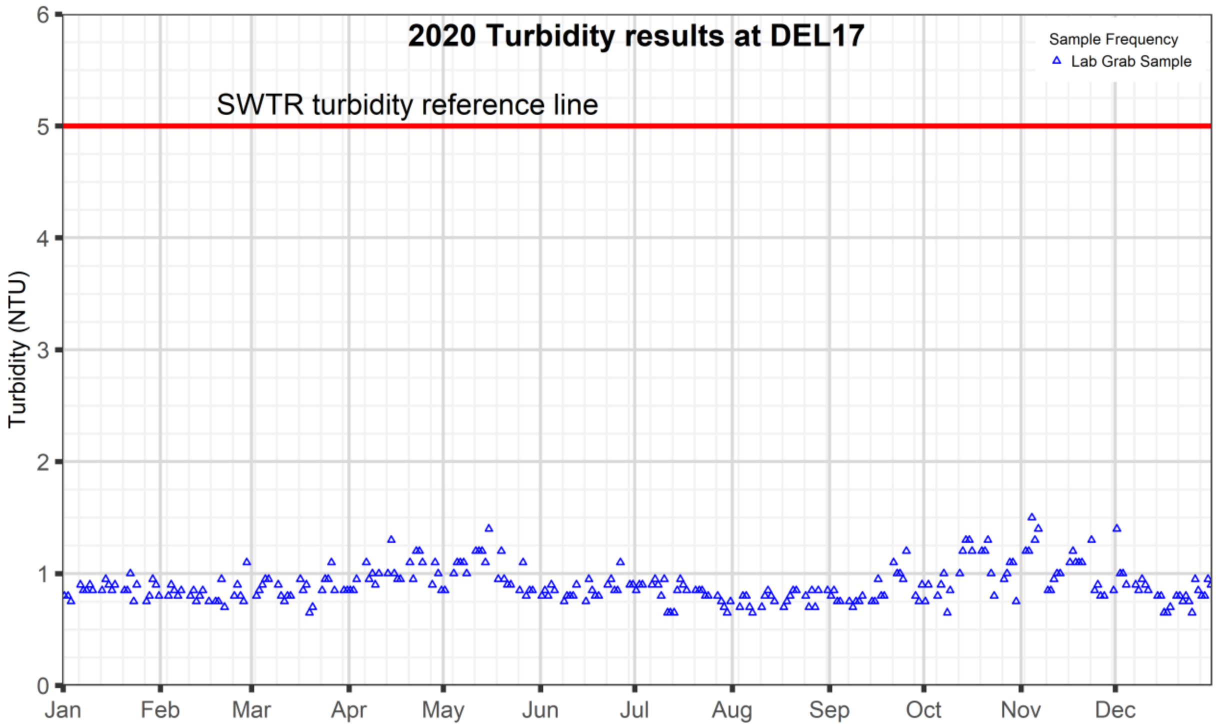
Annual median and single sample maximum for turbidity and fecal coliform are metrics to assess the overall water quality for 2020 and can be compared to the previous year (Table 4.3). Assessment of individual 2020 routine grab samples for each of the Kensico Aqueduct locations was conducted graphically (Figure 4.2, Figure 4.3, and Figure 4.4) by comparing results to Surface Water Treatment Rule (SWTR) limits. Influent sites (DEL17 and CATALUM) are not subject to the SWTR limits, so the SWTR limit line is provided for reference purposes. In order to show the predominately low values more clearly, results greater than the turbidity and fecal coliform y-axis scales are indicated by an arrow above the result. Results below the detection limit include a "drop line" connecting the result to the x-axis and the length of the drop line goes to the top of the censored range. A drop line that goes to one indicates that the result was less than one.

Table 4.3 Kensico keypoint fecal coliform and turbidity metric results.

Analyte	Kensico Sampling Location	Median		Single Sample Maximum	
		2020	2019	2020	2019
Fecal coliform (coliforms 100mL^{-1})	CATALUM	<1	<1	24	E7
	DEL17	1	1	33	30
	DEL18DT	1	1	55	E9
Turbidity (NTU)	CATALUM	1.5	1.5	55	4.5
	DEL17	0.8	0.8	1.5	2.2
	DEL18DT	0.8	0.7	1.3	1.4

The 2020 turbidity and fecal coliform metrics were similar to 2019 except for the single sample maximums (SSM) for CATALUM turbidity and DEL18DT and CATALUM fecal coliform. CATALUM SSM for turbidity was associated with the restart of the Catskill Aqueduct after a 10-week shutdown to remove algal growth within the aqueduct. The impact of the shutdown was mitigated by alum treatment as turbidity results were quickly decreased to near 1.0 NTU within 4 days (Figure 4.3). Generally, elevated turbidity are attributed to adjustments in reservoir operations or rainfall/runoff events. These 2020 events included an Ashokan East Basin intake elevation adjustment in response to an early May runoff event and selectively diverting water from Ashokan West Basin instead of using Ashokan East Basin with periodic intake elevation adjustments between mid-June and early November. The diversions created a volume void to capture late-summer storms. The CATALUM and DEL18DT fecal coliform SSMs coincided with several days of system-wide rainfall in early August. DEL17 turbidity was consistently low throughout the year ranging from 0.7 NTU to 1.5 NTU. However, several fecal coliform results exceeded the reference SWTR benchmark in 2020. These higher fecal coliform results coincide with runoff events in the watersheds of upstream reservoirs Rondout and West Branch.

Turbidity values were well below the SWTR turbidity limit at DEL18DT (Figure 4.4) and the influent locations were almost always less than 5 NTU for the entire year (Figure 4.2 and Figure 4.3). DEL18DT fecal coliform analyses produced two results during the second half of 2020 (1.1 % of all results during second half of 2020). DEL18DT remained non-restricted for 2020 because less than 10 % of all fecal coliform samples were greater than 20 fecal coliforms 100mL^{-1} (Section 3.3.1). For the influent aqueducts, a total of five of the 472 samples were at or exceeded the reference line for fecal coliform. In 2020, Kensico water quality was well within the SWTR requirements for both fecal coliforms and turbidity.



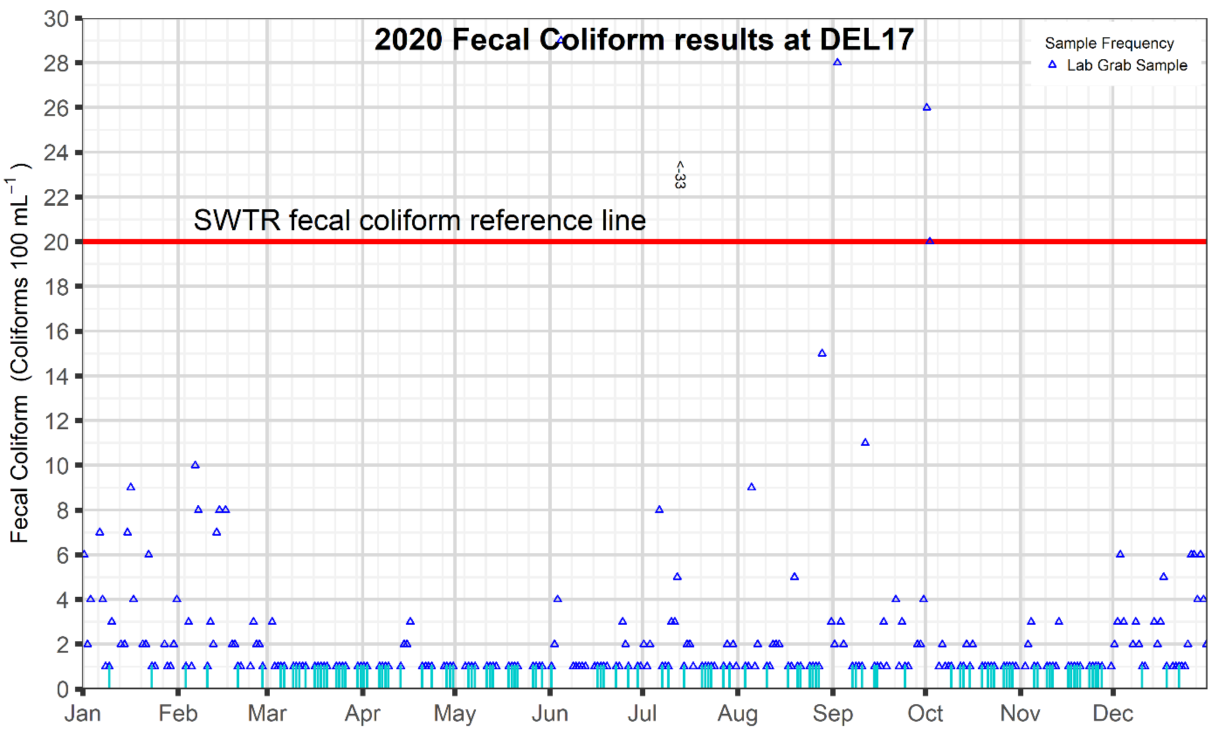
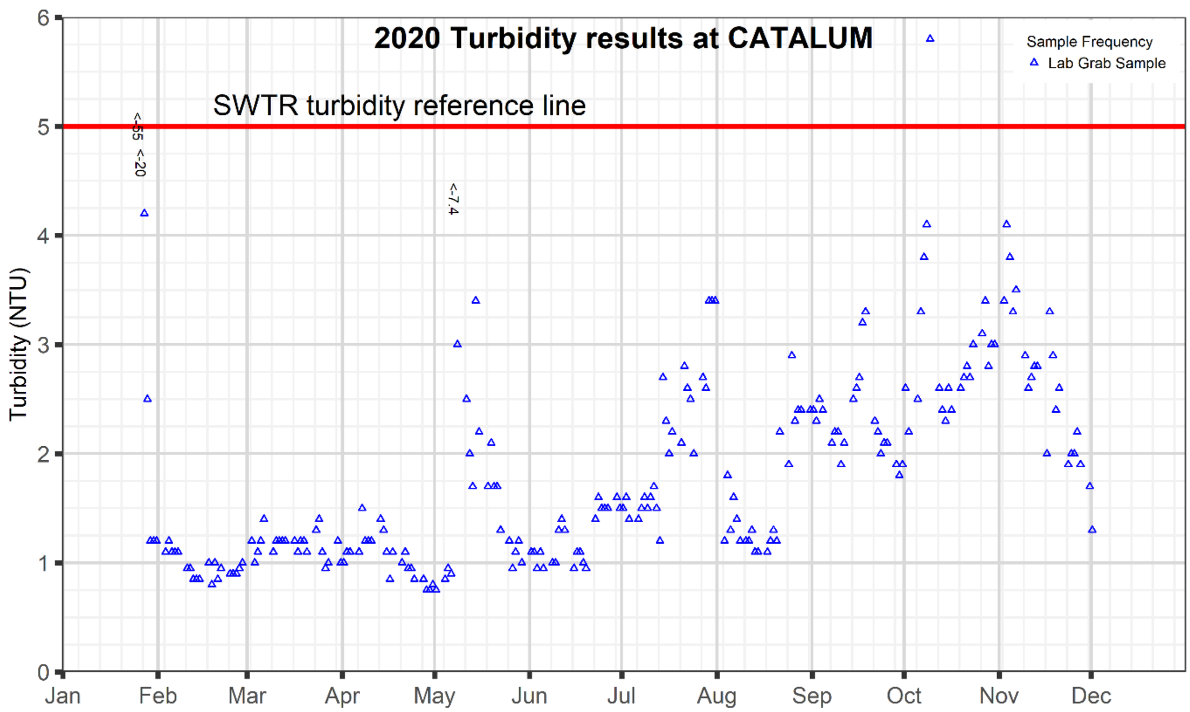


Figure 4.2 Five-day-per-week turbidity and fecal coliform grab samples at DEL17.



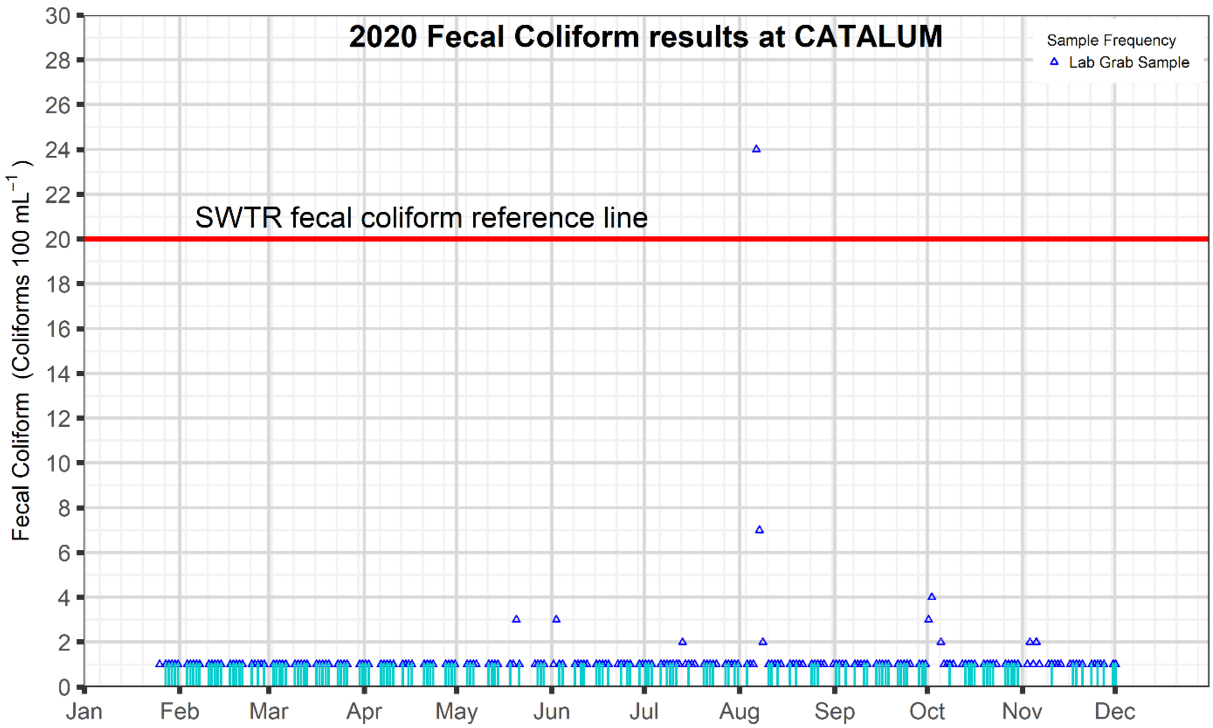
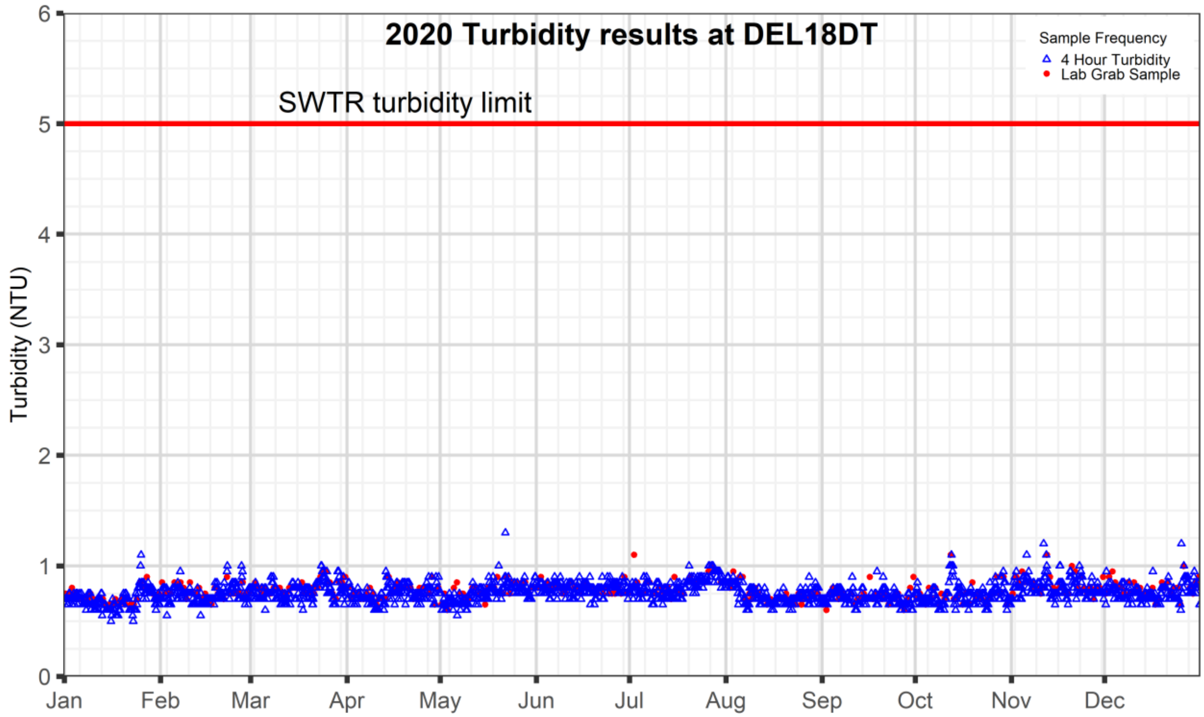


Figure 4.3 Five-day-per-week turbidity and fecal coliform grab samples at CATALUM.



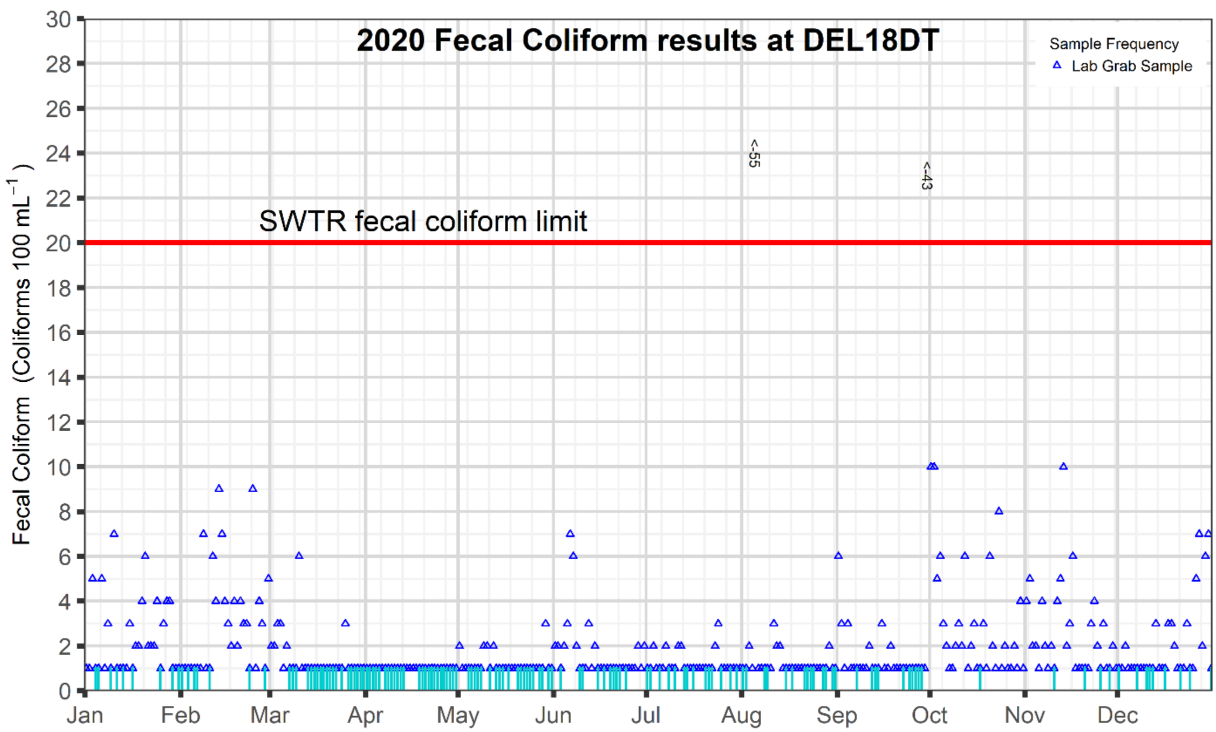


Figure 4.4 Seven-day-per-week turbidity and fecal coliform grab samples at DEL18DT.

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. In response to the COVID-19 pandemic and with approval from the NYSDOH, a suspension of stream water quality monitoring occurred between April 1, 2020, and September 30, 2020, and of reservoir monitoring between April 1, 2020, and June 21, 2020. Routine samples were collected from eight perennial streams and seven 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 a H-flume. Protozoan results for the Kensico streams are reported in section 5.4.

Turbidity and fecal coliform are primary analytes of interest. Sampling results related to COVID-19 monitoring reductions do not provide annual median comparable with historic data. Instead, each monthly stream routine monitoring result was compared to the previous ten-year monthly median with the median value plotted on the fifteenth of the month (Figure 4.5). Turbidity and fecal coliform monitoring results were typically near or below the median value for each month and are likely explained by consistently low monthly runoff in the Kensico basin as estimated from the nearby USGS flow gage Cross River near Cross River (Figure 2.2). Fecal coliform results greater than the previous 10-year 75^{th} percentiles were typically associated with runoff events. The N12 September elevated fecal coliform sample was collected near the beginning of a storm event following approximately three weeks of no precipitation. The rest of the stream sites were collected earlier in the month during the low-flow period.

Reservoir turbidity grab sample results had an annual median for the entire reservoir of 0.9 NTU (Figure 3.1) and individual locations throughout the reservoir were almost all less than 2 NTU throughout the entire year, showing stable turbidity throughout the year (Figure 4.6). Figure 4.6 interpolated concentrations, shading and contour lines, are an estimate of turbidity concentrations and may not fully represent actual concentrations in those portions of the reservoir. Fecal coliform results were also generally low; the 75^{th} percentile in 2020 was 2 fecal coliform $100mL^{-1}$ (Figure 3.2) with approximately 42 percent of the monthly reservoir grab samples resulting in no detectable fecal coliforms and no results greater than 20 fecal coliform $100mL^{-1}$. Fecal coliform results cannot be plotted in the same fashion as turbidity because of the number of censored values.

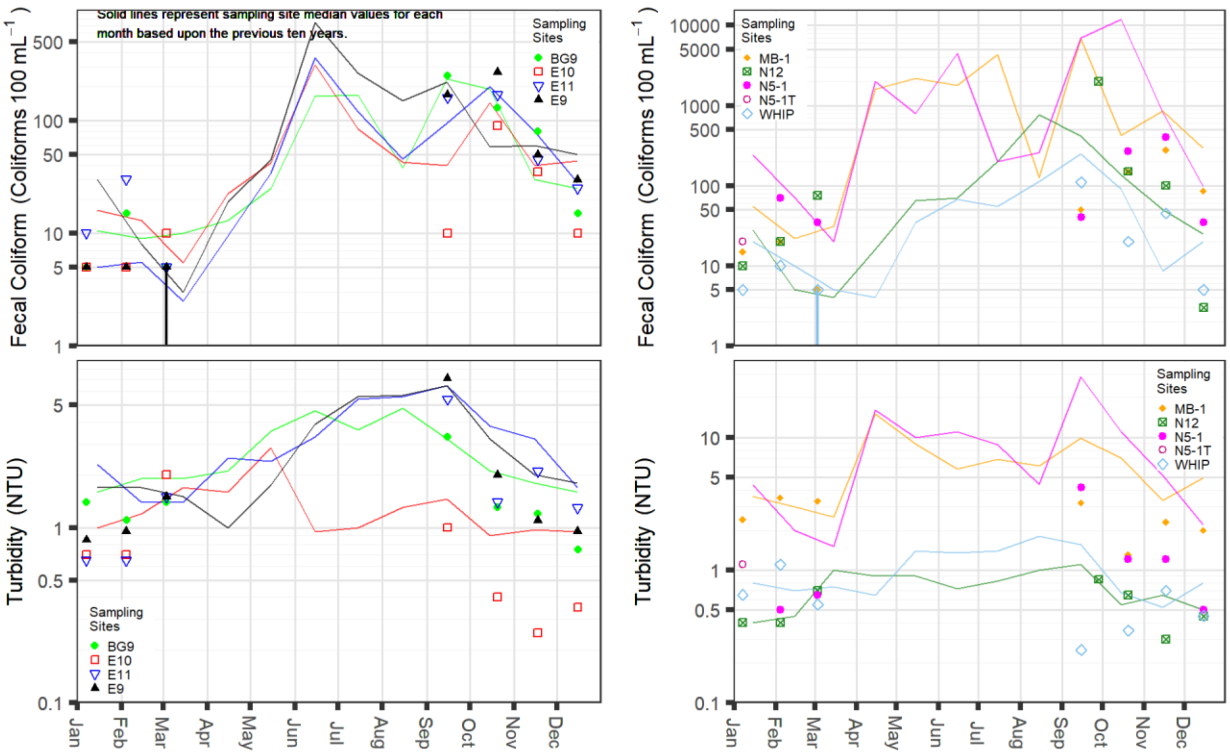


Figure 4.5 Routine Kensico stream monitoring results compared to previous ten-year median.

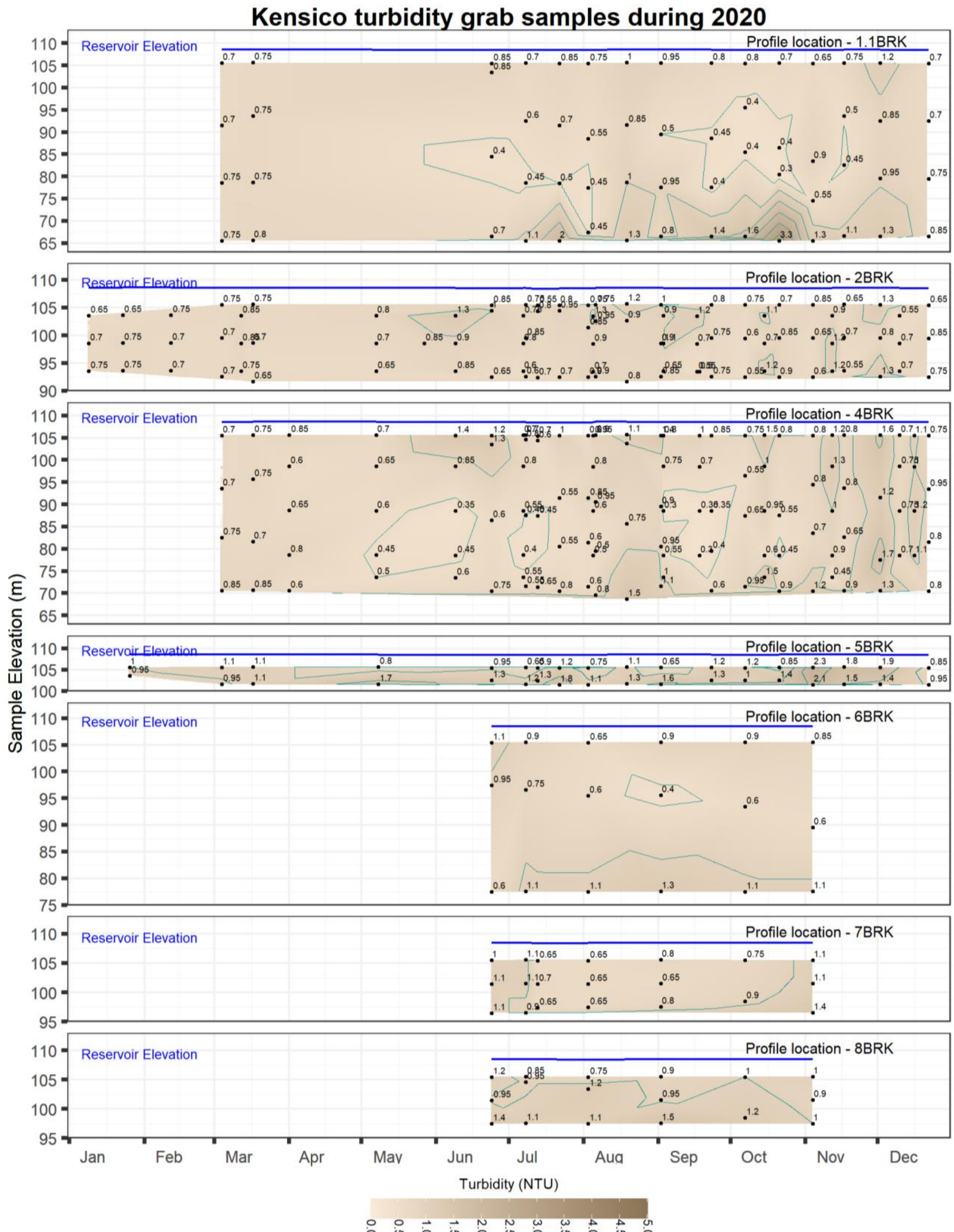


Figure 4.6 Kensico Reservoir turbidity grab sample results for 2020 with analytical measurements marked as points overlaying an interpolated concentration map.

4.3.2. Turbidity Curtain Inspection

The three turbidity curtains in the Catskill Upper Effluent Chamber cove (CATUEC) are designed to redirect water from the CATUEC cove into the main waterbody of Kensico Reservoir and minimize impacts of storm events by local streams. Since September 2012, with the activation of the Catskill/Delaware UV Treatment facility, the CATUEC chamber has been off-line because there is insufficient pressure head to drive water from the chamber to the UV Treatment facility. During a typical year, DEP visually inspects the turbidity curtains at least monthly from fixed shore locations around the cove as part of the on-going maintenance of the curtains. Due to the COVID-19 pandemic, inspections were ended in late March and discontinued for the remainder of 2020. Table 4.4 lists the dates and results of the turbidity curtain inspections carried out in 2020. 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 4.4 Visual inspections of the Kensico Reservoir turbidity curtains.

Date	Observations
01/08/20	The turbidity curtain looks intact and afloat as seen from shore.
01/22/20	Turbidity curtain appears intact and afloat as seen from shore.
02/05/20	All Kensico turbidity curtains are intact and afloat today.
02/19/20	Turbidity curtain appears intact and afloat as seen from shore.
03/04/20	All turbidity curtains appear to be intact and secure.
03/18/20	Turbidity curtain appears intact and afloat as seen from shore.

4.4. Wildlife Management

4.4.1. 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 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 seasonal waterbird population counts increased during the avian migratory and wintering periods, fecal coliform bacteria levels also increased. Continued implementation of avian dispersal measures have led to reduced waterbird counts and fecal coliform levels, 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. One of DEP's Watershed Protection Program objectives was to identify and mitigate all potential sources of fecal coliform bacteria at Kensico Reservoir. Implementation of waterbird dispersal actions starting in autumn 1993 demonstrated an immediate and marked decline in bacteria. 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) includes standard bird management techniques at several NYC reservoirs that were approved by the U.S. Department of Agriculture's Animal and Plant Health Inspection Service's Wildlife Services (USDA), and in part under registration and permit by the U.S. Fish and Wildlife Service (USFWS) and a permit with the New York State Department of Environmental Conservation (NYSDEC). DEP maintains annual depredation permits from 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. Lethal avian management is only implemented at Hillview Reservoir as a last option and was implemented as needed in 2020.

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.

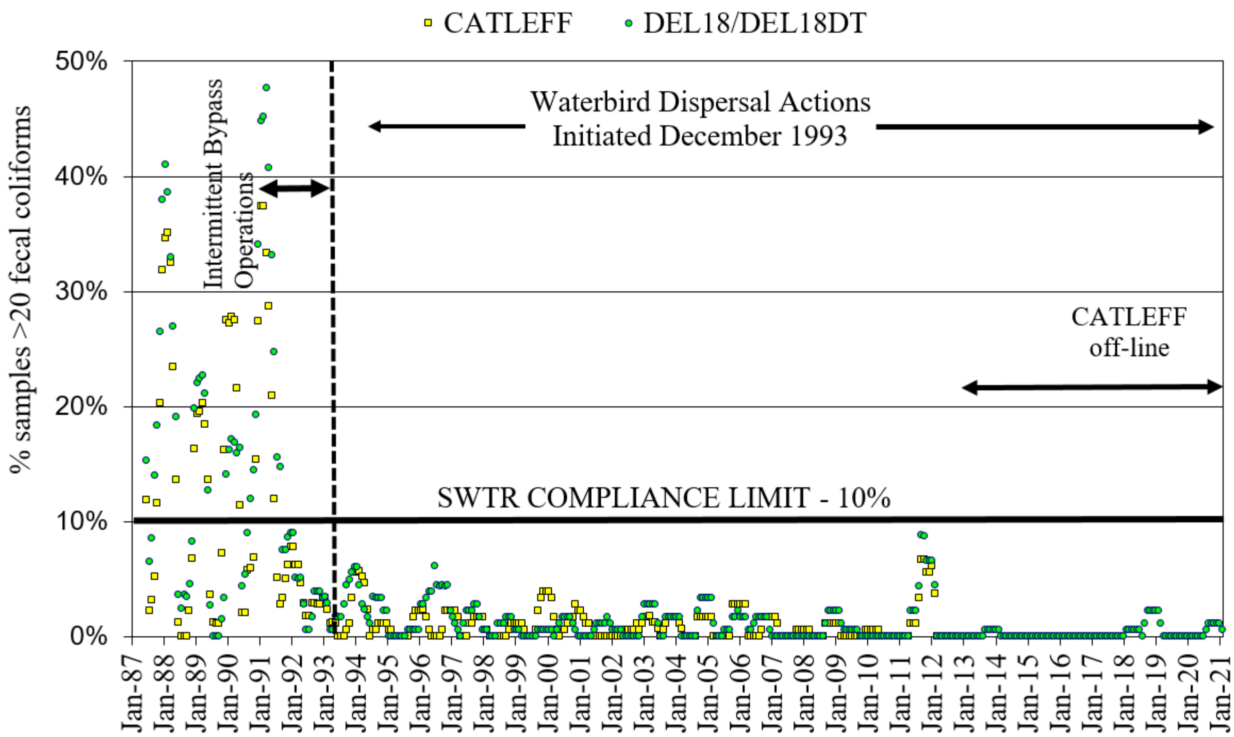


Figure 4.7 Percent of keypoint fecal coliform samples at Kensico Reservoir greater than 20 fecal coliforms $100mL^{-1}$ for the previous six-month period, 1987-2020. The first vertical dashed line indicates the year in which the WMP was implemented.

4.4.2. Terrestrial Wildlife Management

In advance of storm events that are expected to yield substantial precipitation levels, pre-storm wildlife sanitary surveys are conducted adjacent to Delaware Aqueduct Shaft 18 and along stream corridors that enter Kensico Reservoir in the vicinity of the source water intake. All wildlife fecal excrement from birds and mammals were collected during these surveys and identified to species and disposed of in advance of the storms to prevent the feces from being washed into the reservoir.

During 2020, DEP and its contractor conducted 22 wildlife sanitary surveys in advance of significant precipitation events at Kensico Reservoir (Table 4.1). On two of 22 surveys there was no evidence of excrement observed at the collection site. Of the 505 fecal samples collected, 35% were attributed to rabbits (*Sylvilagus spp*.), 31% white-tailed deer (*Odocoileus virginianus*), 7% to raccoons (*Procyon lotor*), and approximately 3% attributed to other mammals. Avian species excrement included 13% from Canada geese and 11% from passerine bird species.

Table 4.5 Wildlife sanitary surveys conducted adjacent to Delaware Aqueduct Shaft Building 18.

Date of Survey	White-tailed Deer	Raccoon	Rabbit	Canada Goose	Coyote	Fox	Mink	Passerine (birds)	Wild Turkey	Meadow Vole	Other/ Unknown Mammal	Total (all species)
01/24/20	0	0	16	0	0	0	0	0	0	0	1	**17**
02/11/20	1	0	1	0	1	0	0	0	0	0	0	**3**
02/24/20	0	2	132	0	1	0	1	0	0	1	0	**137**
03/12/20	3	0	1	0	0	0	0	1	0	0	2	**7**
04/08/20	1	0	0	0	0	0	0	18	0	0	1	**20**
04/22/20	0	0	0	0	0	0	0	3	0	0	0	**3**
04/29/20	0	0	0	0	0	0	0	17	0	0	1	**18**
06/10/20	4	0	0	63	0	0	0	0	0	0	1	**68**
07/07/20	2	0	0	0	0	0	0	0	0	0	0	**2**
07/21/20	0	0	0	1	0	0	0	0	0	0	0	**1**
08/03/20	2	0	0	0	0	0	0	0	0	0	0	**2**
08/13/20	0	0	0	0	0	0	0	0	0	0	0	**0**
09/09/20	0	0	0	0	0	0	0	0	0	0	0	**0**
09/28/20	2	12	0	0	1	0	0	0	0	0	0	**15**
10/11/20	3	1	0	0	0	0	0	0	0	0	0	**4**
10/16/20	3	0	0	0	0	1	0	8	0	0	0	**12**
10/28/20	5	7	0	0	0	0	0	10	1	0	0	**23**
11/10/20	5	1	1	2	0	0	1	0	0	0	0	**10**
11/23/20	68	0	7	0	0	0	1	0	0	0	0	**76**
11/29/20	16	5	1	0	0	0	0	0	0	0	0	**22**
12/16/20	21	5	15	0	0	0	0	0	0	0	0	**41**
12/31/20	22	0	1	0	0	0	0	0	0	0	1	**24**
Total by species	**158**	**33**	**175**	**66**	**3**	**1**	**3**	**57**	**1**	**1**	**7**	**505**

4.5. Kensico Research Projects and Special Investigations

4.5.1. Bryozoans

Background

Bryozoan colonies have been observed in Kensico, and other watershed reservoirs, by DEP staff for decades. Since the late 1980s, the most visible bryozoan has been *Pectinatella magnifica* due to its large, gelatinous, and spherical shape. *P. magnifica* has been seen in coves within the reservoirs and near the shoreline on branches and rocks. One of the most prominent locations for *P. magnifica* colonies to congregate seasonally is at the reservoir outflow at Delaware Aqueduct Shaft 18. Several other bryozoan species can be found in Kensico Reservoir including *Cristatella mucedo*, which looks like a small caterpillar-like bryozoan species and can grow together to cover surfaces in thin mat-like sheets. The presence of *P. magnifica* was inconsequential until autumn 2012 when the Catskill/Delaware Ultraviolet Light Disinfection Facility (CDUV) came on-line. Bryozoan colonies found downstream of Shaft 18 at CDUV caused clogging issues at the 1-inch perforated baffle 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.

Monitoring

DEP staff began monitoring bryozoan colonies in the sluiceways at Shaft 18 using an underwater video camera in 2014. During each survey, the video camera is lowered on a long set of poles down into the sluiceway (upstream of the traveling screens) and high definition (HD) video recordings are created to document the conditions in each of the five sluiceways. Notes on water quality parameters (temperature, turbidity, etc.) and operational conditions (daily flow) are also taken at the time of each visit. Video monitoring is predominantly focused on the access ladder and adjacent wall area in each sluiceway and still frame photos are captured to document colony sizes.

Due to reduced monitoring associated with COVID-19, unfortunately, no video surveys were performed for bryozoans during the 2020 growing season. Three abbreviated surveys were performed, after the primary growing season, on September 3, October 13, and December 13, 2020. These surveys were conducted to inform Operations staff of any areas that might contain high concentrations of colonies and perhaps require divers to enter the sluiceways for removal as in past years.

Collaboration for Gate Closures

Since no in situ observations were conducted during the primary colony growth period of 2020, Water Quality staff collaborated with Water Treatment Operations staff to predict the best course of action for gate closures to minimize colony sizes and population counts. Historical bryozoan occurrence data were analyzed to predict the best sluicegate closures to yield minimal bryozoan growth. Knowing when to reduce flow in the sluiceways, and for how long, has been a key factor in successfully reducing colonial growth and subsequently reducing the potential for occlusion downstream.

As early as June 2, 2020, one of the five sluicegates at Shaft 18 was closed, and the closure was later rotated among three of the five gates as the season progressed (gates 2, 3 and 4). The gate closures were dependent on several factors including historical data, current water temperature, storm events, and other mechanical operations. There were some periods during which operations would not allow for any gate closures (Tropical Storm Isiais, August 2020, etc.). However, those were short in duration and no impact on colony size was expected.

Results

The novel approach of minimizing bryozoan growth at Shaft 18 with periodic closures of the sluiceways even without the benefit of seasonal videography was successful in 2020 as illustrated by Figure 4.8. A review of historical data combined with the collaboration of Water Quality and Water Treatment Operations staff made it an effective program.

Figure 4.8 Comparison photos of Shaft 18 sluiceways 1 and 3 showing the size and condition of *P. magnifica* on October 13, 2020. For scale, each of the ladder rungs is about 12 inches across.

The post-season September, October, and December abbreviated video surveys confirmed minimal to no growth in the sluiceways that had been closed on a rotational basis throughout the season (2, 3 and 4). There was considerably more growth in the sluiceways that remained open the whole season (1 and 5), once again confirming that controlling flow is a viable approach to controlling bryozoan growth. Some mat-like growth of *C. mucedo* was present along with *P. magnifica* in sluiceways 1 and 5, however the abundance was less, possibly due to the observations being made later in the year. Ultimately, the review of historical data records and close collaboration with Operational staff was extremely helpful and resulted in reduced colonial growth in three of the five sluiceways. This effort was enough to prevent issues at Shaft 18 and the downstream CDUV plant in 2020.

4.5.2. Special Investigations within the Watershed

The following five special investigations occurred within the Kensico Reservoir watershed during 2020 and are listed below in chronological order. Each of these special investigations evaluated the potential impact to drinking water quality. A brief summary of each investigation and the corresponding results are shown below.

4.5.2.1. Kensico Shoreline Stabilization Project: January through December 2020

Kensico Reservoir shorelines around the Shaft 18 intake were identified as areas that can significantly contribute to turbidity issues, especially when strong winds blow onto the shoreline. As a result, a plan to stabilize shoreline areas on both sides of Shaft 18 was developed. Construction on the shoreline area farthest away from the intake began in May 2019 and continued through December 2020. Since construction could cause and contribute to reservoir turbidity issues, an intensive monitoring plan was developed. The construction contractor was responsible for monitoring turbidity within the actual construction area while DEP implemented a monitoring plan outside the construction zone to verify that no turbidity associated with the construction left the construction area. This plan consisted of the deployment of three fixed depth automated monitoring buoys outfitted with turbidity sensors. Each buoy has sensors deployed in the middle of the water column and another deployed near the bottom of the reservoir, if depth allowed. These monitoring buoys are located outside the project construction area to provide advanced notice in the event that construction created turbidity leaves the construction area. The monitoring plan also utilizes already deployed fixed depth buoys on Kensico Reservoir at sites 2.9BRK and 2BRK that are part of the WWQO's routine RoboMon Program. Site 2.9BRK is located upstream of the construction area and acts as a control to give a picture of background turbidity levels in the reservoir. Site 2BRK, located directly in front of the Shaft 18 intake, allows confirmation that any turbidity issue from the construction project is settling out before reaching the intake area.

In December 2020, work began on the southwest shoreline, closest to the Shaft 18 building, and two of the automated monitoring buoys were relocated to monitor the new construction area. The remaining automated monitoring buoy remains near the original shoreline project area to detect any issues that may arise from that area.

All of these automated monitoring buoys collect turbidity data at 15-minute intervals and these data are displayed in near real time via the Water Quality WaterHub dashboard. BWS Water Quality and Operations staff constantly monitor the dashboard so that appropriate actions can be taken to ensure that elevated turbidity does not reach the Shaft 18 intake.

In 2020, no contraventions of the Surface Water Treatment Rule (SWTR) turbidity limit were experienced at Shaft 18. This project is ongoing in 2021.

4.5.2.2. N5-1 Special Investigation: January 6, 2020

N5-1 is located on one of eight tributary streams that flow into Kensico Reservoir and it flows into the N5 Cove of the reservoir's main basin. N5-1 is part of a best management practice (BMP) network of detention basins, designed with multiple detention pools to allow for additional settling and microbial die-off while flowing into Kensico Reservoir. On January 6, 2020, Water Quality was notified by contractors working with the Bureau of Environmental Design and Construction (BEDC) that water flowing into the N5-1 BMP detention basins from the upstream watershed exhibited a milky, greenish hued substance on January 5, 2020.

Multiple NYCDEP Bureau of Water Supply directorates and divisions responded (WQ, HAZMAT, WPP, WTO) on January 6, 2020, and the stream no longer exhibited the same conditions as seen the previous day. Conditions appeared to have cleared up. The EOH field unit collected samples from six sites around the N5-1 BMP system, which included the routine effluent site (N5-1), backup routine effluent site (N5-1T), two influent sites up gradient of the BMP (N5-1Main and N5-1TRIB), and two plunge pool sites within the BMP, for turbidity and total and fecal coliform bacteria. The turbidity results ranged from 0.3 to 0.7 NTU at the influent and effluent sites, with higher turbidity results at the plunge pool sites of the BMP, ranging from 3.8 to 6.3 NTU. The total coliform bacteria results ranged from 240 to 360 coliform $100mL^{-1}$ and from 15 (estimated) to 200 coliform $100mL^{-1}$ for fecal coliform bacteria. Since BEDC was managing an active construction project on the N5-1 BMP, the N5 Cove where water enters Kensico Reservoir was boomed off for that project as a precautionary measure. The water quality results from January 6, 2020, were in line with normal N5-1 stream background water quality conditions so no further actions were taken.

4.5.2.3. Catskill Water Supply Alum Treatment: January 25 – January 26, 2020

The Catskill Aqueduct was shut down between the Ashokan and Kensico reservoirs, from November 2019 to January 2020. The CAT-RR shutdown of the aqueduct was primarily to conduct biofilm removal, sluice gate and siphon valve replacement, and other general repairs. Upon resumption of flow, unrecovered sediments liberated following the biofilm removal, were treated with aluminum sulfate (alum) to reduce any potential turbidity increase. With an aqueduct flow of about 190 MGD and the turbidity at about 55 NTU, treatment began at 6 a.m. on January 25, 2020 at the Catskill Aqueduct Pleasantville Alum Treatment Facility at an initial alum dose of 8 mg L^{-1}. This dose was chosen based on the jar testing performed using biofilm samples taken during the shutdown. By 10 a.m., with the flow still at about 190 MGD, operator grab samples at the alum plant showed the turbidity to be about 80 NTU and the treatment dose was increased to 10 mg L^{-1}. The alum dose was reduced back to 8 mg L^{-1} at 7 a.m. on January 26, 2020, with the flow at about 300 MGD and the turbidity measuring about 30 NTU.

Treatment continued until January 27, 2020 at 3:30 pm, when the flow had increased to 585 MGD and the turbidity was less than 5 NTU.

To comply with the Catskill Aqueduct Influent Chamber SPDES Permit and Safe Water Drinking Act (SWDA) as well as assess treatment effectiveness, paired grab sampling and analysis was conducted at Ashokan (EARCM) and Kensico (CATALUM, 5BRK and DEL18DT) for pH, temperature, turbidity, total phosphorus, total suspended solids, and total and dissolved aluminum. Continuous monitoring was also conducted at EARCM, CDIS4-CAT (Catskill Aqueduct – Catskill/Delaware interconnect shaft), CATALUM, Catskill Influent Chamber (CATIC), 2.9BRK and 2BRK (Kensico Reservoir buoy sites), and DEL18DT to provide real time conditions on pH, temperature, and turbidity. Jar tests performed daily, supported the effectiveness of the alum dosing at 8 and 10 mg L^{-1}.

In summary, the alum treatment was successful as the turbidity measured at Shaft 18 remained at less than 1.5 NTU over the course of this treatment event and during the weeks that immediately followed.

4.5.2.4. Whippoorwill Creek Potential Septic Discharge: February 2020

In February 2020, EOH Regulatory and Engineering Program (REP) staff expressed concern related to Whippoorwill Creek head waters in New Castle, specifically with a possible sewage discharge to the stormwater collection system. This area has a small subdivision of approximately 25 houses, all on septic systems. Residents and REP staff have complained about a septic odor in the neighborhood in the past during both wet and dry weather.

Samples were collected from four catch basins within the neighborhood in the creek's watershed on March 9, 2020, under dry conditions. Two of the catch basin fecal coliform results were two orders of magnitude greater (38,000 and 14,000 coliform $100mL^{-1}$) than Whippoorwill Creek's historic values. Additional analyses were performed to determine if the elevated fecal coliform concentrations were originating from human or animal sources. Microbial source tracking (MST) using *Bacteroides* spp. was conducted using polymerase chain reaction (PCR) and all four sites were positive with high concentrations of human markers.

Following the high fecal coliform results, samples were collected from two additional catch basins located further upgradient within the neighborhood on March 11, 2020. These samples resulted in fecal coliform concentrations of <20 and 180 coliform $100mL^{-1}$, suggesting no major fecal input at the time of sampling. The pandemic delayed further investigation into this impact to the watershed until April 2021, when a helicopter flyover using Forward Looking InfraRed (FLIR) technology was used to detect potential septic issues. That data, identifying potential areas of temperature change that might indicate septic contamination that travelled to the surface, is currently being analyzed and follow-up monitoring will occur in catch basins that contain positive FLIR results.

4.5.2.5. Delaware Shaft 18 Supply Conduit Number 8: June through November 2020

An inspection in 2015 of Conduit 8 at Delaware Shaft 18 revealed failed epoxy coatings and a dislodged expansion joint. Testing showed entrained water failed to meet NYSDOH drinking water standards and was kept out of service. Following repairs to the conduit in 2020, a NYSDOH-approved monitoring plan was developed to check for concentrations of mercury, lead, PCBs, and volatile organic compounds. During 2020 sampling was conducted June 23, August 26, and September 2 for all parameters and mercury-only monitoring on November 13. Samples were collected at the top, middle, and bottom elevations of the conduit.

The samples collected on June 23 showed no detections for any measured analyte and the conduit water was discharged to Davis Brook. The conduit was inspected and refilled and sampling was performed on August 23. Only the bottom mercury sample had a positive result of 0.12 µg L^{-1} which was over the laboratory's reporting limit of 0.10 µg L^{-1}. In addition, the August 26 top sample had a chloroform detection of 0.62 µg L^{-1} which was over the laboratory's reporting limit of 0.20 µg L^{-1}. Following the monitoring plan, the same water was resampled at all three elevations seven days later on September 2 for all parameters and there were no detections. NYSDOH requested that the elevation where the August 26 mercury detections were found be resampled and three additional samples were collected from the bottom on November 13 to confirm the September 2 nondetect results. There were no detections in the November 13 samples.

Based on the final data, the NYSDOH allowed the DEP to place Supply Conduit 8 back into service. No follow-up sampling was required.

5. Pathogen Monitoring and Research

5.1.Introduction

Each year DEP monitors the 1,972-square-mile NYC watershed for *Cryptosporidium* and *Giardia* as part of compliance and surveillance monitoring. Samples collected in 2020 for protozoan analysis were analyzed by Method 1623.1 with EasyStain and heat dissociation. During this year, 399 samples were collected and analyzed for protozoan enumeration, plus an additional 39 samples were collected and analyzed by a cell culture immunofluorescent assay (CC-IFA) used to monitor for any infectious *Cryptosporidium* at Hillview Reservoir. The largest portion of the 2020 sampling effort was comprised of keypoint samples collected from Kensico and New Croton reservoirs (38.3%) (Figure 5.1), while samples collected at the outflow of the CDUV plant and the Hillview downtake were the second largest component of protozoan monitoring (26.1%). Stream sampling made up 17.3% of the monitoring, and the upstate reservoir outflows and wastewater treatment plants made up the remaining 15.8% and 2.5%, respectively. The distribution of protozoan sampling effort is usually led by the number of stream samples collected in a given year; however, due to COVID-19 monitoring reductions, streams were not sampled as often as in the past. As a reminder, DEP no longer monitors for human enteric viruses (HEVs) in the NYC watershed (NYSDOH approval, October 2019).

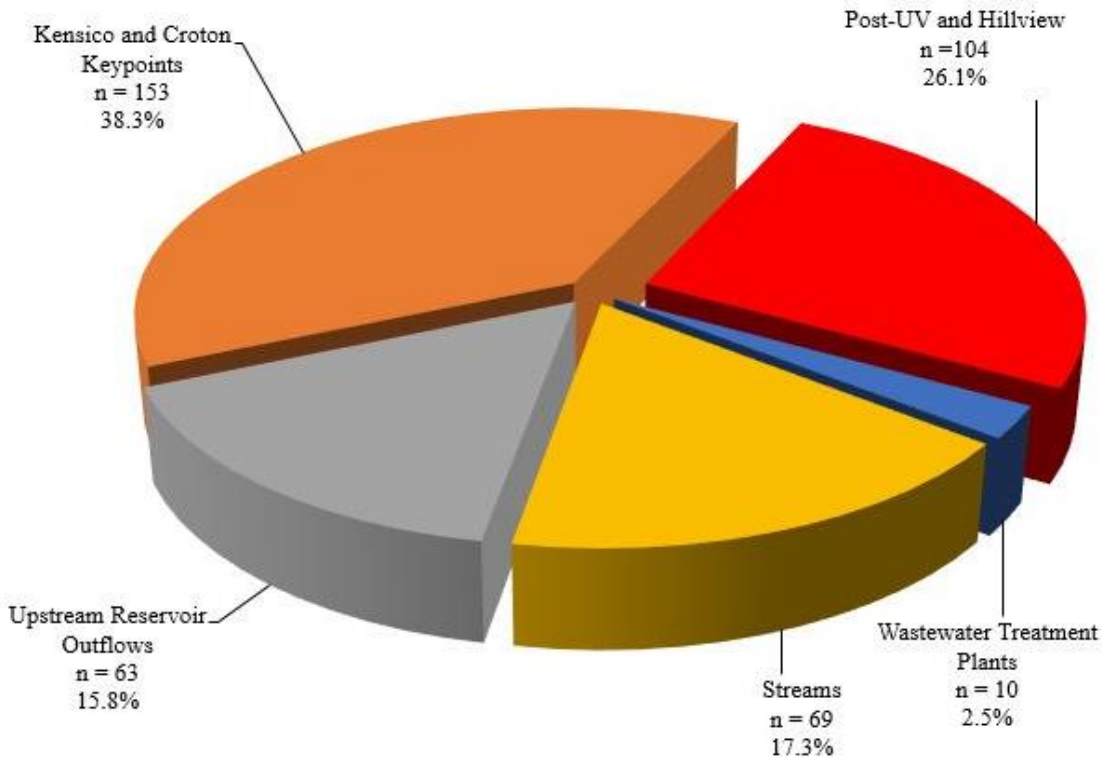


Figure 5.1 DEP protozoan sample collection location distribution for 2020.

In addition to COVID-19 related monitoring reductions, monitoring in 2020 was affected by a few operational changes that warrant mentioning. The Catskill Aqueduct was shut down at various times during 2020 in support of the Catskill Aqueduct Repair and Rehabilitation project, resulting in the inability to collect several protozoan samples at CATALUM, including the first three samples in January and samples from December 7 through to the end of the year. The Catskill Aqueduct south of Kensico Reservoir (CATLEFF) remained shut down in 2020 (since September 2012). Kensico outflow results are posted weekly on DEP's website (https://data.cityofnewyork.us/Environment/DEP-Cryptosporidium-And-Giardia-Data-Set/x2s6-6d2j) and reported annually in this report.

The target volume for DEP protozoan samples is 50L (for Method 1623.1), however, sample volumes may vary. This is particularly the case at stream sites after precipitation events since they tend to have higher turbidities. The results discussed in this chapter are from samples that were 47-53 liters unless otherwise noted. Mean and maximum concentrations are generally stated as (oo)cysts per 50L.

5.2. Source Water Results

Catskill Aqueduct Inflow

In 2020, three of the 45 CATALUM samples were positive for *Cryptosporidium* (6.7%). Two samples had 1 oocyst each and one sample had 2 oocysts (Table 5.1). By comparison, 1 out of 41 samples were positive in 2019 (2.4%). The 2020 mean annual *Cryptosporidium* concentration was 0.09 oocysts, compared to 0.02 oocysts in 2019.

Giardia was detected in 27 out of 45 samples (60.0%) at CATALUM in 2020, compared to 51.2% in 2019; however, slightly fewer samples were collected in 2019 (n=41). Mean *Giardia* concentrations were similar in 2020 when compared to 2019 (1.87 and 1.24 cysts, respectively). A higher maximum *Giardia* result was detected in 2020 (14 cysts) compared to 2019 (6 cysts).

Table 5.1 Summary of *Cryptosporidium* and *Giardia* compliance monitoring data at Kensico and New Croton keypoints in 2020.

	Keypoint Location	Number of Positive Samples	Mean[2]	Maximum
Cryptosporidium (oocysts $50L^{-1}$)	CATALUM (n=45)	3	0.09	2
	DEL17 (n=52)	12	0.35	4
	DEL18DT (n=52)	3	0.06	1
	CROGH[1] (n=4)	0	0.00	0
Giardia (cysts $50L^{-1}$)	CATALUM (n=45)	27	1.87	14
	DEL17 (n=52)	38	3.94	16
	DEL18DT (n=52)	35	1.96	17
	CROGH[1] (n=4)	3	4.00	8

[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 normalized to 50L for determination of means. Zero values are substituted for non-detect values when calculating means.

Delaware Aqueduct Inflow and Outflow

More samples were positive for *Cryptosporidium* at DEL17 in 2020 (23.1%) than in 2019 (11.5%), and the mean annual oocyst concentration for 2020 (0.35 oocysts) was higher than 2019 (0.19 oocysts) (Table 5.1 and Figure 5.2). The same number of *Cryptosporidium* detections occurred at the Kensico outflow (DEL18DT) in 2020, as did in 2019 (three out of 52 samples), with a detection rate of 5.8%. Likewise the mean annual oocyst concentration for DEL18DT was also the same in 2020 as in 2019 (0.06 oocysts L^{-1}).

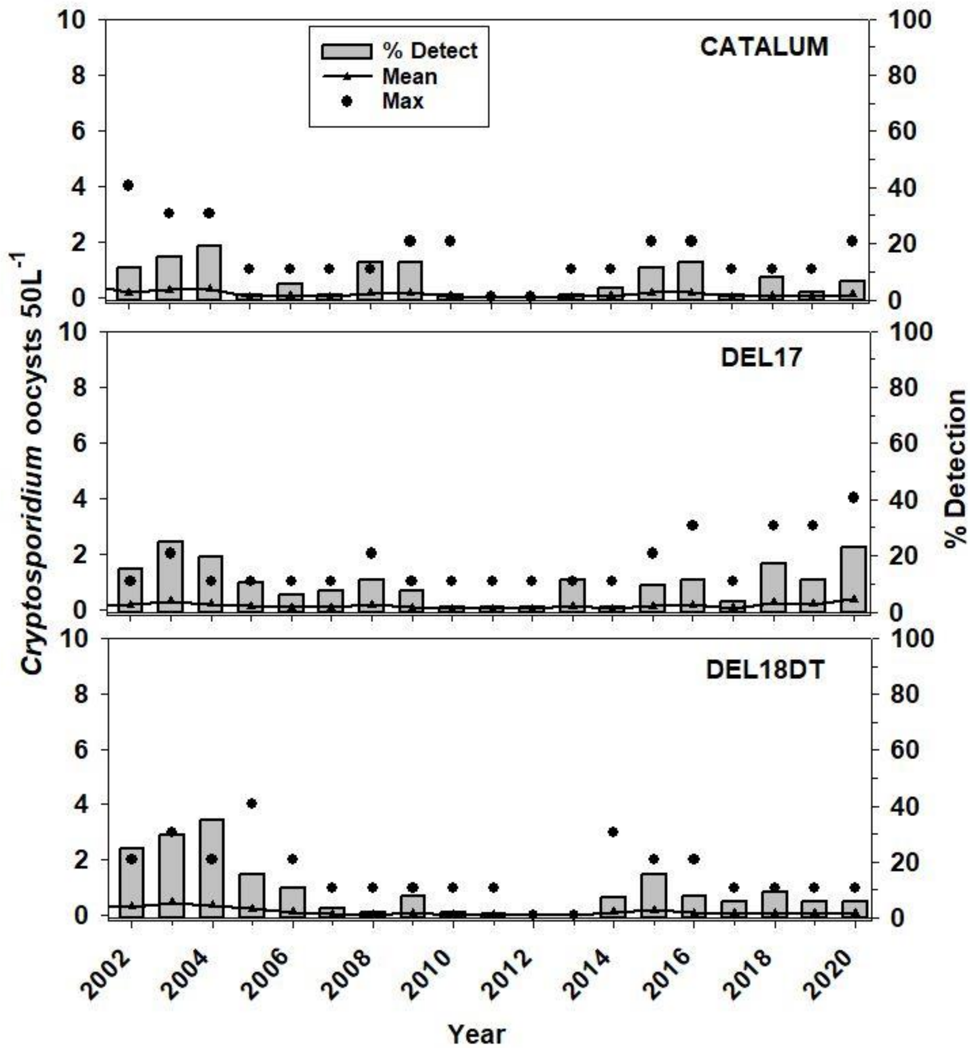


Figure 5.2 *Cryptosporidium* annual percent detection, mean concentration, and maximum result for the Kensico keypoint sites during each year from 2002 through 2020.

The percentage of DEL17 *Giardia* detections in 2020 (73.1%) was lower than in 2019 (86.5%). The mean *Giardia* concentration was also lower in 2020 than 2019 (3.94 and 6.96 cysts, respectively). The Kensico outflow at DEL18DT had a slightly lower percentage of *Giardia* detections in 2020 (67.3%) than in 2019 (71.2%) and the mean *Giardia* concentration was also slightly lower at DEL18DT (1.96 cysts) compared to 2019 (2.15 cysts). The annual *Giardia* mean at DEL18DT was strongly influenced by elevated concentrations in a few samples, including the historic maximum result of 17 cysts on December 28, 2020 (Figure 5.3), which occurred after a period of rain on snow.

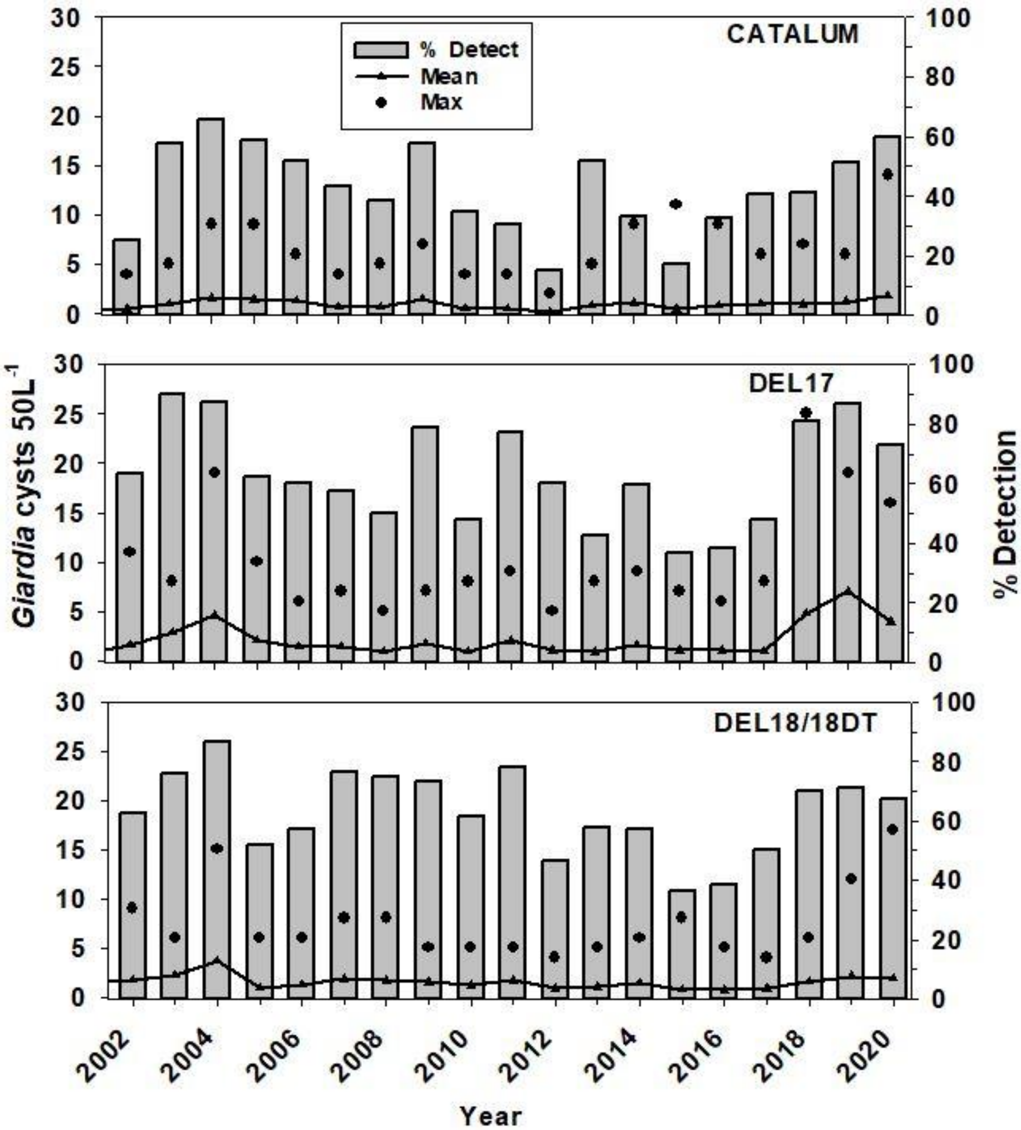


Figure 5.3 *Giardia* annual percent detection, mean concentration, and maximum result for the Kensico keypoint sites during each year from 2002 to 2020.

Croton System

The New Croton Reservoir outflow was sampled quarterly for protozoans in 2020, and all four routine quarterly samples were negative for *Cryptosporidium* (Figure 5.4), as was the case in 2019. *Giardia* were detected in three out of the four samples (75.0%), compared to two of the four samples (50.0%) in 2019. Similarly, the mean annual concentration of *Giardia* was higher in 2020 (4.00 cysts) compared to 2019 (2.74 cysts) (Figure 5.5).

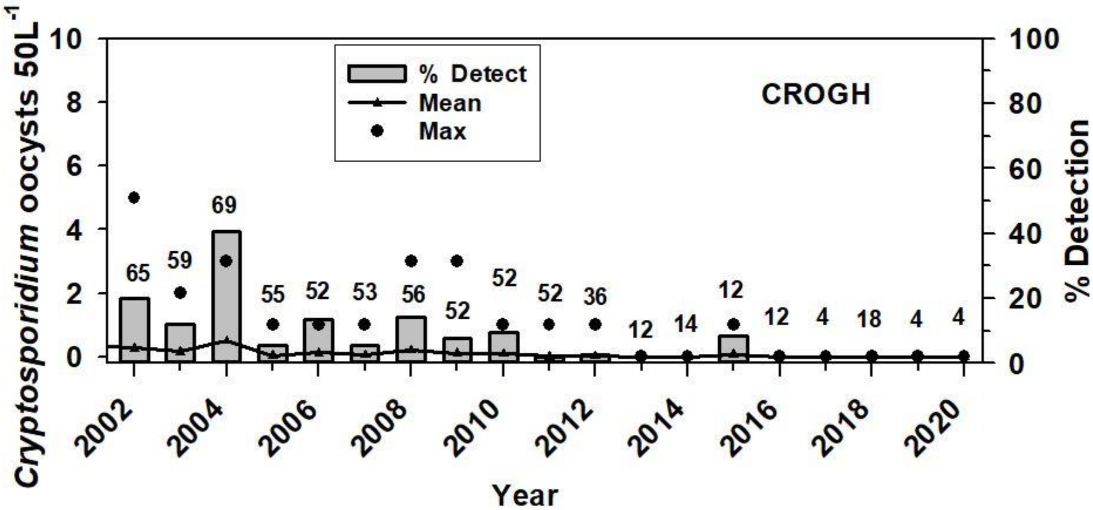


Figure 5.4 C*ryptosporidium* annual percent detection, mean concentration, and maximum result for the New Croton keypoint sites during each year from 2002 to 2020. Numbers above each bar on the Croton System plot indicate sample size.

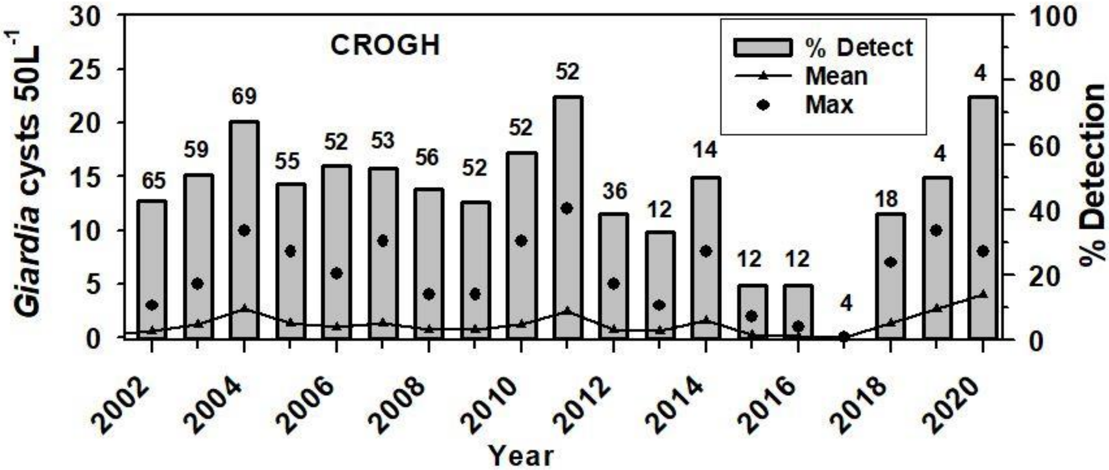


Figure 5.5 *Giardia* annual percent detection, mean concentration, and maximum result for the New Croton keypoint sites during each year from 2002 to 2020. Numbers above each bar indicate sample size.

In general, *Giardia* continues to be detected more frequently and at higher concentrations during winter and spring months compared to summer and autumn (Figure 5.6), as has been noted in previous reports. It is important to note that in the last few years, *Cryptosporidium* and *Giardia* results have been affected by analytical changes to Method 1623.1 with EasyStain (Alderisio, et al. 2017), and the switch from acid to heat dissociation, in addition to the seasonal and long-term variability in occurrence of these organisms in the environment.

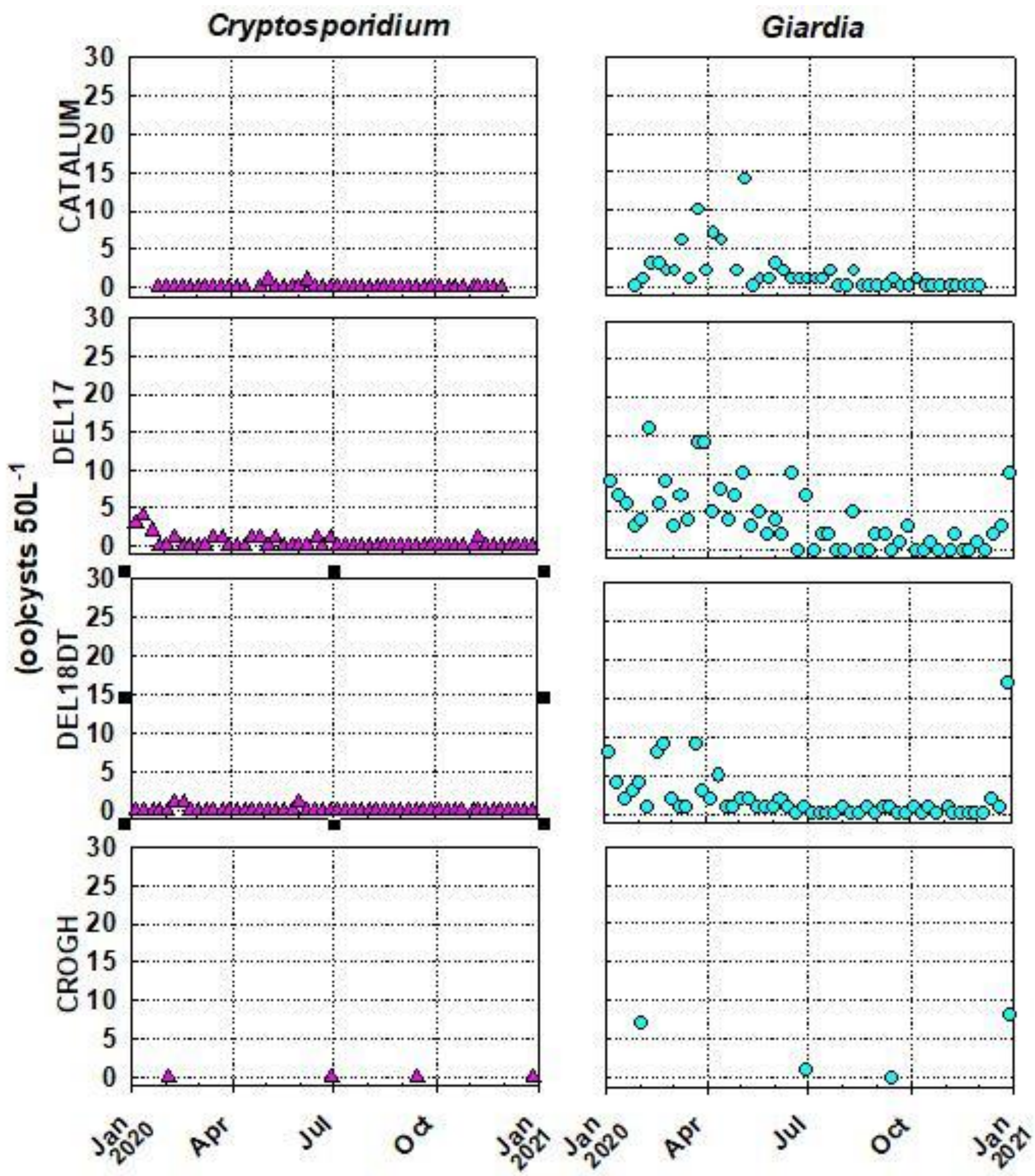


Figure 5.6 Weekly routine keypoint protozoan monitoring results for 2020.

5.2.1. 2020 Source Water Results Compared to Historical Data

Water quality at the different source water sites can vary due to the many influences in their 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. Changes that have affected the program since 2001 include the following: New Croton Reservoir outflow monitoring frequency changed from weekly (October, 2001) 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); the addition of sampling at the Jerome Park Reservoir outflow (1CR21) with the Croton Filtration Plant startup (May 2015); the laboratory's switch from acid to heat dissociation (August 2017); the discontinuation of protozoan sampling at the Jerome Park Reservoir outflow (October 2018) due to having met the obligations of the Long Term 2 Enhanced Surface Water Treatment Rule (LT2); and intermittent shutdowns of the Catskill Aqueduct north of Kensico during 2019 and 2020 for cleaning and rehabilitation work. Each modification has added a layer of complexity when comparing the current year's data to the historical dataset.

Kensico Reservoir

Cryptosporidium

Detections - In 2020, 15 of the 97 total inflow samples (collected at both CATALUM and DEL17) were positive for *Cryptosporidium*, for a combined inflow detection rate of 15.5% (Table 5.2). There were a greater number of detections at the Kensico inflows in 2020 than in 2019 (7 out of 93, 7.5%), and in 2018 (13 out of 104 samples, 12.5%), but well within the annual historical range from 0.9% to 20.5% when combining data from the two inflows. When data were analyzed by system over recent years, CATALUM had three detections in 2020 compared to one out of 41 samples positive in 2019, and four out of 51 samples in 2018. It should be noted that the Catskill Aqueduct was shut down for rehabilitation work a few times in 2020 prohibiting sample collection for most of January, and for all of December, so this was not a complete year of monitoring. DEL17 had twelve detections (23.1% of 52 samples) in 2020, more than in 2019 (6 out of 52 samples, 11.5%), and the highest positivity rate at DEL17 since 2003 (15 of 60 samples, 25.0%).

Table 5.2 Annual sample detection and mean oocyst concentration of *Cryptosporidium* at inflow keypoints to Kensico Reservoir 2002-2020.

Site	CATALUM			DEL17		
Year	**Detects**	**% Detects**	**Mean (50L^{-1})**	**Detects**	**% Detects**	**Mean (50L^{-1})**
2001[1]	5[1]	41.7[1]	0.42[1]	1[1]	8.3[1]	0.08[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
2017	1	1.9	0.02	2	3.8	0.04
2018	4	7.8	0.08	9	17.0	0.25
2019	1	2.4	0.02	6	11.5	0.19
2020	3	6.7	0.09	12	23.1	0.35

[1]Sampling with Method 1623 began on October 15, 2001.

Cryptosporidium detections at the outflow of the reservoir (DEL18DT) were less than at the inflows in 2020 (3 out of 52 samples, 5.8%) and the same as in 2019 and half the historical detection rate 2001-2019 (11.6%, n=1080).

Concentrations - The annual mean concentration of oocysts at CATALUM was < 1 oocyst 50L^{-1} in 2020, as it has been for the period of record since 2002 (Table 5.2). This year the annual mean was just below the historical mean of 0.10 oocysts (2001-2019, n=942) and on the low end of the historical range of zero to 0.29 oocysts for CATALUM. Similar to the Catskill inflow, the annual mean concentration of oocysts at DEL17 was also less than one oocyst (0.35 oocysts), however, the 2020 mean was higher than the historical oocyst mean for DEL17 (0.12

oocysts) (2001-2019, n=967). It was also higher than the range of previous annual means (0.02-0.28 oocysts).

The 2020 *Cryptosporidium* mean concentration at DEL18DT (0.06 oocysts) (Table 5.3) was lower than at either of the two inflow sites; however, when dealing with numbers at such low levels it is difficult to quantify the difference. The DEL18DT mean for 2020 was the same as the means observed in 2017 and 2019 as well as the mean for the previous 10 years (2010-2019 mean=0.06 oocysts, n=532). The 2020 mean was lower than the historical mean (0.14 oocysts, 2001-2019, n=1080).

Table 5.3 Annual sample detection and mean concentration of *Cryptosporidium* at Kensico and New Croton Reservoir source water outflows 2002-2020.

Site	DEL18DT			CROGH / 1CR21		
Year	Detects	% Detects	Mean ($50L^{-1}$)	Detects	% Detects	Mean ($50L^{-1}$)
2001[1]	3[1]	25.0[1]	0.25[1]	4[1]	33.3[1]	0.33[1]
2002	18	25.0	0.31	13	20.0	0.28
2003	21	29.6	0.45	7	11.9	0.17
2004	25	34.7	0.36	28	40.0	0.51
2005	15	15.5	0.23	3	5.5	0.05
2006	7	10.8	0.12	7	13.5	0.13
2007	2	4.0	0.04	3	5.7	0.06
2008	1	1.9	0.02	8	14.3	0.21
2009	4	7.7	0.08	4	7.7	0.12
2010	1	1.9	0.02	5	9.6	0.10
2011	1	1.7	0.02	1	1.9	0.02
2012[1]	0	0.0	0.00	1	2.8	0.03
2013	0	0.0	0.00	0	0.0	0.00
2014	4	7.4	0.11	0	0.0	0.00
2015	8	15.4	0.17	1	2.6	0.03
2016[3]	4	7.7	0.10	9	20.0	5.64
2017[3]	3	5.8	0.06	2	22.2	0.33
2018	5	9.4	0.09	0	0.0	0.00
2019	3	5.8	0.06	0	0.0	0.00
2020	3	5.8	0.06	0	0.0	0.00

[1]Sampling with Method 1623 began on October 15, 2001.
[2]Monitoring at CROGH was modified from weekly to monthly in August 2012, and then reduced to quarterly in Oct 2016.
[3]The source water sampling site for the Croton System was either CROGH or 1CR21 during the LT2 monitoring period (2015-2018).

Giardia

Detections - The *Giardia* detection rate for pooled results at the two inflows (67.0%) was very similar to the detection rate at DEL18DT (67.3%) in 2020. The rate at DEL17 was 73.1%, which was higher than CATALUM at 60.0%. Again it must be noted that the Catskill Aqueduct to Kensico Reservoir was shut down for several weeks in 2020, reducing the sample size from 52 samples to 45. The 60% *Giardia* detection rate at the Catskill inflow was higher than in any of the previous 15 years (range 15.1 – 57.7% 2005-2019). While the 2020 detection rate fell below the maximum detection rate from 2004 (65.4%), it was higher than the historical detection rate of 40.7% (2001-2019, n=941). DEL17 had a lower *Giardia* detection rate in 2020 (73.1%) compared to 2019 (86.5%), however, it was higher than the detection rate over the past 14 years (2005-2018 detection rate 57.4%, n=734). The 2020 detection rate exceeded the historical detection rate of 62.8% (2001-2019, n=966).

The 2020 *Giardia* detection rate at DEL18DT (67.3%) was similar to 2019 and 2018 (71.2% and 69.8%, respectively), but was higher than in any of the six years prior to 2018, (range for 2012-2017 36.5 – 57.7%). Several years prior to 2012 had higher detection rates, such as 2004 (86.3%, the historical maximum annual detection) and 2011 (78.0%). Interestingly, both 2004 and 2011 were years when the watershed experienced significant hurricanes. The 2020 detection rate was slightly higher than the mean historical detection rate for DEL18 (62.8%, 2001-2019 n=1080).

Concentrations - The annual mean *Giardia* concentration at CATALUM in 2020 (1.87 cysts) was the highest annual mean for this site (previous maximum was 1.50 cysts in 2009), and higher than the historical average (2001-2019=0.92 cysts, n=941). This could be a consequence of the lower number of samples in 2020 resulting from aqueduct shutdowns. The annual mean cyst concentration at DEL17 was 3.94 cysts, which is less than 6.96 cysts in 2019 (the highest recorded annual mean), but still greater than the historical mean of 2.13 cysts (2001-2019 n=966). The 2019 mean was preceded by the previous maximum of 4.85 cysts in 2018. Compared to 2019, the number of samples with elevated results (over 10 cysts) has decreased in 2020, and is more in line with observations from 2018. Despite the 2020 DEL17 mean being higher than 15 of the last 18 years of monitoring, the *Giardia* annual mean was less than 2019.

The annual mean concentration at DEL18DT in 2020 (1.96 cysts) was lower than in 2019 (2.15 cysts), but still higher than the annual means from the previous 14 years (2005-2018 means 0.71-1.87 cysts) and slightly higher than the overall historical average from 2001 through 2019 (1.57 cysts, n=1080). Similar to the detection rate, the mean concentration at the DEL18DT outflow (1.96 cysts) fell between the means at the inflows in 2020 (CATALUM=1.87; DEL17=3.94 cysts).

Croton Source Water

Cryptosporidium

None of the four quarterly samples at the New Croton Reservoir outflow (CROGH/CRO1B) were positive for *Cryptosporidium* in 2020 (Table 5.3). *Cryptosporidium* detections have been very infrequent at the New Croton outflow site in the last few years, with only one *Cryptosporidium* oocyst found (February 2015) during the past eight years (2013 – 2020, n=80) (detections in 2016 and 2017 were at 1CR21). There have been only three detections of oocysts at CROGH in the last 10 years (n=168), with a maximum result of 1 oocyst each. This reduced detection of oocysts coincides with a weekly to monthly reduction in monitoring frequency at New Croton in 2012, and an additional sampling reduction from monthly to quarterly in 2017.

Giardia

The rate of *Giardia* detection and mean concentration at the New Croton Reservoir outflow were higher in 2020 (75.0% and 4.00 cysts, respectively) than 2019 (50.0% and 2.74 cysts, respectively). While greater than the historical rate of detection (50%, 344 detections out of 689 samples), the current 75% rate is the same as that seen in 2012, the last year when weekly monitoring was conducted throughout the entire year. Comparing current means to prior years is challenging in the case of New Croton, as monitoring frequency has been reduced twice since 2012. It's important to note that the timing of quarterly sampling can have an influence on the mean for parameters that have a strong seasonal component. In this case, *Giardia* tends to be seasonally elevated in the colder months, so sampling quarterly in the warmer months of March and October would tend to result in a lower annual mean than if samples were collected in January and December. The latter were the months sampled in 2020, which likely played a role in the higher annual mean compared to the historical average (2001-2019=1.27 cysts, n=689).

Seasonality

Elevated *Giardia* concentrations at DEL17 during the colder (early and late) months of 2019 and 2020 made the historically-noted seasonal variation in *Giardia* much more obvious using a locally weighted regression (LOWESS) smoothed line (Figure 5.7). A variation in seasonal concentrations is also more apparent for CATALUM in 2020, with a more pronounced peak in the spring, including the maximum of 14 cysts in early May. Seasonal variation in samples at the Kensico Reservoir outflow (DEL18DT) have reappeared after adding heat dissociation in 2017. LOWESS analysis was not performed for the Croton Reservoir outflow since sampling has been reduced to quarterly.

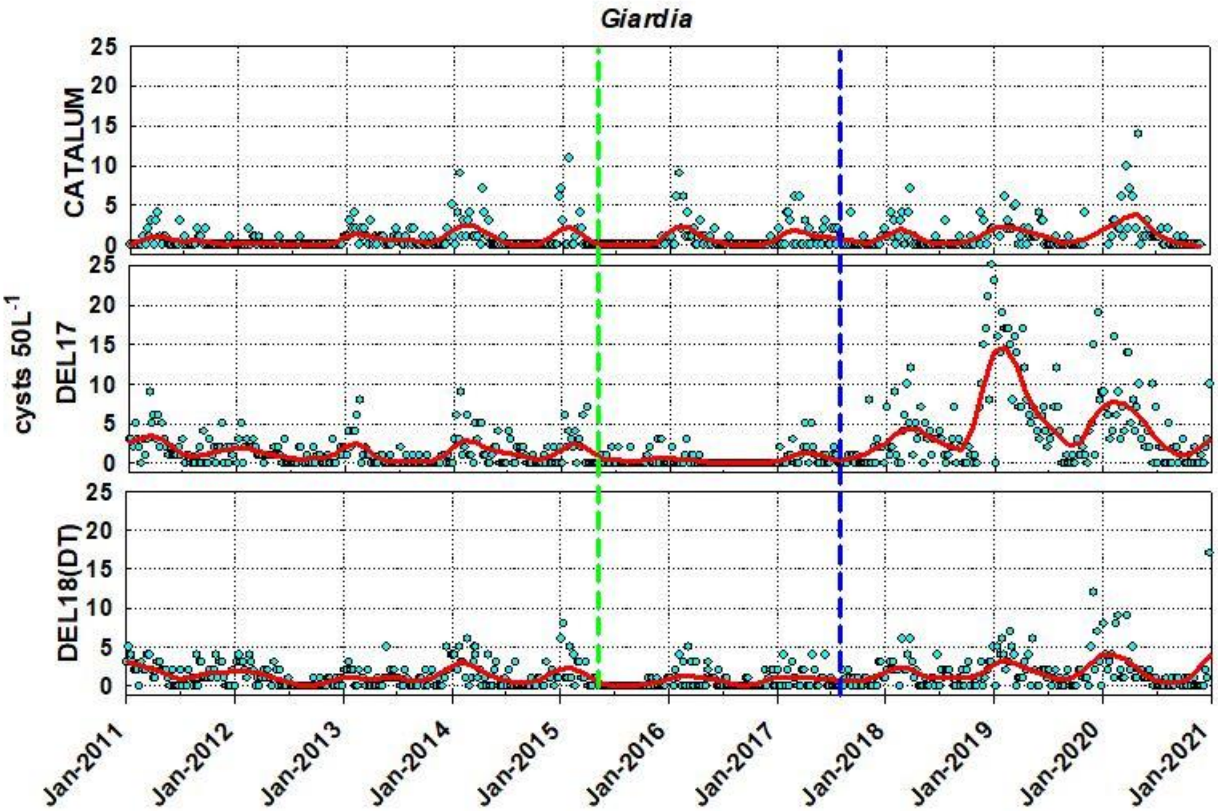


Figure 5.7 Weekly routine source water keypoint results for *Giardia* (circles), and LOWESS 5% smoothed regression (red curved line) from January 1, 2011 to December 31, 2020. The green dashed line indicates the change from Method 1623HV to Method 1623.1 with EasyStain. The blue dashed line indicates the laboratory method modification from acid to heat dissociation.

5.2.2. 2020 Source Water Compared to Regulatory Levels

DEP completed its monitoring requirements for the Long Term 2 Enhanced Surface Water Treatment Rule (LT2, USEPA 2006) in 2018; however, the calculation procedure described in the LT2 is still performed annually by DEP to measure results against the thresholds. The LT2 required utilities to conduct monthly source water monitoring for *Cryptosporidium* and report data from two different two-year periods. The LT2 required all unfiltered public water supplies to "provide at least 2-log (i.e., 99%) inactivation of *Cryptosporidium*" during the monitoring period. If the average source water concentration exceeded 0.01 oocysts L^{-1}, based on the LT2 monitoring criteria, "the unfiltered system must provide at least 3-log (i.e., 99.9%) inactivation of *Cryptosporidium*." The average source water *Cryptosporidium* concentration is calculated by taking the mean of the monthly *Cryptosporidium* mean concentrations at the source water outflows over the course of a 2-year period. For filtered supplies, like the Croton System, the LT2 mean needed to be below 0.075 oocysts L^{-1} to remain in Bin 1, the category that was designated as needing no additional treatment. Since the LT2 monitoring is complete, and the frequency of sample collection at New Croton Reservoir has been reduced to quarterly, assessments of the data for comparison to LT2 thresholds are no longer conducted due to the small sample size.

Unfiltered Supply

The Catskill/ Delaware System is NYC's unfiltered water supply. For the two-year period of 2019 and 2020, there were a total of 104 samples collected at the Delaware outflow of Kensico Reservoir (Table 5.4). The *Cryptosporidium* mean of monthly means for this 24-month period is 0.0011 oocysts L^{-1} for the Delaware outflow, well below the threshold level of 0.01 oocysts L^{-1} for unfiltered systems indicated in the LT2 (Figure 5.8). This calculation is consistent with historical LT2 calculations for NYC source water, which have always remained below the threshold levels. In general, the monthly means for the Delaware outflow began declining in approximately 2004-2005 and continued to decline through 2013. During the 2014-2015 period, an increase was noted in the calculated mean, which coincided with the change to Method 1623.1/EasyStain for protozoan analysis.

Table 5.4 Number and type of samples used to calculate the LT2 values from January 1, 2019 to December 31, 2020.

Site	Number of routine samples 2019-2020	Number of non-routine samples 2019-2020	Total n
Delaware (DEL18DT)	104	0	104

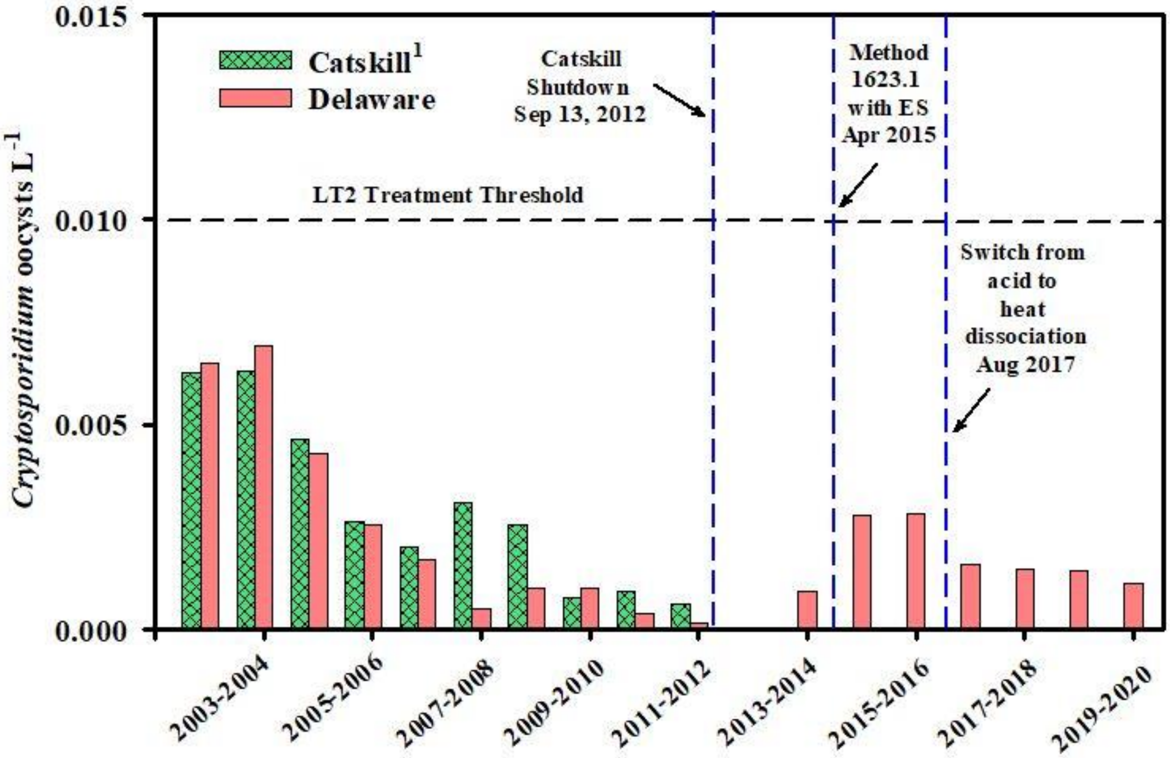


Figure 5.8 *Cryptosporidium* means using LT2 calculation method since initiation of Method 1623HV (1623.1 with EasyStain since April 2015) at the Delaware Aqueduct 2002-2020 and the Catskill Aqueduct 2002-2012.
[1] Monitoring was discontinued at the Catskill Aqueduct effluent from Kensico when it was shut down in 2012.

5.2.3. 2020 Source Water Matrix Spike and Quality Control Results

Quality control (QC) testing performed during protozoan analyses includes both matrix spike (MS) samples and ongoing precision and recovery (OPR) samples. To determine MS recoveries, sample matrices are spiked with known amounts of oocysts and cysts and then analyzed according to the same method used for routine samples. During 2020, recovery of *Cryptosporidium* from the three Kensico keypoint sites ranged from 0-77%, while *Giardia* recovery was 0-62% (The lowest *Cryptosporidium* and *Giardia* MS recoveries for the year occurred in January at CATALUM (both 0%), when QC failed due to a partial sample loss during staining. The highest recoveries for *Cryptosporidium* both occurred in February with 77% at DEL17 and 65% at DEL18DT. The highest *Giardia* recoveries occurred in February and July, at DEL17 (62%) and DEL18DT (also 62%), respectively. With the exception of the January CATALUM MS, where part of the MS was lost during staining, MS results for these sites (performed one in every 20 analyses) were within the acceptable range of the method.

Table 5.5). The lowest *Cryptosporidium* and *Giardia* MS recoveries for the year occurred in January at CATALUM (both 0%), when QC failed due to a partial sample loss during staining. The highest recoveries for *Cryptosporidium* both occurred in February with 77% at DEL17 and 65% at DEL18DT. The highest *Giardia* recoveries occurred in February and July, at DEL17 (62%) and DEL18DT (also 62%), respectively. With the exception of the January CATALUM MS, where part of the MS was lost during staining, MS results for these sites (performed one in every 20 analyses) were within the acceptable range of the method.

Table 5.5 Matrix spike results from keypoint sites in 2020.

Date	***Cryptosporidium* % Recovery**	***Giardia* % Recovery**
	CATALUM	
1/27/2020	0	0
8/3/2020	39	31
	DEL17	
2/18/2020	77	62
6/22/2020	45	38
11/9/2020	44	53
	DEL18DT	
3/16/2020	65	53
7/27/2020	53	62
12/7/2020	41	58
	CRO1T	
2/3/2020	61	55

Weekly OPR testing involves the spiking of reagent-grade water in the laboratory with known amounts of oocysts and cysts. These QC samples are important for testing the method reagents and the laboratory process without interference from the sample matrix. In 2020, 55 OPRs were analyzed, two of which were replacements for OPRs that did not meet the minimum method recovery criteria. In these instances, additional OPR samples were analyzed and acceptable results were always obtained before proceeding with the weekly samples. Ranges of recovery for all 55 protozoan OPR samples in 2020 were 35-90% for *Cryptosporidium* and 10-81% for *Giardia*.

5.3. Upstate Reservoir Outflows

The Catskill and Delaware aqueducts deliver water to Kensico Reservoir from the West of Hudson (WOH) watershed. The WOH watershed consists of six reservoirs in two systems: Ashokan and Schoharie in the Catskill System, and Cannonsville, Neversink, Pepacton, and Rondout in the Delaware System. Five of the six WOH reservoir outflows are monitored monthly, while the Ashokan Reservoir aqueduct is monitored weekly at CATALUM further downstream before it enters Kensico Reservoir. When a reservoir is off-line, monthly reservoir sampling is not required since water from that particular basin is not being delivered to a downstream reservoir for eventual consumption. Since they were off-line for some months of 2020, three of the WOH reservoirs (Schoharie, Neversink and Cannonsville) had less than 12 monthly samples. The sample volume goal is 50L, however, volumes do vary depending on field conditions. The results discussed in this section are from 47-53 liter samples unless otherwise noted, with concentrations standardized to 50L for comparison.

There were 108 samples collected at upstate reservoir outflows, which included 102 samples from WOH reservoir outflows and six samples from Croton Falls Reservoir. Eight of the WOH reservoir outflow samples were collected as part of the continued Rondout Reservoir special investigation involving elevated *Giardia*, which began late in 2018 and continued episodically through 2019 into 2020. DEP responded to the increased *Giardia* with more frequent sampling at the outflow site (monthly to weekly). Weekly monitoring was in effect from January 2020 until the monitoring reductions for COVID-19 took effect in March 2020, when monitoring switched back to monthly.

There was an operational change that resulted in a decrease in sampling at CATALUM, with an increase in sampling at Croton Falls. As mentioned in the previous sections, maintenance activities scheduled for the Catskill Aqueduct mandated several shutdowns during 2020, which prevented weekly monitoring downstream of Ashokan Reservoir at the CATALUM site (including three weeks in January and all of December). As part of this shutdown, water was pumped from Croton Falls Reservoir (EOH) to supplement the Delaware System and six protozoan samples were taken from this outflow site during pumping operations.

Cryptosporidium

In 2020, there were 102 samples collected at WOH reservoir outflows and 10 samples were positive for *Cryptosporidium* (9.8%). This rate of detection is similar to 2019 (8.2%) and 2018 (9.4%). Rondout had the highest oocyst detection rate among the upstate reservoir outflows (4 out of 20 samples, 20.0%), while Pepacton had the lowest with no oocysts detected in any of the 12 monthly samples. Neversink, Cannonsville, and Schoharie each had one *Cryptosporidium* detection in 2020, with very similar detection rates (14.3, 12.5, and 10.0%, respectively) (Table 5.6). The annual *Cryptosporidium* detection rate at Rondout was higher than in 2019 (2.0%, n=50) and greater than its historical detection rate of 5.7% (2002-2019, n=265). This is potentially a result of the greater number of samples collected and analyzed at a time when there were more oocysts (colder months). In the last 19 years, there have only been 19 samples positive for *Cryptosporidium* at Neversink, each detection was annual with only one oocyst (with the exception of one sample with two oocysts in 2003) (2002-2020 detection rate 10.3%, n=185). Similarly, Pepacton has had only 17 samples positive for *Cryptosporidium* since 2002 7.8%, n=218), with all but one result having only one oocyst. The detection rate at the Schoharie outflow in 2020 (10.0%) was quite close to the historical detection rate of 13.8% (2002-2019, n=195). The water representing the outflow of Ashokan Reservoir is sampled downstream at CATALUM (prior to Kensico Reservoir) and there were three *Cryptosporidium* detections out of 45 samples (6.7%), which is more than in 2019 (one out of 41 samples, 2.4%), but quite similar to the historical detection rate of 7.1% (2002-2019, n=930).

Table 5.6 Summary of 2020 protozoan results for upstate reservoir outflows.

		Cryptosporidium				***Giardia***			
Site	**n**	**Mean[1] ($50L^{-1}$)**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**	**Mean[1] ($50L^{-1}$)**	**% Detects**	**Max (Liters sampled)**	**Max (L^{-1})**
Schoharie	10	0.10	10.0	1 (50.2)	0.02	12.06	90.0	24 (50.0)	0.48
Ashokan (CATALUM)	45	0.09	6.7	2 (50.0)	0.04	1.87	60.0	14 (50.0)	0.28
Cannonsville	8	0.25	12.5	2 (50.3)	0.04	9.83	100.0	53 (50.3)	1.05
Pepacton	12	0.00	0.0	0 (50.0)	0.00	3.90	75.0	11 (50.0)	0.22
Neversink	7	0.14	14.3	1 (50.0)	0.02	11.69	100.0	25 (50.0)	0.50
Rondout	20	0.25	20.0	2 (50.0)	0.04	8.04	95.0	22 (50.0)	0.44

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

Concentrations of *Cryptosporidium* remained very low at the WOH upstate reservoir outflows with a maximum result of 2 cysts occurring at Cannonsville, Ashokan, and Rondout reservoirs. The highest mean concentration for the year occurred at both the Cannonsville and Rondout outflows (0.25 oocysts). Ashokan, Neversink, Pepacton, and Schoharie reservoir outflows had annual mean concentrations below 0.15 oocysts and each within the range of what has been observed in past years at each outflow site.

Giardia

There were 79 *Giardia* detections (77.5%) among the 102 samples collected at the WOH reservoir outflow sites. This is quite similar to the detection rate in 2019 (78.0%) which was higher than any of the four years prior to 2019 (27.0%, 2015; 30.6%, 2016; 43.1%, 2017; and 60.4%, 2018). As in 2019, it is important to note there was large variation in the number of samples collected between sites and between years, with Rondout having fewer samples in 2020 (n=20) compared to 2019 (n=50), but still more than in any previous year, due to elevated *Giardia* in the basin. Weekly monitoring was conducted at the Rondout outflow until the middle of March 2020 when the COVID-19 monitoring reductions began. This created an imbalance in monitoring across different seasons during 2020, making comparisons with any prior years much more difficult at this site.

The detection rate for *Giardia* at Rondout in 2020 (95.0%) was similar to the rate found in 2019 (98.0%) and slightly above the detection rate in 2018 (88.2%). The 2020 rate was higher than the historical detection rate of 69.1% (2002-2019, n=265). The highest detection rates in 2020 were found at Cannonsville and Neversink outflows (both 100%); however these sites were sampled least frequently in 2020 (n=8 and 7, respectively) (Table 5.6). The outflow at Cannonsville has had 100% detection rate previously (in 2004 and 2019) but this was well over the historical detection rate of 69.6% (2002-2019, n=184). The same was true for Neversink with elevated detections rates in 2004 and 2019 (100% and 85.7%, respectively), and a historical detection rate of 62.7% (2002-2019, n=177).

Schoharie outflow had a higher detection rate in 2020 (90.0%) compared to 2019 (75.0%), but simple comparison of these two monitoring years does not account for the varying number of samples between 2020 and 2019 (n=10 and 4, respectively). Schoharie was, however, higher than its historical detection rates (2002-2019=79.3%, n=193). Pepacton outflow had similar detection rates in 2020 (75.0%) compared to 2019 (66.7%), but was also higher than the historical detection rate (2002-2019=50.0%, n=206). *Giardia* was also detected more frequently in 2020 in CATALUM samples representing the Ashokan outflow (60.0% positive) compared to 2019 (51.2%) and the historical detection rate (2001-2019=40.7%, n=941).

As for *Giardia* concentrations in the upstate reservoirs, results were higher at most sites than those found in prior years, with the exception of Schoharie and Rondout. Schoharie did have the highest annual mean *Giardia* concentration for the fifth year in a row in 2020 (12.06 cysts), although this was lower than the means from 2019 and 2018 (29.91 and 25.17 cysts, respectively) and much more in line with the historical mean (11.33 cysts, 2002-2019, n=193). Rondout annual mean concentration in 2020 (8.04 cysts) was similar to the means in 2019 (8.77 cysts) and 2018 (8.03 cysts). However, all three means are higher than the historical mean of 3.69 cysts. This is not surprising as annual mean *Giardia* concentrations at the three contributing upstream reservoirs (Cannonsville, Pepacton, and Neversink) were also elevated. The Cannonsville mean concentration was 9.83 cysts in 2020, higher than in 2019 (4.97 cysts), and more than twice the historical mean of 4.50 cysts (2002-2019, n=184). The annual mean for Pepacton (3.90 cysts) was slightly higher than that found in 2019 (2.40 cysts) and higher than the historical mean (2002-2019=1.37 cysts, n=205). The mean *Giardia* concentration at Neversink this year (11.69 cysts) was higher than in 2019 (5.55 cysts) and higher than the historical mean (2002-2019=2.97 cysts, n=177). Ashokan (monitored at CATALUM) was slightly higher in 2020 (1.87 cysts) than in 2019 (1.24 cysts) and higher than the historical mean (2002-2019=0.92 cysts, n=929).

Additional Sampling

As part of required monitoring, weekly samples were collected at Croton Falls Reservoir for six weeks in January and February 2020. Three of the six samples (50.0%) were positive for *Cryptosporidium*, with a mean of 0.67 oocysts for all the samples. *Giardia* were found in 67% of samples, with a mean concentration of 5.17 cysts. *Giardia* results ranged from zero to a maximum of 12 cysts.

5.4. Watershed Streams and WWTPs

Routine monitoring for protozoa was conducted at 16 stream sites throughout the watershed in 2020. A total of 69 watershed stream samples were collected and analyzed by Method 1623.1, with 10 from the WOH watershed and 59 from the Kensico Reservoir (EOH) watershed.

Due to pandemic monitoring reductions, all stream monitoring was discontinued in mid-March 2020. Protozoan sampling of EOH streams around Kensico Reservoir resumed in September 2020, while WOH stream sampling remained suspended through the remainder of 2020. The eight perennial tributaries to Kensico Reservoir were monitored monthly from January through March, and then again from September through December of 2020, with three additional samples collected in response to elevated results in routine samples. The results discussed in this section are from 47-53 liter samples unless otherwise noted, with concentrations normalized to 50L to facilitate comparison of sample results.

In 2020, 10 samples were collected at 10 WWTPs, with one sample positive for protozoans. A discussion of WWTP results is provided at the end of the stream results section for each corresponding region.

West of Hudson Streams

As mentioned, while WOH streams were typically scheduled to be monitored either monthly (S7I, PROXG, and two upstream PROXG sites) or bimonthly (CDG1, S4, S5I, and CBS), WOH stream monitoring was discontinued in March for the remainder of 2020 (Figure 5.9). Hence, only 10 WOH stream samples were collected for protozoan analysis in 2020.

The target volume for protozoan monitoring conducted by DEP is 50 liters; however, these streams do not always allow for full target volume due to filters clogging. The method allows for a minimum of 10 liters for an acceptable sample. As long as 10 liters is achieved, samples are still analyzed. Of the 66 routine samples filtered and analyzed from WOH streams, 51 were between 47 and 53 liters. Fifteen samples had volumes less than 47 liters due to clogging or other issues during field filtration. Due to disparate sample volumes, 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 5.7).

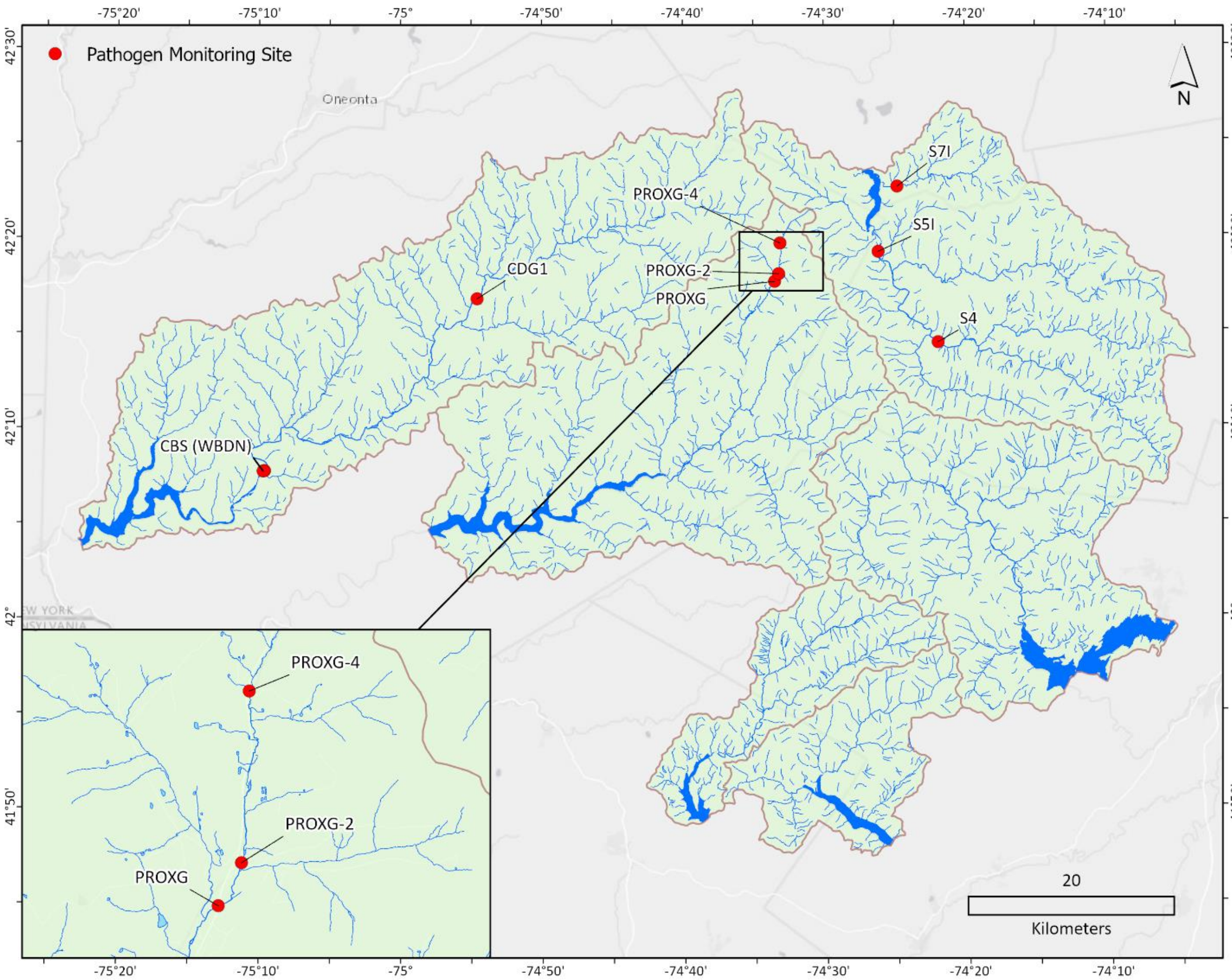


Figure 5.9 WOH stream sites monitored for protozoans in 2020.

Cryptosporidium oocysts were detected in seven out of the 10 routine WOH stream samples (70.0%) in 2020. With the exception of S7i, WOH stream sites were only sampled once in 2020 (Table 5.7). *Cryptosporidium* results at these sites were all low (2 or less oocysts) and within typical annual ranges for each of these sites.

Table 5.7 Summary of WOH stream protozoan results in 2020. Please note, different than in past years, all streams except S7i were sampled only once in 2020.

Site	n	*Cryptosporidium* Mean[1] ($50L^{-1}$)	% Detects	Max (Liters sampled)	Max (L^{-1})	*Giardia* Mean ($50L^{-1}$)	% Detects	Max (Liters sampled)	Max (L^{-1})
CBS	1	2.00	100.0%	2 (50.0L)	0.04	38.00	100.0%	38 (50.0L)	0.76
CDG1	1	1.00	100.0%	1 (50.0L)	0.02	120.0	100.0%	120 (50.0L)	2.40
PROXG	1	2.11	100.0%	2 (47.3L)	0.04	317.12	100.0%	300 (47.3L)	6.34
PROXG-2	1	1.09	100.0%	1 (46.0L)	0.04	490.22	100.0%	451 (46.0L)	9.80
PROXG-4	1	2.00	100.0%	2 (50.1L)	0.04	62.87	100.0%	63 (50.1L)	1.26
S4	1	0.00	0.0%	0 (50.4L)	0.00	65.48	100.0%	66 (50.4L)	1.31
S5	1	1.96	100.0%	2 (51.0L)	0.04	123.53	100.0%	126 (37.6L)	2.47
S7i	3	0.33	33.3%	1 (50.2L)	0.02	34.25	100.0%	43 (50.0L)	0.86

[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 all 10 routine WOH stream samples (100.0%) collected in 2020. While some *Giardia* results were elevated, even the maximum result found in 2020 (451 cysts in a 46.0L sample at PROXG-2) was well within the range of what has been at that site in the past few years. Discovering *Giardia* more frequently and at higher concentrations than *Cryptosporidium* in the NYC Watershed is common, and is most evident at WOH streams where the difference between mean cyst and oocyst concentrations is often one to two orders of magnitude greater (Table 5.7). As monitoring the WOH streams was not conducted for more than the initial months of 2020, no changes were made to the sites upstream of PROXG.

West of Hudson Wastewater Treatment Plants (WWTPs)

Protozoan monitoring of WWTPs was scheduled on a quarterly basis at the eight WOH WWTPs, however monitoring of WWTP was discontinued in March as part of COVID-19 monitoring reductions. Therefore in 2020 each plant was sampled only once, all in the first quarter of 2020. From this set of samples, one was positive for *Giardia* (12.5%) (Table 5.8). None of the eight 2020 WWTP samples were positive for *Cryptosporidium*.

Table 5.8 Protozoan results from the one positive WOH WWTP in 2020.

Date	Site	Plant	Sample Volume (L)	*Cryptosporidium* ($50L^{-1}$)	*Giardia* ($50L^{-1}$)
1/28/2020	Hunter WWTP	Hunter	50.0	0	1

On January 28, a sample was taken at Hunter WTP and found to have 1 *Giardia* cyst. The turbidity report printout from the facility for the 24-hour period on the day of the detection indicated the turbidity remained below the SPDES limit, with the maximum being 0.19 NTUs. There were no operational issues recorded in the log books and therefore no known reason for the very low-level positive detection.

East of Hudson Streams

The Kensico perennial streams were monitored for protozoans for seven out of the 12 months in 2020, from January to March and from September through December. In addition to the 56 routine monthly samples, three additional samples were taken (BG9, E10 and E9) to follow-up on elevated concentrations found in routine samples, for a total of 59 stream samples in 2020.

Cryptosporidium

Cryptosporidium oocysts were detected in 13 out of 56 (22.0%) routine samples at Kensico stream sites in 2020, very similar to the rate of detection in 2019 (24.0%, n=96), albeit with fewer samples. Mean concentrations were lower in 2020 compared to 2019 at seven of the eight sites (all except BG9). BG9 also had the highest mean concentration of *Cryptosporidium* amongst the eight streams in 2020, and the highest single result (18 oocysts) (Table 5.9). Maximum results at the other seven streams (all except BG9) were 4 oocysts or less. Considering the reduced number of samples in 2020, specific comparisons of *Cryptosporidium* detection rates and concentrations for individual sites with previous years is not warranted. However, the 2020 data can be compared to historical results from the boxplots in Figure 5.11 for a picture of relative differences.

Table 5.9 Summary of routine Kensico perennial stream protozoan results for 2020.

Site	n	*Cryptosporidium* Mean[1] (50L⁻¹)	% Detects	Max[2] (50L⁻¹)	Max (L⁻¹)	*Giardia* Mean (50L⁻¹)	% Detects	Max[2] (50L⁻¹)	Max (L⁻¹)
BG9	7	2.57	14.3%	18	0.36	6.71	85.7%	22	0.44
E10	7	0.29	14.3%	2	0.04	10.86	71.4%	66	0.1.32
E11	7	0.00	0.0%	0	0.00	3.24	85.7%	6 (50.1L)	0.12
E9	7	1.86	57.1%	4	0.08	24.10	100.0%	106	2.12
MB-1	7	0.61	28.6%	3	0.06	5.09	85.7%	15	0.30
N12	7	0.43	28.6%	2	0.04	3.28	71.4%	7	0.14
N5-1	7	0.43	14.3%	3	0.06	1.43	71.4%	4	0.08
WHIP	7	0.29	28.6%	1	0.02	0.86	71.4%	2	0.04

[1]Sample volumes not exactly equal to 50L are calculated to per L concentrations and then recalculated to 50L for determination of means. Zero values are substituted for non-detect values when calculating means.
[2]Maximum results are listed as per the target volume of 50L, unless another volume is given in parentheses next to the result.

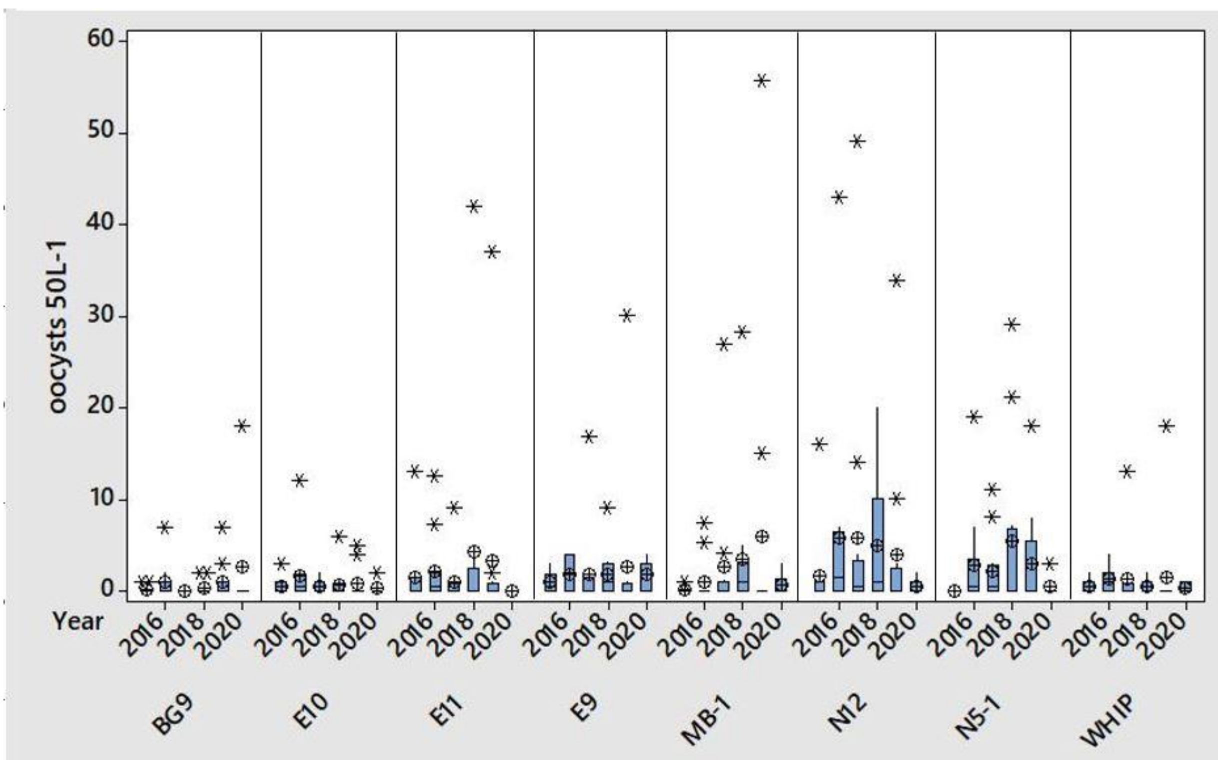


Figure 5.10 *Cryptosporidium* concentrations by year for routine samples at the eight Kensico streams from 2015 through 2020. There were 12 routine protozoan samples per year at each site, with the exceptions of 10 samples at E9 in 2015, and seven samples at all sites in 2020.

Giardia

The *Giardia* detection rate for all routine samples at Kensico streams in 2020 was 80.4%, which was higher than in 2019 (57.3%), although there were almost half as many samples in 2020. Individually, the Kensico streams had detection rates ranging from 71.4% (at four of the streams) to 100% (at E9) in routine samples (Table 5.9). The highest annual mean and maximum result were also at E9. Again, monitoring in 2020 was not like past years in that several months of monitoring were missing in the spring and summer months, making it difficult to compare simple statistics. *Giardia* results from 2020 can be visually assessed in relation to previous years using the boxplots in Figure 5.11. The two highest results at the stream sites were found in samples at E9 (106 cysts in the January sample) and at E10 (66 cysts in the October sample). Additional sampling was performed at these sites and will be discussed in the next section.

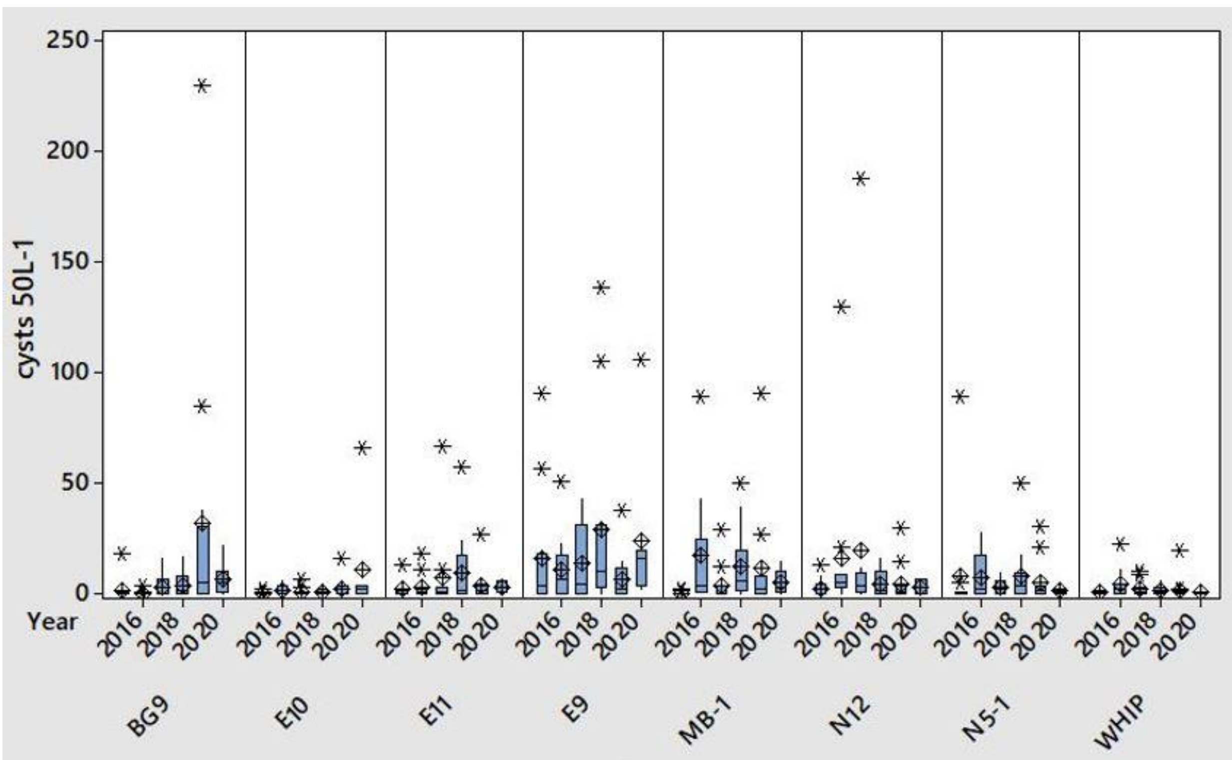


Figure 5.11 *Giardia* concentrations by year for routine samples at the eight Kensico streams from 2015 through 2020. There were 12 routine protozoan samples per year at each site, with the exceptions of 10 samples at E9 in 2015, and seven samples at all sites in 2020.

Additional Samples

Three additional samples were collected in 2020 as part of follow-up investigations after routine samples were found to have elevated levels of protozoans relative to their 10-year 95th percentile guideline. Results for these, as well as routine samples, are provided in Figure 5.12 and Figure 5.13 with the 95th percentiles noted for each individual stream.

The first two additional samples were taken on January 15, after sampling surveys on January 7 indicated elevated protozoan concentrations at BG9 (18 oocysts, >2 oocyst 95th percentile) and E9 (106 cysts, close to the119 cyst 95th percentile). Elevated *Giardia* concentrations had already been observed at E9 in December of 2019, so while the routine sample was not above the 95th percentile, additional sampling was done to ensure concentrations at this site were returning to background values. Results from the January 15 samples were non-detect for *Cryptosporidium* at BG9 and 21 *Giardia* cysts at E9, indicating concentrations were well below the 95th percentiles. Investigation into meteorological factors potentially affecting these samples showed there was no precipitation recorded at Westchester County Airport for a period of 72 hours before either the original or follow up surveys.

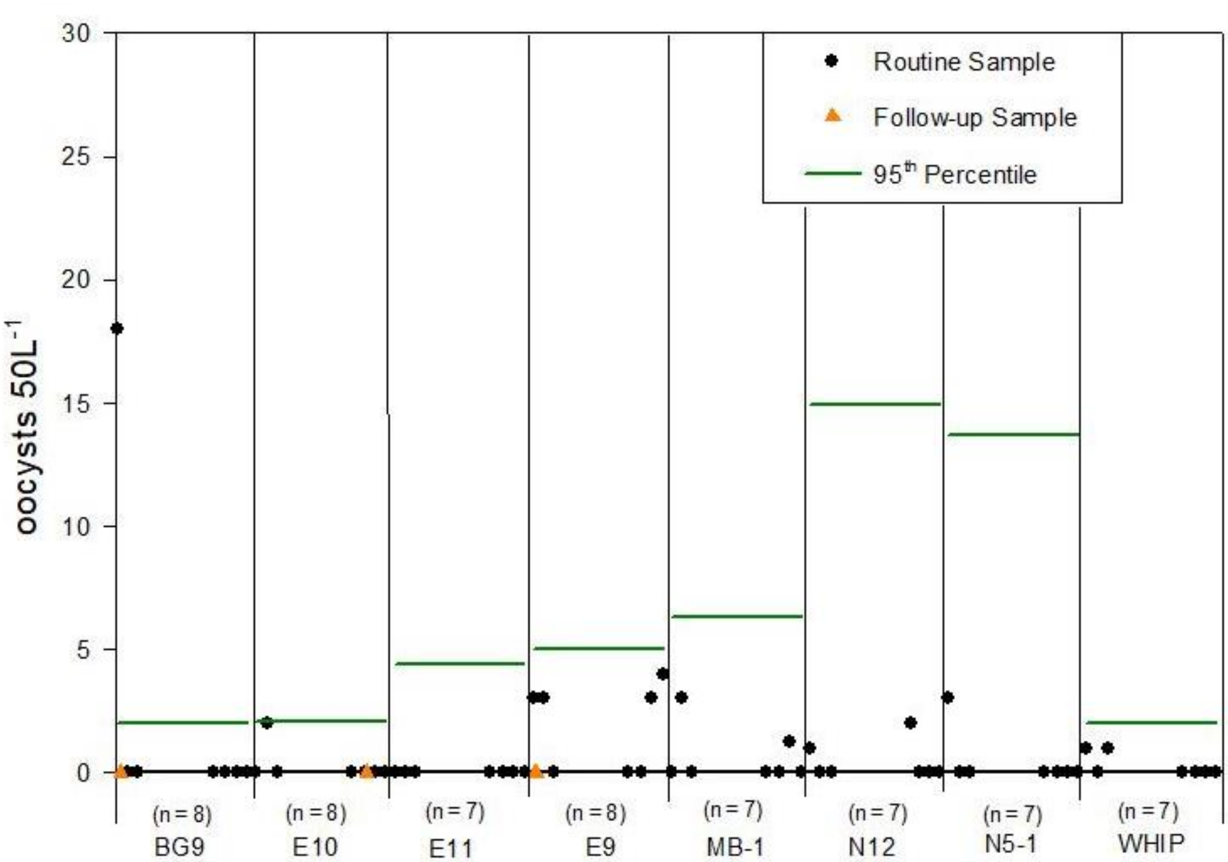


Figure 5.12 *Cryptosporidium* concentrations for samples collected at Kensico streams relative to 10-year 95th percentile values (horizontal green lines).

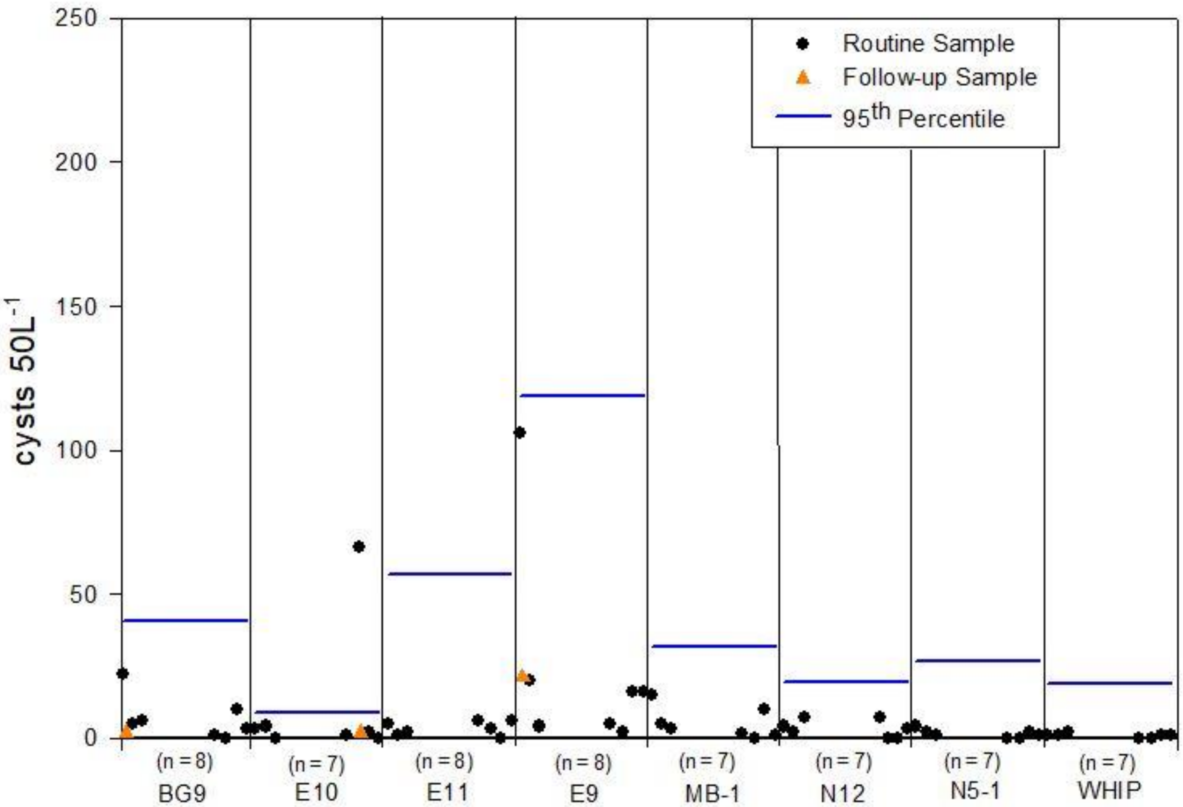


Figure 5.13 *Giardia* concentrations for samples collected at Kensico streams relative to 10-year 95th percentile values (horizontal blue lines).

The third additional sample was collected at E10 after the October 20 sample had 66 *Giardia* cysts, well over the 95th percentile for *Giardia* at this site (9.00 cysts). Precipitation levels prior to the initial routine sample were investigated, however, no rain was detected at Westchester County Airport within 72 hours prior to the sample survey. A follow-up sample was taken on October 26 with results indicating a much lower concentration of *Giardia* (2.00 cysts).

East of Hudson Wastewater Treatment Plants

The EOH treatment plants, Carmel and Mahopac, were sampled in the first quarter of 2020. Samples were collected in February and were negative for both *Cryptosporidium* and *Giardia*.

5.5. Catskill-Delaware Ultraviolet Disinfection Facility and Hillview Reservoir Monitoring

Catskill-Delaware Ultraviolet Disinfection Facility

Routine weekly monitoring of the outflow of the Catskill-Delaware Ultraviolet Disinfection Facility (CDUV) began in January 2018, at site CCCLAB, and continued through

2020. Of the 52 samples collected in 2020, four (7.7%) were positive for *Cryptosporidium* (Table 5.10), which is less than the detection rates in 2019 and 2018 (15.1 and 13.2%, respectively). The annual mean concentration for *Cryptosporidium* in 2020 was 0.13 oocysts and the maximum was 3 oocysts. This was similar to the two previous years when the annual means were 0.26 (2019) and 0.15 (2018) oocysts, with maxima of 4 and 2 oocysts, respectively. *Giardia* were detected in 22 out of 52 samples (42.3%) at CCCLAB in 2020, which is less than the percent detected in 2019 (33 out of 53, 62.3%) and 2018 (27 out of 53, 50.9%). The annual mean concentration in 2020 (1.12 cysts) was similar to the 2019 mean (1.64 cysts), and higher than the 2018 mean (0.68 cysts). The maximum *Giardia* result at CCCLAB in 2020 (8 cysts on January 27) was lower than the 2019 maximum (12 cysts), but higher than that observed in 2018 (3 cysts).

Table 5.10 CDUV Plant protozoan monitoring results summary for 2020.

	***Cryptosporidium* oocysts**	***Giardia* cysts**
n	52	52
Number of Detects	4	22
% Detects	7.7%	42.3%
Mean ($50L^{-1}$)	0.13	1.12
Maximum ($50L^{-1}$)	3	8

The detection of *Cryptosporidium* oocysts and *Giardia* cysts immediately post-UV treatment is a strong reminder that the USEPA method for recovering these protozoans from water (in this case 1623.1) is unable to provide a true measure of public health risk. Cysts and oocysts are counted with this method, even though they have been deactivated by UV light and are no risk to public health.

Hillview

Giardia and *Cryptosporidium* have been monitored weekly at Hillview Reservoir Site 3 since August 2011 as part of the Hillview Administrative Order. During 2020, 52 weekly samples were collected and analyzed by EPA Method 1623.1 with EasyStain and heat dissociation and results are presented in Figure 5.14 and Figure 5.15. In addition, 39 samples (100L) were analyzed by CC-IFA (Alderisio, et al. 2019) at Hillview for *Cryptosporidium* infectivity, and all samples were negative.

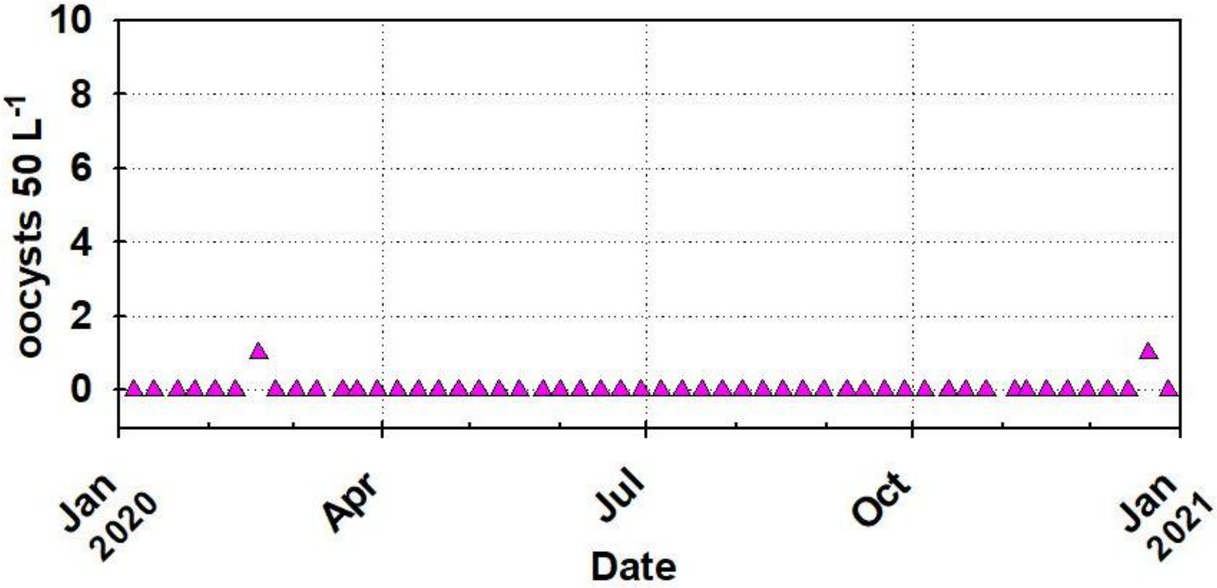


Figure 5.14 *Cryptosporidium* oocyst concentrations for weekly samples at Hillview Site 3 in 2020.

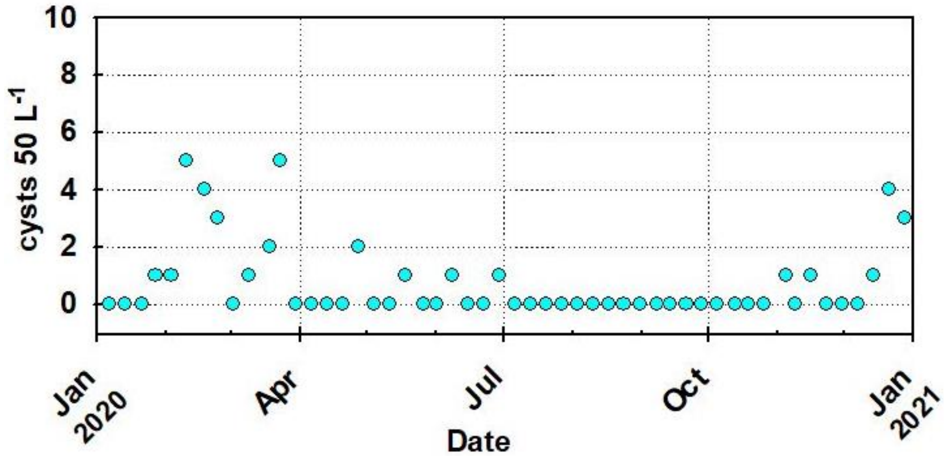


Figure 5.15 *Giardia* cyst concentrations for weekly samples at Hillview Site 3 in 2020.

Cryptosporidium was detected in 3.8% of Hillview samples in 2020 and the annual mean concentration was 0.04 oocysts (Table 5.11). The detection rate and mean were the same in 2019 as well as in a few other past years (2013, 2014, and 2017). The 2020 detection rate and mean concentration were also very close to the historical rate and mean for this site (5.8% and 0.06 oocysts for 2011-2019, n=446). The *Giardia* detection rate was lower in 2020 (32.7%) when compared with 2019 (42.3%), but more in line with rates observed from 2012-2014 (ranging from 31.5 to 35.2%). Annual mean *Giardia* concentrations were lower in 2020 (0.71) when compared with 2019 (0.90 cysts), but still just above the range in annual means observed from

2011 to 2018 (0.13-0.67 cysts) and higher than the historical mean for all years (2011-2019 mean=0.42 cysts, n=446).

Table 5.11 Hillview Site 3 protozoan detections from 2011 to 2020.

	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%
2017	2	3.8%	9	17.3%
2018	5	9.4%	9	17.0%
2019	2	3.8%	22	42.3%
2020	2	3.8%	17	32.7%

[1]Sampling began in August 2011.
Dashed lines indicate method changes; Method 1623.1 with EasyStain – April 6, 2015, heat dissociation at Hillview – March 14, 2016.

6. Water Quality Modeling

6.1. Overview

The Water Quality Modeling section supports protection and improvement of 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. The 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.

This section contains an overview of major activities in the Water Quality Modeling Program that took place in 2020.

6.2. Modeling Evaluation of Watershed Protection Programs

The SWAT-HS model has been applied to evaluate watershed management including agricultural activity that occurred in Cannonsville watershed from early 1990s through 2019. Model simulations were compared with nutrient data for the Cannonsville watershed to test the validity of model predictions. Major watershed management programs that were evaluated include the Watershed Agricultural Program (and associated BMPs), the Septic Remediation and Replacement Program, and the Wastewater Treatment Plant (WWTP) Upgrade Program. Loading estimates using measured data indicate that dissolved phosphorus loading into the Cannonsville Reservoir have declined from about 15,000 kg yr^{-1} in the early 1990s to less than 10,000 kg yr^{-1} in recent years (Figure 6.1). This is a result of combined effect of reductions in point and nonpoint source contributions in response to watershed management actions, along with changes in land use not directly related to management, as reported in DEP (2011). While dissolved phosphorus loads have decreased in recent years the annual precipitation has increased, implying that the actual effect of management programs and land use changes is greater than load reductions observed in recent years. Scenario-based analyses are used to evaluate watershed response to long-term and varying hydro-climatic conditions.

6.2.1. Brief description of the SWAT model

The SWAT model is a spatially semi-distributed model that simulates daily water, nutrients, and sediment loads from nonpoint and point sources. In SWAT, a watershed is divided into sub-watersheds and each sub-watershed is further divided into hydrological response units (HRUs), the basic modeling units. Each HRU is a unique combination of land use, soils, and topography. In SWAT-HS, the soil-water storage capacity is incorporated into HRUs to spatially distribute the runoff responses according to a soil wetness index (Hoang et al. 2017). Daily precipitation, minimum and maximum air temperature, solar radiation, and relative humidity data are used to drive the model. For each HRU, contributions to surface runoff, lateral flow and groundwater is calculated. Dissolved and particulate substances (e.g., nutrients and sediment) in streamflow are estimated at the watershed outlet by relating substance concentrations in runoff and baseflow to watershed and HRU-specific characteristics. Fertilizer and manure application can be included as sources of nutrients in soils and simulated as part of agricultural management practices. Other agricultural practices simulated in the model include tillage, planting, harvesting, grazing, and conservation practices such as vegetative buffers, and cover cropping. Influence of septic systems on water quality is simulated using a biozone algorithm (Jeong et al. 2011).

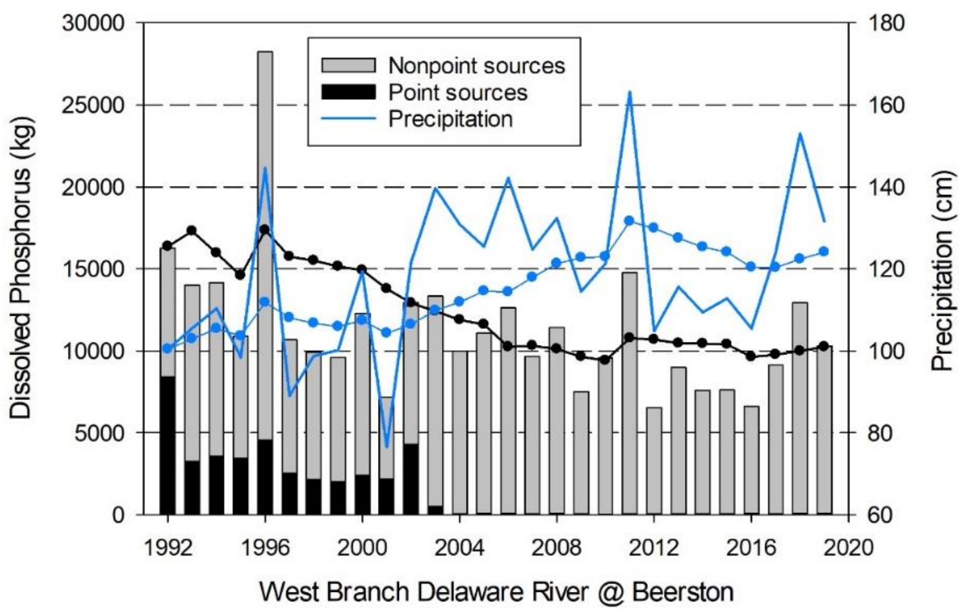


Figure 6.1 Total dissolved phosphorus loading and annual precipitation in the West Branch Delaware River at Beerston (1992-2019). Dotted lines are 10-year moving averages of dissolved phosphorus (black) and precipitation (blue).

6.2.2. Point and Nonpoint Source Reduction Programs Evaluated

Wastewater Treatment Plants (WWTPs)

Daily WWTP phosphorus loads by month were used as input to the model at the corresponding sub-basin location. Significant reductions in P loads in WWTP effluent reflect upgrades to these plants that have occurred over time (Figure 6.1).

Nutrient Management

Nonpoint sources nutrient management in agricultural lands includes fertilizers and manure applied to croplands, and manure management in dairy farms and pastures. The effects of nutrient management plan is simulated by adjusting manure-spreading patterns over time, reflecting both changes in practice as well as changes in farm animal count. Observed decrease in manure P generated in the watershed reflects changes in farm animal count (Figure 6.2).

For croplands, the rotation schedule simulated in the model is four years of corn followed by six years of hay using recommended management practices. This included starter inorganic fertilizer (18% N and 18% P) application on the same day that corn was planted at the rate of 100 kg ha^{-1}. Subsequently, manure is applied at the beginning (April/May) and at the end (September/October) of the growing season. Each application added 2670 kg ha^{-1} of dairy manure, which is equivalent to about 374 kg ha^{-1} dry weight.

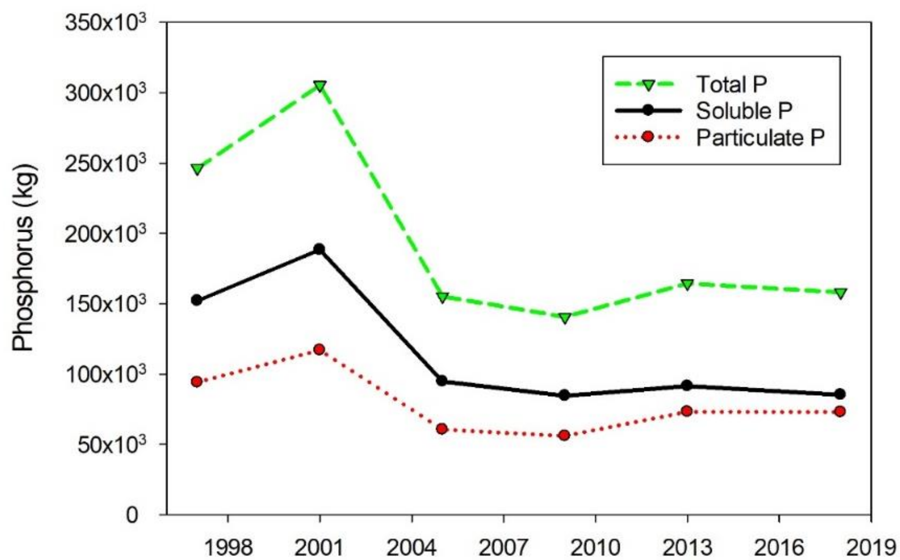


Figure 6.2 Estimated change in manure P production in the Cannonsville watershed. Nutrient content of manure derived from ASAE Standards (ASAE 1998) and SWAT database (Arnold et al. 2013).

Winter Cover Cropping

Winter cover cropping is a conservation practice that benefits the soil by suppressing weeds, managing soil erosion, and improving overall soil quality and nutrient status, with potential to improve water quality. Winter rye is one of the best cover crops to grow in the region as it is extremely adaptive and grows quickly, even in cold or unfavorable conditions (Delaware County SWCD 2019). The Watershed Agricultural Council (WAC) implemented approximately 1,194 acres of cover crops in the Cannonsville basin. Planting usually occurs during the first week of October. It has become a widely adopted practice in recent years, since WAC has initiated aerial application of cover crops with the use of a helicopter. While this program is still in its early phase, the impact of winter cover crops on watershed water quality was evaluated using scenarios of 10%, 25%, 50%, and 100% adoption.

Riparian Forest Buffers

Riparian buffer planting started in NYC watersheds in 1998 as part of the NYC Watershed Conservation Reserve Enhancement Program (CREP) agreement between DEP, New York State, and the United States Department of Agriculture (USDA). The NYC Watershed CREP, which focuses on agricultural land, is implemented in tandem with the NYC Watershed Agricultural Program. The goal of the NYC CREP is to reduce the amount of sediment, nutrients (phosphorus and nitrogen), and pathogens from streams entering the reservoirs in the NYC water supply system. Currently, about 1,305 acres of farmland (cropland and pasture) in the Cannonsville basin is enrolled in the CREP program. Since 2008, additional targeted buffer planting in about 48 acres of non-agricultural riparian (streamside) forested areas in the Cannonsville basin occurred through the Catskill Streams Buffer Initiative, managed by the DEP Stream Management Program (SMP). Scenarios of riparian buffer planting impact on water quality are included in this modeling analysis.

Septic Systems

The impact of the Septic Remediation and Replacement Program is modeled using the number of septic systems repaired. Failing septic systems within 300 feet of a waterbody were assumed to contribute to stream nutrient load through direct discharge. A GIS analysis indicated that out of the 908 septic systems repaired in the Cannonsville basin since 2009, 437 were within 300 feet of a waterbody. A scenario of ponded failure of these septic systems (assuming no repair was performed) was used to assess water quality impacts at the watershed scale.

6.2.3. Watershed Modeling Results

Model Performance

The calibrated SWAT-HS model was able to simulate the observed streamflow and dissolved phosphorus loads very well. The performance of the model can be rated as “very good” as per model evaluation guidelines (Moriasi et al. 2007), for the calibration, validation, and testing periods (Table 6.1). Time series of simulated and observed monthly average loads shows that the model is able to capture the observed variation in loads (Figure 6.3).

Table 6.1 Model performance in simulating monthly average streamflow and dissolved phosphorus loads.

Parameter	Calibration period 2001-2006		Validation period 2007-2010		Testing period 2011-2019	
	R^2	NSE	R^2	NSE	R^2	NSE
Streamflow	0.87	0.86	0.85	0.82	0.90	0.88
Dissolved P	0.77	0.75	0.75	0.70	0.77	0.74

*Streamflow at Walton USGS site and dissolved P loading at Beerston water quality monitoring site

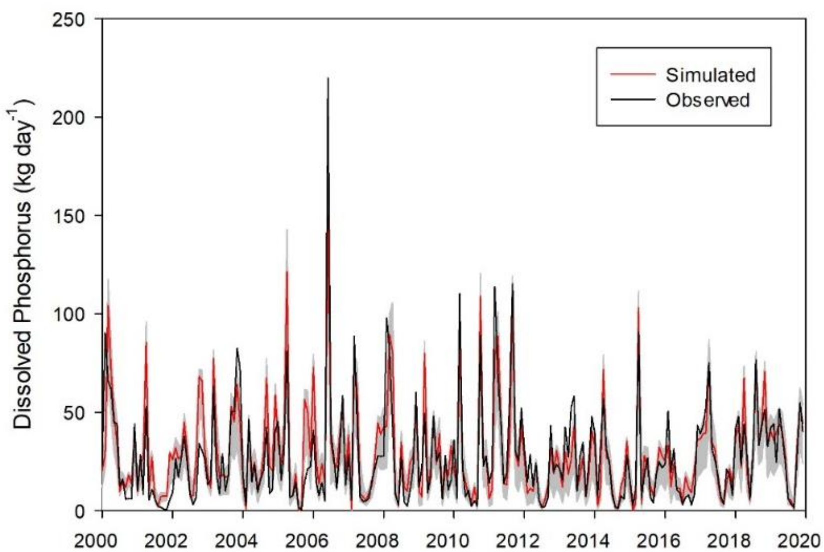


Figure 6.3. Simulated and observed dissolved P loads at Beerston water quality monitoring site. Gray areas indicate uncertainty bounds for predicted values.

Watershed Sources of Dissolved Phosphorus

Model predictions of the average annual contribution of dissolved phosphorus from various watershed sources for recent years is shown in Table 6.2. Agricultural land uses that occupy a relatively small fraction of the watershed area are the single largest anthropogenic source, contributing about 42%. Forests that cover about 64% of the watershed area contribute another 42% to background levels of dissolved phosphorus. Model simulation also indicated that fully functional septic systems contributes a small (<1%) fraction of the load through percolation and groundwater discharge (impact of failing septic systems is presented in a separate section). This amount was comparable in magnitude to the total contributions from all WWTPs. Under current conditions, nonpoint sources dominate and contributes over 99% of the total loading.

Table 6.2 Estimated contribution of dissolved P from different sources in the Cannonsville watershed for the period 2012-2019.

Source	**Land use**		**Areal %**	**Dissolved Phosphorus (kg yr^{-1})**	**% contribution**
Point source	WWTPs		-	63	0.62
Nonpoint Sources	Agricultural	Cropland	4.42	2,916	28.63
		Pasture	10.95	1,196	11.74
		Woodland#	3.66	189	1.86
	Non-agricultural	Forest	63.65	4,322	42.43
		Shrubland‡	10.26	707	6.94
		Urban	4.87	476	4.67
		Septic*	0.05	87	0.85
		Waterbodies	2.11	229	2.25
		Total	**100**	**10,185**	**100**

#Woodland includes shrublands and herbaceous vegetation within farms

‡Shrubland includes brushes and other herbaceous vegetation in non-agricultural lands

*Septic contribution presented here is from fully-functional systems, does not include failing systems

Estimates of Loading Reductions Achieved from Baseline Conditions

Figure 6.4 depicts scenarios of 30-year annual time series of simulated dissolved phosphorus loads from the Cannonsville watershed for calibrated baseline (1990s) and current (2010s) conditions. Loading reductions depicted in this graph represents the combined effects of nonpoint source BMPs and land use changes that occurred between baseline and the current scenario. Point sources are excluded from these scenarios and the differences in loads are entirely due to changes in nonpoint sources. Long-term simulations are used to include a range of hydrologic conditions and to avoid biases in reduction estimates due to differences in hydrology observed during the periods being compared. Estimated average annual loading from nonpoint sources for the baseline period is ~13,400 kg yr^{-1}. In comparison, the average annual loading for the current period is ~8,700 kg yr^{-1}, a ~35% reduction in nonpoint source loading.

Point source contributions are currently less than 1% of the total load (Table 6.2) and represent a significant reduction in source contribution compared to the early 1990s when discharges from WWTPs contributed as much as over 50% of the annual dissolved phosphorus load (Figure 6.1). Upgrades to WWTPs continue to result in reduced phosphorus loading into Cannonsville streams and represent over 98% reduction in point sources compared to early 1990s as reported previously (DEP 2011).

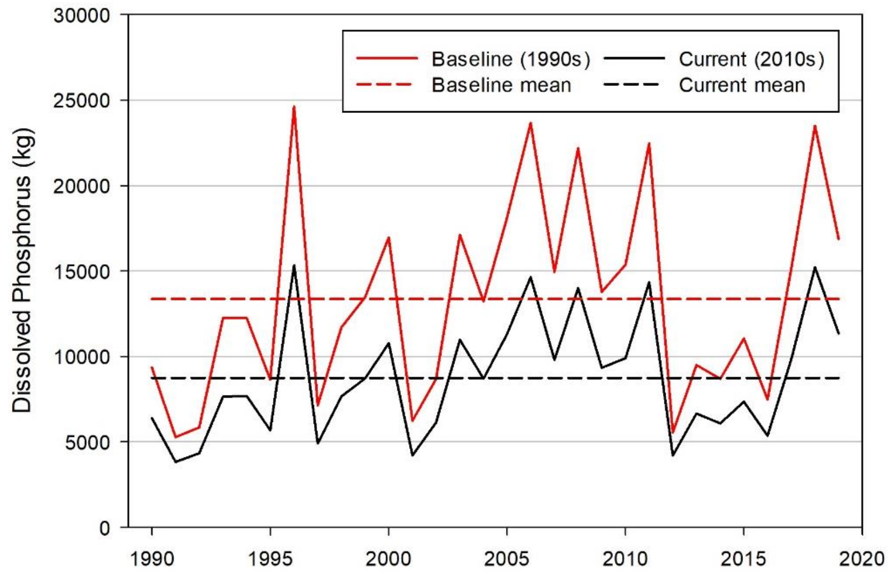


Figure 6.4 Baseline (1990s) vs. current (2010s) scenario based on 30 yr. continuous simulation under same hydrologic conditions. Point sources are excluded in both scenarios.

Impact of Septic Remediation and Replacement

Failing septic systems account for about 8% of all septic systems in the watershed for the period 2010-2019, which is lower than the 13-14% estimated and reported previously (DEP 2011). To account for any error in the estimate of failing septic systems in the modeling analysis, a conservative estimate of about 11% (average of current and previous estimate) of the septic systems were assumed to be failing under current conditions. Table 6.3 shows the potential reductions in dissolved P loading achieved through septic system repairs. This analysis shows an annual reduction in stream loading ranging from 1.8% to 5.4% of the total load with a mean annual reduction of 2.9% for the period 2010-2019. These results highlight the importance of maintaining septic systems in working condition and of timely repairs in minimizing their contribution of nutrient loads to streams.

Table 6.3 Septic upgrade impact on nutrient loading for period 2010-2019.

Scenario	Range in reduction	Mean reduction
Potential contribution of failing septic systems to dissolved P loading (kg yr^{-1})	233-296	269

Scenarios of Vegetative Buffers on Agricultural Lands

The impact of buffer planting was evaluated for the period 2000-2019 using the vegetative filter strip (VFS) method described in White and Arnold (2009). Two sets of scenarios were simulated in addition to scenarios with 100% and no vegetative buffer on agricultural lands (Table 6.4). The first set of scenarios involved random planting of vegetative buffers on agricultural land and the second set involved targeted placement of buffers in near-stream riparian areas. Figure 6.5 illustrates the impact of targeted placement of riparian buffers compared to random placement on stream nutrient reduction. Model simulations show that targeting the most sensitive 30-40% of agricultural areas offers maximum benefit from buffer planting. While the actual percentage of agricultural area affected by buffers is not known, previous reports indicate this to be about 20% (DEP 2011). Nevertheless, this analysis shows the relative magnitude of potential reduction in dissolved phosphorus loading possible through riparian buffers when compared to other BMPs.

A similar scenario on the effect of streamside planting in non-agricultural riparian forested areas shows a 2.4% potential reduction in average annual dissolved phosphorus loading for the period 2010-2019 based on the current level of implementation.

Table 6.4 Scenarios of vegetative buffers on agricultural land (cropland + pasture) simulated.

#	Scenario	Description
1	B0	No vegetative buffer on agricultural land
2	B10	Vegetative buffer on randomly selected 10% of agricultural HRUs
3	B25	Vegetative buffer on randomly selected 25% of agricultural HRUs
4	B50	Vegetative buffer on randomly selected 50% of agricultural HRUs
5	B100	Vegetative buffer on 100% of agricultural land
6	BW1-3	Vegetative buffer on wettest 12% of agricultural land (wetness classes 1-3)
7	BW1-5	Vegetative buffer on wettest 28% of agricultural land (wetness classes 1-5)
8	BW1-8	Vegetative buffer on wettest 53% of agricultural land (wetness classes 1-8)

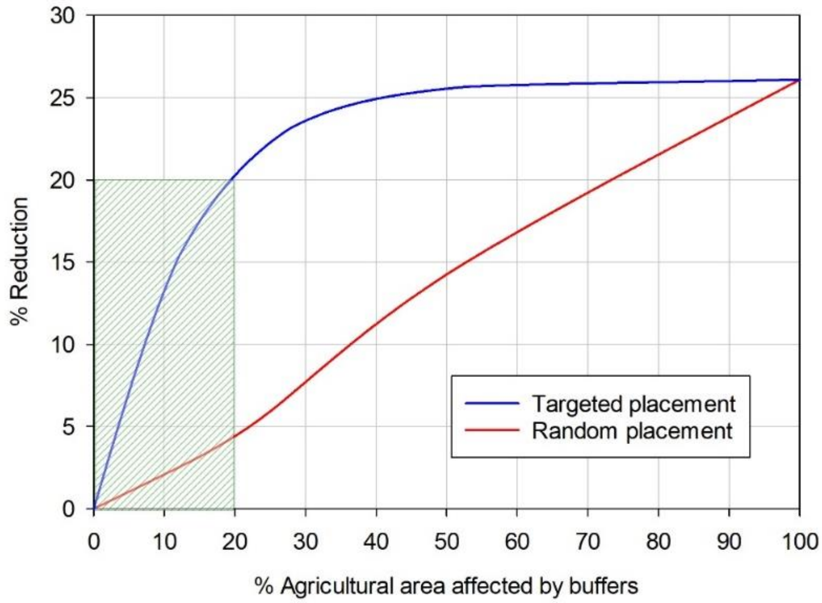


Figure 6.5 Effect of targeted vs random placement of buffers on dissolved phosphorus loading. Shaded area represent likely level of current implementation.

Scenarios of Winter Cover Crops

The impact of planting winter rye as a cover crop on water quality was evaluated using scenarios that consider various levels of implementation. Each scenario is based on a 30-year simulation that considers three cycles of 10-year corn-hay crop rotation. The current level of implementation was estimated to be closer to a scenario that represent 25% of cornfields under winter cover cropping. This scenario showed a small (0.47%) increase in annual dissolved phosphorus loading although slight decreases in sediment (-0.45%), total phosphorus (-1.45%), total nitrogen (-0.64%), and nitrate (-0.29%) were simulated under default model settings. Additional scenarios showed increases in dissolved P loading with increasing winter cover crop acreage. Liu et al. (2019), based on a review of studies in cold climatic regions, concluded that cover crops and crop residues generally prevented soil erosion, nitrate leaching, and loss of particulate P during non-growing seasons, but tended to elevate dissolved P loss relative to bare soils. However, the specific impacts of cover crops on dissolved phosphorus loss are unclear. Kleinman et al. (2005) report on increased dissolved phosphorus in runoff from fields under winter rye as cover crop in lower landscape positions with saturated soils, based on field scale rainfall-runoff experiments in the Cannonsville watershed. Scenarios of reduced cover cropping in saturated and wetter areas of the landscape that accumulate sub-surface lateral flow provides a potential mitigation alternative.

6.2.4. Highlights from Watershed Modeling Evaluation

- The calibrated SWAT-HS model estimated the current sources of stream nutrient loads, assessed loading reductions from point and nonpoint sources achieved over the past 30 years (1990-2019), and simulated scenarios on the impact of various watershed management practices.
- A comparison of model scenarios of 1990s watershed conditions with that of 2010s representing current watershed conditions, subject to same hydro-climatic conditions, shows that nonpoint source contributions of dissolved P have decreased by ~35%.

While the relative importance of eutrophication has declined in recent years, maintaining dissolved P loading rates at the current levels is important for long-term maintenance of the high quality of drinking water.

6.3. Uncertainty Analysis on SWAT-HS Simulated Streamflow for West of Hudson Watersheds

Uncertainty analysis is an important step in any hydrological modeling analysis in evaluating the strength of a calibrated model. It is important to present model outputs in the form of an uncertainty interval in addition to a single value as the "best" estimation. When predicting a variable of interest, different models weigh differently towards various aspects of processes being modeled, due to a plethora of underlying factors governing such processes that have to be estimated and formulated. Although each of these models may produce acceptable predictions, the predictions may differ since the models do not consider all aspects of a process (Darbandsari and Coulibaly 2019). On the other hand, within a single model, there exist some empirical parameters whose value cannot be measured directly. The value of these parameters is usually optimized through a calibration process in which an optimized parameter value is determined by constraining the simulation errors through verification metrics, usually called objective functions. Many different objective functions have been developed and formulated to serve various purposes. Therefore, based on the choice of objective function, the calibration process may result in different sets of parameter values that produce statistically acceptable predictions, but are in significantly different locations in the parameter space (Abbaspour et al. 2017). Hence, picking only one model between many plausible models, or one single simulation driven from one set of optimized parameters within a single model, as a superior in all conditions underestimates the uncertainty and reduces the reliability of predictions. The uncertainty estimated in this manner, which is the traditional approach in hydrological studies, only accounts for model-data mismatches and does not include calibration and between-model uncertainties (Vrugt and Robinson 2007).

A number of techniques have been developed and utilized to incorporate predictions from different sources (such as various competing models or different specifications within a model) to account for and to quantify all possible sources of uncertainty. While early techniques used neural networks and fuzzy systems, usage of Bayes' statistical theorem has been growing over the past 20 years (Dong et al. 2013). Some of the techniques which are known as ensemble-based or multi-model approaches include Generalized Likelihood Uncertainty Estimation (GLUE) (Freer et al. 1996), Ensemble Kalman Filter (EnKF) (Evensen 1994), Bayesian Model Averaging (BMA) (Duan et al., 2007), Bayesian Recursive Estimation (Thiemann et al. 2001), Bayesian Total Error Analysis (BATEA) (Kavetski et al. 2011), Bayesian Hierarchical Models (Huard and Mailhot 2008), and Bayesian Generalized (Non-) Linear Multilevel Models (BGMM) (Bürkner 2017). Among these, BMA has been used most intensively and widely due to its simplicity, easy applicability, and ability to reduce the risk of overfitting. BMA is a statistical method that uses the Probability Distribution Function (PDF) of each of the individual models (ensembles) to quantify the predictive uncertainty and provide probabilistic results (Darbandsari and Coulibaly 2019).

Calibration and validation of SWAT-HS for streamflow simulation in West of Hudson (WOH) watersheds has been reported previously. In this section, we report on the uncertainty analysis on simulated streamflows at the major inflow location of each reservoir watershed for the simulation period of 2001 to 2018. The following sections summarize the method used in uncertainty analysis, criteria for assessment of model performance, and results from the analysis.

6.3.1. Generating Streamflow Ensemble Time Series

The sequential uncertainty fitting (SUFI-2) algorithm in the SWAT-CUP calibration software (Abbaspour 2012) was used to calibrate simulated streamflow to USGS stream gage observations. The calibration and validation periods were 2001-2010 and 2011-2018, respectively. Fourteen parameters (Table 6.5) used by SWAT-HS in the simulation of snowmelt, surface runoff, lateral flow, groundwater contribution, and evapotranspiration, were calibrated by conducting two to three iterations of 2000 simulations each. Parameter ranges used in the final iteration of the calibration period were utilized for a single iteration with 2000 simulations for the validation period. From the final iteration, we chose the best-simulated time series for seven objective functions that gave unique parameter sets and therefore seven unique streamflow time series. Each time series was then used as an ensemble member for uncertainty analysis in a Bayesian Model Averaging procedure. The chosen objective functions were Nash-Sutcliffe Efficiency (NSE), Modified Nash-Sutcliffe Efficiency (MNSE), Regression coefficient (R^2), Modified Regression coefficient (bR^2), Sum of the Squares of Residuals after ranking (SSQR), Percent Bias (PBIAS), and Kling-Gupta Efficiency (KGE). While using R^2 and bR^2 as objective functions aim to minimize the error variance between simulated and measured data, using NSE and MNSE maximizes the ability of the model to replicate temporal trends in measured data (Tolson and Shoemaker 2007). The SSQR focuses on fitting the frequency distributions of the observed and the simulated series. Selecting PBIAS minimizes the overall underestimation and overestimation bias and tries to improve the predictions for the average of the measured data.

The KGE is an objective function that is less sensitive to high values that provides a better estimate of model predictions at all ranges of flows. Therefore, by choosing each of the selected objective function results in parameterization that generates simulations that are statistically acceptable, while being different from each other. In the rest of this chapter, we refer NSE, MNSE, R^2, bR^2, PBIAS, KGE, and SSQR objective functions as OF_1 to OF_7 respectively, to prevent confusion between the name of these functions and model evaluation metrics.

Table 6.5 Parameters considered for streamflow calibration.

Name	Unit	Definition
SFTMP	°C	Snowfall temperature
SMTMP	°C	Snowmelt temperature
SMFMX	mm/ °C	Maximum snowmelt factor
SMFMN	mm/ °C	Minimum snowmelt factor
TIMP	-	Snow pack temperature lag factor
RCHRG_PAF	mm	Fraction of root zone percolation that recharges the surface aquifer
ALPHA_BF	$days^{-1}$	Base flow recession constant
GW_DELAY	days	Groundwater delay
latA	-	Surface aquifer non-linear reservoir coefficient
latB	-	Surface aquifer non-linear reservoir coefficient
EFFPORFAC	-	Fraction of effective porosity that can hold water under saturated conditions
SURLAG	days	Surface runoff lag time
EPCO	-	Plant water uptake compensation factor
ESCO	-	Soil evaporation compensation factor

6.3.2. Bayesian Model Averaging Overview and Model Configurations

Bayesian model averaging (BMA) is a statistical method, which combines PDFs of the ensemble members using Bayes' rule to produce the forecast PDF. Bayes' rule defines the relationship between prior (ensemble) PDFs and posterior (forecast) probability distribution. BMA assumes a prior distribution over the set of all considered ensembles describing the prior uncertainty over each ensemble's capability to accurately describe the data (Fragoso et al. 2018). A very well-known and widely used PDF in BMA is normal probability distribution function. Using an expectation-maximization algorithm, two associated parameters of mean and variance for prior BMA predictions can be calculated. The BMA mean prediction is a weighted average of the individual ensemble predictions, with their posterior probabilities being the weights. The variance is the uncertainty associated with BMA mean prediction, which consists of between-model and within-model errors (Dong et al. 2013). Normal BMA can be used if the variable of interest and its ensemble predictions all follow normal probability distribution. However, streamflow is known to be skewed towards peak values and log-normal, gamma, or Weibull distributions have been found to be better candidates to describe such behavior (Langat et al.

2019). To overcome this problem and use the proposed BMA analysis, a data transformation procedure is required to map the streamflow values from their original space to a Gaussian space. As mentioned in the previous section, the predictions generated using the seven objective functions served as ensemble members for BMA analysis.

In this research, we designed multiple configuration for BMA model construction to explore both the sensitivity of uncertainty to BMA methodology and to investigate the accuracy and reliability of the BMA probabilistic results when employing different approaches to build a BMA model. To this end, we considered three data transformations, including logarithmic, Box-Cox and the empirical normal quantile transformation (ENQT; Peng et al. 2007), applied to the entire time series (complete flow approach) and to flow percentiles (percentile split flow approach). In the percentile split flow approach, the flow distribution is divided into several percentiles and BMA is applied to each independently (Duan et al. 2007). Considering the explained configurations, we ended up having six BMA models, i.e., BMA_1: log transformation and complete flow approach; BMA_2: Box-Cox transformation and complete flow approach; BMA_3: ENQT transformation and complete flow approach; BMA_4: log transformation and percentile split flow approach; BMA_5: Box-Cox transformation and percentile split flow approach; BMA_6: ENQT transformation and percentile split flow approach. Flow split ranges considered for BMA_4 to BMA_6 were 0-10, 10-25, 25-50, 50-75, 75-90, and 90-100 percentiles.

6.3.3. Uncertainty Interval Assessment Criteria

Two verification criteria were employed to quantify the characteristics of the uncertainty interval (also known as the confidence interval (CI)). These metrics were containing ratio (CR), defined as the percentage of observations bracketed by the uncertainty interval, and average bandwidth ratio (BR), equal to the ratio of the average width of the uncertainty band and the standard deviation of the measured data (Abbaspour et al. 2004; He et al. 2018). CR is an indicator for the "goodness" of the uncertainty interval. Therefore, a CR value of 1 is considered ideal. On the other hand, small values of BR show less uncertainty or greater precision and values of lower than 1 are considered satisfactory. The CR and BR are also used for measuring the reliability of the model and quantifying the precision of the results, respectively (Darbandsari and Coulibaly 2019). In uncertainty assessment, CR value of higher than 0.7 and BR value of less than 1.5 are recommended to be adequate when simulating discharge (Abbaspour et al. 2015).

6.3.4. Results

Evaluation of Individual Model (Ensemble Member) Streamflow Simulations

Figure 6.6 illustrates the value of each variable parameter based on the selection of objective function for each watershed. In this figure, each objective function is shown using a different symbol and the shaded band represents the behavioral range. Although each simulation produced by considering different objective functions was acceptable, as observed from the graphs, their associated parameter sets fell at different locations in the parameter space. Overall, the suggested behavioral ranges of parameter sets were narrow, with no sign-change in the value of the parameter indicating relatively lower level of uncertainty during calibration process. Values of the objective functions NSE, KGE, and PBIAS for ensemble member simulations using the seven objective functions simulations versus daily streamflow observations are shown in Table 6.6.

Table 6.6 Deterministic verification assessment of the seven simulations generated using different objective functions for calibration and validation periods.

		Calibration 2001-2010			Validation 2011-2018				Calibration 2001-2010			Validation 2011-2018		
		NSE	**KGE**	**PBIAS**	**NSE**	**KGE**	**PBIAS**		**NSE**	**KGE**	**PBIAS**	**NSE**	**KGE**	**PBIAS**
OF_1	**Ashokan**	0.71	0.77	-3.5	0.79	0.87	-3.6	**Pepacton**	0.75	0.83	8.5	0.65	0.72	10.5
OF_2		0.71	0.76	-5	0.79	0.86	-3		0.74	0.84	5.2	0.63	0.73	4.4
OF_3		0.70	0.81	-4.4	0.79	0.87	-3.6		0.75	0.83	8.5	0.64	0.68	15.9
OF_4		0.52	0.72	-7.3	0.71	0.81	-3.8		0.63	0.76	9.8	0.33	0.63	7.4
OF_5		0.70	0.79	-2.8	0.72	0.85	-0.1		0.70	0.70	0	0.62	0.69	0.6
OF_6		0.68	0.83	-3.1	0.78	0.89	-2.8		0.72	0.86	2.8	0.60	0.79	3.4
OF_7		0.64	0.81	-4.7	0.79	0.87	-3.1		0.68	0.84	0.3	0.62	0.77	7.7
OF_1	**Schoharie**	0.72	0.76	-1.8	0.66	0.80	4	**Neversink**	0.64	0.73	-1.1	0.62	0.7	-2.1
OF_2		0.72	0.75	-5.7	0.57	0.69	-1.5		0.62	0.66	-3.2	0.61	0.74	0
OF_3		0.70	0.85	-2	0.64	0.81	7.3		0.63	0.78	-1.3	0.5	0.75	0.1
OF_4		0.52	0.69	-12.7	0.46	0.69	3.3		0.41	0.68	-3.6	0.37	0.65	-2.3
OF_5		0.72	0.76	-1.8	0.55	0.75	0		0.54	0.54	-1.2	0.61	0.74	0
OF_6		0.70	0.85	-2	0.63	0.82	1.1		0.59	0.79	-2.8	0.57	0.78	-2
OF_7		0.67	0.82	-6.3	0.56	0.74	-2.4		0.58	0.78	-3.4	0.54	0.77	-0.6
OF_1	**Cannonsville**	0.79	0.81	-8.8	0.73	0.78	-4.6	**Rondout**	0.65	0.76	-3.2	0.71	0.83	-4
OF_2		0.79	0.77	-8.4	0.72	0.73	-8.8		0.64	0.69	-2.5	0.69	0.78	-2.4
OF_3		0.79	0.80	-11.7	0.72	0.73	-8.9		0.64	0.78	-2.6	0.71	0.83	-4
OF_4		0.68	0.79	-10.4	0.51	0.70	-12.2		0.39	0.66	-2.1	0.58	0.75	-2.9
OF_5		0.73	0.66	0	0.72	0.75	0		0.61	0.77	0	0.56	0.79	0
OF_6		0.77	0.88	0.7	0.69	0.84	-3		0.61	0.80	-3.8	0.66	0.83	-0.3
OF_7		0.75	0.86	-7	0.68	0.82	-6.4		0.61	0.79	-4.2	0.71	0.83	-4

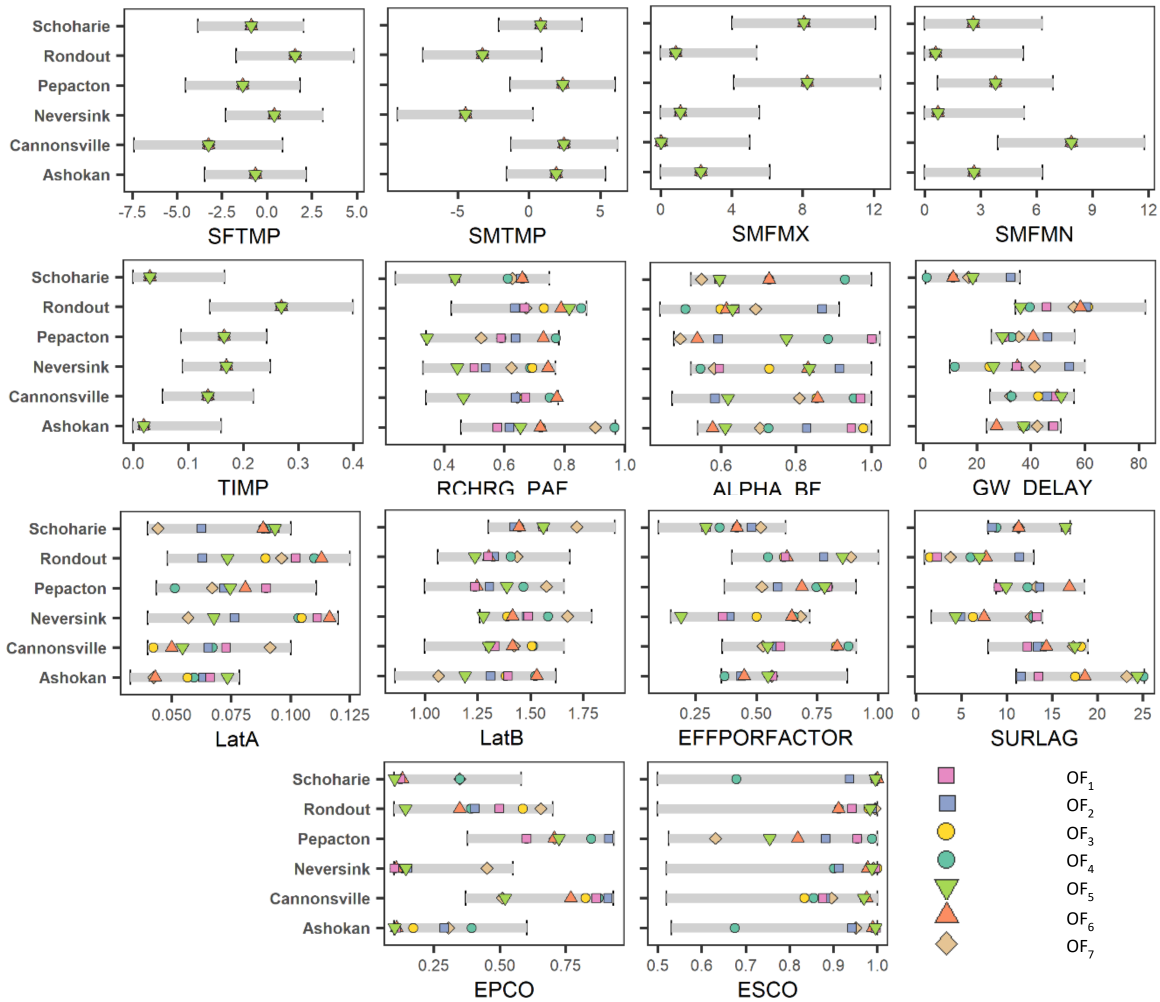


Figure 6.6 Uncertainty ranges of calibrated parameters using different objective functions for WOH watersheds (grey band is the behavioral range).

To better understand the difference in the objective functions' capability of simulating the daily flow variability, the streamflow duration curves for calibration and validation periods are shown in Figure 6.7 and Figure 6.8.

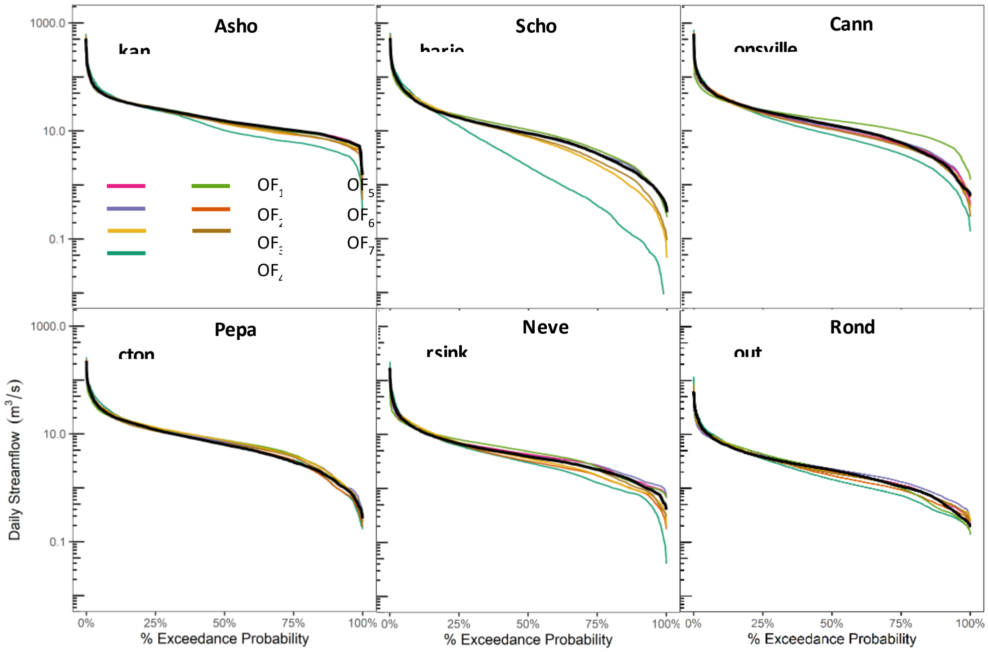


Figure 6.7 Flow duration curves for observed and SWAT-HS simulated streamflow during the calibration period of 2001-2010. The black line is for the observations, while the colored lines are simulated using different objective functions.

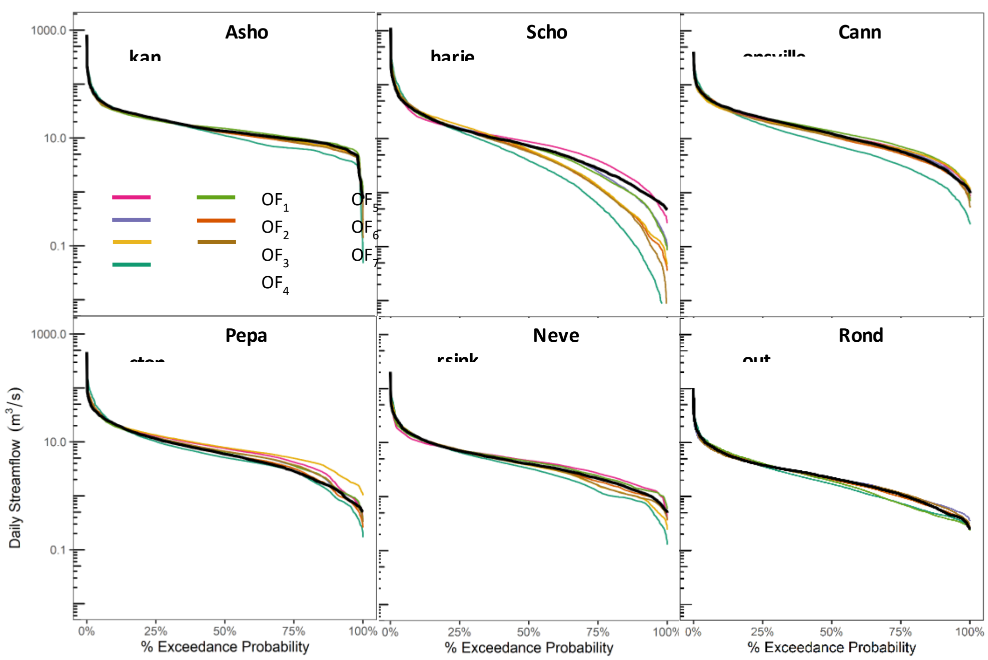


Figure 6.8 Flow duration curves for observed and SWAT-HS simulated streamflow during the validation period of 2011-2018. The black line is for the observations, while the colored lines are simulated using different objective functions.

Evaluation of BMA Models' Streamflow Simulation Uncertainty Assessment

Two probabilistic verification/uncertainty metrics (containing ratio (CR) and bandwidth ratio (BR)) are given in Table 6.7 for behavioral simulations obtained from calibration and BMA analysis. All the metrics were calculated using the 95% uncertainty intervals derived within the range of the 2.5% and 97.5% quantiles.

Table 6.7 95% uncertainty interval characteristics for behavioral set based on NSE (OF_1) and BMAs.

		Calibration 2001-2010		**Validation 2011-2018**			**Calibration 2001-2010**		**Validation 2011-2018**	
		CR	**BR**	**CR**	**BR**		**CR**	**BR**	**CR**	**BR**
OF_1	**Ashokan**	**0.75**	**0.29**	**0.71**	**0.32**	**Pepacton**	**0.73**	**0.43**	**0.78**	**0.53**
BMA_1		0.94	0.81	0.93	0.81		0.94	1.06	0.94	1.04
BMA_2		0.94	0.82	0.81	0.50		0.95	0.94	0.97	1.15
BMA_3		0.94	0.96	0.88	1.04		0.94	1.06	0.95	1.04
BMA_4		0.96	0.62	0.94	0.55		0.97	0.66	0.96	0.65
BMA_5		0.96	0.62	0.15	0.22		0.97	0.66	0.92	1.00
BMA_6		0.94	0.75	0.93	0.66		0.94	0.71	0.93	0.69
OF_1	**Schoharie**	**0.78**	**0.36**	**0.71**	**0.28**	**Neversink**	**0.77**	**0.55**	**0.70**	**0.62**
BMA_1		0.95	0.88	0.95	0.80		0.95	1.11	0.95	1.22
BMA_2		0.95	0.82	0.94	0.67		0.95	1.06	0.97	1.60
BMA_3		0.95	0.92	0.93	0.90		0.94	1.29	0.93	1.46
BMA_4		0.97	0.64	0.95	0.56		0.97	0.70	0.96	0.78
BMA_5		0.97	0.64	0.90	0.45		0.97	0.70	0.90	1.70
BMA_6		0.94	0.74	0.93	0.63		0.95	0.83	0.93	0.98
OF_1	**Cannonsville**	**0.79**	**0.45**	**0.78**	**0.47**	**Rondout**	**0.77**	**0.62**	**0.75**	**0.67**
BMA_1		0.95	1.21	0.96	1.47		0.95	1.18	0.96	1.29
BMA_2		0.96	1.07	0.94	1.21		0.95	1.11	0.97	1.46
BMA_3		0.95	1.12	0.94	1.35		0.95	1.26	0.96	1.42
BMA_4		0.97	0.64	0.94	0.76		0.98	0.72	0.97	0.78
BMA_5		0.97	0.64	0.89	0.64		0.98	0.72	0.97	1.19
BMA_6		0.94	0.74	0.94	0.90		0.95	0.81	0.93	0.90

From quantitative indices in Table 6.7, it can be seen that all BMAs had "good" performance in terms of containing ratio (>0.7) and BR (<1.5) across all watersheds. This, coupled with results from Table 6.6, shows the reliability of SWAT-HS ensemble simulations. The lower value of BR for behavioral sets (the "OF_1" rows in Table 6.7) in comparison to BR values for BMA_1 through BMA_6 indicates that uncertainty is underestimated when only considering individual simulations rather than a set of plausible predictions.

The advantage of having a wider uncertainty band is the higher probability of observed values falling in the uncertainty range. Higher CR values are achieved at the expense of higher BR values and vice versa. BMA analysis, with all different configurations, showed that more than 90% of the observations were captured for both calibration and validation periods, with slightly lower values for validation. Although having higher CR usually comes at the expense of a wider uncertainty band, many of the BMA models were able to achieve a CR values close to 1 and at the same time a lower BR value of less than 1. This was consistent for BMA4 configuration across all watersheds for both calibration and validation periods.

6.3.5. Conclusion

The results of this study show the ability of SWAT-HS to simulate streamflow for all NYC West of Hudson (WOH) watersheds. The performance evaluation metrics of NSE, KGE, and PBIAS showed satisfactory results. NSE and KGE were generally above 0.65 for both calibration and validation periods across all watersheds, while PBIAS stayed relatively low. Regarding uncertainty of the calibration results, assessment of parameter space showed minimal variation between different objective functions, indicating a high level of reliability of the simulation results. Analysis of uncertainty interval using BMA also confirmed the goodness of CI by having average BR less than 1.0 and CR higher than 0.8 and averaging 0.9 with a maximum of 0.97, meaning that the uncertainty band captured 80-97% of the observed streamflow values.

6.4. West of Hudson Reservoir Turbidity Models

During 2020, DEP completed the development and testing of turbidity models for Cannonsville, and Pepacton reservoirs. The models adopt CE-QUAL-W2 (referred to as W2), a two-dimensional hydrothermal and water quality model developed by U.S. Army Corps of Engineers (Cole and Wells 2013) as the provider of transport framework. Linked with W2's transport framework is a three size-class turbidity model that is the same as developed earlier for Schoharie, Ashokan, Neversink, Rondout, and Kensico reservoirs (Gelda and Effler 2007, Gelda et al. 2009, 2012, 2013). With this work, DEP now has turbidity models for all six WOH reservoirs, and the terminal Kensico Reservoir. Note that the W2 models for Cannonsville, Pepacton, and Neversink reservoirs have not been integrated into OST as of this reporting period, but they may be included in the future. A brief summary of the modeling of these two reservoirs is as follows.

6.4.1. Cannonsville Reservoir

Model setup: W2 model is based on finite-difference solution of partial differential equations for laterally averaged fluid motion and mass transport. It represents a reservoir in the form of a grid of cells formed by longitudinal segments and vertical layers. The geometry of the computational grid is determined by the boundaries of the longitudinal segments, the depth interval of the vertical layers, and average cross sectional widths. W2 setup for Cannonsville Reservoir with model segments and locations of inflows, outflows, in-stream and in-reservoir routine water quality monitoring sites is depicted in Figure 6.9. The reservoir was configured into a computational grid of two branches, 52 longitudinal segments, and 45 vertical layers. Model testing (calibration-validation) was performed for 2011-2019 (nine years), the period of most complete available data; however, extended period of application of the model also included a prior interval 1987-2010 (24 years).

Input data required by the model included bathymetry, hourly meteorology (air temperature, dew point, wind, and solar radiation), inflows, outflows, water surface elevation, inflow temperatures and inflow turbidities. Model testing data consisted of in-reservoir and outflow temperatures and turbidities.

Trout Creek flow for 1987-1996 (thereafter, obtained from USGS) was estimated from the following regression developed from historical paired measurements ($r^2 = 0.9$):

$$\log_{10} Q_{Tr} = 1.1278865537 \log_{10} Q_{WBDR} - 1.4255458603$$

Where, Q_{Tr} = Trout Creek inflow ($m^3\ s^{-1}$), and Q_{WBDR} = West Branch Delaware River inflow (WBDR) ($m^3\ s^{-1}$). All inflows and outflows were specified in the model at a daily timestep.

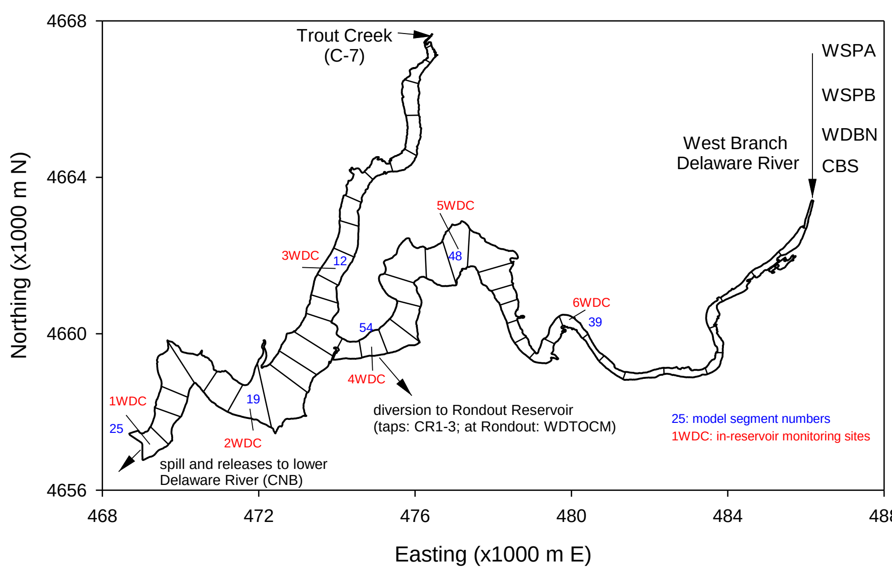


Figure 6.9 Cannonsville Reservoir: Inflows, outflows, in-stream and in-reservoir routine water quality monitoring locations, and W2 model segments. Selected model segments are also numbered according to the numbering scheme of W2.

The model requires specification of turbidity in WBDR and Trout Creek at a daily timestep. The following flow-turbidity relationships were developed using paired observations to estimate turbidity at a daily timestep.

$$\log_{10} Tn_{WBDR} = 0.6457412 - 0.7309948 \log_{10} Q_{WBDR} + 0.610647 (\log_{10} Q_{WBDR})^2; r^2 = 0.4$$

Where, Tn_{WBDR} = WBDR inflow turbidity (NTU), and Q_{WBDR} = WBDR inflow ($m^3 s^{-1}$)

$$\log_{10} Tn_{Tr} = 0.2202692 + 0.5070696 \log_{10} Q_{Tr} + 0.2420892 (\log_{10} Q_{Tr})^2; r^2 = 0.3$$

Where, Tn_{Tr} = Trout Creek inflow turbidity (NTU), and Q_{Tr} = Trout Creek inflow ($m^3 s^{-1}$). Meteorological data were obtained from National Weather Service station at Greater Binghamton Airport and from DEP sites in the watershed.

Model performance: Selected metrics of performance of the model with regard to predictions of temperature and turbidity are discussed here. The model performed well in tracking the seasonal stratification dynamics of the reservoir for 2011-2019, as represented in the patterns of volume-weighted average temperatures in selected water layers at site 1WDC (Figure 6.10). RMSE (root mean square error) was 1.2 ℃ for 0-5 m, 1.0 ℃ for 5-10 m, 1.1 ℃ for 10-20 m, and 1.4 ℃ for 20 m-bottom layers. The vertical details including the depth of thermocline, and temperature gradients, and temporal features including onset of stratification, duration of stratification, and turnover timing were also well simulated. The typical range of RMSE was 0.5 ℃ - 1.5 ℃ for the entire period of simulation. Evaluation of performance for the outflow temperature tests hydrodynamic features of envelope of outflow, in addition to thermal stratification regime aspects. The model indicated good performance for both the withdrawal (site WDTOCM; Figure 6.11), and release plus spill (site CNB) temperatures. RMSEs were 1.9 degrees Celsius and 2.1 degrees Celsius for these two locations. Some uncertainty remains in the specification of withdrawal level(s) and temperature observations that are not representative of the outflow water temperatures (e.g., in-stream warming below dam), that may have contributed to the slightly diminished performance.

In-reservoir vertical patterns of turbidity were generally well simulated (see Figure 6.12, for example, for August 2017-August 2019 interval). Turbidity in WBDR approached 300 NTU during an August 2018 storm and 200 NTU during an April 2019 storm. The model simulated the timing, location and magnitude of peak impact and subsequent attenuation well (Figure 6.12). It is also evident the model did not simulate well the benthic nepheloid layer (BNL) observed at the bottom depths of the reservoir formed during the September-October period (Figure 6.12, profiles 55-55 in 2017; and profiles 73-80). Effler et al. (1998) documented formation of BNL as a recurring phenomenon in this reservoir during the typical drawdown period of summer through early-autumn. Formation of BNL was attributed to the resuspension process; however, the specific sources and mechanisms responsible for formation and maintenance of BNL were not identified. In this study, sensitivity runs were conducted to investigate if current-driven resuspension could explain BNL. It was found that the currents near the sediment-water interface in Cannonsville Reservoir are not strong enough to generate the necessary shear stress to resuspend particles. Near-shore wave-driven resuspension of particles and subsequent transport via sediment focusing could be other possible mechanisms, which could be investigated with a 3-D model. Currently, a 3-D model for Cannonsville Reservoir is not available.

Withdrawal turbidity was well predicted by the model for 2011-2019 (RMSE = 2.5 NTU) that included periods of short-duration high turbidity (> 5 NTU; for example, in 2013 and 2015) events as well as low baseline values (< 5 NTU) (Figure 6.13). Turbidities when the withdrawal was off would have been generally > 10 NTU. Underprediction during summer-early-autumn period is likely due to the model's limitation to simulate BNL. Performance for the outflow location below dam was similar (RMSE = 4.6 NTU), although observations at this site were available only once a month.

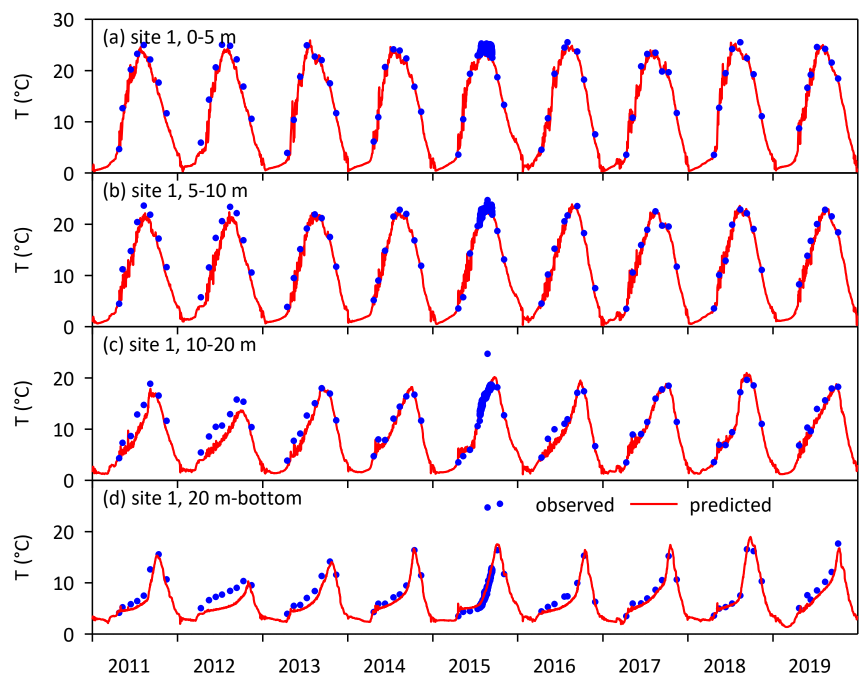


Figure 6.10 Comparison of observed and predicted values of volume-weighted average temperatures in selected layers of water at site 1WDC in Cannonsville Reservoir, 2011-2019: (a) 0-5 m, (b) 5-10 m, (c) 10-20 m, and (d) 20 m-bottom.

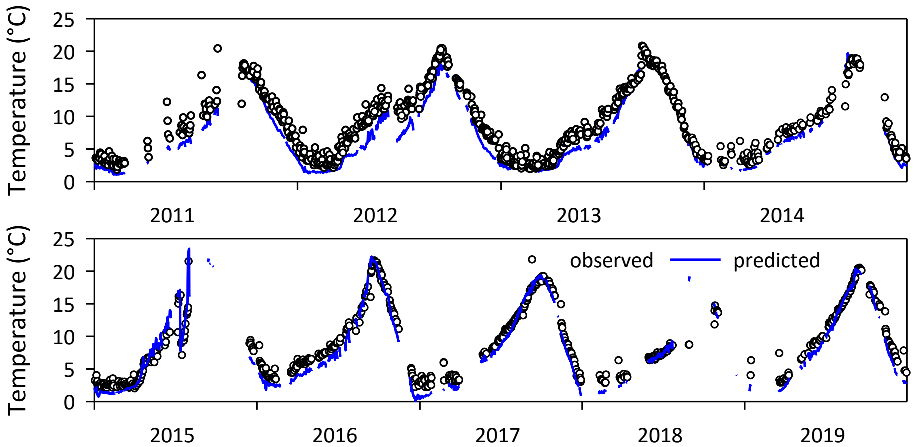


Figure 6.11 Performance of the model for Cannonsville Reservoir presented as comparison of observed and predicted time series of withdrawal temperatures, 2011-2019. Observations are recorded at site WDTOCM at the point of discharge into Rondout Reservoir.

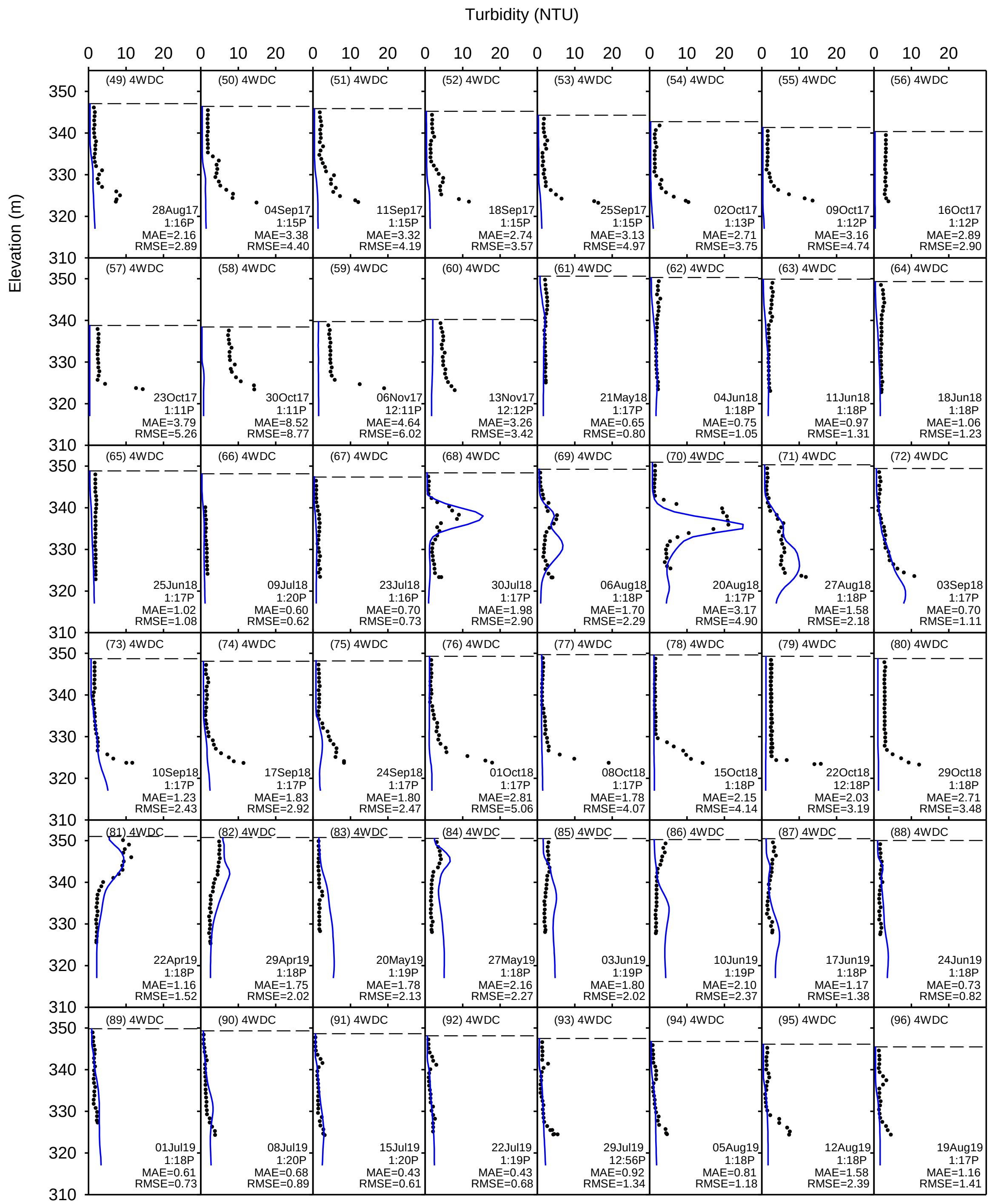


Figure 6.12 Performance of the model for Cannonsville Reservoir presented as comparison of selected predicted and observed vertical depth profiles of turbidity at site 4WDC. MAE and RMSE indicate mean absolute error (°C) and root mean square error (°C), respectively.

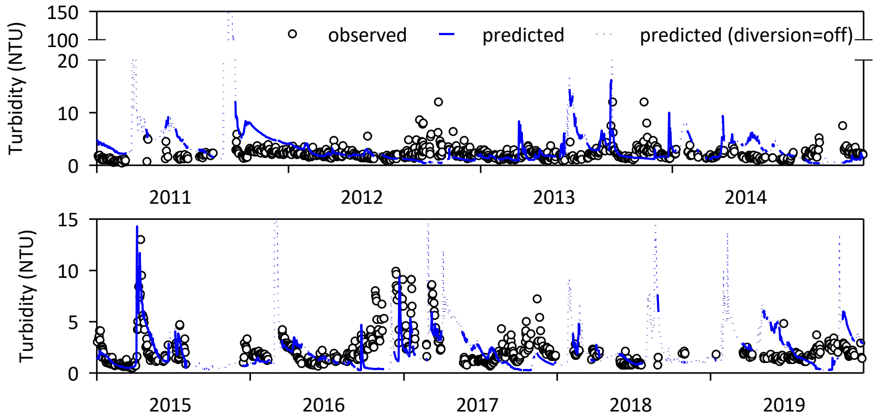


Figure 6.13 Performance of the model for Cannonsville Reservoir presented as comparison of observed and predicted time series of withdrawal turbidities, 2011-2019. Observations are recorded at site WDTOCM at the point of discharge into Rondout Reservoir.

6.4.2. Pepacton Reservoir

Model setup: W2 for Pepacton Reservoir was configured into a computational grid of two branches, 34 longitudinal segments in branch 1 and 5 in branch 2, 56 layers (1 m thick). Additionally, six tributary inputs, a four-level intake, and spill and releases (directed and conservation) were specified (Figure 6.14). Model testing was conducted for 1996-2018, the period of most complete available data; however, extended period of application of the model also included a prior interval 1987-1995. Currently, no high frequency monitoring exists on Pepacton Reservoir. Inflow temperatures were estimated from a stream temperature model for West Branch Delaware River. Inflow turbidities were estimated from the following regression relationships developed from the available data.

East Branch Delaware R.	$T_n = 4.2320714 - 0.0598603Q + 0.007739518\,Q^2$; r^2=0.74
Tremper Kill	$\log(T_n) = 0.1643131 + 0.4957943\log(Q) + 0.3145839\,(\log Q)^2$; r^2=0.44
Platte Kill	$\log(T_n) = 0.0819852 + 0.5917902\log(Q) + 0.3589172\,(\log Q)^2$; r^2=0.53
Mill Brook	$\log(T_n) = 0.0336839 + 0.6771539\log(Q) + 0.4437056\,(\log Q)^2$; r^2=0.49

Where, T_n = turbidity (NTU), and Q = flow ($m^3\ s^{-1}$).

Model Performance: For temperature and turbidity, model performance was evaluated by visualizing in-reservoir vertical profiles, in-reservoir time series plots, and outflow time series plots. Here, two of such plots are presented. Figure 6.15 compares observed and predicted temperatures in selected layers of water at site 3 for 1996-2018 (23 years). Figure 6.16 compares observed and predicted turbidities in withdrawal during the same period. The model simulated the features of thermal stratification well, including the timing of the onset of stratification, duration of stratification, and temperatures of the stratified layers (RMSE = 0.7 °C for 0-5 m and 20 m-bottom layers, and 1.1 °C for 5-10 m and 10-20 m layers; Figure 6.15). Similarly, the model also simulated the impact of most of the runoff events on withdrawal turbidity satisfactorily during the testing period (RMSE = 3.3 NTU, Figure 6.16). Underpredictions, particularly of the low turbidity observations, are attributed to absence of continuously monitored turbidity loading data and uncertainty in the flow-turbidity relationships for the inflow sources. Overall, these results are consistent with the previously reported modeling efforts of other NYC reservoirs (Gelda and Effler 2007, Gelda et al. 2009, 2012, 2013).

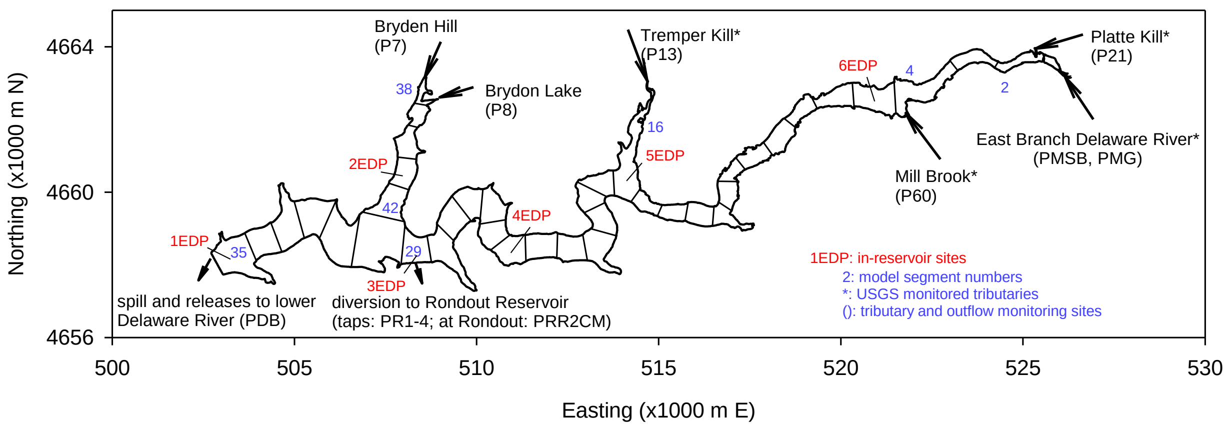


Figure 6.14 Pepacton Reservoir: Inflows, outflows, in-stream and in-reservoir routine water quality monitoring locations, and W2 model segments. Selected model segments are also numbered according to the numbering scheme of W2.

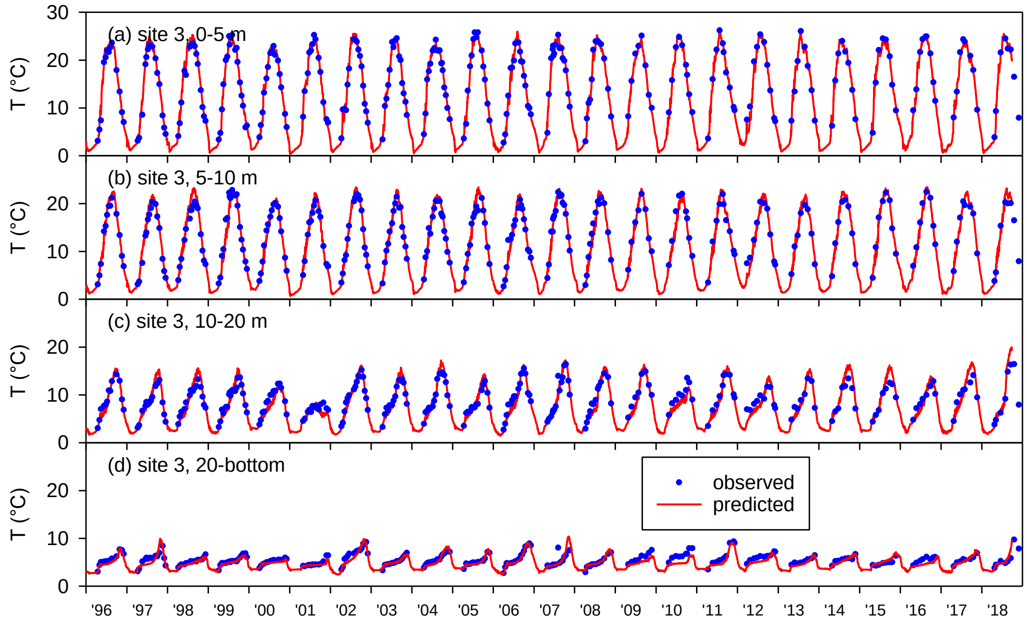


Figure 6.15 Time series of comparison of observed and predicted values of volume-weighted average temperatures (T) in selected layers of water at site 3 in Pepacton Reservoir, 1996-2018: (a) 0-5 m, (b) 5-10 m, (c) 10-20 m, and (d) 20 m-bottom.

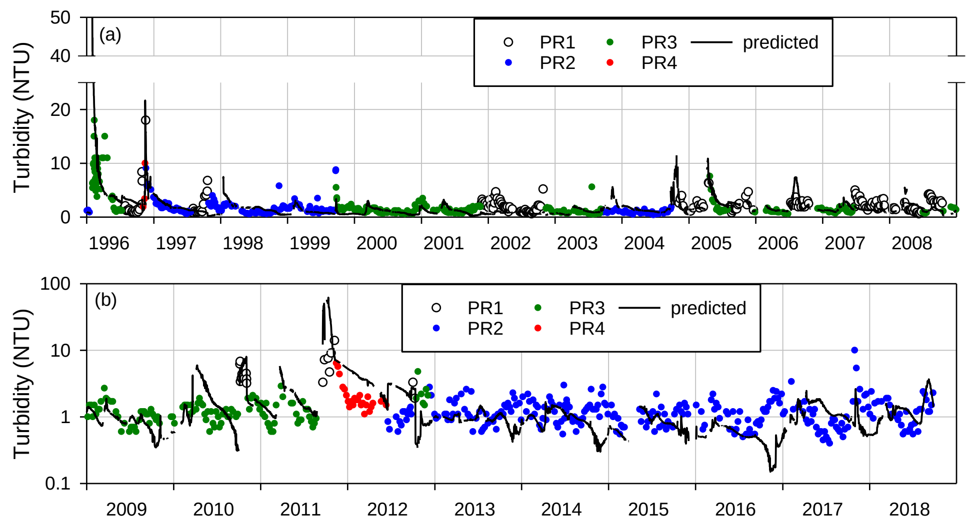


Figure 6.16 Performance of the turbidity model for Pepacton Reservoir presented as comparison of observed and predicted time series of withdrawal turbidity, 1996-2018. Observations are recorded at elevation taps sites PR1, PR2, PR3 and PR4. RMSE = 3.3 NTU. Note the y-axis scale is different in (a) and (b).

6.4.3. Ancillary Tasks Related to Reservoir Modeling

Data Analyses to Support Model Development:

To support development of turbidity models for Cannonsville and Pepacton reservoirs, some of the ancillary tasks completed were the following:

- Regression analysis of meteorological variables observed at watershed sites and offsite (National Weather Service) locations.
- Development of empirical stream temperature models for the West Branch Delaware River at Cannonsville Reservoir.
- Development of discharge-turbidity rating curves for the tributaries of Cannonsville, and Pepacton reservoirs.

6.5. Application of Models to Support Operational and Planning Decisions

DEP continued to use mathematical models such as W2 and OST (Operations Support Tool) to guide reservoir operations as well as long-term planning decisions. Selected examples of models' applications in 2020 are mentioned here.

Applications for planning purposes:

Time of Travel from Proposed Shokan WWTP on Butternut Creek to the West Side of the Dividing Weir of Ashokan Reservoir: Simulation experiments were conducted with a reconfigured W2 model for Ashokan Reservoir to assess the transport and dispersion of a hypothetical conservative tracer discharged into Butternut Creek, West Basin of Ashokan Reservoir. The median time of travel for the peak impact at the dividing weir was 12 days, with a dilution of approximately 10 million fold of WWTP concentration.

Applications for operational purposes:

May 1: Kensico Reservoir turbidity modeling was done to assess if alum addition was required during the planned reopening of Catskill Aqueduct on May 6, 2020 (Catskill Aqueduct Rehabilitation and Repair biofilm removal project). Various combinations of Catskill Aqueduct flow (300 – 500 MGD), duration of transition period (24 – 48 hours), Catskill Aqueduct turbidity during transition period (10 – 100 NTU) and 1.5 NTU after this period were considered. Other specifications included preflushing of Catskill Aqueduct with water from CDIS4 (Catskill-Delaware Interconnection at Shaft 4) for 24 hours with turbidity of 0.8 NTU, and ramping of Catskill Aqueduct at a rate of 50 MGD every hour for discharge rates up to 240 MGD. It was predicted that alum would not be required under plausible scenarios and as it turned out, no alum was necessary and turbidity level at Delaware Shaft 18 remained < 1 NTU.

September-October: Several runs were conducted with Kensico W2 model to evaluate scenarios of extended drawdown of the West Basin of Ashokan Reservoir intended to create void prior to beginning of the refilling season in November. Guided by the model simulations, drawdown continued to an elevation of ~ 569 feet and no impact on turbidity level at Delaware Shaft 18 was observed during this period.

6.6. Hydroclimatological Indicators Determined from Global Climate Model Forecasts

Hydroclimatological indicators were evaluated for Ashokan watershed in the Catskill Mountains region of the New York City water supply watershed. Downscaled and secondary bias-corrected climate projections from CMIP5 (Coupled Model Intercomparison Project Version 5) from 20 global climate models (GCMs) were used to compute climate indices including extreme weather indicators, such as number of frost days, summer days, heat waves, and cold spells (Gelda et al. 2019). Two greenhouse gases emission scenarios (RCP 4.5 and RCP 8.5; RCP: Representative Concentration Pathway) were considered. The same climate projections were used to drive a hydrologic model (GWLF: Generalized Watershed Loading Function) and identify potential changes in the hydrologic components of the watershed, e.g., snowfall, snowpack, and annual peak flow in Esopus Creek (Gelda et al. 2020).

Most of the indices were computed on an annual basis for 1950-2099 to allow identification of extreme weather and hydrologic conditions of multi-year recurrence interval. Selected results are presented in the format of time series plots of multi-model ensemble mean as well as range of indices (Figure 6.17). Results show that observed values of the indices for the historical period are well within the predicted, multi-model ensemble range. Furthermore, several of the indices suggest a significant shift in the hydroclimatology of the watershed in the future (see Table 6.8).

Certain warm weather indicators suggest longer and more frequent heat waves, doubling (to 100) summer days, and increasing tropical nights beginning in the 2030s, while cold weather indicators point to fewer and shorter cold spells, 50% fewer icing days by 2070s, and declining snowfall and snowpack. Average and five-day total precipitation and heavy precipitation days are projected to rise modestly, with no change in maximum consecutive dry and wet days. All precipitation indicators show substantial variability. Average streamflow for December-March is projected to increase by 25% from the first 20 years to the last 20 years of the century, while the projected average for April-May decreases by 18%. It is also expected that one-day peak flow would rise and events with flow larger than Hurricane Irene will occur. Minimum seven-day moving average flow is expected to remain steady (Table 6.8).

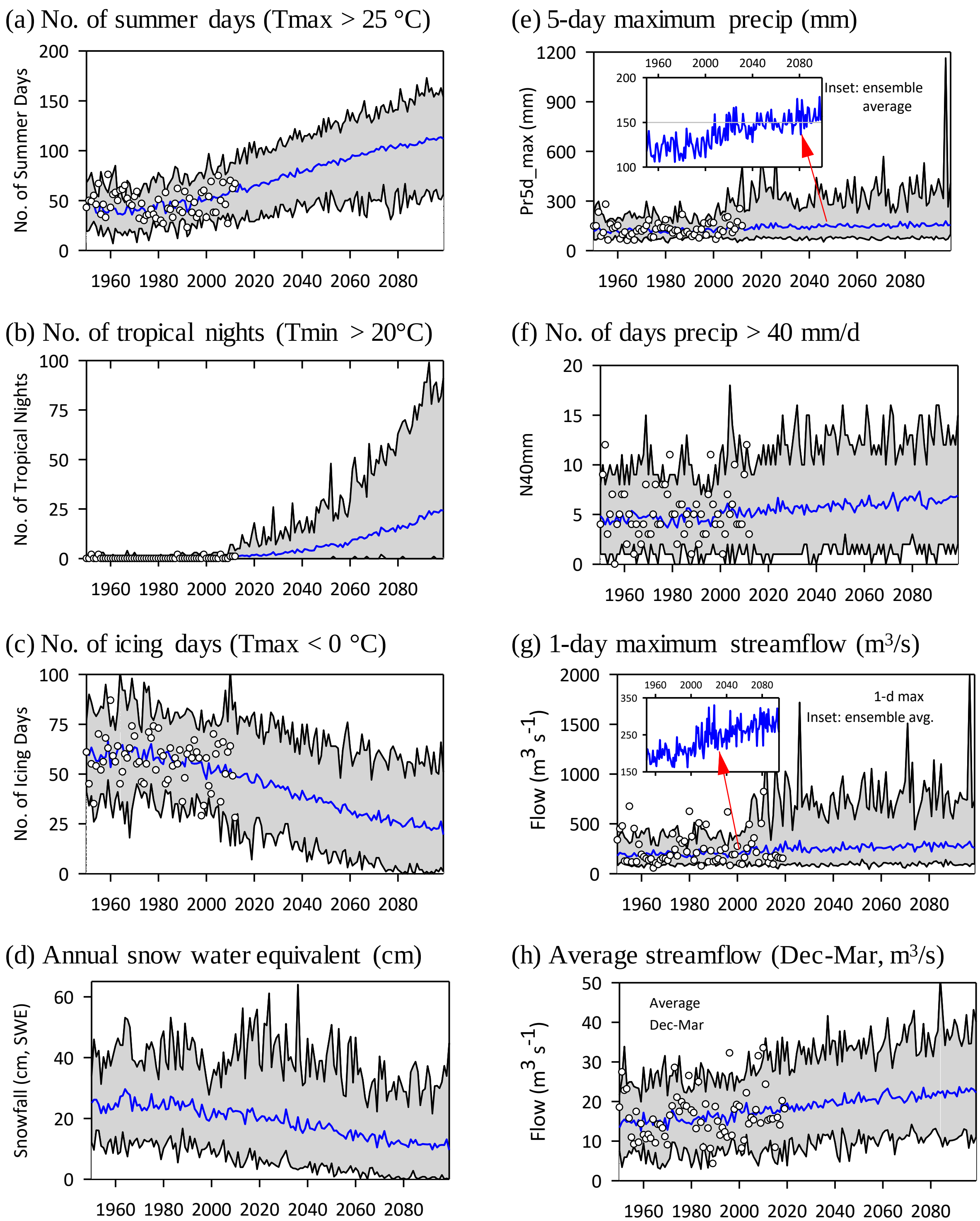


Figure 6.17 Past and projected trends in selected hydroclimatological indicators for Ashokan watershed in the Catskill Mountains region of New York.

Table 6.8 Climate indicators trend: Ashokan Reservoir (40 model-scenario ensemble). All indices were computed from values computed on an annual basis first*.

Climate Indicator		baseline 2000-2019	mid-century 2040-2069	late-century 2070-2099	Change from baseline to		%Change from baseline to	
					mid-century	late-century	mid-century	late-century
	Warm weather indices							
Tmax	Avg. daily maximum temperature (°C)	13.1	15.4	16.8	2.3	3.6	**17.2**	**27.7**
N_HeatW	No. of heat waves	0.3	2.0	3.8	1.7	3.5	**643.3**	**1320.0**
HtW_mxD	Maximum duration of a heat wave (d)	0.9	4.5	8.7	3.6	7.9	**422.2**	**922.4**
NSummrD	No. of summer days (Tmax > 25 °C)	57.6	89.2	106.6	31.6	49.0	**54.9**	**85.0**
NTropNt	No. of tropical nights (Tmin > 20°C)	0.9	7.4	17.9	6.5	17.1	**756.6**	**1990.2**
GSL_NA	Growing season length (d)	150.4	174.3	191.4	23.8	40.9	**15.8**	**27.2**
	Cold weather indices							
Tmin	Avg. daily minimum temperature (°C)	2.1	4.4	5.9	2.3	3.8	**111.2**	**180.0**
N_ColdW	No. of cold spells (Tmax < 0°C for 3 d)	6.2	4.3	3.1	-1.9	-3.0	**-30.4**	**-49.0**
ClW_mxD	Maximum duration of a cold spell (d)	11.9	8.6	6.8	-3.3	-5.1	**-28.1**	**-42.5**
NIcingD	No. of icing days (Tmax < 0 °C)	50.3	33.8	25.2	-16.6	-25.1	**-32.9**	**-49.9**
NFrostD	No. of frost days (Tmin < 0°C)	149.2	121.9	104.8	-27.4	-44.4	**-18.3**	**-29.8**
Snowfall	Snowfall (SWE, cm)	21.7	15.5	11.9	-6.1	-9.8	**-28.3**	**-45.2**
Snowpack3/15	Snowpack (SWE, cm, Mar-15)	7.3	3.1	1.9	-4.2	-5.4	**-58.0**	**-73.4**
	Precipitation Indices							
Avg_all	Average (mm/d)	3.7	3.9	4.0	0.2	0.3	**5.1**	**8.2**
90p_all	90th percentile (mm/d)	11.8	12.3	12.6	0.5	0.8	**4.2**	**6.5**
99p_all	99th percentile (mm/d)	47.8	51.4	53.3	3.6	5.4	**7.4**	**11.3**
Max_all	Maximum (mm/d)	91.3	101.1	106.6	9.8	15.3	**10.7**	**16.7**
N_wet	No. of wet days	139.6	140.6	140.2	1.0	0.6	**0.7**	**0.4**
N_10mm	No. of days > 10 mm/d	42.1	43.4	44.3	1.3	2.2	**3.2**	**5.1**
N_20mm	No. of days > 20 mm/d	19.1	20.5	21.2	1.4	2.1	**7.2**	**11.1**
N_40mm	No. of days > 40 mm/d	5.3	5.9	6.5	0.7	1.2	**12.4**	**22.5**
Avg_wet	Average of wet days (mm/d)	9.8	10.2	10.5	0.4	0.8	**4.3**	**7.8**
Max5Day	5-day maximum (mm)	134.0	148.7	155.6	14.7	21.6	**11.0**	**16.1**

CDD_max	Maximum no. of consecutive dry days	15.0	14.9	15.2	-0.1	0.2	**-0.9**	**1.4**
CWD_max	Maximum no. of consecutive wet days	7.5	7.8	7.9	0.3	0.5	**4.0**	**6.3**
Sum_R95p	Total [of days > 95th percentile (mm)]	413.9	473.2	516.1	59.4	102.3	**14.3**	**24.7**
Sum_R99p	Total [of days > 99th percentile (mm)]	144.7	185.4	208.3	40.7	63.6	**28.1**	**44.0**
SDv_all	Standard deviation (mm/d)	9.7	10.4	10.8	0.7	1.1	**7.2**	**11.6**
	Streamflow Indices							
Avg_s1	Average (Dec-Mar, m3/s)	17.8	20.7	22.0	2.9	4.3	**16**	**24**
Avg_s2	Average (Apr-May, m3/s)	18.9	16.0	15.6	-3.0	-3.3	**-16**	**-18**
Avg_s3	Average (Jun-Sep, m3/s)	4.9	4.6	4.8	-0.2	0.0	**-5**	**-1**
Avg_s4	Average (Oct-Nov, m3/s)	14.6	15.2	15.0	0.6	0.4	**4**	**3**
Avg_all	Average (Jan-Dec, m3/s)	13.1	13.6	14.0	0.5	0.9	**4**	**7**
SDv_all	Standard deviation (m3/s)	22.7	24.5	25.7	1.8	3.0	**8**	**13**
Max1Day	1-day maximum (m3/s)	229.4	261.2	280.5	31.8	51.1	**14**	**22**
Min1Day	1-day minimum (m3/s)	0.3	0.3	0.2	0.0	0.0	**-4**	**-8**
Max3Day	3-day MA maximum (m3/s)	140.7	157.8	168.0	17.1	27.3	**12**	**19**
Min3Day	3-day MA minimum (m3/s)	0.3	0.3	0.3	0.0	0.0	**-3**	**-8**
Max7Day	7-day MA maximum (m3/s)	84.7	91.5	96.1	6.8	11.4	**8**	**13**
Min7Day	7-day MA minimum (m3/s)	0.3	0.3	0.3	0.0	0.0	**-3**	**-7**
Max30Day	30-day MA maximum (m3/s)	43.6	44.3	45.5	0.7	1.9	**2**	**4**
Min30Day	30-day MA minimum (m3/s)	0.6	0.6	0.6	0.0	0.0	**-2**	**-7**
Max90Day	90-day MA maximum (m3/s)	27.6	29.2	29.9	1.5	2.3	**6**	**8**
Min90Day	90-day MA minimum (m3/s)	1.8	1.7	1.7	-0.1	-0.1	**-5**	**-4**
NHPulse	No. of high pulses	13.2	13.9	14.1	0.7	0.9	**6**	**7**
HPulseD	Duration of high pulses (d)	7.6	7.5	7.6	-0.1	0.0	**-2**	**0**
NLPulse	No. of low pulses	5.0	5.2	5.1	0.1	0.0	**3**	**0**
LPulseD	Duration of low pulses (d)	20.1	20.6	21.7	0.5	1.6	**2**	**8**
NRises	No. of rises	58.9	61.3	61.9	2.4	3.0	**4**	**5**
Rise_R	Rate of rises (m3/s/d)	18.1	19.0	19.9	0.9	1.8	**5**	**10**
NFalls	No. of falls	305.4	303.0	302.3	-2.4	-3.0	**-1**	**-1**
Fall_R	Rate of falls (m3/s/d)	-3.5	-3.8	-4.0	-0.4	-0.6	**10**	**17**

**for definitions, see Richter, B. D., et al. (1996). "A Method for Assessing Hydrologic Alteration within Ecosystems. Conservation Biology, 10, 1163-1174, and Sillmann, J., et al. (2013). "Climate extremes indices in the CMIP5 multimodel ensemble: Part 1. Model evaluation in the present climate." J. Geophys. Res. Atmos., 118(4), 1716-1733.*

6.7. Development of Climate Change Indices for the NYC Water Supply Watershed

The effects of climate change on the supply of high quality drinking water are of particular concern for DEP. A changing climate is predicted to result in warmer average temperatures and higher precipitation coupled with shifting hydrologic patterns. To better understand the trends of a changing climate, DEP has been working on the development of climate change indicators for the water supply watershed based on long-term datasets of meteorological, hydrological, and water quality records. The work was initially described in the 2019 Watershed Water Quality Annual Report, and this section will discuss progress made in 2020 on the calculation of these trends.

In 2019, effort was focused on defining the indicators to be analyzed, identify datasets, and initial steps in writing scripts to calculate the indicators and plot results. The base coding was written using the python language to access data stored in a SQL database. Python provides flexible coding structure to summarize the raw time-series data, calculate appropriate trend statistics and plot the results in either static or interactive formats. The analysis coding was written to enable future modifications to easily be made to add new indicators, update the plotting style, use a subset of the period of record, or change the trend statistics used. Trend statistics were initially calculated using linear regression over the period of record available for each indicator. The initial indicators computed were meteorological, focusing on annual trends in precipitation and temperature using NOAA airport and PRISM gridded datasets. Some preliminary results were presented in the 2019 annual report.

In 2020, additional code was written to calculate indicators based on USGS streamflow data, as well as DEP water quality and water supply operations data. In addition, new modules have been created to calculate other trend statistics, such as Sen’s slope, and generate interactive summary plots. While the meteorological indicators are typically based on annual aggregations, such as the number of frost days per year or total annual precipitation volume, many streamflow and water quality indicators vary seasonally, so coding had to be developed to partition annual trends by month. This enables DEP to assess not just annual indicators, such as the change in total streamflow volume, but to explore whether the seasonal pattern of streamflow is changing in accordance with predictions of earlier spring peak flows.

Figure 6.18 displays the results of some sample hydrologic analyses for Schoharie Creek at Prattsville. This gage has recorded observations starting in 1902, providing us with a very long period of record to review for trends. We see a very small increase in the minimum one-day flow from the start of the period of record, corresponding to minimum base flow, but a much larger increase in one-day maximum flow. A possible explanation of this increase could be that more extreme events are resulting in higher peak flows, but this will require further investigation. We are also reviewing how the timing of these flows is changing by analyzing when these minimum and maximum flows occur during each year. Figure 6.18c and d show trends of these extreme flows occurring later in the year, with low-flows later in summer, while maximum flows are also trending later. However, there is clearly a seasonal split between peak flows occurring in late-fall and mid-winter, possibly resulting from different sources, such as extreme precipitation in the fall or snowmelt.

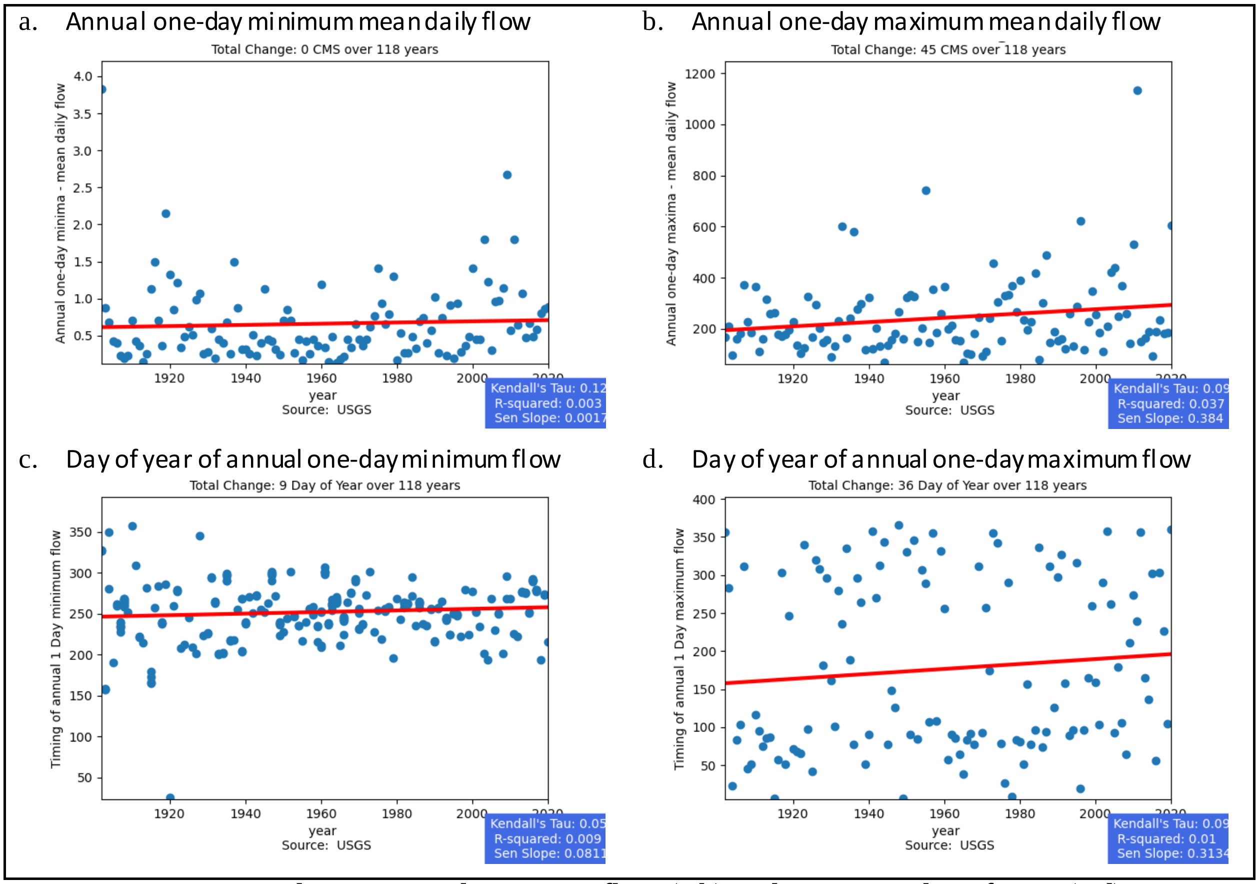


Figure 6.18 Annual extreme 1-day stream flow (a,b) and timing as day of year (c,d) at USGS Gage 1350000 (Schoharie Creek at Prattsville, NY), 1902-2020.

Table 6.9 summarizes the results of extreme flow events at various time-scales for Schoharie Creek at Prattsville. Similar to the one-day extremes, Schoharie Creek does show a shifting pattern in both the flow rate and timing during longer analysis periods. To further investigate the issue of streamflow timing, we have calculated trends of monthly basin-adjusted streamflow depth (Table 6.10). This shows further evidence that the pattern of flow throughout the year is changing, with lower flows in the spring and generally higher flows as other times of the year.

Table 6.9 Annual mean daily streamflow events at USGS Gage 1350000 (Schoharie Creek at Prattsville NY), 1902-2020.

Flow Event	Change Over Time (m^3/s)	Kendall Tau	Sen Slope	Change Over Time (Day of year)	Kendall Tau	Sen Slope
1-day maxima	45.3	0.096	0.384	37.0	0.098	0.3134
1-day minima	0.2	0.123	0.0017	9.6	0.054	0.0811
3-day maxima	32	0.109	0.2789	16.2	0.051	0.1373
3-day minima	0	0.092	0.0013	1.5	0.01	0.0129
7-day maxima	22.5	0.129	0.1909	21.5	0.086	0.2596
7-day minima	0.1	0.067	0.0011	3.1	0.018	0.0263
30-day maxima	5.1	0.072	0.0435	20.5	0.115	0.1739
30-day minima	0.2	0.056	0.0013	1.1	0.009	0.0093
90-day maxima	0.4	0.009	0.0031	0.0	-0.003	0
90-day minima	0.3	0.049	0.0025	-3.0	-0.016	-0.025

Table 6.10 Rate of change in basin-normalized flow depth (mm/day) by month at USGS Gage 1350000 (Schoharie Creek at Prattsville, NY), 1902-2020

Month	Mean Basin-Normalized Flow Depth			Minimum Basin-Normalized Flow Depth			Maximum Basin-Normalized Flow Depth		
	Annual Change (mm)	Kendall Tau	Total Change (mm)	Annual Change (mm)	Kendall Tau	Total Change (mm)	Annual Change (mm)	Kendall Tau	Total Change (mm)
January	0.0006	0.014	0.0708	-0.0021	0.062	-0.2478	0.001	-0.009	0.118
February	0.0008	0.015	0.0944	-0.0046	0.096	-0.5428	0.0013	-0.025	0.1534
March	-0.0079	-0.113	-0.9322	-0.0202	0.012	-2.3836	0.0002	-0.05	0.0236
April	-0.0006	-0.007	-0.0708	0.0006	-0.036	0.0708	-0.0009	0.005	-0.1062
May	0.0016	0.027	0.1888	0.0095	-0.002	1.121	0	0.055	0
June	-0.0002	-0.009	-0.0236	-0.0014	0.057	-0.1652	0.0004	-0.012	0.0472
July	0.0011	0.079	0.1298	0.0044	0.075	0.5192	0.0003	0.082	0.0354
August	0.0003	0.037	0.0354	0.0011	0.088	0.1298	0.0002	0.033	0.0236
September	0	-0.003	0	-0.0002	0.005	-0.0236	0	-0.004	0
October	0.0027	0.086	0.3186	0.0094	0.071	1.1092	0.0004	0.062	0.0472
November	0.0062	0.11	0.7316	0.0264	0.119	3.1152	0.0019	0.106	0.2242
December	0.0074	0.133	0.8732	0.0248	0.22	2.9264	0.0036	0.095	0.4248

DEP is currently reviewing the analyses completed for meteorological, streamflow and water quality indicators, and considering revisions to the methodology such as additional trend metrics or aggregation of individual indicators. Additional indicators may be added to fill gaps in the overall analysis, and will be computed as necessary. Once all analyses are completed, we expect to draft a stand-alone report summarizing the complete results of the project. Future versions of the report can also be published as new data are included in the trends or additional suites of indicators are added to the analysis.

6.8. Development of a Fate and Transport Model for UV_{254} in Neversink Reservoir

The development and validation of a model to predict the fate and transport of disinfection byproduct precursors in water supply reservoirs is an ongoing goal of the water quality modeling section. A model to predict the fate and transport of trihalomethane formation potential (THMfp) and haloacetic acid formation potential (HAAfp) is believed to be the best approach to address the DBP precursor issue in the water supply. As a database of formation potential data from streams, reservoir water columns, and keypoints in the Cannonsville and Neversink systems is being assembled, DEP is developing an alternative model to predict levels of an optical proxy or surrogate for formation potential. The optical measurement for which a model is underdevelopment is UV_{254}, the absorption coefficient for ultraviolet light at a wavelength of 254 nm. Such a model is currently under development for a number of reasons including: (1) UV_{254} is correlated to formation potential in WOH watersheds, (2) UV_{254} is relatively inexpensive to measure, (3) there is currently a more substantial database of UV_{254} measurements relative to formation potential, and (4) as an optical measurement, UV_{254} observations can be quickly reported to a server and used together with other information to guide short term operations of the water supply. UV_{254} is now included in the calculation of a water quality index (WQI) that provides a weighted average measure of overall water quality of source waters.

The model framework selected is UFILS4, a one-dimensional hydrothermal and water quality model developed by the Upstate Freshwater Institute. UFILS4 has been previously applied and validated for hydrothermal and eutrophication predictions for NYC water supply reservoirs. The hydrothermal simulations of UFILS4 have been validated for Cannonsville Reservoir for 1988-2004 (Owens 1998), while the eutrophication predictions have been validated for 1994-2002 (Doerr et al. 1998). The eutrophication component has the ability to simulate cycling of organic carbon (dissolved and particulate), major fractions of inorganic and organic phosphorus and nitrogen, dissolved oxygen, and chlorophyll. UFILS4 has also been applied to simulate THMfp in Cannonsville (Stepczuk et al. 1998) and other WOH reservoirs (Effler et al. 2005).

UFILS4 is a one-dimensional vertical reservoir model; it predicts temperature and water quality on a daily time step over the full depth of the reservoir. Variations in temperature and water quality in horizontal directions are neglected by assuming complete mixing across the length and width of the reservoir basin. The setup and testing of UFILS4 for simulation of temperature and UV_{254} for recent years at Cannonsville was described in the 2019 Watershed Water Quality Annual Report. Here we describe setup and testing for Neversink for the five-year period, 2016-2020.

The first step in the setup of the model is to establish a water balance for the reservoir. For this 1D model application, the water balance considers gauged and ungauged inflows, outflow (spill, dam release, and water supply diversion), and change in storage. Daily values of storage are determined from the observed water surface elevation using the 2015 bathymetric survey of the reservoir completed byUSGS. Gauged inflow is the Neversink River at Claryville, measured by USGS, and the outflows are measured by DEP. The only quantity that is not measured is the ungauged inflow, and daily values of this are computed from a daily water balance. When this computed ungauged inflow is then used in the model inputs, the computed reservoir storage and water surface elevation will match the observations. The observed reservoir water surface elevation for 2016-2020 at Neversink is shown in Figure 6.19. A range of reservoir drawdown conditions occurred, with greater than average drawdown in 2016, very little drawdown in 2018, and typical drawdown in the remaining three years. Application of the model for historic conditions that include this range of conditions presents a good test for the model.

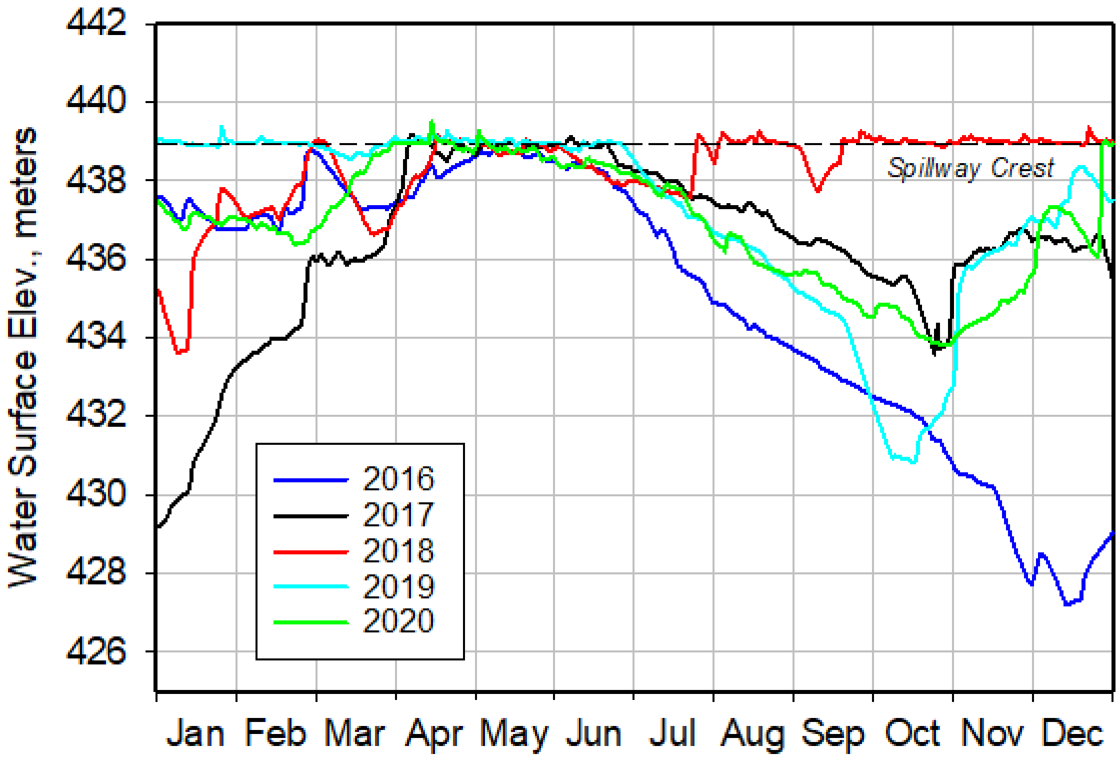


Figure 6.19 Observed water surface elevation in Neversink Reservoir for 2016 through 2020, based on BWS datum. Hydrothermal and water quality model predictions of water surface elevation are identical as a result of the calculation of ungauged inflow to the reservoir.

As an example of these water balance components, the time series of daily values of gauged inflow (Neversink River at Claryville, measured by USGS), ungauged inflow (computed from the water balance), and the spill, dam release, and water supply diversion for April through September 2017 are shown in Figure 6.20.

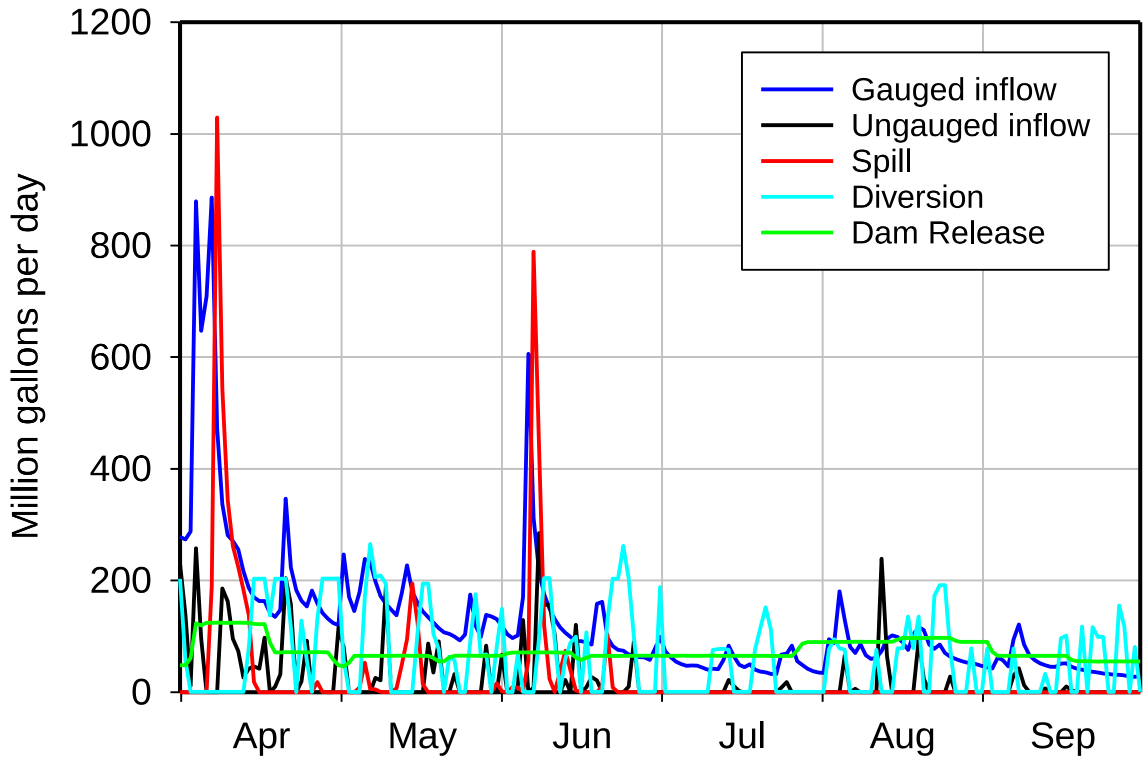


Figure 6.20 Component of inflow and outflow for Neversink Reservoir, April – September 2017. Gauged inflow, spill, diversion and release are measured, and ungauged inflow is computed from a reservoir water balance.

6.8.1. Hydrothermal Model

The hydrothermal model computes the daily variation of water temperature over the full depth of the reservoir, and the daily variation of the temperature of outflows (spill, diversion, and dam release). Input data for the hydrothermal model are the inflow and outflow components described above, daily values of the temperature of inflows, and daily average values of meteorological variables (air and dew point temperatures, wind speed, incident solar radiation, and cloud cover fraction). Stream inflow temperatures are measured by DEP; on days with no measurements, an empirical equation is used to estimate the stream temperature based on the measured air temperature. Meteorology is measured by DEP at a station on the Neversink Dam.

An example of input data for the hydrothermal model is given in Figure 6.21, which shows the variation of daily average air temperature, dew point temperature, and Neversink River water temperature for 2020. The dew point temperature is always less than or equal to the air temperature; as the difference between air and dew point temperature increases, the relative humidity decreases.

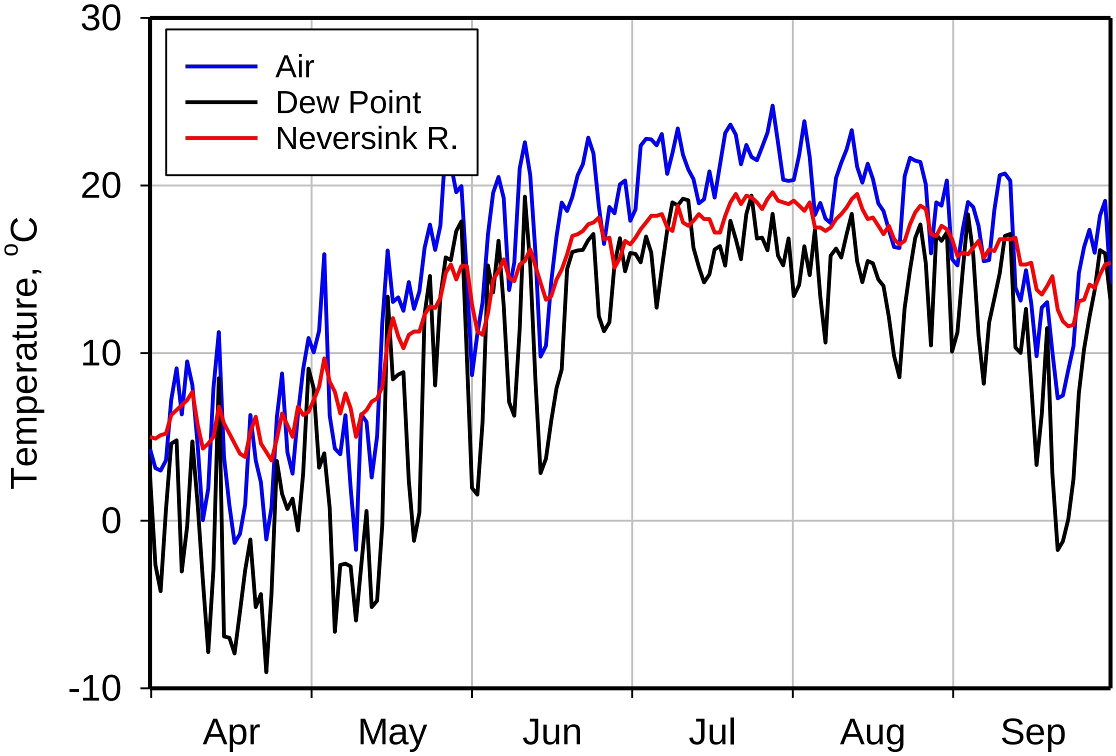


Figure 6.21 Daily temperatures used as input by the hydrothermal model for April – September 2020: air temperature, dew point temperature, and Neversink River water temperature.

The important predictions of the hydrothermal model are the predictions of water temperature over the depth of the water column, and the temperature of the outflows. Here the predictions of water supply diversion temperature are compared with measurements to assess the accuracy of the model. Predictions are compared to observations in Figure 6.22 to Figure 6.26, for 2016 through 2020, respectively. The model predicts diversion temperature only on days when diversion is actually occurring, or when the diversion flow rate is greater than zero.

Table 6.11 shows the total number of days in each of these five years that diversion from Neversink to Rondout was occurring. The temperature predictions are good. Predicted vertical temperature profiles in the water column also compared well to observations. Based on these results, the hydrothermal component of the model has been validated for this five-year period.

Table 6.11 Number of days that the Neversink Aqueduct was in operation for the 5 years of model testing described here.

Year	Neversink Aqueduct in Operation, days
2016	146
2017	150
2018	118
2019	95
2020	140

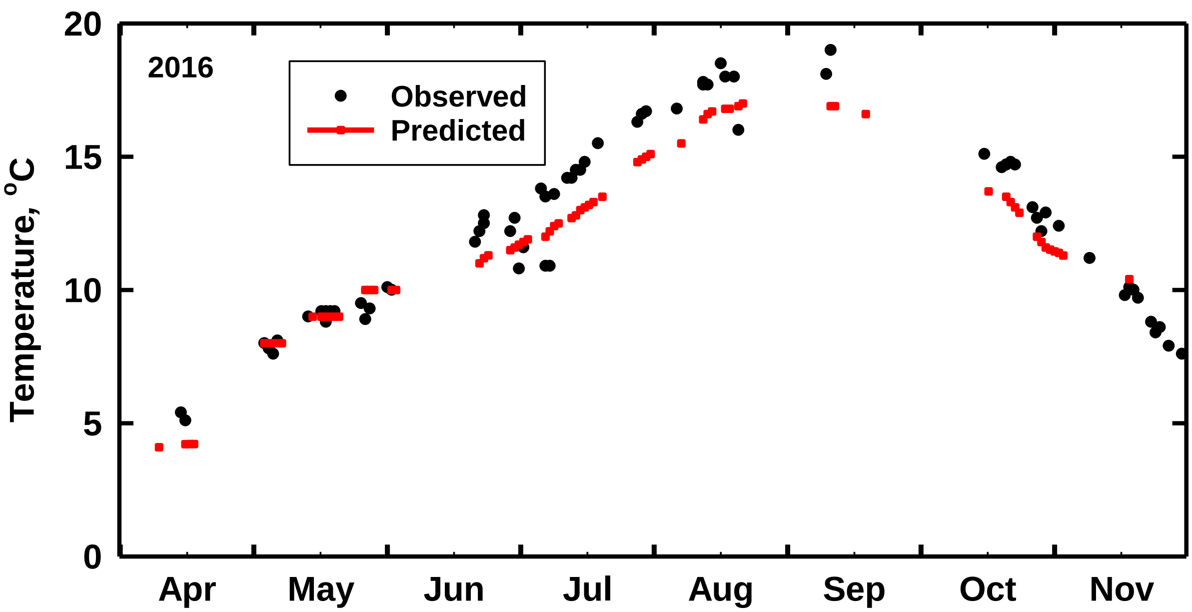


Figure 6.22 Observed and predicted temperature of the drinking water diversion from Neversink Reservoir for April-November 2016. The model makes predictions for days when the diversion rate exceeds 5 MGD.

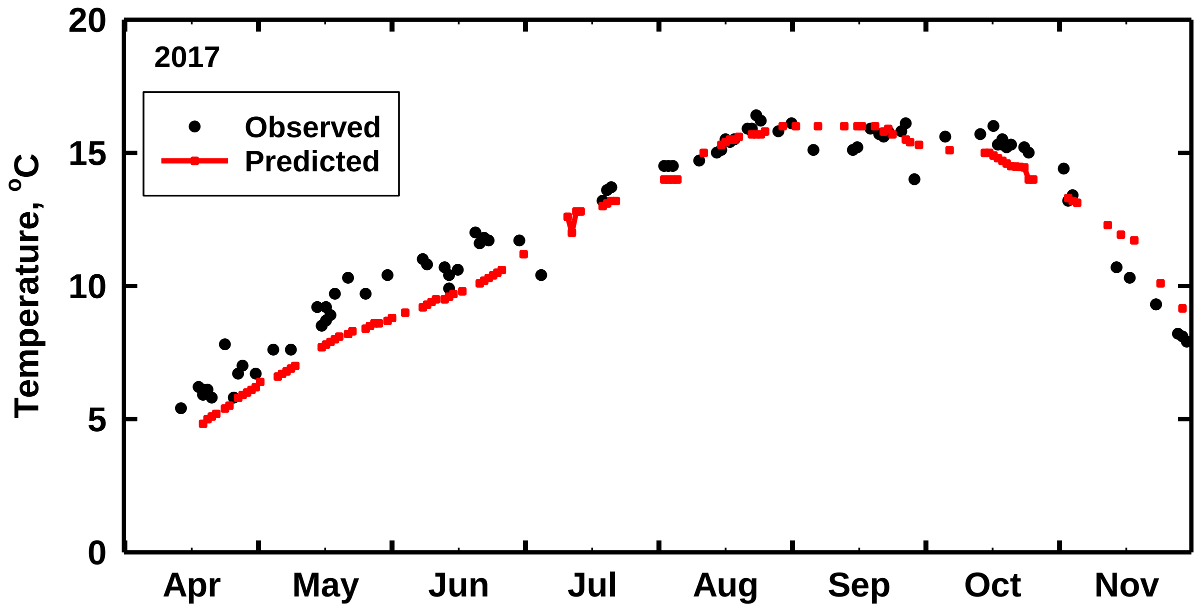


Figure 6.23 Observed and predicted temperature of the drinking water diversion from Neversink Reservoir for April-November 2017. The model makes predictions for days when the diversion rate exceeds 5 MGD.

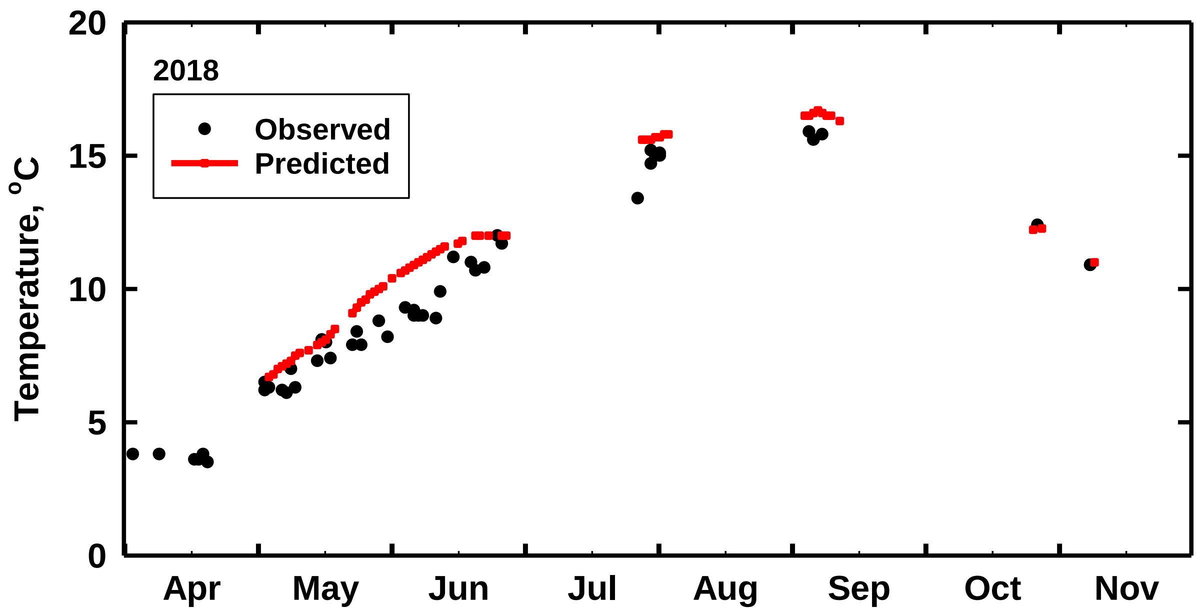


Figure 6.24 Observed and predicted temperature of the drinking water diversion from Neversink Reservoir for April-November 2018. The model makes predictions for days when the diversion rate exceeds 5 MGD.

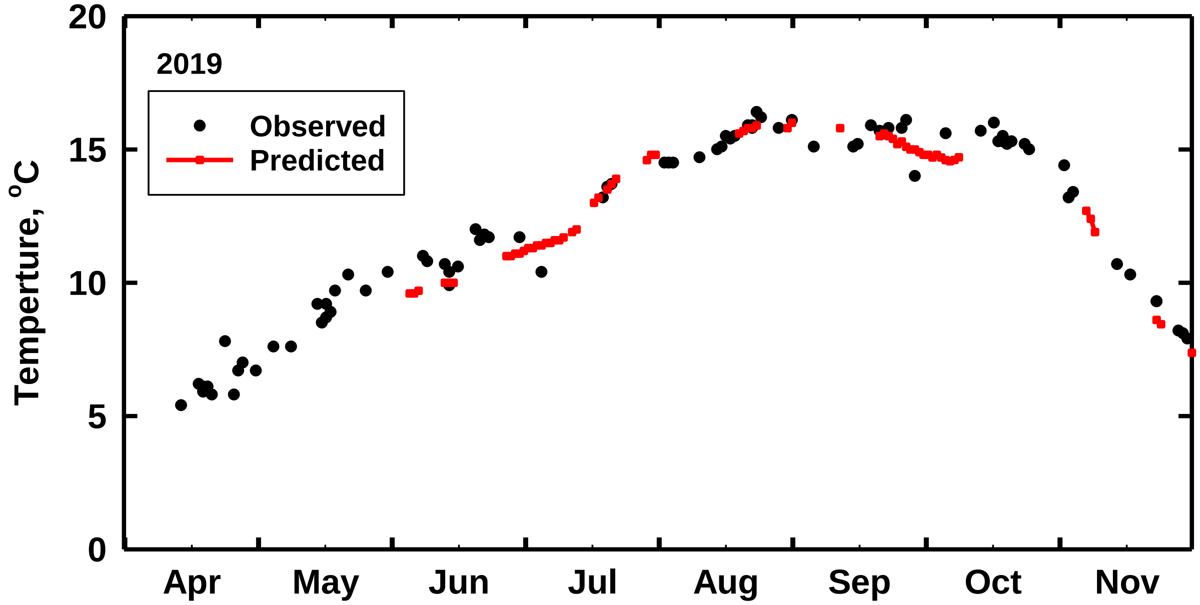


Figure 6.25 Observed and predicted temperature of the drinking water diversion from Neversink Reservoir for April-November 2019. The model makes predictions for days when the diversion rate exceeds 5 MGD.

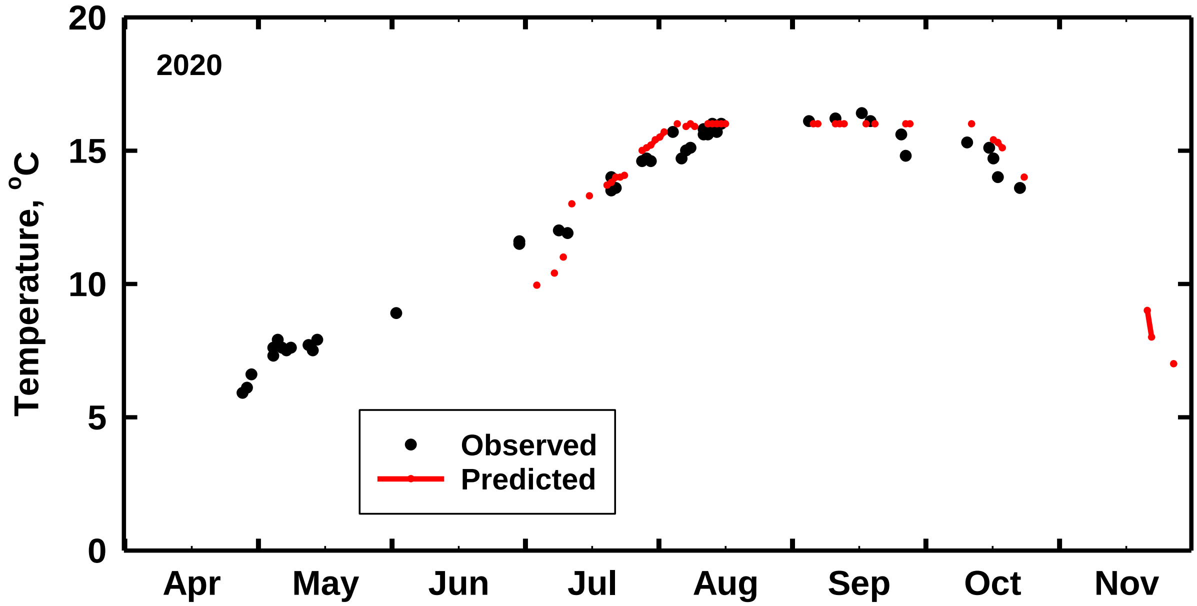


Figure 6.26 Observed and predicted temperature of the drinking water diversion from Neversink Reservoir for April-November 2020. The model makes predictions for days when the diversion rate exceeds 5 MGD.

6.8.2. Water quality (UV_{254}) model

The water quality model requires that a number of other inputs be specified, an important one being the time series of daily levels of UV_{254} in the tributary inflows to the reservoir. UV_{254} has been measured in the Neversink River near its discharge into Neversink Reservoir from 2016 to the present. A total of 314 values of UV_{254} have been measured between July 2016 and the end of 2020 at the Neversink River site. These UV_{254} values, together with the daily average streamflow at Claryville on the measurement day, are shown in Figure 6.27. Using the paired observations shown in this figure, a regression equation was determined to allow estimation of UV_{254} from streamflow. This relationship is

$$\mathrm{UV}_{254} = 0.022 + 0.0035Q - 0.008/Q \qquad (6\text{-}1)$$

where UV_{254} has units of cm^{-1}, and Q is streamflow in m^3/sec. Daily values of the observed streamflow Q, the value of UV_{254} computed from this relationship, and the observations of UV_{254} are shown in Figure 6.28 through Figure 6.32 for the five years of 2016 through 2020, respectively. As would be expected given the scatter displayed in Figure 6.27, there are some periods where this equation overpredicts the observed UV_{254} (late November 2016, Figure 6.28, and late October 2017, Figure 6.29), others where a runoff event seems to have no impact on UV_{254} (January and April 2019, Figure 6.31). In order to provide the most accurate inputs for reservoir model testing, measured values of UV_{254} were used on days that measurements were available. On all other days, this equation was used to estimate UV_{254}. These daily values UV_{254} of were applied to all inflow to Neversink, including ungauged inflows. It should be noted that Eq. 6-1 is provisional relationship that will be revised and updated as additional data is collected. The impact of variation in conditions in the tributary streams can best be evaluated using the loading rate, which in this case is the product of UV_{254} and the streamflow.

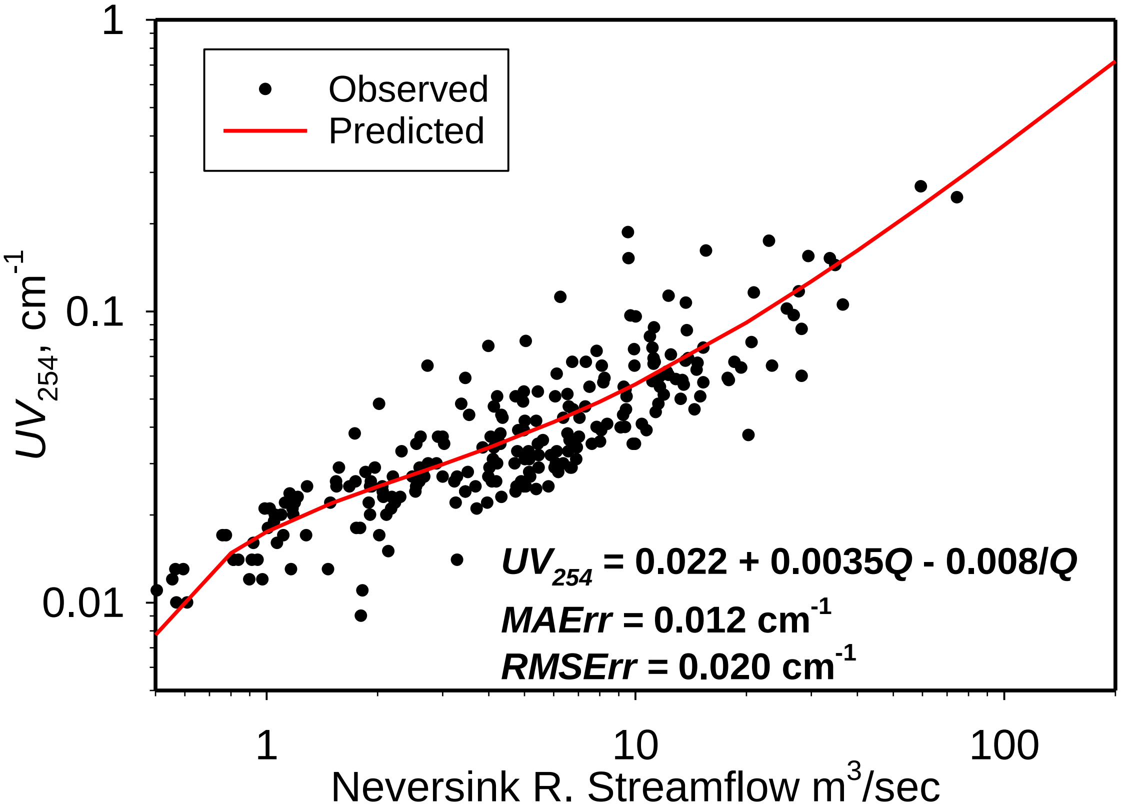


Figure 6.27 Paired observations of UV_{254} and streamflow for the Neversink River at Claryville, showing all data from the period 2016 through 2020. The predicted curve uses the regression equation shown. *MAErr* is the mean absolute error, and *RMSErr* is the root mean square error for all of the observations.

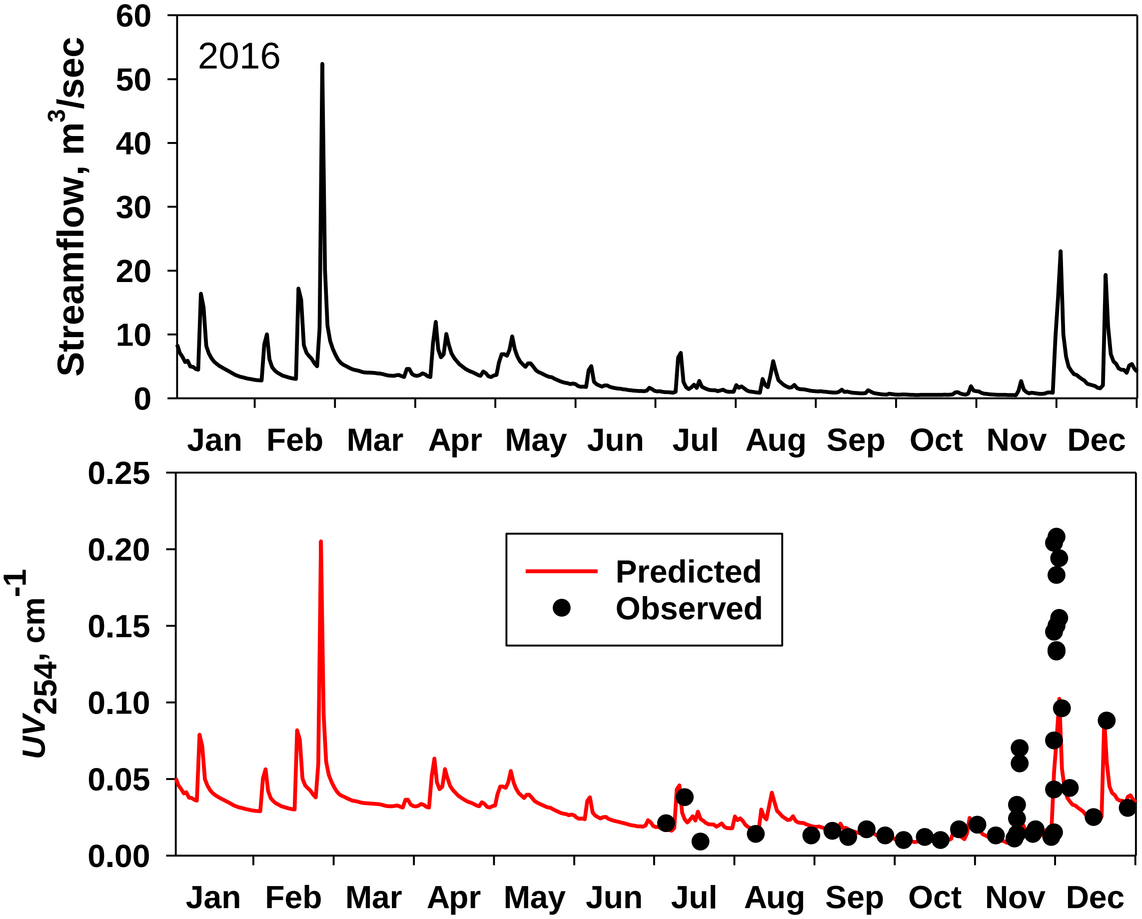


Figure 6.28 Neversink River conditions in 2016: top panel is streamflow at Claryville, bottom panel shows observations of UV_{254}, and model predictions from the regression equation.

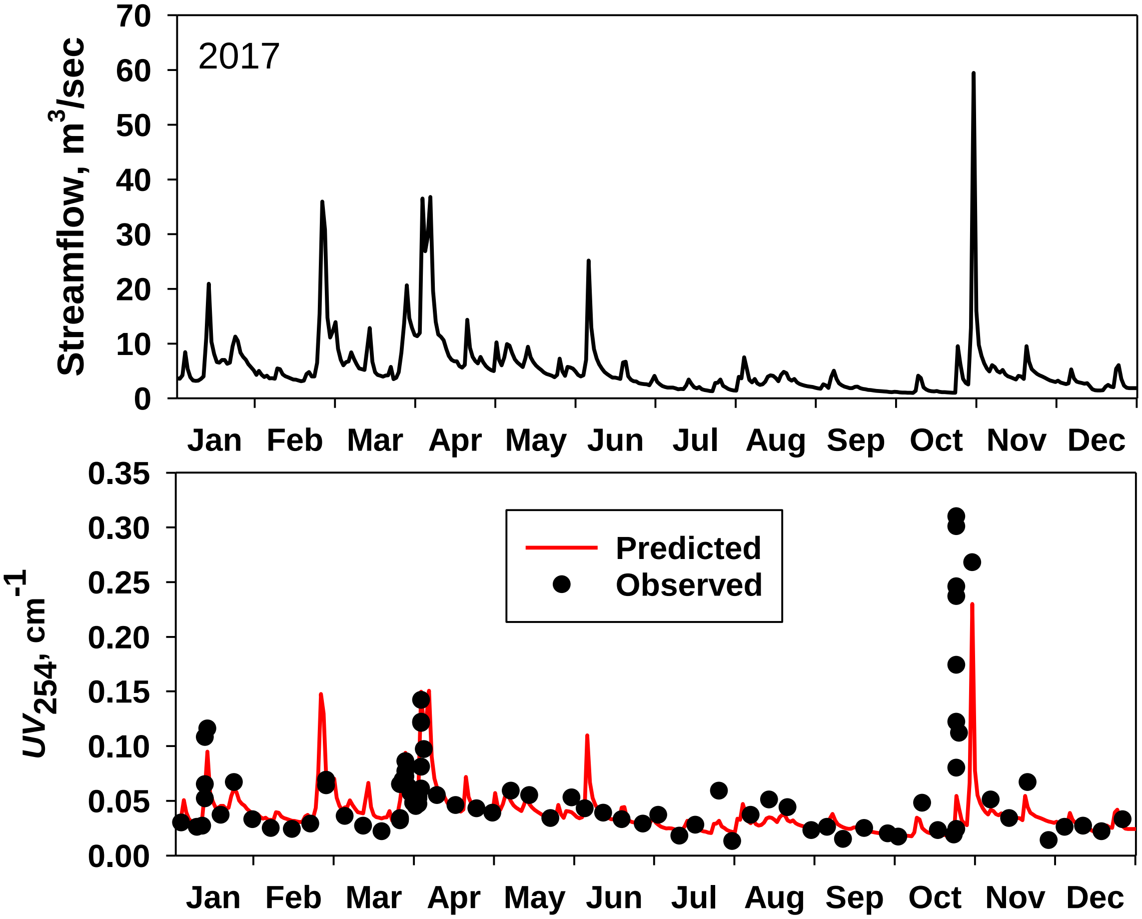


Figure 6.29 Neversink River conditions in 2017: top panel is streamflow at Claryville, bottom panel shows observations of UV_{254}, and model predictions from the regression equation.

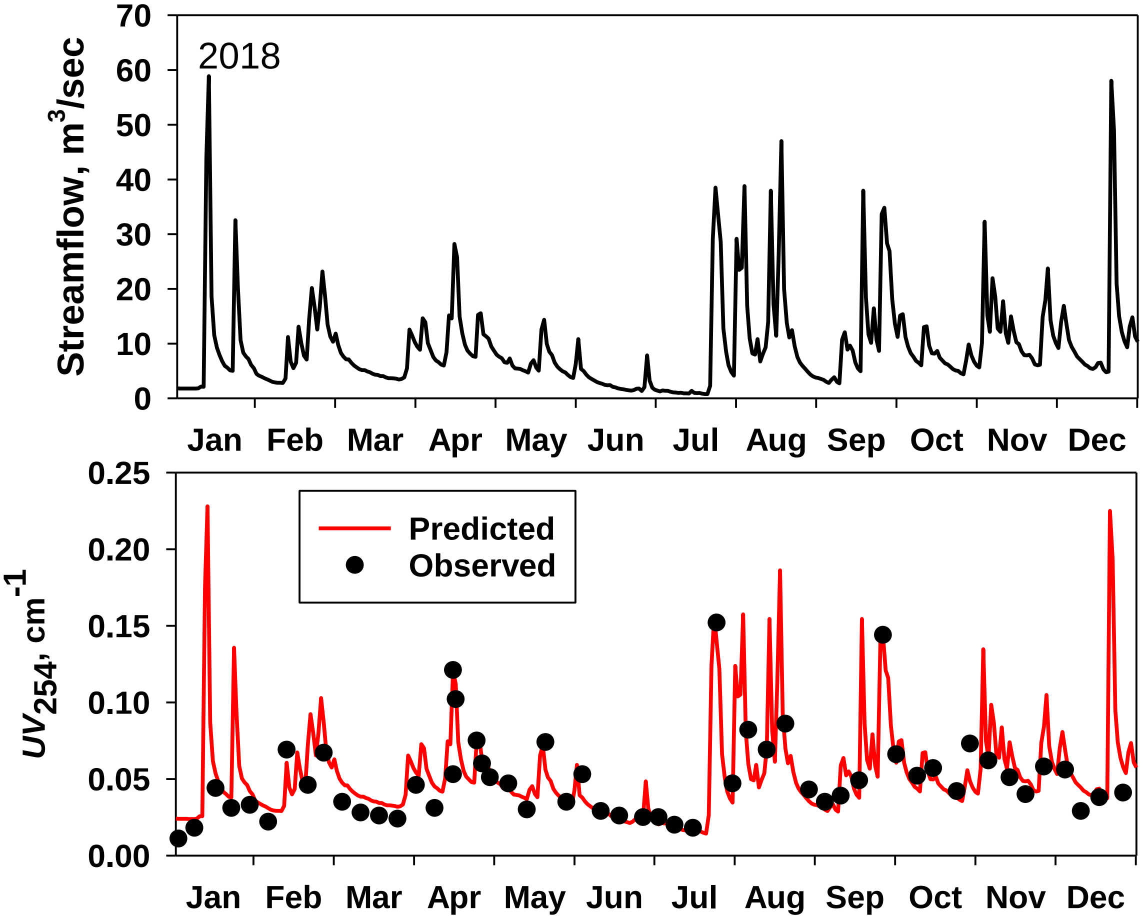


Figure 6.30 Neversink River conditions in 2018: top panel is streamflow at Claryville, bottom panel shows observations of UV_{254}, and model predictions from the regression equation.

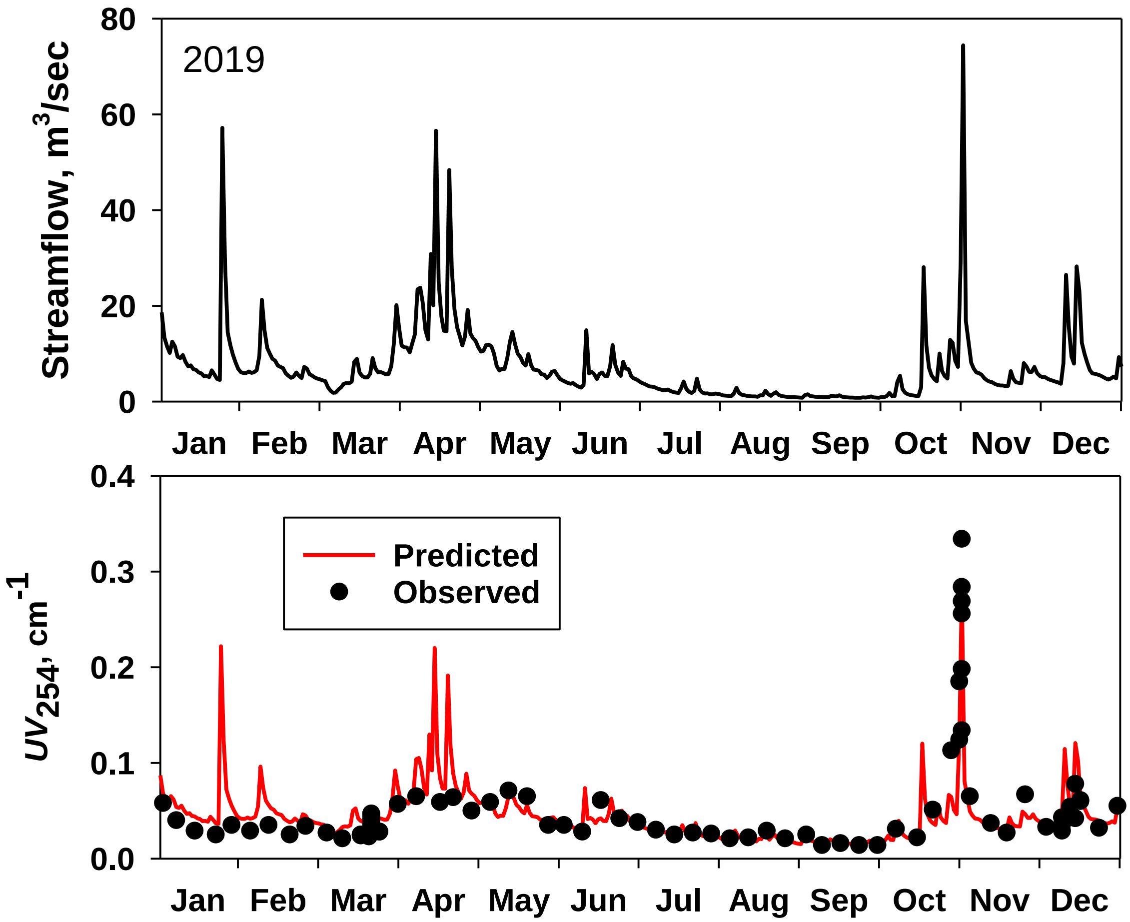


Figure 6.31 Neversink River conditions in 2019: top panel is streamflow at Claryville, bottom panel shows observations of UV_{254}, and model predictions from the regression equation.

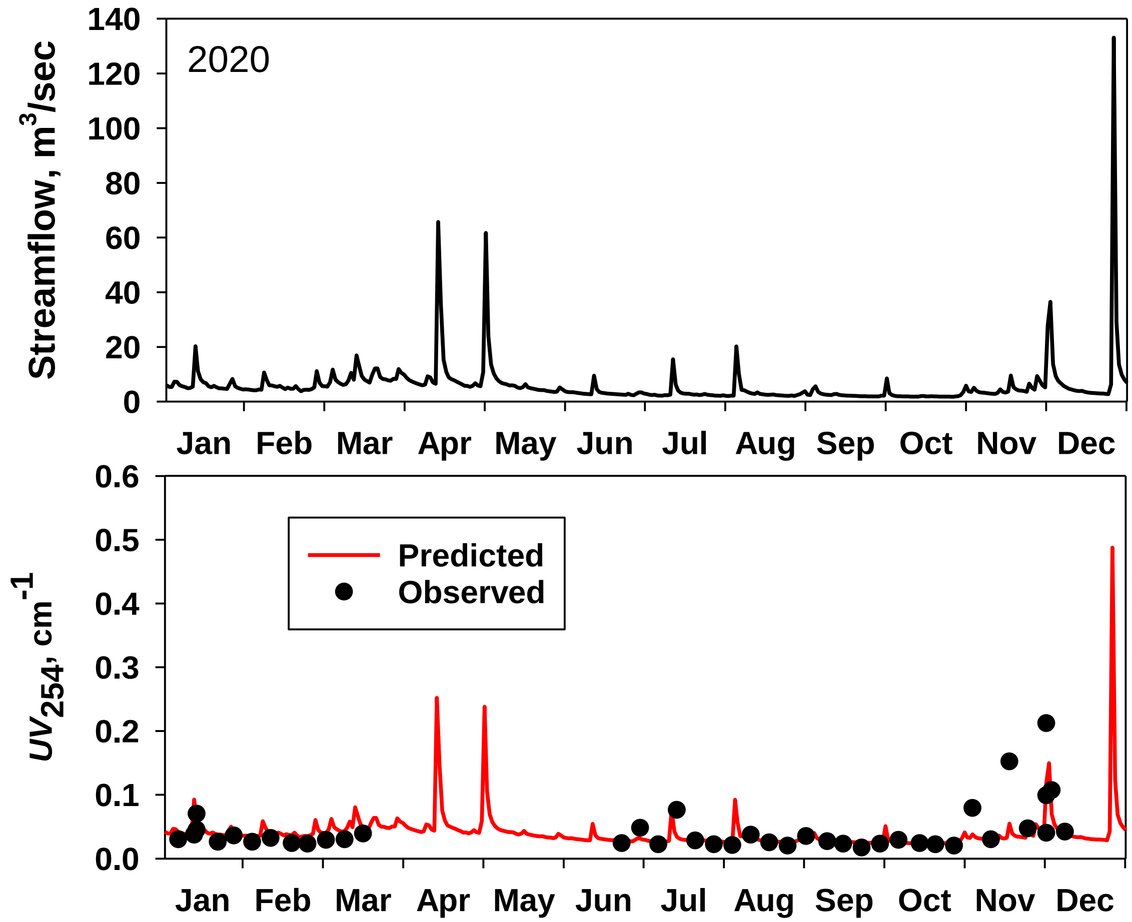


Figure 6.32 Neversink River conditions in 2020: top panel is streamflow at Claryville, bottom panel shows observations of UV_{254}, and model predictions from the regression equation.

Modeling of UV_{254} in the reservoir also requires that relationships quantify the rate of internal (autochthonous) production and loss of UV_{254} in the water column of the reservoir. Similar to the modeling that was conducted for Cannonsville in the 2019 annual report, production and loss processes are neglected in the model application for Neversink described here. This is simplifying initial assumption. With this assumption made, the predicted level of UV_{254} in the reservoir will be completely determined by loading from inflows, and modulated by transport processes that describe how UV_{254} moves through the reservoir to the outflows.

As was done for the hydrothermal modeling described above, the model predictions of UV_{254} in the diversion from the reservoir are compared to observations. This comparison is depicted in Figure 6.33 through Figure 6.37 for the years 2016 through 2020, respectively. For the dry, low inflow conditions of 2016, the model predicts a gradual, steady decrease in UV_{254} over the year (Figure 6.33), while the observations show a more rapid steady decrease. This indicates that a loss process is occurring in the reservoir. In 2017, the model predicts a similar steady decrease until the runoff event in late October, while the observations indicate production and loss is occurring over the spring to fall period.

In the high runoff conditions that occurred in summer and autumn 2018 (Figure 6.35), the model simulated the response of the reservoir to these events with good accuracy. The simulations for 2019 show that the model underpredicted the observed levels throughout the simulation period (Figure 6.36), while in 2020 (Figure 6.37) the model failed to simulate the increases in UV that occurred in September and October.

It is concluded from these modeling results that the assumption that production and loss in the water column of Neversink Reservoir can be neglected is likely not a good assumption. The same conclusion was reached in the previous modeling for Cannonsville Reservoir. Other researchers have invoked internal sources and losses in modeling UV in lakes and reservoirs (Westphal et al. 2004; Jeznach et al 2017). As a result, DEP is now proceeding to enhance the model to include production and loss processes. The production will be related to photosynthesis and respiration associated with phytoplankton growth, while loss processes associated with bacterial decomposition and photodecay will be investigated. These enhancements are ongoing.

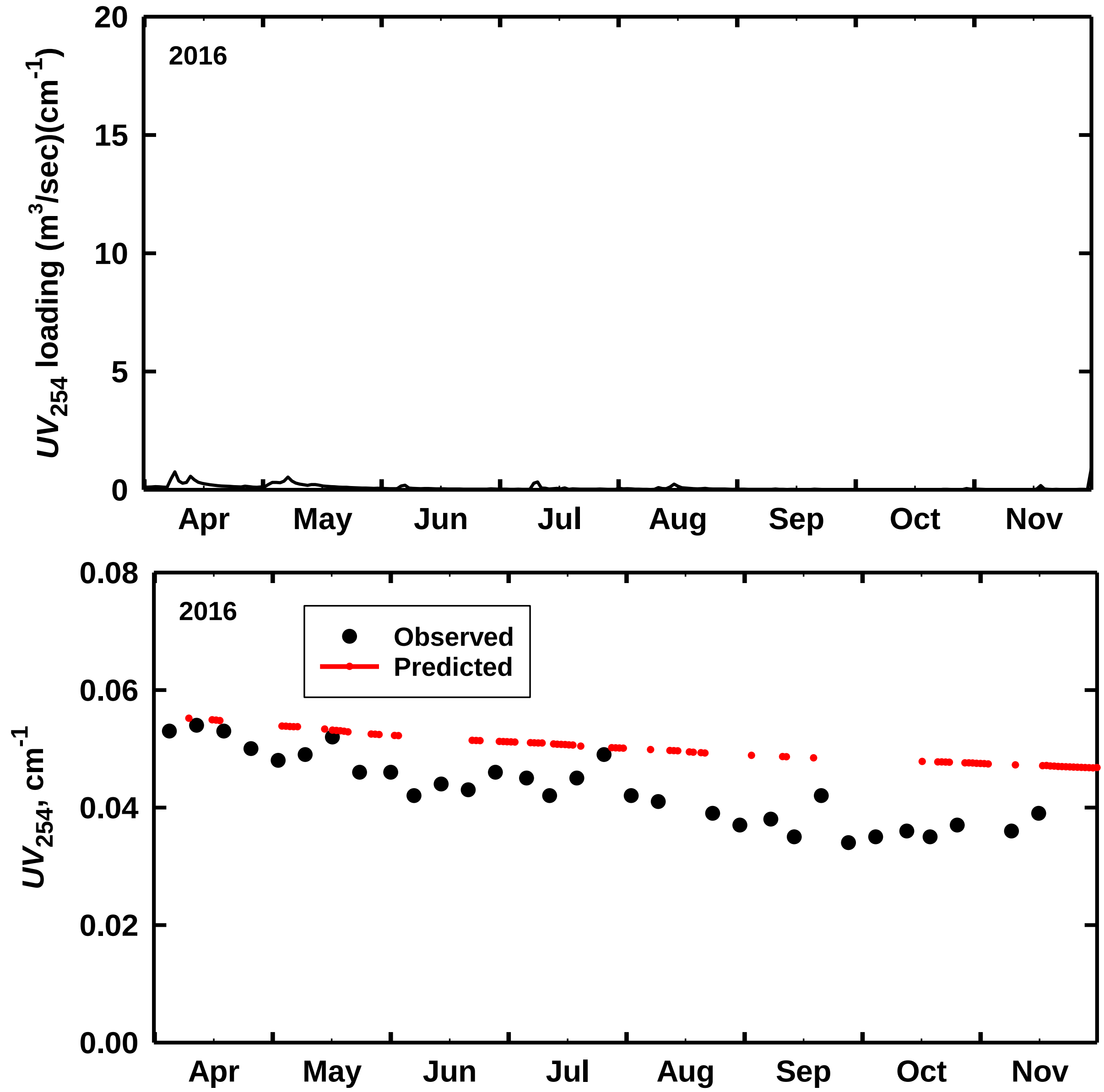


Figure 6.33 Observed and predicted levels of UV_{254} in the diversion from Neversink Reservoir for April-November 2016. Predictions are shown only for days where the diversion exceeded 5 MGD.

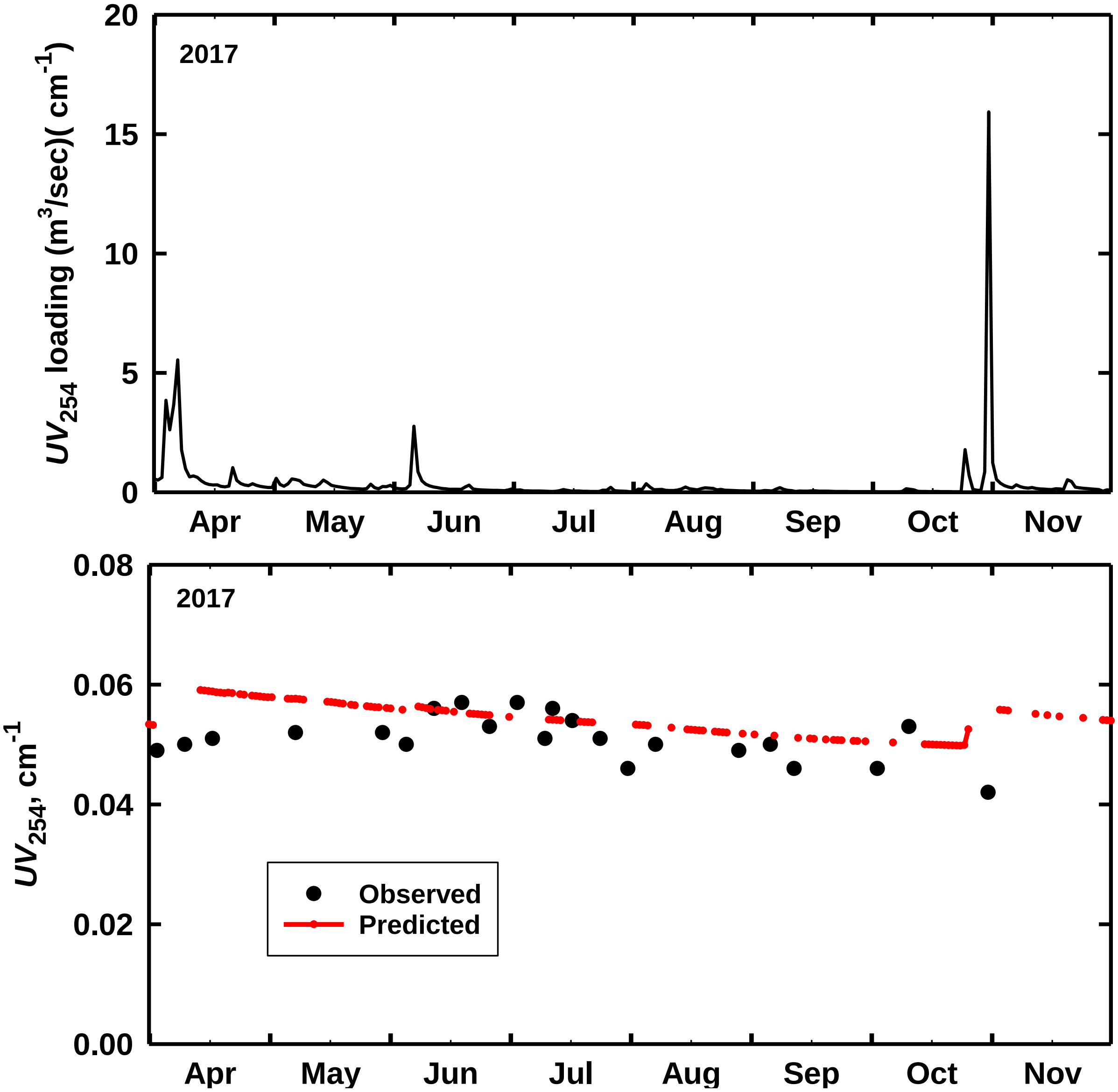


Figure 6.34 Observed and predicted levels of UV_{254} in the diversion from Neversink Reservoir for April-November 2017. Predictions are shown only for days where the diversion exceeded 5 MGD.

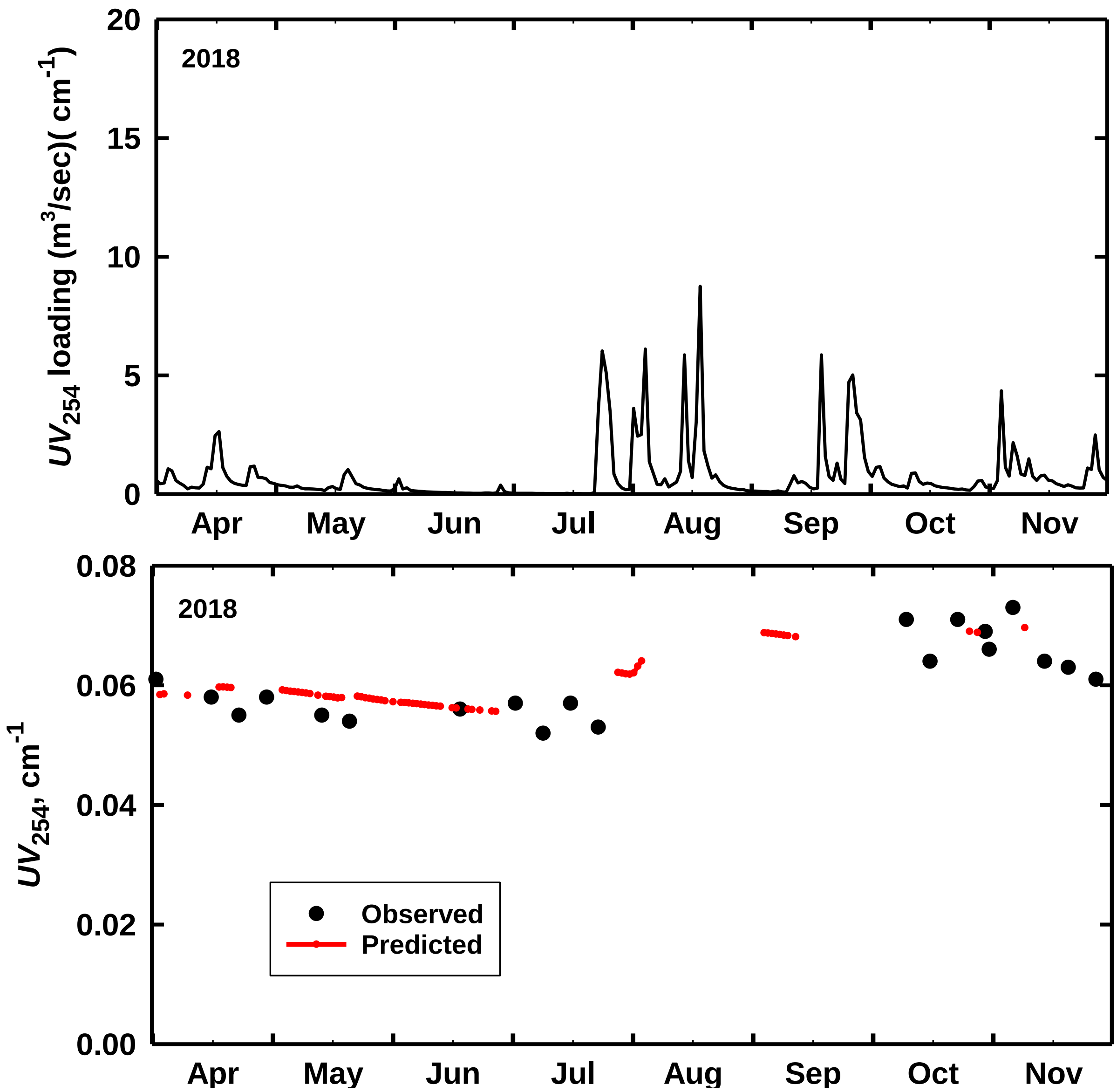


Figure 6.35 Observed and predicted levels of UV_{254} in the diversion from Neversink Reservoir for April-November 2018. Predictions are shown only for days where the diversion exceeded 5 MGD.

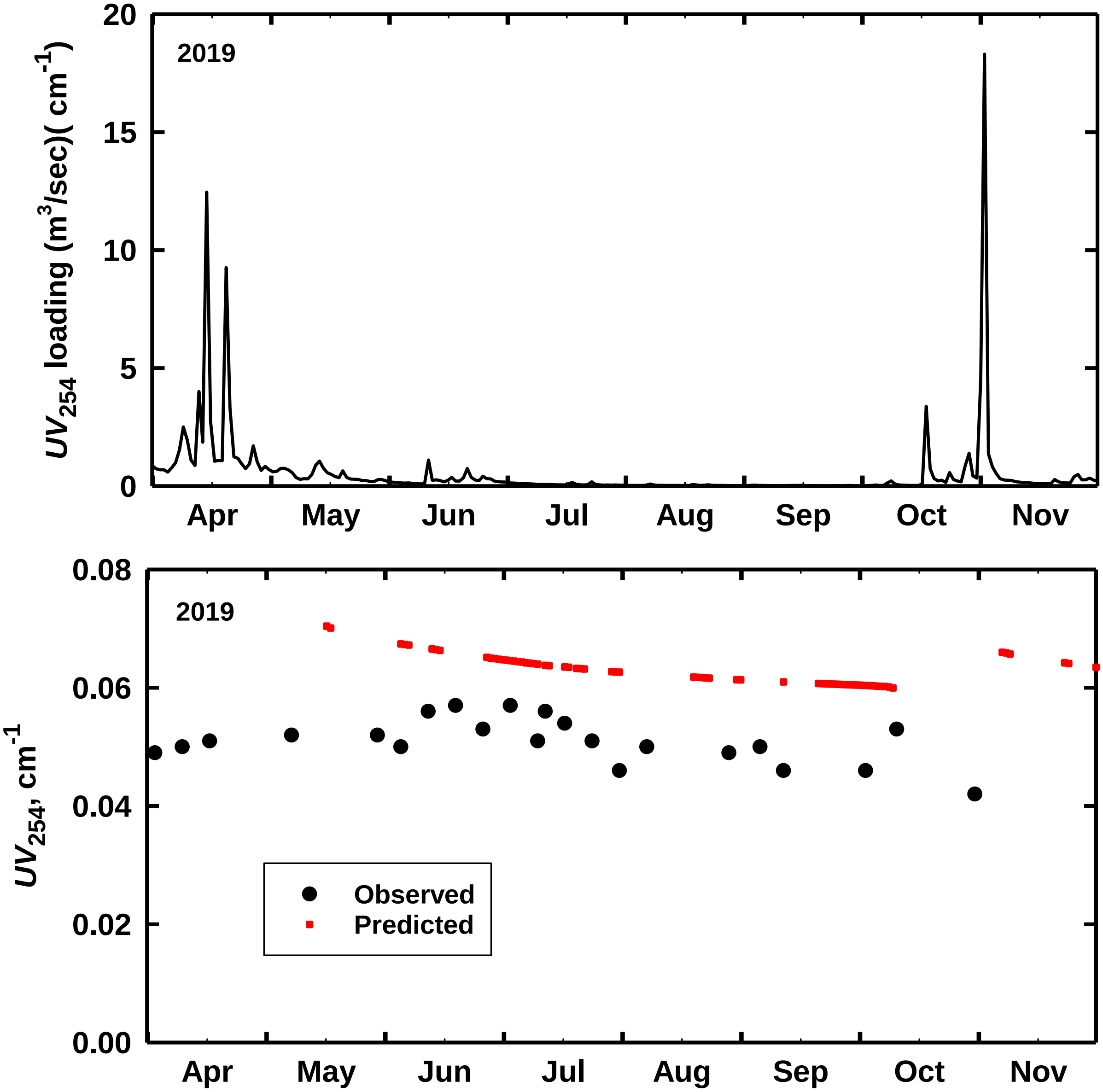


Figure 6.36 Observed and predicted levels of UV_{254} in the diversion from Neversink Reservoir for April-November 2019. Predictions are shown only for days where the diversion exceeded 5 MGD.

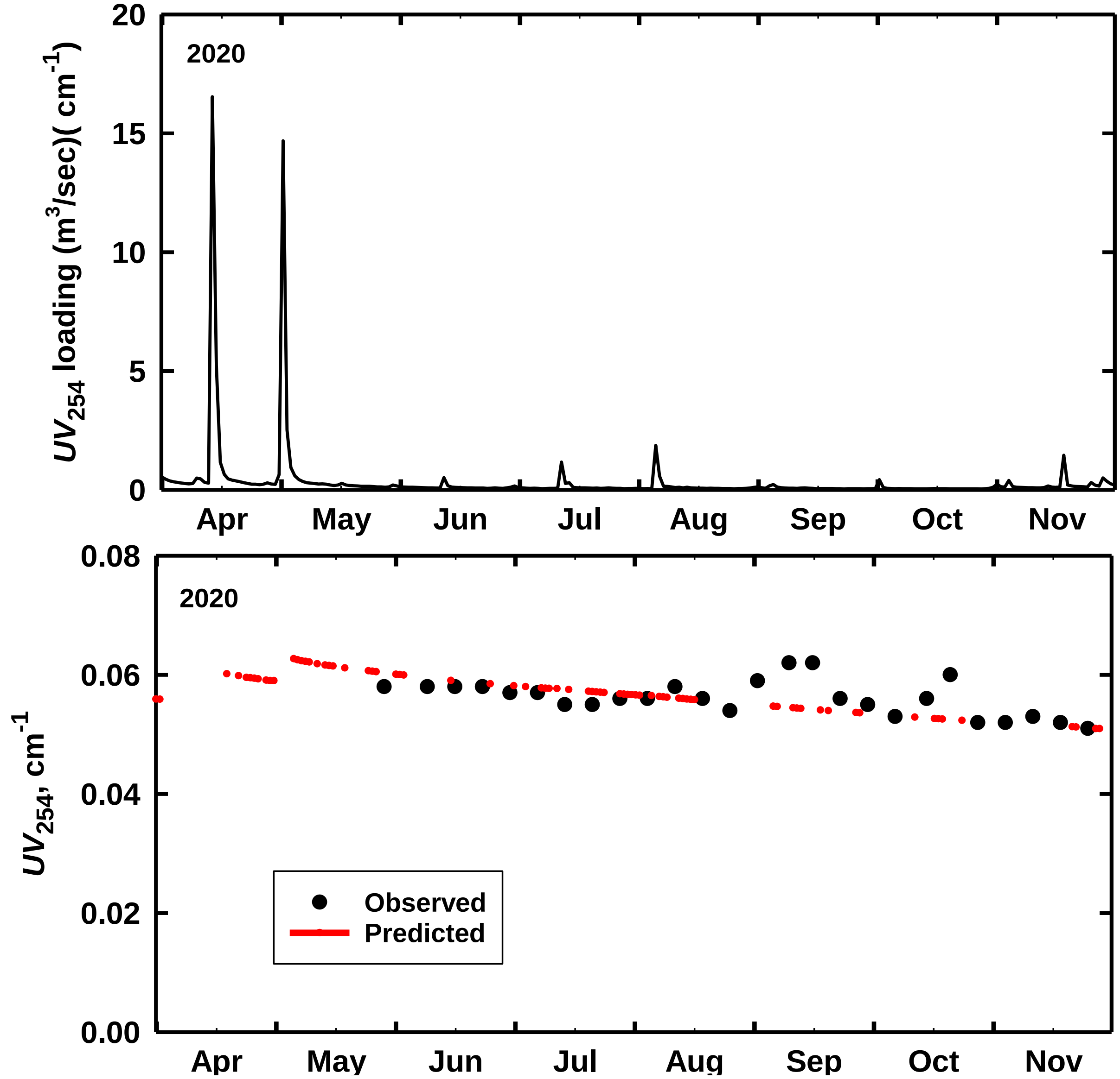


Figure 6.37 Observed and predicted levels of UV_{254} in the diversion from Neversink Reservoir for April-November 2020. Predictions are shown only for days where the diversion exceeded 5 MGD

6.9. Annual Water Quality Modeling Progress Meeting with Regulators

The annual meeting with regulators to present and discuss water quality modeling results was held on October 29, 2020, with attendees joining the meeting online. Staff from the NYSDOH and USEPA attended. This annual meeting is a requirement of the 2017 FAD. The meeting began with an overview of the modeling program and significant events occurring during the previous year, followed by a series of presentations on major modeling projects by

DEP staff and CUNY support scientists. There was ample time for questions and discussion. The agenda for this meeting was as follows:

1. Overview of the Water Quality Modeling Program – Emmet Owens
    a. Staff and CUNY Post-Doctoral Researcher Introductions
    b. CUNY-NYCDEP contract to support water quality modeling: status report
    c. Upcoming FAD requirements: (i) this meeting; (ii) FAD Summary & Assessment Report (March 31, 2021); (iii) annual modeling report, a section of Watershed Water Quality Annual Report (next submission July 31, 2021)
    d. National Academy of Sciences Expert Panel Review of Watershed Protection Programs
    e. Status report and future plans for individual models: SWAT validation; reservoir turbidity model validation; DBP monitoring and modeling
    f. Peer-reviewed publications

2. Reconstruction of Historic Streamflow for West-of-Hudson Watersheds Based on Tree-Ring Chronologies – Arun Ravindranath
3. Development of Climate Change Indices for the West of Hudson Watersheds – Jordan Gass
4. Calibration and Validation of SWAT-HS Hydrology Model for West-of-Hudson Watersheds – Rajith Mukundan
5. Improved Streamflow Predictions Using SWAT-HS and Ensemble Bayesian Model Averaging – Mahrokh Moknatian
6. Summary of Reservoir Turbidity Model Validation – Cannonsville and Pepacton Reservoirs – Rakesh Gelda
7. Testing of a Model to Predict UV_{254} in Cannonsville Reservoir – Emmet Owens

6.10. Water Quality Modeling: Publications and Presentations in 2020

6.10.1. Peer-Reviewed Publications

The following papers authored by members of the Water Quality Modeling section were published in peer-reviewed journals in 2020:

Wang, K., R. K. Gelda, R. Mukundan, and S. Steinschneider, S. 2021. Inter model Comparison of Turbidity Discharge Rating Curves and the Implications for Reservoir Operations Management. J. American Water Resources Assoc., 57(3), 430-448.

Mukundan, R, L. Hoang, R. K. Gelda, M. Yeo, and E. M. Owens 2020. Climate change impact on nutrient loading in a water supply watershed. Journal of Hydrology 586: 124868.

Yeo, M.-H., V. T. Nguyen, and T. A. Kpodonu, 2020. Characterizing Extreme Rainfalls and Constructing Confidence Intervals for IDF Curves using Scaling-GEV Distribution Model. International Journal of Climatology 41(1):456-468.

6.10.2. Conference Presentations

Gelda, R. K., R. Mukundan, A. H. Matonse, E. M. Owens, and J. Mead. 2020. "Assessment of Climate Change Impacts on New York City Water Supply System." World Environmental and Water Resources Congress 2020, 152-166.

Gelda, R. K. "Development and testing of a turbidity model for Pepacton Reservoir." Proc., Watershed Science and Technical Conference, Sept. 2020.

Mukundan, R, and M. Moknatian (2020). "Calibration and Validation of SWAT-HS Hydrology Model for NYC West-of-Hudson Watersheds." Watershed Science and Technical Conference, Sept. 2020.

Ravindranath, A., and A. Frei. "Reconstruction of Historic Streamflow for West-of-Hudson Watersheds Based on Tree-Ring Chronologies", Watershed Science and Technical Conference, Sept. 2020.

Owens, E. M. "Development and Testing of a Fate and Transport Model for UV254 for Cannonsville Reservoir", Watershed Science and Technical Conference, Sept. 2020.

Gass, J., R. K. Gelda, R. Mukundan, and E. M. Owens. "Development of Climate Change Indices for the New York City Water Supply" Watershed Science and Technical Conference, Sept. 2020.

Frei, A., R.K. Gelda, R. Mukundan, E.M. Owens, J. Gass, and J. Chen. "Twenty-first Century Scenarios for Multi-year Dry and Wet Extremes in the Catskill Mountains" Watershed Science and Technical Conference, Sept. 2020.

7. Further Research

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

One of the seven goals in DEP's 2018 Strategic Plan was to leverage innovative approaches to improve performance, and one of the initiatives to help meet this goal challenged DEP to "Engage in cutting-edge research and influence national policymaking." This initiative outlines research priorities to help DEP meet regulatory mandates from our state and federal governments, capture the institutional knowledge of our expert employees, and apply the newest and best technologies to protect the environment and public health. To assist in this effort DEP produced the "DEP Annual Research Summary Report 2019-2020," a publicly available report (DEP 2019-2020 Research Summary Report) that summarizes the 2019 and 2020 research and the state of science within DEP. The report included information on BWS's broad array of 2019 and 2020 research to address future challenges such as source water protection, treatment, water quality and operations.

7.1. Contracts Managed by the Water Quality Directorate in 2020

In 2020, the WQD used nine contracts to enhance its ability to monitor and model the watershed. The contracts supported data collection related to water quantity, water quality, wildlife surveillance, and model development to attain watershed protection and management goals. A brief description of each contract is provided below.

7.1.1. Laboratory Analytical Support Contracts

Eurofins Eaton Analytical Inc. (EEA): This contract is managed by DEP's Distribution Water Quality Operations. EEA conducts various analyses to support the work of DEP laboratories and fill gaps if analyses needed are not performed by DEP. In 2020, analyses that were conducted by EEA under this contract covered a wide variety of analytes.

Watershed samples from aqueducts and reservoirs were analyzed for algal toxins, geosmin, MIB, and total petroleum hydrocarbons. Volatile organic carbon (VOC), semi-volatile organic carbon (SVOC), and glyphosate analyses on selected aqueduct samples were also done. Wastewater treatment plant effluents were analyzed for total Kjeldahl nitrogen, methylene blue active substance (MBAS), and total dissolved solids (TDS). Regulated and unregulated routine drinking water samples required the analysis of cyanide, fluoride, and a number of organic tests to meet regulatory standards.

There were also a number of special projects, including the Emerging Contaminant Monitoring Project (ECMP) to monitor aqueduct samples for UCMR3 analytes (i.e., perfluorinated compounds) and regulated drinking water sites for UCMR4 analytes (i.e., perfluorinated compounds and 1,4-Dioxane). In another study designed to improve our understanding of disinfection byproduct formation potential, reservoir and stream samples were chlorinated and then analyzed for THMs and HAAs.

New England Bioassay: The towns of Walton, Windham and the village of Delhi Wastewater treatment plant effluent and receiving waters were tested for Whole Effluent Toxicity analyses. This testing is required once every five years.

York Analytical Laboratories, Inc.: York was equipped to analyze total petroleum hydrocarbons (TPH), both diesel range organics (DRO) and gasoline range organics (GRO) on Titicus Reservoir samples that were used to continue to track the impact of a fuel truck spill that occurred on the reservoir in 2019. This contract was managed by DEP's Hawthorne Laboratory.

Source Molecular Laboratories: As part of studying the sources of fecal coliforms and protozoans in the watershed, samples were collected as grab samples in the Kensico watershed and sent to this laboratory for microbial source tracking analysis. Analysis includes the search for various Bacteroidales genetic markers through use of polymerase chain reaction (PCR) and other molecular techniques. The goal was to determine if sources are human or animal so they can be isolated and managed to prevent future contamination. An example of this work is provided in Chapter 3 under Kensico Reservoir Special Investigations.

Watershed Assessment Associates: Samples of benthic macroinvertebrates are normally collected annually from the Croton, Catskill, and Delaware system streams and sent to this laboratory for identification of the taxonomic targets set forth in the New York State Stream Biomonitoring Unit's Standard Operating Procedure. Due to COVID-19 monitoring reductions no samples were collected for this project in 2020.

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

DEP contracts with the United States Geological Survey (USGS) to operate and maintain a hydrological monitoring network in the NYC watershed. Under the current agreement, which runs from October 1, 2018 to September 30, 2023, the USGS measures stage and discharge at 60 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 streamflow;

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 streamflow data, and (6) preparing online annual Water-Year Summary reports. The data support DEP's development of multi-tiered water quality models, which is a requirement of the 2017 Filtration Avoidance Determination (FAD) (NYSDOH 2017). The data also provide support to the following FAD watershed protection 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 Modeling Support Contract

Work continued in 2020 on the four-year modeling support contract between DEP and CUNY that extends from April 2019 through March 2023. Work on the contract was significantly impacted by the COVID pandemic. Two of the four post-doctoral modeling support scientists positions were filled for the entire year, a third was filled for part of the year, and the remaining position was unfilled for the entire year. These positions have generally been filled by foreign-born scientists and engineers. During COVID, it was difficult to attract qualified candidates to come to the United States. The support scientists who were working did so from their homes from March through December 2020. Despite these difficulties, the support scientists who were working made good progress on their projects.

In addition, the work by two faculty advisors was curtailed by COVID. Dr. Tammo Steenhuis and Dr. David Reckhow were unable to complete much of the work that had been envisioned. DEP was unable to collect the samples that were to be analyzed at Dr. Reckhow's laboratory at Univ. of Massachusetts-Amherst.

7.1.4. Waterfowl Management

The Waterfowl Management Program (WMP) was developed in response to seasonal elevations of fecal coliform bacteria counts 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 rebid every three to five 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-Renewal), with Henningson, Durham & Richardson, requires staffing of up to 25 contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. The contract will expire on July 29, 2021. DEP will extend the WMP-16R contract for another 9 months by means of a Negotiated Acquisition Extension (NAE) through April 30, 2022, under the same terms. DEP is expected to let a new WMP contract (WMP-21) for three years with an option to renew for two years upon expiration of the NAE.

7.1.5. Bathymetric Surveys of Reservoirs

An inter-governmental agreement was initiated in 2017 with United States Geological Survey (USGS) to conduct bathymetric surveys of the 13 East of Hudson (EOH) reservoirs and 3 controlled lakes. The USGS use a multibeam echosounder to improve the accuracy and spatial resolution of the surveys over previous single-beam transect surveys. The USGS will provide DEP with GIS surfaces of the reservoirs, maps and elevation tables.

The field surveys were conducted between 2017-19, and some data processing occurred outside of the field season. In 2020, the USGS has focused on data cleaning and processing to develop the final dataset. This cleaning includes the review of raw survey point clouds to remove erroneous points, and to convert the data from depth measurements beneath the survey boat to elevations. With the final cleaned data, USGS compiled additional data sources, including single-beam surveys of shallow areas and existing lidar point clouds for nearshore and terrestrial areas to develop final bathymetric surfaces. This process included interpolation techniques to fill any gaps. The draft data were supplied to DEP at the end of 2020 for courtesy review. The contract will conclude on June 30, 2021, when the USGS is will deliver final data products and the summary report.

7.1.6. WISKI Software Support Contract

DEP has continued to expand and enhance usage of the WISKI (Water Information Systems KISTERS) software to collect and view fixed point as well as continuous online data on a web portal, 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 system that supplies 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. The software updates to WISKI 7.4.9, and a new enhanced Alarm Manager are planned for late summer 2021. A new SODA (Synchronous Online Data Acquisition) server was developed in the new SCADA network to move all dataloggers to a more secure network, to better protect against a cyber-attack on our SCADA/DA systems. Build-out of harbor buoy monitoring is completed and is now being moved to the SCADA network. Finally, DEP continues to enhance its ESRI GIS platform and utilize new tools in the platform as they become available to better track and manage water quality.

7.2. Water Research Foundation Project Participation

The Water Research Foundation (www.waterrf.org) is "the leading research organization advancing the science of all things water to meet the evolving needs of its subscribers and the water sector. WRF is a nonprofit, charitable, and educational organization which funds, manages, and publishes research on the technology, operation, and management of drinking water, wastewater, reuse, and stormwater collection, treatment and supply systems—all in pursuit of ensuring water quality and improving water services to the public." DEP has been a subscriber and participant in the research conducted under the WRF since the early 1990s, both as project advisory committee members and as a participating utility, in order to remain current with cutting-edge research for the benefit of the City's drinking water. DEP participated in six Water Research Foundation projects. These projects provide insight into pathogens, emerging contaminants, and corrosivity of source water that can interact with distribution system features and may have operational implications. The current projects in which WQD is involved are described below.

7.2.1. WRF#4616 Hospital Discharge Practices and Contaminants of Emerging Concern (S. Neuman)

This project aimed to provide a holistic view to water utility and healthcare facility practitioners on management of compounds of emerging concern (CECs) in hospital wastewater. Emphasis was placed on identifying information gaps for future research on CEC management at these facilities, with the ultimate goal of establishing practices to improve the protection of both human health and ecosystems.

More specifically, researchers will investigate hospital discharge practices to better understand current best management practices associated with CECs, what actions hospitals are taking to mitigate or reduce that loading, if any, and what actions are feasible beyond what's already being done. It will also investigate what regulations exist regarding such discharge practices and how they are communicated.

7.2.2. WRF#4713 Full Lead Service Line Replacement Guidance (C. Glaser)

Removing an entire lead service line (LSL) eliminates one significant potential source of lead. However, even after full LSL replacement, lead sources can still be present that can contribute to lead levels at the tap. Following a full LSL replacement, lead exposure can come from lead scale that has built up over time within premise plumbing, brass components that contain lead, and lead-based solder.

The objective of this project is to evaluate strategies to reduce lead exposure after conducting full lead service line replacements (FLSLRs). The research will provide accurate and easily understood guidance and reference materials for staff at any U.S. or Canadian water system to use when planning and implementing FLSLRs.

The research team will conduct a literature review of current information related to limiting lead release following lead service line disturbances and evaluate the effectiveness of flushing to reduce lead exposure following FLSLRs at single-family homes. The research will also identify lessons learned from case studies, if any are available, of utilities that have monitored lead release following FLSLR.

7.2.3. WRF#4721 Opportunistic Pathogens in Premise Plumbing (A. Capetanakis)

The incidence of waterborne infectious disease outbreaks attributed to opportunistic pathogens (OPs), which are not regulated by the USEPA, appears to be increasing. Although many studies have surveyed premise plumbing and distribution systems for OPs, there is no unified method to monitor drinking water systems for all OPs of interest. This lack of unified methodology stems from differences in life cycle stages and physiologies of different OPs.

This project aims to develop methods for accurately detecting and quantifying bacterial and protozoan OPs in drinking water systems, with a particular focus on *L. pneumophila*, *P. aeruginosa*, nontuberculous mycobacteria, and *Acanthamoeba* spp. These four OPs represent the greatest health and economic burden posed among those occurring in premise plumbing. Additionally, they collectively encompass the physiological and ecological traits of all known OPs in premise plumbing that make their detection and quantification particularly challenging.

The research team will also develop guidelines for utilities with different levels of expertise and resources on how to implement OP monitoring. The team will also examine the effectiveness of several mitigation strategies to reduce the abundance of Ops, with a focus on in-home premise plumbing modifications.

7.2.4. WRF#4797 Designing Sensor Networks and Locations on an Urban Sewershed Scale with Big Data management and Artificial Intelligence (B. O'Malley, J. Farmwald)

The water sector is undergoing a transformation to digital where data and data management are driving every aspect of a utility's work. To address the water sector's transformation to digital data management, this project seeks to consolidate insights gained from the WRF projects *Designing Sensor Networks and Locations on an Urban Sewershed Scale* (4835) and *Leveraging Other Industries - Big Data Management* (4836) into demonstration projects at multiple facilities with DEP serving as a technical advisor.

The demonstrations are designed to validate sensor-based, real-time monitoring/metering and models/decision support systems on sewershed/sub-sewershed scales, including the application of analytics to solve sewershed network management issues. Based on the insights gained from the demonstrations, a sensor-based network and data management framework will be developed. The framework will provide a clear architectural roadmap and guidance for advancing data and information management, practices, automation of quality assurance/quality control, data use mapping, database management, and data integration for the water sector. The framework will incorporate new and emerging monitoring/metering technologies for real-time decision-making.

7.2.5. WRF#4910 Evaluating Key Factors that Affect the Accumulation and Release of Lead from Galvanized Pipes (C. Glaser)

The objective of this project is to better understand the conditions under which galvanized pipes can contribute to lead at the tap, the magnitude of lead release from galvanized pipes, and factors that can impact accumulation and release of lead from galvanized pipes. To accomplish this, the project will develop cutting edge tools that will evaluate links between galvanized iron pipe (GIP) and lead (Pb) release, by (1) scientifically assessing customers' concerns related to GIP corrosion and possible association with Pb in water, (2) characterizing the nature of iron (Fe) and Pb release to drinking water from known sources, and (3) examining Fe and Pb release from GIP using bench-scale testing. In addition, public education materials will be developed related to GIP and Pb release.

7.2.6. WRF#4911 Sampling and Monitoring Strategies for Opportunistic Pathogens in Drinking Water Distribution Systems (A. Szczerba)

Opportunistic pathogens (OPs) pose a significant health impact but are primarily an issue in premise plumbing systems, which are outside the water utility's jurisdiction. Nonetheless, water utilities may be able to proactively assist their customers and minimize the risks of exposure. This research project seeks to optimize sampling and detection methodologies for OPs (specifically *Legionella pneumophila*, *Pseudomonas aeruginosa*, and non-tuberculous mycobacteria) and devise suitable monitoring strategies to understand their occurrence in bulk water, biofilms, and sediments in drinking water distribution systems. The goal of this project is to establish an optimized sampling and monitoring protocol providing a practical guideline for drinking water utilities to manage the detection of opportunistic pathogens in distribution systems.

7.2.7. WRF#5032 Analysis of Corrosion Control Treatment for Lead and Copper Control (L. Emery)

The objective of this project is to create a guidance document based on science and utility experience for state regulators and water systems recommending when and how to conduct a corrosion control study in anticipation of a treatment change, water quality change, or a requirement and desire to lower lead levels. The approach will include outreach to utilities and states on use of the guidance materials. DEP is serving as a participating utility.

7.2.8. WRF #5080 Assessment of Vulnerability of Source Waters to Toxic Cyanobacterial Outbreaks (C. Korren)

The project objectives include the following:

- Develop a risk assessment for the prediction of the occurrence of different types of cyanobacteria, cyanotoxin occurrence, and the progress toward bloom development

- Develop a model that uses the conventional understanding of the major factors triggering and supporting the growth of cyanobacteria and potential cyanotoxin production
- Calibrate and validate the model with data from a variety of source waters, geographical area, and environmental factors

7.2.9. WRF#5081 Guidance for Using Pipe Loops to Inform Lead and Copper Corrosion Control Treatment Decisions (S. Freud)

By conducting workgroup meetings and workshops, this research will result in guidance for pipe loop construction, operation, sampling, and data interpretation to inform pipe loop implementation for corrosion control studies. A guidance document and a series of tools will be developed for utilities of all sizes, regulators, consultants, and other stakeholders to use in planning, conducting, and interpreting pipe loop study results. This research will advance the understanding of how to conduct "fit-for-purpose" pipe loop studies, resulting in improved public health outcomes through selection and implementation of optimized corrosion control treatment, and by facilitating primacy agency acceptance of study results. Research partners: American Water Works Association and Copper Development Association, Inc.

7.2.10. WRF #5082 Investigation of Alternative Management Strategies to Prevent PFAS from Entering Drinking Water Supplies and Wastewater (M. Murgittroyd)

The overall goal of this project is to provide actionable strategies that lead to effective management of per- and polyfluoroalkyl substance (PFAS) sources impacting drinking water treatment plants and water resource recovery facilities. Key objectives include the following:

- Summarize and provide methodologies to identify potential point and nonpoint sources in the watershed and sewershed, elaborating upon the relative importance of different sources in terms of potential health impacts, treatability, source control, and occurrence.
- Investigate categories of nonpoint sources, such as PFAS-containing products commonly used in commercial, institutional, and other sectors, that collectively enter sewers and water supplies, potentially adding significant and diverse quantities of PFAS.
- Summarize appropriate applications of effective pre-treatment and mitigation measures, such as best management practices (BMPs), permitting at point sources, and potential upstream regulatory and legislative measures for nonpoint sources.
- Summarize impacts of wastewater effluent PFAS on drinking water utilities. Available findings of current WRF project 5031 should be incorporated into this summary.

- Develop a roadmap of multiple strategies to mitigate PFAS prior to entry into drinking water treatment plants and water resource recovery facilities.

7.2.11. WRF #5088 Defining Exposures of Microplastics/Fibers (MPs) in Treated Waters and Wastewaters: Occurrence, Monitoring, and Management Strategies (D. VanValkenburg)

As reports of microplastic pollution increase, along with public interest in this topic, there is a need for clear guidance on microplastics management. This research will critically review microplastic occurrence data in water, fill in data gaps, provide media-specific sampling and monitoring guidelines, and use water cycle-scale mass balance to inform a decision making framework for microplastic reduction strategies.

Microplastic pollution ranges in size from 5 mm down to the nanometer scale and has been detected in remote locations as well as becoming a water quality topic of widespread public interest. The project objective is to evaluate microplastic pollution contributions to the environment from stormwater and other understudied water media to supplement previous research that focused on water resource recovery facility effluent. The project plans to:

- Conduct a systematic literature review to determine data gaps in published research.
- Examine sample collection and preparation for stormwater using adapt NOAA techniques.
- Utilize previously collected data and samples for the smaller size classes.
- Conduct additional sampling, if necessary, for data gap areas.
- Provide guidelines guidance on media-specific sampling and monitoring guidelines.
- Utilize different analysis techniques based on particle size.
- Provide water cycle-scale mass balance to inform decision making framework.

In 2020 initial work on the project started with design of the request for proposal, review of proposals, and narrowing it down to two proposals. In 2021 the project will commence with final selection of the proposal, award, and an initial presentation by principal investigator of the overview of the work that they will undertake.

7.3. Water Utility Climate Alliance (WUCA)

In 2020, DEP continued as one of 12 members of the Water Utility Climate Alliance (WUCA), a group of 12 large water utilities from around the country who collaborate on water supply issues related to climate change. Alan Cohn from the Bureau of Environmental Policy and Analysis continued as DEP's official representative to WUCA in 2020, and Alan participated in a number of online meetings during the year. Emmet Owens from BWS attended two webinars:

1. Applied climate change research program through the decade: Tampa Bay Water's experience, by Tirusew Asefa, Tampa Bay Water, Clearwater FL, January 2020,
2. Review of the joint climate change research project between Bonneville Power Administration, Corps of Engineers, Bureau of Reclamation, University of Washington and Oregon State University, the modeling approached used, and lessons learned, presented by Erik Pytlak, Bonneville Power Administration, March 2020

7.4. Global Lake Ecological Observatory 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. Information about GLEON research can be found at: http://gleon.org/research/projects/. The two projects in which DEP staff participated in 2020 are described below.

7.4.1. GLEON Project: Long-term Dissolved Oxygen (DO) Concentrations in Lakes and Reservoirs

A study on the effects of climate on dissolved oxygen concentrations (DO) in lakes and reservoirs around the globe was initiated in 2016 with GLEON partners. DEP contributed Cannonsville and Neversink reservoir temperature, DO, nutrient, and chlorophyll data and expertise. Following is a summary of the research:

Oxygen within freshwater systems influences the cycling of biologically essential elements carbon, nitrogen, and phosphorus. DO concentrations in lakes are temperature dependent due to gas solubility, and influenced by lake mixing and other biogeochemical mechanisms. Long-term declines in DO in marine waters have been linked to climate warming and increases in nutrient loading, however, little is known about how the DO content of lakes has changed. Using a long-term, globally distributed data set compiled from 400 lakes and 22,983 DO and temperature profiles, it was found that a decline in dissolved oxygen is widespread in both surface and deep-water. The decline in surface waters is primarily associated with reduced oxygen solubility under warmer water temperatures, although in some highly productive warming lakes this is offset by increasing productivity of phytoplankton. The decline in deep waters is not associated changes in oxygen solubility, but rather with stronger thermal stratification and loss of water clarity. Results suggest that climate change and declining water clarity have altered the physical and chemical environment of lakes, which has important implications for essential lake ecosystem services. The study was resubmitted in 2020 to the journal Nature after addressing reviewers' comments on the initial submission and published (https://doi.org/10.1038/s41586-021-03550-y) in June 2021.

7.4.2. GLEON Project: Before the Pipe: Monitoring and Modeling DBP Precursors in Drinking Water Sources

Collaboration on a project to identify important questions and research gaps on disinfection byproduct (DBP) precursors and water supply concerns was put on hold in 2020 due to restricted library access during the global pandemic. Plans to conduct a systematic literature review of the influences of physical and biogeochemical processes on disinfection by-product formation potential in lakes and reservoirs are expected to advance in 2021.

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Appendix A. List of sites for Watershed Water Quality Operations (WWQO) Early Warning Remote Monitoring (EWRM)

List of sites for Watershed Water Quality Operations (WWQO) Early Warning Remote Monitoring (EWRM).

Site	Location	System	Water Type	Parameters
SRR1CM	Schoharie Intake Chamber	Catskill	Raw	Turbidity, pH, Temperature, Specific conductivity
SRR2CM	Shandaken Tunnel Outlet (STO)	Catskill	Raw	Turbidity, pH, Temperature, Specific conductivity
EARRAW	Catskill Aqueduct	Catskill	Raw	Turbidity, pH, Temperature, Specific conductivity
EARCM	Catskill Aqueduct	Catskill	Raw/ Treated	Turbidity, pH, Temperature, Specific conductivity, Chlorine dioxide, Total Chlorine Residual
M-1	Ashokan Release Channel	Catskill	Raw	Turbidity
AEAP	Esopus Creek Upstream STO	Catskill	Raw	Turbidity
RDRRCM	Delaware Aqueduct at Rondout Effluent Chamber (REC)	Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity
NRR2CM	Neversink Tunnel Outlet	Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity
PRR2CM	East Delaware Tunnel Outlet	Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity
WDTOCM	West Delaware Tunnel Outlet	Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity
RR1-RR4	REC Elevation Taps	Delaware	Raw	Turbidity

List of sites for Watershed Water Quality Operations (WWQO) Early Warning Remote Monitoring (EWRM).

Site	**Location**	**System**	**Water Type**	**Parameters**
CDIS4-DEL	Cat/Del Interconnect at Shaft 4 (Delaware)	Delaware	Raw	pH, Temperature, Turbidity (only logging Turbidity)
CDIS4-CAT	Cat/Del Interconnect at Shaft 4 (Catskill)	Catskill	Raw	Turbidity, pH, Temperature, Specific conductivity, Chlorine Dioxide, Total Chlorine Residual
CDIS4- Combined	Cat/Del Interconnect at Shaft 4 (Catskill)	Catskill	Raw	pH, Temperature, Chlorine Dioxide, Total Chlorine Residual, Turbidity, Specific conductivity (only logging Turbidity)
CWB1.5	West Branch Reservoir	Delaware	Raw	Pump used to collect grab samples.
DEL9	Delaware Shaft 9	Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity, Total Chlorine Residual, Sodium bisulfite, Dissolved oxygen
DEL10	Delaware Shaft 10	Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity, Elevation
DEL17	Delaware Shaft 17	Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity, Total Chlorine Residual, Sodium bisulfite, Dissolved oxygen
DEL18DT	Delaware Shaft 18 Downtake	Catskill/ Delaware	Raw	Turbidity, pH, Temperature, Specific conductivity, Flow, Elevation
DEL19	Delaware Shaft 19	Catskill/ Delaware	Pre-Treated	Turbidity, pH, Temperature, Specific conductivity, Free Chlorine Residual, Fluoride Residual

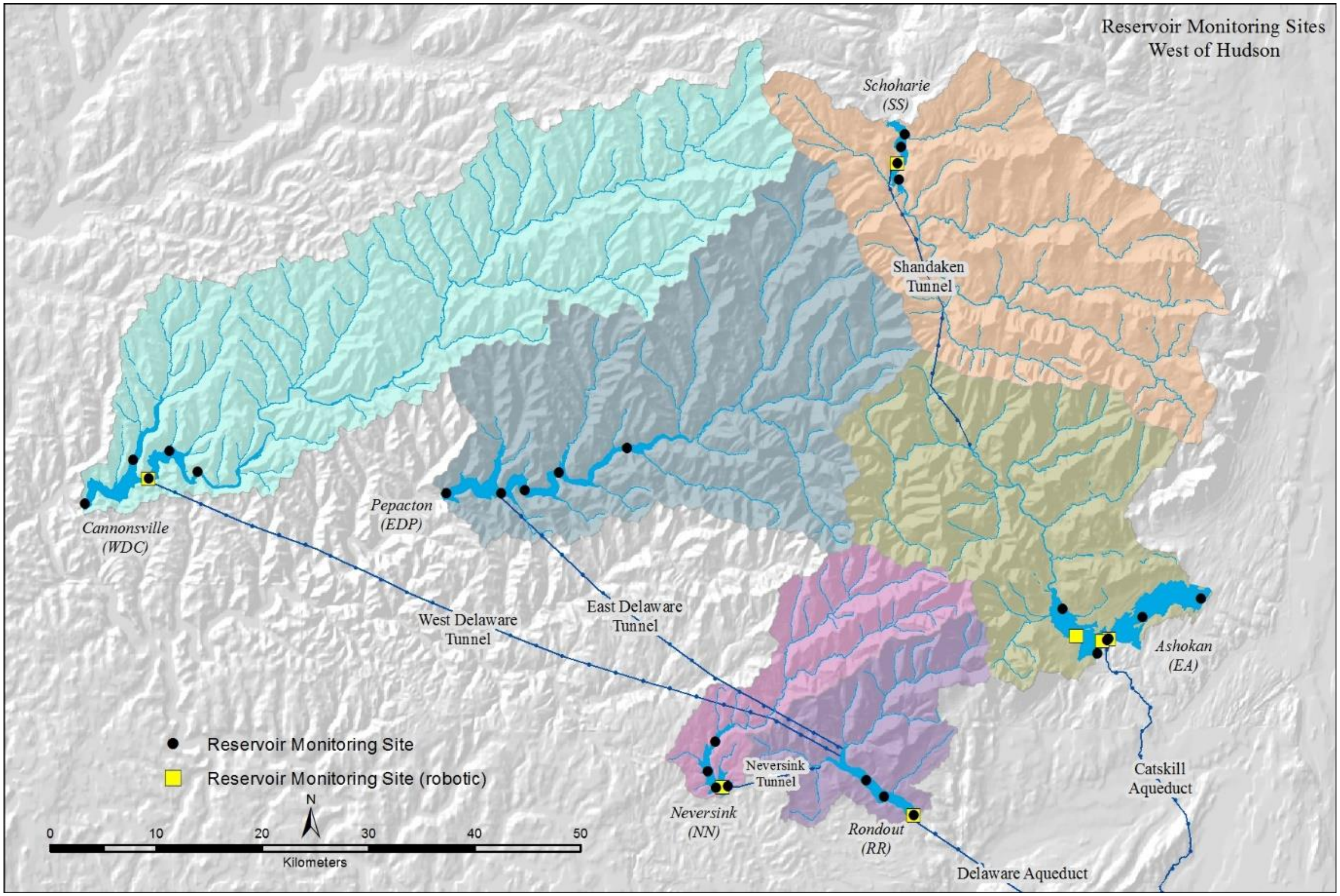
List of sites for Watershed Water Quality Operations (WWQO) Early Warning Remote Monitoring (EWRM).

Site	Location	System	Water Type	Parameters
DEL19LAB	Delaware Shaft 19 Lab	Catskill/ Delaware	Pre-Treated	Turbidity, pH, Temperature, Specific conductivity, Free Chlorine Residual, Fluoride Residual
DELSFB	Delaware South Forebay	Catskill/ Delaware	Pre-Treated	Turbidity, pH, Temperature, Specific conductivity, Free Chlorine Residual, Fluoride Residual
DELSFBLAB	Delaware South Forebay Lab	Catskill/ Delaware	Pre-Treated	Turbidity, pH, Temperature, Specific conductivity, Free Chlorine Residual, Fluoride Residual
CCC	Catskill Connection Chamber	Catskill/ Delaware	Pre-Treated	Turbidity, pH, Temperature, Specific conductivity, Free Chlorine Residual, Fluoride Residual
CCCLAB	Catskill Connection Chamber Lab	Catskill/ Delaware	Pre-Treated	Turbidity, pH, Temperature, Specific conductivity, Free Chlorine Residual, Fluoride Residual
CROFALLSVC	Croton Falls Valve Chamber	Croton	Raw	Turbidity
CROSSRVVC	Cross River Valve Chamber	Croton	Raw	Turbidity
CATALUM	Catskill Alum Plant	Catskill	Raw	Turbidity
CATIC	Catskill Influent Chamber	Catskill	Raw	pH, Temperature
CROGH	CLGH Raw Water	Croton	Raw	Turbidity, pH, Temperature, Specific conductivity, Dissolved oxygen

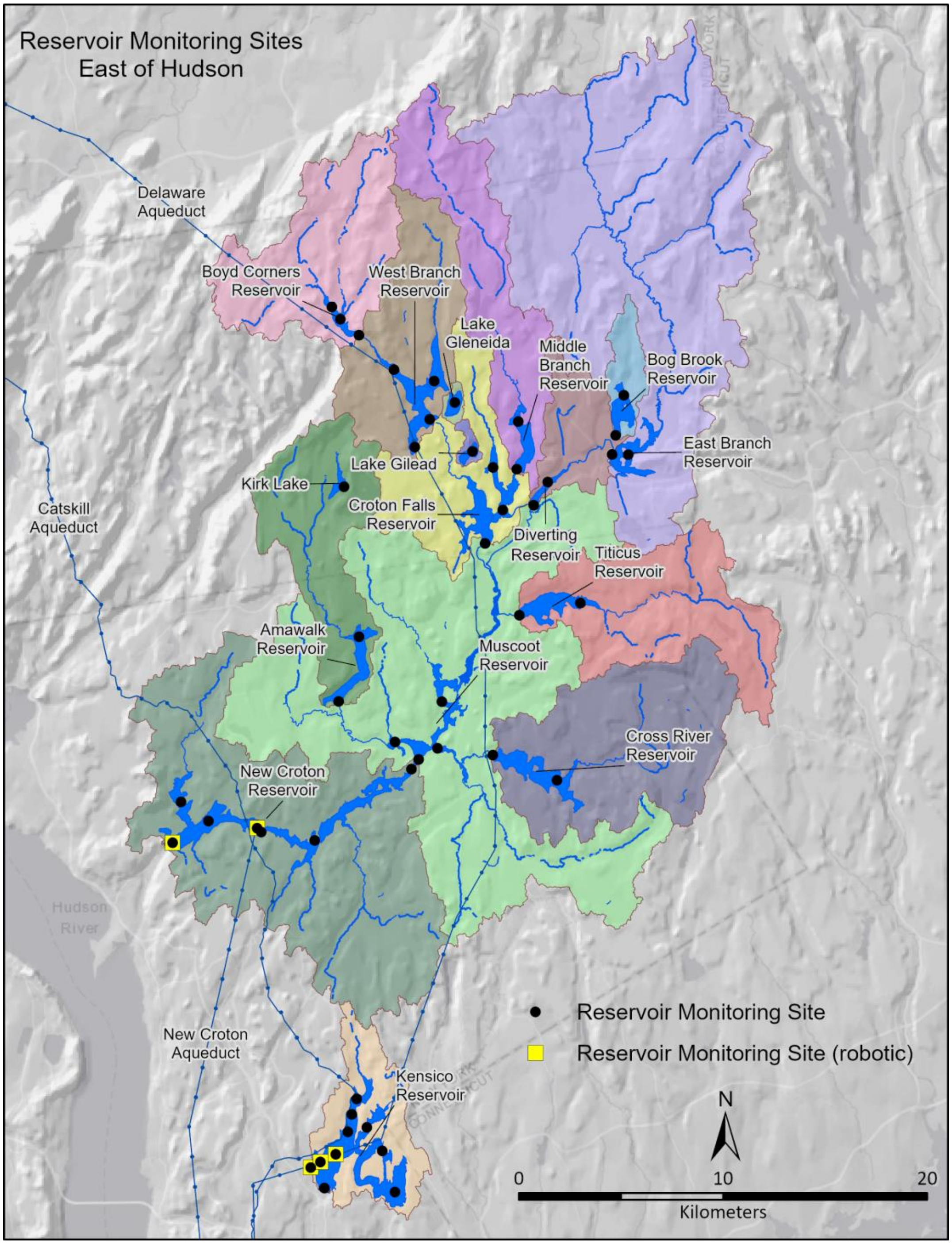
List of sites for Watershed Water Quality Operations (WWQO) Early Warning Remote Monitoring (EWRM).

Site	**Location**	**System**	**Water Type**	**Parameters**
CRO1T	New Croton Dam	Croton	Raw	Turbidity, pH, Temperature, Specific conductivity, Dissolved oxygen
CRO1B	New Croton Dam	Croton	Raw	Turbidity, pH, Temperature, Specific conductivity, Dissolved oxygen
CRO183	CLGH	Croton	Raw	Turbidity, pH, Temperature
CRO163	CLGH	Croton	Raw	Turbidity, pH, Temperature, Specific conductivity,
CRO143	CLGH	Croton	Raw	Turbidity, pH, Temperature, Specific conductivity, Dissolved oxygen

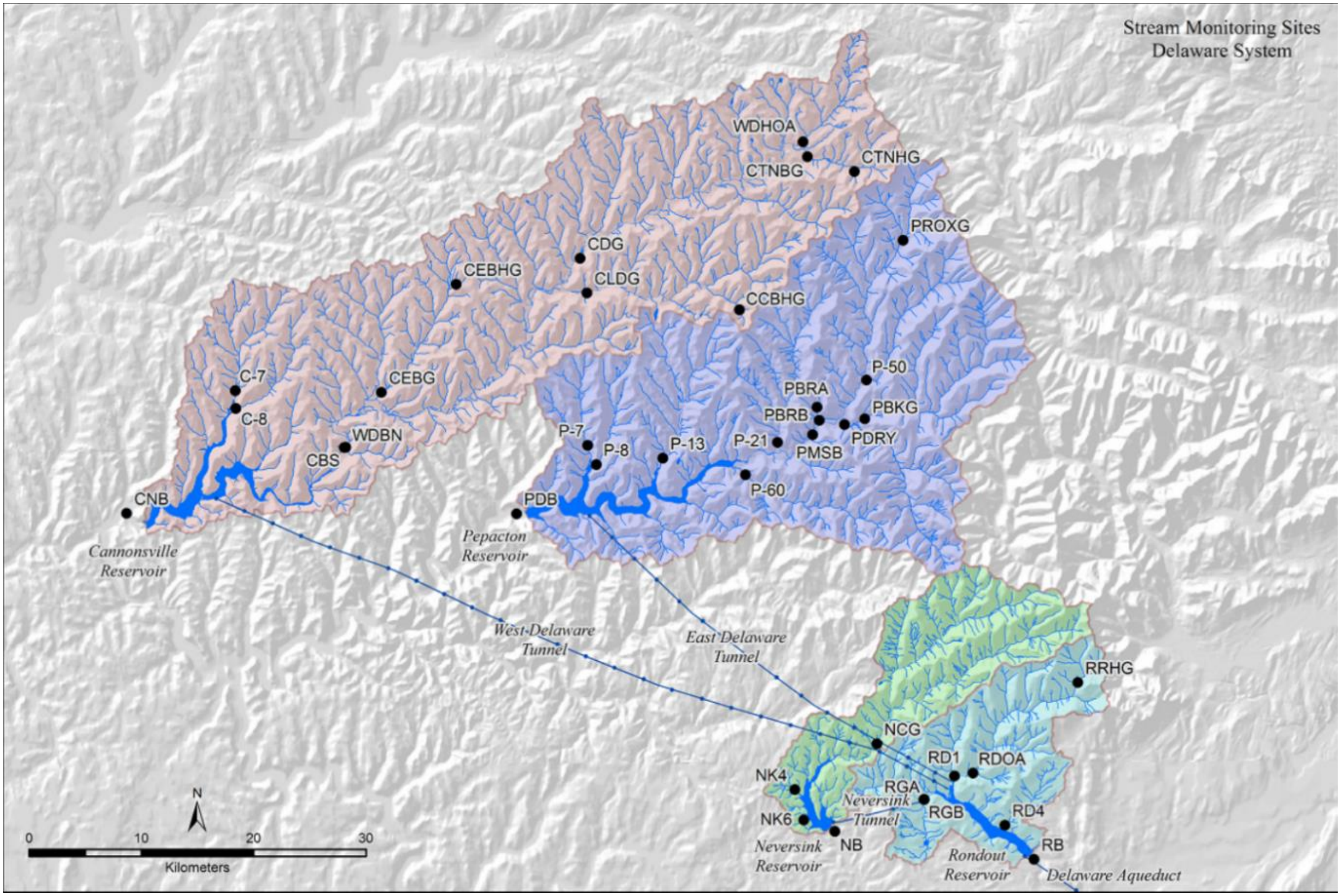
Appendix B. Sampling Locations



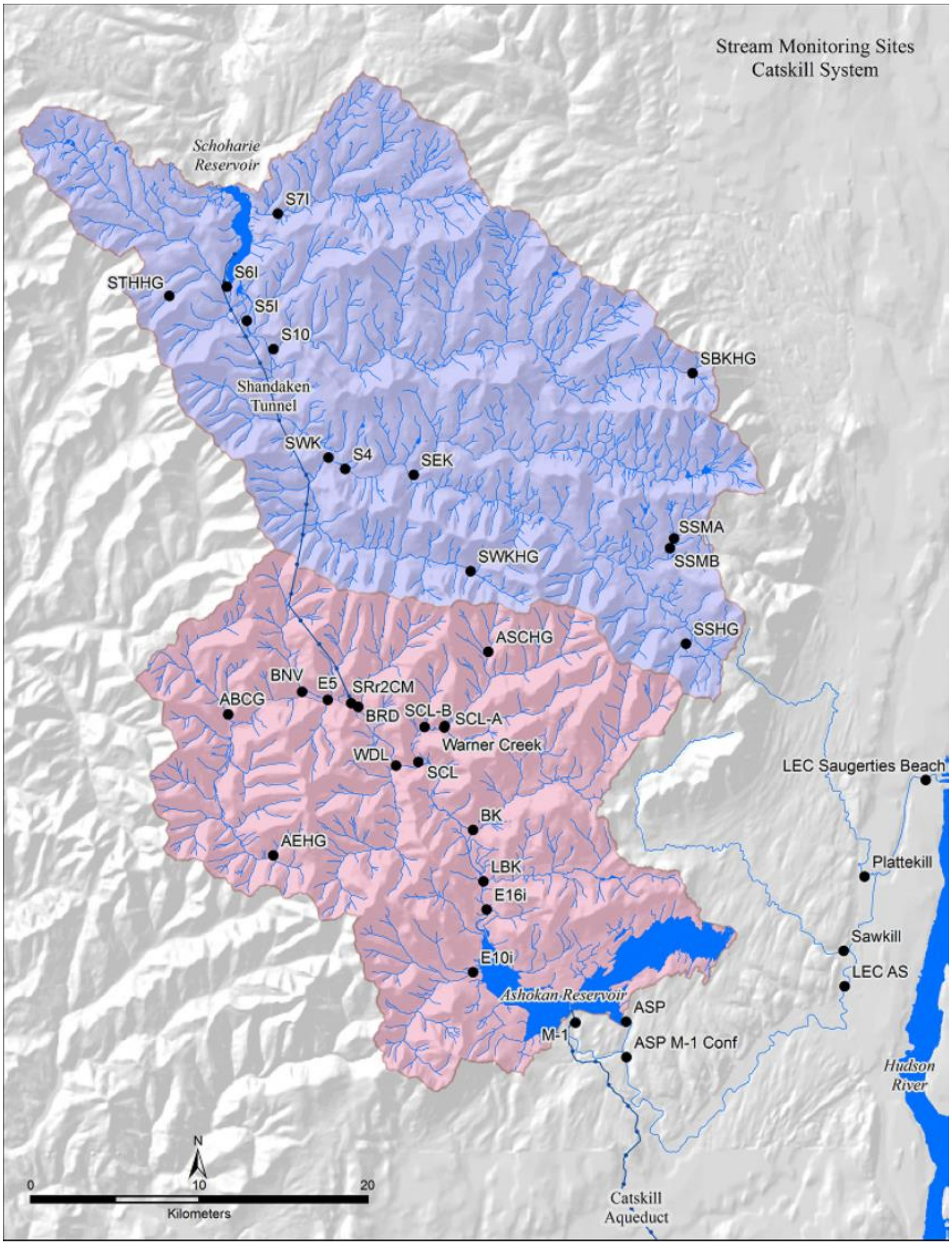
Appendix Figure 1 WOH reservoir monitoring sites [see WWQMP (DEP 2018) for detailed maps].



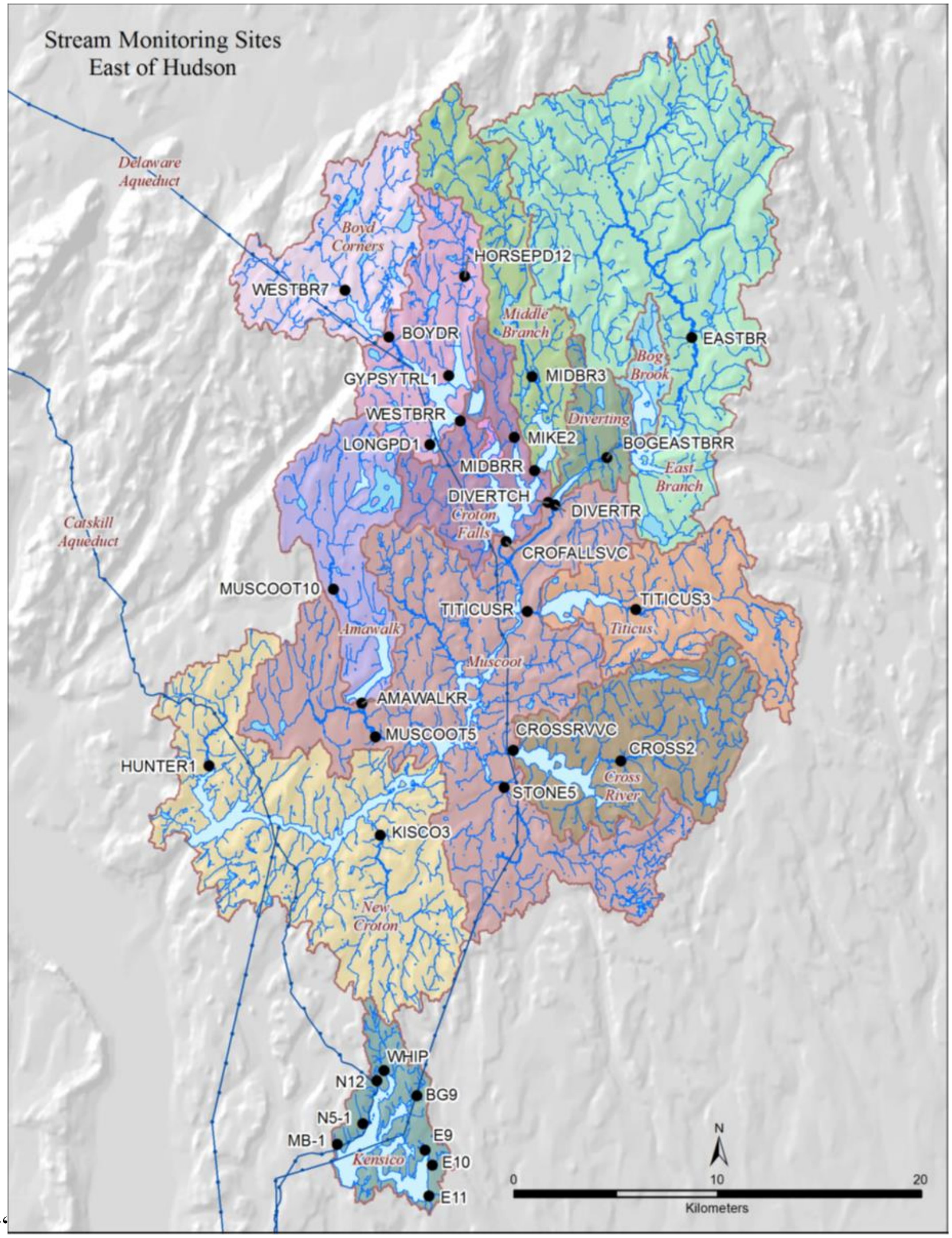
Appendix Figure 2 EOH reservoir monitoring sites [see WWQMP (DEP 2018) for detailed maps].



Appendix Figure 3 Delaware System stream monitoring sites [see WWQMP (DEP 2018) for detailed maps].



Appendix Figure 4 Catskill System stream monitoring sites [see WWQMP (DEP 2018) for detailed maps].



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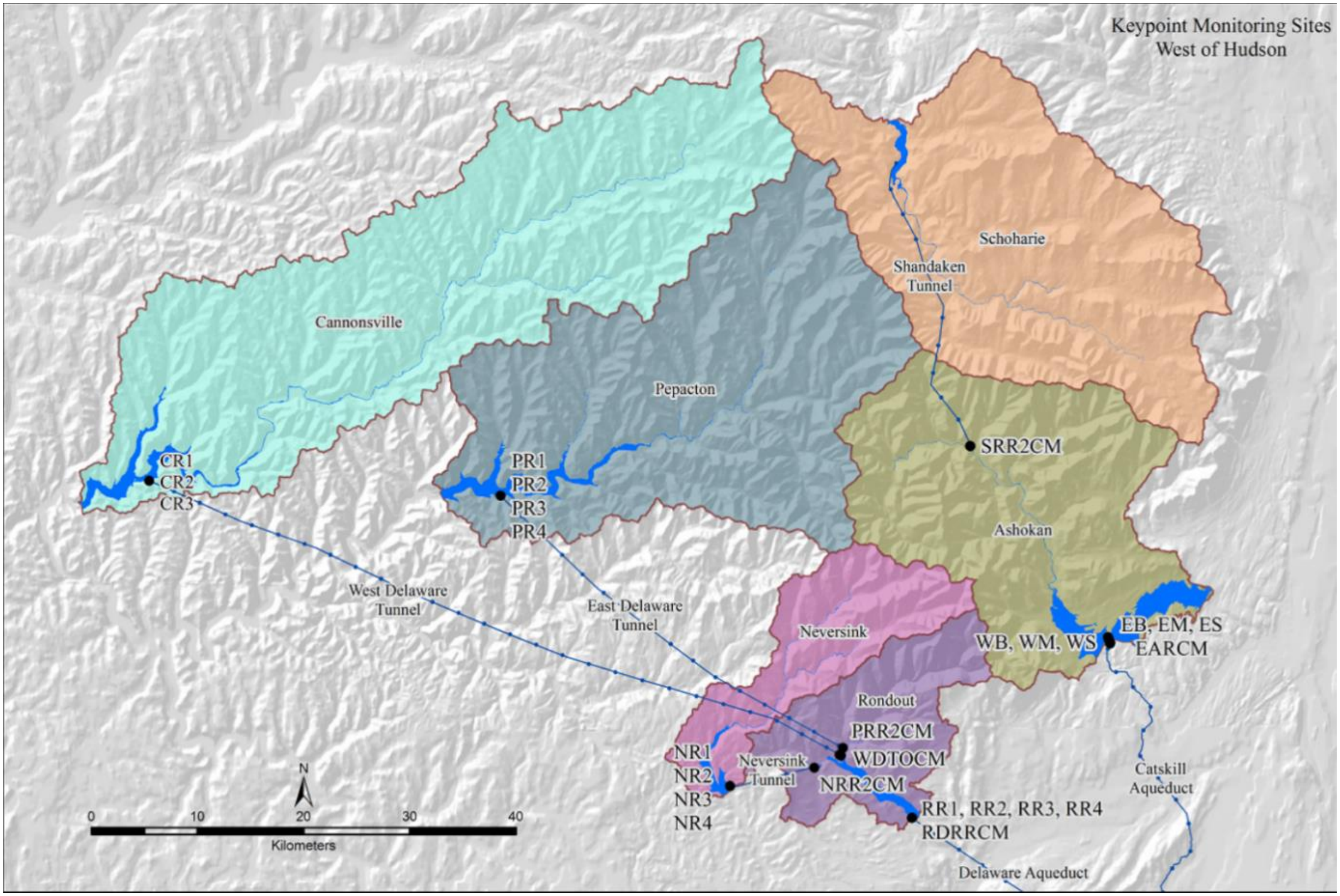
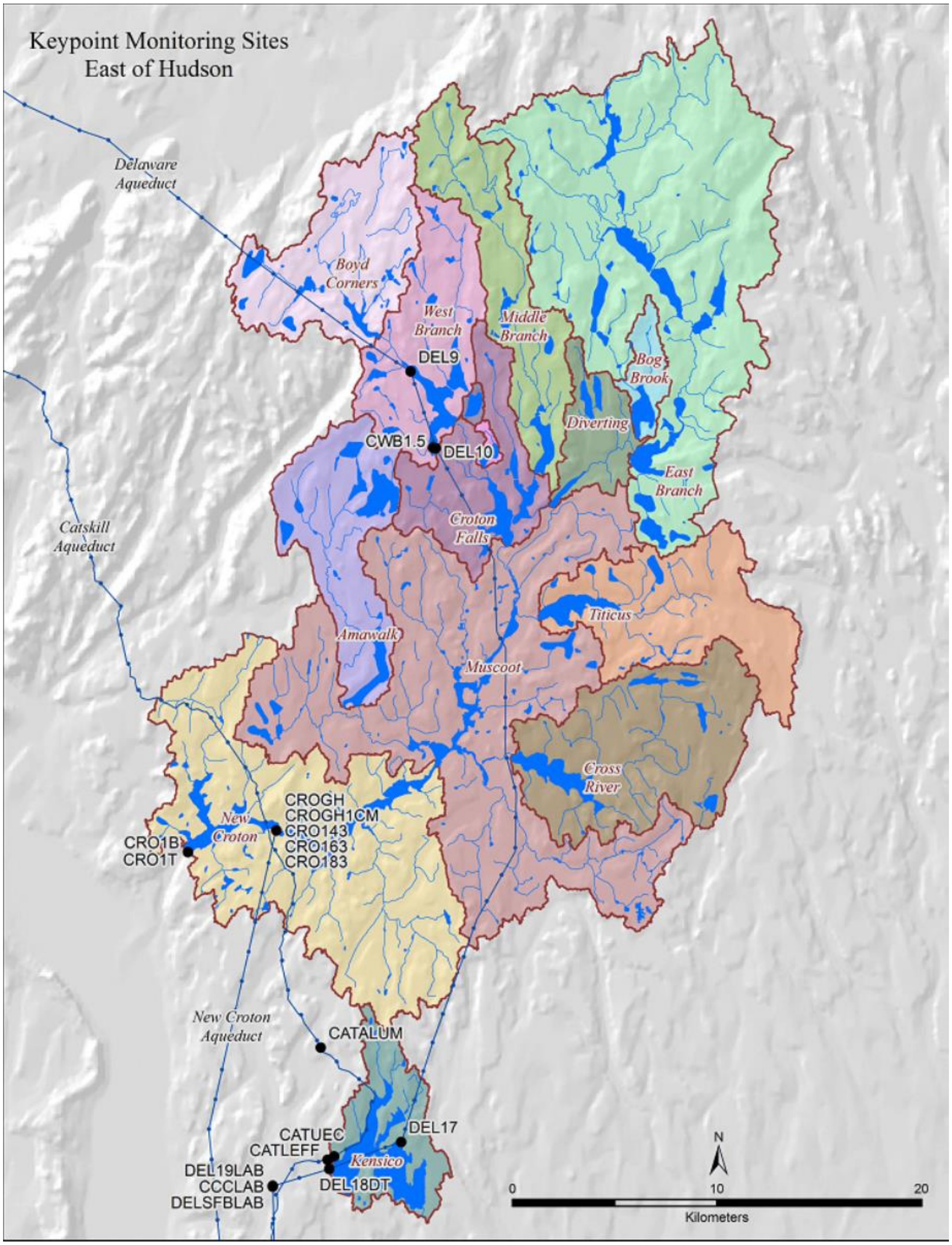
Appendix Figure 5 EOH stream monitoring sites [see WWQMP (DEP 2018) for detailed maps].

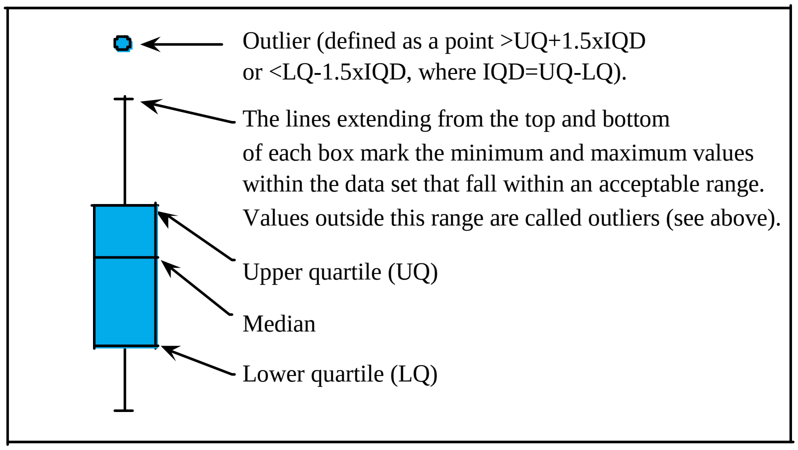


Appendix Figure 6 WOH aqueduct keypoint monitoring sites [see WWQMP (DEP 2018) for detailed maps].



Appendix Figure 7 EOH aqueduct keypoint monitoring sites [see WWQMP (DEP 2018) for detailed maps].

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

Monthly Coliform-Restricted Calculations for Non-Terminal Reservoirs

Reservoir	Class & Standard (Median, Value not > 20% of sample)	Collection Date	N	CONF	Median Total Coliform (coliforms 100mL^{-1})	Percentage > Standard
Boyd Corners	AA (50, 240)	Apr-20	0	0	No Samples	
		May-20	0	0	No Samples	
		Jun-20	7	0	E40	0
		Jul-20	6	0	<100	0
		Aug-20	6	0	E100	17
		Sep-20	0	0	No Samples	
		Oct-20	0	0	No Samples	
		Nov-20	0	0	No Samples	
Cross River	AA (50, 240)	Apr-20	0	0	No Samples	
		May-20	0	0	No Samples	
		Jun-20	3	0	<5 samples/month	0
		Jul-20	3	0	<5 samples/month	0
		Aug-20	3	0	<5 samples/month	0
		Sep-20	3	0	<5 samples/month	0
		Oct-20	3	0	<5 samples/month	0
		Nov-20	3	0	<5 samples/month	0
Croton Falls	A/AA (50, 240)	Apr-20	0	0	No Samples	
		May-20	0	0	No Samples	
		Jun-20	8	0	E5	0
		Jul-20	8	0	E20	0
		Aug-20	8	0	E20	0
		Sep-20	8	0	E20	0
		Oct-20	8	0	<20	0
		Nov-20	8	0	E60	0
Cannonsville	A/AA (50, 240)	Apr-20	0	0	No Samples	
		May-20	0	0	No Samples	

Monthly Coliform-Restricted Calculations for Non-Terminal Reservoirs

Reservoir	Class & Standard (Median, Value not > 20% of sample)	Collection Date	N	CONF	Median Total Coliform (coliforms $100mL^{-1}$)	Percentage > Standard
Cannonsville	A/AA (50, 240)	Jun-20	0	0	No Samples	
		Jul-20	14	0	<50	0
		Aug-20	14	0	E140	21
		Sep-20	14	0	E100	14
		Oct-20	12	0	E30	0
		Nov-20	12	0	E50	8
Pepacton	A/AA (50, 240)	Apr-20	0	0	No Samples	
		May-20	0	0	No Samples	
		Jun-20	15	0	<20	0
		Jul-20	15	0	>=E10	7
		Aug-20	16	0	10	0
		Sep-20	15	0	E20	0
		Oct-20	14	0	E2	0
		Nov-20	14	0	E8	0
Neversink	A/AA (50, 240)	Apr-20	0	0	No Samples	
		May-20	0	0	No Samples	
		Jun-20	13	0	5	0
		Jul-20	12	0	E10	0
		Aug-20	11	0	E15	0
		Sep-20	11	0	E20	0
		Oct-20	11	0	E20	0
		Nov-20	11	0	E10	0
Schoharie	A/AA (50, 240)	Apr-20	0	0	No Samples	
		May-20	0	0	No Samples	
		Jun-20	11	0	E6	9
		Jul-20	11	0	E5	0
		Aug-20	11	0	E50	0
		Sep-20	11	0	E15	0

Monthly Coliform-Restricted Calculations for Non-Terminal Reservoirs

Reservoir	Class & Standard (Median, Value not > 20% of sample)	Collection Date	N	CONF	Median Total Coliform (coliforms $100mL^{-1}$)	Percentage > Standard
		Oct-20	11	0	E30	0
		Nov-20	12	0	E60	25

[1]CONF indicates the number of samples with confluent growth where counts are indeterminate. Median calculations are based on "N" and exclude these CONF samples.

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. Codes associated with data reporting include the following: E: Estimated count based on non-ideal plate; >=: plate count may be biased low based on heavy growth; >: observed count replaced with dilution-based value; <: below detection limit.

Appendix E. 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 1 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 New York State 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 E. Table 1 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	2015 µg L^{-1}	2016 µg L^{-1}	2017 µg L^{-1}	2018 µg L^{-1}	2019 µg L^{-1}	2020 µg L^{-1}
Non-Source Waters (Delaware System)						
Cannonsville Reservoir	14.9	17.0	15.4	14.3	15.6	14.3
Pepacton Reservoir	9.0	10.8	10.3	10.1	9.8	9.4
Neversink Reservoir	6.5	8.0	7.3	6.5	6.5	6.8
Non-Source Waters (Catskill System)						
Schoharie Reservoir	11.9	12.5	12.2	14.9	12.3	9.9
Non-Source Waters (Croton System)						
Amawalk Reservoir	19.3	29.8	26.3	25.4	17.3	NS
Bog Brook Reservoir	19.4	28.4	27.8	19.4	14.1	NS
Boyd Corners Reservoir	9.0	11.3	15.1	14.0	11.5	11.2
Diverting Reservoir	25.8	37.4	31.6	28.7	23.2	NS
East Branch Reservoir	21.3	23.5	25.1	27.5	21.6	NS
Middle Branch Reservoir	27.4	34.1	28.4	29.4	18.3	NS
Muscoot Reservoir	28.5	30.6	36.5	30.6	28.9	NS
Titicus Reservoir	19.5	23.7	25.2	25.0	23.1	NS
Lake Gleneida	35.0	27.0	25.5	21.5	14.9	NS
Lake Gilead	27.1	34.6	33.6	32.7	20.5	NS
Kirk Lake	30.8	27.3	23.3	20.9	18.4	NS
Source Waters (all systems)						
Ashokan West Basin	8.8	12.6	8.2	8.3	7.8	7.8
Ashokan East Basin	7.9	10.3	8.1	7.6	7.4	7.0
Cross River Reservoir	15.7	19.0	23.2	21.1	16.8	19.7
Croton Falls Reservoir	19.4	18.0	23.2	21.5	15.3	21.5
Kensico Reservoir	7.4	7.6	8.8	7.9	6.8	7.7
New Croton Reservoir	16.8	22.1	22.5	26.2	19.5	NS
Rondout Reservoir	7.9	10.0	9.0	8.1	7.8	7.3
West Branch Reservoir	11.3	13.4	14.2	11.8	9.5	10.0

NS: "Not Sampled" – Total phosphorus sampling was reduced during 2020 because of the COVID-19 pandemic resulting in an insufficient number of samples for the annual geometric mean calculation.

Appendix F. Comparison of Reservoir Water Quality Results to Benchmarks

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
Non-Source Waters (Delaware System)								
Cannonsville Reservoir	Total phosphorus (as P) (µg L^{-1})	15	66	32	48	NA	17	KM
	Total dissolved phosphorus (as P) (µg L^{-1})	15	65	3	5	NA	6	
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	66	0	0	NA	2	KM
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	66	0	0	0.3	0.20	KM
	Ammonia (as N) (mg L^{-1})	0.1	65	0	0	0.05	0.01	ROS
	Fecal coliform (coliforms 100mL^{-1})	20	65	2	3	NA	4	KM
	Turbidity (NTU)	5	69	12	17	NA	3.1	
	Total suspended solids (mg L^{-1})	8	30	0	0	5	2.5	KM
	Alkalinity (mg L^{-1})	NA	11	0	0	>=10	19.5	
	Dissolved organic carbon (mg L^{-1})	4	69	0	0	3	1.9	
	Sulfate (as SO4) (mg L^{-1})	15	11	0	0	10	4.8	
	pH (SU)	6.5-8.5	63	24	38	NA	7.28	
	Dissolved Sodium (mg L^{-1})	16	11	0	0	3	8.8	
	Chloride (mg L^{-1})	12	11	9	82	8	13.2	
	Total dissolved solids (mg L^{-1})[3]	50	69	69	100	40	66	
	Chlorophyll a (µg L^{-1})	12	31	3	10	7	7.6	
	Total plankton (ASU mL^{-1})	2000	41	0	0	NA	404	
	Dominant plankton (ASU mL^{-1})	1000	41	0	0	NA	181	
	Secondary plankton (ASU mL^{-1})	1000	41	0	0	NA	92	KM
Pepacton Reservoir	Total phosphorus (as P) (µg L^{-1})	15	88	7	8	NA	10	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	89	0	0	NA	4	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	89	0	0	NA	2	ROS
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	89	0	0	0.3	0.11	KM
	Ammonia (as N) (mg L^{-1})	0.1	89	1	1	0.05	<0.02	>80%
	Fecal coliform (coliforms 100mL^{-1})	20	89	0	0	NA	1	ROS
	Turbidity (NTU)	5	89	4	4	NA	1.8	
	Total suspended solids (mg L^{-1})	8	43	0	0	5	0.8	ROS
	Alkalinity (mg L^{-1})	NA	14	0	0	>=10	14.2	
	Dissolved organic carbon (mg L^{-1})	4	89	0	0	3	1.7	
	Sulfate (as SO4) (mg L^{-1})	15	14	0	0	10	3.2	
	pH (SU)	6.5-8.5	75	15	20	NA	7.22	
	Dissolved Sodium (mg L^{-1})	16	14	0	0	3	5.4	

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Chloride (mg L^{-1})	12	14	0	0	8	8.6	
	Total dissolved solids (mg L^{-1})[3]	50	89	13	15	40	47	
	Chlorophyll a (µg L^{-1})	12	30	1	3	7	4.3	
	Total plankton (ASU mL^{-1})	2000	43	0	0	NA	267	
	Dominant plankton (ASU mL^{-1})	1000	43	0	0	NA	126	
	Secondary plankton (ASU mL^{-1})	1000	43	0	0	NA	54	KM
Neversink Reservoir	Total phosphorus (as P) (µg L^{-1})	15	51	0	0	NA	7	KM
	Total dissolved phosphorus (as P) (µg L^{-1})	15	51	0	0	NA	4	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	51	0	0	NA	<2	>80%
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	51	0	0	0.3	0.14	KM
	Ammonia (as N) (mg L^{-1})	0.1	51	1	2	0.05	0.02	ROS
	Fecal coliform (coliforms 100mL^{-1})	20	69	0	0	NA	1	ROS
	Turbidity (NTU)	5	89	0	0	NA	1.1	
	Total suspended solids (mg L^{-1})	8	18	0	0	5	1.0	ROS
	Alkalinity (mg L^{-1})	NA	6	0	0	>=10	3.8	
	Dissolved organic carbon (mg L^{-1})	4	71	0	0	3	2.0	
	Sulfate (as SO4) (mg L^{-1})	15	6	0	0	10	2.3	
	pH (SU)	6.5-8.5	69	46	67	NA	6.23	
	Dissolved Sodium (mg L^{-1})	16	6	0	0	3	2.2	
	Chloride (mg L^{-1})	12	6	0	0	8	3.6	
	Total dissolved solids (mg L^{-1})[3]	50	89	0	0	40	19	
	Chlorophyll a (µg L^{-1})	12	28	1	4	7	4.4	
	Total plankton (ASU mL^{-1})	2000	46	0	0	NA	231	KM
	Dominant plankton (ASU mL^{-1})	1000	46	0	0	NA	112	KM
	Secondary plankton (ASU mL^{-1})	1000	46	0	0	NA	51	KM
Non-Source Waters (Catskill System)								
Schoharie Reservoir	Total phosphorus (as P) (µg L^{-1})	15	67	4	6	NA	10	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	44	0	0	NA	6	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	41	0	0	NA	3	KM
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	41	0	0	0.3	0.07	ROS
	Ammonia (as N) (mg L^{-1})	0.1	41	1	2	0.05	<0.02	>80%
	Fecal coliform (coliforms 100mL^{-1})	20	66	2	3	NA	4	ROS
	Turbidity (NTU)	5	67	13	19	NA	4.6	
	Total suspended solids (mg L^{-1})	8	67	5	7	5	3.5	KM
	Alkalinity (mg L^{-1})	NA	6	0	0	>=10	19.9	
	Dissolved organic carbon (mg L^{-1})	4	67	0	0	3	2.5	
	Sulfate (as SO4) (mg L^{-1})	15	6	0	0	10	3.1	

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	pH (SU)	6.5-8.5	67	3	4	NA	7.13	
	Dissolved Sodium (mg L^{-1})	16	6	0	0	3	6.6	
	Chloride (mg L^{-1})	12	6	0	0	8	9.6	
	Total dissolved solids (mg L^{-1})[3]	50	67	44	66	40	53	
	Chlorophyll a (µg L^{-1})	12	24	0	0	7	4.4	
	Total plankton (ASU mL^{-1})	2000	41	0	0	NA	207	KM
	Dominant plankton (ASU mL^{-1})	1000	41	0	0	NA	120	KM
	Secondary plankton (ASU mL^{-1})	1000	41	0	0	NA	40	KM
Non-Source Waters (Croton System)								
Amawalk Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
Amawalk Reservoir	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
Amawalk Reservoir	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
Amawalk Reservoir	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
Amawalk Reservoir	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
Amawalk Reservoir	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
Amawalk Reservoir	Turbidity (NTU)	5	0			NA		C19
Amawalk Reservoir	Total suspended solids (mg L^{-1})	8	0			5		C19
Amawalk Reservoir	Alkalinity (mg L^{-1})	NA	0			>=40		C19
Amawalk Reservoir	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
Amawalk Reservoir	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
Amawalk Reservoir	pH (SU)	6.5-8.5	0			NA		C19
Amawalk Reservoir	Dissolved Sodium (mg L^{-1})	20	0			15		C19
Amawalk Reservoir	Chloride (mg L^{-1})	40	0			30		C19
Amawalk Reservoir	Total dissolved solids (mg L^{-1})[3]	175	0			150		
Amawalk Reservoir	Chlorophyll a (µg L^{-1})	15	0			10		C19
Amawalk Reservoir	Total plankton (ASU mL^{-1})	2000	0			NA		C19
Amawalk Reservoir	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
Amawalk Reservoir	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
Bog Brook Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
Bog Brook Reservoir	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
Bog Brook Reservoir	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
Bog Brook Reservoir	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
Bog Brook Reservoir	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Fecal coliform (coliforms $100mL^{-1}$)	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
Boyd Corners Reservoir	Total phosphorus (as P) (µg L^{-1})	15	6	1	17	NA	12	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	6	0	0	NA	5	
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	6	0	0	NA	<2	>80%
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	6	0	0	0.3	<0.02	>80%
	Ammonia (as N) (mg L^{-1})	0.1	6	0	0	0.05	<0.02	>80%
	Fecal coliform (coliforms $100mL^{-1}$)	20	19	0	0	NA	2	KM
	Turbidity (NTU)	5	6	0	0	NA	1.3	
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	6	0	0	6	3.6	
	pH (SU)	6.5-8.5	7	1	14	NA	7.38	
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	6	0	0	150	137	
	Chlorophyll a (µg L^{-1})	15	3	0	0	10	3.2	
	Total plankton (ASU mL^{-1})	2000	3	0	0	NA	192	
	Dominant plankton (ASU mL^{-1})	1000	3	0	0	NA	145	
	Secondary plankton (ASU mL^{-1})	1000	3	0	0	NA	26	
Diverting Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	**Analyte**	**Single Sample Maximum (SSM)**	**Number samples**	**Number that exceed SSM**	**Percent that exceed SSM**	**Annual Mean Standard**	**2020 Mean[1]**	**Note[2]**
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
East Branch Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
Middle Branch Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
Muscoot Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
Titicus Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
Lake Gleneida	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
Lake Gilead	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
Kirk Lake	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	0			NA		C19
	Turbidity (NTU)	5	0			NA		C19
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	Sulfate (as SO4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	0			NA		C19
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	0			150		
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	0			NA		C19
	Dominant plankton (ASU mL^{-1})	1000	0			NA		C19
	Secondary plankton (ASU mL^{-1})	1000	0			NA		C19
Source Waters (all systems)								
Ashokan West Basin Reservoir	Total phosphorus (as P) (µg L^{-1})	15	50	2	4	NA	9	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	49	0	0	NA	4	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	50	0	0	NA	3	KM
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	50	0	0	0.3	0.10	KM
	Ammonia (as N) (mg L^{-1})	0.1	49	0	0	0.05	0.01	ROS
	Fecal coliform (coliforms 100mL^{-1})	20	50	1	2	NA	2	ROS
	Turbidity (NTU)	5	70	11	16	NA	3.9	
	Total suspended solids (mg L^{-1})	8	64	4	6	5	3.2	KM
	Alkalinity (mg L^{-1})	NA	8	0	0	>=10	13.9	
	Dissolved organic carbon (mg L^{-1})	4	50	1	2	3	2.0	
	Sulfate (as SO4) (mg L^{-1})	15	8	0	0	10	2.9	
	pH (SU)	6.5-8.5	60	17	28	NA	6.88	
	Dissolved Sodium (mg L^{-1})	16	8	0	0	3	5.0	
	Chloride (mg L^{-1})	12	8	0	0	8	7.3	
	Total dissolved solids (mg L^{-1})[3]	50	50	1	2	40	38	
	Chlorophyll a (µg L^{-1})	12	18	0	0	7	4.2	
	Total plankton (ASU mL^{-1})	2000	34	0	0	NA	146	

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Dominant plankton (ASU mL^{-1})	1000	34	0	0	NA	71	
	Secondary plankton (ASU mL^{-1})	1000	34	0	0	NA	34	KM
Ashokan East Basin Reservoir	Total phosphorus (as P) (µg L^{-1})	15	46	0	0	NA	8	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	46	0	0	NA	4	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	46	0	0	NA	2	ROS
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	46	0	0	0.3	<0.05	>80%
	Ammonia (as N) (mg L^{-1})	0.1	46	0	0	0.05	<0.02	>80%
	Fecal coliform (coliforms 100mL^{-1})	20	46	1	2	NA	1	ROS
	Turbidity (NTU)	5	52	1	2	NA	1.7	
	Total suspended solids (mg L^{-1})	8	52	0	0	5	1.4	ROS
	Alkalinity (mg L^{-1})	NA	7	0	0	>=10	11.9	
	Dissolved organic carbon (mg L^{-1})	4	46	0	0	3	1.7	
	Sulfate (as SO4) (mg L^{-1})	15	6	0	0	10	3.0	
	pH (SU)	6.5-8.5	41	8	20	NA	6.97	
	Dissolved Sodium (mg L^{-1})	16	6	0	0	3	5.0	
	Chloride (mg L^{-1})	12	6	0	0	8	7.9	
	Total dissolved solids (mg L^{-1})[3]	50	46	0	0	40	39	
	Chlorophyll a (µg L^{-1})	12	17	0	0	7	1.9	
	Total plankton (ASU mL^{-1})	2000	27	0	0	NA	117	KM
	Dominant plankton (ASU mL^{-1})	1000	27	0	0	NA	49	KM
	Secondary plankton (ASU mL^{-1})	1000	27	0	0	NA	24	KM
Rondout Reservoir	Total phosphorus (as P) (µg L^{-1})	15	60	0	0	NA	7	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	41	0	0	NA	3	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	42	0	0	NA	2	ROS
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	42	0	0	0.3	0.14	KM
	Ammonia (as N) (mg L^{-1})	0.1	42	0	0	0.05	<0.02	>80%
	Fecal coliform (coliforms 100mL^{-1})	20	60	0	0	NA	1	ROS
	Turbidity (NTU)	5	68	0	0	NA	0.9	
	Total suspended solids (mg L^{-1})	8	20	0	0	5	0.9	ROS
	Alkalinity (mg L^{-1})	NA	4	0	0	>=10	12.5	
	Dissolved organic carbon (mg L^{-1})	4	42	0	0	3	1.7	
	Sulfate (as SO4) (mg L^{-1})	15	4	0	0	10	3.4	
	pH (SU)	6.5-8.5	60	14	23	NA	7.02	
	Dissolved Sodium (mg L^{-1})	16	8	0	0	3	5.3	
	Chloride (mg L^{-1})	12	4	0	0	8	8.9	
	Total dissolved solids (mg L^{-1})[3]	50	68	3	4	40	43	

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Chlorophyll a (µg L^{-1})	12	18	0	0	7	4.7	
	Total plankton (ASU mL^{-1})	2000	36	0	0	NA	310	KM
	Dominant plankton (ASU mL^{-1})	1000	36	0	0	NA	150	KM
	Secondary plankton (ASU mL^{-1})	1000	36	0	0	NA	58	KM
West Branch Reservoir	Total phosphorus (as P) (µg L^{-1})	15	53	7	13	NA	12	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	53	0	0	NA	4	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	53	0	0	NA	<2	>80%
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	53	0	0	0.3	0.10	KM
	Ammonia (as N) (mg L^{-1})	0.1	53	1	2	0.05	0.01	ROS
	Fecal coliform (coliforms 100mL^{-1})	20	53	0	0	NA	2	KM
	Turbidity (NTU)	5	53	0	0	NA	1.2	
	Total suspended solids (mg L^{-1})	8	5	0	0	5	<0.9	>80%
	Alkalinity (mg L^{-1})	NA	9	0	0	>=10	15.8	
	Dissolved organic carbon (mg L^{-1})	4	53	0	0	3	1.9	
	Sulfate (as SO_4) (mg L^{-1})	15	9	0	0	10	4.3	
	pH (SU)	6.5-8.5	53	8	15	NA	6.95	
	Dissolved Sodium (mg L^{-1})	16	9	0	0	3	7.6	
	Chloride (mg L^{-1})	12	9	4	44	8	12.6	
	Total dissolved solids (mg L^{-1})[3]	50	53	14	26	40	53	
	Chlorophyll a (µg L^{-1})	12	24	1	4	7	4.7	
	Total plankton (ASU mL^{-1})	2000	32	0	0	NA	509	
	Dominant plankton (ASU mL^{-1})	1000	32	0	0	NA	333	
	Secondary plankton (ASU mL^{-1})	1000	32	0	0	NA	93	
Cross River Reservoir	Total phosphorus (as P) (µg L^{-1})	15	18	14	78	NA	22	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	18	0	0	NA	2	KM
	Turbidity (NTU)	5	18	1	6	NA	2.5	
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Dissolved organic carbon (mg L^{-1})	7	0			6		C19
	pH (SU)	6.5-8.5	15	3	20	NA	7.49	

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	18	0	0	150	168	
	Chlorophyll a (µg L^{-1})	15	6	2	33	10	11.5	
	Total plankton (ASU mL^{-1})	2000	6	0	0	NA	581	
	Dominant plankton (ASU mL^{-1})	1000	6	0	0	NA	366	
	Secondary plankton (ASU mL^{-1})	1000	6	0	0	NA	137	
Croton Falls Reservoir	Total phosphorus (as P) (µg L^{-1})	15	51	35	69	NA	29	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	49	8	16	NA	10	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	48	1	2	NA	3	KM
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	48	3	6	0.3	0.20	KM
	Ammonia (as N) (mg L^{-1})	0.1	47	11	23	0.05	0.09	ROS
	Fecal coliform (coliforms 100mL^{-1})	20	48	1	2	NA	4	KM
	Turbidity (NTU)	5	48	13	27	NA	5.9	
	Total suspended solids (mg L^{-1})	8	6	0	0	5	1.8	KM
	Alkalinity (mg L^{-1})	NA	12	0	0	>=40	69.5	
	Dissolved organic carbon (mg L^{-1})	7	47	0	0	6	3.3	
	Sulfate (as SO4) (mg L^{-1})	25	12	0	0	15	8.9	
	pH (SU)	6.5-8.5	51	20	39	NA	8.04	
	Dissolved Sodium (mg L^{-1})	20	12	12	100	15	39.0	
	Chloride (mg L^{-1})	40	12	12	100	30	67.5	
	Total dissolved solids (mg L^{-1})[3]	175	48	48	100	150	286	
	Chlorophyll a (µg L^{-1})	15	23	13	57	10	33.8	
	Total plankton (ASU mL^{-1})	2000	23	8	35	NA	2052	
	Dominant plankton (ASU mL^{-1})	1000	23	9	39	NA	1645	
	Secondary plankton (ASU mL^{-1})	1000	23	2	9	NA	288	KM
Kensico Reservoir	Total phosphorus (as P) (µg L^{-1})	15	130	2	2	NA	8	
	Total dissolved phosphorus (as P) (µg L^{-1})	15	130	0	0	NA	4	KM
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	130	0	0	NA	<2	>80%
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	130	0	0	0.3	0.10	KM
	Ammonia (as N) (mg L^{-1})	0.1	130	0	0	0.05	0.01	ROS
	Fecal coliform (coliforms 100mL^{-1})	20	130	0	0	NA	2	KM
	Turbidity (NTU)	5	130	0	0	NA	0.9	
	Total suspended solids (mg L^{-1})	8	42	0	0	5	0.9	ROS
	Alkalinity (mg L^{-1})	NA	16	0	0	>=10	13.6	
	Dissolved organic carbon (mg L^{-1})	4	130	0	0	3	1.7	
	Sulfate (as SO4) (mg L^{-1})	15	16	0	0	10	3.9	

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	pH (SU)	6.5-8.5	130	29	22	NA	6.93	
	Dissolved Sodium (mg L^{-1})	16	16	0	0	3	7.0	
	Chloride (mg L^{-1})	12	16	8	50	8	11.4	
	Total dissolved solids (mg L^{-1})[3]	50	130	49	38	40	49	
	Chlorophyll a (µg L^{-1})	12	42	0	0	7	4.8	
	Total plankton (ASU mL^{-1})	2000	54	0	0	NA	450	
	Dominant plankton (ASU mL^{-1})	1000	54	0	0	NA	220	
	Secondary plankton (ASU mL^{-1})	1000	54	0	0	NA	106	
New Croton Reservoir	Total phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Total dissolved phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Soluble reactive phosphorus (as P) (µg L^{-1})	15	0			NA		C19
	Nitrate+Nitrite (as N) (mg L^{-1})	0.5	0			0.3		C19
	Ammonia (as N) (mg L^{-1})	0.1	0			0.05		C19
	Fecal coliform (coliforms 100mL^{-1})	20	41	0	0	NA	2	ROS
	Turbidity (NTU)	5	47	2	4	NA	2.1	
	Total suspended solids (mg L^{-1})	8	0			5		C19
	Alkalinity (mg L^{-1})	NA	0			>=40		C19
	Apparent Color (CU)	15	47	43	91	NA	26	
	Dissolved organic carbon (mg L^{-1})	7	47	0	0	6	3.3	
	Sulfate (as SO_4) (mg L^{-1})	25	0			15		C19
	pH (SU)	6.5-8.5	47	5	11	NA	7.58	
	Dissolved Sodium (mg L^{-1})	20	0			15		C19
	Chloride (mg L^{-1})	40	0			30		C19
	Total dissolved solids (mg L^{-1})[3]	175	47	47	100	150	266	
	Chlorophyll a (µg L^{-1})	15	0			10		C19
	Total plankton (ASU mL^{-1})	2000	47	0	0	NA	244	KM
	Dominant plankton (ASU mL^{-1})	1000	47	0	0	NA	134	KM
	Secondary plankton (ASU mL^{-1})	1000	47	0	0	NA	64	KM

NA = not applicable

Summary statistics based upon data request completed 05/06/2021.

Comparison of Reservoir Water Quality Results to Benchmarks

Reservoir	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]

[1]Means for data containing non-detects were estimated using techniques recommended in Helsel (2005) using an R program developed for U.S. Environmental Protection Agency (Bolks et al. 2014).

[2]Note indicates which analysis method was used to determine the statistics when there were censored data. KM indicates Kaplan-Meier, ROS indicates robust regression on order statistics, and >80% indicates that greater than 80% censored data or 5 or fewer samples with greater than 50 % censored data prevents a statistical calculation, so the detection limit, preceded by "<", is reported. C19 indicates no samples were collected as the result of COVID-19 pandemic sample reduction. A blank cell in the Note column indicates that the 2020 mean was calculated as the standard arithmetic average.

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

Appendix G. Comparison of Stream Water Quality Results to Benchmarks

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
Catskill System – Ashokan Basin								
E10I (Bushkill at West Shokan)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.08	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	5	100	NA	6.4	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.2	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.0	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	2.1	
	Chloride (mg L^{-1})	50	5	0	0	10	3.4	
	Total dissolved solids (mg L^{-1})[3]	50	5	0	0	40	21	
E16I (Esopus Brook at Coldbrook)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.16	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	1	20	NA	11.2	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.4	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	2.9	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	4.8	
	Chloride (mg L^{-1})	50	5	0	0	10	7.9	
	Total dissolved solids (mg L^{-1})[3]	50	7	1	14	40	41	
E5 (Esopus Creek at Allaben)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.4	0.17	
	Ammonia (as N) (mg L^{-1})	0.25	3	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	3	3	100	NA	8.3	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	0.9	
	Sulfate (as SO4) (mg L^{-1})	15	1	0	0	10	3.0	
	Dissolved Sodium (mg L^{-1})	10	1	0	0	5	5.2	
	Chloride (mg L^{-1})	50	3	0	0	10	9.9	
	Total dissolved solids (mg L^{-1})[3]	50	3	0	0	40	39	
Catskill System – Schoharie Basin								
S5I (Schoharie	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.15	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
Creek at Prattsville)	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	14.2	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	2.0	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.2	
	Dissolved Sodium (mg L^{-1})	10	2	1	50	5	11.0	
	Chloride (mg L^{-1})	50	5	0	0	10	12.5	
	Total dissolved solids (mg L^{-1})[3]	50	10	7	70	40	61	
S6I (Bear Kill at Hardenburgh Falls)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.37	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	20.1	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	2.1	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	4.8	
	Dissolved Sodium (mg L^{-1})	10	2	2	100	5	18.8	
	Chloride (mg L^{-1})	50	5	0	0	10	22.0	
	Total dissolved solids (mg L^{-1})[3]	50	5	5	100	40	83	
S7I (Manor Kill)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.09	KM
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	19.1	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.8	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.9	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	6.3	
	Chloride (mg L^{-1})	50	5	0	0	10	10.0	
	Total dissolved solids (mg L^{-1})[3]	50	5	2	40	40	53	
Delaware System – Cannonsville Basin								
C-7 (Trout Creek above Cannonsville Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.35	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	13.8	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.3	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	4.9	
	Dissolved Sodium (mg L^{-1})	10	2	2	100	5	10.9	
	Chloride (mg L^{-1})	50	5	0	0	10	14.8	
	Total dissolved solids (mg L^{-1})[3]	50	5	4	80	40	64	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
C-8 (Loomis Brook above Cannonsville Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.36	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	13.5	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.2	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	4.8	
	Dissolved Sodium (mg L^{-1})	10	2	1	50	5	10.6	
	Chloride (mg L^{-1})	50	5	0	0	10	14.6	
	Total dissolved solids (mg L^{-1})[3]	50	5	5	100	40	63	
CBS (formerly WDBN, West Branch Delaware River at Beerston Bridge)	NO3+NO2 (as N) (mg L^{-1})	1.5	10	0	0	0.4	0.58	
	Ammonia (as N) (mg L^{-1})	0.25	10	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	16.5	
	Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	1.6	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	4.9	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	8.4	
	Chloride (mg L^{-1})	50	5	0	0	10	11.6	
	Total dissolved solids (mg L^{-1})[3]	50	10	10	100	40	86	
Delaware System – Neversink Basin								
NCG (Neversink River near Claryville)	NO3+NO2 (as N) (mg L^{-1})	1.5	10	0	0	0.4	0.22	
	Ammonia (as N) (mg L^{-1})	0.25	10	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	5	100	NA	3.1	
	Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	1.3	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	2.0	
	Chloride (mg L^{-1})	50	5	0	0	10	3.1	
	Total dissolved solids (mg L^{-1})[3]	50	10	0	0	40	20	
NK4 (Aden Brook above Neversink Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.17	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	5	100	NA	5.0	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.3	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	2.5	
	Chloride (mg L^{-1})	50	5	0	0	10	4.3	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Total dissolved solids (mg L^{-1})[3]	50	5	0	0	40	24	
NK6 (Kramer Brook above Neversink Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.45	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	0.03	
	Alkalinity (mg L^{-1})	>=10.0	5	4	80	NA	8.7	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	2.1	
	Dissolved Sodium (mg L^{-1})	10	2	2	100	5	20.5	
	Chloride (mg L^{-1})	50	5	0	0	10	32.7	
	Total dissolved solids (mg L^{-1})[3]	50	5	5	100	40	98	
Delaware System – Pepacton Basin								
P-13 (Tremper Kill above Pepacton Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.33	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	13.7	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.3	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.8	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	6.4	
	Chloride (mg L^{-1})	50	5	0	0	10	10.0	
	Total dissolved solids (mg L^{-1})[3]	50	5	4	80	40	51	
P-21 (Platte Kill at Dunraven)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.26	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	13.8	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.4	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.7	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	5.4	
	Chloride (mg L^{-1})	50	5	0	0	10	8.0	
	Total dissolved solids (mg L^{-1})[3]	50	5	1	20	40	46	
P-60 (Mill Brook near Dunraven)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.31	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	3	60	NA	9.2	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.1	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	2.9	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	1.2	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Chloride (mg L^{-1})	50	5	0	0	10	1.8	
	Total dissolved solids (mg L^{-1})[3]	50	5	0	0	40	25	
P-7 (Terry Clove above Pepacton Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.37	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	1	20	NA	11.1	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.2	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.7	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	1.2	
	Chloride (mg L^{-1})	50	5	0	0	10	1.1	
	Total dissolved solids (mg L^{-1})[3]	50	5	0	0	40	28	
P-8 (Fall Clove above Pepacton Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.44	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	11.3	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.1	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.8	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	2.2	
	Chloride (mg L^{-1})	50	5	0	0	10	2.6	
	Total dissolved solids (mg L^{-1})[3]	50	5	0	0	40	32	
PMSB (East Branch Delaware River near Margaretville)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.29	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	14.8	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.3	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	3.3	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	6.3	
	Chloride (mg L^{-1})	50	5	0	0	10	10.3	
	Total dissolved solids (mg L^{-1})[3]	50	5	3	60	40	53	
Delaware System – Rondout Basin								
RD1 (Sugarloaf Brook near Lowes Corners)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.13	KM
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	5	100	NA	4.4	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.2	
	Sulfate (as SO4) (mg L^{-1})	15	1	0	0	10	3.2	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	3.6	
	Chloride (mg L^{-1})	50	5	0	0	10	6.0	
	Total dissolved solids (mg L^{-1})[3]	50	5	0	0	40	27	
RD4 (Sawkill Brook near Yagerville)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.10	KM
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	5	100	NA	4.7	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.8	
	Sulfate (as SO4) (mg L^{-1})	15	1	0	0	10	4.0	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	3.5	
	Chloride (mg L^{-1})	50	5	0	0	10	5.4	
	Total dissolved solids (mg L^{-1})[3]	50	5	0	0	40	27	
RDOA (Rondout Creek near Lowes Corners)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.23	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	5	100	NA	3.4	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	1.0	
	Sulfate (as SO4) (mg L^{-1})	15	1	0	0	10	2.7	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	2.1	
	Chloride (mg L^{-1})	50	5	0	0	10	3.3	
	Total dissolved solids (mg L^{-1})[3]	50	10	0	0	40	21	
RGB (Chestnut Creek below Grahamsville STP)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.28	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	4	80	NA	7.3	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	2.2	
	Dissolved Sodium (mg L^{-1})	10	2	1	50	5	11.5	
	Chloride (mg L^{-1})	50	5	0	0	10	15.8	
	Total dissolved solids (mg L^{-1})[3]	50	5	5	100	40	56	
Croton System – New Croton Basin								
AMAWALKR (Amawalk)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.35	0.22	
	Ammonia (as N) (mg L^{-1})	0.2	3	0	0	0.1	0.05	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
Reservoir Release)	Alkalinity (mg L^{-1})	>=40.0	3	0	0	NA	77.1	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	3.7	
	Sulfate (as SO4) (mg L^{-1})	25	1	0	0	15	10.5	
	Dissolved Sodium (mg L^{-1})	20	1	1	100	15	67.1	
	Chloride (mg L^{-1})	100	3	3	100	35	125.7	
	Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	382	
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.35	0.22	
	Ammonia (as N) (mg L^{-1})	0.2	3	0	0	0.1	0.02	KM
	Alkalinity (mg L^{-1})	>=40.0	3	0	0	NA	74.3	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	3.4	
	Sulfate (as SO4) (mg L^{-1})	25	1	0	0	15	10.6	
	Dissolved Sodium (mg L^{-1})	20	1	1	100	15	29.9	
	Chloride (mg L^{-1})	100	3	0	0	35	54.8	
	Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	230	
BOYDR (Boyd Corners Release)	NO3+NO2 (as N) (mg L^{-1})	1.5	7	0	0	0.35	0.10	
	Ammonia (as N) (mg L^{-1})	0.2	7	0	0	0.1	0.02	KM
	Alkalinity (mg L^{-1})	>=40.0	7	5	71	NA	36.4	
	Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	3.7	
	Sulfate (as SO4) (mg L^{-1})	25	3	0	0	15	7.2	
	Dissolved Sodium (mg L^{-1})	20	3	3	100	15	24.3	
	Chloride (mg L^{-1})	100	7	0	0	35	37.5	
	Total dissolved solids (mg L^{-1})[3]	175	10	0	0	150	139	
CROFALLSVC (Croton Falls Reservoir Release)	NO3+NO2 (as N) (mg L^{-1})	1.5	7	0	0	0.35	0.21	
	Ammonia (as N) (mg L^{-1})	0.2	7	0	0	0.1	0.07	
	Alkalinity (mg L^{-1})	>=40.0	7	0	0	NA	63.5	
	Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	3.1	
	Sulfate (as SO4) (mg L^{-1})	25	3	0	0	15	9.4	
	Dissolved Sodium (mg L^{-1})	20	3	3	100	15	38.3	
	Chloride (mg L^{-1})	100	7	0	0	35	68.4	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Total dissolved solids (mg L^{-1})[3]	175	10	10	100	150	249	
CROSS2 (Cross River above Cross River Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.35	0.23	
	Ammonia (as N) (mg L^{-1})	0.2	3	0	0	0.1	0.02	
	Alkalinity (mg L^{-1})	>=40.0	3	0	0	NA	51.0	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	3.5	
	Sulfate (as SO4) (mg L^{-1})	25	1	0	0	15	8.8	
	Dissolved Sodium (mg L^{-1})	20	1	1	100	15	21.9	
	Chloride (mg L^{-1})	100	3	0	0	35	41.5	
	Total dissolved solids (mg L^{-1})[3]	175	3	1	33	150	172	
CROSSRVVC (Cross River Reservoir Release)	NO3+NO2 (as N) (mg L^{-1})	1.5	7	0	0	0.35	0.05	KM
	Ammonia (as N) (mg L^{-1})	0.2	7	4	57	0.1	0.23	KM
	Alkalinity (mg L^{-1})	>=40.0	7	0	0	NA	52.7	
	Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	3.5	
	Sulfate (as SO4) (mg L^{-1})	25	3	0	0	15	6.3	
	Dissolved Sodium (mg L^{-1})	20	3	3	100	15	21.6	
	Chloride (mg L^{-1})	100	7	0	0	35	40.6	
	Total dissolved solids (mg L^{-1})[3]	175	10	0	0	150	169	
DIVERTR (Diverting Reservoir Release)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.35	0.29	
	Ammonia (as N) (mg L^{-1})	0.2	3	0	0	0.1	0.03	KM
	Alkalinity (mg L^{-1})	>=40.0	3	0	0	NA	74.3	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	3.6	
	Sulfate (as SO4) (mg L^{-1})	25	1	0	0	15	11.6	
	Dissolved Sodium (mg L^{-1})	20	1	1	100	15	39.6	
	Chloride (mg L^{-1})	100	3	0	0	35	66.3	
	Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	254	
EASTBR (East Branch Croton River above East Branch River)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.35	0.17	
	Ammonia (as N) (mg L^{-1})	0.2	3	0	0	0.1	<0.03	>80%
	Alkalinity (mg L^{-1})	>=40.0	3	0	0	NA	79.2	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	2.9	
	Sulfate (as SO4) (mg L^{-1})	25	1	0	0	15	10.8	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
	Dissolved Sodium ($mg\ L^{-1}$)	20	1	1	100	15	26.0	
	Chloride ($mg\ L^{-1}$)	100	3	0	0	35	47.8	
	Total dissolved solids ($mg\ L^{-1}$)[3]	175	3	3	100	150	220	
GYPSYTRL1 (Gypsy Trail Brook above West Branch Reservoir)	NO3+NO2 (as N) ($mg\ L^{-1}$)	1.5	5	0	0	0.35	0.03	KM
	Ammonia (as N) ($mg\ L^{-1}$)	0.2	5	0	0	0.1	<0.02	>80%
	Alkalinity ($mg\ L^{-1}$)	>=40.0	5	5	100	NA	25.9	
	Dissolved organic carbon ($mg\ L^{-1}$)	25	5	0	0	9	4.0	
	Sulfate (as SO4) ($mg\ L^{-1}$)	25	2	0	0	15	7.1	
	Dissolved Sodium ($mg\ L^{-1}$)	20	2	0	0	15	14.4	
	Chloride ($mg\ L^{-1}$)	100	5	0	0	35	25.6	
	Total dissolved solids ($mg\ L^{-1}$)[3]	175	5	0	0	150	102	
HORSEPD12 (Horse Pound Brook above West Branch Reservoir)	NO3+NO2 (as N) ($mg\ L^{-1}$)	1.5	5	0	0	0.35	0.46	
	Ammonia (as N) ($mg\ L^{-1}$)	0.2	5	0	0	0.1	<0.02	>80%
	Alkalinity ($mg\ L^{-1}$)	>=40.0	5	2	40	NA	39.4	
	Dissolved organic carbon ($mg\ L^{-1}$)	25	5	0	0	9	3.0	
	Sulfate (as SO4) ($mg\ L^{-1}$)	25	2	0	0	15	9.8	
	Dissolved Sodium ($mg\ L^{-1}$)	20	2	2	100	15	27.9	
	Chloride ($mg\ L^{-1}$)	100	5	0	0	35	48.5	
	Total dissolved solids ($mg\ L^{-1}$)[3]	175	5	2	40	150	174	
KISCO3 (Kisco River above New Croton Reservoir)	NO3+NO2 (as N) ($mg\ L^{-1}$)	1.5	3	0	0	0.35	0.76	
	Ammonia (as N) ($mg\ L^{-1}$)	0.2	3	0	0	0.1	<0.02	>80%
	Alkalinity ($mg\ L^{-1}$)	>=40.0	3	0	0	NA	74.4	
	Dissolved organic carbon ($mg\ L^{-1}$)	25	3	0	0	9	2.6	
	Sulfate (as SO4) ($mg\ L^{-1}$)	25	1	0	0	15	13.8	
	Dissolved Sodium ($mg\ L^{-1}$)	20	1	1	100	15	43.7	
	Chloride ($mg\ L^{-1}$)	100	3	0	0	35	91.9	
	Total dissolved solids ($mg\ L^{-1}$)[3]	175	3	3	100	150	319	
LONGPD1 (Long Pond outflow above	NO3+NO2 (as N) ($mg\ L^{-1}$)	1.5	5	0	0	0.35	0.26	
	Ammonia (as N) ($mg\ L^{-1}$)	0.2	5	0	0	0.1	0.02	KM
	Alkalinity ($mg\ L^{-1}$)	>=40.0	5	0	0	NA	52.4	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
West Branch Reservoir)	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	4.2	
	Sulfate (as SO4) (mg L^{-1})	25	2	0	0	15	11.9	
	Dissolved Sodium (mg L^{-1})	20	2	2	100	15	39.0	
	Chloride (mg L^{-1})	100	5	0	0	35	71.5	
	Total dissolved solids (mg L^{-1})[3]	175	5	5	100	150	241	
MIKE2 (Michael Brook above Croton Falls Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	4	80	0.35	3.31	
	Ammonia (as N) (mg L^{-1})	0.2	5	0	0	0.1	<0.02	>80%
	Alkalinity (mg L^{-1})	>=40.0	5	0	0	NA	90.3	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	3.4	
	Sulfate (as SO4) (mg L^{-1})	25	2	0	0	15	18.4	
	Dissolved Sodium (mg L^{-1})	20	2	2	100	15	83.2	
	Chloride (mg L^{-1})	100	5	5	100	35	183.2	
	Total dissolved solids (mg L^{-1})[3]	175	5	5	100	150	548	
MUSCOOT10 (Muscoot River above Amawalk Reservoir)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.35	0.73	
	Ammonia (as N) (mg L^{-1})	0.2	3	0	0	0.1	0.03	
	Alkalinity (mg L^{-1})	>=40.0	3	0	0	NA	77.1	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	3.9	
	Sulfate (as SO4) (mg L^{-1})	25	1	0	0	15	14.4	
	Dissolved Sodium (mg L^{-1})	20	1	1	100	15	75.9	
	Chloride (mg L^{-1})	100	3	3	100	35	156.7	
	Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	453	
TITICUSR (Titicus Reservoir Release)	NO3+NO2 (as N) (mg L^{-1})	1.5	3	0	0	0.35	0.23	
	Ammonia (as N) (mg L^{-1})	0.2	3	0	0	0.1	0.02	KM
	Alkalinity (mg L^{-1})	>=40.0	3	0	0	NA	72.5	
	Dissolved organic carbon (mg L^{-1})	25	3	0	0	9	3.5	
	Sulfate (as SO4) (mg L^{-1})	25	1	0	0	15	9.3	
	Dissolved Sodium (mg L^{-1})	20	1	1	100	15	24.2	
	Chloride (mg L^{-1})	100	3	0	0	35	45.5	
	Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	205	
	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.35	0.04	

Comparison of Stream Water Quality Results to Benchmarks

Site	Analyte	Single Sample Maximum (SSM)	Number samples	Number that exceed SSM	Percent that exceed SSM	Annual Mean Standard	2020 Mean[1]	Note[2]
WESTBR7 (West Branch Croton River above Boyd Corners Reservoir)	Ammonia (as N) (mg L^{-1})	0.2	5	0	0	0.1	<0.02	>80%
	Alkalinity (mg L^{-1})	>=40.0	5	5	100	NA	29.4	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	5.5	
	Sulfate (as SO4) (mg L^{-1})	25	2	0	0	15	6.6	
	Dissolved Sodium (mg L^{-1})	20	2	2	100	15	24.6	
	Chloride (mg L^{-1})	100	5	0	0	35	37.2	
	Total dissolved solids (mg L^{-1})[3]	175	5	0	0	150	131	
WESTBRR (West Branch Reservoir Release)	NO3+NO2 (as N) (mg L^{-1})	1.5	5	0	0	0.4	0.13	
	Ammonia (as N) (mg L^{-1})	0.25	5	0	0	0.05	<0.02	>80%
	Alkalinity (mg L^{-1})	>=10.0	5	0	0	NA	14.2	
	Dissolved organic carbon (mg L^{-1})	25	5	0	0	9	2.0	
	Sulfate (as SO4) (mg L^{-1})	15	2	0	0	10	4.8	
	Dissolved Sodium (mg L^{-1})	10	2	0	0	5	7.5	
	Chloride (mg L^{-1})	50	5	0	0	10	12.5	
	Total dissolved solids (mg L^{-1})[3]	50	5	4	80	40	56	

NA = not applicable

Summary statistics based upon data request completed 05/06/2021.

[1]Means for data containing non-detects were estimated using techniques recommended in Helsel (2005) using an R program developed for U.S. Environmental Protection Agency (Bolks et al. 2014).

[2]Note indicates which analysis method was used to determine the statistics when there were censored data. KM indicates Kaplan-Meier, ROS indicates robust regression on order statistics, and >80% indicates that greater than 80% censored data or 5 or fewer samples with greater than 50 % censored data prevents a statistical calculation, so the detection limit, preceded by "<", is reported. A blank cell in the Note column indicates that the 2020 mean was calculated as the standard arithmetic average.

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

Appendix H. Semivolatile and Volatile Organic Compounds and Herbicides

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, 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