New York City Department of Environmental Protection

Watershed Protection Program Summary and Assessment

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Cover photo of Schoharie Reservoir by DEP Photographer Kristen Rendler

Table of Contents

List of Figures

List of Tables

List of Acronyms

AU	Animal Unit
AUV	Autonomous Underwater Vehicle
AWSMP	Ashokan Watershed Stream Management Program
BAP	Biological Assessment Profile
BCD	Bureau of Communicable Diseases
BGD	Billion Gallons Per Day
BIT	Business Information Technology
BLA	Bureau of Legal Affairs
BMP	Best Management Practice
CAT/DEL	Catskill/Delaware
CATUEC	Catskill Upper Effluent Chamber
CAI	Conservation Awareness Index
CCE	Cornell Cooperative Extension
CCEUC	Cornell Cooperative Extension of Ulster County
CDUV	Catskill/Delaware Ultraviolet Disinfection Facility
CE	Conservation Easement
CFI	Continuous Forest Inventory
CREP	Conservation Reserve Enhancement Program
CRISP	Catskill Regional Invasive Species Partnership
CRP	Conservation Reserve Program
CSBI	Catskill Streams Buffer Initiative
CWC	Catskill Watershed Corporation
CWMP	Community Wastewater Management Program
DCPD	Delaware County Planning Department
DCSWCD	Delaware County Soil and Water Conservation District
DEIS	Draft Environmental Impact Statement
DEM	Digital Elevation Model
DEP	New York City Department of Environmental Protection
DMAP	Deer Management Assistance Permit Program
DOE	New York City Department of Education
DOHMH	New York City Department of Health and Mental Hygiene
DPR	New York City Department of Parks and Recreation
DSEIS	Draft Supplemental Environmental Impact Statement
EAB	Emerald Ash Borer
EAF	Environmental Assessment Form
EFC	New York State Environmental Facilities Corporation
EIS	Environmental Impact Statement
EOH	East of Hudson
EOHWC	East of Hudson Watershed Corporation
EWP	Emergency Watershed Protection

FAD	Filtration Avoidance Determination
FEIS	Final Environmental Impact Statement
FEMA	Federal Emergency Management Agency
FMP	New York City Forest Management Plan
FSI	Forest Stand Improvement
GEFS	Global Ensemble Forecast System
GCSWCD	Greene County Soil and Water Conservation District
GI	Gastrointestinal Illness
GIS	Geographic Information System
GPD	Gallons Per Day
GPS	Global Positioning System
HAART	Highly Active Antiretroviral Therapy
HEFS	Hydrologic Ensemble Forecast Service
HEV	Human Enteric Virus
HMGP	Hazard Mitigation Grant Program
IRSP	Individual Residential Stormwater Permit
ISAC	Invasive Species Advisory Committee
ISC	New York State Invasive Species Council
ISWG	Invasive Species Working Group
LAP	Land Acquisition Program
LFA	Local Flood Analysis
LFHMP	Local Flood Hazard Mitigation Program
LiDAR	Light Detection and Ranging
LOWESS	Locally Weighted Scatterplot Smoothing
LTAP	Local Technical Assistance Program
MAP	Management Assistance Program
MARFC	Middle Atlantic River Forecast Center
MFO	Master Forest Owner
MGD	Million Gallons Per Day
MOA	New York City Memorandum of Agreement
MRO	Modification of Reservoir Operations
MS	Matrix Spike
MST	Microbial Source Tracking
NARFC	Northeastern River Forecast Center
NHD	National Hydrography Dataset
NMP	Nutrient Management Plan
NOAA	National Oceanic and Atmospheric Administration
NOV	Notice of Violation
NRCS	Natural Resources Conservation Service
NTU	nephelometric turbidity unit
NWI	National Wetlands Inventory
NWS	National Weather Service

NYC	New York City
NYCDOHMH	New York City Department of Health and Mental Hygiene
NYCFFBO	New York City Funded Flood Buyout Program
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
NYSDOT	New York State Department of Transportation
NYNHP	New York Natural Heritage Program
O&M	Operation and Maintenance
OECD	Organization for Economic Cooperation and Development
OST	Operations Support Tool
PAA	Public Access Area
PFM	Precision Feed Management Program
PRISM	Partnership for Regional Invasive Species Management
RBAP	Riparian Buffer Acquisition Program
RCMP	Riparian Corridor Management Plan
REP	Regulatory and Engineering Programs
RFP	Request for Proposals
RNSP	Rondout/Neversink Stream Program
ROV	Remote Operated Vehicle
RWBT	Rondout-West Branch Tunnel
SAFARI	Shandaken Area Flood Assessment and Remediation Initiative
SCSWCD	Sullivan County Soil and Water Conservation District
SDE	Spatial Database Engine
SDEIS	Supplemental Draft Environmental Impact Statement
SEIS	Supplemental Environmental Impact Statement
SEQRA	State Environmental Quality Review Act
SKT	Seasonal Kendall Test
SMIP	Stream Management Implementation Program
SMP	Stream Management Program
SPDES	State Pollutant Discharge Elimination System
SSMP	Septic System Management Program
SSTS	Subsurface Sewage Treatment System
SUNY	State University of New York
SWAC	Schoharie Watershed Advisory Committee
SWCD	Soil and Water Conservation District
SWPPP	Stormwater Pollution Prevention Plan
SWTR	Surface Water Treatment Rule
TBM	Tunnel Boring Machine
TDA	Trend Detection Assessment
TCR	Total Coliform Rule
TFS	Team Foundation Server

TSI	Timber Stand Improvement
UCSWCD	Ulster County Soil and Water Conservation District
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
VFS	Vegetative Filter Strip
VoPro	Volume Projection
WAC	Watershed Agricultural Council
WaLIS	Watershed Lands Information System
WAP	Watershed Agricultural Program
WCDEF	Westchester County Department of Environmental Facilities
WDRAP	Waterborne Disease Risk Assessment Program
WECC	Watershed Enforcement Coordination Committee
WFP	Whole Farm Plan
WQSP	Water Quality Stream Project
WOH	West of Hudson
WR&R	New York City Watershed Rules and Regulations
WSP	Water Supply Permit
WWQMP	Watershed Water Quality Monitoring Plan
WWTP	Wastewater Treatment Plant

Acknowledgements

The New York City Department of Environmental Protection is charged with providing an ample supply of clean water to more than 9 million people daily. DEP meets this mandate through the efforts of hundreds of dedicated professionals. This report provides a description of the implementation of the many elements of DEP's source water protection program, followed by an examination of their effects on water quality, over more than 25 years. Although the staff members who help make all this possible are too numerous to mention here, their efforts are recognized and appreciated. We acknowledge the Bureau of Water Supply, under the direction of Deputy Commissioner Paul V. Rush, P.E., and its Directorates of Source Water Operations, Water Treatment Operations, Water Quality and Innovation, Watershed Protection Programs and Planning. The vital support of Management Services and Budget and compliance staff, along with the Bureaus of Police and Security, Legal Affairs, Information Technology, Engineering Design and Construction, and the NYC Law Department is also acknowledged.

This document is produced in two sections. The first describes program implementation and was primarily authored by staff in the Watershed Protection Programs Directorate, under direction of Assistant Commissioner David S. Warne. Program managers and authors include: Matt Giannetta, Jeff Graff, Charlie Laing, Paul Lenz, Laurie Machung, Mike Meyer, Beth Reichheld, Terry Spies, John Schwartz, Dave Tobias and Mike Usai.

The second section of this report describes the work of the Water Quality and Innovation Directorate under Lori Emery. The Water Quality Science and Research section was responsible for mathematical analyses that demonstrate the status and long-term trends in water quality, trophic condition, and pathogens as they relate to the watershed protection programs. Primary authors include: Lorraine Janus, Ph.D., Kerri Alderisio, Jim Mayfield, and Anne Seeley. Staff at the New York City Department of Health and Mental Hygiene (DOHMH) provided text and graphics to describe the Waterborne Disease Risk Assessment Program. Sections on DEP's modeling work to optimize water supply management were authored primarily by Emmet Owens, P.E., under the direction of Chief of Staff Jen Garigliano. Additional authors include: Karen Moore, Ph.D., Rich Van Dreason, and Rakesh Gelda, Ph.D.

Additional thanks to Kimberlee Kane, Ph.D. for her review and editing of the document, along with her insights on data presentation. A special note of thanks to Mike Risinit, whose hard work compiling the many sections of this report resulted in a coherent and professional document.

This report is dedicated to Steve Schindler, Director of Water Quality, who retired in 2020. Mr. Schindler provided skilled leadership and service to the NYC water supply consumers in his more than 30 years working for the City. We also dedicate the report to Lorraine Janus, Ph.D., who retired in 2021. Dr. Janus was instrumental in establishing the foundations of the water quality monitoring and analysis programs that support all aspects of the City's source water protection activities.

Executive Summary

New York City's Source Water Protection Program for the Catskill/Delaware Systems

The New York City Department of Environmental Protection (DEP) is responsible for operating, maintaining and protecting the City's water supply and distribution system. This document, New York City's 2021 Watershed Protection Summary and Assessment, has been prepared to comply with the New York State Department of Health's December 2017 Filtration Avoidance Determination (FAD) for the Catskill/Delaware Water Supply Systems.

In 1989, the federal Surface Water Treatment Rule (SWTR) was promulgated requiring filtration of all surface water supplies. The SWTR provided for a waiver of the filtration requirement if the water supplier could meet certain objective and subjective criteria. In the early 1990s, DEP embarked on an ambitious program to protect and enhance the quality of New York City's drinking water. DEP was able to demonstrate that the Catskill/Delaware supply met the objective criteria: (1) The source water met SWTR turbidity and fecal coliform standards; (2) There were no source related violations of the coliform rule; and (3) There were no waterborne disease outbreaks in the City. The subjective criteria of SWTR required DEP to demonstrate through ownership or agreements with landowners that it could control human activities in the watershed which might adversely impact the microbiological quality of the source water. As outlined in the SWTR, issues of concern fall into several categories: coliform bacteria, enteric viruses, *Giardia* sp., *Cryptosporidium* sp., turbidity, disinfection byproducts, and watershed control.

To demonstrate its eligibility for a filtration waiver, DEP advanced a program to assess and address water quality threats in the Catskill/Delaware system. DEP's strategy is based on a simple premise: It is better to keep the water clean at its source than it is to treat it after it has been polluted. To meet the goal of public health protection, DEP has designed and deployed a mix of remedial programs (intended to clean up existing sources of pollution) and protective programs (to prevent new sources of pollution). These efforts provided the basis for a series of waivers from the filtration requirements of the SWTR (January 1993, December 1993, January 1997, May 1997, November 2002, July 2007, May 2014 and December 2017).

Assessing the Potential Threats to the Water Supply

Since the inception of the program in the early 1990s, the City has made great progress in assessing potential sources of water contamination and designing and implementing programs to address those sources. Each year, DEP collects and analyzes tens of thousands of samples from nearly 500 sites throughout the watershed – at aqueducts, reservoirs, streams, and wastewater treatment plants. The purpose of this intensive monitoring effort is to help operate and manage the system to provide the best possible water at all times, to develop a record to identify water quality trends, and to focus watershed management efforts. This robust monitoring program provides the scientific underpinnings for the source water protection program.

Based on the information collected through the monitoring program, DEP developed a comprehensive strategy for the protection of source water quality, designed to address existing sources of pollution and prevent new sources. Each element of the watershed protection effort is conducted at a specific spatial and temporal scale to ensure the maintenance of the already high quality of the Catskill/Delaware waters. This effort yields benefits for water consumers as well as the tens of thousands of people who live, work, and recreate in the watershed, as well as the millions in communities downstream of the reservoirs.

Implementing the Source Water Protection Program and Achievements to Date

In the 1990s, DEP began the complex process of establishing the elements of a comprehensive, long-term watershed protection program. In January 1997, a new era of source water protection and partnership began when the City, the state, the United States Environmental Protection Agency (EPA), watershed communities and environmental and public interest groups signed the New York City Watershed Memorandum of Agreement (MOA). This unique coalition came together with the dual goals of protecting water quality for generations to come and preserving the economic viability of watershed communities. The MOA established the institutional framework and relationships needed to implement the range of protection programs identified as necessary by the City, the state, and EPA.

In December 2017, the New York State Department of Health (NYSDOH), in consultation with EPA, issued a 10-year FAD. The programs identified in the 2017 FAD built on the significant program accomplishments to that time and reflected DEP's continued commitment to long-term watershed protection. The 2017 FAD was the first to include a complete set of program and financial commitments for the full 10-year period. The 2017 FAD demonstrates DEP's ability to continue to implement proven programs, as well as the ability to revise strategies as needed to anticipate and respond to changing conditions. DEP's source water protection program continues to be an international model for sustainable water supply management and public health protection.

In 2018, the National Academies of Science, Engineering and Medicine (NASEM) convened an expert panel to evaluate New York City's source water protection program. This study follows a similar evaluation conducted by NASEM in the late 1990s after the MOA was signed. Over approximately two years, the panel engaged in a comprehensive process, which included eight meetings, dozens of presentations by DEP staff and watershed stakeholders, a number of site visits in the watershed, countless information requests and hundreds of hours of discussion and drafting. Their final report was released in July 2020. The panel was able to synthesize an incredible amount of information about our complex program and watershed conditions, and produce a detailed analysis and discussion.

The report includes a strong endorsement of the work DEP and its partners have undertaken over many years, stating the programs "have admirably supported water quality" with "strong indications" they will continue to be effective in the future. However, the panel's charge was not simply to look at the accomplishments to date, but rather to make recommendations for adjustments to ensure the continued effectiveness of our investments. The report includes 63 major recommendations, ranging from straightforward and relatively modest program adjustments to out-of-the-box thinking. DEP and watershed stakeholders are currently reviewing and evaluating the panel's recommendations, which are expected to be the basis of mid-term modifications to the FAD in 2022.

Effective implementation of this multi-faceted program depends on vital support from and cooperation with the City's watershed partners, with particular emphasis on implementation of several key watershed protection initiatives: the Watershed Agricultural Program; the acquisition of watershed lands; the enforcement of watershed regulations; the Stream Management Program; and the continuation of environmental and economic partnership programs that target specific sources of pollution in the watershed. In addition, DEP continued its enhanced watershed protection efforts in the Kensico reservoir basin and completed the upgrades of non-City owned watershed wastewater treatment plants. Figure E.1 and Figure E.2 map the myriad projects completed by DEP and its partners in the Catskill/Delaware basins, located both west and east of the Hudson, since 1997.

Key watershed protection program highlights include:

Watershed Agricultural Program

Since 1992, the Watershed Agricultural Program (WAP) has promoted a non-regulatory, voluntary, incentive-based and farmer-led approach to controlling agricultural sources of pollution while supporting the economic viability of the watershed's farmed landscape. Working through the Watershed Agricultural Council, the City funds development of farm pollution prevention plans and implementation of structural and non-structural best management practices on. As of the end of 2020, a combined 326 farms east and west of the Hudson had active Whole Farm Plans; 8,586 BMPs have been implemented on all participating farms at a cost of $72 million, not including planning, design and administrative expenses. As of the end of 2020, the Conservation Reserve Enhancement Program (CREP), which pays farmers to take sensitive riparian buffer lands out of active farm use and re-establish a vegetative buffer, had 1,687 acres of riparian buffers under active contract and more that 10,000 head of cattle have been excluded from streams.

Land Acquisition

The Land Acquisition Program (LAP) seeks to protect sensitive lands from development through willing seller/willing buyer transactions. Watershed-wide, the various elements of LAP have secured 152,699 acres. Overall, the City and state now protect nearly 40% of lands in the Catskill/Delaware system. While the overall level of protection is impressive, even higher levels of protection have been achieved in the key basins – Ashokan, Rondout, West Branch and Kensico – which range from 42% to 67% protected.

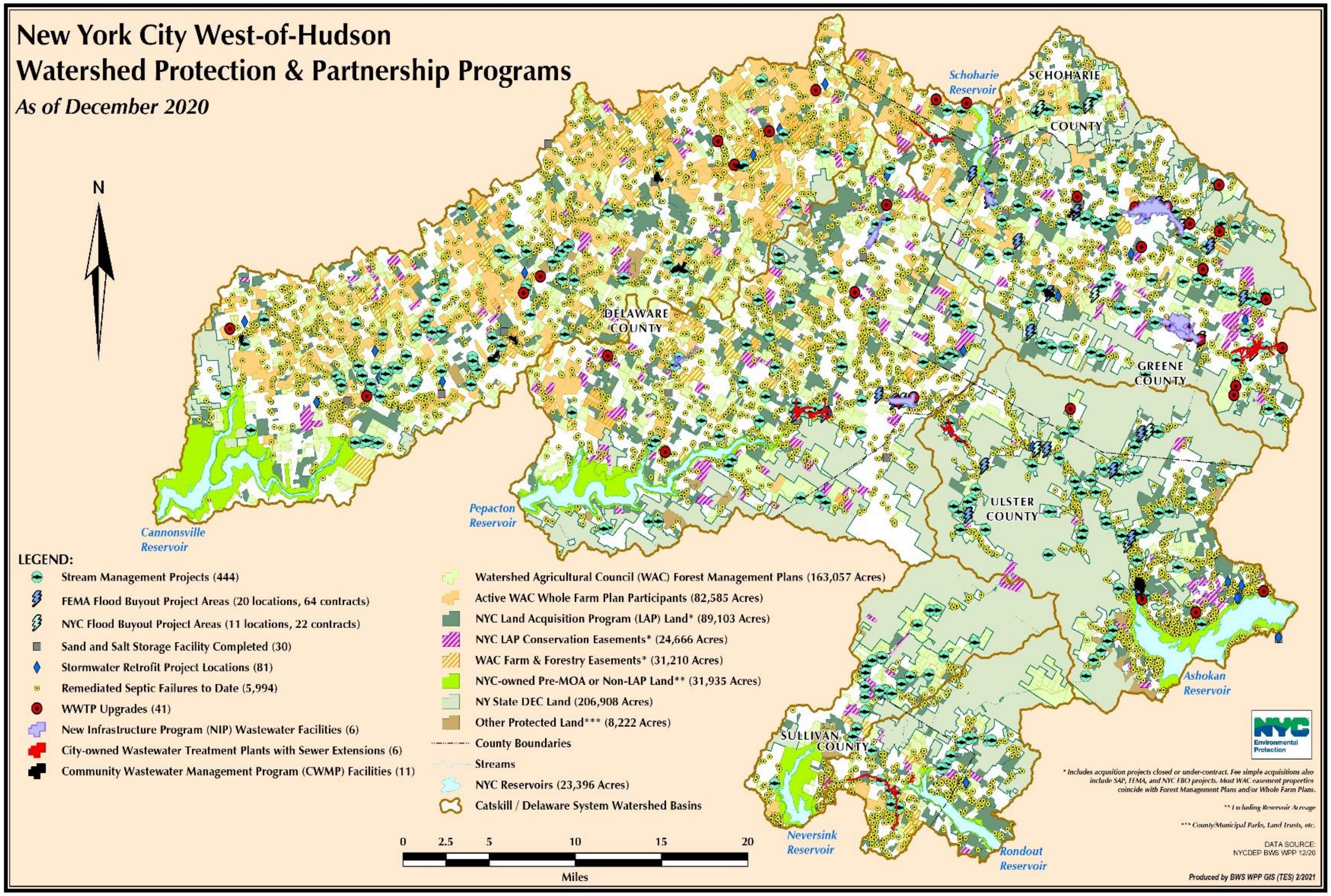


Figure E.1 Map showing status of the partnership programs West of Hudson.

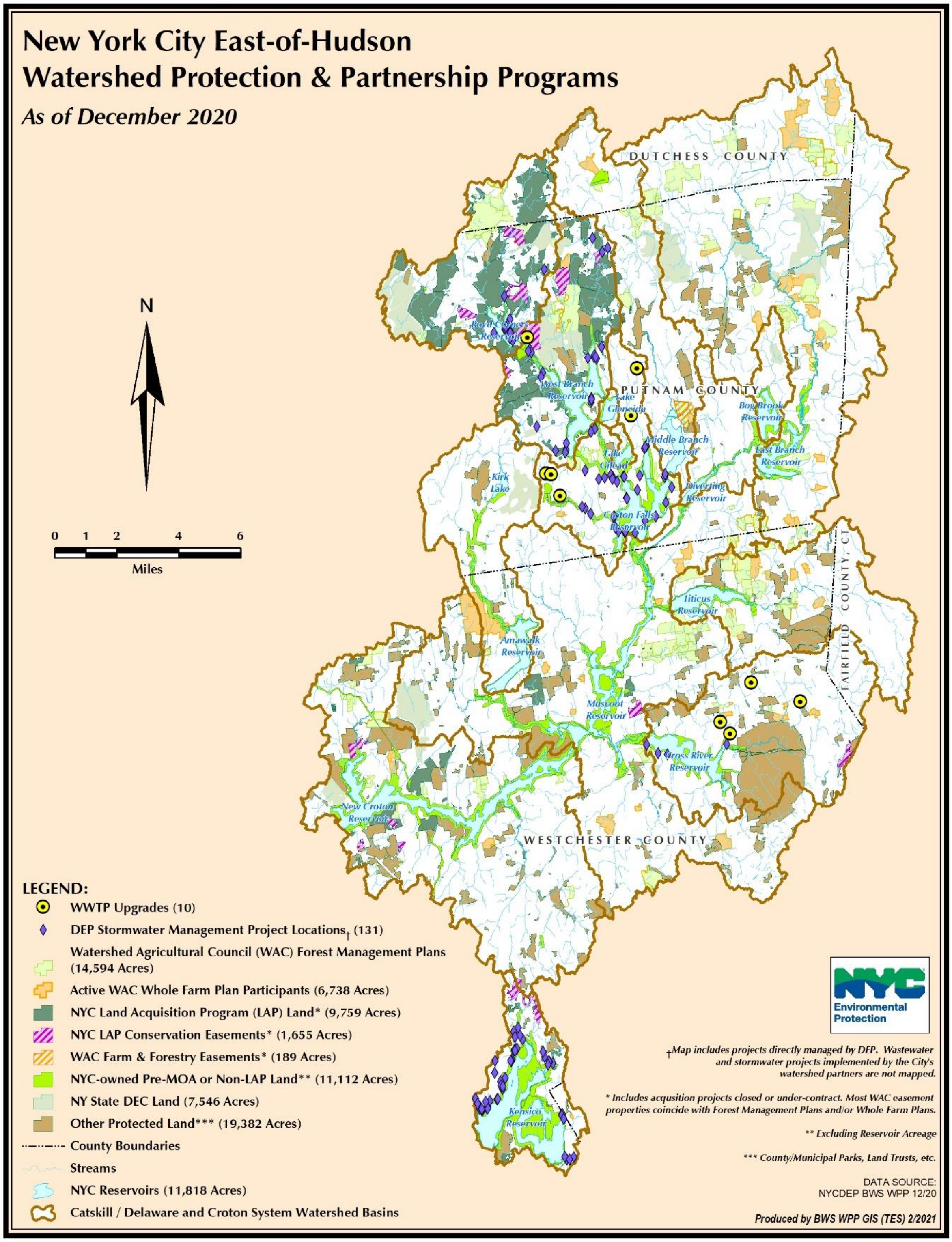


Figure E.2 Map showing status of the partnership programs East of Hudson.

Watershed Regulations

Since 1997, DEP has reviewed more than 23,000 applications for projects that proposed one or more regulated activities, as well as performed regular compliance inspections at regulated wastewater facilities, and responded to violations of permit standards to enforce corrective actions. DEP works with applicants to ensure new development in the watershed is undertaken in a manner that is fully protective of critical water supply resources and overall more than 99% of DEP's regulatory determinations are project approvals. In November 2019, DEP promulgated updated Watershed Regulations. The revisions, which were completed after extensive discussions with watershed stakeholders, are intended to update certain standards and reduce burdens on local economic development, while remaining protective of water quality.

Wastewater Programs

DEP has implemented an array of programs intended to improve the treatment of wastewater across the watershed. The City, in conjunction with its partners, has continued to implement programs that have remediated more than 5,900 failing septic systems. In recent years, DEP and its partners have expanded program eligibility to new classes of properties, ensuring availability of resources to address failure when they happen. All wastewater treatment plants (WWTPs) in the Catskill/Delaware basins – including City- and non-City-owned – have been upgraded to tertiary treatment, and DEP funds a significant portion of ongoing operation and maintenance. New WWTPs, or other community wastewater solutions, have been implemented in four additional communities over the past five years, resulting in more than 270 septic systems being decommissioned.

Stream Management Program

The Stream Management Program (SMP) promotes the protection and/or restoration of stream system stability and ecological integrity by providing for the long-term stewardship of streams and floodplains. Over the past five years, DEP completed 10 projects with a primary focus on water quality; completed Local Flood Hazard (LFA) analyses on 32 population centers; provided funding for 13 LFA-identified projects; and awarded more than 115 Stream Management Implementation Program grants. DEP also advanced important stream studies, which are intended to provide additional scientific basis for future project selection and design.

Waterborne Disease Risk Assessment Program

New York City's Waterborne Disease Risk Assessment Program (WDRAP) continues to collect, analyze, and report health-related data towards two core objectives: (1) To learn about giardiasis and cryptosporidiosis in NYC -- in terms of illness rates, demographic and risk factors; and (2) To track gastrointestinal illness and related indicators to ensure rapid detection of any waterborne outbreak, should one ever occur. Highlights from this assessment period include a publication on cryptosporidiosis epidemiology and a survey of cities to inform our health surveillance programs. The COVID-19 pandemic impacted WDRAP, but all program components continued uninterrupted. There was no evidence of waterborne disease in NYC during this period. WDRAP is a partnership program involving DEP and NYCDOHMH.

Scope of Water Analysis

Water quality analyses presented here include evaluation of status, trends, indices based on macroinvertebrates, pathogens, and comparison on trophic characteristics with standards developed by the OECD for eutrophication control. Significantly, we have retained the information from previous years such that water quality analyses cover a longer time period than the five-year period of the assessment. Approximately 27 years of data (i.e., 1993 through 2019) are used to provide a long-term context for interpretation. Selection of a sufficiently long time captures changes in water quality in response to watershed protection programs. It provides a view of these changes in the context of natural variation caused by events such as floods and droughts, which are not sufficiently represented in a five-year period.

Water Quality Summary for the Catskill System

Water quality status in the Schoharie inflow, reservoir, and outflow from 2017-2019 was good overall. Monthly median fecal coliform counts did not exceed benchmarks and both monthly median turbidity and phosphorus concentrations were low overall. Trophic status ranged from oligotrophic to mesotrophic for the status evaluation period.

Long-term upward trends were identified in the Schoharie basin for turbidity, reservoir fecal coliforms, and conductivity while downward trends were identified for total phosphorus. The increase in turbidity is attributed to the watershed damage caused by large storm events in 2010 and 2011. Fecal coliform increases were also attributed to these storms as well as to more moderate storm events occurring throughout the record. The decline in phosphorus is attributed to recovery from high loads produced by periodic flood events, load reductions associated with the 2001-2002 drought, and from WWTP upgrades. The conductivity increases are likely due to the use of road deicers. There was weak evidence of a long-term increase in reservoir trophic state index (TSI) but since 2003 TSI has trended downward.

Biomonitoring results in 2017 and 2018 indicated that the biological communities of the main inflows to the Schoharie and Ashokan basins (Schoharie Creek and Esopus Creek, respectively) were in good health. In both basins, sites were non-impaired in their most recent year of sample analysis (2018). Due to budget constraints associated with COVID-19, data from 2019 are not currently available. There were no long-term changes at any of the sites with an extended period of record, with the exception of one site on the Batavia Kill (Schoharie basin) that had steep declines in its assessment scores between 2009 and 2013 followed by an increase in recent years.

Annual mean concentrations of cysts and oocysts have continued to be low from 2015 through 2019 in the Catskill system. While there are indications of a potential increase in protozoa beginning in 2017, this is coincident with a method change, so more data are needed to determine if it is a true upward trend. Both Schoharie and Ashokan reservoir outflows demonstrated decreased overall annual mean concentrations of *Giardia* and *Cryptosporidium* compared to upstream sites, continuing the observation of (oo)cysts reductions made in previous years as water passes through the reservoir system. Settling, predation, and die-off continue to be the primary forces believed to be behind the reduction of protozoan values downstream.

Water quality status in the Ashokan West Basin inflow (E16I) and reservoir (EAW) from 2017-2019 was good overall. Monthly median fecal coliform counts did not exceed benchmarks and both monthly median turbidity and phosphorus concentrations were generally low. Trophic status was primarily mesotrophic. Water quality status in the Ashokan East Basin (EAE) and its outflow (EARCM) was also good. Monthly median fecal coliform counts did not exceed benchmarks and both monthly median turbidity and phosphorus concentrations were generally low. Trophic status ranged from oligotrophic to mesotrophic.

Long-term downward trends were evident for total phosphorus at Ashokan's inflow, the reservoir itself and the outflow. These reductions are likely due to WWTP construction and to the cumulative effects of watershed protection programs. Downward fecal coliform trends were considered virtually certain at the inflow, the Ashokan East Basin, and at the outflow. The decrease was attributed to landfill closure and to the low frequency of extreme rain events since 2011. Although long-term turbidity upward trends were considered possible for the inflow and Ashokan West Basin, a marked decrease was noted after 2011 due to the lack of extreme rain events. Long-term upward conductivity trends were identified for all sites in the watershed and likely linked to road deicer usage. Long-term TSI decreases were apparent in both reservoir basins. Periods of low water clarity and the long-term decrease in TP are two likely factors.

The tight clustering of the Catskill reservoirs on the OECD plots indicates ecological conditions during the recent five years were very similar, allowing each basin to respond according to its new steady-state condition. The current water quality is thought to reflect the major effects of the watershed protection programs. Turbidity can severely diminish light penetration in Schoharie, and the West Basin of Ashokan and this presents a severe limitation to algal growth. Schoharie tended to remain subdued in its maximum chlorophyll response. The association of years with high turbidity with high phosphorus values indicates this nutrient is attached to the glacial clays which limit light and subdue algal growth. This supports the exclusion of Schoharie from the phosphorus-restricted basin list. In the more quiescent times of the current five-year assessment, the Ashokan basins have both gravitated toward the OECD lines and fall within the 80% PI. Schoharie transparency, however, remains low indicating that factors other than algal growth limit transparency. The most recent five-year period shows Secchi transparency of greater than five meters due to the low chlorophyll values. In contrast, Secchi depths for Schoharie remain shallow despite low chlorophyll values indicating that suspended particulates limit transparency.

Water Quality Summary for the Delaware System

Overall, the water quality status of all four Delaware System basins for 2017-2019 continues to be very good, which is a reflection in part of the ongoing investment in watershed protection. Monthly median fecal coliform counts were generally low for all reservoirs and their outflows. Monthly median turbidity was low throughout the system, with a median of 0.8 NTU and corresponding median phosphorus value of 8.5 µg L^{-1} for the outflow from Rondout Reservoir (RDRRCM), the terminal reservoir in the Delaware System.

Long-term trend analysis for the Delaware System continues to show a decline in total phosphorus (TP) and trophic state index (TSI) for all basins with the exception of Neversink. These long-term decreases are largely due to upgrades and construction of WWTPs and to the cumulative effects of various watershed protection programs. A short-term recent TP increase was observed for all basins. Possible contributing factors include suspected changes in the flow-TP relationship caused by damage to the watersheds from extreme storms in 2011 and 2012, phosphorus contamination from sample bottles during 2014-2017, and, in the case of the Cannonsville outflow, a change in sample site location. The site relocation also contributed to an upward trend for fecal coliform and turbidity. A recent increase in TSI was observed in all reservoirs and is possibly related to warmer surface water temperatures and increases in residence times at Pepacton and Neversink reservoirs. Long-term conductivity increases were ubiquitous throughout the system and likely the result of road deicer usage.

In 2017 and 2018, biomonitoring was conducted on three sites on the primary river inflow to Cannonsville Reservoir (West Branch Delaware River), two sites on the primary inflow to Pepacton Reservoir (East Branch Delaware River), and one site on the primary inflow to Rondout Reservoir (Rondout Creek). Due to the budget constraints associated with COVID-19, data from 2019 are not currently available. In 2018 for sites in the Cannonsville basin, Site 301 ranked as slightly impaired, while Site 304 was at the high end of slightly impaired, and Site 320 was non-impaired. The 2018 results for the Pepacton basin show Site 316 at the high end of slightly impaired and Site 321 was non-impaired. The Rondout basin site was non-impaired in 2018. The time series showed no long-term changes at any of the sites with an extended period of record.

Cryptosporidium and *Giardia* pathogen monitoring was conducted on the major inflows to all four reservoirs of the Delaware System over the 2002-2019 period. As with the Catskill System, Delaware reservoir outflow protozoan concentrations were lower than those at the monitored inflow streams. There was an increase in the annual mean *Giardia* concentrations at the outflow of Rondout Reservoir during this five-year period (2015-2019), largely due to the unusual increase in *Giardia* cysts that occurred at the Rondout outflow beginning in November 2018. This event is discussed further within the chapter.

The four reservoirs of the Delaware system are well aligned with the OECD standards showing a decrease in biomass coincident with a decrease in phosphorus. This indicates that phosphorus is controlling the level of algal standing crop and eutrophication continues to be controlled through phosphorus concentrations at their reduced levels. Indeed, the Cannonsville biomass has decreased remarkably from previous assessment periods. The least variation in chlorophyll occurs in Rondout. This may be related to the short, nearly constant water residence time of about 1.5 months. In the most recent five years, Neversink shows a slight shift toward increased phosphorus, yet still at very low levels consistent with oligotrophy, and Cannonsville, at the upper end, has shifted toward lower levels of phosphorus and increased transparency. Since all the relationships tend to lie below the OECD line, it can be concluded that factors in addition to chlorophyll limit light in all the Delaware System reservoirs. Time series of the changes in central tendencies over the past 25 years show there have been vast improvements in reducing the trophic condition of Cannonsville Reservoir where greatest phosphorus load reduction has been achieved.

Water Quality Summary for the East of Hudson Catskill/Delaware Basin System

Water quality in West Branch and Kensico basins continued to be excellent during the 2017-2019 assessment period. Median and peak monthly median values were all well below established water quality benchmarks for fecal coliforms, turbidity, and total phosphorus.

Long-term downward turbidity and fecal coliform trends were identified in the local stream inflows to West Branch Reservoir and attributed to stormwater remediation projects. Upward total phosphorus trends were apparent at the local inflows, the reservoir, and the outflow. All reservoir and outflow trends were likely influenced by operational changes which control the blend of waters that comprise the reservoir. Long-term downward trends were identified for turbidity, fecal coliform, and total phosphorus for Kensico Reservoir and for its inflows and outflow. Long-term conductivity trends were upward in both the West Branch and Kensico basins, which was attributed to road deicers. Increases in trophic state index were observed at West Branch while a long-term increase was identified at Kensico.

Biomonitoring results are available for 2017 and 2018 for the largest stream inflow to West Branch Reservoir (Horse Pound Brook), but not the inflow to Kensico Reservoir (Whippoorwill Creek), which was only sampled in 2019. Due to the budget constraints associated with COVID-19, data from 2019 are not currently available. However, the influence of these streams on reservoir water quality is small because the largest inputs are from the Catskill and Delaware reservoirs via the aqueducts. The site on Horse Pound Brook was slightly impaired in all recent years of sampling.

Since 2002, *Giardia* and *Cryptosporidium* monitoring has been conducted at least weekly at the Catskill and Delaware inflows and outflows of Kensico Reservoir (with the exception of the Catskill outflow, which was shut down in September 2012). *Giardia* annual mean concentrations have been relatively low at both the inflows and outflows, until the increase in *Giardia* at Rondout Reservoir in November of 2018, which subsequently increased cyst concentrations entering Kensico at DEL17. The maximum annual mean cyst concentration for this five-year period occurred in 2019 and was 7.0 cysts 50 L^{-1}. *Cryptosporidium* concentrations continued to be an order of magnitude lower than those for *Giardia*, making it difficult to discern differences between inflows and outflows with any level of statistical confidence. For the approximately 18-year period of record with Method 1623/1623.1, the mean Cryptosporidium oocyst concentration at the Kensico source water outflows was very low at 0.14 oocysts 50 L^{-1} (n=1111). As a final note, two method changes were introduced during this reporting period and may be the reason for some changes seen in the data. More monitoring needs to be completed to increase the sample size of the data resulting from the new version of the method in order to confidently determine the extent of any data shifts.

In Kensico and West Branch reservoirs, variation in chlorophyll can be substantial despite that variation in phosphorus levels is minimal. Biomass in these two reservoirs is not so clearly dependent on phosphorus, and this may be related to short (often < 1 month) water residence times. Both chlorophyll and phosphorus have remained low in this recent assessment period (2015-2019), with Kensico in mesotrophic condition bordering on oligotrophy. The most recent years show no unusually high chlorophyll maxima and all reside within the 80% PI of the OECD standard. Secchi depth means show little variation and are in line with phosphorus means. Low Secchi depth values relative to phosphorus indicate that substances other than chlorophyll reduce transparency. In this assessment period, Secchi depths at Kensico tended to be near five meters, indicating excellent transparency. These reservoirs, which receive water from the Delaware System, reflect the same water quality characteristics and responses seen in upstream reservoirs.

Water Quality Summary for the East of Hudson Potential Delaware System Watersheds

Water quality status for the assessment period (2017-2019) for Cross River and Croton Falls basins was generally good. Fecal coliform levels were low in both reservoirs, but occasionally high at the inflow to Cross River Reservoir (WESTBRR) and outflow from Croton Falls Reservoir (CROFALLSVC).Turbidity in both basins was generally low, with a few outliers after storm events. Total phosphorus monthly medians for the reservoirs were above the target value of 15 µg L^{-1} for source waters (median of 17.5 µg L^{-1} and 16 µg L^{-1} for Cross River and the main basin of Croton Falls reservoirs, respectively). Trophic State Index (TSI) was primarily in the eutrophic range for Cross River Reservoir and ranged from mesotrophic to eutrophic in Croton Falls Reservoir.

Long-term turbidity trends were downward for the outflow from the Cross River basin and attributed primarily to recovery from drawdown related to dam repairs. In contrast, the long-term turbidity trend for the Croton Falls outflow was upward, driven largely by the relocation of the sample site. Conductivity trends for both basins were upward and likely due to road deicer usage. A TSI increase was observed at Cross River perhaps related to an increase in total phosphorus (TP) linked to the occurrence of large storms in 2010-2014 and to above average flows in 2018-2019. While a TSI trend was not apparent for Croton Falls, there was a long-term TP decline in the middle basin coincident with wastewater treatment plant upgrades.

Biomonitoring was conducted at Cross River, the primary inflow to Cross River Reservoir in 2019, only. Results are not currently available due to the budget constraints associated with COVID-19.

The current assessment period indicates that the main basins of Cross River and Croton Falls are similar in water quality regarding nutrient and algal concentrations. Site 5 in Croton Falls is clearly more productive than the other sites. This is a eutrophic site not representative of the reservoir as a whole. In the most recent assessment years, Croton Falls 5 has lowest transparency and elevated nutrient levels so it is not surprising that cyanobacteria commonly observed at this site contribute to its low transparency. The most recent years also show that the Secchi depth versus chlorophyll data lie surprisingly close to the OECD line, demonstrating the direct relationship of transparency to the level of algae present. Despite localized algal growth at Site 5, Croton Falls 1 (the site near the dam and potential Delaware intake) is on a par with the water quality of Cross River.

Water Quality Modeling Program

DEP has continued a program of development, testing, and application of climate, watershed, reservoir, and supply system operation models, and database development and data analysis to support modeling, during the current FAD reporting period. While the Generalized Watershed Loading Function (GWLF) model remains available for use in all West of Hudson (WHO) watersheds, DEP is now moving to the use of the Soil and Water Assessment Tool (SWAT) model for these watersheds. DEP has completed testing and validation of SWAT for the Cannonsville watershed, and is currently working on testing and validation for the remaining WOH watersheds. DEP applied SWAT to evaluate reductions in nutrient loads resulting from Watershed Protection Program components in the Cannonsville watershed, with a focus on dissolved phosphorus (P) loading. The model estimated the current sources of stream nutrient loads, assessed loading reductions from point and nonpoint sources achieved over the past 30 years, and simulated scenarios on the impact of various watershed management practices. An assessment on the potential impact of climate change using future climate scenarios was also made.

Comparison of model predictions for current (2010s) watershed conditions to predictions for 1990s watershed conditions, both using the same hydro-climatic conditions, shows that nonpoint source contributions of dissolved P have decreased by ~35% over this 30 year period. Agricultural activity is currently the largest anthropogenic source of dissolved P in the watershed, contributing about 42% of the mean annual loads. Currently point source dissolved P loads are less than 1% of total watershed load, a 98% reduction from the early 1990s and a result of upgrades to WWTPs.

During the FAD assessment period, DEP completed the development and testing of turbidity models for Cannonsville, Pepacton, and Neversink reservoirs. The model framework that was used for these reservoirs is fundamentally the same as the models previously validated for Ashokan, Schoharie, Kensico, and Rondout reservoirs. This model combines the two-dimensional CE-QUAL-W2 hydrothermal and transport model with a three size-class turbidity model. The setup, testing and performance of the model for Cannonsville is described in this report; the procedure and results for Pepacton and Neversink are similar. Rigorous testing was performed for 2011-2019 historic conditions, while additional testing was completed for 1987-2010. The accuracy of predictions of temperature and turbidity in the water column of the reservoir, and in the water supply diversion from the reservoir, were good and were comparable to that achieved in applications to other reservoirs.

DEP also completed an analysis to estimate the impact of climate change on the NYC water supply system. This analysis combined future climate forecasts for the watersheds with watershed and reservoir models and the Operations Support Tool. Current climate forecasts indicate a consistently warmer and generally wetter conditions in the watersheds. Summarizing the system-wide forecasts, a 6% increase in inflow to both Catskill and Delaware system reservoirs is predicted when comparing future (2041-2060) to current (2001-2020) climate. Diversion from the Delaware System is predicted to increase by 9% in the future, while Catskill diversion will decrease by 3%. The return period of various levels of elevated turbidity in major tributaries to the WOH reservoirs is predicted to decrease moderately, consistent with the inflow forecasts.

The number of days per year when diversion turbidity from Ashokan and Rondout reservoirs exceeds certain high values is predicted to increase moderately. Average number of days when the water supply system is under watch, warning or emergency drought conditions remain generally unchanged for the future conditions. The number of days when addition of alum to the Catskill Aqueduct will be required is predicted to increase a small amount.

1. Introduction

1.1 Purpose of this Report

This report has been prepared to comply with Section 5.1 of the December 2017 Filtration Avoidance Determination (2017 FAD), which requires the City to submit a comprehensive report on watershed protection accomplishments and an assessment of water quality to the New York State Department of Health (NYSDOH) by March 31, 2021. The purpose of this report is to summarize the achievements of the programs that comprise the City's overall watershed protection program; to review water quality status and trends in the Catskill/Delaware basins; and, where possible, to demonstrate the link between program activities and changes in water quality.

The report is divided into two main sections: Chapter 3 provides brief summaries of the accomplishments of each of the watershed protection programs for the past five years; and Chapters 4, 5, 6, and 7 summarize water quality monitoring results and modeling analyses, with a goal of assessing current water quality and evaluating the effectiveness of some of those programs.

This document should be viewed as a companion to the regular reports New York City Department of Environmental Protection (DEP) produced detailing program progress and water quality over the past five years. For specific details about the implementation of watershed protection programs, refer to the annual reports prepared pursuant to the FAD for the years 2017 through 2019. DEP has prepared annual Watershed Water Quality Reports for the same period. DEP also produces dozens of quarterly, semi-annual and annual reports on FAD programs, publishes reports on special studies and develops an annual water quality statement, which gives detailed information about water quality. Finally, DEP's web site contains periodic updates on certain programs and other details. Reports and other information about the City's initiatives can be found at https://www1.nyc.gov/site/dep/about/filtration-avoidance-determination.page.

1.2 Water Supply System

The New York City Water Supply System consists of three surface water sources (the Croton, the Catskill and the Delaware) and a system of wells in Queens (the Jamaica System) (Figure 1.1). The three upstate water collection systems include 19 reservoirs and three controlled lakes with a total storage capacity of approximately 580 billion gallons. They were designed and built with various interconnections to increase flexibility to meet quality and quantity goals and to mitigate the impact of localized droughts and water quality impairments. The system supplies drinking water to almost half the population of the State of New York – approximately 8.5 million people in New York City and 1 million people in Westchester, Putnam, Orange and Ulster counties – plus the millions of commuters and tourists who visit New York City throughout the year. Overall in-City consumption in 2020 averaged 981 million gallons a day, the lowest in at least 60 years. Consumption by the City's wholesale clients averaged 103 million gallons per day. (Figure 1.2)

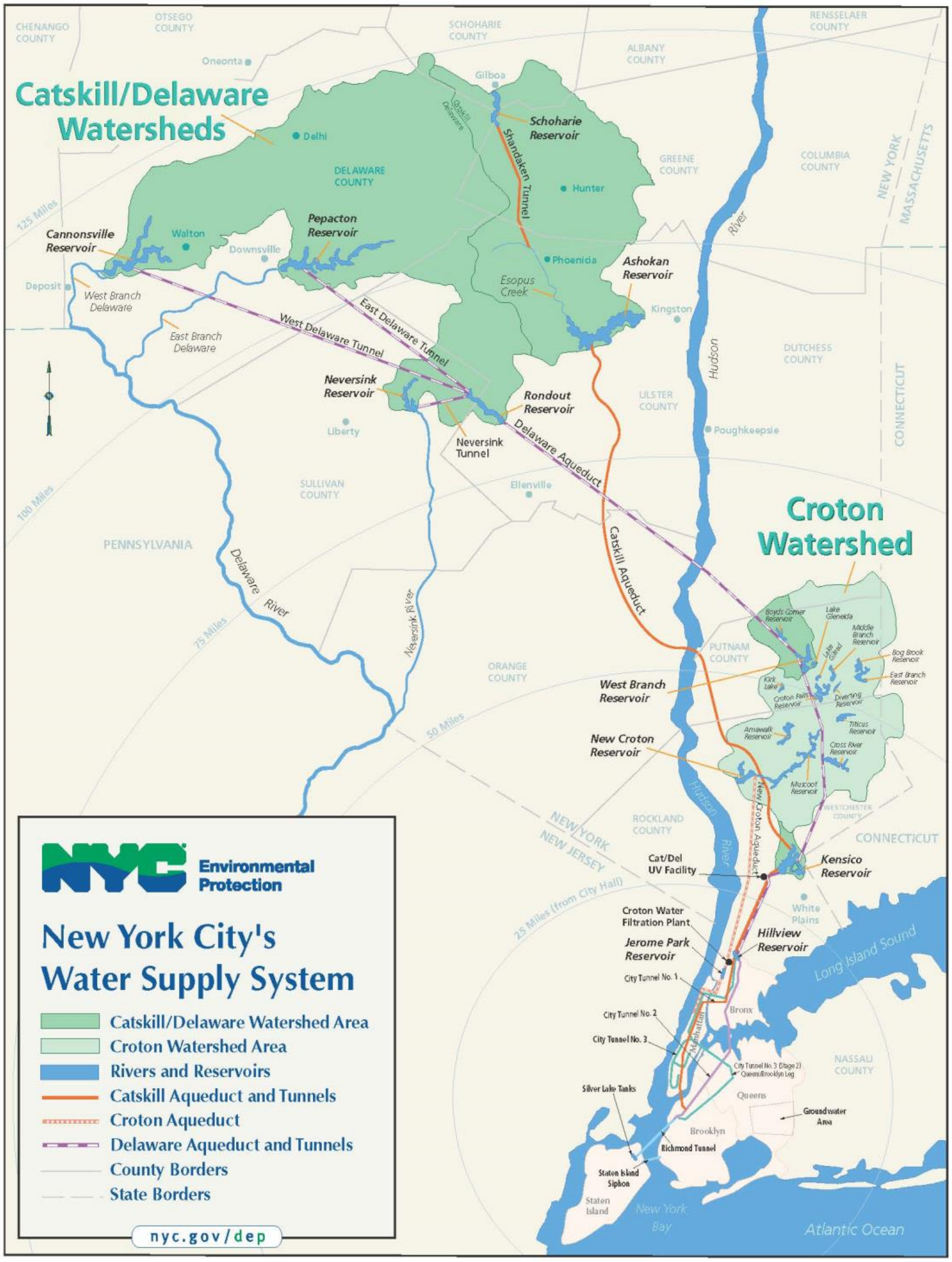


Figure 1.1 Map of New York City water supply system.

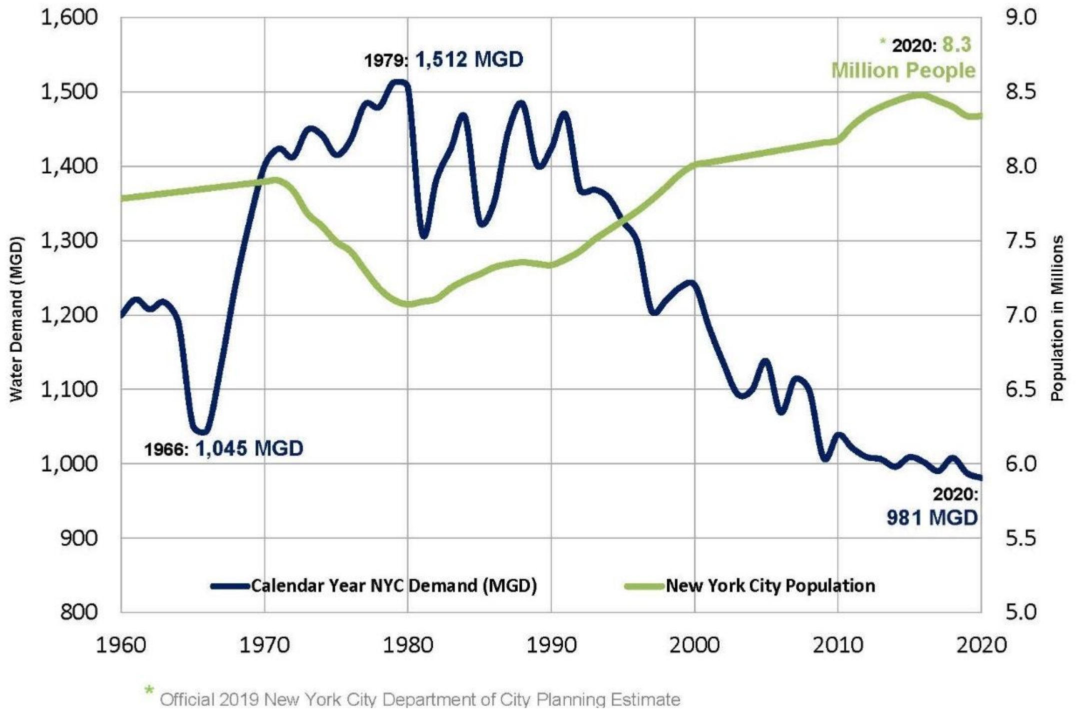


Figure 1.2 New York City consumption projection.

The Croton watershed is located entirely east of the Hudson River in Westchester, Putnam and Dutchess counties, with a small portion in Connecticut. The oldest of the three systems, parts of the Croton System have been in service for more than 175 years. The watershed covers approximately 375 square miles. Croton's 12 reservoirs and three controlled lakes are connected primarily via open channel streams and rivers, and ultimately drain to the New Croton Reservoir in Westchester County. Historically, approximately 10% of the City's average daily water demand has been supplied by the Croton, although in times of drought the Croton System may supply significantly more water.

The Catskill System consists of two reservoirs – Schoharie and Ashokan – located west of the Hudson River in Ulster, Schoharie, Delaware and Greene counties. The Catskill System was constructed in the early part of the 20th century, and Ashokan Reservoir went into service in 1915. Water leaves Schoharie Reservoir via the 18-mile-long Shandaken Tunnel, which empties into the Esopus Creek at Allaben and then travels 22 miles to the Ashokan Reservoir. Water leaves Ashokan via the 92-mile-long Catskill Aqueduct, which travels to Kensico Reservoir in Westchester County. The Catskill System supplies, on average, 40% of the City's daily water supply.

The Delaware System was constructed in the 1950s and 1960s, and is comprised of four reservoirs: Cannonsville, Pepacton, and Neversink in the Delaware River basin, and Rondout in the Hudson River basin. The first three reservoirs supply Rondout; water then leaves Rondout and travels to West Branch Reservoir in Putnam County via the Rondout-West Branch Tunnel. Water from West Branch then flows through the Delaware Aqueduct to Kensico Reservoir. The Delaware System provides the remaining 50% of the City's daily demand. Because waters from the Catskill and Delaware watershed are commingled at Kensico Reservoir, they are frequently referred to as one system: the Catskill/Delaware System.

In the late 1980s, the City decided to apply for filtration avoidance for the Catskill/Delaware System under the terms of the Surface Water Treatment Rule (see 1.3 Regulatory Context). Since that time, DEP and its partner agencies and organizations have developed and deployed a comprehensive watershed monitoring and protection program designed to maintain and enhance the high quality of Catskill/Delaware water. This program has been recognized internationally as a model for watershed protection and has allowed the City to secure a series of waivers from the filtration requirements of the Surface Water Treatment Rule.

DEP is the City agency with primary responsibility for overseeing the operation, maintenance and management of the water supply infrastructure and the protection of the 1,969 square mile watershed. Within DEP, the Bureau of Water Supply (BWS) manages the upstate watershed and infrastructure and all drinking water quality monitoring in-City and upstate. BWS also operates the City's two main distribution reservoirs – Hillview and Jerome Park. The Bureau of Water and Sewer Operations is responsible for the drinking water distribution and sewage collection infrastructure. The Bureau of Engineering Design and Construction manages all large contracts for capital construction and maintenance of the water supply infrastructure. Other bureaus and units within DEP – including Legal Affairs, Environmental Planning and Analysis, Public Affairs and Communications, Customer Service, and budget, personnel and procurement staff – provide vital support services to ensure the smooth operation of the water supply. In addition, staff from the New York City Department of Health and Mental Hygiene assist in certain drinking water programs and staff from the New York City Law Department provide legal support.

1.3 Regulatory Context

The Safe Drinking Water Act (SDWA) amendments of 1986 required the U.S. Environmental Protection Agency (USEPA) to develop criteria under which filtration would be required for public surface water supplies. In 1989, USEPA promulgated the Surface Water Treatment Rule (SWTR), which requires all public water supply systems supplied by unfiltered surface water sources to either provide filtration or meet certain criteria. The filtration avoidance criteria are comprised of the following:

- Objective Water Quality Criteria – The water supply must meet certain levels for specified constituents including coliforms, turbidity and disinfection byproducts.

- Operational Criteria – A system must demonstrate compliance with certain disinfection requirements for inactivation of *Giardia* and viruses; maintain a minimum chlorine residual entering and throughout the distribution system; provide uninterrupted disinfection with redundancy; and undergo an annual on-site inspection by the primacy agency to review the condition of disinfection equipment.
- Watershed Control Criteria – A system must establish and maintain an effective watershed control program to minimize the potential for contamination of source waters by *Giardia* and viruses.

1.4 Historical Context

The City first applied for a waiver for the Catskill/Delaware system from the filtration requirements of the SWTR in 1991. This first application was filed with NYSDOH because, at the time, the City and NYSDOH believed NYSDOH had primacy for all water supply systems in New York State. NYSDOH granted a one-year filtration waiver. Subsequently, it was determined that EPA had retained primacy for the SWTR for the Catskill/Delaware systems. In mid-1992, DEP submitted a 13-volume application to USEPA, describing in detail the City's plans for protecting the Catskill/Delaware supply. On January 19, 1993, USEPA issued a conditional determination granting filtration avoidance until December 31, 1993. The waiver incorporated many elements of the program the City had described in mid-1992, and was conditioned upon the City meeting 66 deadlines for implementing studies to identify potential pollution sources, developing programs to ensure long-term protection of the watershed, and addressing existing sources of contamination in the watershed. USEPA also imposed substantial reporting requirements on the City to monitor its progress.

DEP submitted a second application for continued avoidance to USEPA in September 1993. This application was based upon the knowledge gained by the City through initiation of its watershed studies and programs and laid out a long-term strategy for protecting water quality in the Catskill/ Delaware System. Again, USEPA determined that the City's program met the SWTR criteria for filtration avoidance, although they did express concerns about the program's ability to meet the criteria in the future. On December 30, 1993, USEPA issued a second conditional determination, containing 150 requirements related primarily to enhanced watershed protection and monitoring programs. USEPA also required the City proceed with conceptual design of a filtration facility for the Catskill/Delaware supply so no time would be lost should USEPA decide filtration was necessary in the future.

Two critical pieces of the watershed protection program that DEP described in September 1993, and that USEPA incorporated into the December 1993 determination, were implementation of a land acquisition program and promulgation of revised watershed regulations. DEP was unable to move forward with implementation of those key program elements primarily due to the objections of watershed communities over the potential impact those programs might have on the character and economic viability of their communities. It was against this backdrop that New York Governor George Pataki convened a group of stakeholders to try to come to an accord. The negotiations involved the City, the state, USEPA, representatives of the counties, towns and residents of the watershed, and representatives from environmental groups. In November 1995, the parties reached an agreement in principle setting forth the framework of an agreement that would allow the City to advance its watershed protection program while protecting the economic viability of watershed communities. It took another 14 months to finalize the details of an agreement. In January 1997, the parties signed the Watershed Memorandum of Agreement (MOA). The MOA supplemented the City's existing watershed protection program with approximately $350 million in additional funding for economic and environmental partnership programs with upstate communities, including a water quality investment program and a regional economic development fund. The state issued a land acquisition permit, which was updated in 2010, to allow the City to purchase land in the watershed, and approved a revision to the City’s Watershed Regulations governing certain aspects of new development in the watershed. The City also secured a five-year waiver from the filtration requirements for the Catskill/Delaware System.

In March 2006, the City submitted to USEPA a rigorous, science-based assessment of Catskill/Delaware water quality, followed in December 2006 by an enhanced, comprehensive long-term plan for watershed protection efforts. That long-term plan represented a significant enhancement to the City’s watershed protection efforts and relied in part on the continued support and cooperation of the City’s partners. The plan formed the basis of an updated FAD, issued by USEPA in July 2007. Significantly, the 2007 FAD was the first FAD to cover a full 10-year period, signaling the growing confidence of all parties that source water protection has become a sustainable alternative to filtration for the City’s Catskill/Delaware supply.

Following issuance of the 2007 FAD, USEPA granted NYSDOH primary regulatory responsibility for the SWTR as it applies to the Catskill/Delaware supply. In March 2011, DEP issued another detailed assessment of program activity and water quality, which formed the basis of a revised long-term plan submitted to NYSDOH in December 2011. In late summer 2011, two significant storms swept through the region, devastating communities and significantly impacting water quality in portions of the New York City supply. In the wake of the storms, a large group of watershed stakeholders came together to discuss developing and enhancing certain programs to promote flood resiliency and minimize water supply impacts from future events. Following these discussion, NYSDOH issued a Revised 2007 FAD in May 2014.

In March 2016, DEP released the next five-year summary and assessment report, again confirming the high quality of the New York City supply. In December of that year, following extensive discussions with regulators and watershed stakeholders, DEP submitted a long-term plan, which included detailed program proposals for the period 2017-2027. Following additional review and stakeholder discussion, NYSDOH issued a new FAD in December 2017.

In 2018, the National Academies of Science, Engineering and Medicine (NASEM) convened an expert panel to evaluate New York City's source water protection program. This study follows a similar evaluation conducted by NASEM in the early 2000s after the MOA was signed. Over approximately two years, the panel engaged in a comprehensive process, which included eight meetings, dozens of presentations by DEP staff and watershed stakeholders, several site visits in the watershed, countless information requests and hundreds of hours of discussion and drafting. Their final report was released in August 2020. The panel was able to synthesize an incredible amount of information about our complex program and watershed conditions, and produce a detailed analysis and discussion.

The report includes a strong endorsement of the work DEP and its partners have undertaken over many years, stating that the programs "have admirably supported water quality" with "strong indications" they will continue to effective in the future. However, the panel's charge was not simply to look at the accomplishments to date, but rather to make recommendations for adjustments to ensure the continued effectiveness of our investments. The report includes 63 major recommendations, ranging from straightforward and relatively modest program adjustments to out-of-the-box thinking. The panel's recommendations are currently being reviewed and evaluated by DEP and watershed stakeholders and are expected to be the basis of mid-term modifications to the FAD in 2022.

1.5 Report Details

This report primarily focuses on program activities undertaken since 2016 and continuing through the end of 2020. However, since most of the programs discussed were initiated more than 25 years ago, there is some discussion of program activities that fall before the term of the current FAD. Indeed, the City's watershed protection efforts are best evaluated in the context of the overall program that was initiated in the early 1990s. The significant accomplishments of the City and its partners have been made possible only by the sustained commitment to source water protection.

One of the primary purposes of this report is to evaluate quantitatively how effective the watershed programs have been since 1997, and will be over the long term. The City has taken a basin-by-basin approach, evaluating each reservoir in turn to assess the status and trends in water quality. The water quality analysis presented in this document is an extension of the analysis presented in the 2001, 2006, 2011, and 2016 assessments of DEP's FAD programs. Here DEP presents an analysis covering 27 years of data collection and program implementation. This data includes results collected through the end of 2019. Due to the time needed to process samples, and compile, review and verify data, it was not possible to incorporate any monitoring results from 2020. Long-term data is critical in the evaluation of programs that cover large geographical areas and are implemented over long periods, so analyses have become better as the data record becomes longer. The approach DEP has used is to evaluate water quality in terms of status, trends, and modeling. The status of waterbodies is based on three recent years of data (i.e., 2017 through 2019) and these are compared to regulatory benchmark values. The trends are based on 27 years of data (i.e., 1993 through 2019). Five important analytes were selected, including fecal coliforms, turbidity, phosphorus, conductivity and trophic status. Modeling was conducted to attribute program effects to programs on a watershed-wide basis. All analyses together provide a context to understand program effects.

2. Water Supply Infrastructure Improvements

2.1 Kensico-Eastview Connection

Historically, both the Catskill and Delaware aqueducts conveyed water from Kensico Reservoir to Hillview Reservoir. When the Catskill-Delaware Ultraviolet Light Disinfection (CDUV) Facility (CDUV) was activated in 2012, the section of the Catskill Aqueduct between Kensico Reservoir and CDUV was taken out of service due to hydraulic grade limitations that prohibited the continued gravity conveyance of water to the new facility.

The Kensico-Eastview Connection (KEC) project will construct a new tunnel to provide an additional means of conveying water from Kensico Reservoir to CDUV. The KEC Project is also one of two precursor, critical path projects which must be completed prior to the construction of a cover over Hillview Reservoir and are included in the consent decree.

The scope of the project includes modifications to the existing intake (the Upper Effluent Chamber (UEC)); construction of a new screen chamber, downtake and uptake shafts; construction of the main tunnel from the Kensico campus to the Eastview campus; construction of connecting tunnels (from the UEC to the screen chamber and from the screen chamber to both the new downtake shaft and the Lower Effluent Chamber), and a new chamber connecting the new tunnel to CDUV.

The KEC project scope also increases security at the Kensico campus: Westlake Drive will be relocated to remove public access through the campus, a police booth and perimeter fence will be installed, and a new electrical building will be constructed to consolidate electrical service to the campus and build in redundancy. In addition, the shoreline of the cove in Kensico Reservoir near the UEC will be stabilized from the UEC to the end of the existing shoreline stabilization effort (CRO-543). Wetlands will be created or rehabilitated to mitigate any impacts to existing wetlands by the project.

The first phase of geotechnical borings for the KEC project was completed in 2018. A second phase started in 2019 and is expected to be completed by the end of 2022. By 2021, 30% of the KEC project's design (not including the shoreline stabilization and wetland mitigation components of the project) is anticipated to be completed. The entire KEC project is expected to be completed and online by 2034.

2.2 Catskill Aqueduct Repair and Rehabilitation

The Catskill Aqueduct conveys water by gravity from the Catskill System to Kensico Reservoir. The Catskill Aqueduct is primarily an open channel flow aqueduct, which generally follows the grade of the earth. The flow capacity of the Catskill Aqueduct is approximately 590 million gallons per day (MGD), transmitting roughly 40% of the City's average daily supply. Historical flow records suggest past transmission capacity may have been as high as 660 MGD.

The purpose of the Catskill Aqueduct Repair and Rehabilitation project (CAT-RR) is to ensure structural integrity, restore transmission capacity and extend the useful life of the Catskill Aqueduct. In 2018, construction commenced on the project, including structural inspections, cleaning of a biofilm growth on aqueduct walls, and critical repairs. The project was defined as a critical predecessor project to the Rondout-West Branch Tunnel (RWBT) bypass connection.

The majority of the work is internal to the aqueduct and requires a complete zero-flow shutdown at the headworks at Ashokan Reservoir. Aqueduct shutdowns between late 2018 and early 2020 have allowed the project to accomplish inspection of 59 miles of the 74-mile-long aqueduct (15 miles of pressure tunnels excluded), leak repair, manhole repairs, structural repairs, and cleaning of the aqueduct walls. Work continued in a third shutdown season between late autumn and early winter in 2020 and early 2021. Tasks included completing the replacement of aged mechanical components (siphon blow-off valves), additional biofilm cleaning, and performing leak repairs at deep drainage chamber shafts at two aqueduct pressure tunnels.

The work will provide for the continued reliability of the Catskill Aqueduct, reducing the probability for an unplanned Catskill Aqueduct outage while the Delaware Aqueduct is offline for the RWBT bypass connection starting in autumn 2022.

2.3 Rondout-West Branch Tunnel

The Rondout-West Branch Tunnel (RWBT) of the Delaware Aqueduct conveys water by gravity from the Delaware System to West Branch Reservoir. The Delaware Aqueduct is a pressurized aqueduct, operating on reservoir head, and was constructed deep in underlying bedrock formations. The flow capacity of the Delaware Aqueduct is approximately 840 MGD.

Since the early 1990s, the RWBT has been leaking between 15 MGD and 35 MGD. These leaks express themselves at the ground surface in two areas, Town of Wawarsing and the Roseton area of the Town of Newburgh. The majority of the leaks are in Roseton.

Efforts to evaluate the RWBT’s condition and design and implement a repair have been ongoing since 2011. The selected leak repair includes construction of a new, 2.5-mile-long tunnel beneath the Hudson River that parallels the existing RWBT. This new tunnel will bypass the Roseton leak areas and will connect to the existing RWBT on either side of the Hudson River in the towns of Newburgh and Wappinger.

The two new bypass-tunnel shafts were completed in 2016 (DEP contract BT-1) and construction for the bypass tunnel was awarded in 2016 (DEP contract BT-2). A tunnel boring machine (TBM) was specifically built for this project and lowered into the western shaft, where it was assembled and began boring the tunnel in January 2018. The TBM completed the new bypass tunnel in August 2019 and was removed from the eastern tunnel shaft. Both concrete and steel liners were installed in several steps to create a triple-pass liner approximately three feet thick. A total of 230, 16 foot-diameter steel inter-liners were installed to provide additional tunnel reinforcement in areas of poor rock quality. The final interior liner is composed of smooth concrete.

The bypass will be connected to the existing RWBT and then the leaking section between Newburgh and Wappinger will be decommissioned. The connection work is expected to take between five and eight months, starting in October 2022 and possibly lasting through May 2023. During this time, the section of the Delaware Aqueduct between Rondout and West Branch reservoirs must be offline. Repairs will also be made to eliminate the leak in the Wawarsing area of the RWBT during this outage period by performing grout injections of the tunnel liner cracks identified in this area. Depending on the hydrologic conditions throughout the NYC reservoir watershed, the RWBT connection may be made in one continuous shutdown or up to three shorter shutdowns over three successive autumn seasons.

2.4 Cross River and Croton Falls Pumping Stations

When New York City constructed the Delaware Aqueduct, shafts were built to allow for the introduction of Croton System water into the aqueduct. These connections were intended to provide operational flexibility for the water supply. The connections allow DEP to pump water from Cross River and Croton Falls reservoirs. The original hydraulic pump stations went into service around 1950 and had a combined capacity of approximately 65 million gallons per day.

DEP initiated a project to replace the existing hydraulic pumps at both locations with new, electric pumps. DEP designed the new pump systems to increase the capacity of the pump stations, as well as eliminate the inefficiencies of the hydraulically driven pumps. A new pumping station for Cross River went into service in 2012, with three pumps and a combined capacity of 60 million gallons per day. An entirely new facility was built for the Croton Falls Pumping Station, and was put into service in 2019. The new station houses five pumps, with a total capacity of 180 MGD.

NYSDOH approval is required prior to running the pumping stations at both locations. DEP must submit water quality analyses of at least two weeks of water samples to NYSDOH for review to receive NYSDOH approval. Water samples are taken regularly during the pumping operations to track water quality. In addition, DEP is required to take certain actions around the reservoirs and in the drainage basins in advance of and during pumping operations. Since it was replaced, the Cross River station has been operated a few times for lengths of two to three days. The Croton Falls station ran for more than three months, starting in November 2019 and going into February 2020. Both pumping stations will be ready for extended use during the shutdown of the RWBT. Starting in October 2022, the pumping stations are expected to be needed for six to eight months of service.

3. Watershed Management Programs

3.1 Institutional Alliances

As originally embodied in the 1997 Watershed Memorandum of Agreement (MOA) and subsequently memorialized in dozens of DEP contracts during the past 24 years, a number of non-City entities have contributed to the development, implementation, and evolution of DEP's watershed protection programs. Representatives from watershed communities, locally based contract partners, and environmental organizations all bring their own perspectives to watershed issues. DEP strives to balance these views with its public health mandate to provide safe, clean drinking water to more than 9 million consumers, while complying with the City's complex budgetary and contracting framework as well as numerous state and federal regulatory requirements that derive from the City's Water Supply Permit (WSP) and Filtration Avoidance Determination (FAD).

DEP's Watershed Protection Program serves as a national and international model for how to reliably safeguard an unfiltered public water supply. Although science, engineering, planning, security, and financial investment are all indispensable components of a successful overall program, the active involvement of local stakeholders and affected constituents is also essential. The architects of the 1997 MOA recognized that DEP's delivery of targeted watershed programs depends on strong institutional alliances with local contract partners and a substantial "ownership interest" by watershed communities and residents in the shared long-term goal of stewarding the New York City water supply for future generations.

The MOA's structure continues to stand the test of time, providing a stable foundation for many watershed programs and partnerships established and strengthened during the past two decades. This sentiment was affirmed by the National Academies of Sciences, Engineering, and Medicine (NASEM) in its 2020 Review of the New York City Watershed Protection Program (p.395): "The 1997 MOA and Watershed Protection Program have largely succeeded in maintaining or enhancing water quality for the NYC water supply and providing sustained investments to enhance the economic vitality of watershed communities. Active and evolving partnerships with the Catskill Watershed Corporation, Watershed Agricultural Council, and many other organizations and agencies show the potential – and tradeoffs – of balancing water quality protection with community vitality."

In many ways, the City's ongoing commitment to work cooperatively with local partners toward mutually beneficial outcomes is one of the crowning achievements of DEP's Watershed Protection Program. This section provides a brief summary of key institutional alliances that help make the overall program a collaborative success.

3.1.1 Watershed Agricultural Council

The Watershed Agricultural Council (WAC) was the first locally based partnership that DEP funded to administer and implement voluntary pollution prevention programs as an alternative to watershed regulations. WAC was incorporated in 1993, years before the signing of the MOA, to receive City funds and assist watershed farmers with the development of Whole Farm Plans and the implementation of best management practices (BMPs) that protect water quality. Since WAC's inception, DEP has served as a member of WAC's Board of Directors and all program committees. Other WAC board members include watershed farmers, forest landowners and business representatives, with several new members joining the board in recent years.

Since 1993, DEP has contracted with WAC to provide more than $350 million in City funding to support a portfolio of programs that address both agricultural and forestry sources of pollution. WAC's mission is to promote the economic viability of agriculture and forestry, the protection of water quality, and the conservation of working landscapes through strong local leadership and sustainable public-private partnerships. WAC's core programs include the Watershed Agricultural Program, Forestry Program, Farm and Forest Conservation Easement Programs, and Economic Viability Program (the centerpiece of which is the Pure Catskills Buy Local Campaign). WAC also manages a long-term Stewardship Endowment Fund that is funded almost exclusively by the City pursuant to a prior FAD requirement.

During the current FAD assessment period, WAC continued to evolve as an independent not-for-profit organization while balancing its role as a DEP contract partner responsible for the expenditure of City funds. WAC historically leveraged City funds to diversify its programming and funding base, with the organization receiving more than $30 million in state, federal and private grants over the years. Today, WAC relies almost entirely on DEP contract funding, which requires close coordination with DEP to ensure compliance with the City's complex budgetary and contracting framework. As acknowledged by the NASEM in its FAD Expert Panel Review Report (p.162): "Increasing the collaboration between WAC and NYCDEP will result in more efficient allocation of resources, improved communication, and ultimately improved water quality." WAC is currently undergoing a significant leadership transition as prompted by the unexpected, simultaneous departure of both its executive director and board chair in early November 2020.

3.1.2 Catskill Watershed Corporation

The Catskill Watershed Corporation (CWC) was created in 1997 to implement a diverse portfolio of WOH watershed programs as outlined in the MOA and funded by the City through a succession of DEP contracts totaling more than $506 million to date. CWC's current portfolio of programs address septic system remediation and maintenance (residential and small businesses), stormwater management, community wastewater management, flood hazard mitigation, local consultation and technical assistance, public education, and economic development. CWC continues to successfully administer and leverage the Catskill Fund for the Future, which has awarded more than $98 million in loans over the past two decades.

During the current FAD assessment period, CWC continued to effectively and efficiently deliver a wide range of MOA programs to the mutual benefit of WOH watershed communities and the New York City water supply. In 2019, CWC assumed oversight from DEP for administering the City-funded portion of the MOA-145 Future Stormwater Program, which it now implements in tandem with the MOA-128 Future Stormwater Program.

DEP continues to serve on CWC's Board of Directors alongside 12 locally elected officials from WOH watershed towns, one New York State representative, and one representative from the environmental community; this latter seat was vacant for two years until the governor appointed the Catskill Center in 2018. It is worth noting that several longstanding CWC board members and staff either retired or passed away during this current FAD assessment period, marking a transfer of institutional knowledge from those who were involved in the 1997 MOA to the next generation of leaders who bring new ideas and perspectives that inform local decision-making. As acknowledged by the NASEM in its expert panel review report (p.16): "The MOA is especially important as generational change occurs in leadership positions, field operations, technical support, and community outreach. New Watershed Protection Program participants and community members should think of the MOA as a living document rather than a relic of the late-20th century."

In 2020, CWC completed the construction of a new office building in Arkville, Delaware County that, pursuant to the 2017 FAD, will serve as shared DEP office space to improve staff-level communication, collaboration, and coordination of programs. CWC moved into this 35,000-square foot facility in March, around the time COVID-19 resulted in mandatory office occupancy reductions and teleworking options being adopted by DEP and its partners. DEP initiated occupancy of the Arkville building during the second half of 2020 to achieve the FAD requirement of 26 DEP staff working there by December 31, 2020.

3.1.3 Stream Management Program Partners

Since 1996, DEP has contracted with Soil and Water Conservation Districts (SWCDs) in Delaware, Greene, Ulster and Sullivan counties, and with Cornell Cooperative Extension of Ulster County (CCEUC), to develop and implement the Stream Management Program (SMP) that is tailored within each WOH reservoir basin. Partnership is a core value of the SMP, and DEP recognizes that long-term success depends on a community-based approach with substantial involvement and participation of streamside landowners, local officials, highway departments, code enforcement officers, and other stakeholders. The SMP uses basin-specific action plans to guide the implementation of projects and to conduct extensive education, outreach and training for the broad range of stakeholders. Within each basin, the SMP also relies on locally led program advisory committees who meet quarterly to guide program priorities and fashion multi-objective solutions to complex stream challenges.

Following tropical storms Irene and Lee in 2011, there was a growing recognition among WOH watershed stakeholders about the impacts of climate change, particularly with respect to flood risks and impacts. This led to the development of several new City-funded flood hazard mitigation and buyout programs to assist communities with assessing flood risks and reducing flood impacts through projects that improve community resiliency and water quality. During the current FAD assessment period, the SMP continued to help foster, strengthen, and coordinate a growing network of institutional alliances in support of flood hazard mitigation programming, including the establishment of local flood commissions and the completion of Local Flood Analyses (LFAs) in most WOH population centers.

Together, DEP and its local partners have been able to establish a strong foundation of technical expertise and professional engineering services in support of the SMP, as acknowledged by the NASEM in its 2020 expert panel review report (p.198): "Among the entire suite of Watershed Protection Programs, the Stream Management Program is particularly commendable. The program staff have developed long-term partnerships with many agencies, communities, scientists, and engineers to build an extensive program for stewardship of Catskill Mountain streams and floodplains focused on the overarching goal of protecting and restoring stream system stability and ecosystem integrity." DEP acknowledges the critical leadership role that has been performed every day at the basin-scale program level by Delaware, Greene, Ulster and Sullivan SWCDs, along with CCEUC, to advance the SMP in a successful direction during the past two decades.

It is worth noting that during the current FAD assessment period, a wave of local staff retirements resulted in sweeping leadership changes throughout every SMP partner organization. New executive directors took the helm at Delaware, Greene and Ulster SWCDs, as well as CCEUC, while Sullivan SWCD hired a new coordinator of the Rondout Neversink SMP. Although loss of institutional knowledge is always a concern when longstanding staff retire from their positions, it is encouraging that many of these leadership changes resulted in existing staff being promoted from within the local SMP team as was the case in Greene, Ulster and Sullivan SWCDs.

3.1.4 Environmental Organizations

Environmental organizations have always been vital to the success of DEP's Watershed Protection Program, including MOA signatories such as the Catskill Center, Hudson Riverkeeper, Natural Resources Defense Council, New York Public Interest Research Group, Open Space Institute, and Trust for Public Land. Many of these organizations provide an important perspective during stakeholder discussions and offer key policy suggestions that inform the continued evolution of DEP's Watershed Protection Program.

During the current FAD assessment period, the Catskill Center emerged as a key DEP partner through its contractual oversight of the City-funded Streamside Acquisition Program (SAP). Although the SAP was initiated in 2015, during the past five years the Catskill Center has expanded its organizational capacity with a new roster of staff who strive to collaborate with DEP and local community leaders to support the ongoing development and evolution of the SAP pursuant to the FAD and WSP. While the SAP is not an MOA program, it is a component of DEP's Land Acquisition Program and therefore subject to MOA rules.

3.1.5 East of Hudson Partners

Within the East of Hudson (EOH) watershed, DEP's partners have traditionally included county governments and both locally based and state-administered corporations, including the East of Hudson Watershed Corporation (EOHWC) and the NYS Environmental Facilities Corporation (EFC). During the current FAD assessment period, Westchester and Putnam counties continued to administer City funding provided through the MOA's EOH Water Quality Investment Program while working closely with DEP through delegation agreements with their respective health departments to conduct and perform coordinated reviews of new, modified, and repaired septic systems.

The EOHWC is a local development corporation established in 2011 by watershed municipalities in northern Westchester, Putnam, and Dutchess counties to install stormwater retrofit projects that meet the heightened requirements for phosphorus reduction defined by the New York State Department of Environmental Conservation (NYSDEC). The EOHWC is governed by a board of directors comprised of town supervisors, village mayors, and county executives representing EOH watershed municipalities. The EOHWC works in conjunction with DEP and NYSDEC to assist EOH watershed municipalities with achieving compliance with the heightened requirements of their Municipal Separate Storm Sewer System (MS4) permits. With encouragement from NYSDEC, the EOHWC is currently exploring whether to expand the scope of its program services to address other sources of pollution.

The EFC is a public-benefit corporation that assists communities with undertaking critical water quality infrastructure projects by providing access to low-cost capital, grants, and technical assistance. With respect to DEP's Watershed Protection Program, EFC historically implemented the WWTP Regulatory Upgrade and Capital Replacement Programs, in addition to the EOH Septic System Rehabilitation Reimbursement Program. During the current FAD assessment period, EFC discontinued its involvement in the WWTP programs while continuing to implement the EOH Septic Program for properties in the Kensico, Boyd Corners, Cross River, Croton Falls and West Branch basins. Pursuant to the 2017 FAD, this latter program was expanded in 2019 to basins located upstream of or hydrologically connected to the Croton Falls Reservoir (i.e., Bog Brook, Diverting, East Branch, and Middle Branch).

Finally during the current FAD assessment period, DEP established a new partnership with the New England Interstate Water Pollution Control Commission (NEIWPCC), a regional commission that helps northeastern states to preserve and advance water quality. In 2017, DEP entered into a contract with NEIWPCC to administer the EOH Community Wastewater Grants Program, a 2017 FAD requirement. In 2019, DEP entered into a second contract with NEIWPCC to administer the WWTP Regulatory Upgrade and Capital Replacement Programs following EFC's decision to discontinue its role in these programs.

3.2 Land Acquisition

The goal of the Land Acquisition Program (LAP) is to acquire real property rights in fee simple or conservation easements (CEs), to permanently protect sensitive land to prevent water quality impacts associated with intense land uses and development of impervious surfaces. As such, the role of LAP is not to improve water quality over existing conditions, but rather to ensure that future development will not appreciably impact water quality. The history of acquisitions during 23 years of activity offers a compelling story of land protection in a two thousand square-mile watershed, as assessed here.

Prior to 1997, DEP owned 34,192 acres, or 3.3% of the watershed land in the CAT/DEL watershed (excluding reservoirs). Since 1997, LAP has secured an additional 152,699 acres, or four times the acreage owned prior, bringing DEP-owned or controlled land to 187,507[1] acres in total, or 18.1% of the watershed. Including land protected by other entities such as New York State (NYS), municipalities and land trusts, 405,195 acres, or 39.7% of the entire watershed, are now permanently protected. Figure 3.1 shows the land protected by basin, including land

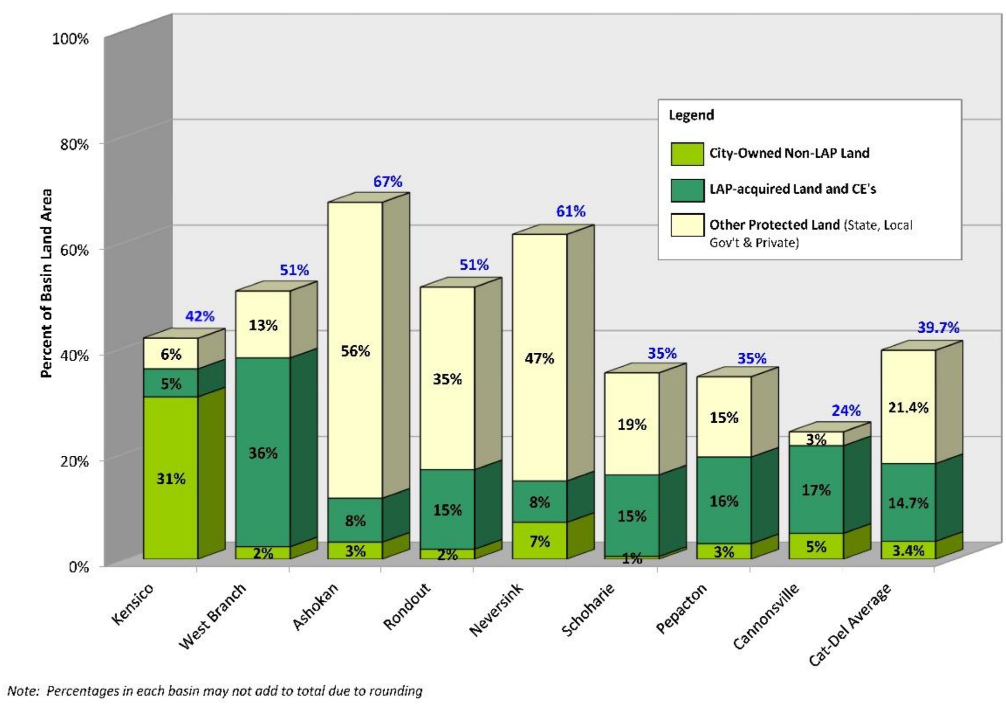


Figure 3.1 Land protected by basin, including land protected by NYS and others.

[1] In addition to the 34,192 acres of water supply land owned prior to 1997, the 187,507 figure includes 316 acres of water supply land acquired since 1997 without LAP funds for non-LAP agency purposes.

protected by NYC, New York State and others[2]; Figure 3.2 shows the acres of land under contract by year and type.

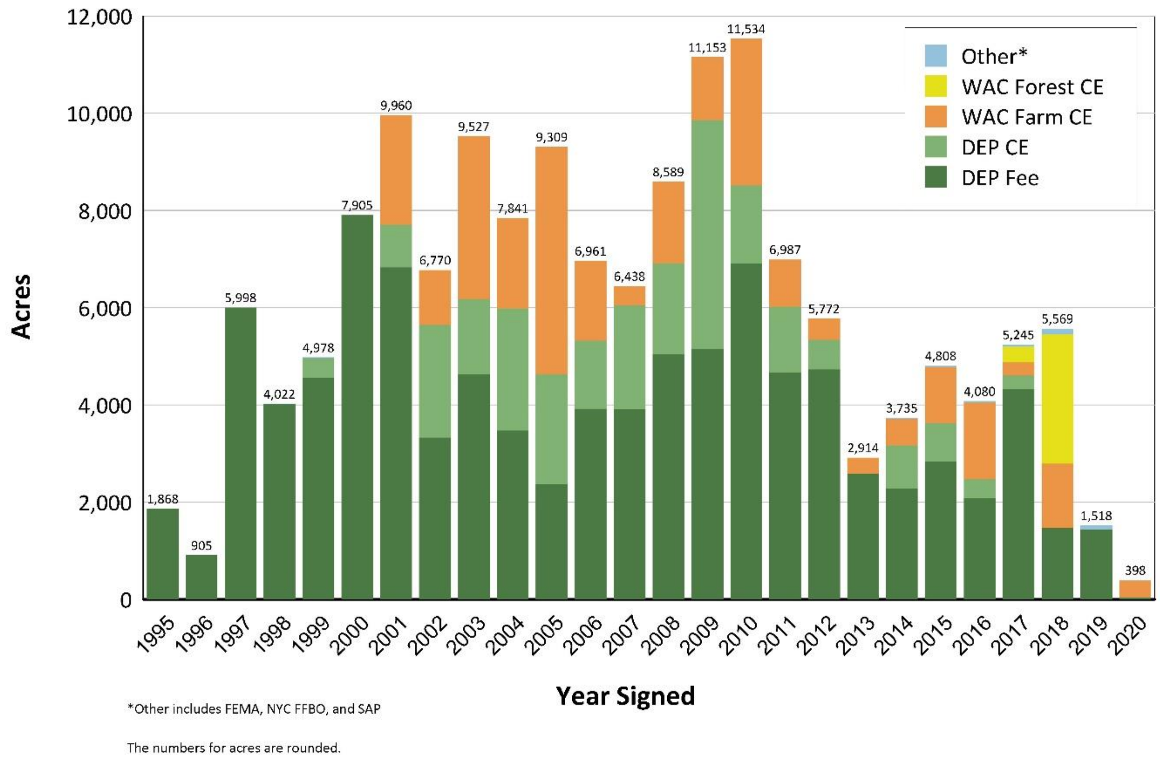


Figure 3.2 Acres in executed contracts by year and type (CAT/DEL System).

The LAP was very active across all program areas during the five-year assessment period. Numerous stakeholder meetings were held during 2016-2018, during which new solicitation and acquisition parameters were developed and have since guided the program. Three partnership programs – the Pilot Forest Conservation Easement Program managed by the Watershed Agricultural Council (WAC), the Streamside Acquisition Program (SAP) managed by the Catskill Center, and the NYC-Funded Flood Buyout Program (NYCFFBO) managed by a consortium of partners – all moved from planning into full implementation phases. Along with LAP core efforts, acquisition programs overall secured 16,810 acres (210 contracts) in signed purchase agreements for the period.

[2] Figure 3.1 and the associated numbers presented in this paragraph are based on a GIS analysis of acreage in various ownership categories within the bounds of the Catskill-Delaware watershed. Since the figures are based on GIS depictions of lands acquired, and do not include acres outside the watershed boundary, they may not agree exactly with program acreage totals reported elsewhere in this report.

3.2.1 Solicitation Goals

Since the inception of LAP, the FAD has required DEP to meet periodic targets for the number of acres of land solicited. Over time, DEP's strategies and criteria for solicitation have evolved in response to the quantity of lands acquired, changing land use and development patterns, and stakeholder input.

During stakeholder negotiations leading to the 2017 FAD, DEP agreed to temporarily halt outgoing solicitation in eight towns, as detailed in the 2017 Side Agreement. Pursuant to those discussions and the 2017 Side Agreement, DEP issued updated town-level assessments in April 2017 for 21 WOH towns. The extensive work that was undertaken to review DEP's 2010 Final Environmental Impact Statement (FEIS) and subsequent revised assessments resulted in new guidelines for LAP solicitation WOH, which were incorporated in the 2018 solicitation modifications. Two-year solicitation plans were issued as required in late 2014 (for 2015-16), late 2016 (2017-18), and late 2018 (2019-2020). These plans reflected solicitation to be undertaken pursuant to new guidelines for surface water criteria (SWC), in which the prior minimum threshold of 7% was raised throughout the WOH watershed to 15% unless a property abuts land already owned by DEP; 30% within half-mile zones surrounding hamlets designated as of 1997; and 50% where DEP has acquired either 60% of the maximum FEIS projection or more than 2,000 acres in a given town since 2010. Once the maximum FEIS projection in a given town is reached, or DEP has acquired an additional 4,000 acres in towns which did not receive a town-level assessment in the FEIS, DEP suspends outgoing solicitation in that town and only responds to incoming inquiries from landowners. Finally, LAP has sought to use the local subdivision process more often so as to leave more developable land in private hands and focus acquisitions to an even greater degree on surface water criteria. All of these adjustments have resulted in a program that is increasingly selective about which parcels, or portions of parcel, are pursued for acquisition. The adjustments also continue the evolution of LAP in consideration of the program's achievements to date as well as watershed conditions. In 2010, revisions to the WSP established a new minimum requirement of 7% SWC for most LAP acquisitions, and in 2018 that minimum was raised to 15% (or higher, depending on several factors such as proximity to hamlets). Prior to 2002, properties acquired in fee simple by LAP in the 20-100 acre range averaged 32% SWC, while during the past few years projects in this size range have averaged over 40%.

Based on DEP's state-of-the-art GIS data, the entire CAT/DEL watershed comprises 1,021,728 acres (excluding reservoirs). As of December 31, 2020, approximately 218,787 acres (21.4%) were owned outright by public agencies other than DEP or land trusts. As of 1997, a total of 34,192 acres (3.3% of watershed land, excluding reservoirs) were owned by DEP. Of the roughly 770,000 acres in private ownership remaining, DEP has solicited the owners of more than 481,000 acres Since 1997, resolicitation of many of these properties has continued, leading to considerable acquisition gains. Between January 1, 2016, and December 31, 2020, over 279,000 acres were solicited.

Two-Year Solicitation Plans

Table 3.1 summarizes the solicitation goals and achievements for DEP and its partners since 2016. The plans were followed with the exception of calendar year 2020, during which almost all outgoing solicitation was halted due to the public health emergency.

Table 3.1 Acreage in LAP's two-year solicitation plans.

	Core LAP		WAC		SAP		FBO	
Year	Planned	Actual	Planned	Actual	Planned	Actual	Planned	Actual
2016	35,000	36,436	8,000	28,799	2,000	620	50	34
2017	35,000	25,933	8,000	41,625	4,000	1,432	100	17
2018	22,000	21,213	25,000	39,512	1,000	1,010	25	26
2019	34,000	39,389	25,000	20,590	1,000	644	25	9
2020	34,000	4,337	25,000	16,757	1,000	619	25	4
Totals	**160,000**	**127,308**	**91,000**	**147,283**	**9,000**	**4,325**	**225**	**90**

3.2.2 Purchase Contracts

Since 1997, LAP initiatives have secured 152,699 acres in fee simple or CE, or four times the acreage owned as of 1997, bringing DEP-owned or controlled land to 187,507 acres, or 18.1% of watershed land. In all, properties protected under LAP initiatives have resulted in permanent protection of 711 miles of streams (one or both banks) and 45,344 acres of riparian buffers as shown in Table 3.2, organized by LAP programs in each basin.

Table 3.2 Summary of riparian buffers (areas within 300 feet either side of a watercourse) and length of streams within NYC-owned land and conservation easements (CEs) in the Cat/Del watershed.

Type of NYC Ownership	% of Watershed Acres	Stream Length (miles)	% total of all Stream Miles in Watershed	Riparian Buffer (acres)	% Total of all Riparian Buffers
NYC-owned (Non-LAP, pre-1997)	5.9%	105	2.7%	6,892	2.8%
LAP-acquired Fee Simple*	9.1%	378	9.9%	24,205	9.7%
LAP-acquired CEs	2.5%	103	2.7%	6,450	2.6%
WAC Farm CEs	2.7%	119	3.1%	7,385	3.0%
WAC Forest CEs	0.3%	6	0.1%	413	0.2%
All NYC-Owned	**20.5%**	**711**	**18.5%**	**45,345**	**18.3%**

Including land protected by other government agencies and land trusts, 405,195 acres or 39.7% of the CAT/DEL watershed are now permanently protected. Figure 3.3 is a map showing the percentage of land protected by sub-basin, including land protected by the City, NYS and others; Figure 3.4 shows the acres in executed contracts by year and program.[3] During the assessment period, 16,810 of these acres (210 contracts) were executed.

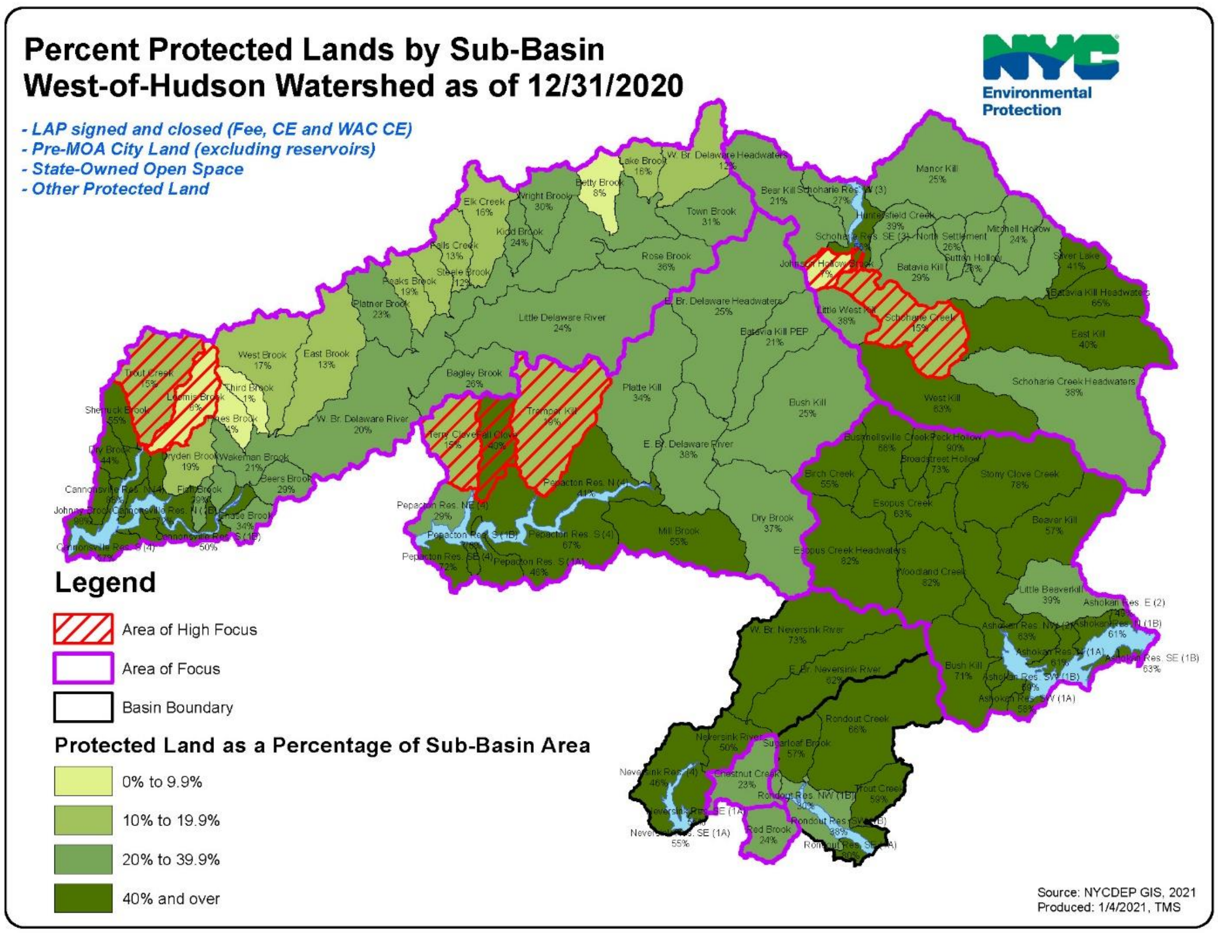


Figure 3.3 Protected status of land in the NYC watershed, by basin

[3] Infrequently, a purchase contract must be rescinded; these situations are almost always due to a seller's inability or unwillingness to complete their obligations. Problems that have resulted in rescissions include significant title defects, unresolvable encroachments, unsatisfied mortgages, and other such intractable issues. When a modestly-sized project (FBO or SAP) is rescinded, LAP's reported acres signed to contract do not change appreciably, but if a larger project is rescinded then prior reported figures for acres signed to contract may create a noticeable difference between current and prior reports. During this reporting period, 271 acres were rescinded.

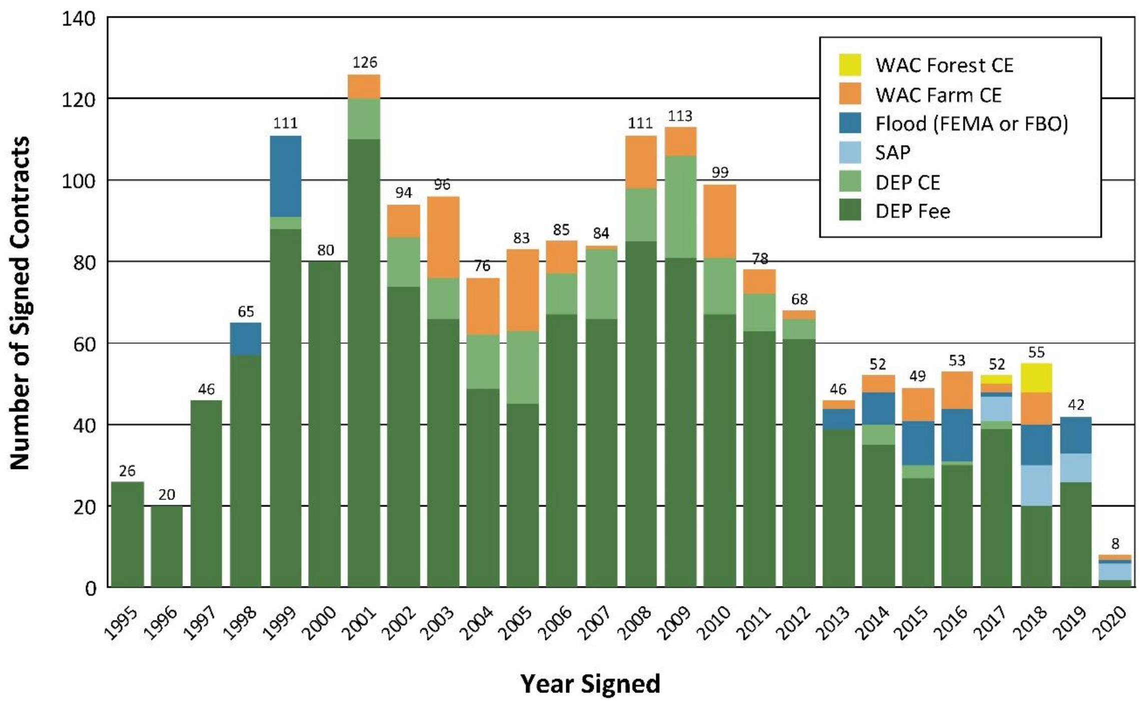


Figure 3.4 Annual executed contracts by program.

3.2.3 Transfer of CEs to NYS

In accordance with MOA Paragraph 82, the City is to grant a conservation easement to the State of New York on all properties acquired by the City in fee simple as part of the LAP. DEP bundles multiple acquisition projects into combined easements by geographic regions within each county to facilitate stewardship by NYSDEC of individual CEs. Since 1997, the City has conveyed 84 conservation easements to the state, which include 1,096 acquisition properties and comprise 73,535 acres. During the five-year assessment period, the City conveyed nine easements covering 66 acquisition properties and 5,285 acres. DEP works closely with NYSDEC and the NYS Attorney General's Office on this process.

3.2.4 Flood Buyout Programs

Federal Emergency Management Agency (FEMA) Program

In response to major storm events in January 1996 and August 2011, DEP was asked to support applications to FEMA by Delaware, Greene and Ulster counties for funding under two hazard mitigation grant programs (HMGP) to purchase flood-damaged properties. Under HMGP, FEMA pays 75% of eligible costs to acquire flood-damaged properties and demolish any improvements. Local communities and/or the landowner are typically responsible for a 25%

local match; in this case DEP agreed to accept those costs regardless of whether the municipality or DEP took title to the property. The grant applications were approved by NYS and FEMA, and subsequently DEP entered into memoranda of agreement with each county to provide assistance by (1) accepting ownership and perpetual property tax obligations of certain properties (all 28 projects, in the case of the 1996 FEMA program), (2) paying for the land portion of the purchase price, and (3) paying for soft costs. In addition, DEP managed the appraisal process and contract preparation and provided technical support to manage the contract and closing due diligence regardless of what entity accepted ownership. Once acquired by either a local municipality or DEP, properties were deed-restricted against further development per FEMA rules, and CEs will be conveyed to NYSDEC. As of the end of the second FEMA program (October 2017), DEP had acquired 50 Flood Buyout Program (FBO) properties and managed the acquisition of 14 more properties by watershed towns. In addition, 22 properties in Delaware County, originally in the FBO MOU Program, were acquired directly by the county with limited assistance by the City.

NYC-Funded Flood Buyout Program (NYCFFBO)

In 2014 DEP developed a new flood buyout program funded entirely by the City and driven by local municipalities. In 2016, DEP issued the NYCFFBO process document, which provided a detailed description of program procedures, and was accompanied by modifications to the Water Supply Permit. Program implementation by DEP and its partners began in the second half of 2016.

Similar to the FEMA program, this program allows for the acquisition of flood damaged or threatened properties with structures, after which the structures are removed and the properties restored to a natural condition, thus mitigating the impacts of future floods. Unlike the FEMA program, properties may also qualify for the NYCFFBO if they are threatened by stream erosion, or if the land they occupy is needed for a flood hazard mitigation project, such as floodplain restoration or a new bridge. The flood hazard mitigation goals of the NYCFFBO are managed locally, with properties to be acquired generally identified through the Local Flood Analysis process. To be considered for the program, a town or village board must pass a resolution specifically endorsing acquisition of the property through the NYCFFBO. Property-specific outreach is managed by outreach coordinators chosen by the municipalities, not the City, and CWC manages the demolition of improvements after closings. The NYCFFBO will pause accepting new projects immediately following a FEMA event, to allow FEMA programs to engage with local communities.

Since the commencement of program activities in 2016, 46 properties have had municipal resolutions passed, 35 appraisals have been conducted and 22 contracts have been executed. Of these 22 contracts, 17 have closed. Figure 3.55 depicts a property acquired under the NYCFFBO Program.

Figure 3.5 Views of a 4.8-acre property before and after demolition of the dwelling. This parcel is on the East Kill in the Town of Jewett and was acquired in 2017 under the NYCFFBO Program.

Overall, the FEMA and NYCFFBO programs are important tools that improve the ability of floodways and floodplains to play buffering roles during flood events. The NYCFFBO Program is particularly useful in that (1) It allows communities to carefully and proactively plan for flood hazard remediation projects outside the stressful periods that immediately follow flood emergencies, and (2) It remains operating to communities and landowners between storm events, when a FEMA program is not available. Table 3.3 shows details of acquisitions under the FEMA and the NYCFFBO Programs.

Table 3.3 Summary of executed contracts by flood program and ownership.

Program	DEP-Acquired		Acquired by Local Municipality		Totals	
	Contracts	Acres	Contracts	Acres	Contracts	Acres
FEMA	50	54.9	14	19.9	64	74.4
NYCFFBO	11	42.1	11	6.5	22	48.6
Total	**61**	**97.0**	**25**	**26.4**	**86**	**123.0**

3.2.5 Streamside Acquisition Program

In 2015, DEP entered a five-year contract with the Catskill Center for Conservation and Development, a watershed-based land trust, to implement a pilot Streamside Acquisition Program (SAP). DEP issued an evaluation of the pilot program in September 2017 and recommended the program continue. All SAP projects purchased to date were appraised, signed to contract and acquired during this reporting period, in all totaling 27 contracts (208 acres). Table 3.4 provides a summary of all executed SAP purchase contracts as of December 31, 2020.

Table 3.4 Summary of executed SAP projects (all fee simple).

Year	Contracts	Acres
2016	0	0
2017	6	40
2018	10	78
2019	7	74
2020	4	16
Totals	27	208

3.2.6 Farm and Forest Easement Programs

WAC Farm Easement Program

Between January 1, 2016, and December 31, 2020, WAC executed and closed on 20 contracts to purchase 3,518 acres of farm easements. Since program initiation, WAC has purchased 157 farm easements totaling 28,225 acres. Figure 3.6 offers a view of one farm protected during the assessment period.

Figure 3.6 A 254-acre farm protected by a farm CE acquired by WAC during 2019 in the Town of Andes.

WAC Pilot Forest Easement Program

In mid-2013 DEP's contract with WAC was enhanced to include this program, intended to secure CEs on forested land. Virtually all forest CEs purchased to date were appraised, signed to contract and acquired during this reporting period, totaling 2,980 acres (nine contracts) to date.

Table 3.5 summarizes WAC CE activities. As shown, 2020 saw a significant slowdown in program activities due to program challenges that included budget drawdowns and pandemic-related program pauses.

Table 3.5 Summary of executed contracts by WAC program.

	Farm CEs		Forest CEs		Totals	
Period	Contracts	Acres	Contracts	Acres	Contracts	Acres
1999-2015	137	24,707	0	0	137	24,707
2016	9	1,579	0	0	9	1,579
2017	2	271	2	323	4	594
2018	8	1,325	7	2,657	15	3,982
2019	0	0	0	0	0	0
2020	1	343	0	0	1	343
Total	**157**	**28,225**	**9**	**2,980**	**166**	**31,205**

3.2.7 Water Supply Permit

DEP continues to meet requirements of the 2010 WSP. The 2017 FAD requires the City to submit to the DEC an application for a permit to succeed the 2010 WSP by June 30, 2022.

3.2.8 Enhanced Land Trust Program

DEP and watershed stakeholders developed a program whereby certain large properties with dwellings may be pursued by land trusts for eventual acquisition of vacant land portions by DEP. At the start of this effort, five towns opted into the program, together including six eligible properties. The town-selected land trusts that have expressed interest were unable to make progress with any of those six landowners. The second five-year period for this program began in 2016, during which towns and land trusts had another opportunity to opt in but none changed their status. The third five-year period begins in 2021, although no additional towns are expected to opt in, nor are any of the six eligible properties expected to evolve into transactions.

The City has also supported the Land Trust Alliance as a lead sponsor of its New York State annual meetings, on the premise that strengthening educational opportunities for local land trusts will yield long-term benefits for acquisition and stewardship of natural resources in the watershed by land trusts. During the reporting period, DEP provided funding to support alliance programming and/or to pay for scholarships for staff of watershed-based land trusts to attend the annual meetings.

3.3 Land Management

DEP's land management activities include three major categories that focus on DEP-owned water supply lands and reservoirs:

- Fee lands and conservation easement management
- Recreational uses
- Agricultural uses

3.3.1 Fee Lands and Conservation Easement Management

DEP continues to acquire land in fee-simple (fee) and conservation easements (CEs). The purchase of watershed lands and CEs, including those purchased by Watershed Agricultural Council (WAC) with DEP funds, is a significant investment. To protect this investment, DEP established protocols for monitoring fee and CE lands and address problems and issues that arise.

Fee Lands Inspection and Monitoring

DEP continues to monitor its 180,755 acres of fee lands, which includes lands acquired before the 1997 Memorandum of Agreement (MOA) (buffer lands around the reservoirs, aqueducts and shaft sites both inside and outside the watershed) and lands acquired under the MOA. DEP also monitors 35,086 acres of reservoirs and 456 miles of shoreline. DEP's Fee-Land Monitoring Policy guides the inspections of watershed lands. The monitoring policy provides guidance for DEP staff to ensure a regular and consistent monitoring regime for the long-term protection of water supply lands and reservoirs.

DEP designates properties as high-priority or standard-priority to help optimize limited staff resources. High-priority properties receive the most use (recreation, land use permits) or are the most vulnerable to encroachment and trespass (many adjacent landowners), and are inspected annually. Standard-priority properties are rural properties without intense use or vulnerability and receive an inspection at least every five years. During the FAD assessment period, high-priority properties have consistently made up about 22% of the portfolio of lands. DEP conducts site visits after receiving complaints of property issues. In the past five years, DEP conducted 3,128 site visits.

In addition to the inspections, DEP performs boundary line maintenance on each water supply property every five years. The objective is ensure all survey monumentation (pins, x-cuts, blazing) and signage is adequate. Observed deficiencies require refreshing monumentation and replacing signs. DEP staff also look for signs of encroachments and/or trespass. During the FAD assessment period, DEP has performed 1,681 boundary line inspections totaling 5,629 miles. DEP painted (blazed) over 5,131 miles of boundary line and posted 3,097 miles with signage.

Encroachments

When DEP discovers encroachments on City-owned lands, often during routine property inspections and other land management or volunteer stewardship activities, DEP works diligently to remedy them, identifying and categorizing potential encroachments as minor, major, or criminal. BWS then coordinates the appropriate response with other entities, including the Bureau of Legal Affairs (BLA) and DEP Police. DEP has developed and implements a protocol to address encroachments, updating as needed during the FAD assessment period. Minor encroachments, such as mowing over the property boundary line, continue to be the most common type. A conversation with or correspondence to the encroaching landowner often resolves the issue. DEP conducts a follow-up site inspection as needed.

For a major encroachment, DEP determines the corrective actions needed based on the severity. DEP Police receive immediate referrals upon discovery of a criminal encroachment. In 2019 and 2020, BWS, BLA, and DEP Police developed a process and flow chart specifically for criminal timber trespass events. While timber trespass events are not common, DEP has had positive outcomes in working with local assistant district attorneys. DEP resolved several encroachments and, when appropriate, restored City land during the FAD assessment period. Examples include an instance of significant rutting and soil disturbance caused by all-terrain vehicles; a neighbor who cut trees, removed part of a City boundary wall, and discharged pool water onto City property; a municipality that was stockpiling construction material; and a contractor who bulldozed an area and removed several trees. In circumstances where there are no negative impacts to water quality or water supply operations, DEP may decide to issue a revocable land use permit (LUP) to cure an encroachment and formalize the use of City-owned lands.

Overall, DEP has not seen an increase in encroachments in recent years. However, DEP received a greater number of trespass calls for motorized uses (e.g., all-terrain vehicles) in 2020 during the COVID-19 pandemic.

Land Use Permits

DEP issues revocable LUPs to qualified entities seeking limited use of City-owned lands where the proposed use is compatible with DEP's land management priorities and no appropriate alternative exists. The purpose of conditions in LUPs is to ensure protection of water quality as well as City-owned property, assets, and infrastructure. Since 2016, DEP has issued an average of 30 LUPs per year to various entities (Table 3.6). Municipalities were by far the most common entities to receive new LUPs during the FAD assessment period. The most common purposes for these LUPs are water utility/use or to support community projects (i.e., recreation, capital projects). LUPs have a term no longer than five years.

Table 3.6 Land use permits issued, 2016-2020

Year	2020	2019	2018	2017	2016
Permits Issued	33	29	37	40	13

DEP also utilizes LUPs to facilitate City-funded projects and partnerships such as the East of Hudson municipal separate storm sewer system program that allowed construction and maintenance of stormwater infrastructure. Many communities obtain LUPs for the withdrawal of water, which requires a LUP to connect to the City's aqueducts. LUPs also provide access to not-for-profit groups for various fundraising events or schools and universities to conduct studies. Utility companies make up the largest number of active LUPs. Since 2016, DEP has seen an increase in requests related to fiber optic and broadband utilities.

Watershed Lands Information System

DEP manages its portfolio of fee and CE inspection duties within the WaLIS spatial database. The database contains journal notes, documents, maps, correspondence, photographs, and records of all inspections. Additionally, WaLIS tracks all LUPs and agricultural use agreements. WaLIS stores the research conducted on City lands to ensure future informed decision-making. It also provides long-term recordkeeping for those decisions. With WaLIS workflow and tracking tools, DEP is able to schedule inspections and set reminders for those that become overdue. WaLIS also provides a way of easily running reports and metrics to track progress. DEP staff involved in fee and CE monitoring and management, at various locations, have access to this database. WaLIS provides mapping tools for users with little or no geographic information system experience and provides the ability to generate professional looking maps. DEP made modifications to WaLIS during the FAD assessment period, such as enhancing the ability to add point locations for all LUPs.

Water Supply Land Signage

All properties owned for water supply protection have signs indicating the allowable recreational uses. Lands not open for recreation are marked with "Posted" signs and those lands around important infrastructure such as an aqueduct are posted with "No Trespassing" signs. Over the past five years, DEP has undertaken an effort to improve its signage on water supply lands. Additionally, DEP has refined its messaging to focus on various issues that have arisen. For example, if DEP needs temporarily to close a recreation unit, DEP may install "No Public Access" signs. To ensure users are getting their boats steam cleaned for the recreational boating program, DEP may install "Stop" signs at all recreational boat launch areas (Figure 3.7). BWS has worked with the DEP Police and the angling community to improve signage on reservoirs to better delineate restricted areas.

Figure 3.7 Recreational sign

Conservation Easement Management

DEP has 176 CE properties totaling 26,321 acres. The number of new CEs acquired over the FAD assessment period has decreased significantly with only 13 new properties entering the portfolio. DEP inspects every CE twice per year with one on-the-ground and one aerial inspection. In 2020, DEP Police uploaded digital mapping data on their helicopter's navigation system, which ensures accurate and efficient flights for monitoring each CE property. Taking pictures of possible violations along with post-flight field inspections are part of the monitoring process.

Most DEP CEs allow for activities such as farming and forestry "as of right," provided they do not exceed certain thresholds. Landowners may apply to DEP for approval when they wish to perform activities beyond the thresholds. Since 2016, timber harvest is the most frequent new activity requested, averaging six per year. Once DEP approves an activity on the CE, that approval is typically good for three to five years, depending on the activity's intensity. Since 2016, DEP renewed livestock or farming approvals on 34 CE properties.

Between 2016 and 2020, 27 CE properties were sold to new owners (i.e., second or third-generation CE landowners), which is about 15% of the portfolio. Nationwide, land trusts report that most violations of the CE deed occur when properties transfer to new owners who may not share the same conservation ethic as the original owner. When DEP learns of a sale, DEP reaches out to the new owner to provide them with a copy of the CE deed and baseline documentation maps. DEP typically requests a face-to-face meeting to discuss the CE terms; some new landowners have questions about their deed and need help with interpretation. All recent new landowners were aware they had a CE on their property.

Violations are typically discovered during routine CE inspections and resolved by landowners once DEP makes them aware of the CE restrictions. These violations are typically due to landowners not understanding their CE deed. The most common violation is landowners performing forestry operations without DEP approval. To address these violations, landowners complete a DEP Forest Activity Plan application for DEP forester review. During the review, DEP foresters focus on the placement of skid and haul roads, and any planned stream or wetland crossings. During the harvest, DEP staff will monitor the work to ensure there are no negative water quality impacts. In 2019, a landowner sued DEP and the City for denying a request to build a structure, which required DEP approval. That litigation is still pending. DEP believes strong landowner relationships are the key to reducing CE violations and DEP continues to strengthen landowner outreach.

DEP collaborates with WAC on their farm and forest easement program. WAC has purchased 157 farm easements totaling 28,074 acres and nine forest easements totaling 2,982 acres. The WAC forest easement program closed on its first easement on September 4, 2018. WAC has experienced many landowners who have sold or subdivided their properties, but to date has not seen an increase in second-generation landowner violations. As with DEP, WAC has a vigorous monitoring schedule and spends time on landowner outreach. Activity approvals and possible violations are reviewed by the WAC easement committee which consists of a DEP representative, no more than three easement landowners, and at least two additional WAC appointees with a background in farming or rural land use issues. DEP staff work with WAC to resolve deed interpretation questions arising from landowner activities. In 2020, DEP began work on the WAC five-year assessment report that will assess stewardship efficiencies, successes, and challenges.

3.3.2 Recreational Uses

DEP manages over 142,538 acres of water supply land open to the public for low-impact recreation. Another 35,086 acres of reservoirs and controlled lakes are also accessible for boating and shoreline fishing. Over time, DEP has significantly increased the amount of land available to the public for recreational uses compatible with water quality protection. This provides opportunities for watershed residents to benefit from this resource and also plays an important role in strengthening local economies and eco-tourism based businesses. Recreational lands are a tremendous resource for watershed constituents. But they also serve as a critical component of DEP's watershed protection efforts, providing a fresh supply of unfiltered water to more than 9 million water customers.

Recreational access also expands the stewardship constituency for the water supply system and the lands that protect water quality. Regular recreational interactions with the natural environment can engender a sense of respect and ownership by the user. This outcome is one that can complement DEP's protection goals and allow for a more engaged recreational user. Over the past five years, DEP continues to open land for recreational uses with a steady increase of new lands added (Table 3.7). As the type and size of lands DEP has acquired changes (i.e., more focus on smaller, streamside properties), new opportunities arise. For example, with the Flood Buyout Program and Streamside Acquisition Program, DEP can expand streamside access and provide greater fishing opportunities on Catskill streams. Another example is DEP opening smaller properties as public access areas with bow hunting, rather than rifle or shotgun, because discharge distances are of concern.

Table 3.7 Lands added for recreation in acres, 2016-2020.

Year	Reservoir Fishing	Hunt Only	Hunt/Hike or Fish Only	Hike Only	Public Access Area	Day Use Area	Total Area
2016	35,831	16,011	8,685	2,357	68,980	110	131,974
2017	35,831	15,737	9,714	2,385	70,429	134	134,230
2018	35,086	16,001	9,728	2,361	73,491	135	136,802
2019	35,086	16,001	11,234	2,361	76,278	135	141,095
2020	35,086	16,001	11,415	2,208	77,693	135	142,538

Over the past five years, DEP has seen a noticeable increase in visitors to the region, resulting in increased use of DEP and surrounding lands and waters for recreation. The recently completed Catskill Recreation Plan, which was a collaborative effort between various stakeholders (including DEP), also highlighted this trend. Identifying smart-growth approaches for recreation in the Catskill region is a plan goal. The plan attempts to identify new recreational opportunities and strategies that meet the region's growing need for recreation and are sensitive to both the public's interests and the natural environment. In 2020, there was a substantial increase in use of recreational lands and waters due to the COVID-19 pandemic and the public's desire to seek out safe and healthy forms of recreation and entertainment. During this period, all trails on DEP land saw significantly more users than in previous years. This mirrored the trend observed by others on their recreational lands, such as the state reporting record growth in hunting and fishing licenses. While some of the increase will likely level off in the future, it's clear that past and emerging trends are likely to continue the importance of maintaining a robust and active recreation program within DEP.

Trails

DEP currently hosts 16 hiking trails on City lands (Table 3.8). The interest in establishing designated hiking trails on water supply lands has been growing during the FAD assessment period and has been an activity that DEP is working to accommodate. In 2017, DEP developed a trail policy that helps guide the growth of these trails and assists permit applicants with securing the proper permissions to build and manage a trail. The policy also provides guidance on locating, constructing, and maintaining trails. Constructed trails avoid negative natural resource impacts by reducing or eliminating erosion, sedimentation, or excessive vegetation removal.

Table 3.8 Hiking trails on City land.

Trail	Trail Partner	Town	County	Miles
Andes Rail Trail	Catskill Mountain Club	Andes	Delaware	1.88
Angle Fly Preserve	Town of Somers	Somers	Westchester	4.08
Ashokan Quarry Trail	Catskill Mountain Club	West Shokan	Ulster	3
Ashokan Rail Trail	Ulster County	Multiple	Ulster	11.5
Bramely Mountain	Catskill Mountain Club	Delhi	Delaware	3.2
Diverting Reservoir Trail	Putnam County Land Trust	Southeast	Putnam	1
Fletcher Hollow/Loomis Brook	Finger Lakes TC	Tompkins	Delaware	24.13
Gilboa-Conesville School Trail	Gilboa-Conesville School	Gilboa	Greene	0.05
Hawk Rock	Town of Kent	Kent	Putnam	1.6
Lake Gleneida Trail	Putnam County DHF	Carmel	Putnam	1.06

Trail	Trail Partner	Town	County	Miles
Long Path Section	NYNJ Trail Conference	Multiple	Greene	3
Palmer Hill	Catskill Mountain Club	Andes	Delaware	3.1
Huntersfield Creek Trail	Town of Prattsville	Prattsville	Greene	1
Shavertown Hiking Trail	Catskill Mountain Club	Andes	Delaware	2.27
Teatown Connector Trail	Teatown Reservation	Yorktown	Westchester	3.83
Windham Recreation Trail	Town of Windham	Windham	Greene	1.5

Use of these trails also provides an opportunity to educate visitors on DEP watershed protection efforts. Through signage, guided hikes, and other forms of outreach, DEP is able to work with its partners to educate the growing number of users. The Catskill Mountain Club (CMC) has installed sign-in registers at three trails on City land and has been tracking use. Between 2017 and 2019 (2020 figures not available), there were 15,331 visitors who signed the trail registers.

Figure 3.8 Red Hill parking area under construction.

These trail projects highlight the great relationship DEP has fostered with partners on recreation. In 2019, the CMC installed a new 3-mile-long trail in the Town of West Shokan called the Acorn Hill Trail. The trail offers a stunning view of the Catskill Mountains and includes a kiosk and parking area. The short 1-mile-long Huntersfield Creek Trail opened in 2019, leading visitors to an amazing view of a series of waterfalls. In 2020, DEP worked with the CMC to extend a portion of their most popular trail, the Shavertown Trail. After DEP completed a forest management project, CMC completed the new extension of the trail. The new spur leads to a vista overlooking the Pepacton Reservoir. Over the past five years, DEP has worked to strengthen its partnership with New York State Department of Environmental Conservation (NYSDEC). To highlight this partnership, in 2018 DEP issued a LUP to NYSDEC to construct the Willow Trailhead parking area, which provided better access to Mount Tobias that is on state forest preserve land. In 2019, DEP issued a LUP to NYSDEC to construct a trailhead parking area to improve access to the extremely popular Red Hill Fire Tower. NYSDEC maintained a small parking area that was very hard to access and was difficult to maintain. Construction on the trailhead began in 2020 (Figure

3.8). Also in 2019, DEP issued a LUP to NYSDEC to install a kiosk and sign at a small under-utilized parking area to a trail leading to Ticetonyk Mountain.

Ashokan Rail Trail

October 2019 marked the partial opening of the Ashokan Rail Trail (ART) along the northern shore of the Ashokan Reservoir. The remainder of the ART opened in March 2020, completing an 11.5-mile-long trail. This trail highlighted a partnership between DEP and Ulster County in which DEP contributed $4.8 million for trail and trailhead construction. There are three trailheads along the trail that include kiosks, interpretive signage, and portable bathrooms. The trail offers spectacular reservoir vistas and scenery of the Catskill Mountains. The trail also provides for universal access with designated parking areas and a smooth hard-packed surface. The trail also allows leashed-dogs. Installed in 2020, collection stations help manage dog waste. DEP also installed trail counters along the trail to track walkers/runners and bicyclists.

During 2020, when the COVID-19 pandemic was resulting in greater numbers of people seeking outdoor recreation opportunities, usage of the ART routinely exceeded more than 1,000 visitors per day. The ART crossed the 150,000-visitor mark in 2020 during the height of the COVID-19 pandemic restrictions, less than a year after opening. By the end of 2020, total trail usage exceeded 235,994 users (Table 3.9).

Table 3.9 Ashokan Rail Trail visitors in 2020.

Month	Boiceville Trailhead	Ashokan Station	Woodstock Dike Trailhead	Total
January	1,355	1,324	4,809	7,488
February	2,730	864	6,627	10,221
March	6,125	3,068	13,948	23,141
April	6,234	3,451	12,131	21,816
May	8,506	5,135	11,703	25,344
June	7,742	4,951	9,734	22,427
July	8,654	5,629	10,483	24,766
August	9,218	5,922	12,505	27,645
September	7,659	5,024	10,347	23,030
October	7,951	4,673	10,588	23,212
November	5,707	3,032	7,646	16,385
December	3,587	1,493	5,439	10,519
Total	**75,468**	**44,566**	**115,960**	**235,994**

This unexpected intensity during peak COVID-19 months led to reports of public safety and health concerns (lack of socially distancing and improper disposal of trash and waste along the trail). Although DEP and Ulster County were able to mitigate these concerns, they nevertheless highlight the balance between watershed recreation and the protection of drinking water for public health.

Boating on the Reservoirs

The recreational boating program on Cannonsville, Pepacton, Neversink, and Schoharie reservoirs is now in the eighth year and continues to be very popular (Table 3.10). The program allows boaters to use vessels such as kayaks and canoes, provided they have been steam cleaned by a DEP-certified vendor and boaters obtain a day or seasonal boat tag. In 2019, DEP extended the recreational boating season by approximately 35 days (beginning May 1 and ending on October 31). This gave seasonal boat tag holders more days to participate in the program.

Table 3.10 Boat tags issued by year.

Year	2015	2016	2017	2018	2019	2020
Total Boat Tags	1,463	1,668	1,646	1,660	1,331	1,354

Since 2016, there has been a steady increase in recreational boating activity, both for vendor-issued boat tags (for privately owned vessels) and vendor rentals. While a few vendors have discontinued steam cleaning or renting boats, the remaining vendors are able to adequately meet demand. During the past five years, there have not been any water quality issues with the recreational boating program. To address future threats, DEP in 2016 discontinued the four-year Cannonsville Trolling Motor Pilot Program, which experienced limited use and created steam-cleaning challenges and enforcement issues.

Currently, all DEP reservoirs are open for fishing from shore or boat. DEP requires boat owners obtain a free DEP boat tag, which requires steam cleaning, before placing a boat on any reservoir. All boats must be steam cleaned and remain on the reservoir in their assigned location. As of 2020, there were over 13,000 boats on City reservoirs moored at 264 boat storage areas managed by DEP. Boat owners must renew their registration every four years.

Throughout the watershed, but more prominently in EOH reservoirs, demand for boating access has reached all-time highs. Many reservoirs are at or near capacity. In the past five years, DEP has visited several EOH boat storage areas to assess expanding certain areas or developing new ones.

DEP Recreation Rules

In 2019, DEP revised its recreation rules, which govern access and activities on water supply lands and reservoirs that are open for recreation. The new rules, which went into effect on June 30, 2019, included many updates that will improve recreational access. Most rule changes provided expanded recreational opportunities for the public while allowing DEP to manage increased use.

Outreach to Recreation Users

DEP continues to increase its outreach efforts to improve communication with DEP's recreational users. By hosting special events, DEP can engage recreation users individually, they get to interact with DEP staff, and DEP learns more about their interests. DEP is encouraged by the success of these events, such as family fishing days, which have attracted hundreds of eager participants.

Since 2016, DEP partnered with watershed community groups to remove litter and recyclables from public recreation areas at nine DEP reservoirs in the Catskills and Hudson Valley. DEP Reservoir Cleanup Day joins dozens of similar events happening across the state as part of the American Littoral Society's annual New York State Beach Cleanup. In many cases, the debris had blown onto the reservoir property from nearby roadsides, or washed up along the shores during storms. Anglers and boaters left some debris at public access areas.

From 2016 to 2019 (reservoir clean ups were not conducted in 2020 due to COVID-19 restrictions), DEP engaged 1,441 volunteers to collect 1,172 bags of debris totaling over 16,517 pounds. This included 16,265 bottles and cans and 4,588 cigarettes butts.

In 2016, DEP released an interactive mapping tool that helps outdoor enthusiasts find more than 500 locations open for recreation on water supply lands and reservoirs. The RecMapper utility allows users to zoom in on any part of the watershed to easily find recreation areas. Users can print detailed property maps; options include sorting by county, parcel size, and recreational activities. Aerial imagery is available for users to see conditions on the ground before they head out. The mapper also includes links to angler maps, hiking trails, boat launch sites, restrictions and closures, and more.

During the FAD assessment period, DEP became much more active in NYSDEC fish and wildlife regional boards. This involves quarterly meetings with NYSDEC staff, county landowners and legislative appointees, and various other stakeholders. By attending these meetings for NYSDEC regions 3 and 4, DEP can provide updates to attendees, learn what other recreation efforts are underway, and share ideas and plans for further recreational initiatives.

Watershed Stewards

In 2016, DEP launched a pilot Watershed Steward Program at Pepacton and Kensico reservoirs. The program is now a permanent part of the recreation program thanks to the success and dedication of the watershed stewards. These are volunteers who not only enjoy recreating on City lands and reservoirs, but are also committed to keeping them clean and healthy. Stewards receive training on several topics, including watershed protection and invasive species. They submit regular reports on problems they encounter, conduct cleanups, and assist with projects such as planting trees on City property. The program has expanded from the original two reservoirs to all East of Hudson reservoirs and a few streams.

Hunting and Deer Management

Healthy forests are one of the cornerstones of DEP's water quality protection efforts. Through sustainable forest management, invasive species controls, and forest regeneration efforts, DEP has been working to protect and enhance this vital resource. Of significant importance is the need to manage negative deer impacts on forest regeneration. DEP regularly meets and communicates with NYSDEC to strategize about deer management tools and hunting on City lands.

The Deer Management Assistance Permit Program (DMAP) reached its tenth year in 2020. Since 2016, 1,913 permits have been issued and 347 deer have been harvested, an 18% success rate (Table 3.11). By providing hunters additional opportunities to harvest deer on water supply lands (mostly adjacent to reservoirs), the DMAP Program has helped DEP reduce the negative impacts on forest regeneration from deer over-browsing.

Table 3.11 Deer Management Assistance Permit Program harvest rate, 2016-2020.

Year	Total Tags Distributed	Total Harvest	Success Rate
2016	310	65	21%
2017	296	56	19%
2018	450	87	19%
2019	435	72	17%
2020	422	67	16%

3.3.3 Agricultural Uses

As with recreational uses of water supply lands, DEP also understands the importance of allowing agricultural uses of its lands and the importance of those lands to many small-scale farmers. Since 2016, new agricultural uses have largely consisted of hay or pasture on areas less than 30 acres. With smaller properties acquired by DEP during the past few years, DEP has seen a corresponding decrease in project size. The number of projects has grown substantially throughout the FAD assessment period to 140 active project; 68% of the farmers leasing land participate in the WAC Whole Farm Plan Program. Table 3.12 shows new projects added each year.

Table 3.12 New agricultural projects by year.

Year	New projects	Acres of new projects
2016	7	157
2017	8	145
2018	12	238
2019	11	191
2020	14	259

As farming practices change and adapt to market trends, making lands available that were historically used for agriculture is important for the farming community. With farming in the

Catskills generally declining, many farmers may not have enough of their own land or may not be able to rent private farmland, so the importance of watershed lands has grown.

All projects require that a vegetated buffer be established and maintained; prior to the City's acquisition, most of the private lands did not have any buffers. In 2019, DEP increased the required buffer from streams and wetlands from 25 feet to 35 feet to provide additional protections. During the FAD assessment period, DEP has made inspecting agricultural use projects a priority (Table 3.13). DEP inspects projects for consistency with the terms of the license agreement between the farmer and DEP. Inspections are prioritized by a project's intensity. For example, properties used for livestock are a higher priority than properties used for harvesting hay.

Table 3.13 Agricultural project inspections.

	2020	2019	2018	2017	2016
Inspections	36	47	40	4	0

3.4 Watershed Agricultural Program

The Watershed Agricultural Program (WAP) reduces the risk of agricultural pollution through the development of Whole Farm Plans (WFPs) and the implementation of best management practices (BMPs), along with the establishment of riparian buffers through the federal Conservation Reserve Enhancement Program (CREP). The WAP is funded by DEP and administered by the Watershed Agricultural Council (WAC) in partnership with Delaware County Soil and Water Conservation District (DCSWCD) and Cornell Cooperative Extension (CCE), along with the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA).

Prior to the 2017 FAD, the WAP identified a significant backlog of BMPs in existing WFPs that exceeded the program's capacity to implement in a timely manner based on historical BMP budgets. To address this, WAC proposed a new WAP metric that prioritized the implementation of backlog BMPs through increased funding levels; previous WAP metrics focused on farmer participation and development of WFPs. The 2017 FAD codified this new metric by requiring the WAP to reduce its BMP backlog while managing its current portfolio of WFPs and minimizing the potential for creating a new backlog of BMPs.

Specifically, the FAD requires the WAP to reduce the backlog of BMPs already identified in WOH WFPs by 50% prior to January 1, 2017. This metric applies to planned but not yet implemented BMPs in WFP pollutant categories I-VI, as well as previously implemented BMPs needing repair or replacement, regardless of pollutant category. To establish a baseline for this FAD metric, DEP and WAC developed an official BMP backlog list dated January 1, 2017, that includes 1,754 total BMPs on WOH farms estimated to cost $35.8 million. This list is comprised of 1,410 BMPs in WFP pollutant categories I-VI (estimated to cost $28.1 million) and 344 repair/replacement BMPs (estimated to cost $7.7 million).

To achieve 50% backlog reductions, the WAP must implement 705 BMPs in pollutant categories I-VI and 172 repair/replacement BMPs by December 31, 2024. The WAP must also design and schedule these BMPs for implementation by December 31, 2022. During this FAD assessment period, DEP and WAC developed a quarterly BMP reporting system to track the planning and implementation of both backlog BMPs and non-backlog BMPs identified after January 1, 2017. DEP entered into a six-year contract with WAC that commenced April 1, 2019, and includes $25 million for accelerated BMP implementation on WOH farms. Pursuant to the FAD, this new contract provides sufficient funding levels to implement at least 60% of backlog BMPs in pollutant categories I-VI and 70% of backlog BMPs needing repair/replacement.

The WAP's accomplishments for the current assessment period are summarized below according to the main program requirements as outlined in the 2017 FAD.

Manage the current portfolio of active WFPs, including the revision of existing plans as needed and the development of new plans on eligible priority farms on a case-by-case basis.

Given that prior FAD metrics focused on farmer participation and WFP development, the WAP has traditionally managed a large and diverse portfolio of WFPs based on differing eligibility standards for large and small farm participants. The 2017 FAD adopted the term "active farm" as a reporting metric intended to reflect all types and sizes of active farms with WFPs. The WAP manages its portfolio of active farms through revisions of existing WFPs and development of new WFPs on eligible farms on a case-by-case basis.

At the end of 2020, the WAP reported 326 total active WFPs, including 251 WOH farms and 67 EOH farms. Of the 259 WOH WFPs, 227 are considered active and eligible. The remaining 32 are classified as active and ineligible based on these farms no longer having at least five animal units (AUs); they remain classified as active farms nonetheless. By comparison, the WAP reported 274 active and eligible WOH WFPs and nine active/ineligible WFPs at the beginning of this assessment period (2016).

During this assessment period, the WAP completed 427 WFP revisions on 368 WOH farms and 59 EOH farms, while developing six new WFPs on WOH farms and three on EOH farms. The significant number of WOH WFP revisions combined with new WFPs resulted in 1,479 newly identified BMPs in addition to the existing backlog. WFP revisions address changes in farm operations, updates to precision feed management or nutrient management plans, deletions of BMPs or additions of low cost/no cost BMPs such as cover crops and liming, as well as the conversion of identified resource concerns into actual planned BMPs.

In addition to managing its current portfolio, the WAP reports that 117 prospective applicants are interested in developing WFPs. The WAP has evaluated water quality concerns on

104 of these farms, of which 37 farms have greater than 10 AUs, 40 farms have less than five AUs , and the remaining 27 farms have between 5-10 animal units (AUs). In March 2020, the WAP adopted new eligibility standards for prospective applicants, requiring a minimum of five AUs and $10,000 in annual farm revenue (the amount required to be eligible for an agricultural tax exemption in New York State). However, the WAP has yet to adopt and apply these standards to its current portfolio of "active farm" participants. As such, the WAP still reports 32 active WFPs that do not meet AU eligibility requirements and 30 active WFPs that do not meet annual revenue eligibility requirements; these ineligible farms account for about 120 BMPs on the official backlog list. Adopting uniform eligibility standards for both new applicants and current participants would allow the WAP to better manage its portfolio of WFPs by focusing on farms that meet eligibility criteria and ostensibly pose more significant pollution risks.

Continue to implement priority BMPs on active participating farms with WFPs, with the dual goals of reducing the existing backlog of BMPs by 50% and limiting the potential backlog for newly identified BMPs.

Through December 31, 2020, the WAP has implemented 8,586 total BMPs on all watershed farms at a cost exceeding $72 million; this included 7,761 BMPs on WOH farms ($65.4 million) and 825 BMPs on EOH farms ($7.3 million). During the period 2016-2020, the WAP implemented 184 BMPs on EOH farms totaling $1.6 million. For WOH farms, the WAP implemented 1,146 BMPs totaling about $11 million, including 514 backlog BMPs totaling about $7 million and 632 non-backlog BMPs totaling approximately $4 million.

As summarized in Table 3.14, of the 514 backlog BMPs, the WAP implemented 283 BMPs in pollutant categories I-VI and 231 repair/replacement BMPs, which reduced the backlog for each category by 20% and 67% respectively. As such, the WAP has exceeded the 50% FAD metric for repair/replacement BMPs, while still needing to implement at least 422 backlog BMPs before December 31, 2024 to achieve a 50% reduction in pollutant categories I-IV. It should be noted that 66 backlog BMPs were actually implemented prior to January 1, 2017, and shouldn't have been included in the official BMP backlog list. However, the WAP counts these BMPs towards achieving the FAD metric since they were implemented and not simply deleted.

Separate from the numbers reported above, the WAP deleted 382 BMPs from the official backlog list (347 in pollutant categories I-VI and 35 repair/replacement) due to farms becoming inactive, changes in farm operations, or WAP data reporting discrepancies. Although not counted towards the FAD metric, which measures implementation, these deleted BMPs contribute to an additional cumulative backlog reduction of 25%. It is worth noting that the WAP deleted more backlog BMPs in pollutant categories I-VI than it actually implemented during this reporting period. The official BMP backlog list as of December 31, 2020, includes 780 remaining BMPs in pollutant categories I-VI and 78 remaining BMPs needing repair/replacement.

The WAP reports that 302 backlog BMPs (277 in pollutant categories I-VI and 25 repair/replacement) and 349 non-backlog BMPs are scheduled for design through December 31, 2021, as identified in WAP's 2021 annual BMP workload. As previously stated, the WAP needs to implement at least 422 backlog BMPs in pollutant categories I-VI to achieve the 50% FAD reduction metric, which averages 106 BMPs per year during 2021-2024. In addition, the WAP has newly identified 1,479 non-backlog BMPs since January 1, 2017, as a result of 365 WFP revisions and six new WFPs on WOH farms. The WAP estimates that approximately 20% of these newly identified BMPs are components associated with a backlog BMP. It should be noted that the creation of a new BMP backlog is a concern for DEP and will be addressed in the WAP Metrics Assessment and Recommendations Report due June 30, 2023, per the FAD.

Table 3.14 Status of the BMP backlog in relation to the FAD metric as of December 31, 2020.

	Official Backlog List	FAD Metric (50% reduction)	Implemented (% reduction)	Deleted (% reduction)
Pollutant Category I-VI	1,410	705	267 (19%)	325 (23%)
Repair or Replacement	344	172	230 (67%)	35 (10%)
Total BMPs (% reduction)	1,754	877	497 (28%)	360 (21%)

Conduct annual status reviews on at least 90% of all active WFPs every calendar year, with a goal of 100%.

Although the number of annual status reviews required each year varies based on the number of active WFPs, on average the WAP completed 95% of all required ASRs on active WOH and EOH farms during this FAD assessment period. DEP continues to support the use of the annual reviews because they ensure the WAP engages all participants on a regular basis, confirms whether BMPs are properly functioning, and allows WAP staff to identify potential new water quality concerns while gathering feedback from participants to further assess the program's success.

Continue to develop and update nutrient management plans (NMPs) on active farms with a goal of maintaining current NMPs on 90% of all active participating farms that require one; continue to offer the Nutrient Management Credit Program to all eligible farms.

For the reporting period, on average, the WAP maintained current NMPs on 95% of active farms requiring one. To meet this metric, the WAP developed or updated an average of 67 NMPs every year on all active WOH and EOH farms. At the close of the reporting period, 222 active farms had current NMPs and 142 active farms were participating in the Nutrient Management Credit Program. This represents an 18% increase from 117 farms receiving credits at the close of 2016. To be eligible for the Nutrient Management Credit Program, participating farms must have at least 25 AUs and must manage at least 50 tons of manure. A total of 146 farms are currently eligible.

Continue to implement the Precision Feed Management (PFM) Program on up to 60 eligible farms.

At the close of the reporting period, the PFM Program had 44 active participants — 42 dairy farms and two beef farms — located in the following reservoir basins: Cannonsville (31), Pepacton (eight), and Schoharie (five). During this period, the PFM Program monitored an average of 2,607 lactating cows annually to determine if herds were staying within phosphorus (P) rationing guidelines. Approximately 44% of all cows under management remained within guidelines; herds that were persistently within P rationing guidelines were not over feeding P and therefore not targeted for P reductions.

Approximately 13% of the cows that were not within P rationing guidelines at the beginning of the reporting period (2016) were targeted for reduction and experienced an average net decrease in manure P excretion of 2,394 kg/year. Approximately 43% of the cows being monitored remained above P rationing guidelines, resulting in an annual average net increase in manure P excretion of 933 kg/year. Feeding cattle is dynamic and keeping herds within annual rationing guidelines is expected to fluctuate. While 13% of cows that were targeted for P reduction showed significant reductions, increases in net manure P excretions in herds that exceeded P rationing guidelines persisted due to a number of variables, including changes to milk markets, milk production rates, and weather conditions affecting crop production (farmers purchased more off-farm forage and increased grain feeding rates).

Overall, continued monitoring across all herds helped limit net P increases in herds that would otherwise likely exceed P rationing guidelines. However, it should be noted that the continued attrition of dairy farms in the WOH watershed has resulted in the PFM program not meeting enrollment goals, so the program is currently developing metrics for beef farms to fill the remaining slots and achieve the FAD goal of 60 participants.

Continue to develop new CREP contracts and re-enroll expiring contracts as needed.

During the period 2016-2020, the WAP enrolled 14 new contracts (85.3 acres of riparian buffers) in CREP, while re-enrolling 69 expiring contracts (791.9 acres). A total of 50 expiring contracts (450.84 acres) were not re-enrolled by the landowners. As of the close of this FAD assessment period, a total of 153 different landowners had enrolled 1,687.4 acres of riparian buffers in 172 active CREP contracts.

During 2020, the USDA conducted a broad review of CREP contracts and determined they had overpaid rental payments on 172 CREP contracts (1,687.4 acres) by approximately $9.60/acre/year. The FSA notified affected landowners in September 2020 and offered the options to accept a reduction in payments going forward, appeal the decision to FSA, or terminate their CREP contracts without penalty. As of the close of this FAD assessment period, 84 landowners holding 111 contracts (1,155.91 acres) accepted the reduction in payment; 12

landowners holding 15 contacts (165.1 acres) appealed the decision; and 37 landowners holding 45 contracts (352.64 acres) terminated their CREP contracts.

Although the WAP expects that CREP BMPs associated with terminated contracts will remain in place as components of WFPs, it is difficult to determine the impact of USDA's determination on new CREP enrollment or re-enrollment going forward. The WAP currently pays for 100% of BMP repair or replacement costs for all CREP re-enrollments. The CREP has facilitated the establishment of riparian buffers for over 20 years and these buffers are a critical and effective water quality practice for farmers to steward their streamside lands.

Continue to implement a Farmer Education Program.

The WAP's Farmer Education Program is led by CCE of Delaware County with assistance from WAC and other partners. During this assessment period, the WAP conducted 137 events attended by 3,052 farmers and 1,059 farm advisors. Approximately 62% of farmers attending these events were from the watershed. Events were comprised of conferences, workshops, and hands-on farm demonstrations and tours, and they focused on all aspects of farm production and environmental management. Popular events included the annual Catskill Regional Agricultural Conference, pesticide application trainings, and several farm tours and workshops covering topics such as livestock production and pasture management. Events are held in a variety of locations within the watershed and are open to all farmers regardless of their participation in the WAP or their adoption of WFPs.

Continue to implement an Economic Viability Program.

During the reporting period, the WAC Economic Viability Program reached an average of approximately 50,000 people annually through its Pure Catskills print guide, while continuously engaging WAP participants and members of the public through e-newsletters, the Pure Catskills website, and special events. WAC sponsored 102 events promoting the marketing and sales of agricultural and wood products from the watershed region, including the Taste of the Catskills event and the Cauliflower Festival. During this period, WAC also initiated a City-funded business planning program and micro-grants program to enhance the economic viability of both farm and forest businesses in the WOH watershed. The micro-grants program awarded 47 grants totaling $168,403 to support business-related activities such as marketing and staff training. The business planning program resulted in the completion of five business plans for the reporting period, which fell short of expectations based on DEP contract deliverables of at least five per year.

In summary, as the WAP continues to transition from past FAD metrics to standards and practices focused on managing BMP implementation on a large portfolio of active farms, it will be incumbent upon the WAP to continue updating certain business processes to support such efforts. These include the adoption of uniform eligibility standards that are applied to both prospective applicants and current participants, while only planning BMPs based on the capacity to implement in a timely manner. The ongoing practice of identifying and planning for every possible water quality concern appears to have created a new BMP backlog in less than five years, which is contrary to the dual goals of the 2017 FAD metric.

Given the dynamics of farming and the potential for ongoing WFP revisions, coupled with ongoing activities such as nutrient management planning, annual status reviews, farmer education, CREP, and Precision Feed Management, the WAP will need to consider a more holistic and comprehensive approach to managing BMP planning and implementation. Because BMP project life cycles are generally two to four years from the planning to implementation stage, the WAP will always have a backlog of BMPs in need of implementation. However, by actively managing active WFPs and planning BMPs based on the capacity for timely implementation, the WAP will be better positioned to utilize current levels of funding to better address priority water quality concerns on priority active farms.

3.5 Watershed Forestry Program

Since 1997, the Watershed Agricultural Council (WAC) Forestry Program has been a partnership between DEP, WAC, and the U.S. Forest Service (USFS) that promotes and supports well-managed working forests as a beneficial land use for watershed protection and economic viability. The WAC Forestry Program combines core DEP contract funds with matching federal grants from the USFS to provide cost sharing, technical assistance, professional training, and educational programs to watershed landowners, loggers, consulting foresters, wood-using businesses, and school-based audiences in both the watershed and New York City.

The 2017 FAD requires the City to contract with WAC to implement the Watershed Forestry Program in accordance with specific activities and milestones summarized and assessed in this report. Two of the program's goals under the 2017 FAD are to continue monitoring the use and progress of the new MyWoodlot.com website as a tool for understanding the needs and interests of watershed landowners, and to explore potential modifications and improvements of the Management Assistance Program (MAP) that may be needed to support and compliment the recently redesigned forest management planning program.

In 2014, WAC moved away from supporting the development of traditional forest management plans, and instead focused on a strategy involving two complimentary planning options: one that incentivized forest landowners to enroll in New York's 480-a Forest Tax Law, and another that encouraged the development of forest landowner management plans or "profiles" through WAC's interactive website MyWoodlot.com.

During the FAD assessment period 2016-2020, the WAC Forestry Program facilitated the enrollment of 242 forested properties totaling 38,933 acres in New York's 480-a Forest Tax Law by providing incentive payments to landowners for developing forest management plans. To be eligible for the 480-a program, landowners must have at least 50 acres of forest, limit subdivision, restrict development, and commit to a rolling 10-year forest management schedule that is enforceable by NYSDEC. The 242 enrolled properties were comprised of 40 newly enrolled plans covering 5,244 forested acres and 202 re-enrolled plans covering 38,689 forested acres.

Since 1998, the WAC Forestry Program has enrolled and re-enrolled a total of 348 properties (properties are defined as distinct ownerships that may consist of one or more tax parcels) into the 480-a program, covering 56,272 forested acres. The significant increase to the size of the portfolio during the reporting period reflects the Forestry Program's success in focusing on supporting initial 480a enrollment and re-enrollment. However, the accuracy of this total enrolled acreage contains a degree of uncertainty given that NYSDEC does not share disenrollment information and WAC only provides funding for updating 480-a plans every five years without tracking whether reenrollment actually occurred. Landowners who disenroll their forestland from 480-a must reimburse the state for all of the tax savings realized through the lifetime of a property's enrollment. Landowners who fail to re-enroll annually lose their property tax reduction but maintain their 10-year commitment to following their forest management plan, including limited subdivision and development. At the end of the 10-year period, the land is no longer encumbered by 480-a restrictions. Since the lack of publicly available 480-a data makes it difficult to assess the impact of disenrollment, it could be useful for the WAC Forestry Program and NYSDEC to collaborate on filling this knowledge gap to better understand the extent of watershed forest land enrollment in the 480-a Forest Tax Law.

Since 2015, WAC has maintained an interactive, educational website called MyWoodlot.com. The intent of this website is to educate landowners about all aspects of their forest while directing them through a series of modules that allows them to develop management goals and create customized plans (profiles) for stewarding their forests and making informed conservation decisions. There are currently 316 MyWoodlot profiles, of which 261 profiles were added during this current assessment period for a 474% increase over the past five years.

In conjunction with its planning efforts, WAC continued to support MAP implementation. During the period 2016-2020, the WAC Forestry Program completed a total of 189 MAP projects covering 1,353 acres, including 78 timber stand improvement projects covering 917 acres; 61 wildlife improvement projects covering 192 acres; 37 invasive species control projects covering 239 acres; four tree planting projects covering five acres; and nine landowner site visits. Stewardship behaviors supported by the MAP are often communicated to watershed forest landowners through the MyWoodlot.com website, thereby encouraging the diffusion of such behaviors among peer landowners. Currently, participation in MAP requires either a 480-a forest management plan or MyWoodlot profile.

The WAC Forestry Program also supported a variety of forestry BMP implementation projects during the past five years, including the completion of 57 stream-crossing projects associated with timber harvest projects, and the temporary loan or cost-share of 36 portable bridges. WAC also distributed over 61 free samples of BMP technology such as geotextile road fabric and rubber belt water deflectors. A total of 243 BMP projects have been completed on active logging jobs, resulting in the stabilization of more than 670 miles of logging trails in the watershed.

It should be noted that during the reporting period, WAC engaged in numerous evaluations of the effectiveness of forestry BMP implementation in the watershed, including a 2018 research study conducted in collaboration with SUNY College of Environmental Science and Forestry;. This study concluded that loggers participating in WAC's forestry BMP programs were significantly more likely to implement forestry BMPs with a higher level of effectiveness and frequency than their non-participating peers.

The Croton Trees for Tribs Program was initially conceived as a program dedicated to the installation of riparian buffer plantings in priority EOH basins. The 2017 FAD establishes a goal of six projects per year, with a focus on Kensico, West Branch, and Boyd Corners basins. In 2018, DEP submitted a FAD report that evaluated the need, opportunities, and options for enhancing riparian buffer protection efforts in the Kensico and EOH FAD basins. In that report, DEP recommended that the WAC Forestry Program explore ways to improve landowner participation in the Croton Trees for Tribs Program in the EOH FAD basins.

During the period 2016-2020, the WAC Forestry Program implemented 35 Croton Trees for Tribs projects covering 3.61 acres or 3,577 linear feet of riparian area. Prior to the current assessment period, WAC restructured the Croton Trees for Tribs Program to serve more of an educational purpose instead of functioning as a strict riparian reforestation initiative focused on landowner participation. Succeeding with landowners at a significant scale would have required a large investment in staff and materials. WAC decided to leverage its existing school bus tour program by integrating it into the Trees for Tribs program and teaching students how to plant trees in riparian areas. This was more in line with WAC's capacity and could also help build upon and enhance a student's classroom education.

To better understand the effectiveness of its overall Forestry Program, WAC conducted its second five-year Conservation Awareness Index (CAI) survey in 2020. Initially conducted in 2015 and codified in the 2017 FAD as a program deliverable, the CAI survey estimates landowner preparedness to make informed conservation decisions about their land related to harvesting timber, paying taxes, and estate planning. In both 2015 and 2020, WAC mailed the CAI survey to 3,000 watershed landowners owning more than 10 acres of forest. A total of 921 landowners (35%) responded in 2015 and 793 (31%) responded in 2020. WAC staff are currently comparing these CAI scores between the two periods and based on landowner demographics. Pursuant to the FAD, DEP will submit a formal evaluation report on the CAI reports by December 31, 2021.

Based on a preliminary analysis, CAI scores appeared to have increased slightly between 2015 and 2020, indicating a higher conservation awareness. CAI scores were highest for estate planning and timber harvesting and lowest for 480-a and conservation easements. While low, the 480-a CAI scores did appear to increase in 2020 after the Forestry Program shifted its focus from forest management planning to encouraging enrollment in the 480-a program. However, it's difficult to attribute recent 480-a enrollment efforts to increasing CAI scores. The 2020 CAI scores also indicate that respondent awareness about MyWoodlot increased slightly, suggesting that awareness about the website is growing. MyWoodlot users also had higher CAI scores across all subject categories and could more readily name forest conservation professionals compared to respondents not engaged in MyWoodlot. These preliminary results suggest that MyWoodlot is effective for educating landowners, who appear to be more likely to adopt positive stewardship behaviors when they know others who engaged in such behaviors.

Landowner education and professional training remained an important focus of the Watershed Forestry Program during the FAD assessment period. WAC continued to collaborate with Cornell Cooperative Extension of Columbia and Greene counties and Cornell University's Master Forest Owners (MFO) Program to conduct dozens of landowner workshops and woods walks each year reaching thousands of people. During the reporting period, WAC organized and implemented 218 landowner education workshops that were attended by 8,205 participants. In addition, 186 landowners who own a total of 8,205 acres of forest participated in MFO site visits, while 437 landowners participated in the "Landowner Letter Series" educational program.

Also during the reporting period, in collaboration with the New York State Trained Logger Certification Program and Cornell Cooperative Extension of Columbia and Greene counties, the WAC Forestry Program sponsored 46 professional logger training workshops attended by 475 participants. Approximately 110 loggers working in the Catskill/Lower Hudson region were "Trained Logger Certified" as of December 31, 2020.

During the period 2016-2020, the four watershed model forests held 449 educational events and hosted 51,262 total visitors. Additionally, WAC staff conducted annual trainings with the host organizations for each model forest to facilitate their adoption of watershed and forest related curriculum into their ongoing educational activities. It is important to note that the number of visitors identified above participated in educational programs at the host facility and not necessarily in the model forests themselves. Even though several model forests remained open for passive recreation during 2020, in-person educational events at all model forests were suspended and certain host organizations were forced to lay off staff due to the COVID-19 pandemic. It remains uncertain whether some of these host facilities will be able to return to their pre-pandemic model forest activities and investments.

Finally, the Watershed Forestry Program continued to devote significant resources to support urban/rural school-based education. During 2016-2020, WAC hosted five annual Watershed Forestry Institutes for Teachers (WFIT) attended by 125 New York City and watershed teachers. The Watershed Forestry Bus Tour Program facilitated 119 bus tours for both New York City and watershed students, allowing 7,262 students, teachers, and adult chaperones to learn about the connection between forests and water quality. Eight virtual bus tours (due to COVID-19) were additionally completed in 2020, which engaged 256 students and teachers. The

Green Connections Program facilitated 16 educational partnerships between New York City and watershed classrooms, connecting 730 students and teachers. WAC's Watershed Forestry Education Community of Practice, a series of events organized to maintain communication with and between teachers participating in WFIT, bus tours and Green Connections, actively engaged 846 teachers during the reporting period.

3.6 Stream Management Program

3.6.1 Introduction

DEP established the Stream Management Program (SMP) to protect and restore stream ecosystems – the stream channel and riparian corridor that together sequester nutrients and conserve sediment which can contribute to the degradation of stream water quality.

DEP and its partners at county Soil and Water Conservation Districts (SWCDs) and Cornell Cooperative Extension of Ulster County (CCEUC) apply state-of-the-science river and floodplain management principles to implement programs and projects, working with stakeholders whose individual actions are fundamentally important to stream stability and riparian integrity.

The SMP process begins with stream feature inventories of current conditions which are used to develop stream management plans. Recommendations in the plans result in program-prioritized Water Quality Stream Projects (WQSPs) and Stream Management Implementation Program (SMIP) projects, which are prioritized by community partners. Projects include geomorphic channel restoration, stream bank and hillslope stabilization, flood hazard mitigation, and riparian plantings. The plan recommendations also inform an extensive and integrated program of education, outreach and training to support the SMP's mission. The National Academies of Science, Engineering and Medicine commended this approach to stream management in 2020 in its multi-year expert panel review.

Following severe flooding in 2011 that focused SMP resources on design and construction of nearly 50 emergency projects, the current assessment period was characterized by few flood flows, enabling SMP to advance core programming. Consequently, when the COVID-19 pandemic hit, SMP was well positioned to implement projects, and few projects were postponed as a result. SMP completed 119 stream projects, restoring stability or riparian buffer to nearly 12 miles of stream (including CSBI projects reported in Section 3.7.2), at a total cost of $21,060,045.

Having established a robust flood hazard mitigation program with its partners and the Catskill Watershed Corporation (CWC) in the prior assessment period, SMP completed Local Flood Analyses (LFAs) with the majority of eligible population centers laying a strong foundation for achieving flood resilience and water quality protection. Additionally, the SMP renegotiated and registered all five SMP partner contracts for additional five-year terms totaling $68.9 million, launched a new stream studies program to inform projects and program evaluation, and, partly prompted by the COVID-19 pandemic, substantially expanded baseline education, outreach, and training into web-based delivery platforms.

3.6.2 Water Quality Stream Projects

Water Quality Stream Projects (WQSPs) prioritize improvements in water quality above other project objectives. The 2017 FAD emphasized the importance of WQSPs relative to other project categories. The 2017 FAD directed SMP and its partners to review, at the reservoir basin scale, water quality status and trends, past Stream Feature Inventories (SFIs) and independent studies to evaluate the potential for WQSPs to improve water quality. The June 2019 report Planning for Stream Feature Inventories and Water Quality Stream Project Site Selection summarized past SFIs and consultations with the partners, identified priority pollutants, and identified the next SFIs to help guide the nomination of WQSPs.

During the FAD assessment period, 10 WQSPs were designed and constructed treating 2.2 miles of unstable stream through full channel restoration or streambank stabilization at a cost of $8,015,707. Six projects (Wright Road, Beaver Kill at Van Hoagland Projects 1 and 2, Woodland Creek at Woodland Valley Landowner’s Association, the West Branch Delaware River More Project and the Schoharie Creek at Kozak) were completed in fulfillment of the Revised 2007 FAD. Four of these six were located in the Ashokan basin, thereby fulfilling the Revised 2007 FAD requirement of seven WQSPs in the Ashokan basin by 2018. Four additional projects were completed pursuant to the requirements of the 2017 FAD: Batavia Kill at Kastanis, Bush Kill at Watson Hollow, East Kill at Colgate Lake Road, and West Branch Neversink River at Clothes Pool. Ten other WQSPs have been nominated under the 2017 FAD and will be constructed in the coming years. Table 3.15 summarizes the completed WQSPs.

Table 3.15 Completed Water Quality Stream Projects.

Basin SMP	Project	Year Completed	Project Category	Project Length (ft.)	Total Cost
Ashokan	Wright Road	2016	Streambank Stabilization	650	$1,221,771
	Beaver Kill at Van Hoagland, Project 1	2017	Full Channel Restoration	600	$691,704
	Beaver Kill at Van Hoagland, Project 2	2017	Full Channel Restoration	700	$691,704

Basin SMP	Project	Year Completed	Project Category	Project Length (ft.)	Total Cost
	Woodland Creek at Woodland Valley Landowner's Association	2018	Full Channel Restoration	1,350	$1,075,795
	Bush Kill at Watson Hollow	2018	Full Channel Restoration	250	$394,955
Delaware	West Branch Delaware River at More Farm	2016	Full Channel Restoration	1,500	$1,295,897
Rondout/ Neversink	West Branch Neversink River at Clothes Pool	2020	Streambank Stabilization	760	$972,312
Schoharie	Schoharie Creek at Kozak	2016	Streambank Stabilization	1,500	$286,043
	Batavia Kill at Kastanis	2017	Full Channel Restoration	3,800	$1,021,231
	East Kill at Colgate Lake Road	2019	Streambank Stabilization	700	$364,295
Total				**11,810**	**$8,015,707**

An iterative design and review process is a critical component of the SMP project development workflow. SMP has been using hydrologic and hydraulic modeling (HEC-RAS) as a standard engineering practice in most projects for many years, modeling a range of flows and design alternatives, in both existing and proposed conditions. HEC-RAS is routinely used to evaluate channel and floodplain velocity, shear stress, and energy and to avoid a significant increase in water surface elevations of the 100-year flow, as required by local floodplain ordinances and associated permits.

During the reporting period, tremendous technological advancements have been made in Unmanned Aerial Systems (UAS), or drones, increasing the precision, accuracy, and efficiency of topographic mapping. Their use in assessment, design and monitoring of projects and channel/bank condition has become standard practice. This has led to increased use of two-dimensional (2D) hydraulic modeling by design engineers for all WQSPs. Projects that recently used these engineering practices include the Clothes Pool on the East Branch Neversink River, constructed in 2020, and the nominated, four-phase Red Falls Project 1 on the Batavia Kill (see below).

The Clothes Pool Project

Stream feature inventories and bank erosion monitoring on the East Branch Neversink River, led by the Rondout Neversink Stream Program (RNSP) beginning in 2011, identified and ranked the Clothes Pool reach as the highest priority for restoration to mitigate suspended sediment and turbidity, and loss of large wood into the stream system. The project area is approximately 760 feet in length and includes an adjacent hillslope failure. The RNSP contracted with Stantec Engineering to develop a natural channel design. The approach included

Figure 3.9 Clothes Pool project showing pre-construction conditions (top) and post-construction conditions (bottom).

geomorphic reference reach surveys, analysis of existing and proposed sediment transport conveyance and capacity using Flowsed and Powersed models, and 2D HEC-RAS hydraulic models. Project elements included a bankfull-stage floodplain bench with root wads at the toe of the hillslope to isolate the eroding glacial till face from hydraulic erosion, and rock structures in the streambed for grade control and flow deflection. Bioengineered soil lifts using heavy coir erosion control fabric were densely layered with willows and graded with an engineered compost/soil. The bioengineering included final planting with native forb, shrub and tree species (Figure 3.9). The total project cost was $972,312.

Restoration at Red Falls

Greene County Soil and Water Conservation District (GCSWCD) substantially advanced the assessment and design of a set of WQSPs along an approximately 6,161-foot long segment of the Batavia Kill at Red Falls. The Batavia Kill Stream Management Plan prioritized the site based on water quality impacts from excessive erosion into extensive glacial lacustrine clay and till deposits, and mass wasting of steep hillslopes exceeding 50 feet in height. Geomorphic and water quality monitoring have identified the reach as the largest contributor of turbidity and suspended sediment in the Batavia Kill watershed.

The Red Falls reach is one of the largest and most complex sites addressed by SMP. GCSWCD completed the design of a four-phase project. Phase 1 was constructed in 2020 and prepares the site for Phases 2 and 3. Phase 1 included 2,900 feet of access road into the site; tree clearing, grading of the floodplain, staging and creation of stockpile areas; and installation of a 1,250-foot long rock-lined passive floodplain channel to facilitate dewatering for Phases 2 and 3, which are scheduled for construction in 2021 and 2022, respectively. Phase 4, planned for 2023, will remove the access road, restore the dewatering channel and revegetate the entire work area. Assessments and design are ongoing for an additional approximately 3,540 feet of stream, located immediately upstream of this area.

3.6.3 Flood Hazard Mitigation

Substantial progress has been made since 2016 implementing each of the four complementary components comprising the Local Flood Hazard Mitigation Program (LFHMP), developed following Tropical Storm Irene in 2011. The LFHMP's goal is to protect water quality and secure a sustainable future for watershed communities by reducing areas of inundation and minimizing floodwater contact with residential and commercial pollutants. Comprehensive evaluations of the LFHMP and the New York City-Funded Flood Buyout Program (NYCFFBO) were completed in June 2020 and June 2019, respectively. Both reports provide details beyond the scope of this report, including specific recommendations for program improvement.

SMP Local Flood Analyses and Recommended Projects

The cornerstone of the LFHMP is the Local Flood Analyses (LFA), a community-led engineering study using updated floodplain maps and associated hydraulic models to identify areas at risk for inundation in West of Hudson watershed population centers and to evaluate mitigation scenarios for those areas. Providing support to flood commissions conducting LFAs was a major accomplishment of the SMP and its partners during the assessment period: 19 LFAs covering 32 population centers were completed at a cost of $1.54 million. Since LFHMP initiation in 2014, 22 LFAs covering 34 population centers have been completed at a total cost of $1.91 million. Figure 3.10 identifies the location and status of LFAs to date. All municipalities

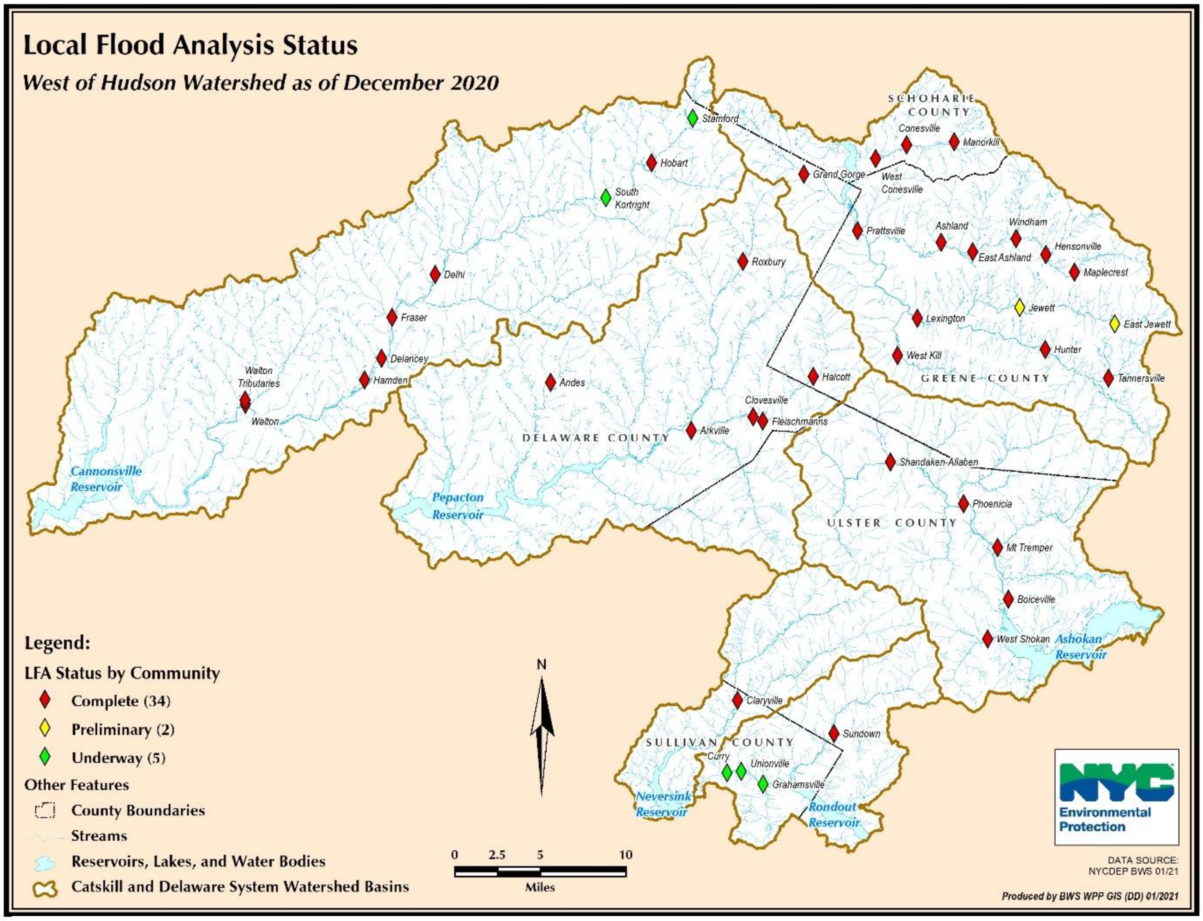


Figure 3.10 Location and status of LFA projects to date.

undertaking an LFA have adopted or accepted them; all completed LFAs are available at catskillstreams.org/lfa. LFAs are now complete for the majority of large population centers. Most of the remaining villages and hamlets have very small population centers with little or no history of flood damage.

Through their LFAs, local flood commissions have identified over 150 flood hazard mitigation project recommendations. Chief among these are infrastructure upgrades, floodplain restoration, streambank stabilization, property protection (elevation and floodproofing), and buyout and relocation projects. Of these, SMP funds the design and construction of projects including floodplain restoration, infrastructure modification and replacement, streambank stabilization, and channel modification. During the assessment period, SMP awarded 20 grants totaling $ 4.58 million supporting the design or construction of 13 LFA-recommended projects as summarized in Table 3.16.

Table 3.16 Summary of LFA project funding awards through the SMP.

Project Name	Contract Type	Amount	Status
Water Street Floodplain Restoration	Design Construction	$224,767 $716,665	Complete Complete
Steele Brook Streambank Stabilization	Construction	$217,000	Ongoing
Steele Brook Debris Removal	Construction	$20,000	Ongoing
Mill Street Floodplain Restoration	Construction	$140,000	Complete
Manor Kill Floodplain Restoration	Design Construction	$92,899 $381,931	Complete Complete
Saw Mill Creek Streambank Stabilization	Design	$140,000	Ongoing
Blue Hill Lodge Streambank Stabilization	Design Construction	$58,744 $506,760	Complete Complete
Town Hall Streambank Stabilization	Design Construction	$58,743 $424,660	Complete Complete
DeSilva Road Culvert Replacement	Design Construction	$72,239 $647,207	Complete Complete
Upper Boiceville Road Culvert Replacement	Design Construction	$72,239 $435,056	Complete Complete
Maltby Hollow Bridge Replacement	Design Construction	$80,000 $219,495	Complete On Hold
Burgher Road Culvert Replacement	Design	$50,683	Ongoing
Hunter Road Elevation Study	Feasibility	$22,124	Complete
Total		**$4,581,212**	

CWC Local Flood Hazard Mitigation Implementation Program

Through its $17 million contract with DEP, the CWC Local Flood Hazard Mitigation Implementation Program (LFHMIP) supports a wide range of flood hazard mitigation efforts. CWC's major accomplishments this period included the completion of 31 feasibility studies, three designs and two elevations under the property protection program; removal of the Mount Pleasant bridge; anchoring of 64 fuel tanks; purchase of the Breakey Motors property for a floodplain restoration project; managing demolition and site restoration of nine structures acquired by the buyout programs; and efforts to relocate nine critical facilities and businesses out of a floodplain. CWC's grants are summarized in Table 3.17.

Table 3.17 Summary of CWC LFHMIP grants and funding allocations.

Type of Project	Number of Grants Awarded	Number of Grants Completed	Total Funding Allocated
Property Protection	60	36	$1,565,868
Relocation	9	5	$1,161,984
Pollution Prevention (Including Tank Anchoring)	43	40	$140,170
Infrastructure	1	0	$1,000,000
Stream-related	5	3	$2,438,842
Demolitions	9	6	$873,889
Buyouts	1	1	$388,550
Total	**128**	**91**	**$7,569,303**

Engineering services contracted by CWC, totaling $824,000, provided technical assessments for flood buyout properties, preparation of demolition plans for NYCFFBO and CWC property acquisitions, and property protection feasibility studies, as well as project-specific engineering services. Additional information on individual grants, including an interactive map, can be found at catskillstreams.org/LFA.

New York City-Funded Flood Buyout Program

Under the 2017 FAD, DEP has committed an additional $15 million to the New York City-Funded Flood Buyout Program (NYCFFBO). As most acquisitions are the result of LFA recommendations, SMP continued to coordinate the acquisition, removal of structures and future-use planning of the properties between the involved municipalities, agencies and contractors. Details on progress under the NYCFFBO details are provided in Section 3.2.

A noteworthy project made possible by the NYCFFBO is the replacement of the Route 28 Bridge at Mount Tremper with a wider span and adjacent levee removal. This project is demonstrating the potential of the LFA to secure support for large and complex infrastructure projects. The Mount Tremper LFA identified this bridge over the Esopus Creek as undersized and that the bridge and the adjacent levee contributed to localized flooding. The LFA further demonstrated that a wider bridge combined with floodplain restoration/levee removal would provide a four-foot reduction in flood depths and velocities during the 100-year flood. To prevent the loss of critical emergency services access during flood events, NYSDOT proposed replacing and widening the bridge from 336 feet to 900 feet and agreed to work with the Ashokan Watershed Stream Management Program, the Town of Shandaken and DEP to acquire properties needed for both bridge widening and restoration of floodplain connectivity. SMP helped coordinate the acquisition of four properties in the project area through the NYCFFBO and coordinated approval for five additional DEP properties in the project area. The project will protect numerous homes and two businesses in Mount Pleasant and ensure access along NYS Route 28 during major flood events. Construction began in 2020 and is expected to be completed in 2021.

3.6.4 Implementing Stream Management Plans

The SWCDs of Delaware, Greene, Sullivan and Ulster counties and CCEUC are the SMP contract partners co-developing and implementing the expansive basin-scale programming that includes stream assessments and monitoring; project selection, design and construction; LFA support; and education and technical training of stakeholders. In 2020, the NASEM expert panel commended DEP, and by extension these partners, for having built the necessary long-term partnerships to create a comprehensive program for stewardship of Catskill region streams and floodplains.

Importantly, five new five-year contracts were negotiated and registered with the partners with a combined value of $68.9 million.

Stream Feature Inventories

Stream Feature Inventories (SFIs) characterize stream condition, prioritize localized or reach scale instability that threatens water quality and/or infrastructure, and ultimately lead to recommendations for action. SFIs were completed on 28 streams covering nearly 146 stream miles during the assessment period and are summarized in Table 3.18.

Table 3.18 Stream feature inventories.

Basin SMP	SFIs completed	Length (miles)
Ashokan	McKinley Hollow, Elk Bush Kill, Little Peck Hollow, Esopus headwaters, Hatchery Hollow, Lost Clove, Little Beaver Kill	34.6
Delaware	Cannonsville: WBDR management units, Steele Brook, Tributary to Elk Creek Pepacton: Huntley Hollow and Little Red Kill	10.8
Schoharie	Bear Kill, Sawmill Creek, East Kill, Gooseberry Creek, West Kill, Batavia Kill, Huntersfield Creek, Little West Kill, Red Kill	71.4

Basin SMP	SFIs completed	Length (miles)
Rondout/Neversink	Rondout: Bear Hole Brook, Stone Cabin Brook, Rondout Creek, Trout Creek, and Sugarloaf Brook Neversink: East Branch Neversink River headwaters and Conklin Brook	29.1
Total	**28**	**145.9**

Stream Management Implementation Program

Successful program delivery hinges on effective coordination with municipalities and other local entities. Throughout the period, the SMP partners met with their advisory councils and working groups to implement recommendations made in stream management plans, track progress and set priorities via annual action plans, as well as administer the Stream Management Implementation Program (SMIP). Stream management plans and annual action plans can be found at https://catskillstreams.org/stream-management-program. In the Ashokan basin, new stream management plans were completed for the Woodland Creek and the Little Beaver Kill.

Community-driven projects are funded by SMP partners through the application-based SMIP. Table 3.19 summarizes the total number of SMIP awards during the FAD assessment period. Since inception in 2009, 275 SMIP grants have been awarded and 86% are complete, 11% are in process and 3% are in design. LFA-recommended flood hazard mitigation projects are tracked separately from SMIP projects and are reported in Section 3.6.3. SMIP project descriptions and funding levels, by basin, are provided at catskillstreams.org/smip.

Table 3.19 SMIP category summary, by basin.

SMIP Category	Schoharie	Ashokan	Delaware	Neversink/ Rondout	Total
Education and Outreach	13	6	0	17	36
Recreation and Habitat Improvements	8	0	4	0	12
Highway/Infrastructure	7	7	3	6	23
Streambank Restoration/Land Owner Assistance	6	2	3	0	11
Planning and Research	2	16	1	5	24
Flood Hazard Mitigation	5	1	1	2	9
Total	**41**	**32**	**12**	**30**	**115**

*The total reflects new projects as well as accounting for withdrawn projects

The SMIP continued to be a source of support for numerous community-driven projects which were divided fairly evenly between education, planning and research projects versus design and construction-related projects. Below are two noteworthy projects.

- Ashokan Watershed Stream Crossing Assessment and Prioritization: In 2018, CCEUC and Ulster County Department of Environment inventoried and assessed 370 public road-stream crossings in the Ashokan watershed and found 76% of the bridges and culverts are partially, mostly, or fully incompatible with stream geomorphology. This information is being used in outreach and training with highway departments and prioritizing further assessments.
- Peekamoose Blue Hole stewards, Town of Denning, Rondout Basin: In partnership with NYSDEC, the Rondout Neversink Stream Program funded stewards who successfully influenced visitors to “leave no trace” and reduce their impacts on this heavily used natural resource.

Summary of SMP Stream Project Delivery

In addition to implementing SMIP-funded stream projects, the SMP partners continued to identify and oversee the full suite of construction-related stream projects accomplished by the program. Table 3.20 summarizes the projects completed during the assessment period including Water Quality Stream Projects (WQSPs, Section 3.6.2), LFA-recommended flood hazard mitigation projects (Section 3.6.3), and SMIP projects (Section 3.6.4). CSBI projects are reported in Section 3.7.2. Excluding CSBI, 47 projects were completed, treating 5 miles and 78.5 acres. For most projects, the SMP partners continued to coordinate design and construction contracts; and provide or coordinate landowner agreements; local, state and federal permits; construction supervision and post-construction monitoring. SMP provided engineering review, construction inspection and professional engineering support through engineering consultants. Figure 3.11 depicts the locations of stream projects by project type.

Table 3.20 Stream Management Program project summary.

Basin	Type of Project	Total Projects Completed	Project Length (ft.)	Project Area (ac.)	DEP Cost	Total Cost
Ashokan	Full Channel Restoration	4	2,900	8.9	$2,709,203	$2,854,158
	Streambank Stabilization	2	1,270	3.3	$460,940	$1,377,269
	Stormwater/Infrastructure	4	475	0.5	$1,457,013	$1,510,013
Delaware	Full Channel Restoration	6	6,120	9.9	$2,260,116	$2,260,116
	Streambank Stabilization	9	3,080	4.5	$1,795,467	$3,211,205
	Stormwater/Infrastructure	3	270	0.5	$371,123	$688,479
	Floodplain Restoration	2	1,440	7.8	$856,665	$1,580,199
Rondout/	Full Channel Restoration	2	1,550	6.5	$951,494	$951,494

Basin	Type of Project	Total Projects Completed	Project Length (ft.)	Project Area (ac.)	DEP Cost	Total Cost
Neversink	Streambank Stabilization	3	1,940	7.5	$1,485,466	$1,485,466
Schoharie	Full Channel Restoration	2	4,400	18.6	$1,196,934	$1,196,934
	Streambank Stabilization	4	2,460	7.7	$1,129,432	$1,129,432
	Stormwater/Infrastructure	6	830	2.8	$1,073,824	$1,892,345
Total		**47**	**26,735**	**78.5**	**$15,747,677**	**$20,137,110**

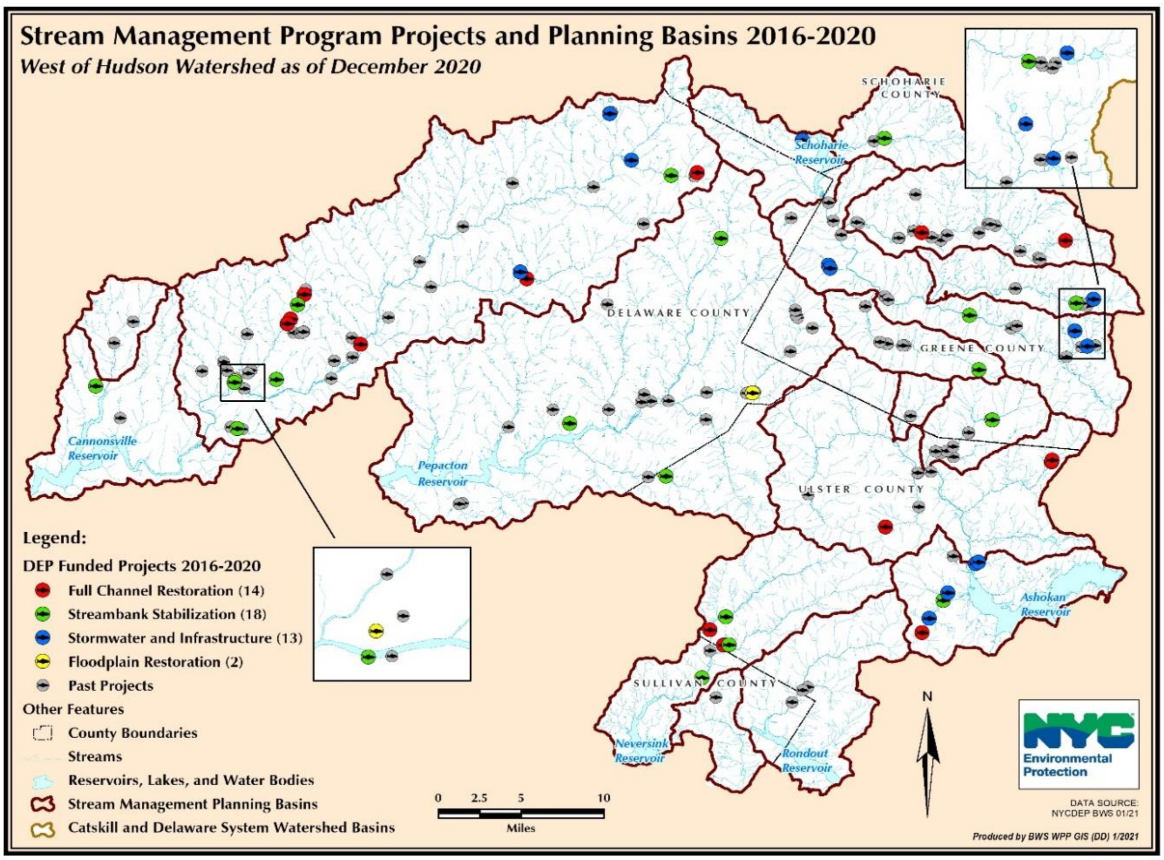


Figure 3.11 Stream projects by project type and basin, 2016-2020.

3.6.5 Education, Outreach and Training

During the reporting period, the SMP deepened its capacity to provide comprehensive education, outreach and training programming to meet the needs of the full range of stakeholders in stream management: municipal officials, streamside landowners, agency resource managers, consulting engineers, K-12 students, college interns, and other audiences.

The reporting period included the following education, outreach and training highlights:

- Through the LFA process, supported the technical education and information needs for 21 flood commissions to understand basic river processes, the National Flood Insurance Program and floodplain maps, and the SMP resources available for FHM projects, substantially advancing the core curriculum in SMP's Training in Best Practices in Stream, Floodplain, and Watershed Management for Municipal Officials: Plan and Schedule.
- To broaden support for education and outreach programming, SMP expanded its SUNY Ulster contract to include a new position, Stream Management Training Program Coordinator.
- Completed the 24th year of the Watershed Conservation Corps summer internship program providing field data to support program implementation. SMP trained 24 interns during the period, and has trained a total of 114 interns since 1996.
- Substantially expanded online educational resources during the COVID-19 pandemic: AWSMP developed its own YouTube channel featuring extensive K-12 and adult programming. Socially distanced outdoor events have been augmented in several basins with virtual outdoor events with video-based distance learning modules (https://www.youtube.com/watch?v=070kENtImsw), and web platforms will remain a significant element in education and outreach efforts post-pandemic.
- Supported 36 education and outreach projects with SMIP funding, including school curriculum development and programs, kiosks, podcasts, videos, educational floodplain models, and scholarships for municipal officials in Floodplain Manager certification training.
- Co-hosted two biennial Catskills Environmental Research and Monitoring (CERM) conferences, delivered 10 basin-specific conferences and symposia (Schoharie Watershed Summit, Annual Angler's Symposium, Ashokan Watershed Conference). Coordinated more than a dozen events bringing regional researchers' work to the general public, including Dave Rosgen's October 2019 talk, "Living with Mountain Rivers in a Changing Climate."
- Provided training for partners, resource managers and engineers in Hydrologic Engineering Centers River Analysis System, Sediment Transport Modeling, Watershed Assessment for River Stability and Sediment Supply, Applied Fluvial Geomorphology, National Oceanic and Atmospheric Administration's Planning and Facilitating Collaborative Meetings, Floodplain Manager Certification, AutoCad, next generation GPS, Levee Mapping, and Erosion and Sediment Control.

- Given the diverse interests of stakeholders – history, local cuisine, geology, or forest ecology – SMP partners continue to generate creative ways to bring stakeholders into the program. For example, the "From Forest to Frying Pan" workshop taught how to grow mushrooms in floodplain logs as an entry point for discussion of the role of wood in the stream and floodplain ecosystem.

3.6.6 Stream Studies

DEP formalized its commitment to science-informed and adaptive stream management through the establishment of the Stream Studies program in 2016 to evaluate and inform SMP's effectiveness in both protecting and improving water quality through enhanced research, assessment and monitoring. SMP substantially advanced two primary research projects during the assessment period: (1) the Esopus basin turbidity source and reduction monitoring and (2) the Catskill bankfull discharge and hydraulic geometry regional curves. SMP also continued work with its partners on improving SFI methodology and supporting SMP basin research initiatives.

Esopus Basin Suspended-Sediment/Turbidity Studies

DEP and United States Geologic Survey (USGS) advanced the 10-year suspended sediment/turbidity source and reduction monitoring research project initiated in autumn 2016. DEP submitted the study design in 2017 to achieve the following objectives:

- Characterize, monitor, and map turbidity source conditions in the Esopus Creek basin.
- Measure and monitor turbidity and sediment flux (sediment concentration and streamflow) to rank Esopus contributing tributaries and map spatial and temporal variations.
- Quantitatively characterize turbidity source dynamics that can be used to identify, rank and prioritize Sediment and Turbidity Reduction Projects (STRPs are a WQSP category), using the Stony Clove Creek sub-basin as an experimental watershed.
- Evaluate STRP efficacy in the Stony Clove Creek sub-basin across a range of scales.

USGS installed and operates 29 turbidity monitoring stations, 13 of which also monitor sediment flux. The Stony Clove Creek sub-basin has 20 of the 29 monitoring stations for turbidity source dynamics and STRP evaluation. DEP and UCSWCD used SFIs to map turbidity sources across the Esopus basin. CCEUC provided funding to USGS to pilot sediment fingerprinting techniques to further identify geologic sources in the study. With this hydrologic, water quality, geomorphologic and existing/future STRP data, USGS, DEP and other researchers have access to sufficient data to achieve the research objectives.

USGS completed four years of continuous water quality monitoring by the end of USGS water year 2020 (September 30, 2020) and DEP continued geomorphic/geologic mapping during this period. Interim results and applications of the research were presented in two 2019 FAD deliverable reports. The first report used the 20 monitoring stations in the Stony Clove Creek sub-basin and the geomorphic and geologic mapping to select three future STRPs to be constructed in 2021 (DEP, 2019a). The second 2019 report was the first of three biennial research status reports that will supplement a five-year interim status report in 2022 and a final report in 2027 (DEP, 2019b).

Following are four primary findings in the 2019 status report, updated to include 2020 observations:

- The first four monitored water years (October 2016 – September 2020) represent an unusually low magnitude flood hydrology, hence the flood events that lead to high magnitude turbidity production had not occurred during this period and limit current analysis of turbidity reduction efforts to runoff conditions at or less than a 2-year flood. A high magnitude flood event did occur in the study area on December 24-25, 2020. It was the largest flood in the Esopus basin since August 2011 and was highly erosive producing sustained elevated turbidity conditions in several sub-basins. USGS and DEP will present preliminary findings of this flood impact on the study in future reporting.
- The relative ranking of Esopus Creek tributaries for the four monitoring years is notably different than the ranking documented in past USGS monitoring periods (McHale and Siemion, 2014). Specifically, Stony Clove Creek was no longer consistently the highest turbidity tributary source to Esopus Creek during the period up to the December 2020 flood. In addition to Stony Clove Creek through USGS water year 2020, Woodland Creek, Beaver Kill, Broadstreet Hollow and Birch Creek were among the highest proportional turbidity tributary sources.
- Analysis of Stony Clove Creek turbidity from late autumn 2010 – September 2020 shows that the suspended sediment flux for daily mean streamflow below 1,000 cubic feet per second was substantively reduced following the construction of eight STRPs between 2012 and 2016 (Figure 3.12).
- Using a SFI protocol with enhanced geologic and geomorphic quantification of turbidity source sediments, repeat high resolution topographic monitoring at selected turbidity source sites, and sediment geochemical fingerprinting, DEP and USGS have demonstrated the importance of (1) geologic sources and (2) stream connectivity with valley bottom glacial features in reach-scale turbidity production at low to moderate flood streamflow conditions.

These findings along with the sub-basin water quality monitoring can improve selection and prioritization of future STRPs in the Ashokan watershed.

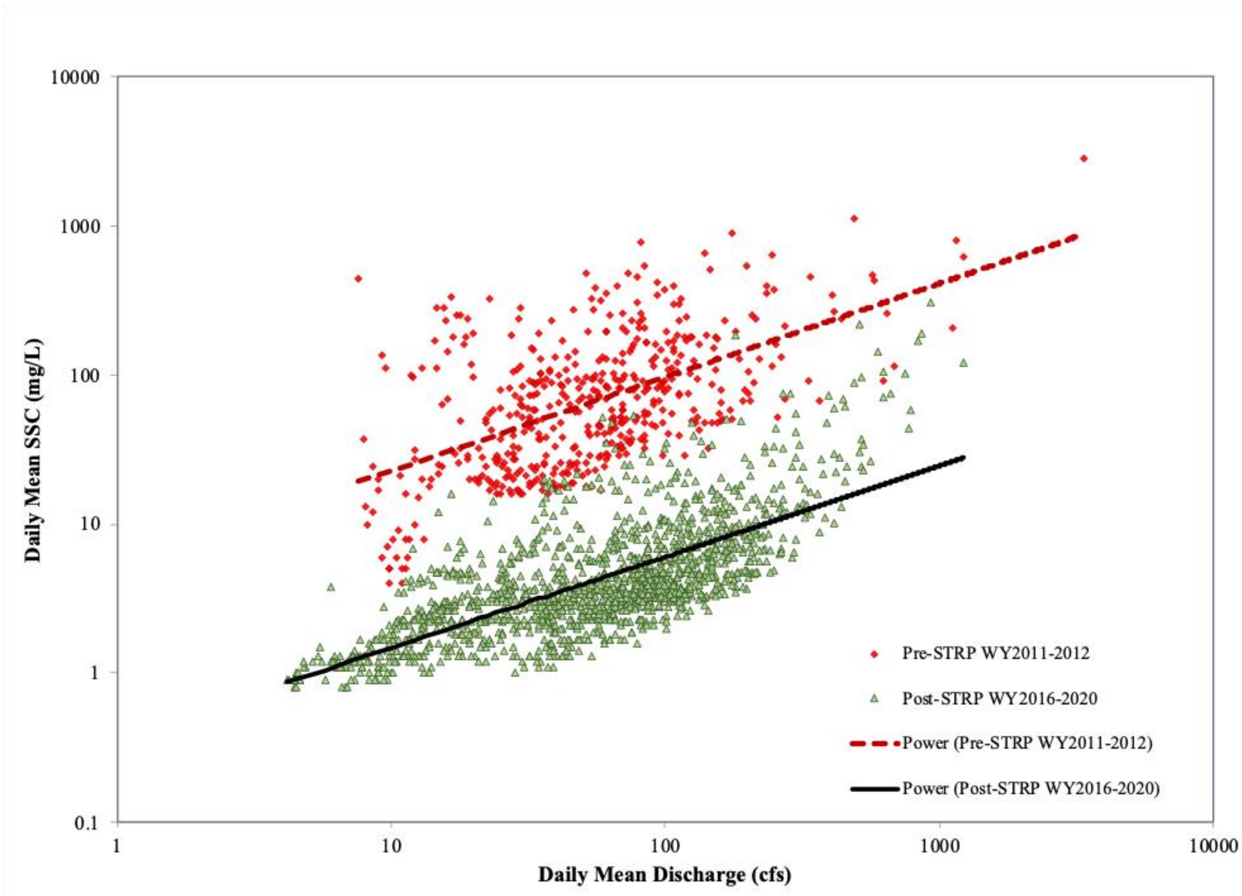


Figure 3.12 Daily mean suspended sediment-discharge relations for pre- and post-STRP implementation in the Stony Clove watershed

Catskill Bankfull Regional Curves

Bankfull discharge is a frequently recurring moderate flood that is important in developing and maintaining stable stream channel dimensions in alluvial channels. Successful stream management requires estimating bankfull discharge and associated channel dimensions for use in project design and assessing stream stability. The primary tool for estimating bankfull discharge and associated channel dimensions is regional regression of field-determined bankfull discharge at USGS stream gages for a broad range of drainage areas. These regionalized regressions are referred to as bankfull regional curves. DEP published a first set of Catskill bankfull regional curves in 2003 (Miller and Davis, 2013).

DEP developed a study design to update the Catskill bankfull regional curves by adding new USGS stream gage study sites not available in the original Catskill regional curves. As of 2018, the current study site sample size has increased from 18 to 25. The updated data allowed

DEP to substantively improve the predictive regionalized relationships and reduce uncertainty. In 2019, DEP presented the results at the NYC Watershed Science and Technical Conference. In 2020, DEP developed an interactive Excel workbook with this data and curves for current use by regional stream managers. The provisional revised regional curves are a substantial improvement and are an important accomplishment towards producing a final published set of new regional curves.

3.7 Riparian Buffer Protection Program

DEP continues to protect and manage riparian buffers as an essential component of an effective overall watershed protection program. To this end, many of DEP's watershed programs, partnerships, and research initiatives actively address the protection, management, and restoration of riparian buffers in the watershed. Publicly owned buffers are protected and/or managed through DEP's Land Acquisition (LAP) and Land Management programs, and private buffers are offered management through Stream Management Program's Catskill Streams Buffer Initiative. DEP and its watershed partners have made substantial progress on the Riparian Buffer Protection Program during the 2016-2020 assessment period.

3.7.1 Acquisition and Management of Riparian Buffers on DEP or Controlled Lands

Through the LAP, DEP secures permanent protection for sensitive riparian buffers. Riparian buffers, often including wetlands and floodplains, are often considered to have a higher water quality protective value than upland areas due to their proximity to streams. Preventing inappropriate development of these areas is a priority for DEP. During the assessment period, LAP extended permanent protection to an additional 69 miles of stream and 4,292 acres of riparian buffer through all of its program elements, an increase of 10.8% and 10.5% respectively since 2015, and an increase of 18.5% and 18.1%, respectively, since inception in 1997. These programs include DEP's core LAP, the NYCFFBO, the WAC Farm and Forest Conservation Easement Programs, and the Streamside Acquisition Program (SAP) managed by the Catskill Center for Conservation and Development in the Schoharie basin.

In its 2020 FAD Expert Panel Review Report, the National Academies of Sciences, Engineering, and Medicine (NASEM) suggested that DEP place more emphasis on acquiring riparian lands on critical areas of tributary streams through the NYCFFBO and SAP. During this assessment period, the NYCFFBO acquired 49 acres while the SAP acquired 208 acres. Although the relative combined acreage may seem minimal compared to broader LAP accomplishments, properties acquired under NYCFFBO and SAP contained an average of 94.2% and 75.6% surface water criteria, respectively. In addition, through DEP's increased selectivity of LAP parcels based on greater percentage of surface water features during the past several years, the average surface water criteria on properties in the 20-100-acre range acquired by the City has increased from roughly 32% in 2002 to over 40% as of 2020.

Table 3.2 summarizes the stream, riparian buffer and floodplains protected by the LAP since inception.

DEP also considers riparian buffer impacts when reviewing requests from outside parties regarding land use activities and projects on DEP lands. In 2019, DEP increased protection of streams and wetlands by increasing from 25 to 35 feet the required buffer around lands leased for agricultural use. See Section 3.3 for more detail on DEP's land management activities.

3.7.2 Catskill Streams Buffer Initiative

The Catskill Streams Buffer Initiative (CSBI) has been implementing riparian buffer protection and enhancement as a component of the SMP throughout this assessment period. CSBI focuses on mapping riparian vegetation to plan riparian buffer establishment; removing invasive species; constructing, monitoring and maintaining riparian restoration projects; and conducting extensive education and outreach. CSBI was initiated in 2009 and was expanded in 2016 with the establishment of a SMP-WAP partnership, the CREP-CSBI pilot program. This pilot is designed to incentivize non-agricultural landowner participation in the CSBI program with lease payments and enhanced planting options. DEP now tracks and reports projects as base CSBI and CREP-CSBI projects.

Native Plant Materials

Central to DEP's overall stream management mission is a commitment to maintaining and restoring ecosystem integrity. To that end, one of the unique aspects of the CSBI is the production of Catskill native plant stock for CSBI projects. The partners continued coordination of contracts to provide local native seed collection, propagation and grow out. These contracts provided 23,000 trees and shrubs for planting at CSBI and CREP-CSBI projects. The CREP program provided an additional 1,500 plants for CREP-CSBI projects, though native sources were not always able to be secured.

Implementation, Monitoring and Maintenance

CSBI coordinators at partnering SWCDs implement the program by recruiting landowners, conducting field assessments to determine project eligibility, analyzing historic information and landowner concerns, and when landowner interests align with eligibility, writing Riparian Corridor Management Plans (RCMPs). RCMPs include a suite of recommendations, from BMPs landowners can do themselves to more substantial planting projects that require SWCD assistance. A total of 33 RCMPs were completed during the period.

During this assessment period, the CSBI and CREP-CSBI together completed 72 projects over 6.9 stream miles and 62.5 acres as summarized in Table 3.21. In 2020, the CSBI program completed 20 projects and no CREP-CSBI projects were completed. Projects represent a diversity of riparian restoration techniques including plant installation and bioengineering practices.

Figure 3.13 illustrates the approximate project locations for all CSBI projects during this reporting period as well as since CSBI inception in 2009. Since 2009, the CSBI program has completed 248 projects over 22.1 stream miles and 159.3 acres. Gaps in the forested riparian buffer were revegetated through installation of over 53,353 trees and shrubs during the assessment period, and more than 97,000 since inception.

Table 3.21 CSBI projects completed by program element, 2016-2020.

Program Element	Number of Projects	Length (miles)	Acres Planted
CSBI	68	5.4	42.9
CREP-CSBI	4	1.5	19.6
Total	**72**	**6.9**	**62.5**

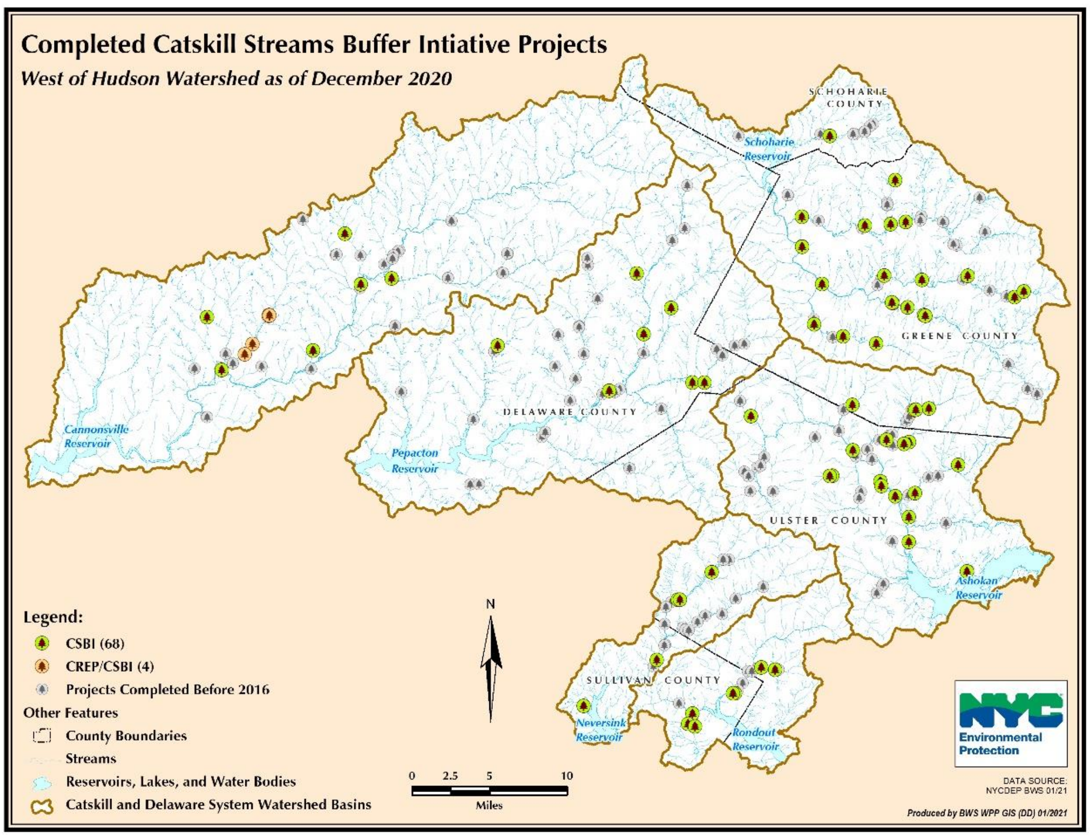


Figure 3.13 Approximate project locations for CSBI and CREP/CSBI pilot projects 2016-2020

Site preparation and protective measures are designed to optimize survival of plantings, improve growth rates and reduce the need for project maintenance. Prior to planting, often for several years, invasive species are removed to the extent possible. At planting, deer fencing, tree tubes, weed mats, beaver deterrents, and herbicides have been used to reduce herbivory and competition. Following planting, monitoring is supervised and tracked by the CSBI coordinators as part of their contracts with DEP and used to identify needed maintenance and adjust future species selection. DEP provides interns secured through SUNY Ulster, SUNY Delhi and SCA AmeriCorps for both monitoring and maintenance.

A CSBI project on a DEP-owned parcel at the confluence of the West Kill and the Schoharie Creek in Lexington reflects the extensive effort to enhance survival. In 2019, the Greene County Soil and Water Conservation District (GCSWCD) planted 1,476 native trees and shrubs over 1,800 linear feet encompassing 2.4 acres to increase streambank stability, slow erosion, increase shade and create wildlife habitat for aquatic and terrestrial animals (including birds and pollinators). Trees, including native maple, oak, cherry and birch, were protected using tree tubes to prevent deer browse and improve survival. Additionally, deer fencing and liquid fence test plots have been installed to monitor tree growth comparing these two protective methods against traditional planting with and without tree tubes. Weed mats were installed to reduce vegetative competition. The site, depicted in Figure 3.14, will be monitored through 2024 and results will inform future plantings. The project also illustrates DEP's coordination across program areas, including Land Acquisition, Land Management and SMP/CSBI.

Catskill riparian soils are often dry, lacking in organic matter and available nutrients and, at times, compacted. As such, they are not ideal for riparian buffer plant establishment. A

Figure 3.14 Riparian restoration through the CSBI program, designed and planted by GCSWCD in 2019 at the confluence of the West Kill and Schoharie Creek in Lexington.

noteworthy advancement, led by the RNSP, applies the soil food web concept to build more favorable soil conditions. Rather than rely on chemical fertilizers that provide a surge of growth that cannot be sustained, RNSP is building soil biodiversity – including microinvertebrates (bacteria and fungi) necessary to make nutrients bioavailable to plants. From there, RNSP established protocols for managing soils in three common settings: terrace hillslopes (compacted till, sandy outwash), pre-existing herbaceous vegetation, and stream restoration project sites where soils are compacted. As needed, soils are prepared at nearby staging areas by mixing compost, biochar, and loam. Mycorrhizal inoculant is applied to root balls at planting and plants are mulched with woodchips. Native microbial life is further re-established in the new soil by adding duff collected from the adjacent mature undisturbed forest floor that is cultured and applied as a "compost tea."

CREP-CSBI Pilot Program

In 2016, the WAC and DCSWCD proposed a two-year pilot program to partner the City-funded CSBI together with the federal Conservation Reserve Enhancement Program (CREP), administered by the WAC, to enable CREP to be implemented on fallow agricultural lands through the CSBI. The program seeks to accelerate riparian buffer establishment on non-agricultural lands by using CSBI as the local match to the CREP, providing a financial incentive to landowners, and using CSBI's flexibility to tailor plantings to site conditions above and beyond the narrow CREP standards (minimum of 35 feet and maximum of 100 feet back from a stream). The program was piloted through the WAC and DCSWCD in Delaware County, and through the Greene and Ulster SWCDs in the Schoharie and Ashokan basins. Sullivan SWCD declined to extend the CREP in the Rondout and Neversink basins due to limited number of eligible parcels.

The two-year pilot commenced in November 2017 and DEP submitted two FAD deliverable reports in November 2019: the first, a set of metrics developed by an interagency team including NYSDOH, NYSDEC and USEPA to guide implementation and evaluation, submitted in November 2018; the second, a comprehensive evaluation of the program. The evaluation recommended the pilot be extended for an additional two years and NYSDOH approved this in 2020.

Using GIS, each county established a set of eligible parcels and conducted landowner outreach. In Delaware County, four projects were completed in 2019, establishing 19.6 acres of buffer over 1.5 miles of the East Brook in Walton. Of the 19.6 acres planted, approximately 12 acres enrolled in CREP. Following outreach in Greene, Ulster and Schoharie counties, no CREP-CSBI projects advanced due to lack of interest.

The length and acreage of the four Delaware County projects demonstrate the potential of the program to increase planted buffer area and improve the planting density. Surveyed Delaware County landowners expressed interest in the program and ranked rental payments as least important among a set of factors motivating their interest in the program. Despite this expressed interest, bringing new landowners to contract under CREP was the primary challenge identified and at the end of the initial two years of the pilot, no additional contracts had been signed. Contributing factors included federal and state funding delays throughout 2019. In 2020, additional delays have been attributable to the pandemic and registration of DCSWCD's SMP contract.

Watershed Agriculture Program and Watershed Forestry Program

Please refer to Section 3.4 and Section 3.5 of this report for information about the riparian buffer protection efforts of the Watershed Agriculture and Forestry programs, including an update about the CREP.

3.8 Waterfowl Management Program

The management of waterbird populations at Kensico Reservoir is essential to meet the requirements of USEPA's Surface Water Treatment Rule (SWTR). DEP's Waterfowl Management Program (WMP) was established to research the relationship between wildlife, particularly waterbirds that inhabit the reservoirs (geese, gulls, cormorants, swans, ducks, and other duck-like birds), and fecal coliform bacteria concentrations in surface water prior to disinfection. Following several years of waterbird population monitoring, DEP identified birds as a significant source of fecal coliform bacteria in Kensico Reservoir. In addition, migratory waterbirds utilizing DEP reservoirs as temporary staging areas and wintering grounds significantly contribute to increases in fecal coliform loadings during 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 of the feeding activity occurs away from the reservoir. Previous DEP annual summary reports (DEP 1993 – 2020) have documented that fecal coliform increases have occurred concurrently with increases in waterbird populations in water samples collected near roosting locations at several reservoirs.

In response, DEP implemented standard waterbird management techniques approved by United States Department of Agriculture, Animal and Plant Inspection Service, Wildlife Services (USDA), New York State Department of Environmental Conservation (NYSDEC) and United States Fish and Wildlife Service (USFWS) to reduce or eliminate the waterbird populations inhabiting the reservoir system. In combination with these standard dispersal and deterrence techniques, an additional measure is used to manage local breeding populations of Canada geese (*Branta canadensis*) and mute swans (*Cygnus olor*): identification of nesting locations and subsequent depredation of eggs and nests.

Since the implementation of the combined dispersal and deterrence measures, there has been a dramatic reduction in both roosting waterbird populations and fecal coliform levels, which has helped DEP maintain high quality water in compliance with SWTR. While developed for Kensico Reservoir in 1992, the WMP was expanded to included five additional reservoirs

(West Branch, Rondout, Ashokan, Croton Falls, and Cross River) for waterbird management on an as needed basis. In addition, DEP has implemented an enhanced wildlife management program which includes waterbirds, terrestrial birds, and mammals at Hillview Reservoir to further protect the water supply.

Implementation of the WMP is described in the sections that follow. The water quality results of the program are described in sections 4-7, in the discussion of each reservoir basin in which the program was implemented.

Waterbird Census

DEP and its contractor conducted surveys to track the number of waterbirds on the reservoirs throughout the year because of the well-established relationship between elevated waterbird counts and increased levels of fecal coliform bacteria in raw water samples. Currently, reservoir waterbird surveys are conducted throughout the calendar year at Kensico and Hillview reservoirs and for part of the year at West Branch Reservoir. Additional surveys are conducted on an as needed basis at reservoirs that are sources or possible sources to Kensico, including Croton Falls, Cross River, Rondout and Ashokan. The frequency of surveys varies based on the reservoir and time of year (Table 3.22).

Table 3.22 Reservoir waterbird mitigation, 2015-2020.

	Time period	**Activities**
Kensico Reservoir		
Monitoring:	Daily Aug. 1 – March 31 and weekly April 1 – July 31	Motorboats, shoreline
Dispersal:	August 1 – March 31 annually	Motorboats, Biondo airboats,
Deterrence:	Year-around as needed	Waterbird, baitfish collection, and wildlife
Depredation:	Egg and nest April - June annually. Canada goose removals as needed	Egg and nest for Canada geese and mute swans, Canada goose removals
West Branch Reservoir		
Monitoring:	Biweekly, August 1 to April 15 annually	Shoreline
Dispersal:	None required during this period.	
Deterrence:	Daily as needed, annually.	Waterbird reproductive
Depredation:	April - June annually	Egg and nest for Canada geese and mute swans
Rondout Reservoir*		
Monitoring:	As needed.	Shoreline
Dispersal:	None required during this period	

	Time period	Activities
Deterrence:	April–June annually	Waterbird reproductive
Depredation:	April-June annually	Egg and nest for Canada geese and mute swans
Ashokan Reservoir*		
Monitoring:	As needed	Not conducted
Dispersal:	None required during this period.	
Deterrence:	April – June annually	Bird netting on shaft building
Depredation:	April - June annually	Egg and nest for Canada geese and mute swans
Croton Falls Reservoir*		
Monitoring:	As needed 2019 and 2020	Shoreline
Dispersal:	None required during this period.	
Deterrence:	April–June annually	Bird netting on shaft building
Depredation:	April-June annually	Egg and nest for Canada geese and mute swans
Cross River Reservoir		
Monitoring:	As needed 2016, 2018, and 2019.	Shoreline
Dispersal:	None required during this period.	
Deterrence:	April–June annually	Waterbird reproductive depredation
Depredation:	April-June annually	Egg and nest for Canada geese and mute swans
Hillview Reservoir		
Monitoring:	Daily, year-round	Shoreline and reservoir
Dispersal:	Daily, year-round	Pyrotechnics, propane
Deterrence:	Daily, year-round	Wildlife sanitary surveys, overhead, railing and
Depredation:	Egg and nest April–August annually. Waterbirds year-round as needed.	Depredation – egg and nest for swallows, starlings, sparrows, and mallards. Waterbird removals.

*These reservoirs can be sources or possible sources of Kensico water.

Waterbird Mitigation

Waterbird Dispersal Actions

Types of bird dispersal activities conducted from 2015 through 2020 is presented in Table 3.22. The current program at Kensico Reservoir employs motorboats, Biondo airboats, and pyrotechnics for waterbird dispersal actions and includes wildlife sanitary surveys in and around water intake areas prior to significant precipitation events. The Hillview Reservoir waterbird dispersal program uses pyrotechnics, propane cannons, and physical chasing techniques with occasional uses of remote-control motorboats and lethal removal of ducks through a USDA, Wildlife Services Cooperative Service Agreement. Additional wildlife mitigation measures have been instituted at Hillview including trapping and removal of mammals along the reservoir perimeter; nest and egg depredation of nesting mallard ducks, swallows, sparrows, and starlings; and daily wildlife sanitary surveys. Overhead bird deterrent wires were maintained over the reservoir surface and additional wires and netting have been installed to prevent terrestrial bird species from nesting and roosting. The program at Kensico is conducted between August 1 and March 31 of each year, while the Hillview program is performed on a daily basis year-round. Beginning daily at 8 a.m. and continuing until approximately 1.5 hours past sunset, bird dispersal activities were conducted reservoir-wide, targeting all species except those designated as endangered and threatened by USFWS and NYSDEC. As needed bird dispersal actions were deemed unnecessary during this reporting period for the five reservoirs source-connected to Kensico (Table 3.22).

Waterbird Depredation Actions

Under a contract between the Westchester County Airport and the USDA Wildlife Services, removals of Canada geese occurred at Kensico Reservoir for aircraft protection. Federal Aviation Administration guidance requires commercial airport operators to develop and implement a plan to identify all aviation hazards such as bird strikes at off-airport properties. In Westchester County, Kensico Reservoir has been identified as an important bird attraction area located on the western side of the airport and therefore subject to bird mitigation actions. From 2015 through 2020, the USDA under DEP permission removed 18 Canada geese to reduce risk of bird strikes to departing from and arriving at the airport aircraft.

Waterbird Deterrence

Egg depredation

DEP conducts annual springtime breeding surveys and egg depredation for Canada geese and mute swans within reservoir property to suppress reproductive success, which in turn eliminates population recruitment and breaks site fidelity of nesting adults. Preliminary surveys of waterbird nests begin in late March for early nesting and continue through late June for late nesters. Each nest and egg is numbered and each egg is punctured with a probe to break the membranes, thereby destroying the embryo. Using the egg puncturing method ensures that each egg is treated and eliminates the possibility of water contamination from oil treatments, generally the method of choice elsewhere (USDA, personal communication). After puncturing, eggs are replaced in the nest to allow incubation to continue (Figure 3.15). A small number of goose nests are typically destroyed late in the breeding season to encourage the birds to relocate off reservoir property during the annual post-nuptial molt, when the birds are rendered flightless for a few weeks.

Terrestrial species such as swallows require nest surveys from April through July and sparrows and starlings require year-around monitoring for nesting activity. All nests are removed along with eggs/young under a USFWS depredation permit required for all species other than starlings. Relatively small numbers of nests of mallards (*Anas platyrhynchos*), cliff swallows (*Petrochelidon pyrrhonota*), barn swallows (*Hirundo rustica*), tree swallows (*Tachycineta bicolor*), house sparrows (*Passer domesticus*), and European starlings (*Sturnus vulgaris*) were also depredated by DEP staff.

All depredation activity was conducted under the terms of a USFWS registration for Canada geese and NYSDEC permit for mute swans. During the reporting period, the WMP conducted 1,485 surveys of 392 nests and depredated 1,753 eggs as shown in Table 3.23 and Table 3.24.

Figure 3.15 Canada goose nest and egg depredation work.

Table 3.23 Egg depredation summary for Canada geese and mute swans, 2015-2020.

Reservoir	Surveys	Canada geese nests (eggs depredated)	Mute swan nests (eggs depredated)	Depredation success rate for Canada geese/mute swans (number surviving young)
Kensico	54	93 (434)	6 (49)	98.41% (7 goslings) / 100% (no cygnets)
West Branch	48	37 (169)	0	100% (no goslings)
Rondout*	20	23 (120)	0	93.75% (8 goslings)
Ashokan	25	42 (209)	0	79.47% (54 goslings)
Croton Falls	50	67 (363)	2 (16)	96.03% (15 goslings) / 100% (no cygnets)
Cross River	48	54 (220)	0	95.24% (11 goslings)

Table 3.24 Egg depredation summary for mallards and swallows, 2015-2020.

Reservoir	Surveys	Mallard nests (eggs depredated)	Swallow nests (eggs depredated)	Depredation success rate for mallards/swallows (number surviving young)
Hillview	1,240	23 (128)	35 (45)	98.41% (7 mallard ducklings) / 100% (swallows)

Baitfish (Alewives)

In response to entrainment of baitfish (mostly alewives (*Alosa pseudoharengus*)) into the water intake structures at Ashokan Reservoir and their subsequent entry into Kensico Reservoir, the DEP waterfowl management contractor installed a temporary collection boom around the Catskill Influent Chamber as needed to collect and remove the dead fish. Table 3.25 presents an estimate of the amount of alewives collected during each bird dispersal season (August 1 through March 31) at Kensico from 2015 to 2020. Alewives are an attractive food source for gulls and some species of ducks. When large numbers of fish are flushing into the reservoir, the gulls become very difficult to manage. Installation of the boom and collections of baitfish are based on daily observations and installed only as needed from year to year.

Table 3.25 Alewife collections, 2015–2020.

Season (August 1 – March 31)	Estimated Amount (pounds)
2015 – 2016	104
2016 – 2017	22
2017 – 2018	644
2018 – 2019	0
2019 – 2020	0

Wildlife Excrement Sanitary Surveys

DEP conducts wildlife sanitary surveys to prevent wildlife excrement from washing into the Kensico Reservoir and potentially elevating levels of fecal coliform bacteria. DEP has identified sampling locations based on proximity to the Delaware Aqueduct Shaft 18 water intake location, which are surveyed approximately 24 to 48 hours prior to significant precipitation events. DEP developed a system of locating, identifying, and removing wildlife excrement as a proactive effort to reduce fecal coliform bacteria and pathogens from potentially entering the water supply.

Table 3.26 Summary of wildlife sanitary surveys, 2015-2020.

Species	Excrement Samples Collected
White-tailed Deer	694
Eastern Cottontail Rabbit	354
Canada Geese	198
Passerine Birds	135
Raccoons	90
Unknown Mammal	44
Opossum	21
Coyote/Fox	10
Mink	9
Meadow Vole	3
Domestic Dog	2
Eastern Gray Squirrel	1
Striped Skunk	1
Mallard	1
Total 14 Species	**1,563**

From 2015 through July 2020, DEP and its contractor conducted 46 wildlife sanitary surveys in advance of significant precipitation events (greater than 1 inch predicted) at Kensico Reservoir (Table 3.26). Of the 1,563 fecal samples collected, 44% were attributed to white-tailed deer (*Odocoileus virginianus*), 23% to rabbits (*Sylvilagus* spp.), 6% to raccoons (*Procyon lotor*), 3% to other mammals (fox species, striped skunk (*Mephitis mephitis*), mink (*Neovison vison*), Virginia opossum (*Didelphis virginiana*), Eastern gray squirrel (*Sciurus carolinensis*), meadow vole (*Microtus pennsylvanicus*), and domestic dog), and 3% to unknown mammals. Avian species excrement included 13% from Canada geese, 9% from passerine bird species and one mallard sample.

3.9 Ecosystem Protection Programs

3.9.1 Wetlands Protection Program

Wetlands provide many functions and values that help maintain the high quality of surface waters in the watershed. They intercept runoff to help abate flooding and prevent erosion. They trap sediments and cycle nutrients. Wetlands also provide stream baseflow, crucial to maintaining aquatic habitat during dry periods, and are often sources of headwater streams. Wetlands also play a role in the carbon cycle, with some types sequestering significant amounts of carbon. Numerous species of wildlife and fish depend on freshwater wetlands for food, shelter, and breeding grounds; many rare, threatened, or endangered species depend on wetland habitat at some point in their life cycles. Wetlands are also important areas for recreation, aesthetic appreciation, and education.

Recognizing these important functions and values, DEP implemented a Wetlands Protection Strategy in 1996. The strategy has been updated with each subsequent FAD renewal, most recently in 2018. The 2018 strategy outlines goals and tactics to characterize the extent and condition of wetlands and to leverage protection through regulatory, land acquisition, stewardship, and outreach programs. A summary of progress in these programs follows.

3.9.2 Wetland Mapping

National Wetlands Inventory (NWI) maps provide baseline data on the distribution, types, and extent of wetlands that are essential to the implementation of regulatory, land acquisition, and other watershed management programs. The most recent NWI was produced for the watershed in 2005 using 2003 and 2004 aerial photography. Because it relied on manual interpretation of remote sensing imagery, there are expected limitations to the NWI’s accuracy. In 2015, DEP completed a study that found incorporation of LiDAR derivatives, orthoimagery, and other spatial datasets into automated mapping protocols increased the accuracy and completeness of wetland mapping and connectivity assessment in pilot areas both in the EOH and WOH watersheds. Mapped vegetated wetland acreage increased by 136% and 74% in the WOH and EOH pilot areas, respectively. In addition, feature accuracy was determined to be 87%

for the WHO area and 93% for the EOH pilot area, as compared to 78% and 77% for the current NWI, respectively. High resolution data sources also enabled detection of stream connections for 98% of wetlands in the pilot areas, opposed to 65% when using lower resolution data sources.

Given the success of the pilot study, DEP developed a contract to expand its methodology to the entire watershed. This contract was awarded in February 2020, work commenced in May, and project completion is anticipated in September 2021. Work to date has included review and improvement of the pilot's automated mapping rules and establishment of visual interpretation protocols for manual editing and classification of wetland polygons where needed. Increasing the accuracy and completeness of wetland maps will benefit decision making for numerous watershed programs. Increased detection of wetlands will improve assessment of potential impacts during regulatory reviews, identification of wetland sites for acquisition, and will inform site selection for stewardship efforts such as forest management. Identification of wetland connections to downstream waters is also key for evaluating wetland function and federal jurisdictional status. In addition, updated maps will provide a new, more accurate baseline for future trends analysis.

3.9.3 Reference Wetlands Monitoring

Reference wetlands provide region-specific benchmarks to evaluate the condition of other wetlands; to guide restoration, creation, and enhancement projects; and to detect long-term trends due to anthropogenic and natural stressors such as climate change. DEP completed its initial collection of vegetation, soils, and water quality data from reference wetlands in the Catskill and Delaware watersheds in 2004 and 2005. These data were summarized in a July 2014 FAD report (Reference Wetland Conditions in the Catskill and Delaware Watersheds of the DEP Water Supply System).

DEP resampled 99 vegetation plots in 18 reference wetlands in 2016 and 2017. These data were collected to assess trends in wetland condition, and to inform future monitoring needs. DEP evaluated both its sampling methods and study sites, and determined that its original plot sampling strategy could be more efficiently designed and brought in line with statewide methods recently developed by the New York Natural Heritage Program (NYNHP) (https://www.nynhp.org/epa-wetland-condition).

To this end, DEP partnered with the NYNHP on a USEPA Wetland Program Development Grant that was awarded to them in 2019 (Improving Onsite and Remote Wetland Functional Assessment: A Focus on New York City Water Supply Basins). For this project, DEP will implement NYNHP wetland conditional and functional protocols at a minimum of 10 wetlands in the watershed. In 2020, DEP completed field work on seven wetlands located in FAD basins on both sides of the Hudson River. Work consisted of GIS-based landscape-scale conditional assessments, implementation of rapid assessment methodology, and detailed vegetation and pollinator sampling at each site (Figure 3.16). By partnering with NYNHP, DEP will not only generate additional information on City-owned wetlands, but will ensure that wetland assessment tools under development will be calibrated to the watershed. These rapid assessment tools will enable DEP to more efficiently evaluate a broad suite of wetlands in its growing land holdings (see Section 3.2) to identify wetland protection and stewardship priorities as needed.

Figure 3.16 New York Natural Heritage Program study plot.

In addition to developing tools that can be applied to rapidly assess many wetlands, DEP also continued to evaluate its long-term reference wetland monitoring program. While vegetation and soil sampling were completed at discrete times, DEP has maintained water level collection from automated monitoring wells throughout the reference locations since 2004. DEP examined well data from the 18 reference wetlands to evaluate whether additional collection was warranted. DEP opted to continue deployment of wells where the record was without significant gaps due to equipment malfunction, vandalism, or other disturbances, as complete long-term data are most beneficial for detecting climate-related trends in wetland hydrologic regimes. DEP retained sites representative of major cover types including emergent, scrub-shrub, hemlock-hardwood forested, and hardwood-forested wetlands, but removed sites where multiple examples of the same cover type were represented. DEP also sought to include under-represented wetland types, and to capture more pristine systems that may be most sensitive to stressors. Through this process, eight wetlands were removed and four sites were identified for potential long-term water table monitoring, bringing the long-term hydrologic monitoring down to 14 reference sites (Figure 3.17).

DEP also evaluated and deployed new well monitoring methodology during this assessment period, as the previously used capacitance-based technology was no longer produced. In 2018, new pressure-based sensors were installed in four sites. DEP installed new loggers alongside older wells. The equipment was set up to record at the same depth and time interval to compare accuracy and responsiveness to rainfall events. The pressure loggers recorded water

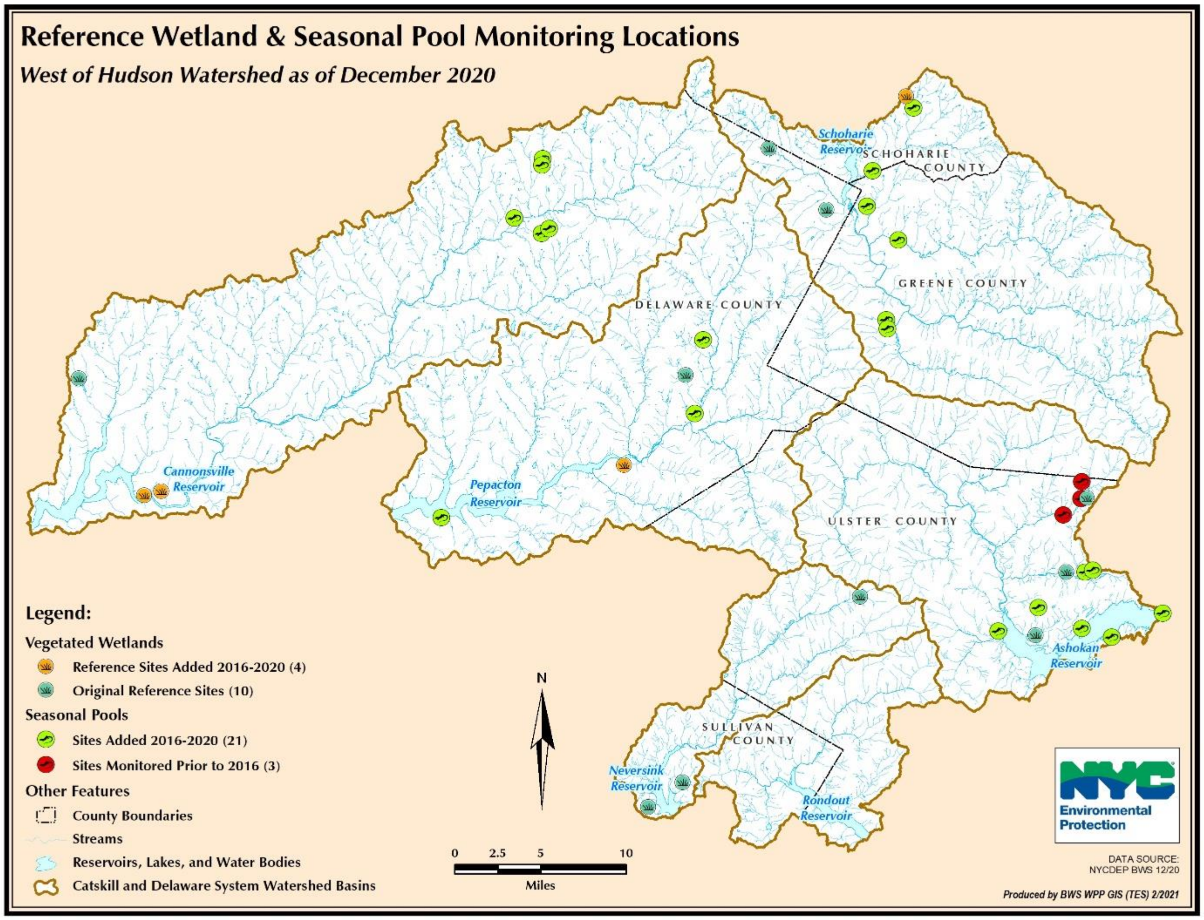


Figure 3.17 Wetlands and seasonal pools monitoring locations.

levels more accurately based on spot water table depth measurements and there was a greater response to precipitation and flooding than shown in the older well data. Nine new loggers were installed in reference wetland sites during the review period.

DEP also continued to study seasonal pools as their condition and productivity can be important indicators of landscape scale ecosystem functioning. Seasonal pools serve as storage basins which trap surface waters and prevent erosion. They recharge shallow sub-surface aquifers and store large quantities of carbon relative to their area. Seasonal pools provide permanent residence and temporary breeding habitat for numerous wildlife species. DEP protects these critical habitats through land acquisition; best management practices in forest management and capital projects; and promotes stewardship through public education.

During the assessment period, DEP added 21 seasonal pools to its monitoring program for a total of 27 (Figure 3.17). DEP has measured pH, DO, specific conductance, and temperature of seasonal pool waters approximately monthly since 2016. DEP also collected data on breeding amphibian species diversity and abundance each spring. Five water level loggers were installed in four pools in the Ashokan Reservoir basin. The loggers record water depth every six hours and the data was used to observe changes over time and in response to precipitation and drought conditions.

DEP wetland scientists and land surveyors collaborated to survey elevations in five seasonal pool basins in the Ashokan basin that were too shallow to be measured by the one meter digital elevation modeling, and for which the true depths and basin areas were unknown. The surveys captured elevations to sub-foot accuracy and horizontal profiles were produced for each pool. DEP used the elevation data for estimating water storage capacity and to characterize seasonal fluctuations in habitat quality for aquatic wildlife.

3.9.4 Watershed Regulatory Program

DEP continued to review federal, state, and municipal wetland permit applications in the watershed to provide comments when alternatives that would avoid, minimize, or mitigate wetland and water quality impacts were identified. From 2016 through 2020, DEP reviewed a total of 142 wetland permit applications in the watershed, the majority of which (113) were in non-FAD basins.

Of the 29 applications in the FAD basins, 22 were submitted pursuant the NYS Freshwater Wetlands Act (NYS Environmental Conservation Law, Article 24), which regulates both state-mapped wetlands and their 100-foot adjacent areas; five were applications pending before local municipalities in New York and Connecticut; and two were federal wetland application (those applications filed under Section 404 of the Clean Water Act, P.L. 92- 500, as amended by P.L. 95-217). Of the 113 applications in the non-FAD portion of the Croton System, 55 were submitted pursuant to Article 24, 43 were applications pending before local municipalities and 15 were federal wetland applications.

The majority of the applications in both FAD (84%) and non-FAD (66%) basins were for activities that would not result in a reduction of wetland area, such as aquatic invasive species management, pond dredging and adjacent area impacts (Figure 3.18). This demonstrates the cumulative effectiveness of wetland protection programs at minimizing permitted encroachments. This analysis does not, however, capture activities that do not require permits or pre-construction notification.

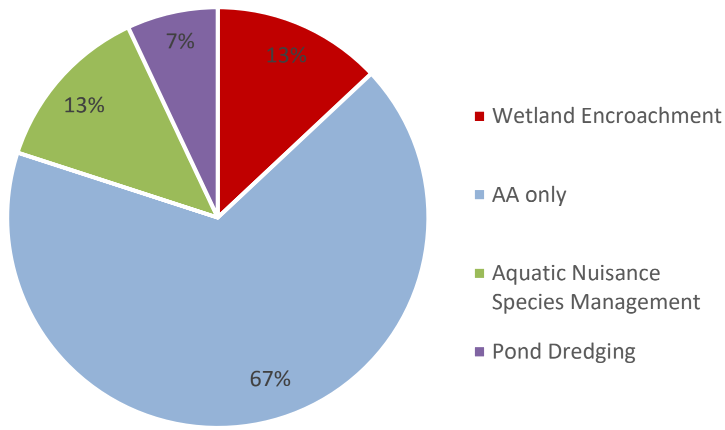


Figure 3.18 Wetland permits reviewed in FAD basins, 2016-2020

In 2018, DEP improved its wetland permit review tracking by entering previously reviewed and new wetland permit applications into its Watershed Lands Information System (WaLIS). WaLIS provides a spatial location of the permit application's proposed disturbance, allowing DEP to map project locations and to cross reference different project reviews by parcel. This enhances information sharing across disciplines and the efficiency of DEP's regulatory reviews. WaLIS manages and archives permit application documents and has a query function that has made reporting and analyses more efficient.

DEP continued to provide input on critical issues surrounding federal wetland jurisdiction under the Clean Water Act as uncertainty over the definition of waters of the United States persisted throughout this assessment period. During this FAD assessment period, the City commented on the U.S. Army Corps of Engineers (USACE) 2017 solicitation for comments proposing regulations that may be appropriate for repeal, replacement, or modification, in accordance with Executive Order 13777 (Enforcing the Regulatory Reform Agenda), which included the compensatory mitigation rule, the Nationwide Permit Program, and the definition of waters of the United States. The City also commented on EPA's 2017 proposed rule to rescind the definition of "waters of the United States" set forth in the 2015 Clean Water Rule ("2015 Rule") and to recodify previously existing definitions of "waters of the United States" that had been adopted by EPA and the USACE in 1986 and 1988. In 2018, the City and Nassau County submitted a brief of amici curiae to the U.S. District Court for the Southern District of New York in support of a multi-state challenge of the 2017 rule, which sought to delay the effective date of the 2015 Clean Water Rule. The City also submitted comments on the February 14, 2019, publication of the rule proposed by the USACE and EPA to define the scope of waters federally regulated under the Clean Water Act (Navigable Waters Protection Rule). In all instances, DEP relied heavily on its geospatial and field data to demonstrate the significance of wetlands and streams in the watershed, to evaluate the potential impacts of regulatory changes on the water supply, and to advocate for continued federal protection of these resources.

In addition, DEP provided comments on the USACE's proposed modification and reissuance of Nationwide Permits and associated regional conditions in 2016 and 2020. These comments generally supported maintaining current disturbance and notification thresholds, requested interagency coordination for proposals in the City's watershed, and suggested language to increase clarity and consistency for applicants. DEP also reviewed two proposed NYSDEC General Permits, one in Region 4 (GP-4-18-001) for certain activities under Article 15, Article 24, and Section 401 of the Clean Water Act; and GP-0-19-002 for Utilities Rights of Way Vegetation Management.

3.9.5 Land Acquisition

According to the NWI and NYSDEC freshwater wetland maps, there are approximately 15,190 acres of wetlands in the CAT/DEL watershed. Since 1997, DEP has protected 3,017 acres, or 19.9%, of these wetlands through its Land Acquisition Program (LAP) (See Section 3.2). This represents an additional 277 acres of wetlands acquired during the 2016-2020 FAD assessment period. In the CAT/DEL watershed, pre-MOA DEP lands contain an additional 970 acres (6.4%) of wetlands, with an additional 1,291 acres (8.5%) of wetlands located on state or other protected lands. Table 3.27 summarizes the acreage of wetlands that have been protected through acquisition for both the CAT/DEL and Croton watersheds. Acquisition of wetlands protects their water quality functions, and also provides recreational and education opportunities as well.

Table 3.27 Wetlands and Deepwater habitats acquired or protected by the NYC Land Acquisition Program in the Catskill/Delaware and Croton systems as of December 31, 2020*

Description	*Acres*	*% of Total Watershed Acreage*	*% of Total Land Acquired*	*% of Total Wetlands or Deepwater Habitats in System*
For Catskill/Delaware (Ashokan, Schoharie, Rondout, Neversink, Pepacton, Cannonsville, West Branch, Boyd Corners, Kensico basins):				
Total Acreage of Entire Watershed	1,048,660			
Total Acreage of Wetlands (both NWI and DEC-regulated) in Entire Watershed (excluding Deepwater Habitats**)	15,190	1.45%		
Total Acreage of Deepwater Habitats in Entire Watershed	28,335	2.70%		
Total Acreage of Wetlands and Deepwater Habitats in Entire Watershed	43,526	4.15%		

Description	*Acres*	*% of Total Watershed Acreage*	*% of Total Land Acquired*	*% of Total Wetlands or Deepwater Habitats in System*
Total Lands Under Contract or Closed by NYCDEP as of 12/31/19†*:	151,881	14.48%		
Within those total lands under contract or closed:				
Total Acreage of Wetlands (both NWI and DEC-regulated, excluding Deepwater Habitats**)	3,017		1.99%	19.86%
Total Acreage of Deepwater Habitats**	202		0.13%	0.71%
Total Acreage of Wetlands and Deepwater Habitats**	3,219		2.12%	7.40%
For Croton:				
Total Acreage of Entire Watershed	212,700			
Total Acreage of Wetlands (both NWI and DEC-regulated) in Entire Watershed (excluding Deepwater Habitats**)	20,025	9.41%		
Total Acreage of Deepwater Habitats in Entire Watershed	10,808	5.08%		
Total Acreage of Wetlands and Deepwater Habitats in Entire Watershed	30,834	14.50%		
Total lands under contract or closed by NYCDEP as of 12/31/19†*:	1,984	0.93%		
Within those total lands under contract or closed:				
Total Acreage of Wetlands (both NWI and DEC-regulated, excluding Deepwater Habitats**)	97.1		4.89%	0.48%
Total Acreage of Deepwater Habitats**	1.6		0.08%	0.02%
Total Acreage of Wetlands and Deepwater Habitats**	98.7		4.97%	0.32%

* Source: WLCP GIS, December 31, 2020. Note: Acres are calculated directly from areas of GIS polygons and therefore may not match exactly other acreage totals submitted by DEP. Watershed statistics calculated from LiDAR-derived 1m basin boundaries updated in 2014.

** Categories considered "Deepwater Habitats" include reservoirs or large lakes (L1), unconsolidated bottom (L2UB), riverbeds (RUB & RRB) or streambeds (RSB). Categories considered wetlands include Palustrine Systems and exclude the Deepwater Habitats classes as well as all upland (U), and unconsolidated shore (L2US).

† Includes fee, conservation easements, and farm easements. Excludes non-LAP and pre-MOA land.

Statistics produced by T. Spies, BWS WPP GIS, 1/12/2021

3.9.6 DEP Forest Management Program

As part of its interdisciplinary review of its proposed forest management projects on DEP lands, DEP wetland scientists delineate on-site wetlands, which are treated as exclusion zones where no disturbance is permitted under normal circumstances. Moreover, the 100-foot-wide area surrounding wetlands is considered a special management zone, within which limits are placed on tree removal and equipment operation. Over the current assessment period, DEP delineated 173 wetlands totaling 100.5 acres across 27 forestry projects proposed on DEP Lands.

In addition to wetland delineations, DEP conducted bog turtle (*Gleptemys muhlenbergii*) habitat surveys on four separate forest management projects. The bog turtle is a state endangered and federally threatened species. DEP conducts habitat surveys on wetlands that meet criteria for having potentially suitable habitat, and might be indirectly impacted by timber harvesting activities. The surveys were reviewed by federal and state regulators as part of endangered species assessment coordination.

3.9.7 Outreach

DEP provided several educational programs throughout the assessment period. With the exception of 2020, DEP celebrated American Wetlands Month each May by issuing a press release describing the importance of wetlands and hosting a pop-up outreach event at the Ashokan Reservoir. The pop-up events were well attended and included displays of wildlife, soils, and plants for public engagement. In 2016, a public program was held at two wetland creation sites along the Bear Gutter Creek in North Castle, NY (Kensico Reservoir basin). DEP led walks in 2019 and 2020 focusing on wetlands and tree identification on the Ashokan Rail Trail, which has received over 200,000 visitors since it opened in autumn 2019. DEP staff were also involved in creating two educational signs that were installed to highlight wetland restoration, flora, and fauna along the Ashokan Rail Trail. Wetlands program staff also annually attend the World Fishing & Outdoor Exposition at Rockland Community College.

DEP also shared findings from its wetland mapping and monitoring programs at several technical conferences. In 2016, DEP presented the findings of the Light Detection and Ranging (LiDAR) Wetlands Mapping project at the Society of Wetland Scientists annual conference in Corpus Christi, Texas; the Watershed Science and Technical Conference in Saugerties, NY; and at the New York State Wetlands Forum annual conference in Suffern, NY. DEP participated in the joint meeting of the New England and Mid-Atlantic Biological Assessment Wetlands Workgroup in Cooperstown, NY in 2018. In 2019, DEP presented findings from the wetland monitoring program and NYNHP collaboration at the annual conference of the Society of Wetland Scientists in Baltimore, MD; the Watershed Science and Technical Conference in Saugerties, NY; and in a webinar hosted by the New England Interstate Water Pollution Control Commission.

3.9.8 Forest Program Management Overview

The primary responsibility of the forest management program is to manage DEP's watershed forests by applying science-based silviculture practices to maintain or enhance conditions ideal for long-term production of high quality water. The program also reviews and monitors proposed forest activities on conservation easement lands and provides forest management guidance on land-use permits and DEP projects. During the five-year period, NYC-owned watershed lands increased from approximately 135,000 acres to 181,000 acres (34%) and the acreage protected under conservation easements increased from approximately 23,700 acres to 26,150 acres (10%).

Seven new foresters were hired by DEP between 2016 and 2018, greatly increasing the capacity of the forestry section and providing support to the four regional foresters. A new program manager was hired in 2019 following the prior manager's retirement.

Forest Management Plan Update

Maintaining healthy and vigorously growing watershed forests is a critical component of DEP's comprehensive long-term watershed protection program. The best regulation of nutrients and the ability to withstand environmental changes is provided by growing a diverse, resilient forest across the watershed.

In 2017, DEP completed an update of the Watershed Forest Management Plan with the principal goal of inventorying those lands acquired by the City since completion of the original Watershed Forest Management Plan in 2011. Forest inventory provides information on the condition of the forest, helping identify issues of concern and priorities for management to help assure ideal conditions for water quality protection. This update was a requirement of the 2010 Water Supply Permit.

The update also revised a number of the conservation practices that provide a framework for planning forest management projects to protect co-occurring natural resources. These include wetlands, riparian areas, and threatened and endangered species. The revisions included procedures for incorporating U.S. Fish and Wildlife Service consultation regarding threatened and endangered species, as well as NYS Historic Preservation Office assessments for historic and archaeological resources. There were also adjustments to special management zones and exclusion zones which addressed forestry activities near sensitive water resources, and a new section on invasive species management was added.

The inventory component of the update added almost 30,000 acres acquired through the Land Acquisition Program (LAP) between 2009 and the beginning of 2018. Their inventory was critical to incorporating these new lands into forest management priorities. The inventory contract was completed by the end of FY20 following thorough quality assurance review of the data by the forestry section.

The forest condition across this patchwork of acquisitions generally mirrored what was described by the original inventory on surveyed LAP lands. While forest composition varied considerably across the watershed, forest condition was often impacted by past management activities. In many cases, this was a history of high-grading or selective harvesting repeated over time, which leads to reduced species diversity, limits opportunities for successful regeneration, and negatively impacts forest health. Coupled with significant deer herbivory on forest regeneration and the impacts of invasive species, this presents a management concern for the DEP foresters now in charge of these lands.

Forestry staff have been working with the SUNY College of Environmental Science and Forestry on a research project intended to test the results of different silvicultural prescriptions on these high-graded forest lands. The project is also intended to demonstrate the use of adaptive silvicultural techniques to cope with the impacts of climate change on our forest ecosystem and, at the same time, encourage regeneration and greater species diversity.

The site for this dual-purpose study is a large 400-acre City-owned property within the Pepacton Reservoir basin (Thompson Hollow, Middletown). It has a fairly typical past history of high-grading under private ownership. A variety of silvicultural prescriptions, including patch cuts (creating clearings of a few acres), will be used to determine the best management techniques suited for shifting this forest to a diverse, resilient condition most protective of water quality.

Forest Management Projects

DEP's primary vehicle for managing watershed forests owned in fee by the City is through carefully designed timber harvest projects that are made available for public bidding. The individual projects are designed for maximum water quality protection through adherence to conservation practices. These include an in-depth review from DEP staff as representatives to the Forestry Interdisciplinary Technical Team.

Since January 2016, 20 forest management projects (timber harvests) were sold totaling 2,652 acres. Eight of these projects were located on properties acquired by the Land Acquisition Program (LAP) while 12 projects took place on high priority reservoir buffer lands (Table 3.28).

Table 3.28 Forest management projects awarded, 2016-2020.

Year project Awarded	Number of pre-MOA Projects Awarded	Number of LAP Projects Awarded	Acres of pre-MOA projects	Acres of LAP Projects	Total Acres
2016	1	2	171	117	288
2017	0	1	0	138	138
2018	3	1	492	83	575
2019	4	3	561	284	845
2020	4	1	726	80	806
Total	**12**	**8**	**1,950**	**702**	**2,652**

Reservoir buffer lands (also known as pre-MOA lands) have traditionally been the highest priority for forest management due to their proximity to the City's reservoirs and importance for filtering runoff into the water supply system. Most of these lands have also not been actively managed since the City acquired them for construction of the water supply, often leaving them in a degraded or senescent, even-aged, old-aged condition. In addition, the forest management plan and update inventoried over 90,000 acres of land acquired by LAP. This watershed-wide inventory has helped guide forestry projects where overstocking or other forest condition concerns are greatest. The hiring of the new foresters in 2017 and 2018 has allowed the program to develop and implement harvest plans on several of these LAP properties along with the important reservoir buffer projects. It has also resulted in a 43% increase in managed forest acres over the previous five-year period on a third more projects.

As in the prior five-year period, project selection continues to be heavily influenced by ongoing impacts from invasive species, particularly emerald ash borer (EAB) and hemlock wooly adelgid. While other hardwood species have not, ash has retained good stumpage value. This has meant that timber harvests with significant ash salvage have provided enough value to subsidize other necessary thinning and forest stand improvement (FSI) work on the same project.

The Hill and Dale Forest Management Project in the Town of Conesville, Greene County is a good example of this approach. Located on property acquired by DEP in 2010, this 80-acre project contains over 85,000 board feet of white ash that is succumbing to infestation by EAB. More than half of the sale's total predicted volume comes from this tree species. The project lies on moderate slopes on a headwater tributary to the Manor Kill which empties directly into the Schoharie Reservoir about five miles to the west. Maintaining a healthy, resilient forest on these slopes and while protecting water quality is clearly of the utmost importance.

Removal of the ash, which is not evenly distributed across the site, will create canopy openings that will encourage regeneration of a variety of tree species. The same regeneration would be much more limited if the ash were left to die, since the trees would gradually succumb over a prolonged period and any canopy gaps would be quickly filled in by neighboring trees. Additional crown thinning will be conducted across the project site to reduce stocking and, therefore, tree-to-tree competition and to favor a healthy, diverse species mix.

Forest management projects follow slightly different priorities in the City's EOH watershed. The City's ownership of forested buffer around these reservoirs is often very narrow strips of land, and land acquisition projects have been focused in the West Branch, Boyd Corners, and Kensico basins. Combined with a more suburban setting, municipal regulations, high deer numbers, and infestations from many invasive species, this ownership pattern has limited the role of traditional timber harvesting as a tool for managing the City's forest lands.

During this assessment period, EOH foresters made strides in developing an EOH stewardship contract to address forest health issues around the reservoirs through invasive species control, pre-commercial FSI thinning, planting, and protection from deer browse. For the initial phase of this contract, 263 acres along New Croton Reservoir were inventoried with additional FAD basins planned for treatment in subsequent phases. Unfortunately contracting issues followed by COVID-19 impacts forced the deferment of this project in 2020, but it remains a forest management priority once funds and conditions allow.

Continuous Forest Inventory

Since 2002, DEP has been establishing and measuring permanent forest plots across the NYC Water Supply lands. The purpose of the Continuous Forest Inventory (CFI) project is to establish the baseline forest condition and track forest health and productivity, tree diversity, and ecosystem changes occurring over time. The findings are expected to accomplish the following:

- Contribute towards assessing forest functioning.

- Track forest response to climate change.
- Develop mathematical models to predict forest growth, mortality, and recruitment.
- Determine which silvicultural treatments are achieving management goals.
- Increase understanding of forest-habitat relationships for species of concern.

Such long-term ecological assessment studies are helpful to guide decisions that will ultimately lead to healthy, managed, resilient, diverse forests that best protect water quality.

Since 2016, DEP established 115 new CFI plots on newly acquired LAP lands in the Rondout, Neversink, and Pepacton basins, as well as the EOH watershed. DEP also inspected datasets collected on CFI plots from 2002 to 2018 for inconsistencies and made corrections as necessary.

In addition to establishing new CFI plots, some preliminary analyses of the Pepacton, Cannonsville, and Schoharie Basins CFI data were conducted in 2019. These initial steps in the data quality analysis of the long-term database will help inform future modifications to the program.

3.9.9 Invasive Species Management

DEP's invasive species program is guided by an Invasive Species Management Strategy (strategy), submitted as a FAD deliverable in 2016, and an interdisciplinary Invasive Species Working Group (ISWG) made up of DEP staff from across the Bureau of Water Supply and DEP Police. The strategy outlines actions to prevent new introductions of invasive species; detect new infestations early and respond to them rapidly; control and manage existing populations to support specific projects; mitigate the impacts of species that cannot be otherwise managed; and restore sites to prevent further impacts. This work is predominantly accomplished through intra-agency collaboration and partnerships. Some of the accomplishments implemented from the strategy in each of the areas above are highlighted here.

Prevention and Pathway Risk Management

The Invasive Species Management Strategy aims to prevent the introduction of invasive species through policies and rules that minimize the risk of new introductions through DEP's activities and other uses of reservoirs and City lands. The major policy focus over the last five years has been firefighting operations. After several large wildland fires necessitated aerial dipping and scooping in City reservoirs in 2015, DEP developed a Wildland Firefighting Dipping/Scooping Operations Policy during the reporting period requiring firefighting equipment be decontaminated before being used in a reservoir. In this process, DEP identified drafting from reservoirs for traditional firefighting and access to reservoirs by local fire departments for training drills as additional potential vectors for invasive species introductions. Drafting, or pumping water into a tanker truck, could introduce invasive species when water from another waterbody is sent down the hose to prime the pump. Drills may involve the use of boats that have not been decontaminated on the reservoirs. A sub-committee of the ISWG was formed to address this. It has been surveying and meeting with municipal fire departments in the EOH and WOH watersheds since 2018 to ascertain how the departments are using City reservoirs for drafting and training. The results will help develop a comprehensive policy that meets the needs of communities and provides as much protection from aquatic invasive species as possible.

Education and outreach is the other critical piece of DEP's strategy for preventing new introductions of invasive species. DEP installed a boot brush station with signage at the newly created Shavertown trailhead in the Pepacton Reservoir basin in 2018, conducted outreach on invasive species at YMCA Camp Seewackamano in 2017 and 2019, and held many pop-up outreach table events at the Ashokan Promenade and several local farmers markets in support of the statewide Invasive Species Awareness Week each year.

Early Detection and Rapid Response

Hydrilla (*Hydrilla verticillata*), first detected in New Croton Reservoir in 2014, has been the largest rapid response effort undertaken by DEP to date. Working with the Water Research Foundation, DEP convened an expert panel in 2017 to assess the options for *Hydrilla* control. The panel recommended chemical treatment with fluridone or endothall-based herbicides. In 2018, 2019, and June 2020, DEP piloted treatment with fluridone-based herbicides in small isolated coves and along exposed shorelines to see how effective the treatment would be in the reservoir, and to better understand the concentration and distance at which fluridone could be detected outside the treatment area. Results have shown success in reducing the population with limited dispersal of the herbicide, but surveys conducted in 2017, 2018, 2019, and 2020 have shown the expansion and spread of *Hydrilla* throughout much of the reservoir. In October 2020, DEP issued an invitation for bids for a large-scale treatment and survey contract that will include treatment and survey work reservoir-wide in New Croton Reservoir and surveys in 11 other EOH reservoirs.

Additionally, DEP has funded researchers working with the Catskill Regional Invasive Species Partnership that have been studying the use of environmental DNA as a surveillance tool for *Hydrilla* and other aquatic invasive plants in several WOH reservoirs. Although the partnership found some early putative positive results, follow-up work has not indicated there are any *Hydrilla* populations in reservoirs outside of New Croton.

Control and Management

DEP has continued to manage priority invasive plants and insects on City lands through manual and mechanical removal, herbicide applications, and biological control. Student interns from SUNY Ulster conducted manual removal projects for species including Japanese barberry (*Berberis thunbergii*), purple loosestrife (*Lythrum salicaria*), and burning bush (*Euonymus alatus*) on several forest management projects and wetland mitigation projects. Additionally, they worked to control emerging invasive species of interest such as Japanese angelica tree

(*Aralia elata*), pale swallow-wort (*Vincetoxicum rossicum*), and mile-a-minute vine (*Persicaria perfoliata*). Contracted herbicide applicators controlled invasive species on forest management projects in addition to in-house control work by a certified applicator among the forestry staff in 2020. The New York Hemlock Conservation Initiative at Cornell University worked through the DEP Land Use Permit program to release several biological control agents for the hemlock woolly adelgid on City lands around Schoharie and Neversink reservoirs.

Mitigation of Impacts

Since 2018, DEP has participated in a project to identify lingering ash trees. The Ecological Research Institute designed the Monitoring and Managing Ash (MaMA) project with researchers from the U.S. Forest Service. They trained 30 DEP staff and partners on the project and the protocols for identifying and surveying ash trees that may hold some resistance to emerald ash borer (*Agrilus planipennis*). DEP staff and SUNY Ulster interns are now monitoring five ash mortality monitoring plots throughout the WOH watershed. More information about the MaMA project is available at: http://www.monitoringash.org/.

The zebra mussel (*Dreissena polymorpha*) is another species that could have a significant negative impact on the water supply. DEP has taken a proactive approach to zebra mussel prevention and detection in their watersheds since the mid-1990s, including a mandatory boat-washing protocol and a monitoring program. There is no way to control zebra mussels once they are established. However, early detection through these surveillance mechanisms will allow DEP to make necessary infrastructure changes to mitigate the damage they might do to intakes and equipment involved in water distribution. The monitoring program consists of the collection of plankton samples for the free-living larval stage, and the deployment of pre-conditioned PVC and veil material to sample the settling stages of the zebra mussel in the reservoirs. Additionally, after the detection of zebra mussels in Lake Mahopac in 2015, DEP began sampling the downstream Muscoot River before it enters Amawalk Reservoir and found veligers in the Muscoot River and Amawalk Reservoir in 2018. DEP then increased its sampling effort in the Muscoot River and Amawalk Reservoir.

In 2018, pumped veliger samples were collected from seven sites along the Muscoot River twice in August and once in October. In 2019 and 2020, these same Muscoot River sites were sampled monthly and bi-monthly, respectively, from May-September. In 2020, concrete block settling substrate was deployed at the Muscoot River sites from May-October. Reservoir zebra mussel sampling was suspended in 2020 due to COVID-19 restrictions. Preliminary results indicate that larval movement into the Amawalk Reservoir is limited by flow; 2018 was a high flow year. In higher flow conditions, there are greater numbers moving from Lake Mahopac into Amawalk Reservoir. No established populations have been found in Amawalk Reservoir to date. DEP will continue monitoring the Muscoot River.

Restoration

DEP filled a new restoration ecologist position to oversee several restoration projects that are planned or underway, and to develop a program to support invasive species management and forest regeneration. This program will work to strategically address challenges posed by invasive species and other factors limiting forest regeneration. Superstorm Sandy left large blowdowns in close proximity to Kensico Reservoir in 2012. Staff and interns continue annual management of Japanese angelica tree and mile-a-minute vine in these areas throughout the assessment period to support the success of restoration plantings.

Intra-Agency Collaboration

The ISWG was formed within DEP in 2008 to develop and implement a science-based, comprehensive plan to identify, prioritize, and address invasive species threats to the water supply. The ISWG met two or three times annually throughout the assessment period to discuss all agency priorities, emerging research, and policy needs. Sub-committees worked to address specific issues including decontamination protocols for boat motors and the development of a policy for managing reservoir firefighting operations.

Partnerships

New York State Invasive Species Advisory Committee

DEP has a seat on the New York State Invasive Species Advisory Committee (ISAC). ISAC created through state invasive species legislation in 2007 to provide information, advice, and guidance to the New York State Invasive Species Council (ISC) on issues related to invasive species impacts, prevention, regulation, detection, and management in the state. DEP's representative served as chair of the committee until October 2017, when she became vice chair, a position held until 2019. The ISAC covered topics including aquatic invasive species spread prevention; the arrival of the Asian long horned tick (*Heamaphysalis longicornis*), spotted lanternfly (*Lycorma delicatula*) and other species; the NYS Invasive Species Comprehensive Management Plan; and updates to the Part 575 prohibited and regulated species list.

Catskill Regional Invasive Species Partnership

DEP continued to work regionally with partners on invasive species management in the Catskills. In 2019, DEP funded the Catskill Regional Invasive Species Partnership (CRISP) and the Catskill Center to develop an invasive species management plan for the Ashokan Rail Trail. DEP participated in CRISP quarterly meetings, helped develop a five-year strategic plan, served on the steering committee, helped prioritize a species list, and aided in decision-making on project funding.

Lower Hudson Partnership for Regional Invasive Species Management (PRISM)

DEP continued to partner with the Lower Hudson PRISM and NYSDEC to survey for giant hogweed (*Heracleum mantegazzianum*) within the watershed. As of 2018, giant hogweed has not been detected on City lands after a 10-year effort to control it. Due to the risk of serious injury and blindness from contact with the plant, the state has been working to eradicate Giant Hogweed since 2008. DEP and the Lower Hudson PRISM are also partnering on the removal of silver vine (*Actinidia polygama*), an early detection species for New York State that crosses City and private lands in Westchester County. DEP served on the PRISM steering committee from 2017 to 2019 and facilitated working groups for capacity building tasks.

3.10 Environmental Infrastructure Programs

3.10.1 WWTP Regulatory Upgrade Program

Under the MOA, DEP agreed to fund the eligible costs of designing, permitting, and constructing upgrades of all non-City-owned WWTPs in the watershed. For the purposes of this program, upgrades mean equipment and methods of operation that are required solely by the Watershed Rules and Regulations (WR&R), and not by federal or state law. DEP completed all WWTP upgrades required under the FAD.

Since the City is obligated to pay for capital replacement of watershed equipment and methods, DEP entered into a Capital Replacement Agreement with the NYS Environmental Facilities Corporation (EFC) in 2015. In 2018, EFC opted to conclude their involvement in the Capital Replacement Program and so, in 2019, DEP entered into an agreement with NEIWPCC to manage this program. In 2020, DEP worked with NEIWPCC to develop the necessary program documents and participation agreements.

During the reporting period, neither EFC nor NEIWPCC made payments to WWTPs for replacement of watershed equipment. Minor equipment (e.g. filter cartridges, pumps) is replaced as needed in order to ensure the facility functions properly and in accordance with the WR&R. DEP is able to directly fund the replacement of minor equipment under established operations and maintenance (O&M) agreements with each WWTP owner.

3.10.2 Septic System Rehabilitation and Replacement Program

Residential Septic System Rehabilitation and Replacement Program

The Septic System Rehabilitation and Replacement Program provides for pump-outs and inspections of septic systems serving single or two-family residences in the WOH watershed, upgrades of substandard systems, and rehabilitation or replacement of systems that are failing or reasonably likely to fail in the near future. The Catskill Watershed Corporation (CWC) administers the septic program. The total City funding commitments for the program have been over $167 million since 1997.

Historically, the septic program has been an inspection and remediation program implemented in a prioritized fashion according to potential impact to the City's water supply. The program initially targeted the 60-day travel time area, followed by areas within defined limiting distances from streams. These priority areas include: 1A (sub-basins within 60-day travel time to distribution that are near intakes), 1B (sub-basins within 60-day travel time to distribution that are not near intakes), P3 (within 50 feet of a watercourse), P4 (between 50 feet and 100 feet of a watercourse), P5 (100 to 150 feet), P6 (150 to 200 feet), P7 (200 to 250 feet); P8 (250 to 300 feet); and P9 (300 to 700 feet). After CWC completed solicitation of homeowners in the aforementioned priority areas, CWC opened the program to the entire WOH watershed in July 2018 and it remains available to all residential property owners. The program has been successful in eliminating pollution from a large number of failing septic systems, many located along streams and in 60-day travel time areas.

In 2019, DEP and CWC amended the program to allow a septic system to be repaired more than once. Under this new provision, the CWC Board of Directors may authorize repeat repairs to occur only after a period of time from the date of construction completion and absent misuse by the property owner. Misuse may include failure to maintain the system, failure to maintain the integrity of an absorption field, or overuse of the system. As part of consideration of such an application, CWC may require an applicant to submit additional documentation, including records of prior maintenance and metered water usage.

In implementing the residential program, CWC solicits homeowner interest and conducts inspections to determine whether systems are functioning properly. Program elements include the following:

- 100% funding to primary residents for eligible costs
- Cost-share (40%) for non-primary residents
- Remediation process managed by home owner.
- Design and construction payments are based upon CWC Schedule of Values.
- CWC staff presence on-site to provide input into repair/replacements.

Table 3.29 shows the number of septic systems managed or remediated from 2016 to 2020. From 1997 through December 2020, 5,913 septic systems were repaired, replaced, or managed under the septic program.

Table 3.29 Number of septic system remediations, 2016 to 2020.

Year	Septic System Remediations
2016	246
2017	177
2018	201
2019	240
2020	261

Expanded Septic System Rehabilitation and Replacement Program

Previously titled the Small Business Septic System Rehabilitation and Replacement Program, the Expanded Septic System Rehabilitation and Replacement Program provides funding to reimburse non-residential properties in the Catskill/Delaware watershed for repairs to septic systems. Pursuant to the 2017 FAD, DEP expanded the program to include governmental entities and not-for-profit organizations, in addition to small businesses. Through CWC, eligible businesses with 20 or fewer employees, not-for-profit organizations with five or fewer locally based employees and governmental entities are reimbursed for 100% of the cost of septic repairs and qualifying modifications and expansions. Additionally, for small businesses with 21 or more employees and not-for-profit organizations with six or more locally based employees, the program provides 75% of the costs of repairs and qualifying modifications up to $100,000 for a single system and 100% of any cost over $100,000. The applicant remains responsible for securing an approved DEP design for the construction of the septic system remediation. Between 2016 and 2020, 11 septic remediations have been completed with program funding, bringing the total remediated to 29 since the program's inception in 2008.

Cluster System Septic System Program

Established in 2011, the Cluster Septic System Program funds the planning, design, and construction of cluster systems in 13 communities in the WOH watershed. Eligible communities may elect to establish districts that would support cluster systems and tie multiple properties to a single disposal system. This enables communities to locate disposal systems on larger sites in areas where existing structures were sited on insufficiently sized lots. In 2019, DEP provided $1 million to the program to allow for O&M costs for communities that implement a cluster system project.

When a septic failure occurs within a cluster area, CWC notifies the municipality of the program and the municipality determines whether to continue to the assessment phase. Since program inception, CWC contacted the towns of Middletown, Neversink, Olive and Shandaken due to septic failures identified in the cluster areas at Clovesville, Neversink, Woodland Valley Road, Travers Hollow, and Shokan. During the reporting period, CWC notified the Town of Middletown of septic failures within the Clovesville cluster septic area. Although septic failures were identified in these cluster system areas, no community elected to address the failures through a cluster septic system and so the failed septic systems were addressed by CWC.

3.10.3 Septic Maintenance Program

Proper septic maintenance is important in prolonging the life and efficiency of a septic system. The key component to avoiding septic failure is periodic tank pumping. Without periodic pumping, sludge and scum layers become too thick and solid materials may flow from the septic tank into the leach field, clogging the pipes and soils and causing system failure. Routine maintenance prevents groundwater pollution and surfacing effluent. While the cost of repairing or replacing a septic system can be expensive, the effort and expense of routine maintenance is relatively minor.

The Septic System Maintenance Program, funded by DEP and administered by CWC, is a voluntary program originally open to homeowners who constructed new septic systems after 1997 or participated in the septic repair program. It is intended to reduce the occurrence of septic system failures through regular pump-outs and maintenance. As part of the program, CWC also develops and disseminates septic system maintenance educational materials.

To participate in the program, the septic system owner contacts CWC to obtain an inspection checklist and a reimbursement form. The homeowner then contracts with a licensed septage hauler to have the septic tank pumped. The hauler completes and signs the CWC inspection checklist. The septic system owner pays the hauler, and then submits the signed checklist and completed reimbursement form to CWC along with a copy of the contractor's invoice and proof of payment. CWC reimburses the septic system owner 50% of eligible costs for pump-outs and maintenance. In 2019, the program was expanded and made available to small businesses, not-for-profits, and governmental entities. Table 3.30 shows participation in the program between 2016 and 2020.

Table 3.30 Septic Maintenance Program participation 2016-2020

Year	Number of septic pump-outs
2016	261
2017	263
2018	308
2019	340
2020	504

Since program inception in 2004, 3,127 septic system owners have been paid 50% of eligible costs for septic system pump-outs and maintenance. The number of septic pump-outs has increased every year for the past 10 years.

3.10.4 Sewer Extension Program

The Sewer Extension Program concluded in 2016. Prior to conclusion, DEP funded the design and construction of wastewater sewer extensions connected to City-owned WWTPs discharging in the WOH watershed. The goal of this program was to reduce the number of failing or potentially failing septic systems by extending the WWTP service to priority areas. Under the program, DEP previously completed projects in the towns of Roxbury (Grand Gorge WWTP), Hunter-Haines Falls (Tannersville WWTP), Neversink (Grahamsville WWTP), and Hunter-Showers Road (Tannersville WWTP).

During the reporting period, DEP completed sewer extension projects in Shandaken (Pine Hill WWTP) and Margaretville/Middletown (Margaretville WWTP). Following construction certification, DEP authorized the Town to commence connection of the sewer laterals, which are now also complete.

3.10.5 Community Wastewater Management Program

The Community Wastewater Management Program (CWMP), funded by DEP and administered by CWC, is a voluntary program that provides for the design and construction of community wastewater systems, including related sewerage collection systems, and/or the creation of septic maintenance districts in identified WOH communities where there is a perceived potential threat to water quality posed by failing and likely to fail septic systems.

Prior to 2016, completed CWMP projects included Bloomville, Boiceville, Hamden, DeLancey, Bovina, Ashland, and Trout Creek. Remaining CWMP projects at the beginning of 2016 included: Lexington, South Kortright, Shandaken, West Conesville, Claryville, Halcottsville, and New Kingston. In total, four CWMP projects were completed during the reporting period (Table 3.31).

Table 3.31 Completed CWMP projects 2016 to 2020.

Community	Project	Flow (gpd)	Septics displaced	Date completed
Lexington	Community Septic System	25,000	61	2016
South Kortright	Pump to Hobart WWTP	20,000	38	2016
Shandaken	Septic Maintenance District	20,000	71	2020
Claryville	Septic Maintenance Districts	37,000	99	2020

The following summaries highlight the accomplishments of the program that were made during the past five years. Pursuant to the 2017 FAD, a wastewater project was proposed for the Shokan hamlet and reporting on that project is included here.

<u>Lexington – Community septic system with pre-treatment</u>

DEP issued a $9,100,000 block grant for a community septic system project in 2012. The approved design flow for the community septic is 25,000 gallons per day (GPD). DEP issued Functional Completion Acceptance for the system in July 2016 and the contractor completed lateral connections and tank installations by the end of 2016. The project is complete.

<u>South Kortright – Sewer collection system and connection to the Hobart WWTP</u>

The $5.7-million South Kortright CWMP project consists of a new conventional sewer system connected to an existing pump station with collected sewage pumped approximately 6 miles to the Village of Hobart WWTP for treatment. The approved design flow for the project is 20,000 GPD. As part of the project, the Hobart WWTP was upgraded to handle the additional flow from South Kortright. DEP issued functional completion acceptance authorizing lateral connections in June 2016. The contractor completed lateral connections in the summer of 2016. The project is complete.

Shandaken – Septic maintenance district

DEP approved the Septic Maintenance District project and a block grant of $6.77 million in May 2017. The project includes 73 properties and an aggregate wastewater flow of approximately 20,000 GPD. The town passed a resolution to proceed with the pre-construction phase of the project in September 2017. DEP issued design approval for the project on September 2019. The town awarded the bid to Evergreen Mountain Contracting, who commenced construction in December 2019. DEP issued construction acceptance for the 24 onsite systems in September 2020. CWC provided the remaining block grant funds of over $5.6 million to the Town of Shandaken in October 2020. The project is complete.

West Conesville – Community septic system

DEP approved the project and block grant of $8,411,000 in July 2017. The approved design flow for the project is 15,000 GPD. The town passed a resolution to proceed to the pre-construction phase of the project in October 2017. DEP issued design approval for the project in March 2020. Evergreen Mountain Contracting is the general contractor for the project and commenced construction of the project at the remote leach field site. Evergreen installed the sand beds, framed the building, and completed a large portion of the directional drilling. The contractor anticipates completing remaining work in 2021.

Claryville – Septic maintenance districts in Denning and Neversink

DEP approved a block grant of $8,655,000 for Claryville in April 2017. The project serves 130 properties (59 in the Town of Denning and 71 in the Town of Neversink) with an aggregate flow of approximately 37,000 GPD. The project consists of septic maintenance districts in two separate towns in two counties. The Town of Denning's portion of the project is $3,760,000 and the Town of Neversink's portion of the project is $4,895,000. The Town of Denning passed a resolution to proceed to the pre-construction phase in July 2017 and the Town of Neversink passed a similar resolution in August 2017. DEP issued design approvals for Denning and Neversink in January and May 2019, respectively. The Town of Denning awarded Delaware Bulldozing the construction contract for the 24 septic system remediations. The Town of Neversink awarded the contract for construction of the nine septic system remediations in Neversink to Polely Construction. DEP issued construction acceptance letters for Denning and Neversink in January and September 2020, respectively. Following project completion, CWC provided the $7.4 million balance of block grant funding to the towns in October 2020.

New Kingston – Community septic system

DEP approved a block grant of $5.2 million for a 9,000 GPD community septic system in October 2018. Residents of the hamlet passed a permissive referendum in favor of the project in June 2019 and the town passed a resolution to enter the pre-construction phase in February 2020. In March 2020, the WAC Easement Committee denied the town’s subdivision request on the property necessary for the community septic system. Work continues on obtaining the land that is needed for the project. In July 2020, the town board held a public hearing to consider the acquisition of land that is under the WAC easement through eminent domain. DEP provided comments on the 65% design drawings in December 2020 and the pre-construction phase is ongoing as of the end of 2020.

Halcottsville – Sewer collection system with connection to Margaretville WWTP

DEP approved the block grant of $8,954,000 in September 2017. The project is a large-diameter gravity sewer with pump station and force main connecting to the New York City-owned Margaretville WWTP with a design flow 14,075 GPD. The Town of Middletown adopted a resolution in December 2018 to proceed to the pre-construction phase. The project engineer submitted the 65% design drawings and facility plan for the project to DEP in June 2020 and the 95% design drawing in December 2020. In December 2020, the town completed the land purchase agreement for the property where the pump station will be located. The pre-construction phase is ongoing as of the end of 2020.

Shokan – MBR WWTP treating combined flow from Shokan and Boiceville

DEP approved the project and block grant of $48,715,000 in August 2020. This amount is roughly double the funding in the program agreement. CWC and the City will need to amend the Shokan contract to add the additional funding. The project would be a collection system in Shokan and the transmission of flow from the Boiceville WWTP to a new membrane bioreactor WWTP in Shokan. The combined flow from the hamlet of Shokan and the hamlet of Boiceville is 243,000 GPD. The Town of Olive passed a resolution to proceed to the pre-construction phase in October 2020. CWC anticipates completing the pre-construction phase in early 2021 and completing it in 18 months to two years.

3.10.6 Stormwater Programs

Stormwater Retrofit Program

Jointly administered by CWC and DEP, the Stormwater Retrofit Program provides funding for the design, permitting, construction, and maintenance of stormwater best management practices to address existing stormwater retrofit runoff in concentrated areas of impervious surfaces. Since its inception, DEP has committed over $27 million for capital, operation and maintenance, and community-wide stormwater infrastructure assessment and planning initiatives.

Planning and assessment projects provide a basis for future capital construction projects. From 2016 through 2020, four planning and assessment project were completed. CWC also updated their program database to more accurately reflect the number of projects completed since program inception. To date, a total of 19 planning and assessment projects have been completed.

During the period 2016 through 2020, 14 stormwater retrofit projects totaling nearly $4.4 million were completed (Table 3.32). During the reporting period, DEP and CWC approved a vacuum truck for Delaware County and a street sweeper for the Village of Delhi, as well as retrofits at the South Kortright Central School, Windham Theatre, and Lake Street in the Village of Fleischmanns.

Table 3.32 Completed stormwater retrofit projects 2016-2020.

Applicant	Funding
Ashokan	
Ulster County – Glenford-Wittenberg Rd.	$159,538.98
Shandaken Highway Garage design	$17,509.59
Cannonsville	
Delaware Valley Hospital	$265,949.50
Delaware County vac truck 2	$553,983.88
South Kortright Central School	$731,744.01
Village of Delhi street sweeper 2	$220,174.00
Delhi Riverwalk Phase I	$31,823.12
Pepacton	
Margaretville Central School	$395,578.59
Roxbury (T) Lake Street	$1,352,965.92
Schoharie	
Hunter Foundation	$75,780.12
(T) Lexington – Hamlet of Lexington	$177,719.64
Windham Theatre	$18,214.40
Greene County sweeper/vac truck 2	$205,070.00
Windham Theatre	$172,470.40

Future Stormwater Controls Programs

The Future Stormwater Controls Programs pays for the incremental costs of stormwater measures required solely by the New York City WR&R above state and federal requirements in stormwater pollution prevention plans and individual residential stormwater plans for new construction after May 1, 1997.

There are two separate programs developed to offset additional compliance costs incurred as a result of the implementation of the City's WR&R. Since 1997, DEP and CWC have worked cooperatively on the Future Stormwater Controls Program (MOA 128) and the Future Stormwater Controls Paid for by the City (MOA 145) Stormwater Programs.

The $31.7 million MOA 128 Program administered by CWC reimburses municipalities and large businesses 100% and small businesses 50% for eligible costs. In 2019, DEP provided CWC with an additional $4,720,869 in funding for the program. Through 2020, CWC has paid over $9 million under the MOA 128 Program for eligible incremental costs for stormwater controls required by the WR&R. Pursuant to the terms of the MOA, CWC has also transferred over $17 million to other eligible watershed protection programs.

The MOA 145 Program reimburses low income housing projects and single-family home owners 100% and small businesses 50% of eligible costs. DEP managed this program since the 1997 MOA. During negotiations on the 2017 FAD, DEP and CWC agreed that CWC could directly manage and administer the MOA 145 Program in the WOH watershed in a manner that could enhance the benefit of the program to the watershed community. The intended benefits include having all stormwater funding programs administered by one agency. Accordingly, DEP transferred administration of the MOA 145 Program to CWC in 2018. DEP provided $2.5 million in initial MOA 145 funding to CWC and is committed to providing adequate funding for the program, as needed. Through 2020, CWC has paid over $800,000 for eligible incremental costs under the MOA 145 Program.

Local Technical Assistance

Grant proposals for Local Technical Assistance Program (LTAP) funding are jointly evaluated by CWC and DEP. The program budget is $1.75 million and provides funding for eligible projects that support watershed protection and community planning to improve water quality in the watershed and enhance the quality of life in watershed communities. Since program inception, 35 LTAP projects have been completed. Two LTAP projects were completed for the period 2016-2020 (See Table 3.33).

Table 3.33 Completed Local Technical Assistance Projects 2016-2020.

Applicant	Project	Funding
Town of Roxbury	Generic Environmental Impact Statement	$40,027.82
Town of Roxbury	Inventory and Comprehensive Plan	$23,877.07

In December 2014, CWC established the Sustainable Communities Planning Program and allocated $150,000 in LTAP funding for towns or villages that completed a Local Flood Analysis (LFA). The money was for developing a new or updating an existing comprehensive plan to identify areas for relocations of residences or businesses that participate in the City-funded Flood Buyout Program.

Two municipalities received funding from CWC and conducted flood relocation studies during the past five years: Lexington and Olive. CWC awarded $20,000 to the Town of Lexington in November 2016 to study relocating structures out of flood hazard areas in the hamlet as part of a hamlet revitalization strategy. The town completed the study in 2019. CWC awarded $20,000 to the Town of Olive in October 2017 to study relocating structures out of flood hazard areas in the hamlet of Boiceville as part of the "Boiceville Feasibility Study and Community Planning." The town completed the study in 2019.

3.11 Kensico Water Quality Control Program

Kensico Reservoir, located in Westchester County, is the terminal reservoir for the City's Catskill/Delaware water supply system. Because it provides the last impoundment of Catskill/Delaware water prior to entering the City's distribution system, DEP has prioritized watershed protection in the Kensico basin.

3.11.1 Wastewater-Related Nonpoint Source Pollution Management Programs

Septic Reimbursement Program

DEP initiated the Kensico Septic System Rehabilitation Reimbursement Program to reduce potential water quality impacts that can occur through failing septic systems. The program is implemented through NYSEFC and provides funding to reimburse a portion of the costs to rehabilitate eligible failing septic systems or connect those systems to an existing sewage collection system. The program is voluntary, with the goal of encouraging property owners to have their septic systems inspected and, if failing, rehabilitated (see Figure 3.19). All residential systems in the Kensico Basin are eligible.

Figure 3.19 Installation of new septic fields at 6 Byram Meadows Road, Mount Pleasant.

Since inception in 2008, a total of 27 systems have been rehabilitated in the Kensico Reservoir basin with nine of those repairs completed between 2016 and 2020. The total amount reimbursed since inception is over $275,000, with approximately $93,000 reimbursed between 2016 and 2020. DEP ensures that NYSEFC has available funding to reimburse septic system rehabilitations as needed.

DEP continues to make residents aware of available funding through annual direct mailings to over 700 eligible properties (Figure 3.20). The mailings include information about the program and NYSEFC contact information. DEP in 2018 contacted key staff in towns and local health departments to remind them of the availability of funding through the program. DEP also placed informational flyers with program contact information in key locations in eligible towns such as town halls and libraries.

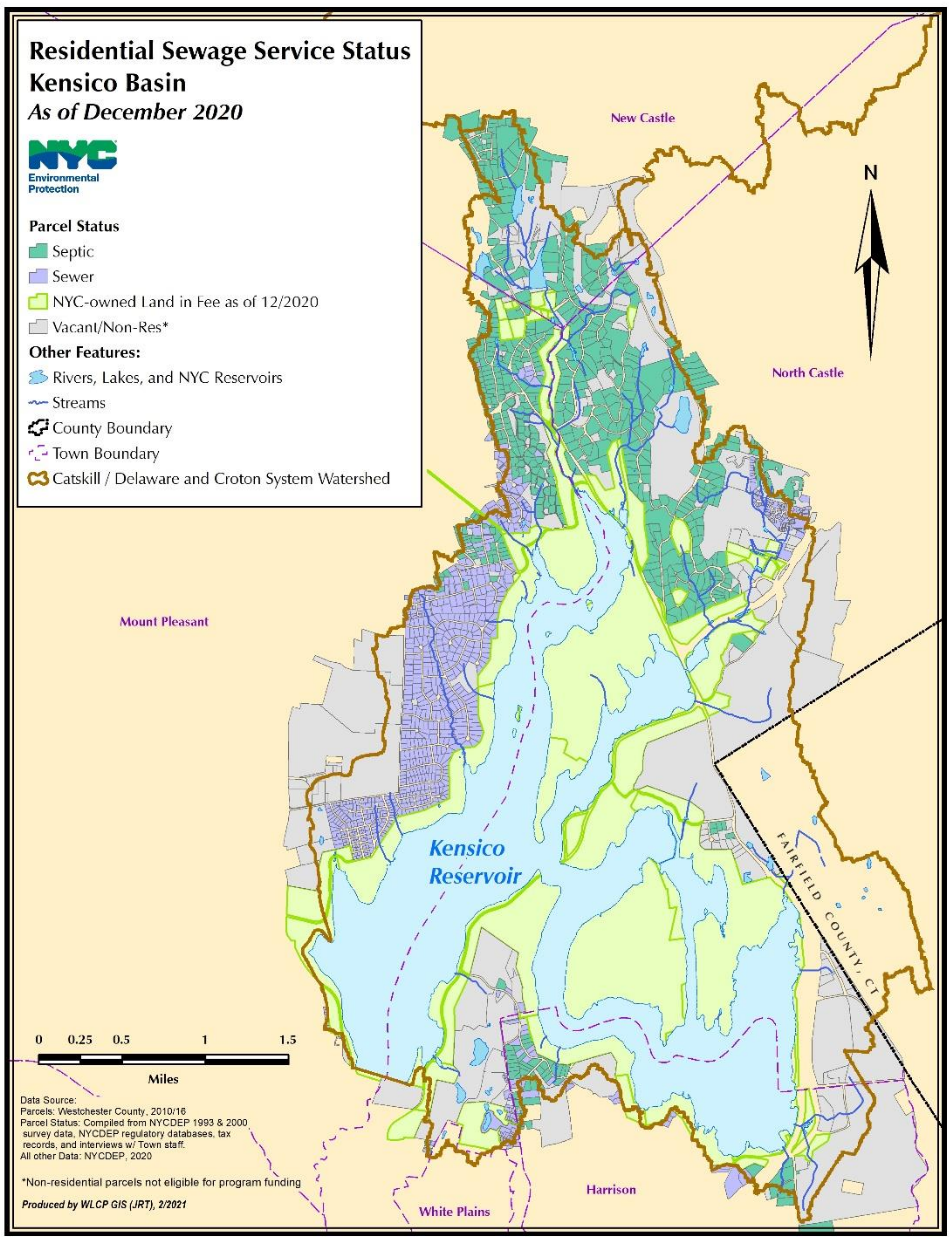


Figure 3.20 Sewer service status of residential parcels in the Kensico Reservoir Basin

West Lake Sewer

The West Lake sewer trunk line, owned and maintained by the Westchester County Department of Environmental Facilities (WCDEF), conveys untreated wastewater to treatment facilities located elsewhere in the county. Defects or abnormal conditions within the sewer line and its components could possibly lead to exfiltration or overflows of wastewater, a serious issue given the proximity of the collection system to Kensico Reservoir. The intent of this program is to work with Westchester County to mitigate risks posed by the line while maintaining collection system access and gravity flow.

DEP previously funded the installation of a Smart Cover sanitary sewer remote monitoring system for the trunk line to provide real-time detection of problems such as leaks, system breaks, overflows, and blockages. WCDEF continues to provide operational and maintenance support, including battery replacement, as necessary. There have been no overflows or concerns to date and the units appear to be working well.

Additionally, DEP visually inspects the trunk line annually to assess the exposed infrastructure, including manholes, for irregularities. The most recent annual full inspection was performed in October 2020. No defects or abnormalities were noted during the 2016-2020 reporting period.

Video Inspection of Sanitary Sewers

DEP established an inspection program for targeted portions of the sanitary sewer system located within the Kensico Reservoir basin. These selected areas, identified as possible areas of concern over the past few years and during prior video inspection of sanitary infrastructure, will be submitted as part of a summary report, which compiles the information obtained as part of the sewer inspection and mapping of the sanitary lines. DEP opened bids for this service in January 2020 and issued a recommendation for award in June 2020. DEP's contractor is anticipated to commence work in early 2021.

3.11.2 Stormwater-Related Nonpoint Source Pollution Management Programs

BMP Inspection and Maintenance

DEP has constructed 47 stormwater management and erosion abatement facilities throughout the Kensico watershed to reduce pollutant loads to the reservoir. DEP and its contractor inspected and maintained these facilities, shown in Figure 3.21, throughout the 2016 to 2020 reporting period, according to the O&M guidelines. Maintenance consisted of grass mowing, vegetation removal, tree removal, fence repair, and sediment and debris removal. All BMPs are performing as designed.

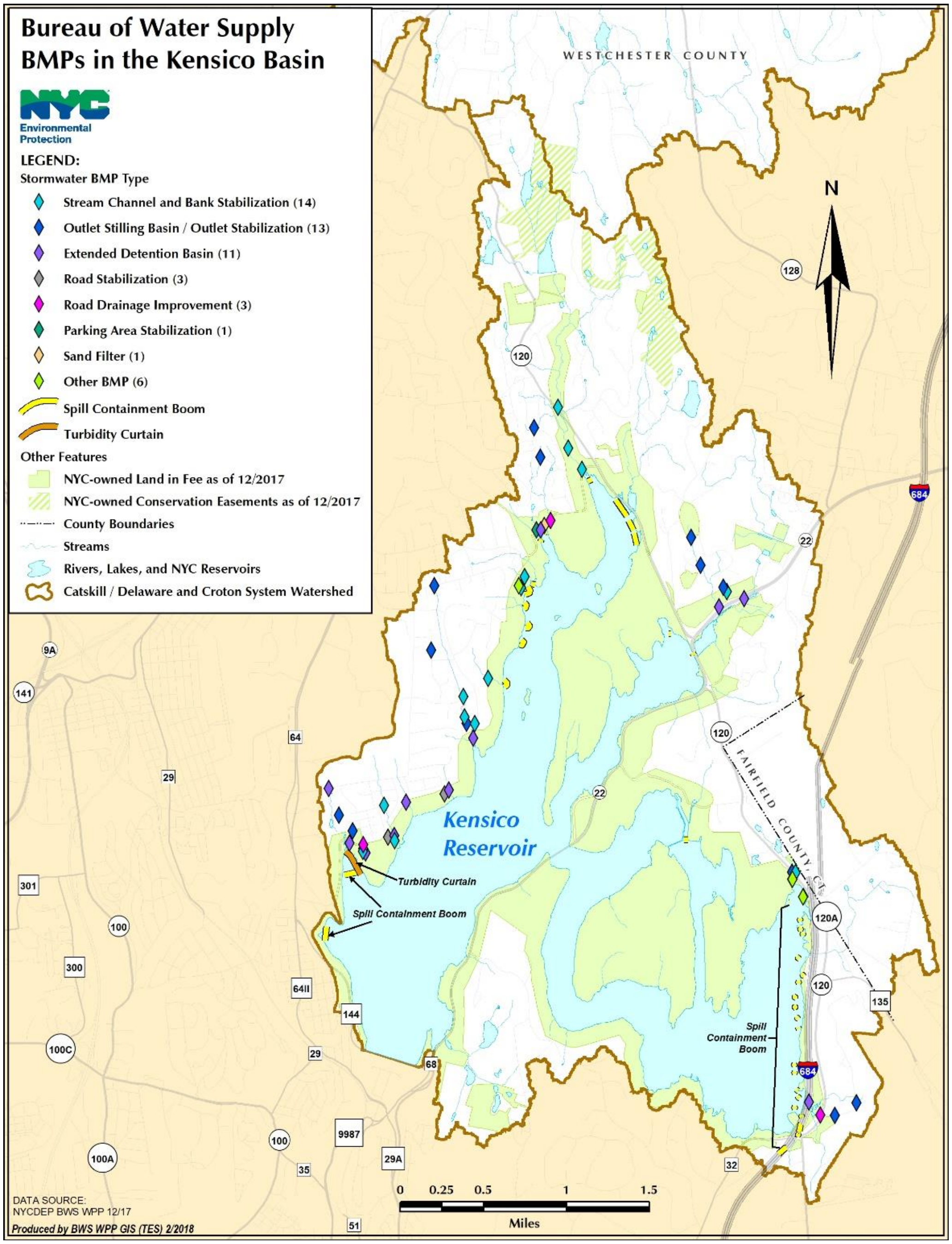


Figure 3.21 BMPs within the Kensico Reservoir Basin.

Spill Containment Facilities

DEP maintains spill containment facilities in and around Kensico Reservoir to improve spill response and recovery, and to minimize water quality impacts in case of a spill. Throughout the five-year reporting period, DEP conducted routine maintenance at the spill boom sites as necessary to ensure they are available in the event of a spill.

During the reporting period, there were no spills that required the deployment of booms. Minor events are noted below.

- December 2018 – Two gallons of petroleum were released into a tributary of Kensico Reservoir. Oil was removed using hydrocarbon absorbents.
- March 2019 – An unknown amount of diesel fuel spilled into a stormwater drain inlet that drains into a Kensico tributary. The fuel was contained and removed using hydrocarbon absorbent material.
- August 2020 – A quart of hydraulic oil leaked from the steering mechanism of a boat into the Kensico Reservoir. No oil was detected in the water and the boat was removed and repaired.
- September 2020 – Three ounces of hydraulic oil were released into the reservoir during a boat launch. The leak was stopped immediately and the impacted area on the boat ramp was addressed with hydrocarbon absorbent pads.

Turbidity Curtain

DEP continues to monitor and inspect the extended primary curtain and the back-up turbidity curtain that are designed to direct flows from Malcolm and Young brooks farther out to the body of Kensico Reservoir. During the reporting period, DEP replaced a 200-foot-long portion of the back-up turbidity curtain. Based on the most recent inspection, no additional repair work was required and the curtains appear to be functioning as intended.

Dredging Assessment

The Catskill Upper Effluent Chamber is situated along the shore of a cove in the southwest section of Kensico Reservoir. Since the Catskill/Delaware Ultraviolet Disinfection Facility (CDUV) began operating, this chamber has been off-line. As part of the Catskill Aqueduct pressurization project, DEP is assessing the intake structure and evaluating the possible need for removing sediment at the effluent chamber. DEP has secured a consultant to complete the assessment and provided bathymetric data for the cove that was collected by USGS. In order to complete the assessment of the entire cove, the consultant collected additional measurements along the shore where the reservoir was too shallow for USGS to collect data. The consultant also deployed divers in the cove to complete a visual inspection. The diving work was delayed due to COVID-19 but was completed in November 2020. Additionally, the consultant will be using bathymetric information of the entire reservoir in effort to develop a sediment model. The consultant anticipates completing the report assessing the need for dredging in the second half of 2021.

Shaft 18 Shoreline Stabilization

Since the CDUV began operating, all water in Kensico Reservoir flows through the Delaware Aqueduct Shaft 18 on the reservoir's southeast shore. Increased reliance on Shaft 18, together with changing weather patterns, necessitates shoreline stabilization measures near the effluent chamber to maintain turbidity levels in compliance with state and federal water quality standards.

DEP hired an engineering firm to study and design a project to stabilize the shoreline on both sides of Shaft 18. The firm completed a basis of design report for shoreline stabilization and protection measures of approximately 700 feet at the western shoreline and approximately 475 feet at the cove area (Figure 3.22).

Between 2015 and 2018, DEP finalized the project design, submitted required permit applications, and solicited bids for construction. In June 2018, DEP issued a commence work order and the contractor commenced mobilization. Initial work at the cove involved placement of turbidity curtains within the reservoir, installation of erosion control measures, site clearing, installation of sheet pile cofferdams and site dewatering (Figure 3.23). Following site prep, the contractor placed rip rap by machine below the water level and by hand above the water level. DEP completed work at the cove in September 2020 (Figure 3.24). The contractor began moving equipment and materials to the western shoreline in late summer 2020 and anticipates beginning construction in December 2020.

Westchester County Airport

The Westchester County Airport is located east of Kensico Reservoir in close proximity to Rye Lake. Because of the airport's closeness to the reservoir, DEP continues to review any activities being proposed at the airport. Below is a summary of DEP's review during the reporting period.

In 2016, DEP reviewed the draft Westchester County Airport Lease Agreement between Westchester County and Empire State Airport Holdings, LLC. While DEP did not assert a legal role with regard to the proposed lease, DEP advised the parties of DEP's regulatory authority over land development or facility expansion that may result from a finalized lease agreement. In 2018, DEP attended a number of public hearings held by Westchester County on the economic impacts, environmental concerns, and overall safety at the airport. In 2019, Westchester County issued a request for proposals that is intended to supplement the Airport Master Plan by seeking alternatives to improve safety and environmental performance relative to stormwater issues and handling of deicing fluid. The resulting documentation will be completed in accordance with the New York State Environmental Quality Review Act (SEQRA). It will identify and evaluate all potentially significant environmental impacts and proposed mitigation resulting from the implementation of the specific components of an updated Airport Master Plan.

Park Place at Westchester is a private 980-space parking garage proposed at 11 New King Street in the Town of North Castle. DEP has provided comments on the project through the

SEQRA process that has been ongoing since 2008 and which included a 2017 final environmental impact statement. DEP continues to review a SWPPP application required

Figure 3.22 Overview of shoreline stabilization improvements at Shaft 18.

pursuant to the WR&R and awaits submission of a revised plan in response to DEP's February 2019 Notice of Complete Application and March 2019 technical comments.

Figure 3.23 View of cove during installation of sheet piling.

An uncapped landfill was identified at the airport in 2015. Since then, Westchester County has performed sampling and laboratory analysis of groundwater, surface water, landfill soils, and accumulated iron flocculent. Results of soil samples collected from eight test pits excavated within the landfill indicated exceedances for certain metals and mercury. It remains DEP's understanding that NYSDEC, the NYS Attorney General's Office, and Westchester County continue to work cooperatively on a Site Characterization Work Plan and, ultimately, a remediation plan.

In accordance with a May 2019 NYSDEC Consent Order, Westchester County prepared a Site Characterization Work Plan to assess PFOS, PFOA, and other groundwater contaminants both on and in the vicinity of the airport and applied for acceptance into the state's Brownfield Cleanup Program. DEP received public notice of the application and formally submitted comments to NYSDEC in July 2020. DEP noted in those comments that it is of utmost importance to determine the extent to which groundwater contamination may be migrating from the airport toward Kensico Reservoir. DEP also urged NYSDEC to evaluate and implement the most effective remedial measures to address on-site contamination and prevent migration of those contaminants.

Figure 3.24 View of cove following placement of rip rap.

3.12 East of Hudson Non-Point Source Pollution Control Program

The East of Hudson (EOH) Nonpoint Source Pollution Control Program seeks to address nonpoint pollutant sources in the four EOH Catskill/Delaware watersheds (West Branch, Croton Falls, Cross River, and Boyd Corners). The program supplements DEP's existing regulatory efforts and nonpoint source management initiatives.

3.12.1 Wastewater-Related Nonpoint Source Pollution Management Programs

Septic Programs East of Hudson

DEP supports Westchester and Putnam counties in their efforts to reduce the potential impacts of improperly functioning or maintained septic systems. Westchester County, Putnam County, and their respective municipalities continue to implement the septic requirements of the NYSDEC MS4 General Permit, which obligates municipalities and counties to implement programs for the regular inspection, maintenance, and rehabilitation of all septic systems.

DEP previously established a Septic System Rehabilitation Reimbursement Program in priority areas of the West Branch and Boyd Corners reservoir basins to reduce potential water quality impacts that can occur through failing septic systems. The program provides up to 50% reimbursement for home owners to rehabilitate deficient septic systems or to connect their homes to an existing sewage collection system. Residents with a demonstrated financial hardship may have their share of the project cost reduced to 25%. The New York State Environmental Facilities Corporation (EFC) administers the program and implements it based on the potential risk a failing septic system might have on reservoir water quality.

In 2016, DEP expanded the program to include priority areas within the Croton Falls and Cross River Reservoir basins. In 2019, DEP further expanded the program to include priority areas upstream and hydrologically connected to the Croton Falls Reservoir basin. The program in these areas provides funding to owners that demonstrate financial hardship and reimburses up to 75% of the costs to repair eligible failing septic systems or connect those systems to a sewage collection system.

Between 2016 and 2020, the program issued reimbursements for 31 septic repairs throughout the EOH Program area. Of the total 31 repairs, 23 were in the West Branch and Boyd Corners reservoir basins with the remaining eight in the Cross River, Croton Falls, and upstream, hydrologically connected basins.

DEP continues to make residents in eligible areas aware of available funding through annual direct mailings to all eligible residents. The mailings include information about the program and EFC contact information. In addition, as part of its outreach efforts in 2018, DEP contacted key staff in towns and local health departments to remind them of the availability of funding and to describe the program. DEP also placed informational flyers with program information in key locations in eligible towns such as town halls and libraries.

EOH Community Wastewater Planning Assistance Program

The 2017 FAD requires DEP to develop and administer a grant program to provide funding to municipalities for preliminary planning for community wastewater solutions for areas in the EOH FAD basins where poorly functioning individual septic systems can possibly impact water quality.

Based on preliminary studies conducted by NYSDEC, the 2017 FAD identified the following areas to be studied: 1) Areas surrounding Lake Waccabuc, Lake Truesdale, and Lake Kitchawan in the Cross River Reservoir basin; and 2) Palmer Lake, Lake Gilead, Lake Casse, Lake View Road, and Mud Pond Brook in the Croton Falls Reservoir basin. Grant funds provided by DEP will be used to finance engineering studies and reports to assist identified municipalities in evaluating wastewater treatment options/solutions that could mitigate water quality impacts. The reports are intended to be used by the municipalities to appropriately plan and determine costs for the identified wastewater solution project so municipalities may seek financing through state or federal funding sources.

In 2018, DEP with NYSDOH approval identified NEIWPCC as the appropriate organization to administer the grant program. In 2019, DEP registered a $3.3-million contract with NEIWPCC for program implementation. In 2020, NEIWPCC entered into contracts with the identified municipalities for engineering studies in all eight identified lake communities. As of December 2020, the identified municipalities finished soliciting engineering services through a competitive RFP process and entered into contracts with the selected engineering firms to complete the wastewater studies in all required lake communities. The contracts between NEIWPCC and the identified municipalities call for completion of final engineering reports by December 2021.

Video Sanitary Sewer Inspections

DEP has established an inspection program for targeted portions of the sanitary sewer system located within the West Branch and Croton Falls reservoir basins. These selected areas, identified as possible areas of concern over the past few years and during prior video inspection of sanitary infrastructure, will be submitted as part of a summary report, which compiles the information obtained as part of the sewer inspection and mapping of the sanitary lines. The bid opening for this service was held in January 2020 with a recommendation for award in June 2020. DEP's contractor is anticipated to commence work in early 2021.

3.12.2 Stormwater-Related Nonpoint Source Pollution Management Programs

Stormwater Retrofit Projects

In an effort to further reduce pollutant loading from stormwater runoff, DEP completed the following nonpoint source reduction projects within the East of Hudson Catskill/Delaware basins.

<u>Maple Avenue, Town of Bedford, Westchester County</u>

The Maple Avenue site consisted of two roadside ditches carrying suspended solids into Cross River Reservoir. In order to prevent the continued buildup of sediment along the hillside and water's edge, DEP engaged a consulting engineer to design a sediment and gravel collection system to concentrate deposition at a location where it can be easily accessed and periodically cleaned. The deposition control system included a hydrodynamic device and filter practice. The project also involved improvements to existing swales, installation of new catch basins with concrete headwalls, and widening and lining a portion of the swales with rip-rap.

Between 2016 and 2018, DEP worked to complete the design and secure necessary permits from the town. The project was subsequently bid and DEP issued an order to commence work on November 5, 2018. Construction of the swale improvements and installation of the catch basins, hydrodynamic device, filter practice, and associated piping began in summer 2020 and was completed in October 2020 (Figure 3.25).

Figure 3.25 Site improvements at Maple Avenue retrofit.

Drewville Road, Town of Carmel, Putnam County

The drainage area of the project site includes asphalt paving on Drewville Road and Drew Lane, impervious roof tops, asphalt parking lots, and wooded and grassy areas. Runoff from the drainage area was collected in a roadside drainage ditch on Drewville Road and drained to Croton Falls Reservoir. The project's primary objectives were to repair the drainage ditch to prevent erosion within the ditch, prevent undermining of the rock wall adjacent to the ditch, and reduce the amount of sediment deposition in the woods and along the Croton Falls Reservoir shoreline. The installed stormwater practice consists of a forebay and a micropool that will extend the detention time of the stormwater, allowing solid material to drop out.

Between 2016 and 2018, DEP completed the design and secured necessary permits from the town. The project was subsequently bid and DEP issued an order to commence work on November 5, 2018. The contractor shortly thereafter begin initial site preparation and clearing at the Drewville Road site. Construction of the stormwater basin and associated infrastructure began in 2019 and was completed in summer 2020 (Figure 3.26).

Figure 3.26 View of Drewville Road site

Stormwater Facility Inspection and Maintenance

DEP developed the Facility Inspection and Maintenance Program to ensure previously constructed stormwater remediation facilities continue to function as designed through routine inspections. Maintenance is completed under the warranty in each facility's construction contract during the first year and under DEP's maintenance program contract thereafter. Inspection and maintenance follow procedures contained in the maintenance contract.

All facilities were inspected annually and maintained, as required, throughout the five-year reporting period. The required maintenance consists of vegetation removal, sediment removal, debris removal, reseeding and mulching, tree removal, and stone riprap repairs. All stormwater facilities are functioning as designed.

Stormwater Retrofit Grant Program

The majority of watershed communities in Putnam, Westchester, and Dutchess counties established the East of Hudson Watershed Corporation (EOHWC) in order to comply with Section IX.A.5.b of the NYSDEC MS4 General Permit, which mandates nonpoint source phosphorous reduction through the construction of stormwater retrofits throughout the EOH watershed. Between 2013 and 2015, DEP provided a total of $20 million to the EOHWC, which included $4.5 million earmarked specifically for retrofit projects in the Cross River and Croton Falls Reservoir basins. EOHWC has now fully expended these funds on the retrofits required under the first five years of their permit compliance.

As part of the 2017 FAD, DEP in 2019 agreed to provide EOHWC with an additional $22 million to support the design and construction of stormwater retrofits in the EOH FAD basins and in the basins upstream of the Croton Falls Reservoir. EOHWC will use these funds toward compliance with the second five-year period of compliance with the MS4 program. Of

Figure 3.27 View of a pocket wetland in the Middle Branch Reservoir basin.

that money, \$7 million is specifically to support stormwater retrofits within EOH FAD basins and \$15 million is dedicated to stormwater retrofits within the basins upstream and hydrologically connected to the Croton Falls Reservoir or within EOH FAD basins.

In August 2019, DEP provided the initial payment of \$15 million to EOHWC. Through 2020, EOHWC has expended or committed over \$4.6 million of the initial payment for retrofit projects in the Boyd Corners, Cross River, Croton Falls, and upstream hydrologically connected basins. Since inception, EOHWC's retrofit program has removed an estimated 379.3 kg P/yr from projects either completed or in design in the EOH FAD or upstream hydrologically connected basins. Retrofit types vary and include detention basins, channel stabilization projects, and pocket wetlands, among others (Figure 3.27).

3.13 Catskill Turbidity Control

Due to the nature of its underlying geology, the Catskill watershed is prone to elevated levels of turbidity in streams and reservoirs. High turbidity levels are associated with high flow events, which can destabilize stream banks, mobilize streambeds, and suspend the glacial clays beneath the streambed armor. The design of the Catskill System considers local geology and provides for settling within Schoharie Reservoir, Ashokan West Basin, Ashokan East Basin, and the upper reaches of Kensico Reservoir. Under normal circumstances, the extended detention time in these reservoirs is sufficient to allow the turbidity-causing clay solids to settle out and the system easily meets the SWTR turbidity standards (5 NTU) at the Kensico effluent. Occasionally after extreme rain/runoff events in the Catskill watershed, DEP has used aluminum sulfate (alum) as chemical treatment to control high turbidity levels.

DEP has completed several studies and implemented significant changes to its operations to better control turbidity in the Catskill System. Many of these measures have been implemented pursuant to the 2002 and 2007 FADs and the Shandaken Tunnel and Catalum State Pollutant Discharge Elimination System (SPDES) permits. A comprehensive analysis, the Catskill Turbidity Control Study, was conducted by DEP with the Gannett-Fleming-Hazen and Sawyer Joint Venture in three phases between 2002 and 2009. Based on the results of this study, DEP implemented several alternatives: a system-wide Operations Support Tool (OST) that allows DEP to optimize reservoir releases and diversions to balance water supply, water quality, and environmental objectives; modifications of operations to better manage high-flow events; an interconnection of the Catskill Aqueduct at the Delaware Aqueduct Shaft 4 to improve overall system dependability; and structural improvements to the Catskill Aqueduct stop-shutter facilities. The Catskill-Delaware Interconnection and the Catskill Aqueduct stop-shutter facilities projects achieved functional completion in 2016.

3.13.1 National Academies Expert Panel review

In September 2016, the National Academies of Sciences, Engineering and Medicine (NASEM) commenced a multi-year expert panel review of the City's use of OST for water supply operations and identify ways the City can more effectively employ OST to manage turbidity. The expert panel had several goals:

- Evaluate the effectiveness of the City's use of OST for water supply operations and identify ways in which the City can more effectively apply OST to manage turbidity.
- Evaluate the performance measures/criteria the City uses to assess the efficacy of the Catskill Turbidity Control Program and recommend additional performance measures if necessary.
- Review the City's proposed use of OST in evaluating the suggested modification to the Catalum SPDES Permit as well as the alternatives to be considered in the environmental review of those proposed changes.

- Review DEP's existing studies of the potential effects of climate change on the City's water supply to help identify and enhance understanding of potential future concerns in the use of OST.

The NASEM chose 11 expert panel members for their extensive practical experience in the following areas: reservoir operations; drinking water treatment; water quality, water quantity and watershed modeling; water-quality monitoring and statistics; and hydro-climate systems and dynamics. The NASEM also ensures that the experts are not directly connected to the New York City water supply and are free from any potential conflicts of interest or biases. The expert panel met a total of six times between 2017 and 2018. The first three meetings had sessions open to the public, including opportunity for direct public comment to the panel. Additionally, the public was able to submit comments through the project website. The final report was released on September 25, 2018 (https://www.nap.edu/catalog/25218/review-of-the-new-york-city-department-of-environmental-protection-operations-support-tool-for-water-supply).

The expert panel strongly endorsed OST for guiding the operation of NYC's water supply, managing risks such as droughts and turbidity events, and planning for the future effects of climate change. They provided a total of 21 individual recommendations, from the very technical to the very general. DEP has completed implementation of most of them, such as updating the input data to OST to include more recent years and conducting more data analysis to show the overall effectiveness of the Catskill Turbidity Program. This analysis was summarized in a March 2019 FAD deliverable entitled "Final Revised Performance Measures/Criteria for Evaluating the Efficiency of Catskill Turbidity Controls." DEP concluded that several recommendations were not feasible in a short-term time frame, such as utilizing ensembles of different hydrologic models. Overall, this review was extremely helpful to DEP in the continued development and utilization of OST.

3.13.2 Operations Support Tool

OST couples computer models of reservoir operating rules and water quality; assimilates near real-time data on stream flow, water quality, and reservoir levels; and ingests streamflow forecasts to predict reservoir levels and water quality up to a year into the future. It is a decision-support system: water supply managers make decisions based on guidance from OST in combination with other forecast information; knowledge of system infrastructure status and other conditions; water supply BMPs; and years of experience operating the system. DEP uses OST daily for operational decisions, as well as planning, water management and policy evaluation purposes.

OST is constantly evolving and incorporating new functionality. Standard modeling practices, such as ongoing retrospective evaluation of model performance, forecast verification, and fine tuning model code and algorithms, are routinely performed. Since 2016, these activities included the development of new software to visualize and export model output, simulation and analysis of the Catskill Aqueduct outage to support daily operations during shutdown periods, modeling to support the Schoharie outlet simulation and Shandaken Tunnel autumn outage, and installation of new OST test and production servers.

A critical component of OST is the baseline model run. A baseline run is the set of rules underlying the daily model runs performed by DEP staff. In 2018, the baseline run was updated based on experience using OST, available recent hydrological drivers, full implementation of new infrastructure such as the Croton Filtration Plant, and approach to system management. The 2018 baseline run included improved routines for reservoir subsystem balancing and modified water quality-based operating rules. In 2019, a new baseline run was created to include model rules to support the Rondout-West Branch Tunnel (RWBT) outage. This run was built upon the 2018 updated version to include the most recent adjustments to system operations, CATALUM updates, as well as other model updates in the Delaware River Basin by the Delaware River Commission (DRBC). With these updates, OST will continue reflecting the current water supply system status and rules and provide necessary flexibility to support multiple infrastructure projects while continuing to be synchronized with the DRBC Planning Support Tool.

In addition to the updates discussed above, other refinements to OST have occurred in the past several years.

- A Forecast Diagnostic Tool was developed which displays the current inflow forecasts compared to a range of historical data (min, max, percentiles) as well as to the past several days of observations and forecasts. This allows modeling staff to quality control the forecasts, which in turn informs interpretation of model output and may lead to coordination with the National Weather Service (NWS) to revise and reissue the forecasts if anomalous forecasts are discovered.
- The 2017 Flexible Flow Management Program agreement as well as the 2016 USGS new bathymetry survey for the West of Hudson reservoirs was incorporated into OST. The update also allows for simulating previous Decree Party Delaware River Basin release agreements.
- The input flow time series was extended from 2012 through September 2017. This inflow file extension is particularly important when using the model to support planning. This extension was also in response to NASEM OST Expert Panel recommendations.
- DEP worked with the NWS to extend the number of traces for the HEFS (Hydrological Ensemble Forecast System) ensemble forecast from 38 to 53. OST relies on HEFS ensemble forecast to support operations on a daily basis. The new ensemble include hydrological information from 1960 to 2012.
- Three new nodes in the Delaware River Basin portion of the model were added: Lordville, Hancock and Bridgeville. The first two locations support thermal release

modeling, which is an important component of the 2017 Flexible Flow Management Program. Bridgeville is important for the OST inflow file development.

- DEP staff developed a version of a Volume Projection (VoPro) model. Starting with the current system status, this software tool allows water supply operators to enter changes in diversion and releases out of reservoirs and receive indications of the system response in terms of reservoir storage. This screening tool is often used to select operational scenarios subsequently run through OST.

During 2020, DEP continued with OST enhancements to more accurately reflect current water supply system rules, infrastructure status, operations and elevate OST flexibility to provide modeling support for various applications. The enhancements included addressing some of the NASEM OST Expert Panel recommendations:

- NWS is developing a Global Ensemble Forecast System version 12 (GEFSv12) to replace the old GEFSv10 (2014), upon which the current HEFS ensemble forecast is based. GEFSv12 development is also using extended meteorological and hydrological data and forcing hindcast ensembles that include the most recent records (through 2019) in response to one of the NASEM OST Expert Panel recommendations. Initial testing confirmed improvements in GEFSv12 forecast skill compared to GEFSv10.
- DEP continued the collaborative work with NWS, through its Northeastern (NERFC) and Middle Atlantic (MARFC) River Forecast centers (RFC), to develop post-processed ensemble forecasts for all OST forecast locations. The new software tool, to be applied and maintained by the two RFCs, is based on the NWS post-processor (EnsPost) and it is expected to be finalized during early 2021.
- In coordination with DEP and as part of EnsPost development, the MARFC started an evaluation of the Sacramento Soil Moisture Accounting Model to possibly replace the Continuous API.
- During 2020, DEP completed new models to support thermal release needs at the additional Delaware River Basin nodes. The thermal models are currently being tested by NYSDEC for future incorporation in OST.
- A new baseline run was created in 2020 to provide modeling work to support the RWBT outage. This run built upon the 2018 updated version to include the most recent adjustments to better reflect system operations, Catalum updates, as well as other model updates in the Delaware River Basin by the DRBC. With these updates, OST will continue reflecting the current water supply system status and rules and provide necessary flexibility to support multiple infrastructure projects while continuing to be synchronized with the DRBC Planning Support Tool.
- DEP staff continued developing a new version of a VoPro model. This new version is specific for the Croton system. VoPro allows water supply operators to, starting with

the current status of the system, enter changes in diversion and releases out of reservoirs and receive indications of the system response, in terms of reservoir storage. This screening tool is particularly important, as a compliment to OST, to evaluate short-term OST operations and to support operations during the RWBT shutdown planned for 2022.

3.13.3 Catalum Consent Order and Environmental Review

Rain events in October and December 2010 caused elevated turbidity levels in the Ashokan Reservoir. In addition to alum at Kensico, DEP also utilized the Ashokan Release Channel as part of a strategy previously approved by NYSDOH and EPA to ensure all drinking water standards were met. Using the channel raised concerns from communities along the Esopus Creek downstream of the reservoir.

In February 2011, NYSDEC commenced an administrative enforcement action against the City for alleged violations of the Catskill Aqueduct Intake Chamber Catalum SPDES permit (NY0264652) regarding operation of the Ashokan Release Channel and alum addition. NYSDEC and DEP negotiated a consent order to resolve the alleged violations, which took effect in October 2013. The consent order included penalties, environmental benefit projects, a schedule of compliance, and an Interim Release Protocol for the channel's operation.

Consistent with the consent order, DEP requested a modification to the Catalum SPDES Permit to incorporate turbidity control measures in water diverted from Ashokan Reservoir and to postpone dredging of alum floc at Kensico Reservoir until completion of certain infrastructure projects in June 2012. The proposed modification is subject to environmental review under the State Environmental Quality Review Act (SEQRA), for which NYSDEC is lead agency. Below is a timeline for the Catalum environmental impact statement (EIS) development:

- NYSDEC released a draft scope for the Catalum EIS for public comment from April 9, 2014, to August 29, 2014. Over 900 comments were received from over 550 commenters.
- The Final Scope was issued on March 22, 2017, and it took into consideration feedback from the public review process and includes responses to the comments received.
- A draft DEIS was submitted to NYSDEC on May 30, 2019.
- NYSDEC released the DEIS for public comment on December 16, 2020, with a 90-day public comment period.

3.14 Monitoring, Modeling and GIS

3.14.1 Geographic Information System

DEP used its Geographic Information System (GIS) for multiple purposes during the assessment period: to support numerous FAD and MOA programs; to manage the City's interests in water supply lands and facilities; to display and evaluate the efficacy of watershed protection through maps, queries, and analyses; and to support watershed, reservoir, and operational modeling efforts. Primary GIS resources include a centralized geodatabase (the GIS library), the Watershed Lands Information System (WaLIS), and Global Positioning System (GPS) technology. This report summarizes GIS technical support for programs and modeling applications; the completion or acquisition of new GIS data layers; improvements to GIS infrastructure; and dissemination of GIS data.

3.14.2 GIS Technical Support

DEP used its GIS to perform technical support and data development, including GPS fieldwork, for a variety of watershed protection programs and modeling applications. A core function of its GIS enables DEP to create customized statistical reports and maps depicting land ownership, land cover extent, hydrographic and topographic features, riparian and flood zones, water supply facilities, or program implementation status over particular basins or political boundaries. DEP continuously develops and maintains these core GIS analyses for program design and planning, engineering screening, regulatory jurisdiction determination, emergency response, water supply operations, and recreational outreach. GIS-derived graphics were also created for reports, posters, presentations, and peer-reviewed publications. A few examples are provided below.

Digital elevation models (DEMs) were used to generate custom sub-basin boundaries for specific water quality sampling locations. DEP also incorporated DEMs into global climate models to generate local predictions of future climate conditions. DEP relies on data such as reservoir bathymetry, SSURGO2 soils, land cover, and land use to drive model analyses.

In 2017, DEP used new higher-resolution GIS data layers for slopes, hydrography, land cover, and other features to update a West of Hudson watershed town-level assessment of developable land as part of FAD discussions with watershed stakeholders. This analysis updated a similar analysis performed in 2009 using older lower-resolution data. DEP also used GIS to determine vulnerability within a 1-hour river travel time downstream of all reservoirs in the event of a dam failure, including depictions of inundation areas, vulnerable populations, critical facilities, and positioning of potential siren systems for emergency notification.

In 2018, hydrography and land cover GIS layers were used to target parcels in West of Hudson basins for potential enrollment in the CREP/CSBI pilot program, using a complex set of criteria based on parcel size, land cover and distance to watercourses. DEP also performed a comprehensive GIS analysis of land cover, land ownership, and wetland types within 300-foot stream buffers for the East of Hudson FAD basins as part of a FAD-mandated assessment report. DEP used GIS to plan for expansion of the East of Hudson septic program in basins upstream of Croton Falls and to target and prioritize specific wastewater service areas in the East of Hudson FAD basins for video inspection.

In 2019, DEP finalized many additional GIS data sets and maps supporting the opening of the Ashokan Rail Trail; these features can be viewed online in DEP's Watershed Recreation Mapping Tool (https://www1.nyc.gov/site/dep/recreation/recreation.page). DEP analyzed coniferous forest land cover data to support the Wetlands Protection Program, and mapped acres of East of Hudson Community water service areas overlapping wastewater service areas, including diverted areas.

In 2020, DEP analyzed locations of all SPDES-permitted facilities and whether they lie within a floodway or 100/500-year floodplain. A set of reservoir firefighting/dipping maps were created for state and local emergency responders. These will be used during wildfire events to direct aircraft to suitable water scooping areas based on required setbacks from facilities, buoys, eagle nests, and other sensitive areas. GIS staff worked with the Regulatory and Engineering Programs division to map exclusion areas for project review, as defined by the 2019 NYC Watershed Final Rules and Regulations, section 18-41(a) for Solid Waste Management Facilities.

3.14.3 Completion or Acquisition of New GIS Data Layers and Aerial Products

New GIS layers were completed during the assessment period resulting from DEP's ongoing data development efforts. USGS, under an inter-governmental agreement with DEP, completed all sonar-generated bathymetric surveys of the six West of Hudson reservoirs and delivered final data in 2017 (the final report is here: https://pubs.er.usgs.gov/publication/sir20175064). Deliverables included raw and corrected survey points, derived topographic surfaces of each reservoir bottom from those points, 2-foot contours of reservoir depth derived from each topographic surface, and stage-area-volume tables in 0.01-foot increments. Based on these products, DEP completed a matrix of capacity changes for each reservoir since construction. Depth grids derived from the bathymetry are being used as inputs to reservoir water quality models. In addition, all official reservoir boundaries and their dependent data in DEP's version of the National Hydrography Dataset National Hydrography Dataset (NHD) have been revised from both new bathymetry and existing 1-meter topography according to recently corrected spillway elevations referenced to the North American Vertical Datum of 1988 (NAVD88).

DEP developed spatial data specific to the needs of the new Streamside Acquisition Program (SAP), such as program criteria, prioritized streams, and eligible properties. Using paper maps and parcel lists provided by towns, a new layer of East of Hudson Designated Main Street Areas (DMSAs) was developed for use in analysis and inclusion into various WaLIS maps.

Also in 2017, DEP released into the GIS library new 0.5-foot resolution orthoimagery data that was collected in partnership with the NYS Digital Orthoimagery Program. Since this imagery was collected wall-to-wall for all counties containing any portion of the watershed or aqueducts, it is also available on the NYS GIS Clearinghouse (https://gis.ny.gov/gateway/mg/).

Under contract with DEP, USGS used boat-based sonar to conduct bathymetric surveys of all 13 reservoirs and three controlled lakes in the East of Hudson watershed according to the same specifications used for West of Hudson reservoir bathymetry mapping. Surveys were completed during the 2017-2019 field seasons. USGS has been working to edit and process raw sensor data into elevation measurements, with draft data expected in late 2020, and final deliverables due in June 2021.

As part of ongoing annual data maintenance, DEP regularly updates or overhauls several existing feature classes. These include mission-critical data for various DEP programs, such as countywide digital tax parcels, City-owned land or interests, state-owned land, water supply facilities, stream restoration projects, septic repairs, and engineering project locations. Work continued on updating GIS layers for all water quality monitoring sites, biomonitoring sites, snow survey and snow pillow sites, and meteorological stations referenced in the Laboratory Information Management System (LIMS). DEP performed annual hydrography and drainage basin data edits, including a matrix of data dependencies. These annual edits are based on corrections observed in the field from Regulatory and Engineering Programs, Water Quality and other DEP staff. The edits have been expanded to now include USGS NHD layers in further basins outside the immediate water supply region to support DEP's Community Water group. Annual updates on locations of sensitive, threatened, or endangered species on City-owned lands were received from the New York Natural Heritage Program (NYNHP) to supplement data collected by the DEP Wildlife Studies Program. Under a less-frequent update cycle, the MOA-designated areas layer was modified based on recent town resolutions. DEP obtained the latest version of SSURGO2 soils data from USDA and numerous other updates from the NYS GIS Clearinghouse, including NYSDOT transportation features and NYSDEC layers.

3.14.4 GIS Infrastructure Improvement

DEP continued to maintain its GIS infrastructure during the assessment period by upgrading ArcGIS Desktop software; diagnosing database performance issues; updating schemas and servers to improve database speed; building and testing new geodatabase scripts; evaluating and refining user security levels on servers for different databases; and backing up all databases. Large format color plotters with built-in scanning capability were procured and installed in the Kingston and Arkville offices. Maintenance was performed on numerous GPS units used by various programs, including replacing aging units, updating data dictionaries, updating software, and tracking inventory for all GPS hardware and software.

DEP also continued to upgrade and maintain WaLIS, which has operated on over 250 DEP user workstations. DEP updated and released versions of WaLIS as needed with new functionality for managing the solicitation process for Streamside Acquisition Program projects, developing and managing forest inventory data on City-owned lands, streamlining mapping code to improve performance, implementing new eligibility rules for Land Acquisition Program solicitation planning, managing wetland permit applications, and tracking East of Hudson septic repairs.

In 2016, a publicly accessible web-based Watershed Recreation Mapping Tool was developed and launched to provide flexibility to the public when searching for a recreation property based on location or partial name. The tool is hosted on the DEP website (https://www1.nyc.gov/site/dep/recreation/recreation.page). In 2018, DEP migrated GIS and WaLIS databases to new faster server infrastructure, which resulted in a marked improvement in application speed. All GIS staff received new GIS-grade workstations in 2019, which improved software performance. Staff migrated tax parcel update scripts to Python 3 and investigated how ESRI portal software may impact GIS users in remote locations through web or mobile applications. DEP began upgrading user software to ArcGIS Pro, which is a major shift from previous versions of ESRI professional desktop GIS software in that it is cloud-based with a more sophisticated user interface.

Since March 2020, non-essential DEP staff were required to work from home due to COVID-19 statewide restrictions. This entailed obtaining laptops from the DEP Business Information Technology (BIT) office, with Virtual Private Network (VPN) capability, loading specific security and remote access software by BIT, and several other preparations. While many staff continue to remotely access their office computers via VPN and run full versions of GIS and WaLIS desktop software, new initiatives were implemented to support DEP's GIS and WaLIS needs while tele-commuting, including:

- NYC Watershed Viewer: DEP developed this ArcGIS JavaScript tool to provide DEP users with the ability to easily view DEP's own GIS layers as well as WaLIS-related data. It enables users to view, query, and print maps from DEP's GIS library without any special software installed on their device except a web browser (Figure 3.28). Users are provided links from this viewer to open WebWaLIS which allows them to edit WaLIS data, upload attachments, and generate WaLIS reports. Previously, the Watershed Viewer could only be accessed within the DEP secure wide-area-network (intranet) but can now be accessed remotely over the internet on any device using a DEP-provided secure login with multi-factor authentication. GIS staff provided user support while users oriented themselves to working from home and discovering the capabilities of this application. Since March, 80 DEP users have made use of the Watershed Viewer.

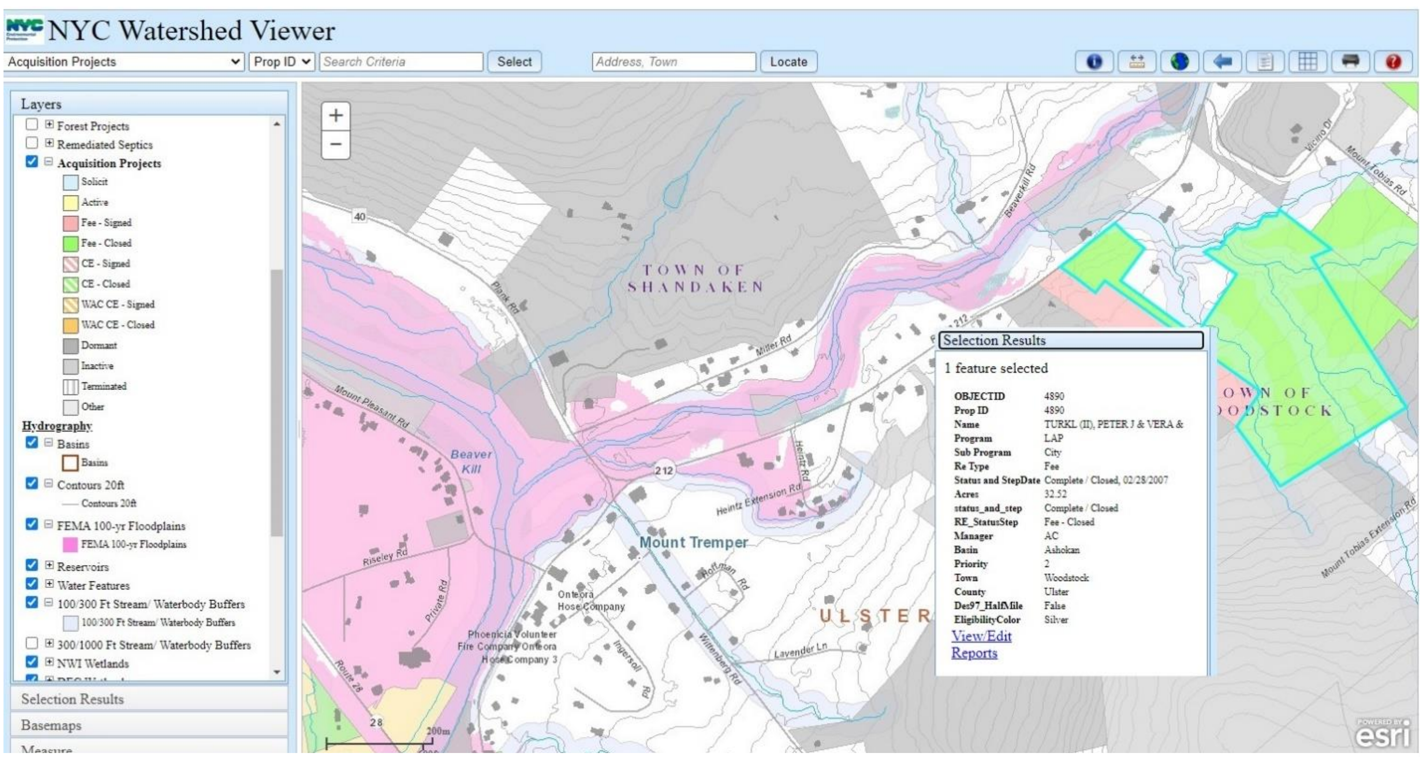


Figure 3.28 A screenshot of the NYC Watershed Viewer displaying a data record detail window on a selected parcel off of the map.

- WebWaLIS: DEP began completely re-coding the entire desktop WaLIS application to be run remotely on a browser with no other special software required. GIS staff resolved many cloud, security, and other network resource issues to develop and release a version of the application in summer 2020. DEP users can now edit their program's data as well as view and upload attachments without the need to remotely access their office computers via VPN and run the desktop version of WaLIS (Figure 3.29). GIS staff tested and added an AutoCad file reader to view survey attachments, and also developed the ability to manage tasks and workflow. Mobile and other capabilities are under development for future versions. At present 77 DEP users access WebWaLIS.

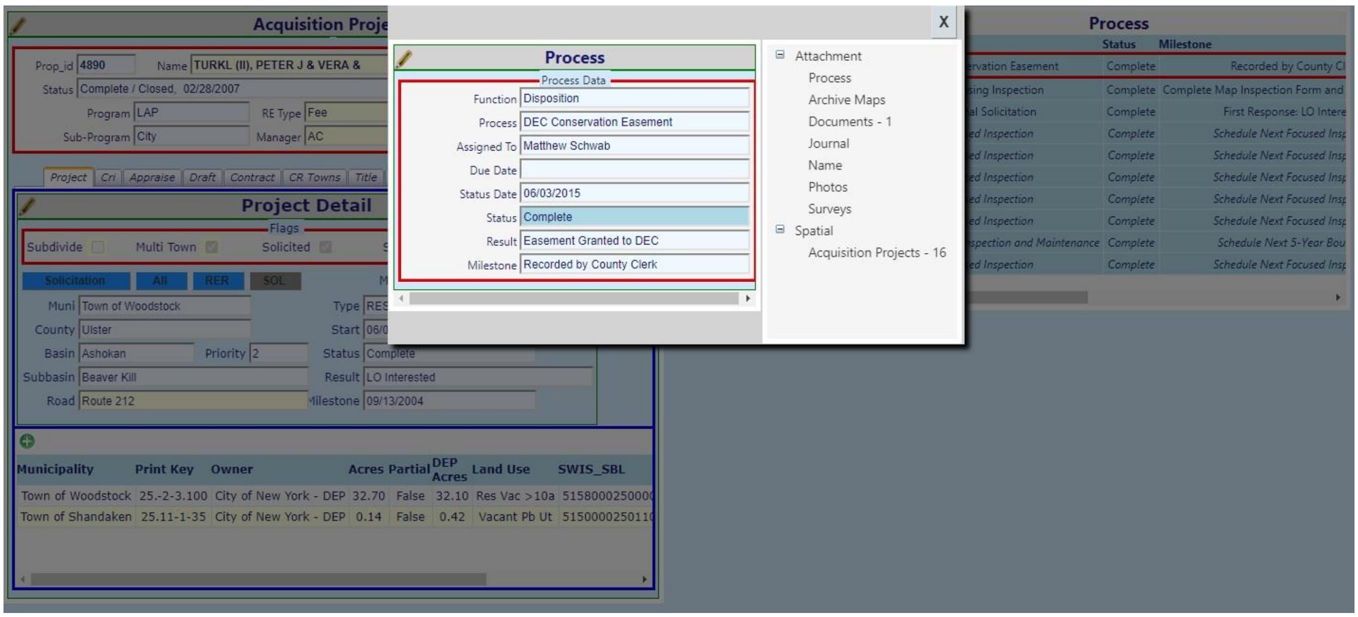


Figure 3.29 A screenshot of the WebWaLIS application, launched from the NYC Watershed Viewer screen, displaying the same Land Acquisition Program data record and related processes from the previous figure.

3.14.5 Data Dissemination to Stakeholders

Using established in-house data sharing policies, DEP reviews all outside requests for GIS data and provides these data to watershed partners and interested parties as required. Each year, DEP provides over 55 stakeholders and communities with semiannual data updates in January and July for newly acquired and existing City-owned lands. DEP shares updated watershed recreation data with Ulster County, WAC, and the Catskill Center for their recreation website mapping applications, and to the NYC Open Data Portal. Throughout the assessment period, DEP responded to data sharing requests from NYSDOH, NYSDEC, NHNHP, NYS

Office of the Attorney General ,WAC, CWC, EOH Watershed Corporation, Catskill Center, New Jersey Department of Environmental Protection, US Army Corp of Engineers, FEMA, Cornell University, City University of New York, New York University, Central Hudson, NY Power Authority, New York/New Jersey Trail Conference, Hudson Highlands Land Trust, New York Botanical Garden, and various counties, towns, and consultants working on DEP-related watershed projects.

3.15 Regulatory Review and Enforcement

The Regulatory and Engineering Programs Division (REP) is the BWS entity responsible for the review of land development activity in the City's watershed, for the inspection of sewage treatment facilities and active construction sites, and for the pursuit of enforcement actions as required.

REP is divided into three regional sections with offices located in the watershed in Arkville, Kingston and Valhalla. In addition, REP includes the SEQRA Coordination Section which manages the bureau's environmental review obligations via coordination with municipal planning boards and state agencies.

Regional section staff primarily review, approve, inspect and monitor subsurface sewage treatment systems (SSTS), wastewater treatment plants (WWTP), sewer systems, stormwater pollution prevention plans (SWPPPs), the construction of new impervious surfaces, and various non-point sources of pollution. Engineering reports, sizing and drainage calculations, and facility plans are reviewed for compliance with the New York City Watershed Rules and Regulations (WR&R) and established New York State technical standards.

SEQRA Coordination

All projects in the NYC watershed are subject to the provisions of New York State Environmental Conservation Law, the corresponding regulations, and the State Environmental Quality Review Act (SEQRA). As an agency with the authority to issue discretionary approval, DEP is subject to the provisions of SEQRA which requires that an approving or funding agency consider the environmental impacts of the entire action before approving any specific element of that action. To comply with the requirements of SEQRA, DEP can either participate in a coordinated review conducted by the lead agency or conduct its own uncoordinated review. These reviews are processed by the SEQRA Coordination Section (SCS) in conjunction with an internal technical team made up of staff with a wide variety of expertise from other units within BWS.

As an involved agency in most instances, DEP's comments alert interested parties to its regulatory authority, are intended to assess any potential adverse impacts associated with the activity, and identify adequate mitigation measures. SEQRA reviews are typically conducted in conjunction with municipal planning boards and the New York State Department of Environmental Conservation (DEC). This cooperative regulatory framework helps to ensure

DEP participation in the review of proposed activities at the earliest stage of project planning. REP has issued comments on 459 SEQRA notices since January 1, 2016.

Project Review

By way of review and strict application of limiting distances and design standards for land development activities, the regulatory program continues in its mission to protect the water supply against contamination, degradation, and pollution of source waters in the watershed.

With regard to the review of new, altered and repaired SSTSs, DEP applies NYS standards for design including the residential system requirements noted in Appendix 75-A which DOH most recently amended in March 2016 and the DEC intermediate system design standards last updated in March 2014. SSTS designers and contractors continue to employ the combination of septic tanks and standard absorption fields to manage on-site wastewater with enhanced treatment units utilized for repairs on marginal or physically constrained sites. DEP received 2,798 SSTS applications during the reporting period, an increase in 32% over the prior five-year reporting period.

From a stormwater standpoint, DEP received 244 applications during this reporting period. Both SWPPP and individual residential stormwater permit (IRSP) applications continue to rely heavily on infiltration and bioretention systems to meet both the treatment and runoff reduction criteria noted in the latest NYS Stormwater Management Design Manual.

Additionally, REP's regional sections review and provide comments on other applications pending before municipal, state and federal agencies that have the potential to adversely impact water quality in the watershed. These regulated activities include stream, wetland and buffer disturbances, mining operations, transportation projects, solid waste management facilities, industrial activities and timber harvests.

Inspections

All new, altered and repaired septic systems are inspected during the construction phase by DEP staff or inspected by local health department personnel pursuant to delegation agreements with respective watershed counties (Putnam, Ulster and Westchester).

REP staff conduct weekly inspections of all approved active stormwater construction sites from commencement of work through final stabilization. Staff are also responsible for investigating citizen complaints of possible violations of water quality standards including turbid discharges, illicit solid waste disposal, leaking petroleum bulk storage, and discharges from improperly stored road salt.

To ensure that WWTPs are being operated and maintained in accordance with the limits established in their State Pollutant Discharge Elimination System (SPDES) permits, DEP inspects all wastewater facilities within the watershed on a quarterly basis. DEP personnel also share their technical expertise with plant management and operators and offer easy-to-implement operational changes. These changes may also result in improvements to plant operation and reduced long-term cost of operations.

Enforcement

DEP reserves the authority to pursue enforcement action upon confirmation of sources of pollution or contamination to the City's water supply. To resolve identified violations in a timely manner, formal Notice of Violation (NOV) procedures are initiated which entail review by DEP/City legal staff. Legal staff remain involved should further steps, including litigation, become necessary.

During the reporting period, DEP issued a total of 44 NOVs for violations of the WR&R. These violations include the failure of residential SSTSs, non-compliance with approved SWPPPs, commencement of construction without prior DEP approval, and the horizontal expansion of a junkyard.

Major Accomplishment

REP's most significant accomplishment during this reporting period was finalizing amendments to the WR&R. New York City first established watershed regulations in 1917 to protect its water supply and provide oversight of activities that might cause contamination. Those regulations were modified significantly in the 1990s with the signing of the Watershed MOA and were last updated in 2010. The latest amendments reflect recent changes in federal and state law as well as addressing issues that have arisen during administration and enforcement of the WR&R.

Effective November 29, 2019, the amendments represent the culmination of a multi-year cooperative process of DEP outreach and valuable feedback from watershed stakeholders. Beginning in 2015, DEP met with regulatory agencies (EPA, NYSDOH, and DEC) and with other parties, including interested environmental groups, the Catskill Watershed Corporation, the Coalition of Watershed Towns and the office of the state Watershed Inspector General to discuss the proposed amendments to the WR&R. Based on feedback, including written comments, DEP incorporated appropriate suggested edits and revisions to the proposed amendments over the next three years.

Pursuant to both SEQRA and City Environmental Quality Review (CEQR) process, DEP circulated an environmental assessment form to stakeholders in May 2018. Upon receiving no comments, DEP determined the amendments were not anticipated to have any potential significant adverse impacts on the environment. DEP adopted a negative declaration on March 14, 2019, in accordance with NYCRR Part 617, the SEQRA Handbook, and the CEQR process as set forth in Title 62 of the Rules of the City of New York.

In accordance with the Citywide Administrative Procedures Act (CAPA), DEP published the proposed amendments in the City Record in September 2018 and held four public hearings in October and November 2018. As required under CAPA, DEP published the amended regulations a second time in the City Record in October 2019 and, pursuant to Public Health Law, initiated publication of the revisions once a week for two consecutive weeks in at least one newspaper with circulation in each watershed county.

While most of the updates reflect changes in state and federal law or improve the clarity of language in the former rules, several substantive revisions were made to remove or reduce burdens to watershed economic development while ensuring that the regulations remain protective of water quality. These include the following:

- The amended regulations establish a category of small, limited-impact projects for which SWPPPs can be simpler, similar to the existing framework for IRSPs. This change was intended to streamline the stormwater approval process for small business owners.
- The regulations replace the prior approach for evaluating alterations and modifications of septic systems, and for determining whether systems that have not been used in some time can be brought back into service. The new process focuses primarily on how well the septic system will serve the proposed use, consistent with public health and water quality concerns.
- The amendments removed the need for separate DEP review and approval of sewage holding tanks while incorporating standards consistent with New York State guidance for both holding tanks and portable toilets.
- The amended regulations eliminated the hardship criterion necessary for obtaining a variance from the regulations. Each variance application will now be reviewed on its merits without the requirement to prove a specific hardship.

In conjunction with promulgation of the amended regulations, REP provided guidance to the regulated community on the amendments via 2019 outreach sessions to local chapters of the American Society of Civil Engineers and the National Society for Professional Engineers. Also, in advance of review by the Executive Committee of the Watershed Protection & Partnership Council and as required by the Watershed MOA, DEP has completed draft versions of all seven applicant’s guides to regulated activities.

3.16 Waterborne Disease Risk Assessment

The underlying goal of the EPA’s Surface Water Treatment Rule series is to protect tap water consumers against waterborne disease, with particular attention to giardiasis and cryptosporidiosis. A NYC program designed to assure that that goal is met is the Waterborne Disease Risk Assessment Program (WDRAP). WDRAP was initiated in 1993, and program elements have been modified and significantly enhanced over the years. The core objectives of WDRAP are the following: (1) Obtain data on the rates of giardiasis and cryptosporidiosis, along with demographic and risk factor information on patients; (2) Provide a system to track gastrointestinal illness (diarrhea or vomiting) to ensure rapid detection of any outbreaks. These two core objectives are met via the two core programs of case surveillance and syndromic surveillance. Besides these core programs, additional activities are carried out relevant to WDRAP. Outreach and educational activities related to increasing awareness of the epidemiology and transmission of waterborne parasitic disease are undertaken. Also, special projects have been pursued. During this assessment period, a manuscript was prepared and published on the epidemiology of cryptosporidiosis in NYC; and a survey of sample cities was undertaken to inform our public health surveillance efforts. WDRAP is jointly administered by the Bureau of Communicable Diseases (BCD) of the New York City Department of Health and Mental Hygiene (DOHMH) and the Bureau of Water Supply (BWS) of the DEP.

Each year, a WDRAP annual report is produced which includes program implementation updates, as well as charts, maps, and other figures presenting data findings. Some brief highlights and other sample findings are provided below for this assessment report (preliminary data compiled through December 2019). Further details, can be found in the WDRAP annual reports, which are available at: https://www1.nyc.gov/site/dep/water/waterborne-disease-risk-assessment.page. Also included below are some brief notes about this past year, 2020. The COVID-19 pandemic had a substantial impact on case counts and the trends observed in syndromic surveillance, and also had an impact on WDRAP staffing/resources. However all WDRAP program elements continued operation throughout the pandemic.

3.16.1 Disease Surveillance

Cryptosporidiosis and giardiasis diagnoses are reportable to DOHMH under the City health code. The vast majority of cases are reported by electronic laboratory reports, which typically include information such as name, residential address, and date of birth. All cryptosporidiosis cases are assigned for interview to collect further demographic information as well as details on potential transmission risks. Giardiasis cases are not typically interviewed unless they are known to be in a position where there is an increased risk of secondary transmission (e.g. involving a food handler, child in daycare, etc.) Brief highlights of case surveillance data are provided below. **Figures appear at the end of the chapter.**

City-wide Trends: Three figures are provided in this chapter which summarize New York City-wide trends from WDRAP to date: Figure 3.30 and Figure 3.31 summarize time trends for giardiasis and cryptosporidiosis, respectively, from 1994/1995 through 2019. Figure 3.32 shows cryptosporidiosis case numbers by year of diagnosis and immune status for 1995–2019.

The figures show that the number of diagnosed and reported giardiasis and cryptosporidiosis cases declined over the first 20 years of this surveillance program. (This decline, specifically in cryptosporidiosis cases, has been attributed to the introduction of highly active antiretroviral therapy (HAART) in the treatment of HIV/AIDS patients, and has been discussed in prior WDRAP reports.) In 2015, a trend of increasing case reports for giardiasis and, particularly, for cryptosporidiosis was observed, and this overall trend has continued through 2019. This increase in case reports coincides with the increasing adoption by clinical laboratories of a new type of diagnostic test. These newly-adopted assays, known as syndromic multiplex polymerase chain reaction panels, can test for the presence of a wide range of enteric organisms including *Cryptosporidium* and *Giardia*. This new test has led to a substantial increase in diagnosed and reported cases – in NYC and elsewhere. The trend of increased giardiasis and cryptosporidiosis cases being diagnosed in NYC is most likely a reflection of improved disease detection related to the new diagnostic tests rather than an actual increase in community level of illness. This issue is discussed in some further detail in the 2019 WDRAP Annual Report. Prior to the availability of these new tests, physicians would have been less likely to request specific testing for *Giardia* spp., and particularly less likely to specifically request testing for *Cryptosporidium* spp. The lower sensitivity of traditional microscopy in addition to higher cost and specific testing requirements likely contributed to a significant rate of under-diagnosis of cryptosporidiosis.

Since 2015, physicians at an increasing number of hospitals and laboratories across NYC can order a single test for a patient with diarrheal disease and evaluate the presence of approximately 20 different pathogens.

Other temporal trends noted are that cryptosporidiosis is highly seasonal, with patients presenting more frequently in the warmer summer months compared to the winter months. Seasonality of giardiasis is less pronounced.

Demographic Highlights: During 2016-2019, the count and rate of giardiasis and cryptosporidiosis were consistently higher among males compared to females, and were typically highest specifically among men aged 20 to 44 years old. The highest rates of infection were typically in Manhattan, commonly clustered in the Chelsea-Clinton neighborhood. However, during the most recent period, rates were also high in northern Manhattan and Brooklyn: This increase observed over time is hypothesized to reflect the growing areas of doctors' offices and hospitals that rely on the syndromic multiplex panel diagnostics as opposed to traditional microbiology diagnostics. Again, this likely reflects improved detection of disease and not an increase in transmission compared with earlier years. Among cryptosporidiosis patients, rates were typically highest among White, non-Hispanic persons followed by Hispanic persons and Black/African American persons. The demographic patterns seen in NYC for both giardiasis and cryptosporidiosis are largely consistent with person-to-person spread, particularly sexual transmission among men who have sex with men, as well as international travel. Additionally, data suggest that neighborhood level poverty is not a determinant for either parasitic infection.

Risk Factor Results: Interviews are conducted of cryptosporidiosis patients to collect data on commonly reported potential risk exposures (e.g., international travel, high-risk sexual activity, contact with animals, tap water consumption), and HIV/AIDS status. While the determination of a statistical association between cryptosporidiosis infection and exposure to possible risk factors cannot be made without reference to a suitable control population, examination of data can reveal interesting and potentially informative patterns. A few findings are included here as examples. Approximately a third of patients reported international travel during their incubation period, particularly among patients aged <20 years. Additionally, men 20-59 years old were more likely to report high-risk sexual practices with an increased risk for fecal contact comparted to older men and women. Although we do not have reliable data on whether a patient identifies as a man who has sex with men (MSM), high rates of cryptosporidiosis among men were consistently identified in areas known to have an above-average proportion of residents who are MSM, such as Chelsea-Clinton. MSM are historically at greater risk for cryptosporidiosis, not only because of a higher prevalence of AIDS in this population but also because of sexual practices that entail a low risk for HIV transmission but increase the risk for fecal contact. With regard to findings related to HIV status, the proportion of cryptosporidiosis patients with a known diagnosis of HIV/AIDS was observed to decrease over time, e.g., from 60% during 2000-2004 to 26% during 2015-2018. (Figure 3.32). Additional discussion of demographics and potential risk exposures of interviewed cases is included in WDRAP annual reports, and also the Emerging Infectious Disease paper discussed in section 3.16.3.

Additionally, a routine cluster detection algorithm detected an outbreak of cryptosporidiosis among the Orthodox Jewish community in Brooklyn in 2019. In total, there were 47 cases diagnosed in August through November 2019, among both young children aged <5 years (36%) and adults >18 years (43%). A supplemental questionnaire revealed that a number of patients reported travel to upstate New York at the start of the outbreak and returned home for the start of the school year in September. Over a third (36%) of patients reported attending or working in child care centers, where exclusions were subsequently carried out (i.e., case patients were excluded from work/school to reduce risk of secondary infection). DOHMH conducted substantial outreach to the Orthodox community, with letters in English and Yiddish sent to child care centers and schools in the community informing the population to wash hands with soap and stay home from work or school if ill. Data gathered by DOHMH indicated that this outbreak was the result of person-to-person transmission within the Orthodox Jewish community in Borough Park and Williamsburg, Brooklyn. This outbreak was deemed not related to the NYC water supply.

3.16.2 Syndromic Surveillance

The tracking of sentinel populations or surrogate indicators of disease ("syndromic surveillance") can be useful in assessing gastrointestinal (GI) disease trends in the general population. Such tracking programs provide greater assurance against the possibility that a citywide outbreak would remain undetected. In addition, such programs can potentially play a role in limiting an outbreak's extent by providing an early indication of a problem so control measures may be implemented rapidly. NYC maintains four distinct and complimentary syndromic systems. Recent summary highlights are provided on each, below.

Hospital Emergency Department Monitoring

Monitoring of hospital emergency departments for gastrointestinal illness (i.e., diarrhea and vomiting) continued during this period. Data is received and analyzed for signals. DOHMH receives electronic data from all 53 of New York City's emergency departments, reporting approximately 11,500 visits per day. There have been no significant changes to this system during this assessment period.

Anti-Diarrheal Medication Monitoring

NYC began tracking anti-diarrheal drug sales as an indicator of GI illness trends in 1995 via a system operated by DEP. In 2015, one ADM pharmacy chain data source dropped out of the program, but two additional pharmacy chains were added. Surveillance with both additional pharmacy chains began in 2016. The current system involves tracking of sales of over-the-counter, non-bismuth-containing anti-diarrheal medications and of bismuth subsalicylate medications, searching for citywide as well as local signals. DOHMH BCD staff review signals on a daily basis to evaluate whether there are any new or sustained signals at citywide and zip-code levels. If there are sustained signals, BCD staff will perform reviews of reportable GI illness, including norovirus and rotavirus, to attempt to rule out a potential waterborne outbreak. Also, other syndromic systems can be consulted to see if concurrent signals are seen. In addition, information on product promotions (e.g., price discounts) are considered as these are known to impact sales volume).

Clinical Laboratory Monitoring

Monitoring of the number of stool specimens submitted to clinical laboratories for bacterial and parasitic testing continued during this period. One very large lab participates, providing data on the number of stool specimens examined per day for (1) bacterial culture and sensitivity, (2) ova and parasites, and (c) *Cryptosporidium*. There have been no significant changes to this system during the assessment period.

Nursing Home Sentinel Surveillance

The nursing home surveillance system remains in operation. Reportable outbreaks are to be communicated to WDRAP staff (as well as to NYSDOH). Specimens are collected for testing for bacterial culture and sensitivity, ova and parasites, *Cryptosporidium*, viruses, and other pathogens. Testing for culture and sensitivity occurs at the NYSDOH Wadsworth Center and viral testing occurs at the NYCDOHMH's Public Health Laboratory. There have been no significant changes to the system since 2002.

Syndromic Surveillance Results Summary

As described in annual WDRAP reports, data from NYC's syndromic surveillance systems have proven useful in demonstrating annual citywide seasonal trends of norovirus and rotavirus. Knowledge of these trends provides a baseline of data which should improve the City's ability to detect aberrations. Data from emergency departments and pharmacy syndromic surveillance systems are received daily. For the clinical lab, system data are received several times a week. Nursing home data are received on an event basis. Data are analyzed for any unusual trends or signals. Monthly summary reports are also prepared and provided by DOHMH to DEP. Data for each year is summarized in the WDRAP annual reports. DOHMH communicates syndromic surveillance findings to DEP on a routine basis and also notifies DEP of any signals of concern. There were no signals of concern reported during this assessment period. There was no evidence of a waterborne disease outbreak in NYC during the assessment period (consistent with prior periods).

3.16.3 WDRAP in 2020 – Impact of COVID-19 Pandemic

WDRAP data collected in 2020 is still preliminary and thus is not included in this report. These data will be presented and discussed in the 2020 WDRAP Annual Report. However, preliminary findings are as follows.

- The arrival of COVID-19 in NYC in March 2020 was followed by a steep decline in diagnosed and reported cases of both giardiasis and cryptosporidiosis, among many other reportable diseases. These declines are explained by the stay-at-home orders issued by state government and subsequent altered healthcare-seeking behavior (e.g., reduced appointments to doctors). In addition, it is possible that actual rates of these illnesses declined due to altered personal behaviors, thus reducing potential risk exposures to the protozoan causing giardiasis and cryptosporidiosis (e.g., reduced person-to-person contact, reduced international travel).
- WDRAP's syndromic surveillance systems' trends were also impacted by the COVID-19 situation, as evident by data trends observed in these systems. The effects observed may be explained by altered behaviors, such as reduced visits to emergency rooms, different patterns with regard to purchasing of anti-diarrheal medications, etc.
- Finally, COVID-19 has had a major impact on the NYCDOHMH BCD, which is where the DOHMH component of WDRAP is based. BCD staff, including WDRAP team members, have been activated to help NYC assess and respond to the pandemic. Workload increased tremendously for BCD due to COVID-19. Despite this fact, all health surveillance activities under WDRAP continued to operate through 2020 and all reporting requirements were met.

3.16.4 Epidemiological of Cryptosporidiosis, EID Publication

In 2019, DOHMH authored a manuscript in collaboration with DEP detailing the epidemiology of cryptosporidiosis in NYC from 1995–2018 (Alleyne, Fitzhenry et al. 2020). The paper appeared in the March 2020 edition of the Journal of Emerging Infectious Diseases. This project involved the assessment of trends in incidence and demographic characteristics for the 3,984 cases of cryptosporidiosis diagnosed during 1995-2018 in NYC, and reported to

NYCDOHMH. The paper discussed prior observations, including that the reported cryptosporidiosis incidence decreased starting in the mid-1990s with HIV/AIDS treatment rollout, but that the introduction of syndromic multiplex diagnostic panels in 2015 led to a major increase in incidence and also to a shift in the demographic profile of reported patients. Demographic and risk factor findings of the data analysis conducted included: Cryptosporidiosis was highest among men 20-59 years of age; 30% of interviewed patients reported recent international travel; and the burden of cryptosporidiosis infection in NYC is likely highest among men who have sex with men (MSM), likely related to transmission during sexual practices that pose high risk for fecal-oral transmission of disease. This paper makes an important contribution to better understanding of cryptosporidiosis epidemiology. Based on the findings, recommendations for public health messaging were made, such as messaging to the MSM population and to certain categories of international travelers.

3.16.5 Outreach/Education

The above noted journal article publication is one example of NYC's efforts to reach out to the public health and medical community on topics relevant to WDRAP. This article, published in the Journal of Emerging Infectious Diseases, and is expected to reach a large audience of public health practitioners and infectious disease clinicians, both in NYC and elsewhere. Some additional outreach/education efforts undertaken during this assessment period are noted below.

In 2018, DOHMH developed a multifaceted campaign to target men who have sex with men in NYC to raise awareness of the risk of cryptosporidiosis and other enteric infections that can be transmitted by fecal/oral contact. DOHMH developed a postcard that was distributed during Pride Week 2018 (a week of celebration of gay, lesbian, bisexual, transgender, and queer people and allies) and created a website highlighting common symptoms, transmission pathways and how to avoid infection specifically for men who have sex with men. World Pride 2019 occurred in NYC. World Pride is a global celebration of the LGBTQ community. DOHMH updated a postcard on enteric communicable diseases among MSM, and handed out the postcards at Pride activities throughout the City in June 2019.

In 2019, DOHMH conducted extensive outreach to the Orthodox Jewish community in Brooklyn alerting them to the existence of an outbreak of cryptosporidiosis, as described above.

Additional outreach during this period was conducted primarily by DOHMH Bureau of Communicable Disease staff, including presentations to clinicians and others at public health/medical schools on the topic of parasitic diseases. DEP BWS staff presentations relevant to WDRAP during this assessment period have been primarily internal or semi-internal –i.e., at WSTC in 2018, and to NASEM Panel October 2018. Talks to the medical and public health communities and others serve to enhance awareness of waterborne diseases, and also may lead to more complete disease diagnosis and reporting.

3.16.6 Survey of Cities on Public Health Surveillance Practices

During this assessment period, NYC undertook a project surveying select U.S. cities about their public health surveillance practices. The project's purpose was to inform NYC about how its WDRAP currently compares with relevant programs in other key cities, and to seek any valuable ideas for potential modification of WDRAP.

The survey project, initiated and led by DEP, began in 2018 and was reinitiated in 2020. (The project was interrupted from autumn 2018 until mid-2020 in order to focus on other critical agency priorities). Providing input and significant assistance on the project during 2018 were representatives from the U.S. Centers for Disease Control/Waterborne Disease Prevention Branch.

A report summarizing the project and survey findings is projected to be completed in spring/summer 2021. In addition, in 2018 an interim report on the project was presented by DEP at the Watershed Science and Technology Conference.

3.16.7 *Cryptosporidium-Giardia* Action Plan & Functional Exercise

NYC's *Cryptosporidium* and *Giardia* Action Plan (CGAP) provides guidance for intra- and inter-agency action and coordination in the event of *Cryptosporidium* oocyst and/or *Giardia* cysts findings at a critical sampling location for NYC's water supply – i.e., Hillview Reservoir-Catskill Aqueduct, Site #3. The CGAP is to be reviewed and updated on an annual basis. DEP met this requirement each year of this assessment period.

In May 2017, a functional exercise of the CGAP was held. The exercise was organized by DEP. Participants included representatives from various DEP divisions as well as NYCDOHMH, NYSDOH, and USEPA. In addition to the exercise day, May 23, 2017, related activities were undertaken prior to and following the event. The purpose of the exercise was to test the procedures currently in place, and to ensure that all key players are familiar with procedures and roles. CGAP Revision #8 (issued by DEP in December 2017) incorporated recommendations developed out of this 2017 functional exercise.

3.16.8 Conclusions

NYC's core ongoing WDRAP operations continued during this assessment period. There were no major programmatic changes implemented by NYCDOHMH or DEP during this time, though some notable additional projects were undertaken. The introduction of syndromic multiplex panel diagnostics had a major impact on the detection of certain microbial diseases, including giardiasis and cryptosporidiosis. WDRAP contributes valuable infrastructure and data to aid NYC in detecting real increases in community infections, and to understanding the impact of methods/system changes on disease rates and trends (e.g., syndromic multiplex panel adoption). The City undertook several activities over the past five years that enhanced our understanding of disease epidemiology in the city (i.e. the EID paper publication about cryptosporidiosis); enhanced our understanding of public health surveillance systems that can help provide assurance of safety (i.e., the city PHS survey); or enhanced the understanding by key affected populations of key enteric diseases and disease risk exposures so that public health precautions can be taken and disease risk can be reduced.

During the assessment period, there was no evidence of an outbreak of waterborne disease in NYC. WDRAP program implementation continues, and reports continue to be prepared and submitted as per the FAD schedule.

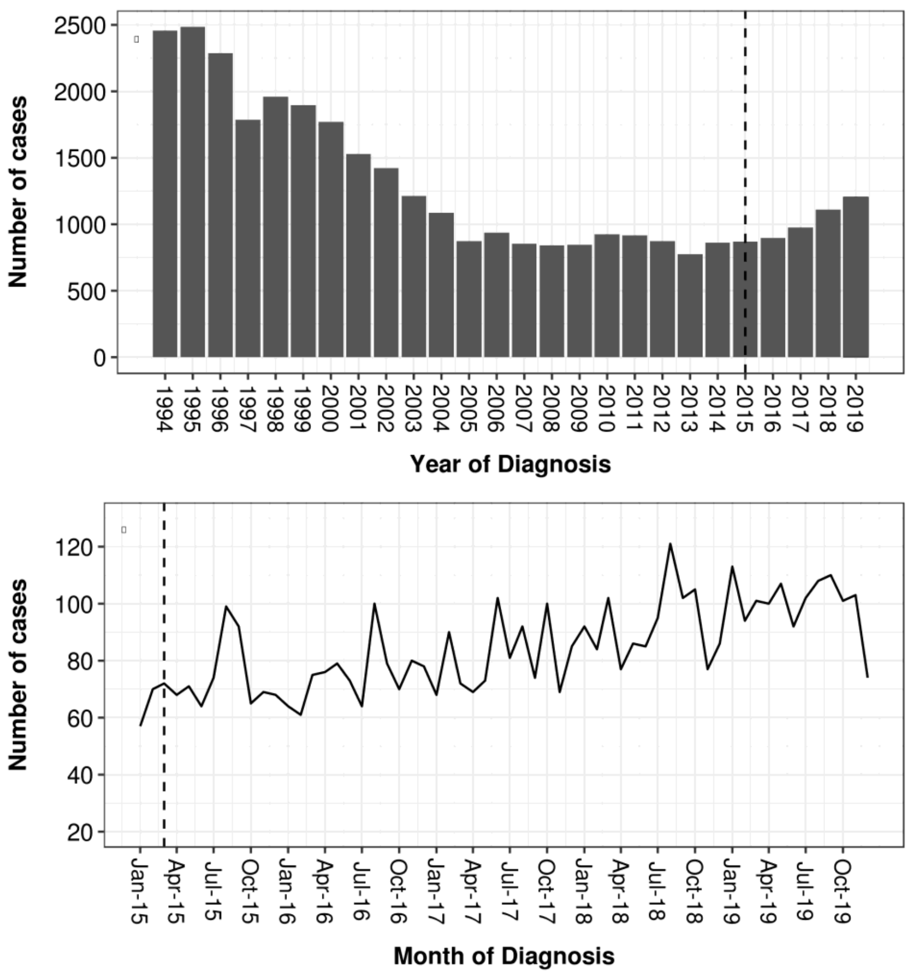


Figure 3.30 Giardiasis trends in NYC

Annual giardiasis counts for all years (top) and monthly counts for the last five years (bottom). The vertical dotted lines show the date when the first NYC laboratory reported results from using syndromic multiplex panels for enteric diseases.

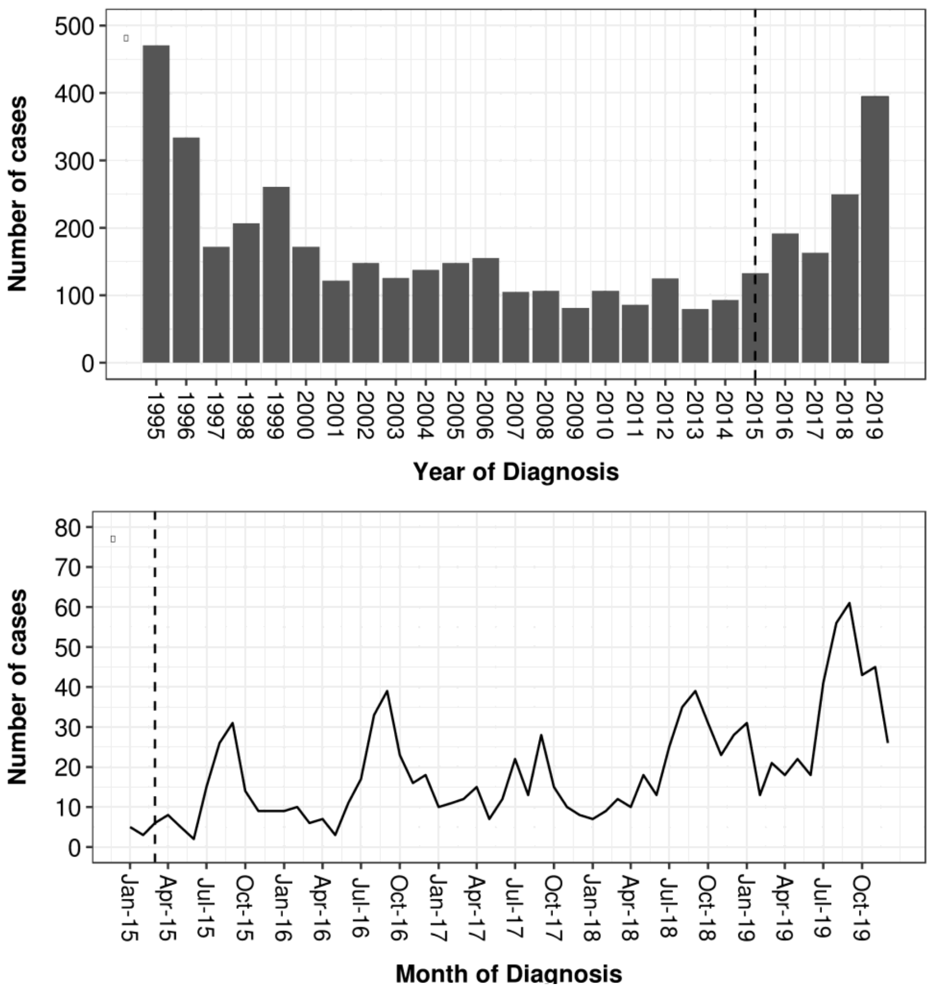


Figure 3.31 Cryptosporidiosis trends in NYC

Annual cryptosporidiosis counts for all years (top) and monthly counts for the last five years (bottom). The vertical dotted lines show the date when the first laboratory NYC reported results from syndromic multiplex panels for enteric diseases.

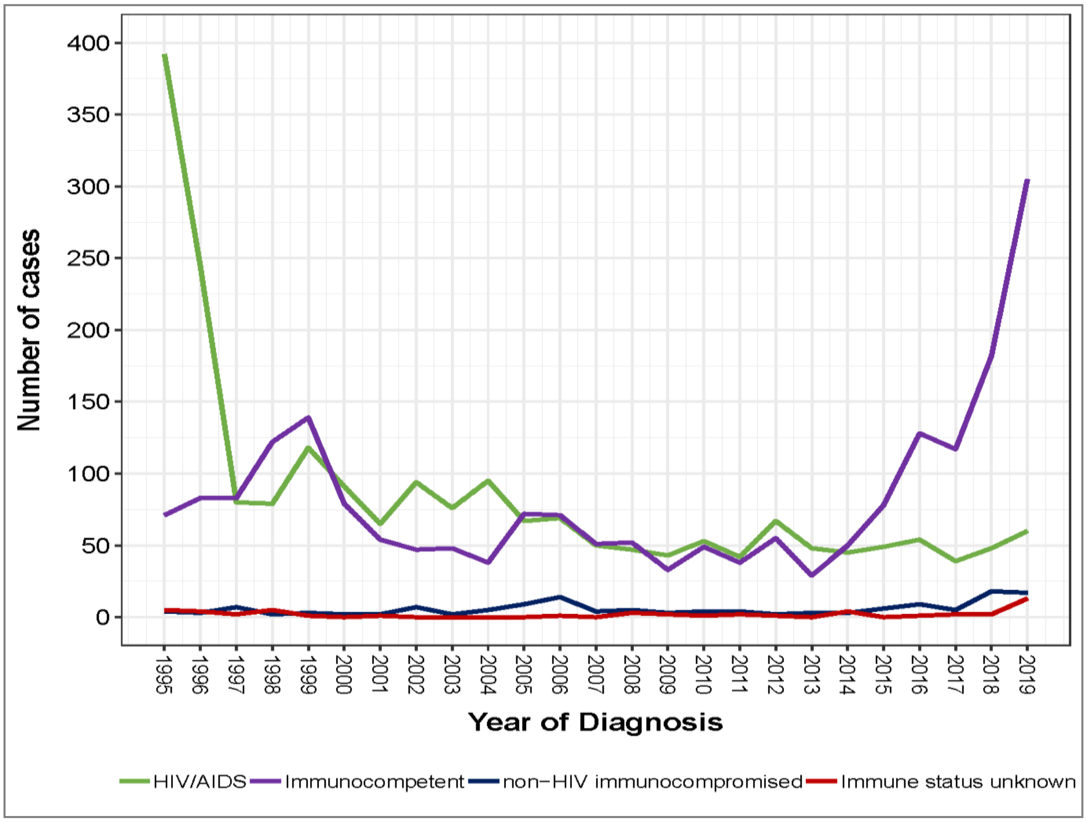


Figure 3.32 Cryptosporidiosis, number of cases by year of diagnosis and immune status, New York City, 1995–2019

3.17 Education and Outreach

During the current FAD assessment period, DEP continued to collaborate with the Catskill Watershed Corporation (CWC), Watershed Agricultural Council (WAC), Cornell Cooperative Extension, Soil and Water Conservation Districts, Catskill Center, the Catskill Regional Invasive Species Partnership, the Lower Hudson Partnership for Invasive Species Management, Trout Unlimited, and other partners to advance a comprehensive watershed education and outreach program. This program strives to increase knowledge and awareness among key audiences about source water protection, land conservation and stewardship, stream corridor protection, stormwater and wastewater, flood response and preparedness, invasive species, watershed recreation, riparian buffers, and other topics.

DEP and its partners use numerous strategies and tools to educate specific audiences and outreach to the broader public. One of the most effective tools for reaching large numbers of constituents continues to be DEP's website (www.nyc.gov/dep), which serves as a repository for

DEP's annual consumer confidence report, press releases, watershed rules and regulations, recreation maps, regulatory guidance documents, environmental education materials, and FAD reports. During the past five years, the Drinking Water section of the DEP website received at least 60,000 views every year, Watershed Protection received more than 10,000 annual views, Watershed Recreation received more than 22,000 annual views, and Environmental Education received more than 8,000 annual views. DEP routinely issued at least 100 press releases every year that focused exclusively on the water supply, watershed protection, watershed recreation, and environmental education programs.

Increasingly, DEP uses social media such as Twitter, Facebook, Flickr, and YouTube, for disseminating real-time updates, announcements, videos, and photos directly to subscribers and followers. During the past five years, DEP has amassed more than 12,600 followers on NYC Water Facebook, more than 4,800 followers on NYC Watershed Facebook, more than 19,800 followers on NYC Water Twitter, and more than 3,600 followers on NYC Water Instagram. DEP's NYC Water Flickr page (https://www.flickr.com/photos/nycwater/) contains nearly 8,000 photos, many of which showcase the activities described in this report.

DEP's Watershed Recreation Program has emerged as a popular way to engage local residents and downstate water consumers in active stewardship of City-owned watershed lands; this was acknowledged by the NASEM in its FAD Expert Panel Review Report (p.227): "The partnership approach and subsequent improvements in recreational access on [DEP] lands is an excellent example of mutually beneficial collaboration by NYC, county governments, and watershed communities. The recreation program exemplifies the spirit and letter of the MOA."

During this FAD assessment period, DEP disseminated a recreation e-newsletter to over 100,000 subscribers who received 8-10 issues each year. DEP organized family fishing events that attracted hundreds of participants, while engaging hundreds of volunteers in annual reservoir clean-up events. DEP also conducted wetland interpretive programs, community-based interpretive hikes, boater safety and wilderness survival trainings, land management workshops for conservation easement landowners, deer biology workshops for hunters, presentations to recreational businesses, and numerous interactive pop-up events associated with New York State Invasive Species Awareness Week. In 2020, DEP curtailed many of its recreational outreach activities, such as reservoir clean-up events and family fishing days, due to the COVID-19 pandemic and subsequent necessary restrictions on public gatherings.

In October 2019, DEP and Ulster County achieved a significant milestone with the opening of the Ashokan Rail Trail, an 11.5-mile-long recreational corridor that provides public access along the north shore of the Ashokan Reservoir. In the final three months of 2019, DEP estimates that more than 18,000 people visited the Ashokan Rail Trail. When the COVID-19 pandemic in 2020 was leading to greater numbers of people seeking outdoor recreational opportunities, usage of the Ashokan Rail Trail routinely exceeded more than 1,000 visitors per day, with more than 200,000 users counted for the whole year. The unexpected intensity of use during peak COVID months led to reports of public safety and health concerns (lack of social distancing and improper disposal of trash and waste along the trail). Although DEP and Ulster County were able to mitigate these concerns, they nevertheless highlight the balance between watershed recreation and the protection of drinking water for public health.

During this FAD assessment period, DEP's Education Office conducted between 300-400 environmental education programs each year that reached nearly 30,000 students, educators, agency staff, and other professionals. DEP accomplished this through classroom visits, guided tours and field trips (including programs at the Visitor Center at Newtown Creek Wastewater Resource Recovery Facility and Jerome Park Reservoir), professional learning opportunities, and the use of multi-disciplinary online and print resources. DEP hosted and collaborated with partners on dozens of after-school, full-day, and multi-day professional learning opportunities for teachers, school administrators, parent coordinators, and non-formal educators.

From 2016-2020, DEP's Water Resources Art and Poetry Contest engaged more than 1,700 students and over 100 educators each year, while Trout in the Classroom annually involved over 20,000 students and over 150 teachers from the watershed and New York City. Although more than 150 in-person education programs were canceled in 2020 due to COVID-19, directly impacting about 8,000 students and educators, DEP's Education Office continued to offer virtual field trips and professional learning opportunities, live trout tank programs, and new digital resources. DEP sponsored several in-City performances of "City That Drinks the Mountain Sky", including a live-streamed performance in 2020, and collaborated with museums to support educational events and exhibitions.

In partnership with WAC, DEP conducted annual watershed forestry bus tours (about 50 City-based, non-formal educators per tour) during most of the report period. In 2020, because of the COVID-19 pandemic, DEP and WAC collaborated to host a virtual version of this annual tour.

In 2017, DEP created an educational map and study guide, "New York City's Water Story: From Mountain Top to Tap," to help students explore the water supply system. In 2019, DEP became a Continuing Teacher and Leader Education sponsor, as approved by the New York State Education Department, which allows state-certified teachers to receive continuing education credit by participating in DEP's professional learning opportunities. In 2020, DEP launched a new climate change education module and hosted a three-part virtual workshop series for educators on climate change and water resources, climate resiliency, environmental justice, and student activism.

With the exception of 2020 (due to COVID-19), every summer DEP's Water-On-The-Go Program has educated thousands of New York City water consumers (residents and tourists) about the source and quality of in-City tap water by placing portable drinking fountains emblazoned with the "NYC Water" logo at busy pedestrian areas and public parks/plazas throughout the five boroughs. DEP staff were present to answer questions and speak directly with members of the public. This was particularly meaningful in 2019 after New York City's unfiltered tap water won the New York State Tap Water Taste Test competition at the New York State Fair the preceding summer.

During this FAD assessment period, the Watershed Agricultural Program organized several dozen farmer education programs each year, including workshops, farm tours, webinars, classroom instruction, producer group meetings, and annual events, such as the Catskill Regional Agricultural Conference and Delaware County "Clean Sweep" Chemical Disposal Day. The Watershed Agricultural Program engaged an estimated 600-800 participants per year in farmer education programs, many of which were converted to online virtual events during 2020 due to COVID-19. During this period, WAC continued to promote its programs through its main website (nycwatershed.org), in addition to promoting local farm and forestry products through the Pure Catskills "Buy Local" Campaign (purecatskills.com) and the annual Pure Catskills Product Guide/Directory. WAC also sponsored the annual Taste of the Catskills Local Food Event that attracts up to 5,000 attendees each year; this event was canceled in 2020 due to COVID-19.

Education is a cornerstone of the WAC Forestry Program, which targets landowners, loggers, foresters, and the wood-products industry with messaging about the value and importance of well-managed working forests. During this FAD assessment period, the WAC Forestry Program continued to expand the MyWoodlot.com website that was launched in 2015 as an interactive resource for educating forest landowners and encouraging stewardship activities; 316 landowners are currently enrolled in the website. WAC sponsored 46 logger training workshops during 2016-2020 that were attended by over 475 participants and resulted in more than 110 individuals achieving Trained Logger Certification (TLC) status. During 2016-2020, the watershed model forests hosted hundreds of educational events reaching thousands of landowners, loggers, students, and members of the public. WAC sponsored 119 watershed forestry bus tours for over 7,262 students and adults, primarily in-City water consumers. A total of 125 teachers attended WAC's annual Watershed Forestry Institute for Teachers during 2016-2020, including the first-ever virtual Institute held in 2020 due to COVID-19. Finally, more than 730 students participated in the annual Green Connections School Partnership Program during this FAD assessment period.

Education is also a cornerstone of the Stream Management Program (SMP), which every year conducts or sponsors a diverse slate of targeted programs (trainings, workshops, public presentations, interpretive hikes, volunteer planting events, school-based activities, etc.) for streamside landowners, local officials, highway departments, flood response professionals, watershed youth, and the scientific community. Examples of key programs held during 2016-2020 include the Ashokan Watershed Conference, Schoharie Watershed Summit/Month, Rondout Neversink Anglers Symposium, Leave No Trace Stream Stewardship Program, Summer Youth Stream Snorkeling Program, Watershed Scientist in Residence Program, Youth

Climate Change Leadership Summit, and the biennial Catskill Environmental Research and Monitoring Conference (which was postponed in 2020 due to COVID-19).

During this FAD assessment period, the SMP continued to host the catskillstreams.org website, where copies of all Local Flood Analyses (LFAs) are available, while supporting basin-specific project advisory committees and stakeholder meetings. The SMP continued to employ the Watershed Conservation Corps, a summer internship program funded by DEP through a contract with SUNY Ulster, which has served as a training ground for more than 120 future stream stewards and scientists since 1996. Unfortunately, this internship was canceled in 2020 due to COVID-19.

One important educational highlight took place in October 2019, when DEP and its SMP partners hosted a week-long training by nationally acclaimed hydrologist Dr. David Rosgen, who also conducted a free public lecture titled “Living with Mountain Rivers in a Changing Climate” that was attended by more than 100 people. This training was critical to ensuring that the next generation of stream managers received key foundational knowledge that has successfully shaped the SMP during the past two decades.

CWC continued to implement a Public Education Grants Program that has awarded 648 education grants since 1997 totaling nearly $3.5 million. During 2016-2020, CWC awarded 159 grants totaling just over $912,000 to schools and organizations in both New York City and the watershed for projects and programs that increase knowledge and awareness of the water supply. During the current FAD assessment period, CWC also sponsored several septic system maintenance workshops every year for homeowners; and numerous annual stormwater, wastewater, and land use planning workshops for municipal officials and local professionals. CWC continued to keep watershed residents informed about issues and programs via its main website (cwconline.org), press releases, e-newsletters, and a special website dedicated to inspiring teachers and educators about the New York City watershed (watersheducators.org).

Finally, DEP and its partners regularly attended numerous community outreach events and speaking engagements during this FAD assessment period. These events enabled staff to interact directly with the public, share scientific knowledge with fellow professionals, and communicate key messages. Event highlights include the Ashland Farm and Machinery Show, Catskill Forest Festival, Catskill Great Outdoor Expo, Delaware County Fair, Grahamsville Little World’s Fair, Greene County Youth Fair, International Restaurant and Food Show, Kingston Summer Showcase, Lower Hudson Valley Engineering Expo, Margaretville Cauliflower Festival, New York ReLeaf Conference, NYC Environmental Expo, NYC Water Day, NYC Watershed Science and Technical Conference, NYS Floodplain Managers Annual Conference, NYS Outdoor Education Association Annual Conference, NYS Outdoor Guides Association Winter Rendezvous, NYS Wetlands Forum, NYS Woodsmen’s Field Days, Northeast Outdoor Show, Olive Day, Pound Ridge Arbor Day Celebration, Rockland Community College World

Fishing and Outdoor Expo, Shandaken Day, SPDES permit outreach meetings, Teatown Eagle Fest, and the Ulster County Fair.

3.18 Expert Panel Review of the Watershed Protection Plan

In March 2018, the National Academies of Science, Engineering and Medicine (NASEM) commenced a multi-year expert panel review of the City's Long-Term Watershed Protection Plan. The goal is to evaluate the adequacy of the Watershed Protection Programs for addressing water quality, water quality trends, and anticipated future activities that might adversely impact the water supply and its ability to comply with 40 CFR §141.71 and §141.171, and 10 NYCRR §5-1.30. Key questions that were put to the expert panel to evaluate included the following:

- Are individual program elements (e.g., agriculture and stormwater best management practices, wastewater technologies, requirements for streamside buffers) based on the most relevant and up-to-date science?
- Are the City's water quality monitoring and modeling, as well as the performance monitoring of individual measures, adequate to assess the effectiveness of the overall watershed protection program? How might they be improved?
- How can operational controls be improved to protect water quality and comply with filtration avoidance determination requirements?
- Can the various watershed protection components (e.g., operational controls, regulatory programs and their enforcement, voluntary programs, and partnership programs) be better balanced to be more effective and sustainable?
- How might the watershed protection program evolve to account for future risks to the water supply, for example due to climate variability, invasive species, and regulatory trends?

The NASEM chose a total of 17 expert panel members who are cutting-edge researchers and specialists with extensive practical experience in the following areas: water supply operations and treatment; watershed and water quality monitoring, modeling and statistics; environmental engineering; watershed ecology and stream management; epidemiology and public health of drinking water; and social sciences (land management, land use planning, economics, water policy). The NASEM also ensures that the experts are not directly connected to the New York City water supply and are free from any potential conflicts of interest or biases.

The expert panel met a total of eight times from 2018 through early 2020. The first four meetings had sessions open to the public, including opportunity for direct public comment to the panel. Additionally, the public was able to submit comments through the project website. Over the course of the study DEP provided extensive documents, presentations on requested programs and topics, facility and project site visits, water quality data, and program data. The final report was released on July 30, 2020 (https://www.nap.edu/catalog/25851/review-of-the-new-york-city-watershed-protection-program).

The expert panel did an incredible job synthesizing 20 years of program development. We greatly appreciate their time, effort and expertise to help guide protection of the NYC Water Supply into the next decade and beyond. The report contains 63 major recommendations and numerous suggestions for enhancement, integration, and evaluation of watershed programs. DEP is carefully reviewing all of the recommendations, meeting with stakeholders, regulators and watershed partners to discuss potential actions. The FAD contains a process to use this report to guide mid-term revisions to the 2017 FAD starting with the submission of the 2021 Long-Term Watershed Protection Plan on December 15, 2021, followed by revisions to the 2017 FAD expected in mid-2022.

4. The Catskill System

4.1 Introduction

4.1.1 The Scope of Water Quality Analyses

Water quality analyses take into account a much longer time period than the five-year assessment period. The time period of the water quality analyses for this assessment extends from 1993 through 2019, which allows us to examine changes over the past 27 years. It provides a view of water quality responses to protection programs within the context of natural variation caused by events such as floods and droughts, which are not sufficiently represented in a five-year period. Long-term data are needed to show the effects of the watershed protection programs because there are time lags between program implementation (causes) and water quality changes (effects). DEP now has the luxury of a robust, long-term data record to examine, which will undoubtedly be used for many other analyses in the future.

The water quality data used in this analysis represent time periods with characteristically different watershed conditions. The data record begins in the early 1990s, which marks the outset of filtration avoidance when many watershed protection programs were in their infancy. The water quality data from this time period represent conditions with fewer watershed protection programs in place than post-filtration avoidance and the decades that follow. Many programs were implemented between 2000 and 2010, and this can be considered a period of non-equilibrium between observations and environmental conditions. The decade of 2010-2020 is expected to be a phase when reservoirs are close to reaching a dynamic equilibrium between new watershed conditions (due to program implementation) and water quality in the reservoirs. In this most recent assessment period, we expect to more clearly see the effects of the watershed programs reflected in water quality, as surface water reaches its new steady state with watershed conditions.

There are several important factors that govern water quality over the long term. Perhaps the two most important are climate as a determinant of precipitation and therefore water residence times, and land use as a determinant of substance loadings (Vollenweider and Kerekes 1980). Water residence times are important because they determine the response rates of reservoirs to watershed protection programs. Substance loadings are important because they set the upper limits for nutrients and biological responses. For this reason, key hydrological features and basin conditions are briefly noted for each reservoir system or basin to set the context for water quality interpretation.

Land use, a major determinant of water quality, is briefly described for each basin, including some highlights of protection program implementation. This serves as an indicator of the relative activity of some programs in the basin in question, but should not be taken as comprehensive; the full program descriptions are covered in earlier chapters of this report. Best management practices for farming, stormwater control through environmental infrastructure, stream management, and septic remediation are among the programs that have reduced the loading of contaminants to the water supply. These programs have a cumulative effect in reducing substance loadings to our waterways and the implementation of remedial watershed protection programs over the past decades has undoubtedly led to improved water quality.

Given the general environmental conditions as a backdrop, we examine the effectiveness of watershed protection programs to maintain a clean water supply through a series of analyses. These include the status and trends of water quality in streams and reservoirs as indicated by various analytes or indices, a macroinvertebrate bioassessment of stream conditions, the trophic response of reservoirs compared to standard regressions, and pathogen assessment. Our objective was to look for central tendencies and trends in the water quality data over an extended time period that includes before, during, and after watershed protection program implementation.

Water quality status and trends are described for selected analytes. Status is presented as a three-year average and trends are evaluated for a 27-year period. The analytes chosen were those most important for the SWTR and meeting the requirements of the 2007 Filtration Avoidance Determination. Statistical techniques for the status and trend analysis were chosen to account for the influence of seasons on long-term trends. In addition, concentrations were flow-adjusted in order to minimize the influence of short-term flow changes on trend detection.

Trends are examined in three ways: by fitting a smoothing function (LOWESS: Locally Weighted Scatterplot Smoothing) through all the monthly data; by performing the non-parametric Seasonal Kendall tests (SKT) for trend significance and trend slope and by estimating trend direction using the Trend Direction Assessment (TDA) technique. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. The SKT method addresses statistical significance of monotonic (unidirectional) change though the period of record. The TDA method calculates probabilities to determine trend direction and uses probability intervals to estimate the likelihood of correctly identifying the trend direction (see Appendix C for a more detailed description of the data processing steps and statistical methods used).

The trophic response of reservoirs to the combined effects of watershed protection programs and major environmental events was examined through four relationships selected from the Programme on Eutrophication sponsored by the Organization for Economic Cooperation and Development (OECD). These four relationships are the following:

1. Chlorophyll versus total phosphorus
2. Maximum chlorophyll versus total phosphorus
3. Secchi depth versus total phosphorus
4. Secchi depth versus chlorophyll.

Annual geometric means of each analyte were plotted on the OECD standard lines that were developed from over 100 other northern temperate zone waterbodies. Annual geometric means were used (as in the standard regressions) in order to best represent the central tendencies without undue influence of the few extreme high values typically recorded. These standard regressions provide a context by which one can identify true outliers and identify the causes for their variation from behavior of the standard relationships. This provides insight for general predictions of water quality and serves as a basis for development of mechanistic water quality models. These analyses highlight the biological responses to major environmental drivers such as hurricanes and floods. For the purpose of this analysis, NYCDEP developed a timeline of major environmental events for different drainage basins to catalogue what happened in each year. By matching the year of major environmental events to a particular response, patterns in the types and extents to which environmental drivers affect water quality can be identified. The identification of years can also indicate overall shifts in nutrients, algal biomass, and transparency over the course of time and, in this instance, over the past several decades to help evaluate the collective effects of the many watershed protection programs.

Macroinvertebrate indices were calculated to provide insight into the ecological conditions of streams and changes in water quality. Macroinvertebrates biologically integrate conditions over time so they are seen as important indicators of stream water quality. The impact of the waterfowl management program and its ability to control and reduce fecal coliform bacteria have been demonstrated over the past 27 years and selected case studies are presented to demonstrate the effectiveness of this program. Notably, terminal reservoirs (i.e., the last open water prior to treatment and distribution) receive the greatest attention in terms of program implementation. Programs are tailored to provide greatest protection near Kensico Reservoir and the distribution system, so it is by design that program intensity is highest in the downstream basins. Waterfowl management is a prime example of that strategy with emphasis on Kensico due to its importance in controlling coliform bacteria for the SWTR compliance.

Finally, an analysis of pathogen transport through the system is provided. In accordance with our mandate to meet regulatory requirements downstream, the focus is on the pathogenic protozoans *Cryptosporidium* and *Giardia*. The geographic distribution of these pathogens, the levels observed in the source waters, and their transport through the system are described. This analysis provides much insight into the benefit of NYC's sequential system of reservoirs and the natural processes that improve water quality as it travels towards distribution. With these approaches, we have examined the relationships between watershed protection and water quality changes. This scope description applies to all four water quality chapters. (It is placed at the beginning of the four chapters and will not be repeated.)

4.1.2 The Catskill System Overview

The Catskill System consists of two reservoirs – Schoharie and Ashokan – located west of the Hudson River in Ulster, Schoharie, Delaware and Greene counties. The Catskill System was constructed in the early part of the 20th century. Ashokan Reservoir went into service in 1915 and Schoharie in 1926. The Catskill System supplies on average 40% of the City's daily water supply. The water residence times for the three Catskill System reservoirs over a 52-year period (1967 to 2019) are depicted in Figure 4.1. The three basins of the Catskill System have characteristically different residence times. Schoharie consistently has the shortest water residence time on account of the high hydraulic load delivered by its large watershed. Schoharie water residence time averages about 1.5 months, Ashokan West Basin averages about two months, and Ashokan East Basin averages about four months. In general, the evolution of a basin to a new steady state is reached in approximately three times the duration of its water residence time. Therefore, we would expect Schoharie to adjust to new loading levels in about four months, whereas Ashokan West would take about six months and Ashokan East about one year

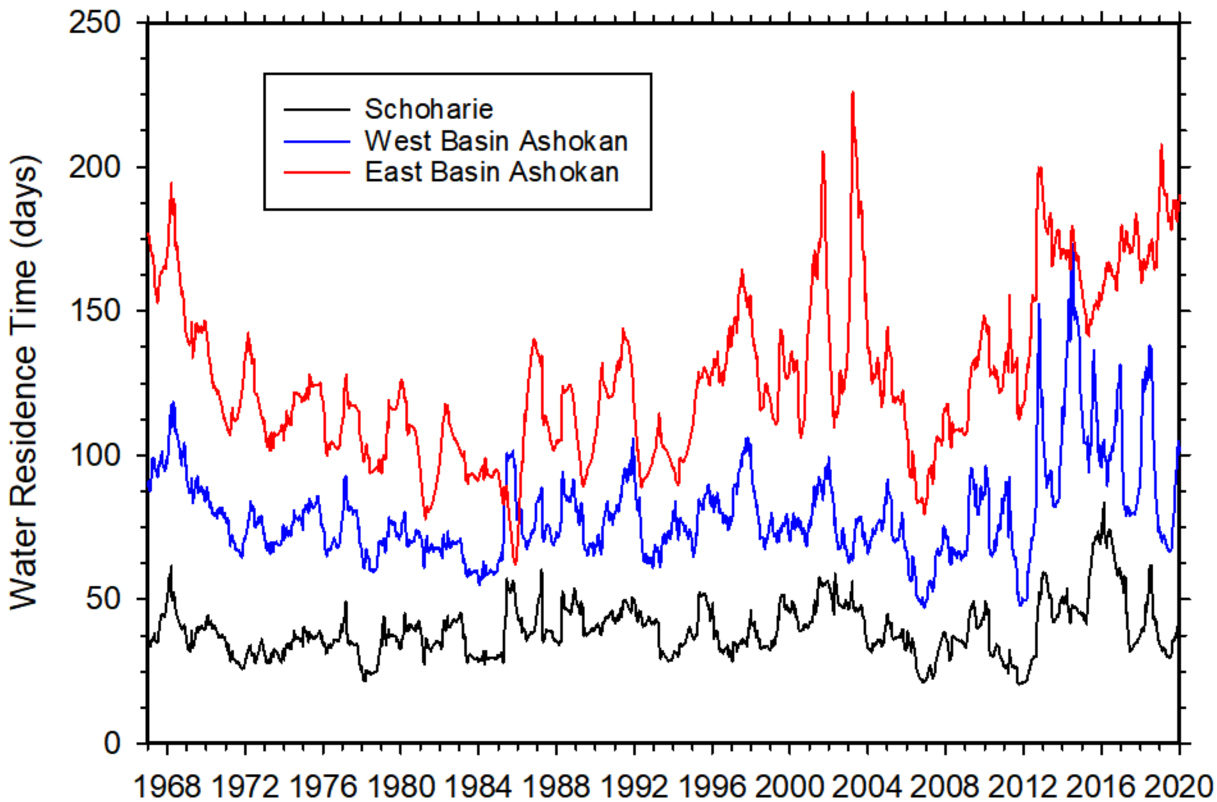


Figure 4.1 Water residence time in the Catskill System Reservoirs, 1967-2019.

to re-equilibrate to a new steady state after a change in its nutrient load.

4.2 The Schoharie Basin

The Schoharie watershed's drainage basin is 316 square miles and includes parts of 15 towns in three counties. Schoharie Creek is the primary tributary flowing into the reservoir, supplying 75% of the flow, while Manor Kill and Bear Kill provide 10% and 8%, respectively.

The Schoharie Reservoir consists of one basin, almost 6 miles in length, and holds 17.6 billion gallons at full capacity.

Land use in the Schoharie basin has remained similar to the last assessment period. Of the 201,658 acres of land in the Schoharie watershed, 79.1% is forested 8.1% is urban or built-up land, 6.2% is in agricultural use, 5.3% is brushland or successional land, 0.1% is classified as barren land, and 1.1% is water. As of December 31, 2020, there were 5,579 acres of agricultural lands with active nutrient management plans in the Schoharie watershed. Since 1996, over 579 total farm best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater in the Schoharie watershed. Of these, 126 BMPs were implemented between 2016 and 2020. These BMPs are associated with over 13,000 acres of farmland (i.e., more than 6% of the drainage basin area). More than 800 septic systems throughout the basin have been remediated. Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Watershed Protection Program sections.

Presently, there are 13 active wastewater treatment plants (WWTPs) located in the Schoharie watershed with a cumulative permitted maximum flow of 2.35 million gallons per day (MGD). Inputs of phosphorus, as well as other pollutants, from WWTPs to Schoharie Reservoir continue to be reduced as a result of DEP's effort to upgrade all surface-discharging WWTPs. The intervention and involvement of DEP's WWTP Compliance and Inspection Program also assures proper operation of these plants to reduce nutrient loadings.

4.2.1 Water Quality Status and Trends in the Schoharie Watershed

Status (Schoharie)

The Schoharie basin status evaluation is presented as a series of boxplots in Figure 4.2. A comparison of Schoharie Creek (S5I), the principal inflow to the reservoir; the reservoir (SS), and the outflow represented at the Shandaken Tunnel Outlet (SRR2CM) is shown. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the evaluation period (2017-2019), fecal coliform bacteria remained well below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the stream inflow site S5I. Consistent with previous evaluations, the reservoir inflow levels were higher than the reservoir and outflow values for fecal coliforms. Median turbidity was highest in the reservoir with a greater range of variability (median 6.4 NTU and interquartile range 13.9 NTU) in contrast to the inflow and outflow. Total phosphorus (TP) increased from inflow to reservoir to outflow, with an inflow median of 9 µg L^{-1}, reservoir median of 13 µg L^{-1}, and outflow median of 15 µg L^{-1}. The majority of values for total phosphorus were below the 20 µg L^{-1} benchmark in Schoharie Reservoir for this period. Trophic State Index (TSI) values for Schoharie Reservoir ranged from oligotrophic to mesotrophic, with a median of 38. Conductivity medians were

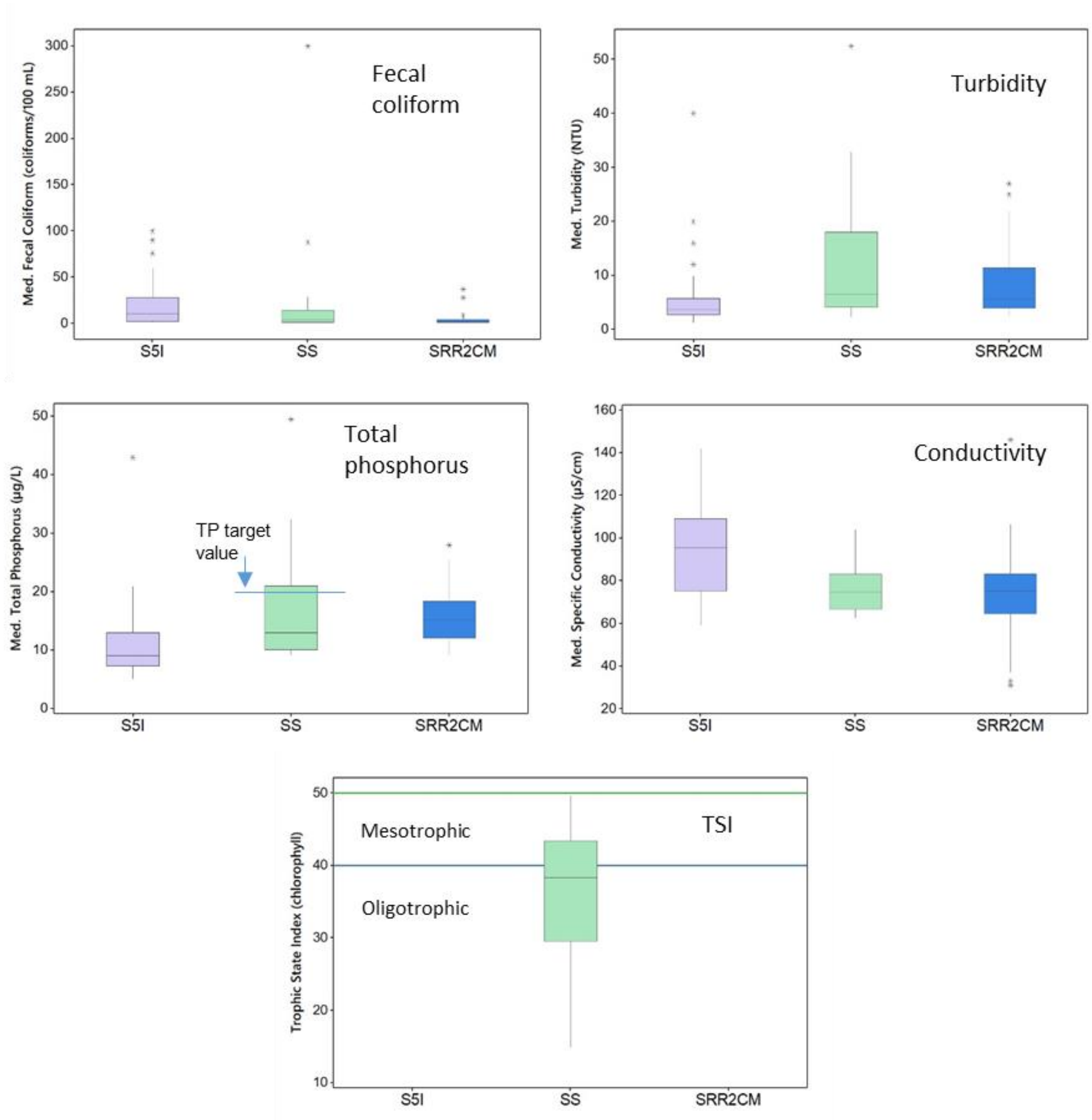


Figure 4.2 Water quality status boxplots using 2017-2019 monthly data for the Schoharie basin main stream inflow at Schoharie Creek (S5I), Schoharie Reservoir (SS), and the outflow at the Shandaken Portal (SRR2CM).

highest at the inflow (96 µS cm^{-1}) and slightly reduced in the reservoir and outflow (median 74 µS cm^{-1} and 75 µS cm^{-1}, respectively).

Trends (Schoharie)

Water quality trend plots are presented in Figure 4.3. Results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 4.1.

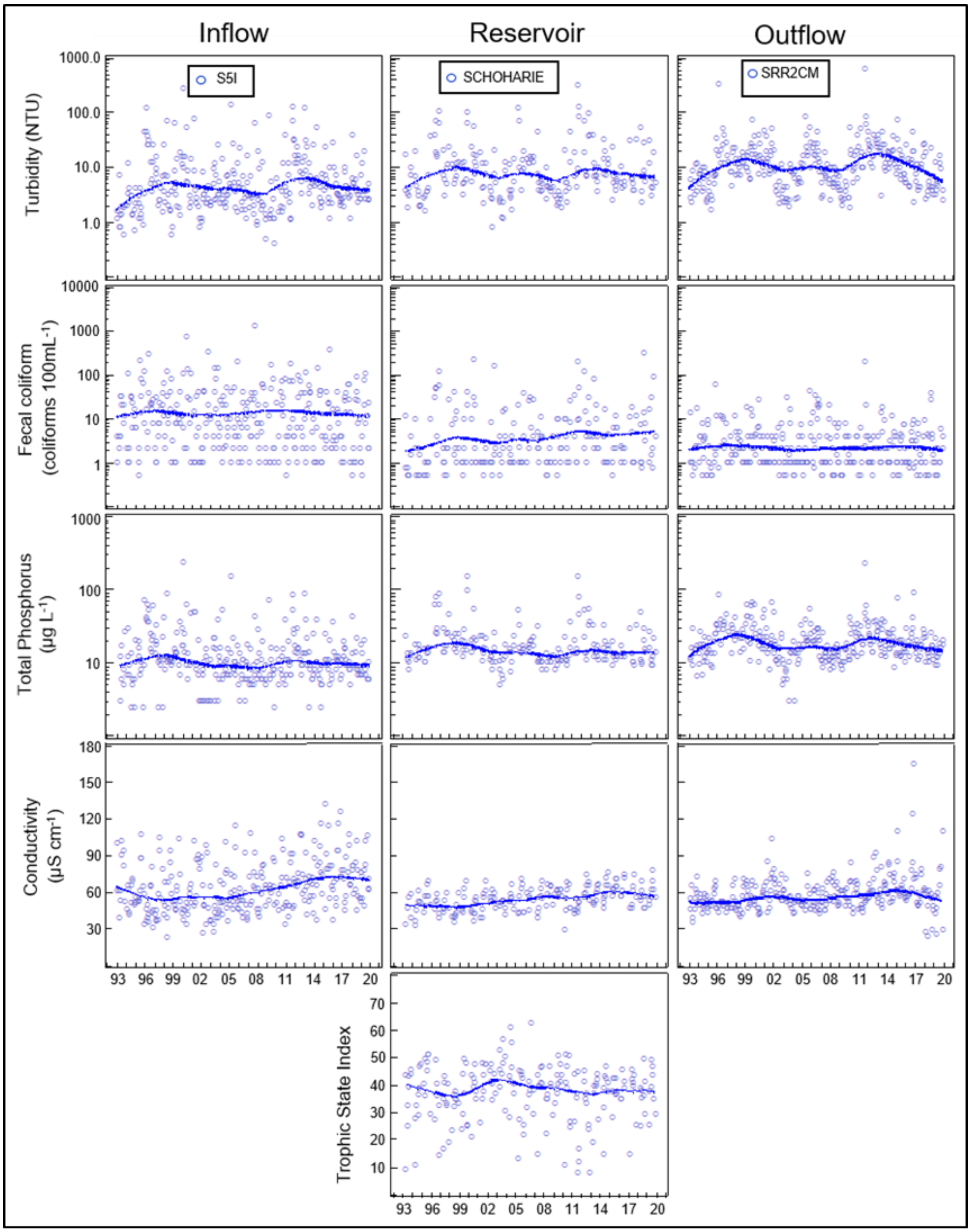


Figure 4.3 Water quality trend plots for the Schoharie basin main stream inflow at Schoharie Creek (S5I), Schoharie Reservoir, and the outflow at the Shandaken Portal (SRR2CM).

Table 4.1 Schoharie basin trends from 1993-2019 for selected analytes.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
S5I	Inflow	Turbidity	313	***	0.05	1.35	Increasing trend virtually certain
S5I	Inflow	Turbidity (Flow Adj.)	313	***	0.039	1.052	Increasing trend very likely
Schoharie	Reservoir	Turbidity	209	*	0.053	0.779	Increasing trend possible
SRR2CM	Outflow	Turbidity	313	NS	0.033	0.33	Increasing trend about as likely as not
S5I	Inflow	Fecal Coliform	309	NS	0	0	Decreasing trend about as likely as not
S5I	Inflow	Fecal Coliform (Flow Adj.)	309	NS	-0.057	-0.708	Decreasing trend about as likely as not
Schoharie	Reservoir	Fecal Coliform	208	***	0.027	1.352	Increasing trend virtually certain
SRR2CM	Outflow	Fecal coliform	312	NS	0	0	Decreasing trend about as likely as not
S5I	Inflow	Total Phosphorus	305	**	-0.056	-0.555	Decreasing trend likely
S5I	Inflow	Total Phosphorus (Flow Adj.)	305	**	-0.07	-0.702	Decreasing trend likely
Schoharie	Reservoir	Total Phosphorus	202	***	-0.125	-0.892	Decreasing trend very likely
SRR2CM	Outflow	Total Phosphorus	304	NS	-0.045	-0.256	Decreasing trend about as likely as not
S5I	Inflow	Conductivity	306	***	0.973	1.201	Increasing trend virtually certain
S5I	Inflow	Conductivity (Flow Adj.)	306	***	1.063	1.313	Increasing trend virtually certain
Schoharie	Reservoir	Conductivity	197	***	0.704	0.965	Increasing trend virtually certain

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
SRR2CM	Outflow	Conductivity	313	***	0.5	0.676	Increasing trend virtually certain
Schoharie	Reservoir	Trophic State Index	207	NS	0.026	0.067	Increasing trend about as likely as not

[1] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

Long-term upward turbidity trends were identified in Schoharie Reservoir and its major inflow, Schoharie Creek (S5I). The increase is largely driven by several large storm events which occurred during 2010 and 201l. Peak turbidity levels were observed in late August and early September 2011, following tropical storms Irene and Lee. Excessive flows associated with these storms caused stream channels to incise into banks, creating new erosional sources and expanding old ones. Although a downward turbidity trend is indicated in recent years, turbidity levels have remained somewhat elevated throughout the Schoharie basin. This is despite the relative absence of large events and below average flow in most years since Irene and Lee.

There is strong evidence of a small increasing fecal coliform trend in the reservoir. As shown by the LOWESS curve, the sharpest increase from 1995 to 1999 was driven largely by a 1995-96 winter flood event and Tropical Storm Floyd in September 1999. A smaller increase from 2001-2005 is probably related to a change in precipitation patterns from two dry years followed by three wet years. Concentrations peaked again in late 2011 and were associated with tropical storms Irene and Lee. More recent fecal coliform concentration peaks in 2018 and 2019 were associated with moderate rain events in the 1-to-2-inch range.

In the previous FAD evaluation (DEP 2016), we reported an absence of any long-term phosphorus trend in the reservoir and a relatively weak decline in Schoharie Creek due to the effects of large storms in 2010 and 2011. Previous to 2010, a declining phosphorus trend was associated with several factors: recovery from historic flooding events during the 1995-96 winter, the 2001-02 drought, point source reductions associated with upgrades to WWTPs. With the addition of five more years of data, downward long-term trends are now evident in the reservoir with evidence for the downward trend becoming stronger in the inflow as the Schoharie basin continues to recover from the storms. The phosphorus decrease since 2011 is also likely enhanced by the generally low annual flow in Schoharie Creek and especially by the relative absence of large storm events through 2019. This downward trend is likely greater than shown given that phosphorus contamination in sample bottles inflated results from late 2014 to 2017 and was most significant in 2016 and 2017 (DEP 2018).

Statistical analysis revealed strong evidence for long-term increases in conductivity for Schoharie Reservoir and for its inflow and outflow. Flow adjustment increased the magnitude of the trend for Schoharie Creek, indicating that dilution/concentration effects of rain events/droughts do not explain the upward trend. Continuing contamination of groundwater with road deicers is the likely explanation.

TDA indicated an upward trend was about as likely as not for TSI, an estimate of algal productivity based on chlorophyll a concentrations. A short-term decline was apparent from 2003-2014, most likely due to low clarity conditions following storm events in 2005 and 2010-2012. Since 2014, TSI appears relatively stable.

In summary, upward trends were identified for turbidity, reservoir fecal coliforms, and conductivity while downward trends were identified for total phosphorus. The increase in turbidity is attributed to the watershed damage caused by large storm events in 2010 and 2011. Fecal coliform increases were also attributed to these storms as well as to more moderate storm events occurring throughout the record. The decline in phosphorus is attributed to recovery from high loads produced by periodic flood events, load reductions associated with the 2001-2002 drought, and from WWTP upgrades. The conductivity increases may be attributable to use of road deicers. While the TDA only indicated an upward trend was about as likely as not for a long term increase in reservoir TSI, the LOWESS analysis indicates improvement since 2003.

4.2.2 Biomonitoring in Schoharie Watershed

The New York City stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in City watershed streams. For methodology details, see Appendix C.

The most recent status of macroinvertebrate communities in the Schoharie basin was evaluated by examining 2017-2018 data from sites located on Schoharie Creek. Due to the budgetary constraints associated with COVID-19, data from 2019's sampling is not available at this time. This stream is the primary inflow to Schoharie Reservoir, draining 75% of the basin. The three sites with data from these years (Sites 202, 204, and 216) are sampled annually; the other four (Sites 237, 238, 240, and 242) are sampled on a rotating basis and were sampled but not analyzed in 2019. An additional site on the Batavia Kill (Site 206), a major tributary to Schoharie Creek whose confluence with that stream is a short distance upstream of Schoharie Reservoir, was also examined because of its rebound after a sustained drop in biological assessment profile (BAP) scores that had been observed in the prior years (2012-2014).

Site 204 (S5I) is located in Prattsville, approximately three-quarters of a mile upstream of Schoharie Reservoir. Sites 216, and 202 are situated about 9 and 17 miles, respectively, upstream of the reservoir. From 2017 to 2018, Sites 202 and 216 were assessed as being non-impaired with site 204 assessed as non-impaired in 2018 (Figure 4.4).

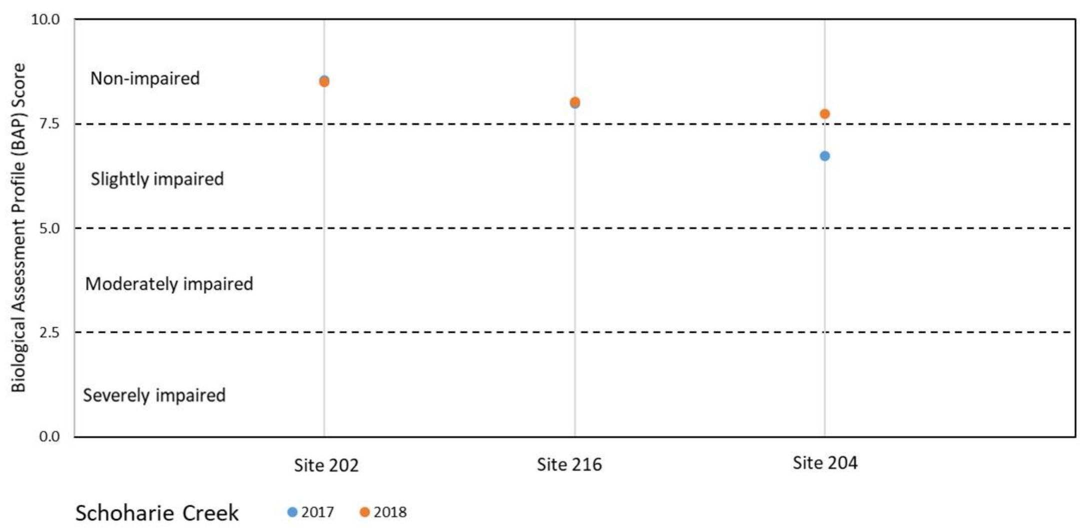


Figure 4.4 Biological Assessment Profile scores for Schoharie Creek, 2017-2018.

The time series trend in BAP scores was based on a site's entire period of record (1994 for Site 202, 1995 for Site 204 and 1996 for Site 216 through to 2018), and examined changes in both the scores and assessment categories. With very few exceptions, Sites 202, 204 and 216 have been assessed as non-impaired during their entire period of record (Figure 4.5). The percentage of hydropsychid caddisflies was low at Sites 202 and 216 with respective 2018 values of 19.4 and 25.0. However, the 2018 percentage of hydropsychids for Site 204 was 58.3.

The time series trend in BAP scores was based on a site's entire period of record (1994 for Site 202, 1995 for Site 204 and 1996 for Site 216, all through to 2018), and examined changes in both the scores and assessment categories. With very few exceptions, Sites 202, 204 and 216 have been assessed as non-impaired during their entire period of record (Figure 4.6). The percentage of hydropsychid caddisflies was low at Sites 202 and 216 with respective 2018 values of 19.4 and 25.0. However, the 2018 percentage of hydropsychids for Site 204 was 58.3.

Site 206 on the Batavia Kill is a routine site located approximately one-quarter mile upstream of Schoharie Creek. The BAP score at this site has experienced large declines since 2008, when there was a drop from the previous year's score of 8.30.

While the 2011 storms may have influenced the results of the post 2011 years, other factors may have been involved for the years preceding 2011. However, in recent years the BAP scores have continued to improve.

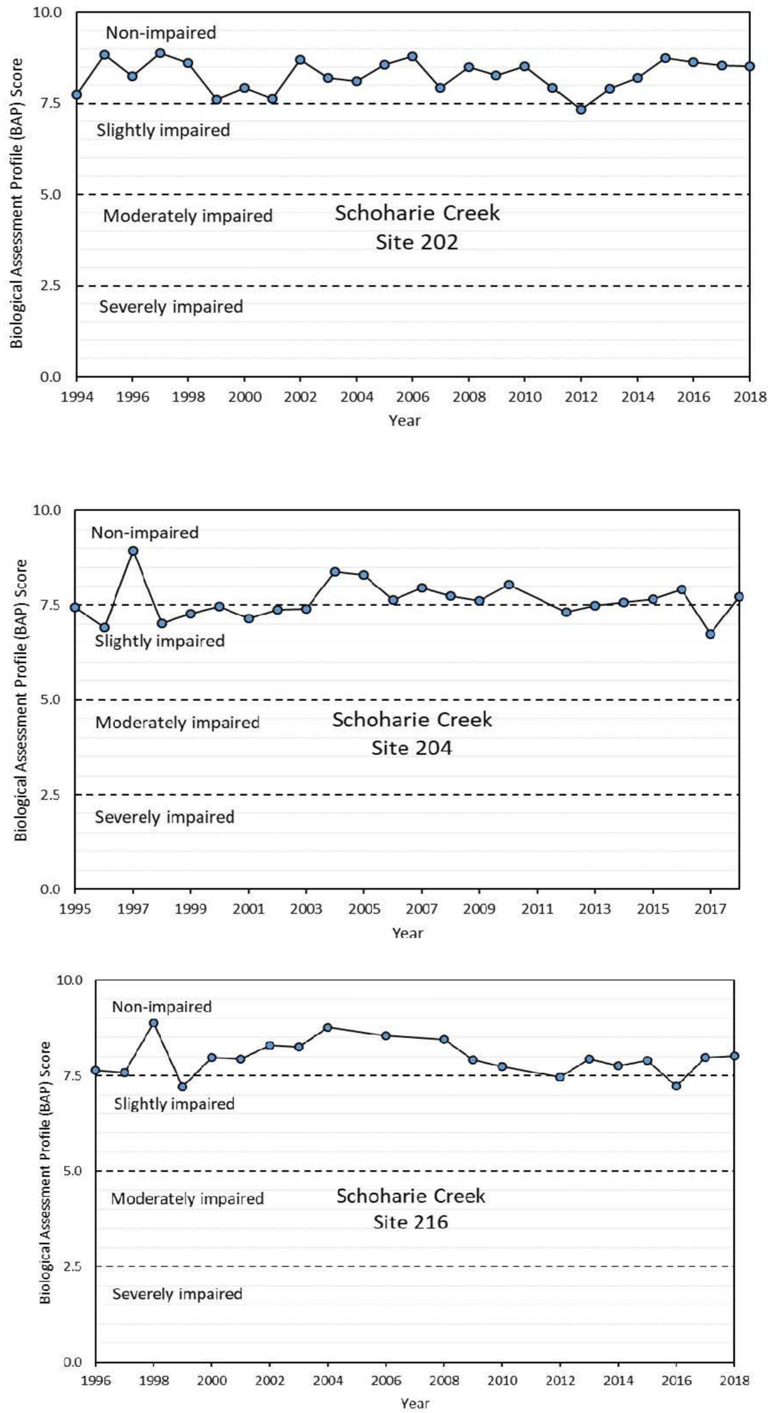


Figure 4.5 Biological Assessment Profile scores for Schoharie Creek, 1994/1995/1996-2018.

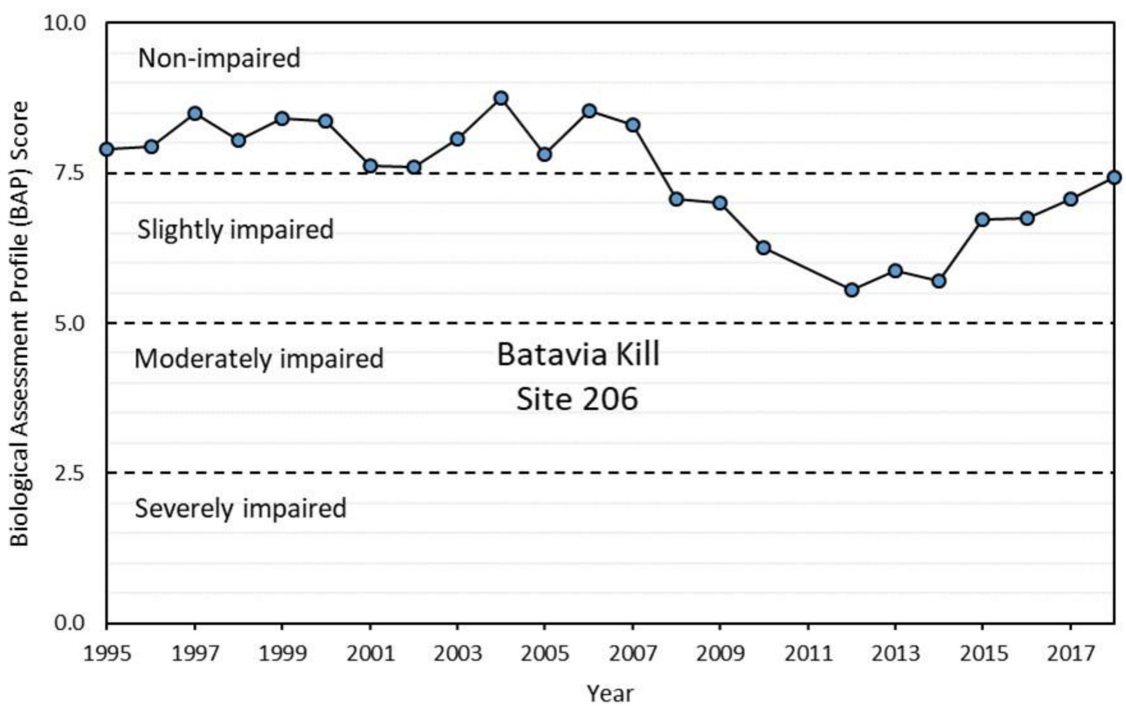


Figure 4.6 Biological Assessment Profile Scores for Batavia Kill at Site 206, 1995-2018.

4.3 The West and East Ashokan Basins

The Ashokan watershed's drainage basin is 255 square miles and includes parts of 11 towns. It was formed by damming Esopus Creek, which eventually flows northeast and drains into the Hudson River. Consisting of two basins separated by a concrete dividing weir and roadway, Ashokan Reservoir holds 122.9 billion gallons at full capacity and was placed into service in 1915. Over the past few years, Ashokan supplied 500 MGD, or approximately 40% of the total average daily consumption, to New York City and upstate consumers.

Bush Kill and Esopus Creek (which also conveys water from Schoharie Reservoir via the Shandaken Tunnel) are the two primary tributaries flowing into Ashokan Reservoir, with the former providing 6.4% and the latter 75.2% of water entering the reservoir. Under normal operating conditions, water enters Ashokan's West Basin and, after a settling period, is withdrawn from its East Basin. It is carried southeast under the Hudson River via the 92-mile-long Catskill Aqueduct, which has a maximum depth underground of 1,114 feet. It enters Kensico Reservoir in Westchester, then travels south via the Delaware Aqueduct to the Catskill-

Delaware Ultraviolet Light Disinfection Facility (CDUV) and into distribution at Hillview Reservoir in Yonkers.

Land use in the Ashokan watershed is classified as follows: 88.3% is forested, 4.9% is urban or built-up land, 1.1% is brushland or successional land, <0.1% is classified as barren land, 5.2% is water, and the remaining 0.5 % is in agricultural use.

As of December 31, 2020, there were 30 acres of agricultural lands with active nutrient management plans in the Ashokan watershed. Since 1996, five BMPs have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater in the Ashokan watershed; no BMPs were implemented between 2016 and 2020. BMPs are associated with approximately 60 acres of farmland. Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place as described in Watershed Protection Program sections (Section 3).

There are five active WWTPs located in the Ashokan watershed with a cumulative permitted maximum flow of 0.6317 MGD. Inputs of phosphorus, as well as other pollutants, from WWTPs to Ashokan Reservoir continue to be reduced as a result of DEP's upgrades of all surface-discharging plants and through the intervention and involvement of DEP's Regulatory Compliance and Inspection Program.

4.3.1 Water Quality Status and Trends in the Ashokan Watershed

Status (West Basin)

Ashokan's West Basin status evaluation is presented as a series of boxplots in Figure 4.7. Only the principal inflow (E16I) and the reservoir (EAW) summaries are shown, since water is rarely withdrawn directly from this basin. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the status evaluation period (2017-2019), all median monthly values for fecal coliform bacteria fell below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the river inflow site E16I, and all median monthly reservoir coliform levels were below the SWTR benchmark of 20 coliforms 100 mL^{-1} used for source waters. There was one sample in early November that approached the fecal coliform benchmark value (19 coliforms 100 mL^{-1}) in the reservoir. Turbidity monthly medians were low for this evaluation period (median 4.05 NTU at the inflow and 2.8 NTU in the reservoir). Total phosphorus (TP) followed a similar pattern with an inflow median of 10 µg L^{-1} and reservoir median of 8 µg L^{-1}. Only one reservoir TP value was above the phosphorus-restricted target value of 15 µg L^{-1} for source waters. Trophic State Index (TSI) values fell primarily in the mesotrophic range. The conductivity monthly median was highest at the inflow (69 µS cm^{-1}) and was slightly lower in the reservoir (median 61.5 µS cm^{-1}).

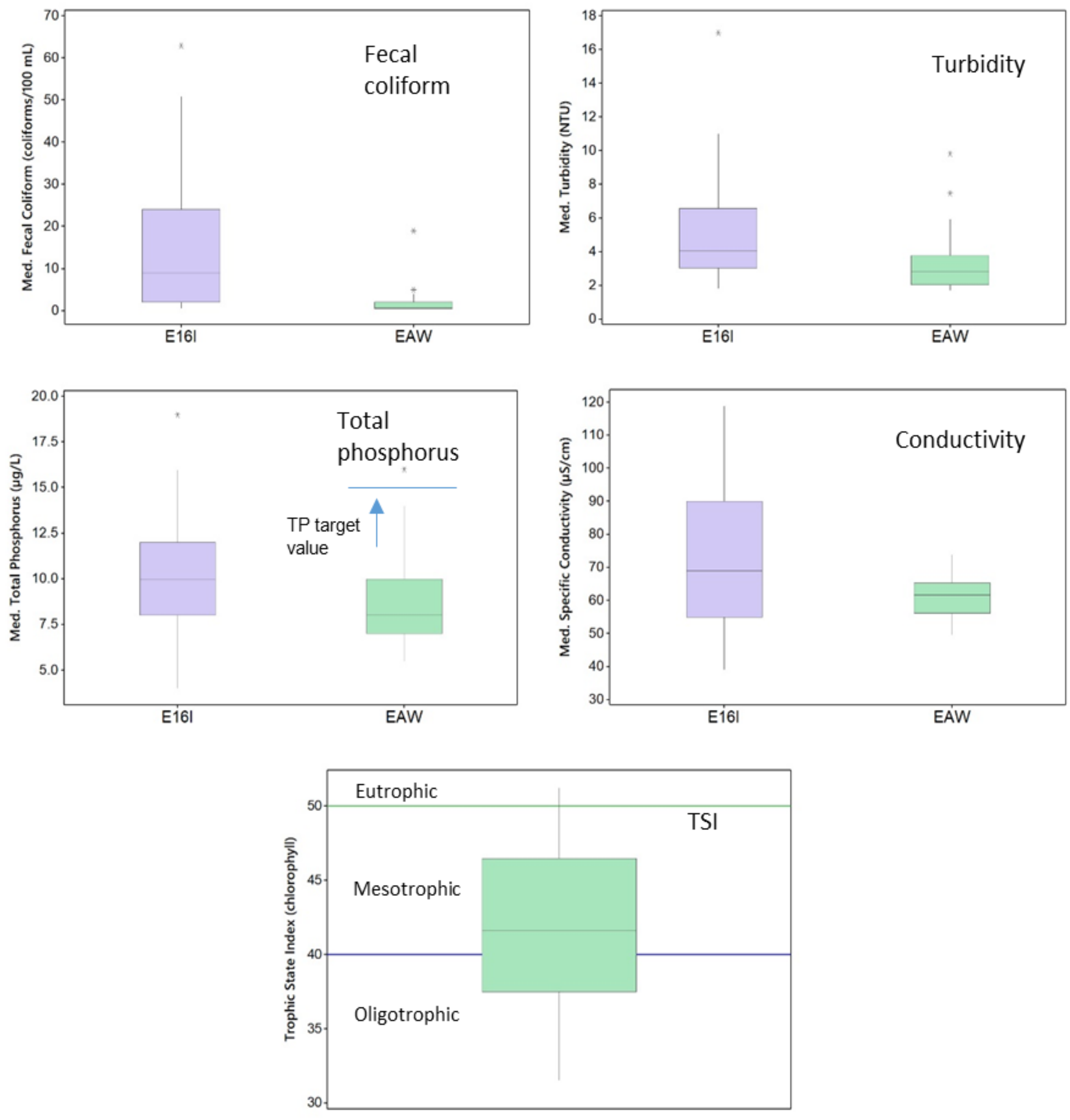


Figure 4.7 Water quality status boxplots using 2017-2019 monthly data for the Ashokan West Basin main stream inflow at Esopus Creek (E16I) and the Ashokan Reservoir West Basin (EAW).

Trends (West Basin)

Water quality trend plots are presented in Figure 4.8 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 4.2. In the previous FAD evaluation (DEP 2016), upward long-term turbidity trends were detected in the West Basin of the Ashokan Reservoir and in its primary input, Esopus Creek (E16I).

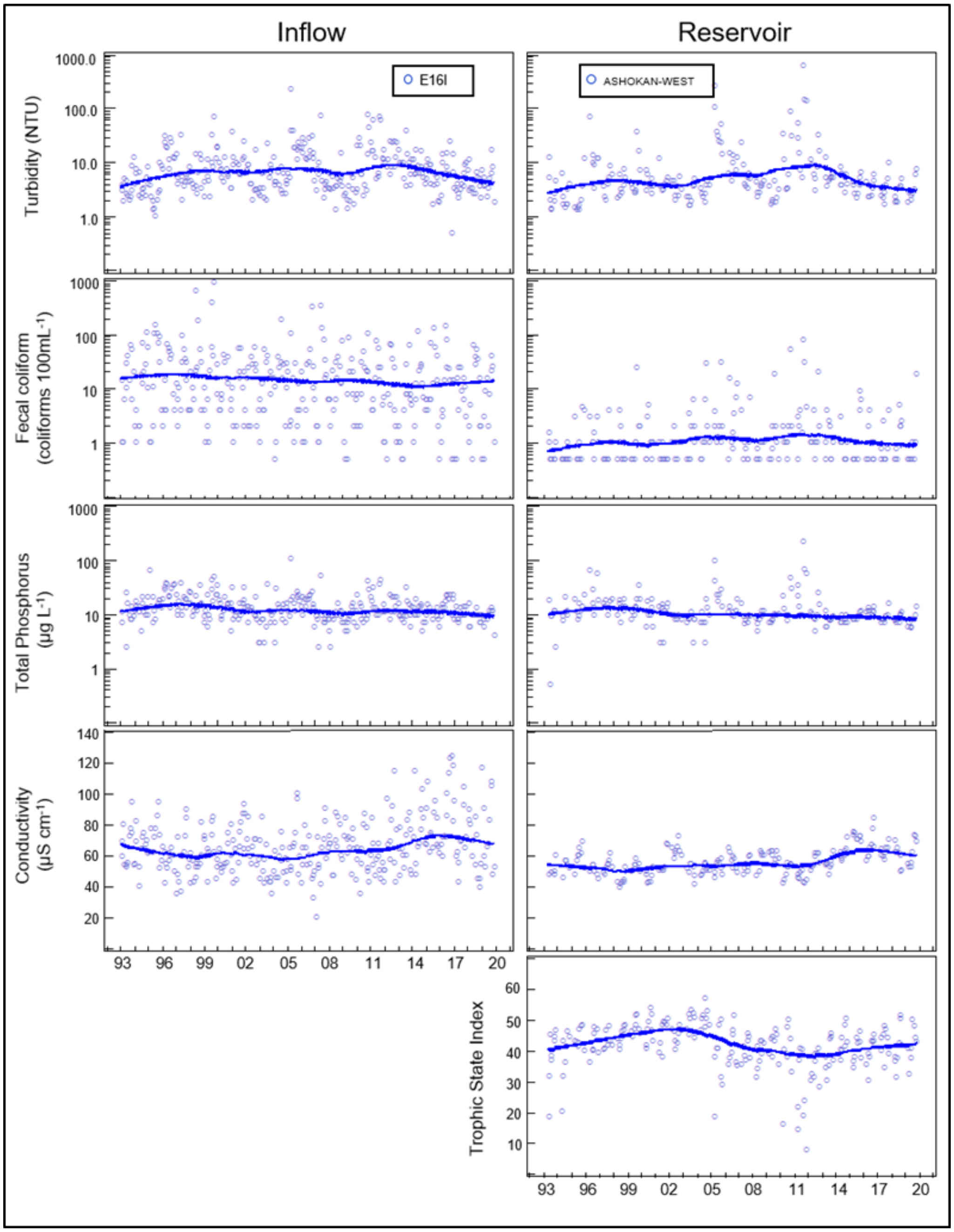


Figure 4.8 Water quality trend plots for the Ashokan West Basin for the main stream inflow at Esopus Creek (E16I) and the Ashokan Reservoir West Basin.

Examination of the LOWESS turbidity plots (DEP 2016) revealed that the upward trend was driven by extremely high turbidity values from multiple events in 2005, 2006, 2010, and, especially, 2011. Additional details are provided in the previous FAD evaluation. In the years since 2011, LOWESS modeling results show a persistent decline in turbidity. The decline is likely due to recovery from the 2010-2011 storms and to the relative absence of large runoff events during the 2012-2019 period. Despite the recent turbidity decline, the SKT and TDA analysis over the entire record (1993-2019) still suggests the possibility of an overall upward trend of small magnitude.

Table 4.2 Ashokan West Basin trends from 1993-2019 for selected analytes.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
E16I	Inflow	Turbidity	323	NS	0.027	0.445	Increasing trend possible
E16I	Inflow	Turbidity (Flow Adj.)	323	*	0.032	0.532	Increasing trend possible
Ashokan-West	Reservoir	Turbidity	215	NS	0.017	0.438	Increasing trend possible
E16I	Inflow	Fecal Coliform	321	***	-0.125	-1.136	Decreasing trend virtually certain
E16I	Inflow	Fecal Coliform (Flow Adj.)	321	***	-0.165	-1.496	Decreasing trend very likely
Ashokan-West	Reservoir	Fecal coliform	215	**	0	0	Increasing trend likely
E16I	Inflow	Total Phosphorus	317	***	-0.166	-1.387	Decreasing trend virtually certain
E16I	Inflow	Total Phosphorus (Flow Adj.)	317	***	-0.156	-1.297	Decreasing trend virtually certain
Ashokan-West	Reservoir	Total Phosphorus	209	***	-0.154	-1.541	Decreasing trend virtually certain
E16I	Inflow	Conductivity	319	***	0.433	0.677	Increasing trend virtually certain
E16I	Inflow	Conductivity (Flow Adj.)	319	***	0.408	0.638	Increasing trend virtually certain
Ashokan-West	Reservoir	Conductivity	202	***	0.449	0.816	Increasing trend virtually certain
Ashokan-West	Reservoir	Trophic State Index	214	***	-0.164	-0.383	Decreasing trend virtually certain

[1]The *p*-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

Long-term fecal coliform trends were not detected for the primary input, Esopus Creek, in the last FAD evaluation. But the addition of five more years of generally lower fecal coliform count data now indicate an overall declining trend at this major stream. In contrast, a long-term, upward fecal coliform trend was detected in the reservoir. Similar to turbidity, this trend appeared to be initiated by the April 2005 flood event, and supported by runoff events in 2006, 2010, and 2011 (Figure 4.8). Since summer 2011, there has been a steady decrease in fecal counts coinciding with a notable absence of large runoff events through 2019.

Except for temporary increases associated with the previously mentioned major runoff events, total phosphorus concentrations in Esopus Creek and in the reservoir have declined over the long-term record. Even after the effects of flow were removed, there is strong evidence of a phosphorus decline suggesting the decline was likely achieved through the implementation of watershed protection programs - in particular the upgrade of the Pine Hill WWTP and establishment of the Boiceville WWTP in 2010. This downward trend is likely greater than shown given that phosphorus contamination in sample bottles inflated results from late 2014 to 2017 and was most significant in 2016 and 2017 (DEP 2018).

A weak upward conductivity trend was detected in Esopus Creek in the last FAD evaluation, but no trend was detected for Ashokan Reservoir's West Basin. With the addition of five more years of data there is now strong evidence of an upward conductivity trend in both the creek and reservoir. The trend persists even after adjusting for flow indicating the increase is due to an increase in ionic substances with road salt being the most likely source.

There is strong evidence of a long-term downward trend for Trophic State Index (TSI). Although TSI consistently increased from 1993-2004, the trend suddenly reversed in April 2005 coinciding with a flooding event. Under the conditions of diminished water clarity caused by turbid floodwater, algae were unable to thrive, as reflected by the decrease in TSI. After a slight increase in TSI, turbid floodwaters again occurred in 2010-2011 keeping productivity levels depressed. The long-term decline of TP may also help explain the decrease in productivity.

In summary, long-term downward trends were evident for total phosphorus, stream fecal coliforms and TSI. The phosphorus reductions are likely due to point source reductions from WWTPs as well as from the cumulative effects of watershed protection programs. The TSI trend appears related to periodic turbid conditions that prevented algal growth and also to reductions in TP. Upward trends were detected for turbidity, reservoir fecal coliform and conductivity. Although long-term increases were identified for turbidity and fecal coliform, attributed to large runoff events in 2005-2006 and 2010-2011, decreasing trends were apparent for both analytes since 2012. Conductivity increases suggest contamination by road deicers.

Status (East Basin)

Ashokan's East Basin status evaluation is presented as a series of boxplots in Figure 4.9. Only the reservoir (EAE) and outflow (EARCM) summaries are shown because water from the

West Basin flows directly to the East Basin. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the status evaluation period (2017-2019), all monthly median values for fecal coliform bacteria for both the reservoir and outflow were below the SWTR benchmark of 20 coliforms 100 mL^{-1} used for source waters. Turbidity was low for the evaluation period, with a median of 1.2 NTU in the reservoir and a median of 1.8 NTU at the outflow. Total phosphorus

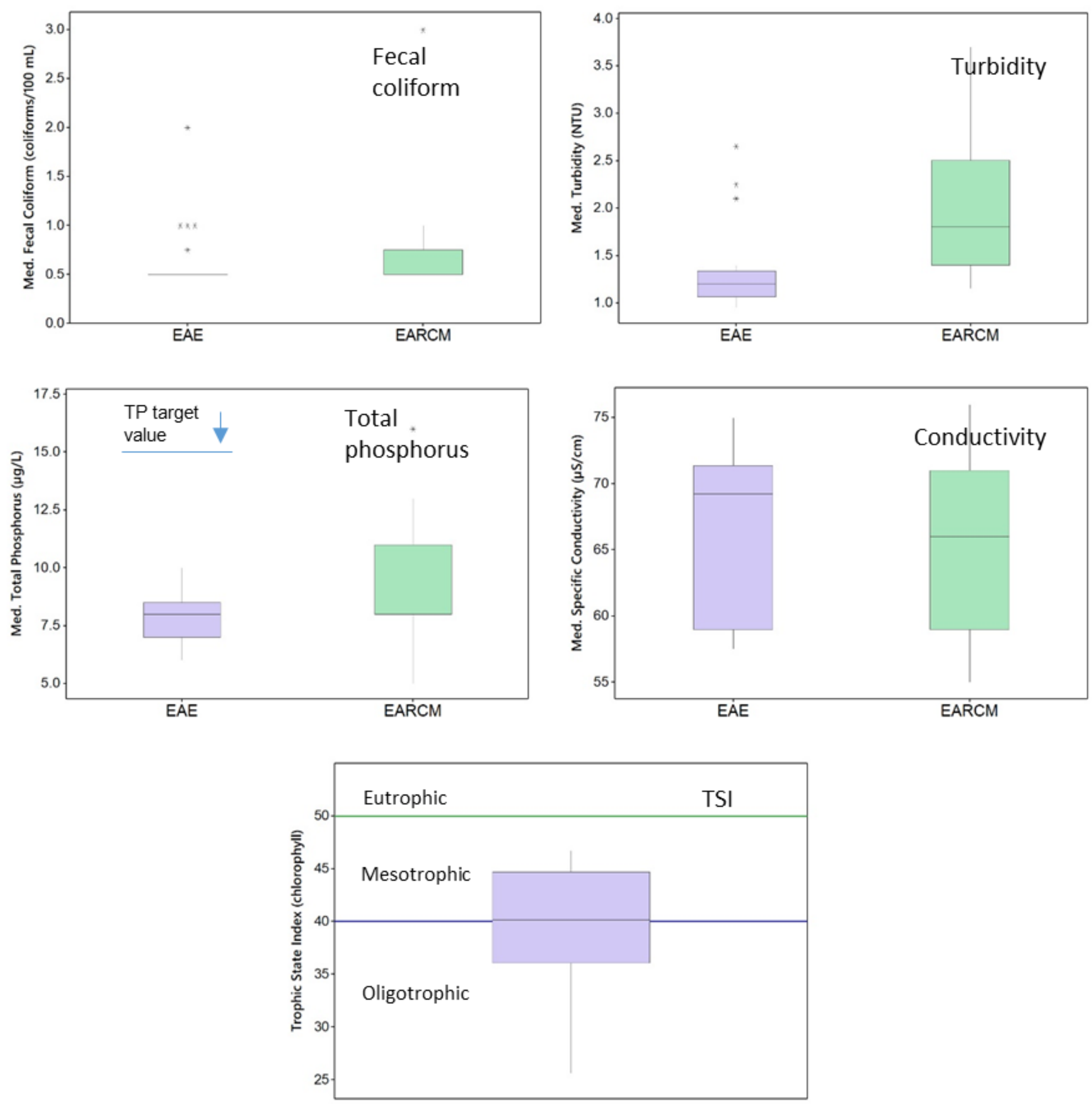


Figure 4.9 Water quality status boxplots using 2017-2019 monthly data for the Ashokan Reservoir East Basin (EAE) and the outflow at the Ashokan gatehouse (EARCM).

(TP) medians for the reservoir and outflow were identical (8 µg L^{-1}). Trophic State Index (TSI) values ranged between oligotrophic and mesotrophic. Specific conductivity monthly medians were similar between reservoir and outflow (69 and 66 µS cm^{-1}, respectively).

Trends (East Basin)

Water quality trend plots are presented in Figure 4.10 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 4.3. The West Basin, the East Basin's primary source of water, is discussed in the preceding section.

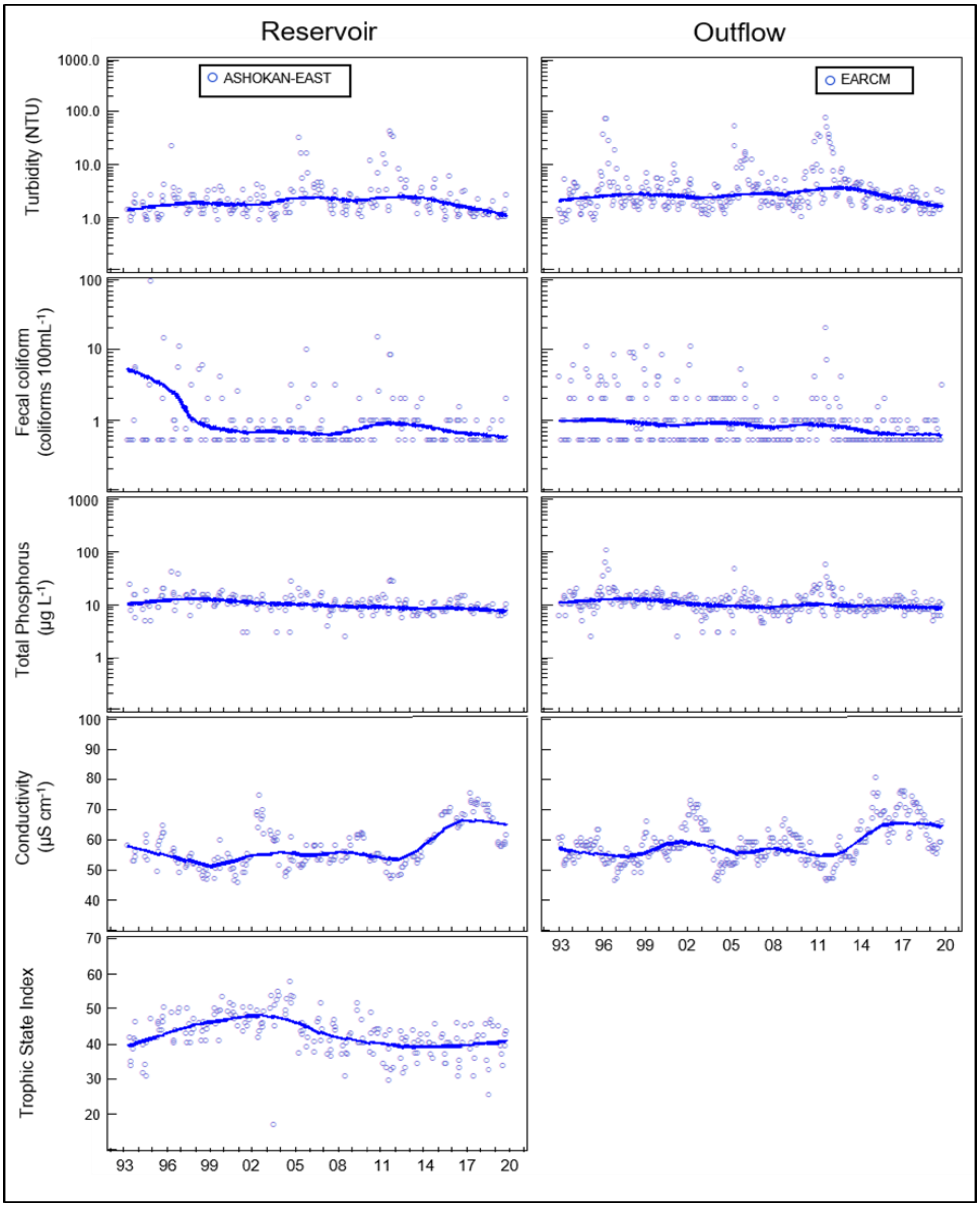


Figure 4.10 Water quality trend plots for the Ashokan Reservoir East Basin and the outflow at the Ashokan gatehouse (EARCM).

Table 4.3 Ashokan East Basin trends from 1993-2019 for selected analytes.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
Ashokan-East	Reservoir	Turbidity	215	NS	0	0	Trend unlikely
EARCM	Outflow	Turbidity	323	NS	0	0	Trend unlikely
Ashokan-East	Reservoir	Fecal coliform	213	NS	0	0	Decreasing trend possible
EARCM	Outflow	Fecal coliform	323	***	0	0	Decreasing trend virtually certain
Ashokan-East	Reservoir	Total Phosphorus	209	***	-0.209	-2.086	Decreasing trend virtually certain
EARCM	Outflow	Total Phosphorus	322	***	-0.117	-1.165	Decreasing trend virtually certain
Ashokan-East	Reservoir	Conductivity	203	***	0.417	0.759	Increasing trend virtually certain
EARCM	Outflow	Conductivity	323	***	0.3	0.526	Increasing trend virtually certain
Ashokan-East	Reservoir	Trophic State Index	210	***	-0.278	-0.651	Decreasing trend virtually certain

[1]The *p*-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$

Long-term upward turbidity trends were not identified in the East Basin and in its output, EARCM. Increases associated with storm events in 2010 and 2011 have given way to lower turbidity levels associated with the milder climate conditions observed in recent years (2012-2019).

There is strong evidence of downward fecal coliform trends in in Ashokan's East Basin and for the outflow of the reservoir. The initial large fecal coliform decrease in the reservoir was offset somewhat by runoff events in 2010-2011. The initial steep decline in the reservoir, as shown by the LOWESS curve has been linked to declining bird populations resulting from closure of local landfills (important winter foraging areas) in the mid to late 1990s.

Despite record flooding in 2010-11, declining trends were identified for total phosphorus indicating watershed protection programs (e.g., WWTP upgrades and new construction) have successfully reduced the phosphorus pool or limited the transport of phosphorus to local streams. This downward trend is likely greater than shown given that phosphorus contamination in sample bottles probably inflated results from late 2014 to 2017 and was most significant in 2016 and 2007 (DEP 2018).

In the last FAD evaluation (DEP 2016) long-term upward conductivity trends were not detected in the reservoir or its outflow. With the addition of five more years of data, there is now strong evidence of upward trends in both the reservoir and outflow. The increase coincides in timing and magnitude with the West Basin and its major inflow Esopus Creek (Figure 4.10). The source of the conductivity increase is likely associated with road deicers.

A long-term downward trend was identified for Trophic State Index (TSI). No flooding events have occurred in the Esopus since 2011 that may have impacted water clarity and caused impairment to algal productivity in recent years. Instead, decreasing phosphorus trends tied to WWTPs are the probable explanation for the decreased productivity and downward TSI trend.

In summary, long-term downward trends were evident for total phosphorus, fecal coliforms, and TSI while upward trend were identified for conductivity. The decrease in phosphorus is attributed to watershed programs like WWTP construction and upgrades. The decrease in fecal coliforms is likely the result of declining bird populations brought about by landfill closures. The decreasing TSI trend is attributed to lower phosphorus concentrations associated with WWTP construction and upgrades. Increasing conductivity trends are related to road deicer usage and to a lesser extent lower flows. Long-term trends were not evident for turbidity.

4.3.2 Biomonitoring in the Ashokan Watershed

The New York City stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in City watershed streams. For methodology details, see Appendix C.

The most recent status of macroinvertebrate communities in the Ashokan basin was evaluated by examining 2017-2018 data from sites located on Esopus Creek. Results from data collected in 2019 are not currently available due to budgetary constraints associated with COVID-19. The Esopus is the primary inflow to Ashokan Reservoir, draining 75% of the basin. Two of the sites with data from these years (Sites 215 and 227) are routine sites sampled annually; the other two (Sites 256 and 260) are sampled on a rotating basis and were sampled only once during the 2017-2019 reporting period.

Sites 227, 215 (E5), 256, and 260 (AEHG) lie roughly 9.5, 13, 17, and 24 miles, respectively, upstream of the reservoir. Both of the two routine sites (Sites 215 and 227) were assessed as non-impaired in 2017 and 2018. The rotating sites (Sites 256 and 260) were also both assessed as non-impaired in the year (2017) they were sampled (Figure 4.11).

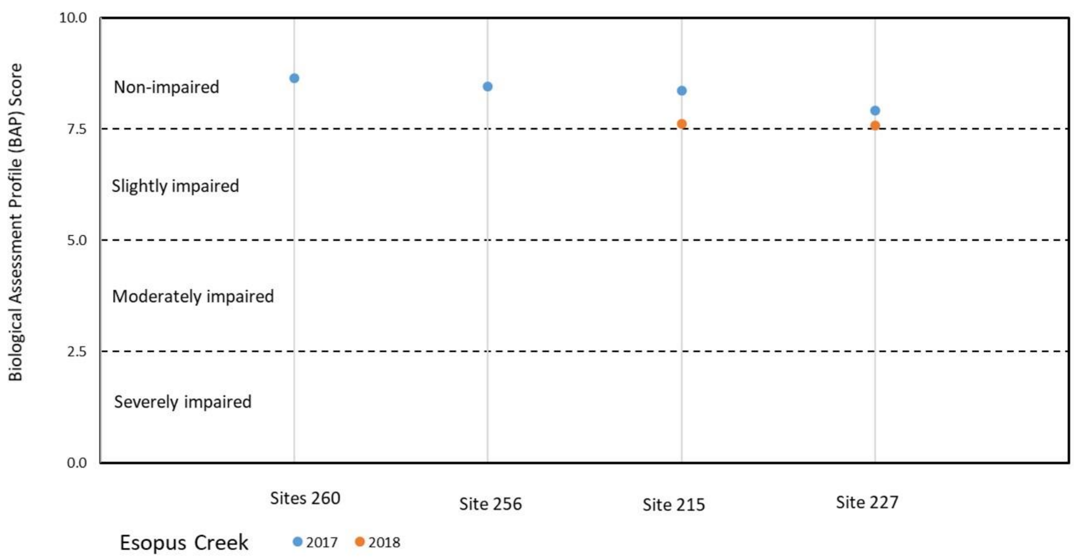


Figure 4.11 Biological Assessment Profile scores for Esopus Creek, 2017-2018.

The time series trends in BAP scores was based on a site's entire period of record (1996 for Site 215 and 1999 for Site 227, both through to 2018), and examined changes in both the scores and assessment categories. No trend is shown at either of the sites (Figure 4.12 and Figure 4.13). It should be noted that after tropical storms Irene and Lee, while only a possible cause, both sites had drops in both their BAP scores and a rise in the percentage of hydropsychid caddisflies in 2012. At Site 215, the 2012 percentage was 39.4 while in 2018 it was only 8.42. At Site 227 the percentage went from 65.2 in 2012 down to 15.63 in 2018.

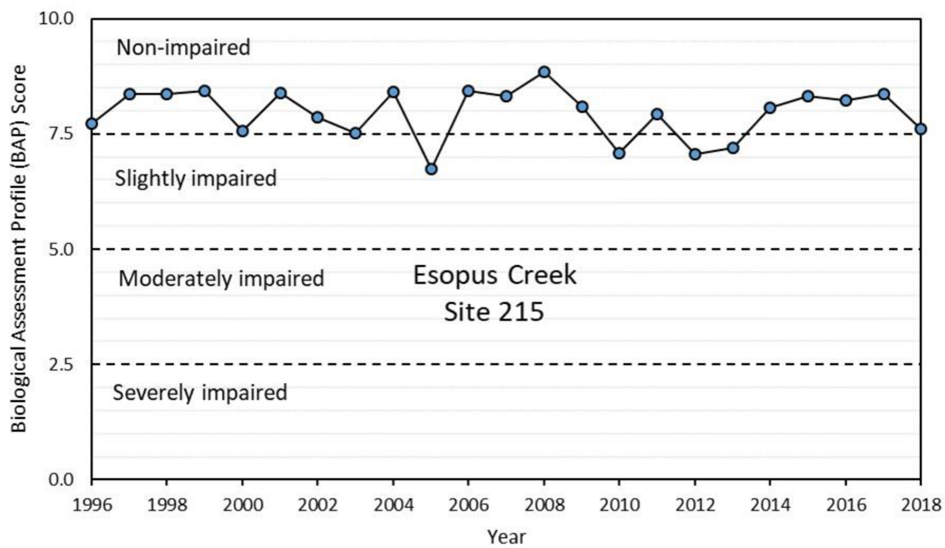


Figure 4.12 Biological Assessment Profile scores for Esopus Creek Site 215, 1996/1999-2018.

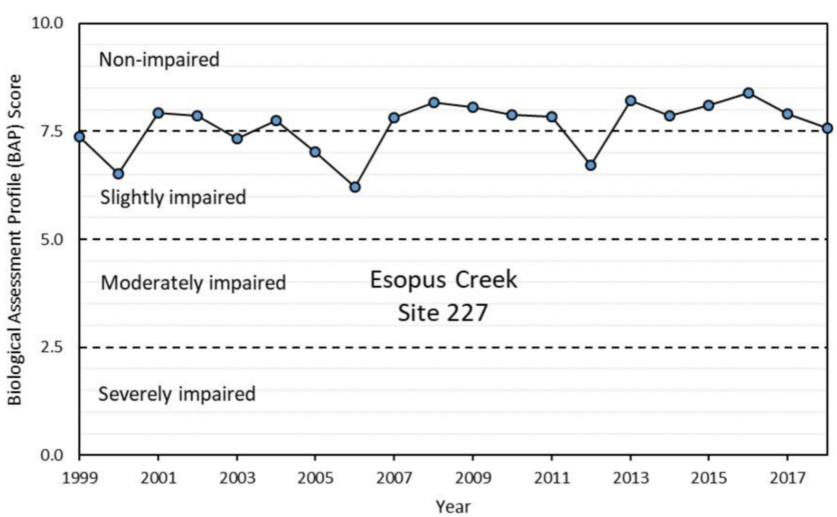


Figure 4.13 Biological Assessment Profile scores for Esopus Creek Site 227, 1996/1999-2018.

4.4 Trophic Response of Catskill Reservoirs

The plots in this assessment period show the most recent five-year period as bold symbols, with all preceding years shown as lightly-shaded symbols of the same color. Chlorophyll versus total phosphorus in Catskill System reservoirs is plotted in Figure 4.14. In the past, Schoharie Reservoir shows many deviating years on the low side indicating it is not infrequent there is a very low overall response of algal biomass to the phosphorus present. The years with particularly low algal biomass (1996 through 1998 and 2011 to 2012) are all associated with high flows and high turbidity. Turbidity can severely diminish light penetration in Schoharie, and the West Basin of Ashokan, for months at a time. This presents a severe limitation to algal growth. In the most recent five-year period, all three basins' (Schoharie, Ashokan East, and Ashokan West) values tend to cluster within the 80% confidence intervals. The values have moved closer to the expectation indicated by the OECD standards, with the Schoharie on the low side due to lower light (more shallow Secchi transparency). It's interesting to note in the absence of the OECD standards as a reference, it could be concluded that chlorophyll is negatively related to phosphorus. However in this case, it is the dominant effect of shading by clay particles with which the phosphorus is associated that creates the negative relationship.

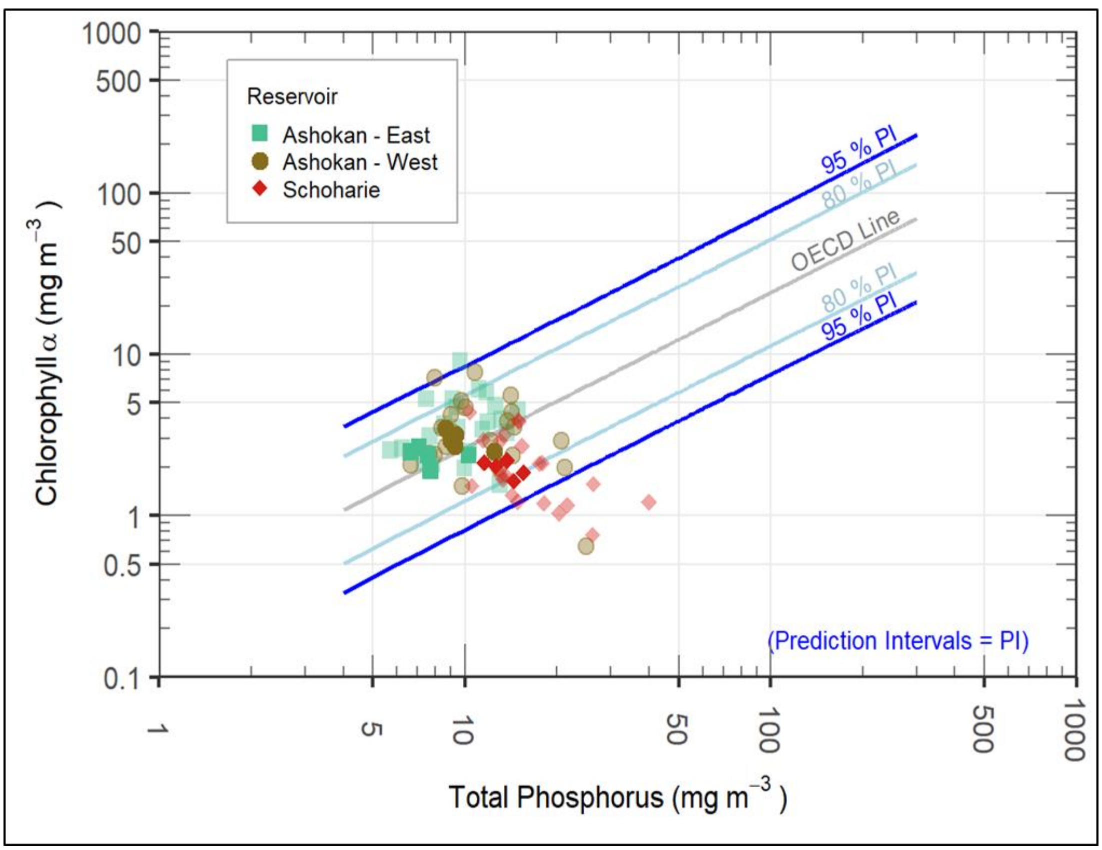


Figure 4.14 Chlorophyll versus total phosphorus in Catskill System reservoirs.

The annual maximum value of chlorophyll versus total phosphorus is plotted for each year in Figure 4.15. The chlorophyll maximum reflects the potential for algal biomass development when other factors (light and nutrients) are not limiting. Highest maxima were observed in all three Catskill System reservoir basins in 2003-2004, similar to the highest annual mean chlorophyll values, and in 2006, when major storms did not occur during the growing season. In the most recent period, all three basins tended to cluster around the OECD line with maximum chlorophyll observed in the West Basin of Ashokan. Schoharie tended to remain subdued in its chlorophyll response. All three basins remained within the 80% prediction interval.

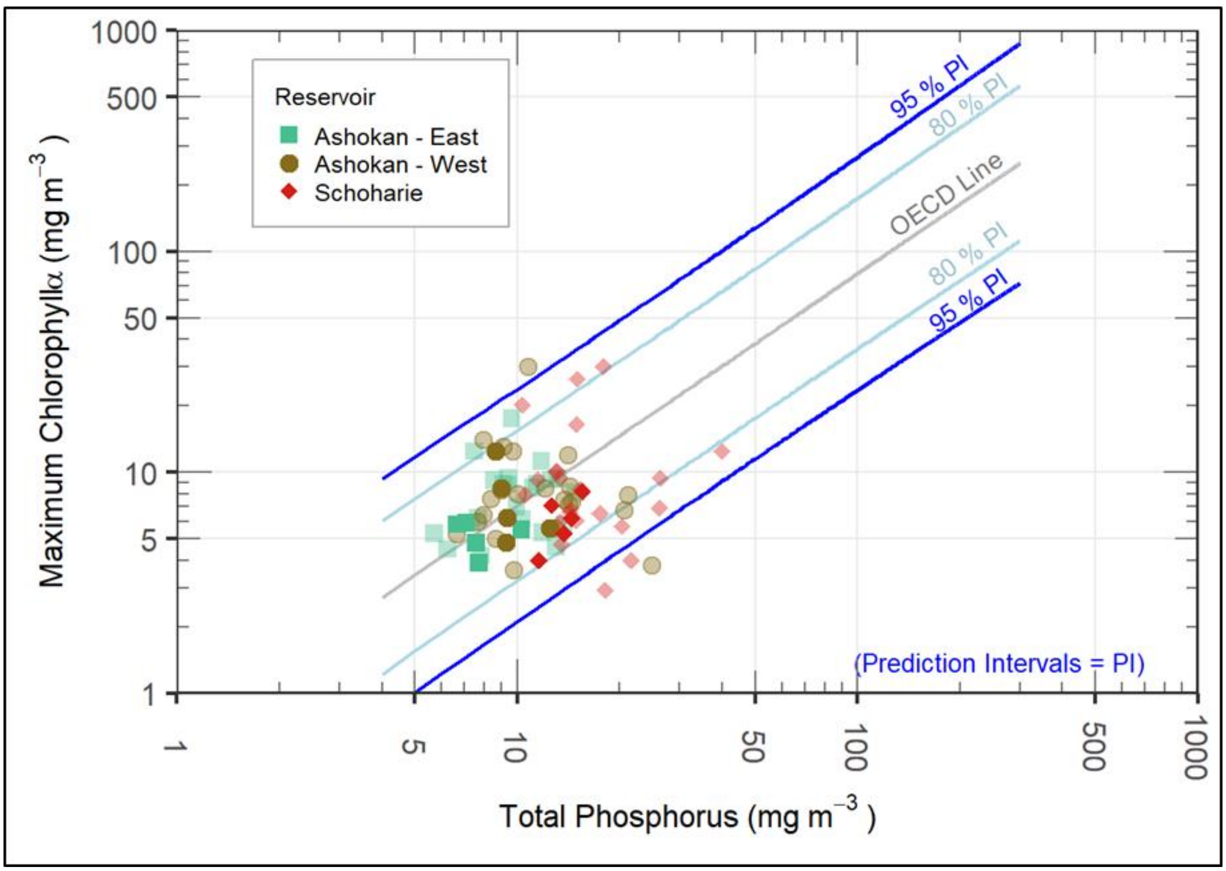


Figure 4.15 Maximum chlorophyll versus total phosphorus in Catskill System reservoirs.

Secchi depth versus total phosphorus annual mean values are plotted in Figure 4.16. The most prominent feature of the plot is that in past years there are many exceptionally low values for Schoharie and the West Basin of Ashokan. These all occur in years with floods, caused by tropical storms and hurricanes, and turbidity events including 1996, 2005, 2011, and 2012. In 2001, a spring turbidity event lasted for more than six months in Schoharie and four months in Ashokan, which led to the low transparency and high phosphorus values. The association of years with high turbidity with high phosphorus values indicates this nutrient is attached to the glacial clays which create the inordinately low transparencies. In the more quiescent times of the current five-year assessment, the Ashokan basins have both gravitated toward the OECD line and fall within the 80% prediction intervals (PI), however Schoharie transparency remains lower than the 80% PI indicating that factors other than nutrient-induced algal growth limits transparency.

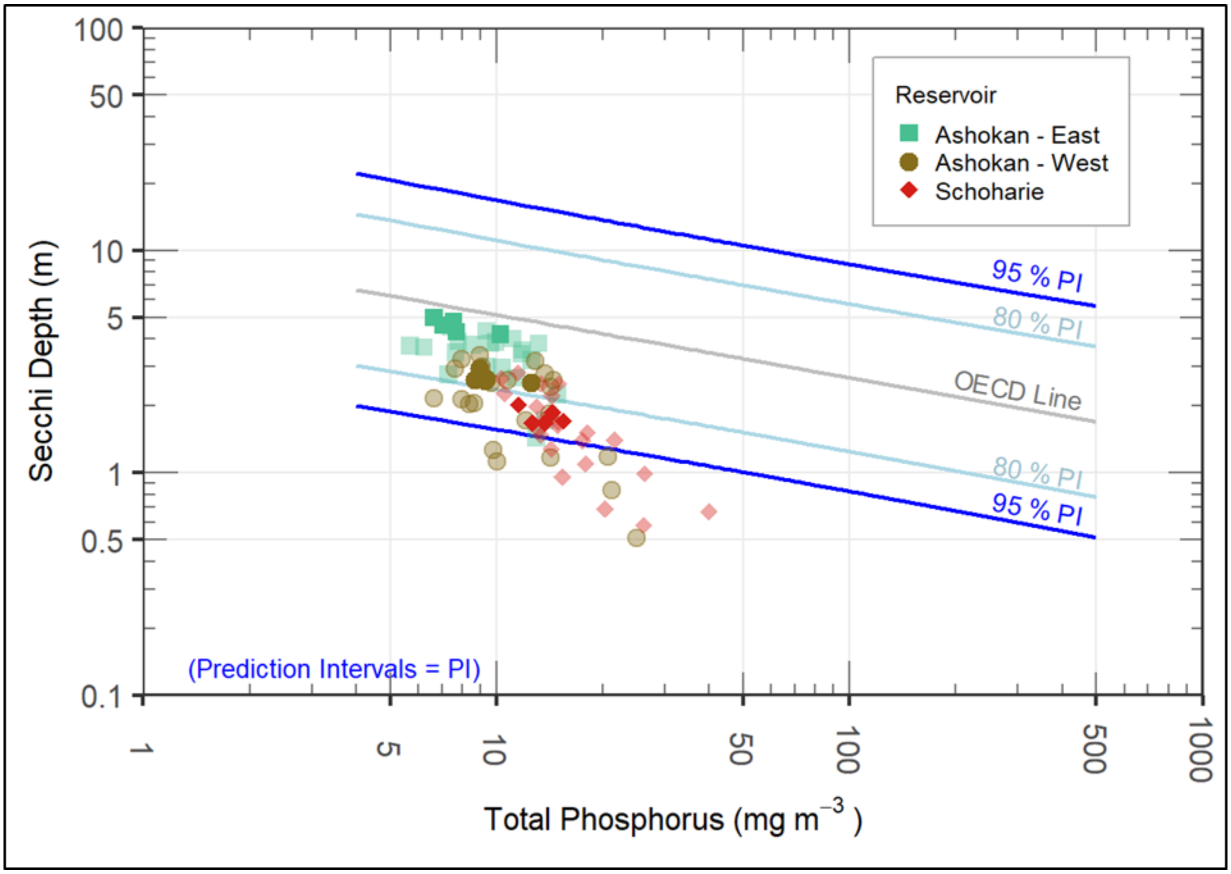


Figure 4.16 Secchi depth versus total phosphorus in Catskill System reservoirs.

Secchi depth versus chlorophyll is plotted in Figure 4.17. This plot demonstrates that transparency of the surface water is typically not controlled by algal biomass in Schoharie, nor in the West Basin of Ashokan. Similar to the reasons for low Secchi depths described in the previous relationship with total phosphorus, transparency is highly limited in years with floods caused by tropical storms and hurricanes, and turbidity events. The most recent five-year period shows Secchi transparency of greater than five meters due to the low chlorophyll values during this assessment. In contrast, Secchi depth for Schoharie remain low despite low chlorophyll values indicating that other factors, such as suspended particulates, limit transparency.

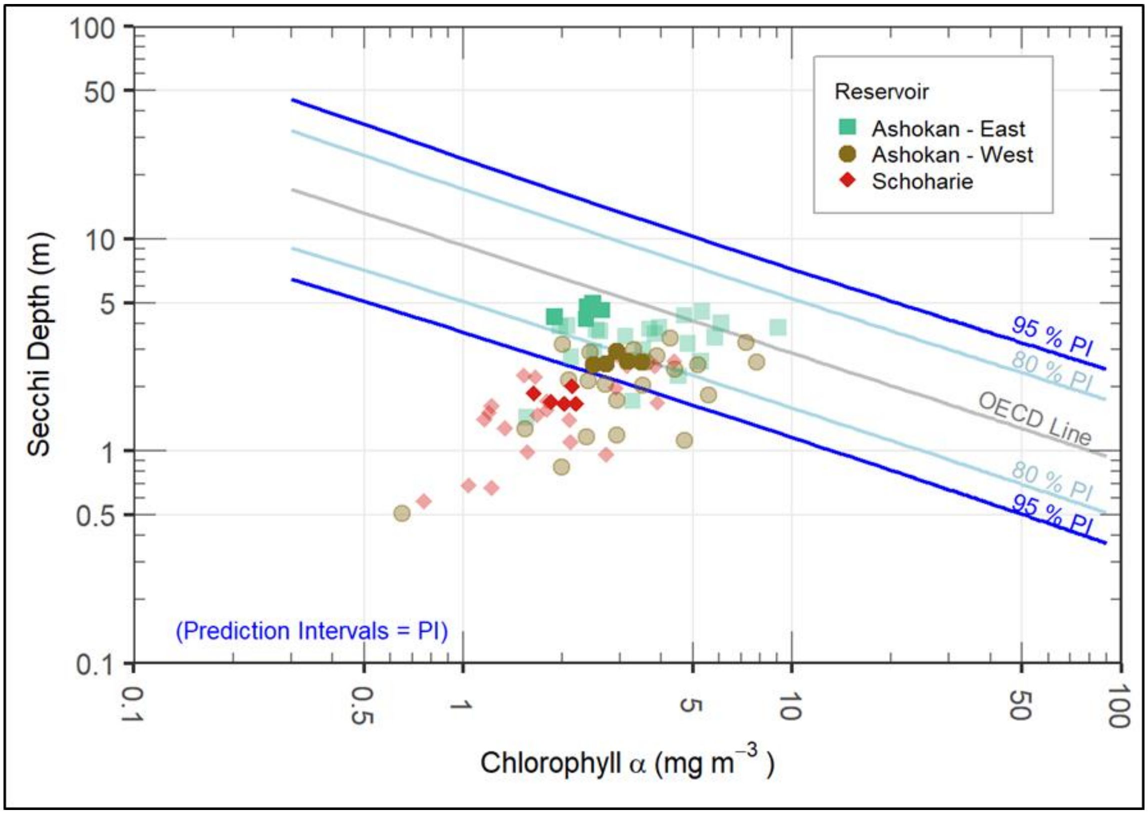


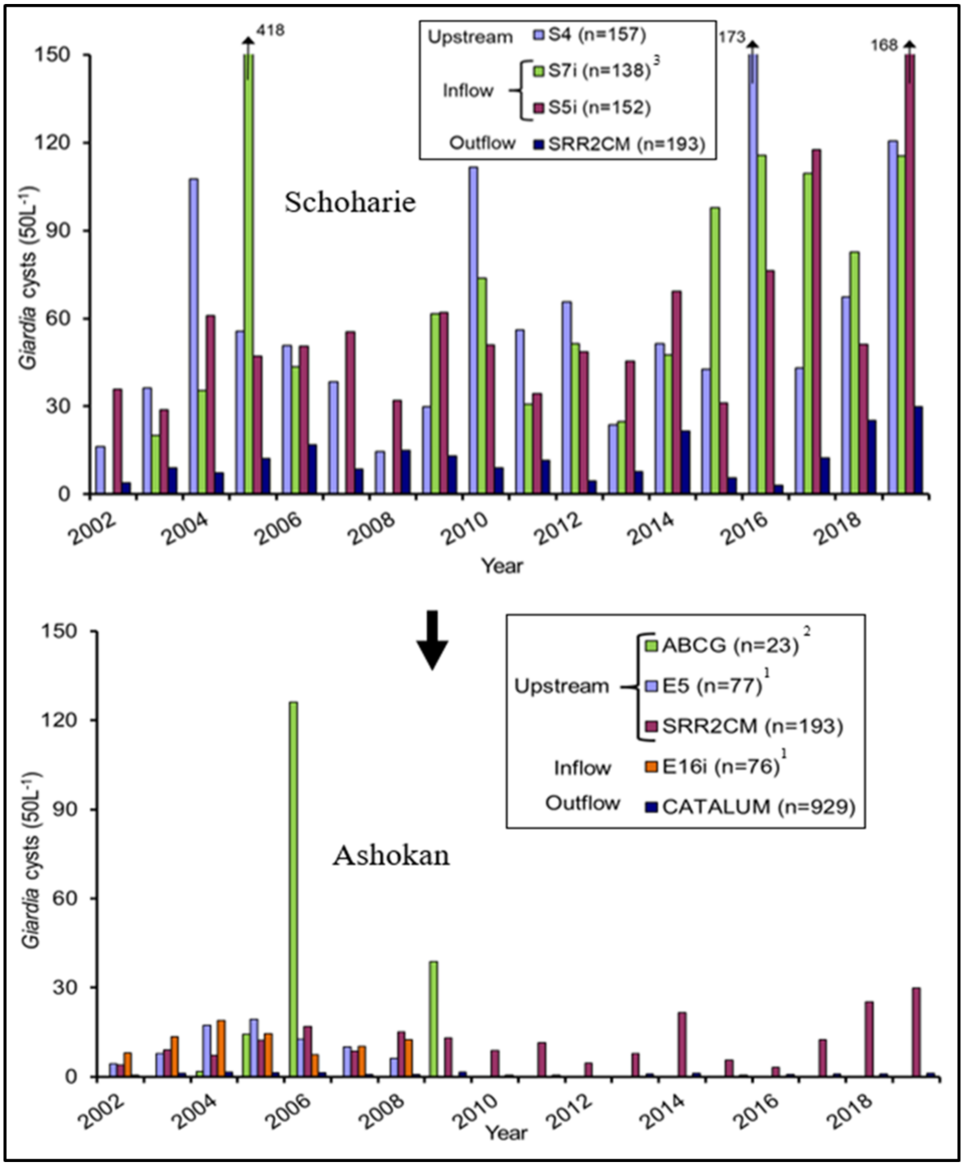
Figure 4.17 Secchi depth versus chlorophyll in Catskill System reservoirs.

4.5 Catskill System Protozoa: Sources and Attenuation

4.5.1 Upstream Sites and Reservoir Outflows

DEP has sampled for protozoa (*Giardia* and *Cryptosporidium*) in the Catskill system using EPA Method 1623 and, later, 1623.1 since June 2002. Three stream sites, located above the Schoharie Reservoir, were monitored at various times over the monitoring period: S7I (Manor Kill), S4 (Schoharie Creek at Lexington, upstream of S5I), and S5I (Schoharie Creek at Prattsville). Four sites representing inflow to the Ashokan basin were also monitored at various times: ABCG (Birch Creek), E5 (Esopus Creek, upstream of the Shandaken Tunnel), SRR2CM (Shandaken Tunnel outlet), and E16I (Esopus Creek just before entering Ashokan Reservoir). Data are presented in (oo)cysts per 50 liters, and means have been calculated with data normalized to that volume.

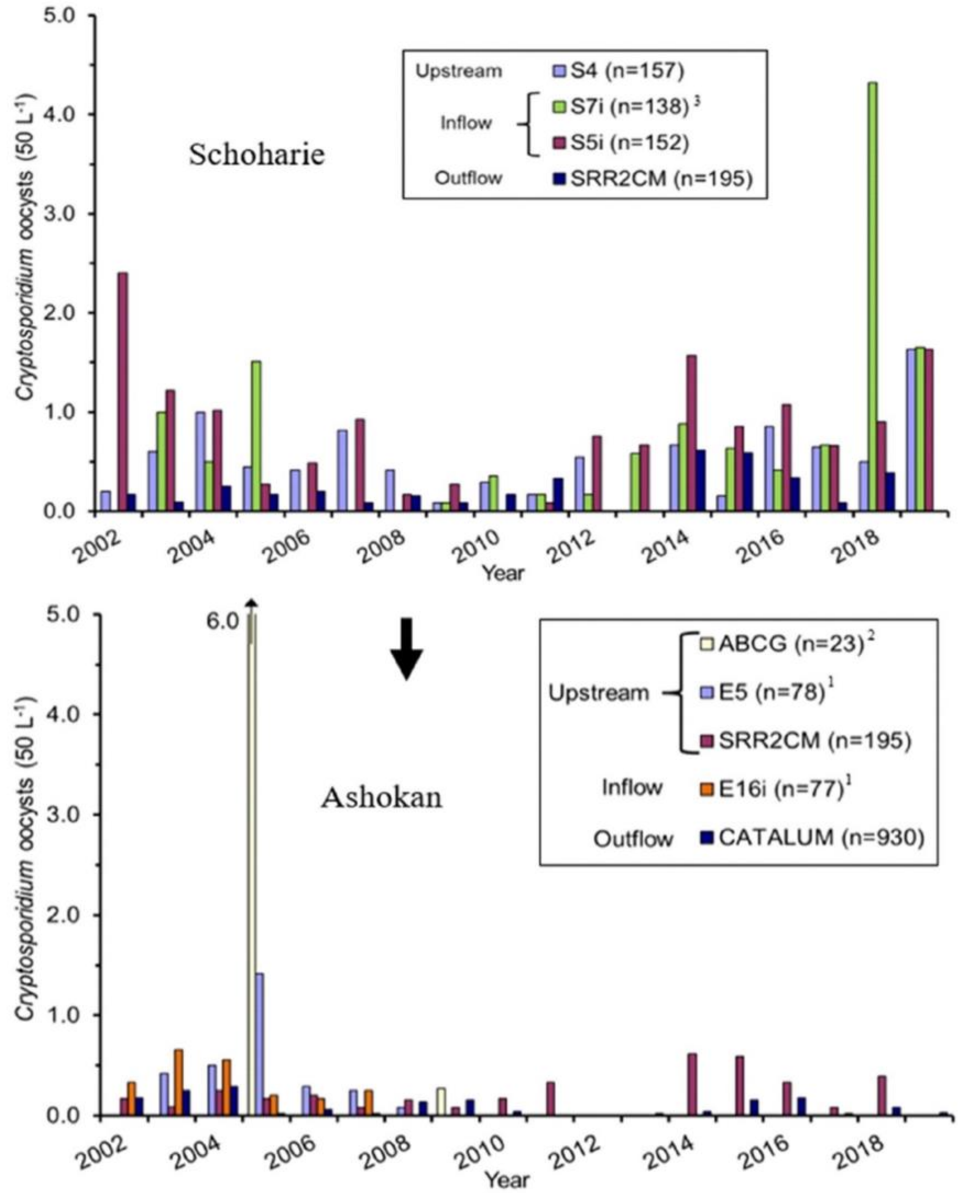
As previous FAD Assessment reports have indicated (DEP 2011, DEP 2016), when protozoan concentrations at the tributary streams from the recent 2015-2019 period are compared to those at the reservoir outflows [SRR2CM (Schoharie Reservoir outflow) and CATALUM (representing the Ashokan outflow)], in nearly all cases it is clear there are processes occurring in each reservoir (e.g., settling, predation, UV exposure, die-off) that reduce the concentrations of protozoa found at the outflow sampling points (Figure 4.18 and Figure 4.19).



[1]Monitoring at E5 and E16i was discontinued after 2008.
[2]Monitoring occurred at ABCG from 2003 to 2006 and in 2009.
[3]Monitoring at S7i began in 2003, ceased in 2007 and 2008, and resumed in 2009.

Figure 4.18 Annual mean concentrations of *Giardia* found at Catskill monitoring sites from June 2002 – December 2019, using Methods 1623HV and 1623.1 (all samples). Individual sample results were normalized to per 50L concentrations prior to averaging.

While concentrations of *Giardia* cysts from the upstream sites vary annually depending on weather and watershed characteristics, and not all sites were monitored every year, the annual



[1]Monitoring at E5 and E16i was discontinued after 2008.
[2]Monitoring occurred at ABCG from 2003 to 2006 and in 2009.
[3]Monitoring at S7i began in 2003, was ceased in 2007 and 2008, and resumed in 2009.

Figure 4.19 Annual mean concentrations of *Cryptosporidium* found at Catskill monitoring sites from June 2002 – December 2019, using Methods 1623HV and 1623.1 (all samples.) Individual sample results were normalized to per 50L concentrations prior to averaging.

mean *Giardia* concentrations at the reservoir outflows are consistently less than those at the stream inflows in each basin.

From 2015-2019, the total mean *Giardia* concentrations at the Catskill outflows were 12.0 at SRR2CM (Schoharie), and 0.89 at CATALUM (representing Ashokan).) There appears to be a potential increase in concentrations over this period; however, it is believed to be associated with the change to a method in August 2017 with improved recovery. More time and data are needed to determine if it is method related or a true upward trend. Over the entire 2002-2019 monitoring period, the total mean *Giardia* concentrations at the same outflows were 11.3 and 0.9, for Schoharie and Ashokan, respectively (Table 4.4), which are similar to the means from the most recent five-year period. These outflow concentrations are lower than the range of means found at the inflows over the same 2002-2019 sampling period, which were 54.8-85.3 at the three Schoharie upstream sites (S4, S5I and S7I), and 11.3-37.8 at the Ashokan upstream sites. Moreover, as the water flows downstream from the Schoharie basin through the Ashokan basin, additional reductions in protozoa are noted.

Table 4.4 Historical mean concentrations for protozoans sampled at Catskill monitoring sites from 2002-2019, according to EPA Method 1623HV or 1623.1 (all samples).

	Last Year Sampled	*Cryptosporidium* (oocysts $50L^{-1}$)		*Giardia* (cyst $50L^{-1}$)	
		N	Mean	N	Mean
Schoharie					
Schoharie Creek upstream (S4)	2019	157	0.50	157	59.48
Schoharie inflow 1 – Schoharie Creek (S5i)	2019	152	0.70	152	54.82
Schoharie inflow 2 – Manor Kill (S7i)	2019	138	0.91	138	85.33
Schoharie outflow (SRR2CM)	2019	195	0.21	193	11.33
Ashokan					
Birch Creek upstream of Esopus Creek (ABCG)	2009	23	1.17	23	37.80
Esopus Creek above Shandaken Tunnel Outlet (E5)	2008	78	0.46	77	11.57
Schoharie outflow at Shandaken Tunnel outflow (SRR2CM)	2019	195	0.21	193	11.33
Esopus Creek inflow to Ashokan (E16i)	2008	77	0.30	76	12.35
Ashokan outflow (Kensico inflow at CATALUM)	2019	930	0.09	929	0.92

Similarly, although at much lower concentrations, *Cryptosporidium* annual mean concentrations were lower at the reservoir outflows than the sites upstream of the reservoir (Figure 4.19, Table 4.4). For the period of 2015-2019 the total mean concentration of oocysts at the Schoharie and Ashokan reservoir outflows were 0.32 and 0.09, respectively. Over the entire 2002-2019 monitoring period, the total mean *Cryptosporidium* concentrations at the outflows were 0.21 for Schoharie, and 0.09 for Ashokan, which, like *Giardia* means, are similar to the means from the past five years. These outflow concentrations are lower than the 2002-2019 range of means at the inflows which were 0.50-0.91 for upstream of Schoharie, and 0.21-1.17 for upstream of Ashokan (Table 4.4). Both Catskill System basins have continued to provide attenuation of cysts and oocysts resulting in reductions of protozoan concentrations at reservoir outflows compared to concentrations at upstream sites.

Interestingly, these historical means are extremely close to those reported in the last summary and assessment report five years ago (DEP, 2016), when Schoharie outflow *Cryptosporidium* and *Giardia* means were 0.18 and 10.67, respectively; and Ashokan Reservoir outflow means were 0.10 and 0.90, respectively.

4.5.2 Catskill WWTPs

During the period from 2002 through December 2019, DEP sampled eight WWTPs for protozoa in the Catskill System to monitor long-term performance of WWTP upgrades. Some sites were discontinued, while others were added as the upgrades occurred. All routine samples were collected quarterly. In some cases, extra samples were collected as a follow-up to an unusual result; in other cases, samples were not collected due to plant operations or other reasons. Three of the eight plants — Ashland (2012), Prattsville (2009-2019), and Tannersville (2002-2008) — had no detections of *Cryptosporidium* or *Giardia*. Overall, 283 samples were collected.

Giardia was detected in 11.0% of the WWTP effluent samples (31 of 283) in the Catskill System during this period. *Giardia* detections at the WWTP effluents have fluctuated throughout the years (Figure 4.20). Annual percent detections of *Cryptosporidium* and *Giardia* at Catskill WWTP monitoring sites from June 2002-December 2019, using Methods 1623HV and 1623.1. Individual sample results were normalized to per 50L concentrations prior to averaging. Five of the plants had at least one detection of *Giardia* since 2002, ranging in maxima from 1 to 82 cysts $50L^{-1}$ and the two highest concentrations were detected during this past five-year period. Table 4.5 provides a detailed breakdown of the number of detections by plant and year of detection, along with the percent detection and maximum concentrations.

Cryptosporidium oocysts were detected in 1.8% of the samples (5 of 283) collected at the Catskill System WWTPs from 2002-2019. Oocysts were detected at half of the plants monitored at various times over this 18-year period, which included Hunter Highlands, Hunter, Windham, and Pine Hill; with maxima ranging from 1 to 4 oocysts $50L^{-1}$ (Table 4.5).

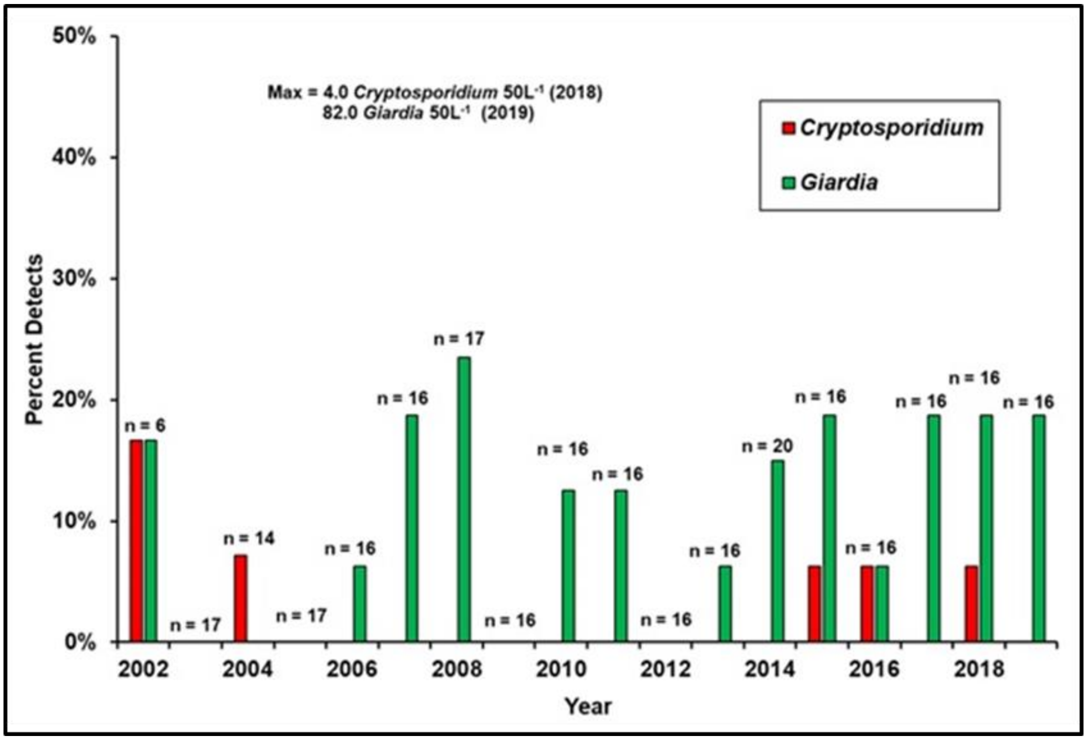


Figure 4.20 Annual percent detections of *Cryptosporidium* and *Giardia* at Catskill WWTP monitoring sites from June 2002-December 2019, using Methods 1623HV and 1623.1. Individual sample results were normalized to per 50L concentrations prior to averaging.

As mentioned in the previous summary and assessment report (DEP, 2016), the Hunter Highlands collection site HHE was relocated to site HHBD in 2009. This was due to the belief that wildlife had access to the water prior to its reaching the effluent and could have been contaminating the final sample with *Giardia* cysts. Since *Giardia* detections have continued at the HHBD effluent site at almost the same rate (20% compared to 23% before the site change), and since the maximum value for all sites (82 *Giardia* $50L^{-1}$) occurred here, the original hypothesis needs further investigation. There have been no detections of *Cryptosporidium* since the site change to HHBD; notably there had been only one positive sample at HHE prior to the switch.

Table 4.5 Catskill WWTP protozoan detects per year and maximum concentrations, 2002 to September 2015; NS = not sampled.

Basin WWTP	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	% Detect	n	Max Conc. ($50L^{-1}$)
Giardia																					
Schoharie																					
Hunter Highlands (HHE)*	NS	0/5	0/3	0/4	1/5	2/4	3/5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	23%	26	7.0
(HHBD)*	NS	NS	NS	NS	NS	NS	NS	0/4	1/4	1/4	0/4	0/4	1/4	2/4	0/4	2/4	1/4	1/4	20%	44	82.0
Hunter (Hunter WTP)	NS	NS	NS	NS	NS	NS	NS	0/4	1/4	0/4	0/4	1/4	1/4	0/4	0/4	0/4	1/4	0/4	9%	44	2.0
Grand Gorge (SGE)	0/2	0/4	0/4	0/4	0/3	1/4	0/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4%	25	1.0
Windham (Windham WTP)	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	1/4	0/4	0/4	1/4	1/4	1/4	1/4	1/4	2/4	18%	44	3.0
Ashokan																					
Pine Hill (EPE)	1/2	0/4	0/3	0/5	0/4	0/4	1/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	8%	26	40.0
Cryptosporidium																					
Schoharie																					
Hunter Highlands (HHE)*	NS	0/5	1/3	0/4	0/5	0/4	0/5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4%	26	3.0
(HHBD)*	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0%	44	0.0
Hunter (Hunter WTP)	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	0/4	1/4	0/4	0/4	0/4	2%	44	1.0
Windham (Windham WTP)	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	1/4	0/4	0/4	1/4	0/4	5%	44	4.0
Ashokan																					
Pine Hill (EPE)	1/2	0/4	0/3	0/5	0/4	0/4	0/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4%	26	1.0

4.6 Water Quality Summary for the Catskill System

DEP has continued to enhance watershed protection in the Schoharie basin. Since 2004, three large WWTPs have been constructed in Hunter, Windham, and Prattsville. Even with these additions, the total phosphorus load decreased from 240 kg $year^{-1}$ in 2004 to < 50 kg $year^{-1}$ in 2009. In addition, more than 100 septic systems have been remediated since 2004, increasing total remediations to over 800 since the WWTP upgrade and septic rehabilitation programs began.

Water quality status in the Schoharie inflow, reservoir, and outflow from 2017-2019 was good overall based on the status of key analytes. Monthly median fecal coliform counts did not exceed benchmarks and both monthly median turbidity and phosphorus concentrations were low overall. Trophic status ranged from oligotrophic to mesotrophic for the evaluation period.

Long-term upward trends were identified in the Schoharie basin for turbidity, reservoir fecal coliforms, and conductivity while downward trends were identified for total phosphorus. The increase in turbidity is attributed to the watershed damage caused by large storm events in 2010 and 2011. Fecal coliform increases were also attributed to these storms as well as to more moderate storm events occurring throughout the record. The decline in phosphorus is attributed to recovery from high loads produced by periodic flood events, load reductions associated with the 2001-2002 drought, and from WWTP upgrades. The conductivity increases may be attributable to use of road deicers. While the TDA only indicated an upward trend was about as likely as not for a long term increase in reservoir TSI, the LOWESS analysis indicates improvement since 2003.

Biomonitoring results in 2017 and 2018 indicated that the biological communities of the main inputs to the Ashokan and Schoharie basins (Esopus Creek and Schoharie Creek, respectively) were in good health. In both basins, the sites remained as non-impaired in their most recent year of sample analysis (2018). Unfortunately, due to the budgetary constraints associated with COVID-19, data from 2019's sampling is not available at this time. The time series showed no long-term changes at any of the sites with an extended period of record. One site on the Batavia Kill, however, had for unknown reasons experienced steep declines in its assessment scores between 2009 and 2013, but those values have climbed over the last several years.

Annual mean concentrations of cysts and oocysts have continued to be low from 2015 through 2019 in the Catskill System. While there are indications of a potential increase in protozoa beginning in 2017 at some sites, this is believed to be a consequence of switching to a method with improved recovery in August 2017. More time and analyses are needed to determine if it is due to the new method, or if it is a true upward trend. In any event, outflow annual mean concentrations for *Cryptosporidium* have continued to be <1 oocyst $50L^{-1}$ throughout the monitoring period. Not unlike Schoharie Reservoir, the outflow of Ashokan Reservoir demonstrates decreased overall annual mean concentrations of *Giardia* and *Cryptosporidium* compared to upstream, indicating a reduction in concentrations through the reservoirs (2002-2019). This translates to the delivery of lower concentrations to the source water at Kensico Reservoir. Settling, predation, and die-off continue to be the primary forces believed to be behind the reduction of protozoan values downstream.

Watershed protection efforts continue to benefit water quality in the Ashokan basin. Since the last reports, phosphorus loads from WWTPs were dramatically reduced from 50 kg year^{-1} to a level much less than half that value. The reduction in load was primarily due to improvements to the Pine Hill and Camp Timberlake WWTPs. Over 1,200 septic systems have also been repaired.

Water quality status in the Ashokan West Basin inflow (E16I) and reservoir (EAW) from 2017-2019 was good overall based on the status of key analytes. Monthly median fecal coliform counts did not exceed benchmarks and both monthly median turbidity and phosphorus concentrations were low overall. Trophic status was primarily mesotrophic for the status evaluation period. Water quality status in the Ashokan East basin (EAE) and outflow (EARCM) from 2017-2019 was good overall based on the status of key analytes. Monthly median fecal coliform counts did not exceed benchmarks and both monthly median turbidity and phosphorus concentrations were low overall. Trophic status ranged from oligotrophic to mesotrophic for the status evaluation period.

Long-term downward trends were evident for total phosphorus at E16I, in both basins of Ashokan Reservoir and at the outflow (EARCM). These reductions are likely due to WWTP construction and to the cumulative effects of watershed protection programs. Downward fecal coliform trends were considered virtually certain at E16I, EAE, and at the outflow (E16I). The decrease was attributed to landfill closure and to the low frequency of extreme rain events since 2011. Although long-term turbidity upward trends were considered possible for E16I and EAW, a marked decrease was noted after 2011 due to the lack of extreme rain events. Long-term upward conductivity trends were identified for E16I, EAW, EAW and the outflow (EARCM) and likely linked to road deicer usage. Long-term TSI decreases were apparent at EAW and EAE. Periods of low water clarity and the long-term decrease in TP are two likely factors.

The most recent five-year period is interesting in the tight clustering of each basin in the OECD plots, indicating that ecological conditions and responses during those five years were very similar and allowing each basin to define its characteristic response during a relatively steady-state condition. Turbidity can severely diminish light penetration in Schoharie and the West Basin of Ashokan for months at a time and this presents a severe limitation to algal growth. In the most recent five-year period, all three basins' (Schoharie, Ashokan East, and Ashokan West) values tend to cluster within the 80% confidence intervals and have moved closer to the expectation indicated by the OECD standards. Schoharie was on the low side due to lower light (more shallow Secchi transparency). In the most recent period, all three basins tended to cluster around the OECD line with maximum chlorophyll observed in the west basin of Ashokan. Schoharie tended to remain subdued in its maximum chlorophyll response. The association of years with high turbidity with high phosphorus values indicates this nutrient is attached to the glacial clays which create the inordinately low transparencies and consequently subdued algal growth. Despite the high phosphorus values in Schoharie, these do not materialize as algal biomass and this supports the exclusion of Schoharie from the phosphorus-restricted basin list. In the more quiescent times of the current five-year assessment, the Ashokan basins have both gravitated toward the OECD lines and fall within the 80% PI. However Schoharie transparency remains lower than the 80% PI indicating that factors other than nutrient-induced algal growth limit transparency. The most recent five-year period shows Secchi transparency of greater than five meters due to the low chlorophyll values during this assessment. In contrast, Secchi depths for Schoharie remain shallow despite low chlorophyll values indicating that other factors, such as suspended particulates, limit transparency.

5. The Delaware System

5.1 Introduction

5.1.1 The Scope of Water Quality Analyses

The scope of water quality analyses is presented at the beginning of the first water quality chapter on the Catskill System. In order to avoid repetition, the reader should refer to the beginning section of that chapter for a description of the array of analyses and approach we have taken. Significantly, we have retained the information from previous years such that water quality analyses cover a longer time period than the five-year period of the assessment. Instead, approximately 27 years of data are used to provide a long-term context for interpretation. Selection of a sufficiently long time captures changes in water quality in response to watershed protection programs. It provides a view of these changes in the context of natural variation caused by events such as floods and droughts, which are not sufficiently represented in a five-year period.

Trends are examined in three ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests (SKT) for trend significance and trend slope, and third by estimating trend direction using the Trend Direction Assessment (TDA) technique. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. The SKT method addresses statistical significance of monotonic (unidirectional) change though the period of record. The TDA method calculates probabilities to determine trend direction and uses probability intervals to estimate the likelihood of correctly identifying the trend direction. See Appendix C for a more detailed description of the data processing steps and statistical methods used.

5.1.2 The Delaware System Overview

There are several important factors that govern water quality over the long term. Perhaps the two most important are climate, as a determinant of precipitation and water residence times, and land use, as a determinant of substance loadings. For this reason an overview of each is provided to set the context for water quality interpretation.

Water residence times are important because they determine the response rates of reservoirs to watershed protection programs. The water residence times for the four reservoir basins in the Delaware System over a 52-year period (1967 to 2019) are depicted in Figure 5.1.

The four basins of the Delaware System have characteristically different residence times. Rondout has the shortest and least variable water residence time. This is a result of the way the system operates. It consistently receives a high hydraulic load delivered by the three upstream reservoirs and it averages about 1.5 months of residence time. Residence times of Cannonsville and Neversink are very close to each other at about four months and typically follow the same pattern. Pepacton has the longest water residence time (averaging about eight to nine months) due to its very large volume. In general, the evolution of a basin to a new steady state is reached in three times the duration of its water residence time. For example, Rondout would adjust to new loading levels in about six months, whereas Pepacton would take more than two years to re-equilibrate to a new steady state.

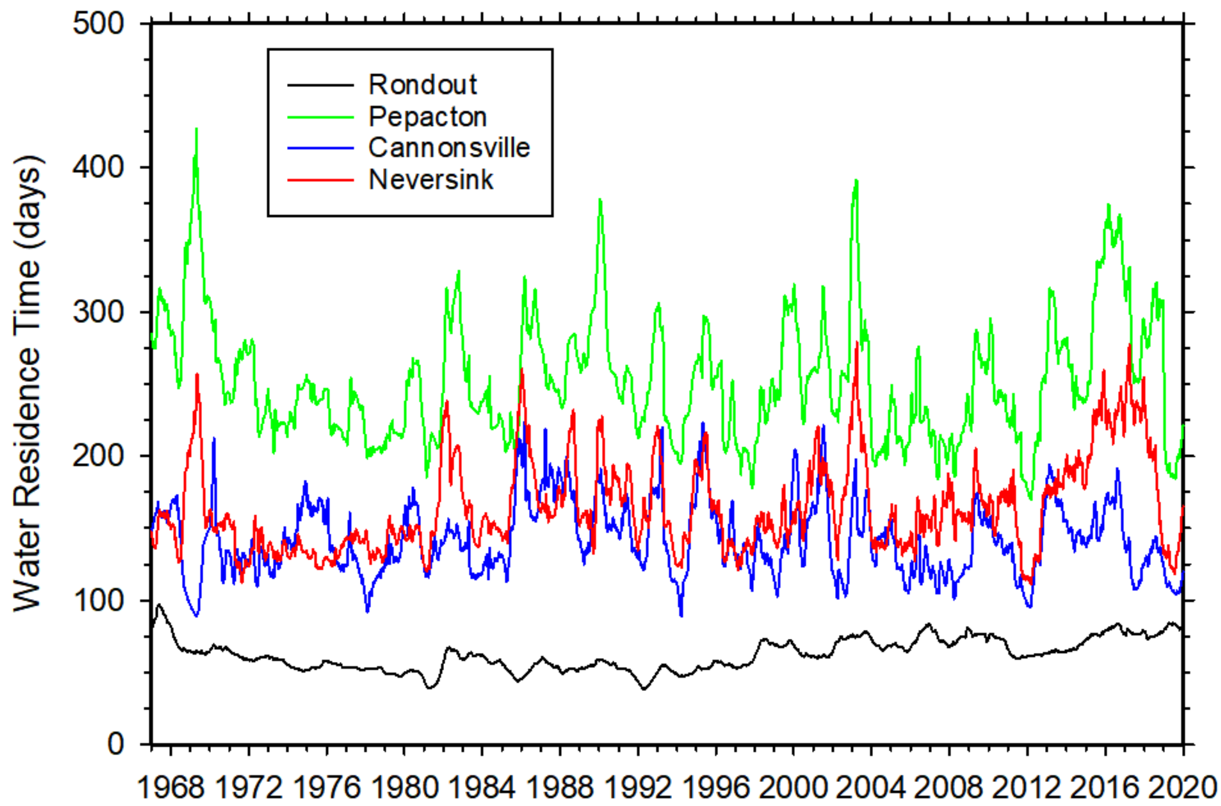


Figure 5.1 Water residence time in the Delaware System reservoirs, 1967-2019.

5.2 The Neversink Basin

Neversink Reservoir is located in Sullivan County, approximately 5 miles northeast of the Village of Liberty and more than 75 miles from New York City. Placed into service in 1954, it was formed by the damming of the Neversink River, which continues south and eventually drains into the lower Delaware River. The reservoir holds 34.9 billion gallons at full capacity and provides 163 million gallons per day (MGD) (13.5% of the total average daily consumption) to New York City and an additional 1 million upstate consumers.

The Neversink is one of four reservoirs in the Delaware System, the most recent of the City's three systems. The water withdrawn from the reservoir travels six miles in the Neversink Tunnel to the Rondout Reservoir. There it mixes with water from the other two Delaware system reservoirs, Cannonsville and Pepacton, before draining south via the 85-mile-long Delaware Aqueduct, which runs below the Hudson River to West Branch Reservoir in Putnam County and Kensico Reservoir in Westchester.

The Neversink watershed's drainage basin is 92 square miles and includes portions of six towns. The Neversink River is the main tributary supplying the reservoir, providing a 73% water contribution. The land-use breakdown for the Neversink watershed is 91.5% forested, 3.0% urban, 1.4% brushland, 2.7% is water, and 1.4% is in agricultural use with approximately 1,400 acres in Whole Farm Plans. Therefore, the vast majority of this watershed is forested.

As of December 31, 2020, there were 306 acres of agricultural lands with active nutrient management plans in the Neversink watershed. Since 1996, over 69 total farm best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, and pathogens, in the Neversink watershed with 24 BMPs implemented between 2016 and 2020. Other protection programs are also in place as described earlier. There are no permitted WWTPs in the Neversink watershed.

5.2.1 Water Quality Status and Trends in the Neversink Watershed

Status (Neversink)

The Neversink basin status evaluation is presented as a series of boxplots in Figure 5.2. A comparison of the main inflow to the reservoir Neversink River (NCG), the reservoir (NN), and the outflow (NRR2CM) is shown. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the evaluation period (2017-2019), fecal coliform bacteria remained well below the NYSDEC stream guidance value of 200 fecal coliforms 100 $mL^{-1}$for the river inflow. Reservoir fecal coliform levels (SS) were lower than the inflow and outflow values. Outliers for fecal coliforms were associated with autumn storm events. Turbidity in the Neversink basin is among the lowest in the entire NYC Water Supply watershed with only one outlier of 6.9 NTU at the outflow (NRR2CM) after an autumn storm event in 2019. Monthly median reservoir total phosphorus (TP) values were low, with a median of 7.5 µg L^{-1}. The Trophic State Index (TSI) values for Neversink Reservoir ranged from oligotrophic to mesotrophic with the exception of August 2018 during a wet period when TSI was in the eutrophic range. Conductivity ranges and medians were low at all sites as in previous assessments.

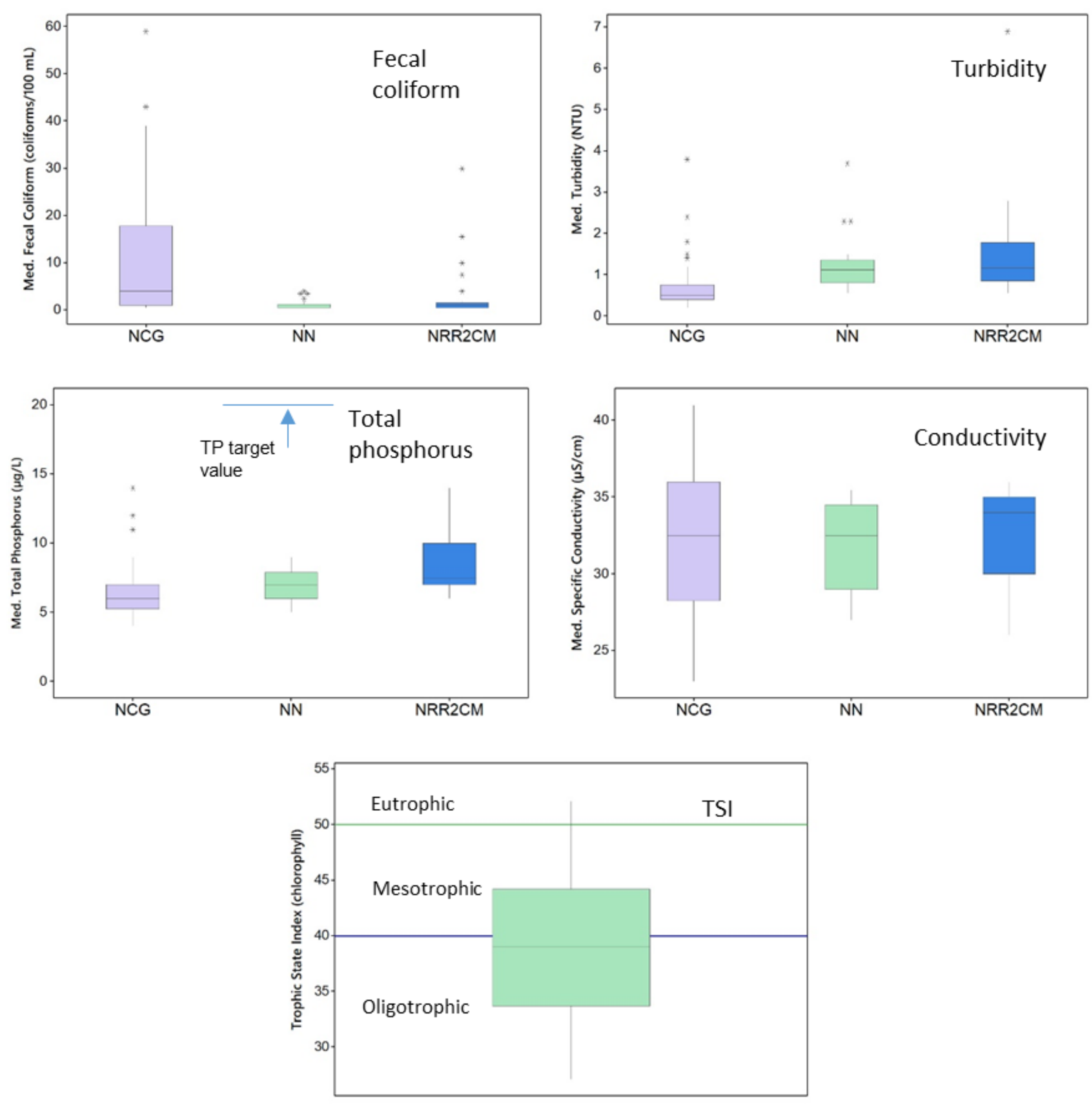


Figure 5.2 Water quality status boxplots using 2017-2019 monthly data for the Neversink basin main stream inflow at the Neversink River (NCG), Neversink Reservoir (NN), and the outflow at the Neversink gatehouse (NRR2CM).

Trends (Neversink)

Water quality trend plots for the Neversink basin are presented in Figure 5.3 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 5.1.

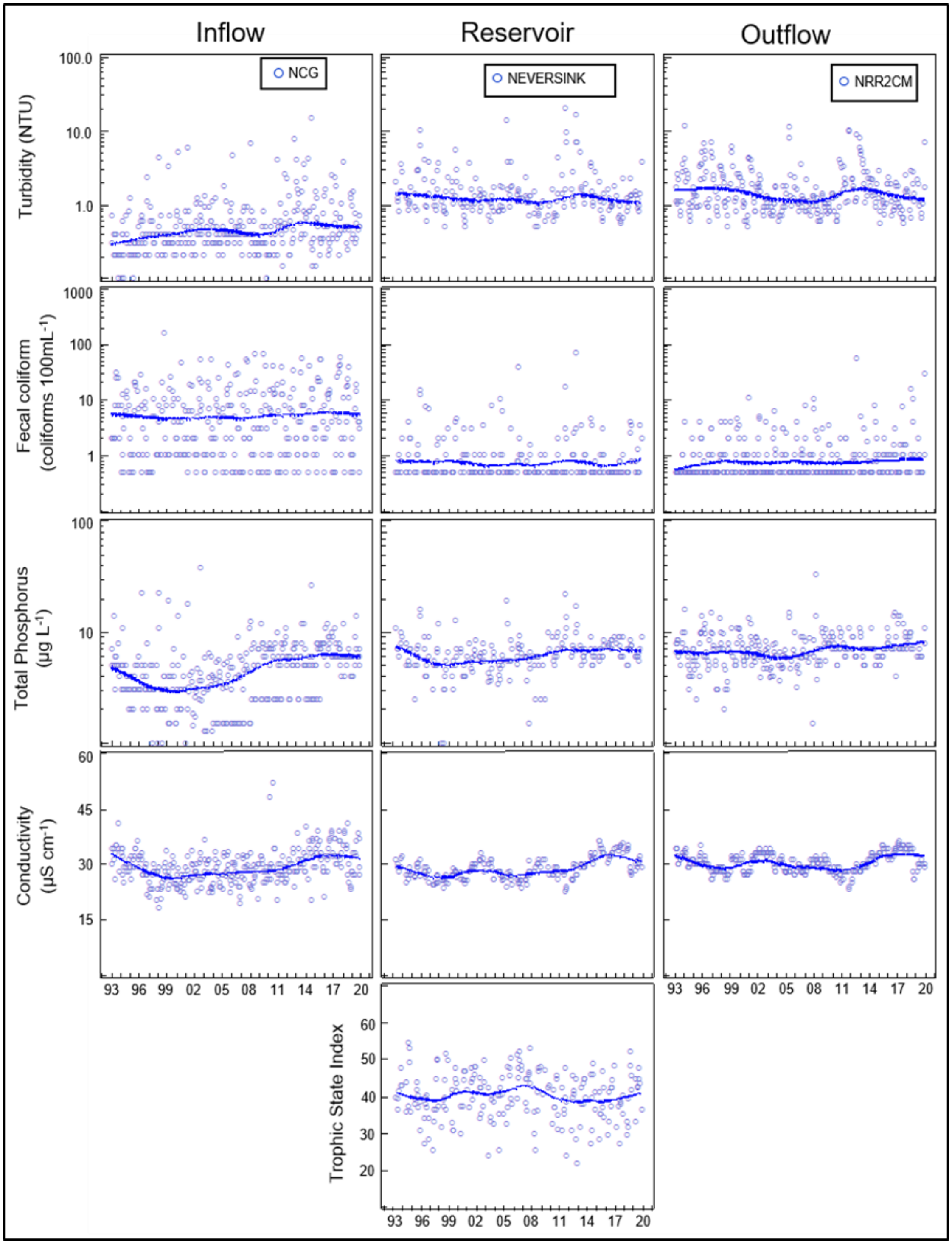


Figure 5.3 Water quality trends for the Neversink basin for the main stream inflow at the Neversink River (NCG), Neversink Reservoir, and the aqueduct outflow at the Neversink gatehouse (NRR2CM).

Table 5.1 Neversink basin trends from 1993-2019 for selected analytes.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
NCG	Inflow	Turbidity	323	***	0.007	1.787	Increasing trend virtually certain
NCG	Inflow	Turbidity (Flow Adj.)	323	***	0.008	2.098	Increasing trend virtually certain
Neversink	Reservoir	Turbidity	210	*	-0.006	-0.463	Decreasing trend possible
NRR2CM	Outflow	Turbidity	302	*	-0.004	-0.355	Decreasing trend possible
NCG	Inflow	Fecal Coliform	323	*	0	0	Increasing trend possible
NCG	Inflow	Fecal Coliform (Flow Adj.)	323	NS	0.015	0.365	Increasing trend possible
Neversink	Reservoir	Fecal coliform	209	NS	0	0	Decreasing trend about as likely as not
NRR2CM	Outflow	Fecal coliform	298	***	0	0	Increasing trend very likely
NCG	Inflow	Total Phosphorus	320	***	0.12	2.424	Increasing trend virtually certain
NCG	Inflow	Total Phosphorus (Flow Adj.)	320	***	0.116	2.344	Increasing trend virtually certain
Neversink	Reservoir	Total Phosphorus	209	***	0.057	0.954	Increasing trend virtually certain
NRR2CM	Outflow	Total Phosphorus	278	***	0.056	0.794	Increasing trend virtually certain
NCG	Inflow	Conductivity	323	***	0.15	0.518	Increasing trend virtually certain

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
NCG	Inflow	Conductivity (Flow Adj.)	323	***	0.207	0.712	Increasing trend virtually certain
Neversink	Reservoir	Conductivity	208	***	0.176	0.624	Increasing trend virtually certain
NRR2CM	Outflow	Conductivity	301	***	0	0	Increasing trend very likely
Neversink	Reservoir	Trophic State Index	210	NS	-0.042	-0.106	Decreasing trend about as likely as not

1 The p-values for each trend test are symbolized as follows:
NS (Not Significant) = p ≥ 0.20, * = p < 0.20, ** = p < 0.10, *** = p < 0.05.

There was strong evidence for an upward turbidity trend in the Neversink River at site NCG. As previously reported (DEP 2016), the increase was largely driven by extreme runoff events in 2010 and from tropical storms Irene and Lee in 2011. In addition, another large storm, the 4th highest peak flow on record, occurred from September 17-18, 2012, and was confined almost exclusively to the Neversink watershed. Turbidity levels remained slightly higher than historic baseline levels through 2019 despite an absence of extreme events. It is likely that storm damage to the watershed altered the flow-turbidity concentration relationship, causing flows to produce more turbidity than the pre-extreme period. In contrast, there is some moderate evidence of downward turbidity trends in the reservoir and outflow. Although the extreme storms affected the reservoir and outflow, downward turbidity trends in the earlier part of the record seem to have offset the storm-related increase. The discrepancy between the reservoir and inflow may also be an artifact of the sampling programs. Turbidity inputs are sampled once per month on a fixed frequency, which may miss storm events that produce significant turbidity inputs to the reservoir.

There was moderate evidence of a long-term upward trend for fecal coliforms in the inflow and strong evidence of an increase in the outflow, which is seemingly at odds with the trend results for the reservoir, where a possible downward trend was identified. The monthly outflow results are comprised of a median of daily samples whereas the reservoir data is from one monthly survey (with no samples collected from December through March). It is likely then that the discordant trend results are an artifact of these different sampling strategies.

In the last FAD evaluation (DEP 2016), there was strong evidence of long-term upward total phosphorus trends in the reservoir and inflow, but no trends were identified in the outflow. With the addition of five more years of data, now all three show an upward trend although phosphorus levels on a whole remain relatively low. While the increase was clearly related to storms occurring during 2010-2012, it is not clear why phosphorus has continued to increase given the relative absence of large storm events in the 2013-2019 period. In part, the increase may be attributable to phosphorus contamination of sample bottles that occurred from late 2014 to 2017 but was most significant in 2016 and 2017 (DEP 2018).

Strong evidence of long-term upward conductivity trends was identified for the inflow, outflow, and reservoir. In the last FAD evaluation, only weak evidence of an upward trend was discovered and only for the inflow. The increase is largely driven by a gradual rise from 1998-2011 and a sharper increase thereafter. Road deicer usage is the suspected reason for the increasing trend.

There was weak evidence for a long-term TSI decrease in Neversink Reservoir. However, suppression of algal populations from flooding events in 2010-2012 seems to be waning as TSI has trended upwards in recent years. The possible increasing upward trend in phosphorus (contamination issues not withstanding) as well as residence time (Figure 5.3) may also be factors. Increased residence time allows algae more time to utilize available nutrients.

In summary, upward trends were identified for turbidity, total phosphorus, fecal coliforms and conductivity when considering the entire record (1993-2019). The turbidity and phosphorus increases are attributed to slow recovery from flooding events from 2010-2012, perhaps prolonged by storm-related damage to the landscape. Bottle contamination may also be a factor for the phosphorus increase. Reasons for the increase in fecal coliforms were not apparent.

5.3 The Pepacton Basin

Pepacton Reservoir is located in Delaware County along the northern edge of the state's forever wild Catskill Park, 12 miles south of the Village of Delhi and more than 100 miles northwest of New York City. The reservoir was formed by the damming of the East Branch of the Delaware River, which continues west and joins the lower Delaware River. Placed into service in 1955, Pepacton is approximately 15 miles long and holds 140.2 billion gallons at full capacity, which makes it the largest reservoir in the City system by volume. Currently, Pepacton supplies roughly 24% of the total average daily consumption. Water withdrawn from the Pepacton Reservoir enters the East Delaware Aqueduct and flows southeast for 25 miles into the Rondout Reservoir before heading south via the 85-mile-long Delaware Aqueduct to West Branch and Kensico reservoirs.

The Pepacton watershed's drainage basin is 371 square miles, and includes parts of 13 towns in three counties. Four main tributaries flow into Pepacton: East Branch Delaware River contributes 44%, Platte Kill provides 9.5%, and Tremper Kill and Millbrook Stream provide 9% and 7%, respectively. The Pepacton watershed has a land-use breakdown as follows: 77.7% is forested, 6.4% is urban, 6.3% is brushland, 2.6% is water, and 6.9% is in agricultural use.

As of December 31, 2020, there were 7,171 acres of agricultural lands with active, nutrient management plans in the Pepacton watershed. Since 1996, over 849 total farm best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, and pathogens in the Pepacton watershed with 201 BMPs implemented between 2016 and 2020. Approximately 40 environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects, and about 900 septic systems throughout the basin have been remediated. Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place as described in the Watershed Protection Program sections.

There are seven wastewater treatment plants sited in the Pepacton watershed with a permitted total flow of 0.7295 MGD. Inputs of phosphorus, as well as other pollutants, from WWTPs to Pepacton Reservoir continue to be reduced. This is a result of DEP's effort to upgrade all surface-discharging plants, including upgrade of the City-owned Margaretville plant and other WWTPs in the basin, and also through the intervention and involvement of DEP's WWTP Compliance and Inspection Program.

5.3.1 Water Quality Status and Trends in the Pepacton Watershed

Status (Pepacton)

The Pepacton basin status evaluation is presented as a series of boxplots in Figure 5.4. A comparison of the East Branch Delaware River (PMSB) (the main inflow to the reservoir), the reservoir (EDP), and the aqueduct outflow (PRR2CM) is shown. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the evaluation period (2017-2019), fecal coliform bacteria were above the NYSDEC stream guidance value of 200 fecal coliforms 100 mL^{-1} for the river inflow on three occasions (July 2018, July and August 2019). Fecal coliforms were low in both the reservoir and outflow. Turbidity in the Pepacton basin is typically low, and the largest outlier at the inflow (PMSB) was associated with a storm event (40 NTU). Monthly median reservoir total phosphorus (TP) values were well below the target value of 20 µg L^{-1} (median 10.5 µg L^{-1}), but one outlier at the inflow (PMSB) was associated with the October 2017 storm event (97 µg L^{-1}). The Trophic State Index (TSI) values for Pepacton Reservoir fell primarily in the mesotrophic range, with two months (May and September 2018) falling in the eutrophic range. Conductivity medians were highest at the inflow (PMSB) and ranged from 61 to 145 µS cm^{-1}, with a median of 90.5 µS cm^{-1}.

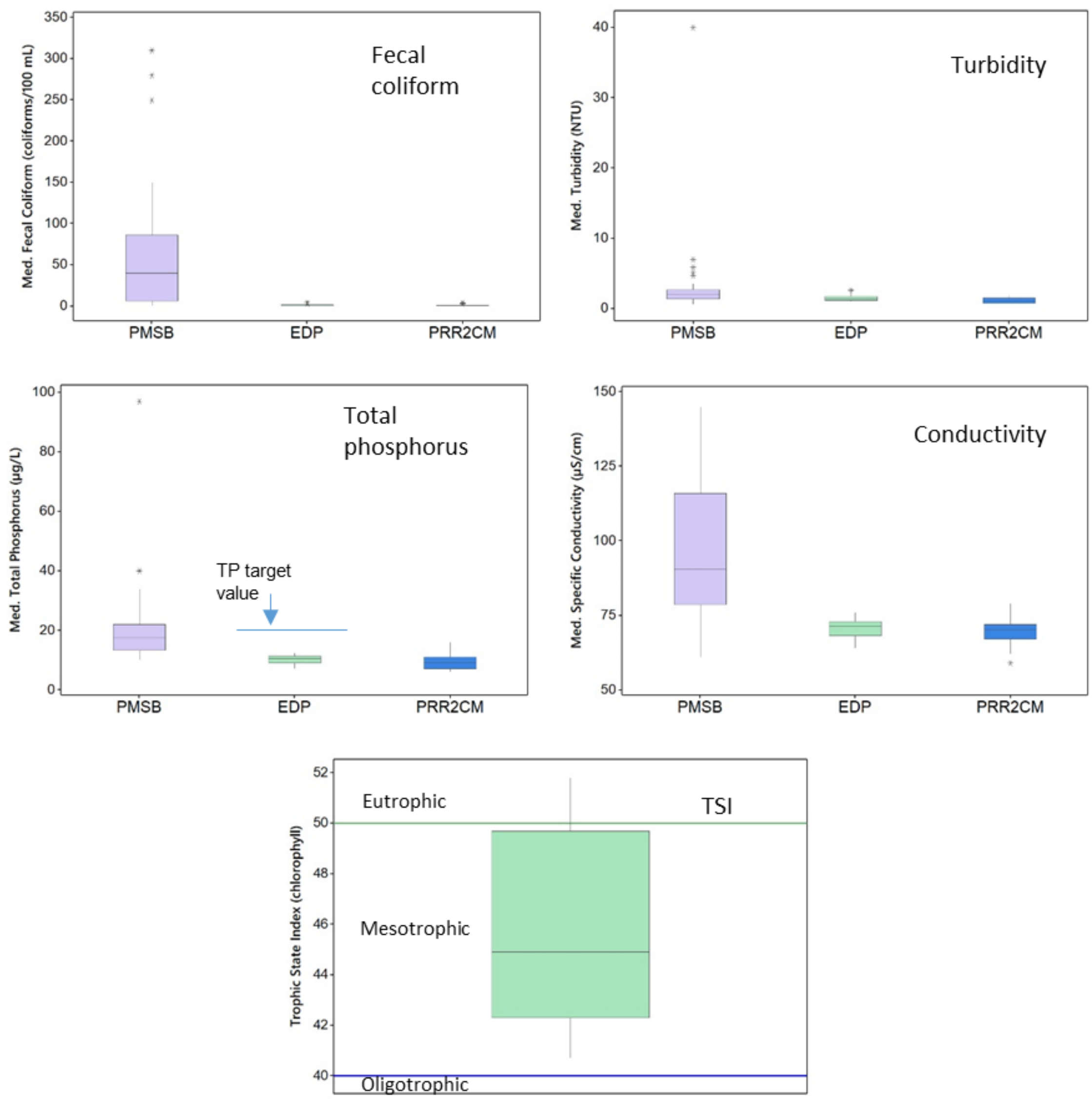


Figure 5.4 Water quality status boxplots using 2017-2019 monthly data for the Pepacton basin main stream inflow at the East Branch Delaware River (PMSB), Pepacton Reservoir (EDP), and the aqueduct outflow at the Pepacton gatehouse (PRR2CM).

Trends (Pepacton)

Water quality trend plots for the Pepacton basin are presented in Figure 5.5 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 5.2.

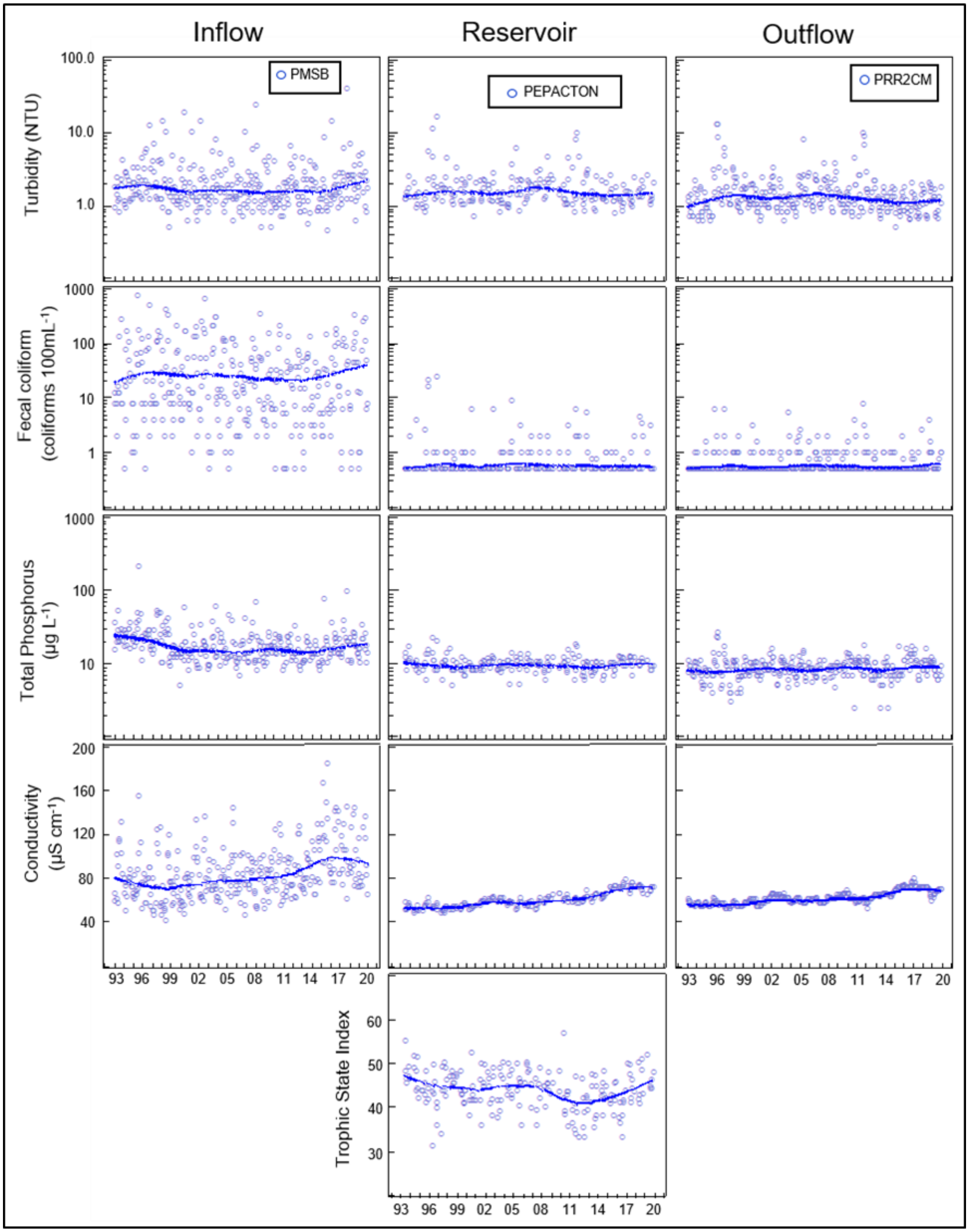


Figure 5.5 Water quality trend plots for the Pepacton basin for the main stream inflow at the East Delaware River (PMSB), Pepacton Reservoir, and the outflow at the Pepacton gatehouse (PRR2CM).

Table 5.2 Pepacton basin trends from 1993-2019 for selected analytes.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
PMSB	Inflow	Turbidity	323	NS	0	0	Decreasing trend about as likely as not
PMSB	Inflow	Turbidity (Flow Adj.)	323	*	-0.007	-0.451	Decreasing trend possible
Pepacton	Reservoir	Turbidity	204	NS	-0.004	-0.246	Decreasing trend possible
PRR2CM	Outflow	Turbidity	320	***	-0.005	-0.439	Decreasing trend very likely
PMSB	Inflow	Fecal Coliform	316	NS	-0.055	-0.346	Decreasing trend possible
PMSB	Inflow	Fecal Coliform (Flow Adj.)	316	NS	-0.022	-0.14	Trend unlikely
Pepacton	Reservoir	Fecal coliform	204	NS	0	0	Trend unlikely
PRR2CM	Outflow	Fecal coliform	319	NS	0	0	Trend exceptionally unlikely
PMSB	Inflow	Total Phosphorus	318	***	-0.153	-0.93	Decreasing trend virtually certain
PMSB	Inflow	Total Phosphorus (Flow Adj.)	318	***	-0.16	-0.969	Decreasing trend virtually certain
Pepacton	Reservoir	Total Phosphorus	203	NS	0	0	Decreasing trend about as likely as not
PRR2CM	Outflow	Total Phosphorus	310	***	0.022	0.269	Increasing trend very likely
PMSB	Inflow	Conductivity	321	***	1.003	1.254	Increasing trend virtually certain
PMSB	Inflow	Conductivity (Flow Adj.)	321	***	1.113	1.391	Increasing trend virtually certain
Pepacton	Reservoir	Conductivity	197	***	0.742	1.269	Increasing trend virtually certain
PRR2CM	Outflow	Conductivity	320	***	0.556	0.911	Increasing trend virtually certain

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
Pepacton	Reservoir	Trophic State Index	201	***	-0.109	-0.25	Decreasing trend virtually certain

The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

Possible downward turbidity trends were identified in the inflow and reservoir but considered highly likely for the outflow. The change per year was very small (0.004-0.007NTU) and is probably related to generally low annual flows and the infrequent extreme rain events since 2011.

Trends were not identified for fecal coliforms in the inflow, reservoir or outflow. Although downward trends were not detected in the reservoir, the temporal plots (Figure 5.5) suggest strong coliform attenuation within the reservoir resulting in much lower coliform counts compared to the input.

There was strong evidence of a small TP increase in the outflow from Pepacton Reservoir. Reasons are not clear especially since there was strong evidence of a long-term TP decline in the inflow. At the inflow site, phosphorus concentrations decreased from 1993-1999. This was especially true from 1996 through 1999, a period that coincided with upgrades to the Margaretville WWTP (completed in 1999). Part of the decline can also be attributed to recovery from flooding events in late 1995 and early 1996; and to the cumulative effects of the various watershed programs that have been employed in the basin. In recent years, an upward TP trend is observed particularly at the outflow. This trend is suspect because at least some portion of the increase may be attributable to phosphorus contamination of sample bottles that occurred from late 2014 to 2017 but was most significant in 2016 and 20017 (DEP 2018).

Upward long-term conductivity trends were identified in the inflow, reservoir, and outflow. Although drought and high flow events certainly produce short-term effects, the primary driver of the upward trend is likely the use of road deicers.

A long-term downward trend was identified for TSI, which may be related to decreased nutrients associated with watershed programs and WWTP upgrades. However, a shorter-term uptrend has also been apparent since 2011. The increase may be related to increased residence time and warmer surface water temperatures both of which are favorable for algal growth.

In summary, conductivity increases were apparent throughout the basin. Long-term downward trends were observed for TSI, for turbidity at all locations, and for TP at the inflow. The increase in conductivity is likely driven by usage of road deicers. Long-term downward trends for TP and TSI could be linked to the effectiveness of watershed protection programs. The recent short-term TSI increase may be related to a trend of higher reservoir residence time and warmer surface water temperatures. A long-term, albeit very small, upward TP trend was observed for the reservoir outflow and a recent short-term increase was also apparent in the inflow. Although reasons for the increase are not clear these trend results may be somewhat impacted by the phosphorus contamination of sample bottles that occurred in more recent years.

5.3.2 Biomonitoring in the Pepacton Watershed

The New York City stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in City watershed streams. For methodology details, see Appendix C.

The most recent status of macroinvertebrate communities in the Pepacton basin was evaluated by examining 2017-2018 data from sites located on the East Branch of the Delaware River. Unfortunately, data from 2019's sampling is not available at this time due to the budgetary constraints associated with COVID-19. This stream is the primary inflow to Pepacton Reservoir, draining 45% of the basin. Two sites with data from these years (Sites 316 and 321) are routine, and sampled annually.

Site 316 (PMSB) in Margaretville lies approximately five miles upstream of Pepacton Reservoir and Site 321 (EDRB) is about 13 miles upstream. Site 316 went from assessed as non-impaired in 2017 to slightly impaired in 2018, while Site 321 was assessed as non-impaired in both years (Figure 5.6).

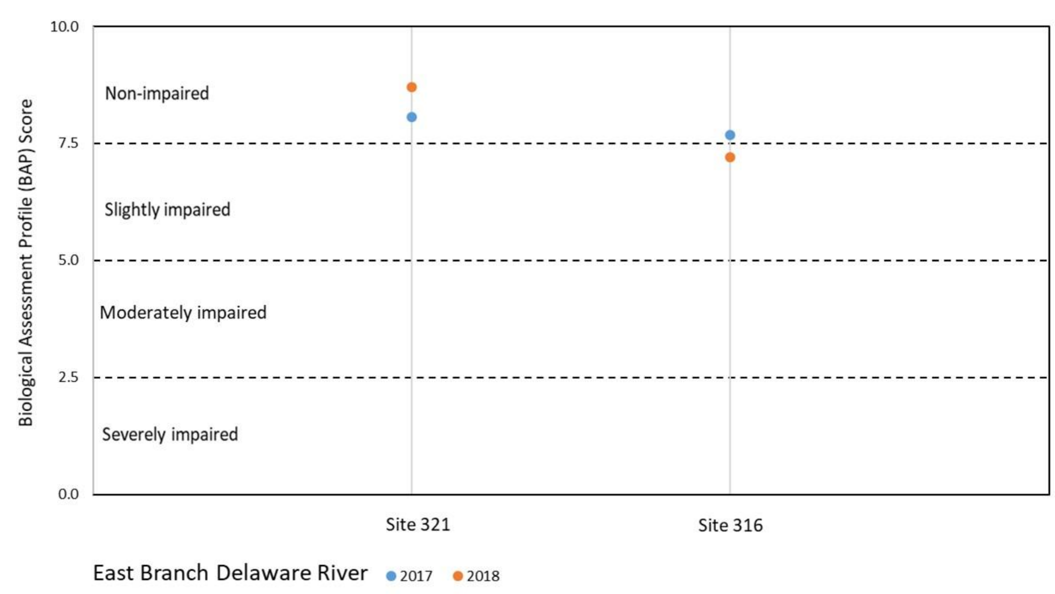
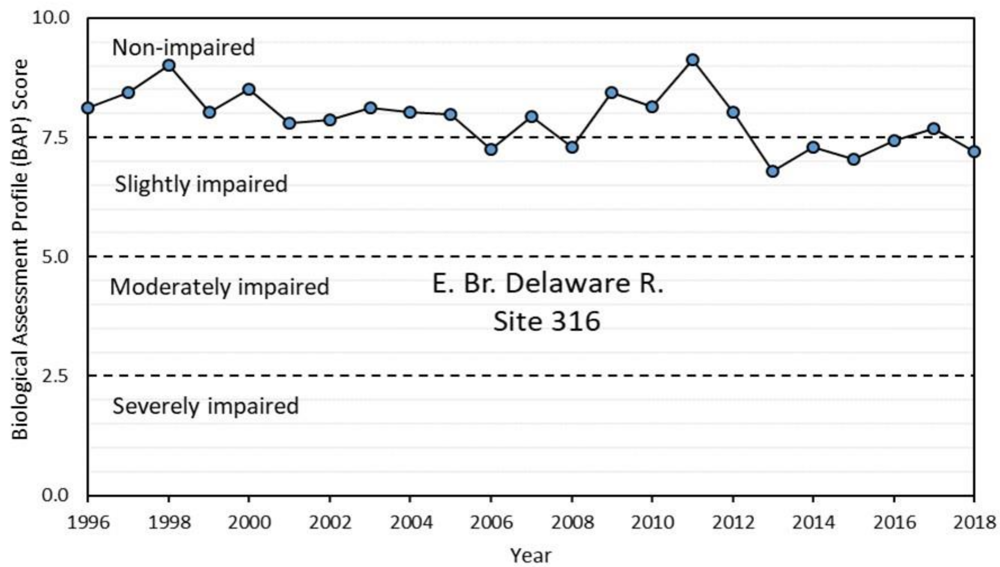


Figure 5.6 Biological assessment profile scores for East Branch Delaware River, 2017-2018.

The time series trend in BAP scores was based on a site's entire period of record (1996-2018), and examined changes in both the scores and assessment categories (Figure 5.7). While Site 316 fell to slightly below the non-impaired status, neither that site nor Site 321 showed any consistent trend in status change. DEP will continue to monitor these sites in future years. One of the items to be considered is the percentage of hydropsychid caddisflies found at these sites.



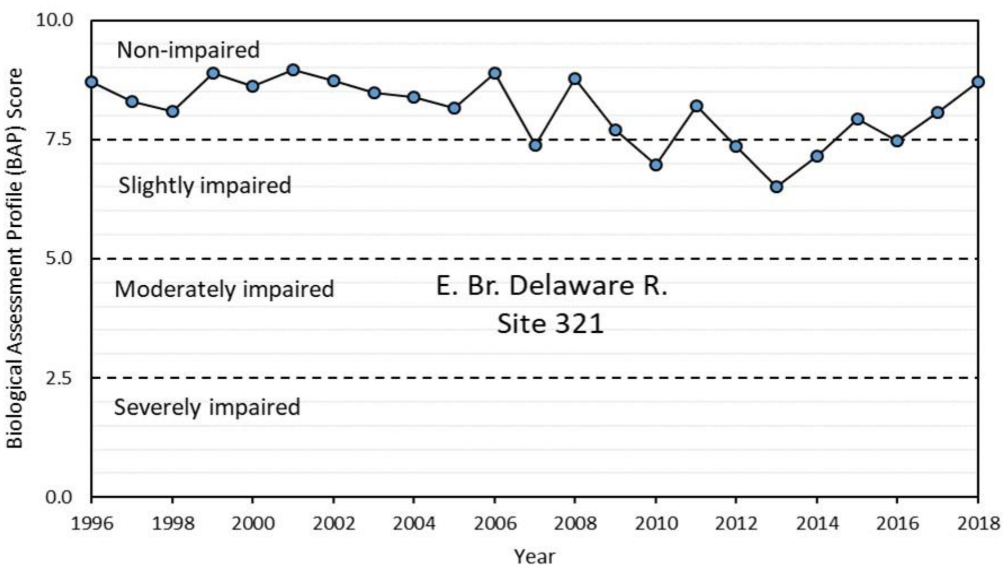


Figure 5.7 Biological assessment profile scores for East Branch Delaware River, 1996-2018.

The percentage has been elevated for several years but both showed a drop in the percentage in 2018. At Site 316, the percentage dropped from a high of 55.8% in 2016 to 31.4% in 2018. At Site 321 the percentage dropped from a high of 59.6 % in 2013 to 18.2% in 2018.

5.4 Cannonsville Basin

Cannonsville Reservoir is located at the western edge of Delaware County, southwest of the Village of Walton and about 120 miles northwest of New York City. Placed into service in 1964, it holds 95.7 billion gallons at full capacity. Currently, Cannonsville supplies 86 MGD or roughly 7.1% of the total average daily consumption to New York City and an additional one million upstate consumers. The Cannonsville is one of four reservoirs in the City's Delaware System and the most recent in New York City's Water Supply. Water drawn from Cannonsville enters the West Delaware Tunnel and travels 44 miles to the upper end of Rondout Reservoir. From there, it's carried in the 85-mile-long Delaware Aqueduct under the Hudson River to the West Branch and Kensico reservoirs.

The Cannonsville watershed's drainage basin is 455 square miles, the largest basin in the City's system, and includes parts of 17 towns, all in Delaware County. Trout Creek and West Branch Delaware River are the two primary tributaries flowing into Cannonsville, the former providing approximately 4.5% and the latter approximately 77%. Presently there are five wastewater treatment plants (WWTPs) sited in the Cannonsville watershed with a maximum combined flow of 3.5 MGD SPDES permits. The Cannonsville watershed land-use breakdown is as follows: 63.6% forested, 6.9% urban, 8.1% brushland, 2.1% water, and 19.1% in agricultural use.

Under a 1954 U.S. Supreme Court ruling, New York City can take up to 800 million gallons a day from the Delaware River, provided it releases enough water to insure adequate flow in the lower Delaware for New Jersey and other downstream users. The Office of the Delaware Rivermaster, in conjunction with the New York State Department of Environmental Conservation (DEC), oversees releases from Cannonsville and other Delaware System reservoirs to help manage flow in the lower West Branch Delaware River for the benefit of habitat and water users downstream.

As of December 31, 2020 there were 34,675 acres of agricultural lands with active, nutrient management plans in the Cannonsville watershed. Since 1996, over 5,050 total farm best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, and pathogens in the Cannonsville watershed with 1,157 BMPs implemented between 2016 and 2020. Over 60 environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects and approximately 1,100 septic systems throughout the basin have been remediated. Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place as described earlier in this document.

There are four additional discharges in the Cannonsville watershed with a cumulative permitted maximum flow of 2.7 MGD. Three are cooling water discharges and one is a landfill leachate discharge. Inputs of phosphorus, as well as other pollutants, from WWTPs to Cannonsville Reservoir continue to be reduced as a result of DEP's effort to upgrade all surface-discharging plants, including the Walton and Delhi WWTPs, Kraft Dairy, and other WWTPs in the basin, and also through the intervention and involvement of DEP's WWTP Compliance and Inspection Program.

5.4.1 Water Quality Status and Trends in the Cannonsville Watershed

Status (Cannonsville)

The Cannonsville basin status evaluation is presented as a series of boxplots in Figure 5.8. A comparison of the main inflow, West Branch Delaware River (WDBN), the reservoir (WDC), and the outflow (WDTOCM) is shown. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the evaluation period (2017-2019), fecal coliform bacteria remained below the NYSDEC stream guidance value of 200 fecal coliforms 100 mL^{-1} for the stream inflow site, with the exception of one outlier in October 2019. Reservoir and outflow fecal coliform levels were low (median in the reservoir site was 4 fecal coliforms 100 mL^{-1}). Turbidity was generally low, with a median at the outflow site (WDTOCM) of 1.8 NTU. Median monthly total phosphorus (TP) was highest at the inflow (CBS), with a range of 10 to 41 µg L^{-1} and median of 20 µg L^{-1}. The reservoir median for TP ranged from 12 to 22.5 µg L^{-1} with a median of 16 µg L^{-1}. The Trophic State Index (TSI) values for Cannonsville Reservoir had a 50/50 split between mesotrophic and eutrophic range, with a median of 49.9. Median conductivity was higher (median 99.5 µS cm^{-1}) and spanned a wider range (60 – 177 µS cm^{-1}) at the inflow (CBS), and was less variable and lower in the reservoir (WDC) and outflow (WDTOCM) with medians of 88 and 93 µS cm^{-1}, respectively.

Trends (Cannonsville)

Water quality trend plots for the Cannonsville basin are presented in Figure 5.9 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in

Table 5.3.

Decreasing turbidity trends were identified for the reservoir and outflow. Recovery from flood events in late 1995-early 1996, April 2005 and June 2006 is partly responsible for the decrease. Periods of low inputs in years affected by droughts (2001-2002, 2016) or years where large events (>2 inches) were scarce (2007-2009 and 2012-2019) are additional factors. Extensive implementation of agricultural BMPs in the watershed is yet another factor. There was very little evidence for a long-term downward trend in the inflow. Most nonpoint impacts occur during storm events, which are not effectively captured using the monthly fixed frequency sampling strategy employed in our analysis.

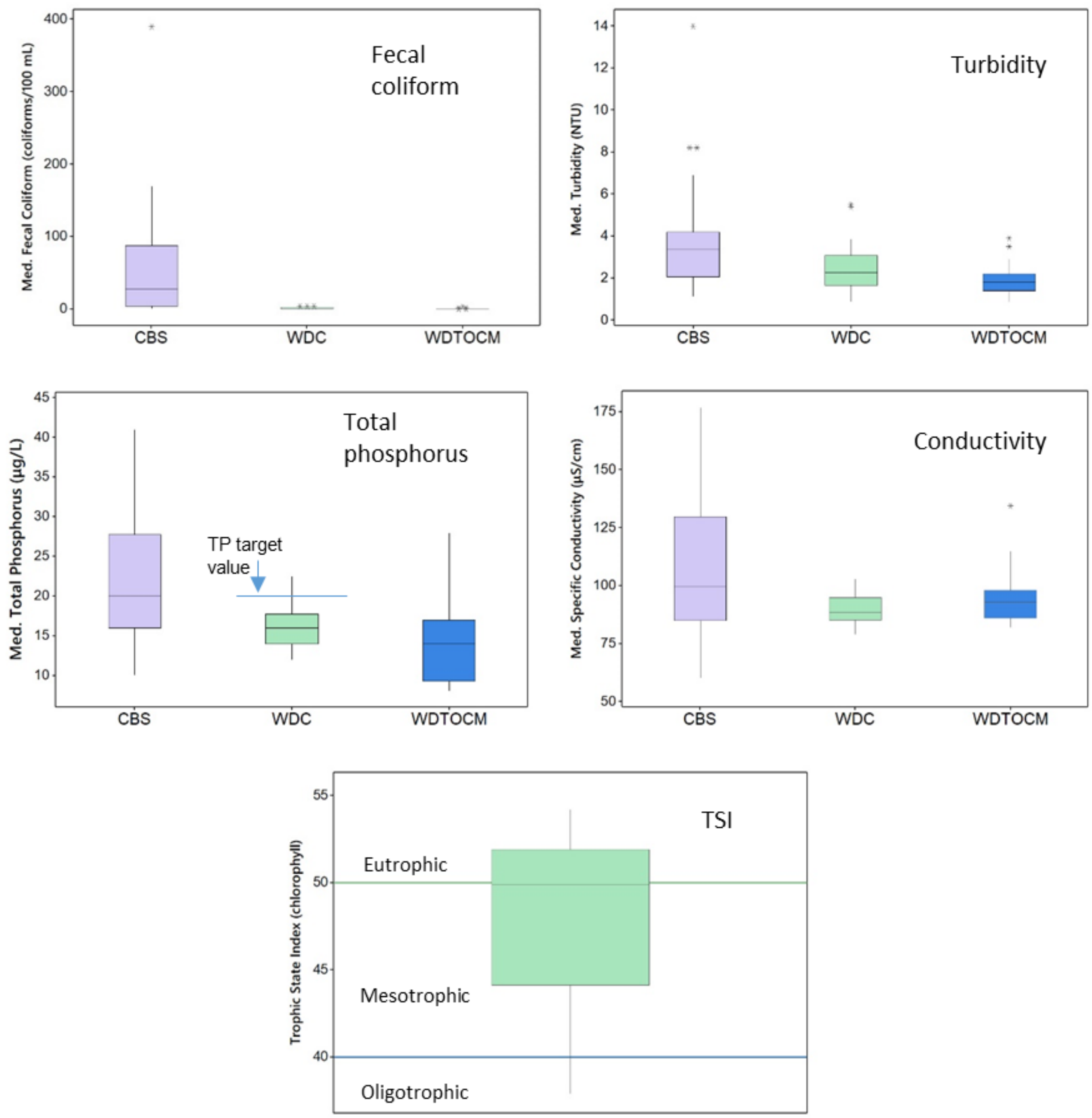


Figure 5.8 Water quality status boxplots using 2017-2019 monthly data for the Cannonsville basin main stream inflow at the West Branch Delaware River (WDBN), Cannonsville Reservoir (WDC), and the outflow at the West Delaware Tunnel Outlet (WDTOCM).

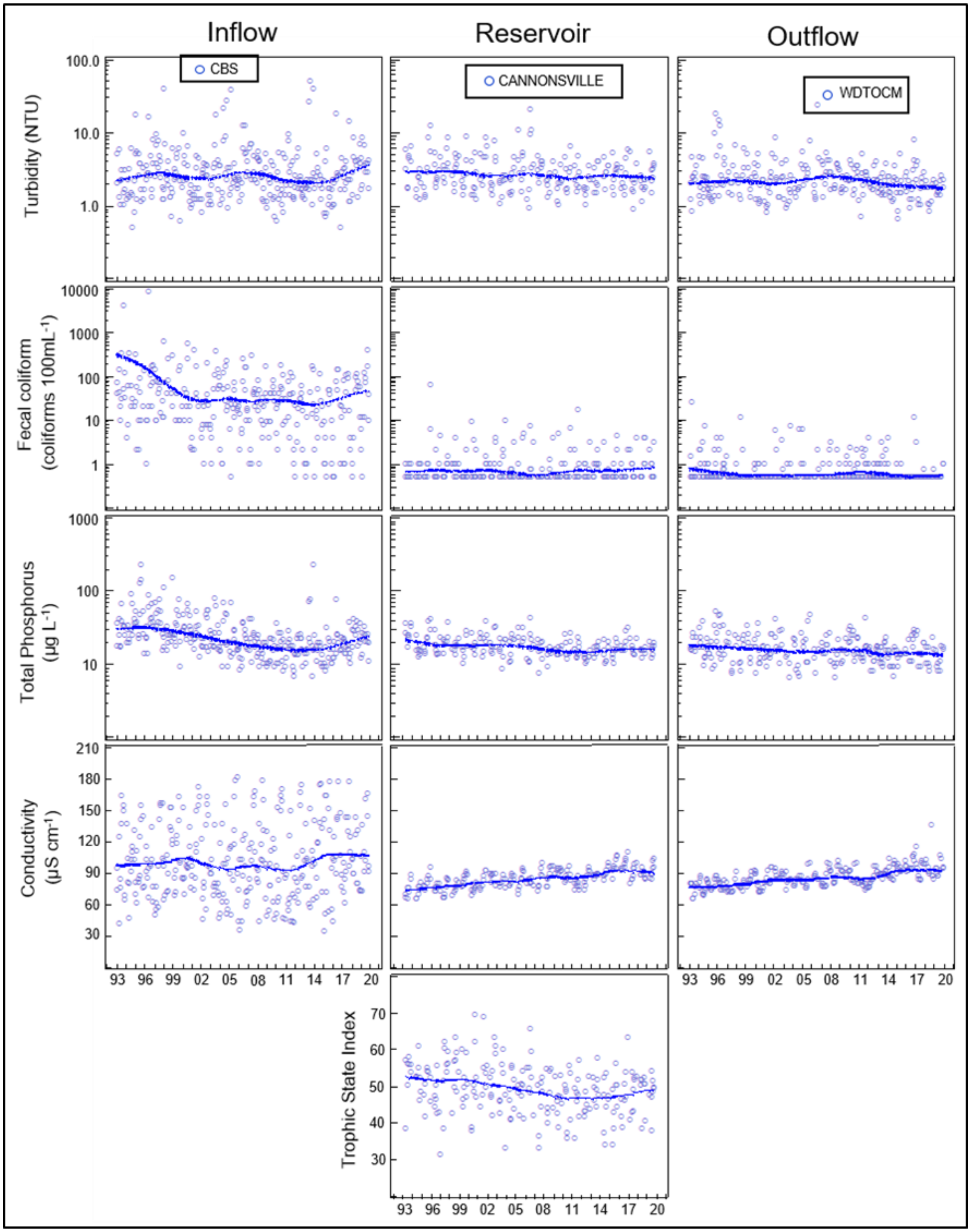


Figure 5.9 Water quality trend plots for the Cannonsville basin main stream inflow at the West Branch Delaware River (CBS), Cannonsville Reservoir, and the outflow at the West Delaware Tunnel Outlet (WDTOCM).

Table 5.3 Cannonsville Basin trends from 1993 to 2019 for selected analytes..

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
CBS	Inflow	Turbidity	324	NS	0	0	Trend extremely unlikely
CBS	Inflow	Turbidity (Flow Adj.)	324	NS	-0.004	-0.181	Decreasing trend about as likely as not
Cannonsville	Reservoir	Turbidity	215	***	-0.023	-0.915	Decreasing trend virtually certain
WDTOCM	Outflow	Turbidity	271	***	-0.021	-0.997	Decreasing trend virtually certain
CBS	Inflow	Fecal Coliform	314	***	-0.234	-1.143	Decreasing trend very likely
CBS	Inflow	Fecal Coliform (Flow Adj.)	314	***	-0.352	-1.717	Decreasing trend virtually certain
Cannonsville	Reservoir	Fecal coliform	214	NS	0	0	Increasing trend about as likely as not
WDTOCM	Outflow	Fecal coliform	270	***	0	0	Decreasing trend very likely
CBS	Inflow	Total Phosphorus	322	***	-0.687	-3.27	Decreasing trend virtually certain
CBS	Inflow	Total Phosphorus (Flow Adj.)	322	***	-0.611	-2.91	Decreasing trend virtually certain
Cannonsville	Reservoir	Total Phosphorus	209	***	-0.192	-1.165	Decreasing trend virtually certain
WDTOCM	Outflow	Total Phosphorus	246	***	-0.168	-1.122	Decreasing trend virtually certain
CBS	Inflow	Conductivity	322	***	0.344	0.354	Increasing trend very likely

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
CBS	Inflow	Conductivity (Flow Adj.)	322	***	0.852	0.878	Increasing trend virtually certain
Cannonsville	Reservoir	Conductivity	211	***	0.727	0.871	Increasing trend virtually certain
WDTOCM	Outflow	Conductivity	271	***	0.7	0.833	Increasing trend virtually certain
Cannonsville	Reservoir	Trophic State Index	212	***	-0.211	-0.427	Decreasing trend virtually certain

[1] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$

The more recent increasing trend in the primary inflow at site CBS (Figure 5.9) may be due in part to a sample location change in July 2016. For safety concerns, the site was moved about 500 feet downstream. There it could be accessed from the shore by pumping the sample through a pipe submerged in the stream. Paired samples indicated a bias to higher turbidity, fecal coliform, and phosphorus at the new site with the bias increasing at higher flows.

Long-term fecal coliform downward trends were identified for the Cannonsville inflow and outflow. Widespread implementation of agricultural BMPs and the relative infrequency of large runoff events after 2011 are probable factors. The recent short-term upward increase at the inflow is likely due to the aforementioned change in sample site location.

Long-term downward TP trends were identified for the inflow, reservoir, and outflow. As previously reported (DEP 2016), phosphorus peaked at the inflow in 1996 and, except for temporary increases due to large storms, has generally been in decline. A portion of the decline may be explained by recovery from flooding events in late 1995, early 1996, and June 2006, but the majority of the decline coincides with various WWTP upgrades and to load reductions from a food production plant located in Walton. Other factors include reductions resulting from extensive septic repairs, implementation of agricultural BMPs, and a decline in dairy farming in the watershed. The more recent upward trend at CBS may be because of the sampling location change. Some portion of the increase may also be attributable to phosphorus contamination of sample bottles that occurred from late 2014 to 2017 but was most was most significant in 2016 and 2017 (DEP 2018).

Increasing conductivity trends were apparent for the inflow, reservoir, and outflow. In the previous FAD evaluation, an uptrend was not identified for the inflow. After flow adjustment, the percent change increased more than two-fold suggesting road deicer usage was the primary reason for the increase.

A long-term down trend was identified for TSI in Cannonsville Reservoir. The LOWESS curve revealed that most of the decrease occurred from 1993 to 2012, coinciding with lower TP concentrations and enhanced by periods of low clarity associated with flooding events in 2006. Since 2012, however, the LOWESS curve describes a gradual increase in TSI. The increase coincides with increasing surface temperatures (not shown).

In summary, at some locations downward long-term trends were detected for turbidity, fecal coliforms, and phosphorus. Upward trends were detected for conductivity. The decreases in turbidity may be linked to recovery from flooding events in 1995-1996, April 2005, and June 2006. Low inputs during drought (2001-2003, 2016) and from periods characterized by few extreme runoff events (2007-2009, 2012-2019) is another factor. Recovery from various flooding events may also contribute to the declines in phosphorus; but load reductions from agricultural BMPs, wastewater treatment plants and a food manufacturing facility may be the primary cause. Phosphorus reductions and low water clarity in 2005-2006 help to explain the overall decrease in trophic state. However, a more recent increase in TSI was apparent starting in 2012, which may be related to increasing surface water temperatures. The conductivity increases are likely caused by increases from anthropogenic sources, in particular road salt. Recent short-term increases in turbidity, TP and fecal coliforms at the Cannonsville inflow are attributed to a change in sample site location.

5.4.2 Biomonitoring in the Cannonsville Watershed

The New York City stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in watershed streams. For methodology details, see Appendix C.

The most recent status of macroinvertebrate communities in the Cannonsville basin was evaluated by examining 2017-2018 data from sites located on the West Branch of the Delaware River. Due to the budgetary constraints associated with COVID-19, results from the 2019 data are not available at this time. The West Branch of the Delaware River is the primary inflow to Cannonsville Reservoir, draining 77% of the basin. Three of the sites with data from these years (Sites 301, 304, 320) are routine and sampled annually.

Site 320 (WDBN) in Beerston lies approximately 1.5 miles upstream of Cannonsville Reservoir. Sites 304 (WSPB), and 301 (WDHOA) are situated about five and 42 miles, respectively, upstream of the reservoir. Sites 301 and 304 are located a short distance downstream of WWTPs. Site 320 was assessed as non-impaired in both 2017 and 2018. Sites 301 and 304, the two upstream routine sites, both had modest drops in status both to slightly impaired (Figure 5.10).

The time series trend in BAP scores was based on a site's entire period of record (1994-2018 for Sites 301 and 304; 1996-2018 for Site 320), and examined changes in both the scores and assessment categories (Figure 5.11). While the graphs show no trend in a site's status, one possible cause for the slight decline in the status of Sites 301 and 304 in 2018 might be the increase in the percentage of hydropsychid caddisflies. At Site 301 in 2018, the percentage of hydropsychids was 60.8 and at Site 304 the percentage was 37.3.

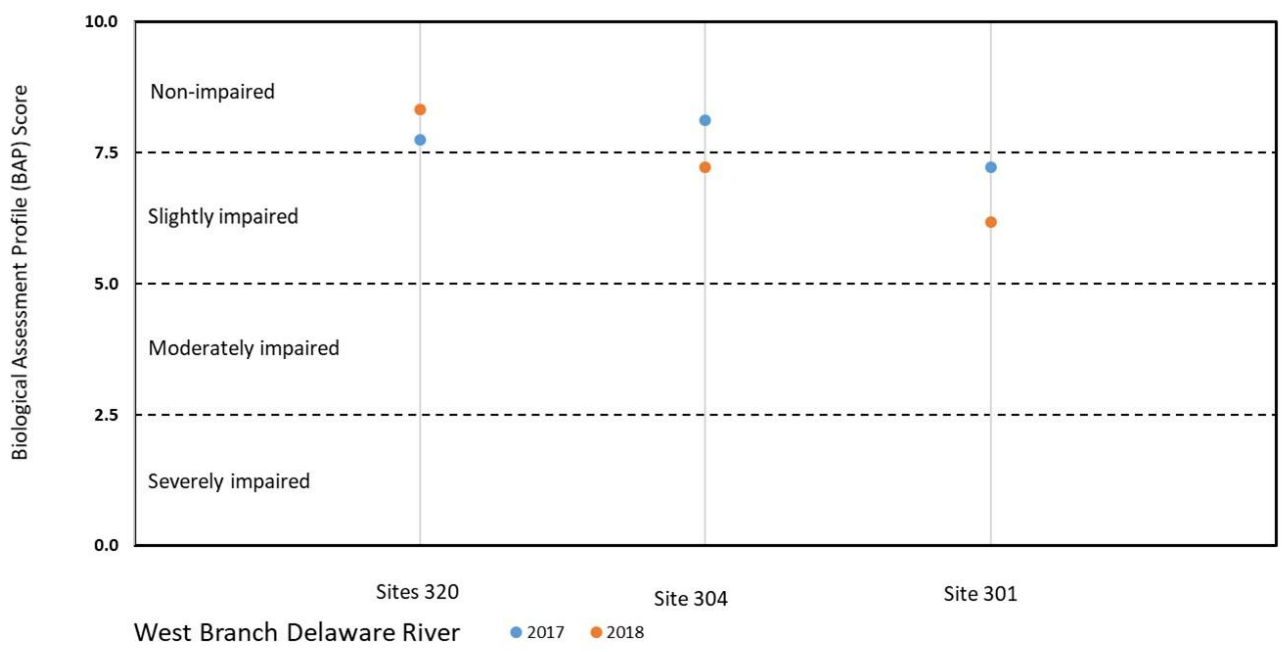


Figure 5.10 Biological Assessment Profile scores for West Branch Delaware River, 2017-2018.

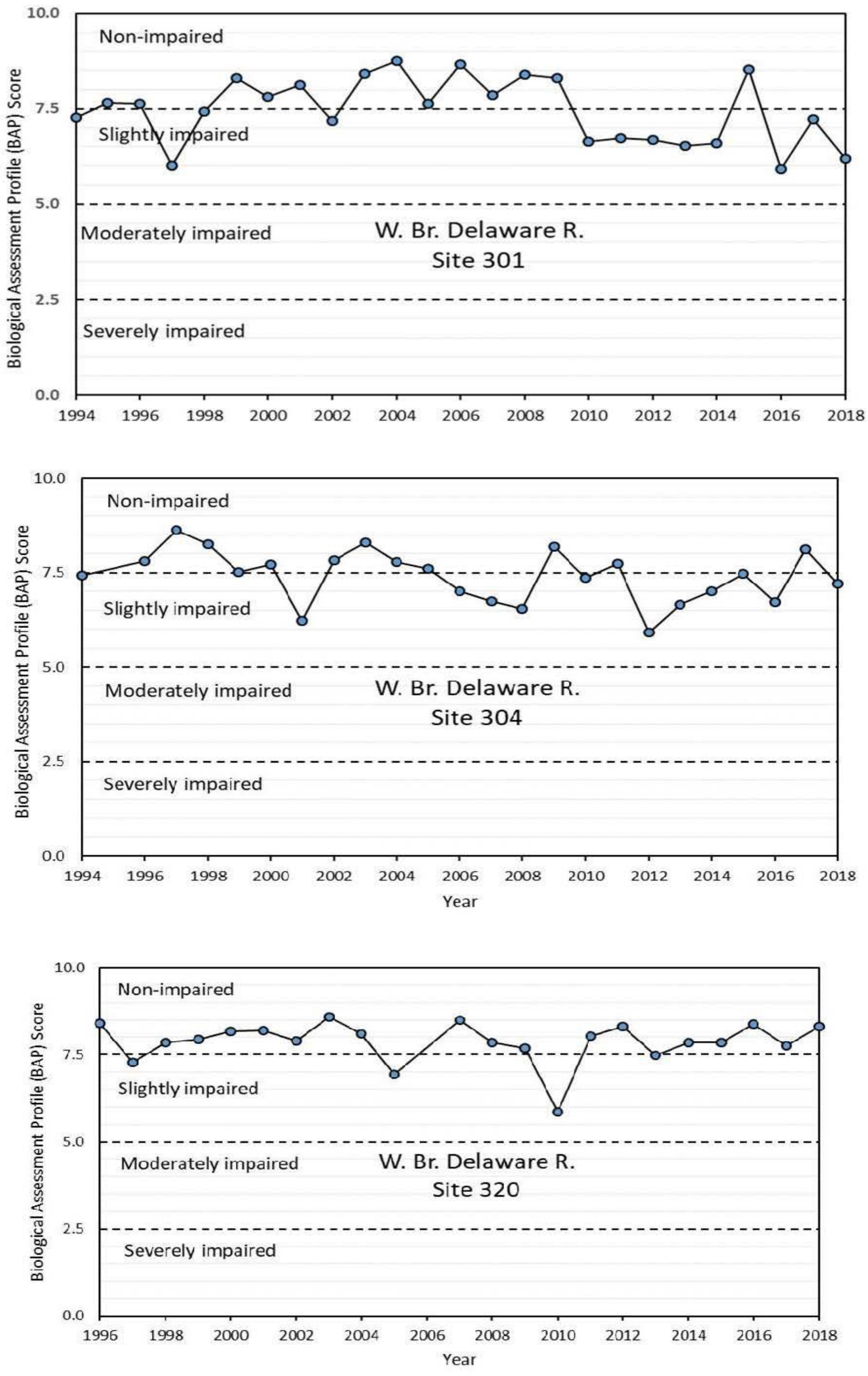


Figure 5.11 Biological Assessment Profile scores for West Branch Delaware River, 1994/1996-2018.

5.5 Rondout Basin

Rondout Reservoir is located on the southern edge of the Catskill Park, approximately 65 miles northwest of New York City. Placed into service in 1950, it was formed by the damming of Rondout Creek. The creek continues southeastward and drains into the Hudson River at Kingston. The reservoir consists of one basin, almost 6.5 miles long, which holds 49.6 billion gallons at full capacity. Currently, Rondout's own watershed supplies 160 MGD or roughly 13.2% of the total average daily consumption to New York City and an additional 1 million upstate consumers.

Rondout is one of four reservoirs in the Delaware System and it serves as the central collecting reservoir for water from Pepacton, Cannonsville, and Neversink reservoirs. Since the Delaware System supplies approximately 50% of New York City's water, Rondout plays a critical role in the City's overall water supply system. Rondout is diverted southeast into the 85-mile long Delaware Aqueduct, which runs below the Hudson River to West Branch Reservoir and then Kensico Reservoir.

Rondout's watershed area is 95 square miles and includes parts of seven towns. Four main tributaries flow directly into Rondout Reservoir, with Rondout Creek supplying 40% of flow while Chestnut Creek provides 22%. Sugarloaf Brook delivers another 8.4% and Sawkill Brook an additional 6.6% of flow. The Rondout watershed land-use breakdown is as follows: 86.1% is forested, 5.2% is urban, 1.9% is brushland, 3.6% is water, and 3.3% is in agricultural use.

As of December 31, 2020, there were 1,081 acres of agricultural lands with active, nutrient management plans in the Rondout watershed. Since 1996, over 98 total farm best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, and pathogens in the Rondout watershed with 20 BMPs implemented between 2016 and 2020. Eight environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects. Over 350 septic systems throughout the basin have been remediated. Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place as described earlier.

There is a single active WWTP (Grahamsville) in the Rondout watershed with a permitted maximum flow of 0.18 MGD. Inputs of phosphorus, as well as other pollutants, from the WWTP to Rondout Reservoir continue to be reduced as a result of upgrading the City-owned Grahamsville plant.

5.5.1 Water Quality Status and Trends in the Rondout Watershed

Status (Rondout)

The Rondout basin status evaluation is presented as a series of boxplots in Figure 5.12. Inflows include water diverted from Neversink Reservoir (NRR2CM), Pepacton Reservoir (PRR2CM), Cannonsville Reservoir (WDTOCM), and Rondout Creek (RDOA). The reservoir is designated as RR and the output is designated as RDRRCM. A comparison of the inflows, reservoir, and the outflow is shown. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the evaluation period (2017-2019), fecal coliform bacteria remained well below the NYSDEC stream guidance value of 200 fecal coliforms 100 mL^{-1} for aqueduct inflow sites (NRR2CM, PRR2CM, and WDTOCM). By contrast, the principal river inflow to Rondout Reservoir, Rondout Creek (RDOA), had a wider range of fecal coliforms, with two high outliers (130 fecal coliforms 100 mL^{-1} in September 2018 and 31 fecal coliforms 100 mL^{-1} in November 2018). But all values fell below the guidance value. Reservoir (RR) and outflow (RDRRCM) fecal coliform levels were low, with only a few outlier values above the detection limit.

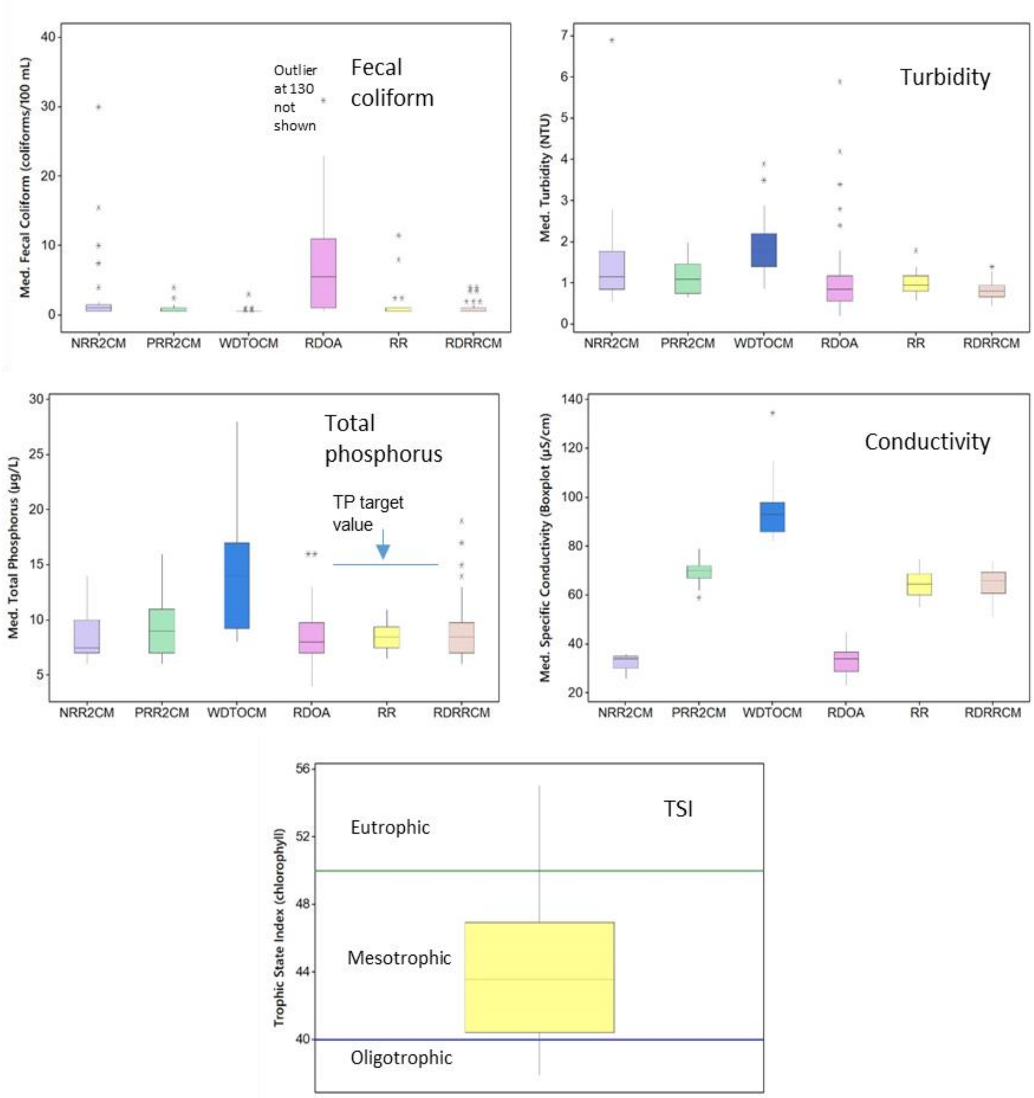


Figure 5.12 Water quality status boxplots using 2017-2019 monthly data for the Rondout basin inflows from Cannonsville (WDTOCM), Pepacton (PRR2CM), and Neversink (NRR2CM) reservoirs and from the main stream inflow at Rondout Creek (RDOA); Rondout Reservoir (RR); and the outflow at the Rondout gatehouse (RDRRCM).

Turbidity was generally low at all sites. Median monthly total phosphorus (TP) for the reservoir was 8.5 µg L^{-1}, well below the target value of 15 µg L^{-1}. The Trophic State Index (TSI) values for Rondout Reservoir fell primarily within the mesotrophic range, with a median of 44. Conductivity medians were highest at the inflow from Cannonsville (WDTOCM) and lower in the reservoir (RR) and outflow (RDRRCM), with medians of 65 µS cm^{-1} and 66 µS cm^{-1}, respectively.

Trends (Rondout)

Water quality trend plots for the Rondout basin are presented in Figure 5.13 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 5.4.

Trend interpretation is difficult for Rondout Reservoir since it receives water from four major sources: diversions from Neversink, Cannonsville and Pepacton reservoirs as well as from a local stream, Rondout Creek (RDOA). Downward long-term turbidity trends were observed for all of the upstream reservoir inputs but there was also strong evidence for an upward trend for Rondout Creek. Since this inflow only accounts for about 11% of the total flow to the reservoir, diversions from the upstream reservoirs offset the input from Rondout Creek, resulting in a possible decreasing trend in the reservoir and strong evidence for a downward trend in the outflow.

The direction of fecal coliform trends varied among Rondout's inflows. There was evidence of an increasing trend from the Neversink outflow (NRR2CM) and decreasing trends at outflows from Cannonsville (WDTOCM) and Rondout Creek (RDOA) with no trend identified at the Pepacton outflow (PRR2CM). Reasons for the decrease at RDOA are not apparent, but because it is a much higher source of fecal coliforms than the upstream reservoir inputs, improvements here can be considered a positive sign for reservoir water quality. No trends were observed for Rondout Reservoir or outflow but the generally low values compared to RDOA illustrate the reservoirs' capacity to attenuate pathogens through processes such as die-off and sedimentation.

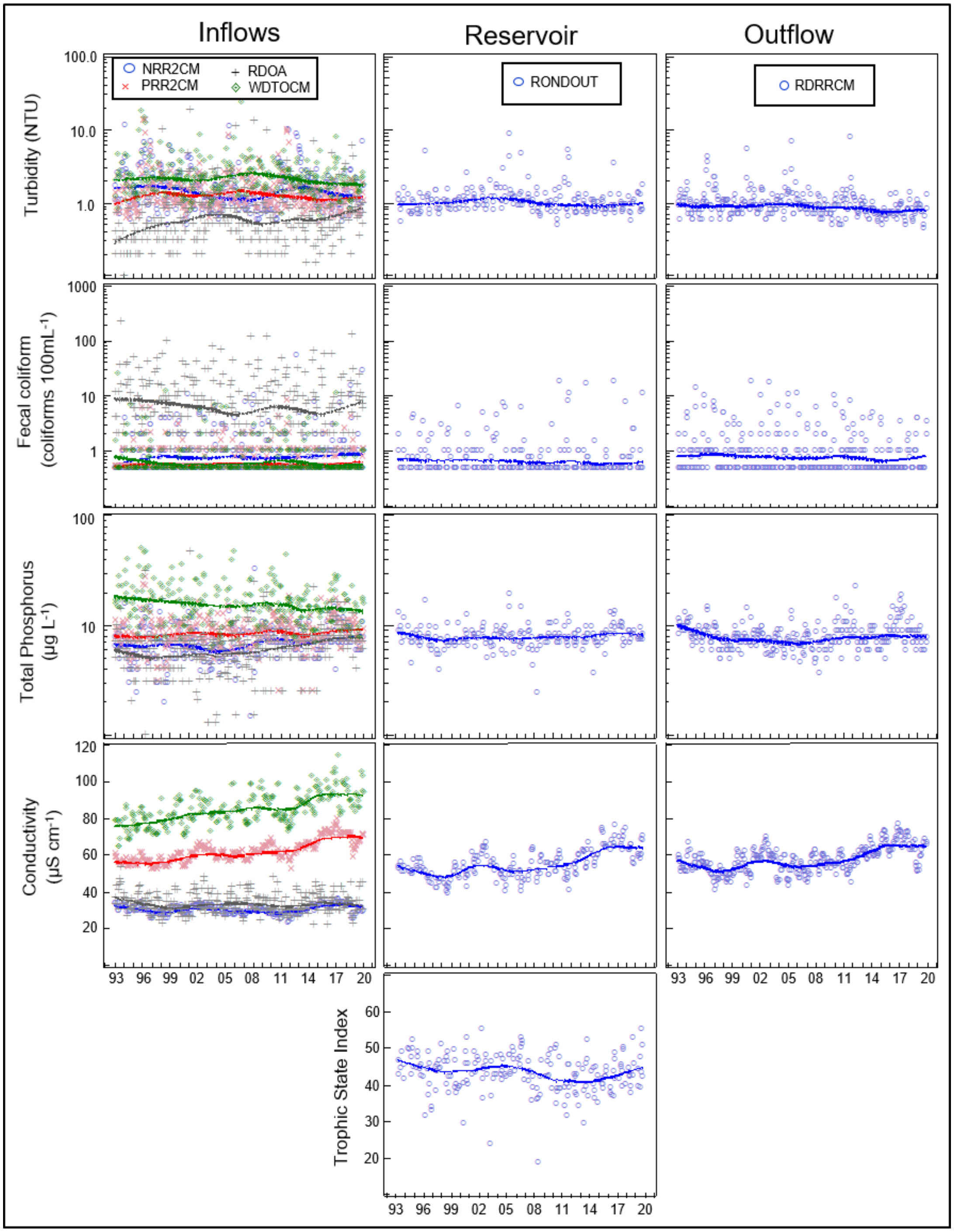


Figure 5.13 Water quality trend plots for the Rondout basin inflows from Cannonsville (WDTOCM), Pepacton (PRR2CM), and Neversink (NRR2CM) reservoirs and the main stream inflow, Rondout Creek (RDOA); Rondout Reservoir; and the outflow at the Rondout gatehouse (RDRRCM).

Table 5.4 Rondout Basin trends from 1993 to 2019 for selected analytes.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
NRR2CM	Inflow	Turbidity	302	*	-0.004	-0.355	Decreasing trend possible
PRR2CM	Inflow	Turbidity	320	***	-0.005	-0.439	Decreasing trend very likely
WDTOCM	Inflow	Turbidity	271	***	-0.021	-0.997	Decreasing trend virtually certain
RDOA	Inflow	Turbidity	323	***	0.01	2	Increasing trend virtually certain
RDOA	Inflow	Turbidity (Flow Adj.)	323	***	0.009	1.858	Increasing trend virtually certain
Rondout	Reservoir	Turbidity	213	*	-0.003	-0.278	Decreasing trend possible
RDRRCM	Outflow	Turbidity	324	***	-0.008	-0.855	Decreasing trend virtually certain
NRR2CM	Inflow	Fecal coliform	298	***	0	0	Increasing trend very likely
PRR2CM	Inflow	Fecal coliform	319	NS	0	0	Trend exceptionally unlikely
WDTOCM	Inflow	Fecal coliform	270	***	0	0	Decreasing trend very likely
RDOA	Inflow	Fecal Coliform	324	***	-0.042	-0.832	Decreasing trend virtually certain
RDOA	Inflow	Fecal Coliform (Flow Adj.)	324	*	-0.056	-1.114	Decreasing trend possible
Rondout	Reservoir	Fecal coliform	213	**	0	0	Decreasing trend likely

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
RDRRCM	Outflow	Fecal coliform	324	***	0	0	Decreasing trend virtually certain
NRR2CM	Inflow	Total Phosphorus	278	***	0.056	0.794	Increasing trend virtually certain
PRR2CM	Inflow	Total Phosphorus	310	***	0.022	0.269	Increasing trend very likely
WDTOCM	Inflow	Total Phosphorus	246	***	-0.168	-1.122	Decreasing trend virtually certain
RDOA	Inflow	Total Phosphorus	321	***	0.099	1.656	Increasing trend virtually certain
RDOA	Inflow	Total Phosphorus (Flow Adj.)	321	***	0.108	1.794	Increasing trend virtually certain
Rondout	Reservoir	Total Phosphorus	210	***	0.025	0.313	Increasing trend very likely
RDRRCM	Outflow	Total Phosphorus	320	NS	0	0	Trend extremely unlikely
NRR2CM	Inflow	Conductivity	301	***	0	0	Increasing trend very likely
PRR2CM	Inflow	Conductivity	320	***	0.556	0.911	Increasing trend virtually certain
WDTOCM	Inflow	Conductivity	271	***	0.7	0.833	Increasing trend virtually certain
RDOA	Inflow	Conductivity	320	NS	0	0	Decreasing trend about as likely as not
RDOA	Inflow	Conductivity (Flow Adj.)	320	*	0.03	0.092	Increasing trend possible

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
Rondout	Reservoir	Conductivity	211	***	0.591	1.085	Increasing trend virtually certain
RDRRCM	Outflow	Conductivity	324	***	0.5	0.877	Increasing trend virtually certain
Rondout	Reservoir	Trophic State Index	207	***	-0.108	-0.249	Decreasing trend very likely

[1]The *p*-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

Upward TP trends were identified in all Rondout Reservoir inflows except for Cannonsville (WDTOCM), where there was strong evidence of a downward TP trend. The decrease at WDTOCM is especially significant since this input generally has the highest phosphorus concentrations. Decreases here have been linked to WWTP upgrades and to extensive watershed improvements, e.g., agricultural BMPs. Despite the noted decrease at WDTOCM, an upward TP trend was identified for Rondout Reservoir presumably due to increasing TP trends at most Rondout inflows. These results indicate a worsening situation in the Delaware System. In the last FAD evaluation, no long-term TP increases were identified for the inflows, reservoir, or outflow. The TP increase at PRR2CM is especially significant because transfers from Pepacton tend to dominate the inputs to Rondout. In addition, transfers have increased since 2014 while transfers from Neversink and Cannonsville have decreased. The increasing trends at NRR2CM, PRR2CM, and RDOA appear in part to be driven by extreme rain events occurring during 2010-2012. However, some portion of the increase is probably attributable to phosphorus contamination of sample bottles that occurred from late 2014 to 2017 but was most was most significant in 2016 and 2017 (DEP 2018).

An upward conductivity trend was identified in the reservoir coinciding with increases observed in all inflows except RDOA. Shorter-term conductivity trends appear to be controlled by precipitation patterns. In wet years (e.g., 2003-2011) dilution causes conductivity to decrease. During drier periods (e.g., 1998-2001 and 2012-2016), base flow becomes a larger portion of the inflow causing conductivity to increase. Increasing chloride concentrations from road salt is likely the primary driver of the long-term trend. Adjusting for flow at the major inputs to the headwater reservoirs that supply water to Rondout indicated that the slope of the upward trend increased after removing the variation caused by flow.

Although a long-term downward TSI trend was identified for Rondout Reservoir, a shorter-term increase is apparent since 2012, which is also evident to some extent in all the headwater waters that provide water to Rondout. Several factors were identified which may help explain the TSI increases in the headwater reservoirs. These factors included increased surface water temperature at all reservoirs, TP increases at Neversink, and increasing residence times for Pepacton and Neversink.

In summary, downward trends were detected for turbidity at all headwater inflows with a local stream (RDOA) trending upward. Decreasing fecal coliform trends ranged from possible to certain at the reservoir, the outflow, WDTOCM, and RDOA with no trend discernable at PRR2CM. An increasing trend was identified at the inflow from Neversink (NRR2CM). Long-term upward phosphorus trends were identified for all inflows with the exception of WDTOCM, which was identified as downward. However, these results are suspect due to bottle contamination issues that occurred in 2016 and 2017. Phosphorus declines at WDTOCM have been linked to a combination of wastewater treatment upgrades and other watershed improvement projects in the Cannonsville basin. All sites in the basin have experienced long-term increases in conductivity. Road deicers are the suspected primary driver of these trends. A long-term downward trend was identified for TSI. However, a recent increase was identified by LOWESS analysis for Rondout and all the headwater reservoirs that provide water to Rondout. These increases were associated with rising surface water temperatures as well as an increase in residence times for Pepacton and Neversink.

5.5.2 Biomonitoring in the Rondout Watershed

The New York City stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. For methodology details, see Appendix C.

The most recent status of macroinvertebrate communities in the Rondout Basin was evaluated by examining 2017-2018 data for a single site (310) located on Rondout Creek. Due to the budgetary constraints associated with COVID-19, data from 2019's sampling is not available at this time. This stream is the primary inflow to Rondout Reservoir, draining 40% of the basin.

Site 310 is located in the Town of Neversink, near Lowes Corners, approximately one mile upstream of Rondout Reservoir. The site received a slightly impaired assessment in 2017 and a non-impaired assessment in 2018 (Figure 5.14).

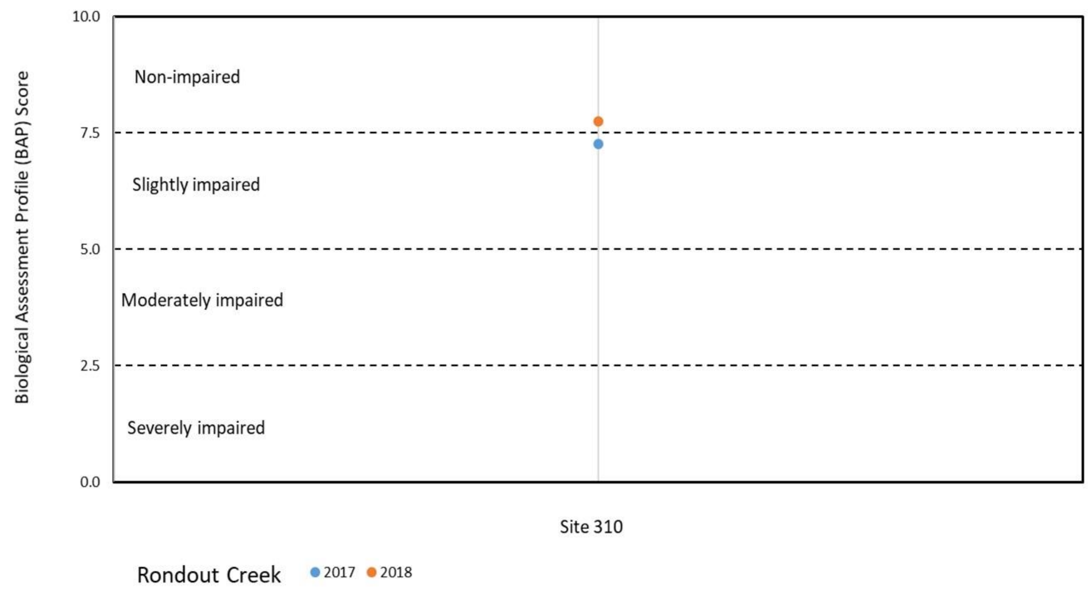


Figure 5.14 Biological assessment profile scores for Rondout Creek, 2017-2018.

The time series trend in BAP scores was based on the site's entire period of record (1995-2018), and examined changes in both the scores and assessment categories. (Figure 5.15). Given that five of the eight assessments at Site 310 have been non-impaired (four preceding the three years of slightly impaired assessments, and one in the year following (2013)), it is unclear if this trend will persist. One possible cause for the drop in BAP scores is an increase in the percentage of hydropsychid caddisflies. In 2017, the percentage was 42.9. In 2018 the percentage dropped to pre-2001 percentage of 6.5. DEP will continue to monitor the site to obtain a clearer picture of what changes, if any, are occurring there.

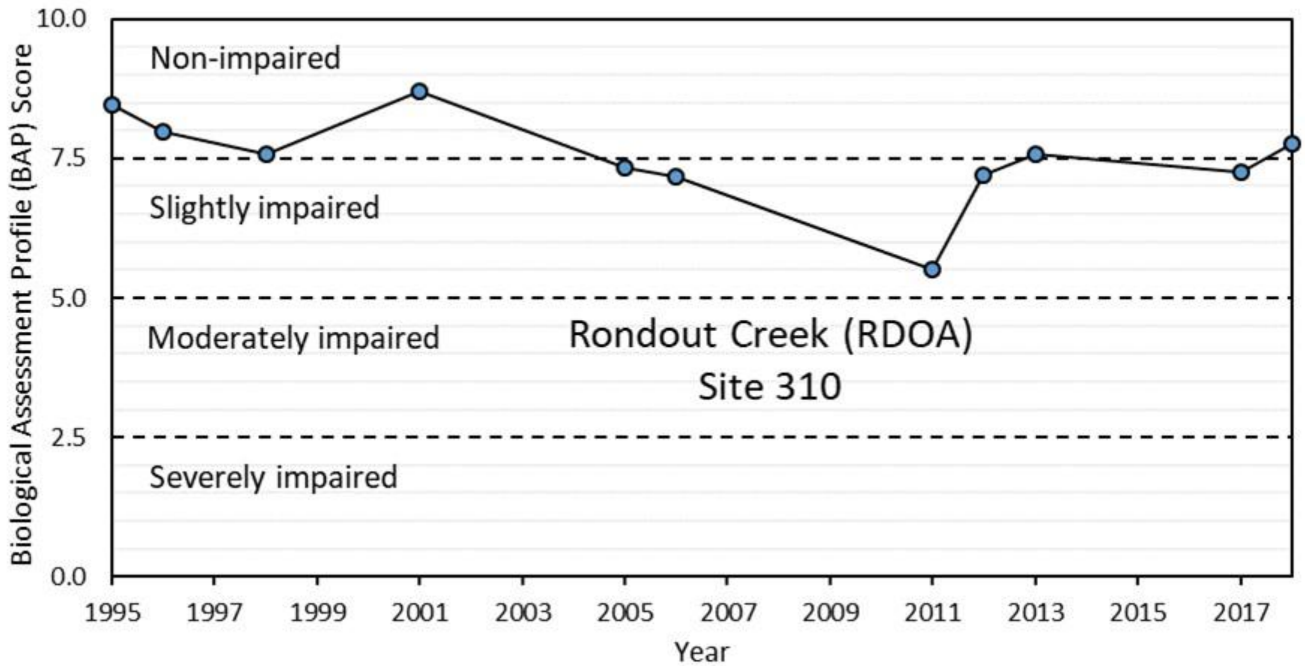


Figure 5.15 Biological assessment profile scores for Rondout Creek, 1995-2018

5.6 Trophic Response of Delaware Reservoirs

A series of four plots were used to examine the trophic response of Delaware System reservoirs. Annual geometric means of chlorophyll versus total phosphorus are plotted in Figure 5.16. The majority of points lie above the standard OECD line and the most recent five years are no exception. Several factors may contribute to this effect in a consistent way creating this shift. The data points represent the growing season rather than the entire year, and may tend to be high for that reason. Possibly more sensitive laboratory measurement methods were used for chlorophyll than for the data used to calculate the regression. Field collection methods may have also differed. Nonetheless, all four reservoirs are well aligned showing a decrease in biomass in line with a decrease in phosphorus levels. In decreasing order, Cannonsville, Pepacton, and Neversink each cluster around a characteristic biomass level set by their nutrient contents. As a blend of the other three reservoirs, Rondout is in an intermediate position. This indicates that phosphorus is controlling the level of algal standing crop and eutrophication continues to be controlled through phosphorus concentrations at their reduced levels. Indeed, the Cannonsville biomass has decreased remarkably from previous assessment periods.

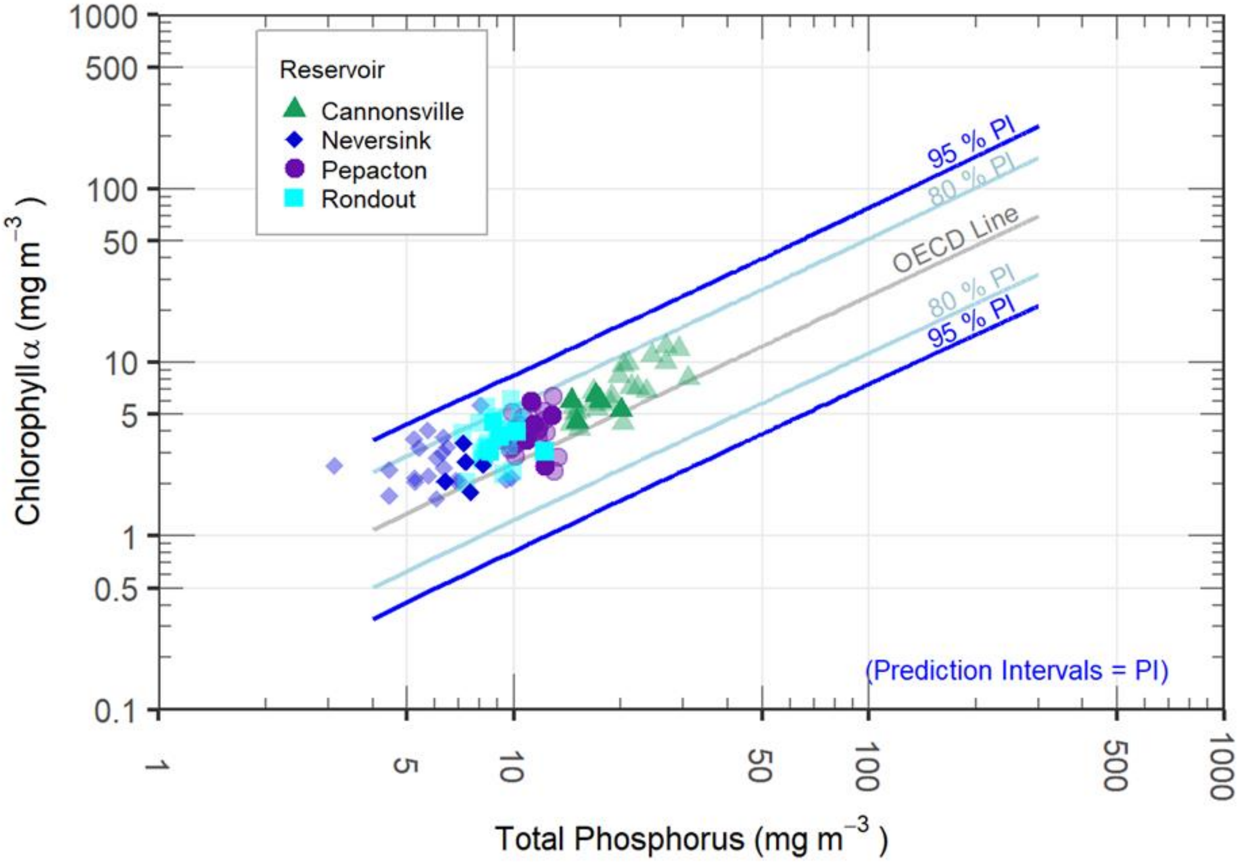


Figure 5.16 Chlorophyll versus total phosphorus for Delaware System reservoirs.

Maximum chlorophyll is plotted versus total phosphorus in Figure 5.17. Again the chlorophyll concentrations are consistently above the standard regression line, so the same methodological differences play a role as in the previous plot. In this relationship, the variation is greater in the maximum biomass attained than for annual mean chlorophyll, with some values exceeding the upper 95% PI. The maximum values may not always be captured due to low frequency of sampling, and maxima may not always be attained if other factors depress the standing crop. The least variation occurs in Rondout. This may be related to the short, nearly constant water residence time of about 1.5 months. The constant flow through this reservoir may tend to flush nutrients and phytoplankton downstream before there is sufficient time for maximum growth. As expected, reservoirs retain their same relative positions as in the plot of annual mean chlorophyll values.

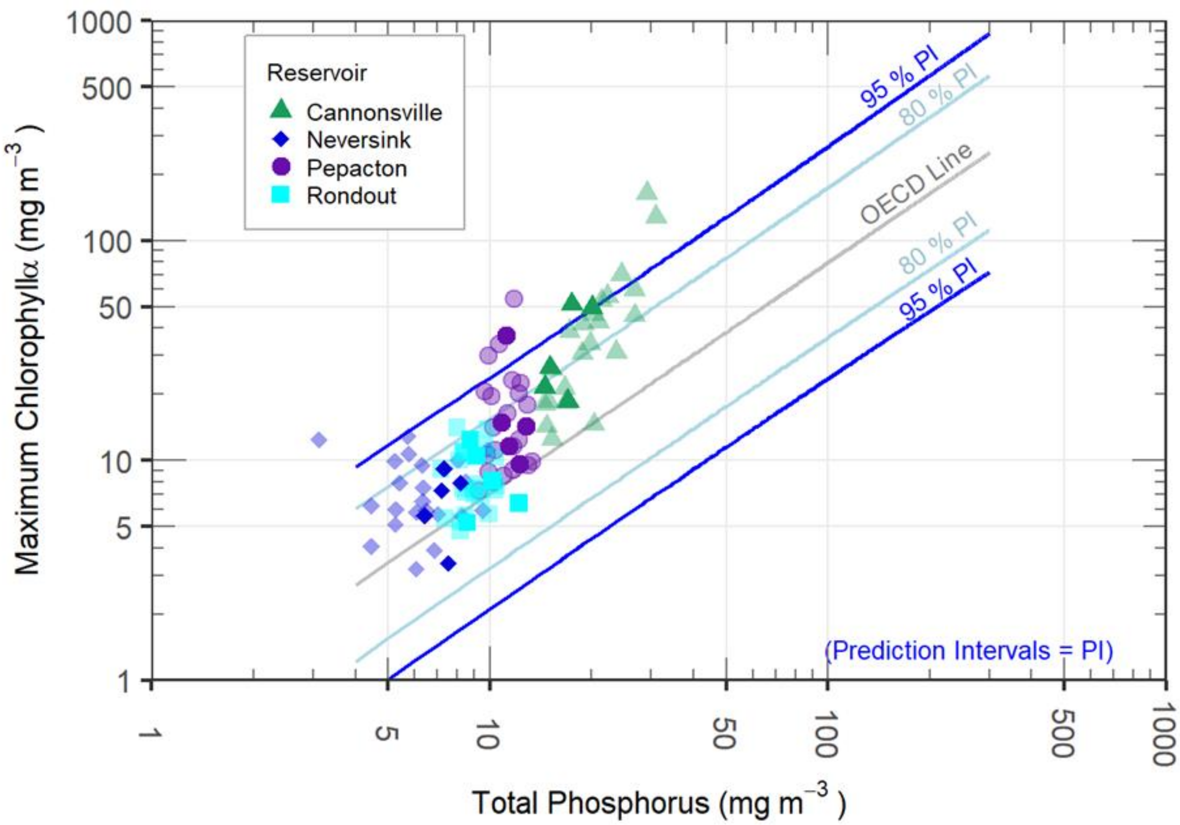


Figure 5.17 Maximum chlorophyll versus total phosphorus in Delaware System reservoirs.

Secchi depth versus total phosphorus is plotted in Figure 5.18. Secchi depths are consistently lower than expected at the reported concentrations of phosphorus, but well aligned with the standard line, and with relatively low variation. In the most recent five years, Neversink shows a slight shift toward increased phosphorus, yet still at very low levels consistent with oligotrophy, and Cannonsville, at the upper end, has shifted toward lower levels of phosphorus and increased transparency. Since all the relationships tend to lie below the OECD line, it can be concluded that factors in addition to chlorophyll may limit light and those factors moderate the light climate in these reservoirs in a consistent way.

Secchi depth versus chlorophyll is plotted in Figure 5.19. The observed Secchi depths are less than expected at the reported concentrations of chlorophyll. As was concluded above, the limitation of transparency is evidently influenced by factors in addition to algal biomass in all the Delaware System reservoirs.

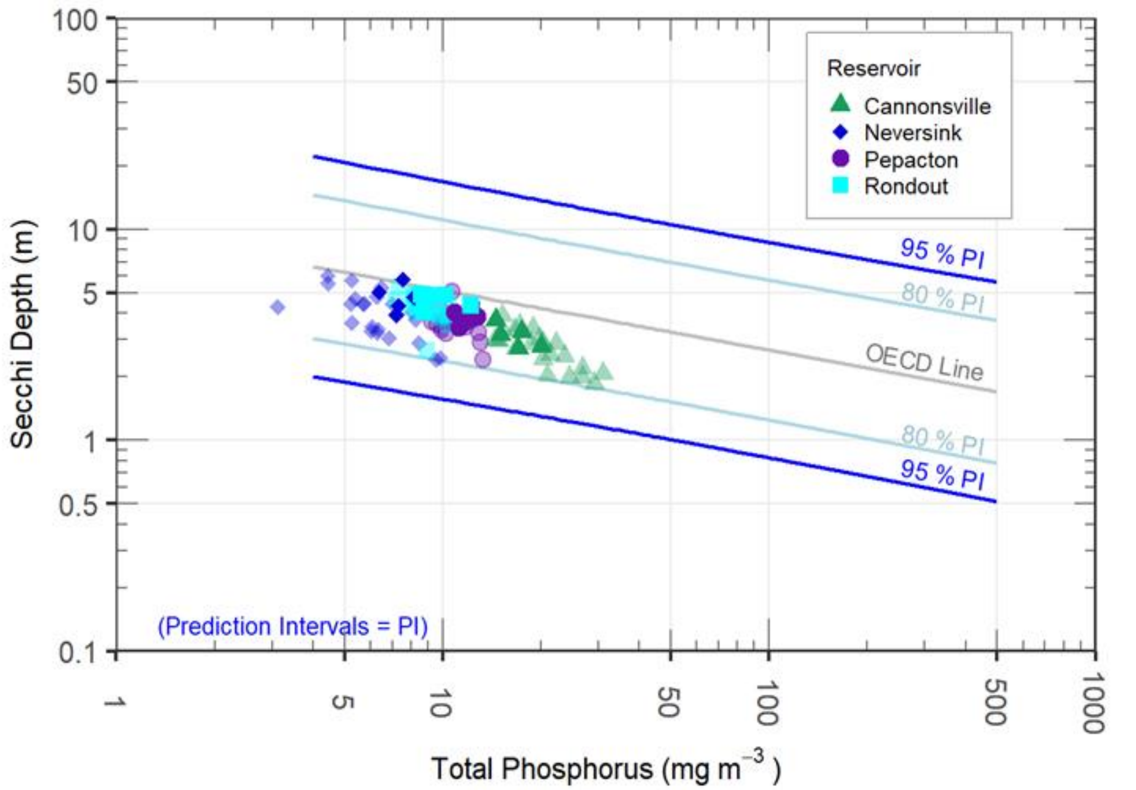


Figure 5.18 Secchi depth versus total phosphorus for Delaware System reservoirs.

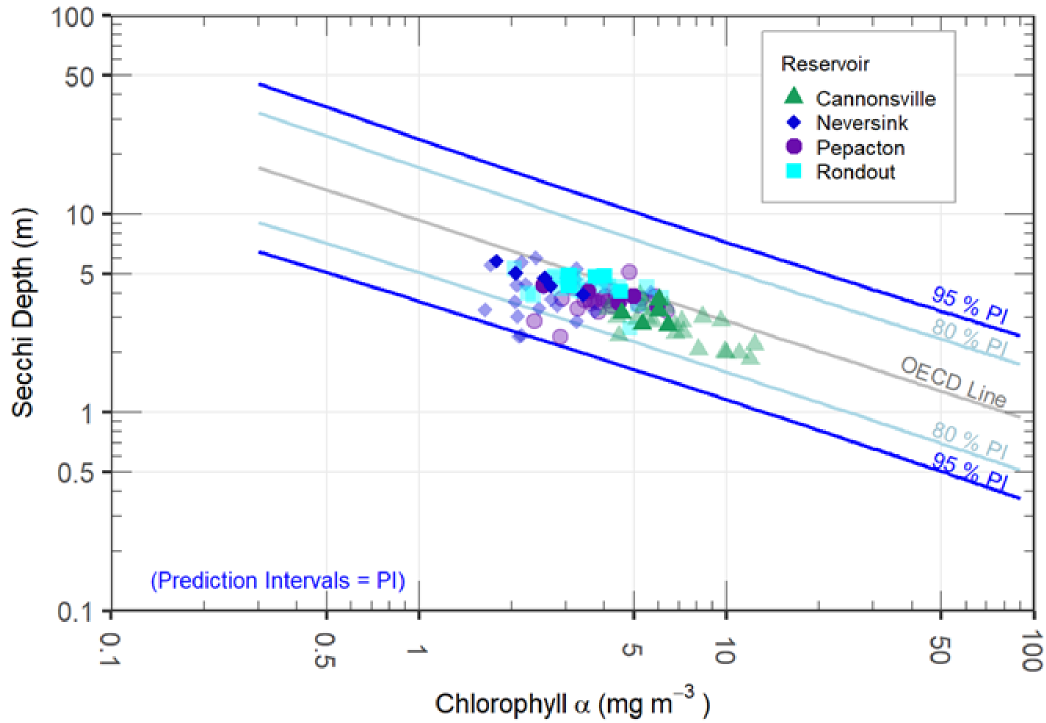


Figure 5.19 Secchi depth versus chlorophyll in Delaware System reservoirs.

Examining time series of the changes in central tendencies over the past 25 years (also see Appendix C) for geometric mean phosphorus (Figure 5.20), mean chlorophyll, maximum chlorophyll (Figure 5.21), and Secchi depth, it is very obvious there have been vast improvements in Cannonsville Reservoir where greatest phosphorus load reduction has been achieved. More subtle changes have taken place in the other reservoirs and the trends statistics are appropriate for characterization of those changes. In contrast, the variations in the Catskill System reservoirs are highly influenced by extreme hydrological events that can cause turbidity events that persist in the reservoirs for several months. (The full set of these plots is provided in Appendix C.)

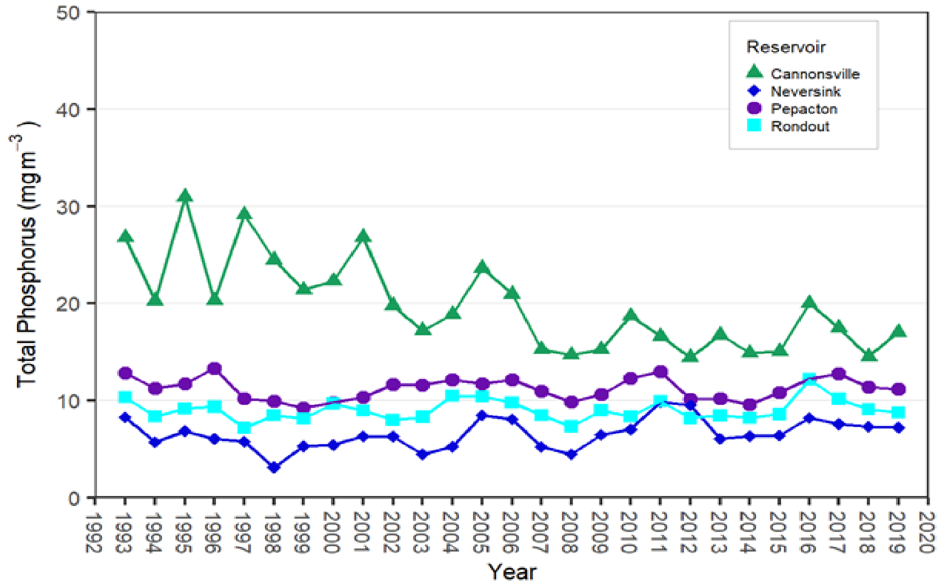


Figure 5.20 Annual geometric means for total phosphorous at Delaware System reservoirs (1993 – 2019).

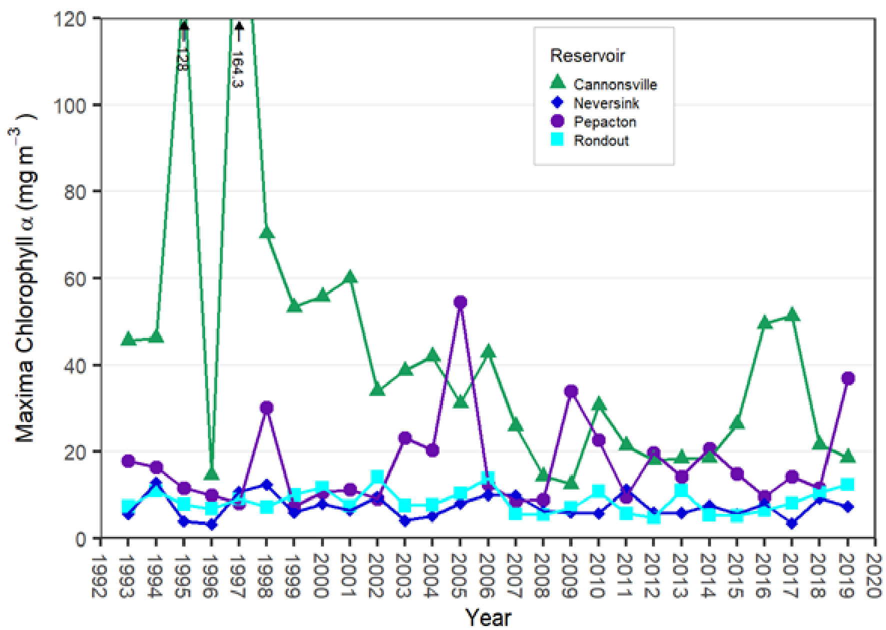


Figure 5.21 Annual maxima for chlorophyll *a* at Delaware System reservoirs (1993 – 2019).

5.7 Delaware System Protozoa: Sources and Attenuation

5.7.1 Upstream Sites and Reservoir Outflows

Giardia and *Cryptosporidium* have been monitored at tributaries upstream of the reservoirs in the Delaware System since 2002. Not all sites were sampled every year; however, the locations included two stream sites upstream of Pepacton Reservoir, two upstream of Cannonsville Reservoir, and one upstream of Neversink Reservoir. In addition, one stream and the three reservoir inflows were monitored as they entered Rondout Reservoir. The sites upstream of Pepacton Reservoir were PROXG and PMSB (East Branch Delaware River at Roxbury and East Branch Delaware River below the Margaretville WWTP); those upstream of Cannonsville Reservoir were CDG1 and CBS (West Branch Delaware River upstream of Delhi and West Branch Delaware River at Beerston, (formerly known as WDBN). The sampling at the PMSB site was discontinued in 2010 to provide sampling resources for a protozoan study in the Schoharie basin. One tributary site along the Neversink River (NCG) was studied above Neversink Reservoir from 2002 through 2008. The four inflows to Rondout Reservoir were the Pepacton, Cannonsville, and Neversink reservoir outflows, as they enter Rondout; and the main tributary to Rondout Reservoir, Rondout Creek, was also routinely monitored, at RDOA from 2002 to 2008.

Upstream samples were collected at the inflow of one of the three reservoirs that are located above Rondout Reservoir during the 2015-2019 period. That monitoring site, WDBN, is one of the main upstream inflows to Cannonsville Reservoir and had a 2015-2019 mean *Giardia* concentration of 41.77 cysts $50L^{-1}$. The mean outflow of Cannonsville Reservoir during the same five-year period was much lower at 4.38 cysts, suggesting the continuation of a reduction of cysts as water passes through the reservoir system. While sites upstream of Neversink and Pepacton reservoirs were not monitored for protozoa during this period, mean *Giardia* concentrations at the outflows remained low at 1.65 and 1.28 cysts, respectively (Figure 5.22 and Figure 5.23).

This is similar to the results observed in the Catskill System (Chapter 4). Since the concentrations at these three reservoir outflows (providing aqueduct inflow to Rondout) have already been reduced to low, single digit mean concentrations (<5 cysts), it is often difficult to detect a significant reduction at the outflow of Rondout. This, combined with an event of increased *Giardia* in Rondout, which began in 2018 (see Section 5.7.3), may explain why the 2015-2019 mean *Giardia* concentration at the outflow of Rondout (5.87 cysts) was higher than the inflow concentrations.

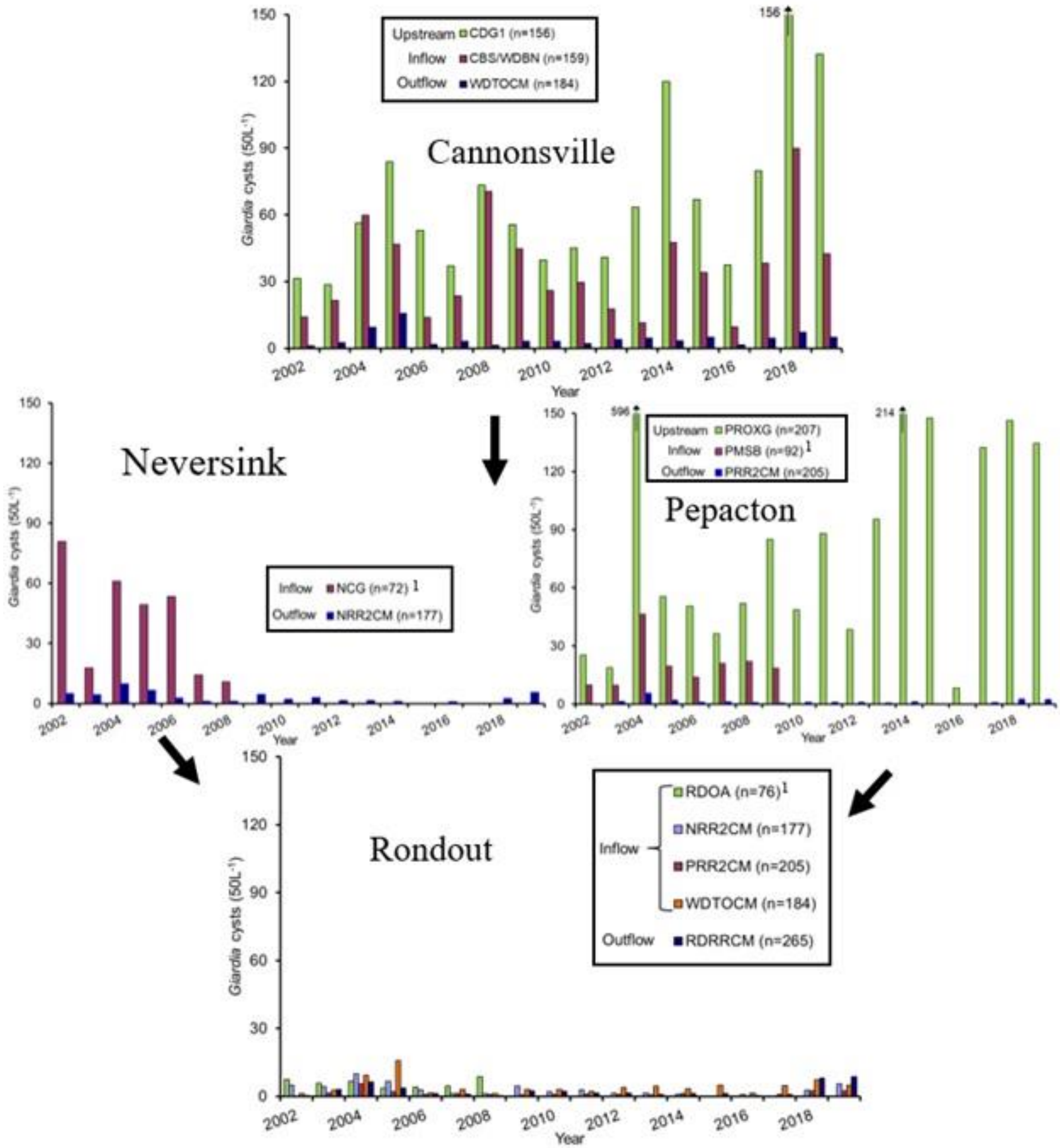


Figure 5.22 Annual mean concentrations of *Giardia* found at Delaware monitoring sites from June 2002–December 2019, using Methods 1623HV and 1623.1. Individual sample results were normalized to per 50L concentrations prior to averaging.

Over the entire 2002-2019 monitoring period the mean *Giardia* concentrations per 50 liters at the reservoir outflows upstream of Rondout Reservoir were 4.50 cysts at Cannonsville,

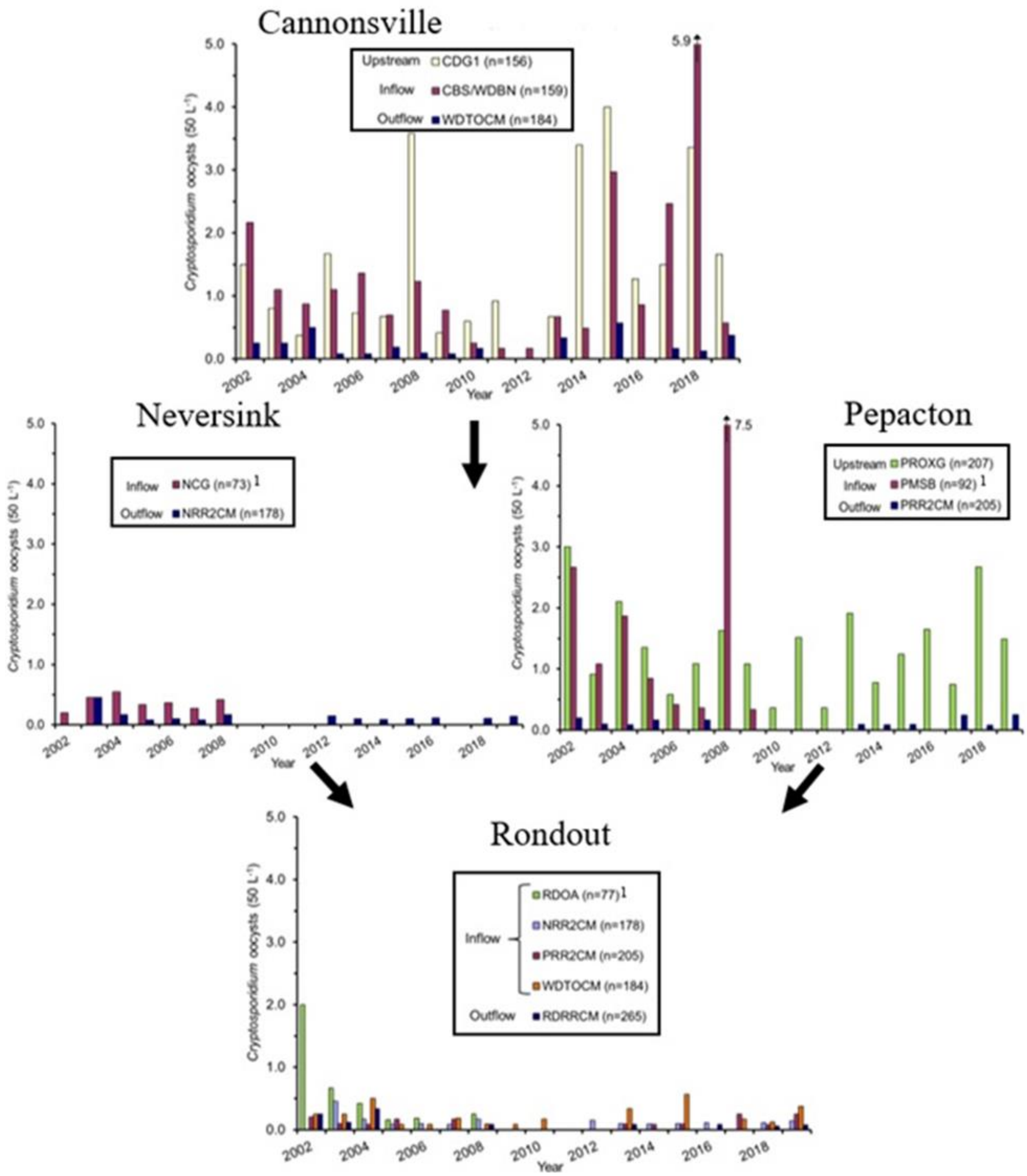


Figure 5.23 Annual mean concentrations of *Cryptosporidium* found at Delaware monitoring sites from June 2002–December 2019, using Methods 1623HV and 1623.1 (all samples.) Individual sample results were normalized to per 50L concentrations prior to averaging

2.97 at Neversink, and 1.37 at Pepacton; while the mean outflow of Rondout was 3.69. These values are lower than the range of *Giardia* concentrations seen at the direct inflows over the same period (21.0-37.3 cysts, not including sites further upstream).

For the 2002-2019 period, the upstream site in the Pepacton basin (PROXG) had the highest overall mean *Giardia* concentration (114.89 cysts $50L^{-1}$) (Table 5.5), followed by the Cannonsville stream site CDG1 (62.30 cysts $50L^{-1}$) and Neversink stream site NCG (37.34 cysts $50L^{-1}$). These are the same streams that had the highest concentrations of *Giardia* in the last summary and assessment report five years ago, and occurred in the same order of decreasing concentration.

Table 5.5 Mean concentrations for protozoans sampled at Delaware monitoring sites from 2002–2019, according to EPA Method 1623HV or 1623.1 (all samples).

	Last Sampled	*Cryptosporidium* (oocysts $50L^{-1}$)		*Giardia* (cyst $50L^{-1}$)	
		N	Mean	N	Mean
			Cannonsville		
Cannonsville upstream (CDG1)	2019	156	1.38	156	62.30
Cannonsville inflow (CBS/WDBN)	2019	159	1.16	159	36.22
Cannonsville outflow (WDTOCM)	2019	184	0.17	184	4.50
			Pepacton		
Pepacton upstream (PROXG)	2019	207	1.32	207	114.89
Pepacton inflow (PMSB)	2009	92	1.89	92	21.03
Pepacton outflow (PRR2CM)	2019	205	0.08	205	1.37
			Neversink		
Neversink inflow (NCG)	2008	73	0.38	72	37.34
Neversink outflow (NRR2CM)	2019	178	0.11	177	2.97
			Rondout		
Cannonsville outflow (WDTOCM)	2019	184	0.17	184	4.50
Pepacton outflow (PRR2CM)	2019	205	0.08	205	1.37
Neversink outflow (NRR2CM)	2019	178	0.11	177	2.97
Rondout Creek inflow (RDOA)	2008	77	0.38	76	5.60
Rondout outflow (RDRRCM)	2019	265	0.07	265	3.69

Although much lower concentrations were observed, the pattern for *Cryptosporidium* detection was similar: Annual mean concentrations were greater at the stream inflow sites compared to the reservoir outflows (Table 5.5). In the case of the three reservoir inflows, those concentrations were much lower and, as a result, were close to the <1 oocyst concentration at the Rondout outflow. While still very low, sites upstream of Pepacton Reservoir had the highest oocyst concentrations (mean <2 oocysts $50L^{-1}$), followed by Cannonsville and then Neversink. From 2002 through 2019, the outflow of Rondout Reservoir has been negative for *Cryptosporidium* in 10 of the 18 years. When positive, concentrations have been low (1-2 oocysts $50L\text{-}^{1}$). Detections occurred in all months, except for August. This suggests no significant seasonal trend, likely due to such low concentrations.

5.7.2 Delaware WWTPs

DEP sampled eight WWTPs for protozoa in the Delaware System from 2002 through 2019 in order to monitor long-term performance of treatment plant upgrades. Some sites were discontinued, while others were added as the upgrades have occurred. All routine samples were collected quarterly. In some cases, extra samples were collected as a follow-up to an unusual result. In other cases, samples were not collected due to various reasons (operational, etc.). Overall, 334 samples were collected.

Detection of *Giardia* at the effluents of WWTPs in the Delaware System from 2002-2019 was 10.5% (35 out of 334 samples). For the recent 2015-2019 period, the frequency of detection was much lower at 1.3% (1 out 80 samples). The annual percent detections for all Delaware plants combined are shown in Figure 5.24. The Grahamsville plant has two collection sites on record since collection was relocated from RGC to RGMF in 2009 due to the belief that wildlife were contaminating the water with *Giardia* prior to it reaching the effluent (Table 5.6). Since the switch to the new site, all 44 samples collected through 2019 have been negative for *Giardia*, and only one sample was positive for *Cryptosporidium* (1 oocyst $50.8L^{-1}$ in November 2016), suggesting that wildlife contamination post-treatment was likely occurring in the past.

The detection of *Cryptosporidium* positive samples at the Delaware plants was infrequent from 2002-2019 at 1.5% (5 out of 334), with a range of concentration from 1-2 oocysts $50L^{-1}$.

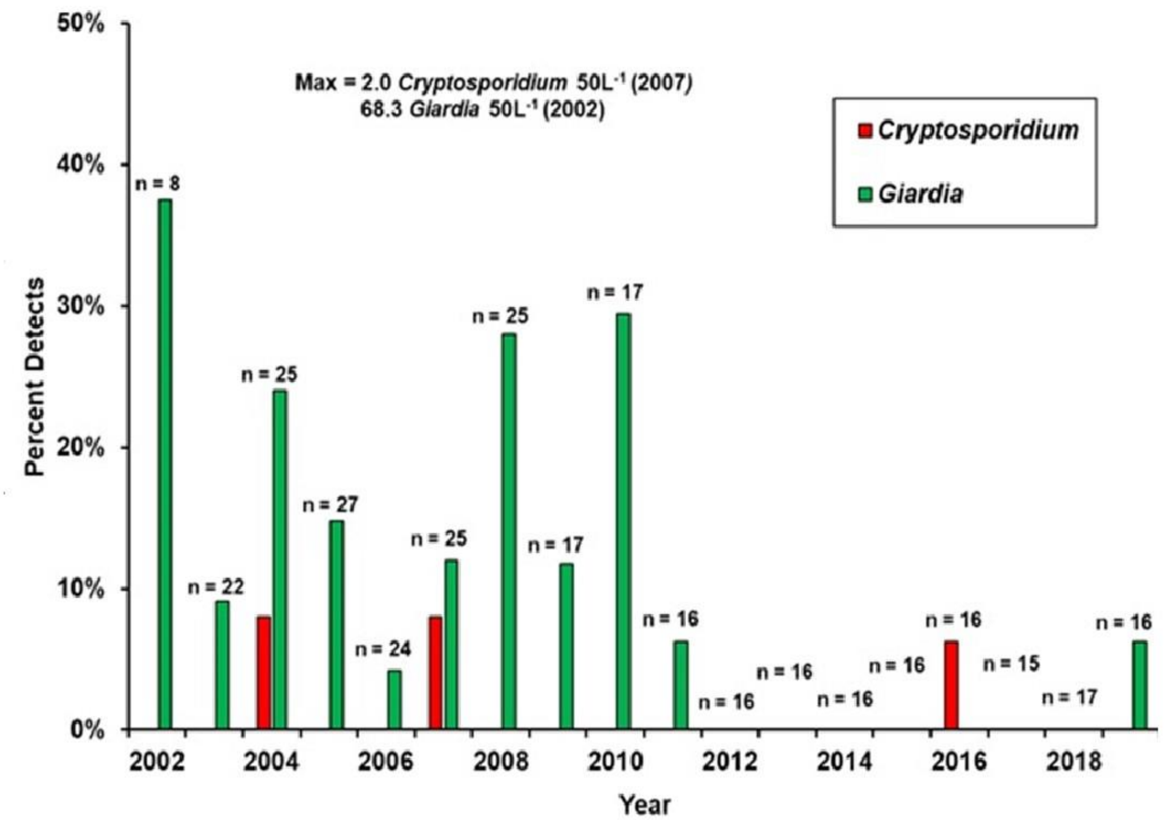


Figure 5.24 Protozoan detection frequency in effluents of upgraded Delaware System WWTPs, 2002–December 2019.

Table 5.6 Delaware WWTPs with protozoan detects from 2002 to December 2019. NS = not sampled.

Basin WWTP	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	% Detect	n	Max Conc. $(50L^{-1})$
										Giardia											
Pepacton																					
Andes (PANDE)	NS	NS	NS	NS	NS	NS	NS	0/5	0/4	1/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	2%	45	2.0
Fleischmanns (PFTP)	NS	NS	NS	NS	NS	NS	NS	2/4	1/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	1/4	9%	44	7.0
Cannonsville																					
Delhi (DTP)	1/1	0/4	0/4	0/4	0/4	0/4	0/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4%	25	17.0
Stamford (STP)	0/1	0/3	1/4	2/4	1/4	0/4	2/4	0/4	4/5	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	14%	69	4.0
Walton (WSP)	1/1	0/4	0/4	0/4	0/4	0/4	1/5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	8%	26	68.3
Rondout																					
*Grahamsville (RGC)	1/2	2/4	5/5	2/7	0/4	3/5	4/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	55%	31	39.0
(RGMF)	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/4	0/3	0/5	0/4	0%	44	0.0
										Cryptosporidium											
Pepacton																					
Margaretville (MSC)	0/2	0/3	1/4	0/4	0/4	0/4	0/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4%	25	2.0
Cannonsville																					
Hobart (HTP)	0/1	0/4	1/4	0/4	0/4	0/4	0/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	4%	25	1.0
Rondout																					
*Grahamsville (RGC)	0/2	0/4	0/5	0/7	0/4	2/5	0/4	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	6%	31	2.0
(RGMF)	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	0/4	1/4	0/3	0/5	0/4	2%	44	1.0

*RGC site was changed to RGMF in February 2009 due to suspected wildlife contamination post-filtration.

5.7.3 Rondout Reservoir *Giardia* Special Investigation

In mid-November 2018, elevated levels of *Giardia* were detected in weekly (50L) samples collected at the Delaware inflow to Kensico Reservoir (DEL17). Review of the monthly samples collected upstream at the outflow of Rondout Reservoir (RDRRCM) indicated a normal result for October but an elevated result for November. An additional sample collected at RDRRCM in late November confirmed the increase in cysts in Rondout Reservoir with a concentration of 18 *Giardia*. Similar results were seen three days later in the weekly DEL17 sample, supporting the already obvious connection between RDRRCM and DEL17. At the time, West Branch Reservoir was operating in float mode and only contributing flow to DEL17 as needed. Subsequent testing at CWB1.5 on December 2 resulted in only 1 *Giardia* cyst, suggesting West Branch was not a source of elevated *Giardia*.

The strongest initial hypothesis regarding source was that *Giardia* cysts in the Rondout watershed were mobilized by rain and rain on snow events that occurred in November after several months of extremely wet antecedent conditions (Figure 5.25). Precipitation in the preceding months hit record levels. Moreover, *Giardia* cysts can persist for several months in cold water, prolonging the event. *Giardia* results remained elevated (compared to historical data) at the aforementioned sites through August 2019 and increased again in November 2019.

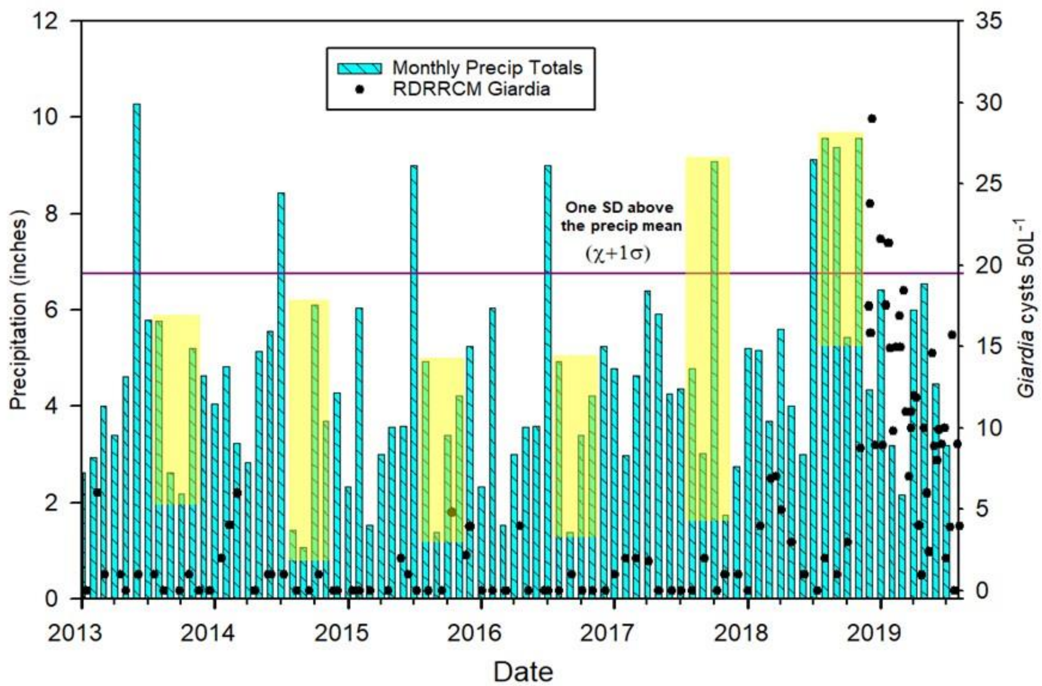


Figure 5.25 Rondout *Giardia* and precipitation in the Rondout watershed 2013-2019.

Based on the information available, the elevated *Giardia* leaving Rondout Reservoir appeared to be from more than one source and were likely transported into the reservoir as a result of the record rainfall and runoff occurring just prior to the increase in November 2018 (Alderisio and Pace, 2019; Bartlett and Alderisio, 2020). This included rain on snow. An unusually wet year occurred in 2018 and there was record rainfall in the few months directly preceding this event (July, August, September and November). *Giardia* persisted in the reservoir at this time of year due to continued precipitation throughout the event and the extended preservation of cysts in cold, moist conditions which surpassed travel time through the reservoir.

Preliminary loading estimates from the local beaver scat do not solely account for the concentrations seen in the reservoir. In fact, the Pepacton diversion and streams contribute equal or greater *Giardia* loading to the reservoir compared to the local beavers. At least three different genotypes/subtypes of *Giardia duodenalis* were identified at the outflow of Rondout, the inflow of Kensico, and an unnamed tributary. One of these three types was identical to the only type found in the Rondout beavers (assemblage B subtype 2), and the other two types were not isolated from beavers. These molecular data suggest that the local beavers were not the only potential source of *Giardia* in Rondout Reservoir. While it is possible for these other types to exist in beavers, they were not found in any beavers in this study and could be from other animals not as well represented as the beavers in the scat data set. In addition, the assemblage A subtype 2 identified has been isolated from human sources more often than animals. More positive DNA samples from the watershed would need to be studied to better understand the sources of cysts found in the water.

Since *G. duodenalis* assemblages A and B are both zoonotic, and therefore cross-infective, it is difficult to distinguish between sources without direct genetic matches between a source and the contamination. Further study of local wildlife scat and an investigation of any suspect human sources would be needed to increase the chances of finding such a match on a molecular level.

Kensico and Hillview reservoir outflow *Giardia* remained within seasonal norms throughout this event and were below levels described in the *Cryptosporidium* and *Giardia* Action Plan that would have required additional action.

5.8 Water Quality Summary for the Delaware System

Exceptional improvements in watershed protection have been implemented throughout the Delaware System. Seventeen WWTPs have been constructed or upgraded since 1996, resulting in dramatic reductions to the phosphorus load. Three of these 17 plants are located in the Pepacton watershed and came online after 2004. The septic remediation program continues to be very active. Since 2004, about 455 systems have been repaired for a grand total of nearly 1,900 since 1997. In addition, nearly 2,500 agricultural BMPs have been implemented since 1996 with over 80% occurring in the Cannonsville watershed.

Overall, the water quality status of all four Delaware System basins for the 2017-2019 assessment period continues to be very good, which is a reflection in part of the ongoing investment in watershed protection. Monthly median fecal coliform counts were generally low for all reservoirs and their outflows. Monthly median turbidity was low throughout the system, with a median of 0.8 NTU and corresponding median phosphorus value of 8.5 µg L^{-1} for the outflow from Rondout Reservoir (RDRRCM), the terminal reservoir in the Delaware System.

Long-term trend analysis for the Delaware System continues to show a decline in total phosphorus (TP) and trophic state index (TSI) for all basins with the exception of Neversink. These long-term decreases are largely due to upgrades and construction of WWTPs and to the cumulative effects of various watershed protection programs. A short-term recent TP increase was observed for all basins. Possible contributing factors include suspected changes in the flow-TP relationship caused by damage to the watersheds from extreme storms in 2011 and 2012, phosphorus contamination from sample bottles during2014-2017 and, in the case of the Cannonsville outflow, a change in sample site location. The site relocation also contributed to an upward trend for fecal coliform and turbidity. A recent increase in TSI was observed in all reservoirs and is possibly related to warmer surface water temperatures and increases in residence times at Pepacton and Neversink reservoirs. Long-term conductivity increases were ubiquitous throughout the system and likely the result of road deicer usage.

During the 2017-2018 period, biomonitoring results were obtained from three sites on the primary stream input to Cannonsville Reservoir (West Branch Delaware River), two sites on the primary input to Pepacton Reservoir (East Branch Delaware River), and one site on the primary input to Rondout Reservoir (Rondout Creek). Due to the budgetary constraints associated with COVID-19, data from 2019's sampling is not available at this time. The 2018 results for the Cannonsville basin show Site 301 as slightly impaired, Site 304 at the high end of slightly impaired, and Site 320 as non-impaired. The 2018 results for the Pepacton basin show Site 316 at the high end of slightly impaired, and Site 321 as non-impaired. The Rondout basin showed a 2018 result of non-impaired. The time series showed no long-term changes at any of the sites with an extended period of record.

Cryptosporidium and *Giardia* pathogen monitoring was occasionally conducted on the major inflows to all four reservoirs of the Delaware System over the 2002-2019 period. As with the Catskill System, Delaware reservoir outflow protozoan concentrations for the 2015-2019 period were less than the monitored inflow streams, suggesting reservoir processes such as die-off, sedimentation, and predation continued to be effective barriers throughout the entire 2002-2019 period. There was an increase in the annual mean *Giardia* concentrations at the outflow of Rondout Reservoir during this five-year period (2015-2019), largely due to the unusual increase in *Giardia* cysts occurring at the Rondout outflow beginning in autumn 2018.

The four reservoirs of the Delaware system are well aligned with the OECD standards showing a decrease in biomass in line with a decrease in phosphorus levels. In decreasing order, Cannonsville, Pepacton, and Neversink each cluster around a characteristic biomass level set by their nutrient contents. As a blend of the other three reservoirs, Rondout is in an intermediate position. This indicates phosphorus is controlling the level of algal standing crop and eutrophication continues to be controlled through phosphorus concentrations at their reduced levels. Indeed, the Cannonsville biomass has decreased remarkably from previous assessment periods. Variation is greater in the maximum chlorophyll than annual mean chlorophyll. The maximum values may not always be captured due to low frequency of sampling, and maxima may not always be attained if other factors depress the standing crop. The least variation occurs in Rondout. This may be related to the short, nearly constant water residence time of about 1.5 months. In the most recent five years, Neversink shows a slight shift toward increased phosphorus, yet still at very low levels consistent with oligotrophy. Cannonsville, at the upper end, has shifted toward lower levels of phosphorus and increased transparency. Since all the relationships tend to lie below the OECD line, it can be concluded that factors in addition to chlorophyll limit light in all the Delaware System reservoirs. Time series of the changes in central tendencies over the past 25 years show that there have been vast improvements in reducing the trophic condition of Cannonsville Reservoir where greatest phosphorus load reduction has been achieved.

6. East of Hudson Catskill/Delaware Basins

6.1 Introduction

6.1.1 The Scope of Water Quality Analysis

This chapter covers the water quality history of Kensico, West Branch, and Boyd Corners reservoirs. The outline of the scope of water quality analyses is presented at the beginning of the chapter on the Catskill System. To avoid repetition, the reader should refer to the description there for the approach we have taken. In brief, water quality analyses cover a longer time period than the five-year period of this assessment. Approximately 27 years of data are used to provide a long-term context for interpretation. This provides a view of these changes in the context of natural variations (such as floods and droughts) which are not sufficiently represented in a five-year period. As noted previously, the early part of the record (1993 through 2000) represents the beginning of program implementation, 2000 through 2010 represents a period when DEP had achieved a high degree of watershed protection implementation, and 2010 through 2019 (i.e., the current assessment period) is a period when we begin to see reservoirs achieve a steady state with the new environmental conditions of decreased nutrient loads.

Trends are examined in three ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests (SKT) for trend significance and trend slope, and third by estimating trend direction using the Trend Direction Assessment (TDA) technique. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. The SKT method addresses statistical significance of monotonic (unidirectional) change though the period of record. The TDA method calculates probabilities to determine trend direction and uses probability intervals to estimate the likelihood of correctly identifying the trend direction. See Appendix C for a more detailed description of the data processing steps and statistical methods used.

Phosphorus contamination noted for the Delaware and Catskill systems' samples was found to be minimal in samples collected in EOH FAD basins.

6.2 The West Branch and Boyd Corners Basins

West Branch Reservoir is located in Putnam County approximately 35 miles from New York City. It was formed by the damming of the West Branch of the Croton River, which continues south to Croton Falls Reservoir and consists of two basins, separated by Route 301. The reservoir holds 8 billion gallons at full capacity and was placed into service in 1895, initially as part of the City's Croton water supply system.

West Branch functions primarily as part of the Delaware water supply system, serving as a supplementary settling basin for the water from Rondout Reservoir, which enters West Branch via the Delaware Aqueduct. West Branch Reservoir also receives water from its own small watershed and Boyd Corners Reservoir. Boyd Corners Reservoir is 1.5 miles in length and holds 1.7 billion gallons at full capacity. First placed into service in 1873, the dam, spillway, and outlet works were rebuilt in 1990 as part of the City's complete overhaul and modernization of the 19 reservoirs in its water supply system. Water from West Branch flows via the Delaware Aqueduct into the Kensico Reservoir.

Land use in the West Branch watershed is as follows: 67.2% is forested, 19.3% is urban, 1.2% is brushland or successional forest, 11.3% is water, and 0.8% is in agricultural use. The Boyd Corners watershed drainage basin is 22 square miles. Land use breakdown in the Boyd Corners watershed is as follows: 79.2 % is forested, 12.5% is urban, 1.6% is brushland or successional forest, 6% is water, and 0.7% is in agricultural use.

There are no wastewater treatment plants in the Boyd Corners basin and only one WWTP (a seasonal camp) in the West Branch basin with a permitted maximum flow of 0.0203 MGD. Inputs of phosphorus, as well as other pollutants, from the WWTP to West Branch decreased following a plant upgrade in 2005. A further protection measure through a septic repair reimbursement program is available to priority parcels in the Boyd Corners and West Branch basins to promote continued water quality improvement.

6.2.1 Water Quality Status and Trends in the West Branch and Boyd Corners Watersheds

Status (West Branch)

The West Branch Basin status evaluation is presented as a series of boxplots in Figure 6.1. The inflows include water diverted from Rondout Reservoir (DEL9), Boyd Corners release (BOYDR), and Horse Pound Brook (HORSEPD12). The reservoir is designated as CWB and the outflow is designated as WESTBRR. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the status evaluation period (2017-2019), fecal coliform bacteria remained below the NYSDEC stream guidance value of 200 fecal coliforms 100 mL^{-1} for all inflows with the exception of Horse Pound Brook (HORSEPD12), with a monthly median of 25 fecal coliforms 100 mL^{-1} and five values that exceeded the guidance value. Three of the highest outliers occurred in summer 2018 during a wet period with convective storms (2,800 coliforms 100 mL^{-1} in July, 200 coliforms 100 mL^{-1} in August, and 500 coliforms 100 mL^{-1} in September). Reservoir fecal coliform levels were comparatively low, with only one outlier of 21 fecal coliforms 100 mL^{-1} in October 2018. Turbidity in the West Branch basin is typically low, as was the case for the 2017-2019 assessment period with a reservoir (CWB) monthly median turbidity of 1.9 NTU. Monthly median reservoir total phosphorus (TP) values were below the target value of 15 µg L^{-1} with one exception in October 2017, when median TP was 16 µg L^{-1}. The Trophic State Index (TSI) values ranged from oligotrophic to eutrophic, with a median of 45 in the mesotrophic range. Conductivity medians were higher from local inflows (BOYDR median 234 µS cm^{-1} and

HORSEPD12 median 280 µS cm^{-1}). Low-ionic strength water from Rondout Reservoir (DEL9) had a monthly median of 65 µS cm^{-1} and the West Branch Reservoir (CWB) monthly median conductivity was 178 µS cm^{-1} for the evaluation period.

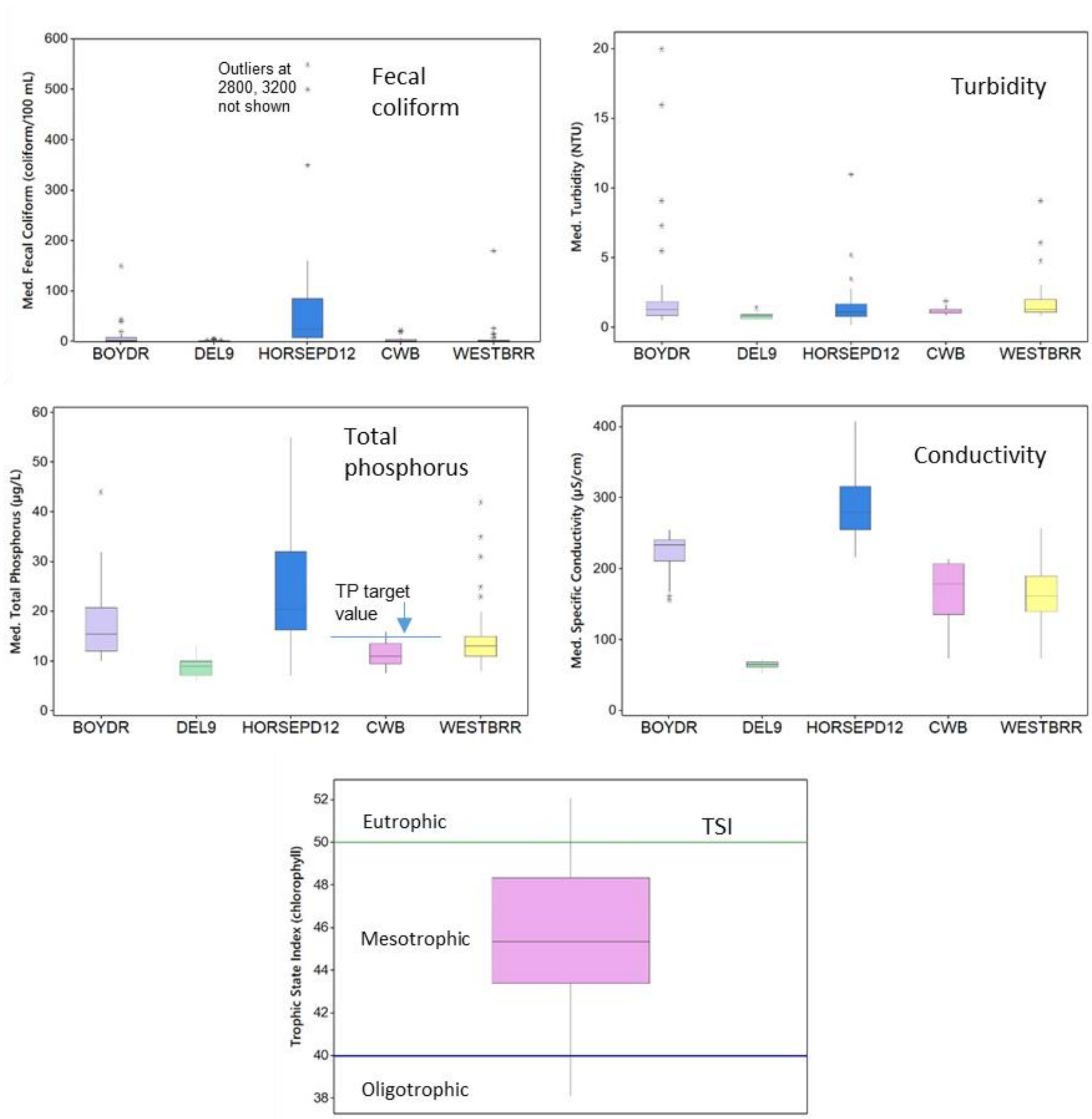


Figure 6.1 Water quality status boxplots using 2017-2019 monthly data for the West Branch basin for the inflows from Rondout Reservoir (DEL9), the main stream inflows at Boyd Corners Reservoir release (BOYDR) and Horse Pound Brook (HORSEPD12), West Branch Reservoir(CWB), and West Branch Reservoir Release (WESTBRR).

Trends (West Branch)

Water quality trend plots for the West Branch basin are presented in Figure 6.2 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 6.1.

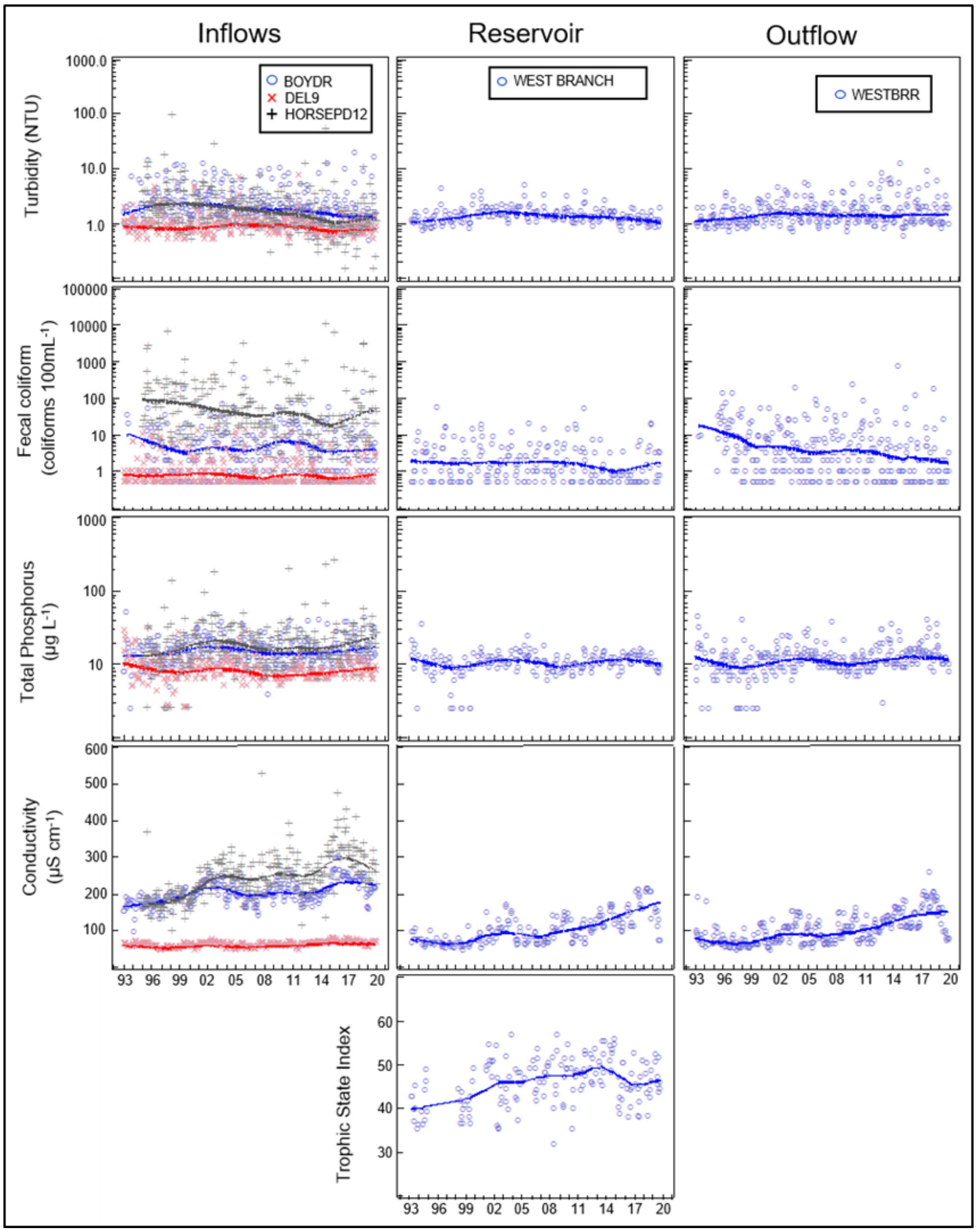


Figure 6.2 Water quality trend plots for the West Branch basin for the inflow from Rondout Reservoir (DEL9), the main stream inflows at Boyd Corners Reservoir release (BOYDR), and Horse Pound Brook (HORSEPD12); West Branch Reservoir (CWB); and the outflow at the West Branch release (WESTBRR).

Table 6.1 West Branch inflow, reservoir, and outflow trends from 1993 to 2019.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
BOYDR	Inflow	Turbidity	318	***	-0.033	-1.755	Decreasing trend virtually certain
DEL9	Inflow	Turbidity	323	***	-0.005	-0.535	Decreasing trend virtually certain
HORSEPD12	Inflow	Turbidity	298	***	-0.053	-3.299	Decreasing trend virtually certain
HORSEPD12	Inflow	Turbidity (Flow Adj.)	278	***	-0.067	-4.182	Decreasing trend virtually certain
West Branch	Reservoir	Turbidity	214	NS	-0.002	-0.165	Decreasing trend about as likely as not
WESTBRR	Outflow	Turbidity	317	***	0.009	0.652	Increasing trend virtually certain
BOYDR	Inflow	Fecal coliform	295	NS	0	0	Trend extremely unlikely
DEL9	Inflow	Fecal coliform	323	***	0	0	Decreasing trend virtually certain
HORSEPD12	Inflow	Fecal Coliform	297	***	-0.82	-3.28	Decreasing trend virtually certain
HORSEPD12	Inflow	Fecal Coliform (Flow Adj.)	277	*	-2.912	-11.65	Decreasing trend possible
West Branch	Reservoir	Fecal coliform	214	***	0	0	Decreasing trend virtually certain
WESTBRR	Outflow	Fecal coliform	292	***	-0.115	-5.106	Decreasing trend virtually certain

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
BOYDR	Inflow	Total Phosphorus	312	**	0.059	0.393	Increasing trend likely
DEL9	Inflow	Total Phosphorus	310	***	0	0	Decreasing trend very likely
HORSEPD12	Inflow	Total Phosphorus	294	***	0.143	0.84	Increasing trend virtually certain
HORSEPD12	Inflow	Total Phosphorus (Flow Adj.)	274	NS	0.084	0.494	Increasing trend about as likely as not
West Branch	Reservoir	Total Phosphorus	206	***	0.05	0.477	Increasing trend very likely
WESTBRR	Outflow	Total Phosphorus	311	***	0.124	1.132	Increasing trend virtually certain
BOYDR	Inflow	Conductivity	314	***	1.919	0.96	Increasing trend virtually certain
DEL9	Inflow	Conductivity	323	***	0.429	0.726	Increasing trend virtually certain
HORSEPD12	Inflow	Conductivity	295	***	5.068	2.111	Increasing trend virtually certain
HORSEPD12	Inflow	Conductivity (Flow Adj.)	275	***	4.872	2.03	Increasing trend virtually certain
West Branch	Reservoir	Conductivity	207	***	3.276	3.412	Increasing trend virtually certain

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
WESTBRR	Outflow	Conductivity	312	***	3.005	3.14	Increasing trend virtually certain
West Branch	Reservoir	Trophic State Index	172	***	0.187	0.407	Increasing trend virtually certain

[1]The *p*-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

The water in West Branch Reservoir is derived mainly from the Delaware System's Rondout Reservoir via the Delaware Aqueduct (DEL9) and from its primary local inflows, Boyd Corners Reservoir release (BOYDR) and Horse Pound Brook (HORSEPD12). The relative contributions from these sources are dependent on the operational status of the Delaware Aqueduct. Operational changes may be initiated to satisfy volume requirements in the City, to work on the aqueduct, or to address a water quality issue occurring in the reservoir. As discussed below these operational changes cause fluctuations in water quality, which can influence trend calculations and complicate interpretation.

From 1993 to 1998, West Branch was operated in "reservoir" mode at least 66% of the time. In "reservoir" mode, water from the Delaware Aqueduct is diverted directly into the reservoir and exits through the aqueduct (at DEL10). In this scenario, residence time is extremely short (11 to 18 days) and Rondout water accounts for 90% of the inflows into West Branch. During 1999 and 2000, the reservoir was operated in "reservoir" mode about 50% of the time and in "float" mode the other 50% of the time, and in 2001 and 2002 it was operated almost exclusively in "float" mode (95%). In "float" mode, DEL9 at the upstream end of the reservoir remains closed while DEL10 is kept open allowing water from West Branch to enter the Delaware Aqueduct at a very low rate. Usually, more time spent in "float" mode means a longer residence time, resulting in a higher proportion of water from local streams. During 2003, time in "reservoir" mode was increased to about 44%, time in "float" mode reduced to 40%, and time in "by-pass" mode increased to 16%. In "bypass" mode, West Branch is totally from the Delaware Aqueduct (no inflow, no outflows) and again local streams become the exclusive source of water to the reservoir. Local stream inflows continued to be influential from 2004-2009, with West Branch in "float" or ""bypass" mode 71% of the time. This percentage dropped to 57% in 2010-11 but increased to greater than 95% from 2012-2018 before dropping to 66% in 2019.

During the first five years of the data record, West Branch was essentially operated as an extension of the Delaware Aqueduct - thus minimizing the influence of inflows from local sources. During most of the last 22 years, West Branch was operated in such a way that often increased the relative contributions of local (i.e., Croton stream) inflows. The effect on water quality is illustrated by the long-term trend in reservoir conductivity. From 1999 to 2002, conductivity increased as the time in "float" and "bypass" mode increased. Although days in "float" and "bypass" decreased in 2003, two prior years of drought had caused conductivity of the Croton inflows to increase dramatically, which caused reservoir and outflow conductivity to peak in 2003. An upward trend occurred because more conductive local waters comprised a greater percentage of the reservoir volume. Very wet weather caused conductivity to decrease in the Croton inflows and in the reservoir from 2004 to 2007. In 2008 and 2009, conductivity in the Croton inflows and in the reservoir (and outflow) rose to levels equivalent to years affected by drought (2001-2003). This increase coincided with an increase in chlorides that has been observed throughout the Croton watersheds (Van Dreason 2011), but also to more time in "float" mode. The primary sources of the chlorides are road deicers (Heisig 2000). Conductivity decreased in 2010-11 due to more time in "reservoir" mode but increased from 2012-2018 as time in "float" mode increased above 95%.

Only weak evidence of a downward turbidity trend was indicated by TDA analysis for the reservoir. However, downward trends were identified as virtually certain for all outflows, while an upward trend of low magnitude was identified for the reservoir outflow. Stormwater remediation projects have been completed in both the West Branch and Boyd Corners watersheds and may have contributed to the turbidity downtrends observed in the local inflows.

Downward fecal coliform trends were evident for all sites except for the Boyd Corners inflow. Less frequent large rain events and low rainfall totals in most years since 2011, as well as the aforementioned local stormwater remediation projects, are likely factors contributing to the long-term downturn. The recent short-term increase is associated with above average annual flows from July 2018 through June 2019. The fecal counts observed in the outflow are generally higher than in the reservoir because the highest counts occur during winter months when the reservoir is not sampled. The downward trend at Horse Pound is noteworthy since this inflow typically contributes much higher fecal counts than inflows from Rondout Reservoir or Boyd Corners.

A downward TP trend was identified at the Rondout Reservoir inflow while increasing trends were considered likely to virtually certain at most local Croton inflows, as well as at West Branch Reservoir and its outflow. The downward trend is likely due to ongoing efforts to manage TP throughout the Delaware System. Despite this decrease, upward trends were still observed in the reservoir and its outflow likely due to the greater influence of local Croton water, especially from 2012-2019 when the reservoir was predominantly in "float" mode.

The increasing trend in TSI values can be ascribed to rising reservoir surface water temperatures and to the TP contribution from local sources during the latter part of the data record. In part, these changes are related to operational changes, which control the blend of waters that comprise West Branch Reservoir

In summary, conductivity increases were apparent in all inflows, in the reservoir, and in the outflow. Decreasing turbidity trends were identified in the Boyd Corners and Horse Pound inflows coincident with the completion of stormwater remediation projects, while a small increasing trend was apparent in outflow. Fecal coliform exhibited a downward trend at all inflows, at the reservoir and its outflow. A decreasing total phosphorus trend was identified at the Rondout Reservoir inflow, which is likely associated with ongoing watershed programs. However, upward TP trends were identified in the other inflows, the reservoir and outflow. The TP increases and reservoir temperature increase likely contributed to the upward trend identified for TSI. Local stream trends may be related to efforts to better manage stormwater runoff.

6.2.2 Biomonitoring in the West Branch and Boyd Corners Watersheds

The New York City stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in City watershed streams. For methodology details, see Appendix C.

The most recent status of macroinvertebrate communities in the West Branch basin was evaluated by examining 2017-2018 data for a single site (146) on Horse Pound Brook. Due to budgetary constraints associated with COVID-19, data from 2019's sampling is not available at this time. This stream is the primary inflow to West Branch Reservoir, draining 20% of the basin. The site is routine and is sampled annually, as opposed to non-routine sites that are sampled on a rotating basis.

Site 146 (HORSEPD12) is located in Carmel, approximately two miles upstream of West Branch Reservoir. From 2017 to 2018, it was assessed as being slightly impaired (Figure 6.3).

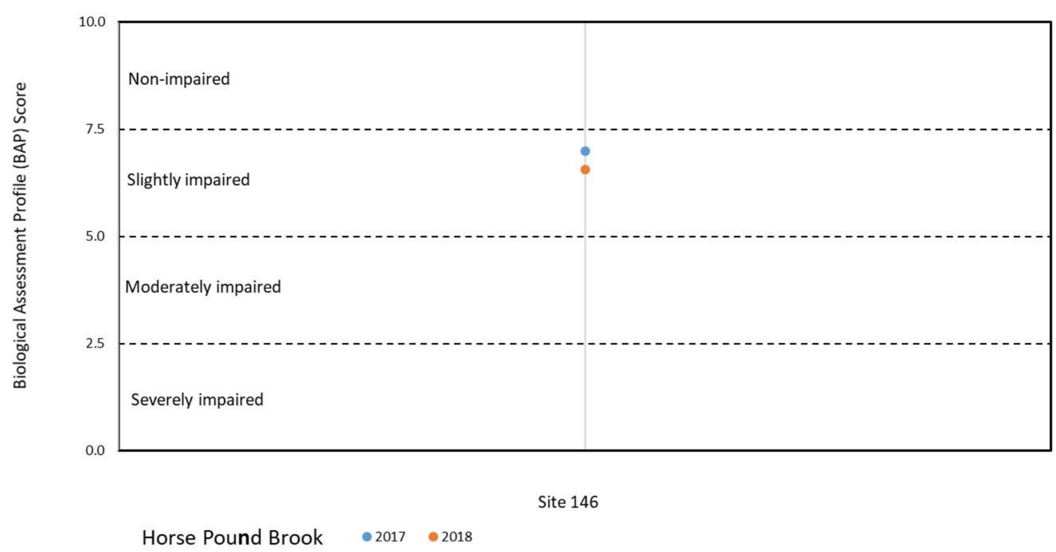


Figure 6.3 Biological Assessment Profile scores for Horse Pound Brook, 2017-2018.

The time series trend in Biological Assessment Profile (BAP) scores was based on the site's entire period of record (2004-2018), and examined changes in both the scores and assessment categories (Figure 6.4). There was an increase in non-impaired in 2006 but the underlying reason for the recent declines remains unclear. There has been no significant development in the stream's watershed and no issues with wastewater treatment plant discharges have been identified. The percent hydropsychids caddisflies was 42% in 2014, the site's lowest BAP score, but then rose to 56.3% in 2016 and dropped to 50% in 2018, so the presence of hydropsychids is not thought to be an issue. Additionally, no changes in water chemistry have been noted.

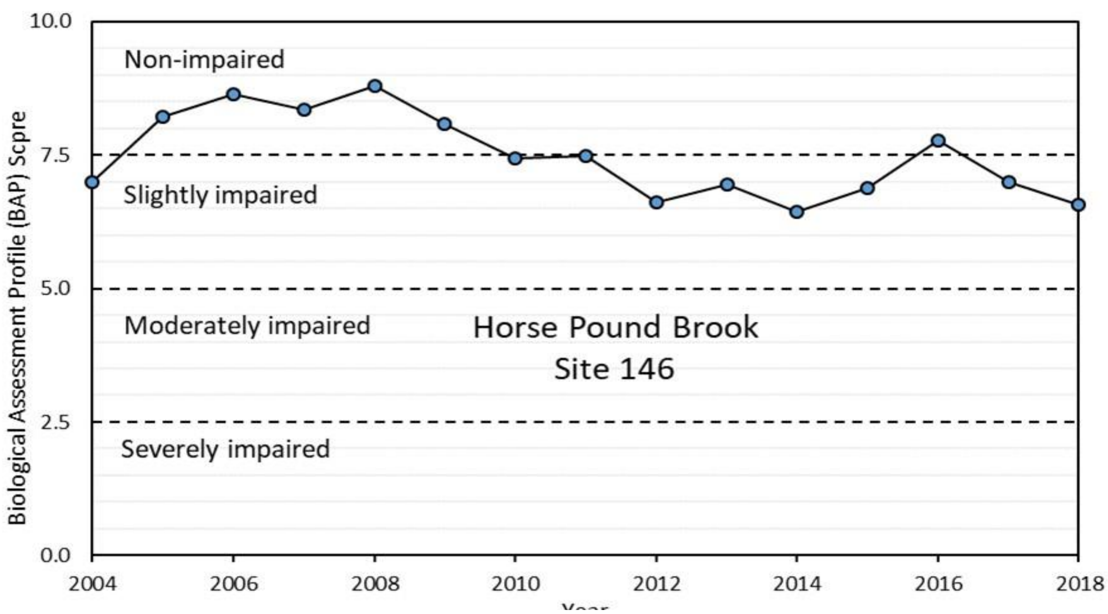


Figure 6.4 Biological Assessment Profile scores for Horse Pound Brook, 2004-2018.

6.3 The Kensico Basin

Kensico Reservoir is located in Westchester County, about 15 miles north of New York City limits. Although formed by the damming of the Bronx River, it receives most of its water from reservoirs west of the Hudson through the Catskill and Delaware aqueducts. Kensico consists of a western main basin that receives Catskill Aqueduct water and an eastern Rye Lake portion that receives Delaware Aqueduct water. These mix in the main basin before entering the Delaware Aqueduct at Shaft 18. The Catskill Aqueduct, south (or downstream) of Kensico Reservoir, is currently off-line until work is completed to pressurize the flow to the Catskill/Delaware Ultraviolet Light Disinfection Facility (CDUV). Kensico Reservoir holds 30.6 billion gallons at full capacity and was placed into service in 1915. As the final reservoir in the Catskill/Delaware system before water enters the distribution network, Kensico Reservoir is subject to federal water quality standards for coliforms and turbidity under the SWTR.

The Kensico watershed's drainage basin is 13 square miles. The land use breakdown for the Kensico watershed is as follows: 42.7% is forested, 28.2% is urban, 2.4% is brushland or successional forest, 26.0% is water, and 0.5% is in agricultural use.

DEP watershed protection programs have been effective in preserving the high quality of the water in Kensico Reservoir. More than 97% of the water in the reservoir is delivered via the Catskill or Delaware aqueduct. Kensico was one of the earliest focal points of DEP's watershed protection activities and is certainly the most intensely studied basin in the system. Those study efforts have led to implementation of targeted controls to address localized threats to water quality.

A cumulative total of 45 stormwater and erosion abatement facilities have been installed in the Kensico basin since 1997, significantly reducing the turbidity and fecal coliforms entering the reservoir. To further reduce turbidity entering Kensico from two streams near the Catskill Effluent Chamber, DEP installed a back-up turbidity curtain completed in 2009. This curtain is routinely monitored and is of importance when the Catskill Aqueduct intake is in operation. A septic repair reimbursement program is available to all parcels in the Kensico basin to promote continued water quality improvements.

6.3.1 Water Quality Status and Trends in the Kensico Basin

Status (Kensico)

The Kensico Basin status evaluation is presented as a series of boxplots in Figure 6.5. The inflows include Rondout Reservoir via West Branch Reservoir (DEL17, i.e., the Delaware Aqueduct), and the diversion from Ashokan Reservoir (CATALUM, i.e., the Catskill Aqueduct). The reservoir is designated as BRK and the outflow is designated as DEL18DT. A site map, description of the sampling program, and details on data preparation and boxplot interpretation are provided in Appendix C.

For the evaluation period (2017-2019), reservoir fecal coliform levels were below the SWTR limit of 5 fecal coliforms 100 mL^{-1}. Turbidity in the Kensico basin is typically low, as was the case for the assessment period. Monthly median reservoir total phosphorus (TP) values were well below the target value of 15 µg L^{-1} with a median of 8 µg L^{-1}. The Trophic State Index (TSI) values for Kensico Reservoir fell primarily in the mesotrophic range, with some values in the oligotrophic range. Conductivity was relatively low in the reservoir (BRK) with a median of 78 µS cm-1, reflecting the character of Catskill/Delaware inflows.

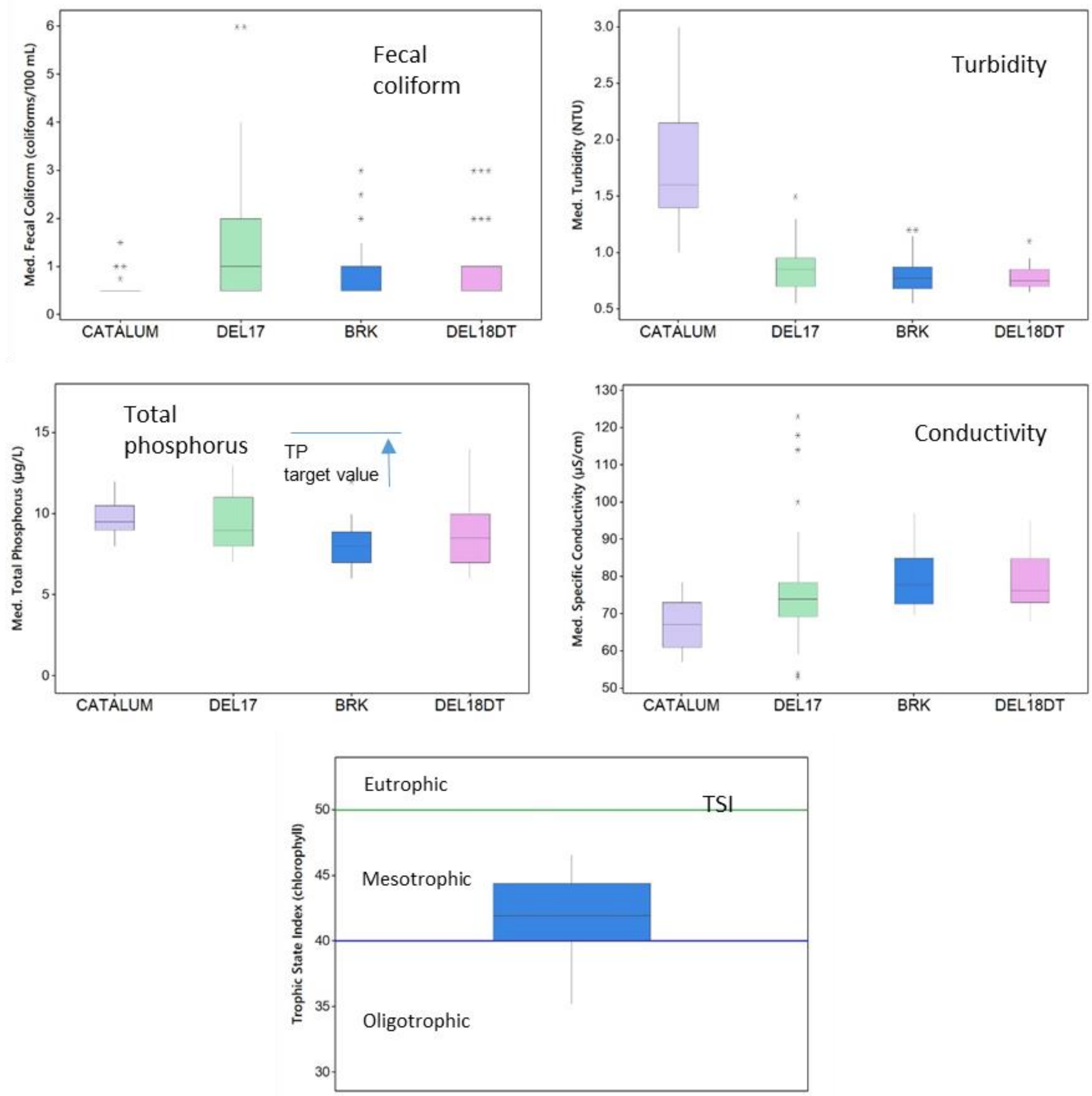


Figure 6.5 Water quality status boxplots using 2017-2019 monthly data for the Kensico basin inflows from the Catskill Aqueduct (CATALUM) and the Delaware Aqueduct (DEL17), Kensico Reservoir (BRK), and the outflow at the Kensico Reservoir gatehouse (DEL18DT).

Trends (Kensico)

Water quality trend plots for the Kensico basin are presented in Figure 6.6 and results of the Seasonal Kendall trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 6.2. As previously noted, CDUV was brought on-line in September 2012; as a result, all water leaving Kensico since 2012 is through the Delaware outflow and is sampled at DEL18DT.

In contrast to results reported in the last FAD evaluation (DEP 2016), there was strong evidence for long-term turbidity downward trends in the Delaware Aqueduct inflow (DEL17), in the reservoir, and in the Delaware outflow (DEL18DT). A possible decrease was also identified in the Catskill Aqueduct inflow (CATALUM). These downward trends are explained by the relative absence of runoff events since tropical storms Irene and Lee occurred in summer 2011. Note that during times of excessive turbidity alum is applied just downstream of the Catskill inflow sampling site. As a result, the turbidity levels actually entering Kensico Reservoir are much lower, generally being reduced to <1 NTU before traveling very far in the reservoir. It is for this reason that the periodic turbidity peaks shown for the Catskill inflow are absent from the reservoir.

Although the slope estimator test produced a long-term change of zero for fecal coliforms at all sites in the Kensico basin, the TDA analysis indicated a downward trend direction was virtually certain at these sites. The Sen's Slope estimate is not accurate when the data being analyzed have many tied values (e.g. fecal coliforms). See Appendix C for a more detailed description of slope values of zero. Additional evidence of the decline and its magnitude is indicated by examination of the LOWESS curves at these sites. The downward trend in the reservoir is also attributed to the waterfowl management program in place at Kensico since 1993 (see Section 3.8). Prior to that year, samples often exceeded 20 fecal coliforms 100 mL^{-1}. Since then, most of the monthly median counts have been 1 fecal coliform 100 mL^{-1} or less than the detection limit, with the highest monthly median counts reaching 5 fecal coliforms 100 mL^{-1} in most years. Elevated counts in 2003 coincided with a temporary lapse in the annual waterfowl management contract.

Strong evidence of long-term downward TP trends was identified in the Catskill inflow, the reservoir and Kensico outflow with a downward trend considered possible for the Delaware inflow. Wastewater treatment plant (WWTP) upgrades in the Cannonsville, Ashokan and Schoharie basins as well as the construction of a new plant in the Ashokan basin are the mostly likely explanation. The on-going implementation of agricultural BMPs and the septic system replacement in these upstate basins probably played a role as well. Starting in 2012, however, the LOWESS curves indicate an increasing trend at all sites especially apparent in the Delaware inflow. Although some recent TP increase have been observed in the Delaware System (and some of it due to sample bottle contamination), the water quality of the Delaware inflow was also influenced by operational changes. The Delaware inflow is dominated by water from Rondout Reservoir, which is a blend of water from Cannonsville, Pepacton and Neversink reservoirs and Rondout Creek, and the West Branch, Cross River, and Croton Falls Reservoirs depending upon system operations. A portion of the TP increase in the Delaware inflow from Rondout is from decreasing usage of the comparatively low TP Neversink Reservoir and the periodic increase of higher TP water from Cannonsville. The relative impact of the Delaware inflow on Kensico has been further enhanced in recent years by greater usage of Delaware water while repairs to the Catskill Aqueduct required it to be periodically off-line.

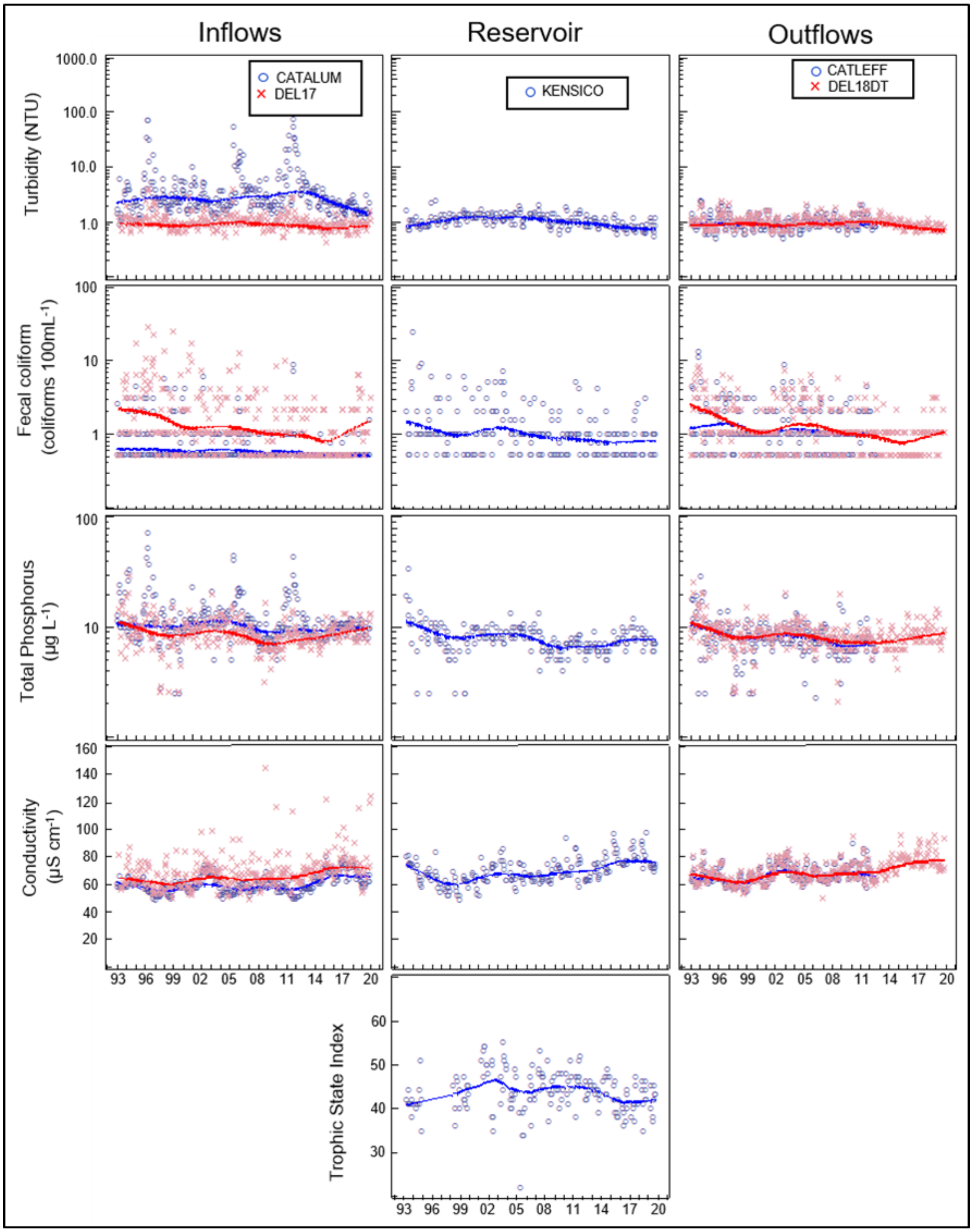


Figure 6.6 Water quality trend plots for the Kensico basin inflows from the Delaware Aqueduct (DEL17) and the Catskill Aqueduct (CATALUM), Kensico Reservoir (BRK), and the outflows at the Kensico Reservoir gatehouses (DEL18DT and CATLEFF).

Table 6.2 Kensico Basin inflow, reservoir, and outflow trends from 1993 to 2019.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
CATALUM	Inflow	Turbidity	323	*	-0.012	-0.521	Decreasing trend possible
DEL17	Inflow	Turbidity	321	***	-0.006	-0.694	Decreasing trend virtually certain
Kensico	Reservoir	Turbidity	216	***	-0.013	-1.195	Decreasing trend virtually certain
CATLEFF	Outflow	Turbidity	237	NS	0	0	Trend unlikely
DEL18DT	Outflow	Turbidity	324	***	-0.004	-0.422	Decreasing trend virtually certain
CATALUM	Inflow	Fecal coliform	323	***	0	0	Decreasing trend virtually certain
DEL17	Inflow	Fecal coliform	321	***	-0.02	-2.042	Decreasing trend virtually certain
Kensico	Reservoir	Fecal coliform	216	***	0	0	Decreasing trend virtually certain
CATLEFF	Outflow	Fecal coliform	237	***	0	0	Decreasing trend virtually certain
DEL18DT	Outflow	Fecal coliform	324	***	0	0	Decreasing trend virtually certain
CATALUM	Inflow	Total Phosphorus	321	***	-0.059	-0.588	Decreasing trend virtually certain
DEL17	Inflow	Total Phosphorus	318	NS	0	0	Decreasing trend possible
Kensico	Reservoir	Total Phosphorus	205	***	-0.067	-0.837	Decreasing trend

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
							virtually certain
CATLEFF	Outflow	Total Phosphorus	235	***	-0.111	-1.389	Decreasing trend virtually certain
DEL18DT	Outflow	Total Phosphorus	318	***	-0.045	-0.568	Decreasing trend virtually certain
CATALUM	Inflow	Conductivity	323	***	0.265	0.448	Increasing trend virtually certain
DEL17	Inflow	Conductivity	321	***	0.464	0.702	Increasing trend virtually certain
Kensico	Reservoir	Conductivity	214	***	0.58	0.846	Increasing trend virtually certain
CATLEFF	Outflow	Conductivity	237	***	0.318	0.482	Increasing trend virtually certain
DEL18DT	Outflow	Conductivity	324	***	0.556	0.817	Increasing trend virtually certain
Kensico	Reservoir	Trophic State Index	175	**	-0.078	-0.18	Decreasing trend likely

[1]The *p*-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

Upward conductivity trends were identified for all sites in the Kensico basin and were likely due to greater usage of road deicers throughout the Catskill/Delaware System. Delaware inflow conductivities exceeding 80 µS cm^{-1} are likely associated with usage of water from West Branch Reservoir where median conductivity has ranged from 100 to 150 µS cm^{-1} in recent years (Figure 6.6).

There was moderate evidence of a long-term downward trend for TSI in Kensico Reservoir. Peak TSI occurred 2001-2003, coinciding with the productivity increase (from increased clarity) noted for Ashokan Reservoir (DEP 2006). Low values in 2005 were associated with two rounds of alum treatment in April and October, which, in addition to reducing turbidity, decreased available nutrients in the reservoir. Reasons for the decrease from 2013-2019 were not clear as the decrease occurred despite a trend of generally increasing TP in the reservoir.

In summary, long-term downward trends were identified for turbidity, fecal coliform, TP and TSI at all sites in the Kensico basin. Turbidity declines are linked to the relative absence of extreme events post Irene and Lee in 2011. Fecal coliform counts were consistently low and appear to be decreasing due to decreasing counts from the Catskill and Delaware inflows, and because of the Waterfowl Management Program's harassment activities. TP declines are attributed to WWTP upgrades and to the cumulative effects of ongoing watershed protection programs throughout the Catskill/Delaware System. The more recent upward TP trend is likely related to operational changes. Greater usage of road deicers throughout the Catskill/Delaware System are considered the primary driver for the upward conductivity trends. The reason for the TSI decrease is not known.

6.4 Trophic Response of EOH Catskill/Delaware Basins

Chlorophyll versus total phosphorus in Kensico and West Branch reservoirs is plotted in Figure 6.7. While the variation in chlorophyll can be substantial, the variation in phosphorus levels is minimal. Biomass in these two reservoirs is not so clearly dependent on phosphorus,

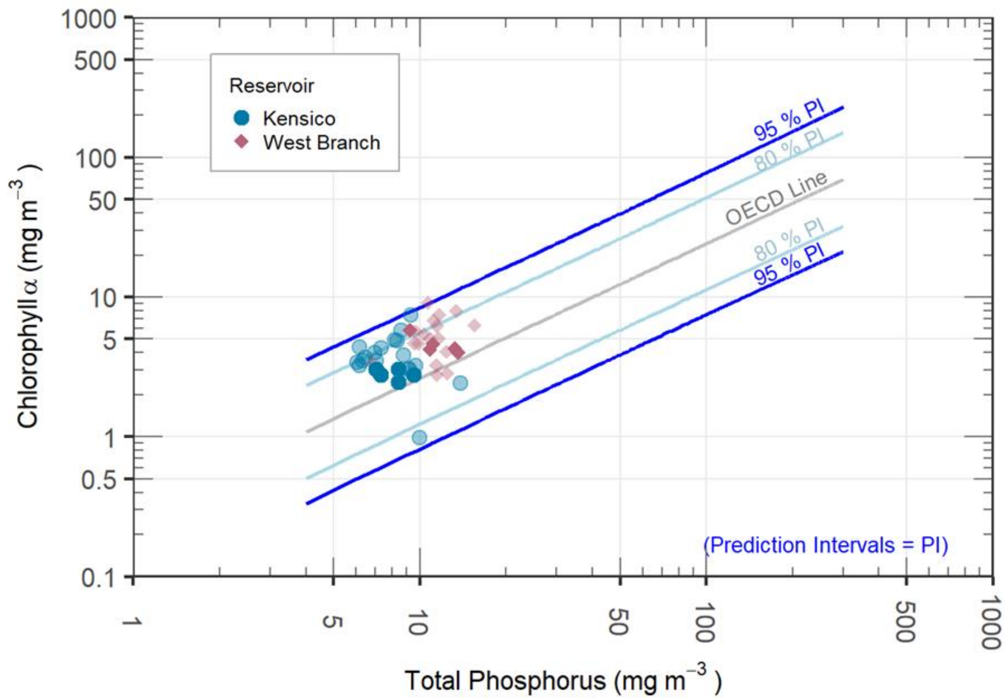


Figure 6.7 Chlorophyll versus total phosphorus in West Branch and Kensico reservoirs

and this may be related to short water residence times. Chlorophyll annual means were high in both reservoirs in 2001 and 2013-2014. In 2005, two separate turbidity events which required alum treatment of the Catskill Aqueduct inflow to Kensico occurred in spring and autumn, and these periods of alum treatment resulted in exceptionally low (<1 mg m^{-3}) chlorophyll means in both reservoirs. Both chlorophyll and phosphorus have remained low in this recent assessment period (2015–2019), with Kensico in mesotrophic condition bordering oligotrophy.

The annual maximum values of chlorophyll versus total phosphorus are plotted for each year in Figure 6.8. In 2003, 2007-2009, and 2013, there were no major storms and these are years when chlorophyll maxima were relatively high. Both reservoirs had low maxima in 2005 in a year of high turbidity and alum treatment of the Catskill inflow. No high chlorophyll values appear and all reside within the 80% PI of the OECD standard in recent years, with Kensico displaying lower algal production than West Branch.

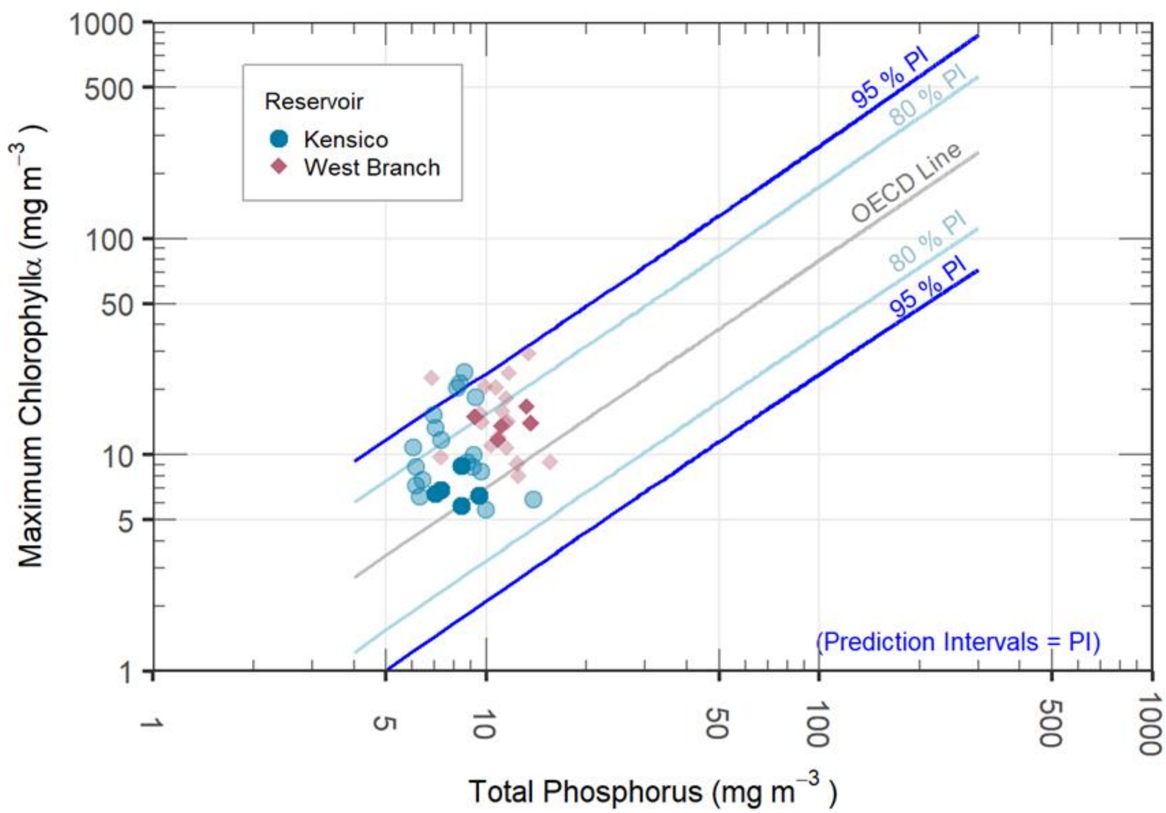


Figure 6.8 Maximum chlorophyll versus total phosphorus in West Branch and Kensico reservoirs.

Secchi depth versus total phosphorus annual mean values are plotted in Figure 6.9. Secchi depth means show little variation and are in line with phosphorus means. This plot reflects the same observation of low Secchi depth values relative to phosphorus as seen in the

Catskill/Delaware System reservoirs, indicating that substances other than chlorophyll depress transparency.

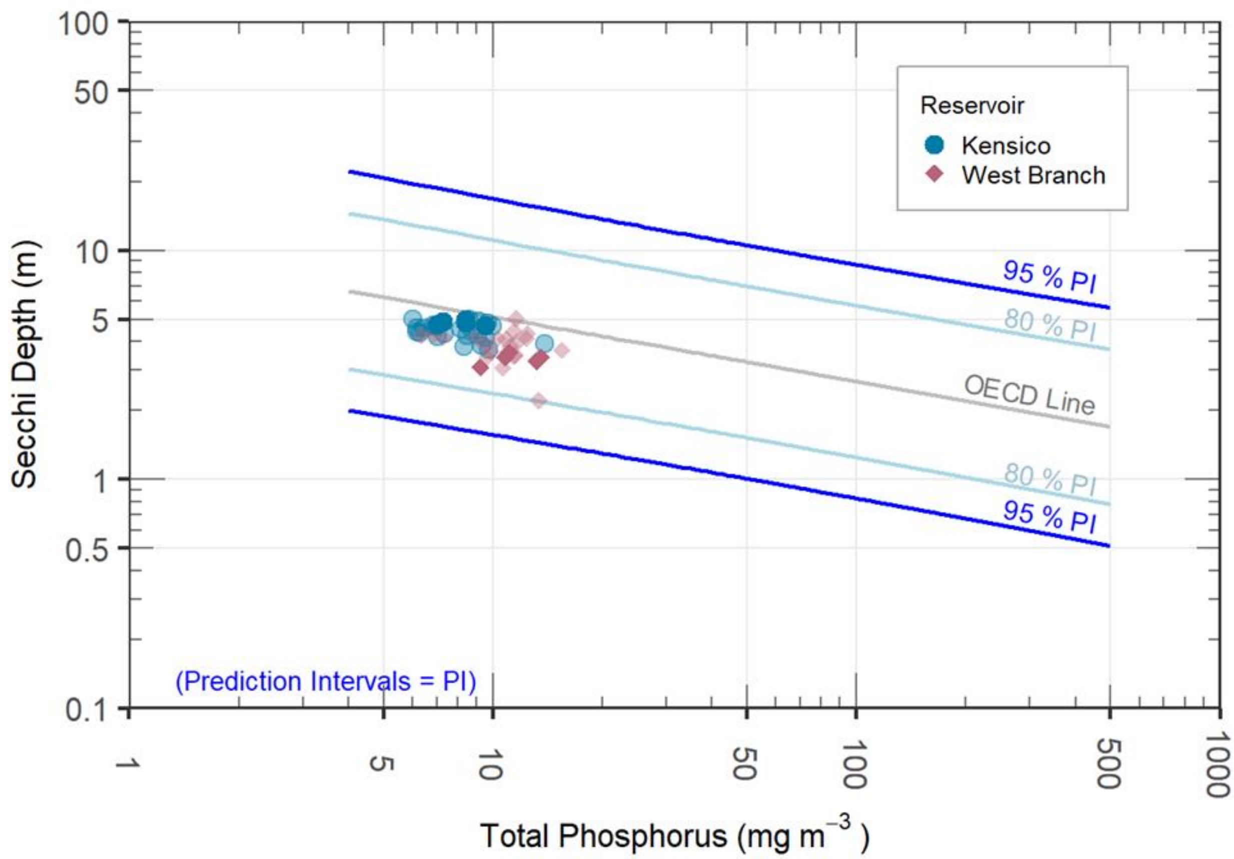


Figure 6.9 Secchi depth vs total phosphorus in West Branch and Kensico reservoirs

Secchi depth versus chlorophyll is plotted in Figure 6.10. This plot demonstrates that transparency of the surface water is typically influenced by the chlorophyll levels. Interestingly, both reservoirs had factors other than chlorophyll limiting transparency particularly in 1993, 2004, and 2005. Hurricane Ivan and two tropical storms delivered heavy precipitation and flooding during these years. In this assessment period, Secchi depths at Kensico tended to be deep indicating excellent transparency.

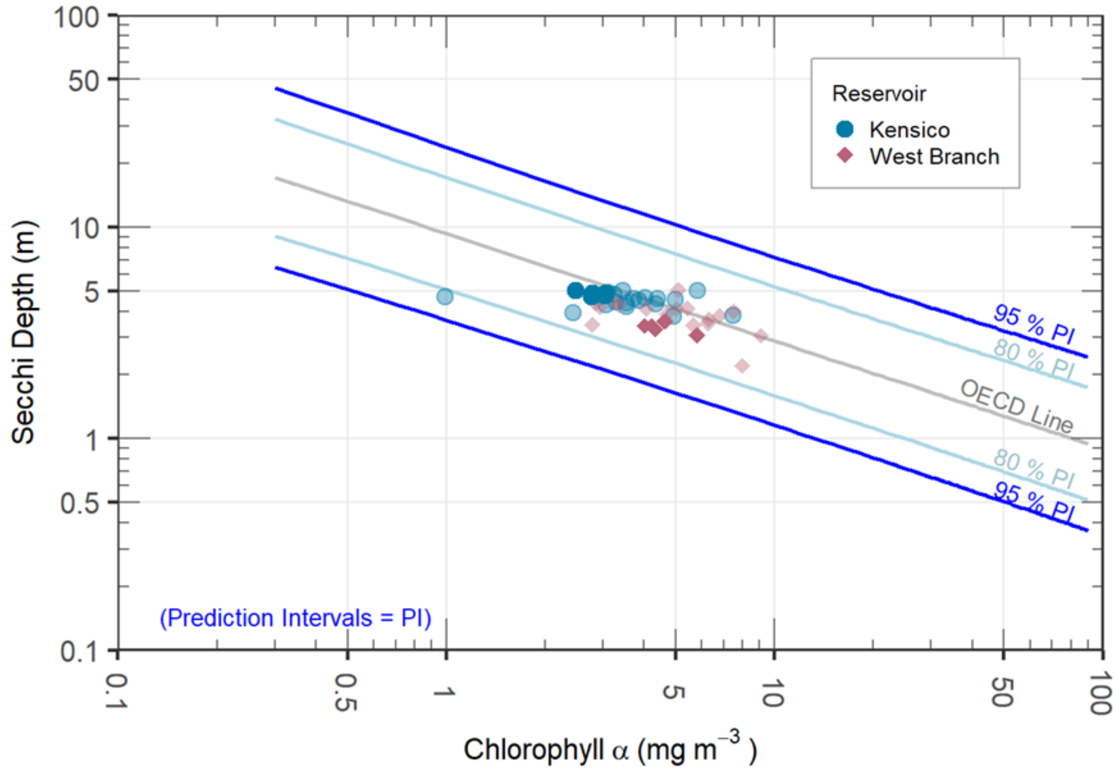


Figure 6.10 Secchi depth versus chlorophyll in West Branch and Kensico reservoirs

6.5 EOH Catskill/Delaware Basin Protozoa: Sources and Attenuation

6.5.1 Upstream Sites and Reservoir Outflows

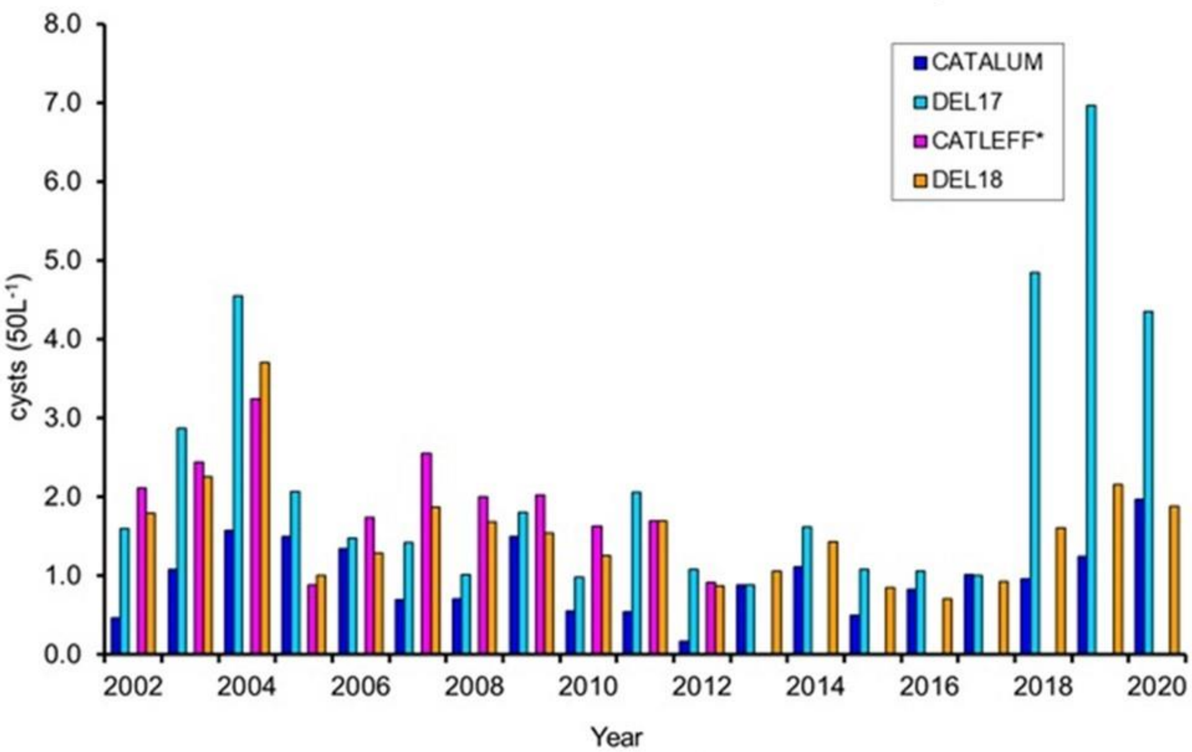
DEP has sampled for *Giardia* and *Cryptosporidium* at the two source water inflow sites located upstream of Kensico Reservoir (CATALUM and DEL17), and at the two outflow sites as the water enters the Catskill and Delaware Aqueducts (CATLEFF and DEL18DT) at least weekly since 2002. An exception is the CATLEFF location, which has not been sampled since September 2012 when CDUV came on-line. As discussed previously, that portion of the aqueduct remains closed since it is not yet pressurized. The Delaware Aqueduct at Kensico Reservoir (DEL18DT) has been the only outflow from Kensico Reservoir since September 2012. USEPA Methods 1623HV 50L (2002-March 2015) and 1623.1 (April 2015-present) have been used to collect and process samples. Even more recently (August 2017) another method adjustment was made to change from acid to heat dissociation. A broad summary of the data acquired during this sampling period is provided here, with a focus on 2015 through October 2020. Unlike the previous upstate protozoan sections, data past December 2019 is included here to provide the most up-to-date information since it is the terminal reservoir providing the majority of the water for distribution.

Giardia

During this nearly 19-year period (January 2002-October 2020), 1,965 *Giardia* samples were collected at the Kensico inflows and 1,794 samples at the outflows (reminder, sampling at CATLEFF was discontinued in 2012). Since the outflows represent the final source water prior to treatment they are sometimes sampled more often, especially when water quality results suggest resamples are necessary (e.g., increased turbidity).

The mean concentration of *Giardia* per 50 liters at the outflow of Kensico (DEL18DT) during the recent 2015 through October 2020 period was low at 1.34 cysts (n=304). The mean at DEL18DT for the entire sampling period from 2002 through October 2020 was slightly higher at 1.58 cysts (n=1111). Samples for the Catskill outflow (operating up until September 2012) indicate a *Giardia* mean of 1.93 (n=695). These outflow means are bracketed by the range in annual *Giardia* means at the two aqueduct inflows to Kensico, 0.17-6.96 cysts, with a mean of 2.25 cysts (n=997) from 2002-October 2020 at the Delaware inflow (DEL17) and 0.97 (n=968) at the Catskill inflow (CATALUM). The Delaware inflow mean *Giardia* concentration for the more recent 2015-October 2020 period was slightly higher at 3.19 cysts (n=304). While this is a slightly higher mean concentration compared to the overall period, it is likely a result of two changes that occurred in this recent five-year period: the analytical method was improved in 2017 to increase the recovery of *Giardia* cysts, and there was an increase in *Giardia* cysts that began in Rondout Reservoir in 2018 (which is the main source of flow to DEL17). Additional years of sampling are required to determine the weight of these events on the overall change in concentration at Kensico inflows. The Catskill inflow mean for 2015-October 2020 at 1.04 cysts (n=287) was similar to the 2002-2020 mean (noted above as 0.97).

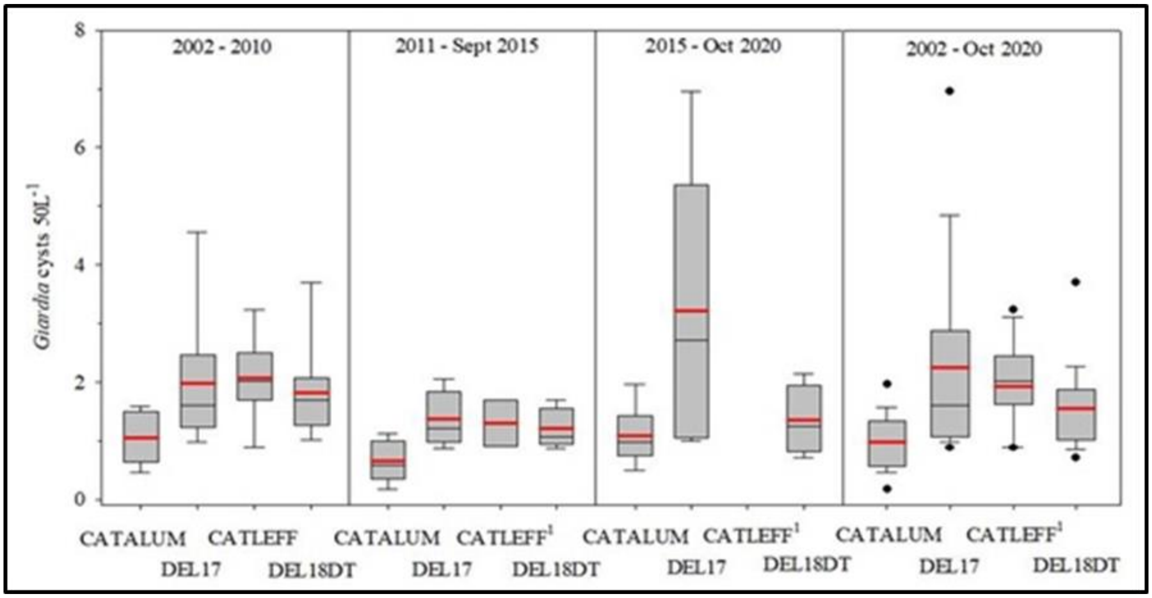
Individual annual mean concentrations of *Giardia* at the inflows and outflows of Kensico Reservoir were examined (Figure 6.11). The annual mean *Giardia* concentrations at the inflows to Kensico Reservoir have generally fluctuated between near zero and 2 cysts $50L^{-1}$ throughout the years. The exceptions being 2003 and 2004 when the Delaware inflow annual means were higher (maximum 4.5 cysts $50L^{-1}$) (Figure 6.11), and more recently from 2018, 2019 and up to October 2020 when Delaware inflow means were again elevated to 4.8, 7.0 and 4.3 cysts respectively. These increases were due to known elevated concentrations of cysts coming from Rondout Reservoir down to DEL17, the Delaware aqueduct inflow to Kensico. Both 2003-2004 and 2018-2019 were times of heavy rains and snowmelt, and necessitated the addition of alum at the Catskill inflow in April 2005. The Rondout area in 2018 experienced near record levels of precipitation, snowmelt and stream flow transporting large amounts of *Giardia* cysts into the reservoir (see Section 5.7.3 for Rondout special investigation). Moreover, this occurred at a time of year when cold water temperatures aided the persistence of cysts. For the most part, the Delaware System inflow contributes more *Giardia* to Kensico Reservoir through the aqueduct when compared to the Catskill System, even when alum is not being added. Alum addition, however, could be a contributing factor to lower *Giardia* concentrations in the Catskill aqueduct when it is added.



*Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued after September 2012.

Figure 6.11 Kensico keypoint *Giardia* annual mean concentrations (cysts $50L^{-1}$) for 2002 through October 2020.

When the mean concentrations of *Giardia* are summarized by the two previous and the current reporting periods at each site, the results are interesting (Figure 6.12). With the exception of the elevated *Giardia* from Rondout Reservoir feeding into Kensico in the recent five-year period, the site means have not changed significantly over the 18-year period of record using Method 1623/1623.1. The Catskill outflow (CATLEFF) results are difficult to compare since sampling ended in 2012 and there are eight less years of data.



[1]Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued after September

Figure 6.12 Means of annual means of *Giardia* concentrations at the Kensico influents and effluents for the three FAD summary and assessment report periods (2002-2010, 2011- Sept. 2015, and 2015-Oct. 2020) and the entire period of record (2002-Oct. 2020). The red bar represents the mean of annual mean concentrations.

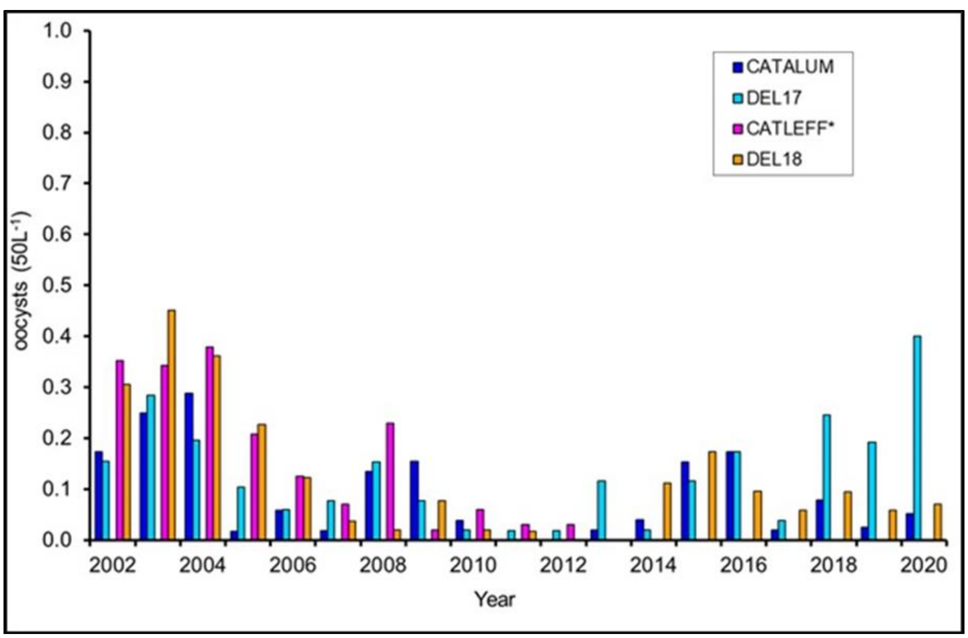
Cryptosporidium

The database available for *Cryptosporidium* analysis is very similar to *Giardia*, with 1,967 results for the inflows, and 1,795 results for the outflows (sampling at CATLEFF was discontinued in 2012). While the tests are done simultaneously, these numbers are slightly different than those for *Giardia* because occasionally results for one organism may not be successful (e.g., stain uptake) but the other organism's result is still valid. In these rare situations, results from only one of the organisms is reported.

The *Cryptosporidium* concentrations at the inflows and outflow of Kensico Reservoir are similar. The outflow of Kensico Reservoir (DEL18DT) had a *Cryptosporidium* mean of 0.09 oocysts $50L^{-1}$ (n=304) for the recent 2015-October 2020 period. For the entire 1623/1623.1 sampling period (2002-October 2020), the outflow mean was slightly higher but similar at 0.14 oocysts (n=1111). Again, the Catskill outflow has not been sampled since September 2012. The overall mean from 2002-2012, however, was also similar at 0.19 oocysts (n=684), indicating low mean oocyst concentrations over the years. By comparison, the inflow mean concentrations for the entire 2002-October 2020 period were 0.13 (n=998) at the Delaware inflow (DEL17), and 0.09 (n=969) at the Catskill inflow (CATALUM). For the shorter, current 2015-October 2020 period, the Delaware inflow showed a slightly higher mean at 0.19 oocysts (n=304) compared to

0.09 oocysts for the comparable period at the Kensico outflow. The Catskill inflow *Cryptosporidium* concentration remained unchanged from the long term period, 2015 to October 2020 (n=287), at 0.09 mean oocysts for the.

Individual annual mean *Cryptosporidium* concentrations at Kensico Reservoir sites were examined from January 2002 through October 2020 (Figure 6.13). Most notable is that the maximum annual mean value is only as high as 0.45 oocysts $50L^{-1}$ for the nearly 18-year period. An additional observation is that for the past 11 years (since 2009) the outflow annual means at Kensico have remained below 0.2 oocysts. A decrease in annual mean oocysts from the early 2000s to approximately 2009 is apparent (attributed to Watershed Protection Programs, ex. WWTP upgrades), and they remained low until approximately 2015 when the first method change occurred to improve recovery (April 2015). A second method change occurred in August 2017; however, that change was more directed at improving *Giardia* recovery. Also notable is that the outflow mean concentrations are often slightly higher than the inflows – especially early in the monitoring record (2002-2006). This may be due to contributions from local Kensico tributaries, especially during storm events, and may also be due to the difficulties of measuring oocysts at such low levels. Lastly, while still relatively low, the increase in annual mean oocyst concentrations at DEL17 (inflow from Rondout) is quite prominent in 2018, 2019, and so far in 2020. This corresponds to the period of increased *Giardia* cysts in the Rondout Reservoir and may indicate (1) the *Giardia* source(s) also contained *Cryptosporidium*, and/or (2) that the unusually high precipitation, snow melt and runoff during this period transported both increased



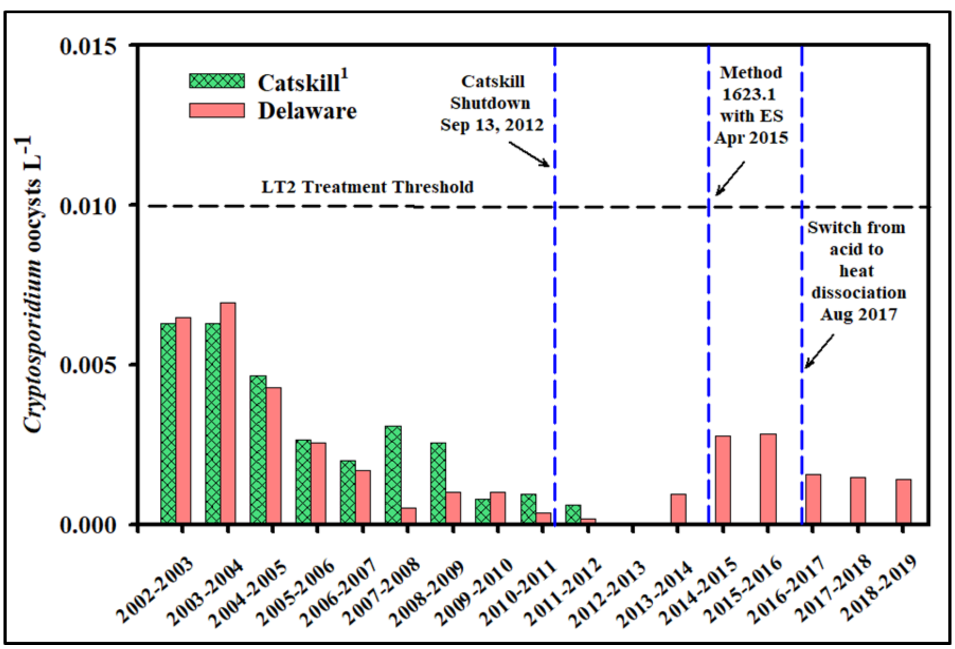
*Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued after September 2012.

Figure 6.13 Kensico keypoint *Cryptosporidium* annual mean concentrations (oocysts $50L^{-1}$) for 2002 through October 2020.

Giardia and *Cryptosporidium* from multiple sources into the reservoir through tributaries and overland flow.

As a note, it is important to remember that method changes were made to increase the recovery of protozoans watershed-wide in 2015 and again in 2017. The amount of data "post method changes" needs to be increased with additional years of monitoring in order to accurately define true changes in the data if they exist.

In addition to routine data analysis, DEP has performed calculations consistent with the guidelines set forth in the Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA 2006). The rule required utilities to conduct monthly source water monitoring for *Cryptosporidium* and report data from two, two-year periods. The LT2 required all unfiltered public water supplies to "provide at least 2-log (i.e., 99 percent) inactivation of *Cryptosporidium*" during the two monitoring periods. If the average source water concentration during the sampling periods exceeded 0.01 oocysts L^{-1} based on the LT2 monitoring, "the unfiltered system must provide at least 3-log (i.e., 99.9 percent) inactivation of *Cryptosporidium*." The average source water *Cryptosporidium* concentration is calculated by taking a mean of the monthly *Cryptosporidium* mean concentrations at the source water outflows over the course of two years. Although not required since the LT2 monitoring is over, results have been calculated here (Figure 6.14) with data through the most recent full two-year period (January 1, 2018-December 2019), using all routine and non-routine samples.



[1]Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued in September 2012, as a result, the two periods containing 2012 data contain 21 months of data rather than 24.

Figure 6.14 LT2 calculations for *Cryptosporidium* mean of monthly means (2002-2019).

The 2018-2019 mean of monthly means for *Cryptosporidium* was 0.0014 oocysts L^{-1} for the Delaware effluent, well below the LT2 threshold level of 0.01 oocysts L^{-1}. This is consistent with NYC source water historical LT2 calculations, which have always remained below the threshold level.

Discussion

Among the years with the lowest *Giardia* and *Cryptosporidium* annual mean concentrations for both inflows and outflows at Kensico Reservoir was 2012, the year following tropical storms Irene and Lee in September 2011. Perhaps the considerable flow from the two tropical storms flushed most of the protozoa from the system (including some of the hosts, ex. small mammals and habitat destruction), leaving less (oo)cysts available to be transported into the reservoir until fecal material again increased to measurable levels. Alternatively, perhaps operational and treatment decisions reduced concentrations the following year. In any event, the combined inflow *Giardia* contribution in 2012 was a 18-year annual mean low of 0.62 cysts $50L^{-1}$, and the lowest combined outflow mean concentration was in 2016 at 0.71 cysts, with 2012 a close second at 0.89 cysts $50L^{-1}$. For *Cryptosporidium*, the lowest mean inflow concentrations occurred in 2011 and 2012 when both means were 0.01 oocysts $50L^{-1}$. The lowest outflow year was 2013 when the DEL18DT mean oocyst concentration was zero; however, it was not a "combined mean" since CATLEFF was shut down. Subsequently, the year with the lowest combined outflow mean was 2012 with a mean of 0.02 oocysts $50L^{-1}$.

Another factor to consider when providing perspective on occurrence is the ability to recover the organisms from the matrix. When matrix spike (MS) recovery sample results were examined for the 2002- 2019 period, the overall mean recoveries for *Giardia* were 42.27% and 47.93% for the Catskill and Delaware inflows, respectively, and 46.97% and 49.41% for the outflows (Table 6.3). Similarly, the Cryptosporidium percent recovery at the inflows to Kensico Reservoir were 45.63% and 52.73% for Catskill and Delaware respectively, and 48.44% and 50.49% at the outflows. The combined means of the inflows and outflows are well within the variability of the method (the difference between MS samples and their duplicates) and are not considered different. In fact, the similarity of these numbers over such a long period of time is an indication of the water matrix's consistency, and also a testimony to strong reproducibility in sample collection and analytical procedures used by DEP staff when processing the samples. This is further supported by the tight range of the standard deviations with respect to this method. Some of these standard deviations are higher than those mentioned during the last report period, and this increase is believed to be a result of changing methods twice in the current period (2015-2019).

Table 6.3 Summary statistics for Kensico keypoint annual mean matrix spike recovery from 2002-2019.

	Cryptosporidium				*Giardia*			
2002-2019	CATALUM	DEL17	CATLEFF	DEL18DT	CATALUM	DEL17	CATLEFF	DEL18DT
n	18	18	11	18	18	18	11	18
Mean	45.63	52.73	48.44	50.49	42.27	47.93	46.97	49.41
Std. Deviation	12.76	10.65	6.87	9.43	10.22	15.70	6.67	8.51
Min	17	37	36	29	21	16	38	34
Max	67	70	60	67	58	80	56	73

The MS annual mean data were examined for the periods when *Giardia* and *Cryptosporidium* occurrence were at their highest and lowest concentrations to see if there might be a connection with percent recovery. For the 2003-2004 timeframe, when cyst and oocyst occurrence was at a high annual mean for both the inflows and outflows of Kensico Reservoir, recoveries were in fact very good - ranging between 45% and 57% recovery. For the 2012 period, when cyst and oocyst annual mean occurrence was at a low at the inflows and outflows, the MS recoveries ranged slightly lower, between 29% and 51%. Therefore, in addition to operational/ treatment changes and the flushing of the system potentially causing protozoan reductions after the storms, slightly lower MS recovery may also have been a factor in detecting less protozoa during the post-storm period. This information is certainly helpful when considering the big picture. However, it should be noted that there have been years with higher recovery and low occurrence, and also years when there has been low recovery and higher occurrence. This suggests that MS percent recovery is not the sole driving factor behind occurrence overall. Moreover, these data are annual mean occurrence and annual mean percent recovery; they are not paired with sample collection throughout the year. As has been well documented in the past, MS recoveries and (oo)cyst occurrence also vary by season within a year, and that aspect of the data is not reflected in this analysis.

When temporally examining MS recoveries at the current Kensico inflows and outflow, three different method periods have been identified (Figure 6.15). The first period is when Method 1623 and Merifluor stain were used for the analysis of protozoa in NYC raw water, and it is the longest period (2002-2015). The second, is from April 2015 to August of 2017 when Method 1623.1 and EasyStain became the routine method. Last, is from August 2017 to the present when Method 1623.1 with EasyStain continued, however, the option to use heat dissociation was selected over acid dissociation. This last change was specifically intended to improve *Giardia* recovery.

The first method change slightly improved MS recovery for *Giardia* in some samples, but continued to result in some very low recoveries as well (Figure 6.15). However, since the implementation of second method change (using heat rather than acid dissociation) *Giardia* recovery has improved and, as of this time, has eliminated the extremely low recoveries. Results thus far indicate that heat dissociation is an improved method variation over acid in the NYC water matrix for *Giardia* (Table 6.4). As with all method changes, more data is needed to increase the sample size with the newer method (currently in the single digits per site) and ultimately compare those data to previous methods before making a final determination on the potential impact.

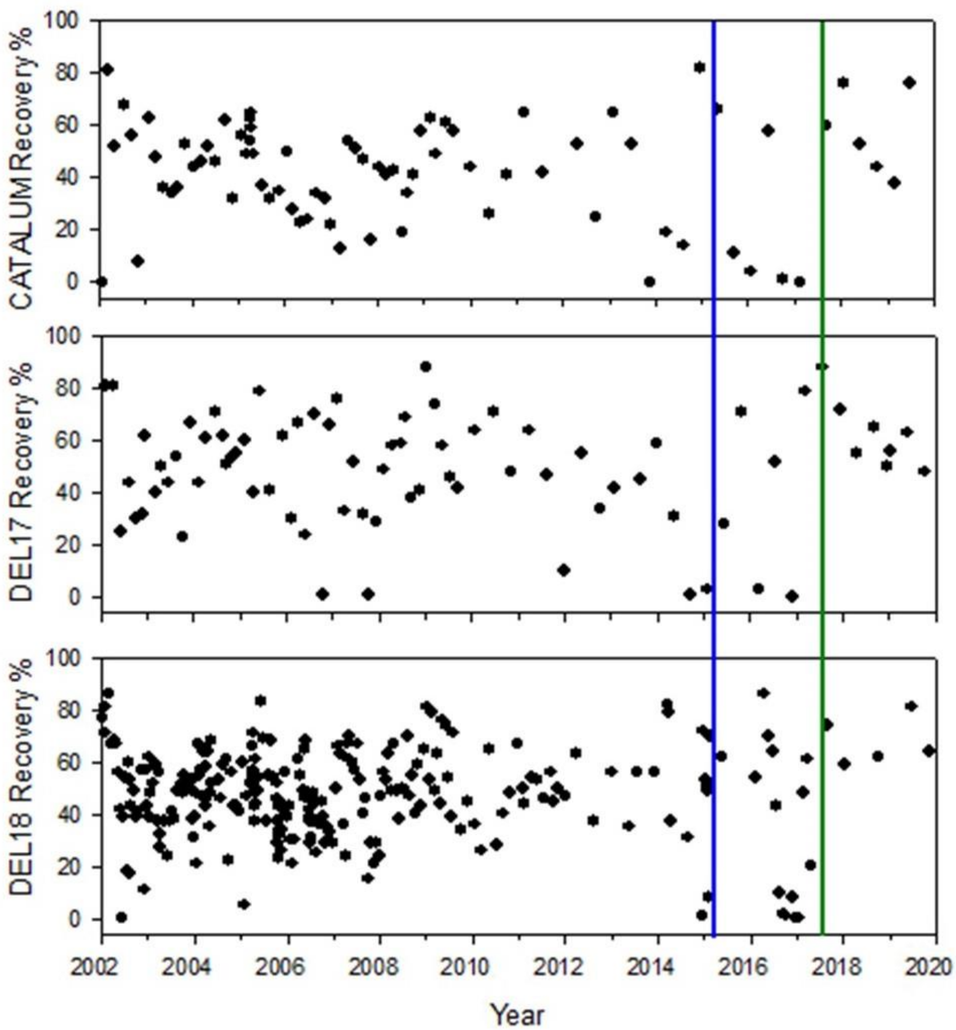


Figure 6.15 Matrix spike *Giardia* recovery percentage at Kensico Reservoir keypoints 2002-2019. The blue line represents a method change from 1623HV to 1623.1 with EasyStain and acid dissociation. The green line represents a method change from acid dissociation to heat disassociation.

Table 6.4 Mean matrix spike recovery percentages for three different method variations at the three Kensico keypoints currently sampled (with sample count in parentheses beside each mean.)

	Percent Recovery		
	1623 with Merifluor	1623.1 with EasyStain and Acid Dissociation	1623.1 with EasyStain and Heat Dissociation
Giardia			
CATALUM	42.97 (64)	23.33 (6)	57.83 (6)
DEL17	48.21 (62)	45.86 (7)	58.43 (7)
DEL18DT	47.71 (223)	35.27 (15)	68.00 (5)
Cryptosporidium			
CATALUM	44.28 (64)	55.67 (6)	51.83 (6)
DEL17	48.71 (63)	63.57 (7)	66.29 (7)
DEL18DT	50.31 (223)	62.07 (15)	60.60 (5)

For *Cryptosporidium*, the story is a little different. The first method change in April 2015 appears to have improved recovery of oocysts and lessened the standard deviation of the data (Figure 6.16). With one or two outliers as exceptions, the second method change to heat dissociation does not appear to have had a significant change on the MS recoveries for oocysts yet. At this time, it appears either the added wash step with Method 1623.1, the change to EasyStain, or both changes in the second period have had a positive effect on the recovery of *Cryptosporidium* in this matrix. Heat dissociation appears to have had no major influence at this time (Table 6.4). As mentioned above, more data is needed to determine if these observations hold true over time.

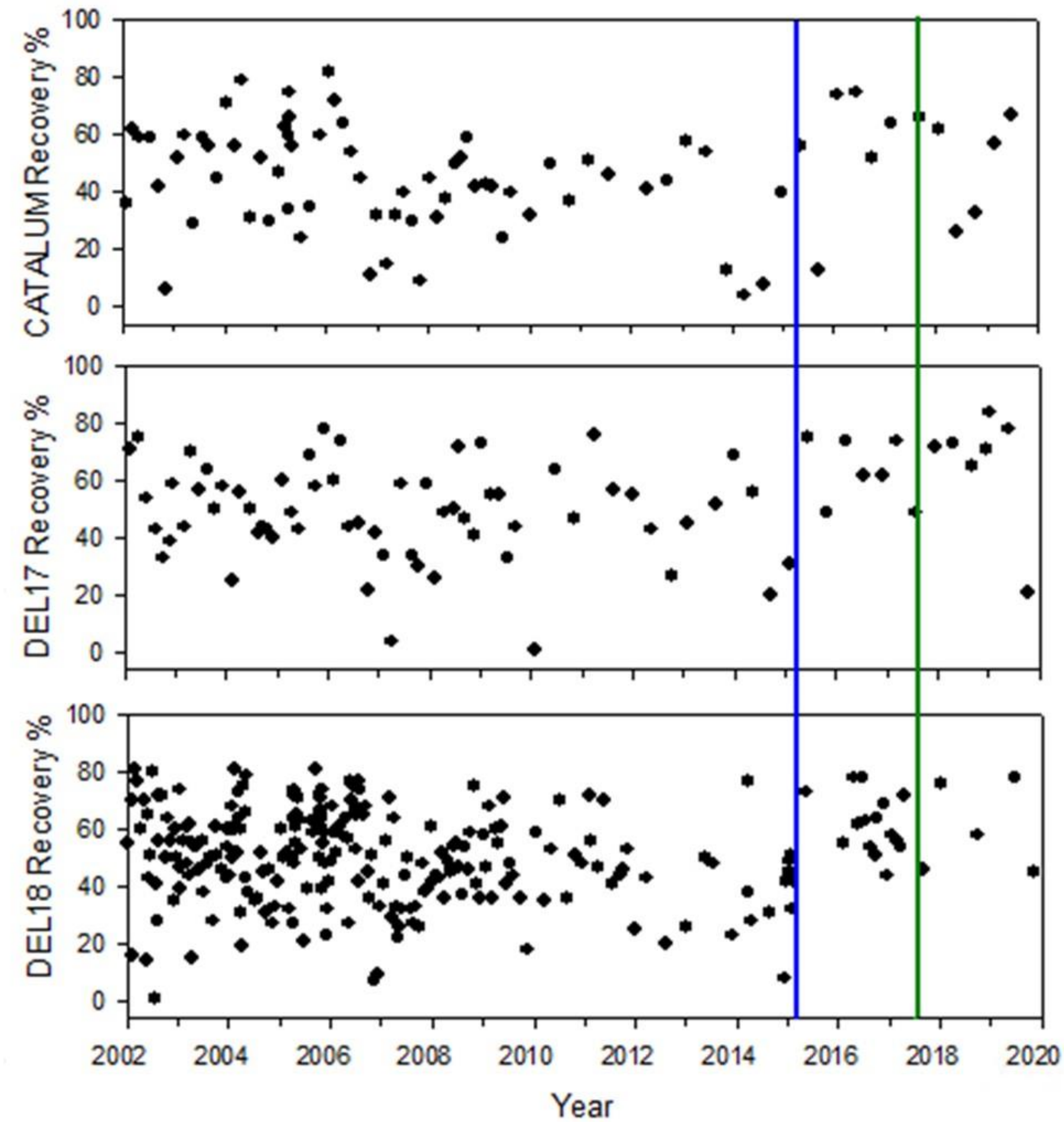


Figure 6.16 Matrix spike *Cryptosporidium* recovery percentage at Kensico Reservoir keypoints 2002-2019. The blue line represents a method change from 1623HV to 1623.1 with EasyStain and acid dissociation. The green line represents a method change from acid dissociation to heat disassociation.

6.6 Water Quality Summary for the East of Hudson Catskill/Delaware System

DEP has continued enhancing watershed protection in the West Branch, Boyd Corners, and Kensico basins. Thirty-seven stormwater remediation projects were completed in the 2003-

2009 period in the West Branch and Boyd Corners basins. In the Kensico basin, 41 projects have been completed since 1997. In 2009, a second turbidity curtain was installed in the Malcolm Brook cove to protect the water entering the Catskill Effluent Chamber from stormwater runoff. The Waterfowl Management Program continued its long-term efforts to reduce waterbird populations on and around Kensico Reservoir.

Water quality in West Branch and Kensico basins continued to be excellent during the 2017-2019 assessment period. Median and peak monthly median values were all well below established water quality benchmarks for fecal coliforms, turbidity, and total phosphorus. Long-term downward turbidity and fecal coliform trends were identified in the local stream inflows to West Branch Reservoir and attributed to stormwater remediation projects. Upward total phosphorus trends were apparent at the local inflows, the reservoir, and the outflow. All reservoir and outflow trends were likely influenced by operational changes which control the blend of waters that comprise the reservoir. Long-term downward trends were identified for turbidity, fecal coliform, and total phosphorus for Kensico Reservoir and for its inflows and outflow. Long-term conductivity trends were upward in both the West Branch and Kensico basins, which was attributed to road deicers. Increases in trophic state index were observed at West Branch while a long-term increase was identified at Kensico.

Biomonitoring results are available for 2017 and 2018 for the largest stream input to West Branch Reservoir (Horse Pound Brook), but not the input to Kensico Reservoir (Whippoorwill Creek). Whippoorwill Creek was sampled in a single year (2019). Unfortunately, due to the budgetary constraints associated with COVID-19, data from 2019's sampling is not available at this time. Note, however, that the influence of these streams on reservoir water quality is small because the largest inputs are from the Catskill and Delaware reservoirs via the aqueducts. The site on Horse Pound Brook was slightly impaired in all recent years of sampling.

Since 2002, *Giardia* and *Cryptosporidium* monitoring has been conducted at least weekly at the Catskill and Delaware inflows and outflows of Kensico Reservoir (with the exception of the Catskill outflow, which was shut down in September 2012). *Giardia* annual mean concentrations have been relatively low at both the inflows and outflows, generally ranging from 0-4.8 cysts 50 L^{-1}. This is an increase from the 0-2.5 cyst general range in the previous report. An exception to this range occurred in 2019, when the maximum cyst concentration was 7.0 cysts 50 L^{-1}. This again is coincident with the time period of increased *Giardia* from Rondout. *Cryptosporidium* concentrations continued to be an order of magnitude lower than those for *Giardia*, making it difficult to discern differences between inflows and outflows with any level of statistical confidence. For the approximately 18-year period of record with Method 1623/1623.1, the mean Cryptosporidium oocyst concentration at the Kensico source water outflows was very low at 0.14 oocysts 50 L^{-1} (n=1111). As a final note, two method changes were introduced during this reporting period and may be the reason for some changes seen in the data. More monitoring needs to be completed to increase the sample size of the data resulting from the new method version to confidently determine the extent of any data shifts.

In Kensico and West Branch reservoirs, variation in chlorophyll can be substantial despite that variation in phosphorus levels is minimal. Biomass in these two reservoirs is not so clearly dependent on phosphorus, and this is likely related to short (often < 1 month) water residence times. Maximum values of chlorophyll seem to develop in years when there is no disturbance from major storms. These two reservoirs follow the same observation of low Secchi depth values relative to phosphorus as seen in all the Catskill-Delaware System reservoirs.

In this recent assessment period (2015–2019), both chlorophyll and phosphorus have remained low, with Kensico in mesotrophic condition bordering oligotrophy. The most recent years show chlorophyll values all within the 80% PI of the OECD standard, with Kensico displaying lower algal production than West Branch. Secchi depth means show little variation and are in line with phosphorus means. This plot reflects the same observation of low Secchi depth values relative to phosphorus as seen in the CAT/DEL reservoirs, indicating that substances other than chlorophyll reduce transparency. In this assessment period, Secchi depths at Kensico tended to be deep indicating excellent transparency. These reservoirs, not surprisingly, reflect the same water quality characteristics seen in the other Delaware System reservoirs.

7. East of Hudson Potential Delaware System Basins

7.1 The Cross River and Croton Falls Pump Stations

This chapter covers the water quality history of Cross River and Croton Falls reservoirs, two of the 12 reservoirs in the City's Croton system. Cross River and Croton Falls are included in this report because they are both equipped with pump stations that allow DEP to pump water into the lower portion of the Delaware Aqueduct as needed. The water in these reservoirs is therefore a supplement to Delaware water and undergoes similar scrutiny.

The pump stations are rarely used. The Cross River pump station was operated in 1995 during a drought. The Croton Falls pump station was in use from December 5-28, 2009, to augment the supply while repairs were made to the Rondout-West Branch Tunnel. The pump stations were rebuilt over the last decade to increase capacity from the two reservoirs. This has improved system reliability during drought or operational water shortages and is expected to be in use during the Rondout-West Branch Tunnel shutdown for repair of the Delaware Aqueduct leak under the Hudson.

Both pump stations were tested briefly in 2018. In 2019, a test of the Cross River pump station was conducted on November 19-20 and the Croton Falls pump station was tested on June 26 and from June 28-July 1. The Croton Falls pump station was run periodically in November and December 2019 to meet demand while the Catskill Aqueduct was shut down for maintenance.

7.2 The Cross River Basin

The Cross River Reservoir is located in northeastern Westchester County about 25 miles north of the New York City limits. It was formed by the damming of the Cross River, which flows westward to the Muscoot Reservoir. It was placed into service in 1908. The reservoir consists of one basin, approximately 3.2 miles in length, and holds 10.3 billion gallons at full capacity. Water from the reservoir flows into the Cross River and Muscoot Reservoir, and from there flows to the New Croton Reservoir. After travelling through the 24-mile-long New Croton Aqueduct, the water reaches Jerome Park Reservoir and the Croton Water Filtration Plant where it enters New York City's distribution system.

Cross River Reservoir watershed’s drainage basin is 30 square miles in Westchester County, NY with a small part in Fairfield County, CT. There are four WWTPs located in the Cross River drainage basin, which collectively produce about 0.08 MGD of flow. Land use in the Cross River watershed consists of 59.1% forested, 28.1% urban, 2.3% brushland, 7.3% water, and 3.2% in agricultural use.

Information on watershed protection programs are provided in previous sections of this report, but among the highlights in improvements over the trend analysis period include four environmental infrastructure projects that have been in place since 2008; these control stormwater in the Cross River basin. Additionally, a septic repair reimbursement program is available to priority parcels in the Cross River basin to promote continued water quality improvements.

Presently, there are four active wastewater treatment plants (WWTPs) located in the Cross River basin, which are permitted with a collective flow of 0.137 MGD. The intervention and involvement of DEP's WWTP Compliance and Inspection Program also assures proper operation of these plants to reduce nutrient loadings.

7.2.1 Water Quality Status and Trends in the Cross River Watershed

Status (Cross River)

The Cross River basin status evaluation is presented as a series of boxplots in Figure 7.1. A comparison of the inflow (CROSS2), reservoir (CCR), and the outflow (CROSSRVVC) is shown. All values below the maximum detection limit for fecal coliform and total phosphorus were converted to half the detection limit. For additional details on methodology and boxplot interpretation, see Appendix C.

For the status evaluation period (2017-2019), median monthly fecal coliform bacteria exceeded the NYSDEC stream guidance value of 200 fecal coliforms 100 mL^{-1} on seven occasions in the three-year period, with the highest exceedances in June and October 2019 (580 and 2,000 fecal coliforms 100 mL^{-1}, respectively). Reservoir (CCR) and outflow (CROSSRVVC) were low throughout the evaluation period (medians at or below the detection limit of 1 fecal coliform 100 mL^{-1}). Turbidity was generally low at all sites and reservoir (CCR) monthly medians ranged from 1.3 to 3.1 NTU, with no values above the SWTR limit of 5 NTU. Median monthly total phosphorus (TP) for the reservoir was 17.5 µg L^{-1}, with several values above the target value of 15 µg L^{-1} for source waters. The Trophic State Index (TSI) values for Cross River Reservoir fell within the eutrophic range primarily, with a median of 52.5. Conductivity was highest at the inflow (298 µS cm^{-1}) and slightly lower in the reservoir and outflow (medians of 290 and 285 µS cm^{-1}, respectively).

Trends (Cross River)

Water quality trend plots form the Cross River basin are presented in Figure 7.2 and results of the Seasonal Kendal trend (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 7.1.

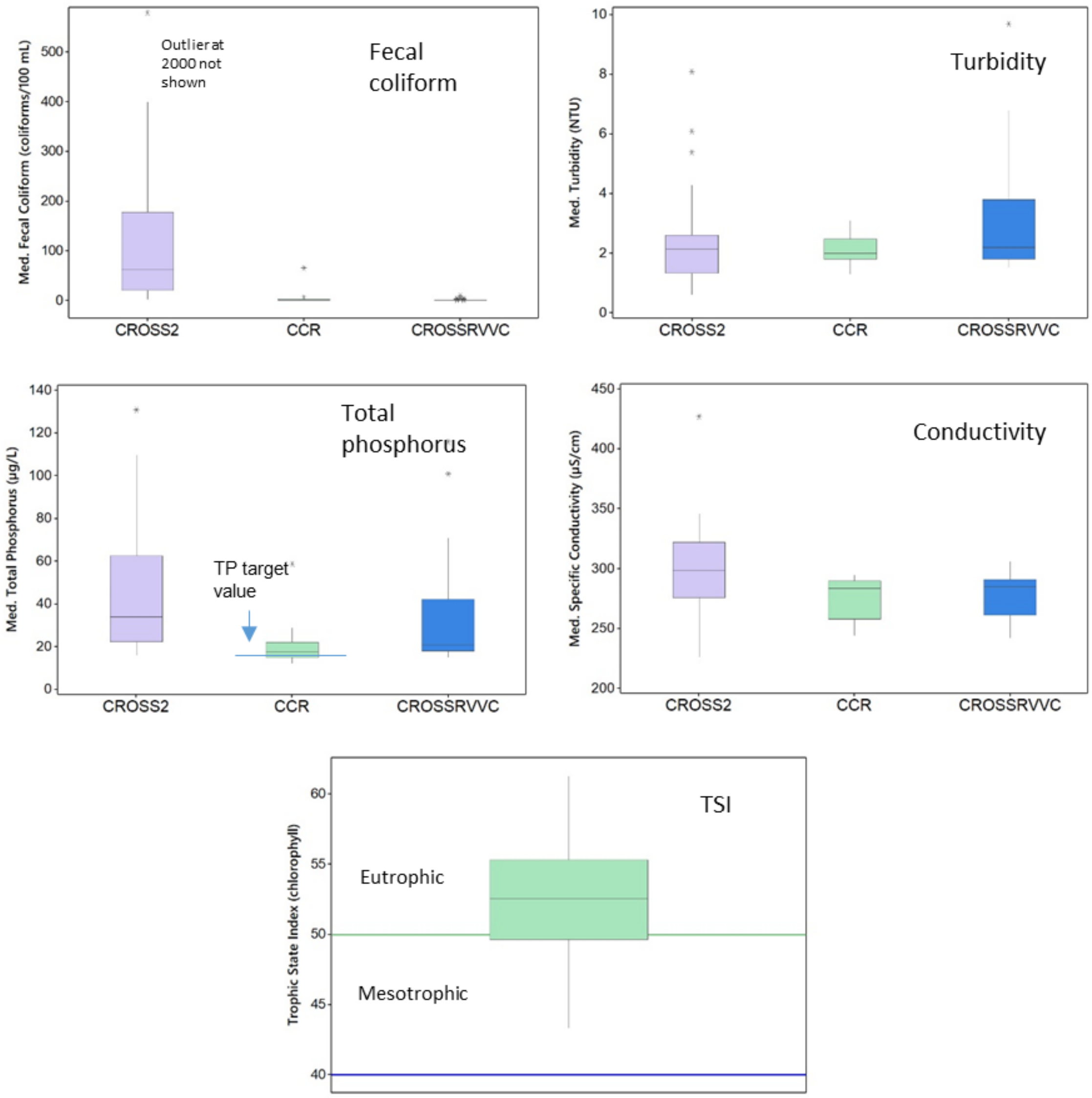


Figure 7.1 Water quality status boxplots using 2017-2019 monthly data for the Cross River basin main stream inflow at Cross River (CROSS2), Cross River Reservoir (CCR), and the outflow at the Cross River release (CROSSRVVC).

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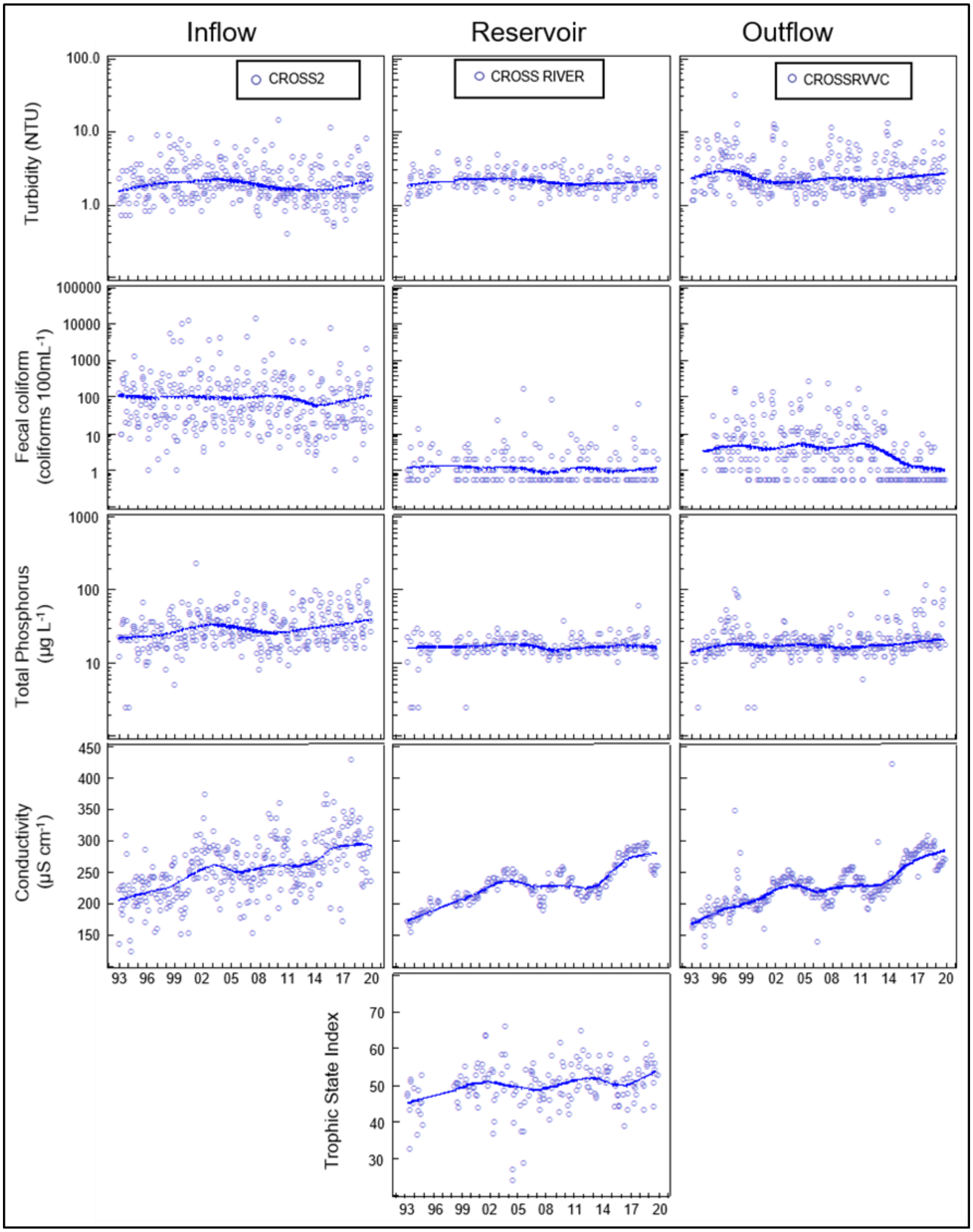


Figure 7.2 Water quality trend plots for the Cross River basin main stream inflow at Cross River (CROSS2), Cross River Reservoir, and the outflow at the Cross River release (CROSSRVVC).

Table 7.1 Cross River Basin (inflow, reservoir, and outflow) trend results for 1993 – 2019.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
CROSS2	Inflow	Turbidity	320	NS	-0.007	-0.372	Decreasing trend possible
CROSS2	Inflow	Turbidity (Flow Adj.)	285	***	-0.016	-0.875	Decreasing trend very likely
Cross River	Reservoir	Turbidity	201	NS	0	0	Decreasing trend possible
CROSSRVVC	Outflow	Turbidity	317	NS	-0.006	-0.294	Decreasing trend possible
CROSS2	Inflow	Fecal Coliform	321	**	-0.333	-0.574	Decreasing trend likely
CROSS2	Inflow	Fecal Coliform (Flow Adj.)	286	NS	-0.417	-0.719	Decreasing trend possible
Cross River	Reservoir	Fecal coliform	200	*	0	0	Decreasing trend possible
CROSSRVVC	Outflow	Fecal coliform	293	***	-0.088	-4.398	Decreasing trend virtually certain
CROSS2	Inflow	Total Phosphorus	319	***	0.399	1.534	Increasing trend virtually certain
CROSS2	Inflow	Total Phosphorus (Flow Adj.)	285	***	0.45	1.73	Increasing trend virtually certain
Cross River	Reservoir	Total Phosphorus	194	NS	0	0	Increasing trend about as likely as not
CROSSRVVC	Outflow	Total Phosphorus	315	***	0.133	0.741	Increasing trend virtually certain

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
CROSS2	Inflow	Conductivity	322	***	3.224	1.292	Increasing trend virtually certain
CROSS2	Inflow	Conductivity (Flow Adj.)	286	***	2.609	1.046	Increasing trend virtually certain
Cross River	Reservoir	Conductivity	198	***	3.242	1.436	Increasing trend virtually certain
CROSSRVVC	Outflow	Conductivity	317	***	3.432	1.525	Increasing trend virtually certain
Cross River	Reservoir	Trophic State Index	182	***	0.161	0.321	Increasing trend virtually certain

[1] The *p*-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$

A long-term downward turbidity trend was identified for the inflow to Cross River Reservoir. There was also weak evidence of long-term downward trends for the reservoir and outflow. The large increase in the outflow from 1995-1997 was due to drawdown of the reservoir to perform repairs to the dam. The downward trend observed here is driven by the recovery from this operation. Note that the reservoir was not sampled in 1996-1997 because of the drawdown and lack of boat access. The recent turbidity increase at the inflow represents a return to more average conditions following very low flows in 2015 and 2016.

There was moderate to weak evidence of a downward fecal coliform trend in the inflow and reservoir. Although a decreasing trend is evident for the outflow, these results are impacted by a sample location change. For much of the record, outflow fecal coliform counts were much higher than those in the reservoir due to bird activity at the outflow-sampling site, a pool formed by a weir constructed across the stream. Field staff have indicated that this pool is a popular foraging area for geese and ducks. This site was moved to a protected location within a shaft building in 2013, coinciding with the sudden drop in coliform counts shown in Figure 7.2.

Long-term upward TP trends were identified for the inflow and outflow. Storm events occurring during the 2010-2014 period caused TP to increase which was sustained by above average flow in 2018 and 2019. Adjusting for flow effects increased the slope of the trend indicating that flow was partially masking the true trend. The TP increase observed in the outflow may be confounded by the relocation of the sample site in the shaft building. High TP values generally occurred during summer and fall months when phosphorus is released from reservoir sediments under conditions of anoxia. Note that EOH FAD basin samples were analyzed at a DEP laboratory located in Westchester County, N.Y. that did not experience phosphorus contamination.

Upward conductivity trends were identified for all sites in the Cross River basin. Increased usage of road salt deicers and subsequent groundwater contamination are likely the most important factors influencing this trend. Short-term changes in precipitation patterns and drawdown were additional factors that affected the observed patterns. Drought conditions caused the large increases observed in 2001-2002 and in 2016 while the downturns in 2003-2006 and 2018-2019 were associated with very wet years. High values, unique to the output in 1997, were due to drawdown from dam repair work.

A long-term upward trend was identified for TSI although intermittent downturns occurred in 2004, 2005, and 2015. The long-term increase generally coincides with the increasing TP observed for the inflow. Earlier in the record, the relatively high value in 2001 appears to be a temporary response to refilling the reservoir in 1998 and drought in 2001-2002.

In summary, a downward turbidity trend was evident in the output largely due to recovery from elevated levels related to dam repairs occurring early in the record. There was moderate to weak evidence of a downward fecal coliform trend in the inflow and reservoir. Although a decreasing trend is evident for the outflow these results are compromised by a sample location change. An upward TP trend in the inflow was observed and coincided with the occurrence of storms from 2010-2014 and by above average flow in 2018-2019. Upward conductivity trends were identified at all sites and likely associated with road salt deicers with short-term fluctuations caused by precipitation patterns and reservoir drawdown in 1996-1997. An increasing TSI trend was detected and roughly coincident with the upward TP trend. With the exception of conductivity, all water quality upward trends observed for the outflow are likely impacted due to the re-location of the sample site in 2013.

7.3 The Croton Falls Basin

Croton Falls Reservoir is located in the towns of Carmel and Southeast, more than 30 miles north of New York City. The reservoir was formed by the damming of the West Branch and Middle Branch of the Croton River, which flow south and drain into the Muscoot Reservoir, and then New Croton Reservoir. The reservoir consists of three basins, separated by causeways. Water flows between basins through culverts under the roadways. Croton Falls Reservoir holds 14.2 billion gallons at full capacity and was placed into service in 1911.

The Croton Falls drainage basin is 16 square miles and land use consists of 50.2% forested, 36.9% urban, 1.8% brushland or successional land, and 10.7% water. There is no land in agricultural use. There are five WWTPs in the Croton Falls watershed basin, which collectively release approximately 0.94 MGD of flow.

Since 2008, seven environmental infrastructure projects were completed, with the most recent project completed in 2020 to control stormwater in Croton Falls Reservoir. Currently, a septic repair reimbursement program is available to priority parcels in the Croton Falls basin to promote continued water quality improvements. Additional information on this and other programs occurring in the watershed are provided in previous sections of this report.

Presently, there are four active WWTPs located in the Croton Falls basin with a cumulative permitted maximum flow of 1.568 MGD. Inputs of phosphorus and other pollutants from WWTPs continue to be reduced as a result of DEP's efforts to upgrade all surface-discharging plants, including the upgrade of the City-owned Mahopac WWTP, and through the intervention and involvement of DEP's WWTP Compliance and Inspection Program.

7.3.1 Water Quality Status and Trends in the Croton Falls Watershed

Status (Croton Falls)

The Croton Falls basin status evaluation is presented as a series of boxplots in Figure 7.3. The two inputs to the main (downstream) basin of Croton Falls Reservoir are the West Branch Reservoir Release (WESTBRR) and the middle basin of Croton Falls Reservoir (3CCF). The middle basin receives water from Michael Brook and Middle Branch Reservoir. The reservoir is designated as CCF and the sampling site in the main basin is 1CCF. The outflow site is designated as CROFALLSVC. All values below the maximum detection limit for fecal coliform and total phosphorus were converted to half the detection limit. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2017-2019), monthly median fecal coliforms did not exceed the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the WESTBRR inflow site. Fecal coliforms were generally low in the reservoir (3CCF, 1CCF), with three exceedances of the guidance value of 20 fecal coliforms mL^{-1} for the main reservoir basin (1CCF) (outliers shown in Figure 7.3). Turbidity was generally low at all sites, with a monthly medians of 1.5 NTU in the main basin of the reservoir (1CCF) and outflow (CROFALLSVC), with the maximum outlier at the outflow (12 NTU) in October 2018. Median monthly total phosphorus (TP) for the middle basin of the reservoir (3CCF) was 23 µg L^{-1} and was 16 µg L^{-1} for the main basin of the reservoir (1CCF). The Trophic State Index (TSI) values for Croton Falls Reservoir ranged from mesotrophic to eutrophic, with a median of 52.5 in the eutrophic range. Conductivity was highest at the outflow (CROFALLSVC) with a monthly median of 473 µS cm^{-1}.

Trends (Croton Falls)

Water quality trend plots for the Croton Falls basin are presented in Figure 7.4 and results of the Seasonal Kendall test (SKT) and Trend Direction Assessment (TDA) analysis are provided in Table 7.2.

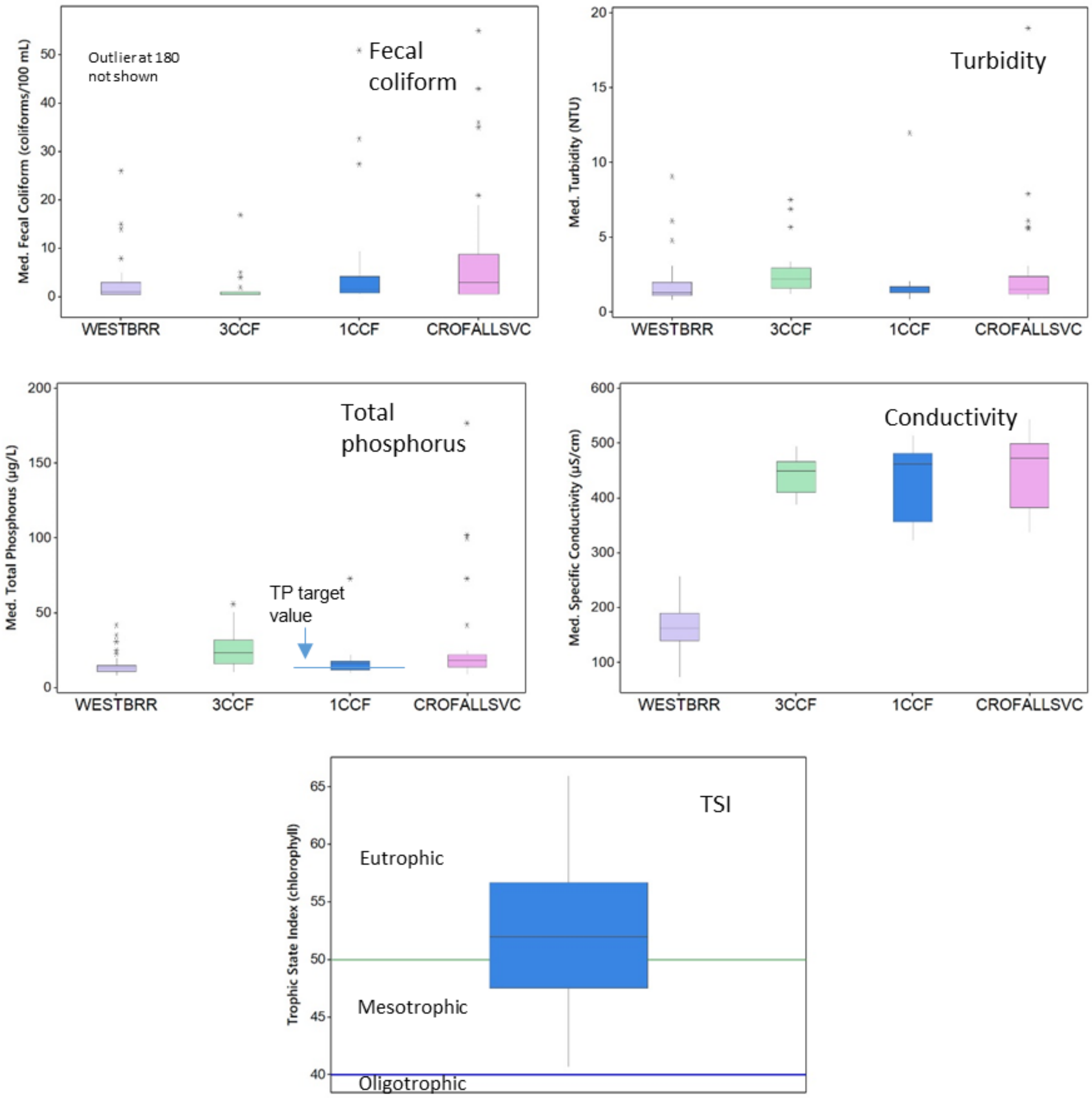


Figure 7.3 Water quality status boxplots using 2017-2019 monthly data for the Croton Falls basin inflow from the West Branch release (WESTBRR), the middle basin of Croton Falls Reservoir (3CCF), the main basin of the reservoir (1CCF), and the outflow at the Croton Falls release (CROFALLSVC).

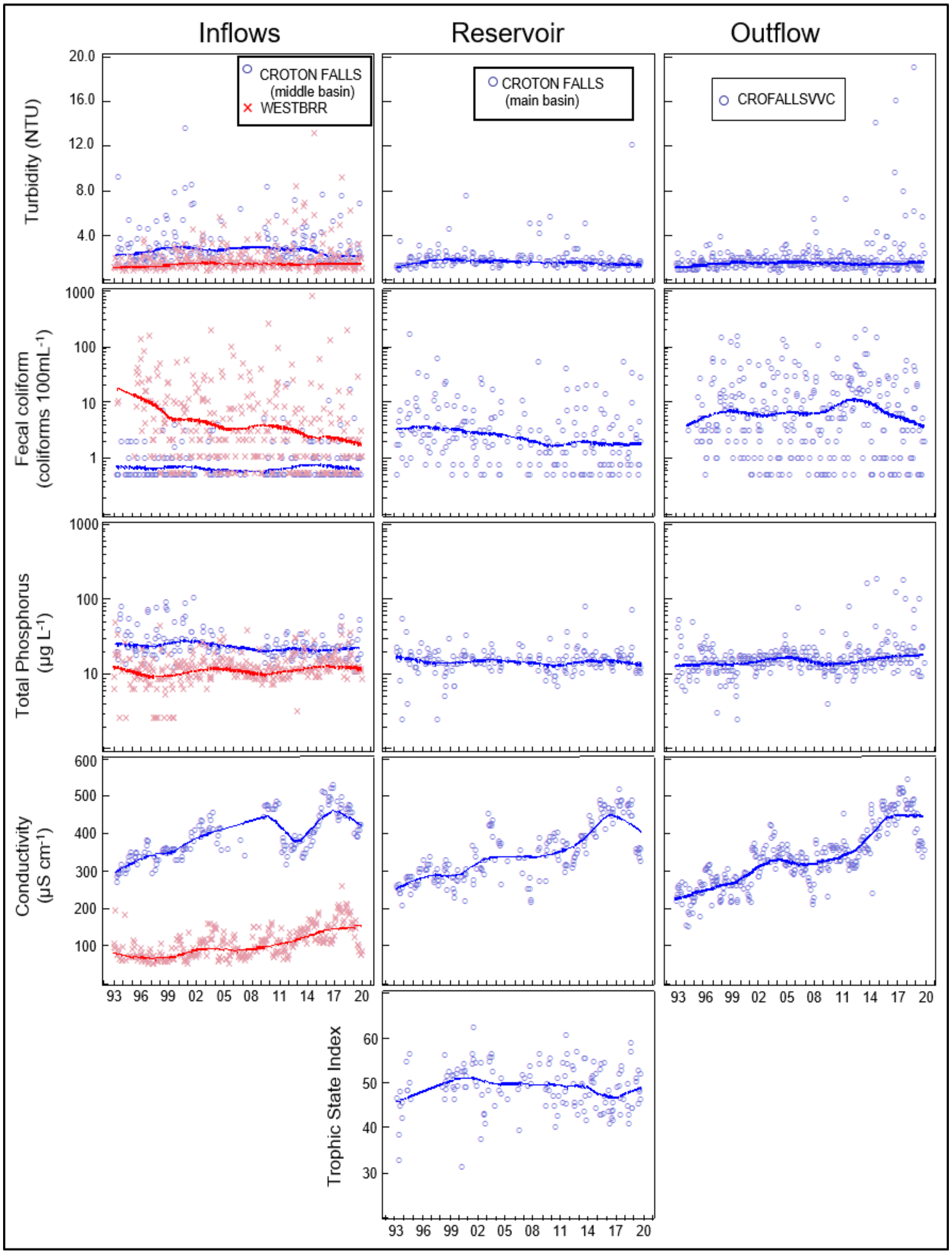


Figure 7.4 Water quality trend plots for the Croton Falls basin inflows from the West Branch release (WESTBRR) and the middle basin of Croton Falls Reservoir (3CCF), the main basin of the reservoir (1CCF), and the outflow at the Croton Falls release (CROFALLSVC).

Table 7.2 Croton Falls Basin (inflows, reservoir, and outflow) trend results for 1993 – 2019.

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
WESTBRR	Inflow	Turbidity	317	***	0.009	0.652	Increasing trend virtually certain
Croton Falls (middle basin)	Inflow	Turbidity	176	**	-0.012	-0.48	Decreasing trend likely
Croton Falls (main basin)	Reservoir	Turbidity	192	***	-0.007	-0.392	Decreasing trend very likely
CROFALLSVC	Outflow	Turbidity	320	***	0.007	0.442	Increasing trend very likely
WESTBRR	Inflow	Fecal coliform	292	***	-0.115	-5.106	Decreasing trend virtually certain
Croton Falls (middle basin)	Inflow	Fecal coliform	166	NS	0	0	Increasing trend about as likely as not
Croton Falls (main basin)	Reservoir	Fecal coliform	192	***	-0.055	-2.601	Decreasing trend virtually certain
CROFALLSVC	Outflow	Fecal coliform	295	***	-0.038	-0.769	Decreasing trend very likely
WESTBRR	Inflow	Total Phosphorus	311	***	0.124	1.132	Increasing trend virtually certain
Croton Falls (middle basin)	Inflow	Total Phosphorus	171	***	-0.284	-1.264	Decreasing trend virtually certain
Croton Falls (main basin)	Reservoir	Total Phosphorus	188	NS	0	0	Trend exceptionally unlikely
CROFALLSVC	Outflow	Total Phosphorus	316	***	0.143	0.951	Increasing trend virtually certain

Site	Description	Variable	N	*p*-value[1]	Sen slope	Percent change yr^{-1}	Trend Direction Assessment
WESTBRR	Inflow	Conductivity	312	***	3.005	3.14	Increasing trend virtually certain
Croton Falls (middle basin)	Inflow	Conductivity	173	***	5.107	1.344	Increasing trend virtually certain
Croton Falls (main basin)	Reservoir	Conductivity	190	***	7.259	2.18	Increasing trend virtually certain
CROFALLSVC	Outflow	Conductivity	316	***	8.557	2.625	Increasing trend virtually certain
Croton Falls (main basin)	Reservoir	Trophic State Index	156	NS	-0.066	-0.135	Decreasing trend about as likely as not

[1] The *p*-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

The hydrology of Croton Falls is very complex. The main basin of the reservoir receives inflows from its local watershed via an unnamed stream, which is not monitored; the reservoir's middle basin; and from the West Branch Reservoir release (WESTBRR). The middle basin is comprised of waters from the reservoir's upper basin, from Diverting Reservoir via a channel, but mostly from the Middle Branch Reservoir outflow. The West Branch inflow is a mixture of waters from West Branch, Boyd Corners and Rondout reservoirs — the proportions of which are determined by the operational status of the Delaware Aqueduct. Note also that a limited number of reservoir samples were collected from 2004-2009 due to dam rehabilitation.

Downward turbidity trends were identified for the middle and main basins with upward trends observed for the WESTBRR inflow and Croton Falls Reservoir outflow. The turbidity increase in the inflow likely resulted from operational changes upstream at the West Branch Reservoir. (For details, see Section. 6.2). The turbidity increase at the CROFALLSVC outflow is an artifact of a sampling location change. In 2013, the sample was collected in the shaft building at the base of the dam. Previously it had been collected outside of the shaft building in the stream formed by the reservoir release. The sporadic high values shown in the plot occurred in late summer and fall and are probably due to the aeration of anoxic water, which will produce turbidity when dissolved iron particles quickly precipitate out of solution.

Downward trends were identified for fecal coliforms in the inflow from West Branch Reservoir (WESTBRR) and in the main basin of Croton Falls Reservoir. The concentration and trend direction of coliform counts at these locations are similar suggesting greater influence of the West Branch inflow relative to the inflow from the middle basin. Reasons for the downward trend in the inflow from West Branch are not clear. More elevated fecal counts are observed in the outflow than in the reservoir because the higher counts generally occur during winter months when the reservoir is not sampled. The downturn after 2013 is likely due the aforementioned sample location change to the shaft building.

Upward TP trends were identified for the inflow at WESTBRR, but a downward TP trend was evident for the middle basin inflow presumably due to upstream WWTP upgrades. The increase at the WESTBRR inflow was relatively small and likely related to operational changes upstream at the West Branch Reservoir.

As indicated by the LOWESS curve, conductivity in the outflow increased from approximately 220 $\mu S\ cm^{-1}$ in 1993 to 450 $\mu S\ cm^{-1}$ in 2019. Similar increases were apparent for the reservoir's main basin and, to a lesser extent, the middle basin inflow. Increasing conductivity in the Croton Falls basin is likely due to increases in development activity, principally road salt (Heisig 2000, Van Dreason 2011). A smaller increase was detected in the West Branch inflow. This increase was probably due to Delaware Aqueduct operational changes that increased the relative contribution of Croton inputs to West Branch Reservoir during the latter half of the data record (see Section 6.2).

There was weak evidence for a long-term downward trend in TSI likely associated with the aforementioned decreasing TP concentrations.

In summary, upward trends were detected for turbidity and conductivity, while both upward and downward TP trends were evident in the Croton Falls basin. The TP decrease in the middle basin likely reflects WWTP upgrades. The increase in turbidity, TP, and conductivity at the WESTBRR inflow are likely due to Delaware Aqueduct operational changes. The conductivity increases observed elsewhere were likely due to development activity in the Croton Falls watershed. With the exception of conductivity, all water quality upward trends observed for the outflow are likely impacted due to the relocation of the sample site in 2013.

7.4 Trophic Response of Croton Falls and Cross River Basins

A series of four plots were used to examine the trophic response of Cross River and Croton Falls reservoirs. Chlorophyll versus total phosphorus in the Cross River and Croton Falls reservoirs is plotted in Figure 7.5. For Croton Falls, sites 1, 3, and 5 are located in the lower, middle, and upper basins, respectively. The separate basins of Croton Falls are plotted individually because Site 5 is isolated from the main body of the reservoir by a causeway and tends to be more stagnant than other sites. This site is more eutrophic than the other sites. Overall, chlorophyll increases with phosphorus levels as expected. However the range of phosphorus is limited in Cross River and other factors influence the standing crop of algae. In

2004 and 2005, tropical storms and heavy precipitation depressed chlorophyll levels in both Cross River and Croton Falls reservoirs. In contrast, 2001 to 2003, 2006, and 2011 were years when standing crops of algae tended to be high. These years included a drought during the 2001 to 2003 time period and the remaining years (2006 and 2011) were influenced by autumn tropical storms in the preceding season and again in autumn of the years noted. The current assessment period indicates that the main basins of Cross River and Croton Falls are similar in nutrient and algal concentrations. Site 5 in Croton Falls is clearly more productive than the other sites as observed in previous years.

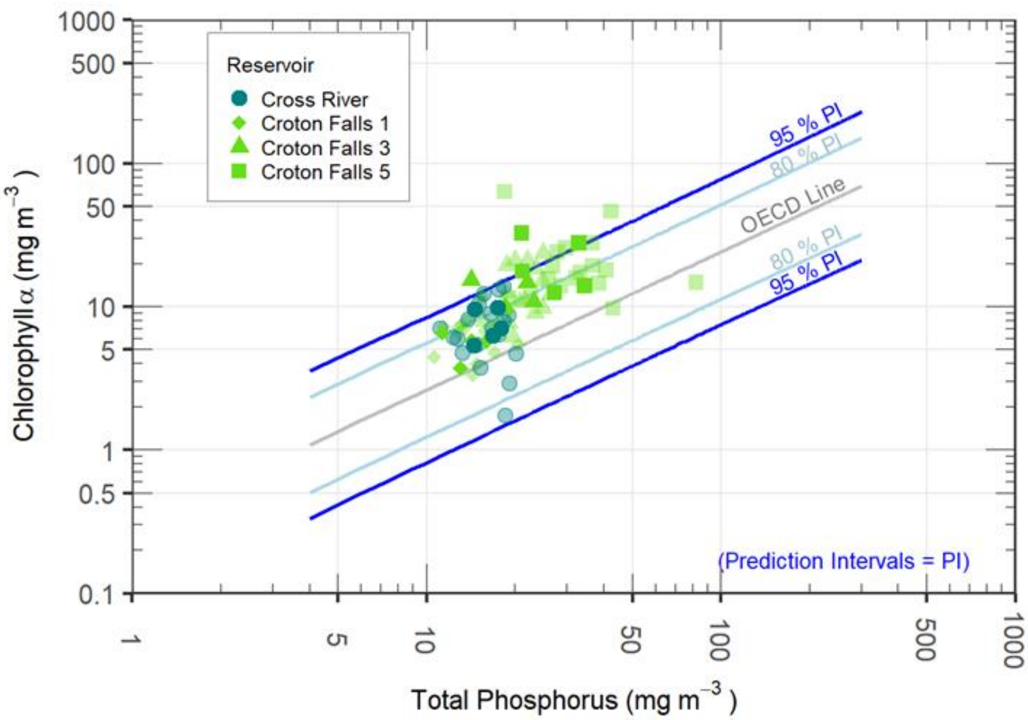


Figure 7.5 Chlorophyll versus total phosphorus in Cross River and Croton Falls reservoirs.

The annual maximum value of chlorophyll versus total phosphorus is plotted for each year in Figure 7.6. Again 2001-2003 and 2006 stand out as years with high chlorophyll in both Cross River and Croton Falls. Both the lack of disturbance during drought and heavy precipitation in advance of the growing season are conditions that apparently lead to high standing crops of algae. Cross River and Croton Falls react to precipitation events in approximately the same way. The most recent years show that three of five years are above the 95% PI for site Croton Falls 5, which reflects the high production in this relatively stagnant basin (due to the causeway). This is a chronically eutrophic site not representative of the reservoir as a whole. Croton Falls 1, the site near the dam and intake, is on a par with the water quality of Cross River.

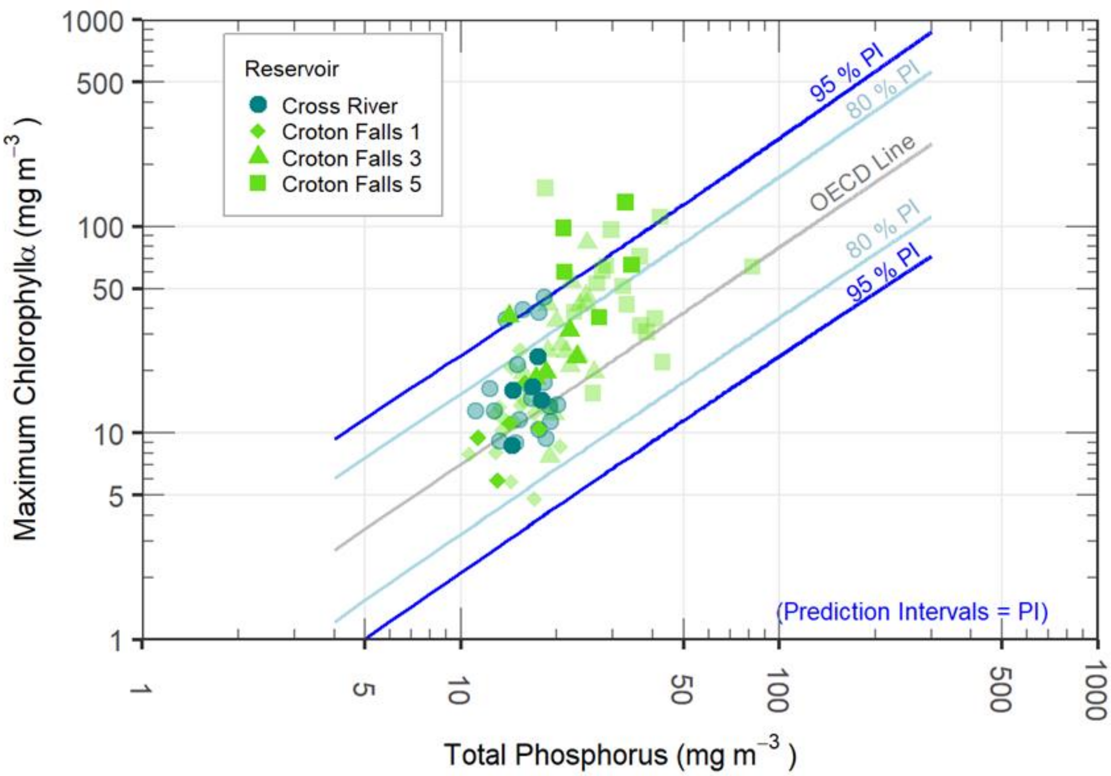


Figure 7.6 Maximum chlorophyll versus total phosphorus in Cross River and Croton Falls Reservoirs.

Secchi depth versus total phosphorus annual mean values are plotted in Figure 7.7. Similar to other Catskill and Delaware reservoir plots, the Secchi depths are approximately described by the phosphorus levels, however the values all lie below the standard. Non-phosphorus bearing particles may therefore contribute to limiting transparency. For Cross River, the highest phosphorus level and most shallow Secchi depth occurred in 1996 when Tropical Storm Bertha affected the area. In contrast, the deepest Secchi depths were observed at Croton Falls at Site 1 during a quiescent period during and following the drought of 2002 (i.e., 2002 through 2004). In the most recent assessment years, Croton Falls 5 has lowest transparency and this is not surprising considering its elevated nutrient levels. Cyanobacterial blooms commonly observed at this site contribute to low transparency.

Secchi depth versus chlorophyll is plotted in Figure 7.8. This plot demonstrates that transparency of these reservoirs is typically governed by algal growth. Nearly all points approximately conform to the OECD relationship and fall within the 80 % confidence intervals.

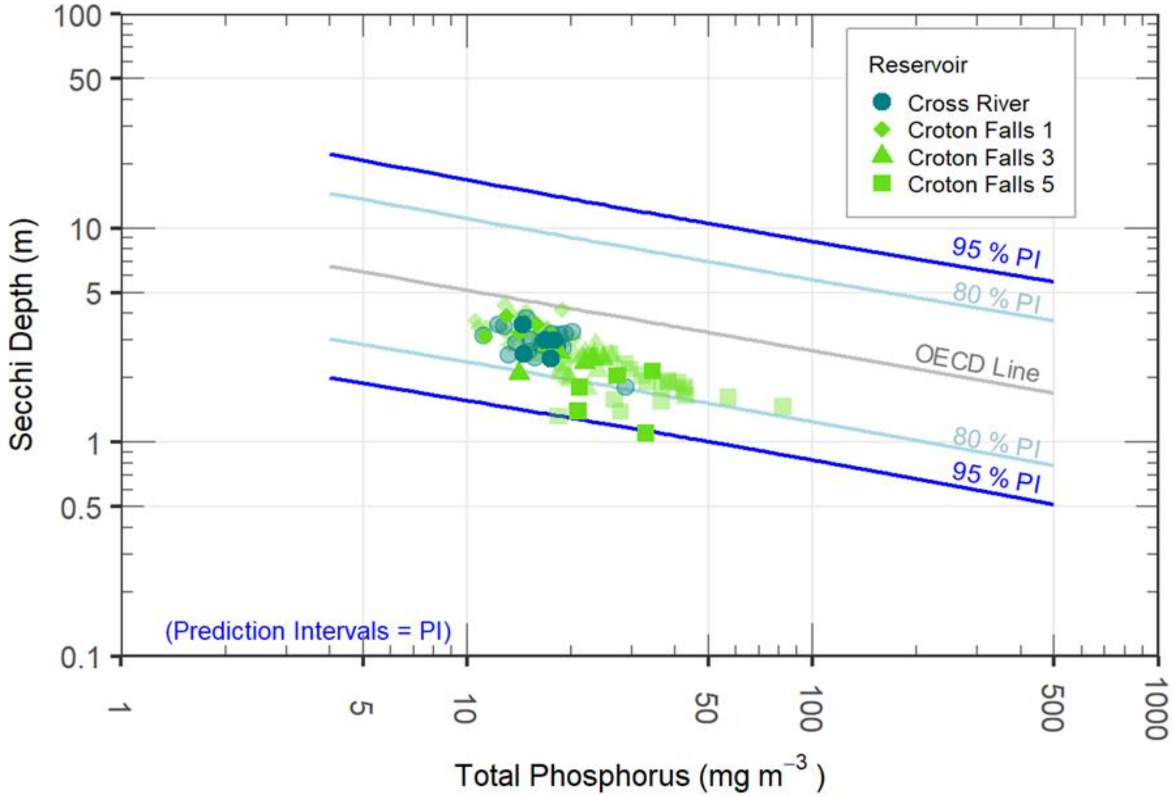


Figure 7.7 Secchi depth versus total phosphorus in Cross River and Croton Falls reservoirs.

The greatest variation for Cross River occurred in 2004 when there was exceptionally low chlorophyll coincident with a more or less average Secchi depth. Tropical Storm Frances and Hurricane Ivan occurred in September that year and seem to have affected the mean transparency. Years with Secchi depths less than expected seem to be 1993, 1994, and 2005, indicating transparency was influenced by non-algal particles. In 2001-2003, drought conditions resulted in Secchi depths tending to be slightly deeper than expected at the chlorophyll levels observed, so settling may have contributed to minimal levels of non-algal particles in these years. The most recent years lie surprisingly close to the OECD line demonstrating the close relationship of transparency to the level of algae present.

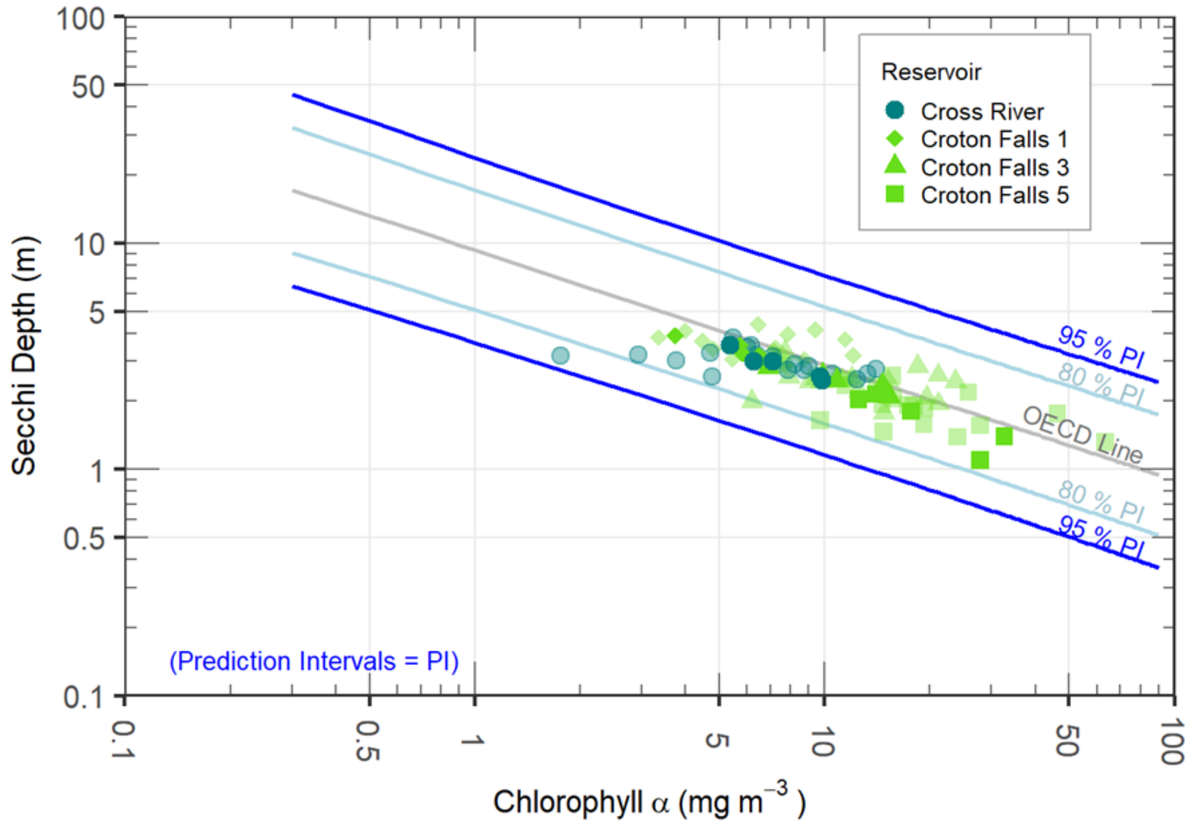


Figure 7.8 Secchi depth versus chlorophyll in Cross River and Croton Falls reservoirs.

7.5 Water Quality Summary for the Potential Delaware System Basins

Improvements are ongoing in the Cross River and Croton Falls watersheds. Thirty-two stormwater control projects, mostly in the Croton Falls basin, were completed by 2009. Upgrades to WWTPs in the Cross River basin were initiated in 2008-2009. Some upgrades have also occurred in the Croton Falls basin, including the diversion of three WWTPs to the NYC-owned Mahopac WWTP. Consequently, phosphorus loads in the Croton Falls basin have decreased from 2,400 kg year $^{-1}$ in 1994 to about 100 kg year $^{-1}$ in 2009.

Water quality status for the assessment period (2017-2019) for Cross River and Croton Falls basins was generally good. Fecal coliform levels were low in both reservoirs, but occasionally high at the inflow to Cross River Reservoir (WESTBRR) and outflow from Croton Falls Reservoir (CROFALLSVC). Turbidity in both basins was generally low, with a few outliers after storm events. Total phosphorus monthly medians for the reservoirs were above the target value of 15 µg L^{-1} for source waters (median of 17.5 µg L^{-1} and 16 µg L^{-1} for Cross River and the main basin of Croton Falls reservoirs, respectively). The median Trophic State Index

(TSI) was primarily in the eutrophic range for Cross River Reservoir and ranged from mesotrophic to eutrophic in Croton Falls Reservoir.

Long-term turbidity trends were downward for the outflow from the Cross River basin and attributed primarily to recovery from drawdown related to dam repairs. In contrast, the long-term turbidity trend for the Croton Falls outflow was upward, driven largely by the relocation of the sample site. Conductivity trends for both basins were upward and likely due to road deicer usage. A TSI increase was observed at Cross River, perhaps related to an increase in total phosphorus (TP) linked to the occurrence of large storms in 2010-2014 and to above average flows in 2018-2019. While a TSI trend was not apparent for Croton Falls, there was a long-term TP decline in the middle basin that was coincident with wastewater treatment plant upgrades.

Biomonitoring was conducted at Cross River, the primary inflow to Cross River Reservoir. The only year the site was sampled was 2019. Unfortunately, due to the budgetary constraints associated with COVID-19, data from 2019's sampling is not available at this time.

The current assessment period indicates that the main basins of Cross River and Croton Falls are similar in water quality regarding nutrient and algal concentrations. Site 5 in Croton Falls is clearly more productive than the other sites. This is a eutrophic site not representative of the reservoir as a whole. The most recent years show that three of five years are above the 95% PI for site Croton Falls 5, which reflects the high production in this relatively stagnant basin (due to the causeway). In the most recent assessment years, Croton Falls 5 has lowest transparency and elevated nutrient levels so it is not surprising that cyanobacteria commonly observed at this site contribute to its low transparency. The most recent years also show that the Secchi depth versus chlorophyll data lie surprisingly close to the OECD line demonstrating the direct relationship of transparency to the level of algae present. Despite localized algal growth at site 5, Croton Falls 1 (the site near the dam and potential Delaware intake) is on a par with the water quality of Cross River.

8. Modeling Evaluation

8.1 Introduction

The DEP water quality modeling program is involved in the development, testing and application of models that simulate historic and future climate conditions, and simulate individual watersheds and reservoirs and the entire water supply system. Model development and testing is undertaken to evaluate a new water quality problem, such as precursors of disinfection byproducts, or when a more accurate, realistic model is applied to investigate a water quality issue evaluated earlier with another model. Validated models are used to evaluate the impact of climate change on the water supply, and to assess the impact of watershed protection programs on drinking water quantity and quality.

In the current reporting period, DEP has developed a new set of future climate scenarios for the water supply watersheds based on the most recent generation of global climate models, and utilized improved downscaling procedures to generate forecasts applicable to the sites in our watersheds. We have made a significant investment in applying and testing the Soil and Water Assessment Tool (SWAT) watershed model to the West of Hudson watersheds. Here we present the application of SWAT to evaluate components of the watershed protection program in the Cannonsville watershed. Using the climate scenarios described above, this model application considered the individual and combined impacts of these programs and climate change.

In reservoir modeling, the application of DEP's two-dimensional turbidity model to additional West of Hudson watersheds is summarized here. The Operations Support Tool (OST) was applied using the future climate scenarios described above to forecast the impact of climate change on the operation and reliability of the supply system, and of future water quality. The initial steps in the development and testing of a UV_{254} reservoir model are described; UV_{254} is being evaluated as a possible proxy for disinfection byproduct precursors.

All modeling activities are supported by weather, watershed, reservoir, and aqueduct data. Progress on the development of a modeling database during the reporting period is described here. In addition, our progress on the development of a system to analyze this data to identify the impact of climate change is also summarized.

8.2 Modeling Evaluation of Watershed Protection in the Cannonsville Watershed

Watershed models can be used to evaluate the effects of best management practices (BMPs) implemented by watershed management programs. Analysis of watershed management activities and changes in land use within the context of varying weather and environmental conditions requires understanding key processes and interactions that control generation and transport of water and constituents in the watersheds. Simulation models provide a framework for understanding these interactions and their effects on water quality and quantity. DEP uses watershed models to evaluate the impact of watershed protection programs and climate change on streamflow and water quality in their water supply watersheds. Model applications allow DEP to make a quantitative comparison of individual programs and identify their relative effectiveness. DEP has recently developed and tested a modified version of the spatially semi-distributed Soil and Water Assessment Tool (SWAT) model that is capable of realistic simulations of streamflow and water quality.

SWAT-hillslope (SWAT-HS) is the modified version of the SWAT model capable of simulating variable source area (VSA) hydrology in mountainous regions with humid climate. This model can provide a better estimation of surface runoff and has the ability to predict the location of saturated areas, both of which are key elements in transferring substances from upland areas to the valley bottom and eventually to the receiving waterbody. Initial application and testing of SWAT-HS model for the small (~37 km2) Town Brook headwater watershed of Cannonsville basin, showed its ability in predicting streamflow and saturation-excess runoff with reasonable accuracy when compared to field observations (Hoang et al., 2017). Later, the application and testing of the model was scaled-up to the entire Cannonsville watershed (~1,178 km2), to evaluate model performance in predicting both streamflow and water quality. The result of this analysis also showed acceptable model performance in streamflow and water quality simulations (Hoang et al., 2019).

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 Watershed Agricultural Program (and associated BMPs), Septic Remediation and Replacement Program, and 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 8.1). 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). Dissolved phosphorus loads have decreased in recent years and 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. In addition, future climate scenarios are used to assess the impact of changing climate on nutrient loading.

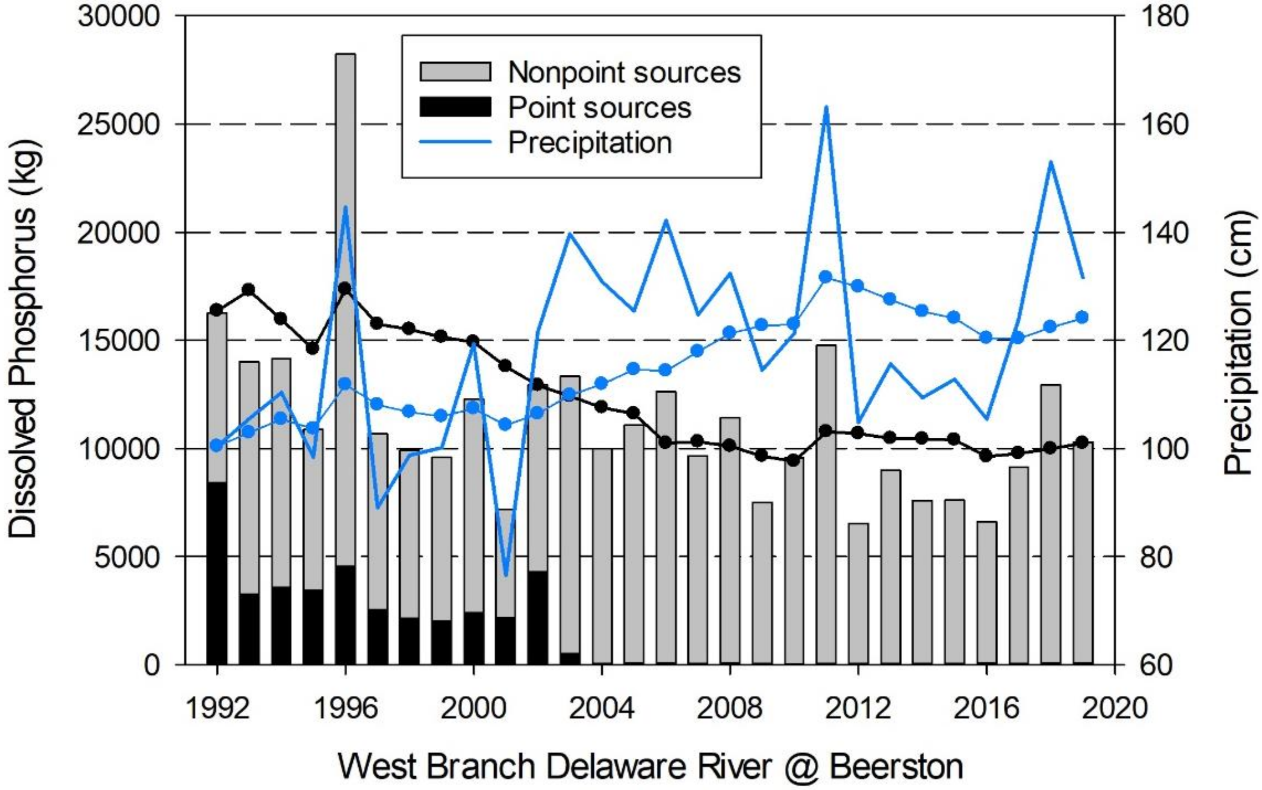


Figure 8.1 Dissolved phosphorus loading and annual precipitation in the West Branch Delaware River at Beerston (1992-2019). Dotted lines are 10-year moving averages of dissolved phosphorus (black) and precipitation (blue).

8.2.1 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). The spatial distribution of runoff by soil wetness index provides a more realistic identification of runoff generating areas in the NYC watersheds, with important consequences for simulation of pollutants typically transported by runoff. Figure 8.2 illustrates the concept of soil wetness classes derived from topographic wetness index for the Town Brook watershed. A wetness map divides the watershed based on increasing soil-water-storage capacity, from downslope to upslope regions and the decreasing likelihood of being saturated.

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. The model also simulates plant growth and nutrient uptake by plants as part of the nutrient cycle, and mechanistically simulates nutrient processes occurring in the soil that may result in buildup or loss of soil nutrients. Influence of septic systems on water quality is simulated using a biozone algorithm (Jeong et al. 2011). A detailed description of the governing equations that the model uses for simulating processes within a watershed can be found in the SWAT User's Manual (Neitsch et al., 2011).

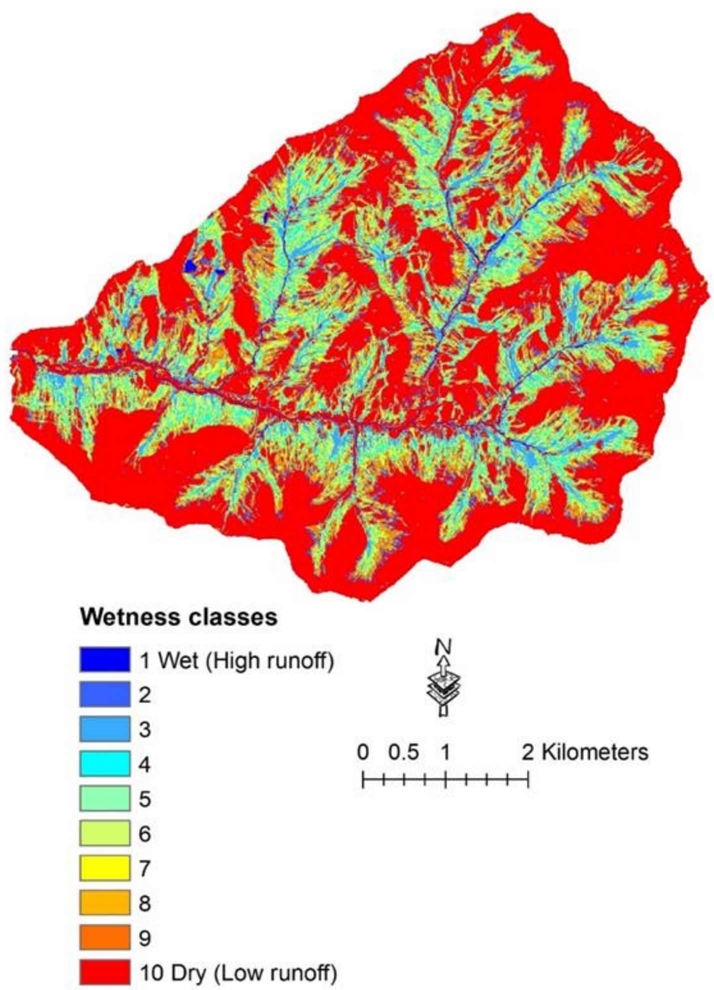


Figure 8.2 Illustration of wetness classes based on topographic wetness index, representing the likelihood of the landscape to saturate and generate surface runoff.

Nutrient loads generated from different land uses, from septic systems, and from point sources are explicitly tracked in SWAT and summed to provide total loads delivered to the watershed outlet. The explicit tracking of loads from different sources is the key to evaluating the effects of watershed management on nutrient loading. Nonpoint source watershed management entails application of BMPs that typically focus on removing nutrients from specific sources. In SWAT-HS, the effects of BMPs on nutrient load is simulated either mechanistically (e.g. nutrient management, cover cropping and septic system upgrades) or a combination of mechanistic and empirical reduction factors derived from the literature (e.g. vegetative buffers).

8.2.2 Point and Nonpoint Source Reduction Programs Evaluated

Wastewater Treatment Plants

Wastewater treatment plant (WWTP) phosphorus loads for the period 1990-2019 were estimated from WWTP effluent monitoring data. For Cannonsville basin, total phosphorus loads from WWTPs were partitioned into 60% dissolved vs. 40% particulate phosphorus for Walton WWTP, and 92% dissolved vs. 8% particulate for the other WWTPs, based on WWTP monitoring data (DEP, 2011). Daily WWTP 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 8.1).

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 (Table 8.1).

Table 8.1 Major livestock counts in Cannonsville watershed based on WAC program data.

Animal type	1997	2001	2005	2009	2013	2018
Dairy	8,428	11,014	4,871	4,228	3,834	3,429
Young Dairy	5,671	5,159	4,333	3,885	4,159	3,468
Beef	350	425	471	588	1,906	2,096
Young Beef	164	327	221	426	1,748	2,366

The total amount of manure produced was estimated based on the number of cattle and their typical daily amount of manure production. This includes the amount of manure deposited during cattle grazing and manure collected in barnyards. These amounts are estimated by multiplying the total manure produced by the proportion of time (hours) spent by cattle outside and inside barnyards. Manure P application rates are estimated from animal unit data, P content of manure, and manure spreading schedule data from the farm program. Table 8.2 shows the estimated manure P generated in the Cannonsville watershed and used as model input. Observed decrease in manure P generated in the watershed reflects changes in farm animal count (Figure 8.3).

Table 8.2 Estimated manure phosphorus (kg) generated in the Cannonsville watershed.

Form	1997	2001	2005	2009	2013	2018
Soluble P	152,000	188,000	95,000	85,000	91,000	85,000
Particulate P	94,000	117,000	60,000	56,000	73,000	73,000
Total P	246,000	305,000	155,000	141,000	164,000	158,000

*Nutrient content of manure derived from ASAE Standards (ASAE, 1998) and SWAT database (Arnold et al., 2013)

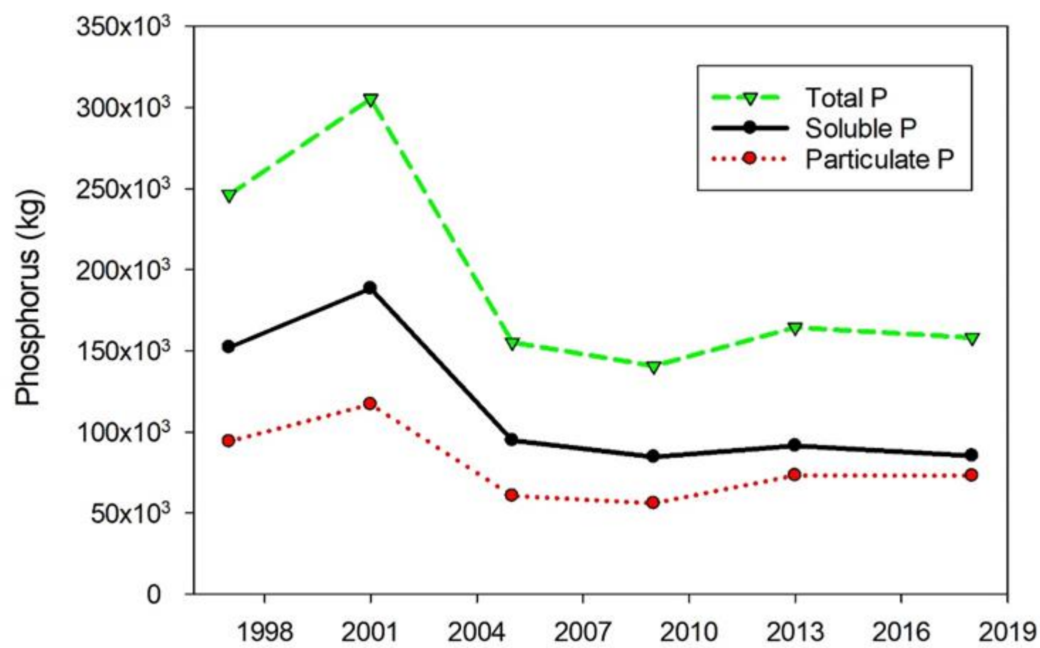


Figure 8.3 Estimated change in manure P production in the Cannonsville watershed

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 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 2,670 kg ha^{-1} of dairy manure, which is equivalent to about 374 kg ha^{-1} dry weight.

To account for the effect of excluding cattle from near-stream areas, the contribution of manure from grazing in areas prone to saturation was removed in pastures based on observations from James et al. (2007) who studied cattle behavior in near-stream zones of four dairy farms in the Cannonsville watershed. The amount of manure removed was uniformly distributed in areas not prone to saturation to reflect management practices adopted since the early 2000s. To capture the effects of building manure storage and improving barnyards, it was assumed this manure was stored in storage facilities, used partly to fertilize croplands, and the remainder was spread in pastures not prone to saturation. Additional details can be found in Hoang et al. (2019).

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 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.

Precision Feed Management

Precision Feed Management (PFM) involves the implementation of the precise balancing of dairy cattle diets for animal requirements and utilizing homegrown feeds to reduce overfeeding and import of purchased feed nutrients, particularly phosphorus, and accumulation of these nutrients in dairy farm soils (DEP, 2009). Delaware County PFM program has demonstrated reductions in annual phosphorus and nitrogen excretions in manure by an average of 22% (5.2 kg/cow/year) and 8% (12.6 kg/cow/year), respectively. Since 2016, the PFM program is a part of the NYC Watershed Agricultural Program (WAP). Recent analysis of manure data in participating farms have demonstrated as much as 30% reduction in manure P content. Due to the dynamic nature of dairy cattle, feeding, and differences between farms, large variations are found in manure P change among farms/herds in response to PFM. Establishing a baseline feed nutrient status is expected to cause the manure nutrient content reduction to trend. Reported net reduction in manure P excretion for the 2018 PFM program year was 1,602 kg. This includes 43 participating dairy farms (32 in the Cannonsville basin, six in the Pepacton and five in the Schoharie basin) and one beef farm in the Cannonsville basin. In comparison, the achieved reduction in P excretion is only 1% of the total manure P produced in the Cannonsville watershed in 2018 (Table 8.2). For 2019, the PFM program reported a net increase in manure P excretion by 5,447 kg showing large inter annual variability. In this context, the impact of PFM on annual watershed input of total P was estimated considering 25%, 50%, and 100% adoption of PFM program in dairy farms across the watershed and, in each case, achieving an ideal target of 30% reduction in net manure P excretion of ~8 kg P/cow/yr. Under these scenarios, the total manure P generated in the Cannonsville watershed in 2018 would have reduced by approximately 9%, 17%, and 35%, respectively. Manure P reductions of such magnitude will take several years to achieve as PFM is a relatively new program and, therefore, water quality impacts of PFM is not attempted.

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 CREP, which focuses on agricultural land, is implemented in tandem with WAP. The goal of the 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. 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 water body 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.

8.2.3 Climate Change Scenarios

The SWAT-HS model calibrated to current conditions was applied to assess the impact of climate change on dissolved phosphorus loading and to determine if a change in climate has the potential to negate any improvements to water quality achieved since 1990s. Land use and management practices were unchanged in the assessment of the change in nutrient loading from baseline (2010s) to end of the century (2099) due to a change in climate alone. The downscaled future climate variables (air temperature, precipitation, relative humidity, and solar radiation) from 20 global climate models (GCMs) was used as input to the model. Additional details of climate scenarios can be found in Section 8.3 and in Gelda et al. (2019).

8.2.4 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 8.3). A scatterplot of simulated and observed dissolved phosphorus loads at the Beerston water quality monitoring site show that simulated and observed values are comparable (Figure 8.4). Time series of simulated and observed monthly average loads shows the model is able to capture the observed variation in loads (Figure 8.5).

Table 8.3 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

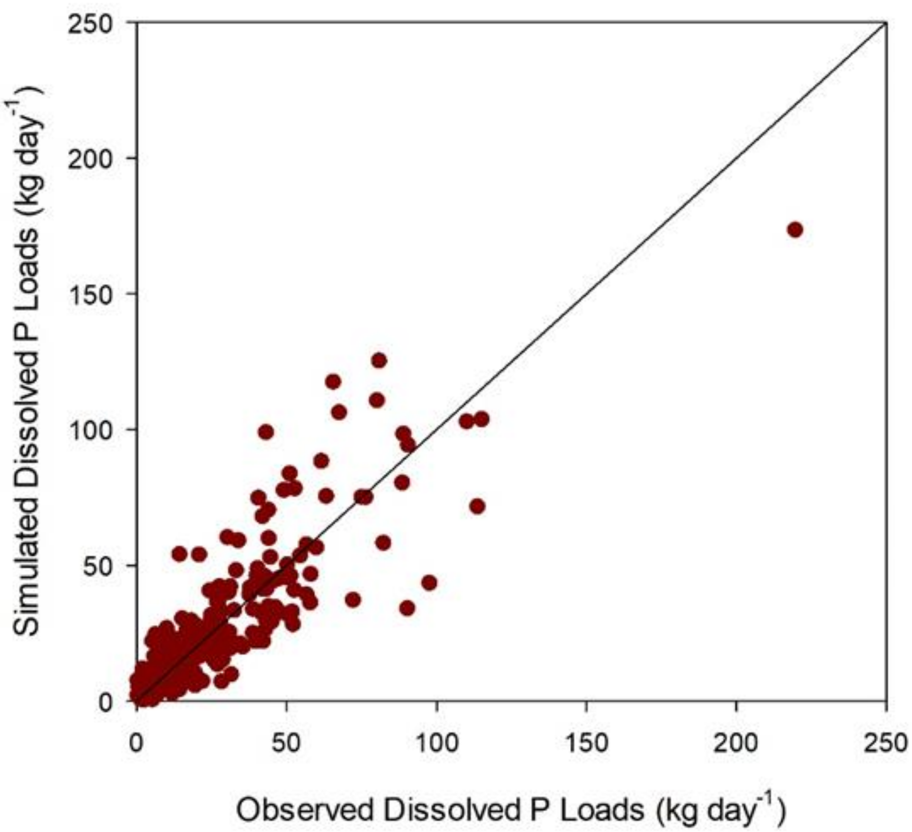


Figure 8.4 Scatterplot of simulated vs observed monthly average dissolved P loads for the period 2000-2019.

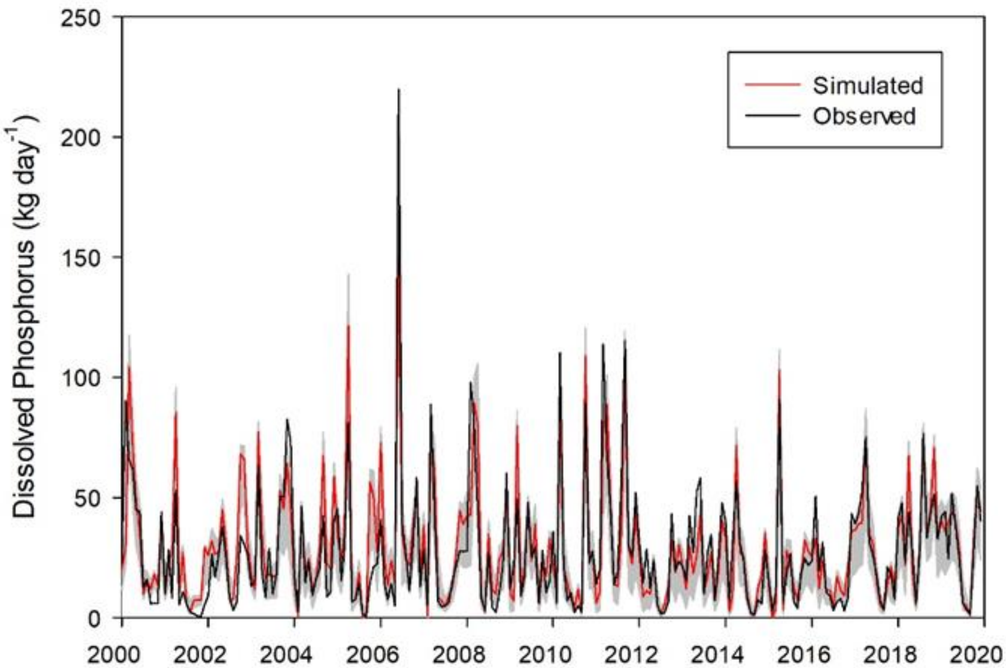


Figure 8.5 Simulated and observed dissolved P loads at Beerston water quality monitoring site. Gray areas indicate uncertainty bounds for predicted values.

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 8.4. Agricultural land uses that occupy a relatively small fraction of the watershed area is 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 8.4 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[ǂ]	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 with farms

[ǂ]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 8.6 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 8.4) 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 8.1). 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).

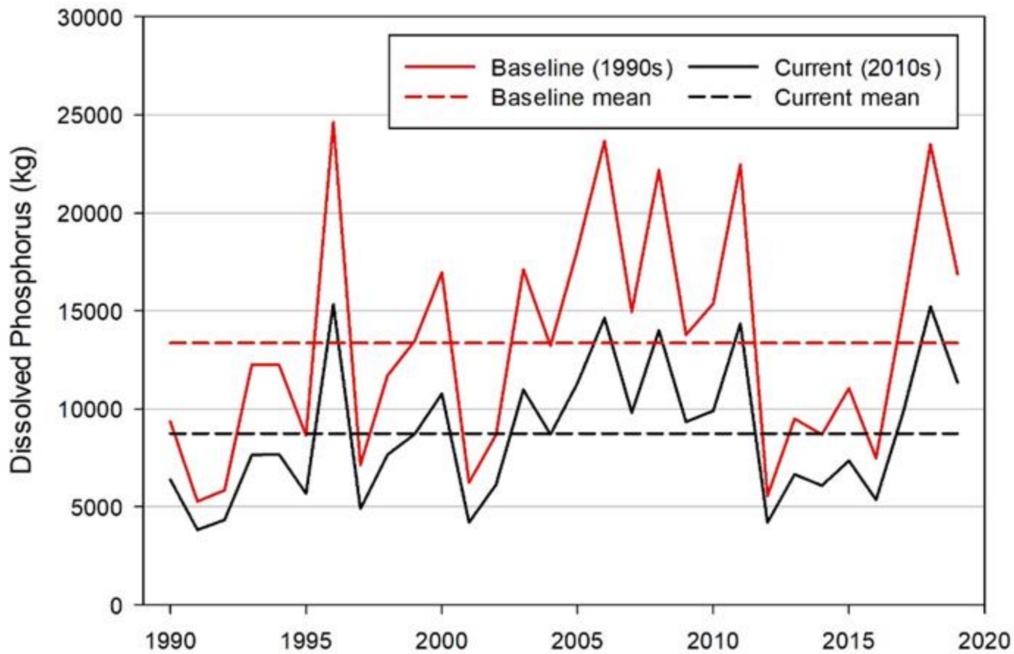


Figure 8.6 Baseline (1990s) vs. current (2010s) scenario based on 30-year continuous simulation under same hydrologic conditions. Point sources are excluded in both scenarios.

Figure 8.7 depicts baseline versus observed scenario predictions of cumulative dissolved phosphorus load at Beerston for 2000-2019. The baseline scenario markedly overestimates (~50%) dissolved phosphorus loads. This is expected given the observed reduction in dissolved phosphorus loadings from 1992 – 2019 (Figure 8.1). Simulated and observed cumulative loads for the period closely matched (~1% overestimation) although the model overestimated during the initial years and underestimated during later years. Overall, these results are similar and consistent with earlier analysis using the GWLF watershed model for the period 2000-2009 (DEP, 2011), and substantiate the ability of SWAT-HS to simulate the observed dissolved P loads under changing nonpoint source management conditions as they occurred.

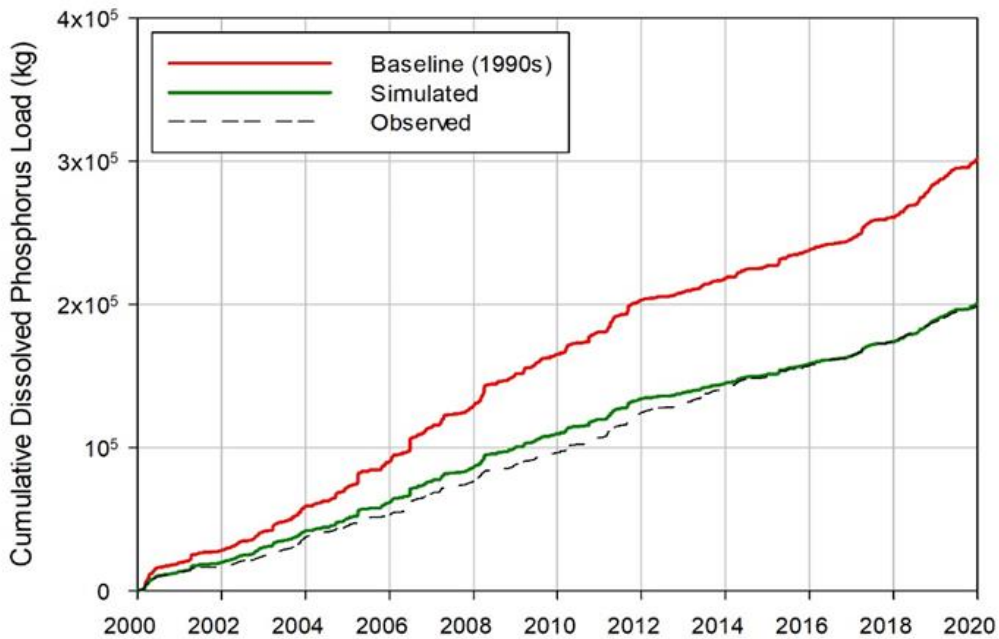


Figure 8.7 Baseline (1990s) scenario versus observed 20-year cumulative loads to estimate reduction in loading from nonpoint sources.

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 8.5 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 8.5 Septic upgrade impact on nutrient loading, 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). This is one of the two alternative approaches in SWAT for simulating field buffers, the other being a simpler method that attenuates pollutants in runoff directly as a function of the field buffer width. The VFS method is more appropriate considering the semi-distributed nature of SWAT and reflects the impact of concentrated flows (Lee et al. 2020). One of the important parameters in the VFS method is the fraction of the field area to buffer area estimated using the total area of riparian buffers on agricultural land (cropland and pasture combined). Two sets of scenarios were simulated in addition to scenarios with 100% and no vegetative buffer on agricultural lands (Table 8.6). 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 8.8 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.

Table 8.6 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)

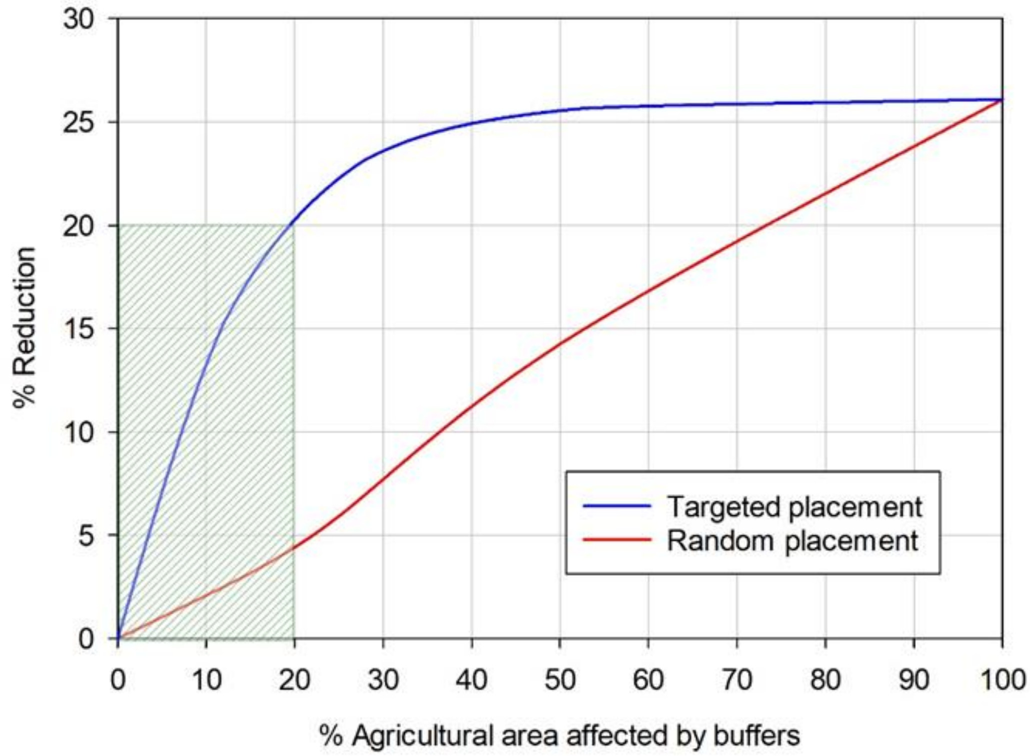


Figure 8.8 Effect of targeted vs random placement of buffers on dissolved phosphorus loading. Shaded area represent likely level of current implementation.

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 2010-2019.

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 (Table 8.7). 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 the R25 scenario that represent 25% of corn fields 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 (Figure 8.9). 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. Avoiding cover cropping in the wettest 10-20% of cropland areas seems to minimize any negative impact on water quality (Figure 8.9).

Table 8.7 Winter cover crops scenarios simulated

#	Scenario	Description
1	R0	Simulation without winter cover crop
2	R10	Winter rye as cover crop in 10% of cropland HRUs
3	R25	Winter rye as cover crop in 25% of cropland HRUs
4	R50	Winter rye as cover crop in 50% of cropland HRUs
5	R100	Winter rye as cover crop in 100% of cropland areas
6	WC4-10	No cover crop in wettest 10.5% (wetness classes 1-3) of cropland areas
7	WC6-10	No cover crop in wettest 23.4% (wetness classes 1-5) of cropland areas
8	WC9-10	No cover crop in wettest 46.7% (wetness classes 1-8) of cropland areas

Assessment of Climate Change Impact

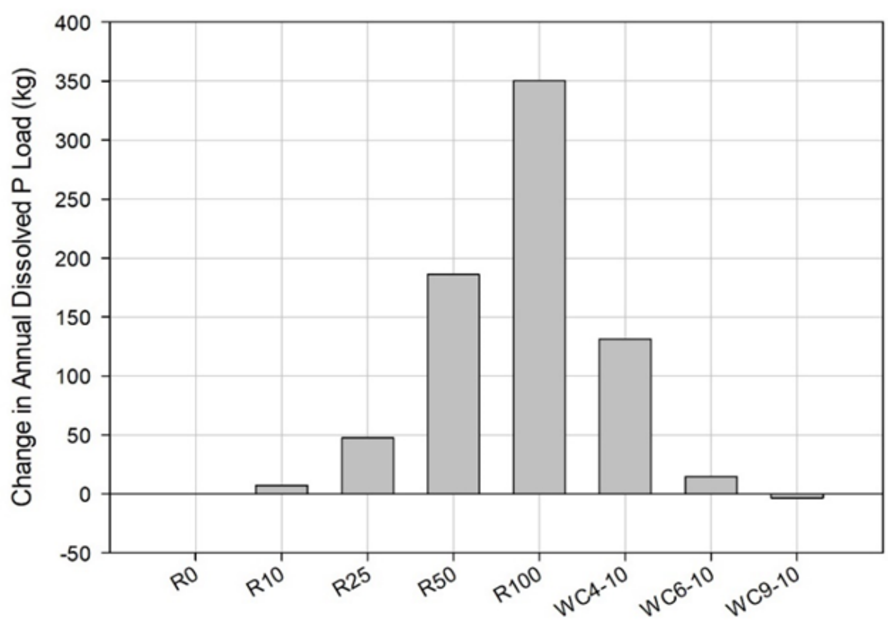


Figure 8.9 Impact of winter cover crops on annual dissolved P loads at Beerston.

Future climate impact on inter-annual variation in dissolved phosphorus loads over decades starting from 2010s shows a moderate increase in mean annual loads of about 3.8% in 2050s although the annual loads where within similar ranges (Figure 8.10). By the end of the century (2090s), the mean annual loads may increase by about 9.2%, and the range in annual loads may widen especially at the higher end. An increase in frequency and magnitude of large storm events and its impact on nutrient loading in the Cannonsville watershed under future climate has been previously reported (Mukundan et al. 2020). Records show that although large streamflow events have occurred in the recent past (e.g. June 2006, August-September 2011), a long-term impact on reservoir water quality due to excess nutrients from these events has not occurred. The observed decreasing trend in soil P values over the past 20 years (Dewing, personal communication) in several farms in the watershed as reported in NASEM (2020) is promising. Although this modeling analysis assumed constant management input in agricultural lands, observed reductions in soil P levels due to changes in management practices over the years may result in a long-term watershed response that attenuates the contribution of P in runoff. Therefore, the actual loading of dissolved P in response to future climate could be lower than predicted in this modeling analysis. In addition, the uncertainty in projected future climate is greater toward the end of the century when compared to the middle of the century.

8.2.5 Summary of Watershed Modeling Evaluation

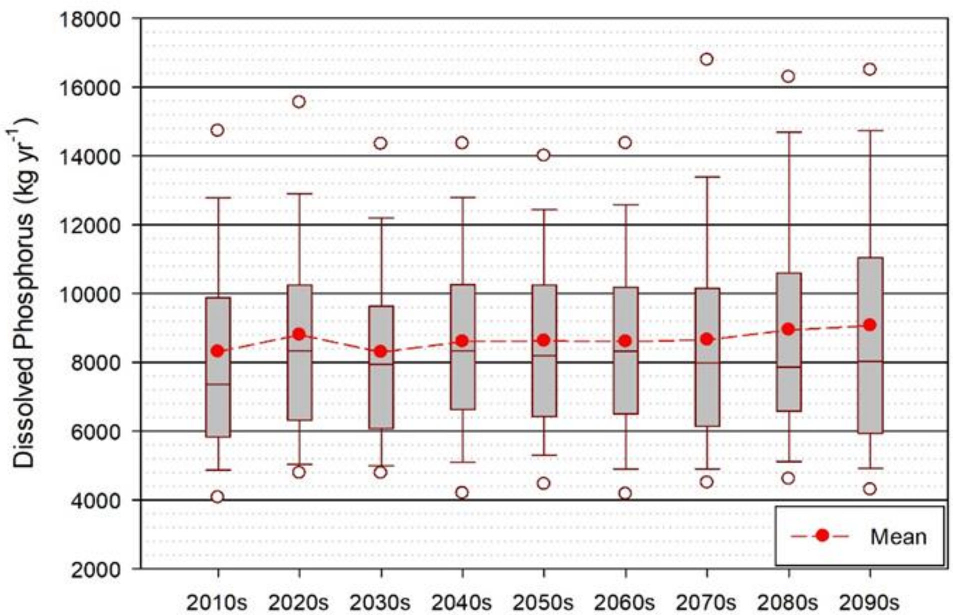


Figure 8.10 Simulated annual dissolved P loads at Beerston under future climate. Each boxplot is based on 200 values (20 GCMs x 10 years). Minimum and maximum values shown are the 5th and the 95th percentile values.

This modeling analysis describes the application of the recently developed SWAT-HS watershed model to assess stream loading of dissolved P in the Cannonsville watershed. The spatial distribution of runoff by soil wetness classes predicted by this model provides a more realistic identification of runoff generating areas in the NYC watersheds, and simulation of pollutants transported by runoff, when compared to earlier modeling analyses. The calibrated 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. An assessment on the potential impact of climate change using future climate scenarios is also included.

Water quality monitoring data indicate a decline in annual dissolved P loading over the past 30 years even though the mean annual precipitation increased during the same period. A comparison of model scenarios of 1990s watershed conditions with that of 2010s representing current watershed conditions, subject to same hydro-climatic conditions, show nonpoint source contributions of dissolved P have decreased by ~35%. This is in addition to reductions in point source contributions. Current contribution of point sources is less than 1%, a 98% reduction from early 1990s, indicating that upgrades to WWTPs continue to result in reduced phosphorus loading into Cannonsville streams. Agricultural activity in the watershed is currently the single most dominant anthropogenic source of dissolved P in the watershed, contributing about 42% of the mean annual loads. Forests that occupy a vast majority of the watershed area contributes an equal amount to background levels of dissolved phosphorus.

Simulations depicting the impact of septic systems repair in the watershed during the period 2010-2019 indicate the Septic Remediation and Replacement Program has contributed to a 2.9% reduction in average annual dissolved P loads. Scenarios on the impact of vegetative buffers on agricultural lands show the potential to reduce the annual loads by as much as 25%. Targeted planting of buffers in near stream riparian areas appears to provide the maximum benefit compared to random planting of field buffers across the watershed. The concept of targeting the dominant runoff generating areas is applicable to most BMPs where the goal is to minimize nutrient export in runoff. Simulations 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.

Winter cover cropping has become a widely adopted conservation practice in recent years to reduce soil erosion and improve water quality in the Cannonsville watershed. While cover cropping is generally considered a beneficial practice to improve water quality, SWAT-HS simulations were able to identify sensitive areas in the landscape where cover cropping may not be the best option for dissolved P reduction. These are the lower landscape positions with saturated soils; this conclusion based on modeling is consistent with an independent field study in the Cannonsville watershed. Model simulations suggest that avoiding cover cropping in near stream, saturated areas seems to reduce any potential negative impact on water quality.

Assessment of future climate impact indicate a moderate increase in dissolved P loading by the middle of the century and continuing through to the end of the century. The projected magnitude of increase is small when compared to reductions in loadings achieved over the years. The reported decreasing trend in soil P values in several farms in the watershed suggest the actual increase in loadings due to a change in climate may be smaller than predicted in this modeling analysis.

In this assessment period, the SWAT-HS model simulated the observed dissolved P loading in the Cannonsville watershed. The simulated loads closely matched the observed loads for the recent periods (2000-2019) and were much lower than loads predicted under the 1990s scenario, indicating significant reduction in nonpoint sources over the years. While the relative importance of eutrophication has declined in recent years, maintaining the dissolved P loading rates at the current levels is important for long-term maintenance of the high quality of drinking water.

8.3 Reservoir Modeling and Operations Support Tool Applications

8.3.1 West of Hudson Reservoirs Turbidity Models

During the FAD assessment period, DEP completed the development and testing of turbidity models for Cannonsville, Pepacton, and Neversink 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 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, Rondout, and Kensico reservoirs (Gelda and Effler 2007, Gelda et al. 2009, 2012, 2013). With this work, DEP has turbidity models for all six West of Hudson 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; that task will be completed in the future. A brief summary of the modeling of Cannonsville Reservoir is as follows. Performance of the Pepacton and Neversink reservoir models is similar to that of the Cannonsville model and will be documented separately.

Cannonsville Reservoir

Model setup: The 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 and thickness 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 8.11. 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 (r2 = 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 QWBDR = West Branch Delaware River inflow (WBDR) ($m^3 s^{-1}$). All inflows and outflows were specified in the model at a daily timestep.

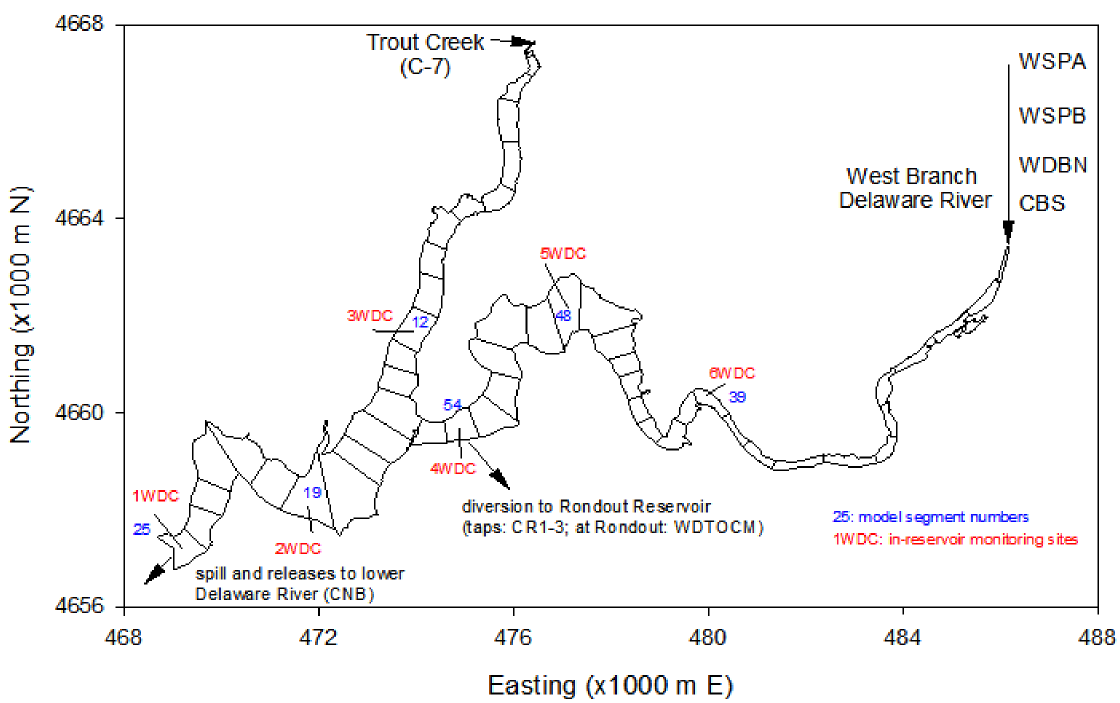


Figure 8.11 Cannonsville Reservoir: Inflows, outflows, in-stream and in-reservoir routine water quality monitoring locations, and w2 model segments. Selected model segments are also numbered according to the numbering scheme of w2.

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 Binghamton Airport and from the DEP site at Cannonsville Dam. Data from the dam site were correlated with that from the airport site. Then using these correlations, long term data for the model were generated.

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

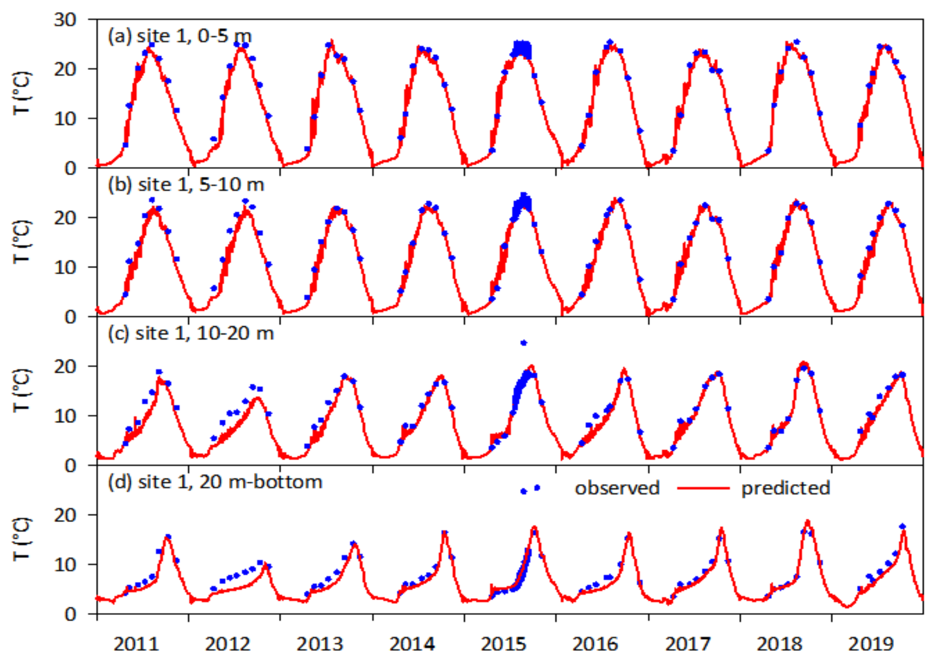


Figure 8.12 Comparison of observed and predicted values of volume-weighted average temperatures in selected layers of water at site 1WDC in Cannonsville Reservoir, 2011-2019: (a) 0-5 m, (b) 5-10 m, (c) 10-20 m, and (d) 20 m-bottom.

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 8.12). RMSE (root mean square error) was 1.2 °C for 0-5 meters, 1.0 °C for 5-10 meters, 1.1 °C for 10-20 meters, and 1.4 °C for 20 meter-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 °C - 1.5 °C 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 8.13), and release plus spill (site CNB) temperatures. RMSEs were 1.9 °C and 2.1 °C 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 **Error! Reference source not found.**, for example, for August 2017-August 2019 interval). Turbidity in WBDR approached 300 NTU during the August 2018 storm and 200 NTU during the April 2019 storm. The model simulated the timing, location and magnitude of peak impact and subsequent attenuation well Figure 8.14). 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 September-October period (Figure 8.14**Error! Reference source not found.**, profiles 55-55 in 2017; and profiles 73-80). Effler et al. (2009) documented formation of BNL as a recurring phenomenon in this reservoir during the typical drawdown period of summer through early autumn. Formation of

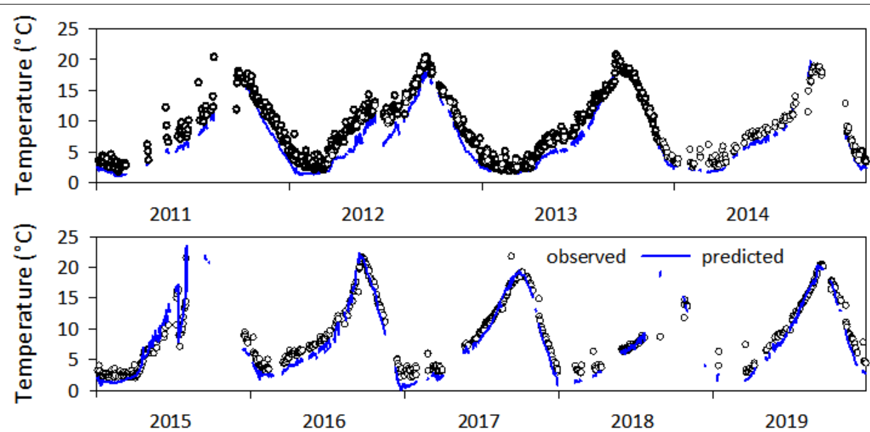


Figure 8.13 Performance of the model for Cannonsville Reservoir presented as comparison of observed and predicted time series of withdrawal temperatures, 2011-2019. Observations are recorded at site WDTOCM at the point of discharge into Rondout Reservoir.

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

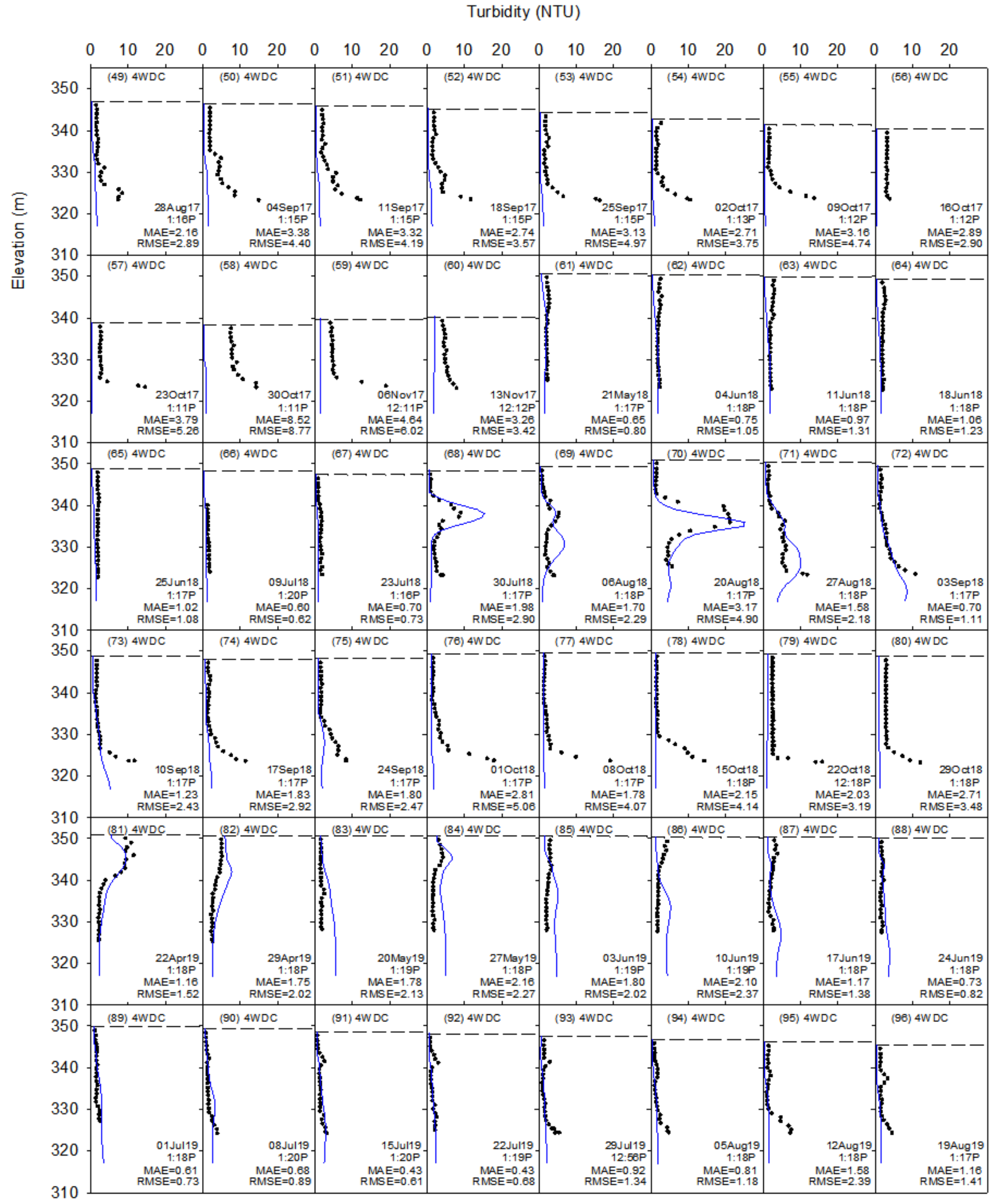


Figure 8.14 Performance of the model for Cannonsville Reservoir presented as comparison of selected predicted and observed vertical depth profiles of turbidity at site 4WDC. MAE and RMSE indicate mean absolute error (°C) and root mean square error (°C), respectively

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 8.15). Turbidities when the withdrawal was off would have been generally > 10 NTU. Underprediction during the 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.

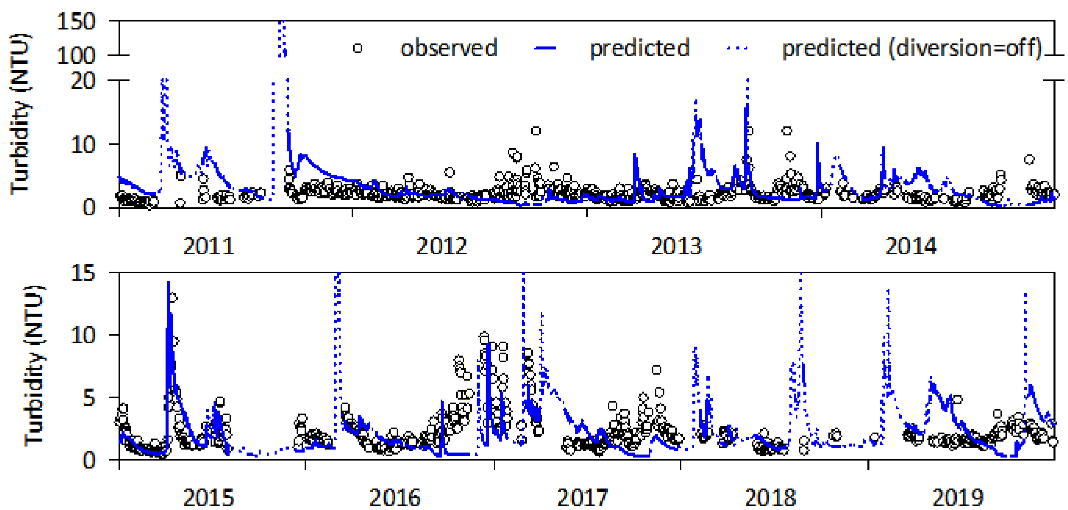


Figure 8.15 Performance of the model for Cannonsville Reservoir presented as comparison of observed and predicted time series of withdrawal turbidities, 2011-2019. Observations are recorded at site WDTOCM at the point of discharge into Rondout Reservoir.

8.3.2 Assessment of Climate Change Impacts on Water Supply System

During this FAD reporting period, DEP assessed impacts of climate change on the drinking water supply. A detailed reporting of that assessment is given by Gelda et al. (2020); a summary is given here. Models of global climate, watershed hydrology and water quality, receiving waterbodies, and system operations were linked (Figure 8.16), and simulations were conducted for an array of future climate scenarios. We developed GCM-scenario combinations using output from 20 GCMs and two RCP (greenhouse gas emission) scenarios (RCP 4.5 and RCP 8.5; total = 20 × 2 = 40) for Catskill and Delaware watersheds centroids and reservoirs, and the terminal Kensico Reservoir locations (Gelda et al. 2019).

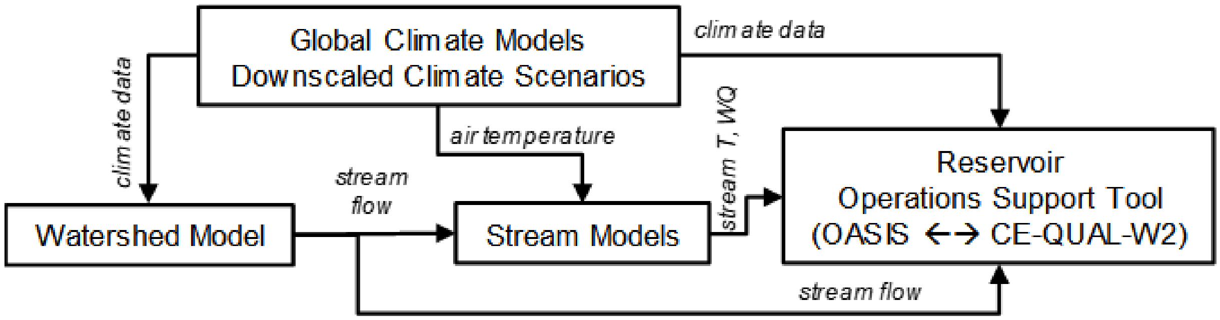


Figure 8.16 System of models for assessing impact of climate change on NYC's water supply system. Stream T, WQ refers to stream temperature and water quality; OASIS and CE-QUAL-W2 are reservoir operations and reservoir water quality models, respectively.

The temperature and precipitation changes as projected according to the 20 GCMs and two climate scenarios for Ashokan Reservoir watershed are presented in Figure 8.17. All projections indicate warmer climate while six projections indicate decrease in precipitation by up to 5% and in one projection by 10%, for 2041-2060 as compared to for 2001-2020 interval. Typical magnitude of increases in annual average daily temperature and precipitation are 2 °C and 5%, respectively for all NYC watersheds.

Multi-model ensemble average values of snowfall and snowpack indicate a decreasing trend in both metrics. From the baseline conditions of 2001-2020 to future conditions of 2041-2060, annual snowfall is projected to decrease by 25% and annual snowpack (by March 15) is projected to decrease by 54% in the watershed, with potential to decrease further in late century. Decrease in snowfall is a direct result of warmer temperatures causing more of the precipitation to fall as rain, and melting of snowpack earlier in the year. These changes in snowpack accumulation and melt manifest into increased streamflow during December through mid-March, and decreased streamflow during mid-March through April. December-mid-March streamflow in Esopus Creek at Coldbrook is 27% higher for 2041-2060 than for 2001-2020, while mid-March-April flow is 14% lower. Average summertime low flow is largely unchanged, and annually, streamflow is greater by 6%. See Mukundan et al. (2019) for further analyses on impact of climate change on streamflow in the streams of the NYC watershed.

Annual changes in inflow, release, spill, diversion, and storage components of the water balance for the Delaware and Catskill subsystem of reservoirs are presented in Table 8.8. Notable differences between the current and future operations on an annual basis are reduced diversion from Catskill subsystem (–3%) and increased use of Ashokan Release Channel (+30%) to release water from the West Basin (Table 8.8).

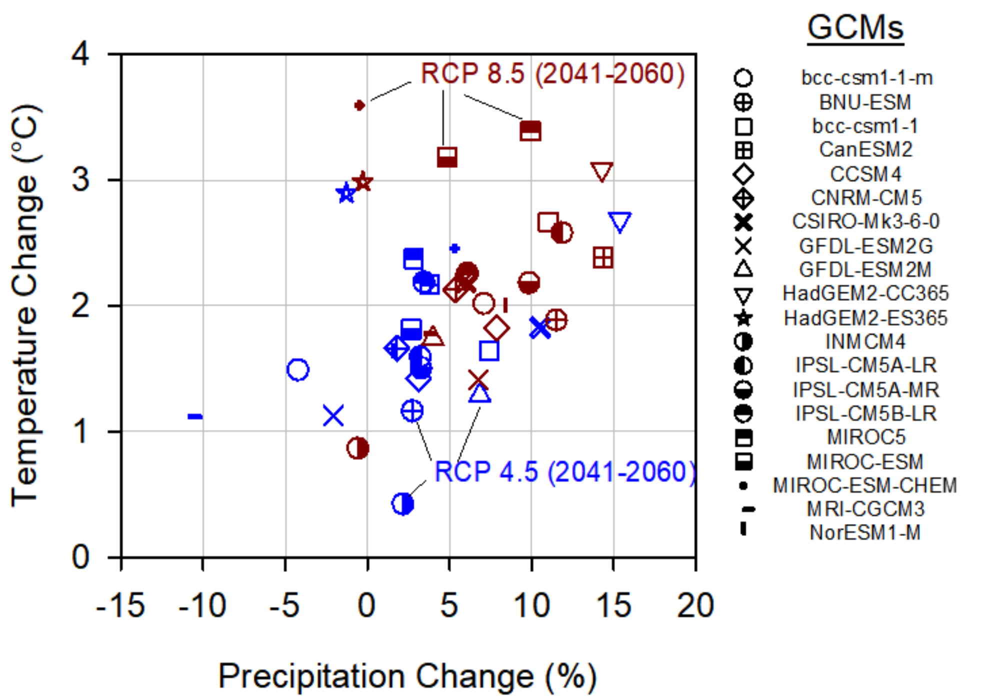


Figure 8.17 Change in annual average temperature (°C) and precipitation (%) from 2001-2020 to 2041-2060 under climate scenarios of RCP 4.5 and RCP 8.5 for Ashokan Reservoir watershed, as projected by 20 GCMs.

Reduced diversion from the Catskill subsystem is due to increase in turbidity in the future. In response to a warming climate, stream temperatures are projected to rise by about 1.4 °C on average in the watershed for 2041-2060. The combined effect of warmer streams and warmer air temperature will be increased in-reservoir and diversion temperatures. Monthly average temperatures of diversion from Schoharie Reservoir via Shandaken Tunnel is expected to rise by 1 °C. We have not yet evaluated the impact of warmer discharges from the Shandaken Tunnel on the health of ecosystem of Esopus Creek, particularly cold water fishery habitat.

Table 8.8 Annual average and percent change in components of reservoir water budget from baseline (2001-2020) to future (2041-2060) conditions using climate projections from an ensemble of 20 GCMs under climate scenario of RCP 8.5.

	Delaware subsystem			Catskill subsystem		
	Baseline	Future	% Change	Baseline	Future	% Change
Inflow (m^3 s^{-1})	52.68	55.68	6	31.44	33.43	6
Release (m^3 s^{-1})	23.51	24.28	3	3.09	4.00	30
Spill (m^3 s^{-1})	3.82	3.53	-8	11.15	12.52	12
Diversion (m^3 s^{-1})	24.12	26.40	9	16.39	15.94	-3
Storage (m^3)	1.03 x10^9	1.05 x10^9	1	4.53 x10^8	4.60 x10^8	2

10^9 m^3 = 264.17 billion gallons; 1 m^3 s^{-1} = 22.8245 million gallons per day

Computed turbidity for the baseline and future periods from 20 GCMs were analyzed to discern changes in frequency and magnitude of extreme events. Daily turbidities in excess of 100 NTU are slightly more likely to occur for the future conditions than for the baseline conditions in Rondout, Schoharie, and Esopus creeks (Table 8.9). Furthermore, extreme turbidity levels, such as 99.9th percentile (corresponding to approximately once every 33 years) will likely increase by varying magnitude (typically 50%), with the possibility of a decrease in Rondout Creek during January-February.

Table 8.9 Recurrence interval (years) of selected threshold levels of turbidities in three tributaries for baseline (2001-2020) and future (2041-2060) conditions using climate projections from an ensemble of 20 GCMs under climate scenario of RCP 8.5.

Turbidity Level (NTU)	Rondout Creek		Schoharie Creek		Esopus Creek	
	Baseline	Future	Baseline	Future	Baseline	Future
50	1.4	1.2	0.2	0.2	0.2	0.1
100	5.3	2.8	0.6	0.5	0.4	0.3
200	13.8	8.4	1.6	1.2	1.0	0.7
500	44.4	28.2	5.3	4.0	3.7	2.5
1000	80.0	131.7	15.4	10.4	9.1	6.8

Impact on Reservoir Diversion Water Quality: Assessment of turbidity in the diversion waters under future conditions not only reflect the impact of climate but also the impact of dynamically adapting reservoir operations to those changing conditions. Results from the linked reservoir operations and water quality model runs within OST indicate there may be modestly higher frequency of exceedances of selected turbidity levels, though none reach a level of concern (Figure 8.18).

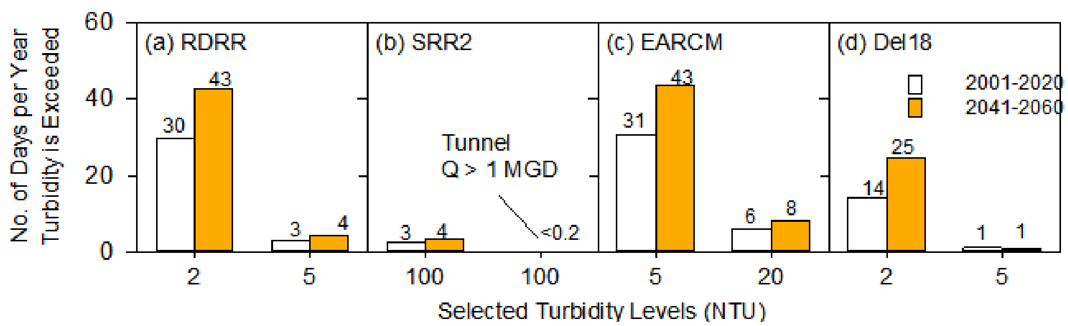


Figure 8.18 Predicted number of days per year when turbidity is exceeded by specific levels at a. Rondout Reservoir diversion, RDRR; b. Schoharie Reservoir diversion, SRR2; c. Ashokan Reservoir diversion, EARCM; and d. Kensico Reservoir diversion, Del18, for baseline (2001-2020) and future (2041-2060) climate scenarios (20 GCMs; RCP 8.5).

For example, Rondout Reservoir diversion turbidity may exceed 2 NTU on 43 days y^{-1} in the future as compared to 30 days y^{-1} under the current baseline conditions. Exceedances of 5 NTU will increase from 3 to 4 days y^{-1}. Turbidity in the diversion from Kensico Reservoir is simulated to exceed 5 NTU 1 day y+ for both the current and future climate conditions. This result suggests updating operating rules in OST will be required because other than instances caused by short, localized events, 5 NTU has never been exceeded during actual historical operations in the baseline period.

System Performance Indicators: The NYC Water Supply System is a within-year system, i.e., it refills each year, in contrast to over-year systems which contain multiyear drawdown periods and are seldom full. This study found average standardized net inflow index (Vogel 1999), m = 2.4 (range 1.6 – 3.6) for the future climate as compared to m = 2.3 (range 1.5 – 3.4) for the current climate, indicating that the NYC system remains a within-year system, which is consistent with the 6% increase in average inflow. The probability of the system delivering its stated yield in a year following failure remained very high (median r = 0.98; Figure 8.19). The steady-state probability of delivering its yield, without failure, in a given year was also very high (median Ra = 0.993; Figure 8.19 b). Vulnerability remained substantially less than unity, suggesting that the system will always recover within a year (Figure 8.19 c).

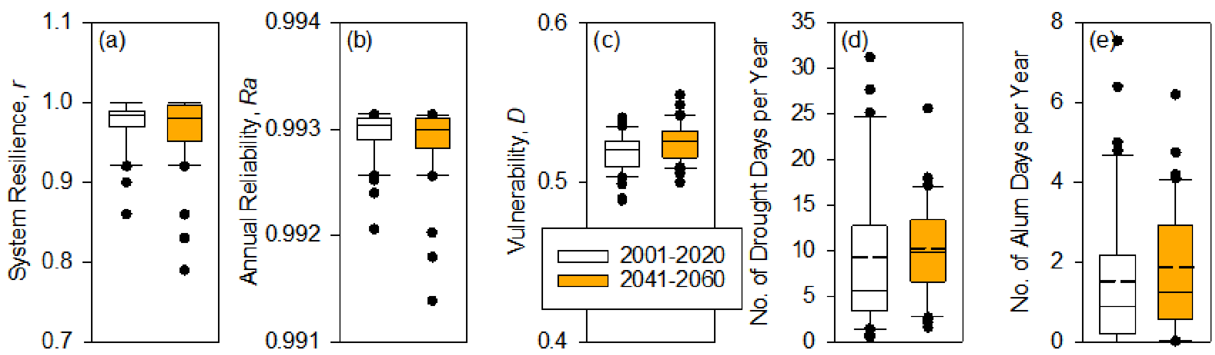


Figure 8.19 Performance indices of NYC water supply system for baseline (2001-2020) and future (2041-2060) climate scenarios (20 GCMs; RCP 4.5 and RCP 8.5 combined): a. system resilience; b. annual reliability; c. vulnerability; d. drought days; e. alum addition days.

Average number of days when the water supply system is under watch, warning or emergency drought conditions remain generally unchanged for the future conditions (8–10 days per year; Figure 8.19 d). However, the variability resulting from different scenarios is reduced for the future conditions likely due to increased inflow and absence of any prolonged multi-year dry periods in the future. An important water quality metric for the NYC system is the use of alum to reduce turbidity. On average, alum may be required for < 2 days y^{-1} (range 0–8 days, y^{-1}) under all, baseline and future, climate scenarios investigated here (Figure 8.19 e). Overall, all future climate scenarios continue to project high resiliency, reliability and low vulnerability of the system with minimal impact on water quality. For further details see Gelda et al. (2020).

8.3.3 Application of Models to Support Operational and Planning Decisions

DEP continued to use mathematical models such as W2 and OST to guide reservoir operations as well as long-term planning decisions during the FAD assessment period. Selected examples of model applications are summarized here.

<u>Applications for planning purposes</u>:

Rondout-West Branch Tunnel (RWBT) Shutdown Evaluation: The purpose of this evaluation was to estimate the impact of a lapse in alum treatment (“alum gap”) at Kensico Reservoir during the RWBT shutdown. In all, 36 scenarios were investigated encompassing a range of alum gap durations of 1-7 days, Catskill Aqueduct flow scenarios (no reduction, and reduction from 636 to 275 during gap), Catskill Aqueduct turbidity scenarios, and three initial turbidity levels in Kensico. Both the daily median turbidity, and the daily maximum turbidity of all traces (addressing uncertainty in meteorology), were predicted to be less than 5 NTU in all scenario runs (WWQAR 2018).

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 and transported to the 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.

<u>Applications for operational purposes:</u>

April 7, 2016: OST was used to evaluate various scenarios when heavy precipitation was expected to move into the region on April 8, 2016. Esopus Creek peak flow was projected to peak at ~3,500 CFS, and the Ashokan West Basin storage void was less than 500 MG. Management questions were related to the impact of increasing the dividing weir flow to 1 BGD to avoid spilling over, and if this could be done without significant impact on the water quality of the East Basin. In addition, with Ashokan storage below the conditional seasonal storage objective, it may be desirable to increase the flow at Shandaken Tunnel Portal (STP) from 300 MGD to 400 MGD. Could there be any water quality concerns in these scenarios?

For all scenarios, STP turbidity at SRR2CM was projected to trend downward gradually from 15 NTU to 9 NTU over the next four weeks. The probability of exceeding 10 NTU at EARCM was predicted to be less than 10%. The results also indicated there would be little benefit in turning off the STP, consistent with the findings of an earlier study that the contribution of STP to the total turbidity loading to Ashokan Reservoir is generally lower during high runoff events (UFI, 2007). At the 90th percentile, an early benefit of dividing weir flow at

2,000 MGD was predicted but it was short-lived. After April 13, 2016, runs with dividing weir flow as 1,500 and 2,000 MGD predicted higher turbidity.

June 6, 2016: OST was used to evaluate the impact of a turbid plume entering into Schoharie Reservoir. For selected operational scenarios, the turbid plume in Schoharie Creek was shown to have no impact on SRR2CM turbidity.

July 11, 2016: Approximately 7 inches of rainfall occurred during July 8-9, 2016, in the East Mountain Brook region of the Rondout watershed. This triggered localized bank failures resulting in turbid discharge into Rondout Creek. Immediately following the storm, turbidity at the mouth of Rondout Creek was > 1250 NTU, and within two days of the storm the turbidity was 20–30 NTU in the upstream portion of the reservoir. Model runs were conducted to answer questions such as what and when will be the peak turbidity at the point of diversion (RDRR) and how long would it take before turbidity level returns to normal (pre-storm). Predictions indicated that for the first seven days, turbidity was expected to be above 1 NTU (probability of exceedance 100%) but below 2 NTU (probability of exceedance 0%). By early August, it was projected to exceed 3.5 NTU with 25% probability. These outcomes allowed managers to adjust operations so as to minimize the impact. Additional runs with updated hydrologic forecasts, changed operations of the upstream reservoirs as well as Rondout Reservoir, and updated in-reservoir initial conditions provided further guidance to managers on the optimum operation strategy for Rondout and its upstream reservoirs. Turbidity was projected to remain well within the tolerance limit for this reservoir for the entire duration of these runs; these forecasts were later confirmed by observations.

January 12, 2017: The Rondout-PA (Position Analysis) model was used to evaluate the impact of turbid discharge from Cannonsville Tunnel. On January 12-13, 2017, a moderate rain event (peak flow at WBDR 3330 CFS) caused elevated discharge and turbidity (~ 100 NTU) at the mouth of WBDR (monitoring site CBS), which entered Cannonsville Reservoir as turbid plume reaching the intake and resulting in elevated turbidity (10 NTU) at WDTO on January 18, 2017. Turbidity at Rondout diversion (RDRR) was projected to remain ~ 1 NTU in the near term.

May 1, 2020: Kensico Reservoir turbidity modeling was done to assess if alum addition was required during the planned reopening of Catskill Aqueduct on May 6, 2020 following the Catskill Aqueduct Rehabilitation and Repair (CatRR) biofilm removal project. Various combinations of Catskill Aqueduct flow (300–500 MGD), duration of transition period (24–48 hours), Catskill Aqueduct turbidity (range of 10–100 NTU during the transition period and 1.5 NTU thereafter) were considered. Other specifications included pre-flushing of Catskill Aqueduct with water from CDIS4 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 all plausible scenarios. In the days following the reopening, no alum was necessary and turbidity level at Delaware Aqueduct Shaft 18 remained < 1 NTU.

8.3.4 Ancillary Tasks Related to Reservoir Modeling

Meteorological data extension: As recommended by OST Expert Panel (NASEM 2018), during 2019, the meteorological dataset underlying OST was extended up to 2018 to include recent climate change and associated hydrologic conditions. This resulted in an additional 20 traces, bringing the total to 68 traces for a typical position analysis run.

Global Ensemble Forecast System (GEFS) Weather Data Verification: Forecasts of weather variables (minimum and maximum temperatures, and precipitation) provided by GEFS of NOAA were explored for possible direct use by DEP's hydrologic models. The GEFS forecast consist of 11 equal probability members of an ensemble at 3-hour interval for days 1-8 and one-half degree latitude/longitude spatial resolution, and at 4-hour interval for days 8-16 at two-thirds degree spatial resolution. It was found these forecasts had systematic bias and could not be used without correcting for the bias.

Data Analyses to Support Model Development: To support development of turbidity models for Cannonsville, Pepacton, and Neversink reservoirs, some of the ancillary tasks completed were: (1) regression analysis of meteorological variables observed at watershed sites and offsite (National Weather Service) locations, (2) development of empirical stream temperature models for the West Branch Delaware River at Cannonsville Reservoir, and Neversink River at Neversink Reservoir, and (3) development of discharge-turbidity rating curves for the tributaries of Cannonsville, Pepacton, and Neversink reservoirs.

Relative Contribution of Turbidity Loads from Esopus Creek versus Shandaken Tunnel: This analysis was updated in 2016 and again in 2019. The contributions from the Shandaken Tunnel have continued to remain very low for the entire period of the analysis.

Probabilistic Model for Rondout Reservoir: A stand-alone probabilistic forecasts model for Rondout Reservoir (Rondout-PA) was developed prior to the integration of Rondout W2 model into OST. Rondout-PA had the added capability of using short-term ensemble forecasts of hydrological inputs, turbidity, and climatology as the model drivers, and generating probabilistic forecasts of turbidity. Now that the Rondout W2 has been integrated into OST, Rondout-PA is no longer used.

8.3.5 Development and Testing of a UV_{254} Model for Cannonsville Reservoir

The 2017 Filtration Avoidance Determination includes a required ongoing activity to "develop and test fate and transport models for organic carbon and disinfection byproduct (DBP) precursors in Cannonsville and Neversink reservoirs." DEP's current long term plan is to develop, test, and validate a model that predicts DBP precursors as quantified by trihalomethane and haloacetic acid formation potential, beginning with Cannonsville and Neversink. Prediction of the formation potential of the source waters supplied by reservoirs is believed to be the best predictor of the DBP concentrations that would occur in the distribution system. Routine monitoring for DBP formation potential in the tributaries, reservoir water column, and keypoints of these two reservoirs began in 2015. At the same time, monitoring for a number of "optical proxies" for DBP precursors was initiated. Due to the expense and, more importantly, the time associated with formation potential tests, the identification of an optical proxy that would allow the accurate estimate of formation potential concentration from a proxy measurement would be extremely valuable. An optical proxy would allow a field measurement to be reported in near real time. With an accurate relationship between the proxy and formation potential, the precursor concentration can then be estimated. High-frequency optical measurements allow the variation of precursor levels over time scales as short as minutes to be estimated.

The monitoring in tributary streams, reservoirs, and keypoints that is necessary to support this effort involves the high-frequency measurement of candidate optical proxies together with low-frequency measurements of THM and HAA formation potential. At the end of 2019, the following is a summary of the status of this effort.

An accurate relationship between an optical proxy and formation potential has not been identified. Using the data collected to date, there is a significant amount of scatter and uncertainty in relationships between single or multiple proxies and formation potential. This is true even when samples are limited to a single system - either Cannonsville or Neversink. When data from both systems are combined, the variability is greater. We may be obtaining this current result for the following reasons. First, it may simply be the case that none of the optical measurements are a good proxy for the conditions that exist in these two reservoirs and watersheds. A review of the attempts by other researchers to identify a proxy relationship in other water supplies has generally had the same results. An accurate optical proxy may simply not exist.

Second, we may not have collected enough data to be able to say with confidence that we have a relationship that is reliable over the range of climatic and hydrologic conditions existing in these watersheds. We know the hydrologic conditions in the West of Hudson watersheds over the last four years have not included any of the very large runoff events that can result in the infrequently occurring high concentrations of precursors and turbidity. We do believe we need more data over a greater range of hydrologic and climatic conditions.

The effort to identify a good proxy for DBP precursors has led to the valuable conclusion that UV_{254} is the proxy has seems to most promising. Based on this preliminary result, the Water Quality Directorate began using UV_{254} as a measure of DBP water quality in 2019. This was done by directly using measurements of UV_{254} as a measure of water quality – with higher UV_{254} indicating lower water quality. This was not done by adopting a relationship between formation potential and UV_{254}. Measurements of UV_{254}, together with measurements of turbidity, fecal coliform count, and phytoplankton counts are then combined using weighting factors for each to yield a single measure or index of overall water quality. This water quality index is currently being used to guide operation of the water supply.

Due to this interest in UV_{254} as measure of water quality related to DBP precursors, DEP has initiated an effort to simulate the fate and transport in our reservoirs, beginning with

Cannonsville. We have one and two-dimensional models that have proven to be capable of simulating the reservoir transport and mixing processes that affect all dissolved or particulate constituents, including UV_{254} and DBP precursors. The challenge in modeling the fate and transport of UV_{254} and DBP precursors in the reservoirs is in simulating the production and loss processes of these constituents in the reservoirs.

Here we describe the initial efforts to simulate the fate and transport of UV_{254} in Cannonsville. Consistent with the general approach in model development to keep it simple, the simulations presented here are based on the following assumptions:

1. The fate and transport of UV_{254} can be simulated using a mass balance modeling approach, despite the fact that UV_{254} is an optical property and is not a measure of mass.
2. A one-dimensional transport model may be used in the initial phase of model development and testing.
3. UV_{254} behaves conservatively in the water column of the reservoir, so that internal (autochthonous) production and loss processes are negligibly small and can be neglected.

The first assumption is supported by the experience of DEP and others in reservoir modeling. DEP has successfully applied models based on mass balance to the optical property of turbidity. In addition, others have successfully simulated UV_{254} in drinking water reservoirs using a mass balance model (e.g., Jeznach et al., 2017). A one-dimensional model is being used in this initial modeling effort largely because it captures the most important spatial variations in reservoir water quality (vertical) but is also simple, allowing constituent production and loss processes to be added, deleted, or modified quickly, and provides short execution times. It is anticipated that following successful initial work with the one-dimensional model, a switch to the two-dimensional framework of CE-QUAL-W2 will be made.

The last assumption is simply made to keep the initial application simple. It is of interest to see how the model will perform under this assumption. Based on the limnological and water supply literature, there is good reason to believe that in a mesotrophic reservoir like Cannonsville, algal photosynthesis and respiration will, at least during certain parts of the year, act as a significant source of UV_{254}, and of precursors. Similarly, bacterial decomposition and perhaps photolysis may be significant loss processes in the water column of the reservoir.

UV_{254} is an optical property of water. It measures the extent to which ultraviolet light at a wavelength of 254 nanometers is absorbed by water. The laboratory analysis involves passing such light through a water sample. If I0 is the light intensity entering the water sample, IS (<I0) is the light intensity leaving the sample, and d is the distance that the light has passed through the sample, then

$$UV_{254} = -\frac{1}{d}\ln\left(\frac{I_S}{I_O}\right)$$

and thus the units of UV_{254} are inverse length, typically cm^{-1}.

Water Balance

The first step in applying the model to Cannonsville Reservoir for these four years is the development of a water budget. The two largest inflows to the reservoir, the West Branch of the Delaware River (WBDR) and Trout Creek, are gaged by the USGS. In addition, daily average outflows from the reservoir, including drinking water diversion, releases at the dam to the lower river, and spill, are measured by DEP. These inflow and outflow records, together with the daily values of reservoir storage, were used to compute daily estimates of the ungaged inflows to the reservoir. The following water balance equation was used:

$$\Delta V/\Delta t = Q_G + Q_U - Q_S - Q_D - Q_R$$

where ΔV = change in reservoir volume (storage) occurring over the time interval Δt= (1 day), Q_G = gaged inflow (sum of WBDR and Trout Cr.), Q_U = ungaged inflow, Q_S = rate of spill, Q_D = rate of diversion, and Q_R = rate of release. This water balance equation neglects groundwater seepage, evaporation, and direct precipitation onto the reservoir water surface. These neglected components are assumed to be small compared to the errors in measurement of the inflows and outflows.

Daily values of reservoir storage were obtained using observations of reservoir water surface elevation, which are shown in Figure 8.20 for 2016 through 2019. In all four years, the reservoir was full on or around June 1, a goal for operation of each reservoir in the supply system. With regard to reservoir drawdown following June 1: 2017 and 2019 were typical years with the maximum reservoir drawdown of about 12 meters occurring in late October. The maximum drawdown in 2016 was about 21 meters occurring in late November as a result of a dry summer and fall. By contrast, 2018 was a wet year, with the maximum drawdown following spring refill being only about 3 meters in late July.

All modeling work described here used the reservoir bathymetry measurements made in 2015 by USGS (Nystrom, 2018) in defining the reservoir volume and area as a function of reservoir water surface elevation. Using this information, daily values of reservoir volume or storage V were determined from the daily observations of water surface elevation.

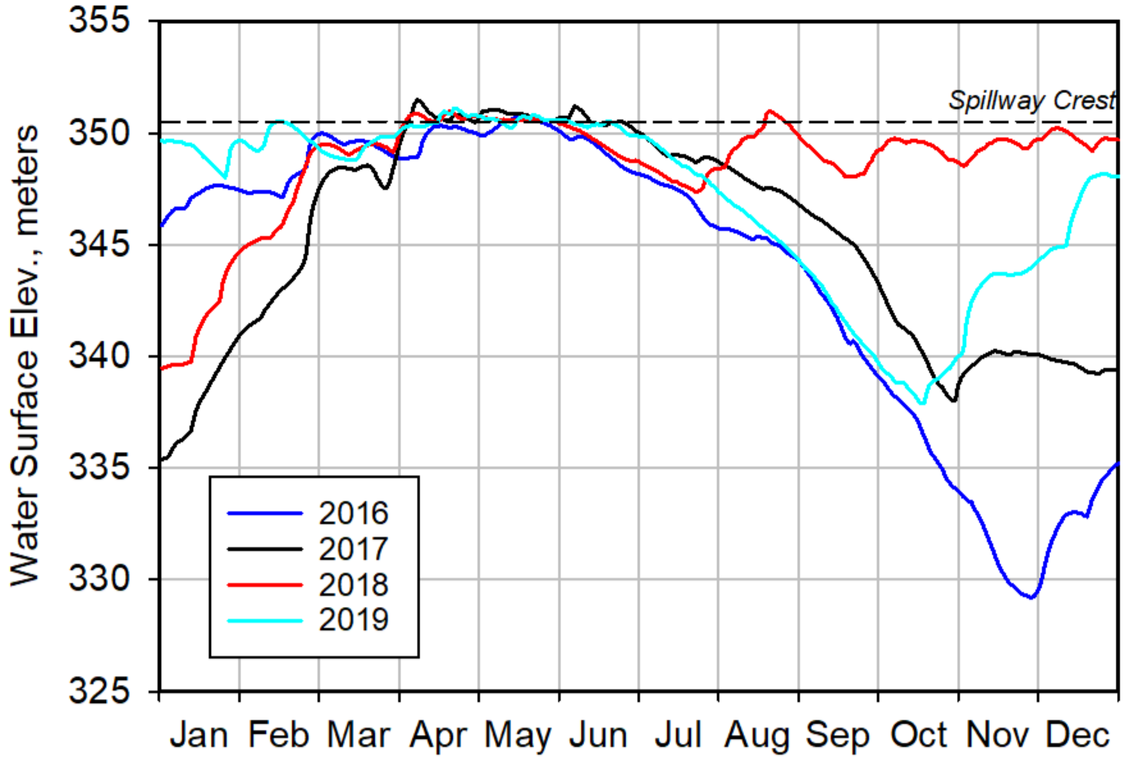


Figure 8.20 Water surface elevation of Cannonsville Reservoir for 2016 through 2019.

Using this information, daily values of reservoir volume or storage V were determined from the daily observations of water surface elevation. With the observations of inflow and outflow in the above water balance equation, the ungaged inflow Q_U was calculated for each day. The resulting values of ungaged inflow for each day in 2019 are shown in Figure 8.21 Inflows to Cannonsville Reservoir, including West Branch Delaware River (WBDR) and Trout Creek, and ungaged inflows computed from reservoir water balance, for 2019. For each of the four years, the total ungaged inflow volume as a fraction of the total inflow volume (gaged plus ungaged) is very close to the drainage area of the reservoir that is ungaged as a fraction of the total reservoir drainage area, which generally provides a consistency check on these calculations.

This set of four years represents a range of reservoir drawdown conditions, with 2016 having larger drawdown, 2017 and 2019 being more average drawdown conditions, and 2018 having lower drawdown.

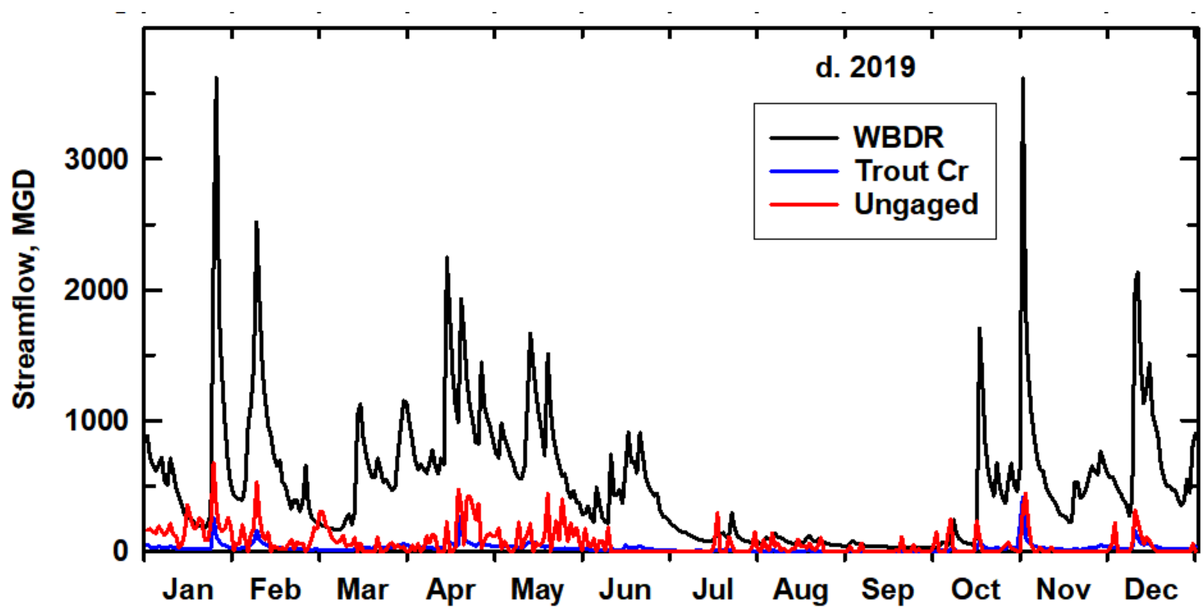


Figure 8.21 Inflows to Cannonsville Reservoir, including West Branch Delaware River (WBDR) and Trout Creek, and ungaged inflows computed from reservoir water balance, for 2019.

With regard to the impact of drawdown on water quality, a quantity of interest is the average annual reservoir hydraulic residence time. The cumulative probability distribution of average annual residence time for Cannonsville for the period 1967-2019 is shown in Figure 8.22, with the individual values for 2016 to 2019 highlighted. These four years cover a moderate portion of the historical range, but there were many years where the residence time was outside the range observed in 2016 to 2019. For example, the “dry” year of 2016 had an annual residence time that is only slightly larger than the median value.

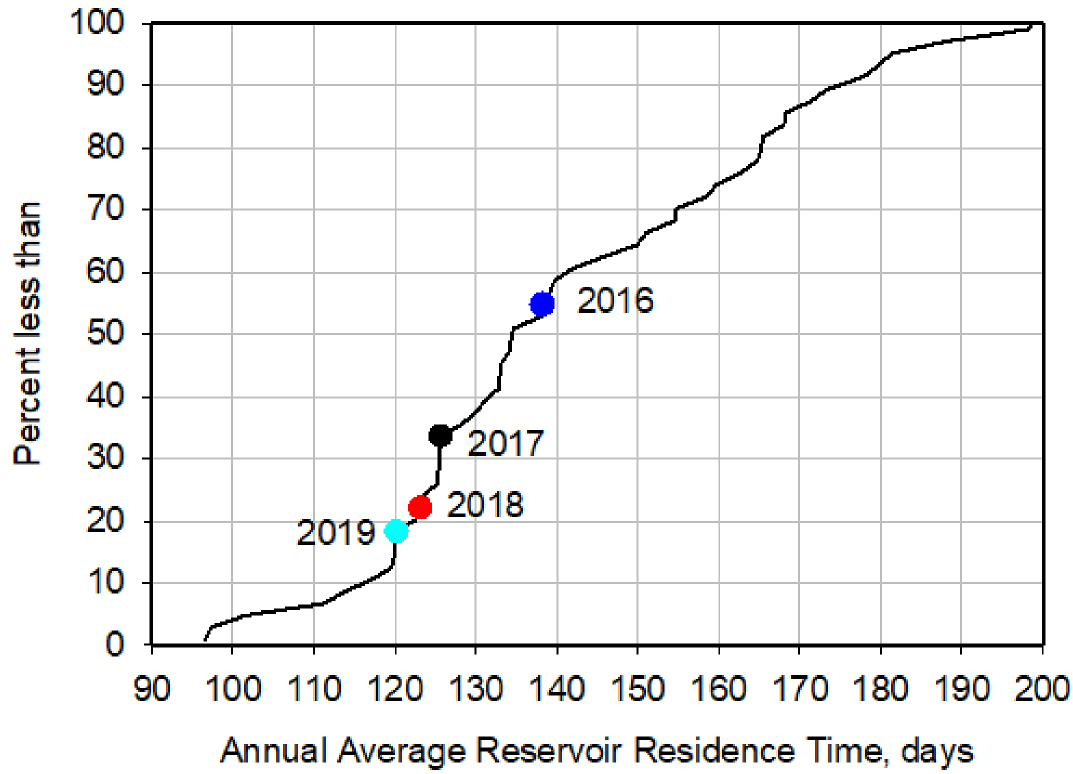


Figure 8.22 Cumulative probability distribution of annual reservoir hydraulic residence time for Cannonsville Reservoir for 1967 through 2019 (53 years).

Hydrothermal submodel

The next step is the application of the hydrothermal portion of the reservoir model to Cannonsville for these four years. The hydrothermal model used here is UFILS4, a one-dimensional (vertical) model, meaning it predicts spatial variations in reservoir characteristics only in the vertical direction. The hydrothermal and water quality submodels are the two main components of this reservoir model.

UFILS4 has been previously applied to many NYC Water Supply reservoirs. The hydrothermal component of UFILS4 was applied and validated for Cannonsville (Owens, 1998). An early version of a eutrophication/water quality was similarly tested and validated for Cannonsville (Doerr et al. 1998): That model was used in evaluation of water quality management alternatives (Owens et al. 1998), in evaluating impacts of climate change (Pierson et al. 2013), and in the prediction of trihalomethane (THM) precursors (Stepczuk et al. 1998).

UFILS4 was also used in the evaluation of watershed protection programs in DEP's 2011 Watershed Protection Program Summary and Assessment report (NYCDEP, 2011). While these applications were all for Cannonsville, the hydrothermal and eutrophication submodels have also been tested and validated for all other West of Hudson reservoirs. In addition, the hydrothermal submodel has also been applied and tested for all East of Hudson reservoirs.

The primary quantities that are predicted by the hydrothermal submodel are the vertical variation of temperature in the water column of the reservoir, and temperature of the diversion, release, and spill from the reservoir, each at a daily time interval or timestep. In addition, the following quantities are also calculated at a daily timestep:

1. Water surface elevation, total volume (storage), and surface area of the reservoir
2. Vertical water motion (velocity) in the water column associated with inflow to and outflow from the water column at different elevations.
3. Turbulent mixing or diffusion in the water column.
4. The five components of heat transfer (flux) at the reservoir water surface: short-wave solar radiation, long-wave atmospheric radiation, back radiation from the water surface, evaporative heat transfer, and conductive heat transfer.
5. The flux of solar radiation over the depth in the water column.
6. The vertical distribution of stream inflow to the reservoir, including the effect of positively-buoyant (warm) and negatively-buoyant (cool) inflow.
7. The vertical distribution of reservoir outflow, commonly known as selective withdrawal.

The vertical distribution of these various quantities is generally determined by breaking the water column of the reservoir up into a number of discrete layers. The thickness of subsurface layers is set to 1 meter, while the thickness of the surface layer and the total number of layers may vary over time due to drawdown or refilling.

This model requires input data. Some of this data is static and describes characteristics of the reservoir that do not change with time, including:

1. Bathymetry – A table describing the reservoir storage volume and surface area as a function of water surface elevation over the entire reservoir depth.
2. The number, elevation, and geometry of the outlet structures: drinking water intakes, dam release structure, and spillway characteristics.
3. Bathymetric characteristics of the reservoir in the immediate vicinity of the major reservoir inflows – WBDR and Trout Creek.
4. The temperature profile in the reservoir water column at the start of the simulation.

In addition, the hydrothermal submodel requires daily time series of the following conditions over the duration of the simulation period:

1. Rate of gaged and ungaged inflow Q_G and Q_U as described above.
2. Temperature of inflows
3. Rate of spill, diversion, and release, Q_S, Q_D, and Q_R, as described above.
4. The intake structure in use for drinking water diversion (there are three intakes).
5. Weather conditions at the reservoir site including:
    a. Incident solar radiation
    b. Air temperature
    c. Dew point temperature, or relative humidity
    d. Wind speed and direction
6. Some measure of clarity in the water column such as light attenuation coefficient, or Secchi disc transparency.

DEP maintains a weather station at the Cannonsville Dam where solar radiation, air and dew point temperature, and wind are measured. These high-frequency measurements are averaged to yield daily average values which are used by the model. The daily air temperature measurements for the April through October interval of each of the four years is shown in Figure 8.23. Similarly, the daily stream temperature for WBDR is shown in Figure 8.24. As the

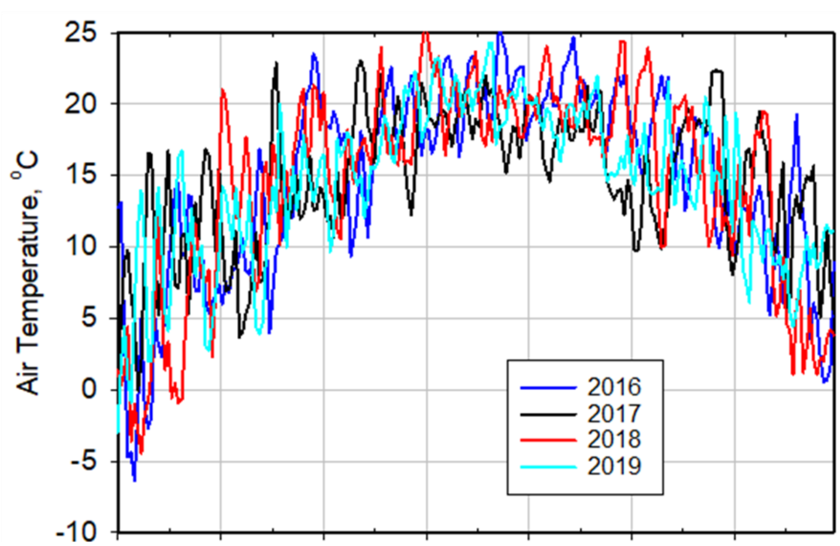


Figure 8.23 Air temperature measured by NYCDEP at the meteorological station located at the Cannonsville Dam, for the April-October interval of 2016 through 2019.

temperature of other streams is not available, it was assumed that the temperature of Trout Creek and of the ungaged inflows is the same as WBDR.

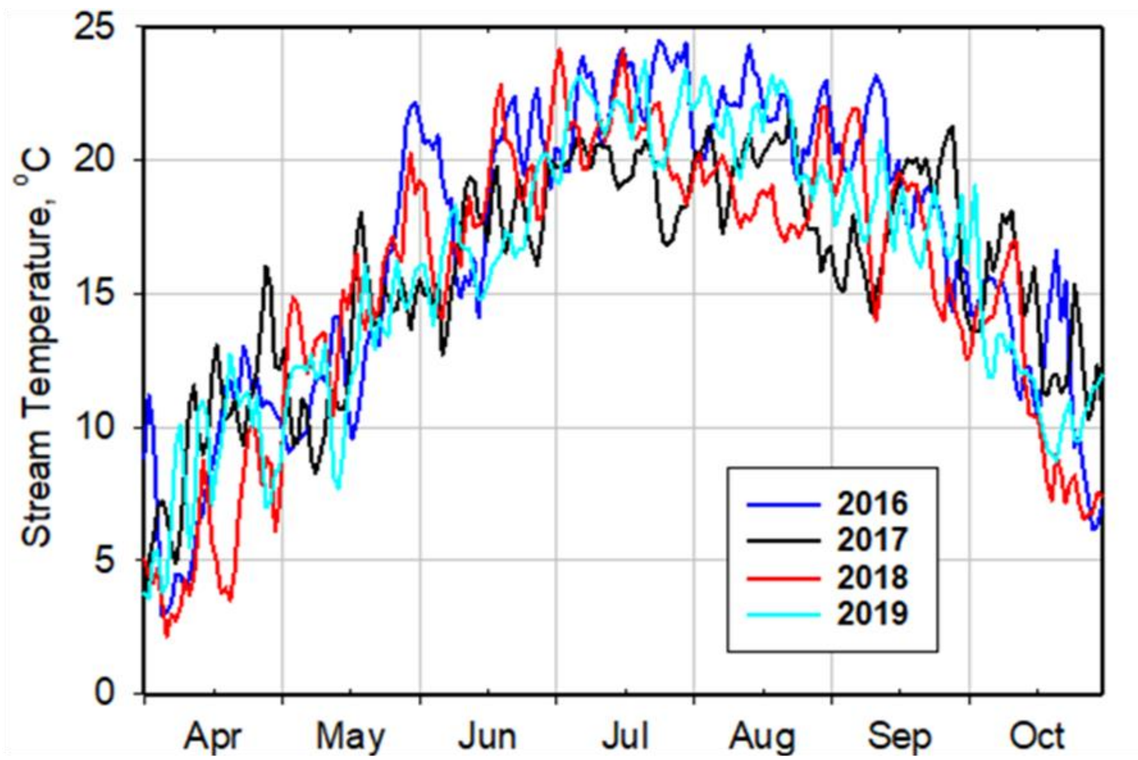


Figure 8.24 Stream temperature for the West Branch Delaware River for the April-October interval of 2016 through 2019.

Prior to this current work involving modeling of the 2016-2019 period, the hydrothermal submodel has previously been setup, tested, calibrated, and validated for Cannonsville for the years 1994 through 2004. As a part of that calibration process, the value of a number of system-specific model coefficients was identified. These coefficients are associated with simulation of various process including surface heat transfer, vertical turbulent diffusion, and inflow mixing. In the simulations completed in the current project for 2016-2019, the values of these model coefficients that were determined in the earlier model testing were used without modification.

Selected predictions of water column temperature for four dates in 2019 are shown in Figure 8.25. Features of the thermal stratification, including surface temperature, hypolimnetic temperature, and thermocline depth, are simulated accurately. The results for 2016 through 2018 are similar.

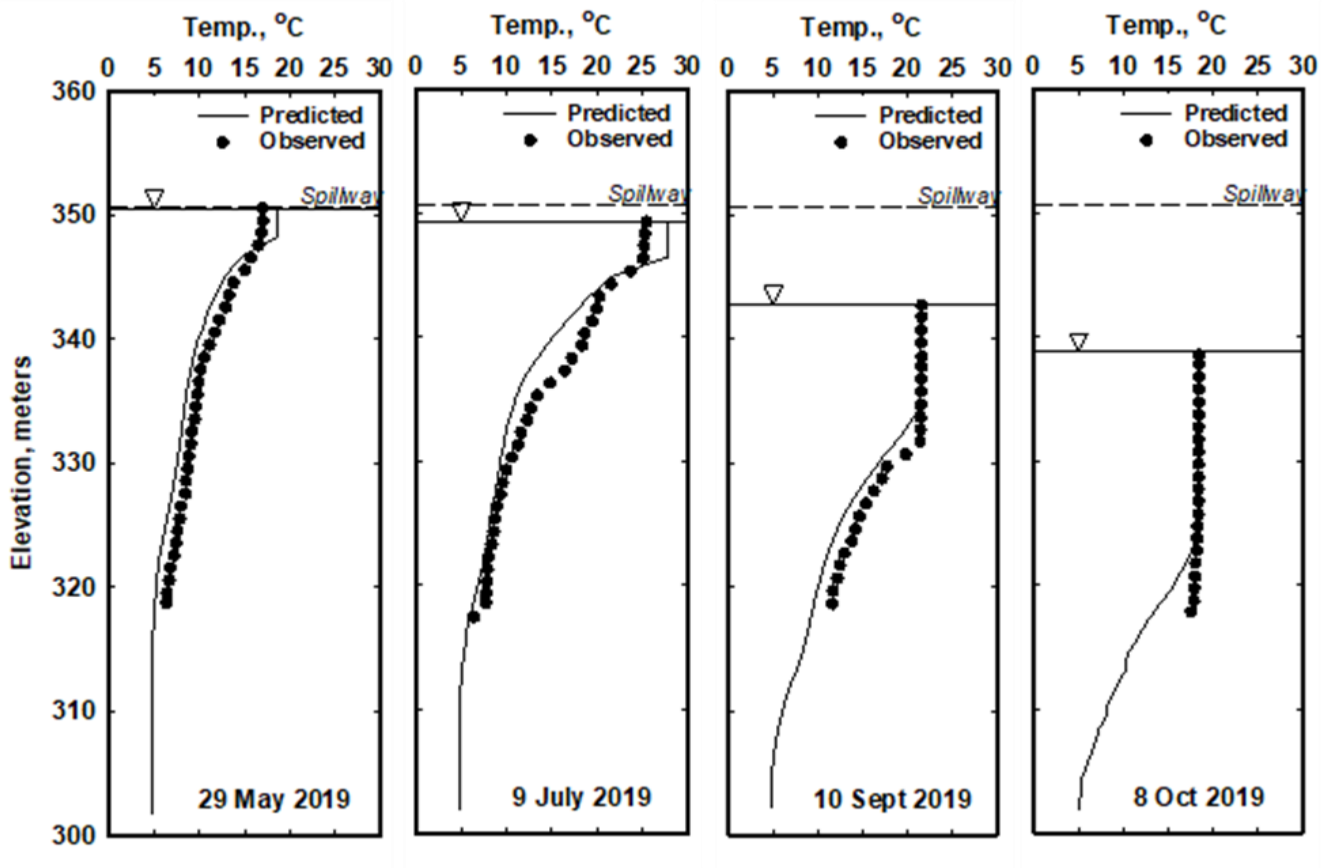


Figure 8.25 Measured and predicted temperature profiles for 4 dates in 2019. Measurements were made at Station 4 adjacent to the drinking water intake structure.

The accuracy of the hydrothermal predictions can also be evaluated by comparing predictions of the temperature of the drinking water diversion to observations. This comparison is shown for 2019 in Figure 8.26. The model is underpredicting the temperature of the diversion by about 1 to 2 degrees Celsius in July and August. The results are similar for the earlier three years. These hydrothermal model simulations were made using model coefficient values determined in the earlier model application to Cannonsville. Adjustment of these coefficients to improve the model predictions so the model yields accurate predictions for all years will be evaluated in future modeling work.

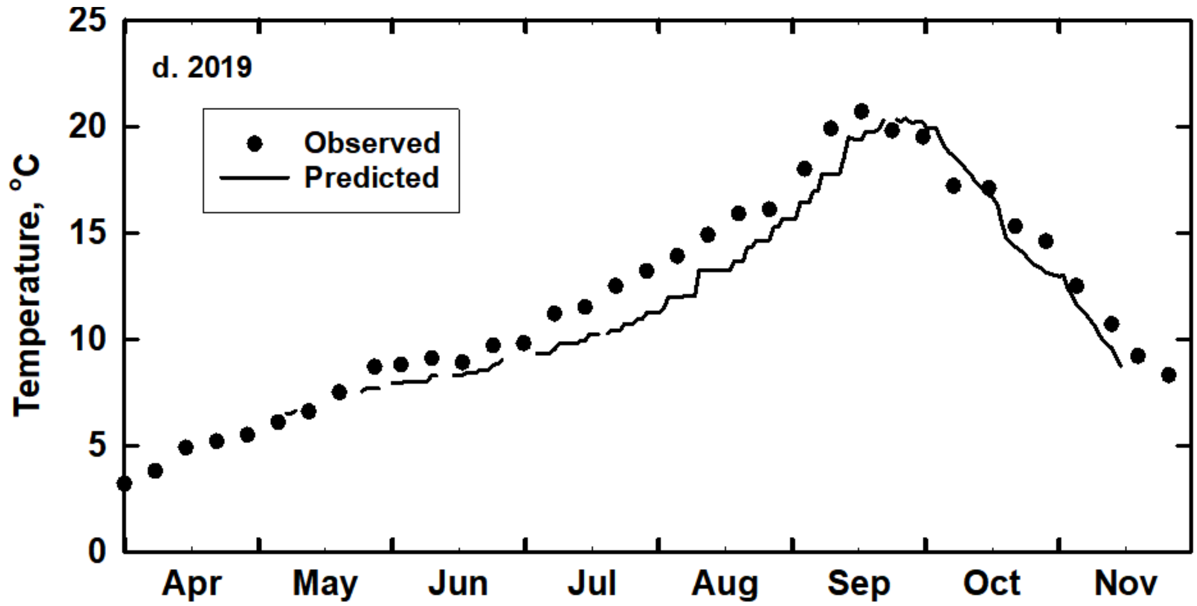


Figure 8.26 Observed and predicted temperature of the drinking water diversion from Cannonsville Reservoir for 2019

Water quality (UV_{254}) submodel application

Due to the assumption that UV_{254} behaves conservatively in the water column of the reservoir, the additional model components necessary to simulate UV_{254} are relatively minor. This single state variable is added to the model, with the transport and mixing of UV_{254} determined by the hydrothermal model. The only additional model input data required is a time series of UV_{254} in the tributary streams entering the reservoir.

The model requires that a value of UV_{254} for stream inflow is specified for each day of simulation. During dry weather periods, and during some wet weather periods, measurements of UV_{254} in the WBDR at Beerston were generally made once per week from mid-2016 through 2019. More frequent observations of UV_{254} were made during some wet weather, high streamflow periods. In order to estimate UV_{254} on days with no measurements, an empirical relationship of UV_{254} to streamflow, an empirical rating curve, was developed. The paired observations of UV_{254} and streamflow for 2016-2019 that were used to develop this relationship are shown in Figure 8.27.

A number of alternative forms for the empirical relationships were explored. The expression yielding the smallest error is:

$$UV_{254}=0.046+0.00056\ Q-0.025/Q$$

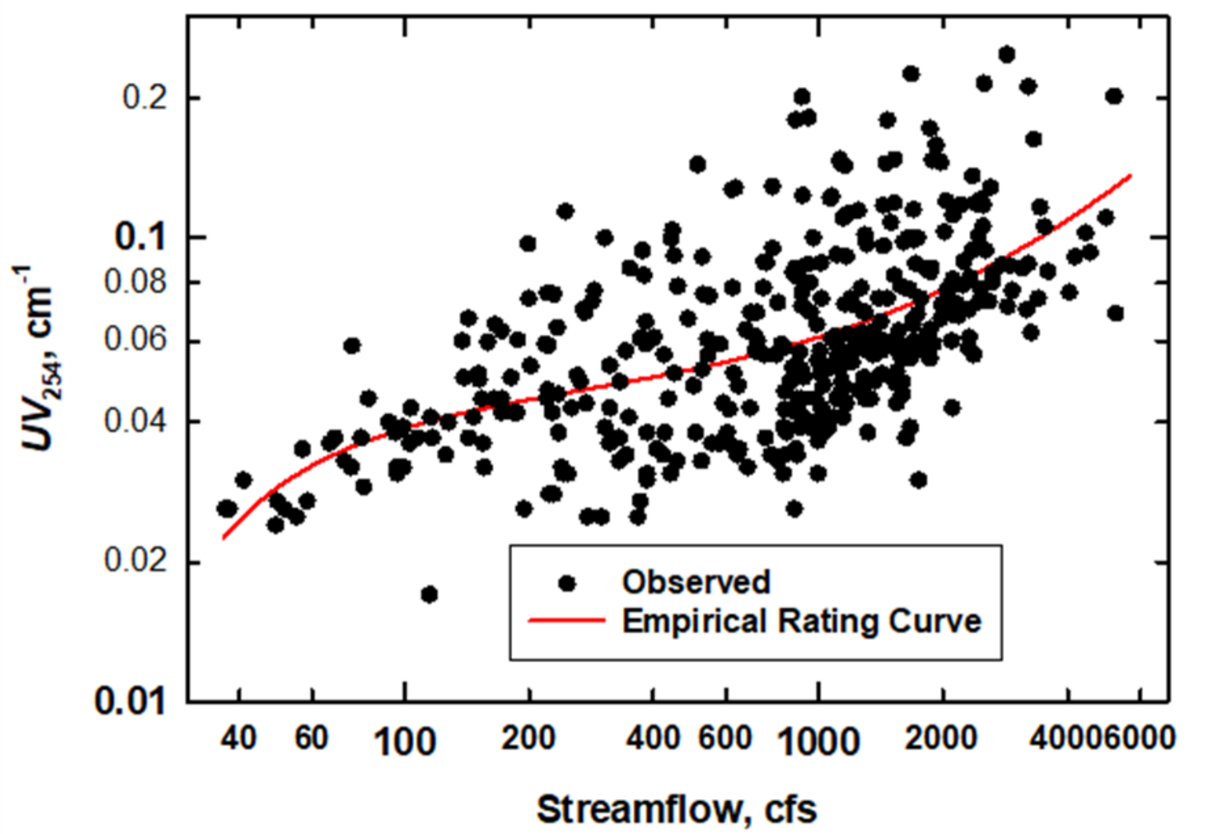


Figure 8.27 Paired observations of UV_{254} and daily streamflow for the West Branch Delaware River at Walton, 2016 through 2019. The rating curve is given by the preceding UV_{254} equation.

where UV_{254} is in cm^{-1}, and Q is WBDR daily average streamflow in m^3/sec. The equation above is a provisional relationship based on the data from the 2016-2019 interval for the West Branch Delaware River (WBDR) inflow to Cannonsville Reservoir. In this modeling analysis, a value of UV_{254} is required for all inflows to the reservoir for each day during the duration of the model simulation period. In this analysis, for WBDR the observed value was used on days when observations were made and the value from this empirical equation was used on all other days. For Trout Creek and the ungaged inflows, the daily value used for WBDR was applied to these inflows as well. The WBDR streamflow, measurements of UV_{254}, and computed estimates of UV_{254} from the rating curve equation for 2019 are shown in Figure 8.28.

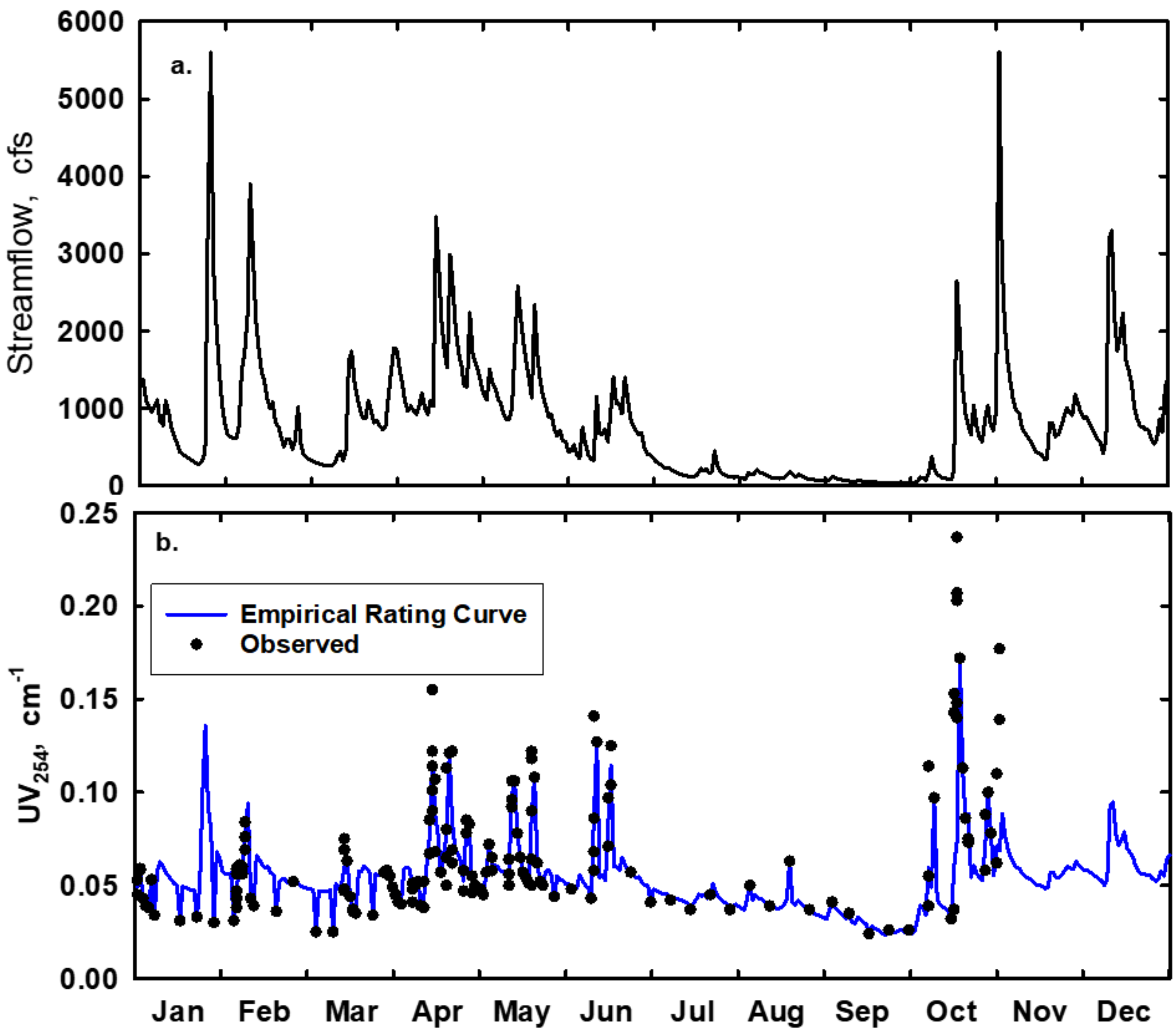


Figure 8.28 (a) Observed streamflow, and (b) observed and estimated UV_{254} for the West Branch Delaware River in 2019.

With UV_{254} of the stream inflows to the reservoir specified, the model was operated to simulate UV_{254} in the water column of and outflows from the reservoir. The resulting levels of UV_{254} predicted in the reservoir are primarily driven by the UV_{254} and flow of the tributaries entering the reservoir. The vertical distribution of UV_{254} is driven by the depth at which the tributary streams enter the water column. Generally, if the stream temperature is warmer than the surface waters of the reservoir, the inflow will enter and mix with the reservoir surface waters. If the stream is cooler, the stream will tend to plunge to a depth in the reservoir where the temperature is equal to the stream temperature. Vertical variations in $UV_{254\ \text{then}}$ develop in response to the dynamics of the streamflow, stream temperature and UV_{254} in the stream. These vertical variations are modified by vertical water motion in the water column, and are smoothed by turbulent mixing between adjacent layers.

The simulated vertical profiles of UV_{254}, together with observations, are shown for four dates in 2019 in Figure 8.29. For this year, the model generally overpredicted UV_{254} levels through the summer and autumn. Results for the other years were similar, and lead to the conclusion that the predictions could likely be improved by considering production and loss in the water column.

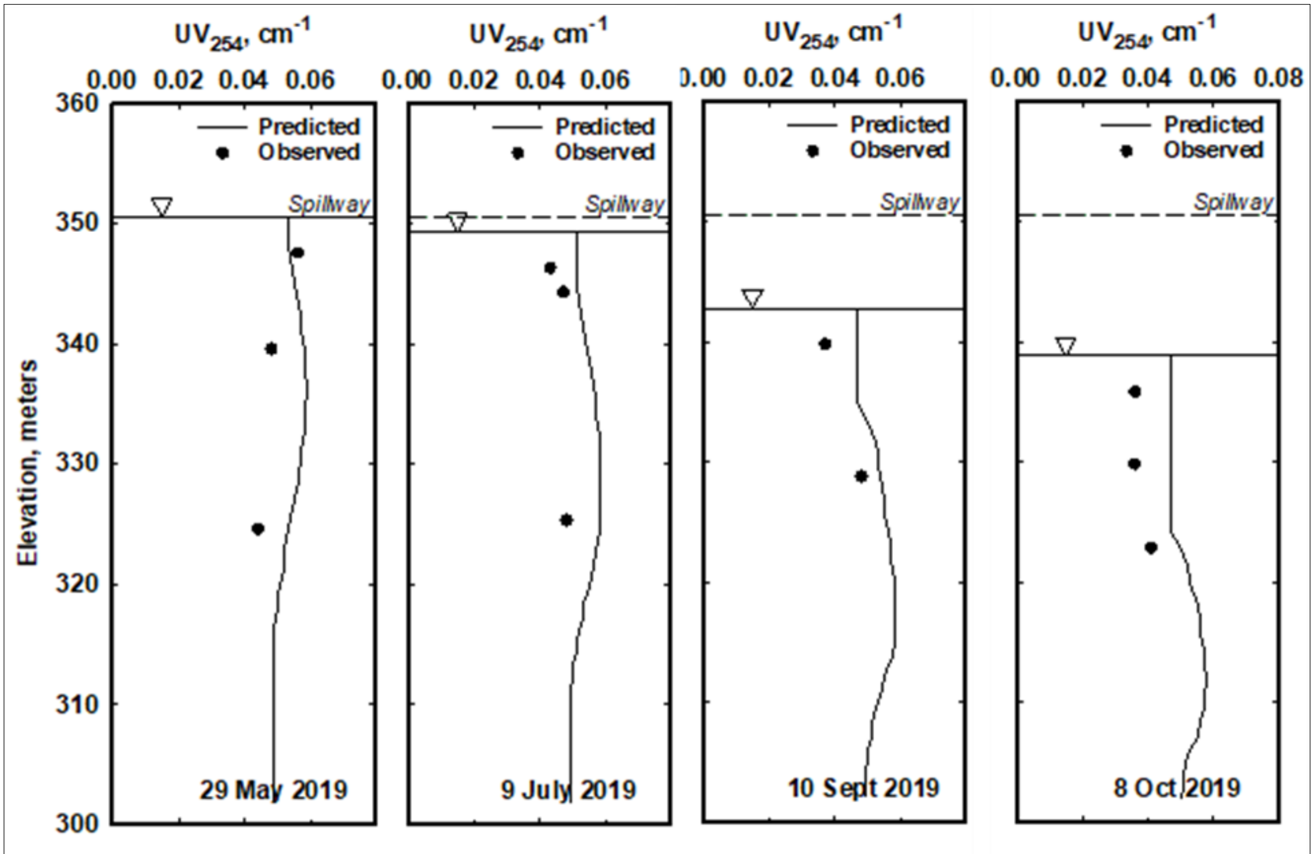


Figure 8.29 Predicted and observed vertical profiles of UV_{254} for 4 dates in 2019.

Predictions and observations of UV_{254} in the water supply diversion from Cannonsville are shown in Figure 8.30 for 2019, which show overprediction for most of the summer followed by underprediction in late summer to autumn. Generally, the model failed to capture the dynamics of UV_{254} in the diversion over large portions of these f years, an indication that significant levels of internal production and loss are occurring in the reservoir.

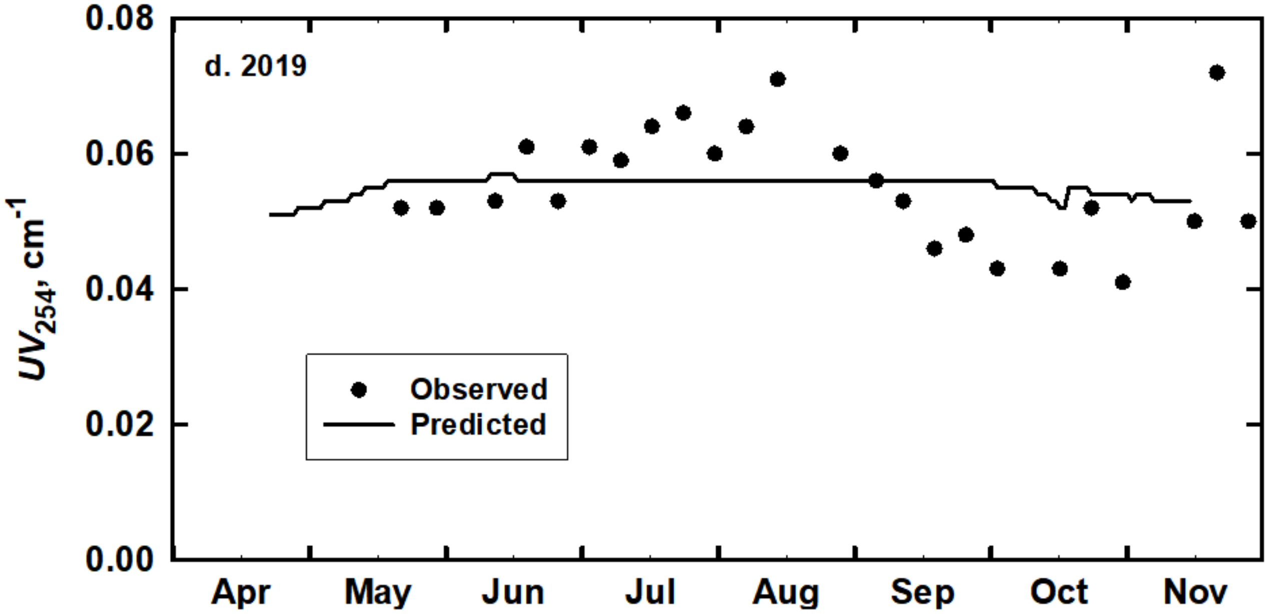


Figure 8.30 Observed and predicted UV_{254} for the drinking water diversion from Cannonsville Reservoir in 2019.

Summary of UV_{254} modeling

The model for UV_{254} presented here captured one of the important features that was identified in the observed data: the magnitude of the increase in UV_{254} in the water column of the reservoir in response to runoff events such as that occurring in August and September 2018. However, other features were not simulated well, most importantly the observed dynamics in UV_{254} in summer and autumn of 2017 and 2019, where production apparently occurred in mid-summer, followed by loss of UV_{254} in autumn.

The linkage between algal photosynthesis and respiration and production of DBP precursors in surface water bodies has been documented in a number of studies (e.g. Liu et al. 2018). Data and modeling analyses of THM precursors in Cannonsville in the late 1990s indicated the importance of internal production of precursors (Stepczuk et al. 1998a, Stepczuk et al. 1998b). While the trophic state of Cannonsville Reservoir has improved from eutrophic to mesotrophic in the last 20 years, it remains likely that algal activity in the reservoir results in the production of DBP precursors in the reservoir, at least during certain periods. Previous modeling work with UFILS4 has indicated that algal activity has resulted in production of precursors that is generally of the same order of magnitude as loading from the watershed (Effler et al. 2005). Regarding loss processes, it has been found that bacterial decomposition is a significant loss process for THM precursors that affects a significant, labile fraction of the precursors in the New

York City reservoirs. With these findings based on DBP precursors, it is reasonable these conclusions would apply to UV_{254} as well.

So, while starting simple in the development and testing of a model is a reasonable approach, it appears that additional accuracy in modeling may be achieve by adding production and loss processes to the model. The next step in the development and testing of a UV_{254} model for Cannonsville will be to add internal production and loss processes. This work is ongoing.

8.4 Database Development and Data Analysis

8.4.1 Development of a Modeling Database

DEP's water quality models, including SWAT, CE-QUAL-W2, UFILS4, and others, require a large suite of data to develop, calibrate, and run operationally. These models also generate a significant volume of output files which must be parsed, interpreted, and archived. To improve availability to modeling data, DEP has been developing a database designed to house and serve data for the variety of models utilized. Data which had typically been gathered from authoritative sources and manually formatted for each model are now retrieved, stored, and formatted using automated processes.

During the reporting period 2016-2019, the modeling database was created using SQL Server and populated with model input datasets and select model results. The goal of the database is to streamline access to important data used and produced by DEP modelers, with emphasis placed on storing data used by multiple models, are not as easily accessible, or data acquisition time requirements (i.e. download time) would be too high. For example, NOAA meteorological and forecast data require significant effort to download and process raw files into useable input files. By automating the download and data storage, NOAA data are now available as needed for any model. In contrast to these external datasets, DEP water quality sampling data have been made available through internal means via a web-accessible interface, which requires only minimal reformatting to convert data into model-specific input files without making a duplicate copy in the modeling database.

DEP will continue to assess datasets as they become available to determine whether they should be incorporated into the modeling database. Datasets have been downloaded manually from sources such as NASA North American Land Data Assimilation System, NOAA Snow Data Assimilation System, and others. These are among the datasets that will be evaluated for inclusion. Additionally, to improve model run archiving, select output data from other SWAT and CE-QUAL-W2 will be included as the database is expanded.

8.4.2 Automation Processing for Modeling Tasks

To populate the modeling database and improve its functionality for DEP modelers, a series of automation scripts have been developed using the Python language. Python is a robust coding language capable of data harvesting, transformation and analysis. It integrates well with other software used by DEP, including SQL databases, GIS spatial analysis, and data analysis written in R code. During the reporting period, scripts have been developed to automatically download the latest data for the input datasets listed in Table 8.10 from the data owner, transform the data into an appropriate format for the database, and load the reformatted data into the database. Additional code has been written to access internal datasets for water quality sampling and prepare model input files. A key distinction for the internal data process is that these data are not loaded into the modeling database because a local copy of the data would not improve data preparation speed, and the data redundancy would incur costs in terms of data storage and maintenance needed to keep the most current version.

Table 8.10 Summary of the categories and indicators of climate change expected to be calculated.

Categories and Indicators
Meteorology
Frost and icing days
Growing season length
Minimum and maximum temperature
Precipitation volume and intensity
Wet/dry spell
Hydrology
Mean monthly streamflow
Magnitude of extreme flow
Timing of extreme flow
Reservoir Characteristics
Thermocline depth
Ice on/ice off
Water supply operations and water quality
Alum addition days and mass
Diversion temperature at EWRM sites
Diversion turbidity
Watershed snow pack
Drought warnings
Seasonal reservoir spill

Python scripts have extended the capability of the modeling section to automatically complete model runs from start to finish. The GWLF watershed model (Haith and Shoemaker 1987; Schneiderman et al. 2007), which was developed to predict streamflow entering each of the six West of Hudson reservoirs, was the first model implemented for operational automation with scripts written to complete data preparation, model execution, output post-processing, data visualization and dissemination. By using the PRISM meteorological data in combination with GEFS ensemble forecasts, GWLF is able to calculate a range of 16 days of forecasted streamflows, automatically updated daily to inform decision-making. Following the completion of the model run, the code compiles all streamflow values, makes any necessary bias corrections and stores all output predictions in the modeling database. Finally, charts are generated for each reservoir, and can be automatically disseminated via email to any interested staff. Future versions of this process will incorporate interactive charts rather than static images which will be updated in an HTML-based dashboard.

8.4.3 Climate Change Trend Analysis

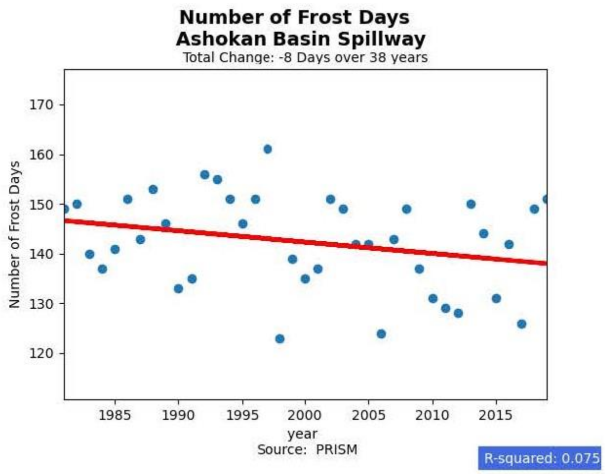
The impacts of climate change on the NYC Water Supply watershed are of particular concern to DEP. The watershed is expected to experience higher temperatures, increased precipitation paired with more extreme storm events, and changes in the seasonal timing of streamflow via a reduced winter snowpack. An expert panel created by the National Academies of Science, Engineering and Medicine, as a part of its review of DEP's Operations Support Tool, recommended that "NYC DEP should consider coordinating with other New York City and regional agencies to create and update a Climate Resiliency Indicator and Monitoring System for the New York metropolitan region and assess climate change." (National Academies of Sciences 2018) Acting on this recommendation, the Water Quality Modeling Section has developed a suite of indicator metrics to describe the trends of change in meteorology, hydrology, reservoir characteristics, as well as water quality and supply system operations using long-term datasets. Table 8.10 summarizes the types of analyses that are being conducted as a part of this project. The analyses are completed through a series of python scripts and SQL queries to enable the indicators to be updated annually to investigate changing trends as more data become available.

During the reporting period, work has been initiated to calculate climate indicator trends, focusing initially on meteorology and hydrology, using the long-term datasets described above. The trends described in this section are preliminary, which may require additional investigation to provide context to the results and may result in the refinement or addition of new indicator metrics.

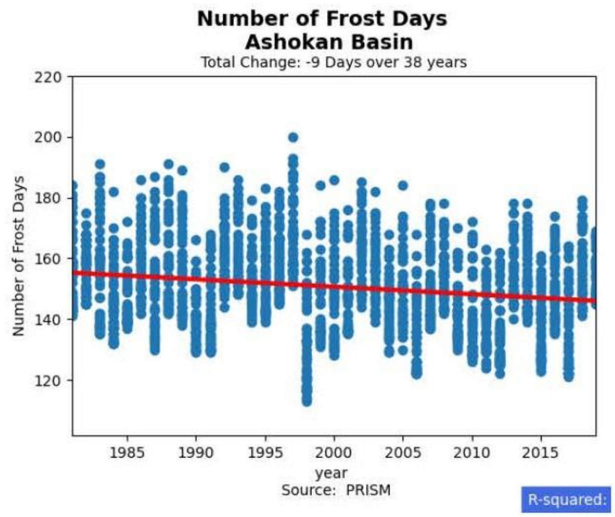
Summary of Climate Change Trends – Meteorology

To calculate meteorological climate trends, both NOAA airport observations and PRISM gridded data were used. No airport observation stations are located within the water supply watershed. The nearest airports are in Albany, White Plains and Binghamton. By contrast, PRISM data includes approximately 324 grid cells within the West of Hudson watershed. This flexibility allows indicator calculations at individual grid cells—for example, the cell containing each reservoir spillway—as well as basin or watershed averages. Figure 8.31 shows a sample set of results for NOAA and PRISM data for a single indicator. The change is calculated using a simple linear regression, and shows a decrease in the number of frost days per year over the respective periods of record at all locations.

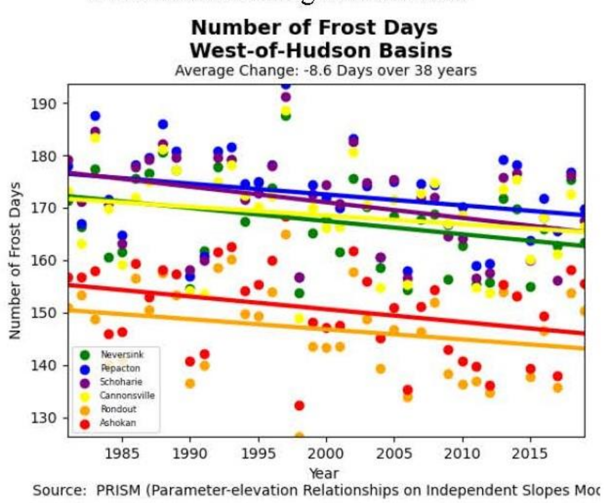
a. PRISM results for a single grid cell located at the spillway for Ashokan Reservoir



b. PRISM results for all individual grid cells located within the Ashokan Reservoir watershed.



c. Average results for each watershed in the WOH district using PRISM data



d. Results of NOAA airport observations.

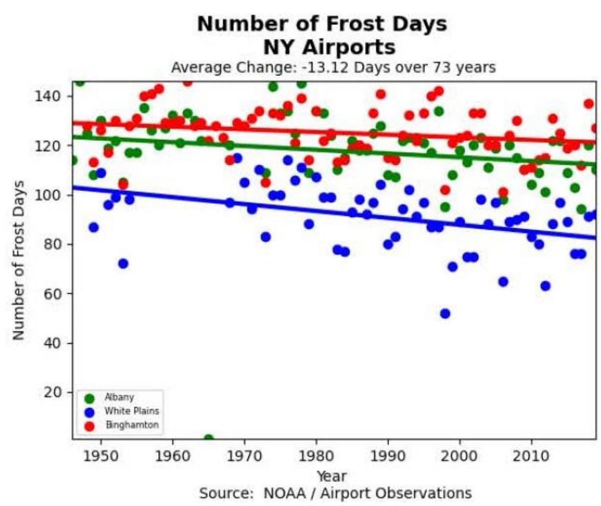


Figure 8.31 Results of a sample meteorology climate indicator calculated for the NYC watershed: Annual number of frost days (days with minimum daily temperature < 0° C)

Summary of Climate Change Trends – Hydrology

The United States Geological Survey (USGS) operates a nationwide network of stream gages measuring a variety of hydrologic conditions including streamflow. In the West of Hudson watershed, there are currently 21 active gages with daily streamflow measurements dating back as far as the early 20th century. Using observations collected from these gages, changes to the hydrological regimes can be characterized in terms of annual streamflow, extreme flow magnitude and timing, and seasonal patterns. The indicators being calculated for this project have been developed based on Richter et al. (1996). To assess the trends present in the data, the linear regression method used for meteorology data has been replaced with the Mann-Kendall test and Sen's slope.

Figure 8.32 depicts results for a suite of extreme streamflow metrics for a single gage, Schoharie Creek at Prattsville. While there is relatively little change in low-flow events over time, there is an increase in streamflow during high-flow events. During the reporting period, several additional hydrological indicators have been calculated and are currently being evaluated.

Future Work

The work presented in this section summarizes completed portions of results of the climate change indicators project. The analysis of climate change trends in the NYC watershed is ongoing, with the analyses of changes to the reservoir characteristics and water quality and supply operations being developed. The use of simple linear regressions has been a useful tool for initial trend exploration. However, more robust statistical methods to analyze the long-term trends in the data will be investigated, and enhancements will be made to the trend calculations.

Once all indicators have been calculated, a report will be written detailing the results through 2020. As this analysis is intended to be updated annually, revised trends will be released with each additional year of data. These updates will enable DEP staff to review not just the current climate change trends, but the change in those trends over time to assess whether the impacts of climate change are accelerating. Additionally, code will be written to create a browser-based interface to enable users to explore the analysis results through interactive charts and calculations.

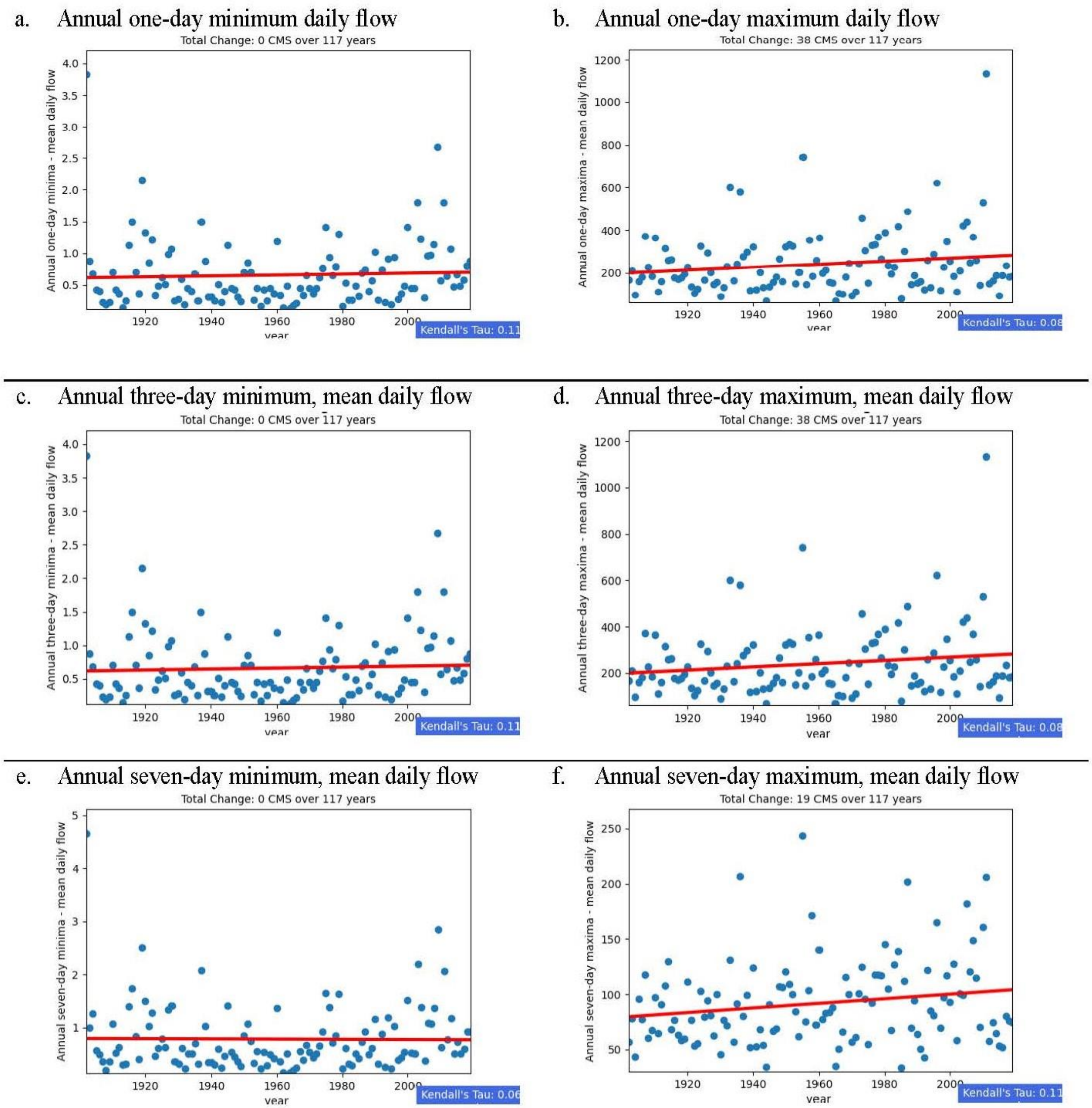


Figure 8.32 Results of a streamflow indicators calculated for the USGS gage Schoharie Creek at Prattsville showing change in minimum and maximum flow over several periods

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Appendix A: Filtration Contingency Planning

Background

In 1993, USEPA issued a Filtration Avoidance Determination (FAD) for the Catskill/Delaware (CAT/DEL) System that required the DEP to proceed with conceptual and preliminary design of a water filtration facility that could be built in the event that filtration was deemed necessary.

The 1997 FAD contained deliverables requiring final design of a water filtration system and completion of a final environmental impact statement (FEIS). DEP was able to seek relief from these deliverables if DEP adequately addressed the remaining conditions of the FAD and the CAT/DEL System appeared likely to meet federal water quality standards for the foreseeable future. As contemplated by the 1997 FAD, the DEP applied for and later received relief from the final design deliverable and related EIS activities, including the release of a draft environmental impact statement and the completion of an FEIS. As conditions for relief, the DEP agreed to perform biennial updates of the preliminary designs for a water filtration facility, conduct feasibility studies for ultraviolet (UV) light disinfection, and, if the technology was found suitable, design and construct a UV light disinfection facility.

As a condition of relief from completing final design deliverables for the CAT/DEL filtration planning process, the 2002 FAD required the DEP to produce biennial updates to the preliminary design for a CAT/DEL filtration plant (in addition to constructing an ultraviolet light disinfection facility, which was placed into full service in October of 2012). The 2007 FAD continued the requirement that DEP submit to USEPA and NYSDOH on a biennial basis a report updating the preliminary design of the CAT/DEL filtration facilities and discussing the analysis and re-design work.

In 2017, as the work supporting the preliminary plans was more than 25 years old, the FAD required the City to contract for a comprehensive review of filtration methods and technologies and develop a new conceptual design for a filtration facility. Similar to the earlier FAD requirements, completing this facility planning study now aimed to minimize the time required to commence filtration in the event that filtration became required.

The design review process specified under the FAD includes:

- A review of water quality for the CAT/DEL System.
- A review of current and potential future regulatory requirements.
- A review of treatment technologies that may be suitable for treatment.
- Bench testing of potential treatment methods to gather data.
- Large scale pilot studies

- Development of a conceptual design incorporating the filtration methods and technologies determined best to meet the City's treatment goals.

Filtration Design Update

The water-treatment plant design developed under the prior FAD was based on ozone-direct filtration (ozone-DF). While this process was appropriate when selected in the mid-1990s, DEP was required under the 2017 FAD to evaluate whether ozone-DF remains the best filtration treatment alternative considering current available technologies. DEP developed a design contract with two tasks: Task 1 includes a water quality and regulatory review, technology evaluation, and bench-scale testing; and Task 2 includes a more detailed evaluation of the recommended treatment alternatives, refinement of design criteria through pilot testing, and development of a conceptual design of the best treatment alternative for CAT/DEL water. Consistent with the milestones specified in the 2017 FAD for the CAT/DEL filtration plant design, DEP advertised a new contract on January 31, 2017, and issued Notice to Proceed as of January 24, 2018, to a consulting engineering firm specializing in water-treatment plant design.

During 2018, the consultant completed a water quality and regulatory review using DEP historical records spanning 1987 through 2017. The water quality evaluation focused on parameters directly affecting the pilot testing and conceptual design. The consultant issued a Water Quality Regulations and NYC Water Quality Data Report in July 2018. DEP and the consultants utilized the findings of that report to establish water quality goals for the treatment system.

In late 2018 to early 2019, the consultant initiated a comprehensive technology evaluation to identify all suitable water treatment technologies for the CAT/DEL water supply. The consultant team, DEP, and the advisory committee, a group of industry experts providing specialized technical guidance; developed criteria to select potential technologies. Seven potential treatment process trains were developed (UV and chlorine are existing processes in the CAT/DEL System and would follow any treatment train selected for design).

Beginning in July and continuing through December 2019, the consultant conducted bench-scale testing in a laboratory setting to evaluate the relative performance of the proposed unit processes and to evaluate chemical dose ranges required for coagulants and oxidants. The objective of the bench-scale investigations were:

- To evaluate the relative performance of proposed unit processes and the chemical dose ranges required for coagulants and oxidants.
- To select which pre-oxidants and coagulants will be carried forward in pilot studies.
- To determine whether use of the proprietary MIEX process would be warranted for treatment of CAT/DEL water.
- To determine whether the use of a ballasted flocculation process would provide any advantage for treatment of CAT/DEL water.

- To determine whether membranes were viable and if they should be evaluated further.
- To select the process trains to advance to Task 2 pilot testing.

The consultant submitted a final report to DEP in May 2020 achieving these objectives. Based on the results of the bench-scale testing and the screening analysis, the consultant recommended four treatment trains for future pilot studies.

- Direct Filtration (Baseline): Ozone → Coagulation → Flocculation → Possible Intermediate Oxidant → Filtration → UV → Chlorine
- DAF/ Filtration: Ozone → Coagulation → Flocculation → DAF → Possible Intermediate Oxidant → Filtration → UV → Chlorine
- MIEX/Membrane Filtration: Ozone → MIEX® → Possible Intermediate Oxidant → MF/UF → UV → Chlorine
- Coagulation/Membrane Filtration: Ozone → Coagulation → Flocculation → Possible Intermediate Oxidant → MF/UF→ UV→ Chlorine

Consistent with the FAD milestones, DEP submitted the report to the NYSDOH in June 2020. Submission of the final report completed Task 1 of the design contract.

Appendix B: Rondout-West Branch Tunnel (2011-2020)

Efforts to evaluate the condition of, and to continue to develop dewatering and repair plans for, the Rondout-West Branch Tunnel (RWBT) have been ongoing from 2011 through 2020 and involve the following components:

- Hydraulic investigations of the RWBT;
- Autonomous underwater vehicle (AUV) inspection of the RWBT;
- Remote Operated Vehicle (ROV) inspection of the RWBT in Wawarsing, NY;
- Risk assessment;
- Tunnel and shaft rehabilitation program; and
- Award and commencement of construction contracts.

Hydraulic Investigations of the RWBT

Through investigations of the RWBT, DEP assessed the magnitude of leakage exfiltrating from the aqueduct in Roseton and Wawarsing, NY. Various efforts to study the nature of the leaks are described below.

- Tunnel Monitoring Program- The object of this program is to determine if tunnel conditions are changing. DEP and consultants routinely monitor tunnel flow rates, operational trends, and surface expressions to determine the quantity of the leak.
- Tunnel Testing Program- DEP conducts hydrostatic tests and backflow tests on a routine basis when NYC demand and operational conditions allow. The hydrostatic test involves temporarily shutting down the RWBT and isolating it from the reservoirs at both ends. When this is done, the water level in the tunnel drops due to the leakage which is measured to calculate an accurate total exfiltration leakage rate. The backflow test involves shutting down the tunnel to allow water to flow backwards into the tunnel from West Branch Reservoir. Water flowing past the downstream flowmeter is measured as a negative flow reading which is interpreted as the total exfiltration leakage rate. There has been one hydrostatic test and four backflow tests since 2011 with results showing that the RWBT's exfiltration leakage rate is stable. The last test was conducted in 2013.
- Surface investigations in areas of Roseton and Wawarsing- Water is suspected to be leaking from the tunnel in two areas with surface expressions evident at the land surface. To better understand the lateral extent of the RWBT leak, the United States Geologic Survey (USGS) performs monitoring of 43 water wells and two surface water locations throughout the Wawarsing area and consultants monitor multiple surface expressions and wells in the Roseton area. Engineering teams catalogue surface leakage expressions on an average monthly basis. During tunnel depressurizations, daily monitoring is performed, however this has not occurred since 2013.

AUV Inspection of the RWBT

Under the AUV program, a robotic vehicle capable of freely navigating the tunnel from end to end is used to photograph the interior surface of the RWBT in a single inspection lasting 12 hours. Previous inspections were performed in 2003 and 2009. In 2014, DEP completed a third AUV inspection of the interior surface of the tunnel which gathered roughly 150,000 photographs of the interior surface of the tunnel's liner.

ROV Inspection of the RWBT in Wawarsing, NY

Under the ROV program, an independent robotic vehicle photographed the interior RWBT liner in the vicinity of suspected leakage areas in Wawarsing. Cracks in the liner were identified and exfiltration was documented during the inspection. The areas were carefully catalogued to instruct the future liner grouting repair program to occur in 2022.

Risk Assessment

In 2011, a technical review committee (TRC) reviewed prior risk assessment and associated data, including tunnel monitoring, tunnel testing, surface investigations, and the AUV program, along with existing data from the original tunnel construction and the 2003 "Horizontal Boring Program." The TRC issued its findings in early 2012 which indicated the risk of tunnel collapse during the future full unwatering was negligible, and that tunnel inflows were estimated at 20 MGD. This information was used to inform the design of dewatering systems that are currently under construction.

Tunnel and Shaft Rehabilitation Program

The Tunnel and Shaft Rehabilitation Program construction contract began in 2007. The work has included substantial site improvements at various shaft locations to provide improved access to and ventilation of the tunnel, procurement of most of the "long-lead" items that would be required for a tunnel emergency (such as steel liner and special vehicles for use in the tunnel), and dives to replace the existing bronze gate valve and to investigate the bronze door both within Shaft 6 of the RWBT.

The work was substantially complete in September 2014 and resulted in the Shaft 6 RWBT unwatering pump station being operable and ready to unwater the RWBT for inspection and repair of the tunnel during the 2022 connection.

The 50 million gallons per day pumping station, which is capable of dewatering the RWBT under any expected conditions, is now ready to operate. The pump station is tested on a monthly basis.

A protocol for the unwatering and re-watering of the RWBT is currently in production.

Roseton Bypass Tunnel

Planning for a Roseton bypass tunnel began in 2009. An engineering consultant team was selected to investigate and plan a new section of tunnel specifically to bypass the worst leak areas in Roseton, N.Y. A bypass design was completed by 2012 and construction work on two access shafts began in 2013. The bypass tunnel construction began in 2017 and mining for the tunnel was completed in 2019. The installation of 16-foot-diameter steel inter-liners was completed in 2020 and final concrete lining is approximately 75% complete as of the end of 2020. Upon completion of this effort, the tie-in of this 2.5-mile- long bypass to the existing RWBT will commence. During the execution of the tie-in, workers will grout the leaks in the Wawarsing area of the RWBT from within the dewatered tunnel. DEP expects the bypass project to be completed in autumn 2023.

Water for the Future Program

Planning for an extended shutdown of the RWBT to make necessary repairs and bypass led to formation of the Water for the Future (WFF) Program. The program manages in a coordinated fashion all projects related to completion of the RWBT bypass and repair to ensure successful completion and track projects that could delay the RWBT construction. Two major portions of the WFF Program include repair and rehabilitation of the Catskill Aqueduct and Demand Management.

During the RWBT connection period, the Catskill Aqueduct will be required to operate at maximum capacity for up to eight months duration. The Catskill Aqueduct Repair and Rehabilitation (CATRR) project focuses on the section of the aqueduct between Ashokan Reservoir in Ulster County and Kensico Reservoir in Westchester County. The goals of the project are to ensure reliability of the Catskill Aqueduct, restore hydraulic performance, and repair or replace mechanical components that are at the end of their useful life. CATRR project scope focuses on inspection of the entire aqueduct, repairing deficiencies (including concrete and mechanical components), and removal of a biofilm layer on the interior walls to improve the hydraulic characteristics of the tunnel thereby restoring aqueduct capacity. CAT-RR construction commenced August 2018 and the second round of tunnel shutdowns were completed in April 2020. The third round of shutdowns was initiated in November 2020 and was underway until February 2021.

Two related projects include building chemical addition facilities at the Ashokan Screen Chamber (CAT-213E) and the Pleasantville Alum Plant (CAT-213F) to deliver chlorination and dechlorination chemicals, respectively. Substantial completion is expected in spring 2021.

Another measure to make up the loss of water from the Delaware System when the RWBT is out of service is to enhance demand management. Several projects have been implemented to reduce overall water demand in the City and upstate communities that rely on the City's water supply. Projects include toilet replacements with higher efficiency units, park spray shower enhancements, education programs, and enhanced leak detection.

Appendix C: Water Quality Status and Trends Data Analysis

Sites

Site selected for water quality status and trends are listed in Appendix C Table 1 and Appendix C Table 2 as well as shown pictorially in Appendix C Figure 1 and Appendix C Figure 2. Reservoirs included in the assessment include all Catskill and Delaware System reservoirs, West Branch Reservoir (acting as a balancing reservoir for water received from Rondout Reservoir), Cross River and Croton Falls reservoirs (can be pumped into the Delaware Aqueduct prior to its entering Kensico Reservoir), and Kensico Reservoir (normally the main source reservoir for the entire system sans the Croton System).

For each of these reservoirs, the primary goal is to select sites that are identifiable as the primary inflows and outflows for each reservoir system considered. For all reservoirs except Kensico Reservoir, the inflow sites selected are surface-water main channels located immediately upstream of the reservoirs and, when appropriate, aqueducts delivering water from upstream reservoirs, and therefore represent the bulk of water entering the reservoirs for their respective watersheds. Rondout, West Branch, and Kensico reservoirs receive aqueduct inflows from upstream reservoirs. Reservoir outflow locations are normally aqueducts except for West Branch, Cross River and Croton Falls, where the reservoir outflows are the releases.

Appendix C Table 1 Inflow (surface-water and aqueduct keypoints), reservoir, and outflow (aqueduct keypoints and reservoir releases) monitoring locations included in the water quality status and trends analysis.

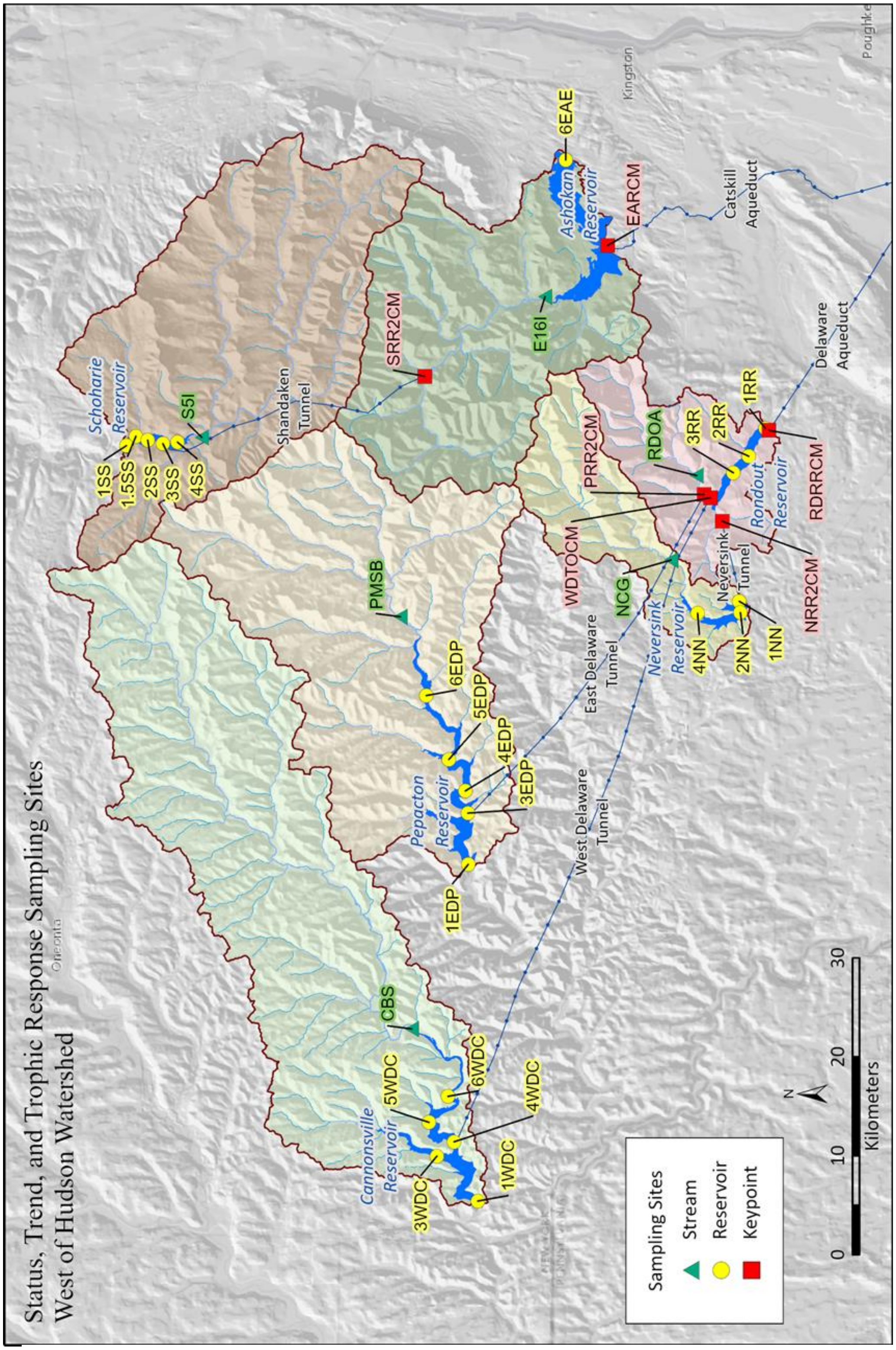
System/District	Inflows[1]	Reservoirs[3]	Outflows[1]
Catskill	S5I[s]	Schoharie (SS)	SRR2CM
	E16I[s]	Ashokan (West—EAW)[2]	—
	—	Ashokan (East—EAE)[2]	EARCM
Delaware	NCG[s]	Neversink (NN)	NRR2CM
	PMSB[s]	Pepacton (EDP)	PRR2CM
	CBS	Cannonsville (WDC)	WDTOCM
	NRR2CM[k], PRR2CM[k], WDTOCM[k], RDOA[s]	Rondout (RR)[2]	RDRRCM
East-of-Hudson	DEL9[k], BOYDR[s], HORSEPD12[s]	West Branch (CWB)[2]	WESTBRR

System/District	Inflows[1]	Reservoirs[3]	Outflows[1]
	CATALUM[k], DEL17[k],	Kensico (BRK)[2]	CATLEFF[D], DEL18DT
	CROSS2[s]	Cross River (CCR)[2]	CROSSRVVC
	WESTBRR[s], CCF (middle basin)	Croton Falls (CCF-main basin)[2]	CROFALLSVC

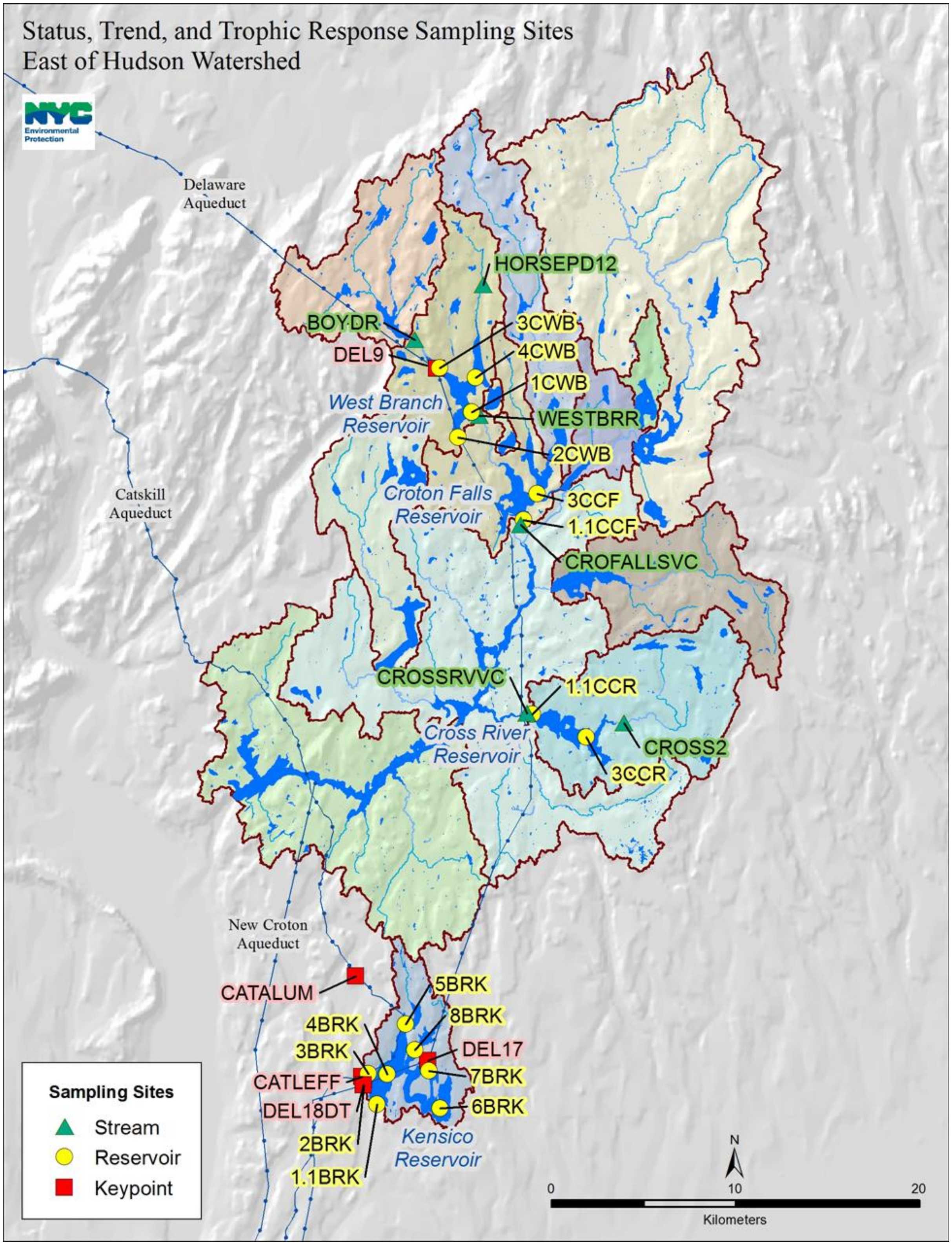
[1] The superscripts [s] and [k] refer to surface-water and aqueduct keypoints, respectively; all outflows are aqueduct keypoints except for WESTBRR, CROSSRVVC and CROFALLSVC which are reservoir releases. Superscript [D] refers to a site where sampling was discontinued September 2012.

[2] Indicates a source or potential source water.

[3] Reservoir designations represent an amalgam of multiple locations and depths (see text).



Appendix C Figure 1 Sampling sites for the West of Hudson status and trends analysis.



Appendix C Figure 2 Sampling sites for the East of Hudson status and trend analysis.

Appendix C Table 2 Median number of samples collected per month for status and trend analysis, 1993-2019.

Site	Type	Fecal coliform	TP	Conductivity	Turbidity	Chlorophyll *a*
CATALUM	Keypoint	23	4	23	23	0
CATLEFF[D]	Keypoint	30	2	31	31	0
DEL17	Keypoint	23	4	23	23	0
DEL18DT	Keypoint	31	2	31	31	0
DEL9	Keypoint	4	4	4	4	0
EARCM	Keypoint	20	2	22	22	0
NRR2CM	Keypoint	12	2	14	14	0
PRR2CM	Keypoint	15	2	18	18	0
RDRRCM	Keypoint	20	2	22	22	0
SRR2CM	Keypoint	16	4	19	20	0
WDTOCM	Keypoint	11	1	13	13	0
BRK	Reservoir	21	21	22	21	8
CCF (main)[1]	Reservoir	2	3	3	3	1
CCF (middle)[2]	Reservoir	1	2	2	2	1
CCR	Reservoir	3	5	5	5	2
CWB	Reservoir	8	8	8	8	4
EAE	Reservoir	8	8	8	8	3
EAW	Reservoir	9	9	9	9	3
EDP	Reservoir	14	15	15	14	5
NN	Reservoir	9	9	9	9	3
RR	Reservoir	10	10	10	10	3
SS	Reservoir	11	11	11	11	4
WDC	Reservoir	13	14	14	14	5
BOYDR	Release	1	1	1	1	0
CROFALLSVC	Release	1	1	1	1	0
CROSSRVVC	Release	1	1	1	1	0
WESTBRR	Release	1	1	1	1	0
CBS	Stream	1	1	1	1	0
CROSS2	Stream	1	1	1	1	0
E16I	Stream	1	1	1	1	0

Site	Type	Fecal coliform	TP	Conductivity	Turbidity	Chlorophyll *a*
HORSEPD12	Stream	1	1	1	1	0
NCG	Stream	1	1	1	1	0
PMSB	Stream	1	1	1	1	0
RDOA	Stream	1	1	1	1	0
S5I	Stream	1	1	1	1	0

[1] The main basin is represented by site 1.1CCF (see Appendix C Figure 2).

[2] The middle basin is represented by site 3CCF (see Appendix C Figure 2).

[D.] The site was discontinued in September 2012.

Data collection

Historically, the Directorate of Water Quality (DWQ) had multiple groups responsible for routine water quality monitoring. The DWQ field operations staff would perform the routine monitoring for reservoir, stream, and reservoir release while the DWQ laboratory operations staff were responsible for keypoint and wastewater treatment plant (WWTP) monitoring. Starting September 2018, all monitoring responsibilities were consolidated under the DWQ field operations groups and continue the same routine monitoring design. Keypoint, stream, reservoir release, and WWTP routine monitoring used for this report are collected year round at a specified location. Reservoir routine monitoring used for this report are collected from April-November from multiple depths at the dam, mid-reservoir, near major stream influent areas, and at other important sites, such as near aqueducts. The full sampling programs are described in DEP (2018).

To ensure the accuracy of trend analysis it is important to maintain consistency in sampling and analytical methodology throughout the period of record. Unfortunately, several changes were instituted for the collection of reservoir surface samples that may affect trend results. From 1993-2001 surface samples were composited from the air-water interface down to the depth of the 1% light level. In 2002, these integrated surface samples were replaced by a 3-meter discrete sample collected using a Van Dorn sampler. The depth of integration also changed. From 1993-1998, the 1% light depth was based on an initial light measurement made in the air above the water surface. From 1999-2001, the location of the initial light measurement was corrected to begin just below the air-water interface. Because of this change, the depth of the photic zone increased by 10-20%. For the purpose of this report, we assumed that these sampling changes had minimal effect on water quality measurements. However, the effect is not known.

Analytes

The analytes considered for status and trends analysis are turbidity, fecal coliform, total phosphorus (TP), and conductivity, plus reservoir trophic state index (derived from chlorophyll a measurements). These are considered the most important water quality indicators for the City water supply. Although ELAP-approved methods were used, several changes occurred during the period of record that could affect trend results. Important method changes for this period of interest include the following:

- 1999
    - Turbidity – Instrument change from the Hach Ratio X/ turbidimeter to the Hach 2100AN turbidimeter.
- 2000
    - Chlorophyll a - Instrument change from the fluorometer to HPLC.
    - Total Phosphorus – Change in digestion method prior to analysis.
- 2007
    - Chlorophyll a – Analysis moved from Grahamsville Laboratory to the Ben Nesin Laboratory.
- 2007-2008
    - Total Phosphorus – Instrument change from Alpkem to Lachat.
- 2008
    - Total Phosphorus – Analysis moved from Grahamsville and Ben Nesin laboratories to the Kingston Laboratory.
- 2009
    - Conductivity – Changed from in-situ measurements using multi-parameter field sondes for routine monitoring (1993 – 2010) to collecting a grab sample for analysis in the laboratory. Requirement of the Quality Assurance program for ELAP certification of conductivity results. In-situ limnology profile measurements continue be performed with multi-parameter field sonde. The effect has not been determined but initial comparisons indicate the effect to be minimal.
- 2014
    - Bottle Change – To meet ELAP requirements, in August 2014 all bottles used for preserved samples, except trace metals, were switched from polypropylene (PP) to high density polyethylene (HDPE).

For turbidity and total phosphorus, there was a comparison between old and new methods that suggested the new method yields higher values, but more work is needed to determine a correction factor.

Trophic State Index (TSI) was calculated from the chlorophyll a concentration using the following equation (Carlson, 1977):

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

where chlor a = chlorophyll a concentration (μg L^{-1}).

Only samples collected from the photic zone (either integrated samples taken from the surface to the 1% light level, or discrete samples taken at 3m depth) were used to calculate TSI. For trends in Kensico, West Branch, Croton Falls and Cross River reservoirs, 1995-1997 data were not used because of chlorophyll a extraction problems.

Methodology

Prior to status and trend analysis, data were screened for outliers by plotting the data and by comparing each point to an expected range of values based on similar location, season, and in the case of reservoirs, depth. Suspect data was flagged and the original records reviewed to determine if a transcription error had occurred. All discovered transcription errors were corrected. Remaining outliers were removed only if they were far outside the normal range of historic data. Occasionally, when fecal coliform counts were predicted to be high (in response to a runoff event) large dilutions (>5:1) were used in the laboratory to analyze fecal coliform data. If fecal coliforms were not observed in the diluted sample we judged that dilution rendered the sample unreliable and set these results to missing.

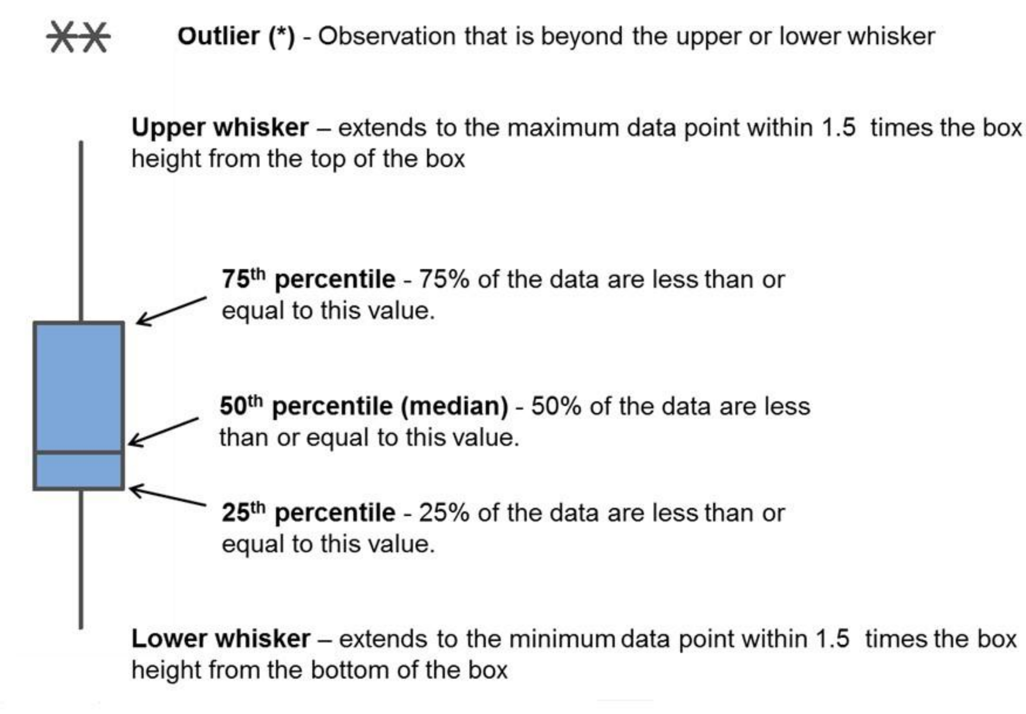
To create a balanced dataset, steps were taken to minimize potential impacts of changes in sampling frequency during the period of record which may produce a bias in the data, thereby obscuring or enhancing a trend. The following steps included:

1. Eliminating all special investigations and restricted data
2. Coliform results with left sensoring greater than <5 coliforms 100 mL^{-1} (<10, <20, <100, etc…) were converted to missing.
3. Calculate a monthly median value for each month for each analyte of interested for all sites. Values below the detection limit were converted to one-half the detection limit for statistical analysis. Future work will explore using more robust methods, like the R Statistical package NADA, to calculate median values without converting nondetects to one-half the detection limit.
4. Ensure consistent representation. If less than 75% of the normal reservoir monthly sample load was not available for reservoirs with four or more sites, a monthly median was not calculated for that particular month for that reservoir, and the month set to missing. For reservoirs with three sites or less, 50% of the sample load was required.

Status Methods

In an assessment of water quality status, the time period used has to be sufficiently short so that any trends are minimized, but sufficiently long to minimize short-term fluctuations. A three-year time period was considered appropriate and monthly medians from the years 2017–2019 were used. Values below the detection limit were converted to one-half the detection limit for statistical analysis. Box plots have been used as a visual aid to graphically display water quality status based on select analytes. Appendix C Figure 3 provides a key for interpreting the box plots.

A guidance value of 200 coliforms 100 mL^{-1} based on a calculation developed for streams by the New York State Department of Environmental Conservation (6 NYCRR Part 703.4(b)) is included in the discussion of stream fecal coliform status. For reservoirs, fecal coliform data are compared to Surface Water Treatment Rule (SWTR) standards (20 coliforms 100 mL^{-1} for fecal coliform) as a benchmark value. While these standards do not apply to source water reservoirs, they are used for reference purposes. Similarly, the TP benchmark in the status plots (15 µg L^{-1} for potential source water or terminal reservoirs and 20 µg L^{-1} for headwater or non-source reservoirs) is based on phosphorus-restricted “target values” developed by DEP. The calculations for phosphorus-restricted basins are different and covered in the Watershed Water Quality Annual Report, so the use here is for comparative purposes. Trophic state index (TSI) benchmarks, where reservoirs with values <40 are considered oligotrophic; those with values between 40 and 50 are mesotrophic; and values >50 are eutrophic, were based on Carlson (1977).



Appendix C Figure 3 Description of the boxplot statistics used in status evaluations.

Trend Methods

Two independent techniques were used to detect trends. In the first approach, locally weighted scatterplot smoothing (LOWESS) curves were fit to the data to visually describe both the long-term and intermediate data patterns (Cleveland 1979). The second approach used the non-parametric Seasonal Kendall Test (SK) to test for monotonic change (Hirsch et al. 1982). The Censored Kendall Technique was used in cases where a high percentage of the data were left censored (Helsel 2012).

LOWESS curves were fitted to monthly medians of the data to describe long-term and prominent short-term trends. If more than 50% of the month's data were left censored, the median was set to one-half the instrument detection limit. The non-parametric LOWESS technique was chosen because, unlike parametric methods such as linear regression, it provides a robust description of the data without pre-supposing any relationship between the analytes and time, and because the distribution of the data does not need to be of a particular type (e.g., normal). The LOWESS technique is also preferable to parametric methods because it performs iterative re-weighting which lessens the influence of outliers and highly skewed data.

LOWESS curves were constructed using the PROC LOESS procedure in SAS 9.2 (SAS 2010). In PROC LOESS, weighted least squares are used to fit linear or quadratic functions to the center of a group of data points. The closer a data point is to the center, the more influence or weight it has on the fit. The size of the data group is determined by the smooth factor chosen by the user. In our analysis we chose a smooth factor of 0.3, which means that 30 percent of the data are used to perform the weighted least squares calculation for each data point. Through experimentation we found a smooth factor of 0.3 provided a good description of the overall long-term trend and important intermediate trends as well.

Increasing the number of iterations or re-weightings that PROC LOESS performs on the data can further reduce the influence of outliers. With each iteration, data points are weighted less the further they are removed from the data group. Selecting one iteration corresponds to no re-weighting. Given the prevalence of extreme values commonly observed in coliform data, we found that selecting one iteration produced a fit that was excessively driven by outliers. Three iterations, corresponding to two re-weightings, has been recommended in other studies (see e.g., Cleveland 1979) and yielded a good fit with DEP's coliform data. For the other analytes presented (e.g., turbidity, TP) the number of iterations chosen had little discernable effect on the LOWESS fit. For ease of presentation, in this report, LOWESS curves for all analytes were determined using three iterations.

The occurrence of long-term monotonic trends was tested for statistical significance using the non-parametric SK test (Hirsch *et al*. 1982). The magnitude of detected trends was determined using the Seasonal Kendall Slope Estimator (SKSE) (Hirsch *et al*. 1982).

The SK tests were performed using TimeTrends, a freeware software program for analyzing water quality data. TimeTrends was originally developed by Ian Jowett while at the New Zealand's National Institute of Water and Atmospheric Research (NIWA) and the most recent version was downloaded from https://www.jowettconsulting.co.nz/home/time-1. TimeTrends was developed to carry out statistical and trend analyses or equivalence tests, and the current version now provides trend detection assessment, which is discussed below. The Seasonal Kendall test poses the null hypothesis that there is no trend; the alternative hypothesis being that there is in fact an upward or downward trend (a two sided test). The *p*-values for all trend tests are symbolized as follows:

p- value	Significance	Symbol
$P \geq 0.20$	None	NS
$p < 0.20$	Moderate	*
$p < 0.10$	High	**
$p < 0.05$	Very High	***

The lower the p value, the more likely the observed trend is not attributable to chance. Note that the term "NS" does not mean that there is no trend but rather that the null hypothesis of no trend cannot be rejected (at the p = 0.2 level of significance—80% confidence level), and that any apparent trend could be attributed to chance.

A strong advantage of the non-parametric test is that there are no assumptions made, apart from monotonicity, about the functional form of any trend that may be present. The test merely addresses whether the within-season/between-year differences tend to be monotonic. Outliers also have a lesser effect on the non-parametric tests because non-parametric tests consider the ranks of the data rather than actual values. The effects of serial correlation are always ignored; this is justified because the scale of interest is confined to the period of record (Loftis et al. 1991, McBride 2005).

The SKSE technique is used to estimate trend magnitude (i.e., amount of change per year). In this technique, slope estimates are first computed for all possible data pairs of like months. The median of these slopes is then determined. This median is the Seasonal Kendall Slope Estimator. Note it is possible to obtain a statistically significant trend with the Seasonal Kendall Test, yet obtain a zero change per year using SKTE. This is an odd feature of the procedures and is a function of the fact that the trend test and the slope estimate are performed independently of each other. It occurs when there are many tied values in the dataset, e.g., many non-detects. When that happens, the trend slope computation, which is based on the median of all slopes between data pairs of the same month, produces a value of zero, even though the trend analysis, which is based on median data ranks, may produce a significant result.

Note that in practice one can rarely, if ever, say there is no trend. All one can say is that you have failed to detect a trend at a certain level of confidence. In fact, there is nearly always a trend and the null hypothesis of no trend is nearly always false to begin with! Note also that p values produced with data having different n values are not comparable (McBride, 2005).

As discussed in Helsel et al 2020, new techniques have been developed for presenting results from trend assessments (e.g., McBride, et al. 2014, McBride 2019) and are being used more widely in the scientific literature. In the trend detection assessment the focus is on determining the direction of the trend (increasing or decreasing) regardless of its magnitude and uses descriptive words to provide describe an estimate of the likelihood of the detected direction being correct. The method assumes over time there is always a trend. The traditional trend analysis can categorize trends as "insignificant' if they fail to satisfy a predetermined significance level, e.g. 0.05, and thus miss out on information that may help decide if water quality is improving or not. McBride's methodology estimates a Sen slope from the data, then uses Bayesian Credible Intervals to compute confidence intervals around the slope to calculate probabilities that the trend is either increasing or decreasing. Breakpoints, instead of a single probability, e.g., 0.95, are used on scale and assigned descriptive language (e.g., a trend is "likely increasing" or "very likely increasing") to convey the likelihood of the trend direction being correct (See Appendix C Table 3). The TimeTrends software uses the methodology of McBride (2019) to perform the trend detection assessment.

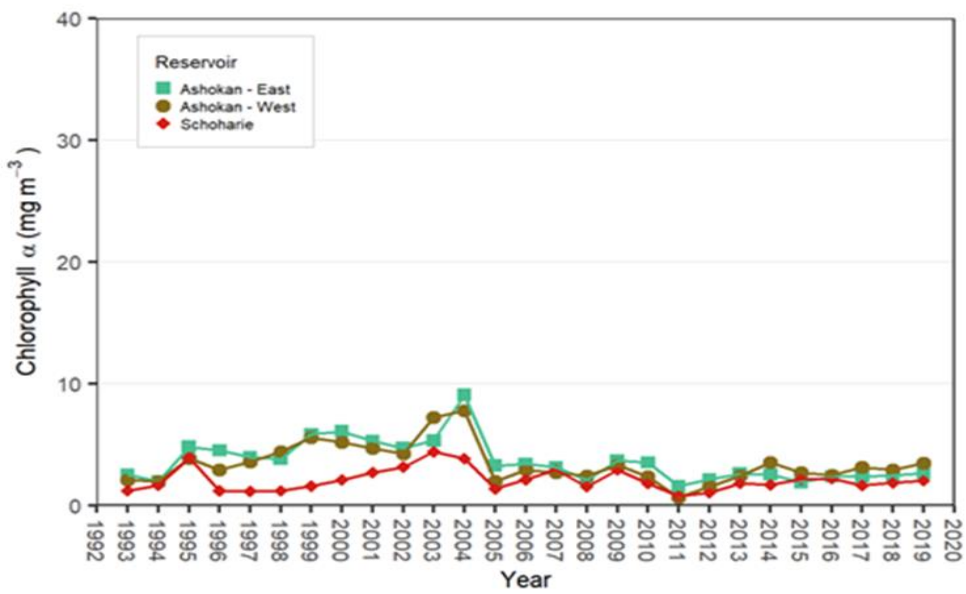
Appendix C Table 3 Likelihood scale used in the TimeTrends software trend detection assessment.

Kendall *P*-Value	Confidence Limits (%)	Slope Direction probability	Term
0.01	99	>=0.995	Virtually certain
0.05	95	>=0.975	Very likely
0.1	90	>=0.95	Likely
0.33	67	>=0.835	Possible
0.67	33	>=0.665	About as likely as not
0.9	10	>=0.55	Unlikely
0.95	5	>0.525	Extremely unlikely
0.99	1	<=0.505	Exceptionally unlikely

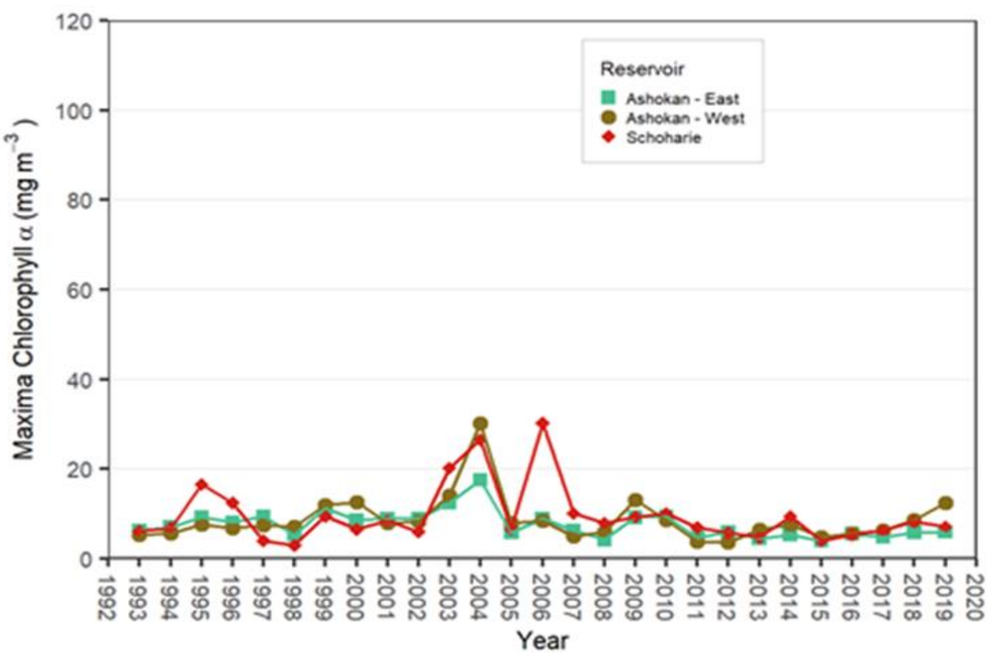
Biomonitoring Methods

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. Samples are collected annually between July and September using the “traveling kick” method, which consists of disturbing the stream bottom of a riffle habitat area and holding a net downstream to catch macroinvertebrates released into the water column by this disturbance. A subsample of approximately 100 organisms is taken from each sample and the macroinvertebrates in it are identified and enumerated. From these data, a series of five metrics is generated which yield five independent metric values: species richness (the total number of taxa identified in the subsample); EPT richness (the total number of taxa in the subsample belonging to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies); Hilsenhoff Biotic Index (the average of the biotic index values for all individuals identified in the subsample (a taxon’s biotic index value corresponds to the taxon’s assumed tolerance to organic pollution)); Percent Model Affinity (the similarity of the subsample’s composition to the ideal composition of an undisturbed stream riffle community as defined by the SBU); and the Nutrient Biotic Index-Phosphorus (the average of the NBI-P values for all individuals identified in the subsample (the NBI-P tolerance value is a measure of a taxon’s assumed tolerance to phosphorus loading).

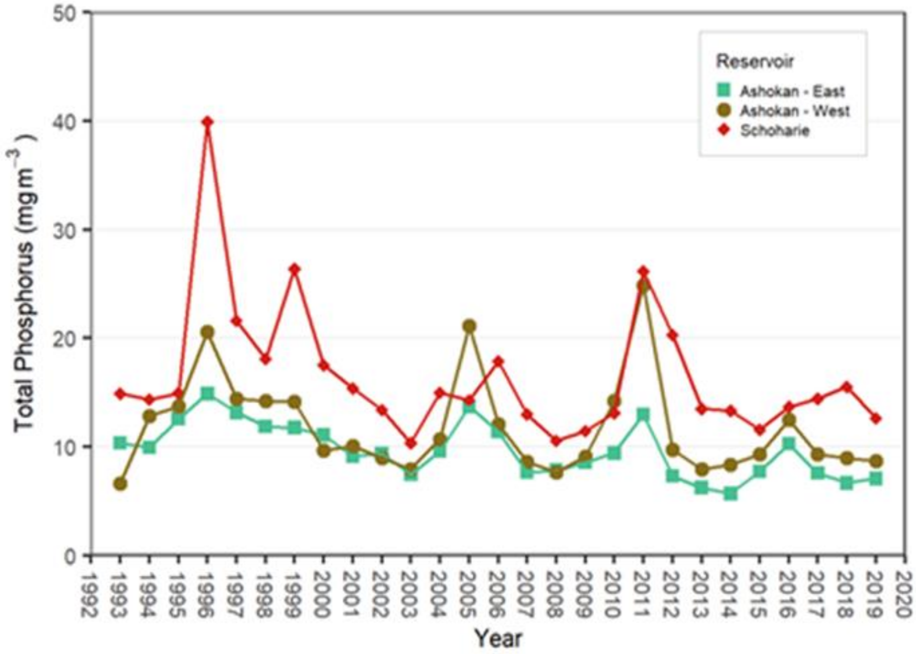
Time series plots for trophic parameters in the Catskill, Delaware, and selected East of Hudson reservoirs.)



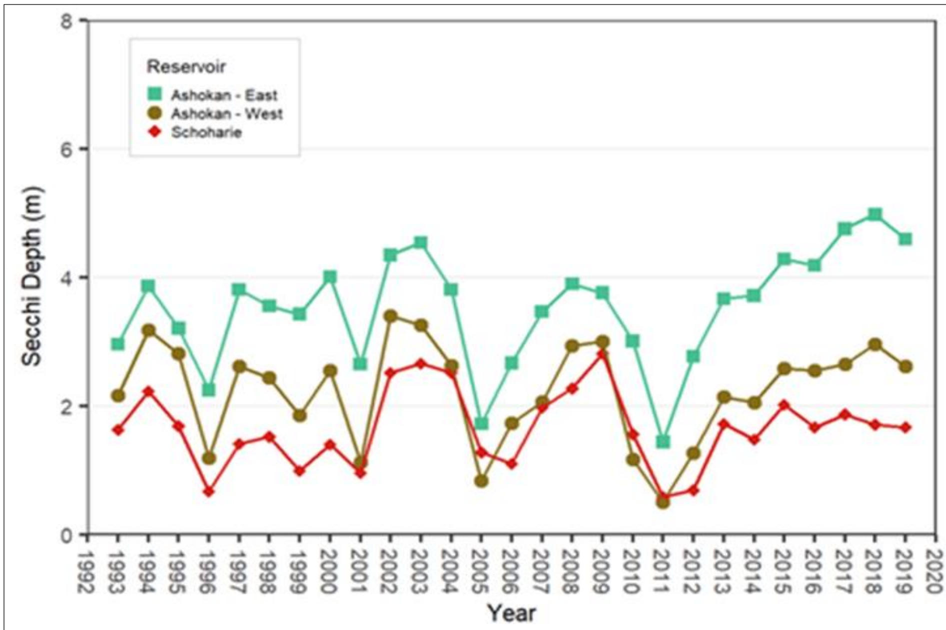
Appendix C Figure 4 Annual geometric means for Chlorophyll *a* at Catskill reservoirs (1993 - 2019).



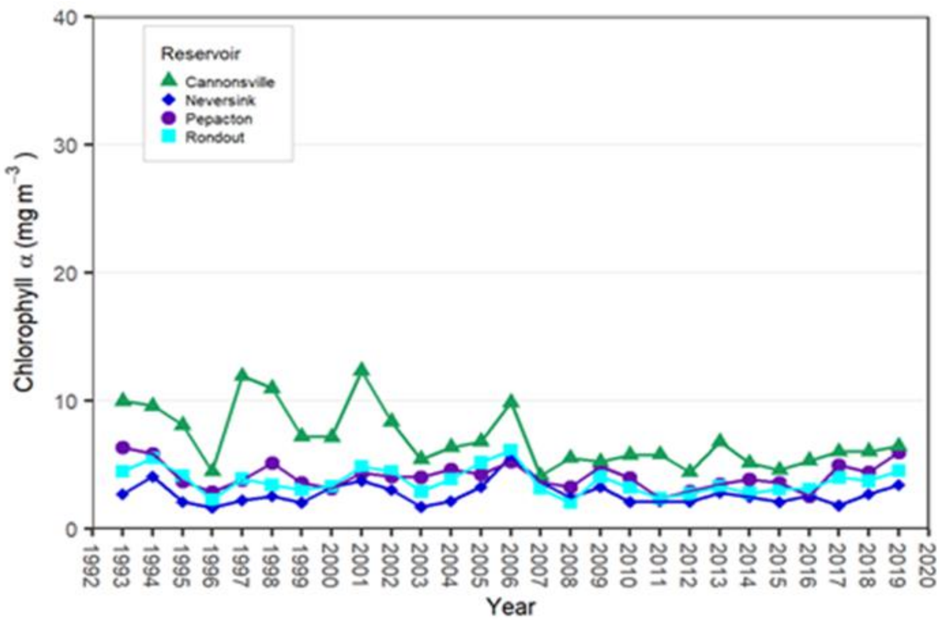
Appendix C Figure 5 Annual maxima for chlorophyll *a* at Catskill reservoirs (1993 - 2019).



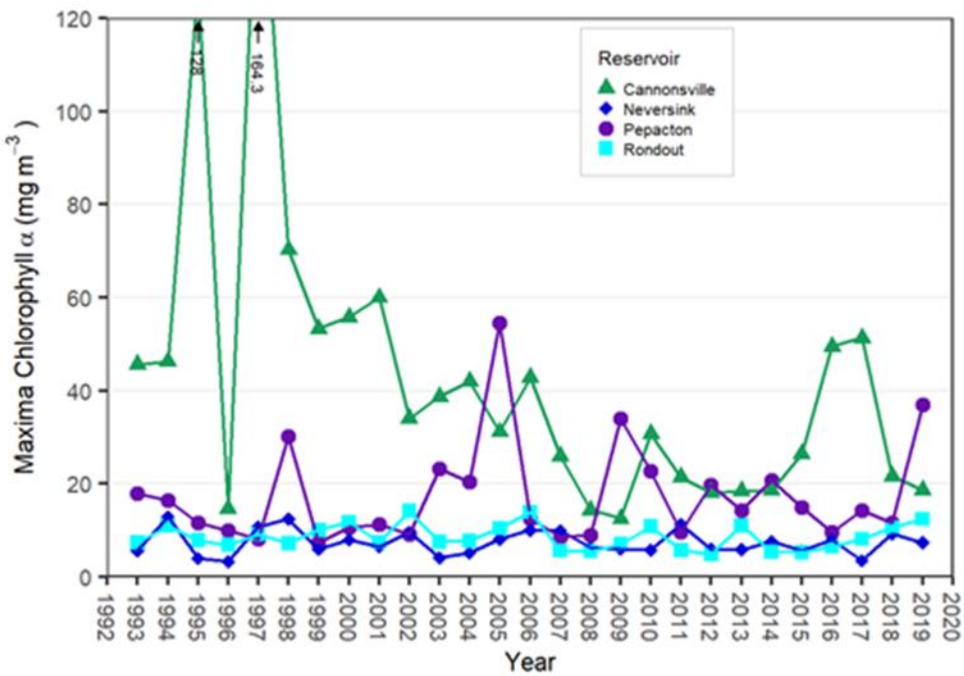
Appendix C Figure 6 Annual geometric means for total phosphorous at Catskill reservoirs (1993-2019).



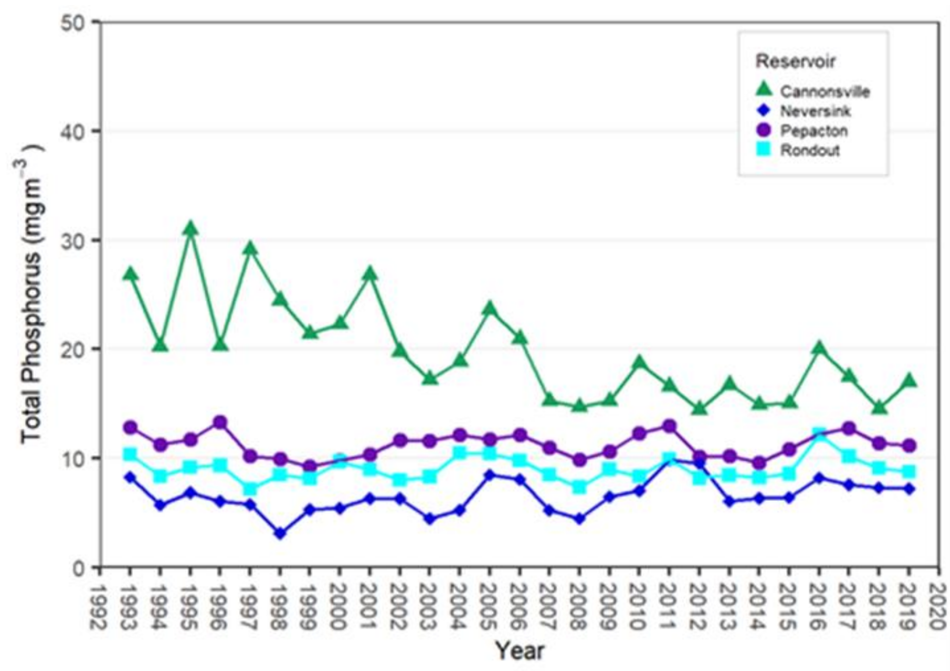
Appendix C Figure 7 Annual geometric means for Secchi depth at Catskill reservoirs (1993-2019).



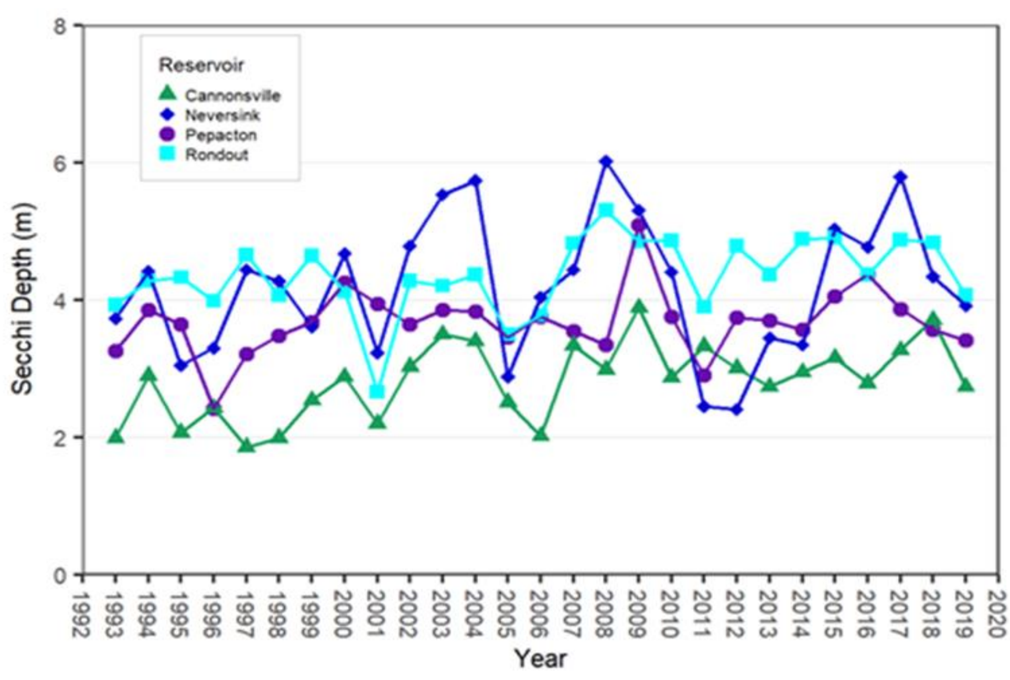
Appendix C Figure 8 Annual geometric means for chlorophyll *a* at Delaware reservoirs (1993-2019).



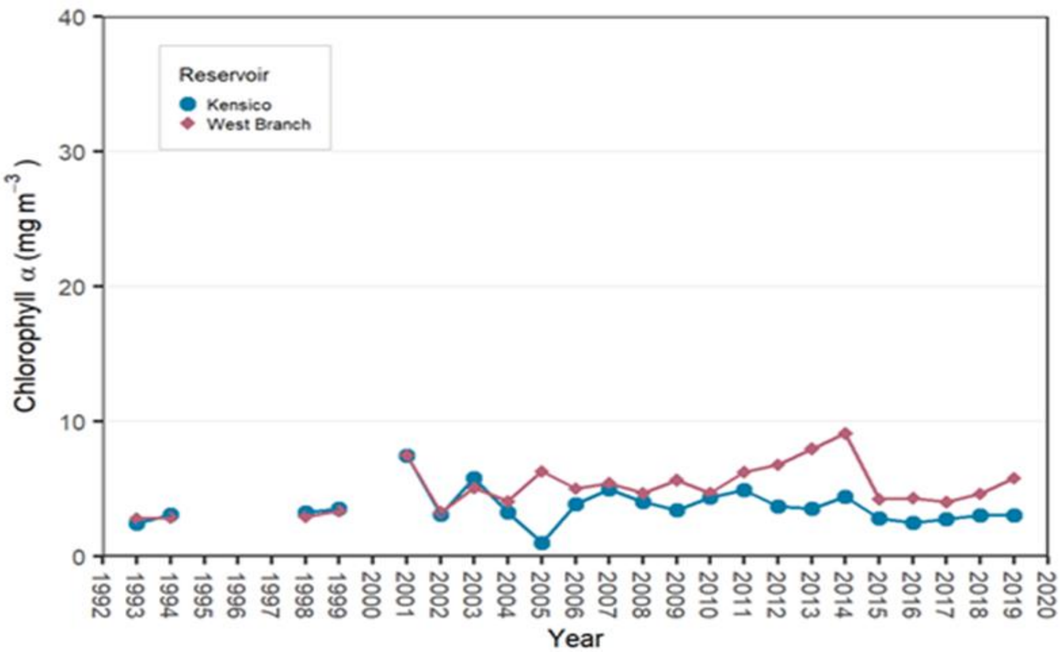
Appendix C Figure 9 Annual maxima for chlorophyll *a* at Delaware reservoirs (1993-2019).



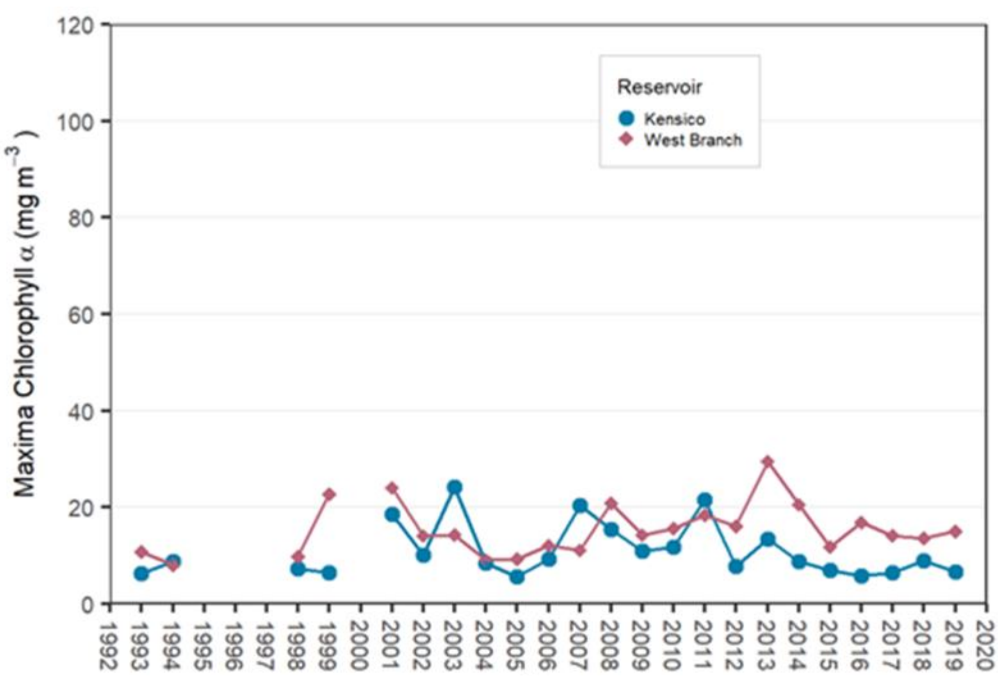
Appendix C Figure 10 Annual geometric means for total phosphorous at Delaware reservoirs (1993-2019).



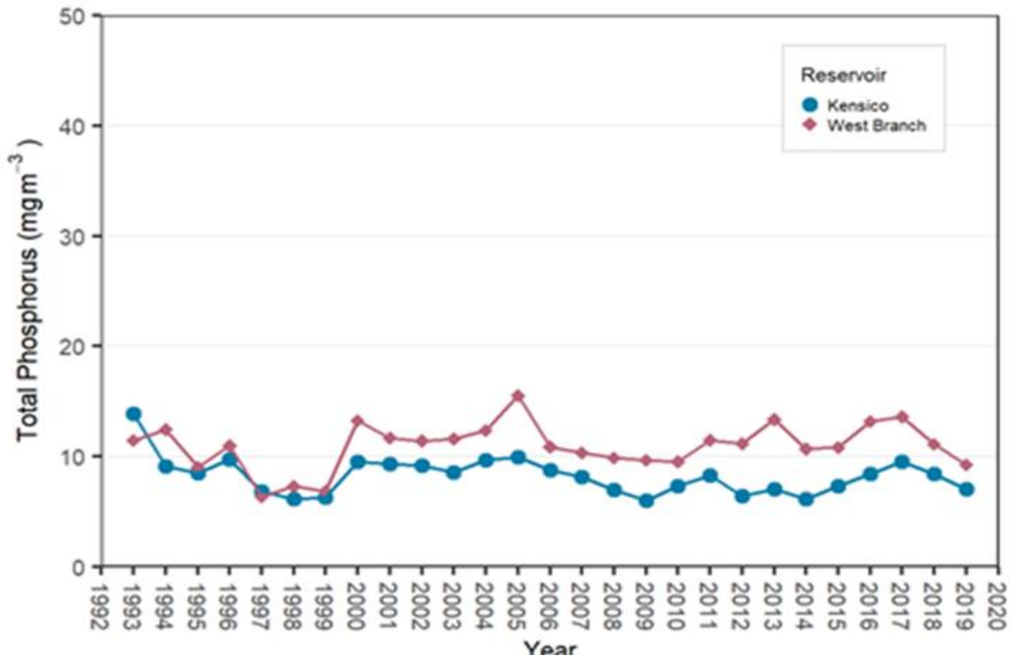
Appendix C Figure 11 Annual geometric means for Secchi depth at Delaware reservoirs (1993-2019).



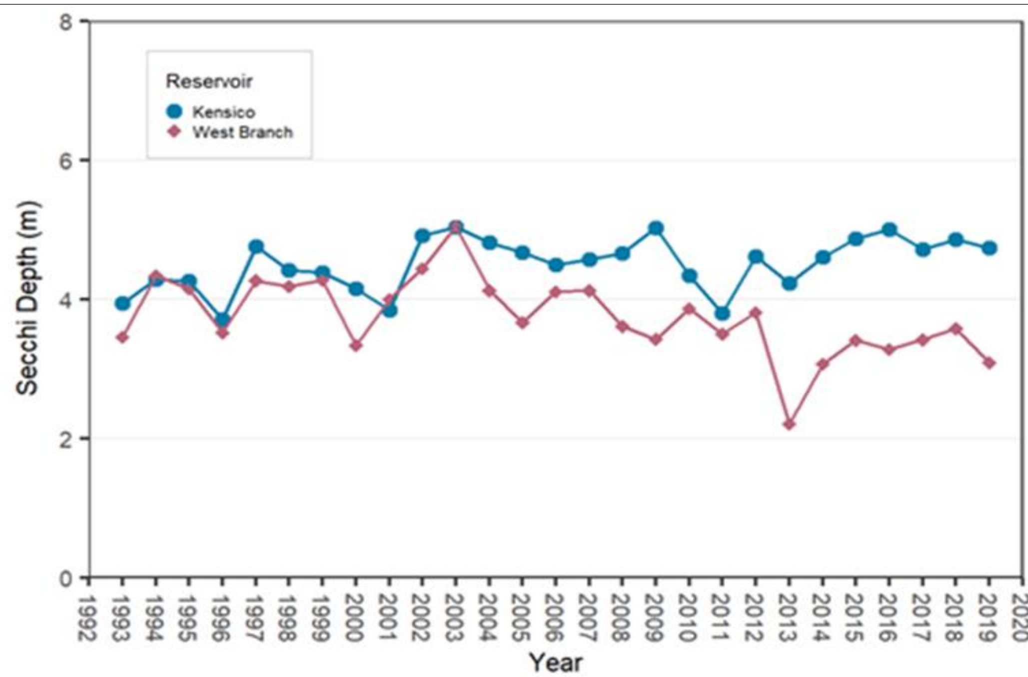
Appendix C Figure 12 Annual geometric means for chlorophyll *a* at West Branch and Kensico reservoirs (1993-2019).



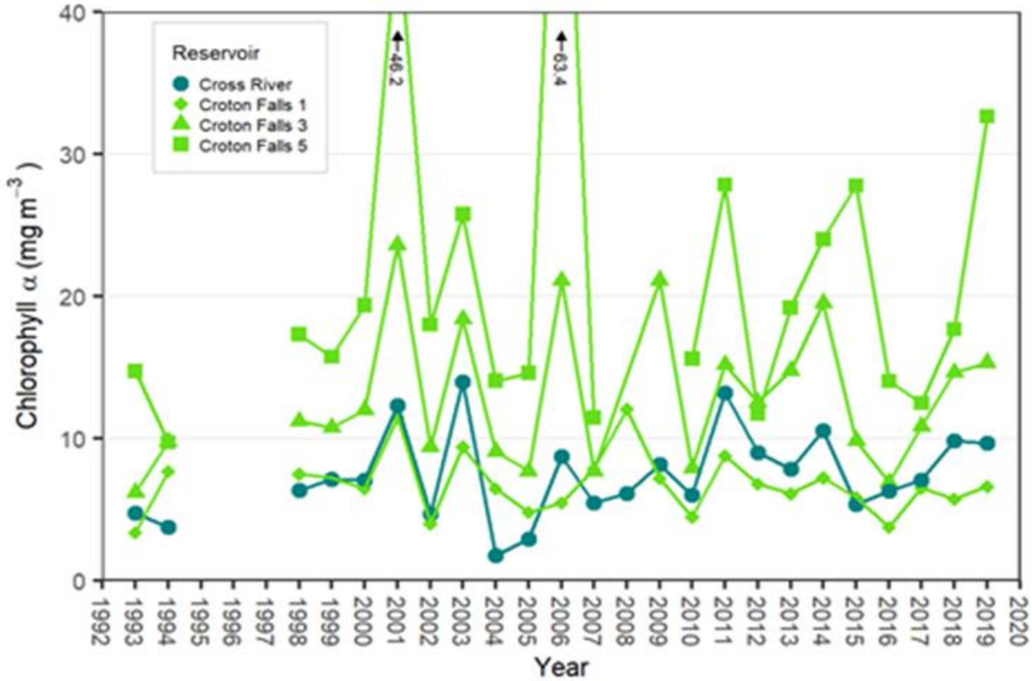
Appendix C Figure 13 Annual maxima for chlorophyll *a* at West Branch and Kensico reservoirs (1993-2019).



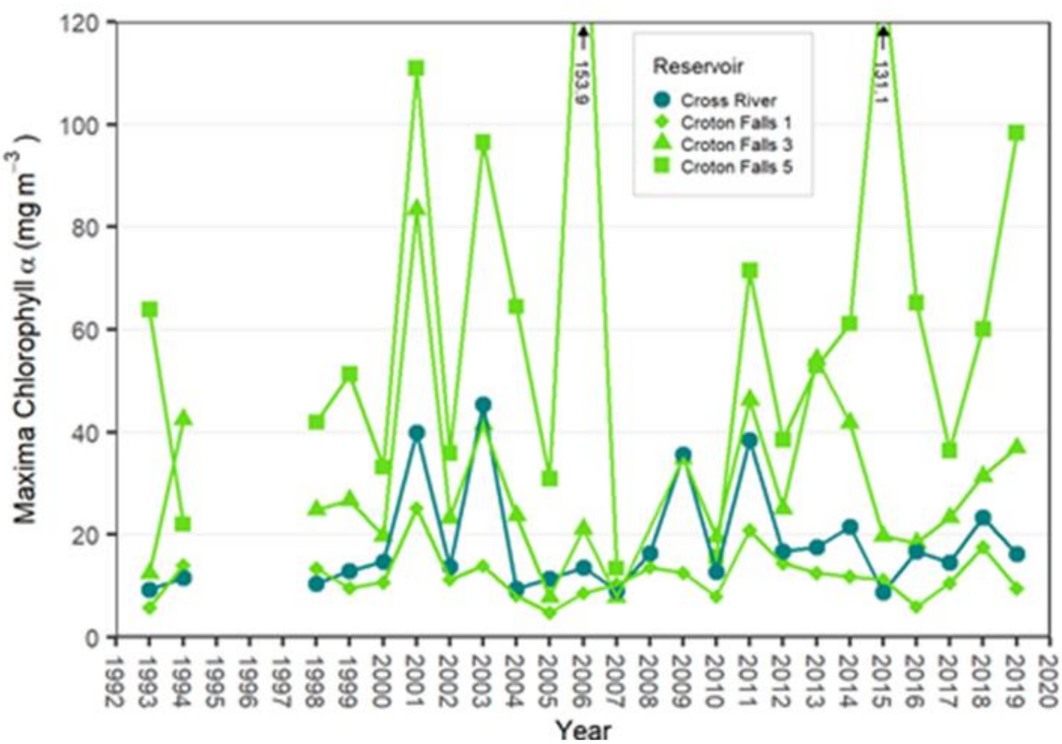
Appendix C Figure 14 Annual geometric mean for total phosphorous at West Branch and Kensico reservoirs (1993-2019).



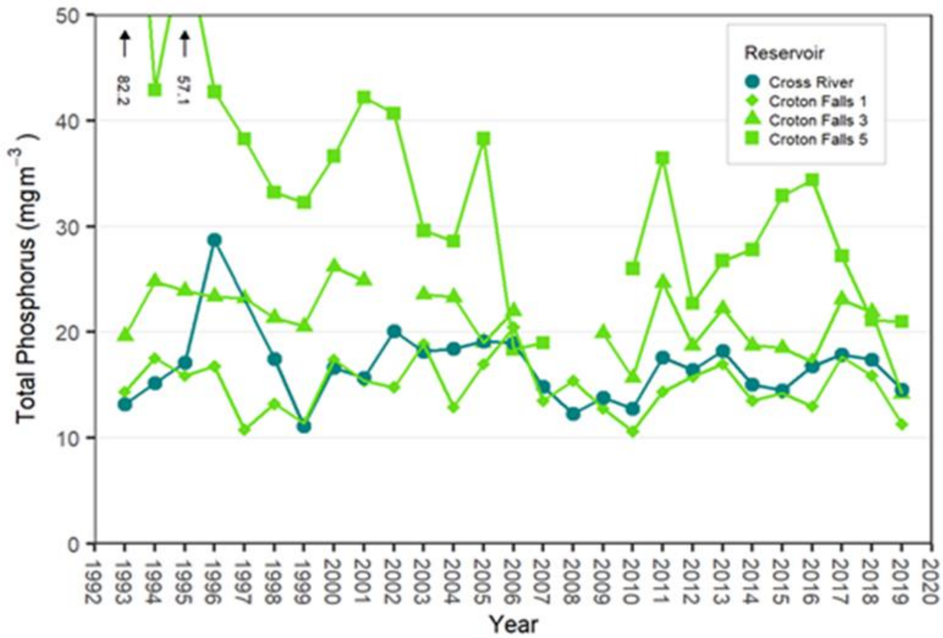
Appendix C Figure 15 Annual geometric mean for Secchi depth at West Branch and Kensico reservoirs (1993-2019).



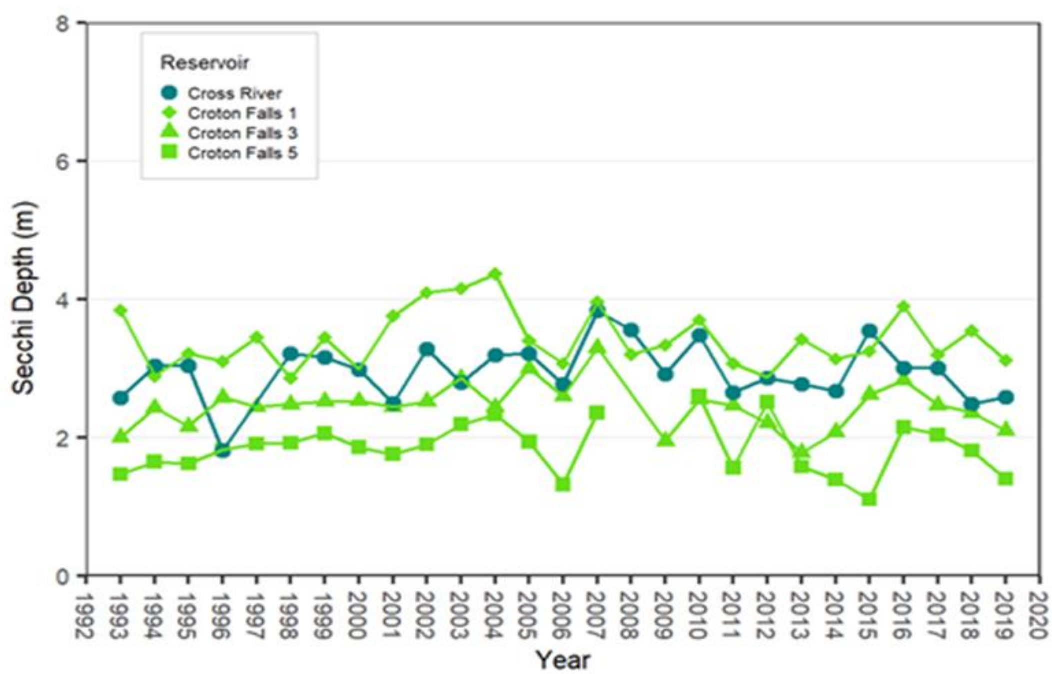
Appendix C Figure 16 Annual geometric means for chlorophyll a at Croton Falls and Cross River reservoirs (1993-2019).



Appendix C Figure 17 Annual maxima for chlorophyll *a* at Croton Falls and Cross River reservoirs (1993-2019).



Appendix C Figure 18 Annual geometric means for total phosphorous at Croton Falls and Cross River reservoirs (1993-2019).



Appendix C Figure 19 Annual geometric means for Secchi depth at Croton Falls and Cross River reservoirs (1993-2019).

Appendix D: Drought Management

For the years 2016-2020, it was not necessary to invoke any of the components of DEP's Drought Management Plan, as precipitation, runoff, and storage levels all remained sufficiently high.

The Drought Management Plan has three phases—Drought Watch, Drought Warning, and Drought Emergency—that are invoked sequentially as conditions dictate. The Drought Emergency phase is further subdivided into four stages with increasingly severe mandated use restrictions. Guidelines have been established to identify when a Drought Watch, Warning, or Emergency should be declared and when the appropriate responses should be implemented. These guidelines are based on factors such as prevalent hydrological and meteorological conditions, as well as certain operational considerations. In some cases, other circumstances may influence the timing of drought declarations.

- Drought Watch: A Drought Watch is declared when there is less than a 50% probability that either of the two largest reservoir systems, the Delaware (Cannonsville, Neversink, Pepacton, and Rondout Reservoirs) or the Catskill (Ashokan and Schoharie Reservoirs), will fill by June 1, the start of the water year.
- Drought Warning: A Drought Warning is declared when there is less than a 33% probability that either the Catskill or Delaware System will fill by June 1.
- Drought Emergency: A Drought Emergency is declared when there is a reasonable probability that, without the implementation of stringent measures to reduce consumption, a protracted dry period would cause DEP's reservoirs to be drained. This probability is estimated during dry periods in consultation with the NYS Drought Management Task Force and the NYS Disaster Preparedness Commission. The estimation is based on analyses of the historical record, the pattern of the dry period months, water quality, subsystem storage balances, delivery system status, system construction, maintenance operations, snow cover, precipitation patterns, use forecasts, and other factors. Because no two droughts have identical characteristics, no single probability profile can be identified in advance that would generally apply to the declaration of a Drought Emergency.

DEP continues to encourage consumers to conserve water and to observe DEP's year-round water use restrictions, including a prohibition on illegally opening fire hydrants.