New York City Department of Environmental Protection

Watershed Protection Program Summary and Assessment

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

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List of Acronyms

AUV	autonomous underwater vehicle
AWSMP	Ashokan Watershed Stream Management Program
BMP	best management practice
BODR	Basis of Design Report
CAT/DEL	Catskill/Delaware
CATUEC	Catskill Upper Effluent Chamber
CDIC	Catskill/Delaware Interconnection Chamber
CDUV	Catskill/Delaware Ultraviolet Disinfection Facility
CE	conservation easement
CP	Forest Management Plan Conservation Practices
CREP	Conservation Reserve Enhancement Program
CRISP	Catskill Regional Invasive Species Partnership
CSBI	Catskill Streams Buffer Initiative
CUNY	City University of New York
CUNRF	City University of New York Research Foundation
CWC	Catskill Watershed Corporation
CWMP	Community Wastewater Management Program
DEM	Digital Elevation Model
DEP	New York City Department of Environmental Protection
DMAP	Deer Management Assistance Permit
DOHMH	New York City Department of Health and Mental Hygiene
EAB	emerald ash borer
EFC	New York State Environmental Facilities Corporation
EIS	environmental impact statement
ELAP	Environmental Laboratory Approval Program
EOC	Emergency Operations Centers
EOH	East of Hudson
EOHWC	East of Hudson Watershed Corporation
EWP	Emergency Watershed Protection
FAD	Filtration Avoidance Determination
FBO	Flood Buyout
FEIS	Final Environmental Impact Statement
FEMA	Federal Emergency Management Agency
FMP	New York City Forest Management Plan
GCSWCD	Greene County Soil and Water Conservation District
GI	gastrointestinal illness
GIS	Geographic Information System
GPS	Global Positioning System
GWLF	Generalized Watershed Loading Functions
HEFS	Hydrologic Ensemble Forecast Service

HMGP	Hazard Mitigation Grant Program
IRSP	individual residential stormwater plan
ISAC	Invasive Species Advisory Committee
ISC	New York State Invasive Species Council
ISWG	Invasive Species Working Group
JV	Joint Venture
LAP	Land Acquisition Program
LFA	Local Flood Analysis
LiDAR	Light Detection and Ranging
LIMS	Laboratory Information Management System
LT2ESWTR	Long-term 2 Enhanced Surface Water Treatment Rule
MAP	Management Assistance Program
MFO	Master Forest Owner
MGD	million gallons per day
MMI	Milone & MacBroom, Inc.
MOA	New York City Memorandum of Agreement
NHD	National Hydrography Dataset
NMP	nutrient management plan
NRCS	Natural Resources Conservation Service
NTU	nephelometric turbidity unit
NWI	National Wetlands Inventory
NYC	New York City
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
OECD	Organization for Economic Cooperation and Development
OST	Operations Support Tool
PRISM	Partnership for Regional Invasive Species Management
RBAP	Riparian Buffer Acquisition Program
ROV	remote operated vehicle
RWBT	Rondout-West Branch Tunnel
SEQRA	State Environmental Quality Review Act
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
SWCD	Soil and Water Conservation District
SWE	snow water equivalent
SWPPP	stormwater pollution prevention plan

SWTR	Surface Water Treatment Rule
THM	trihalomethane
TP	total phosphorus
TSI	Trophic State Index
TTHM	Total trihalomethane
UCSWCD	Ulster County Soil and Water Conservation District
UFI	Upstate Freshwater Institute
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
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
WFP	whole farm plan
WOH	West of Hudson
WRF	Water Research Foundation
WR&R	New York City Watershed Rules and Regulations
WSP	Water Supply Permit
WSPS	Water and Sewer Permitting System
WWQMP	Watershed Water Quality Monitoring Plan
WWTP	wastewater treatment plant

Acknowledgements

The New York City of Environmental Protection is charged with providing an ample supply of clean water to nearly 9 million people. DEP meets this mandate through the efforts of hundreds of dedicated professionals. This report provides both 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 20 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 Operations, Water Quality, 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.

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The second major section of this report describes the work of the Water Quality Directorate under Steven Schindler. The Division of Water Quality Science and Research (WQSR), under the direction of Lorraine Janus, Ph. D., was responsible for mathematical analyses that demonstrate the current status and long-term changes in water quality, trophic condition, and pathogens as they relate to the watershed protection programs, and the modeling work in which DEP is currently engaged for optimum water supply management. Section Chiefs include: Kerri Alderisio, Jim Mayfield, Emmet Owens, P.E., and Anne Seeley. Sharon Balter, M.D. and staff at the Department of Health and Mental Hygiene (DOHMH) provided text and graphics to describe the Waterborne Disease Risk Assessment Program. Additional authors include: Karen Moore, Ph. D., Rich Van Dreason, Martin Rosenfeld, Rakesh Gelda, Ph. D, and Christopher Nadareski. Graphics were contributed by Jordan Gass, Radan Homolac, Christian Pace, and David Quentin.

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This report is dedicated to Mark Zion, a valued member of DEP's water quality modeling team and dear colleague who departed this earth much too soon.

Executive Summary

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

The New York City (NYC) 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 2016 Watershed Protection Summary and Assessment*, has been prepared to comply with the New York State Department of Health's (NYSDOH) May 2014 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 NYC'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, (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 that 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 by-products, 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 and May 2014).

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 more than 450 sites throughout the watershed – at aqueducts, reservoirs, streams and wastewater treatment plants (WWTPs). 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, and the millions in communities downstream of the reservoirs.

Implementing the Source Water Protection Program & Achievements to Date

Through much of the 1990s, DEP struggled to assemble and implement the elements of a comprehensive and long-term watershed protection program. In January 1997, a new era of source water protection and partnership began when the City, the State, United States Environmental Protection Agency (USEPA), watershed communities and environmental and public interest groups signed the NYC 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 USEPA.

In July 2007, the USEPA, in consultation with NYSDOH, issued a 10-year FAD. The programs identified in the 2007 FAD built on the significant program accomplishments to that time and reflected DEP's continued commitment to long-term watershed protection. The 2007 FAD required a mid-term review and update, which was completed by NYSDOH in May 2014 (the Revised 2007 FAD). The Revised 2007 FAD incorporated a mix of core on-going programs and new initiatives targeted at evolving threats to water quality such as flood events and invasive species. Two significant storms in the late summer of 2011 focused the efforts of all stakeholders on identifying strategies to enhance flood protection in the watershed. The Revised 2007 FAD demonstrates DEP's ability to continue to implement proven programs, as well as the ability to adapt 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.

Effective implementation of this multi-faceted program depends on support from and cooperation with the City's watershed partners. DEP regularly works with many agencies, organizations and communities throughout the region to advance initiatives. These partnerships are vital to the continued success of the source water protection program and recognize the need to strike a balance between protecting water quality and preserving the communities in the watershed. The contributions of many of these groups are acknowledged throughout this report.

Significant progress continues on implementation of several key watershed protection initiatives: the Watershed Agricultural Program; the acquisition of sensitive watershed lands; the enforcement of Watershed Regulations; the Stream Management Program (SMP); 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 WWTPs. Figures ES.1 and ES.2 map the myriad projects completed by DEP and its partners in the Catskill/Delaware and Croton watersheds 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 (WAC), the City funds development of farm pollution prevention plans and implementation of structural and non-structural best management practices (BMPs). To date, 195 large farm operations in the Catskill/Delaware watersheds have signed up for the WAP, representing 92% of identified large farms. DEP implemented approximately 7,100 BMPs on all participating farms at a cost of $57 million, not including planning, design and administrative expenses. 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, has enrolled more than 2,000 acres of riparian buffers and an estimated 11,000 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, DEP has secured 113,595 acres in fee simple or conservation easement (CE), with another 24,667 acres of farm easements secured by the WAC. Overall, the City and State now protect 38% 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 41% to 66% protected.

Watershed Regulations

Since 1997, DEP has reviewed more than 16,100 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.

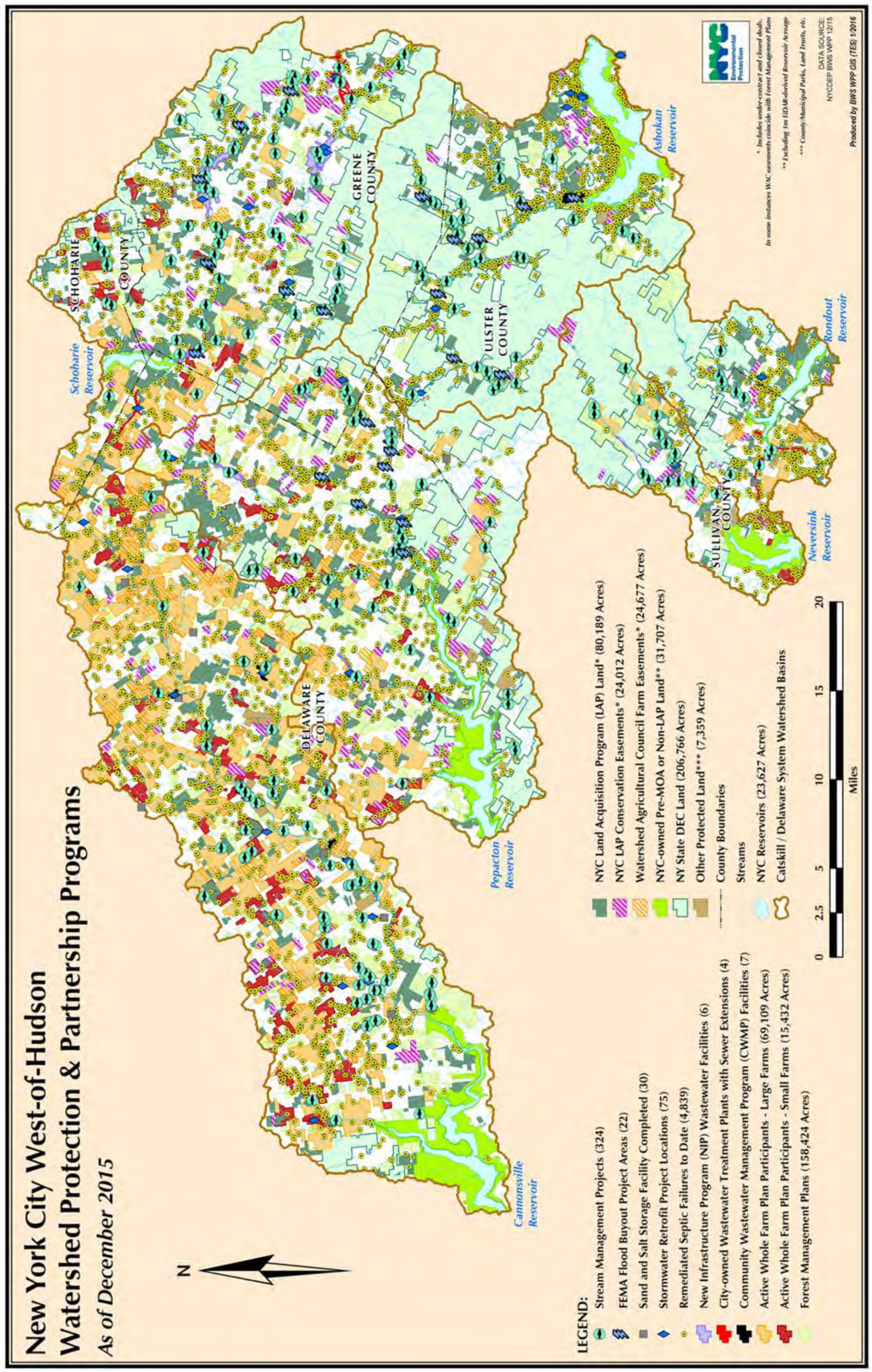

Figure E.1 Map showing status of the partnership programs West of Hudson.

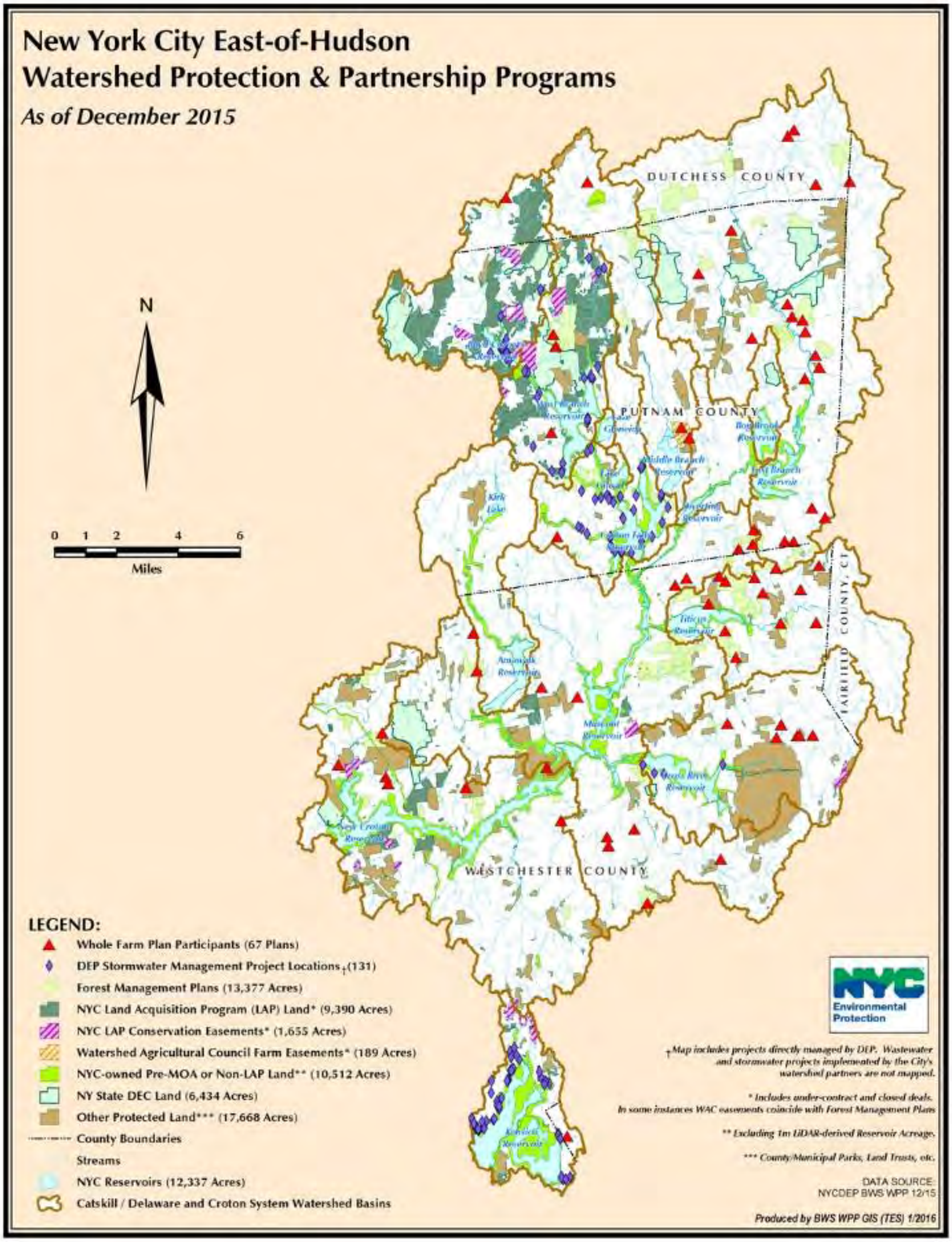

Figure E.2 Map showing status of the partnership programs East of Hudson.

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 nearly 4,900 failing septic systems. All WWTPs – 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 13 communities, resulting in more than 2,333 septic systems being decommissioned.

Stream Management Program

The 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, a significant focus of the SMP was responding to the devastating storms of 2011, and working closely with federal, State and local partners to implement restoration projects. DEP augmented SMP funding to support new science-based efforts for local flood hazard mitigation, to protect water quality and improve community resiliency.

Ultraviolet (UV) Disinfection Facility

In 2012, DEP began operation of a UV disinfection facility to treat all water from the Catskill/Delaware supply. The facility, the largest of its kind in the world, provides an additional barrier for public health protection and complements DEP's efforts to keep the water clean at the source.

Waterborne Disease Risk Assessment Program

The Waterborne Disease Risk Assessment Program (WDRAP) continues to track in-City disease rates, with a goal of identifying whether there are any outbreaks that can be linked to the water supply. The Program evaluates multiple data streams daily and over longer periods, and has continued to refine surveillance activities. There was no evidence of an outbreak of waterborne disease in NYC during this period, including following three severe storms (Irene, Lee, and Sandy).

Scope of Water Quality Analysis

Water quality analyses cover a longer time period than the current five-year assessment period, and extends from 1993 through 2014, which allows DEP to examine trends over more than two decades. It provides a view of water quality changes in the context of variation caused by natural events such as floods and droughts, which are not sufficiently represented in a five-year time 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). The water quality data from the early 1990s represents conditions at the outset of Filtration Avoidance when many watershed protection programs were in their infancy. Sufficient time has now passed since programs have been in place that the major effects of programs on water quality should be apparent. Since many programs were implemented in the decade between 2000 and 2010, the current conditions are a phase when the effects of the watershed programs are expected to be 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). Given the general environmental conditions in each basin, DEP examines 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, the trophic response of reservoirs, and pathogen assessment. The objective was to look for central tendencies and trends in the water quality data over an extended time period during and after watershed protection program implementation.

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 analyses highlight the biological responses to major environmental drivers such as hurricanes and floods. 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 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 22 years and selected case studies are presented to demonstrate the effectiveness of this program. Finally, an analysis of pathogen transport through the system 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, DEP has examined the relationships between watershed protection and water quality changes.

Water Quality Summary for the Catskill System

Large storm events in 2010 and 2011 adversely impacted water quality in the Catskill System basins. However, the reservoirs recovered rapidly and water quality was good from 2012-2014. Monthly median fecal coliform counts did not exceed benchmarks and although monthly median phosphorus concentrations exceeded the benchmark of 20 µg L^{-1} the suspended particulates limited light and growth so no excessive phytoplankton growth occurred. Trophic status ranged from oligotrophic to mesotrophic for both the Schoharie and Ashokan reservoirs.

Long-term upward turbidity trends were detected throughout the Catskill System attributed to the 2010 and 2011 storm events. Fecal coliform trends were also upward for Schoharie and the West Basin of Ashokan Reservoir due to the storms but declined overall for the East Basin, likely the result of die-off and declining bird populations. The trend in total phosphorus (TP) was downward in Ashokan but the large storm events caused phosphorus to increase and negate the downward trends previously observed for the Schoharie Reservoir and its output. Schoharie Creek (S5I) has a declining TP trend suggesting a rapid recovery from major storm events which is likely to be reflected in the reservoir and output in the future.

Three sites above Schoharie Reservoir and the reservoir outflow have been routinely monitored for *Cryptosporidium* and *Giardia* since 2002. Annual mean concentrations of cysts and oocysts continued to be low from 2011 through September 2015. Protozoan concentrations also decrease as the water flows through the Schoharie and Ashokan reservoirs. Settling, predation, and die-off continue to be the main forces believed to be behind the reduction of protozoan values downstream.

Water Quality Summary for the Delaware System

Overall, the water quality status of all four Delaware System basins continues to be very good, which is a reflection in part of the ongoing investment in watershed protection. Monthly median fecal coliform counts were at or near detection limits for all reservoirs and their outflows with very few exceptions. During the 2012-2014 assessment period, monthly median turbidity was low throughout the system, with a value around 1 NTU and corresponding median phosphorus value of 8 µg L^{-1} for the outflow from Rondout Reservoir, the terminal reservoir in the Delaware System.

Long-term trend analysis for Delaware System basins for 1993-2014 showed continued improvement for some water quality parameters. Results varied between basins, and major storm events were a factor in the patterns of observed change. Neversink showed strong upward trends in turbidity and total phosphorus attributed to 2010-2011 storms. By contrast, turbidity trends for Pepacton and Cannonsville were downward. Downward trends in fecal coliform bacteria and TP were seen in some locations in Pepacton, Cannonsville, and Rondout basins and thought to reflect the water quality benefits of watershed protection programs. Overall, trends in trophic state index (TSI) were downward. Upward trends in conductivity were seen in all basins and attributed to increases in chloride and decreases in precipitation.

Cryptosporidium and *Giardia* pathogen monitoring is conducted on the major inflows to all four reservoirs of the Delaware System. As with the Catskill System, reservoir outflow results for the 2011-2015 period were much reduced compared to those for inflow streams, indicating that reservoir processes such as die-off, sedimentation, and predation continued to be effective barriers throughout the entire 2002-2015 period.

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 2012-2014 assessment period. Median and peak monthly median values were all well below established water quality benchmarks for fecal coliforms, turbidity, and TP. Decreasing trends in turbidity, fecal coliforms, and TP in the inputs to West Branch were attributed to improvements made through watershed protection programs. Likewise, for the Kensico basin, TP trends declined in the inputs, reservoir, and output. Conductivity trends were upward in both West Branch and Kensico basins. Increases in productivity were also found in both basins.

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 generally low at both the inflows and outflows, ranging between 0 and 2.5 cysts 50 L^{-1}, with the exception of 2004 when the maximum of 4.5 cysts 50 L^{-1} was the annual mean during a time of heavy rains and snowmelt. *Cryptosporidium* counts 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 nearly 14-year period of record, the mean *Cryptosporidium* oocyst concentration at the Kensico source water outflows was very low (0.18 oocysts).

Water Quality Summary for the EOH Potential Delaware System Watersheds

During 2012 through 2014, water quality in the Cross River and Croton Falls basins was generally good. Fecal coliform levels were low in both reservoirs, and occasionally high at the inflow to Cross River Reservoir and outflow from Croton Falls Reservoir. TP monthly medians for the reservoirs were at or above the target value of 15 $\mu g\ L^{-1}$ for source waters (median of 16.5 $\mu g\ L^{-1}$ and 15 $\mu g\ L^{-1}$ for Cross River and the main basin of Croton Falls). The median TSI was in the eutrophic range for both reservoirs and the basins remain listed as phosphorus-restricted.

Trends in turbidity were downward for the output from Cross River basin and attributed primarily to recovery from drawdown related to dam repairs. By contrast, the turbidity trend for Croton Falls was upward. Conductivity trends for both basins were upward and likely due to a combination of factors including development activity and precipitation patterns. Increases in the TP trend in the Cross River basin accompanied by an increasing trend in TSI coincided with storm events, particularly in recent years. A decline in the phosphorus trend in the middle basin of Croton Falls Reservoir was coincident with WWTP upgrades.

Trophic Response of Reservoirs

The trophic response of DEP's reservoir system over the past two decades provides some useful observations that support current operations and policies. It is well known that the control of algal standing crops is essential because they can potentially lead to deterioration of water quality. The approach to eutrophication control has been watershed protection programs that target phosphorus reduction and storm water control. The long-term database now available fully supports that approach.

Phosphorus reduction through WWTP upgrades, agricultural programs, and stormwater control has been an effective way to reduce the water quality problems associated with eutrophication. The data show that Catskill, Delaware, and Croton System reservoirs all respond with algal standing crops proportional to phosphorus concentrations.

Transparency is also important because it determines the depth of the surface layer in which algae can grow (i.e., the euphotic zone) and therefore the biological productivity potential of the system (i.e., from algae to fish). Most of the time, and in nearly all reservoirs, Secchi depth transparency is controlled by algae. The exceptions are Schoharie Reservoir and the West Basin of Ashokan Reservoir, where turbidity events severely limit algal growth.

Examining the changes over the past 25 years for mean and maximum chlorophyll, phosphorus, and Secchi depth, it is clear that in Cannonsville Reservoir, where greatest phosphorus load reduction has been achieved, there have been vast improvements. 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 dependent on extreme hydrological events and turbidity that can persist in the reservoirs for several months. Kensico appears to have slowly decreasing phosphorus levels, while West Branch seems to drift up, which may be due to operations. In the EOH reservoirs equipped with pump stations that can supplement the Delaware Aqueduct, Cross River is typically on a par with Site 1 of Croton Falls, however, the upstream sites of Croton Falls tend to be more eutrophic.

Water Quality Modeling Program

Building on past work, DEP has continued to identify and apply new models, develop alternative modeling approaches, and improve the framework of previously applied models. In watershed modeling, the Soil and Water Assessment Tool (SWAT) model has been applied to several West of Hudson (WOH) reservoirs. A revised version of SWAT, known as SWAT-Hillslope, was developed by DEP and was used to estimate water, nutrient and sediment loading from the upper Esopus Creek watershed in the Ashokan Reservoir watershed. The model calculations of sediment yield indicated that 37% of the total sediment load from the upper Esopus watershed came from Stony Clove creek, followed by 7% from Woodland Creek, 5% from Beaverkill, and less than 2% from the remaining tributaries of upper Esopus Creek.

The majority of the watershed is forested and DEP has begun applying the forest ecosystem model RHESSys to the Biscuit Brook subbasin. RHESSys is a spatially distributed hydrologic and ecological model that simulates water and constituent dynamics over a range of spatial scales. Testing of two alternative hydrologic modes within the RHESSys framework has started.

DEP continues to use the Generalized Watershed Loading Function (GWLF) model. This watershed model was used in studies performed during the reporting period to simulate the impacts of climate change on runoff and reservoir quantity and quality. In Cannonsville Reservoir GWLF was linked with (1) a single phytoplankton class reservoir eutrophication model, (2) a multiple phytoplankton class eutrophication model. Both models predict a lower peak chlorophyll occurring earlier in the spring under future conditions. GWLF was also used to evaluate the impact of climate change on stream turbidity in Esopus Creek. The annual turbidity loading from Esopus to Ashokan Reservoir will increase by only 3 to 5%. However, the model predicted that turbidity in Esopus during the months of November through February will increase up to 45% for the 2046-2065 period and up to 68% for the 2081-2100 period, compared to current conditions. When these predicted loads were used as inputs to the two-dimensional reservoir turbidity model for Ashokan, the average winter (November through February) reservoir turbidity is increased by 11% and 17% for the 2046-2065 and 2081-2200 time intervals, respectively.

Turbidity models based on the US Army Corps of Engineers CE-QUAL-W2 model framework have previously been developed for Schoharie, Ashokan, and Kensico Reservoirs. In the current reporting period, these models were all upgraded and the upgraded turbidity model was applied, tested and validated for Rondout Reservoir. These turbidity models, combined with the OASIS system operations model, form the basis for DEP’s Operations Support Tool (OST).

1. Introduction

1.1 Purpose of this Report

This report complies with Section 5.1 of the May 2014 Filtration Avoidance Determination (Revised 2007 FAD), which requires that the City submit a comprehensive report on watershed protection accomplishments and an assessment of water quality to the NYSDOH by March 31, 2016. 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 (CAT/DEL) 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 4 provides brief summaries of the accomplishments of each of the watershed protection programs for the past five years; and Chapters 5, 6, 7 and 8 use water quality monitoring results and modeling to assess current water quality and evaluate the effectiveness of some of those programs. In addition, Chapter 2 provides a case study of the impacts of Tropical Storm Irene and Tropical Storm Lee on the NYC water supply, and the actions taken in response.

This document should be viewed as a companion to the regular reports DEP produces 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 2011 through 2014. Annual Watershed Water Quality Reports have been prepared 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 up-dates on certain programs and other details. Reports and other information about the City's initiatives can be found at http://www.nyc.gov/html/dep/html/watershed_protection/index.shtml.

1.2 Water Supply System

The NYC 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) (see 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 – over eight million people in NYC and one million people in Westchester, Putnam, Orange, and Ulster Counties – plus the millions of commuters and tourists who visit the City throughout the year. Overall consumption in 2015 averaged approximately 1.1 billion gallons a day, which includes both in-City and upstate demand. In-City, overall demand has decreased dramatically since 1990 as a

Figure 1.1 Map of the New York City water supply system.

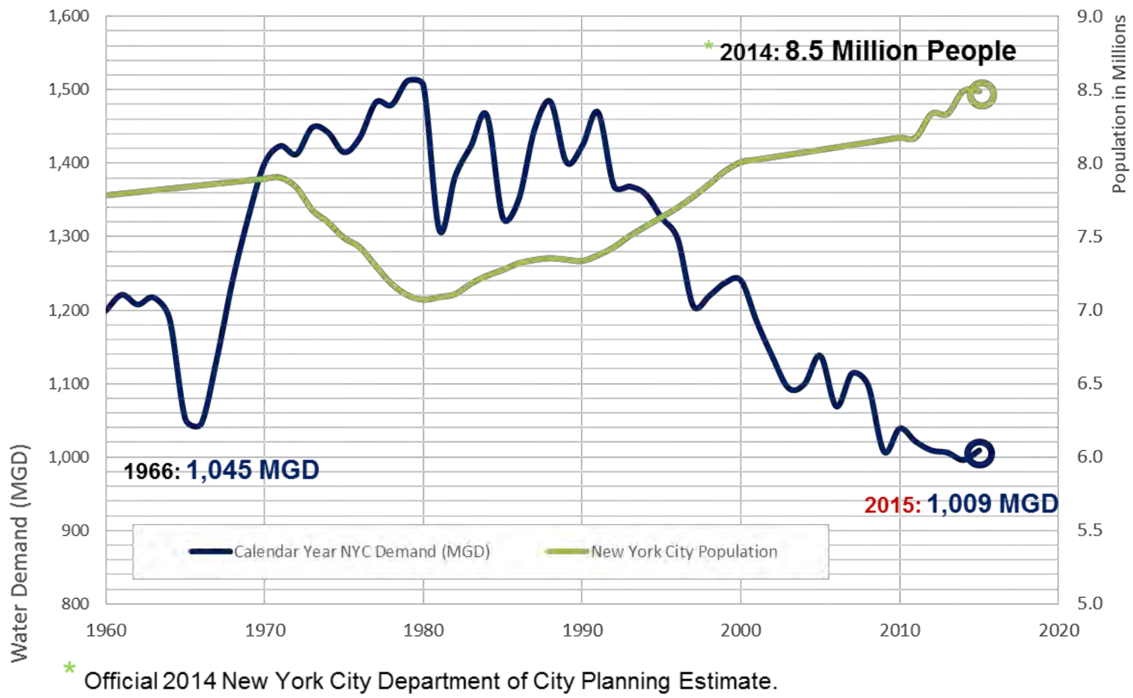

Figure 1.2 New York City consumption projection.

direct result of significant investments by DEP in demand management. Figure 1.2 shows water demand in New York City since 1960, documenting a 30% decrease in the past 25 years, despite rising population.

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 manages the upstate watershed and infrastructure and all drinking water quality monitoring in-City and upstate. The Bureau of Water and Sewer Operations operates the City's two main distribution reservoirs – Hillview and Jerome Park – and 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, Planning & Assessment, Public Affairs, and budget, personnel and procurement staff – provide vital support services to ensure the smooth operation of the water supply. In addition, staff from the NYC Department of Health and Mental Hygiene (DOHMH) assist in certain drinking water programs and staff from the NYC Law Department provide legal support.

The Croton watershed is located entirely east of the Hudson River in Westchester, Putnam and Dutchess Counties, with a small portion in the State of Connecticut. The oldest of the three systems, parts of the Croton system have been in service for more than 170 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.

In 2015, DEP completed construction and began operation of a water treatment plant to filter the Croton Supply. While the Croton system met all current health-based regulatory standards for an unfiltered surface water supply, it has experienced periodic violations of the aesthetic standards for color, taste and odor. In addition, DEP did not believe that the Croton system would be able to meet stricter disinfection by-product rules recently promulgated. Now that the Croton water treatment plant is in service, DEP can once again reliably deliver Croton water to NYC consumers.

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 100 years ago in 1915. Water leaves Schoharie Reservoir via the 18-mile Shandaken Tunnel, which empties into the Esopus Creek at Allaben and then travels 12 miles to the Ashokan Reservoir. Water leaves Ashokan via the 75-mile long Catskill Aqueduct, which travels to the 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 the 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 CAT/DEL system.

In the late 1980s, the City decided to apply for filtration avoidance for the Catskill/Delaware system under the terms of the SWTR (see "Regulatory Context", below). 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 CAT/DEL 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 SWTR.

1.3 Regulatory Context

The Safe Drinking Water Act (SDWA) amendments of 1986 required United States Environmental Protection Agency (USEPA) to develop criteria under which filtration would be required for public surface water supplies. In 1989, USEPA promulgated the 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 by-products.
- 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 CAT/DEL 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 that NYSDOH had primacy for all water supply systems in New York State (NYS). NYSDOH granted a one-year filtration waiver. Subsequently, it was determined that USEPA had retained primacy for the SWTR for the CAT/DEL systems. In mid-1992, DEP submitted a thirteen-volume application to USEPA, describing in detail the City's plans for protecting the CAT/DEL 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 the City's 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 that the City proceed with design of a filtration facility for the CAT/DEL supply, so that no time would be lost should USEPA decide that 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. Primarily due to the objections of watershed communities over the potential impact that those programs might have on the character and economic viability of their communities, DEP was unable to move forward with implementation of those key program elements. It was against this backdrop that Governor 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 that set 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, and in January 1997, the parties signed the Watershed 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 5-year waiver from the filtration requirements for the CAT/DEL 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 CAT/DEL supply.

Following issuance of the 2007 FAD, USEPA granted NYSDOH primary regulatory responsibility for the SWTR as it applies to the CAT/DEL 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 NYC supply (see Chapter 2 of this report for a detailed case study on these storms and the response actions taken). 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 discussions, NYSDOH issued a Revised 2007 FAD in May 2014.

1.5 Report Details

This report primarily focuses on program activities undertaken since 2011 and continuing through the end of 2015. However, since most of the programs discussed were initiated more than 20 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 and 2011 assessments of DEP’s FAD programs. Here DEP presents an analysis covering 22 years of data collection and program implementation. This data includes results collected through the end of 2014. Due to the time needed to process samples, and compile, review and verify data, it was not possible to incorporate any monitoring results from 2015. Long-term data is critical in the evaluation of programs that cover large geographical areas and are implemented over long periods of time, 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., 2012 through 2014) and these are compared to regulatory benchmark values. The trends are based on 22 years of data (i.e., 1993 through 2014). 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. Tropical Storm Irene and Tropical Storm Lee

2.1 Overview

In the late summer of 2011, the NYC Watershed was directly impacted by two tropical events – Tropical Storm Irene and Tropical Storm Lee. Hurricane Irene weakened to a tropical storm as the center of circulation passed over NYC on August 28, 2011. The storm continued on a northward path passing directly over the NYC Water Supply watersheds. The rainfall from Irene was historic in magnitude causing devastating flooding throughout the watershed. Particularly hard hit were the Catskill and Delaware watersheds where catastrophic damage occurred to many watershed communities. The Federal Emergency Management Agency (FEMA) declared the damage from Irene a major disaster on August 31, 2011 (FEMA-DR-4020). Already stressed from the impacts of Tropical Storm Irene, 10 days later the region experienced a second major event, Tropical Storm Lee. Turbid runoff again inundated watershed reservoirs further exacerbating water quality conditions.

Despite the unprecedented nature of this event, DEP was able to maintain compliance with all drinking water regulations and deliver an uninterrupted supply of high quality drinking water to its customers. No turbidity event as defined by the SWTR was reported, no boil water order was issued, and all harmful bacteria (e.g., fecal coliform, *Escherichia coli*) and protozoan species (e.g., *Cryptosporidium*, *Giardia*) were adequately controlled. Operational flexibility, treatment capability, water quality monitoring, water supply modeling, and watershed partnerships all worked together to protect the water supply for nearly 9 million residents of NYS. This event showcases the phenomenal resiliency of the water supply and the highly integrated nature of system operations.

2.2 Advance Planning

DEP closely monitors tropical storms to track their path and provide advance warning. In the days before the event, when it became apparent that the watershed was going to be impacted by rainfall and significant runoff from Tropical Storm Irene, DEP began to implement a range of activities including: inspection of critical facilities, topping off fuel tanks and water treatment chemicals, readying facilities and staff to respond. Staff developed and implemented enhanced water quality monitoring, reviewed wet weather operational plans for WWTPs, and emptied reserve tanks in preparation for high flows.

DEP also took a series of operational control actions to lower reservoir levels creating available storage capacity to capture runoff from the storm.

- The Ashokan Release Channel (ARC) was operated in accordance with the NYS Department of Environmental Conservation (NYSDEC)/DEP Draft Interim Operating Protocol. NYSDEC and communities along the lower Esopus Creek requested that the release be maximized to aid in flood protection. The additional drawdown provided benefit for both flood protection and for turbidity control.

- The Gilboa Dam siphons were activated to lower the level of Schoharie Reservoir.
- Enhanced releases were made from the Delaware reservoirs according to the rules in the Flexible Flow Management Plan.

Anticipating that Tropical Storm Irene would produce a turbidity event in the Catskill System, DEP prepared to initiate alum treatment on the Catskill Aqueduct to prevent highly turbid water from being delivered to Kensico Reservoir. DEP discussed with regulators the likelihood of needing alum treatment on the Catskill Supply and readied the Catskill Alum Plant for use. Because of this proactive approach on August 29, 2011, when highly turbid runoff from Tropical Storm Irene began to affect the quality of water entering the Catskill Aqueduct, DEP was able to quickly obtain regulatory approval and begin alum treatment prior to the elevated turbidity entering Kensico Reservoir.

Communication is absolutely critical before, during and after major events. In the days leading up to the storm, DEP reached out to a number of governmental and private entities to ensure the watershed was as storm-ready as possible and that the lines of communication were open. Specifically, DEP contacted:

- The water supply regulators, specifically NYSDOH, NYSDEC and U.S. Environmental Protection Agency
- The emergency managers in Delaware, Greene, Schoharie, Sullivan and Ulster Counties. One of DEP's dam safety engineers was also deployed to the NYS EOC for technical assistance in Albany.
- Downstream town supervisors and County Emergency Managers to provide information on the National Weather Service predicted reservoir elevations and discharges
- Schoharie County to discuss the potential failure of the temporary bulkhead on the top of the Gilboa Dam
- Both DEP and private contractors working on active construction sites in the watershed
- Operators of non-City owned WWTPs
- Watershed stakeholders, such as Catskill Watershed Corporation (CWC), WAC and County Soil and Water Conservation Districts (SWCDs).

2.3 Storm Event and Short-term Responses

2.3.1 Rainfall and Runoff

National Weather Service reports indicated that Tropical Storm Irene produced over 11 inches of rain at Slide Mountain, and 13.3 inches in East Jewett in the Schoharie watershed. Radar based NEXRAD precipitation predictions by the National Oceanic and Atmospheric Administration (NOAA) indicated that areas of the Schoharie watershed near Windham might have received up to 16.5 inches of rainfall from this event (Figure 2.1). Many locations in the

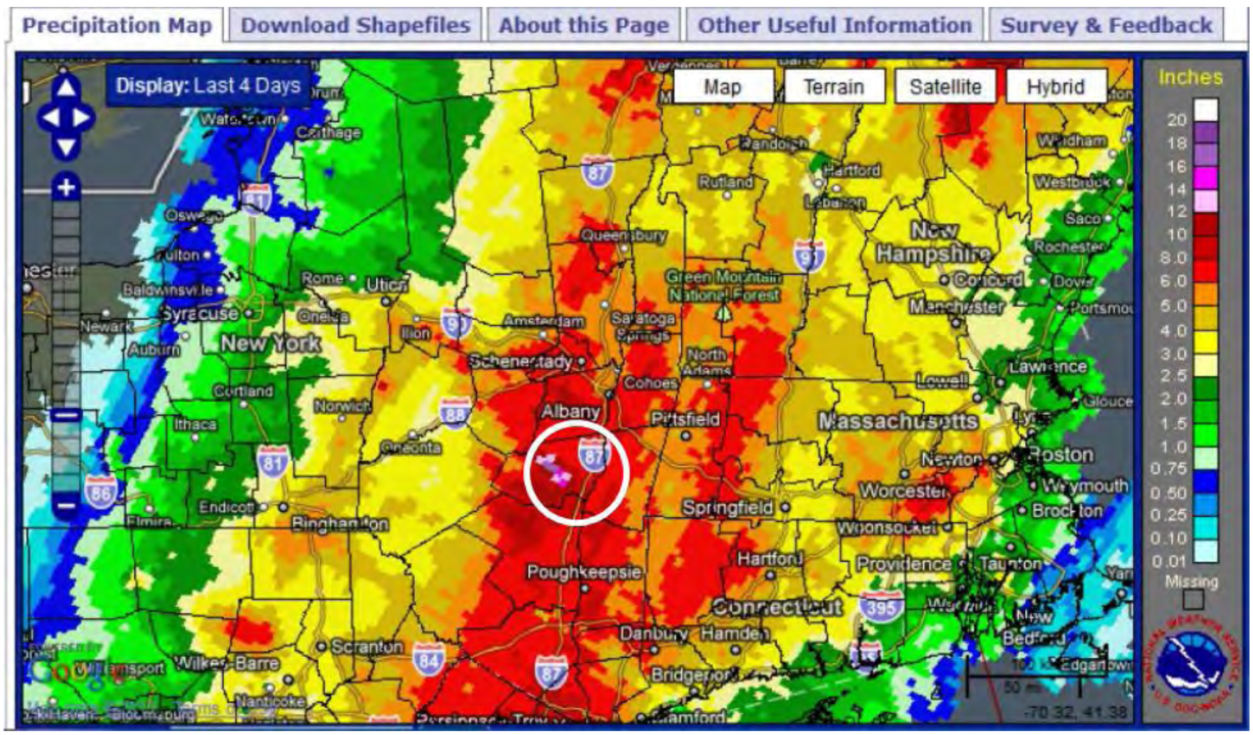

Figure 2.1 NOAA radar of Albany NY, showing areal precipitation estimate following T.S. Irene.
The circle is highlighting an area near Windham in Greene County that was estimated to have received between 12-16 inches of rainfall.

Catskill Mountains received up to 10 inches of rain in a 12-hour period, causing record runoff and flash flooding. Twenty-three United States Geological Survey (USGS) stream gages in the Catskill and Delaware watersheds recorded new maximum flow readings during this historic event, including gages on five of six NYC Water Supply reservoir main stems.

This widespread flooding caused catastrophic damage to watershed communities, washing out many roads and bridges, damaging many homes and causing widespread power outages. Damage was so severe throughout watershed counties that FEMA declared a major disaster on August 31, 2011 (FEMA-DR-4020) and began providing assistance to flood victims and communities.

On September 7, 2011, ten days after the catastrophic flooding from Tropical Storm Irene the watershed received a second significant rain and flooding event caused by Tropical Storm Lee. Runoff from Lee caused many watershed streams to exceed flood stage for the second time in less than two weeks.

Rainfall and runoff from these storms also affected the East of Hudson (EOH) reservoir watersheds. USGS stream gages on the Titicus River, Cross River and East and West Branches of the Croton River all recorded new record maximum flow readings during these two major storms.

2.3.2 Water Quality Impacts

The record runoff from Tropical Storm Irene inundated the Catskill and Delaware System reservoirs, quickly degrading water quality. By mid-day on August 28, 2011, the Esopus Creek gage peaked at 23.34 feet, the highest peak ever recorded in the 79-year history of the gage. Turbidity measurements recorded at this gage exceeded 3,000 NTU prior to peak stage when the instrument went off-line due to the storm. At Ashokan Reservoir, highly turbid stormwater quickly filled the west basin, and a subsequent limnology survey indicated that turbidity ranged from 150-3,000 NTU throughout the basin. This highly turbid water began to spill over the dividing weir into the east basin on August 28, 2011. On August 29, 2011, the level of turbidity entering the Catskill Aqueduct was 75 NTU which increased to >100 NTU in the following days (Figure 2.2).

Water quality in both West Branch and Kensico Reservoirs was also affected exhibiting high fecal coliform levels. This limited DEP's operational flexibility to use the Delaware System to dilute high turbidity levels from the Catskill System. For Kensico Reservoir, post-storm analyses later showed that local watershed runoff primarily caused the unusually high levels of fecal coliform bacteria throughout the reservoir, not the inflows from the aqueducts.

Figure 2.2 Ashokan Reservoir showing the dividing weir and the contrast of turbidity levels between the East and West basins immediately after the storms.

2.3.3 Water Supply Operations and Treatment

In the days and weeks following the two storms, DEP undertook many operational changes, utilizing the flexibility within the water supply system to ensure continued compliance with drinking water standards. For example, all flow was shut off from the three upstream Delaware System reservoirs, and the Shandaken Tunnel in the Catskill System was shut down to prevent the delivery of highly turbid Schoharie water to Ashokan.

Alum Treatment (Catskill System)

On August 29, one day following the storm and before highly turbid water in the Catskill Aqueduct reached Kensico Reservoir, DEP initiated alum treatment. When alum treatment began, the level of turbidity leaving Ashokan Reservoir was 75 NTU; turbidity peaked at 240 NTU on September 8. With the west basin of Ashokan Reservoir filled with highly turbid floodwater and water temperatures cooling through the fall, which hindered the settling of turbidity-causing particles, these turbid conditions persisted for many months. Turbidity levels in the water entering the Catskill Aqueduct remained greater than 30 NTU through January 30, 2012 and greater than 10 NTU through April 16, 2012, over 230 days after the initial storm event. Alum treatment of the Catskill Supply continued for 260 days, the longest treatment event on record, ending on May 15, 2012.

To limit the amount of turbid water being delivered to Kensico by the Catskill Aqueduct during treatment events, DEP typically reduces flow to minimum levels. During this treatment event, DEP also installed and removed the stop-shutters in the Catskill Aqueduct twice based on turbidity levels and system flow demands. Stop shutters allow for an even greater reduction in flow within the aqueduct while still ensuring adequate water levels for communities along the aqueduct to continue to withdraw water.

The operational directives of managing flow from the Catskill Aqueduct and treating with alum were successful in protecting the effluent from Kensico Reservoir. Despite these elevated turbidity levels, DEP maintained compliance with SWTR and FAD requirements. It was a noteworthy achievement that DEP was able to continuously deliver high quality drinking water despite the devastating impacts from Tropical Storm Irene and Tropical Storm Lee.

Chlorine Treatment (Delaware System)

Water quality monitoring indicated that elevated levels of bacteria entered Kensico Reservoir from both the Catskill and Delaware aqueducts and from local watershed runoff. Immediately following Tropical Storm Irene, fecal coliform counts in Kensico Reservoir source water effluent samples (CATLEFF and DEL18) began to exceed 20 fecal coliforms $100mL^{-1}$. Reservoir surveys indicated runoff from the storms had caused elevated bacteria levels throughout Kensico Reservoir. Runoff from Tropical Storm Lee exacerbated water quality conditions in the Catskill and Delaware Systems, and consequently at Kensico Reservoir. For a second time fecal coliform counts in reservoir effluent samples began to exceed 20 fecal coliforms $100mL^{-1}$. Exceeding the 20 fecal coliforms $100mL^{-1}$ in greater than 10% of these samples in a six month period would result in DEP violating the SWTR, and thus could possibly jeopardize the FAD.

To be protective of public health and to maximize the chance of remaining compliant with SWTR requirements for filtration avoidance, DEP decided to treat Delaware System water entering Kensico Reservoir with chlorine to reduce the fecal coliform bacteria load entering Kensico Reservoir. Alum treatment of the Catskill System was already underway. Therefore, additionally treating the Catskill System with chlorine to further assist in reducing bacterial loads to Kensico was not practical. DEP also believed it was unnecessary since the flocculation process of alum treatment would assist in settling much of the bacteria entering Kensico from the Catskill Aqueduct.

On September 9, DEP began chlorine treatment of the Delaware System upstream of Kensico Reservoir. This treatment consisted of adding chlorine, in the form of sodium hypochlorite, into the Delaware Aqueduct at Shaft 10, located at West Branch Reservoir, and dechlorinating Delaware Aqueduct water at Shaft 17 using sodium bisulfate just prior to it being discharged into Kensico Reservoir. Chlorine treatment reduced the concentration of fecal coliform entering Kensico Reservoir to generally <1 total coliforms $100mL^{-1}$. This reduced loading of fecal coliform bacteria to Kensico Reservoir contributed to the reduction in fecal coliform concentrations measured at the Kensico effluents. It is important to recognize that, despite an unprecedented number of fecal coliform exceedances at the Kensico effluents following these two events, no fecal coliforms were detected entering the drinking water distribution system following primary disinfection.

2.3.4 Gilboa Dam Emergency

The Gilboa Dam is located at the northern point of the Schoharie Reservoir and was constructed between 1919 and 1927. Based on an engineering study completed in 2005, it was determined that Gilboa Dam required immediate rehabilitation to meet modern safety guidelines. Certain emergency structural measures were implemented in 2006, and the main reconstruction started in 2009, and was ongoing in the summer of 2011 as Tropical Storm Irene approached.

On August 28, when the storm hit, water levels in the reservoir rose faster than the National Weather Service predicted (Figure 2.3). DEP engineers tried to reach the dam to observe conditions but roads were impassible. Based on video surveillance, the temporary bulkhead is estimated to have failed around 10:40 am on August 28th. At 12:04 pm the four extensometers at the dam, which measure movement, went into alarm condition – shortly thereafter, all communication with the instruments was lost. By 12:10 pm the video feed of the dam was lost as well. Even though DEP did not believe that the dam was in danger of imminent failure, the rapid rise in the reservoir elevation toward record elevation with the loss of electronic monitoring devices due to the storm increased the potential risk to communities below the dam. DEP therefore decided to activate the Gilboa Dam Emergency Action Plan for a Condition Orange Event – unusual condition exists at the dam but dam failure is not expected. The Water

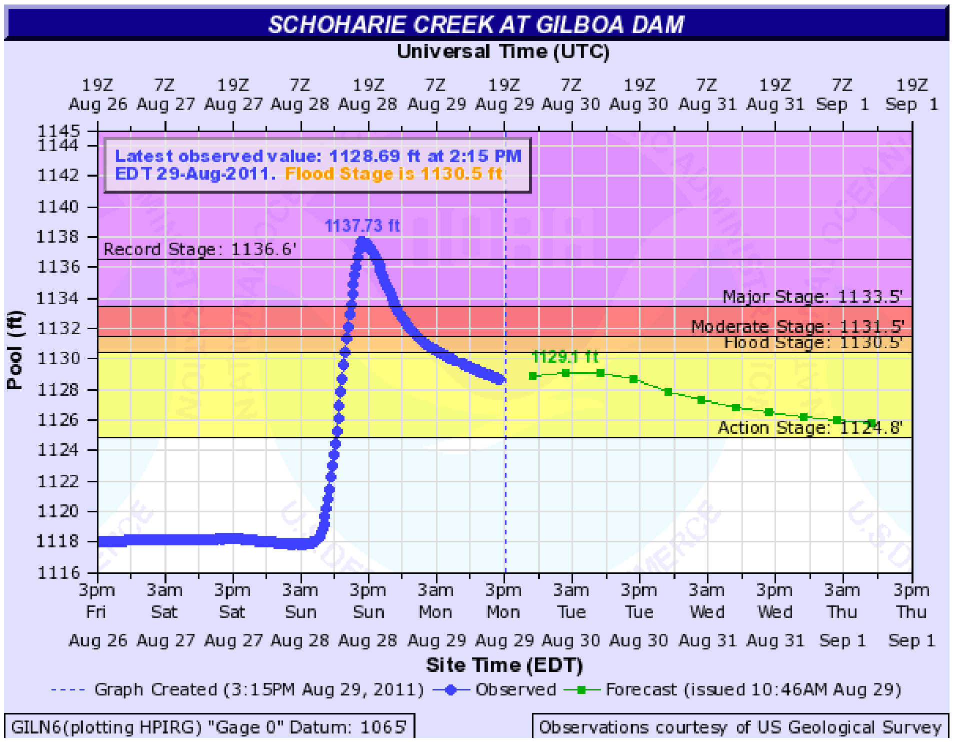

Figure 2.3 This outflow hydrograph provides a plot of the pool level at Schoharie Reservoir versus time.
It demonstrates that the reservoir level rose and peaked very quickly, within approximately a nine-hour-period. The plot indicates that peak level occurred around 14:00 hours on Sunday, August 28th. Readings taken at the Schoharie Tunnel Intake Chamber (STIC) on the west side of the reservoir showed a peak elevation of 1,137.97 feet from 14:35 to 14:55 hours.

Supply Control Center notified Schoharie County, which activated its emergency siren system to initiate an evacuation of the projected inundation areas. A DEP dam safety engineer was finally able to reach the site at 2:00 pm and relay reports of current conditions. Later that day the water levels and area flooding started to subside (Figure 2.4 and Figure 2.5).

The Schoharie Reservoir pool elevation peaked around 2:00 pm, August 28, at 1137.97 feet – 1 foot 1 inch greater than the previous record of 1136 feet set in June 1996. While the dam was never at risk of failure, the evacuation downstream may have saved lives in one neighborhood whose houses were washed away by the floodwaters. Just upstream of the reservoir, the USGS gage in Prattsville peaked at approximately 120,000 cubic feet per second (cfs) – more than twice the flow of the previous record flood in 1996 and rated as more than the 500 year flood level (Figure 2.6).

2.3.5 Enhanced Water Quality Monitoring

DEP implemented an enhanced water quality monitoring program throughout the watershed before, during, and in the days and weeks that followed the storms. In addition to increasing the monitoring frequency of reservoir, keypoint, and stream water quality samples, alum jar tests were performed on the Catskill Aqueduct water at least weekly and whenever turbidity changed by more than 15 NTU. Pathogen (*Cryptosporidium* and *Giardia*) monitoring at the Kensico effluents was increased in accordance with DEP's Turbidity Action Plan based on turbidity levels at DEL18 and CATLEFF. DEP performed monitoring far in excess of these requirements to ensure that up to date data were available to assist with the operation of the water supply.

Figure 2.4 The crest of Gilboa Dam at approximately peak spill elevation (STIC Gauge 1,137.94 ft) at 14:20 hours, August 28.
The photo was taken from the West Parapet looking east.

Kensico Reservoir Monitoring

As part of the enhanced monitoring program, DEP conducted 41 surveys – an additional 23 above the normal number of surveys – from August 29, 2011 through May 7, 2012 on Kensico Reservoir to provide data on current water quality conditions and to help determine the effects of Catskill Aqueduct turbidity on Kensico Reservoir. Many of these reservoir surveys were performed during winter months. Cold weather made sampling difficult, yet surveys were performed at least weekly throughout the entire event. In addition to these survey data, DEP also maintained an automated sampling buoy in the middle of the main basin that collected turbidity measurements at 1-meter intervals four times daily and two buoys with three fixed-depth transmissometers at the two intake sites. Beginning December 1, these automated data were reported in lieu of limnology data on alternating weeks. This intense monitoring of Kensico Reservoir was helpful in supporting operational decision-making and reservoir modeling.

Figure 2.5 The spillway on the morning of August 29. The view is from the East Training Wall facing west. In the foreground, the crest notch at the east end of the spillway created by recent stone masonry demolition activities as part of the reconstruction project is visible. Flows from the gated crest notch at the opposite end of the spillway is also visible. Flows over the stair-stepped spillway (control section) and within the side channel appear normal for this type of flow situation.

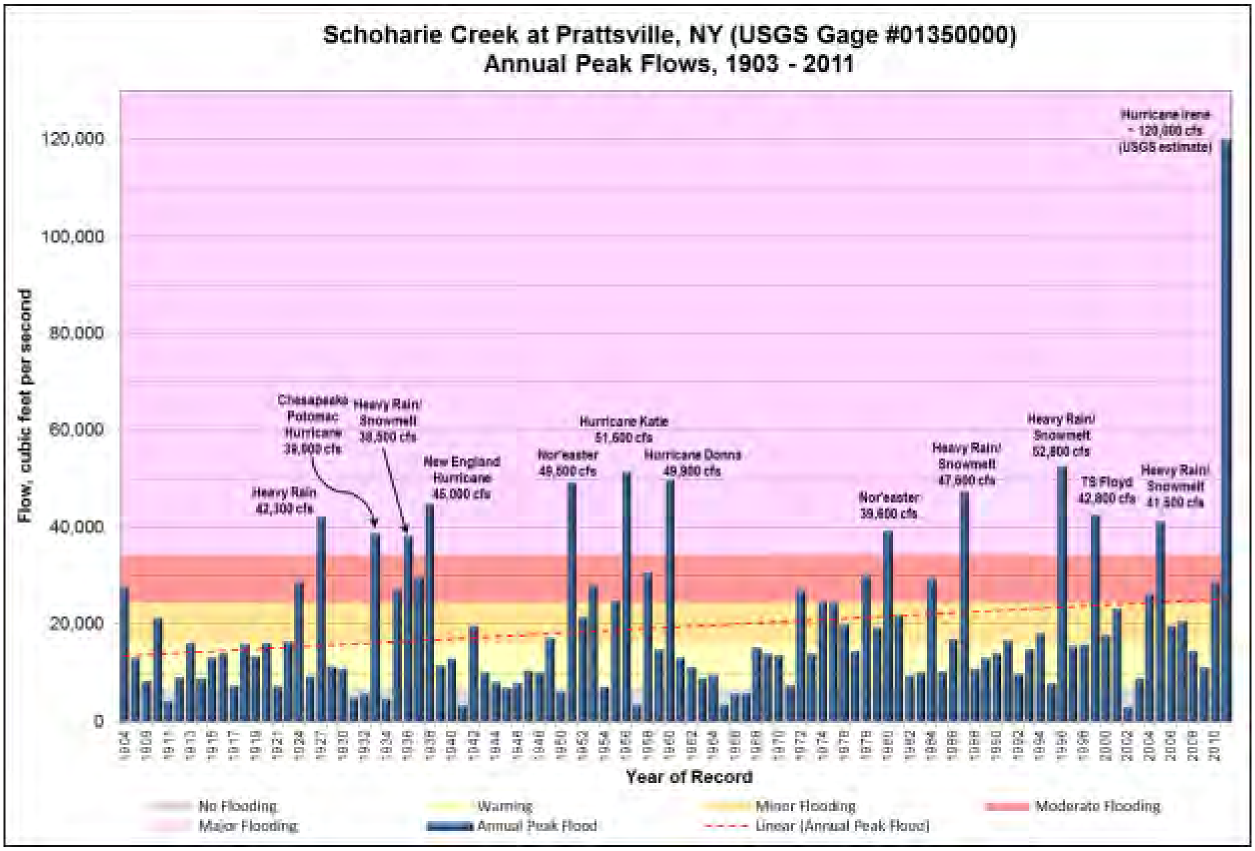

Figure 2.6 Annual Peak Flows at the Schoharie Creek at Prattsville (USGS Gage).

DEP maintained continuous monitoring pH instrumentation at the Catskill Influent Chamber to measure the pH of treated Catskill water entering Kensico Reservoir as required by the Alum Treatment Monitoring Protocol and for process control purposes. The pH monitoring equipment remained operational (97% of the time) for the duration of the alum treatment event providing operators and managers with near real-time pH readings.

Reservoir Monitoring

In addition to the Enhanced Monitoring Program at Kensico, DEP conducted increased monitoring at Ashokan, Rondout, Cannonsville and Pepacton Reservoirs unless ice conditions prevented boat access to the reservoir. This monitoring provided important information to assist in operating the Water Supply during and following these highly unusual storm events. A total of 25 surveys were performed on Ashokan Reservoir and an additional 16 surveys were performed on Delaware system reservoirs during this treatment event.

Keypoint Monitoring

To help support operational decisions, DEP increased the frequency of turbidity and fecal coliform monitoring at Ashokan and Rondout keypoints and elevation taps following the storms. Monitoring frequencies were increased to seven days per week through September 16, at Ashokan keypoints and through October 6, at Rondout keypoints. Elevation tap monitoring remained enhanced at 2-3 times per week through October 14.

2.3.6 Modeling

DEP used its highly sophisticated reservoir and system models to evaluate operational measures for their effectiveness in minimizing the use of Catskill system water, maintaining Kensico effluent turbidity at acceptable levels, and reducing the total amount of alum used. Most simulations used the LinkRes modeling system, and its component 2D CEQUAL W2 reservoir model to simulate turbidity values within the reservoir and aqueduct withdrawals. The CEQUAL W2 model has been set up and tested for Schoharie, Ashokan West and East Basins, and Kensico Reservoir. For some simulations, the latest version of the Operations Support Tool (OST) was utilized. The OST incorporates the OASIS water system model with the W2 reservoir model along with statistically based forecasts of streamflow for predicting future reservoir water quality and storage levels and future aqueduct flows.

From August 2011 to May 2012, DEP conducted 13 separate sets of modeling simulations to support water supply operating decisions. Numerous scenarios of different Catskill and Delaware System turbidity and flow inputs were modeled to predict their effects on Kensico effluent turbidity levels. In general, most model runs were used to guide treatment operations so that simulated turbidity levels at both Kensico effluents would not exceed regulatory levels.

Early in the aftermath of the event, from August through October, model results assisted in the selection of Delaware and Catskill Aqueduct flow rates that would allow DEP to continue to optimally mix turbid alum-treated Catskill water with untreated elevated turbidity water from the Delaware System into Kensico Reservoir. The enhanced monitoring of Kensico Reservoir supported the modeling performed during this period. This enhanced monitoring included detailed transmissometer readings to provide added horizontal and vertical resolution of turbidity distribution within the reservoir. This enhanced monitoring was used in conjunction with the modeling to refine model inputs and parameters and reduce the uncertainty associated with the settling rates of alum-treated Catskill System turbidity and the elevated turbidity from the Delaware System.

In December, a run of the latest version of the OST was performed to better understand the potential time period over which elevated turbidity in the Ashokan Reservoir would continue to require alum treatment. The results indicated that elevated turbidity would continue for an extended period into the spring of 2012. Finally, during February 2012 – May 2012 another series of Kensico Reservoir modeling applications were simulated to aid in understanding the Catskill System turbidity level that would allow alum use to be terminated.

2.4 Response Actions

Despite the advance notice and extensive pre-storm planning, the structural damage from the double storm was significant. Although water supply infrastructure suffered some damage, more significant damage occurred in the watershed. Local governments throughout the watershed were struggling to repair basic infrastructure and clear the debris. DEP and other City staff reached out to help.

2.4.1 Watershed Repairs

Debris Removal

For months after Tropical Storm Irene and Tropical Storm Lee, woody and manmade debris was strewn throughout the watershed. FEMA had a program to remove debris immediately around public infrastructure but beyond ~100’ upstream of the infrastructure much debris remained. To supplement the FEMA program, DEP and the CWC developed a $2.5 million program focused on the debris lying outside of FEMA’s designated zones. This program also provided funding to address the garbage that had been deposited during the storms. In some instances this included hazardous debris such as oil and propane tanks, but it also included tons of other garbage that damaged the aesthetic quality of the Catskills – an area where the economy depends upon tourism. The Debris Program funded 85 individual debris removal proposals, some of which constituted multiple sites.

Tannersville WWTP Access

The storm caused the washout of approximately 100 feet of pavement to the Village of Tannersville’s Allen Road that provides access to the DEP’s Tannersville WWTP (Figure 2.7). The flooding during Tropical Storm Irene also caused erosion that exposed and damaged sewers and water mains. The repair work, on behalf of the Village, included the replacement of a two barrel culvert crossing of Allen Brook with a single arch culvert to prevent debris blockage and the repair of utilities, guiderails, road approaches.

Figure 2.7 Wash out on the Access Road for the Tannersville Wastewater Treatment Plant.

Similarly, broken house laterals and broken sewer lines were repaired in Margaretville, with replacement of hundreds of feet new sewer line. Some thousand feet of less severely damaged sewer line were inspected by close circuit TV and areas needing rehabilitation or replacement were identified. In total, approximately 565 feet of sewer main in Tannersville were repaired, and approximately 3,000 feet of sewer main in Margaretville are planned for rehabilitation projects.

Bridge Inspections and Repair

DEP deployed staff to inspect bridges throughout the watershed. Staff from DEP's SMP helped assess 46 bridges and two flood control structures in Windham for their safety.

Figure 2.8 Bushkill Bridge, Route 28A in West Shokan.

- Bushkill Bridge (Route 28A in West Shokan). During the storm Bushkill Creek washed out an area by the bridge, causing the loss of approximately 100 feet of roadway for one lane, along with support material and the embankment below (Figure 2.8). The repair work included the restoration of the northwestern approach, one pier, and additional stream stabilization measures.
- Lowes Corner Bridge (Route 55A in Grahamsville). Rondout Creek experienced heavy flows during the storms and this caused slope failures at both of the embankments adjacent to the bridge. The repair work included the restoration of the roadway embankment slope protection, and a reinforced bridge base along the eroded bank and wingwall and abutment footing.
- Schoharie Bridge (NYS Route 990V in Gilboa). Schoharie Creek experienced heavy flows as the Gilboa Dam crested during the storm. As a consequence, approximately 245 feet of bank protection was lost in the eastern abutment of the bridge downstream of the dam. The repair work included temporary access from Route 990V to the stream bottom, installation of temporary erosion and sediment control measures, installation of cofferdams, and securing the retaining wall along the bank for abutment and wingwall footings.

Gilboa Dam

Tropical Storm Irene damaged sections of the spillway, construction staging area and work platforms. The repairs, totaling $10.7 million, took place quickly under the pre-existing rehabilitation contract. DEP also assisted with $300,000 toward the repair of Schoharie County's emergency siren system for Gilboa Dam.

Stream and Floodplain Restoration and Clean-up

Between August 29 and October 31, thirty-five full time SMP and County SWCD staff contributed over 12,000 hours of service to the watershed communities to assist with stream, culvert, bridge clearing and restoration to naturally stable forms (Figure 2.9). The districts, working with local highway crews and contractors, addressed extensive debris jams at bridges and culverts and road washouts. Stream reaches were also cleared using an emergency stream intervention protocol to ensure streams were not overwidened and deepened, which would exacerbate future erosion and flood hazard risk. The districts and DEP provided best stream channel dimensions to crews working in 52 locations, and work was overseen at 103 stream reaches.

Figure 2.9 DEP and Greene County Soil and Water Conservation District (GCSWCD) oversaw the clearance of 6,400 feet of the Batavia Kill between Maplecrest and Hensonville. The project entailed removal of floodborne debris, management of excess sediment deposition in the active channel to create a unified flow path, grading of stream banks, repair of the access road to the Windham landfill, and reseeding the disturbed areas.

2.4.2 Community Support

DEP worked with local communities and assisted in the recovery and rebuilding of watershed communities, while also protecting the watershed. Tropical Storm Irene devastated areas of the Catskills and Mid-Hudson Valley, washing away homes, businesses, roads, bridges and railroad tracks. As part of community assistance DEP deployed $1 million in resources—including heavy equipment, technical assistance, and materials—to help the hard-hit watershed communities.

- Regulatory Reviews. To ensure that cleanup efforts were implemented as quickly and efficiently as possible, DEP suspended enforcement of certain Watershed Regulations in the WOH watershed provided activities were taken in response to Tropical Storm Irene and were immediately necessary to protect life, health, property, and natural resources and were conducted with easily adopted, common-sense protections.

- Business Recovery Assistance. DEP provided $1 million to help WOH businesses recover from flood damage through the Flood Recovery Fund established by the CWC.
- Debris Removal Assistance. DEP deployed equipment and personnel to Prattsville, Windham, Margaretville, Phoenicia, Arkville, Fleischmanns, Wawarsing, and other communities. Dozens of NYC employees used dump trucks, backhoes, excavators, loaders, and chainsaws to assist in removing debris.
- Sewer Pumping. A Vactor truck and crew from NYC was deployed to clean manholes in Margaretville. Sewer maintenance crews from the City, deployed flusher trucks and rodders to clean the collection system in the Village and other non-City owned WWTPs Hunter, Windham and Fleischmanns.
- Temporary Park Space. The Village of Fleischmanns and Town of Prattsville were severely impacted by Tropical Storm Irene and Tropical Storm Lee.
    - The Village of Fleischmanns lost its village park during the floods. Working with the Village, DEP issued a land use permit to allow use of its land for a temporary park in 2012.
    - In Prattsville, DEP completed an extensive cleanup of DEP land that later became the Devasego Park. The new park expands recreational use of DEP parcels in the Town of Prattsville, which is part of an ongoing planning and recovery strategy to transform an area damaged by Tropical Storm Irene.

2.4.3 Post-Storm Review

Internal Review

After unusual or emergency situations such as this, once the flurry of activity has settled down, DEP typically reviews the decisions made and the actions taken to correct any identified deficiencies or streamline specific activities in the future. For this event, DEP compiled an After Action Report (AAR) for DEP's overall response as well as separate AARs for the alum treatment and chlorine treatment. The Tropical Storm Irene AAR contained a list of detailed recommendations which were assigned to various divisions for investigation or implementation. These actions were tracked over the subsequent months to ensure completion by the responsible parties and better preparation for the next major storm.

External Review

Following Tropical Storm Irene and Tropical Storm Lee, fecal coliform levels increased and remained elevated throughout the Kensico Reservoir basin for some time. This situation was unusual and in October 2011 DEP hired the Joint Venture (JV) of HDR and Gannett Fleming to evaluate DEP's response to these storms, and investigate possible sources that could have contributed to these elevated fecal coliform levels within Kensico Reservoir to better understand the potential impacts if this type of event were to occur in the future. The JV produced a final report in May 2012. Key findings of the external review include:

- DEP operational actions during, and in the aftermath of Tropical Storms Lee and Irene were reasonable, appropriate, and highly effective. Experiencing two tropical storms within approximately 10 days was an unprecedented event for any water supply agency. DEP staff followed protocol, were prepared and organized, and implemented adjustments within the water supply system in both a timely and methodical manner. DEP was proactive in undertaking various preparatory activities prior to Tropical Storm Irene's landfall, and the rapid response times to water quality changes following the storms significantly contributed to maintaining a safe and adequate water supply.
- The qualitative analysis and available data strongly suggest that Kensico Reservoir sub-basin contaminant loads that are located close to the effluent keypoints are more important to effluent coliform concentrations than loads from the influent aqueducts or loads from distant watershed sub-basins. Local fecal coliform bacterial loads from tributaries near the intake structures appear to be particularly important to Kensico Reservoir effluent coliform concentrations due to their location.
- Within the Kensico Basin, higher stormwater runoff volume was more attributable to Tropical Storm Lee than Tropical Storm Irene in 83% of the analyzed sub-basins. This finding supports the concept that very large storms yield higher runoff (on a flow per inch of rainfall basis) than average storms because of disproportionately higher runoff from pervious areas. The timing of the tropical storms during a relatively wet summer implies that very high levels of precipitation are required to saturate the ground to the point where pervious areas exhibit relatively high runoff properties. In addition, the fecal coliform loading response during these saturated ground conditions may only require a slight amount of runoff to scour and transport accumulations of fecal matter on pervious surfaces compared to impervious surfaces that wash-off more frequently.

The report also included a number of recommendations for future storm preparation.

2.5 Programmatic Changes

2.5.1 BWS Hurricane Preparedness, Response & Recovery Actions Timeline

While DEP has Emergency Action Plans (EAPs) and Standard Operating Procedures (SOPs) for a wide variety of situations, Tropical Storm Irene and Tropical Storm Lee highlighted the need for an additional guidance document specific to hurricanes. The BWS Hurricane Preparedness, Response & Recovery Actions Timeline lays out the major steps taken for each phase of an incident, including but not limited to:

- Annual activities to remain prepared for major storms (e.g., inspecting stormwater BMPs and flush reservoir bypasses)
- Planning period starting a week before a forecasted storm is anticipated (e.g., establish communication with the Office of Emergency Management at the State, County, and local levels)
- Mobilization and storm arrival (e.g., staging of staff and resources)
- Response and damage assessment (e.g., provide briefing on storm impact and response efforts to regulators)
- Restoration and recovery (e.g., draft AARs and develop Improvement Plans)

The detailed, action-specific operational guidance will make storm preparation more efficient in the future.

2.5.2 Flood Studies, Mapping and Future Resiliency

- Prior to Tropical Storm Irene, DEP committed $7 million to improving flood studies and maps in the WOH watershed through a contract with FEMA. The improved floodplain maps will enable communities to evaluate the impact of land use decisions on flood hazards and risks and recover faster. The maps and their studies provide communities with the tools needed to enhance their flood resiliency.
- DEP, working with the County SWCDs, has established flood hazard mitigation grant funding for communities participating in the Stream Management Program. The funds will be designated for projects that demonstrate the ability to reduce future flood losses, improve flood resiliency, and protect water quality.
- DEP committed $3.5 million through its Stream Management contracts with County SWCDs to provide the local match for Federal Emergency Watershed Protection (EWP) Program projects. This contribution leveraged over $9.3 million in federal funds for these projects. These projects will reduce future flood risk to culverts and bridges, reconnect streams to their floodplains, and stabilize stream banks adjacent to roadways and improved property.

3. Water Supply Infrastructure Improvements

The NYC water supply system, developed over more than 150 years, is vast, complex and flexible. In addition to supporting a program of ongoing maintenance, DEP has invested in certain system enhancements in recent years. These enhancements will increase the reliability and flexibility of the system, and position DEP to continue to provide an ample supply of clean, safe water to its customers.

3.1 Catskill/Delaware Ultraviolet Light Disinfection Facility

The Catskill/Delaware Ultraviolet Disinfection Facility (CDUV) was placed into full service in October 2012. The facility is located on a DEP 153-acre property in the towns of Mount Pleasant and Greenburgh in Westchester County. The CDUV, the largest of its kind in the world, consists of fifty-six 40-million-gallons-per-day ultraviolet (UV) disinfection units, and is designed to disinfect a maximum of 2.4 billion gallons of water per day (Figure 3.1).

Figure 3.1 CAT/DEL ultraviolet disinfection facility.

The facility was built in part to fulfill the requirements of the Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), which requires additional treatment for many water suppliers that use surface water sources. For unfiltered surface water sources, such as the CAT/DEL system, the LT2ESWTR requires two types of disinfection. First, water is disinfected with chlorine before arriving at the CDUV. Once at the facility, the water flows under UV light as an additional measure to protect against potentially harmful microbiological contaminants, such as *Cryptosporidium* and *Giardia*.

From 2011 through 2015, DEP focused efforts on the validation of the UV dose. In accordance with the terms of an administrative order between USEPA/NYSDOH and DEP, DEP met the requirement to deliver a dose of 40mJ/cm2 to all the water delivered through the CDUV by December 1, 2012. DEP submitted the UV final validation report to NYSDOH on October 21,

2013. NYSDOH approved the Phase II validation testing but requested additional information on previous testing performed in 2005 and 2008-2009. DEP revised and resubmitted the Validation Report on January 22, 2014.

Based on NYSDOH's response to DEP's proposal, DEP has proceeded with programming changes at the CDUV to provide for an alternate (lower) UV dose. On December 29, 2014 DEP reduced the dose to 29.40 mJ/cm^2 at four UVUs to commence phasing in the dose reduction plan. By February 28, 2015 all 56 units had been reprogrammed and were running to provide 2-log *Cryptosporidium* inactivation based on an Ultraviolet Transmittance of 80%. On March 3, 2015, DEP reduced the dose to 24.17 mJ/cm^2 on all 56 units, and the data are being reviewed to move to the next phase of automating the lower dose set point.

After Hurricane Sandy in 2012, it became evident that extreme weather events can lead to trapped material in the upstream side of the UV units. DEP installed additional access hatches to allow for easier cleaning of the baffle plates within the UV units. Additional activities during the 2011-2015 time period include development and approval of a staffing plan and testing to ensure the facility can operate during regional blackout conditions.

3.2 Croton Water Filtration Plant

The Croton System is separate from the CAT/DEL System and is not covered by the FAD. Since the early 1990s, DEP has been pursuing the siting, design, construction and startup of a filtration facility to treat Croton water. In May 2015, the Croton Filtration Plant was put into service for the first time, delivering filtered water to the distribution system. The Plant restores DEP's ability to reliably deliver Croton water to consumers, and enhances the overall flexibility of the water supply.

3.3 Catskill Aqueduct – Delaware Aqueduct Interconnection at Shaft 4

The Catskill Aqueduct conveys water from the Catskill System, by gravity, 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). The Rondout-West Branch Tunnel (RWBT) of the Delaware Aqueduct conveys water from the Delaware System, by gravity, to the West Branch Reservoir. The Delaware Aqueduct is a pressurized aqueduct, operating on reservoir head, and is built deep within the bedrock of the earth. The flow capacity of the Delaware Aqueduct is approximately 840 MGD. Vertical shafts were used to support the construction of the Delaware Aqueduct at various intervals along its length. Shaft 4 was intentionally located adjacent to the Catskill Aqueduct where the Delaware Aqueduct crosses deep underneath the Catskill Aqueduct, to allow for construction of a facility into transfer Delaware water to the Catskill Aqueduct.

DEP has substantially completed construction of the CAT/DEL Interconnection Chamber (CDIC) to connect Shaft 4 to the Catskill Aqueduct. The facility controls the flow of water and reduces the pressure from the Delaware Aqueduct to the open channel flow of the Catskill. Up to 365 MGD can be safely transferred from the Delaware Aqueduct to the Catskill Aqueduct.

This facility enables blending of Catskill System and Delaware System waters, for enhanced water quality purposes, for balancing of the Catskill and Delaware reservoirs independent source water systems, and for some partial redundancy in the delivery ability of the aqueduct systems. Furthermore, under certain valve configurations, the capacity of the Delaware Aqueduct increases from approximately 840 MGD to 990 MGD, enabling DEP to deliver more Delaware system water to NYC on an as needed basis.

3.4 Operations Support Tool

To assist water supply operators in managing the large and complex system, DEP developed the OST. 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 make predictions of reservoir levels and water quality up to a year into the future. One of the key features in OST is ensemble runoff forecasts. In 2012, DEP announced a $1 million partnership with the National Weather Service (NWS) to develop state-of-the-art forecasts of streamflow in the watershed. The agreement allowed NWS to accelerate development of the Hydrologic Ensemble Forecast Service (HEFS) to coincide with the development of OST. HEFS provides several different streamflow forecasts, collectively called an "ensemble." The ensemble forecast driving OST results in an ensemble of predictions of future conditions, from which range (minimum and maximum) and likelihood (probability) information can be derived. HEFS forecasts include short-term meteorological drivers that account for upcoming storm events. The forecasts also use DEP's snowpack monitoring data to estimate magnitude and timing of snowmelt, which is included in the streamflow forecast.

Using OST with HEFS forecasts, water supply managers can test different operational scenarios and predict the outcome in a probabilistic context. For example, OST can be used to model several different withdrawal rates from each reservoir during the winter and calculate the probability of refilling each reservoir and the entire system in spring under each rate. OST has also provided support for modified operations during construction work, such as the Gilboa Dam rehabilitation and projects related to the repair of the Delaware Aqueduct. OST also supports system operation during construction of new infrastructure, such as the CDIC at Shaft 4. This type of data-based, forecast-driven probabilistic risk assessment and scenario testing capability enhances a manager's ability to make informed decisions, and is what makes OST unique in the world. It's important to note that OST is a decision support system, not a decision making system. Water supply managers make decisions based on guidance from OST in combination other forecast information, knowledge of system infrastructure status and other conditions, water supply BMPs, and years of experience operating the system. OST has been in use at DEP since November 2013, with over 2,100 model runs executed between then and November 2015.

CDIC and the Croton Filtration Plant provide operational flexibility and robustness that enhance system reliability. Both facilities are modeled within OST. During turbidity events in the Catskill system when flow from Ashokan Reservoir must be reduced or shut down entirely, Delaware water can be moved into the Catskill Aqueduct via CDIC and additional Croton System water can be utilized. When the RWBT is shut down for several months to connect the bypass tunnel, the Croton System will be essential to meet demand. It will also be critical during dry periods and droughts. Using Croton water on a daily basis can reduce the total volume of Catskill and Delaware water needed over the course of a year, which in turn sustains higher storage in those reservoirs, and increases probability of refill and overall system reliability. Finally, one of the key operating principles of the reservoir system is to be able to balance storage in all the reservoirs in such a way that they can all be refilled in the spring, prior to the start of drawdown in the summer and fall. Spatial variability in rainfall and runoff, water quality differences among the various reservoirs, and a wide range of operational and infrastructure considerations affecting diversion rates from individual reservoirs throughout the year make it challenging to achieve this balance. The long-range predictive capabilities of OST with forecasted inflows, combined with the operational flexibility added by CDIC and CDUV, allows DEP to selectively divert appropriate quantities of the best quality water at any given time while providing a high probability of rebalancing and refilling the system. These factors contribute significantly to helping DEP meet the mission of reliably providing an adequate quantity of high-quality water.

4. Watershed Management Programs

4.1 Institutional Alliances

This and previous Summary and Assessment Reports appropriately focus on the status and trends of water quality and the implementation of watershed protection programs. However, as we approach the 20th anniversary of the MOA, it is valuable to take note of the non-City entities that have influenced development of the MOA and continue to play an important role in the evolution of the DEP's Long Term Watershed Protection Program. Representatives of watershed communities and environmental organizations bring their own perspective to watershed issues. Their views are balanced by DEP as well as DEP's regulators in the development and review of each application by DEP for FAD renewal.

DEP's Long-term Watershed Protection Program serves as an international model for how to sustainably safeguard our most valuable natural resource: water. While science, engineering, planning, security and financial investment are indispensable components of a successful watershed protection program, the active involvement by local stakeholders is also essential. The architects of the MOA recognized that delivery of the programs depends on a substantial "ownership interest" by watershed communities.

The MOA's structure is standing the test of time, providing the stability of a sound foundation and at the same time showing the capacity for adaptation to a changing environment. The core commitment, to work together toward sustainable and mutually beneficial outcomes, is really the crowning achievement of DEP's Long Term Watershed Protection Program. The remainder of this section of the report provides summaries of the key institutional alliances that hold the watershed protection program together.

4.1.1 Watershed Agricultural Council

The WAC was the first local partnership developed to implement watershed protection programs in the DEP watershed. It began in 1993, years before the signing of the MOA, to encourage farmers to voluntarily develop whole farm plans (WFPs) and install BMPs as an alternative to regulating agriculture for better pollution prevention. DEP entered into contract with WAC in 1993 in recognition of the fact that local "ownership" of the management and processes for implementing BMPs on farms offered the best hope for long-term pollution prevention and for sustaining productive farming traditions in the Catskills.

Since WAC's inception, DEP has contracted for more than $250 million in programming with WAC. WAC's core mandate is working with farmers to develop WFPs and implement BMPs to reduce pollution risks. WAC has also developed a robust farm CE program to promote long-term preservation of farm land throughout the watershed. WAC also works with owners of forested lands to implement forest management plans (FMP) and a new pilot CE program tailored specifically to forested land. The thread connecting all of WAC's programs is landowner education on techniques of efficient and effective watershed protection.

DEP is a member of WAC's Board of Directors and a member of each of the numerous committees where policy initiatives are molded into program guidelines. The remaining Board members are local farmers, forest landowners and business representatives, nominated for membership by the Board of Directors.

As mentioned in the 2011 Summary and Assessment Report, between 2006 and 2011, WAC had begun an extensive process of internal policy development and governance guidance and had transitioned to a new leadership team. Additionally WAC instituted various internal financial controls aimed at improved risk management. WAC has continued this maturation process during the current FAD assessment period by further refining internal governance systems and transparency. As a result, over the past two decades WAC has matured into an internationally-recognized leader in the protection of water quality under agricultural and forestry land uses.

4.1.2 Catskill Watershed Corporation

The CWC was created to implement numerous programs related to watershed protection, economic development and public education called for by the MOA in 1997, and the organization has since taken on additional program activity spawned by subsequently-issued FADs.

DEP is a member of CWC's Board of Directors and a member of each of the numerous committees. The remaining Board members are local elected officials, as well as a representative of New York State and a representative from the environmental community.

The range of programs administered by CWC includes septic repair programs, stormwater programs, community wastewater management programs (CWMP), various local technical assistance programs, economic development programs and a public education program. More recently, largely in response to tropical storms Irene and Lee in 2011, CWC developed the Flood Hazard Mitigation Implementation Program to assist communities at implementing local flood mitigation projects identified through scientific analysis.

CWC has effectively and efficiently delivered a wide range of environmental and economic benefits flowing from the MOA to communities and to the benefit of water quality. CWC continues to exercise sound fiscal control and in doing so has become an international model for balancing regional pollution prevention and local economic development needs.

4.1.3 Stream Management Program Partners

Since 1996, DEP has partnered with Delaware, Greene, Ulster and Sullivan County SWCDs and with Cornell Cooperative Extension of Ulster County (CCEUC) to develop and implement the SMP. Among the SMP's core values is a recognition that success depends on a community-based approach, meaning that stakeholder involvement, especially participation by riparian landowners and land use managers like local, county and State highway department and local code enforcement officers, is fundamental. The program's core elements include planning, annual action plans, stream reach-scale restoration and stream bank stabilization projects, and extensive education, outreach and training for the broad range of stakeholders. The program's institutional foundation is the program advisory committees comprised of local leaders and agency advisors who meet quarterly to guide program priorities. The SMP is where soil, water and people meet and where partner institutions fashion multi-objective solutions to complex stream challenges.

Throughout the reporting period there has been growing recognition of the impacts of climate change, particularly relating to flood risks. DEP and its stream partners have stepped up to develop new programs to assist communities in assessing flood risks and developing new strategies and programs to reduce risks and to improve community sustainability and water quality. To a greater extent than ever before, the circle of involvement in stream management, with the leadership of County SWCDs and CCEUC, has integrated residents and local officials into the process through the establishment of flood commissions working to identify flood hazard mitigation projects. CWC has also joined the larger stream management effort with its development of the Flood Hazard Mitigation Implementation Program in 2015.

Together, SMP partners are able to leverage their expertise and local integration to advance programing well beyond where DEP could on its own.

4.1.4 Environmental Organizations

Environmental organizations have been vital to the success of the watershed program, including MOA signatories the Catskill Center for Conservation and Development, the Hudson Riverkeeper, the New York Public Interest Research Group, the Open Space Institute and the Trust for Public Land. These organizations provide an important perspective and offer policy suggestions as part of the dialog that forms the basis of the continuing evolution of DEP's overall watershed protection programs.

4.1.5 East of Hudson Partners

Whereas West of the Hudson partner organizations coordinate with localities to develop and implement programs and projects, within the EOH watershed it is principally the county governments, Westchester County and Putnam County, that are DEP's main partners in watershed protection. These counties administer funding provided by DEP in the MOA's EOH Water Quality Investment Program. Additionally, the formation of the East of Hudson Watershed Corporation (EOHWC), composed of representatives of municipalities in Westchester, Putnam and Dutchess counties, has facilitated development of stormwater programming to meet the requirements of New York State Municipal Separate Storm Sewer System program.

4.2 Land Acquisition

4.2.1 Overview

The goal of the LAP is to acquire real property rights, either land in fee simple or 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 almost 20 years of activity offers a compelling story of land protection in a two thousand square-mile watershed, as outlined below.

Prior to 1997, DEP owned 34,192 acres, or 3.3% of the watershed land in the CAT/DEL System (excluding reservoirs). Since 1997, LAP has secured an additional 138,272 acres, or four times the acreage owned prior, bringing DEP owned or controlled land to 172,464 acres in total, or 16.7% of the watershed. Including land protected by other entities such as NYS, municipalities and land trusts, 387,000 acres, almost 38% of the entire watershed, are now permanently protected. Figure 4.1 shows the land protected by basin, including land protected by New York State and others; Figure 4.2 shows the acres of land under contract by year and type.

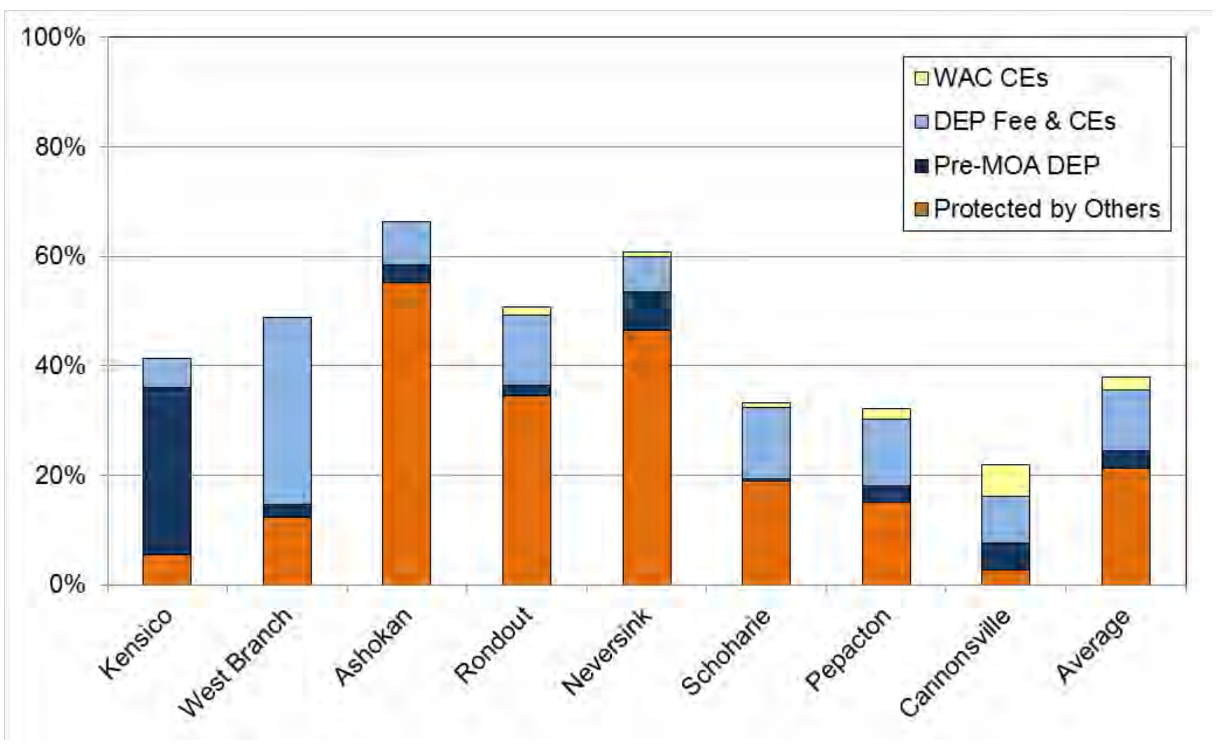

Figure 4.1 Land protected by basin, including land protected by New York State and others.

In addition to quantity, both the quality and location of land acquired is important. Location within the watershed is a fundamental aspect of each property; failing to increase protection levels in certain priority areas, basins, or sub-basins could still leave the overall system vulnerable. In this the City has also made significant progress; Figure 4.1 also shows the status of protected land by basin, while Figure 4.3 shows the protected status of sub-basins, both indicating substantial advance since 1997.

In addition to the quantitative figures above, the *quality* of the land acquired is likewise critical, for it would do little to protect the watershed from the impacts of future development if all land acquired was distant from tributaries and/or undevelopable cliffs. Section 4.2.8 describes the length of streams and acreage in riparian buffer protected by the DEP, and as compared with the largest landowner in the watershed, NYS.

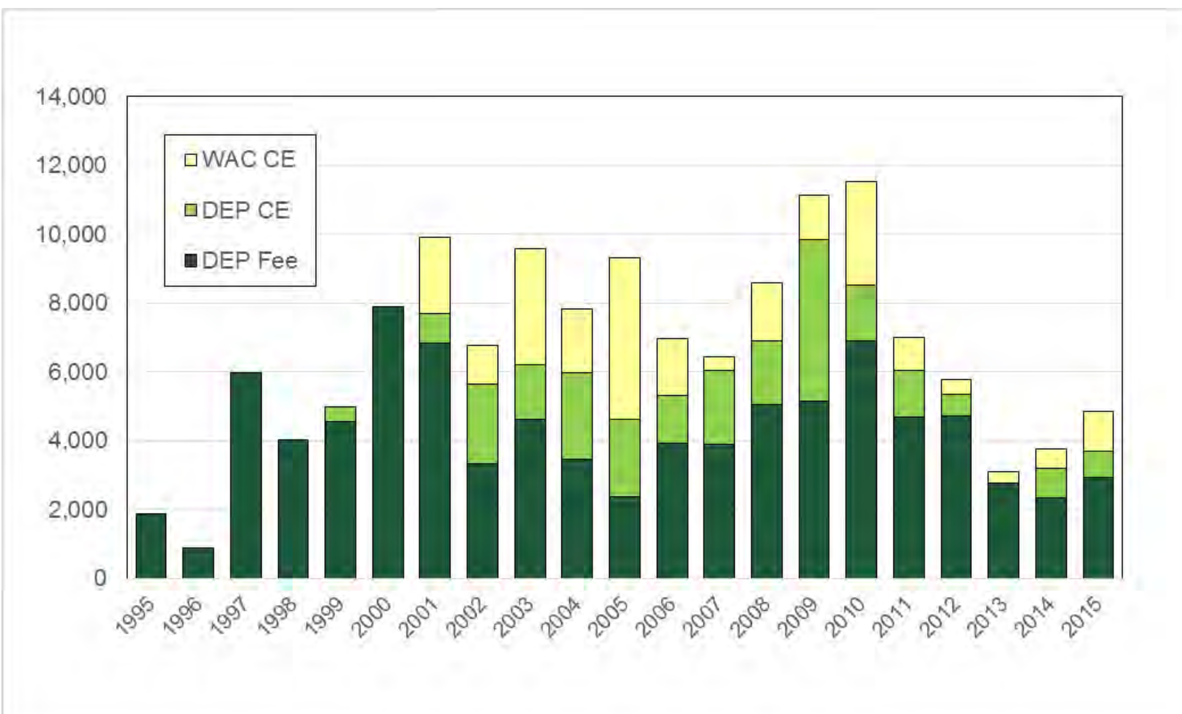

Figure 4.2 Acres in executed contracts by year and type (Catskill/Delaware System).

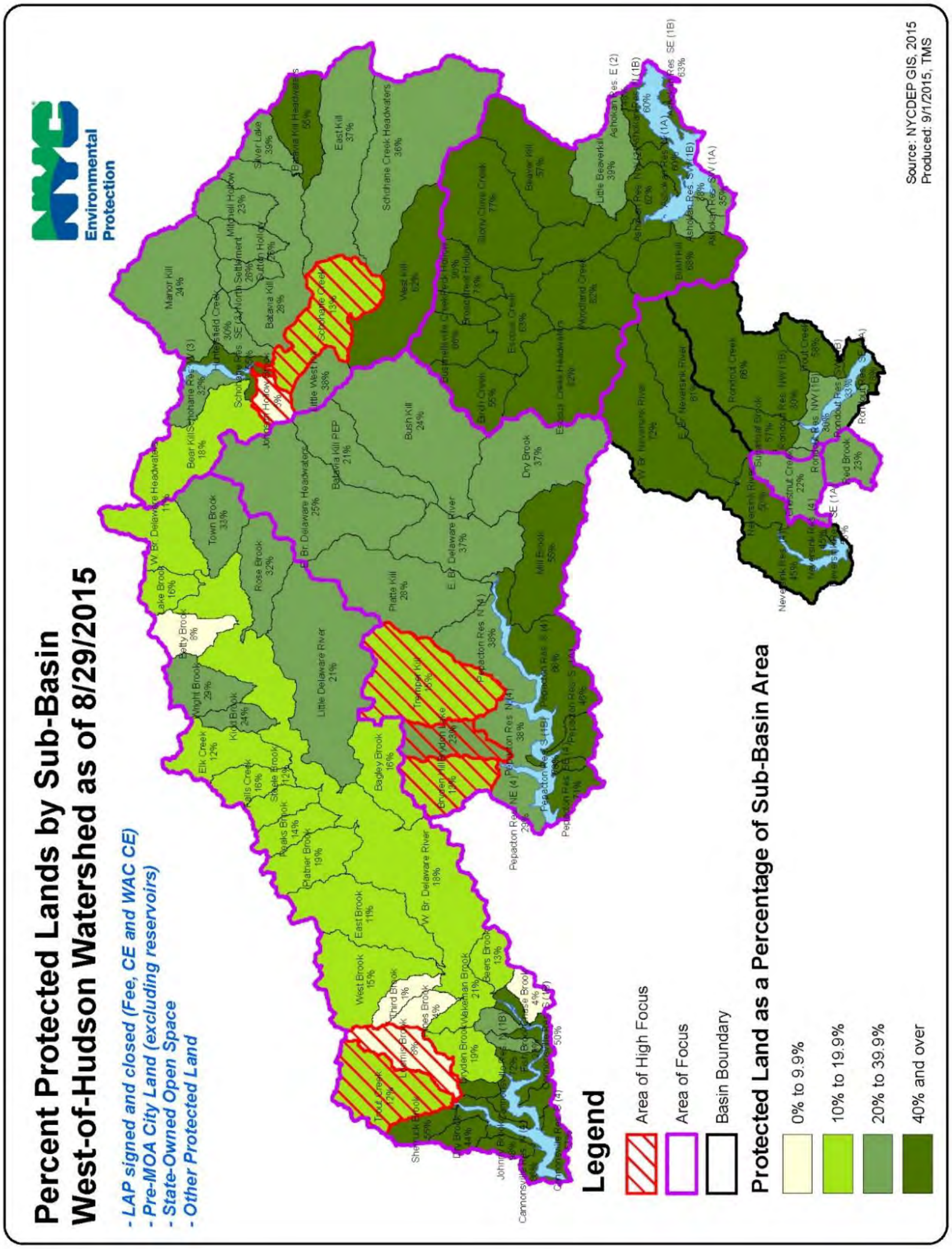

Figure 4.3 Protected status of sub-basins.

Through the prism of these three factors – acreage, the quality of these acres, and protected status of basins and sub-basins – DEP's acquisition strategies, combined with positive landowner responses to a diverse suite of programs, have successfully and substantially advanced water quality protection.

4.2.2 Solicitation

Based on recently updated GIS data, the entire CAT/DEL watershed (including all WOH basins as well as the West Branch/Boyd Corners and Kensico basins EOH) comprises 1,021,453 acres (excluding reservoirs). Of these, approximately 216,755 acres (21.2%) are owned outright by public agencies other than DEP or land trusts. As of 1997, a total of 34,192 acres (3.3%) of land (excluding reservoirs) were owned by DEP. Of the ~770,000 acres in private ownership remaining, DEP solicited the owners of more than 355,050 acres during the first eight years of the program. Pursuant to the 2007 FAD, the DEP issued a Solicitation Plan covering 2008-2010, which called for the solicitation of another 90,000 acres of previously unsolicited land through 2010. Since 1997, repeat solicitation of most of these acres has continued, leading to considerable gains. Between January 1, 2011 and December 31, 2015, over 284,000 acres were solicited and 21,085 acres were signed to purchase contract (fee and CE) by DEP. DEP counts over 475,000 acres as solicited since 1997, resulting in acquisition of 113,595 acres in fee simple and CE by the DEP (an overall success rate of roughly 24%), and another 24,677 acres of farm easements secured by WAC. Since 1997, LAP has thus quadrupled the DEP's ownership interest and control of real property.

4.2.3 LAP Programs

Fee Simple Lands

Between January 1, 2011 and December 31, 2015, NYC executed 246 contracts to acquire 17,465 acres (see Figure 4.4 and Figure 4.5). Since 1997, NYC has secured 1,301 contracts to buy land in fee simple totaling 88,316 acres (Figure 4.2 and Figure 4.6). During the five-year reporting period, which represents 26% of the overall program timeframe, roughly 20% of land in fee simple was secured. Total land acquired in fee simple by NYC represents 65% of the overall total of 138,272 acres protected since 1997 (which includes NYC fee simple, NYC CEs, and WAC farm CEs). Figure 4.1 describes the status of protected land by basin and indicates that in general, basins identified by the 1997 MOA as higher priority continue to enjoy much higher levels of permanently protected land. Figure 4.3 offers a more refined view, showing protected status for WOH at the sub-basin level.

Figure 4.4 An example of a recently acquired fee simple land.
The view southwest from the end of a private road serving twelve vacant building lots comprising 130 acres with over a mile of streams which drain to the Pepacton Reservoir. The property, in Andes, New York, was signed to purchase contract in early 2015.

Conservation Easements

DEP's CE Program

Between January 1, 2011 and December 31, 2015, NYC executed 22 contracts for CEs, comprising 3,620 acres. Since 1997, NYC has secured 167 CEs totaling 25,279 acres. CEs acquired by NYC represent 18% of the overall total of 138,272 acres acquired under LAP (see Figure 4.6). A revision and update of the CE policy was completed November 2011 resulting in the use of a ranking system as an evaluation tool leading to more consistent decisions regarding acquisitions. As a result, there has been a concentration on larger CE projects and CEs in high focus areas when possible.

Figure 4.5 Day-hikers at a 240-acre tract in Bovina acquired by DEP in 2014.
The property contains roughly 3,600 linear feet of tributaries to the Cannonsville Reservoir, and abuts two farm easements acquired by WAC, as well as a 1,500+ acre reforestation area owned by NYS.

WAC Farm Easement Program

Between January 1, 2011 and December 31, 2015, WAC executed 22 contracts to purchase 3,424 acres under Farm Easements. Since program initiation, WAC has executed contracts to purchase 137 farm easements totaling 24,677 acres (see Figure 4.6).

WAC Pilot Forest Easement Program

In mid-2013 the program contract with WAC was enhanced to include this program, intended to secure CEs on forested land. As of the end of this reporting period, one forest easement has been appraised and no contracts have been signed.

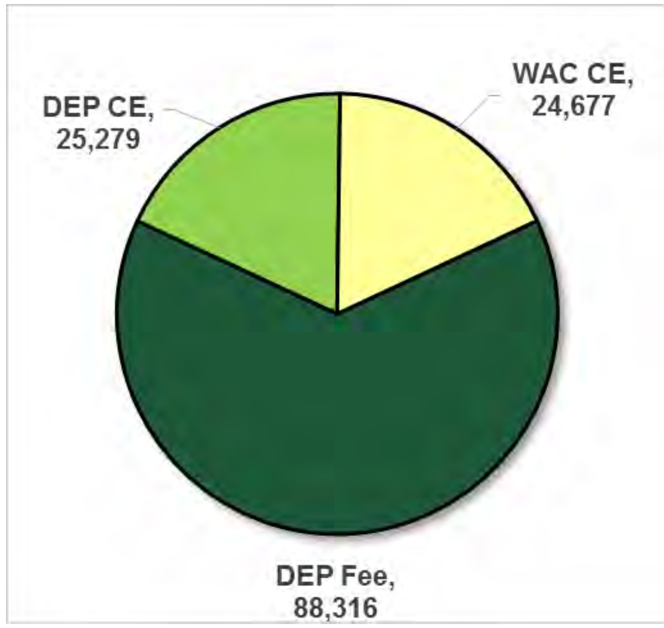

Figure 4.6 Total acres by type since 1997.

4.2.4 Enhanced Land Trust Program

Following the 2010 Water Supply Permit (WSP), five towns opted into the program, together including six eligible properties. The self-selected land trusts involved were unable to meet with progress on any of the six landowners. The second five-year period for this program begins in 2016, during which towns and land trusts have another opportunity to opt in.

4.2.5 Riparian Buffer Acquisition Program (RBAP)

As detailed in Special Condition 29 of the WSP, the 2014 Revisions to the 2007 FAD required the City to hire a land trust to implement a program to acquire real property interests along stream buffers. On July 15, 2015, a five-year program contract was executed with the Catskill Center for Conservation and Development (CCCD), a watershed-based land trust, to implement the RBAP. Initial landowner solicitations are expected to begin in early 2016. An evaluation of the pilot program, to be issued in early 2018, will make recommendations, based on the success of the program, as to whether the RBAP should be continued and/or be expanded beyond the Schoharie Basin.

4.2.6 FEMA Flood Buyout Program

In response to tropical storms Irene and Lee in 2011, DEP was asked to support applications by Greene, Delaware and Ulster Counties to FEMA for funding under the Hazard

Mitigation Grant Program (HGMP) to purchase flood-damaged properties. Under HGMP, FEMA pays 75% of eligible costs to acquire property and demolish improvements thereon. 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 municipality or DEP takes title to the property. The grant applications were approved by FEMA, and subsequently DEP entered into MOUs with each County to provide assistance by (1) accepting ownership of certain properties, (2) paying for the land portion of the purchase price, (3) paying for soft costs. In addition, LAP staff provided technical support to manage closing documents and certain tasks for properties to be acquired by local municipalities. Once acquired, properties are deed-restricted against further development per FEMA rules, and a CE will also be conveyed to NYSDEC by the owner. As of December 31, 2015, DEP has acquired seven Flood Buyout Program (FBO) properties and assisted in the acquisition of seven more properties by watershed towns. An additional 22 purchase contracts remain in the closing process and are expected to close in 2016. In addition, 22 properties in Delaware County, originally in the FBO MOU Program, did not need the City matching funds and the county chose to close on those in 2016, directly with FEMA.

The FEMA program described above is distinct from a similar initiative during 1996-2000, when DEP partnered with FEMA and Delaware County to acquire 28 properties impacted by the floods of January 1996.

4.2.7 DEP-Funded Flood Buyout Program

In 2014, DEP developed both a Program Plan and a more detailed Process Memo for implementation of a new flood buyout program funded entirely by DEP. Similar to the FEMA program, this program will allow for the acquisition of flood-damaged or threatened properties with structures, after which the structures are removed and the properties restored or repaired to a natural condition, thus mitigating the impacts of future floods. Since 2014 DEP has moved forward with many complex steps required to initiate the program. These included holding multiple stakeholder meetings to reach consensus, completing an environmental impact review under State Environmental Quality Review Act (SEQRA), finalizing a property evaluation and selection process, and hiring the CWC to manage the outreach and assessment at the onset of the program. A proposal to modify the WSP was submitted to NYSDEC during 2015. DEP has finalized model documents for landowner communications, purchase contracts, CEs to be conveyed to NYS, and land management agreements.

4.2.8 Riparian Buffers Protected

Prior to 1997, the City controlled 7,566 acres of riparian buffers (defined here as land within 300 feet of stream banks), or 3.0% of buffers in the watershed. Under LAP from 1997 through 2015, the City protected an additional 21,668 acres of buffers under fee simple acquisition and 6,373 acres under CEs; WAC protected 6,729 acres of buffers within farm easements during this period. Through 2015, the City thus acquired 13.6% of riparian buffers in the watershed. Thus, including lands owned by the City before 1997, the City now protects over

16% of the 300-foot stream buffers identified in the Catskill/Delaware watershed, roughly consistent with the percent of the watershed protected by the City overall. When other entities (DEC, land trusts, etc.) are included, a total of 87,584 acres of identified 100-foot stream buffers are protected, or 34.3% of the 255,175 acres of 300-foot stream buffers identified in the CAT/DEL watershed. (For more on stream buffers, see Figure 4.16 and Section 4.6.)

4.2.9 Wetlands Protected

Within the CAT/DEL watershed, 15,190 acres are identified as wetlands, of which the DEP has acquired 2,740 acres (18.0%). For more on DEP's wetland protection programs, see Figure 4.22 and Section 4.9.

4.3 Land Management

DEP's land management activities include five major categories and are focused on the DEP's water supply lands and reservoirs. They include:

- Fee Land Inspection and Monitoring
- CE Monitoring
- Recreational Uses
- Agricultural Uses
- Land Use Permits

DEP continues to acquire land in fee and CEs and has made a significant investment purchasing watershed lands and CEs, including those purchased by the WAC with DEP funds. To protect these investments, DEP has established protocols for monitoring fee and CE lands on a regular basis and for following up to rectify problem and issues that arise.

4.3.1 Property and Conservation Easement Monitoring

Fee Lands

DEP continues to monitor its 167,072 acres of fee lands which includes lands acquired before the MOA (buffer lands around the reservoirs, aqueducts and shaft sites both inside and outside the watershed) and lands acquired under the MOA. Lands are inspected per DEP's Fee-land Monitoring Policy that was developed in 2010. DEP also has 35,831 acres of reservoirs and 498 miles of shoreline that are monitored. The monitoring policy is designed to provide guidance for DEP staff to ensure a regular and consistent monitoring regime to ensure long-term protection of water supply land. To help optimize limited staff resources, properties are designated as high priority and standard priority. High priority properties are those that 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 those rural properties without intense use or vulnerability and are inspected at least every five years. Twenty-six percent of all properties are designated as high priority.

In addition to the inspections above, DEP performs boundary line maintenance on every water supply property every five years. The goal is to walk the property boundary and make sure all survey monumentation (pins, x-cuts, blazing) and signage is adequate. If deficiencies are observed, monumentation is refreshed and signs are replaced. DEP staff also look for signs of encroachments and/or trespass. If trespass from all-terrain vehicles is observed for example, DEP may install additional signage and perhaps a gate or other obstruction. In some cases, DEP Police are notified and may perform an investigation.

Conservation Easements

DEP has 163 easement properties totaling 23,858 acres with the average size of an easement property being 146 acres. DEP inspects every CE twice per year with one on-the-ground inspection and one aerial via helicopter or small plane. Most DEP easements 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 threshold. To date, forestry and agricultural use make up the highest number of landowner requests.

Between 2011 and 2015, 11 easement properties were sold to new owners (i.e., second-generation easement landowners), which is roughly 10% of the easements that have been held by DEP for more than five years. Nationwide, land trusts report that most violations of the easement deed occur when properties are sold 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 easement deed and baseline maps. DEP typically requests a face-to-face meeting to discuss the easement terms, walk the property and introduce the DEP staff responsible for monitoring. Since 2011, DEP has not had a major violation of its easements and has not had to bring any legal action. DEP believes strong landowner relationships are the key to reducing easement violations and DEP will continue to strengthen our landowner outreach.

DEP works closely with WAC on their farm and forest easement program. WAC has purchased 137 farm easements totaling 24,677 acres with an average size of 185 acres. WAC has experienced several landowners who have sold 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 two easement landowners, and at least two more WAC appointees with a background in farming or rural land use issues. DEP staff work with WAC to resolve deed interpretation questions that arise from landowner activities.

Water Supply Land Signage

All properties owned for water supply protection have signs indicating the appropriate 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. This effort is guided by a sign design manual DEP developed to provide a consistent message to the public and reduce sign clutter. The manual provides the framework for staff to determine the best message, layout and size of signs for various uses. DEP began using various icons on its recreation signs to further aid in user understanding of the signs. DEP also installed many updated signs informing the public about entering reservoir areas and developed various educational signs. DEP has also worked on regional efforts to improve signage for recreation destinations which will highlight DEP lands.

4.3.2 Recreational Uses

The Catskill region has a long tradition of hunting and fishing, and DEP lands play a vital role in providing recreational opportunities. DEP lands open for recreation help stimulate local tourism and recreation industries as well. DEP now has over 130,000 acres of land open for public recreation. Another 35,831 acres of reservoirs and controlled lakes are also accessible for boating and shoreline fishing (Figure 4.7).

Trails

DEP has been working with partners to open family-oriented trails on DEP land, those that are more conducive for a family with small children or less-abled people to walk the trail in less than an hour or two. These types of trails were identified by many stakeholders as lacking in

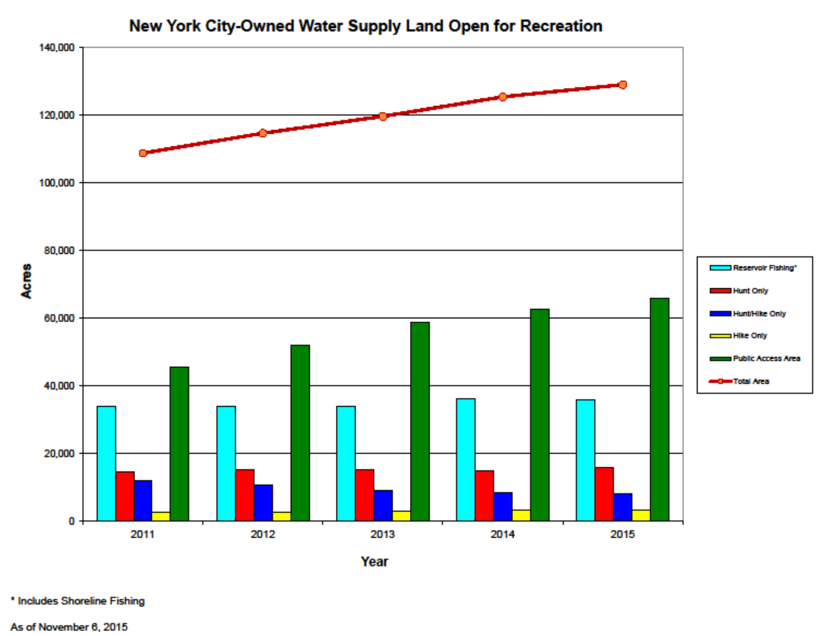

Figure 4.7 Number of acres open for recreation between 2011 and 2015.

Figure 4.8 Hiking the Finger Lakes Trail over DEP Land.

the Catskill region. DEP also worked with the Finger Lakes Trail Conference to move a section of their State-wide trail network off public roads and onto DEP land (Figure 4.8).

These trail projects highlight the great relationship DEP has fostered with partners on recreation. The Catskill Mountain Club installed a trail register on the Palmer Hill and Shavertown Trail. Per trail registry records from October 2014 to October 2015, the Shavertown Trail was used by 1,200 hikers while 797 hikers used the Palmer Hill Trail. This only counts hikers who signed in so the actual use is likely higher.

Recreational Boating

In 2012, the successful recreational boating pilot program on Cannonsville Reservoir was made permanent. Additionally, the program was expanded to three other reservoirs, Pepacton, Neversink and Schoharie. The program allows boaters to use vessels such as kayaks and canoes, provided they have been steam cleaned by a DEP-certified vendor, to get a day or seasonal boat tag. Seasonal boat tag holders may leave their vessel on the reservoir for the boating season which generally runs from Memorial Day through Columbus Day weekend. In 2013 and 2014, DEP purchased and installed boat racks to help organize storage for seasonal tag holders. DEP, in cooperation with CWC, also developed a program to allow certified vendors to rent canoes and kayaks for use on the reservoirs. CWC also purchased boat racks to allow vendors to store vessels on the reservoirs so customers would not have to transport them (thereby increasing accessibility) and to reduce risk from invasive species. Since 2012, there has been a steady

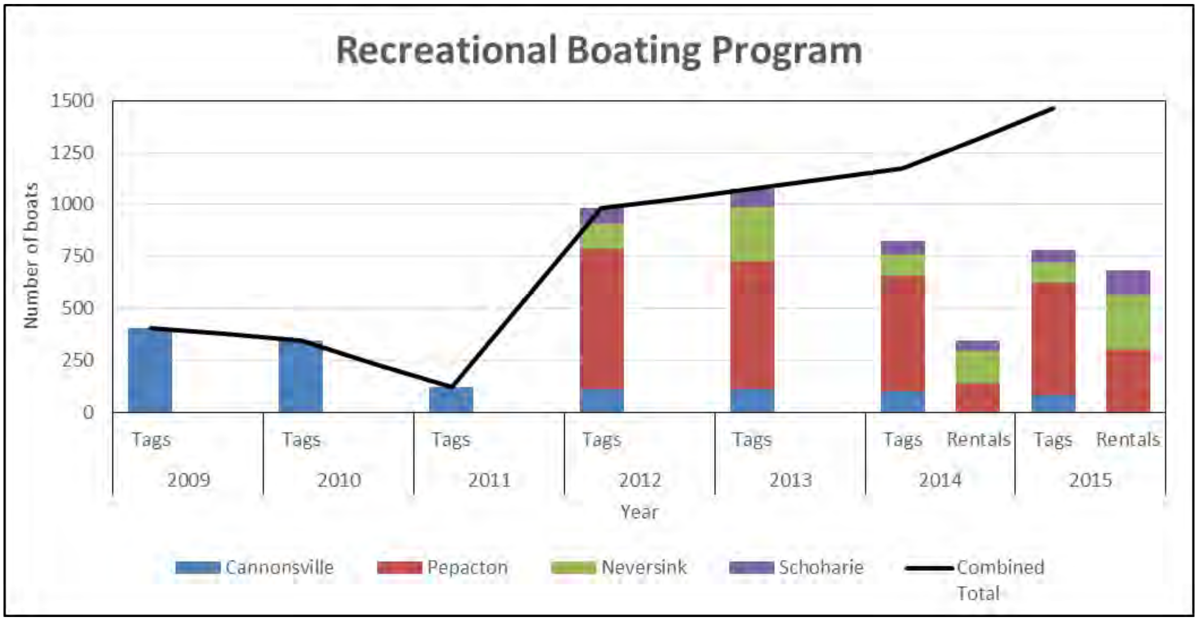

Figure 4.9 Recreational boating activity.

increase in recreational boating activity both for vendor-issued boat tags (for privately owned vessels) and vendor rentals (Figure 4.9).

Outreach to Recreation Users

DEP has increased its outreach efforts to better communicate with our recreational users. We have found that by hosting special events, we can engage our recreation users on a one-to-one basis, they get to interact with DEP staff and we learn more about their interests. We have been encouraged by the success of these events, such as Family Fishing Days, and have attracted hundreds of people who are eager to participate (Figure 4.10).

Figure 4.10 Family Fishing Day at the Pepacton Reservoir.

In 2014 and 2015, 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. The DEP Reservoir Cleanup Day joins dozens of similar events happening across NYS as part of the American Littoral Society's annual NYS Beach Cleanup (Figure 4.11). In many cases, the debris had blown onto the reservoir property from nearby roadsides, or had washed up along the shores from storms. Some was also left behind at access areas used by the public for fishing and boating. The CWC co-sponsored the event and provided gloves and bags for the volunteers. For the 2015 event, 347 volunteers collected more than 100 bags of debris from Ashokan, Cannonsville, Kensico, Lake Gleneida, Muscoot, New Croton, Neversink, Pepacton, and Rondout Reservoirs. Recyclable materials were separated from trash as the volunteers collected the debris from the cleanup areas and recorded their findings.

Figure 4.11 Reservoir Clean Up Day at the Ashokan Reservoir.

DEP publishes an annual recreation newsletter and is stepping up efforts to communicate with the 112,000 DEP Access Permit holders, most of whom have provided us with their e-mail addresses. Additionally, DEP participates in public internet forums such as www.Westchesterfishing.com and www.NYBass.com in which recreation users can communicate directly with DEP staff.

Hunting and Deer Management

Forestland in the Northeast, both privately and publicly owned, is suffering from inadequate forest regeneration due to excessive deer browse. In an effort to reduce these impacts on DEP lands, DEP has relied on recreational deer hunting and has opened most of its lands to hunting. However, traditional deer hunting alone may not provide the deer herd reduction that is required for forest regeneration. To compound the problem, the number of licensed deer hunters is decreasing nationally and in New York State.

One of the best strategies to manage deer populations is to increase the harvest of female deer (antlerless deer) and accordingly, DEP has ramped up its program to secure Deer Management Assistance Permits (DMAPs) from the NYSDEC (Table 4.1). By securing these DMAPs, DEP can distribute them to hunters who can use them exclusively on DEP land. Additionally, in 2014, DEP implemented an "earn-a-buck program" which required hunters to harvest does on certain Ashokan Reservoir lands before they could harvest a buck.

Table 4.1 DMAPs secured by DEP and associated anterless deer harvests.

Year	Unit	DMAPs obtained	Antlerless Deer Harvested
2012	Ashokan	46	7
2013	Ashokan	100	20
2014	Ashokan	100	15
	Neversink	100	36
	Johnny Brook	80	12
2015	Ashokan	100	14
	Neversink	100	28
	Johnny Brook	65	9
	West Settlement	15	1
	East Fishkill	16	0

4.3.3 Agricultural Uses

As with recreational uses of DEP land, DEP also understands the importance of allowing agricultural uses of its land and the importance of those lands to many small-scale farmers. The number of projects has grown substantially throughout the 2011 to 2015 period (Table 4.2). Seventy-four percent of the farmers using DEP land are enrolled in the WAC WFP Program that incorporates the DEP lands being used. All projects require that a vegetated buffer be established and maintained; most of the lands did not have any buffer while being farmed as private lands before DEP acquired the property.

Table 4.2 Yearly total number and acres of agricultural projects.

Year	Projects	Acres
2011	64	1,574
2012	75	1,823
2013	87	2,156
2014	95	2,332
2015	112	2,735

4.3.4 Forest Management Program Overview

The primary responsibility of the forest management program is to manage DEP's watershed forests applying science-based silvicultural practices. The program also reviews and monitors proposed forest activities on CE lands and provides forest management guidance on land-use permits and DEP projects. During the five-year period, managed DEP lands increased from approximately 109,000 acres to 135,000 acres (23%) and CEs increased from approximately 17,000 acres to 23,700 acres (39%).

Forest Management Plan

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 response to environmental changes is provided by vigorously growing diverse forests across the watersheds.

To establish a long-term vision and direction for the DEP forest lands, DEP completed the first comprehensive watershed Forest Management Plan in partnership with the US Forest Service, TEAMS Enterprise unit in November 2011. ("Plan" – available at: http://www.nyc.gov/html/dep/html/watershed_protection/forest_management.shtml). The first comprehensive forest inventory of DEP lands was conducted on approximately 95,000 acres during 2009-2010 which provided the current and baseline conditions of the forest for the Plan. The forest inventory consisted of approximately 9,528 plots evenly distributed throughout the forest and included assessments of (1) site conditions, including disturbance history and deer impacts, (2) overstory forest conditions, including species, diameter and condition, and (3) understory conditions, including seedling and sapling populations, interfering vegetation, and invasive plants.

The Plan identified overstocked forest conditions and a skewed forest stand age distribution as the top two critical forest issues. Based on the forest inventory, almost half of the forest stands are overstocked (48%) which results in significant competition and increased forest stress. The forest stand age distribution is skewed to an older forest, with 61% having an effective age greater than 81 years old. This indicates a potential decrease in forest vigor and a reduced resiliency to respond to forest impacts. Other items identified include a lack of forest regeneration, significant deer herbivory on forest regeneration, promotion of interfering species resulting from deer overabundance and deer herbivory, and existing or potential invasive forest insect and disease issues.

DEP developed a set of Conservation Practices (CPs) to provide a framework for planning forest management projects to protect co-occurring natural resources such as wetlands, riparian areas, and threatened and endangered species. The CPs establish a Forestry Interdisciplinary Technical Team comprised of various DEP groups and outline an internal review process for developing projects. Resource management standards are also implemented through BMPs, special management zones, and exclusion zones.

The Plan identified approximately 40,000 acres (42% of the forest) that need active forest management over the next 10 years (2011-2021) to meet the desired forest conditions.

Forest Management Projects

Since January 2011, 15 forest management projects (timber harvests) were sold totaling 1,856 acres. Four projects were planned projects while 11 projects were reactive projects (Table 4.3).

Table 4.3 Number of forest management projects over the last five years.

Year project sold	Number of planned projects	Number of reactive projects	Planned acres	Reactive acres	Total acres
2011	1	1	43	10	53
2012	1	0	123	0	123
2013	1	6	111	692	803
2014	0	3	0	298	298
2015	1	1	237	342	579
TOTALS	4	11	514	1,342	1,856

Planned projects are those projects that are identified, planned and implemented following the recommendations of the Plan to transition a portion of the forest into the desired forest conditions. Often these target transitioning forest stands from overstocked and/or over mature conditions to younger and more vigorously growing trees.

Reactive projects are those projects that are planned and implemented in response to unexpected events that impact the forest. The primary negative impacts on forests during the five-year period were from blowdowns caused by weather events (427 acres, largely due to tropical storms), by ash tree mortality resulting from emerald ash borer (EAB) outbreaks (897 acres), and eastern hemlock decline resulting from hemlock woolly adelgid (HWA) infestations (8 acres).

Hurricane Sandy toppled trees on approximately 49 acres on four sites around Kensico Reservoir. A timber harvest was conducted to remove the downed trees. Since Kensico Reservoir is critical, part of the disturbed area (15 acres) was further treated. To restore the ecological function of the sites, the treatment included tree and shrub planting, invasive plant control, and installation of deer fencing. The trees and shrubs selected are compatible with the unique site conditions and a variety of species were chosen to promote species diversity following the goals of the FMP. Due to the high white-tailed deer population in the region, the plants are protected by either an eight foot high deer fence around the site or with tree tubes depending on the site. The fence and tree tubes are scheduled to be removed once the plants become established above the feeding zone of deer.

A second restoration project was also completed in the Kensico Reservoir basin at one of the sites impacted by a tornado in 2006. Following the 2006 harvest of damaged trees, DEP anticipated that the sites would be restored through natural regeneration with the sites re-seeded from trees on-site. Extensive deer herbivory and competition from invasive plants precluded the establishment of natural regeneration. Therefore the Kensico Tornado Restoration project was implemented in 2014-15, covering approximately five acres. The project included invasive plant control, tree and shrub planting, and installation of deer fencing and tree tubes. The fence and tree tubes are scheduled to be removed once the plants become established above the feeding zone of deer.

Forest Invasives – Emerald Ash Borer

During the five-year period, 2011-15, the forest management program also focused on monitoring the spread of EAB through the watershed and responding to EAB impacts on DEP lands. EAB is an invasive insect that infests and kills ash trees. Ash is the sixth most common tree on DEP lands, comprising 7% of all trees.

EAB was initially discovered in the Hudson Valley, in Saugerties, NY, on July 15, 2010. Since the discovery, DEP has worked closely with the NYSDEC (Region 3 and Forest Health units) and the United States Forest Service (USFS), Northeast Area, Forest Health Protection Unit. In cooperation with NYSDEC and USFS, DEP assisted in the EAB infestation delineation in early 2011, sampling 37 plots on DEP lands resulting in two confirmed infestations.

Monitoring continued in 2012 and 2013, utilizing sentinel and trap trees to monitor and control the spread of EAB. Sentinel and trap trees are ash trees specifically girdled to stress the trees and attract EAB. The trees were annually felled and analyzed for EAB. The data was used to monitor the spread in the Ashokan basin.

Information developed from the monitoring and delineation program was used to plan and implement forest management projects aimed at mitigating the impact of EAB on the watershed forest. Additionally, DEP partnered with NYS Department of Transportation (NYSDOT) in removal of EAB infested trees on DEP lands adjacent to Route 28 in the Ashokan basin for public safety. The EAB monitoring and response has continued in the Ashokan basin, and expanded into the Schoharie, Rondout and Cannonsville basins.

4.3.5 Invasive Species Management

Recognizing the threat that invasive species pose to water quality, water supply infrastructure, and the watershed, DEP has been taking strides to construct a program to comprehensively address the prevention, early detection, rapid response and management of the most damaging invasive species. The need for such a program continues to be made evident by the impacts of the extreme weather events that have impacted the region. Forest blowdowns create openings in the canopy for light and edge habitat while flooding creates soil disturbance and movement of large amounts of material downstream. These disturbances, which are related to climate change, have proven a challenge to managing the impacts of invasive species (Bradley et al. 2009).

Invasive Species Working Group

The Invasive Species Working Group (ISWG) within DEP was formed in 2008 to develop and implement a science-based, comprehensive plan to identify, prioritize, and address invasive species threats to the water supply and to coordinate this work within DEP. The ISWG has met quarterly to achieve that goal by addressing individual components of the plan including the completion of the Early Detection and Rapid Response Plan in 2011, and the development of a scope for the broader Invasive Species Strategy in 2014. Simultaneously, the group has been working to implement elements of the plan as they are being developed and to collaborate on emerging issues.

Elements of the Early Detection and Rapid Response Plan that have been implemented include:

- A priority species list of the 44 top threats to water quality
- A centralized reporting and tracking system
- A passive monitoring program including an Education and Outreach Strategy that provides trainings and targeted outreach events
- An active monitoring program including a two-year aquatic invasive species inventory and mapping contract, recreational boat launch area surveys, Asian long-horned beetle campground surveys, a spiny water flea monitoring program, and aquatic plant surveys

Management Activities

Since 2011 many areas have been targeted for the control of a variety of invasive species that threaten the ecosystem services that the watershed provides.

- Ashokan Reservoir Basin – As described above, DEP has partnered with NYSDEC to slow the spread of the EAB and to reduce the impacts to the basin of the rapid loss of a dominant tree species by implementing a number of forest management projects. In addition to the removal of trees to combat EAB, the invasive plants Japanese barberry, multiflora rose, Oriental bittersweet, common and glossy buckthorn, and Japanese knotweed have been controlled to promote successful regeneration of tree species. Purple loosestrife was controlled at a wetland mitigation site to promote colonization by native species that will improve the functionality of the constructed wetland.
- Kensico Reservoir Basin – Three major invasive plant control projects have taken place in the Kensico Basin, all to support tree planting project success.
    - Mile-a-minute vine, porcelain berry, and Japanese barberry were controlled at a forest restoration site that was designed to restore canopy after a tornado blowdown. Both manual and chemical control were done as well as two releases of the mile-a-minute biological control weevils, *Rhinoncomimus latipes*.
    - Japanese barberry, Japanese knotweed, Japanese angelica tree, Japanese stiltgrass, Oriental bittersweet and garlic mustard were all controlled at a stream restoration project on the Whippoorwill Creek, a major tributary to Kensico Reservoir.
    - Japanese angelica tree was controlled in a reforestation project area targeting a blowdown from Superstorm Sandy.
- Pepacton Reservoir Basin – A long-term project to eradicate swallow-wort using a combination of chemical and manual removal continued through 2015. Stem counts wavered

between low hundreds and over a thousand due to difficulty detecting this species at a low abundance in dense vegetation and its long-lived seed bank. These results indicate that in this type of mixed habitat, eradication of this species is not feasible. Future work on this site may be conducted by partners.

- West Branch and New Croton Basins – Japanese barberry and multiflora rose were controlled at two proposed forest management project sites to prevent regeneration challenges from competition once they are harvested.
- Croton Falls and Cross River Basins – Mile-a-minute vine was controlled manually in locations where the plants were present in manageable numbers.

Partnerships

Successful management of invasive species in the watershed requires partnership to work across property boundaries and to develop policies that will slow the introduction of these species. To that end, DEP has participated in three important statewide and regional groups:

- NYS Invasive Species Advisory Committee (ISAC) –DEP is named in a 2008 statute as one of the 25 members of the Committee which was formed to provide information, advice, and guidance to the NYS Invasive Species Council (ISC) on issues related to invasive species impacts, prevention, regulation, detection and management in the state. Since 2011, ISAC has advised the ISC on the development of invasive species regulations to prohibit and regulate the sale of some of the most harmful invasive species, regulations to prevent the spread of hitchhiking aquatic organisms on boats and trailers, and it supported the development of a statewide Invasive Species Awareness Week. In 2015, the DEP representative was selected to be the Chair of the ISAC.
- Catskill Regional Invasive Species Partnership (CRISP) – DEP is an active member of the Executive Committee responsible for long-term strategic and short-term project planning for this group which covers an area of six counties encompassing the entire WOH watershed. CRISP has worked with DEP on two major efforts in the Pepacton Basin, the swallow-wort eradication project, and a two-year pilot program for boat launch stewards in 2013-2014. Summer interns and volunteers greeted boaters who were launching boats as part of the DEP's recreational boating program on weekend days throughout the height of the summer season to spread the word on invasive species spread prevention, inspect boats to ensure compliance with cleaning protocols, and collect data on usage.
- Lower Hudson Partnership for Regional Invasive Species Management (LH PRISM) – Since receiving a NYSDEC contract to fund their activities in 2013, the LH PRISM has become active in supporting projects to combat invasive species in the EOH watershed. DEP serves on the Steering Committee and aided in strategic planning, the development of a governance structure and annual project selection. DEP has worked on a giant hogweed survey and

control work in partnership with LH PRISM on DEP lands and in 2015 participated in a broad-based survey for focal species.

Education and Outreach

DEP presented in 2011, 2013, and 2015 at the Watershed Science and Technical Conference on the Early Detection and Rapid Response Plan, the swallow-wort eradication project and on *Hydrilla verticillata*. In 2012 and 2013 DEP presented on the EAB Slow Ash Mortality protocol on Ashokan water supply lands at the New York and New England Society of American Foresters annual meetings. DEP sat on a project advisory committee for a Water Research Foundation Tailored Collaboration project "Management of Disruptive Aquatic Species in Pacific Northwest Drinking Water" and presented its Invasive Species Program at a workshop in Seattle that included 30 water supply utilities in the Pacific Northwest and British Columbia in 2011. Additionally, DEP presented at the Cornell Cooperative Extension (CCE) In-Service Invasive Species Session on the ISAC's education and outreach efforts.

4.4 Watershed Agricultural Program

The Watershed Agricultural Program (WAP) reduces the risk of agricultural pollution through the development of Whole Farm Plans and the implementation of BMPs, along with the establishment of riparian buffers through the federal CREP. The WAP is funded by DEP and administered locally by the WAC in partnership with Delaware County SWCD and CCE, with the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA) both providing technical and financial assistance.

As the current FAD assessment period began, DEP had just submitted a comprehensive WAP Evaluation FAD Report that summarized the WAP's accomplishments and recommended a series of proposed metrics and the adoption of a new BMP Prioritization Methodology; this new methodology was used by the WAP throughout the FAD assessment period while several new metrics that focused on maintaining 90% participation rates were adopted pursuant to the mid-term FAD revisions. In January 2015, DEP submitted another WAP Evaluation FAD Report that evaluated the BMP Prioritization Methodology, reviewed the adequacy of current WAP metrics, and justified developing fewer than 50 new WFPs as per the mid-term FAD revisions. In May 2015, DEP's request to develop fewer than 50 WFPs was approved by the FAD regulators who also agreed that the WAP's current metrics along with criteria for future WFP development should continue to be reviewed and assessed as the program evolves; this report will contribute to the ongoing dialogue about WAP metrics.

During the current FAD assessment period, the WAP developed 55 new WFPs on five large farms, 29 small farms, and 21 EOH farms. To date, the WAP has developed 443 WFPs in total, of which 351 remain active (79%); these 443 WFPs include 250 large farms (185 remain active), 116 small farms (99 remain active), and 77 EOH farms (67 remain active). These statistics illustrate the importance of using the nuanced term "active farm" or "active WFP" when tracking or reporting on the WAP's accomplishments or metrics. DEP is pleased to report that every WAP metric was met or exceeded during the last five years, including the FAD requirements described below.

Maintain at least 90% active large farm participation. As of December 2015, 195 active large farms are participating in the WAP out of a total known universe of 212, which represents a 92% participation rate; this rate fluctuated between 91-94% during each of the last five years depending upon the known universe of large farms and their activity status. It is worth noting that several large farms that signed up for the WAP many years ago continue to be counted as participants despite their refusal to adopt or follow WFPs; this nuance raises an important question about the relevancy of using large farm participation rates to measure program success as opposed to tracking and reporting on the total number of participants (large or small farms) who actively engage in the WAP vis-à-vis the development and implementation of WFPs. As DEP noted in recent FAD reports, achieving a specific participation rate within the large farm demographic was relevant two decades ago when the WAP represented an untested voluntary alternative to regulations and it was critical to achieve a critical mass of participating farms for water quality protection. Two decades later, however, the WAP is a mature program that provides a myriad of water quality benefits resulting from over 350 active WFPs on all types and sizes of farms; this latter statistic would seem to provide a more meaningful measure of program success because it accurately reflects the cumulative engagement of all active farms while excluding the handful of large farms that signed up for the WAP but in reality are not active participants along with the dozen or so large farms who continue to refuse participation after two decades of attempted recruitment. Ultimately, the WAP is a voluntary program, which means that farmer participation is neither mandatory nor enforceable, and there will always exist a certain number of farms who either don't sign up or who sign up but don't adopt WFPs. With this in mind, it no longer seems relevant to keep using the large farm participation rate as a primary metric when in reality the WAP works with hundreds of farms of all sizes and types who are actively engaged.

Conduct annual status reviews on at least 90% of all active WFPs. Although the number of status reviews required each year varies based on the number of active WFPs, the WAP nevertheless completed an average of 318 status reviews each year on large, small and EOH farms; this equates to an average annual completion rate of about 94% by the end of each December, an accomplishment that jumps to 100% within one month following the end of each calendar year. As part of the annual status review process, the WAP also confirmed the number of inactive WFPs every year, a statistic which increased from 75 farms in 2011 to 87 farms in 2015. DEP continues to support this metric because it ensures that the WAP engages with all participants (and non-active farms) on a regular basis, which in turn ensures that BMPs are properly functioning and that potential new water quality issues are quickly identified; annual status reviews also provide a valuable opportunity for gathering feedback from watershed farmers to further assess the program's success.

Maintain current nutrient management plans (NMP) on 90% of all participating large farms. During the last five years, the WAP maintained current NMPs on 94-100% of all participating large farms, with the actual number of farms needing these plans fluctuating between 174 farms and 180 farms annually. To meet this metric, the WAP developed or updated an average of 56 NMPs every year on large farms. In total, the WAP developed or updated over 433 NMPs on all active large, small and EOH farms during 2011-2015, a statistic that DEP feels more accurately reflects the WAP's overall accomplishments than focusing only on the large farm demographic. It is also worth noting that in 2015, the WAP developed a comprehensive Nutrient Management Guide that will be circulated to all participating farms beginning in 2016 as an educational tool and reference manual covering all aspects of following a NMP.

Continue to make the Nutrient Management Credit Program available to at least 100 watershed farms (note: before this metric was codified in the mid-term FAD revisions, the original metric was 80 farms in the Cannonsville basin). During the current FAD assessment period, the number of farms receiving nutrient management credits increased every year, from 91 farms receiving credits in 2011 to nearly 120 farms receiving credits in 2015. More than 100 farms per year have received nutrient management credits since 2012.

Execute a contract change order with WAC to fund and implement a Precision Feed Management (PFM) Program on up to 60 eligible farms. Pursuant to the mid-term FAD revisions, DEP developed a PFM proposal in consultation with WAC and CCE that was submitted to the FAD regulators in September and approved in October 2014. Over the next 12 months, DEP worked with WAC to develop and execute a contract change order to fund and implement the PFM Program, while also working with WAC and CCE to develop and finalize farm eligibility selection criteria that were shared with the FAD regulators during the summer of 2015. The PFM Program was initiated in October 2015, with WAC and CCE both hiring new staff and conducting farmer outreach to identify and screen prospective PFM participants. Consistent with the timeline listed in the PFM proposal approved by the FAD regulators, implementation of PFM on the first 20 farms is scheduled to begin during 2016.

Implement new BMPs and repair/replace existing BMPs on active participating large, small and EOH farms according to a BMP Prioritization Methodology. As mentioned earlier, in 2011 the WAP adopted a new framework for scheduling and implementing BMPs across all participating farms in a manner that provides the greatest protection to water quality. During 2011-2015, the WAP implemented 992 new BMPs totaling \$4 million in addition to repairing/replacing 246 failing or outdated BMPs totaling \$2.4 million. To date, the WAP has implemented approximately 7,100 BMPs totaling \$57 million on all active participating large, small and EOH farms. In 2015, DEP evaluated the BMP Prioritization Methodology and concluded that it functions as intended by directing the WAP to implement highest priority BMPs that provide the greatest protection of water quality while ensuring that older or failing BMPs are repaired/replaced as needed. DEP also acknowledged a growing "backlog" of BMPs that continually exceeds the WAP's capacity for timely implementation; this workload is one reason DEP requested a temporary moratorium on new WFPs, because new plans were being developed on lower priority farms while the BMPs on these farms were not being implemented due to other higher priority water quality concerns. To help address this workload issue, in 2015 the WAP revised the farm ranking criteria to give more weight to farms with larger numbers of animal units and to elevate the priority of certain BMPs related to concentrated nutrient sources near streams, such as barnyards and livestock feeding areas.

Develop new and re-enroll expiring CREP contracts. During the current FAD assessment period, 26 new contracts (164.7 acres of riparian buffers) were enrolled in CREP, while 29 expiring contracts (301.9 acres) were re-enrolled and 21 expiring contracts (136 acres) were not re-enrolled by choice of the landowners. As of December 2015, a total of 2,016 acres of riparian buffers are enrolled in 198 active CREP contracts representing 152 different landowners. As anticipated by the WAP several years ago, CREP re-enrollment and the implementation or repair/replacement of CREP-related BMPs became a steadily increasing priority focus of the WAP during the current FAD assessment period, due to the timing of when a large number of original CREP contracts started to expire; this CREP re-enrollment workload is another reason why DEP requested a temporary moratorium on new WFPs, to allow the WAP to focus its resources and staff capacity on highest priority CREP activities.

Implement the Farmer Education and Farm-to-Market Programs. During 2011-2015, the WAP conducted more than 140 farmer education programs that were attended by over 3,400 participants, of which 44% were watershed farmers and 32% were other farmers; these diverse educational programs consisted of conferences, farm tours, webinars, producer group meetings, and workshops covering various topics such as nutrient and pathogen management, soil health, crop production, livestock nutrition, and business planning/succession. The Farm-to-Market Program continued to oversee and implement the Pure Catskills Campaign while sponsoring dozens of workshops and attending dozens of outreach events to promote the purchase of local watershed products.

In summary, one theme to emerge over the past five years involves the ever-changing universe of active watershed farms and how this translates into useful metrics for tracking and evaluating the WAP's accomplishments. When the current FAD assessment period began in 2011, the universe of active large farms was estimated to be 201, of which 191 farms were WAP participants (95%) and 185 participants had WFPs (97%); by the end of 2015, the universe of active large farms is now estimated to be 212, of which 195 farms are WAP participants (92%) and 185 participants have WFPs (95%). During this period, new farms were identified and some became inactive, some farms joined the WAP while over a dozen farms continued to refuse participation, two farms withdrew from the WAP, and one farm was suspended. In addition, these statistics don't reflect the uncertain number of small farms that have since become large farms or vice versa because the WAP only categorizes its participants as being a large or small farm at the original time of enrollment.

The fluctuating universe of farms not only affects the WAP's ability to establish accurate baseline metrics for tracking and reporting actual participation rates from one year to the next, especially within a particular demographic, but this nuance potentially mischaracterizes program accomplishments by diverting attention away from the cumulative water quality benefits afforded by all active farms participating in the WAP. Twenty years ago, after successfully developing WFPs on ten pilot farms, the WAP was tasked with one primary FAD goal: to sign up 85% of all large commercial farms in the WOH watershed by 1997 and to develop and implement WFPs on these participating large farms. At the time this metric was established, many of DEP's other watershed programs either didn't exist or didn't exist at their current scope and scale. The subsequent expansion and comprehensive nature of DEP's Long-Term Watershed Protection Strategy over the past two decades mirrors the similarly comprehensive expansion of the WAP from a 10-farm pilot program to a complicated and highly nuanced program that now engages hundreds of large, small and EOH farms in a myriad of important activities such as Whole Farm Planning, NMPs, nutrient management credits, annual status reviews, farmer education, CREP, and the most recent programmatic addition: Precision Feed Management.

4.5 Stream Management Program

4.5.1 Introduction and Highlights

DEP established the SMP to protect and restore stream ecosystems – the stream channel and the adjacent riparian corridor that together function to sequester nutrients and conserve sediment which can contribute to the degradation of stream water quality. The DEP SMP and its network of partners at County SWCDs and CCEUC, extend state-of-the-science river and floodplain management projects and programs to stakeholders whose individual actions are fundamentally important to stream stability and riparian integrity. The SMP strategy begins with stream feature inventories contributing to stream management plans ultimately resulting in Stream Management Implementation Program (SMIP) grant funded projects and program-prioritized projects. These projects include geomorphic restoration, stream bank stabilization, flood hazard mitigation and riparian plantings. The SMP also delivers education, outreach and training to support its mission.

The most significant accomplishments of the SMP during this assessment period were largely unplanned and resulted from DEP's response to Tropical Storms (TS) Irene and Lee. These actions include: extensive technical assistance in the response and recovery efforts following TS Irene and Lee, accelerated post flood implementation of stream stabilization and restoration projects with federal NRCS and FEMA flood recovery funds, development of a comprehensive flood hazard mitigation program including the Local Flood Analysis (LFA) to identify projects that improve community resiliency and reduce flooding impacts on water quality, the CWC's Local Flood Hazard Mitigation Implementation Program with a $17 million budget over a ten year contract term to fund flood resiliency projects.

These new and unplanned activities were completed in addition to the continuation and expansion of the base SMP. Highlights during the assessment period include:

- Designed and constructed seven restoration projects in the Stony Clove Creek watershed, treating 1.67 miles of stream length and reducing turbidity and suspended sediment at flows less than bankfull discharge
- DEP and/or SWCDs constructed 79 projects, including 25 reach-scale channel restoration projects, totaling nearly $25 million and treating a length of 15.6 miles
- Completed design and construction of 37 EWP Projects following TS Irene, using $4.2 million to leverage $11.5 million in federal funds
- Completed design and construction of 134 Catskill Streams Buffer Initiative (CSBI) projects treating 11 miles of stream length and planting 60 acres (Section 4.6.2)
- With NYSDEC, established the biennial Catskill Environmental Research and Monitoring conference to provide researchers and managers working in the Catskills an opportunity to share findings and develop inter-disciplinary projects, and co-hosted the first two conferences
- Developed and distributed updated Flood Insurance Rate Maps and Flood Risk Mapping Tools
- Established the LFA as a new component of the SMP to identify the most cost effective flood hazard mitigation projects
- Established 12 flood commissions, completed four LFAs and substantially completed another three
- Submitted a training plan for municipal officials and registered a contract with State University of New York (SUNY) Ulster to enable ramped up training for watershed stakeholders

4.5.2 Stream Management Implementation Program

The SMIP remains one of the core activities that engages local decision makers in stream management plan implementation. During this period, 33 towns and villages adopted their stream management plan and signed memorandums of understanding with their local SWCD to collaboratively work on stream issues and participate in SMIP. SMP partners also continued to develop stream management plans: the 2003 Chestnut Creek (Rondout) plan was updated, and management plans were developed for the Neversink River, Third Brook, Beaver Kill, Bushnellsville Creek and the Bush Kill. Additional stream feature inventories were completed in five Neversink River and four Esopus Creek tributaries setting the stage for project and program priorities in the future.

SMP completed annual action plans that detail basin priorities and schedules, and tracks progress towards meeting program commitments. The basin specific action plans can be found at http://catskillstreams.org/major-streams/.

The SMIP across the WOH watershed have matured through repeat funding rounds and through December 2015 have funded a total of 156 proposals with $8,144,134 (Table 4.4). SMIP awarded projects range from the restoration of 1,500' of the Manor Kill in Conesville (Schoharie), to the replacement of a hydraulic constriction on Mallory Brook in the Town of Hamden (Delaware), to a quantitative assessment of water quality in the Upper Esopus Creek (Ashokan). More information, and descriptions of the wide range of SMIP projects can be viewed at http://catskillstreams.org/stream-management-program/grants/.

Table 4.4 SMIP category summary, since inception.

SMIP Category	Schoharie	Ashokan	Delaware	Neversink/ Rondout	Total
Education and Outreach	16	22	1	1	40
Recreation and Habitat Improvements	7	0	8	0	15
Stormwater & Critical Area Seeding	3	0	3	0	6
Highway/Infrastructure	10	13	9	2	34
Stream Restoration/ Landowner Assistance	7	6	10	0	23
Planning and Research	4	22	0	0	26
Flood Hazard Mitigation	5	3	4	0	12
Total	52	66	35	3	156

Throughout this period, the historic damages associated with Tropical Storm Irene forced most teams to focus their efforts on flood recovery. The direct link between stream feature inventories (or other assessments) driving project recommendations was relaxed to respond to and recover from the flood and optimally leverage federal resources. Stream feature inventories are key in the identification and prioritization of reach-scale water quality threats and in diagnosing stream system instability. These instabilities are often the symptom of an issue that can be addressed by SMIP, whether it be an undersized culvert, a poorly planned stormwater outfall or a landowner/municipal stream bank erosion issue. Together, these two SMP components, stream feature inventories and SMIP, create an efficient mechanism for meeting both the needs of local municipalities and DEP's water quality.

4.5.3 Partnerships and Education

Education and outreach (E&O) programming remains a fundamental building block of broad-based commitment to responsible stream stewardship, improved understanding among key stakeholders and decision-makers of best policy and practices, and professional development of program staff actively engaged in technical extension and restoration project design, at both DEP and partner organizations.

Education, Outreach and Training Highlights during the reporting period include:

- Supported 40 E&O proposals with SMIP funding.
- Through the LFA process, brought focus to the benefits and costs associated with dredging of Catskill rivers, advancing the understanding of the impacts of dredging more broadly.
- Sponsored and coordinated 18 conferences and symposia, including two biennial Catskill Environmental Research and Monitoring conferences (a third is scheduled for 2016) to provide researchers and managers working in the Catskills an opportunity to share findings and develop inter-disciplinary projects.
- Coordinated 124 technical trainings, including three levels of workshops on the mechanics of stream process and hydraulic modeling using Hydrologic Engineering Centers River Analysis System, for municipal officials and flood advisory committees, agency staff, and stream restoration designers.
- Delivered 109 presentations by SMP program and partnership staff at local, regional and national events and conferences
- Hosted a training in the role of roadside ditches in fine sediment loading and best practices for mitigation with proper seeding and mulching
- Presented 28 Emergency Stream Intervention workshops for post-flood responders
- Published more than 20 factsheets and newsletters addressing the full range of stream management issues.
- Advanced development of a training program for municipal officials on key stream management topics (FAD deliverable Plan submitted, November 2013) and awarded a new contract to SUNY Ulster to include funding for a new stream management training initiative.
- Hosted five annual summer intern teams from SUNY Ulster, a total of 33 students trained in the essential components of stream assessment and management, as well as Student Conservation Association interns.
- In an emphasis on reinvigorating our public school-based programs, new innovative initiatives were developed in the Ashokan and Rondout/Neversink basins.

4.5.4 Floodplain Management

Floodplain Mapping and Modeling

Under a $7 million contract with FEMA, DEP initiated the restudy of floodplains in the WOH watersheds in mid-2011. By 2013, FEMA's contractors had completed preliminary maps for most of the area and initiated the map review and adoption process. Under this project, FEMA restudied a total of 413 river miles including full detailed study of 227 miles, limited detail of 36 miles and approximate study of 150 miles. Greene County has adopted the revised maps and Ulster, Delaware and Sullivan counties are proceeding with map adoption, expected in 2016. In addition to producing new maps, the partnership with FEMA has provided the SMP with a complete set of hydraulic models for the detailed study areas for use in the LFA effort and helped train public officials in floodplain management and the requirements of the National Flood Insurance Program. This training contributed to the over 20 WOH professionals achieving their certification in floodplain management.

Tropical Storm Irene Response and Recovery

Immediately following Tropical Storm Irene, the SMP and partners coordinated with State, county and municipal efforts, to provide guidance and technical assistance on a wide range of projects. Initial steps involved identification and assessment of damaged stream reaches or infrastructure, followed by prioritization of intervention level and technical assistance and supervision of remediation actions. SWCD, DEP and SMP consultants worked directly with municipal leaders, highway departments and contractors to ensure the extent and type of stream intervention was appropriate and provided improved methods aimed at facilitating both stability and the recovery of natural processes. In total, the SWCDs, DEP and consultants inspected 46 bridges, provided technical assistance and design guidance on 52 projects, and supervised in-stream channel work at 103 stream reaches. DEP also worked closely with CWC staff to evaluate 123 applications under the newly created CWC Debris Program. The CWC program provided up to $2.5 million to clear flood debris from properties where the potential remobilization of debris in future high water events could threaten infrastructure. The CWC program cleared hazardous debris such as oil and propane tanks, but also removed tons of other garbage, on a total of 85 sites.

As Federal funds became available through FEMA and the NRCS EWP program, DEP and the SWCDs assisted with facilitating the programs and provided the funding cost share necessary. Both FEMA and EWP projects are described in Section 4.5.5.

Flood Hazard Mitigation Programs

A working group of state and county agencies as well as stakeholders to the MOA formed in late 2011, and met through 2013 to define additional flood recovery and flood hazard mitigation programs. As a result of this effort, DEP agreed to fund four new flood hazard mitigation programs including the LFA, CWC Flood Hazard Mitigation Implementation Program (CWC FHMIP), the DEP-funded FBO and the FHM fund under the existing SMIP grants of the Stream Management Program (FHM-SMIP).

Development of the LFA began in 2012 and resulted in preparation of a template scope of services for employing engineering consultants who would work with municipally appointed flood committees to identify the factors exacerbating flooding in population centers, options for

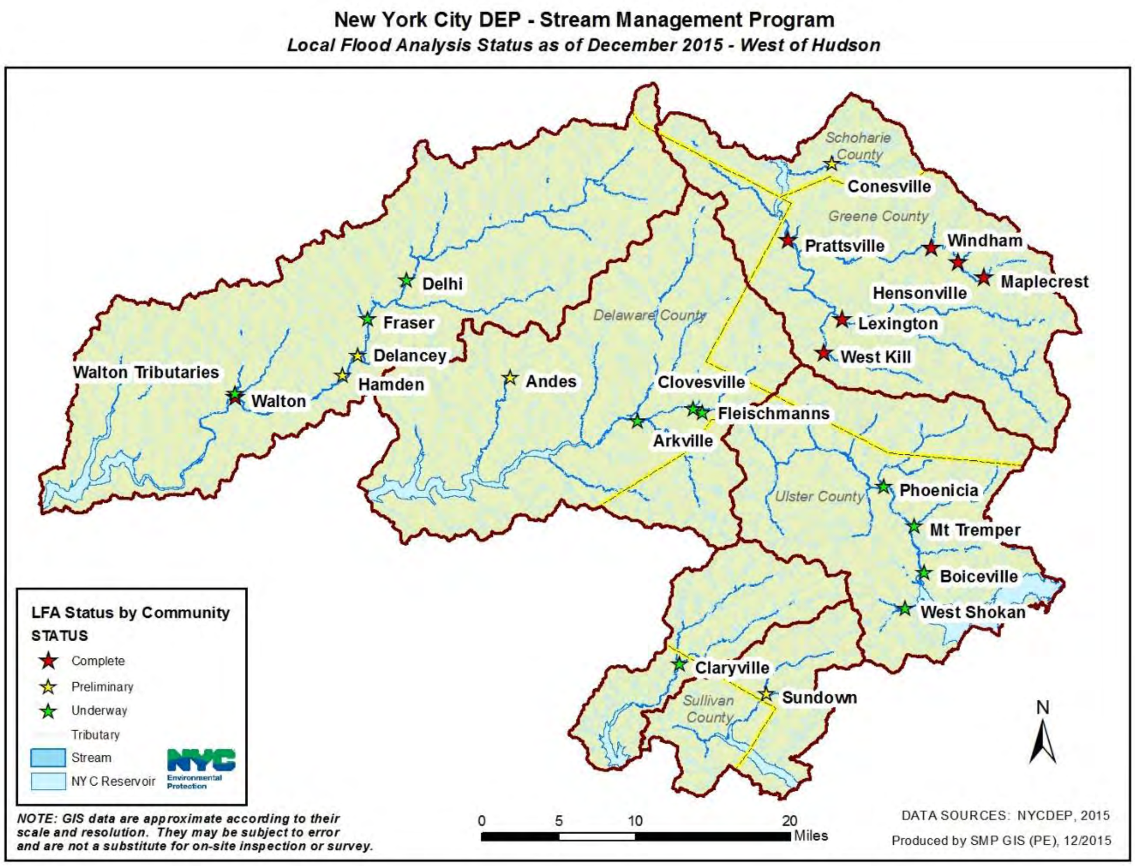

Figure 4.12 Map of LFA status.

mitigating flooding and estimate the benefits and cost of the options. The program was launched in 2013 and to date $985,000 has been obligated to LFA contracts. LFAs have been completed in seven population centers, are substantially complete in five other centers, on-going in six centers and are just starting in five centers (23 total centers). These areas represent some of the most flood-prone areas within the WOH watershed (Figure 4.12).

Each LFA involves the public in a series of comprehensive discussions of flooding, analysis methodology, mitigation options, project feasibility and the consideration of potential remedial actions. This process requires an intensive meeting schedule and each flood commission will hold 3-4 public meetings, 4-8 flood commission meetings, and 2-3 village or town board meetings. Through this process, the stream program coordinators, consultants and agency advisors engage in a dialog with municipal leaders, code enforcement officers, planning board members, business representatives and other participants from the community. While the public consultation process can be lengthy, it is necessary to ensure the community considers all options and ultimately supports any recommended mitigation options.

The LFA process gives communities a unique opportunity to test the options for mitigating flooding and the value of the LFA has been demonstrated in many population centers. In Prattsville, the hydraulic modeling demonstrated the degree of backwatering and inundation resulting from an undersized NYS bridge and catalyzed NYS to replace the bridge with a much wider span that will substantially mitigate flooding in the Village. In Walton, the LFA process identified the incremental reduction in flood damages associated with a set of flood hazard mitigation projects. In autumn 2015, the Village undertook removal of a building that was partially responsible for preventing flood waters from getting back into the West Branch Delaware River.

In June 2015, a $17 million contract for funding the CWC FHMIP commenced. The program will support stream projects to reduce flood impacts, secure sources of pollution, assist residents relocating within the community under the FBO Program with wastewater issues, and extend the post flood debris cleanup program. CWC opened it first round of funding in June 2015 and the Village of Walton submitted grant applications for feasibility studies for an LFA recommended project. This project proposes to remove fill from a historic floodplain as a means of lowering base flood elevations by approximately 0.5 feet in the commercial area of the Village.

Development of the FBO progressed in 2014 and 2015 with the preparation of the program process document which identifies property categories of the program (anchor business, critical facility, residential), types of threats to be mitigated (inundation or erosion) and the criteria considered when determining property eligibility. DEP worked with county Stream Program partners to explain the FBO to the watershed communities through the SMP Project Advisory Committees and Flood Commissions. DEP has hired a Flood Hazard Mitigation Coordinator to implement the program with DEP, CWC and the SMP partners. CWC and DEP have agreed to enable CWC to provide support for outreach to communities and property owners as well as eligibility assessment of buyout properties through the CWC FHMIP.

4.5.5 Stream Projects

The primary goals of DEP stream management projects include water quality improvement through the reduction of bed or bank erosion and other pollutants, infrastructure and/or property protection (flood hazard mitigation), aquatic habitat enhancement, and riparian restoration or protection.

The SMP developed project design submission standards for the purpose of establishing baseline requirements for design documentation and quality for SWCDs, partnering agencies, and consultants involved in implementing projects funded by the SMP. The standards establish specific delivery milestones (conceptual, 30%, 60%, 90%, 100%) for project planning, design, and deliverables, and guide consistency in the format and content of project reporting and contract documents (drawings and specifications) at each milestone. After District review and input, the design submission standards were implemented in early 2011 and progressively implemented through this assessment period. The design submission standards have also been formally incorporated into the new SMP contracts and in the autumn 2015, DEP and the SWCDs commenced quarterly meetings on project design.

Despite the impact of Tropical Storm Irene, assessments continued during the reporting period, providing the important basis for project selection and for monitoring project performance. Scientific studies were funded with SMIP grants to inform stream management as well, and can be found at www.CatskillStreams.org.

- In the Rondout Neversink basin, stream feature inventories were completed for the Neversink River and five tributaries and the Chestnut Creek. The team completed three geomorphic studies including assessment of erosion potential at large eroding banks, hydraulic channel geometry and two reference reaches on the West Branch Neversink River. This work culminated in a report for the Neversink River with local hydraulic geometry relationships to support prioritization of future restoration efforts.
- In the Schoharie basin, 54 reach scale surveys were conducted to monitor performance at 25 former project sites.
- In the Ashokan basin, stream feature inventories were completed for the Beaverkill, Bushnellsville Creek, Bush Kill, Birch Creek, Warner Creek, Stony Clove Creek, Woodland Creek and Malby Hollow. The team conducted project performance monitoring each year for projects completed since 2011.
- In the Delaware basin, a watershed management plan was developed for the Third Brook based on a corridor assessment.

Following Tropical Storm Irene, the NRCS initiated the EWP Program. The program is designed to help people and conserve natural resources by relieving imminent hazards to life and property, and can provide up to 75% of the construction cost of emergency measures. For the first time, project eligibility included a new formula, derived by the NRCS, which factored suspended sediment into the benefit cost analysis, which allowed available SMP funding to serve as the local match for many projects. This allowed eroding stream banks in remote areas, not adjacent to infrastructure or homes, to become eligible for this federal program solely for their contribution to suspended sediment in a public drinking water supply. This enabled projects under design pre-flood to be eligible for NRCS cost share.

The EWP program was activated on April 1, 2012 and project selection progressed through spring and summer 2012. Projects were selected based on the availability of local cost share, degree of threat to infrastructure and private property and degree of erosion/contribution to suspended sediment. The SMP teams and NRCS evaluated more than 100 potential project sites and completed Damage Survey Reports (DSR). A total of 37 projects have been advanced by the SMP through design and construction. An extensive amount of staff time was redirected to support the evaluation, design and implementation of the EWP projects between 2011 and 2015 and progress was made to advance the incorporation of natural channel design principles into the EWP program. Additionally, DEP utilized its consultants to design and inspect the construction of several large EWP projects in the Stony Clove, West Kill and East Branch Delaware watersheds. The effort resulted in the restoration or stabilization of 4.36 miles of stream in the WOH watersheds. In total, $11.5 million in federal funds and $4.2 million in DEP funds have been disbursed for project construction.

SMP and program partners were able to leverage federal funds under the EWP program to complete several major projects in the Catskill system, which were previously identified in stream management plans as water quality projects targeted at fine suspended sediments. These projects included West Kill at State Route 42, West Kill at County Route 6, and East Kill at Apple Hill (Site #1 & 2) in the Schoharie Basin, as well as Stony Clove at Chichester (Sites #1, 2, 3, & 4), Stony Clove at Warner Creek Confluence, Stony Clove Lane, and Warner Creek - Site 5 in the Ashokan Basin. These projects alone represent $8.9 million in EWP Funds and $3.4 million in DEP funds. The details of all 37 projects cost shared with the EWP can be found at www.CatskillStreams.org/.

Tropical Storm Irene also damaged several previously constructed reach scale demonstration projects in the Schoharie basin where the flooding approached or exceeded the 500 year flood. Because the projects targeted turbidity reduction and were publicly financed, FEMA funds were secured for the repairs. GCSWCD oversaw the repairs, which were completed in 2015. DEP SMP was able to leverage approximately $2.5 million in FEMA funds toward the $3.3 million total repair costs. The projects included five on the Batavia Kill: Holden, Conine, Maier Farm, Brandywine, Ashland Connector, and two on the West Kill: Shoemaker and Long Road, and one on the Stony Clove: Lanesville.

During this assessment period, DEP and/or SWCDs constructed 25 full channel restoration projects, 44 stream bank stabilization projects, 9 stormwater and infrastructure projects, and one floodplain restoration project totaling $24.9 million. Table 4.5 provides a summary of the completed projects by reservoir basin and major project category. Figure 4.13 displays the locations of the projects accomplished during the assessment period. Additional information on specific projects can be found at www.catskillstreams.org

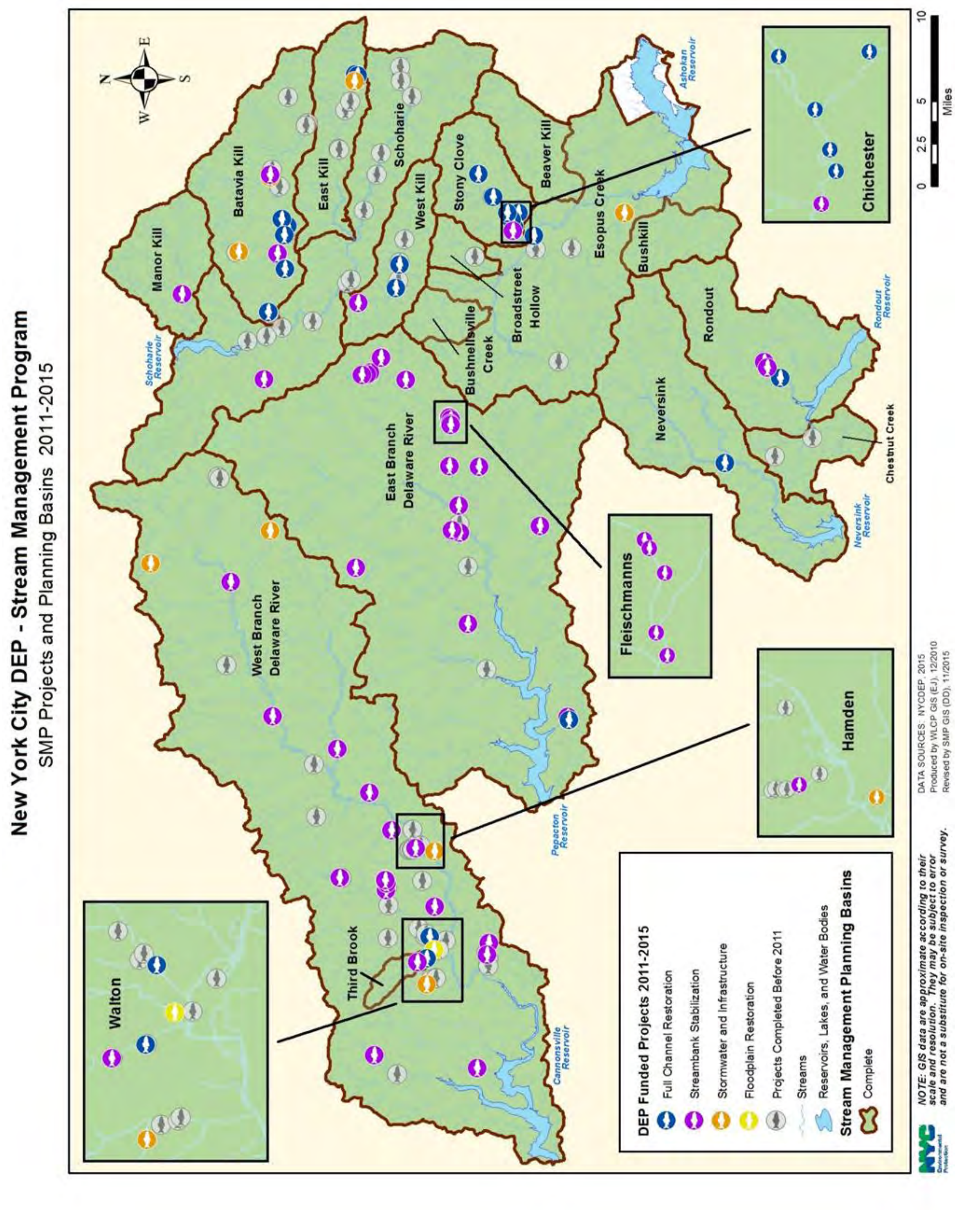

Figure 4.13 Stream Management Program projects and planning basins 2011-2015.

Table 4.5 Stream Management Program project summary.

Reservoir Basin	Project Category	Total Projects Completed	EWP Projects	FEMA Repair Projects	Project Length (ft.)	Project Area (ac.)	DEP Cost	Total Cost
Schoharie	Full Channel Restoration	12	3	8	44,100	75.1	$5,788,696	$9,218,892
	Streambank Stabilization	5	3	0	5,450	24.4	$618,200	$2,108,590
	Stormwater & Infrastructure	4	0	2	475	0.6	$73,706	$294,470
	Floodplain Restoration	0	0	0	0	0.0	$0	$0
Delaware	Full Channel Restoration	3	1	0	4,365	6.8	$226,850	$639,644
	Streambank Stabilization	36	23	1	11,088	13.6	$1,087,126	$3,059,423
	Stormwater & Infrastructure	4	0	0	654	1.7	$454,430	$454,430
	Floodplain Restoration	1	0	0	500	3.0	$115,836	$313,326
Ashokan	Full Channel Restoration	8	6	2	14,110	27.0	$2,529,259	$7,264,817
	Streambank Stabilization	1	0	0	300	1.0	$132,069	$132,069
	Stormwater & Infrastructure	1	0	0	100	0.2	$107,479	$107,479
	Floodplain Restoration	0	0	0	0	0.0	$0	$0
Rondout/ Neversink	Full Channel Restoration	2	0	0	1,700	6.5	$711,718	$711,718
	Streambank Stabilization	2	1	0	1,400	2.0	$467,228	$615, 720
	Stormwater & Infrastructure	0	0	0	0	0.0	$0	$0
	Floodplain Restoration	0	0	0	0	0.0	$0	$0
Total		79	38	8	84,242	161.9	$12,312,597	$24,920,579

Stony Clove Watershed Restoration Projects

During this assessment period, the Ashokan Watershed Stream Management Program (AWSMP) focused its stream restoration efforts in the Stony Clove watershed based on the documented evidence that it is a chronic source of turbidity and a high yielding source of suspended sediment. According to water quality monitoring by USGS, Stony Clove Creek accounted for approximately 40% of the entire suspended sediment load entering the Ashokan Reservoir from 2010-2012. Geologic and geomorphic investigations begun in the mid-1990s identified the primary sources and subsequent investigations monitored the spatial and temporal distribution of these sources. In 2010, DEP worked with Ulster County SWCD (UCSWCD) and Milone & MacBroom, Inc. (MMI) to complete a river assessment in the vicinity of Chichester. DEP and UCSWCD also hired Clear Creeks Consulting to assess the suspended sediment source conditions in Warner Creek – the largest tributary stream to Stony Clove Creek. Both investigations identified visually significant sources of suspended sediment that could be remediated through stream restoration practices. Additional sites were identified following the erosional impacts of Tropical Storm Irene.

Working with MMI and the NRCS, DEP and UCSWCD advanced a set of six turbidity reduction stream projects in Stony Clove Creek and Warner Creek from 2012 – 2015 (Table 4.6); a seventh project is a repair to the Stony Clove at Lanesville project. A total of 8,830 feet of unstable stream with extensive erosional contact with glacial material was treated and restored to a stable condition and removed from contact with the primary turbidity source sediments. The total cost of these projects was $7,293,390. Figure 4.14 and Figure 4.15 show before and after conditions for two of the turbidity reduction projects.

Table 4.6 Watershed restoration project summary.

Project	Town	Year	Length	Cost
Stony Clove at Chichester – Site 1	Shandaken	2012	650	$1,020,369
Stony Clove at Chichester – Sites 2/3/4	Shandaken	2013	1,650	$1,547,182
Warner Creek – Site 5	Shandaken	2013	800	$495,465
Stony Clove/Warner Creek Confluence	Shandaken	2014	1,300	$1,585,454
Stony Clove Lane	Shandaken	2014	455	$540,146
Stony Clove at Wright Road	Hunter	2015	2,675	$1,802,985*
Stony Clove – Lanesville (repair)	Hunter	2014	1,300	$301,789

*Project is not closed out. Final cost is estimate.

Prior to construction, DEP and USGS had established water quality monitoring stations above and below some of the projects. The preliminary data is showing a marked reduction in turbidity originating in the treated stream reaches at the range of measured flows which to date have been at or below the bankfull discharge. DEP and USGS are planning a multi-year study to resume sampling at several of the previously monitored stream gaging locations in the Upper Esopus Creek watershed, and to include increased sampling and monitoring in the Stony Clove watershed for the same period of time. The study will continue to improve DEP's understanding of the distribution and conditions of suspended sediment sources and help inform and guide the effectiveness of stream restoration projects in reducing turbidity.

Figure 4.14 Stony Clove at Chichester, sites 1-4, before construction, October 2011.

Figure 4.15 Stony Clove at Chichester, sites 1-4, after construction, May 2015.

4.6 Riparian Buffer Protection Program

DEP continues to protect and manage riparian buffers as an important 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 DEP Watershed. Publicly owned buffers are protected and/or treated through DEP's Land Acquisition and Management programs, and private buffers are addressed through the SMP's CSBI and the WAP. Through the CSBI and other existing programs DEP and its watershed partners have made substantial progress on the Riparian Buffer Protection Program during the 2011-2015 assessment period.

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

Through the LAP, DEP secures permanent protection for sensitive riparian buffers. DEP is also initiating a pilot RBAP. Details on the protection of buffers through acquisition can be found in Section 4.2.8.

DEP considers riparian buffers when reviewing requests from outside parties regarding land use activities and projects on DEP lands. See Section 4.3 for more detail on DEP Land Management.

4.6.2 Catskill Streams Buffer Initiative

CSBI has been implementing riparian buffer protection and enhancement efforts as a component of the SMP (see Section 4.5 for the comprehensive effort of the SMP) throughout this assessment period. Work focuses on mapping riparian vegetation, corridor planning, designing and constructing stream restoration projects, removing invasive plants, and conducting extensive education and outreach.

Native Plant Materials

Maintaining and restoring ecosystem integrity are an important component of DEP's overall stream management mission. Thus, providing Catskill native plant material through local native seed collection, propagation, and grow-out continue to be one of the unique aspects of the CSBI.

From 2011-2015 DEP and its watershed partners have received 29,500 gallon-sized trees and shrubs grown from locally collected seed for use in streamside plantings. Since the inception of the CSBI program, 72,000 herbaceous plugs, 17,500 tubelings, and over 44,000 gallon-size trees and shrubs have been produced from locally collected seeds.

Implementation

Five CSBI coordinators at partnering SWCDs, along with one DEP coordinator, provide the base for implementing the program. Applications are invited twice per year to allow for project eligibility field assessments to be conducted during months when the sites are free of snow cover. After analyzing historic information and landowner concerns, CSBI coordinators propose a suite of recommendations that range from BMPs landowners can do themselves to more substantial practices that require SWCD assistance. Sixty-seven River Corridor Management Plans were completed during this period of assessment, bringing the grand total to 111.

During this assessment period, CSBI completed 134 projects, which includes 14 in 2015. These projects represent a diversity of riparian restoration techniques, including plant installation and innovative bioengineering practices. Figure 4.16 illustrates approximate project locations for CSBI pilot and full projects. These projects enhanced riparian vegetation on more than 60 acres and over 11 miles of stream bank length. Figure 4.17 shows the cumulative miles of riparian buffer planted for this assessment period. Gaps in existing riparian forest were restored through

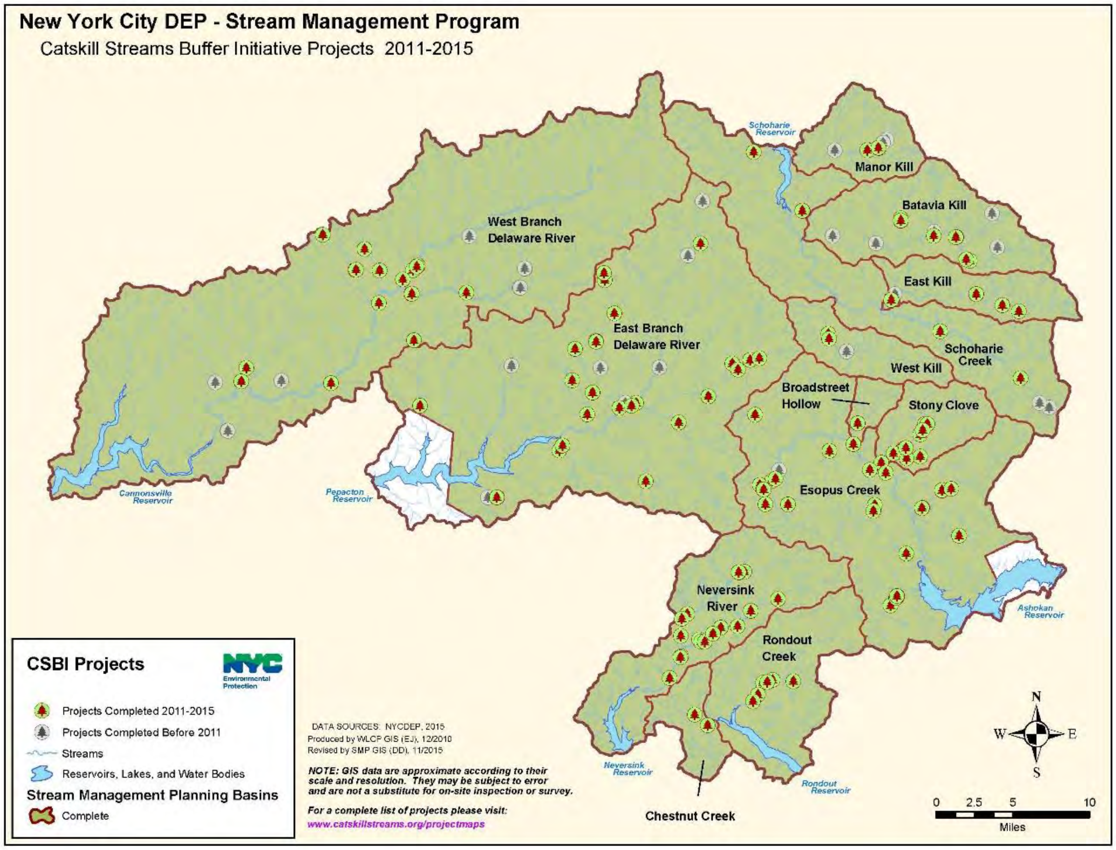

Figure 4.16 Approximate project locations for CSBI pilot and full projects.

the installation of over 40,000 plants, all species native to the Catskills region. Projects can be viewed at www.CatskillStreams.org.

Each field season DEP contracts with SUNY Delhi for a crew of interns who conduct monitoring and management of the project sites. During the five year assessment period, 15 interns logged approximately 150 days in the field with DEP and program partner staff supporting stewardship of the project sites.

Another important aspect of project implementation is the control of invasive species populations so that native plants may grow without unnatural competition. The SMP makes substantial efforts to suppress, and in some cases eradicate streamside invasive plant populations. This assessment period included multiple invasive control projects, but a notable highlight was the efforts made to quickly eradicate a newly discovered occurrence of Japanese knotweed on the Neversink River, which is one of the last locations where this invasive has not yet become fully established. Through a collaborative effort between DEP, partner staff, and the CRISP, a rapid application of herbicide has suppressed this Japanese knotweed occurrence. Future monitoring efforts will be focused on identifying and trying to eliminate any reoccurrences.

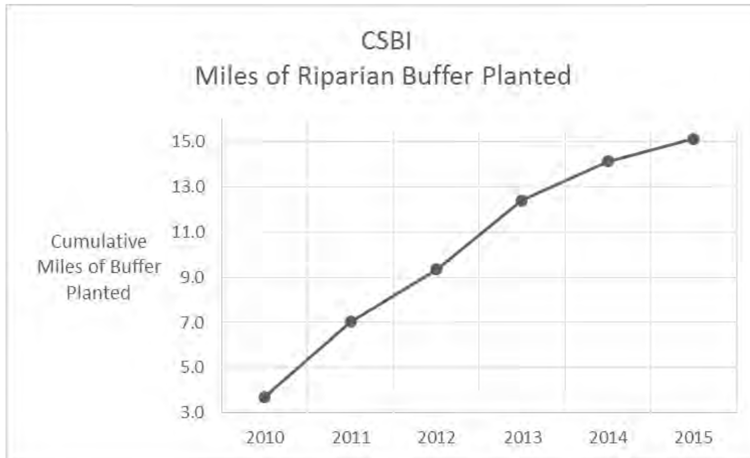

Figure 4.17 Cumulative miles of riparian buffer planted.

Evaluation

A variety of mechanisms are used to evaluate the effectiveness of the CSBI. A vegetation monitoring protocol was developed and implemented for the program to allow for quantification of overall plant growth and survivability over the first five years following installation, as well as to help determine the effectiveness of installation techniques. During this assessment period, monitoring plots have been established on more than 90 project sites for the purpose of vegetation monitoring. In addition to this monitoring protocol, landowners who receive a riparian planting through CSBI are encouraged to participate in photo and visual assessments periodically to help keep the program informed of project conditions, as well as to educate and engage the landowners in streamside stewardship.

The experience gained during this assessment period has helped to guide future program development in ways that should increase the success of future projects. The overall survivability of certain plant species has shaped which plants will be grown for use in this program, as many of the species used have flourished on project sites, while others have been less successful or have become susceptible to newly introduced invasive pests. Advanced bioengineering techniques have become a focus of this program as a solution to minor bank erosion issues, and staff will continue to enhance their skills by seeking training in this field.

The annual Riparian Buffer Working Group provides the program with a platform to discuss changing dynamics in the field. In recent years representatives from partner programs across the watershed have used this meeting to further develop programs and bring newly acquired tools to the group. In 2015 this meeting was used to provide a short bioengineering workshop to educate the group on implementing riparian restoration projects along unstable stream banks. Moving forward one of the goals of this meeting will be to continue to bring in regional and national level expertise to help increase the knowledge base of local professionals.

Watershed Agriculture Program & Watershed Forestry Program

Please refer to Section 4.3.4 and Section 4.9.5 of this report for information about the riparian buffer protection efforts of the Watershed Agricultural and Forestry Programs, including an update about the CREP.

4.7 Environmental Infrastructure Programs

Improperly managed wastewater and stormwater present a serious potential threat to surface water quality in the Catskill region. For that reason, DEP has invested hundreds of millions of dollars since 1997 to retrofit or repair existing municipal and residential infrastructure and in some cases construct new systems to handle wastewater and stormwater. Projects have been completed in virtually every corner of the CAT/DEL watershed, ranging from individual septic system repairs to large publicly-owned sewage treatment works and stormwater collection systems. In total, the projects completed to date and those underway have effectively eliminated thousands of potential sources of coliforms, pathogens and nutrients.

4.7.1 WWTP Regulatory and State Pollutant Discharge Elimination System (SPDES) Upgrade Program

As part of 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 further agreed to pay the annual costs of operation and maintenance of the upgraded facilities.

In 2011 the upgrade of all WOH WWTPs was completed along with the nine WWTPs located in the Croton Falls and Cross River basins that were included as part of the FAD. Over the past five years DEP has continued to fund the operation and maintenance costs of eligible expenses for the regulatory equipment and processes for the upgraded WWTPs. In addition to funding, DEP has worked closely with the operators of WWTPs to insure their proper operation.

In 2015 DEP funded and executed a Capital Replacement Agreement with the NYS Environmental Facilities Corporation (EFC) to replace failing equipment that was installed as part of the Upgrade Program.

4.7.2 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 CWC administers the septic program. The total DEP funding commitments for the program have been over $90 million since 1997.

The septic program is an inspection and remediation program implemented in a prioritized fashion according to potential impact to the DEP's water supply. Initially targeted were 60-day travel time areas, 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). In implementing the Program, CWC solicits homeowner interest within priority areas and conducts inspections to determine whether or not systems are functioning properly. A system found to be failing is eligible to receive CWC funding. Program elements include:

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

During the period from 2011 through 2015, CWC continued to implement the Program by priority areas. Program eligibility continues to expand based on the level of Program activity. Most recently, the Program expanded to include septic systems located within 700 feet of a watercourse. Table 4.7 shows the number of septic systems remediations paid for under the Program from 2011 to 2015.

Table 4.7 Number of septic system remediations from 2011 to 2015.

Year	Septic System Remediations
2011	227
2012	292
2013	275
2014	244
2015	276

From 1997 through December 2015, 4,879 septic systems were repaired, replaced, or managed under the septic program.

The Septic System Rehabilitation and Replacement Program has been successful in eliminating pollution from a large number of failing septic systems, most of which are located along streams and in 60-day travel time areas.

Small Business Septic System Rehabilitation and Replacement Program

The Small Business Septic System Rehabilitation and Replacement Program helps pay for the repair or replacement of failed septic systems serving small businesses (those employing

100 or fewer people) in the CAT/DEL watershed. Through CWC, eligible business owners are reimbursed 75% of the cost of septic repairs, up to a maximum of $40,000. To be eligible, failing commercial septic systems must be 700 feet or less from a watercourse or within the 60-day Travel Time Area. The small business owner is responsible for securing an approved DEP design and for the construction of the septic system remediation. The small business owner then seeks reimbursement for these costs from the program. Between 2011 and 2015, twelve small business septic remediations have been completed with program funding, bringing the total remediated to fifteen since the program's inception in 2008.

Cluster System Septic System Program

The Cluster Septic System Program funds the planning, design, and construction of cluster systems in thirteen communities in the WOH watershed. Through CWC, the Cluster Septic System Program Rules were adopted in April 2011. 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. To date, no communities have participated in the cluster septic system program.

4.7.3 New Sewage Treatment Infrastructure Program

The New Sewage Treatment Infrastructure Program (NIP) concluded in 2012. Prior to conclusion, DEP provided nearly $80 million to fund the assessment of wastewater infrastructure needs and provide technical assistance and funding for the construction of the recommended wastewater solutions. DEP completed New Sewage Treatment Infrastructure projects in the following municipalities: Andes (2005); Hunter (2005); Roxbury (2005); Windham (2005); Fleischmanns (2007); and Prattsville (2007). The Town of Shandaken did not advance a project for Phoenicia, resulting in the conclusion of the NIP in 2012.

4.7.4 Sewer Extension Program

The Sewer Extension Program funds the design and construction of sewer extensions connected to DEP WWTPs discharging in the WOH watershed. The goal of this program is to reduce the number of failing or potentially failing septic systems by extending the WWTP service to priority areas. DEP already completed projects in the towns of Roxbury (Grand Gorge WWTP), Hunter-Haines Falls (Tannersville WWTP) and Neversink (Grahamsville WWTP).

From 2011 to 2015, DEP achieved several significant milestones in the implementation of the three remaining projects in the towns of Shandaken (Pine Hill WWTP), Middletown (Margaretville WWTP), and Hunter-Showers Road (Tannersville WWTP). Successful program implementation remains dependent upon completion of certain municipal actions. While this does not allow the DEP to entirely control project completion times, DEP completed design and initiated construction for all three projects and completed the construction of one of them. The Showers Road-Hunter sewer extension project was completed in October 2015. DEP anticipates that the sewer extension projects in Shandaken and Middletown will be completed in 2016.

The following summaries highlight the accomplishments of the program that were made during the past five years:

Town of Hunter – Showers Road (Tannersville WWTP)

DEP completed the project's design plans and specifications in July 2013 and went to bid in September 2013. DEP commenced construction in April 2014 and completed construction in October 2015. The Town has authorized house connections and they are now underway.

Town of Shandaken (Pine Hill WWTP)

DEP completed the project's design plans and specifications in August 2013 and went to bid in October 2013. Construction commenced in September 2014 and is ongoing. Construction could not be completed in 2015 due, in large part, to field changes needed to a submersible pump station and the contractor's inability to successfully bore under Route 28. The Route 28 crossing was changed to open cut and has since been completed. DEP and the contractor are working through a change order for the pump station and anticipate that it will installed in the first half of 2016.

Margaretville/Middletown (Margaretville WWTP)

DEP completed the project's design plans and specifications in March 2014 and went to bid in April 2014. Construction commenced in June 2015 and is ongoing. Bidding was delayed in part due to the time required by the Town of Middletown to amend the language in the Town's Sewer Use Law. Construction could not be completed in 2015 due, in large part, to field changes required to expand the storage capacity of individual grinder/ejector pumps, address field conditions, and redesign sections of sewer that were in close proximity to a steep stream embankment. DEP and the contractor are working to address a variety of change orders and anticipate remaining work to be completed in 2016.

4.7.5 Community Wastewater Management Program

The CWMP provides funding for the design and construction of community wastewater systems, including related sewerage collection systems, and/or the creation of septic maintenance districts, including septic system replacement, rehabilitation and upgrades and operation and maintenance of the district in identified WOH communities where there is a perceived potential threat to water quality posed by failing and likely to fail septic systems.

Established under the 2002 FAD, the CWMP initially addressed wastewater needs in five communities – Bloomville, Boiceville, Hamden, DeLancey, and Bovina. These projects are all complete. In 2006, a sixth community, Ashland, was added to the program. Through the initial and revised 2007 FAD, DEP provided funding for the final eight communities: Trout Creek, Lexington, South Kortright, Shandaken, West Conesville, Claryville, Halcottsville, and New Kingston. Table 4.8 shows the CWMP projects that were completed from 2011 to 2015.

Table 4.8 CWMP projects completed 2011-2015.

Community	Project	Flow (gpd)	Septics displaced	Date completed
Ashland	Recirculating Sand Filter WWTP	30,000	89	2011
Trout Creek	Community Septic System	16,000	54	2014

CWMP projects are underway in the following communities:

Lexington – Project consists of a small diameter gravity sewer system to an Orenco pretreatment to subsurface disposal. DEP approved a $9.1 million block grant for the project. Construction of the wastewater facility and the collection system was completed in 2015. Lateral connections will commence in the spring of 2016.

South Kortright – Project is a conventional sewer collection system with sewage pumped to the Hobart WWTP via the Allen Residential Center pump station. DEP approved a $4.9 million block grant for the project. Construction of the collection system and upgrades to the Hobart WWTP were approximately 85% complete by the end of 2015. Lateral connections will commence in the spring of 2016.

Shandaken – The Preliminary Engineering Report concluding the project's Study Phase was issued in December 31, 2015. The next step is for DEP, in consultation with CWC and the Town of Shandaken, to review the recommendations in the report.

West Conesville – The Preliminary Engineering Report concluding the project's Study Phase was issued in December 31, 2015. The next step is for DEP, in consultation with CWC and the Town of Conesville, to review the recommendations in the report.

Claryville – The Study Phase commenced in 2015.

Halcottsville – The Study Phase commenced in 2015.

New Kingston – The Study Phase commenced in 2015.

4.7.6 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 the system to fail. 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 open to home owners who constructed new septic systems after 1997 or participated in the septic repair program, and 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 homeowner contacts CWC to obtain an inspection check list 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 check list. The homeowner pays the hauler, and then submits the signed check list and completed reimbursement form to CWC along with a copy of the contractor's invoice and proof of payment. CWC reimburses the home owner 50% of eligible costs for pump-outs and maintenance. Table 4.9 shows participation in the program by year.

Table 4.9 Septic maintenance program participation 2011-2015.

Year	Number of septic pump-outs
2011	112
2012	153
2013	178
2014	209
2015	224

Since Program inception in 2004, 1,451 home owners have been paid 50% of eligible costs for septic system pump-outs and maintenance.

4.7.7 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 BMPs to address existing stormwater retrofit runoff in concentrated areas of impervious surfaces. Since its inception, the total program budget has risen to over $27 million for capital, operation and maintenance, and community-wide stormwater infrastructure assessment and planning initiatives.

During the reporting period, CWC and DEP worked cooperatively on modifications to the Retrofit Program Rules. The revised rules were adopted in early 2015 and provide for an annual application and review process. The rules also maintain the option for CWC or DEP to propose retrofits outside the annual application process if the project is particularly effective. Funding preference is given to construction grant project applications where a planning and assessment contract has already been successfully completed or where a CWMP project is in process.

Planning and assessment projects provide a basis for future capital construction projects. From 2011 through 2015, two planning and assessment projects were completed. To date, a total of 14 planning and assessment projects have been completed.

Table 4.10 Completed stormwater retrofit construction projects 2011-2015.

Applicant	Project description	Grant amount
Ashokan		
Town of Hurley	Bristol Hills Subdivision – Collection, Conveyance, Sedimentation	$110,886
Cannonsville		
Town of Tompkins	Hamlet of Trout Creek stormwater improvements	$136,673
Town of Walton	Bob Gould Road – Collection, Conveyance, Sedimentation	$59,720
Town of Walton	Oxbow Hollow – Collection, Conveyance, Sedimentation	$137,990
Town of Walton	Collection, Conveyance, Sedimentation	$71,949
Pepacton		
Village of Andes	County Route 2 and Coulter Road – Collection, Conveyance, Sedimentation	$957,358
Town of Andes	High Street – Collection, Conveyance, Sedimentation	$239,710
Village of Fleischmanns	Little Red Kill / Schneider Avenue – Collection, Conveyance, Sedimentation	$187,826
Town of Roxbury	Lake Street – Collection, Conveyance, Sedimentation	$1,352,966
Schoharie		
Town of Ashland	Hamlet of Ashland stormwater improvements	$365,966
Greene County SWCD	Sugar Maples – Collection, Conveyance, Sedimentation	$153,503
Greene County SWCD	Windham Mountain – Collection, Conveyance, Sedimentation	$279,630
Mountain Top Library	Haines Falls Free Library – Collection, Conveyance, Sedimentation	$195,983
Town of Windham	Masonic Temple Access Road – Collection, Conveyance, Sedimentation	$22,475

From 2011 through 2015, 14 stormwater retrofit projects totaling over $4.2 million were completed (See Table 4.10). Projects focused on street drainage, stormwater separation and highway maintenance activities.

Future Stormwater Controls Program

The Future Stormwater Controls Program pays for the incremental costs of stormwater measures required solely by the DEP Watershed Regulations above State and federal requirements in stormwater pollution prevention plans (SWPPPs) and individual residential stormwater plans (IRSP) 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 DEP's Watershed Regulations. The $31.7 million Future Stormwater Controls Program is administered by CWC and reimburses municipalities and large businesses 100% and small businesses 50% for eligible costs. Another program, Future Stormwater Controls Paid for by DEP, reimburses low income housing projects and single family home owners 100% and small businesses 50% of eligible costs.

Through 2015, CWC has paid out nearly $5 million for eligible incremental costs for stormwater controls required by DEP's Watershed Regulations. Pursuant to the terms of the MOA, CWC has also transferred over $16 million to other eligible watershed protection programs.

Local Technical Assistance

Grant proposals for Local Technical Assistance Program funding are jointly evaluated by CWC and DEP. The program budget is $1,750,000 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 Local Technical Assistance projects were approved by the CWC Board for funding. Three of the thirty-five projects remain open through December 2015 (Table 4.11).

Table 4.11 Open local technical assistance projects.

Applicant	Project	Funding
Town of Roxbury	Generic EIS	$84,000
Town of Roxbury	GEIS Additional Funding	$9,200
Town of Roxbury	Inventory and Comprehensive Plan	$25,000

In December 2014, the CWC Board established the Sustainable Communities Planning Program and allocated $150,000 in Local Technical Assistance Program for towns or villages that have completed a LFA to fund new or update existing comprehensive plans to identify areas for relocations of residences or businesses that participate in the DEP Flood Buyout Program.

4.8 Waterfowl Management Program

The management of water bird populations at Kensico Reservoir is essential to meet the requirements of USEPA's SWTR. DEP's Waterfowl Management Program (WMP) was established to research the relationship between wildlife, particularly water birds 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 water bird populations monitoring, DEP identified birds as a significant source of fecal coliform bacteria in Kensico Reservoir. In addition, it was determined that migratory populations of water birds utilize DEP reservoirs as temporary staging areas and wintering grounds and therefore significantly contribute to increases in fecal coliform loadings during autumn and winter, primarily from direct fecal deposition in the reservoirs. These water birds 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 reports (DEP 1993 – 2014) have documented that, in water samples collected near roosting locations at several reservoirs, fecal coliform increases have occurred concurrently with increases in water bird populations.

In response, DEP implemented the use of standard bird management techniques approved by the USDA, the NYSDEC and the United States Fish & Wildlife Service (USFWS) to reduce or eliminate the water bird 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 water bird 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 water bird management on an as needed basis. In addition, DEP has implemented an enhanced wildlife management program at Hillview 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 Chapters 5 – 8, in the discussion of each reservoir basin in which the program was implemented.

4.8.1 Water Bird Census

DEP initiated water bird surveys to track the number of water birds on the reservoirs throughout the year because of the well-established relationship between elevated water bird counts and increased levels of fecal coliform bacteria in raw water samples.

Currently, reservoir water bird surveys are conducted throughout the calendar year. The frequency of surveys varies based on the reservoir and time of year.

4.8.2 Water Bird Mitigation

Bird Dispersal Actions

A list of bird dispersal activities conducted from 2011 through 2014 is presented in Table 4.12. The current program at Kensico Reservoir employs motorboats, Biondo Airboats, and pyrotechnics for water bird dispersal actions and includes wildlife sanitary surveys in and around water intake areas prior to significant precipitation events. The Hillview Reservoir water bird 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 contract. Additional wildlife mitigation measures have been instituted at Hillview including removal of mammals along the reservoir perimeter, nest and egg depredation of nesting swallows, sparrows, and starlings, and daily wildlife sanitary surveys. 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 am 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 the federal government or NYS. As needed bird dispersal actions were deemed unnecessary for the five as needed reservoirs during this reporting period and is presented in Table 4.12.

Water Bird Deterrence

Egg depredation

DEP conducts annual springtime breeding surveys and egg depredation for Canada Geese (*Branta canadensis*) and Mute Swans (*Cygnus olor*) within reservoir property to suppress reproductive success, which in turn eliminates population recruitment and breaks site fidelity of nesting adults. Preliminary surveys of water bird 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. A small number of geese 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, and is summarized in Table 4.13. Additionally, DEP, in conjunction with the NYSDEC, continued an annual Canada Geese banding project Putnam County to track local goose movements throughout the watershed but subsequently discontinued the program from 2012 through 2014. Band identifications helped identify local breeding, feeding and loafing areas, which in turn may aid in implementing BMPs (i.e., elimination of feeding areas may eliminate presence on reservoirs).

Table 4.12 Reservoir water bird mitigation, 2011-2014.

Reservoir	Dates of Water Bird Dispersal Actions/Deterrence	Water Bird Dispersal Actions and Deterrence Measures Used
Kensico	Dispersal and Deterrence: January 2011 – present	Water bird dispersal – motorboats, Biondo Airboats, pyrotechnics Deterrence – water bird reproductive depredation, Alewife collection, and wildlife sanitary surveys
West Branch*	Dispersal: None required during this reporting period Deterrence: April – June annually	Deterrence – water bird reproductive depredation
Rondout*	Dispersal: None required during this reporting period Deterrence: April – June annually	Deterrence – water bird reproductive depredation
Ashokan*	Dispersal: None required during this reporting period Deterrence: April – June annually	Deterrence – water bird reproductive depredation
Croton Falls*	Dispersal: None required during this reporting period Deterrence: April – June annually	Deterrence – water bird reproductive depredation
Cross River*	Dispersal: None required during this reporting period Deterrence: April – June annually	Deterrence – water bird reproductive depredation
Hillview	Dispersal and Deterrence: Daily, year-around continuous or as needed (January 2011 – December 2014)	Water bird dispersal – pyrotechnics, propane cannons, remote-control motorboats, duck depredation. Mammal trapping. Deterrence – water bird and terrestrial songbird species reproductive depredation, wildlife sanitary surveys, overhead, railing and roof-top bird deterrence wires, Daddi-long-legs, netting, Alewife surveys and removal.

*Indicates reservoir mitigation only occurs as needed.

Table 4.13 Egg depredation summary for Canada Geese and Mute Swans, 2011 – 2014.

Reservoir	Year	Surveys	Canada Geese Nests (eggs depredated)	Mute Swan Nests (eggs depredated)	Depredation Success Rate for Canada Geese/Mute Swans (number surviving young)
Kensico	2011	6	26 (142)	1 (6)	98% (3 goslings)/100%
	2012	7	16 (65)	1 (9)	93% (5 goslings)/100%
	2013	8	16 (81)	0 (0)	96% (3 goslings)/NA
	2014	10	20 (86)	1 (7)	98% (2 goslings)/100%
West Branch	2011	4	12 (45)	0 (0)	90% (5 goslings)/NA
	2012	4	8 (34)	0 (0)	94% (2 goslings)
	2013	4	7 (35)	0 (0)	100% (0 goslings)/NA
	2014	5	5 (26)	0 (0)	100% (0 goslings)/NA
Rondout	2011	1	0 (0)*	0 (0)	0%/NA
	2012	1	3 (21)	0 (0)	75% (7 goslings)/NA
	2013	3	7 (27)	0 (0)	75% (9 goslings)/NA
	2014	4	4 (12)	0 (0)	100% (0 goslings)/NA
Ashokan	2011	1	3 (4)	0 (0)	21% (15 goslings)/NA
	2012	2	3 (16)	0 (0)	52% (15 goslings)/NA
	2013	3	4 (17)	0 (0)	100% (0 goslings)/NA
	2014	4	5 (29)	0 (0)	64% (16 goslings)/NA
Croton Falls	2011	4	12 (55)	0 (0)	95% (3 goslings)/NA
	2012	4	12 (70)	0 (0)	92% (6 goslings)/NA
	2013	4	13 (64)	2 (11)	100% (0 goslings)/100% (0 cygnets)
	2014	7	10 (45)	1 (6)	100% (0 goslings)/100% (0 cygnets)
Cross River	2011	5	12 (32)	0 (0)	100% (0 goslings)/NA
	2012	3	9 (47)	0 (0)	98% (1 goslings)/NA
	2013	3	5 (23)	0 (0)	82% (5 goslings)/NA
	2014	5	9 (48)	0 (0)	100% (0 goslings)/NA
Hillview	2011	91	0 (0)	0 (0)	NA/NA
	2012	91	0 (0)	0 (0)	NA/NA
	2013	91	0 (0)	0 (0)	NA/NA
	2014	91	0 (0)	0 (0)	NA/NA

*Nest depredation for Canada Geese was restricted due to nesting Bald Eagles within protective buffer areas under federal and NYS laws.

Alewives

In response to entrainment of Alewives (*Alosa pseudoharengus*), a baitfish, 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 to remove the dead fish that collected at the boom. Table 4.14 presents an estimate of the amount of Alewives collected during each bird dispersal season (August 1 through March 31) at Kensico from 2010 to 2014. Alewives are an attractive food source for gulls and some species of ducks, and when large numbers of fish are flushing into the reservoir, the gulls become very difficult to manage.

Table 4.14 Alewife collections, 2010 – 2014.

Season (August 1 – March 31)	Estimated Amount (lbs.)
2010 – 2011	0
2011 – 2012	115
2012 – 2013	800
2013 – 2014	41

4.9 Wetlands Protection Program

Wetland ecosystems provide services that extend well beyond their boundaries to help maintain the high quality of surface waters in the watershed. They slow stormwater runoff to help abate flooding and prevent erosion. Waters that pass through wetlands are filtered by a variety of mechanisms that remove sediments and nutrients, thereby improving water quality. Wetlands also provide stream baseflow, crucial to maintaining aquatic habitat during dry periods, and are often the sources of headwater streams. Wetlands also play a role in the carbon cycle, with some types sequestering significant amounts of carbon in their sediments. Wetlands provide fish and wildlife habitat that support high biodiversity and productivity that are also important to providing water quality services. They also provide cultural ecosystem services such as recreation, aesthetic appreciation, and education.

Recognizing these important functions and values, DEP has multiple programs in place to protect wetlands, as well as to identify, map, study, and further understand these ecosystems. DEP characterizes the types and distribution of wetlands throughout the watershed through its mapping and monitoring programs to identify trends and inform management. Wetland protection is achieved through project and regulatory reviews, voluntary programs such as land acquisition, Watershed Agricultural Farm and Forest programs, and DEP's management of its own lands.

4.9.1 Wetland Mapping

The National Wetlands Inventory (NWI) provides baseline data on the distribution, types, and extent of wetlands in the watershed, which is essential to the implementation of regulatory protection, land acquisition, and other watershed management programs. The NWI has also provided the baseline for several wetland status and trends studies for the watershed, which have demonstrated a decrease in rate of loss of vegetated wetlands since the 1980s, and a net increase in the acreage of ponds, both of which are consistent with national trends.

The most recent NWI was produced for the watershed in 2005 using 2003 and 2004 aerial photography. Because it was produced through manual interpretation of remote sensing imagery, there are expected limitations to the NWI's accuracy. Between 2010 and 2013, DEP acquired 2009 high resolution aerial photography, along with Light Detection and Ranging (LiDAR) point, and LiDAR-derived land cover, topographic, and hydrographic data. In 2015, DEP completed a pilot study through a partnership with the Regional Application Center for the Northeast, to determine if these data sources coupled with advanced automated mapping protocols could increase the accuracy and completeness of wetland maps. The study also examined whether the LiDAR-derived high resolution hydrography data could improve the assessment of wetland connectivity. The wetland mapping pilot study first assessed the LiDAR and LiDAR-derived layers to determine their suitability for wetlands mapping using automated Object Based Image Analysis protocols (OBIA). No systematic issues in data quality were identified that would significantly impact the mapping effort. Next, OBIA modeling protocols were developed for automated wetland mapping. These protocols incorporated LiDAR point data, orthoimagery, and LiDAR-derived digital elevation maps, contours, a normalized digital surface model, and a compound topographic index. The model was designed to over predict wetland occurrence as errors of commission are easier to address than errors of omission. The model was run for the entire watershed, and manual editing was completed in 15 pilot areas located both East and West of Hudson (Figure 4.18). Manual edits removed errors of commission, added or extended polygons to correct errors of omission, while retaining confirmed wetland areas. Following standard NWI protocols, NWI Cowardin classifications were added to each polygon.

Because it followed standard NWI protocols, manual editing produced an NWI-compliant map that nearly doubled the acreage of mapped vegetated wetlands in the pilot areas as compared to the 2005 NWI (Figure 4.19). Mapped vegetated wetland acreage increased by 136% and 74% in the West and East of Hudson pilot areas, respectively. Forested wetlands WOH had the largest increase in mapped acreage, with a 220% increase (Table 4.15). This was largely due to increased detection of evergreen wetlands by the model, whose mapped acreage increased by 400%. Because OBIA relied heavily on topography it identified areas whose hydrologic signature is typically masked by evergreen canopy and therefore missed by standard photointerpretation alone.

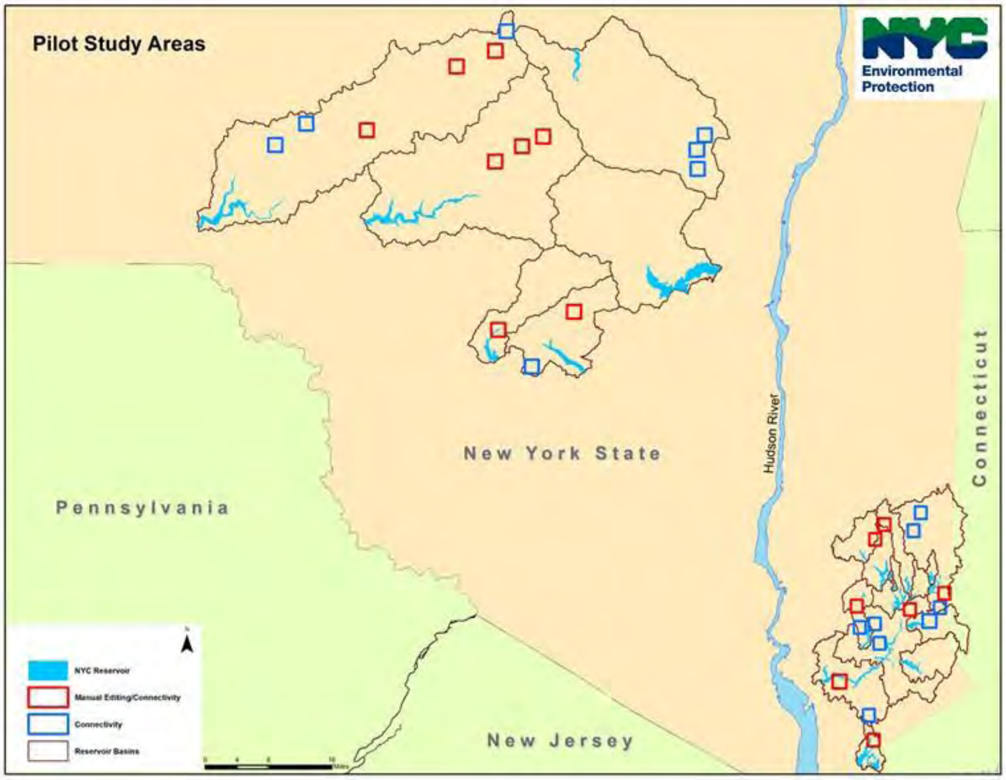

Figure 4.18 Sites for the wetland mapping pilot project.
Manual editing of the model output was conducted in the red pilot areas. Wetland connectivity assessment was completed for all pilot areas shown.

The pilot study also successfully demonstrated the utility of LiDAR-derived local resolution (1:1000) stream data for assessing wetland connectivity to watershed streams. Assessing the spatial relationship between wetland polygons against local resolution National Hydrography Data (NHD) revealed that just 10% of NWI wetlands in the pilot areas lack mapped connections to the stream network, as opposed to 35% when comparing against lower resolution stream data. Further evaluation of high resolution orthophotography and topography revealed that just 2% of NWI wetlands in the pilot areas lack connections to watershed streams. This is a significant finding as connectivity to surface waters is linked to both wetland function and federal jurisdictional status.

The 2015 pilot wetland mapping project demonstrated the potential to improve the completeness of wetland mapping and connectivity assessment for the entire watershed. Future assessment of the pilot wetland maps is expected to verify the accuracy of this approach, since NWI-compliant manual editing followed the automated mapping protocol. Additionally, the

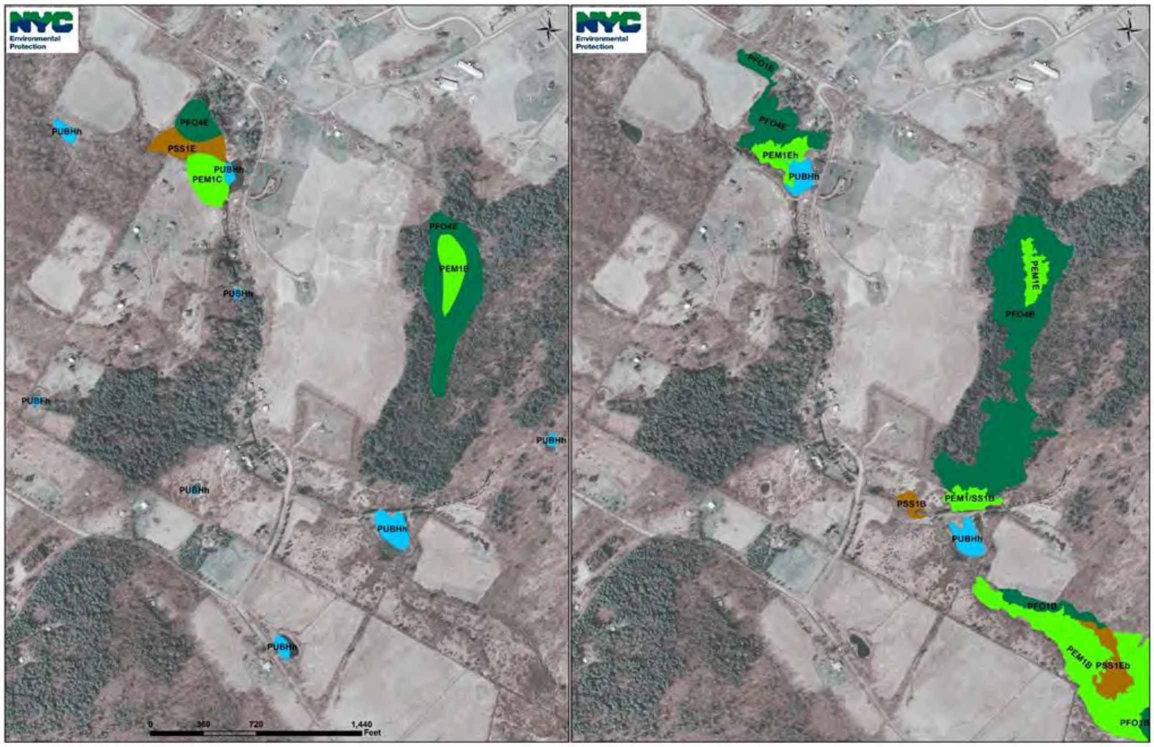

Figure 4.19 USFWS 2005 NWI map (left) and the pilot NWI-compliant map produced for a WOH pilot area (right).
Increases in mapped vegetated wetland areas are evident in the eastern portion of the study area. Removal of polygons smaller than 0.5 acres excluded some ponds from the NWI-compliant map, these ponds will be included in any future mapping efforts. NWI mapping codes are defined in Classification of wetlands and deepwater habitats of the United States (Federal Geographic Data Committee, 2013).

increased detection of wetland connections to downstream waters is a significant finding, as connectivity is linked to both wetland function and federal jurisdictional status. Expansion of the wetland connectivity assessment to the entire watershed could also benefit the National Hydrography Database, as newly identified surface connections would increase the completeness of that coverage as well.

Table 4.15 Acreage comparison of the original NWI and the Pilot NWI-compliant layers. Refer to Classification of wetlands and deepwater habitats of the United States for NWI mapping codes (Federal Geographic Data Committee, 2013).

	West of Hudson			East of Hudson		
	Original NWI	Pilot NWI-Compliant Layer	Percent Change	Original NWI	Pilot NWI-Compliant Layer	Percent Change
Waters/Unvegetated Systems						
RUB/RSS	58.6	98.5	68.2	0.0	12.4	NA
L1UB	157.5	165.8	5.3	523.6	551.4	5.3
PUB	46.6	21.4	-54.1	139.5	134.1	-3.9
Total	262.6	285.7	8.8	663.1	697.9	5.2
Vegetated Wetlands						
PEM	115.6	236.3	104.3	41.0	63.4	54.7
PSS	40.2	95.0	136.6	52.9	147.8	179.2
PFO	43.7	139.8	220.2	347.1	558.3	60.8
Total	199.5	471.2	136.2	441.0	769.5	74.5
Grand Total Waters and Vegetated Wetlands	462.1	756.9	63.8	1104.1	1467.4	32.9

4.9.2 Reference Wetlands Monitoring

DEP has collected vegetation, soils, and hydrologic data from 21 reference wetlands comprising 117 acres throughout the Catskill and Delaware watersheds for over a decade. Reference wetlands provide region-specific data on the characteristics of relatively undisturbed, self-sustaining wetlands, which can be used as a benchmark for wetland assessment, trends analysis, and to guide wetland restoration, creation, or enhancement projects.

In 2014, DEP analyzed vegetation, soils, and hydrologic data collected from 129 reference wetland plots since 2004 to provide a benchmark for hardwood, hemlock hardwood, scrub-shrub, and emergent wetland conditions. The findings are summarized in a July 2014 FAD report (Reference Wetland Conditions in the Catskill and Delaware Watersheds of the DEP Water Supply System) that includes measures of frequency and abundance of 214 native wetland species, the range and median of organic matter, nutrient, and pH levels from 50 soil samples, as well as descriptors of the depth and duration of wetland saturation or inundation from approximately 15,000 growing season measurements recorded at 35 wells. This report provides region-specific knowledge that will benefit future wetland assessment, mitigation, trend analysis, and education efforts in the watershed. In addition to summarizing data collected to date, DEP also continued to collect hydrologic data from monitoring wells in the reference wetlands (Figure 4.20).

4.9.3 Wetlands Regulatory Program

Figure 4.20 Data collection from an Ecotone™ monitoring well in the Schoharie basin (SMS).

DEP continued to review federal, State, and municipal wetland permit applications in the watershed, and provided comments when alternatives that would avoid, minimize, or mitigate wetland and water quality impacts were identified. Project plans were often modified in response to DEP's comments, resulting in less wetland or adjacent area impacts, increased or modified mitigation practices, and additional erosion and sediment control measures than originally proposed.

From 2011 to 2014, DEP reviewed 112 wetland permit applications in the watershed, the vast majority of which (n=108) were EOH. Seventy-six of those applications 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. Thirty-four reviews were of applications pending before local municipalities in New York and Connecticut. Just two 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) was reviewed.

The low number of federal wetland applications is likely due to several factors including a) the limits of federal jurisdiction to discharge to waters of the United States-which do not include upland buffers nor certain types of wetlands in light of recent Supreme Court decisions (see below), b) the avoidance of wetland impacts achieved through SEQRA and local and state permitting processes, and c) the availability of nationwide permits under the federal program.

An assessment of the 112 wetland permit applications reviewed over the FAD assessment period shows that 71% were for proposed activities that would not result in wetland loss such as aquatic nuisance species management, stream crossings, pond dredging and adjacent area impacts (Figure 4.21). This is consistent with the findings DEP's most recent wetland status and trends studies, which shows fairly low rates of wetland loss.

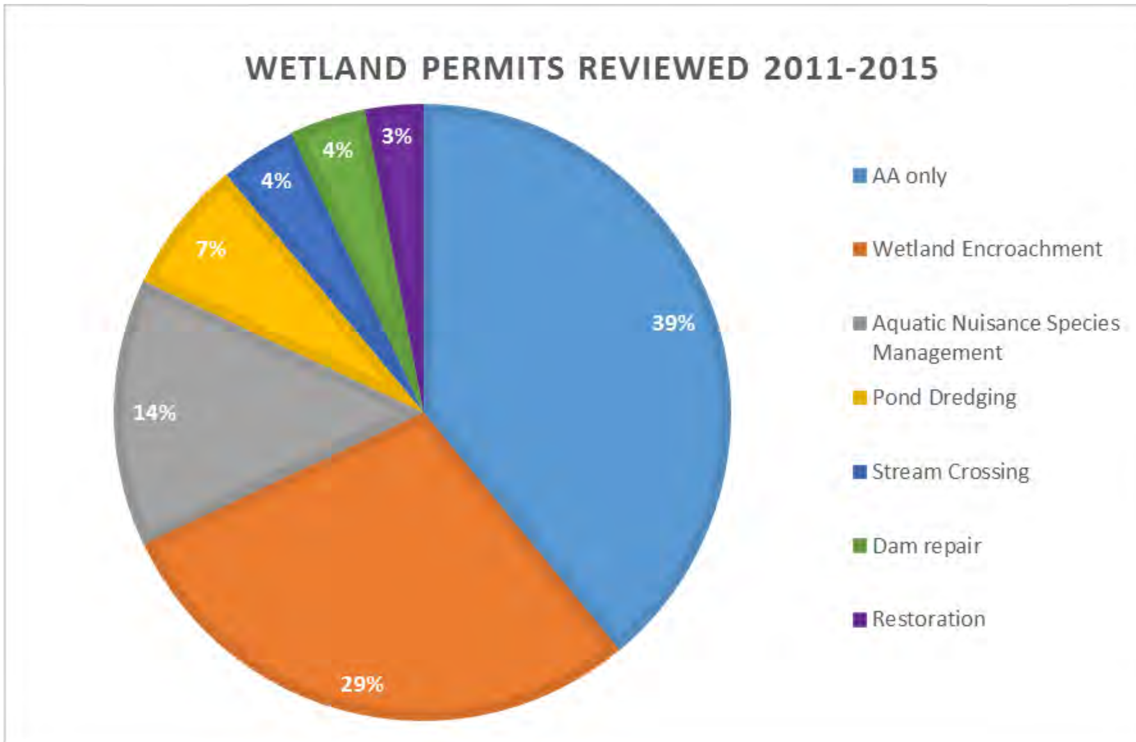

Figure 4.21 Wetland permits reviewed in 2015 summarized by activity. AA includes permits that would result in adjacent area disturbance only, with no direct wetland impacts. Wetland encroachment indicates those projects proposing wetland fill. The remaining proposed activities would not result in decreased wetland acreage.

DEP also continued to provide input on issues surrounding federal wetland jurisdiction under the Clean Water Act in light of United States Supreme Court's decisions in Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers, 531 U.S. 159 (2001) and Rapanos v. United States, 547 U.S. 715 (2006). These decisions left significant uncertainty surrounding the jurisdiction of non-navigable waters and their adjacent wetlands. The City issued comments on the Draft Guidance on Identifying Waters Protected by the Clean Water Act (76 Fed. Reg. 24479) in 2011, on the USEPA's Science Advisory Board's report "Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence" in 2013, and on the proposed rule regarding the definitions of 'waters of the United States' (79 Fed. Reg. 22197) in 2014. DEP drew heavily on the findings of its wetland mapping, reference wetland monitoring, and LiDAR-derived National Hydrography update to provide the DEP with comments regarding the extent and function of wetlands potentially impacted by these Supreme Court decisions and subsequent proposed rules and guidance documents. In all cases, DEP indicated its support for broad federal jurisdiction over streams and wetlands, the protection of which is critical to maintaining the high quality of DEP's water supply.

4.9.4 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 2,740 acres, or 18.0%, of these wetlands through its LAP (See Section 4.2). This represents an additional 326 acres of wetlands acquired during the 2011 through 2015 FAD assessment period. In the CAT/DEL watershed, pre-MOA DEP lands contain an additional 973 acres (6.4%) of wetlands, with 1,259 acres (8.3%) of wetlands located on State or other protected lands. Table 4.16 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 (Figure 4.22).

Figure 4.22 This wetland complex, Yankeetown Pond in Woodstock, was acquired through fee acquisition and opened for recreation in the summer of 2015. This diverse wetland complex includes shrub swamp, hemlock-hardwood swamp, fringing marsh, and quaking bog community types.

4.9.5 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 in which 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 113 acres of wetlands for forestry projects proposed on DEP Lands. These delineations provide DEP with field-scale data on the characteristics of wetlands on DEP lands, and support remote wetland mapping efforts such as the LiDAR pilot project.

4.9.6 Outreach

DEP Wetlands Program engaged the general public, peers, and staff in wetlands education and outreach during the 2011-2015 assessment period.

In 2014 and 2015, DEP conducted educational wetland walks on DEP parcels. The walks took place both East and West of Hudson. They were open to the general public and highlighted the characteristics of wetlands, common wetland plants and animals, as well as wetland functions and their importance to the watershed. DEP also delineated wetlands within the 264-acre Clearpool Model Forest to support the model forest management objectives and presented its findings as part of Clearpool Adult Workshop Series. Wetlands program staff also provided in-house training on state and federal wetland regulations.

DEP presented findings from its wetland mapping and monitoring programs at several conferences including the Watershed Science and Technical Conference, the NYS Wetlands Forum, and the Catskill Environmental Research and Monitoring Conference. DEP wetland staff were regular participants of these conferences over the assessment period, and highlighted findings from various wetland monitoring and mapping projects.

DEP continued to distribute the educational pamphlet *Wetlands in the Watersheds of the New York City Water Supply System* at outreach events, conferences, and upon request.

4.10 Watershed Forestry Program

The Watershed Forestry Program is a partnership between DEP, the WAC, and the USFS that promotes and supports well-managed working forests as a beneficial land use for watershed protection and economic viability. The WAC 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 (teachers and students) in both the watershed and NYC.

Table 4.16 Wetlands and deep water habitats acquired or protected by LAP in CAT/DEL and Croton systems as of December 31, 2015.

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%		
Total Lands Under Contract or Closed by NYCDEP as of 12/31/15†*:	135,547	12.93%		
Within those total lands under contract or closed:				
Total Acreage of Wetlands (both NWI and DEC-regulated, excluding Deepwater Habitats**)	2,740		2.02%	18.04%
Total Acreage of Deepwater Habitats**	185		0.14%	0.65%
Total Acreage of Wetlands and Deepwater Habitats**	2,925		2.16%	6.72%
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	10,809	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 12/31/15†*:	1,991	0.94%		
Within those total lands under contract or closed:				
Total Acreage of Wetlands (both NWI and DEC-regulated, excluding Deepwater Habitats**)	97.6		4.90%	0.49%
Total Acreage of Deepwater Habitats**	1.7		0.09%	0.02%
Total Acreage of Wetlands and Deepwater Habitats**	99.3		4.99%	0.32%

* Source: WLCP GIS, December 31, 2015. 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 Fall 2013.

** 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.

During the current FAD assessment period, WAC continued to support the development, implementation and evaluation of FMPs, while the planning program itself was redesigned during this period. Beginning in 2012, based on research indicating that WAC plans do not necessarily translate into better sustainable forest management or implementation of BMPs when compared to plans that are enrolled in the NYS Forest Tax Law (480-a program), WAC initiated a multi-year assessment of its FMP program as detailed in prior FAD reports; this internal assessment resulted in two complimentary planning options being developed for forest landowners. First, beginning in July 2014, WAC discontinued funding traditional plans for landowners having fewer than 50 acres of forest while requiring that new WAC plans must be enrolled in the 480-a program; to be eligible for the 480-a program, landowners must have at least 50 acres of forest and commit to a rolling 10-year forest management schedule that is enforceable. A second planning option was developed for all forest landowners regardless of their acreage, and it consists of a new interactive website called MyWoodlot (mywoodlot.com) that was launched near the end of 2015; the intent of this website is to educate landowners about all aspects of their forest while directing them through a series of interactive modules that allows them to develop management goals and create a customized plan for stewarding their forest and potentially engaging with a forester for specific activities. Since the MyWoodlot website has only existed in beta test mode following a year-long development process, there are no statistics to report at this time except that initial user feedback has been overwhelming positive.

It is important to recognize that after 18 years of funding new FMPs along with updates of existing plans, one issue to emerge involves the growing challenge of tracking and reporting on cumulative FMP accomplishments. During the first several years of the program, all plans funded by WAC represented new acreage enrolled by single landowners; these plans and acreages were easy to track because there was no overlap between landowners or tax parcels. As the years progressed, some landowners having WAC plans eventually sold their properties, which often resulted in new landowners developing their own WAC plans on acreages that were previously enrolled by someone else. Similarly, many landowners with existing WAC plans subsequently updated their plans or developed new plans because they subdivided their original acreage, added new parcels, or aggregated separate parcels that were previously covered by multiple plans. Yet another complication results from landowners updating their existing WAC plans because they harvested timber and needed a new forest management schedule, or else they enrolled in the 480-a program which requires plan updates every five years. As more and more landowners updated their WAC plans once, twice, or even three times over the past 18 years, it is not uncommon for successive plan updates to contain different forested acres or no riparian acres, because the latter acreage is only delineated and funded during the development of the initial plan.

Despite ongoing attempts to analyze property tax parcel data and help clarify certain nuances such as overlapping acreages between multiple landowners or plans, the fact remains that tracking cumulative plan accomplishments is no longer a straightforward exercise. For example, if a WAC plan was developed 18 years ago but the property was never sold and the landowner never updated the plan or engaged with the WAC after all these years, should the original plan and its acreage still be tracked and counted as a current program accomplishment? A similar question occurs when landowners develop plans on tax parcels that are subsequently subdivided into new tax parcels and then those new tax parcels are enrolled in a different WAC plan by a different landowner: should the original plan still be tracked and counted when all or part of the original acreage has been re-enrolled under a new plan by a new landowner?

It is important to recognize that the complexity caused by real property transactions and forest land ownership changes not only affects the accuracy of tracking and reporting on cumulative accomplishments over time, it also affects the consistency and accuracy of evaluating the implementation status of five-year old WAC plans (a FAD requirement) because an increasing number of plans being evaluated each year are actually updates to plans that were previously evaluated; a related complication results from the use of landowner surveys to support the evaluation, since greater numbers of landowners are asking to be removed from WAC's mailing list after completing multiple surveys for multiple plans over many years. Given that the planning program itself has now been evaluated and modified, this means that future WAC plans will either be enrolled in the 480-a program (which requires implementation) or be developed online through the MyWoodlot website. One promising feature of the MyWoodlot website is that it allows for easy tracking and reporting of all types of landowner activities with just a few simple keystrokes. In light of these developments, it is probably time to reconsider the necessity of evaluating five-year old WAC plans as a continued FAD requirement.

As for specific planning accomplishments during the current FAD assessment period, the WAC funded 389 FMPs covering over 61,159 acres of forest and 6,352 riparian acres. Of these 389 WAC plans, 220 were first-time enrollments and 169 were updates to existing plans. In terms of plan implementation, the WAC continued to implement the Management Assistance Program (MAP), which offers cost-sharing to support the following practices: timber stand improvement, riparian improvements, wildlife improvements, tree planting/deer fencing, and invasive species control. During the FAD assessment period, a total of 265 MAP projects were completed by landowners, including 116 timber stand improvement projects, four riparian improvement projects, 89 wildlife improvement projects, 18 tree planting/deer fencing projects, and 38 invasive species control projects.

During the past five years, the Watershed Forestry Program also supported a variety of forestry BMP implementation projects, including the installation or remediation of 202 forest roads, the completion of 59 stream crossing projects associated with timber harvest projects, and the temporary loan or cost-share of 39 portable bridges. During 2011-2015, WAC also distributed over 110 free samples of BMP technology such as geotextile road fabric and rubber belt water deflectors, while continuing to implement the Croton Trees for Tribs Program that was pilot tested in 2010, evaluated in 2011, and codified into a deliverable of six projects per year pursuant to the mid-term FAD revisions. A total of 42 Trees for Tribs projects were completed during 2011-2015; these projects involved 815 volunteers who planted 1,659 trees and shrubs along 5,353 linear feet of streams.

With regards to professional training for loggers and foresters, the Watershed Forestry Program sponsored 53 logger training workshops during 2011-2015 that were attended by over 630 participants. These workshops were conducted in collaboration with the NYS Trained Logger Certification (TLC) Program and resulted in more than 100 participants achieving TLC status by the end of the FAD assessment period. WAC also conducted a half dozen forester training workshops during this same period, which resulted in 48 consulting foresters becoming or remaining "watershed qualified" to write WAC FMPs for landowners.

Landowner education remained an important focus of the Watershed Forestry Program during the FAD assessment period, with WAC collaborating with CCE of Greene/Columbia 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. For example, CCE implemented a "You and Your Forest" informational letter series that directly engaged 317 landowners during 2011-2015, while the MFOs Program engaged over a dozen trained landowners who in turn conducted more than 70 property site visits for other landowners. It is also worth noting that during the past five years, WAC and its partners significantly increased their use of four watershed model forests as venues for hosting landowner education events that covered topics ranging from maple syrup production to invasive species management to apple tree pruning. In addition to the Frost Valley, Lennox, and Siuslaw model forests that were all previously established, in 2011 the Watershed Forestry Program formally established an EOH model forest at the Clearpool Environmental Education Camp in Putnam County, which fulfilled an important FAD requirement.

The Watershed Forestry Program continued to devote significant resources towards urban/rural school-based education during the past five years, with a big change occurring in 2013 when WAC hired its own watershed forestry environmental educator to oversee and strengthen its three core programs: the Watershed Forestry Institute for Teachers, the Green Connections School Partnership Program, and the Watershed Forestry Bus Tour Grants Program. Prior to the WAC educator being hired, the annual Watershed Forestry Institute was temporarily discontinued and re-evaluated during 2012-2013 after attracting only seven teachers in 2011 (historically this event has averaged nearly 20 participants per year since 1999); the Institute was successfully rebooted in 2014 with 24 participants and 16 participants in 2015. Also during the FAD assessment period, 16 schools from the watershed and NYC created urban/rural partnerships through the Green Connections Program, which benefited over 1,300 students. The WAC also sponsored over 70 watershed forestry bus tours that engaged over 4,200 participants, primarily students and teachers from NYC.

Finally, the Watershed Forestry Program continued to support economic viability projects during the current FAD assessment period, with a focus on providing marketing and utilization support to approximately 90 wood-using businesses through the Catskill WoodNet website (www.catskillwoodnet.org); this website regularly attracts nearly 2,000 visitors per year while over 700 people subscribe to the monthly e-newsletter. It is also worth mentioning that in 2014, WAC Forest Products Marketing & Utilization position was morphed into a different position due to a realignment of USFS grant funding combined with a strategic decision by the WAC to integrate its agricultural and forestry economic initiatives under one Economic Viability Program umbrella that focuses primarily on the Pure Catskills Campaign. In October 2014, the WAC Pure Catskills Campaign was rebranded and officially re-launched with an expanded emphasis on marketing both local farm and forestry products to potential consumers.

4.11 Education and Outreach

During the current FAD assessment period, DEP continued to collaborate with the CWC, the WAC, CCE, county SWCDs, the CRISP, the Lower Hudson Partnership for Invasive Species Management, and other partners to inform and educate both upstate watershed residents and downstate water consumers about the importance of source water protection, environmental stewardship, land use planning, stream corridor protection, stormwater and wastewater management, flood response and preparedness, invasive species control, and other FAD-related topics. DEP also continued direct outreach to all types of audiences.

DEP and its partners use numerous strategies and communication tools to educate specific audiences and to more broadly raise knowledge and awareness among members of the general public. One of the most effective tools for reaching large numbers of constituents continues to be DEP's website (www.nyc.gov/dep), which features detailed information about the water supply, drinking water quality, watershed protection, and watershed recreation. Over the years, DEP's website has provided a valuable repository for the annual consumer confidence report, program brochures, newsletters, press releases, watershed regulations, recreational opportunities, regulatory guidance documents, environmental education materials, and even FAD reports. Increasingly, DEP also uses social media such as Twitter, Facebook, Flickr, and YouTube as another effective tool for disseminating timely announcements directly to subscribers and sharing stories and accomplishments through photographs and videos.

During the current FAD assessment period, DEP worked to improve its reporting of watershed education and outreach accomplishments in terms of the primary and secondary audiences targeted by specific programs and the estimated number of people reached through various programs and events. In general, DEP has attempted to categorize its audiences in terms of water consumers, watershed landowners/homeowners, students and teachers, elected officials and municipal leaders, watershed professionals (an overarching group that includes loggers, foresters, highway departments, contractors, engineers, agency staff, etc.), recreational users, and of course the general public which tends to reflect large community outreach events with all types of audience members in attendance.

In 2011, DEP was able to document at least 380 unique events that took place in the upstate watershed or five boroughs of NYC and were sponsored or directly attended by DEP and/or a watershed partner such as WAC, CWC, CCE or county SWCDs; at the time, DEP estimated that approximately 431,450 people attended those events, of which approximately

28,150 participants were specific audiences targeted by specific programs while the rest were members of the general public who attended a large community outreach event such as a county fair or a local festival. Over the next few years, DEP was able to improve its tracking of watershed-related education and outreach accomplishments so that 446 unique events were identified in 2012 (estimated 765,000 participants), 526 unique events were identified in 2013 (estimated 665,500 participants), and 611 unique events were identified in 2014 (estimated 858,000 participants). Although a majority of these estimated participant numbers reflect approximate attendance at large public outreach events where audience contact might be fleeting and limited to the distribution of handouts or the perusal of an informational exhibit, DEP is confident in reporting that tens of thousands of specific target audiences have been directly educated or trained every year through the programs highlighted below.

The annual Trout in the Classroom Program, a partnership between DEP and Trout Unlimited, engages hundreds of teachers along with thousands of students in both NYC and watershed schools in the raising of baby trout from eggs while teaching about water quality, healthy ecosystems, and the connections between the upstate watershed and the City's drinking water; the program culminates with many participating students releasing their trout into a watershed stream during a full day of outdoor environmental education activities such as macro invertebrate sampling and interpretive nature hikes (Figure 4.23).

Figure 4.23 Students releasing trout they raised in the classroom, as part of the Trout in the Classroom Program.

DEP's Water Resources Art & Poetry Contest engages over a thousand NYC and watershed students every year in the creation of original artwork or poetry that reflects an appreciation for water resources and the NYC water supply; the annual awards ceremony held in Manhattan also provides an opportunity for hundreds of parents (water consumers) to become more informed about the source and quality of their drinking water. In 2015, this program attracted 1,350 students from 75 schools, which represents the highest participation rate in the program's 29-year history.

DEP's Water-On-The-Go Program educates hundreds of thousands of NYC residents and tourists (water consumers) about the source and quality of the City's tap water. Every summer, the program places portable drinking fountains emblazoned with the "NYC Water" logo at busy pedestrian areas and public parks/plazas all around the five boroughs where DEP staff are also present to answer questions and speak with members of the public. In 2015, Water-On-The-Go fountains and staff were present at over 300 public events in all five boroughs, including 17 flagship locations and approximately 66 special events.

Through the efforts of WAC in partnership with CCE, the WAP conducts or supports dozens of educational programs every year, including workshops, farm tours, webinars, classroom instruction, producer group meetings, and key annual events such as the Catskill Regional Dairy and Livestock Conference, Old Salem Horse Show, Farm to Market Conference, and Delaware County's Clean Sweep Chemical Disposal Day; these various programs and events attract hundreds of watershed farmers, agribusinesses, and professionals every year, in addition to restaurant managers, chefs, and operators of farmers markets who actively participate in the Pure Catskills "Buy Local" Campaign (www.purecatskills.com). WAC also keeps its constituents informed via its website (www.nycwatershed.org), press releases, e-newsletters, and periodic attendance at local events such as the Delaware County Fair.

Education has always been a significant component of the Watershed Forestry Program, which traditionally targets landowners, loggers, foresters, and the wood-products industry as the primary audience. During the current FAD assessment period, the WAC collaborated with CCE, SUNY College of Environmental Sciences and Forestry, the NYS Trained Logger Certification Program, and Cornell University's MFO Program to conduct or sponsor hundreds of educational programs that included training workshops, woods walks, informational mailings (the "You And Your Forest" letter series for landowners), and numerous events at all four watershed model forests. The Watershed Forestry Program also continued to implement a popular trifecta of urban/rural school-based education initiatives that engage dozens of teachers and thousands of students every year from schools based in the watershed and NYC; these urban/rural education initiatives include the Watershed Forestry Institute for Teachers, the Green Connections School Partnership Program, and the Watershed Forestry Bus Tour Program (which, it is worth noting, has funded dozens of watershed trout releases for hundreds of NYC students participating in Trout in the Classroom).

Education and outreach are also major components of DEP's SMP and its local CCE and SWCD partners, who every year conduct or sponsor a diverse slate of targeted programs for streamside landowners, local officials, highway department staff, flood response professionals, and members of the scientific community. Key examples of programs include training workshops, public presentations and lectures, interpretive stream hikes, volunteer riparian planting events, and popular annual events such as the Ashokan Watershed Conference, Schoharie Watershed Summit, and the Catskill Environmental Research and Monitoring Conference. In addition, the SMP continues to host a unique website devoted to stream corridor protection (www.catskillstreams.com) while continuing to participate in numerous basin-specific project advisory committees and stakeholder meetings. Finally, one important activity that has evolved during the course of the current FAD assessment period has been the Stream Management Program's substantial participation in numerous LFA meetings and presentations, which has led to the creation of several flood commissions in a number of WOH watershed towns.

CWC continues to implement a Public Education Grants Program that awarded 128 grants totaling $752,637 during 2011-2015; these grants were awarded to schools and organizations in both NYC and the watershed for projects and programs that include water quality testing experiments, Trout in the Classroom, field trips to environmental education centers, performances of Arm of the Sea Theater, and development of audiovisual materials or interpretive displays pertaining to the water supply. During the current FAD assessment period, CWC sponsored a series of 2-3 annual septic system maintenance workshops for homeowners along with several annual stormwater, wastewater, and land use planning workshops for municipal officials and local professionals. CWC also keeps watershed residents informed via its website (www.cwconline.org), press releases, an e-newsletter, and periodic attendance at local events such as the Margaretville Cauliflower Festival.

Finally, DEP's LAP has continued to work with land trusts and watershed communities to conduct periodic outreach relating to real property acquisitions, CEs, and more recently, DEP flood buyouts. In addition, DEP's Land Management Program has greatly expanded opportunities for recreational users and the general public to access DEP lands for guided interpretive hikes, reservoir clean-ups, family fishing days, and recreational boating. In 2015, for example, nearly 350 volunteers participated in nine separate reservoir clean-up events while more than 250 people participated in three separate reservoir family fishing days; these modest figures don't include the thousands of people who hike DEP lands or enjoy recreational boating every year on a regular basis.

4.12 Regulatory Review and Enforcement

Recognizing the potential impacts development can have on water quality, DEP has administered a regulatory program in the NYC watershed for more than 100 years. The WR&R (or Regulations) were substantially revised in 1997, following extensive negotiations with communities, environmental stakeholders and regulators as part of the Watershed MOA process, and are designed to ensure that when development occurs, wastewater and stormwater impacts are considered and addressed. DEP believes that well designed and properly constructed development is fully compatible with the protection of water quality. The Regulations were updated in 2010, to reflect changes in federal and State law and address issues that had arisen during administration of the Regulations since 1997.

4.12.1 Project Review

DEP reviews proposed projects within the NYC Watershed to ensure compliance with the WR&R. DEP review and approval is required for all WWTPs, new and repaired subsurface sewage treatment systems (SSTSs), certain sewer connections, preparation of SWPPPs, and the construction of certain impervious surfaces. In addition, DEP reviews and issues permits or approvals for IRSPs and for impervious surfaces associated with stream crossings, piping, or diversions (CPDPs). DEP encourages all potential applicants to schedule a pre-application conference to discuss proposed projects and familiarize applicants with DEP's requirements and process.

Once approvals are issued, DEP conducts field inspections to ensure that projects are being constructed in accordance with their approvals.

Since the promulgation of the revised Regulations in 1997, DEP has observed certain trends in the number of applications approved. Across all regulatory categories in the entire NYC watershed, DEP has received more than 14,000 applications since 1997. The vast majority of these applications have been approved, with more than 99% of all applications that have received a determination being approved. In the CAT/DEL watershed WOH, since 2005 approximately 85% of all applications received have been for either new or remediated SSTSs. In that time, the overall trend for new SSTS approval has been down, with applications roughly equal between Catskill system and Delaware system basins (see Figure 4.24). For comparison, a similar trend

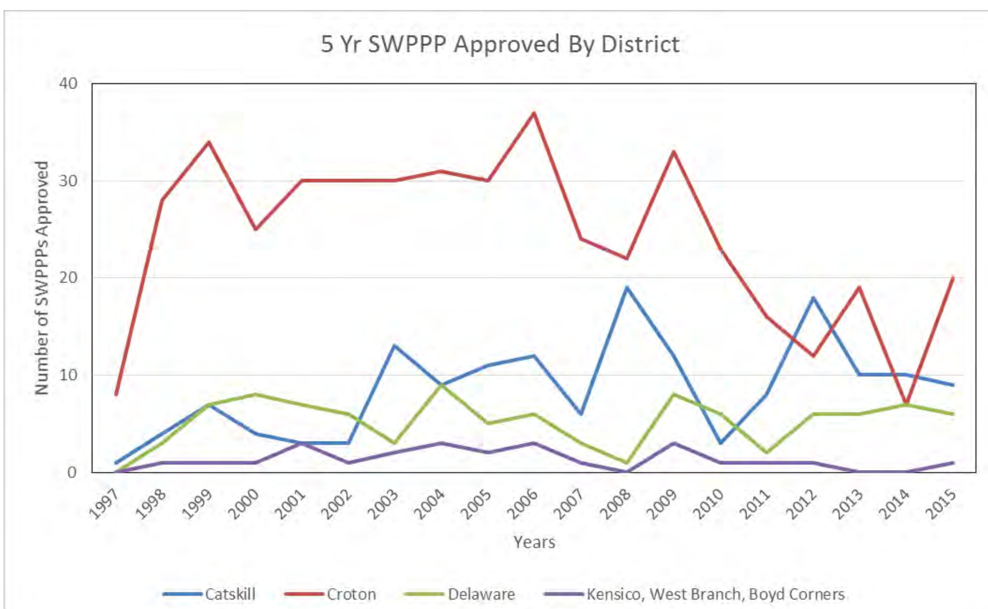

Figure 4.24 Five year SWPPP approved by district.

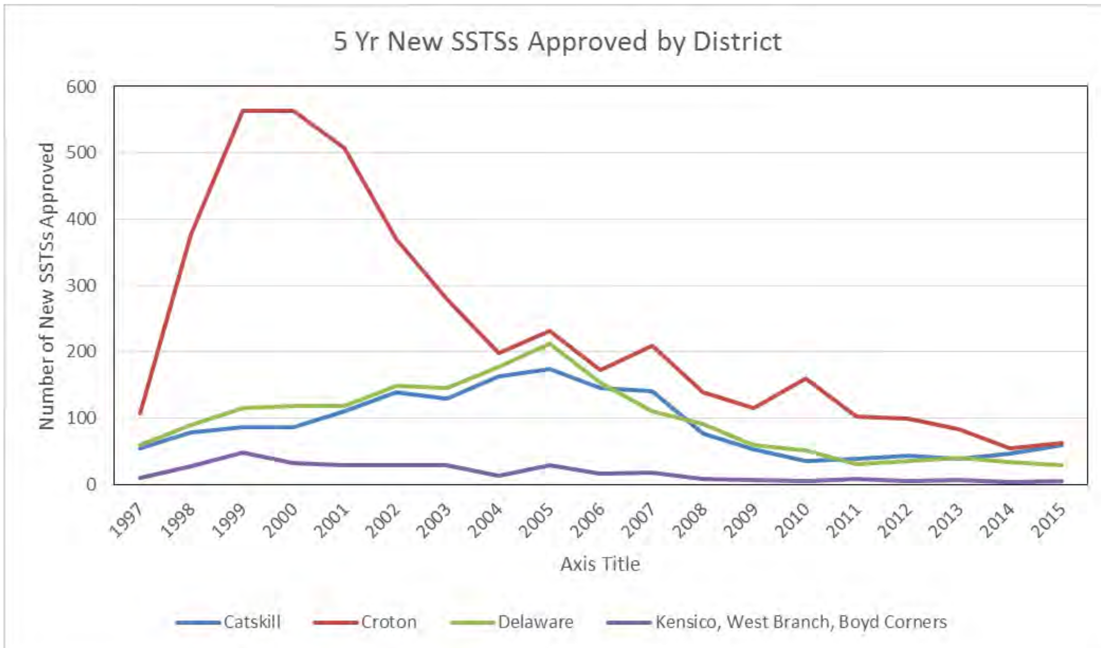

Figure 4.25 Five year new SSTSs approved by district.

has been observed in the EOH Croton system basins. For remediated SSTS, there has been some year-to-year variation, but the numbers of approvals have been roughly steady over the past decade (see Figure 4.25). Delaware system basins have consistently seen slightly more SSTS repairs than Catskill basins. The numbers of new SWPPP approvals are on the whole much lower than new or remediated SSTS, since far fewer projects meet the thresholds that require a SWPPP. Year-to-year variation in approvals is fairly high and Catskill basins consistently have more approvals than Delaware basins (see Figure 4.26).

DEP continued to delegate review of certain septic system applications to three county health departments which are located within the watershed: Putnam County Department of Health, Ulster County Department of Health, and Westchester County Department of Health. The delegation of projects to the health departments has proven to be a good coordinated program between DEP and the health departments. DEP continues to delegate the residential projects while conducting joint reviews on other projects with the health departments. DEP has had discussions with the health departments to assess the delegation agreements and propose changes for the future that will benefit the program and provide a better coordinated regulatory effort.

Following Tropical Storm Irene and Tropical Storm Lee, to ensure that cleanup and reconstruction efforts could be implemented as quickly and efficiently as possible, DEP temporarily suspended enforcement of certain stormwater and wastewater requirements of the

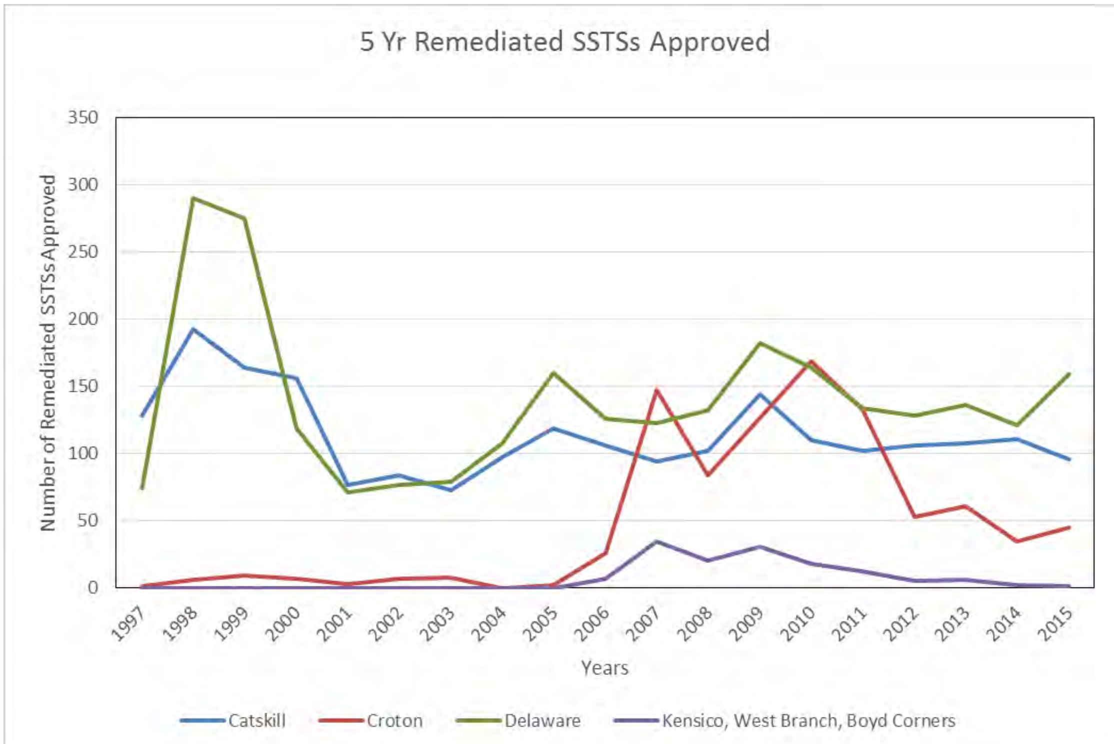

Figure 4.26 Five year remediated SSTSs approved.

Regulations in the WOH watershed, so long as such actions were necessary to address immediate threat to life, health, property, general welfare or natural resources in the wake of the storm. DEP quickly established temporary permitting satellite offices in three locations – Tannersville, Lexington, and Margaretville – where staff were available to provide assistance to watershed landowners, answer questions, and expedite DEP regulatory reviews.

4.12.2 Regulatory Compliance and Inspection

DEP has in place a comprehensive program to inspect and monitor WWTPs that discharge into the watershed. There are 30 active WWTPs WOH and nine active WWTPs in the EOH FAD basins that are inspected on a regular schedule. In addition to regular inspections, DEP conducts follow-up inspections, when necessary. Similarly, at least two inspections per year are conducted at non-contact cooling water discharges to surface waters, groundwater remediation systems, landfills, and oil/water separators. Treated industrial waste discharges to groundwater, via surface application, are inspected four times per year.

If a DEP inspection reveals that non-complying conditions exist and corrective action is necessary, a follow-up inspection is scheduled to ensure that corrective actions are implemented, and that an effort is being made to return the facility to compliance or to correct operational deficiencies. DEP's goal is always to quickly restore plants to good working order quickly through cooperative efforts with plant operators. However, if chronic violations of SPDES parameters are occurring, DEP, in conjunction with NYSDEC and local health departments, may issue a Notice of Violation and participate in a Compliance Conference with the owner/operator to discuss problems and possible corrective actions. Following such an enforcement initiative, DEP may periodically conduct a follow-up, unannounced visit to ensure that the facility is continuing in its efforts to remain in compliance. If corrective action is not taken by the owner/operator, further enforcement actions are discussed at the quarterly Watershed Enforcement and Coordination Committee meetings with NYSDEC.

In general, WWTPs in the watershed continue to show consistent compliance with their SPDES permits. This is due to a number of factors, including the DEP-funded WWTP Upgrade Program; the decommissioning of certain outdated facilities, which have been connected to other upgraded facilities; and DEP's support of plant operators through the inspection program.

Reports of inspections of specific facilities as well as enforcement actions are available in the bi-annual FAD Reports submitted by DEP.

4.13 Kensico Water Quality Control Program

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

4.13.1 Wastewater 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 EFC 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. DEP rolled out the program according to priority phases and currently, all residential systems in the Kensico Basin are eligible.

Since inception in 2008, a total of 20 systems have been rehabilitated with 16 of the rehabilitations occurring since 2011. DEP continues to make funding available for septic system rehabilitation as needed. DEP also mails letters to residents in the Kensico Basin annually to remind them of the availability of program funding.

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. Given the proximity of the collection system to Kensico Reservoir, potential defects or abnormal conditions within the sewer line and its components could lead to exfiltration or overflows of wastewater. The intent of this program is to work with the county to mitigate risks posed by the line while maintaining the collection system's location and gravity flow.

During the reporting period, DEP installed a sanitary sewer remote monitoring system for the trunk line to provide real-time detection of problem events such as leaks, system breaks, overflows, and blockages. The Smart Cover technology for remote monitoring of manholes was completed in July 2012. DEP and WCDEF have full access to the Smart Cover website which displays information on a variety of data including real-time liquid levels, summary of past liquid levels, alarms, notifications, and maintenance completed. There have been no overflows or indications of concern of high liquid levels in the manholes since the system's installation. WCDEF provides operations and maintenance on the units through an inter-municipal agreement between DEP and WCDEF, which includes service of the units and battery replacement as necessary. The units appear to be working well.

DEP also conducts an annual visual inspection of the trunk line to assess the condition of exposed infrastructure, including manholes, for irregularities. The most recent annual full inspection was performed in October 2015. Routine partial inspections were also conducted at various times throughout the year in association with ongoing maintenance of Kensico stormwater BMPs in the vicinity of the line. No defects or abnormalities have been noted during the reporting period.

Video Inspection of Sanitary Sewers

DEP established an inspection program for select portions of the sanitary sewer system located within the Kensico basin. DEP completed the project to inspect portions of the sanitary sewer system located within the Kensico watershed in 2011. None of the inspected pipe sections demonstrated any significant defects or deterioration.

4.13.2 Stormwater Programs

Kensico Action Plan

DEP developed the Kensico Action Plan (KAP) in an effort to build on the successful watershed management and protection strategies already existing within the Kensico basin. Following a detailed mapping and modeling of the catchments within the Kensico watershed, the KAP proposed four stormwater treatment facilities. From 2011 to 2015, DEP awarded the contract to construct the sites and completed full construction. A brief description of the four sites is as follows:

Drainage Improvements in the N-1 Catchment

Observations during high flows indicated that overland flow that was expected to flow into BMP 13 bypassed this structure and instead discharged into BMP 12. As a result, more runoff than expected reached BMP 12, causing it to be less effective, and minimal runoff was received by BMP 13, reducing its treatment benefit. DEP constructed new catch basins to intercept this flow and redirect it to BMP 13 thereby enhancing the performance of both basins.

Whippoorwill Creek Stream Stabilization

Several areas of the Whippoorwill Creek stream exhibited stream bank erosion. Several stabilization techniques were utilized to re-direct streamflow away from these banks, forcing the stream energy to the center of the stream. The project reduced the sediment load to Kensico Reservoir without the construction of a large-scale basin.

N7 - Sub-Basin Pipeline System

A riprap-lined channel in the N7 catchment area received flow from upgradient impervious surfaces and was not properly stabilized. Stream velocities, compounded by the steepness of the slope, contributed to the erosion of this channel. The completed project piped a 420 foot section of the channel to reduce erosive velocities and stabilize the area above the pipe. The pipeline includes a bypass for a water quality treatment unit, designed to remove solids from stormwater as it flows through the pipe before being discharged to the reservoir. Following construction, all disturbed areas were seeded and steep sloped areas were stabilized. Photos of the site before, during, and after construction are shown in Figure 4.27.

N12 – Extended Detention Basin

DEP constructed an off-line extended detention basin in this catchment to treat stormwater runoff while allowing baseflows from the stream to by-pass the structure. Construction of the basin involved diverting the stream during construction; building the earthen embankment, inlet and outlet chambers, flumes, and forebay; replacing and installing new piping; installing new security fence and guide rail; seeding all disturbed areas; and planting wetland plants within the basin.

BMP Inspection and Maintenance

DEP has constructed 47 stormwater management and erosion abatement facilities throughout the Kensico watershed to reduce pollutant loads conveyed to the reservoir by stormwater. The facilities, shown in Figure 4.29 were routinely inspected and maintained as needed throughout the reporting period in accordance with the Operation and Maintenance Guidelines. Maintenance consisted of such activities as grass mowing, vegetation removal, tree removal, and sediment and debris removal. All BMPs are performing as designed.

Spill Containment Facilities

DEP installed, and now maintains, spill containment facilities in and around Kensico Reservoir. The facilities improve spill response and recovery, thereby minimizing water quality impacts in the event of a spill. DEP conducts 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 was one spill that required the deployment of booms. In June 2011, home heating oil was discharged within the Kensico Watershed off of Nannyhagen Road near the Catskill Influent Chamber cove. DEP HazMat deployed booms within the area to prevent transport of oil. DEP HazMat followed up to ensure proper clean-up and it was determined that no oil left the Reservoir via water supply intakes.

Turbidity Curtain

DEP continues to monitor the extended primary curtain and the back-up turbidity curtain, designed to direct flows from Malcolm and Young Brooks further out to the body of the reservoir and to provide enhanced protection for water entering the Catskill Upper Effluent Chamber (CATUEC). DEP conducts inspections of both turbidity curtains as needed to ensure they are properly functioning. The most recent inspection occurred in October 2015. Based on these inspections, no immediate repair work was required and the turbidity curtains appear to be functioning as intended.

A

B

C

Figure 4.27 Sub-basin pipeline system, one of the Kensico Action Plan stormwater projects.
A) N7 before construction, B) installation, C) after construction.

4.13.3 Other Programs

Shoreline Stabilization

Catskill Upper Effluent Chamber

The CATUEC is situated along the shore of a cove in the southwest section of Kensico Reservoir. DEP had previously explored the possible need for a shoreline stabilization project to mitigate the resuspension of near-shore materials near CATUEC during wind events. However, the CATUEC went off-line after the CAT/DEL UV Disinfection Plant went into service in 2012, minimizing concerns regarding potential resuspension of near-shore materials near that facility. As part of the Catskill Aqueduct pressurization project, DEP will determine the most appropriate location for an intake and it is not known if CATUEC will be selected. Therefore, further review of a potential shoreline project will occur as part of the site selection under the Catskill Aqueduct pressurization project.

Shaft 18

Shaft 18 is situated along the shore in the southwest section of Kensico Reservoir. Since the CAT/DEL UV Disinfection Plant was placed in service, all water in the Kensico Reservoir flows through the Delaware effluent chamber at Shaft 18. This has changed the pattern and velocity of flow in the reservoir. Reliance on Shaft 18 as the sole effluent from Kensico Reservoir, together with changing weather patterns, necessitates measures to harden the shoreline in the vicinity of the effluent chamber to maintain turbidity levels in compliance with federal water quality standards.

DEP has begun to assess the scope of a project to stabilize the shoreline on both sides of Shaft 18. In 2014, DEP hired an engineering firm to study and design the proposed stabilization project. The firm has completed a technical memorandum on the design issues and has completed a draft Basis of Design Report (BODR). Based on the draft BODR, the project will implement shoreline stabilization and protection measures of approximately 700 linear feet at the western shoreline and approximately 475 linear feet at the cove area (See Figure 4.28). In 2015, DEP continued work on the design of the project and submitted several permit applications including the Town of Mount Pleasant Wetlands and Steep Slope Permit Applications and the Joint Application to NYSDEC and the Army Corps of Engineers.

Route 120

The NYSDOT completed a project to resurface I-684 and construct stormwater treatment basins in the I-684 median from just south of the new Lake Street overpass in New York northward to the bridge over Tamarack Swamp in Connecticut. No additional work is currently planned.

Figure 4.28 Proposed location of the Shaft 18 shoreline stabilization.

Westchester County Airport

The Westchester County Airport is located east of Kensico Reservoir in close proximity to Rye Lake. DEP continues to review any activities that are being proposed at the airport. The Westchester County Department of Public Works and Transportation is in the process of developing an Airport Master Plan, which is currently in the information-gathering phase. During the reporting period, DEP reviewed and attended public meetings on the plan, as necessary.

Westchester County Airport is working on an expansion and internal improvements to the terminal building. A new building is being built next to the terminal and will provide a separate area for a high-tech in-line baggage screening system. All the work proposed is outside of the watershed limit.

In February 2015, DEP provided SEQRA review comments on a proposal to construct a 1,450 space parking garage at 11 New King Street, known as Park Place at Westchester County Airport. The project will require discretionary approval from DEP related to stormwater runoff and new impervious surfaces. The project is not located on airport property.

In July 2015, DEP issued a Land Use Permit (LUP) to Westchester County Public Works & Transportation to allow their consultants to access DEP owned land to perform an environmental assessment (EA). The purpose of the EA is to determine the impacts, if any, of removing, removing and replanting, or topping of trees that may be affected by Westchester County Airport's forthcoming Off-Airport Obstruction Removal Environmental Assessment Project.

4.14 East of Hudson Non-Point Source Pollution Control Program

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

4.14.1 Wastewater Programs

Septic Programs East of Hudson

From 2011 to 2015, DEP provided support to Westchester and Putnam Counties in their efforts to reduce the potential impacts of improperly functioning or maintained SSTSs. This has included support for Westchester County Health Department's operation of its Septic System Management Program (SSMP) database and web-based SSMP database access tool. The database includes available information on septic applications, septic repairs, and pump-outs.

Westchester County, Putnam County, and their respective municipalities continue to implement the septic requirements of the NYSDEC MS4 General Permit (GP-0-10-002) that became effective in May 2011. As required by the MS4 permit, programs are in place for inspection, maintenance, and rehabilitation of septic systems. The Town of Bedford began implementation of a septic reimbursement program in 2015. Other Towns and Westchester County have expressed that they may explore establishing similar programs.

In 2015, DEP initiated a Septic System Rehabilitation Reimbursement Program in the West Branch and Boyd Corners Reservoir Basins to reduce potential water quality impacts that can occur through failing septic systems (see Figure 4.29). The Program provides up to 50%

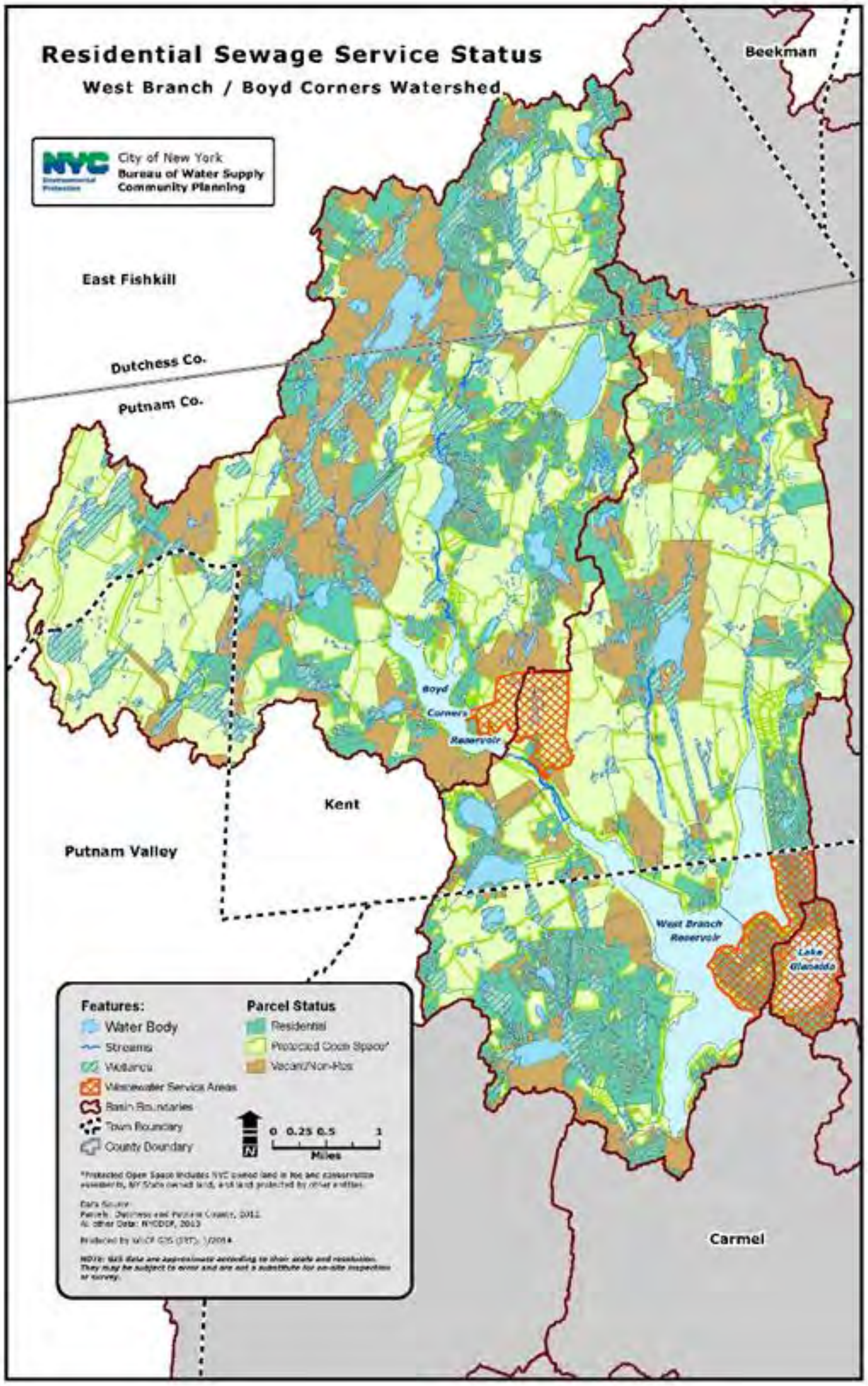

Figure 4.29 Residential sewage service in West Branch and Boyd Corners.

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 Program has been rolled out in phases based on distance of a property to the nearest watercourse.

In June 2015, DEP mailed letters to residents within 50 feet of a watercourse notifying them of the availability of funding. The mailing included information about the Program as well as contact information. There was limited participation of the first priority area and so DEP opened the Program to residents between 50 and 100 feet of a watercourse in November 2015.

Also in June 2015, DEP submitted a proposal for a septic program in the Croton Falls and Cross River Reservoir basins. To address comments received from regulators on the proposal, DEP revised the Program in November 2015 in order to address any gaps that may exist among the septic programs already in place. The expanded Program will provide funding to residences that have a demonstrated financial need by reimbursing a portion of the costs to rehabilitate eligible failing septic systems or connect those systems to an existing sewage collection system. DEP's Program will be implemented by EFC and cover the eligible portions of the Croton Falls and Cross River Reservoir Watersheds that are not covered by one of the other septic reimbursement programs that are already in place. DEP will implement the Program based on the potential risk that a failing septic system might have on reservoir water quality.

4.14.2 Stormwater Programs

Stormwater Retrofit Projects

To further reduce pollutant loading from stormwater runoff, DEP is working on multiple nonpoint source reduction projects within the EOH CAT/DEL basins. DEP is implementing five large stormwater remediation projects that are located on both DEP and private land. Three of the projects are complete and two are in the final stages of permitting.

During the reporting period, DEP completed the following projects:

Michael Brook, Town of Carmel, Putnam County - The project repaired a severely eroded drainage ditch that drains directly into the Croton Falls Reservoir. Numerous trees and other debris that had accumulated at the juncture of Croton Falls Reservoir and Michael Brook were relocated outside the watercourse of Michael Brook.

Sycamore Park, Long Pond Road/Crane Road, Town of Carmel, Putnam County - The project removed a gravel parking area within the wetland buffer zone and replaced it with new porous grass paving. The project stabilized the parking areas and removed the source of gravel migration into the wetlands. DEP installed landscape improvements and barriers to prevent future parking from encroaching into the wetlands. DEP also reconstructed the culvert outfall outside of the wetland and installed include two biofiltration areas to collect and treat runoff from the paved areas.

Nemarest Club, Town of Kent, Putnam County - The project replaced a partially collapsed and undersized culvert with a larger span concrete structure capable of conveying the 100-year storm. The project minimizes sediment runoff from the damaged roadway entering Boyd Corners Reservoir. DEP also relocated large rocks that were in-channel near the road crossing and installed forebays adjacent to the culvert.

During the reporting period, DEP continued work on the following projects, which will be bid together when the full design packages are approved and all permits are secured.

Maple Avenue, Town of Bedford, Westchester County - The Maple Avenue site consists of two roadside ditches carrying suspended solids into Cross River Reservoir. To prevent the continued buildup of sediment along the hillside and water's edge, a sediment and gravel collection system was designed to concentrate deposition at a location where it can be easily accessed and periodically cleaned. The deposition control system includes a hydrodynamic device and filter practice. DEP will also install improvements to the swales consisting of installation of new catch basins with concrete headwalls, and widen and line a portion of the swales with rip-rap. These measures will ensure that a majority of the stormwater runoff is captured. The system is designed to handle the combined flow, with an engineered overflow controlling the flow of clean water over a weir and to the reservoir. From 2011 to 2015, DEP worked to complete design and secure the necessary permits from the Town of Bedford. The project will be bid with the Drewville Road project.

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 paved parking lots, and wooded and grassy areas. Runoff from the drainage area is collected in a roadside drainage ditch on Drewville Road and drains to Croton Falls Reservoir. The primary objectives of the project are 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 shoreline of the Croton Falls Reservoir. The stormwater measures consist of a forebay and a micropool which will extend the detention time of the stormwater, allowing solid material to drop out.

From 2011 to 2015, DEP worked to satisfy the requirements of the Town of Carmel in their review of the project. This included accommodating the Town's request for moving the basin and changing the vegetative screening that was requested to reduce the visual impact. The Town's requests made it necessary for DEP to amend its contract with its engineering design consultant and created significant project delays. The Town is now comfortable with the proposed project. In October 2015, DEP submitted the Joint Permit Application and the application for stormwater discharges from construction activities under the SPDES General Permit. In November, DEP received the permit for stormwater discharges from construction activities under SPDES General Permit. Both applications are pending approval. The project will be bid with the Maple Avenue project.

Stormwater Facility Inspection and Maintenance

The Facility Inspection and Maintenance Program was developed to ensure that previously constructed stormwater remediation facilities continue to function as designed. New facilities that are brought on line are added to the routine inspection program. Inspection and maintenance follow procedures identified in the Operation and Maintenance Guidelines contained in the maintenance contract.

Stormwater Infrastructure Mapping and Inspection Program

DEP developed a program to video inspect and digitally map the sanitary infrastructure in the EOH CAT/DEL system. DEP completed the project in 2011 and provided the video files, digital mapping data, and summary report to the Towns for import and analysis.

Funding Program—Croton Falls/Cross River

DEP established a $4.5 million grant program to reduce stormwater pollution in the Cross River and Croton Falls basins. DEP later agreed to reallocate these funds toward the municipalities that participated in a regional stormwater entity in the EOH watershed.

In November 2011, the majority of watershed communities in Putnam, Westchester, and Dutchess Counties established the EOH 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. In 2012, DEP and the EOHWC finalized the funding agreement that would transfer both the $4.5 million provided under the Croton Falls/Cross River Funding Program as well $15.5 million in additional funding. Westchester and Putnam County also agreed to provide an additional $18.2 million in funding from the respective Water Quality Investment Program (WQIP) funds for a total of approximately $38.2 million. In early 2014, DEP provided the full $4.5 million to the EOHWC and these funds have been fully expended.

4.15 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 that underlie the streambed armor. The design of the Catskill System takes into account the 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. However, occasionally after extreme rain/runoff events in the Catskill watershed, DEP has had to use aluminum sulfate (alum) as chemical treatment to control high turbidity levels.

Since 2002, DEP has undertaken a number of studies and implemented significant changes to its operations in order 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 SPDES Permits. A comprehensive analysis, the Catskill Turbidity Control Study, was conducted by DEP with the Gannett-Fleming-Hazen and Sawyer JV in three phases between 2002 and 2009. Based on the results of this study, DEP selected several implementation alternatives, specifically: a system-wide Operations Support Tool that allows DEP to optimize reservoir releases and diversions to balance water supply, water quality, and environmental objectives; 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.

During the past five years DEP has modified operations at Ashokan Reservoirs utilizing the Operations Support Tool in part to meet the Interim Release Protocol in the Catalum SPDES consent order (effective date October 2013) and in part to divert more water from the Ashokan West Basin when water quality permits for better overall control of turbidity. Historically, the East Basin was used to supply the aqueduct because of higher water quality, however, greater withdrawals from the West Basin creates a void that can better capture storm flows and allows for additional settling of suspended sediment. In addition to operational changes, DEP has pursued implementation of the other selected alternatives. Details on the Operations Support Tool and Shaft 4 interconnection can be found in Chapter 3 of this report. Details on the stop shutter facilities are described below.

In addition to the structural and operational changes listed above, DEP's multi-tiered water quality modeling program provides modeling and technical support to the program to control turbidity in the Catskill system. The water quality models are an integral part of the Operations Support Tool and provide valuable information used to operate the water supply to minimize the impact of turbidity events while considering longer-term system operating requirements. Details on the modeling efforts related to Catskill Turbidity are provided in section 9.4.

Catskill Aqueduct Stop Shutter Facilities

The Catskill Aqueduct stop shutter project is ongoing. Improvements to the stop shutter installation process consist of fabricating new lightweight aluminum stop shutters and building hoist system improvements that will allow DEP staff to install and remove stop shutters more quickly than current operations allow, and provide shutters that will seal more effectively. The improved stop shutter facilities will continue to require service personnel to operate on-site equipment and coordinate the timing of shutter installation and removal. The improved stop shutters will enable DEP to decrease the minimum flow in the Catskill Aqueduct to approximately 25 MGD.

The complete specifications and drawings were reviewed in early 2014 and approved for letting the construction contract out to bid. The contract was registered and the contractor was issued a December 1, 2014 Order to Commence Work date. Construction activities continued through 2015. The first stop shutter and one lifting device were fabricated and delivered to the Wallkill site for test fitting and acceptance. Several design changes were made as a result of this fit test. The revised design for the stop shutters was accepted (following a second fit test) and the Contractor was given approval to manufacture the remaining shutters. A change order was developed to provide the required electrical work for this project. Safety railings and gantry cranes were also installed at several facilities.

The construction schedule includes “black-out” periods (May 1-September 30) during which the contractor will not be allowed to shut down the Catskill Aqueduct to conduct the required performance testing of the new stop shutters. The schedule for performance testing and acceptance of the shutters is also dependent on water supply operations and demand.

Catalum Consent Order and Environmental Review

Rain events in early October and early 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 that all drinking water standards were met. This use of the Release 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 includes penalties, environmental benefit projects, a schedule of compliance and an Interim Release Protocol for operation of the Ashokan Release Channel.

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

NYSDEC released a draft scope for the Catalum environmental impact statement (EIS) for public comment on April 9, 2014; the comment period closed on August 29, 2014. Over 900 comments were received from over 550 commenters. NYSDEC and DEP continue to evaluate the comments and potential changes to the scope and a final scope is expected in 2016. In addition, DEP continued to collect fish/benthic data, observe stream geomorphic conditions, and monitor wetlands along the lower Esopus Creek. The Catalum EIS will evaluate the potential for significant adverse environmental impacts to both the Ashokan Reservoir/lower Esopus Creek and Kensico Reservoir that may occur from implementation of the turbidity control measures proposed to be incorporated into the Catalum SPDES Permit as well as from the postponement of dredging of Kensico Reservoir. The EIS will evaluate a suite of alternatives at Ashokan

Reservoir, along the Catskill Aqueduct and at Kensico Reservoir as well as implementation of DEP's turbidity control measures as a whole. Where potential adverse impacts are identified, reasonable and practicable measures that have the potential to avoid, mitigate, or minimize these impacts will be identified.

4.16 Monitoring, Modeling, and GIS

4.16.1 Monitoring

DEP conducts extensive water quality monitoring throughout the watershed. The 2009 Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009), which was delivered to NYSDOH, USEPA, and NYSDEC in October 2008, describes this monitoring plan. The plan and its associated addenda are designed to meet the broad range of DEP's many regulatory and informational requirements. The monitoring plan was updated in early 2016. The overall goal of the plan is to establish an objective-based water quality monitoring network, which provides scientifically defensible information regarding the understanding, protection, and management of the DEP water supply. The objectives of this monitoring plan have been defined by the requirements of those who ultimately require the information, including DEP program administrators, regulators, and other external agencies. As such, monitoring requirements were derived from legally binding mandates, stakeholder agreements, operations, and watershed management information needs. The plan covers four major areas that require ongoing attention: Compliance, FAD Program Evaluation, Surveillance Monitoring, and Modeling Support (see below), with many specific objectives within these major areas.

The compliance objectives of the sampling plan are focused on meeting the regulatory compliance monitoring requirements for the DEP watershed. This includes the requirements of the SWTR (USEPA 1989) and its subsequent extensions, as well as the DEP WR&R (WR&R 2010), the Croton Consent Decree, administrative orders, and SPDES permits. The sampling sites, analytes, and frequencies are defined in each objective according to each specific rule or regulation and are driven by the need of the water supply as a public utility to comply with all regulations. Since this monitoring is mandatory, it must comply with all USEPA, NYSDOH, and DEP regulations.

As DEP's water supply is one of the few large water supplies in the country that qualifies for Filtration Avoidance, based on both objective water quality criteria and subjective watershed protection requirements, USEPA has specified many requirements in the 2007 FAD and the Revised 2007 FAD that must be met to protect public health. These objectives form the basis for DEP's ongoing assessment of watershed conditions, changes in water quality, and ultimately any modifications to the strategies, management, and policies of the long-term watershed protection program. DEP also conducts a periodic assessment of the effectiveness of the watershed protection program. DEP's water quality monitoring data, including data relating to stream benthic macroinvertebrates, are essential to perform this evaluation. Program effects on water quality are reported in the Watershed Protection Summary and Assessment reports (e.g., DEP

2011a), which are produced every five years. (For the current five-year water quality assessment, see Chapters 5–8.)

The goals of DEP's water quality monitoring efforts are to:

- Provide water quality results for keypoints (i.e., aqueduct locations), streams, and reservoirs collected through routine programs to guide operations, assess compliance, and provide comparisons with established benchmarks. Describe these results and ongoing research activities in Watershed Water Quality Annual Reports.
- Use water quality data to evaluate the source and fate of pollutants and assess the effectiveness of watershed protection efforts. Provide a comprehensive evaluation of watershed water quality status and trends, and other research activities, to support assessment of the effectiveness of watershed protection programs.
- Actively participate in forums (e.g., seminars, discussion groups) for the exchange of information between DEP and outside agencies regarding watershed research activities and pathogen investigative work.
- Coordinate a technical working group on pathogen studies to discuss the latest research on pathogen sources, transport, and fate in the environment; effectiveness of management practices in reducing pathogen concentrations; and identifying additional monitoring and/or research needs.
- Provide after-action reports on all chemical treatment activities and other significant or unusual events.

These goals are met by targeting specific watershed protection programs and examining overall status and trends of water quality. Water quality represents the cumulative effects of land use and DEP's watershed protection and remediation programs. The ultimate goal of the watershed protection programs is to maintain the status of DEP's water supply, as one of the few large unfiltered systems in the nation, far into the future.

The WWQMP contains several objectives that provide information to guide the operation of the water supply system, other objectives to help track the status and trends of constituents and biota in the system, and specific objectives that include aqueduct monitoring for management and operational decisions. The aqueduct network of sampling points consists of key locations (referred to as keypoints) along the aqueducts, developed to track the overall quality of water as it flows through the system. Data from these key aqueduct locations are supplemented by reservoir water quality data. Another surveillance objective relates to developing a baseline understanding of potential contaminants, including trace metals, volatile organic compounds, and pesticides. Another summarizes how DEP monitors for the presence of zebra mussels in the system, a surveillance activity meant to trigger actions to protect the infrastructure from becoming clogged by these organisms. The remaining objectives pertain to recent water quality status and long-term trends for reservoirs, streams, and benthic macroinvertebrates in the Croton

System. It is important to track the water quality of the reservoirs to be aware of developing problems and to pursue appropriate actions. Together, these objectives allow DEP to maintain an awareness of water quality for the purpose of managing the watershed, developing protective programs and policies, and guiding operation of the supply to provide the highest quality drinking water possible.

Finally, non-routine water quality monitoring, referred to as Special Investigations (SIs), are conducted when appropriate to document man-made or natural events occurring in the watershed that have the potential to negatively affect water quality. Sewage conveyance overflows and oil spills are anthropogenic events requiring monitoring. These events are documented in SI reports. Also, major storm and runoff events that impact the water supply may necessitate intense water quality monitoring to forecast the movement of the contamination, provide guidance for operations to avoid treatment, or ensure the efficacy of treatment. These events are also documented in individual reports as appropriate.

Samples collected under the auspices of the WWQMP are brought to DEP laboratories for analysis. The laboratories are certified by NYSDOH's Environmental Laboratory Approval Program (ELAP) for over 100 environmental analyses in the non-potable and potable water categories. These analyses include physical analytes (e.g., pH, turbidity, color, conductivity), chemical parameters (e.g., nitrates, phosphates, chloride, chlorine residual, alkalinity), microbiological parameters (e.g., pathogenic protozoans, total and fecal coliform bacteria, algae), trace metals (e.g., lead, copper, arsenic, mercury, nickel), and organic parameters (e.g., organic carbon).

Water quality data collected according to the monitoring plan are analyzed and interpreted in several major routine reports. DEP produces a Watershed Water Quality Annual Report (e.g. DEP 2014a) which is submitted to NYSDOH, NYSDEC, and USEPA in July of each year. This document contains chapters covering water quantity (e.g., the effects of droughts or excessive precipitation during the reporting period), water quality of streams and reservoirs; watershed management, and water quality models (terrestrial and reservoir). In 2014, the limnology and hydrology information provided in the annual report was supported by an extensive monitoring effort. Monitoring was conducted at approximately 201 routinely-sampled reservoir and stream sites, resulting in over 4,900 samples and over 115,000 analyses. Protozoan sampling consisted of 509 routine samples that were analyzed for *Giardia*, *Cryptosporidium*, turbidity, pH, and temperature at 42 sampling sites (including keypoints). In addition, 126 samples were collected at eight sites for human enteric virus examination. Biomonitoring samples were collected at 39 sites to assess stream conditions.

In addition to the water quality monitoring discussed above, DEP has developed and continues to expand a Robotic Water Quality Monitoring Network (RoboMon) in the watershed. Continuous monitoring data are obtained at key upstate reservoirs and watershed tributaries to provide critical data for immediate use in decision making by water supply managers, as well as for water quality model development and model forecasting.

The robotic network is configured with sensors that measure an array of parameters particularly related to features of pollutant transport (e.g., temperature, specific conductivity, and turbidity). Robotic platforms are deployed year-round at Kensico Reservoir, and depending on environmental conditions from April through November on Ashokan, Rondout, Neversink, Cannonsville, and Schoharie Reservoirs. Some of these reservoir buoys include meteorological stations on the surface. Reservoir profiling buoys take measurements through the water columns at one-meter increments from surface to bottom every six hours. Kensico's program also includes two fixed-depth buoys equipped with three transmissometers each measuring water transparency near the Delaware Aqueduct intake site. Water quality robotic monitoring huts (RoboHuts) are also located on the major stream inflows to the reservoirs (Esopus, Rondout, and Neversink Creeks) for year-round data collection. The stream RoboHuts capture data every 15 minutes. During the 2014-15 winter under-the-ice buoys were deployed and tested in Ashokan Reservoir to provide subsurface data during winter ice cover conditions. In 2015, DEP upgraded RoboMon further to include chlorophyll, phycocyanin, dissolved oxygen and colored dissolved organic matter in an effort to improve DEP's reservoir loading models and ultimately improve DEP's understanding of the factors that influence disinfection by-product formation potential. These enhancements were made at the existing site on the Neversink River, the existing buoy on Neversink Reservoir, and a newly installed buoy on Cannonsville Reservoir.

A data transmission system delivers water quality measurements to DEP staff in near real-time. Data are transmitted via cellular modem from the robots to DEP every six hours. The data are stored and reviewed in DEP's Laboratory Information Management System (LIMS). The data are also used to inform operational decisions through the OST. The OST accesses the LIMS database automatically for data retrieval. Reservoir and stream water quality data are also available from DEP's RoboMon Network to aid in rapid decision making. In 2015, the RoboMon project produced nearly 1.9 million measurements at 20 sites.

4.16.2 Modeling

DEP has developed watershed, reservoir, and system operations models, and has applied these models both individually and in linked simulations to support the goal of ensuring the delivery of adequate quantities of high quality drinking water now and in the future. During this five-year reporting period, these models have been, and continue to be used to evaluate the effects of changes in land use, watershed management, point source pollution controls, climate change, water supply system operation, and water demand.

DEP has undertaken this model development and application work both with DEP employees, and with postdoctoral researchers working under DEP contracts with the City University of New York Research Foundation (CUNYRF). The first DEP-CUNYRF contract was concluded during the reporting period. In August, 2014, a second four-year contract supporting four full time postdoctoral researchers and five part-time faculty advisors was initiated. These researchers are currently working in the following areas: (1) evaluation of climate change, (2) evaluation of FAD programs and land use changes, and (3) simulation of dissolved organic carbon and disinfection byproducts in DEP watersheds and reservoirs.

Through roughly mid-2014, application of models to evaluate the status and control of eutrophication in the Delaware system of reservoirs (in particular Cannonsville) was one focus of the modeling program. The Generalized Watershed Loading Function (GWLF) and Soil Water Assessment Tool (SWAT) watershed models were applied to simulate streamflow and nutrient loads for various land use, watershed management and climate change scenarios. In many cases, these flows and loads were then used as inputs to reservoirs models to predict the impact on eutrophication including phytoplankton abundance and speciation, nutrient dynamics, and hypolimnetic oxygen depletion. In the last 18 months of the reporting period, coincident with the start of the new CUNYRF contract, the focus of eutrophication-related work has shifted to simulation of organic carbon and disinfection byproducts in Cannonsville and Neversink reservoirs. Application of the model Regional Hydro-Ecologic Simulation System (RHESSys) to forested portions of the watershed was initiated during the reporting period. DEP is exploring alternative reservoir model frameworks for simulating these substances, including the General Lake Model/Aquatic Ecosystem Dynamics (GLM/AED) model supported by the Global Lake Ecological Observatory Network (GLEON).

Model development and application to evaluate the occurrence of episodes of high turbidity in the Catskill system continued as a focus of DEP's water quality modeling program. Watershed models such as GWLF and SWAT were used to simulate suspended solids and turbidity loading from Catskill system watersheds, and a reservoir turbidity model based on the CE-QUAL-W2 two-dimensional framework has been applied to Schoharie, Ashokan, and Kensico Reservoirs in the Catskill system as well as Rondout Reservoir in the Delaware system. LINKRES is a software application developed by DEP that allows linked hydrothermal simulations for all WOH reservoirs plus Kensico. Specifically for turbidity simulations, LINKRES can complete linked simulations of Schoharie, Ashokan, Rondout, and Kensico. LINKRES has the capability of conducting positional analysis simulations, where repeated simulations for multiple meteorological conditions based on historical records are used. Positional analysis generates model predictions in the form of probabilistic distributions that reflect uncertainty in future weather conditions.

DEP is also continuing the development and routine application of the OST. OST combines water quantity (balance) models for the entire water supply system, meteorological and streamflow forecasting, data acquisition links to near real-time monitoring and other system data, system optimization features, and data visualization tools. For the Catskill system (Schoharie, Ashokan, and Kensico), OST contains the CE-QUAL-W2 turbidity models described above, so that OST can evaluate alternative operational strategies to minimize turbidity impacts and select an optimal strategy.

To complete system-wide evaluations of the effects of climate change on the DEP water supply system, DEP initiated the Climate Change Integrated Modeling Program (CCIMP), involving the linked application of global climate model predictions, watershed, reservoir, and system operations models. In Phase I of CCIMP, completed in 2013, future climate predictions for the WOH watersheds were downscaled from global climate models using the change factor method, a widely used but relatively simple procedure. In Phase II, stochastic weather generators are under development for these watersheds, which allow more sophisticated downscaling procedures to be used, and facilitates application of so-called bottom-up approaches for evaluating the impact of climate change. These approaches to forecasting future local meteorology in the watersheds are being used to forecast future water quality, including eutrophication, dissolved organic carbon and disinfection byproducts, and turbidity.

4.16.3 Geographic Information System

DEP's upstate Geographic Information System (GIS) was used during the assessment period to manage DEP's interests in the lands and facilities of the upstate water supply system, and to display and evaluate the potential efficacy of watershed protection programs through maps, queries, and spatial analyses. The GIS was also used to support watershed and reservoir modeling of water quantity and quality, as well as modeling of water supply system operations. GIS activities that support numerous FAD and MOA watershed management applications are described in annual reports. These activities are categorized as GIS technical support, development of new GIS data layers and aerial products, GIS infrastructure improvement, or GIS data dissemination.

DEP GIS staff provide technical project support, manage the centralized GIS infrastructure, laboratory, and database content, and develop proposals to address future GIS needs. GIS resources were utilized by staff at offices throughout the watershed, directly and via the Watershed Lands Information System (WaLIS).

GIS Technical Support

A primary GIS accomplishment during the assessment period was implementing watershed-wide data upgrades to the central GIS library for hydrography, reservoir basin boundaries, topography, and all related data sets. Derived from both 1-meter LiDAR and 1-foot orthoimagery, these datasets show significantly more features at a much higher resolution than previous GIS products (Figure 4.30). This marks the first time DEP has updated hydrography data since the start of the upstate GIS system in the early 1990s. Before this update, the best available hydrography information was 1:24,000 scale USGS "blue line" data, mainly derived from 1940-1970 aerial photos. A comparison of this high resolution data with older 1:24,000 scale USGS data is shown in Figure 4.31.

As part of the data implementation process, the GIS Program coordinated activities between the FEMA, NYSDOT, and DEP surveyors to verify that FEMA specifications for source LiDAR accuracy were met, thus ensuring data could be used in subsequent floodplain

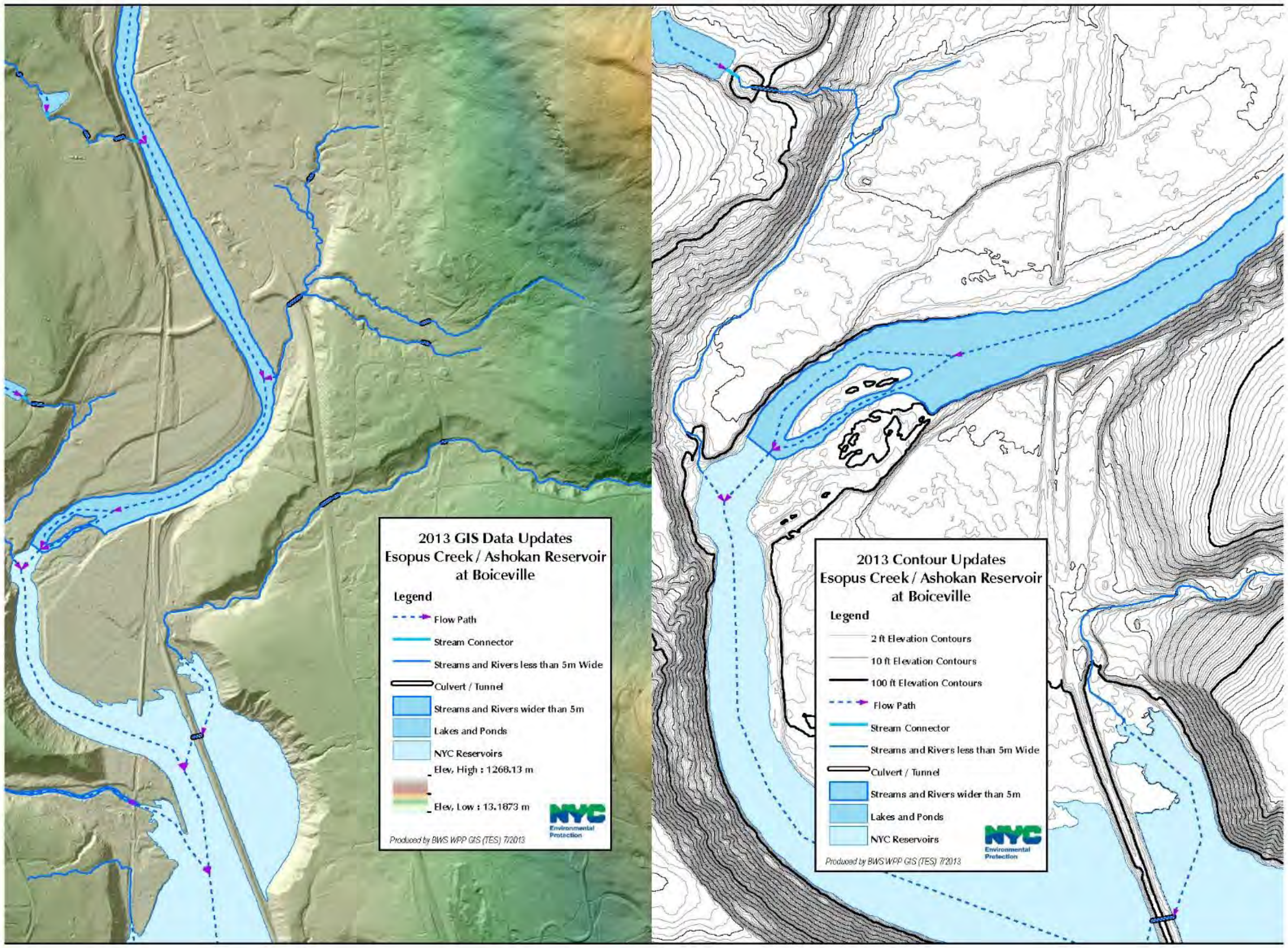

Figure 4.30 A portion of the LiDAR-generated hydrography GIS data in NHD format for the Esopus Creek at Boiceville, NY, in the Ashokan Basin.
This hydrography dataset was developed to cover the full extent of the NYC reservoir basins, and includes culverts, stream centerlines, water body polygons with their flow paths, and a 1-meter hydro-conditioned DEM. In the right image are 2-foot elevation contours derived from the 1-meter DEM displayed as shaded relief in the left image.

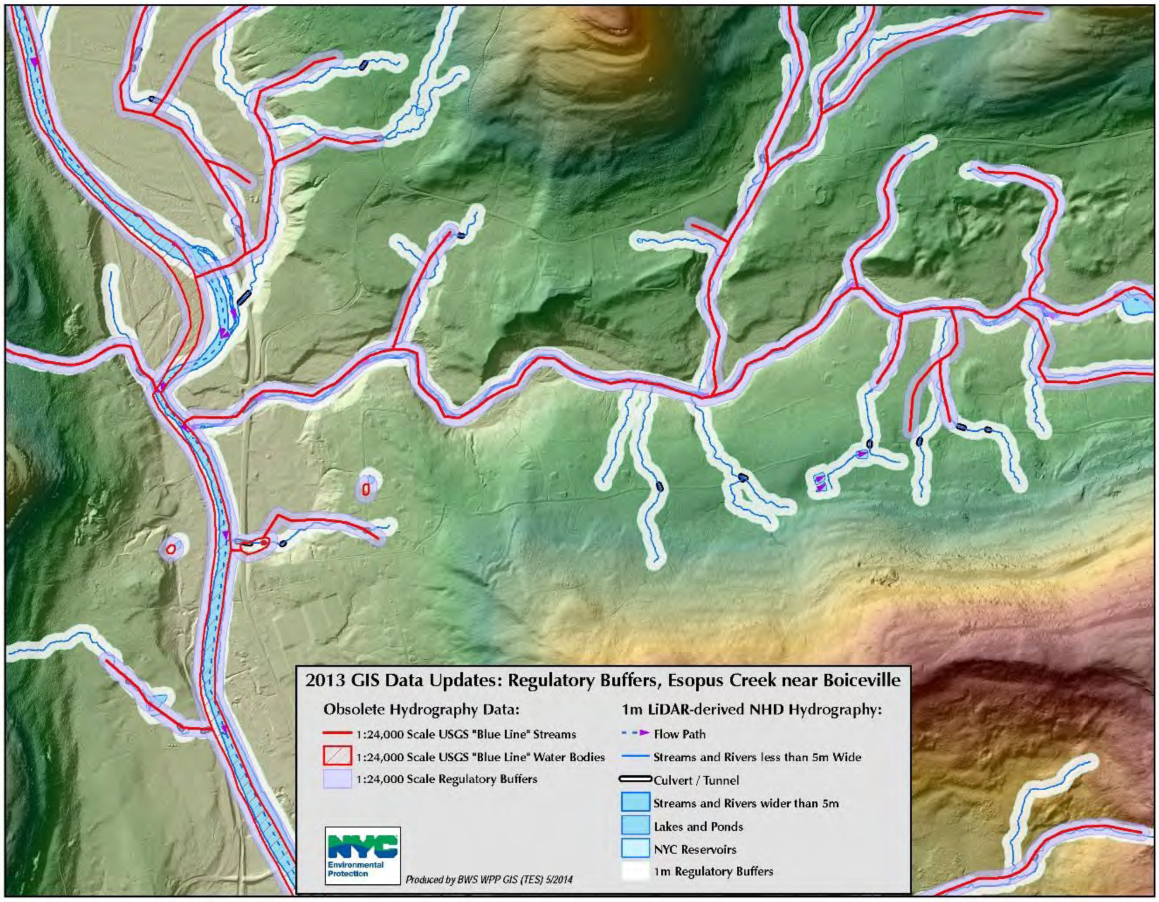

Figure 4.31 A comparison of 100-foot regulatory setbacks based on newly-mapped LiDAR-derived hydrography to setbacks generated from older 1:24,000 scale hydrography.
The increase in mapped water features has an effect on the inventory of known land cover, parcels, and buildings that may now be eligible for certain watershed partnership programs, BMP implementation, or acquisition.

mapping initiatives. DEP staff performed extensive quality-assurance field checks of the new watershed boundary, and ensured sufficient accuracy for regulatory application. All hydrography-related data dependencies were then updated in GIS and WaLIS. Finally, staff created all sub-basin GIS delineations in-house using LiDAR-derived catchments.

Some noteworthy changes in watershed statistics due to the newly mapped features are a 17.8% increase in delineated stream miles (581 miles) for the CAT/DEL watershed, and a 9.3% increase (74 miles) for the Croton watershed. There is a 51.6% increase in the acreage of non-reservoir lakes and ponds for the CAT/DEL watershed and a 14.9% increase for the Croton watershed. While there was no significant change in the overall size of the DEP watershed due to more accurate mapping of the drainage, some individual basins gained significant acreage at the expense of, or lost significant acreage to, their neighboring basins.

The GIS Program also provided technical support and data development, including extensive Global Positioning System (GPS) fieldwork, for a variety of protection programs and modeling applications:

- Generated customized statistical reports depicting the breakdown of land cover classes, including impervious surfaces, on DEP lands or particular watershed basins, using the latest high-resolution datasets delivered in 2013
- Compiled and analyzed Comprehensive Forest Inventory (CFI) plot location data and created GIS tools to facilitate importation of plot data from other formats
- Updated CWC Septic Repair Program prioritization based on proximity to newly-mapped streams
- Created WOH hydrologic derivative rasters from the 1-meter Digital Elevation Model (DEM) to screen for stream reaches with greater stream power and potential erosion
- Analyzed regional rainfall totals and mapped emergency response activity after tropical storms Irene, Lee (2011) and Sandy (2012)
- Supported climate change impact assessment

Completion or Acquisition of New GIS Data Layers and Aerial Products

Many significant new GIS layers were completed as the result of major data development efforts:

- Local Resolution National Hydrography Dataset (NHD), LiDAR-derived: watershed and individual reservoir basin delineations at 1-meter resolution, now the new official representation; water features in USGS NHD format, including streams, rivers, lakes, ponds and DEP reservoirs at 1-meter resolution; DEM and shaded relief models at 1-meter resolution, and two-foot elevation contours as seamless data wall-to-wall for WOH and EOH watersheds, with index contours at 2-, 20-, and 100-foot levels
- High-resolution Land Cover and Land Use: ten-year update of land use, land cover, and impervious surface data; 16 land-cover categories, with 0.5-acre minimum mapping unit (MMU) and calculated accuracy at 97%; three categories of impervious surface (road, building, other impervious), with 400-sq. ft. MMU and calculated accuracy at 93%
- Floodplain Data Update: integrated latest FEMA digital flood insurance rate map data for each watershed county into GIS and WaLIS; completed all required updates to reports, maps, business tables, and derived GIS layers that have dependencies on floodplain data; notified users of changes, especially those in the Land Acquisition and Regulatory Programs.

- Bathymetric Surveys of WOH Reservoirs: raw and corrected survey points, a derived topographic surface of the reservoir bottom from those points, 2-foot contours of reservoir depth derived from the topographic surface, and a stage-area-volume table in 0.01-foot increments; USGS completed surveying all six reservoirs, requiring coordination with Operations and DEP Police, draft data forthcoming

Several existing feature classes were updated or overhauled as part of ongoing annual data maintenance. These include mission-critical data sets for various DEP programs, such as annual digital tax parcels for all watershed counties, DEP-owned land or interests, NYS-owned land, DEP 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 LIMS.

GIS Infrastructure Improvement

The GIS Program also develops, upgrades, and maintains WaLIS, which currently operates on the workstations of over 250 DEP users. New maps and data viewers were set up to begin to track upstate water connections to DEP aqueducts, as well as billing and consumption information related to those connections. Crystal Reports software is continually used to develop and maintain hundreds of built-in customized WaLIS server reports for all DEP user groups. In an effort to convert stand-alone software into a thin-client browser application, a web-based "lite" version of the WaLIS parcel viewer (NYC Watershed Viewer) was developed, tested and deployed to users. In order to facilitate field data entry into WaLIS by Regulatory and Engineering Programs staff, a tablet application was completed and is now actively working with several customized data forms. Tools were created to enable staff using WaLIS to access water quality data from DEP's LIMS.

Several hardware components of GIS infrastructure were upgraded. The migration of all GIS and WaLIS databases onto a new server cluster was completed in 2013. This required a significant amount of coordination and support from DEP IT staff, and implementation of additional power sources in the Kingston building. All aerial imagery, elevation data, and WaLIS attachments were migrated to a large storage array for raster data. In 2014, the Bureau procured and deployed 47 GIS and Modeling "power user" workstations and two large-format color plotters. Maintenance was performed on numerous GPS units used by various programs, including updating data dictionaries, updating software, and inventorying all GPS hardware and software.

All ESRI GIS software licensing continues to be coordinated and managed at the Agency level through an ESRI Enterprise Licensing Agreement (ELA), which was renewed in 2012. In addition to the ESRI ArcGIS User and Server applications, the ELA provides DEP with licenses of ESRI ArcEngine Runtime and ArcEngine Developer's Toolkit for use in continued development and deployment of the WaLIS application.

Data Dissemination to Stakeholders

Using data sharing policies developed in cooperation with DEP Legal, the GIS Program reviewed all outside requests for GIS data, and either emailed or wrote approved data to CDs or portable drives as required for data sharing. Over 50 stakeholders and communities are currently on a schedule to receive semiannual data updates for newly-acquired and existing DEP Water Supply lands, and were sent these data via email each January and July of the assessment period. The GIS program continuously filled data sharing requests for 1-meter LiDAR-derived hydrography, topography, and reservoir basin data to partners and stakeholders such as WAC, CWC, EOHWC, NYSDEC, NYS Office of the Attorney General Watershed Inspector, SUNY College of Environmental Science and Forestry, SUNY Albany, Columbia University, New York Natural Heritage Program, The Nature Conservancy, and various watershed county and town offices. Numerous other individual GIS data layers were sent to contractors and consultants working on various DEP-related projects, including those for various road, bridge, or dam repairs, as well as the RWBT Bypass Project.

4.17 Waterborne Disease Risk Assessment

New York City's Waterborne Disease Risk Assessment Program (WDRAP) was established to: (1) obtain data on the rates of giardiasis and cryptosporidiosis, along with demographic and risk factor information on case-patients; (2) provide a system to track diarrheal illness to ensure rapid detection of any outbreaks; and (3) attempt to determine the contribution (if any) of tap water consumption to gastrointestinal disease. WDRAP was initiated in 1993, and has been modified over the years, including with the implementation of significant enhancements. Enhanced disease surveillance and syndromic surveillance continue as WDRAP's core ongoing components. In addition, some outreach/education activities are undertaken, and various special projects have been implemented during some years. The program is jointly administered by the Bureau of Communicable Diseases (BCD) of the 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 are provided below for this assessment report (data compiled through December 2015). WDRAP annual reports are available at: http://www.nyc.gov/html/dep/html/drinking_water/wdrap.shtml. (Report frequency changed over the years. Beginning in 2013, WDRAP reporting is on an annual basis.)

4.17.1 Disease Surveillance

Enhanced disease surveillance was implemented to ensure complete reporting of all laboratory-diagnosed cases of giardiasis and cryptosporidiosis, and to collect demographic and risk factor information on cases. Brief highlights are provided below.

- **Trends**: Overall NYC rates of giardiasis and cryptosporidiosis have been on a general downward trend over the years of this surveillance program. A 65% decrease in giardiasis cases was observed in NYC from 1994 to December 2015, and a 72% decrease in cryptosporidiosis cases was observed from 1995 to October 2015. (See Figure 4.32 and Figure 4.33, respectively). The most likely cause of the decline in cases of cryptosporidiosis was the advent of highly active anti-retroviral therapy (HAART). NYC cryptosporidiosis rates have been comparable to national rates, although they have trended down in recent years while national rates have increased. Rates of giardiasis nationally have also declined.

An increase in cryptosporidiosis cases was noted in the autumn of 2015. The increase was observed especially in the area of one of the university hospitals. Further investigation linked many of the cases to “Biofire”, a rapid test for many enteric organisms that had been made newly available in the hospital. Specimens were confirmed at NYSDOH laboratory. All cases were interviewed. The increase in cryptosporidiosis cases observed in late 2015 is thought to represent an increase in testing rather than an increase in cases. (Cryptosporidiosis is believed to be underdiagnosed under the testing protocol that is typically followed).

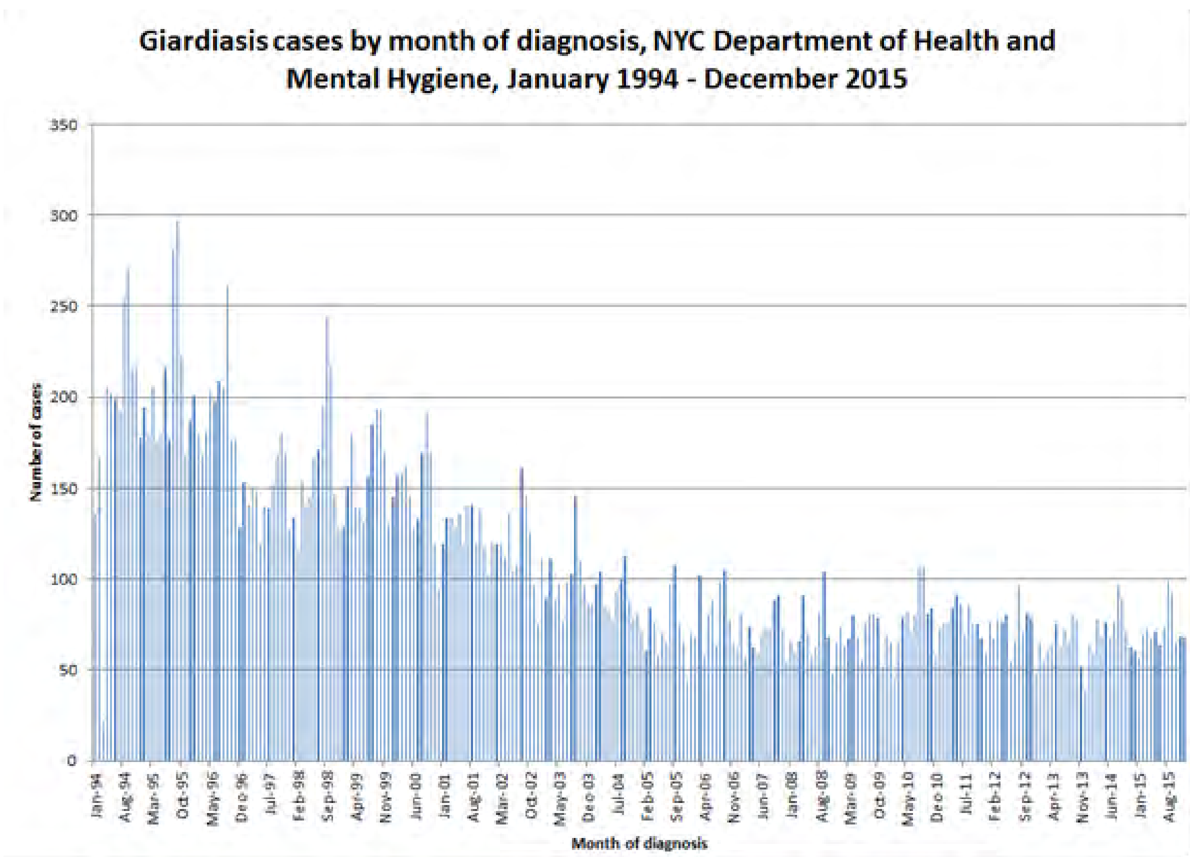

Figure 4.32 Giardiasis trends in NYC.
[Note: Giardiasis active surveillance began in NYC July 1993]

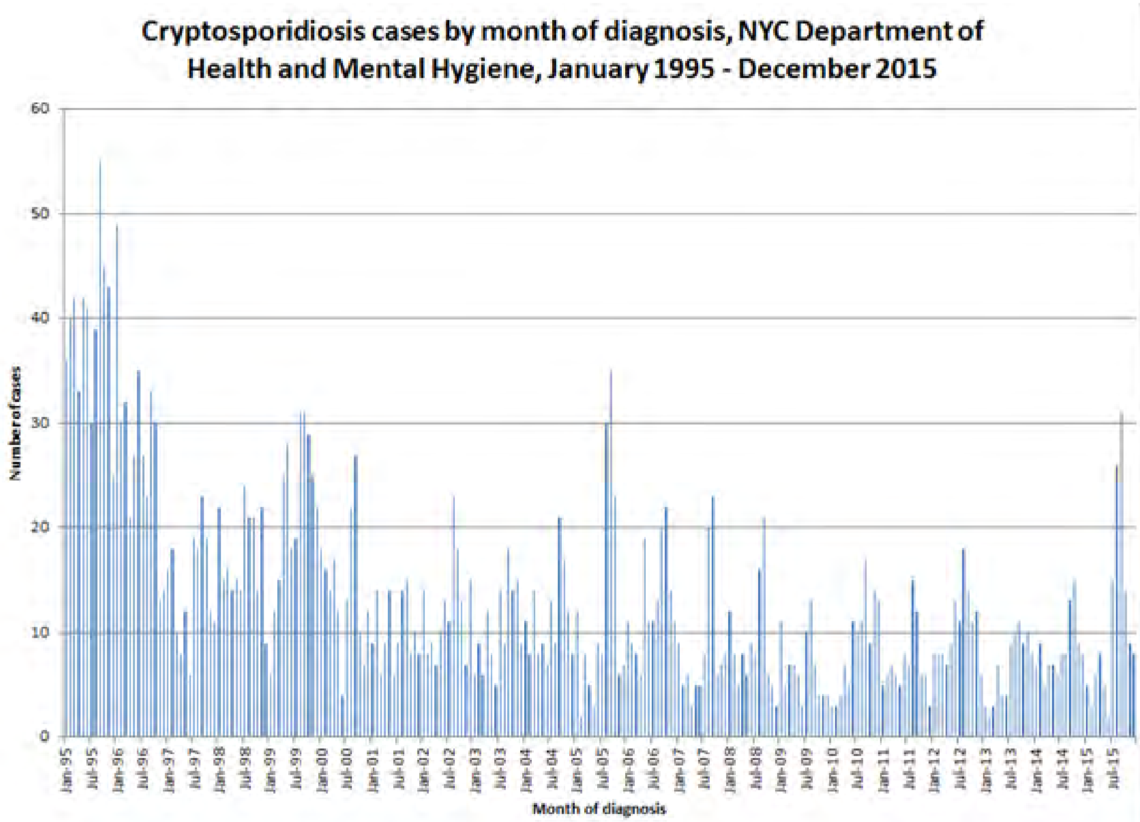

Figure 4.33 Cryptosporidiosis trends in NYC.

[Note: (1) Cryptosporidiosis became a reportable disease in NYC Jan 1994, and active surveillance began November 1994. (2) See WDRAP annual reports regarding case increases observed in August 2000 and August 2005 (i.e., cases linked to group travel to resorts, and to suspected reporting bias, respectively). Regarding Autumn 2015 increase, see "Trends" subsection in this chapter (i.e., new test available).

- **Demographic Highlights**: The highest rates of both giardiasis and cryptosporidiosis are generally seen in children and in men aged 20-59. The borough with the highest rates for both infections is Manhattan. Among cryptosporidiosis patients the most common race/ethnicity varies from year to year; among giardiasis cases little information on race/ethnicity is available. With regard to socioeconomic status, data suggest that poverty is not a determinant for either cryptosporidiosis or giardiasis. The demographic patterns seen in NYC for both giardiasis and cryptosporidiosis are largely consistent with person-to-person spread and travel.
- **Risk Factor Results**: Interviews are conducted of cryptosporidiosis patients to collect data on commonly reported potential risk exposures, tap water consumption, and HIV/AIDS status. However, the determination of an association between cryptosporidiosis infection and exposure to possible risk factors cannot be made without reference to a suitable control population. In an attempt to see if there are any patterns of interest, data have been compared

between cryptosporidiosis patients who are immunocompromised due to HIV/AIDS and cryptosporidiosis patients who are immunocompetent, looking at four potential risk categories (i.e., international travel, recreational water contact, animal contact, and high-risk sex) using the chi-square test.

Two changes that were made in WDRAP data collection, analysis and reporting during this assessment period include:

- In 2011, WDRAP began reporting disease rates by neighborhood poverty (or SES level), as part of a DOHMH-wide effort to better assess whether various disease rates are related to economic disparities.
- In the 2012 annual report WDRAP staff began to report both confirmed and probable cases of cryptosporidiosis (previously all cases were reported as confirmed). (See 2012 WDRAP Annual Report for further details).

4.17.2 Syndromic Surveillance

Syndromic surveillance systems have been implemented with the aim of monitoring gastrointestinal disease trends in the general population via tracking of sentinel populations or surrogate indicators of disease. Such syndromic tracking programs provide greater assurance against the possibility that an outbreak would remain undetected. In addition, such programs can potentially play a role in limiting the extent of an outbreak by providing an early indication of a problem so that control measures may be rapidly implemented. NYC maintains four distinct and complimentary syndromic systems. Recent summary highlights are provided on each, with the only major change occurring in the OTC-ADM system(s) during this assessment period.

Hospital Emergency Department Monitoring

Monitoring of hospital emergency departments (EDs), for gastrointestinal illness (i.e., diarrhea and vomiting) continued during this period. Data are received and analyzed for signals. DOHMH receives electronic data from 51 of NYC's 53 EDs, reporting approximately 11,500 visits per day, roughly 98% of all ED visits citywide. There have been no significant changes to this system during this assessment period.

Medication Monitoring

Major modifications/enhancements to NYC's anti-diarrheal medication surveillance program have been made over the years including the initiation and expansion of the DEP's ADM program and the initiation of DOHMH's Over the Counter (OTC) medication sales systems. The two systems were merged in 2012 into one ADM-OTC operated by DOHMH. The first full year of operation of the merged OTC-ADM system was 2013. DOHMH conducted an evaluation of the impact of the merger of the two systems and a final report on the evaluation was prepared, and sent to NYSDOH and USEPA June 18, 2014.

In late 2015, one participating store chain declared bankruptcy and thus that data stream was lost from the ADM-OTC system. However, offsetting this loss of data is the addition of two new store chains to the system, which is in progress, and which we anticipate will add over 300 new stores. One of the two newly participating store chains began submitting files in November 2015. Data analysis is expected to begin in early 2016 (after adequate baseline has been achieved). With regard to the second new store chain, test data has been reviewed, data transfer issues are being resolved, and we anticipate data from this chain to be included in the ADM-OTC analysis sometime in spring 2016.

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 (following closing of other lab in 2010), providing data on the number of stool specimens examined per day for (1) bacterial culture and sensitivity, (2) ova and parasites, (3) *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. There are currently eight nursing homes participating. Reportable outbreaks are to be reported 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. Testing for culture and sensitivity occurs at the NYCDOHMH's Public Health Laboratory. On May 1, 2011, the DOHMH discontinued parasitology testing. Parasitic analysis of samples (i.e., O&P, and *Cryptosporidium*) now occurs at NYSDOH Wadsworth Center. Otherwise, there have been no significant changes to the system since 2002.

Syndromic Surveillance 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, per DOHMH. Knowledge of these trends provides a baseline of data which should improve the City's ability to detect aberrations. Data from ED and pharmacy syndromic surveillance systems are received daily and for the clinical lab system is 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 are summarized in the WDRAP annual reports. DOHMH communicates syndromic surveillance findings on a routine basis per above, 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 outbreak in NYC during the assessment period.

4.17.3 Outreach/Education

Some outreach and education activities continued during the current assessment period, however, level of effort is reduced compared with the beginning of the WDRAP program (when such outreach was felt to be more necessary). Outreach is primarily conducted 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 staff has also presented WDRAP topics at NYC colleges/universities, and symposiums events. Such talks serve to enhance awareness of waterborne diseases, and also may lead to more complete disease diagnosis and reporting.

During this period, DOHMH published a City Health Information (CHI) Bulletin for health care providers which made note of the importance of testing for enteric illness in men who have sex with men, as this population is at particularly high risk for infection with cryptosporidiosis and giardiasis. See report at: http://www.nyc.gov/html/doh/downloads/pdf/chi/chi-33-4.pdf.

4.17.4 *Cryptosporidium* and *Giardia* Action Plan & Water Security Initiative

During this assessment period, DEP developed the Hillview *Cryptosporidium* and *Giardia* Action Plan (CGAP) to provide guidance for intra- and inter-agency action and coordination in the event of *Cryptosporidium* oocyst and/or *Giardia* cysts findings at Hillview Reservoir-Catskill Aqueduct (Site 3). The CGAP was first completed and made effective August 2011, and has since been updated and revised. The CGAP essentially has replaced the earlier-developed DEP *Cryptosporidium* Action Plan (CAP) for Kensico Reservoir.

During 2012, WDRAP staff and others from DOHMH and NYSDOH completed a functional exercise of the CGAP. This exercise fulfilled a requirement under the Hillview Administrative Order on Consent and built upon lessons learned as part of DEP's consequence management planning and incident management training. The findings and suggestions for improvement were reviewed and incorporated into revisions to the CGAP that became effective January 1, 2013.

From 2009 – 2012, DEP worked under a grant awarded by USEPA to participate in the Contaminant Warning System Demonstration Pilot Project. With regard to WDRAP, under this grant, DEP generated enhanced documentation of public health surveillance programs, communicated with other participating cities on public health surveillance activities, and reviewed and shared lessons learned. Final report was submitted by DEP to USEPA in December 2012.

4.17.5 Major Storms & Public Health Monitoring

Three very major storms hit NYS in the years 2011 - 2015, for which WDRAP data were reviewed to determine whether there was evidence of an increase in gastrointestinal illness in the period afterward. The storms (and when they hit New York) were as follows: Tropical Storm Irene (late August of 2011), Tropical Storm Lee (early September of 2011), and Hurricane Sandy (late October of 2012). Both giardiasis/cryptosporidiosis records and syndromic surveillance findings were reviewed to see if any notable increase was observed. There was no disease increase apparent in the case surveillance data, nor in the syndromic surveillance data, in the periods following these three major storms.

Hurricane Sandy had a major impact on populations and operations in many areas of NYC, and some effects were felt in NYC's public health monitoring programs as well. DOHMH undertook special measures following Hurricane Sandy to maintain effective public health monitoring, and also to investigate a possible increase in giardiasis cases. DOHMH developed a modified trends analysis program, to account for reduced disease reporting resulting from disruption of services in several hospitals, laboratories and medical practices in the aftermath of the hurricane. In addition, DOHMH interviewed giardiasis case-patients for a period to determine whether a possible increase in giardiasis cases was related to Hurricane Sandy. In summary, health surveillance activities did not indicate an increase in giardiasis or cryptosporidiosis rates due to Hurricane Sandy.

4.17.6 Conclusions

During the current assessment period (2011-2015), a significant change in WDRAP was the merging of the ADM and OTC systems in 2012. More recently were changes (loss and additions) in the chains participating in the ADM-OTC system. Other changes have been relatively minor, such as the number of hospitals in the emergency department system, resulting from the consolidation of the health care system in NYC. Rates of giardiasis and cryptosporidiosis have declined markedly in NYC over the years of this surveillance program. There has been no evidence of an outbreak of waterborne disease in NYC during WDRAP implementation, including during this assessment period. WDRAP implementation continues, and reports continue to be prepared and submitted as per the FAD schedule.

5. Catskill System

5.1 The Scope of Water Quality Analyses

A description of the approach and scope of the water quality analyses is given in Appendix C. In brief, the water quality analyses cover approximately 22 years of data to provide a long-term context for interpretation. This time span provides a view of these changes in the context of natural variation (such as floods and droughts) and allows sufficient time for program implementation to impact water quality. The water quality data used in this analysis begins in 1993, which represents conditions at the outset of filtration avoidance when many watershed protection programs were in their infancy. The data from this decade represents conditions with fewer watershed programs in place. The time period from about 2000 through 2014 represents a time when watershed protection programs have reached a high level of implementation.

5.2 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 Reservoir in 1926. Water leaves Schoharie Reservoir via the 18-mile Shandaken Tunnel, which empties into the Esopus Creek at Allaben and then travels 11 miles to the Ashokan Reservoir, which consists of a West Basin and an East Basin. Water leaves Ashokan via the 92-mile long Catskill Aqueduct, which travels to the Kensico Reservoir in Westchester County. 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 45 year period (1966 to 2015) are depicted in Figure 5.1. 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 that is delivered by its large watershed. Schoharie water residence time averages about one and a half months, Ashokan West averages about two months, and Ashokan East 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 that Schoharie would adjust for example, to a new loading level in about four months, whereas Ashokan West would take about six months and Ashokan East about one year to re-equilibrate to a new steady state after a change in its nutrient load.

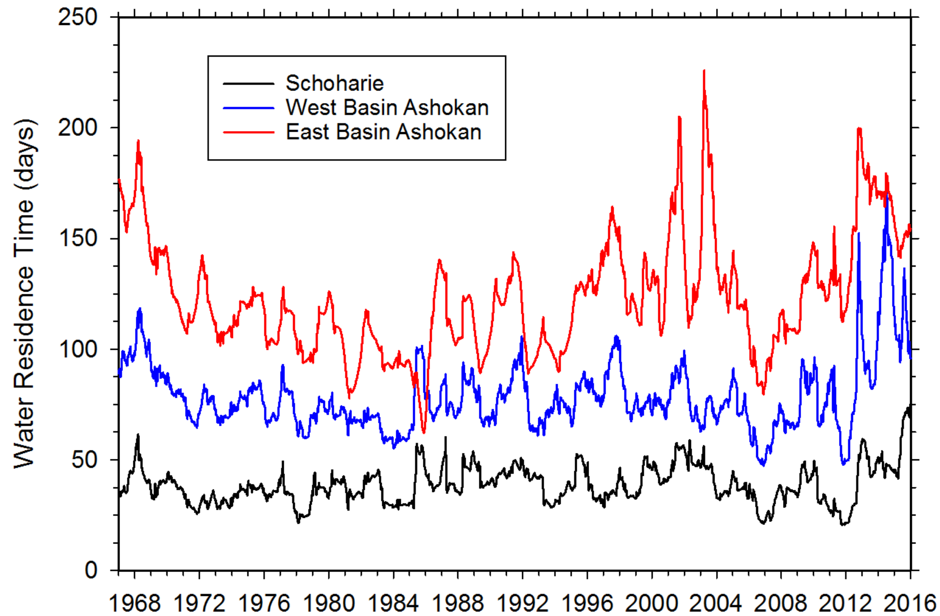

Figure 5.1 Water residence times in the Catskill System Reservoirs, 1966 - 2015.

5.3 The Schoharie Watershed

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.

5.3.1 Land Use in the Schoharie Watershed

Of the 201,658 acres of land in the Schoharie watershed, 79.1% is forested, 8.1% is urban or built-up land, 5.3% is brushland or successional land, 0.1% is classified as barren land, 1.1% is water, and the remaining 6.2% is in agricultural use (Figure 5.2). (Note that agricultural

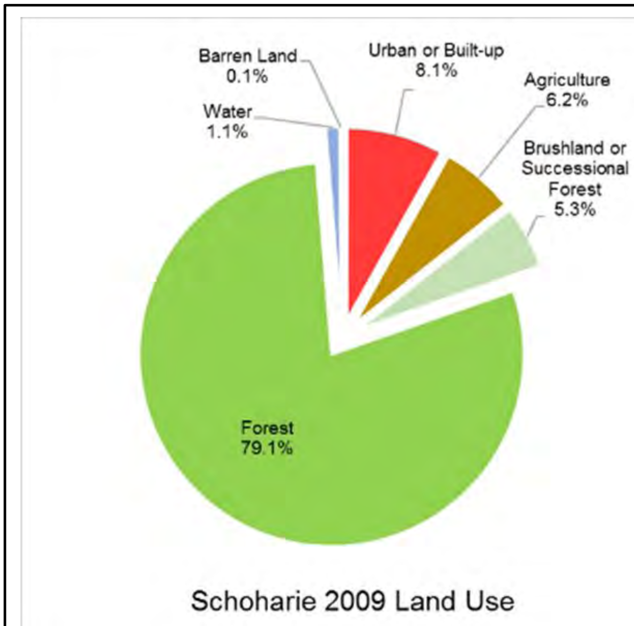

Figure 5.2 Schoharie drainage basin land use based on 2009 data.

land use acreage differs between this pie chart and the subsequent bar chart because the agricultural program includes grassland and brushland used as farmland.) The Schoharie watershed also has 2.3% of impervious surface.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

5.3.2 Program Implementation in the Schoharie Watershed

Since 1996, over 300 total BMPs have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater in the Schoharie watershed agricultural areas (Figure 5.3). These BMPs are associated with approximately 7,000 acres of farmland (i.e., more than 3% of the drainage basin area). Over 80 environmental infrastructure projects have been constructed since 1999, consisting of both stormwater control facilities and stream management projects, with approximately 20 of those being completed since 2010. More than 800 septic systems throughout the basin have been remediated. Other protection programs related to forestry,

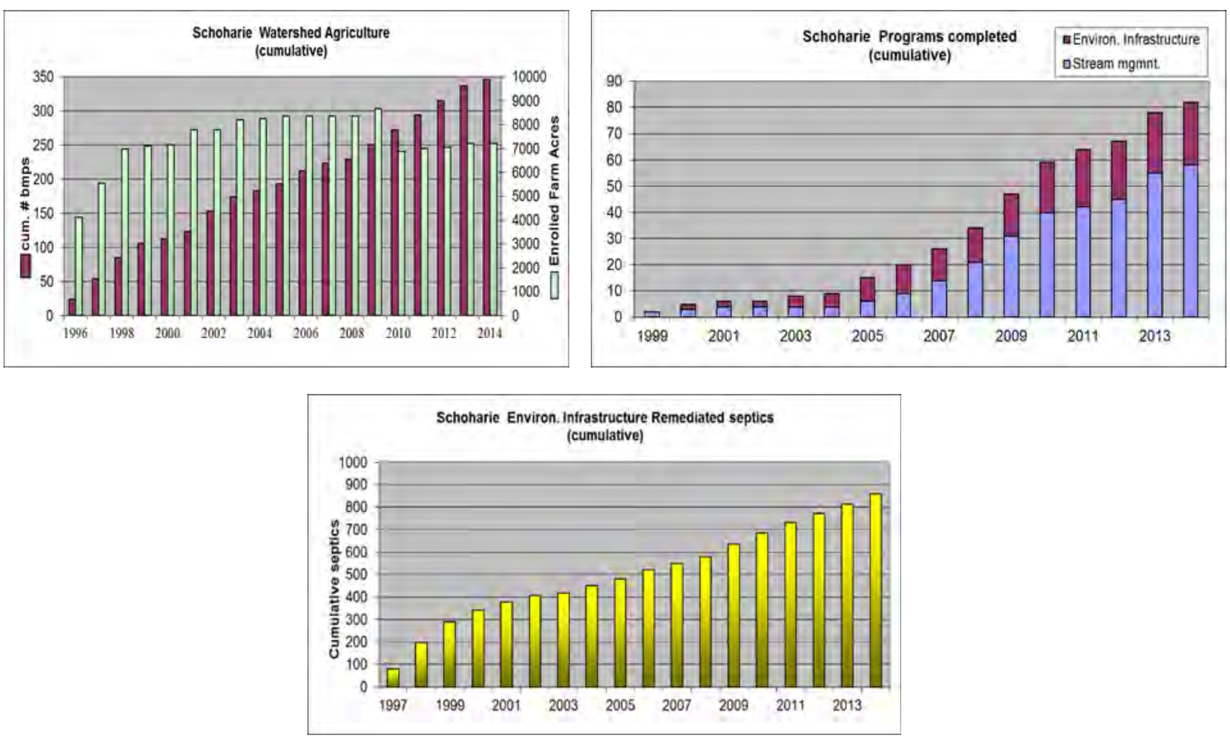

Figure 5.3 History of watershed programs in Schoharie drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control and stream management projects, c) septic system remediation. Bars represent cumulative plots.

wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Watershed Protection Program sections. (Figure 5.3).

5.3.3 Wastewater Treatment Plant and Load Reductions in the Schoharie Watershed

Presently, there are 12 WWTPs sited in the Schoharie watershed, producing approximately 0.715 MGD of flow. On the basis of the most recent SPDES permits, the plants are limited to a collective release of 2.2 MGD of flow. Inputs of phosphorus, as well as other pollutants, from WWTPs to Schoharie Reservoir has been reduced as a result of DEP's upgrades of all surface-discharging WWTPs, including upgrades of the DEP-owned plants at Tannersville and Grand Gorge, and the addition of new infrastructure plants at Windham, Prattsville, and Ashland. DEP's WWTP Compliance and Inspection Program (described in Chapter 4) also assures proper operation of these plants to reduce nutrient loadings.

As illustrated in Figure 5.4 phosphorus loads (as TP) declined considerably from 1994 to 2014, mainly as a consequence of the upgrades to the largest plants, at Tannersville and Grand Gorge. Phosphorus inputs have been further reduced with the completion of new plants in Windham, Prattsville, and Ashland constructed as part of DEP's New Infrastructure Program. The increase in flow seen between 2004 and 2014 reflects the completion of these plants. Even with these higher flows, total phosphorus loads reached an all-time low after 2004.Water Quality Status and Trends in the Schoharie Watershed.

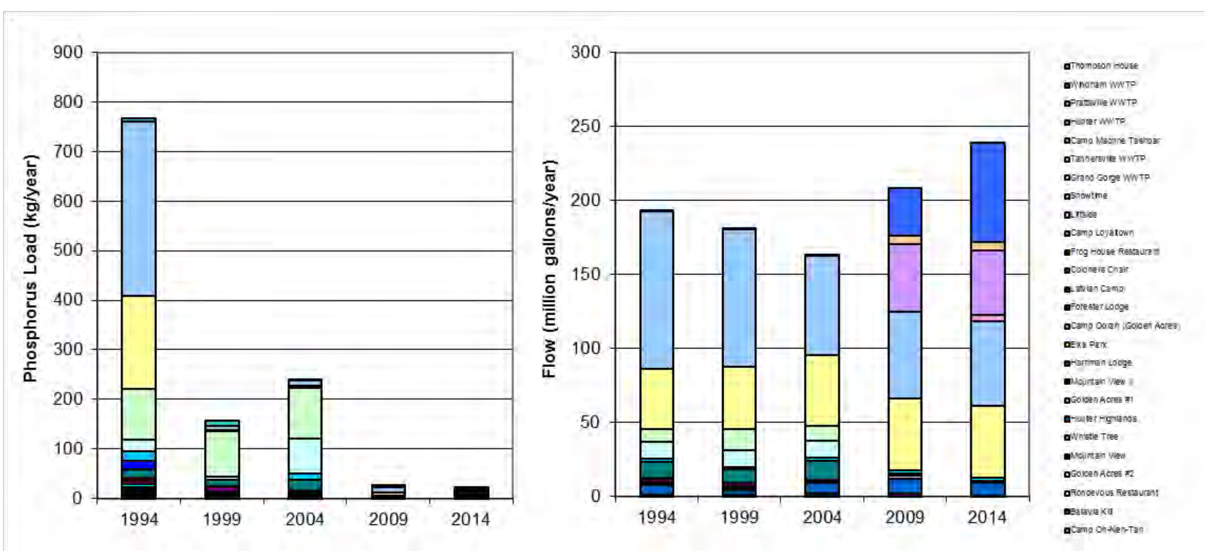

Figure 5.4 Wastewater treatment plant total phosphorus loads and flows in the Schoharie drainage basin, 1994 – 2014.

5.3.4 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 5.5. A comparison of Schoharie Creek (S5I), the principal input to the reservoir, the reservoir (SS), and the outflow represented at the Shandaken Tunnel Outlet (SRR2CM) is shown. All values below the maximum detection limit for fecal coliform and total phosphorus were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2012-2014), fecal coliform bacteria remained well below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the stream inflow site. Consistent with previous evaluations, the reservoir inflow levels were higher than the reservoir and outflow values. Turbidity was impacted by the extreme events of 2011 (see Chapter 2 for more information on the Irene/Lee events in August-September 2011) and reservoir drawdown for dam rehabilitation and operations. While turbidity was slightly elevated at the inflow (likely a residual effect of 2011 events), it was higher in the reservoir with a greater range of variability (median 10.4 NTU and interquartile range 22 NTU), and highest at the outflow with a smaller range (median 20 NTU and interquartile range 13.9 NTU). Likewise, total phosphorus (TP) followed a similar pattern with an inflow median of 9 µg L^{-1}, reservoir median of 15.5 µg L^{-1}, and outflow median of 20.5 µg L^{-1}. Although reservoir TP values extended above the phosphorus-restricted target value of 20 µg L^{-1}, phytoplankton growth was not excessive due to the higher turbidity levels that made light the limiting factor. Consequently, the TSI values for Schoharie Reservoir fell primarily within the oligotrophic range. Conductivity medians were highest at the inflow (91.5 µS cm^{-1}) and slightly reduced in the reservoir and outflow (median 79.25 µS cm^{-1} and 81.5 µS cm^{-1}, respectively).

In summary, water quality was good during the 2012-2014 status assessment period in the Schoharie basin. Exceedances of the of 20 µg L^{-1} benchmark for total phosphorus in Schoharie Reservoir did not result in marked increases in phytoplankton growth, because for this reservoir, light is generally the limiting factor due to suspended particulates.

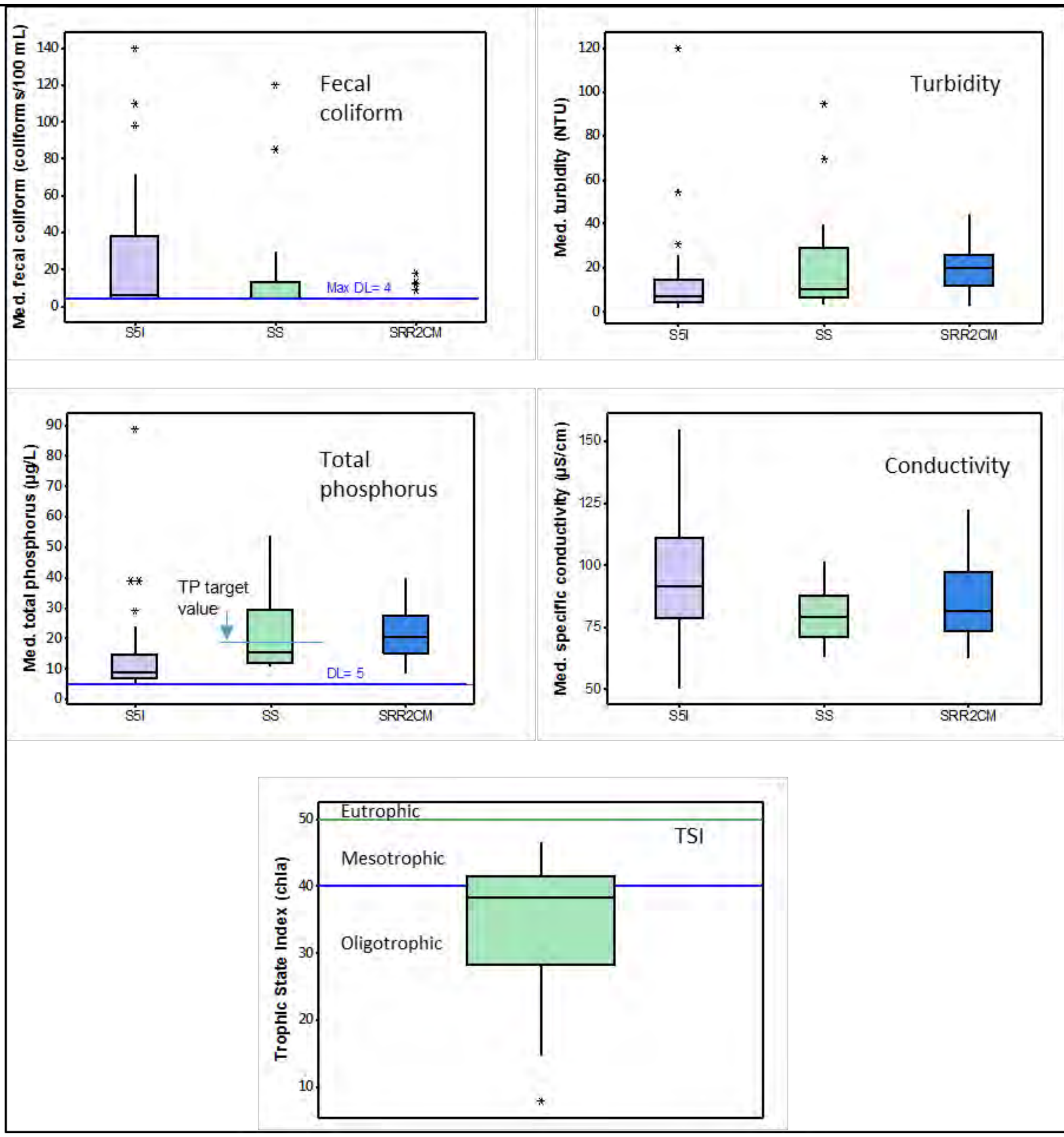

Figure 5.5 Water quality status boxplots using 2012-2014 monthly data for the Schoharie basin main stream input at Schoharie Creek (S5I), Schoharie Reservoir (SS), and the output at the Shandaken Portal (SRR2CM).

Trends (Schoharie)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used.

Water quality trend plots are presented in Figure 5.6. For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. Results of the Seasonal Kendall trend analysis are provided in Table 5.1.

Table 5.1 Schoharie basin trends from 1993-2014 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
S5I[3]	Input	Turbidity	254	0.07	*	0.05
Schoharie	Reservoir	Turbidity	173	0.12	***	0.13
SRR2CM	Output	Turbidity	234	0.20	***	0.36
S5I	Input	Fecal coliform	250	0.02	NS	
Schoharie	Reservoir	Fecal coliform	173	0.16	***	0.00
SRR2CM	Output	Fecal coliform	225	0.02	NS	
S5I[3]	Input	Total Phosphorus	248	0.08	**	0.01
Schoharie	Reservoir	Total Phosphorus	167	-0.08	*	-0.09
SRR2CM	Output	Total Phosphorus	243	0.03	NS	
S5I[3]	Input	Conductivity	250	0.15	***	0.07
Schoharie	Reservoir	Conductivity	165	0.26	***	0.62
SRR2CM	Output	Conductivity	225	0.19	***	0.52
Schoharie	Reservoir	Trophic State Index	167	0.01	NS	

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.
[3] Data were adjusted for flow prior to trend analysis - see Appendix C.

Long-term upward turbidity trends were detected in Schoharie Reservoir, its major input, Schoharie Creek (S5I), and in its output. The increase is largely due to frequent large storm events which occurred during 2010 and 2011. Peak turbidity levels were observed in late August, early September 2011 following Tropical Storm Irene and Tropical Storm Lee. Excessive flows associated with these storms caused stream channels to incise into banks and streambeds creating new erosional sources and expanding old ones. Despite an absence of large events since Irene and Lee, turbidity levels have remained elevated throughout the Schoharie basin. Impacts on stream channels from large storms are often long-lasting and complete recovery from Irene and Lee will take additional time.

In the previous FAD evaluation (DEP 2011) we reported strong long-term phosphorus declines for the input, reservoir and output of the Schoharie watershed. However, the large storm events in 2010-2011 caused phosphorus to increase and negate the downward trend previously observed for the output. Despite these large storms, a weak declining long-term phosphorus trend was still observed for the reservoir and a moderately strong, but very small increase was detected for Schoharie's primary input, Schoharie Creek (S5I). Many factors probably contributed to the decline including: recovery from large storm events in January 1996, May 2005 and August-September 2011; drought in 2001-2002; lack of large storm events from 2007-2009; and completion of WWTP upgrades around 2000. The rapid recovery in Schoharie Creek, post Irene and Lee, suggests that total phosphorus in the reservoir should continue to recover in the foreseeable future.

An increasing trend was detected for fecal coliforms in the reservoir. Although the change per year is estimated as zero, due to the preponderance of tied, low values, the Tau value is positive, indicating an upward trend. 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 Storm Irene and Tropical Storm Lee.

Strong long-term increases in conductivity were detected in Schoharie Reservoir and in its input and output. The input became much less after adjusting for flow indicating that conductivity is largely controlled by precipitation and runoff. Since flow adjustment did not account for the entire increased usage of road deicers as suggested by a 78% increase in reservoir chloride from 1993 to 2014 best explains the observed increase in conductivity.

No long-term (1993-2014) trends were detected for TSI, an estimate of algal productivity based on chlorophyll *a* concentrations. However, a short-term decline was apparent since 2003, and was most likely due to low clarity conditions following storm events in 2005 and 2010-2012.

In summary, upward trends were detected at some locations for turbidity, fecal coliforms, total phosphorus, and conductivity while downward trends were detected for total phosphorus in the reservoir. The increase in turbidity is attributed to large storm events in 2010 and 2011. Fecal coliform increases were also attributed to these storms as well as to storm events occurring earlier in 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, the lack of runoff events from 2007-2009 and from WWTP upgrades. The conductivity increases may be attributable to greater use of road deicers. Declines in water clarity explain the recent downward trend in trophic state.

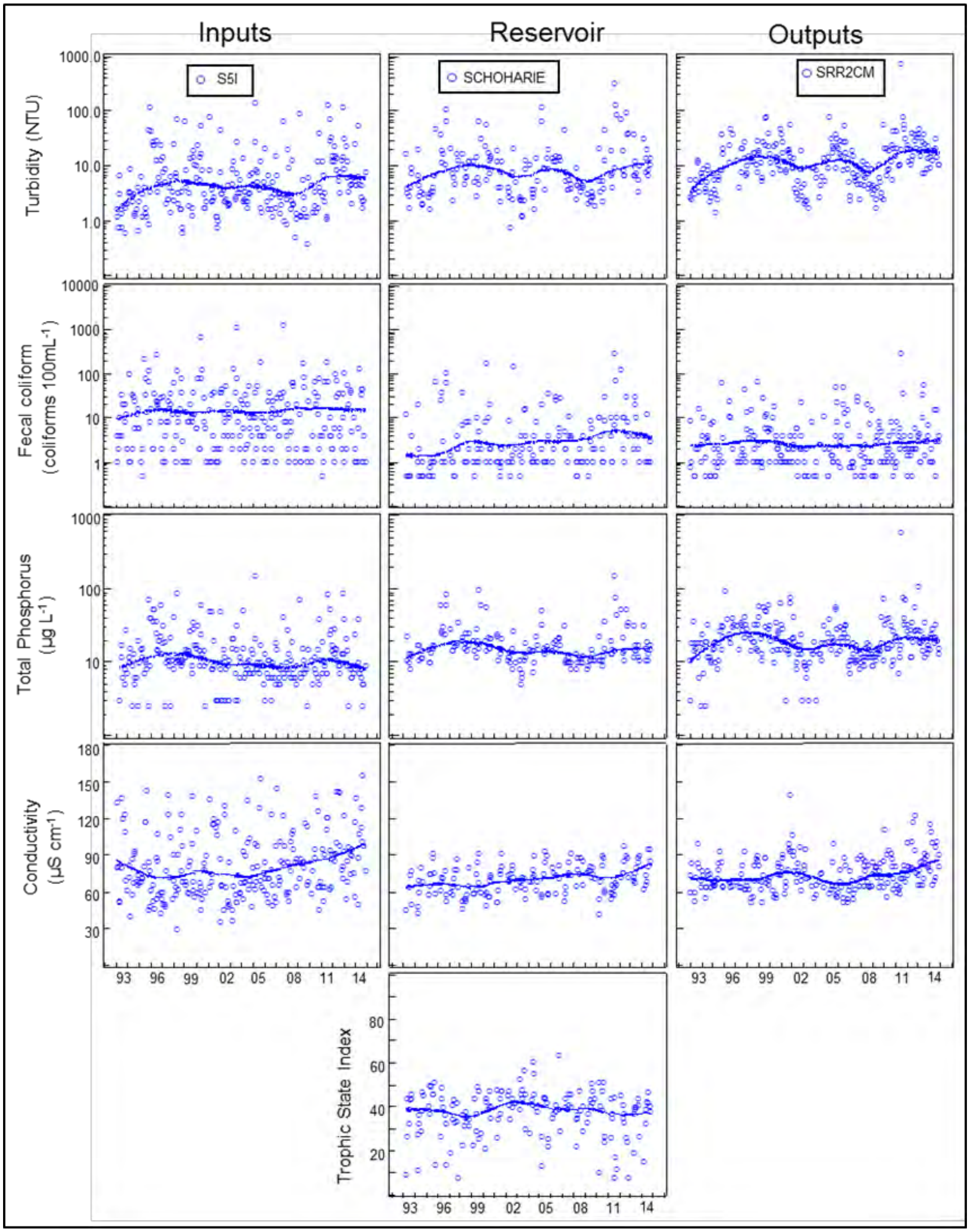

Figure 5.6 Water quality trend plots for the Schoharie basin main stream input at Schoharie Creek (S5I), Schoharie Reservoir, and the output at the Shandaken Portal (SRR2CM).

5.3.5 Biomonitoring in Schoharie Watershed

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

The most recent status of macroinvertebrate communities in the Schoharie Basin was evaluated by examining 2012-2014 data from sites located on Schoharie Creek. This stream is the primary inflow to Schoharie Reservoir, draining 75% of the basin. Three of the sites with data from these years (Sites 202, 204, and 216) are routine, that is, they are sampled annually; the other four (Sites 237, 238, 240, and 242) are sampled on a rotating basis and were sampled only once during the 2012-2014 period. An additional site on the Batavia Kill, a major tributary to Schoharie Creek whose confluence with that stream lies only a short distance upstream of Schoharie Reservoir, was also examined because of the sustained drop in Biological Assessment Profile (BAP) scores that have been observed there over the last several years.

Site 204 (S5I) is located in Prattsville, approximately three-quarters of a mile upstream of Schoharie Reservoir. Sites 242, 240, 216, 202, 238, and 237 are situated about 4, 6, 9, 17, 21, and 24 miles, respectively, upstream of the reservoir. From 2012 to 2014, all sites were assessed as being non-impaired, with two exceptions. In 2012, the year following Tropical Storm Irene and Tropical Storm Lee, all three routine sites had BAP scores just slightly under the 7.5 non/slightly impaired threshold (202—7.33, 204—7.31, 216—7.47), and in 2013, Site 204 assessed as slightly impaired, with a score that was, again, barely below the threshold (7.49) (Figure 5.7). These results indicate the presence of optimal conditions for the benthic community. Sites were dominated in most years by mayflies, in particular isonychiid and heptageniid mayflies, two of the most sensitive mayfly taxa. Also frequently present in substantial numbers were the less sensitive baetid mayflies, and, at Sites 202 and 204, hydropsychid caddisflies. Scores at Site 204 were lower than at the other sites, which is generally consistent with data from previous years. Reasons for this are unclear. Extensive surveys conducted along the length of Schoharie Creek from 2001 to 2004 failed to detect disturbances that might explain

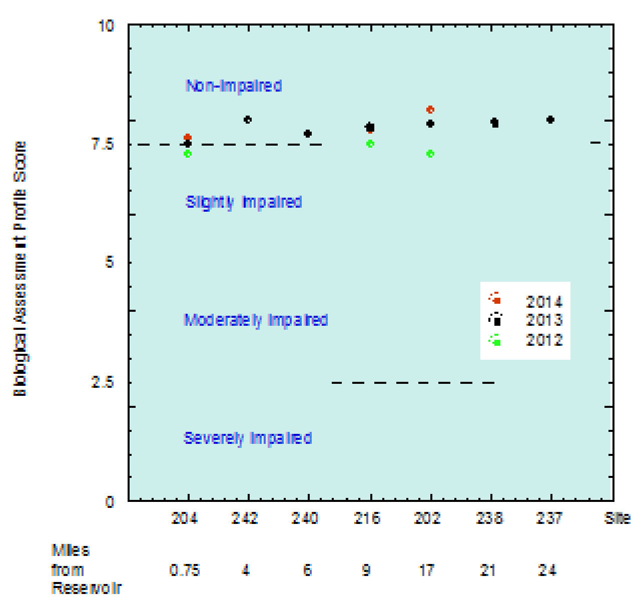

Figure 5.7 Biological Assessment Profile scores for Schoharie Creek, 2012-2014.

the lower scores. The samples collected at Sites 237, 238, 240, and 242 in 2013 represent a repeat of those surveys, and yielded similar results. Impact Source Determination, NYSDEC's procedure for identifying impacts that exert deleterious effects on a water body, was inconclusive when applied to the surveyed sites. Thus, at Site 204, the procedure implicated nonpoint nutrients as the impact source in 2012, but no source was identified for 2013, even though the site was assessed as slightly impaired that year, or for 2014, when the site was non-impaired. Sites 202 and 216 had similarly ambiguous results. No impacts were identified for Sites 237, 238, 240, and 242, which is consistent with their non-impaired assessment.

Trend analysis was based on the routine sites' entire period of record (which ranged from 5 to 21 years in length), and examined changes in both scores and assessment categories. Long-term trends in biomonitoring scores at the three routine sites on Schoharie Creek (202, 204, 216), as well as three of the rotating sites (237, 238, 240) were examined using the non-parametric Mann Kendall trend test, which seeks to determine whether a given value—here, the BAP score—increases or decreases over time. No significant trend was detected at sites 202, 216, or any of the rotating sites, while a weak upward trend was detected at Site 204 ($p = 0.183$) (Figure 5.8).

With very few exceptions, Sites 202 and 216 have been assessed as non-impaired during their entire period of record. The last time either received a slightly impaired rating was in 2012, doubtless a reflection of the impact of Tropical Storm Irene and Tropical Storm Lee the previous year; prior to that, neither had experienced an impaired assessment in over 10 years. Site 204, by contrast, has not had a consistent assessment record, with 10 slightly impaired and nine non-impaired assessments over its 19-year period of record. Nevertheless, eight of the last 10 assessments at the site have fallen into the non-impaired category. Sites 237 and 238 have been assessed as non-impaired in all years sampled and Site 240 in all but one (slightly impaired (BAP = 7.10) in 2003).

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 it suffered a drop from the previous year's score of 8.30 to what was then a new low of 7.07. The shift in categories from non-impaired slightly impaired constitutes a highly significant downward trend ($p = 0.006$) (Figure 5.9). In 2014, the score was 5.70, only slightly higher than 2012's record low of 5.55. Overall, the average score from 2008 to 2014 was 6.24, considerably lower than the 8.17 average for prior years (1995-2007). The lower average also reflects a difference in assessment: six consecutive slightly impaired assessments from 2008 to 2014 versus 13 consecutive non-impaired assessments from 1995 to 2007. The drop in BAP has been driven by a sustained increase in hydropsychid caddisfly numbers and a concomitant reduction in the number of mayflies, the effect of which has been to depress the PMA, total taxa, and HBI metrics; this in turn is what has led to the lower BAP scores. While the 2011 storms

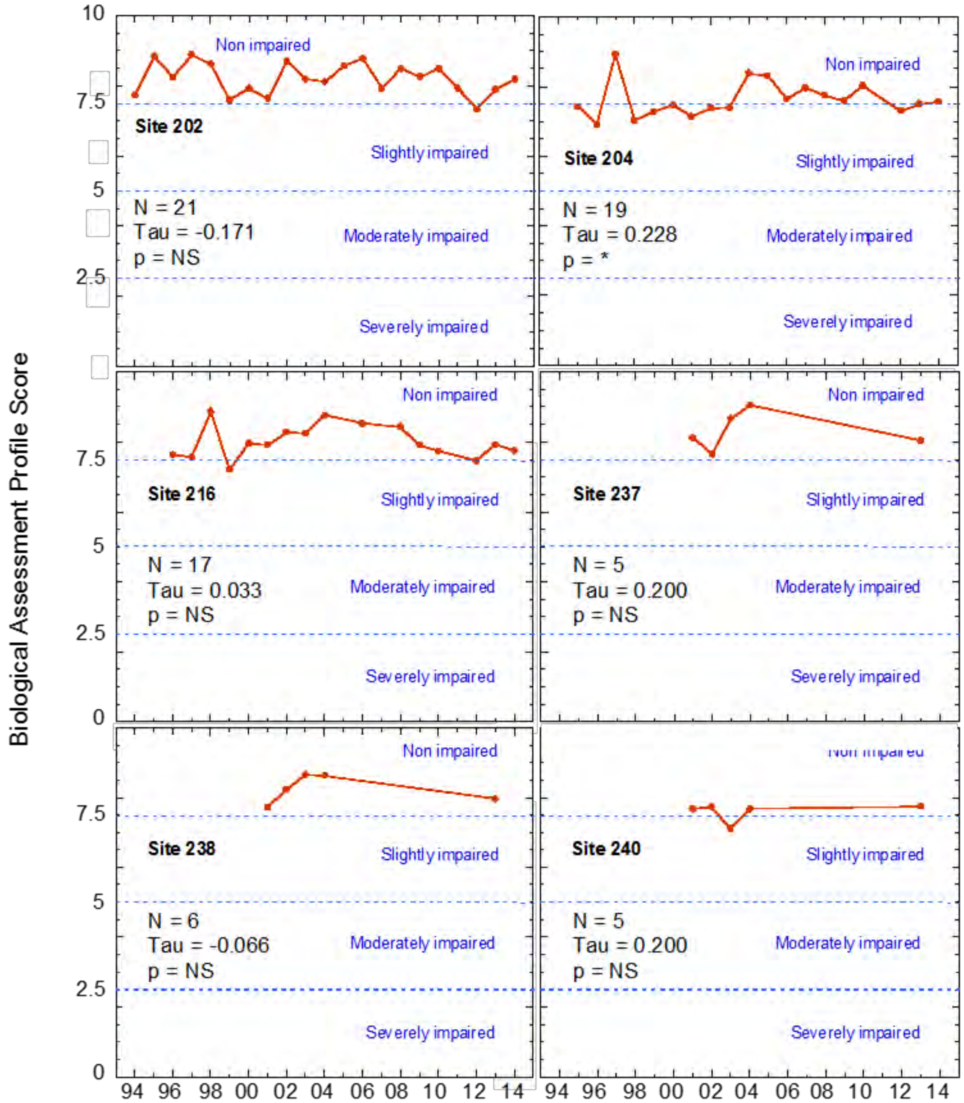

Figure 5.8 Biological Assessment Profile scores for Schoharie Creek, 1994-2014.
Results of the Mann Kendall trend test are shown as follows: $p \geq 0.20$ (NS—Not Significant), * = $p < 0.20$. N = number of observations, Tau = Mann Kendall test statistic.

may have influenced the results of the last four years, other factors must be involved, at the very least for the years preceding 2011. No significant land use changes upstream of the site that might be responsible for these changes are known to have occurred. DEP will continue to monitor the site.

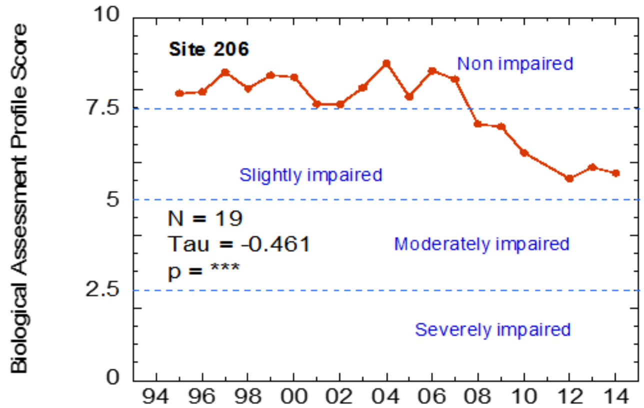

Figure 5.9 Biological Assessment Profile Scores for Batavia Kill at Site 206, 1995-2014. Results of the Mann Kendall trend test are shown as follows: *** = $p < 0.05$. N = number of observations, Tau = Mann Kendall test statistic.

5.4 The Ashokan Watershed

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, it 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 NYC and upstate consumers.

Bush Kill and Esopus Creek, which also convey 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 Catskill Aqueduct, which has a maximum depth of 1,114 feet. It enters Kensico Reservoir in Westchester, then travels south via the Delaware Aqueduct to the Ultraviolet (UV) Treatment Plant and into distribution at Hillview Reservoir in Yonkers.

5.4.1 Land Use in the Ashokan Watershed

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 (Figure 5.10). The Ashokan watershed also has 1.4% of impervious surface.

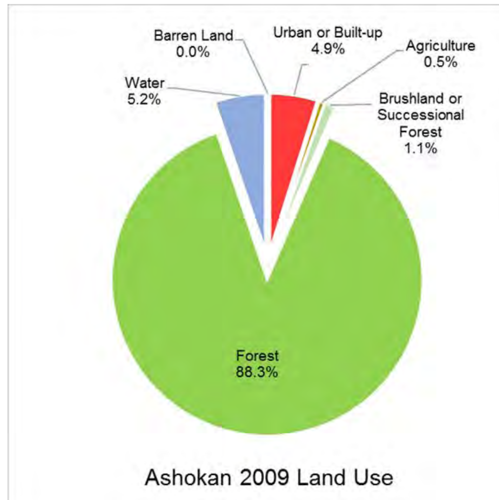

Figure 5.10 Ashokan basin land use based on 2009 data.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and

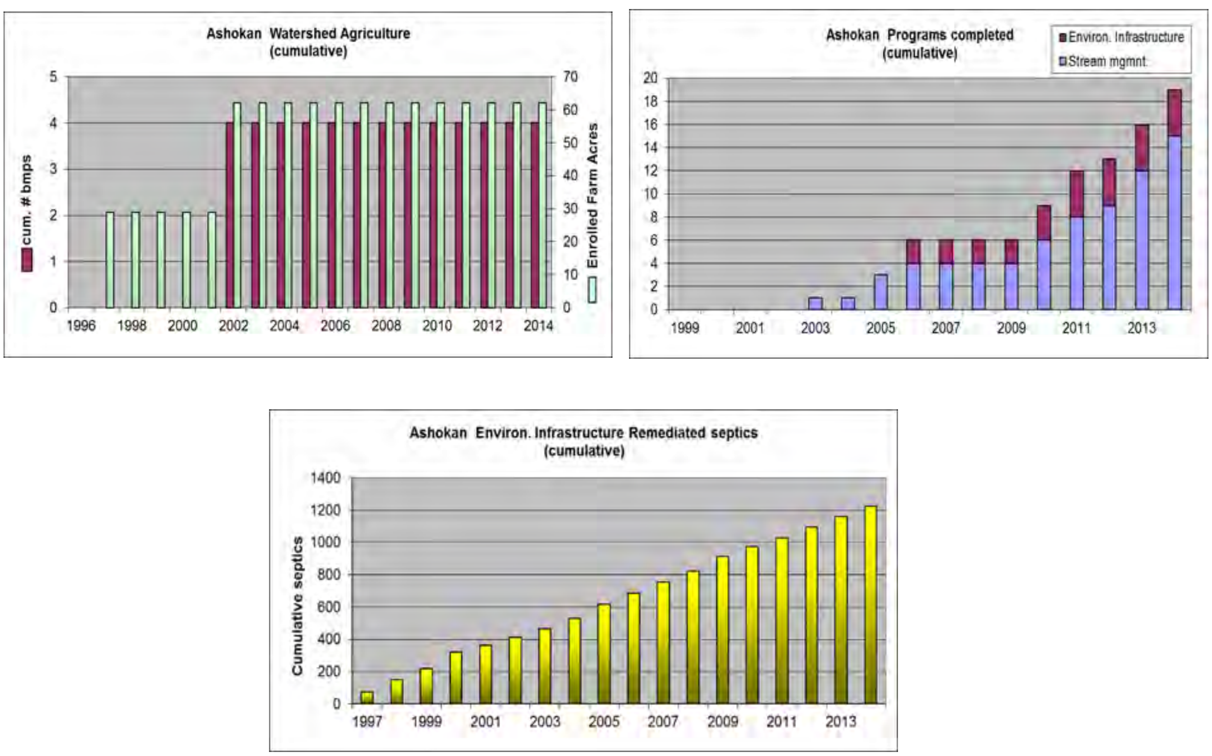

Figure 5.11 History of watershed programs in Ashokan drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control and stream management projects, c) septic system remediation. Bars represent cumulative plots.

other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

5.4.2 Program Implementation in the Ashokan Watershed

Since 1996, four BMPs have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater in the Ashokan watershed (Figure 5.11). These BMPs are associated with approximately 60 acres of farmland. Approximately 19 environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects. The number of remediated septic systems has continued to increase steadily over the years to just over 1,200 repairs overall (Figure 5.11). Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place as described in Watershed Protection Program (Section 4).

5.4.3 WWTPs and Phosphorus Load Reductions in the Ashokan Watershed

Presently there are four WWTPs sited in the Ashokan watershed, producing approximately 0.215 MGD of flow. The newest plant, located in the town of Boiceville, was completed in 2010 and includes the wastewater system formerly serving the Onteora Central School and a number of septic systems. According to the most recent SPDES permits, the plants are limited to a collective release of 0.621 MGD of flow. Inputs of phosphorus, as well as other pollutants to Ashokan Reservoir from WWTPs have been reduced by DEP's upgrades of all surface-discharging plants, including upgrade of the DEP-owned Pine Hill plant, and DEP's WWTP Compliance and Inspection Program. As illustrated in Figure 5.12 phosphorus loads (as total phosphorus) declined considerably from 1994 to 1999 and remained low into 2014. Overall, the phosphorus loads to Ashokan Reservoir were reduced from 220 kg yr^{-1} in 1994 to less than 30 kg yr^{-1} since 1999. The reduction was largely due to the upgrade of the largest plant, Pine Hill. Phosphorus load fluctuations at Camp Timberlake are proportionate to changes in flow. The final upgrade in 2005 reduced phosphorus loads from that facility. Mountainside Restaurant, a small plant, began discharging sub-surface in 2005. Another small plant, Woodstock Percussion, started operation in the East Basin's watershed in 2009. In 2014 the phosphorus load was at its lowest level.

5.4.4 Water Quality Status and Trends in the Ashokan Watershed

Status (West Basin)

Ashokan's West Basin status evaluation based on the principal inflow (E16I) and the reservoir (EAW) is presented as a series of boxplots in Figure 5.13. All values below the maximum detection limit for fecal coliform were estimated according to statistical methods for censored data described by Helsel (2012). All other featured analytes were above their reporting limits. It is important to note that the reporting limit for fecal coliform bacteria is shown as a horizontal (blue) line and values below are masked from view because the distribution below the

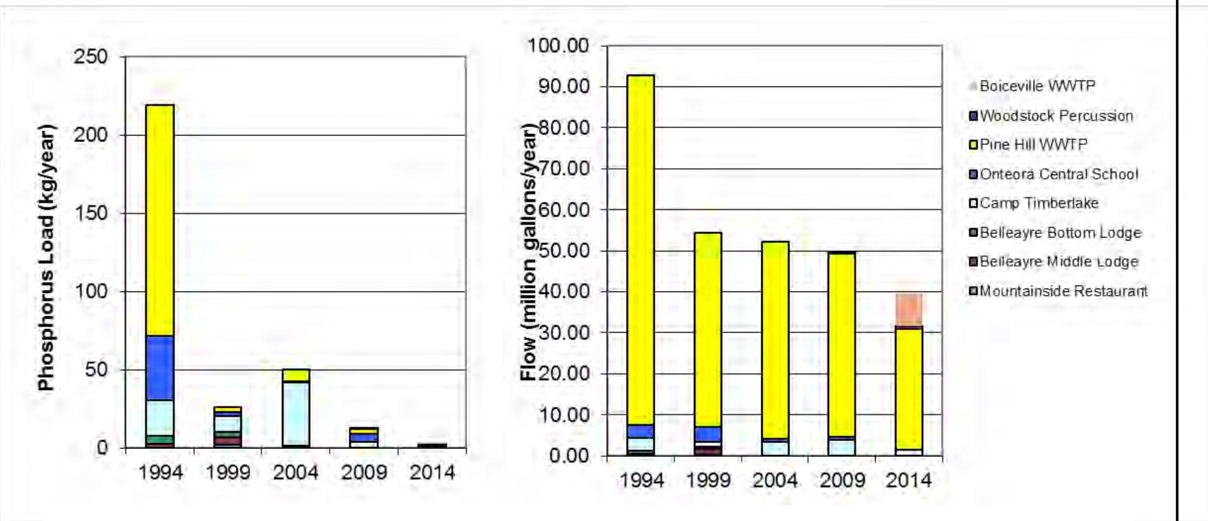

Figure 5.12 Wastewater treatment plant total phosphorus loads and flows in the Ashokan drainage basin, 1994 – 2014.

reporting limit is unknown. For additional details on methodology and boxplot interpretation see Appendix C.

For the status evaluation period (2012-2014), 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 and all median monthly reservoir coliform levels were below the SWTR benchmark of 20 total coliforms 100 mL^{-1} used for source waters. Turbidity was impacted by the extreme events of 2011 (Irene/Lee events in August-September 2011), and was higher at the inflow (median 9.2 NTU) than in the reservoir (median 5.35 NTU). Total phosphorus (TP) followed a similar pattern with an inflow median of 11.5 µg L^{-1} and reservoir median of 8 µg L^{-1}. Only two reservoir TP values were above the phosphorus-restricted target value of 15 µg L^{-1} for source waters. TSI values ranged between oligotrophic and mesotrophic. The conductivity monthly median was highest at the inflow (68 µS cm^{-1}) with much greater variability (interquartile range 28 µS cm^{-1}) and lower in the reservoir (median 57.75 µS cm^{-1}; interquartile range 7 µS cm^{-1}).

In summary, water quality was good during the 2012-2014 status assessment period in Ashokan's West Basin. Exceedances of benchmark of 15 µg L^{-1} for total phosphorus were rare. Higher median turbidity occurred in the year following the extreme storm events of 2011, and declined over the assessment period.

Trends (West Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall

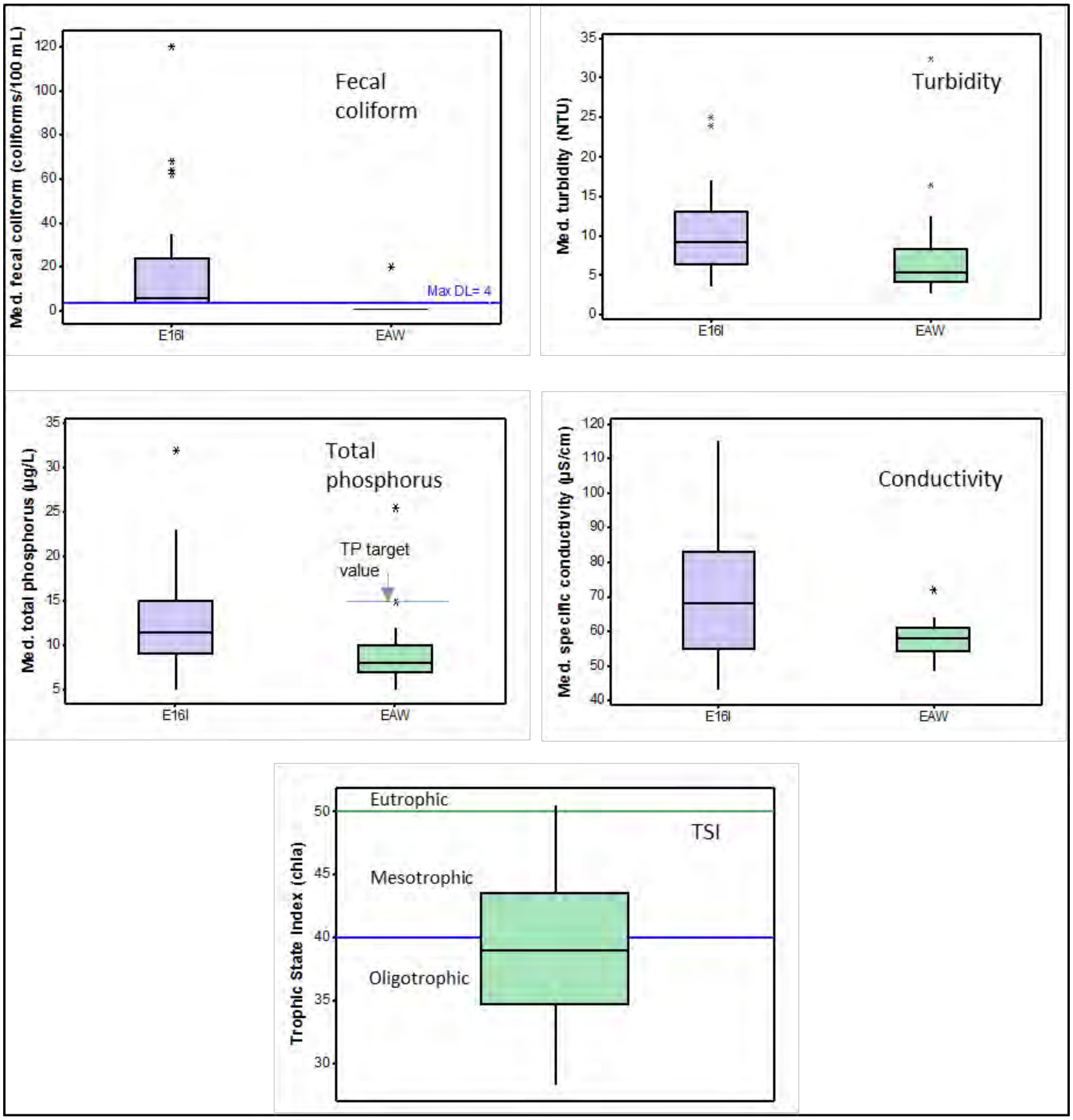

Figure 5.13 Water quality status boxplots using 2012-2014 monthly data for the Ashokan West Basin main stream input at Esopus Creek (E16I) and the Ashokan Reservoir West Basin (EAW).

tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used.

Table 5.2 Ashokan West Basin trends from 1993-2014 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
E16I	Input	Turbidity	264	0.14	***	0.12
Ashokan-West	Reservoir	Turbidity	174	0.24	***	0.12
E16I	Input	Fecal coliform	261	-0.09	***	-0.09
Ashokan-West	Reservoir	Fecal coliform	173	0.10	***	0.00
E16I	Input	Total Phosphorus	261	-0.12	***	-0.19
Ashokan-West	Reservoir	Total Phosphorus	168	-0.17	***	-0.17
E16I	Input	Conductivity	263	0.07	*	0.18
Ashokan-West	Reservoir	Conductivity	162	0.10	**	0.18
Ashokan-West	Reservoir	Trophic State Index	168	-0.19	***	-0.22

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

Water quality trend plots are presented in Figure 5.14. For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. Results of the Seasonal Kendall trend analysis are provided in Table 5.2.

Strong upward long-term turbidity trends were detected in the West Basin of the Ashokan Reservoir and in its primary input, Esopus Creek (E16I). Examination of the LOWESS turbidity plots reveal that the upward trend was driven by extremely high turbidity values from multiple events in 2005, 2006, 2010, and especially in 2011. On April 1-3, 2005 a 3-day rain-on-snow event produced extensive runoff and flooding in the CAT/DEL System Water Supply watersheds. The Ashokan Reservoir watershed received the highest amount of rainfall in the region with 103 mm (4.05 in) over the three-day period. Turbidity remained high in 2006 due primarily to three factors: (1) carry-over from the previous year's April and October flooding events, (2) a high diversion rate from Schoharie Reservoir throughout 2006 to facilitate dam repair, (3) large rain events in mid-May and late June 2006. Turbidity gradually declined to typical levels by 2008-2009 but multiple spring and fall rain events in 2010 followed by wide-spread flooding associated with Tropical Storm Irene and Tropical Storm Lee during the summer of 2011 caused turbidity to reach its highest levels since 1993.

A long-term, although weak, upward fecal coliform trend was detected in the reservoir and, similar to turbidity, appeared to be initiated by the April 2005 flood event, and supported by runoff events in 2006, 2010, and 2011 (Figure 5.14). Since summer 2011, there has been a steady decrease in fecal counts coinciding with a notable absence of large runoff events through 2014. Statistically significant long-term trends were not detected for the primary input, Esopus Creek.

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

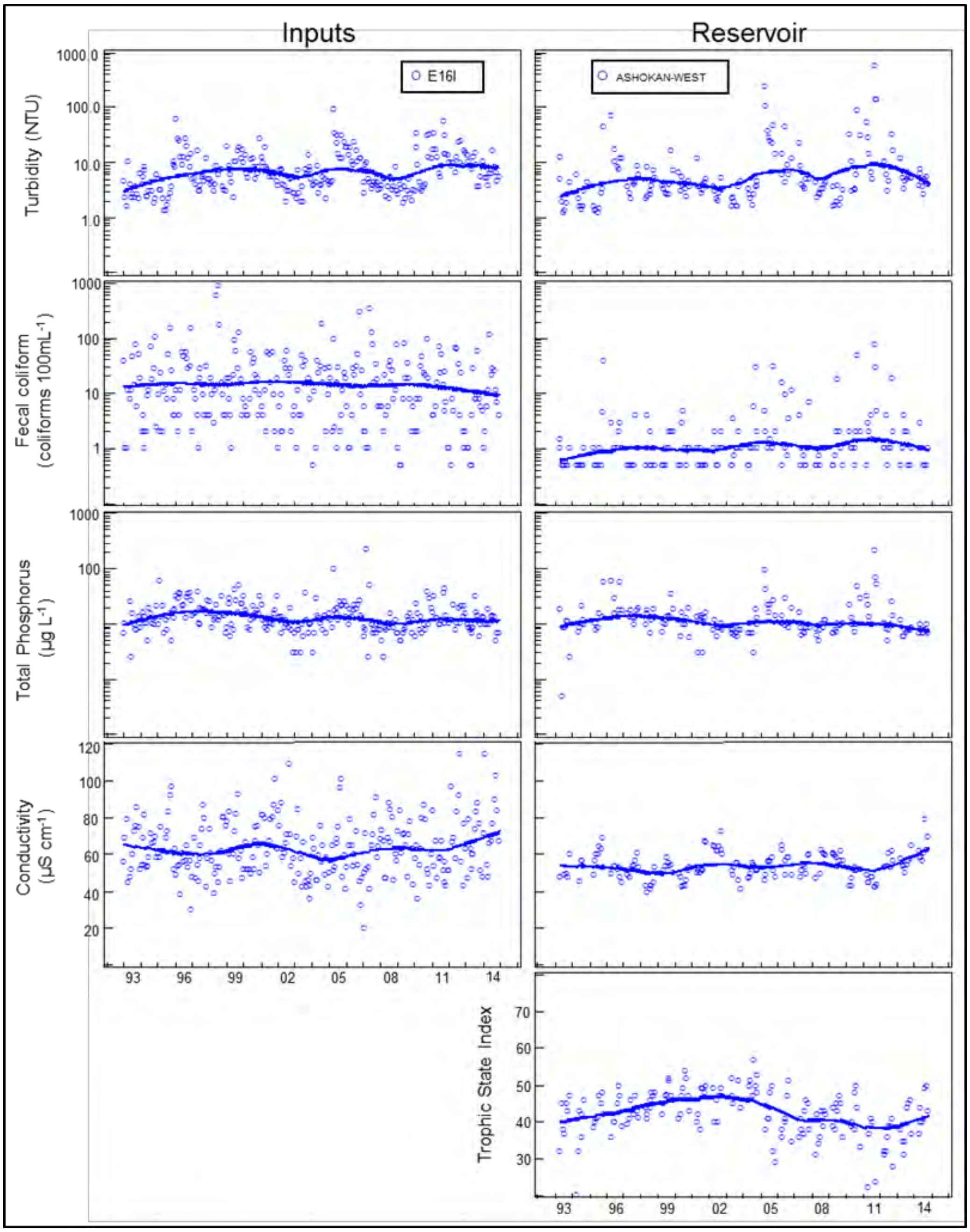

Figure 5.14 Water quality trend plots for the Ashokan West Basin for the main stream input at Esopus Creek (E16I) and the Ashokan Reservoir West Basin.

the long-term record. Although a short-term decline can be attributed to drought in 2001-2002, the overall decline was likely achieved through the implementation of watershed programs, and in particular to the upgrade of the Pine Hill WWTP and the establishment of the Boiceville

WWTP in 2010. It is a testament to the robustness of the watershed programs that phosphorus concentrations have continued to decline despite the occurrence of record flood events during the later years of the considered time period.

A weak upward conductivity trend was detected in Esopus Creek and a moderately strong increase was apparent in the reservoir. The long-term upward trends appear to be driven by relatively low annual precipitation during the last three years of the period considered. Note that higher conductivities were also observed in 2002 when drought conditions prevailed.

A long-term downward trend was detected for 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 short recovery in TSI, turbid floodwaters again occurred in 2010-2011 keeping productivity levels depressed. Note that TSI appears to be rebounding starting in 2012 presumably due to the lack of runoff events and the resulting improved clarity levels.

In summary, downward trends were evident for total phosphorus despite the occurrence of record floods. Upward trends were detected for turbidity, fecal coliform and conductivity. The increase in turbidity and fecal coliform is attributed to large runoff events in 2005-2006 and 2010-2011. Conductivity increases coincided with a decline in precipitation over the last three years of the data record.

Status (East Basin)

Ashokan's East Basin status evaluation is presented as a series of boxplots in Figure 5.15. Only the reservoir (EAE) and output (EAR) summaries are shown, because water from the West Basin flows directly to the East Basin. All values below the maximum detection limit for fecal coliform were estimated according to statistical methods for censored data described by Helsel (2012). All other featured analytes were above their reporting limits. It is important to note that the reporting limit for fecal coliform bacteria is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the status evaluation period (2012-2014), all median monthly values for fecal coliform bacteria for both the reservoir and outflow fell below the SWTR benchmark of 20 total coliforms 100 mL^{-1} used for source waters. Turbidity was impacted by the extreme events of 2011 (Irene/Lee events in August-September 2011), and was slightly higher at the outflow (median 4.02 NTU) than in the reservoir (median 2.38 NTU). Total phosphorus (TP) followed a similar pattern with an outflow median of 9 µg L^{-1} and reservoir median of 7.5 µg L^{-1}. No reservoir TP median values were above the phosphorus-restricted target value of 15 µg L^{-1} for source waters. TSI values ranged between oligotrophic and mesotrophic, with a median in the mesotrophic range. The conductivity monthly medians were similar between reservoir and outflow (54 and 56 µS cm^{-1}, respectively).

In summary, water quality was good during the 2012-2014 status assessment period in Ashokan's East Basin. Fecal coliform bacteria were low in both East and West basins. Turbidity was lower in the East Basin than the West Basin, and exceeded the SWTR benchmark of 5 NTU rarely. Note that the 5 NTU criterion does not apply directly to the ambient level for the reservoirs and is used only as a reference to compare with what is required at the point just prior to disinfection.

Trends (East Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods and flow-adjustment is indicated, as appropriate, in the trend statistics table (Table 5.3).

Water quality trend plots are presented in Figure 5.16 and results of the Seasonal Kendall trend analysis are provided in Table 5.3. The West Basin, the East Basin's primary source of water, is discussed in the preceding section (Trends (West Basin)).

Table 5.3 Ashokan East Basin trends from 1993-2014 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
Ashokan-East	Reservoir	Turbidity	176	0.28	***	0.04
EARCM	Output	Turbidity	264	0.19	***	0.05
Ashokan-East	Reservoir	Fecal coliform	175	-0.05	*	0.00
EARCM	Output	Fecal coliform	264	-0.15	***	0.00
Ashokan-East	Reservoir	Total Phosphorus	171	-0.30	***	-0.25
EARCM	Output	Total Phosphorus	262	-0.14	***	-0.13
Ashokan-East	Reservoir	Conductivity	165	0.05	NS	
EARCM	Output	Conductivity	264	0.01	NS	
Ashokan-East	Reservoir	Trophic State Index	171	-0.22	***	-0.27

1 Tau refers to the Seasonal Kendall Test Tau statistic.

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

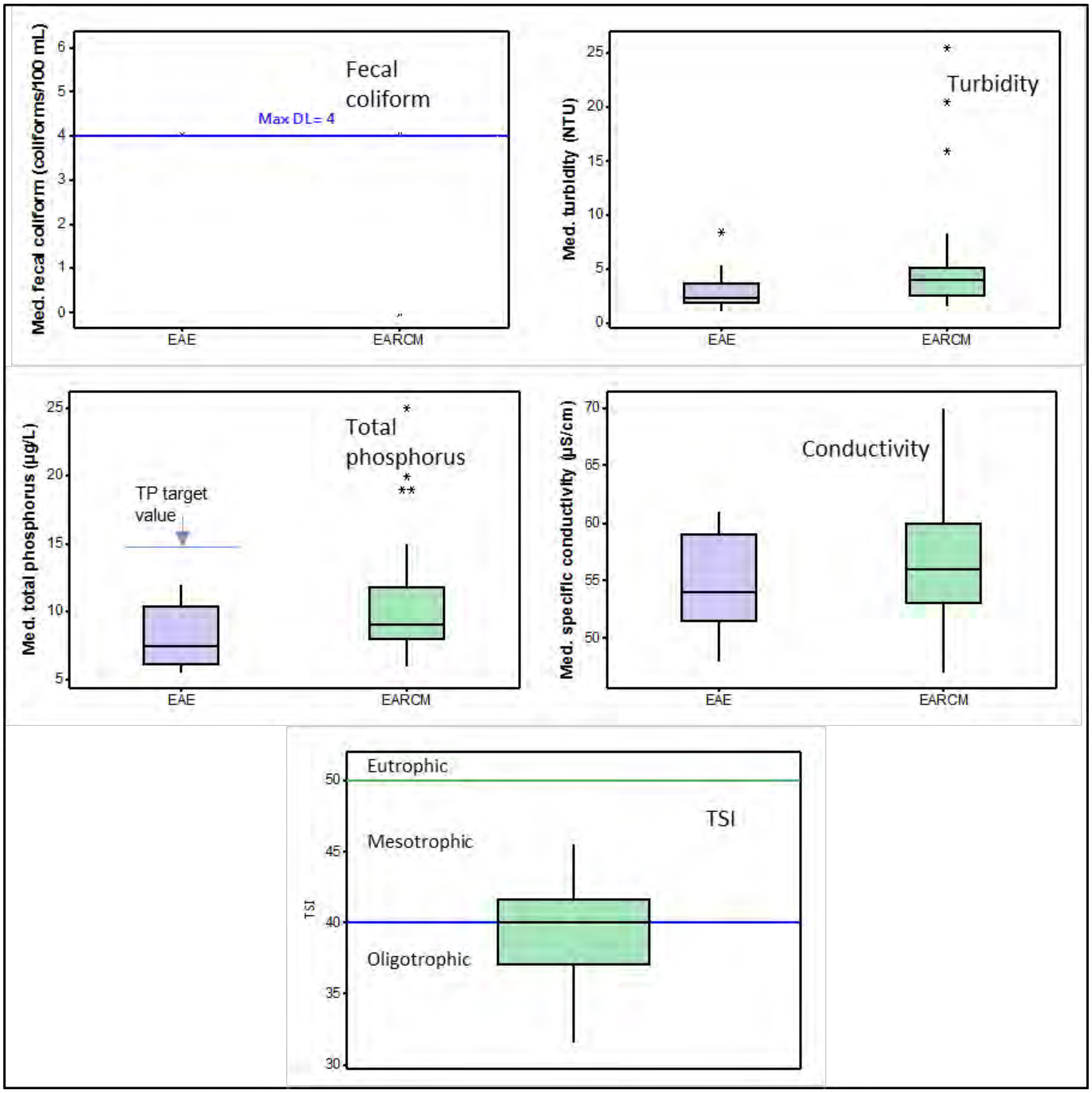

Figure 5.15 Water quality status boxplots using 2012-2014 monthly data for the Ashokan Reservoir East Basin (EAE) and the output at the Ashokan gatehouse (EARCM).

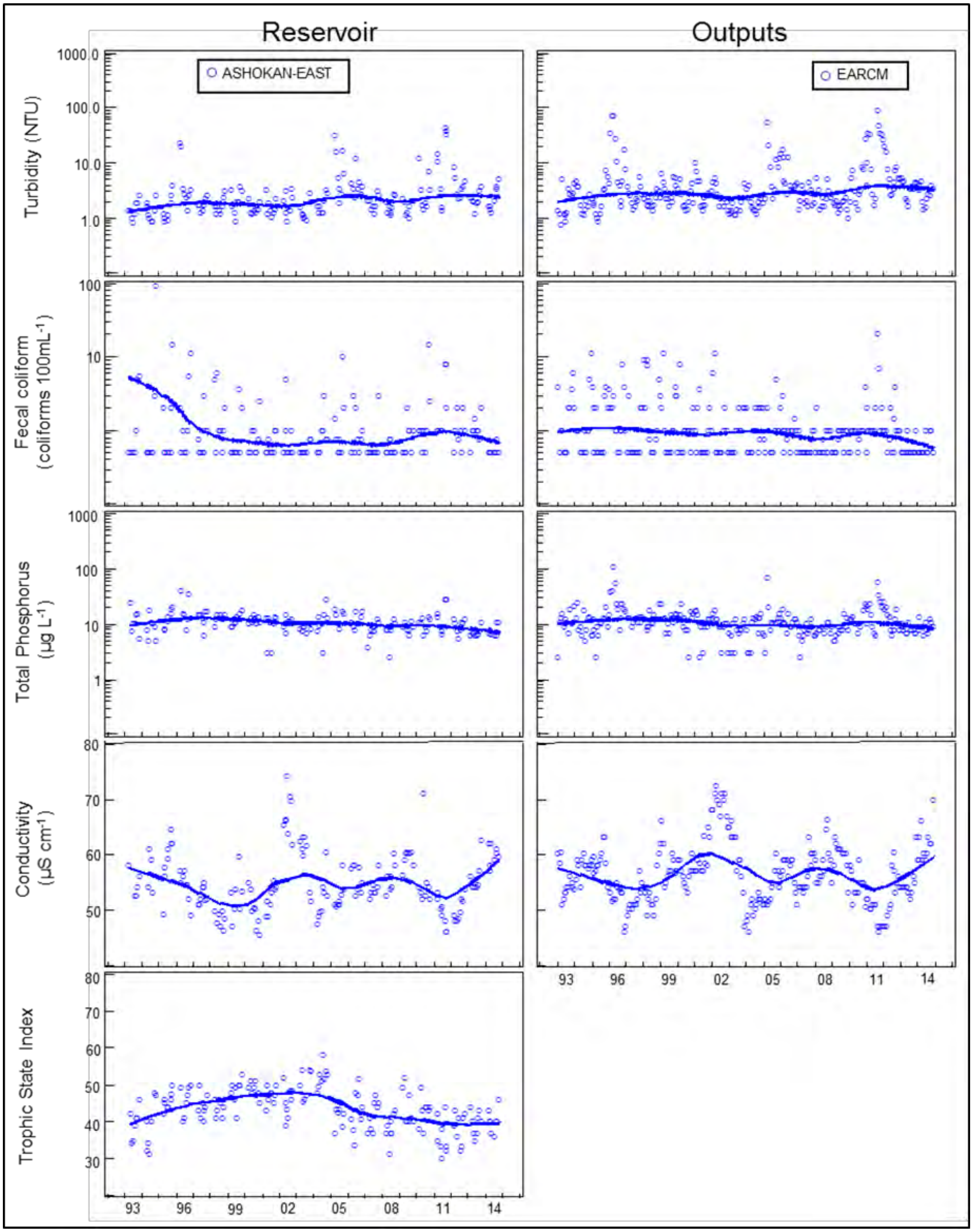

Figure 5.16 Water quality trend plots for the Ashokan Reservoir East Basin and the output at the Ashokan gatehouse (EARCM).
For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%.

Long-term upward turbidity trends were detected in the East Basin and in its output, EARCM. Since trends were not detected in the last FAD Assessment, the current uptrend is due to the more recent turbidity events in 2010-2011. Turbidity peaks during this time are clearly evident on the turbidity plot in Figure 5.16. Significant turbidity events are also indicated for January 1996 and spring 2005.

A weak downward fecal coliform trend was detected in Ashokan's East Basin but a strong downward trend was detected in the output of the reservoir. The initial large fecal coliform decrease in the reservoir was offset somewhat by runoff events in 2010-2011. Although the change per year was estimated as zero, due to the preponderance of tied, low values, the sign of the Tau statistic is negative indicating a downward trend. A better estimate of change may be derived using the LOWESS curve. In Figure 5.16, the reservoir LOWESS curve starts at about 5 coliforms 100mL-1 and by around 2001 stays at one or below detection, a downward change of approximately 80%. The decrease has been linked to declining bird populations resulting from closure of local landfills (important winter foraging areas) in the mid to late 1990s (DEP 2010a).

Despite recent record flooding, strong declining trends were detected for total phosphorus indicating that the 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.

Long-term upward conductivity trends were not detected in the reservoir or its output. In this basin conductivity has a strong negative correlation with precipitation. The distribution of low precipitation (high conductivity) years seems to offset the high precipitation (low conductivity) years resulting in no long-term trend. The LOWESS curves clearly illustrate the variability induced by drought and storms.

A long-term downward trend was detected for TSI. Although TSI consistently increased from 1993-2004, this increasing trend was offset by a sharp decrease caused by the major flooding/turbidity event in April 2005. More recent flooding events in 2006, 2010, and 2011 have also reduced water clarity and in turn, TSI, with no indication of recovery through 2014.

In summary, downward trends were evident for total phosphorus, fecal coliforms and TSI. The decrease in phosphorus occurred despite recent record floods and 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. Significant upward trends were detected for turbidity and were attributed to recent flooding events. The decrease in TSI is also attributed to the recent flooding events.

5.4.5 Biomonitoring in the Ashokan Watershed

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

The most recent status of macroinvertebrate communities in the Ashokan basin was evaluated by examining 2012-2014 data from sites located on Esopus Creek. This stream 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, that is, they are sampled annually; the other eight are sampled on a rotating basis and, with one exception, were sampled only once during the 2012-2014 period.

Site 213 (E16I) in Boiceville lies approximately three-quarters of a mile upstream of Ashokan Reservoir. Sites 255, 268, 267, 227, 266, 265, 215 (E5), 256, and 260 (AEHG), are situated roughly 4.5, 6.5, 8, 9.5, 10, 12, 13, 17, and 24 miles, respectively, upstream of the reservoir. Of the two routine sites, one (Site 215) was non-impaired in 2014 after being assessed as slightly impaired in 2012 and 2013, while the other (Site 227) was rated non-impaired in 2013 and 2014 following a slightly impaired assessment in 2012. Among the rotating sites, Sites 256, 266, 267, and 268 were non-impaired in the single year they were sampled, while the rest—Sites 213, 255, 260, and 265—were assessed as slightly impaired (Figure 5.17).

Site 213 was sampled in both 2012 and 2013 and was assessed as slightly impaired on both occasions. The 2012 result reflects the high number of hydropsychid caddisflies present in the sample, which depressed the total taxa, PMA, and NBI-P metrics. Spikes in the number of these organisms have occurred at this site in the past and were present at many sites in the CAT/DEL basins following Tropical Storm Irene and Tropical Storm Lee (including Sites 215 and 227). At Site 213, as at many of the other sites experiencing these increases, a decline in the hydropsychid population occurred in the year following the peak. The site remained slightly impaired in 2013, however, as another group of organisms, baetid mayflies, replaced the hydropsychids as a dominant group in the benthic community.

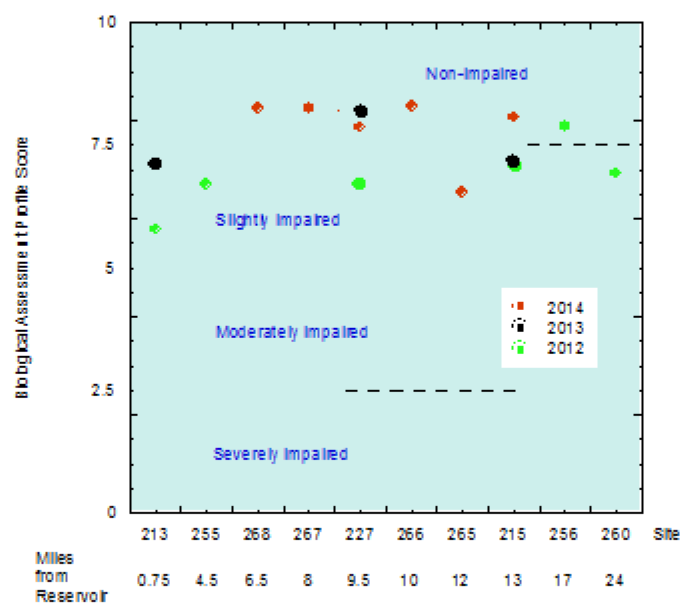

Figure 5.17 Biological Assessment Profile scores for Esopus Creek, 2012-2014.

An increase in hydropsychids was also observed at Site 255, contributing to that site's slightly impaired assessment in 2012. Further sampling was not performed there during the 2012-2014 period, so it is not known if declines in these organisms occurred in subsequent years.

Trend analysis was based on the entire period of record for sites whose record extended over a period of at least five years. Three sites fell into this category: the two routine sites (Sites 215 and 227), with a record of 19 and 16 years, respectively, and Site 213, with a 6-year record. The analysis examined changes in both scores and assessment categories.

Long-term trends in biomonitoring scores were examined using the non-parametric Mann Kendall trend test, which seeks to determine whether a given value—here, the BAP score—increases or decreases over time. No significant trend was detected at any of the sites (Figure 5.18).

At both routine sites, non-impaired assessments have consistently been the rule. Slightly impaired results, however, have periodically occurred, four times at Site 215 and six times at Site 227. The most recent occurrences, recorded in 2012 and 2013, may be attributable at least in part to disturbances caused by Tropical Storm Irene and Tropical Storm Lee. The two slightly impaired assessments at Site 213, also possibly related to impacts from Irene and Lee, follow four previously non-impaired assessments recorded between 1996 and 2008.

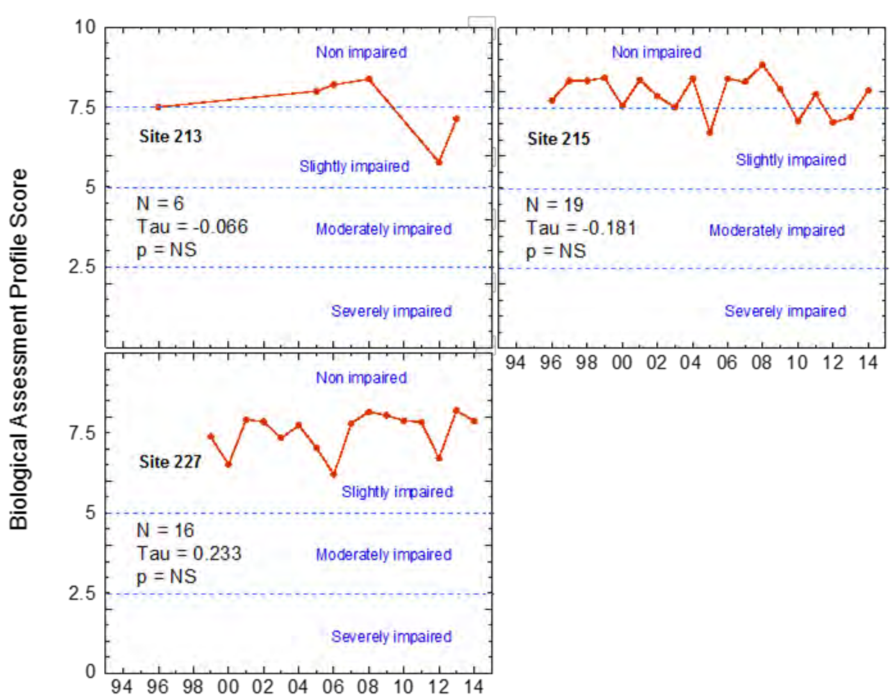

Figure 5.18 Biological Assessment Profile scores for Esopus Creek, 1996-2014.
Results of the Mann Kendall trend test are shown as follows: $p \geq 0.20$ (NS—Not Significant). N = number of observations, Tau = Mann Kendall test statistic.

5.4.6 Waterfowl Management Program: Ashokan Reservoir

Waterfowl management in Ashokan Reservoir is only conducted on an as needed basis per the Revised 2007 FAD. Weekly water bird population monitoring surveys were conducted weekly and throughout the year from January 1, 2011 through March 13, 2013 and reduced to as needed from March 14, 2013 through December 31, 2014. The reservoir is divided into two main basins, each with a water intake chamber located near a dividing weir.

Water bird populations peaked above 10,000 birds in the mid-1990s, but dropped precipitously thereafter. Average number of water birds per night based on weekly surveys was 607 (average Canada Geese/night was 42, Gulls/night was 269, and other water birds/night was 296). This decline, however, has not occurred as a result of mitigation. Rather, it is probably related to the closure of two regional landfills in the mid-to-late 1990s, which resulted in the loss of key winter foraging for the gulls. As a result, over time, gull migration patterns shifted away from the reservoir. The East Basin is the primary water bird roosting area, where high numbers of gulls, ducks, and geese have been recorded seasonally (Figure 5.19). The high fecal coliform bacteria levels recorded in 2011 were related to Tropical Storm Irene and Tropical Storm Lee. There appears to be a possible association with the increase number of water birds and the elevated fecal coliform bacteria during the late summer/early autumn of 2012. Additional

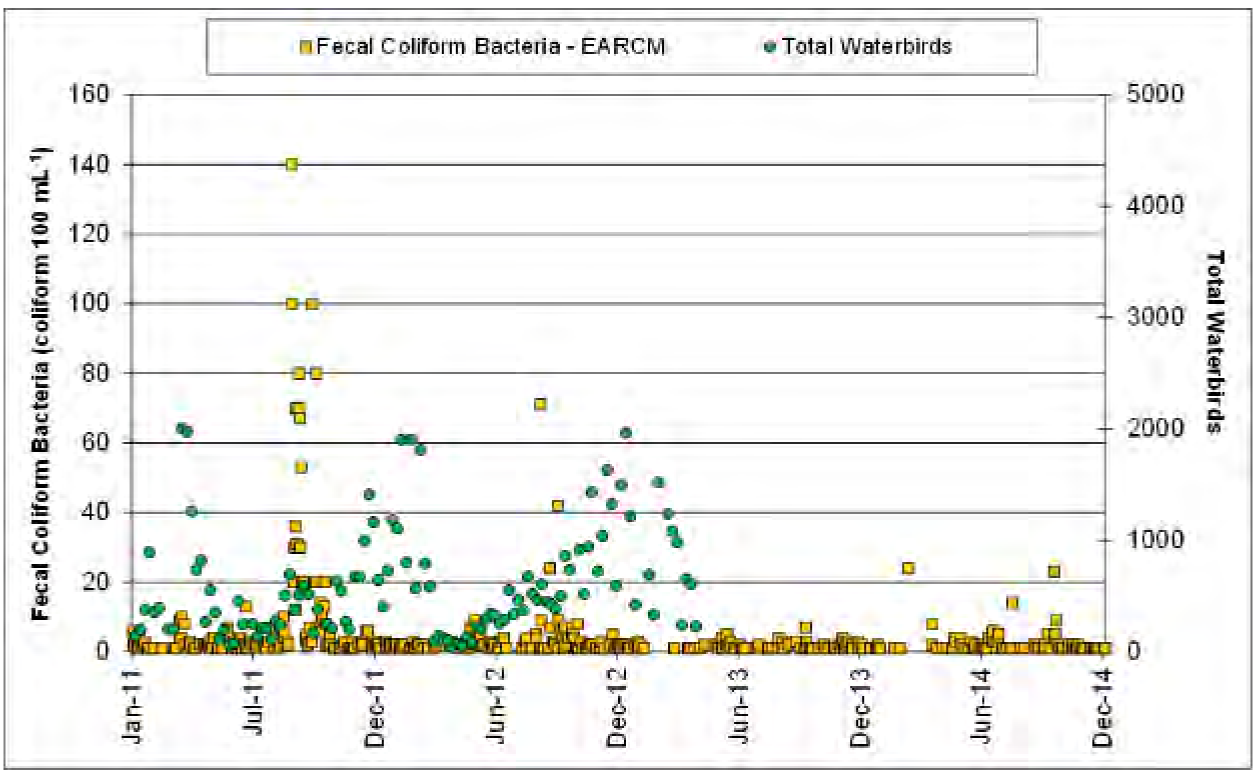

Figure 5.19 Fecal coliform bacteria (CFU 100 ml^{-1}) versus total water birds at Ashokan Reservoir East Basin Effluent (EARCM), January 1, 2011 – December 31, 2014.

unaided daytime surveys were conducted by DEP during routine daytime site visits. Because of the relatively low fecal coliform bacteria levels, it was not necessary to activate the as needed bird management options during the current assessment period.

5.5 Trophic Response of Catskill Reservoirs

Chlorophyll vs. total phosphorus in Catskill System reservoirs is plotted in Figure 5.20. Schoharie Reservoir shows many deviating years on the low side indicating that it is not infrequent that 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 and this presents a severe limitation to algal growth. Ashokan East and West Basin values tend to cluster within the 80% confidence intervals, however, there are also a few years when algal biomass is high. This occurs in 2003 and 2004 during a relatively calm period, without major tropical storms.

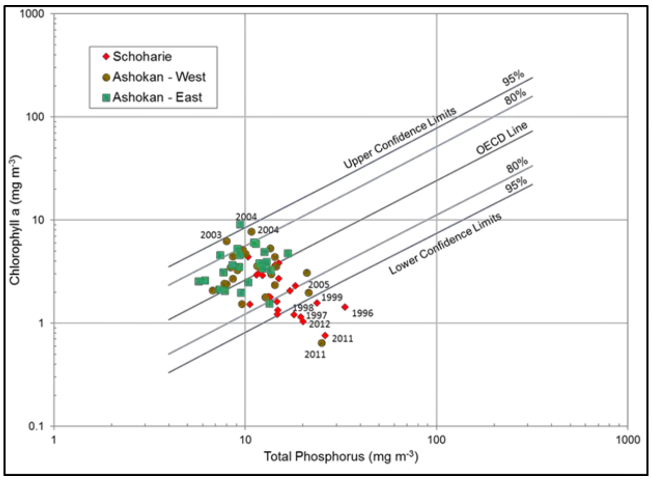

Figure 5.20 Chlorophyll vs. total phosphorus in Catskill System reservoirs.

The annual maximum value of chlorophyll vs total phosphorus is plotted for each year in Figure 5.21. The chlorophyll maximum reflects the potential for algal biomass development when other factors are not limiting. Highest maxima were observed in all three Catskill System Reservoir basins in 2003 to 2004, similar to the highest annual mean chlorophyll values, and in 2006, when major storms did not occur during the growing season.

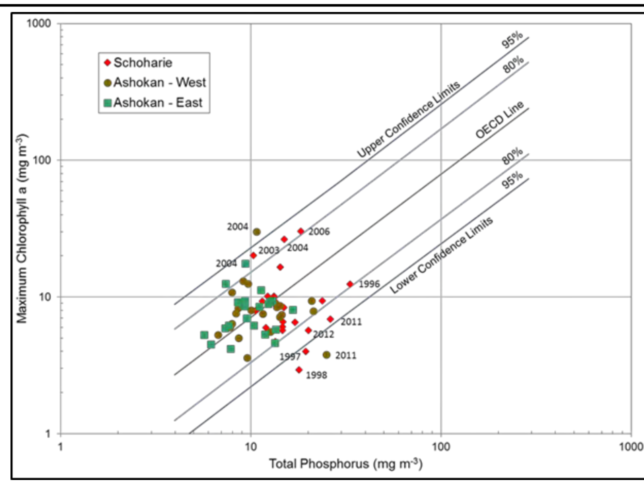

Figure 5.21 Maximum chlorophyll vs. total phosphorus in Catskill System

Secchi depth vs. total phosphorus annual mean values are plotted in Figure 5.22. The most prominent feature of the plot is the fact that there are many exceptionally low values for Schoharie and the West Basin of Ashokan. These all occur in years during which floods, caused by

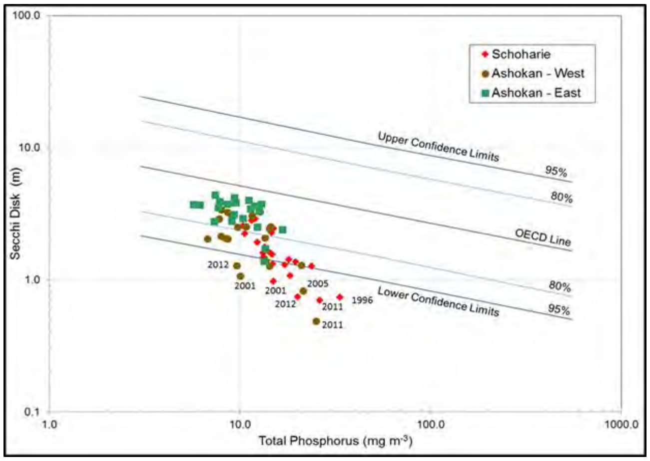

Figure 5.22 Secchi depth vs. total phosphorus in Catskill System reservoirs.

tropical storms and hurricanes, and turbidity events occurred including 1996, 2005, 2011, and 2012. In 2001, a spring turbidity event lasted for more than 6 months in Schoharie and 4 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 that this nutrient is attached to the glacial clays which create the inordinately low transparencies.

Secchi depth vs. chlorophyll is plotted in Figure 5.23. 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.

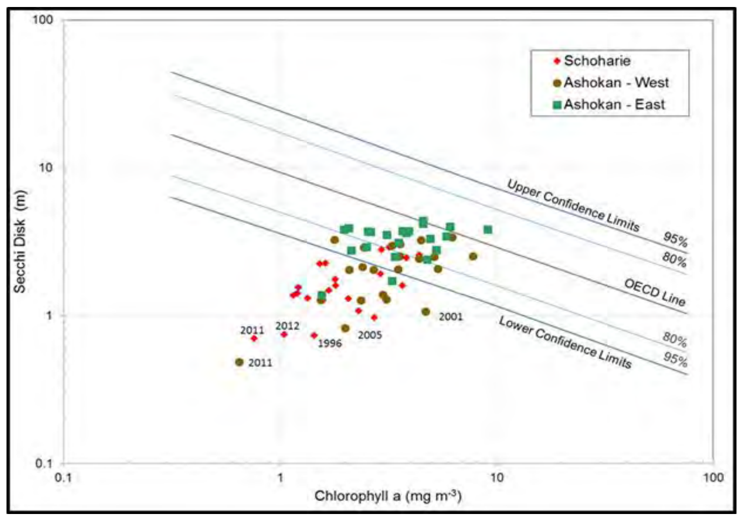

Figure 5.23 Secchi depth vs. chlorophyll in Catskill System reservoirs.

5.6 Catskill System Protozoa: Sources and Attenuation

5.6.1 Upstream Sites and Reservoir Outflows

DEP has sampled for protozoa (*Giardia* and *Cryptosporidium*) in the Catskill system from June 2002 to September 2015. Three sites were monitored above the Schoharie Reservoir: S7I (Manor Kill), S4 (Schoharie Creek at Lexington, upstream of S5I), and S5I (Schoharie Creek at Prattsville). Four sites were monitored in the Ashokan basin: ABCG (Birch Creek), E5 (Esopus Creek, upstream of the Shandaken Tunnel), SRR2CM (Shandaken Tunnel outlet), and E16I (Esopus Creek just before entering Ashokan Reservoir).

As noted in the 2011 FAD Assessment (DEP 2011), when protozoan data from the reservoir inflow sites are compared to that of the reservoir outflows [SRR2CM (Schoharie Reservoir outflow) and CATALUM (downstream of the Ashokan outflow in a closed aqueduct)] in most cases it is clear that 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 5.24 and Figure 5.25). While concentrations of cysts from the upstream sites vary from year to year depending on weather and watershed characteristics, the annual mean *Giardia* concentrations at the outflows are consistently far less than the combined mean of the upstream sites in each basin. Over the approximate 13 year sampling period, the three Schoharie upstream sites (S4, S5I and S7I) demonstrated mean concentrations of *Giardia* cysts (ranging from 43.0 - 51.6 cysts $50L^{-1}$) which is significantly higher than the mean concentration found at SRR2CM (10.7 cysts 50 L^{-1}) according to an analysis of variance (ANOVA) (p-value<0.001). Moreover, as the water flows downstream from the Schoharie basin through the Ashokan basin, additional reductions in protozoa are noted.

Similarly, although at much lower concentrations, *Cryptosporidium* mean concentrations were lower at the reservoir outflow than the sum of the sites upstream of the reservoir (Table 5.4). On occasion (e.g., 2014) comparable concentrations of *Cryptosporidium* were observed at the Schoharie outflow compared to the individual inflow concentrations; however, when considering the sum of the multiple inflows the outflow still showed an overall reduction. In any event, the reservoirs in both Catskill System basins have continued to provide attenuation of protozoa for a significant reduction in protozoan concentrations at reservoir outflows compared to concentrations at upstream sites.

As a supplement to the routine sampling mentioned above, monitoring was performed upstream of Site S7i on the Manorkill as a case study to identify potential sources of *Giardia* cysts along the stream corridor. Site S7i was selected for this enhanced sampling since it had the highest mean *Giardia* concentration compared to other sites. In all, ten additional sub-sites were monitored on a rotating basis over the course of five years to help determine areas of elevated cyst contribution upstream of S7i. The sample sites located furthest upstream resulted in no considerable *Giardia* levels, while some locations in between showed substantial concentrations of cysts. Results from this case study indicate that a stretch of the corridor identified to have beaver dams and lodges, and an outfall that drains a pond known to be inhabited by small aquatic mammals, are the likely sources of *Giardia* that contribute to the S7i site downstream. Additional information on this study is discussed in the 2014 Water Quality Annual Report (DEP, 2014).

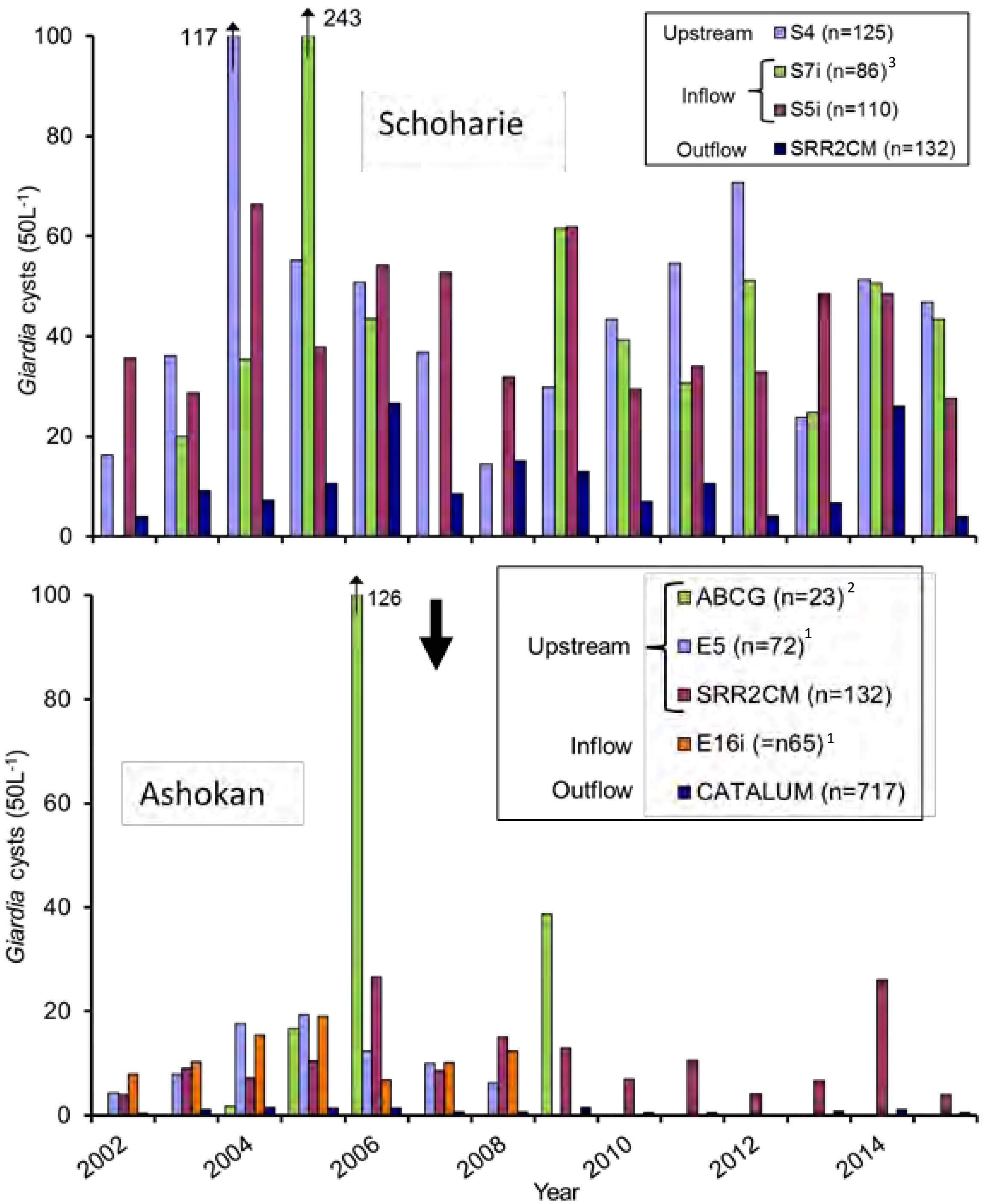

Figure 5.24 Annual mean concentrations of *Giardia* found at Catskill monitoring sites from June 2002 – September 2015, using Methods 1623HV and 1623.1 (40 – 60L samples only.)
Individual sample results were normalized to per 50L concentrations prior to averaging. [1]Monitoring at E5 and E16i was discontinued 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.

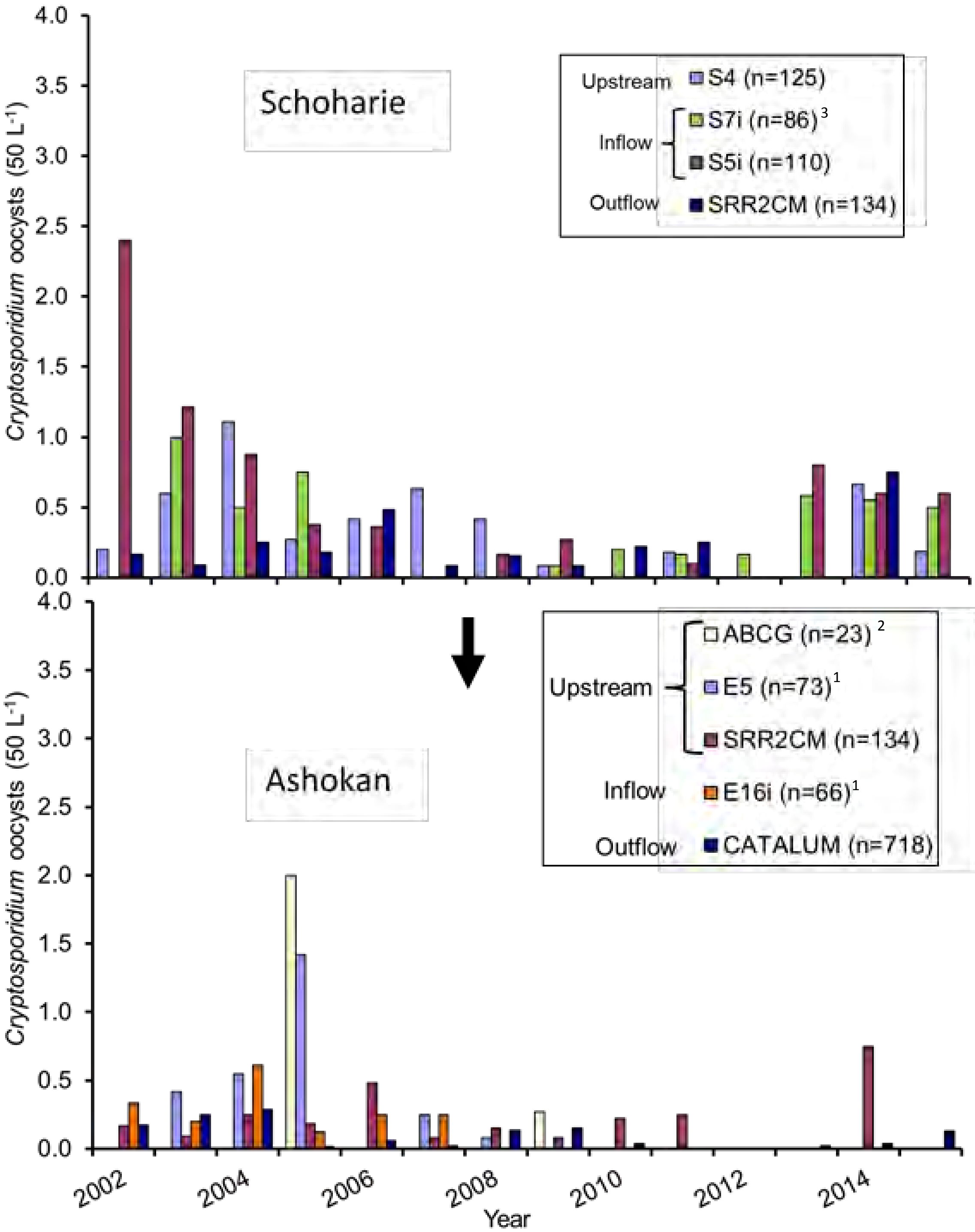

Figure 5.25 Annual mean concentrations of *Cryptosporidium* found at Catskill monitoring sites from June 2002 – September 2015, using Methods 1623HV and 1623.1 (40 – 60L samples only.)
Individual sample results were normalized to per 50L concentrations prior to averaging. [1]Monitoring at E5 and E16i 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.

Table 5.4 Mean concentrations for protozoans sampled at Catskill monitoring sites from 2002 – September 2015, according to USEPA method 1623HV or 1623.1 (40-60L samples only).

	Cryptosporidium (oocysts $50L^{-1}$)		*Giardia* (cysts $50L^{-1}$)	
	N	Mean	N	Mean
Schoharie				
Schoharie Creek upstream (S4)	125	0.36	125	45.83
Schoharie inflow 1 – Schoharie Creek (S5i)	110	0.49	110	43.00
Schoharie inflow 2 – Manorkill (S7i)	86	0.34	86	51.64
Schoharie outflow (SRR2CM)	134	0.18	132	10.67
Ashokan				
Birch Creek upstream of Esopus Creek (ABCG)	22	0.41	22	39.20
Esopus Creek above Shandaken Tunnel outlet (E5)	73	0.44	72	11.42
Schoharie outflow at Shandaken outlet (SRR2CM)	134	0.18	132	10.67
Esopus Creek inflow to Ashokan (E16i)	66	0.24	66	11.89
Ashokan outflow (Kensico inflow at CATALUM)	730	0.10	729	0.90

5.6.2 Catskill WWTPs

During the period from 2002 through September 2015, 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. Overall, 215 samples were collected.

Detection of *Giardia* in the effluents of WWTPs in the Catskill System occurred in 8.84% (19 detections out of 215 samples) of the samples collected during this period. *Giardia* detections at the WWTP effluents have fluctuated throughout the years and a portrayal of annual percent detections of cysts for all Catskill plants are shown in Figure 5.26. All plants studied had at least one detection of *Giardia* since 2002, ranging in maxima from 1 to 40 cysts $50L^{-1}$. Table 5.5 provides a detailed breakdown of the number of detections by plant and year of detection, along with the percent detection and maximum concentrations. The Hunter Highlands collection site was relocated from site HHE to site HHBD in 2009 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.

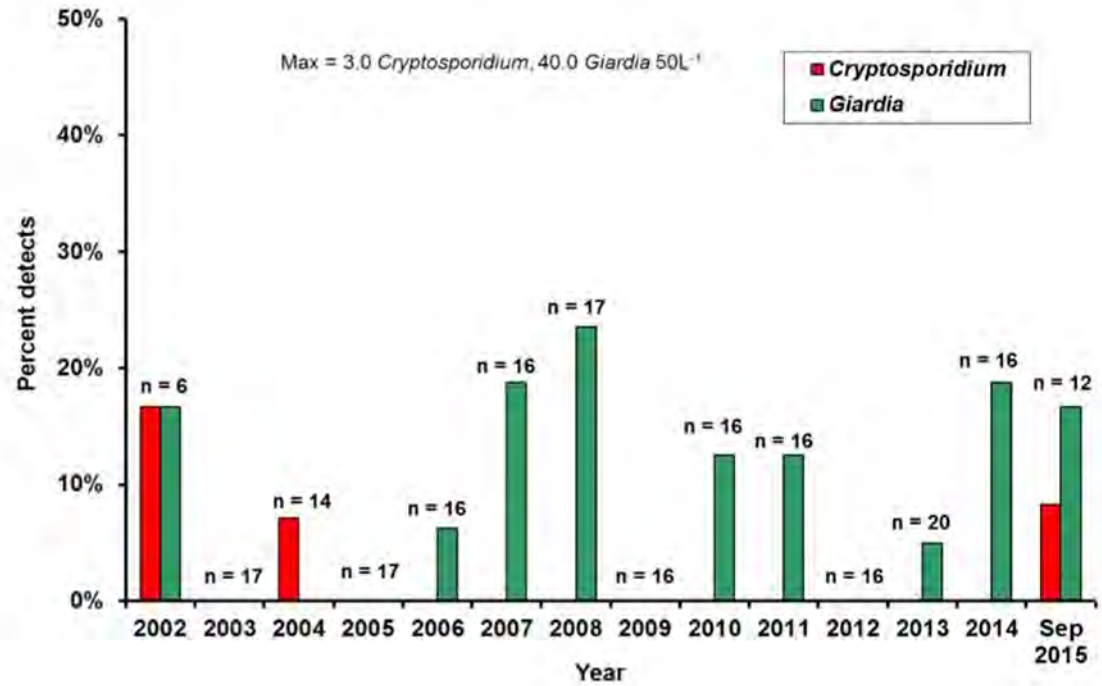

Figure 5.26 Annual mean concentrations of *Cryptosporidium* found at Catskill WWTP monitoring sites from June 2002 – September 2015, using methods 1623HV and 1623.1 (40 – 60L samples only).

As stated in the 2011 FAD Assessment (DEP 2011), there were no protozoan detections at HHBD at the time of report production; however, since that time there have been four *Giardia* detections at this new site. Since detections have continued, additional reviews of plant operations for the time period around each detection were conducted. With the exception of the 2015 *Giardia* detection, each instance seems to have occurred either while the Hunter Highlands plant underwent some operational abnormality (short-cycling dual sand filters) or when the sample was not representative of the final effluent (e.g., recirculation procedure). *Cryptosporidium* was detected 1.91% of the time (three detections out of 215) in the Catskill System WWTPs. *Cryptosporidium* oocysts were detected once each at three different plants (Pine Hill 2002, Hunter Highlands original site 2004, and Windham 2015) during this 13-year period with concentration maxima ranging from one to three oocysts $50L^{-1}$ (Table 5.5).

Table 5.5 Catskill WWTP protozoan detects per year and maximum concentrations, 2002 to September 2015. NS = not sampled.

Basin	WWTP	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Sep 2015	Percent detection	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	23% n = 26	7.0
	Hunter Highlands (HHBD)*	NS	NS	NS	NS	NS	NS	NS	0/4	1/4	1/4	0/4	0/4	1/4	1/3	15% n = 27	11.0
	Hunter (Hunter WTP)	NS	NS	NS	NS	NS	NS	NS	0/4	1/4	0/4	0/4	1/4	1/4	0/3	11% n = 27	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	4% n = 25	1.0
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	8% n = 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	4% n = 26	3.0
	Hunter Highlands (HHBD)*	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	0/3	0% n = 27	0.0
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	4% n = 26	1.0

*HHE site was changed to HHBD in March of 2009 due to suspected wildlife contamination post treatment.

5.7 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 Schoharie Reservoir from 2012-2014 was good. Monthly median fecal coliform counts did not exceed benchmarks and although monthly median phosphorus concentrations exceeded the benchmark of 20 µg L^{-1} with correspondingly high turbidity there was not excessive phytoplankton growth since suspended particulates limited light and growth. Trophic status ranged from oligotrophic to mesotrophic.

Long-term upward turbidity trends were detected in the principal inflow, Schoharie Creek (S5I), the reservoir, and its outflow and attributed to large storm events in 2010 and 2011. Peak turbidity levels were observed in late September, early August 2011 following Tropical Storm Irene and Tropical Storm Lee. An increasing trend was detected for fecal coliforms in the reservoir, attributed primarily to storm events. Previous long-term phosphorus declines for the input, reservoir and output of the Schoharie watershed were reported after WWTP upgrades. However, the large storm events in 2010-2011 caused phosphorus to increase and largely negate the downward trends previously observed for the reservoir and its output. A declining long-term phosphorus trend in Schoharie Creek (S5I), suggests rapid recovery from major storm events which is likely to be reflected in the reservoir and output in the future.

Biomonitoring results 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 the Ashokan basin, most sites were assessed as non-impaired in their most recent year of sampling, while in the Schoharie basin, non-impaired results prevailed in all years except during the year following Tropical Storms Irene and Lee, when disturbances caused by those storms likely contributed to results just below the non/slightly impaired threshold. No long-term trend was detected at any of the six sites on Esopus Creek and Schoharie Creek that had an extended period of record. One site on the Batavia Kill, however, has for unknown reasons experienced steep declines in its assessment scores over the last several years, the result of a sustained increase in hydropsychid caddisfly numbers and a reduction in the number of mayflies. Reasons for these declines are unclear.

Waterfowl management in Ashokan Reservoir has been conducted on an as needed basis. Since 2003, water bird numbers on Ashokan have decreased dramatically. This decrease is primarily attributable to closure of local landfills and a consequent shift in gull migratory patterns. Based on the low numbers of birds reported DEP determined it was not necessary to activate the as needed waterbird dispersal program during the assessment period.

Three sites above Schoharie Reservoir have been routinely monitored for *Cryptosporidium* and *Giardia* since 2002 as well as its outflow. Annual mean concentrations of cysts and oocysts have continued to be low from 2011 through September 2015, with evident decreases in concentration as the water passes through the reservoir to the outflow. One exception was in 2014, when the Schoharie outflow annual mean concentration of oocysts was similar to the inflow levels. Not unlike Schoharie, Ashokan inflows, including the inflow from Schoharie, continue to show a reduction of protozoan concentrations through the reservoir (2002-September 2015). The end result being consistently lower concentrations leaving Ashokan Reservoir flowing to the source water reservoir at Kensico. Settling, predation, and die-off continue to be the main 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 the result of improvements to the Pine Hill and Camp Timberlake WWTPs. Over 1,200 failing septic systems have also been repaired.

Water quality status in the West Basin of Ashokan Reservoir was good during the 2012-2014 assessment period. Monthly median fecal coliform counts were below benchmark values. Higher median turbidity occurred in the year following the extreme storm events of 2011. Only two reservoir TP values were above the phosphorus-restricted target value of 15 µg L^{-1} for source waters. TSI values ranged between oligotrophic and mesotrophic.

The trend in total phosphorus was generally downward even with the occurrence of record floods. Turbidity, fecal coliform and conductivity showed upward trends, and the increase in turbidity and fecal coliform is attributed to large runoff events in 2005-2006 and 2010-2011. Conductivity increases were coincident with a decline in precipitation over the last three years of the assessment period.

Water quality status in the East Basin of Ashokan Reservoir was even better than the West Basin, with lower median month turbidity (2.4 NTU as compared to 5.4 NTU). All monthly median fecal coliform counts were below the maximum detection limit. The TSI was in the oligotrophic to mesotrophic range.

Trends for total phosphorus, fecal coliforms and TSI were downward. Phosphorus decreased despite recent record floods, credited in part to watershed protection programs. The decrease in fecal coliforms is likely the result of declining bird populations brought about by landfill closures. Significant upward trends were detected for turbidity and were attributed to recent flooding events. A decrease in TSI is also attributed to the recent flooding events, since suspended particulates limit light for phytoplankton growth.

Schoharie Reservoir, and to a large extent the West Basin of Ashokan, do not conform to the usual behavior of most northern temperate water bodies with respect to trophic response.

Algal biomass (as measured by chlorophyll) response is exceptionally low relative to total phosphorus concentrations, except for a few instances when maxima develop in hydrologically uneventful years. Secchi depths are inversely related to phosphorus, i.e., high phosphorus is associated with years of low Secchi depths and occurrence of turbidity events. This indicates the association of phosphorus with re-suspended clay particles that cause high turbidity typical of the region. Secchi depths do not relate to chlorophyll (algal biomass) so algae are not a major determinant of transparency. Since light is severely limited in Schoharie, algae cannot grow to the extent expected on the basis of the phosphorus levels. 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 contrast, the East Basin of Ashokan Reservoir, which is typically more transparent than the other basins, exhibits responses closer to the OECD standards. Major storms are by far the major determinants of the physical, chemical, and biological conditions in the Schoharie and the West Basin of Ashokan Reservoirs. As watershed programs to improve turbidity control advance, the programs devoted to reductions in nutrient levels will become more important as determinants of algal biomass. Fortuitously, many of the programs address both nutrients and sediments at the same time.

6. Delaware System

6.1 The Scope of Water Quality Analyses

A description of the approach and scope of the water quality analyses is given in Appendix C. In brief, the water quality analyses cover approximately 22 years of data to provide a long-term context for interpretation. This time span provides a view of these changes in the context of natural variation (such as floods and droughts) and allows sufficient time for program implementation to impact water quality. The water quality data used in this analysis begins in 1993, which represents conditions at the outset of filtration avoidance when many watershed protection programs were in their infancy. The data from this decade represents conditions with fewer watershed programs in place. The time period from about 2000 through 2014 represents a time when watershed protection programs have reached a high level of implementation.

6.2 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 45-year period (1967 to 2015) are depicted in Figure 6.1.

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 is operated. It consistently receives a high hydraulic load that is delivered by the three upstream reservoirs and it averages about 1.5 months residence time. Residence times of Cannonsville and Neversink are very close

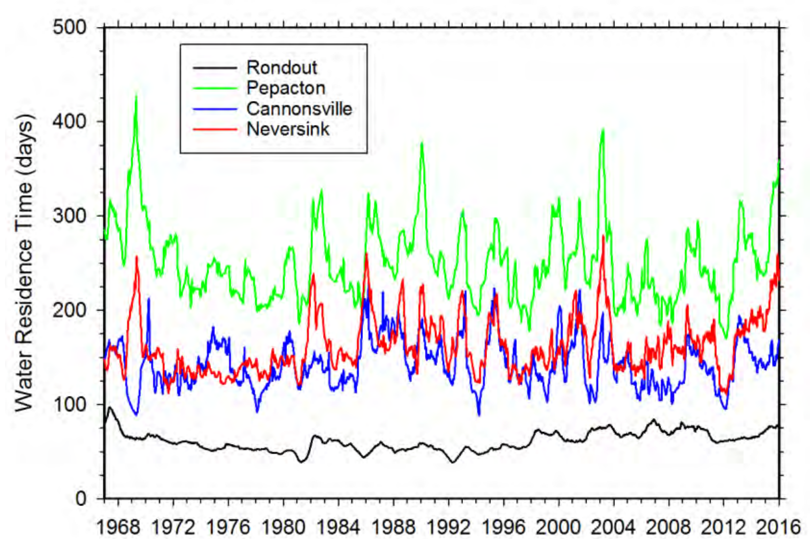

Figure 6.1 Water residence time in the four Delaware System reservoirs.

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, so Rondout would adjust to e.g., new loading levels in about six months, whereas Pepacton would take more than two years to re-equilibrate to a new steady state.

6.3 The Neversink Watershed

Neversink Reservoir is located in Sullivan County, approximately five miles northeast of the Village of Liberty and more than 75 miles from NYC. 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 MGD, or 13.5% of the total average daily consumption to NYC and an additional one million upstate consumers.

The Neversink is one of four reservoirs in the Delaware water supply system, the newest of the 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 and Kensico. At Kensico, it mixes with Catskill system water before traveling to the Hillview Reservoir in Yonkers, at the City's northern boundary, where it enters the water supply distribution system.

6.3.1 Land Use in the Neversink Watershed

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. Presently there are no WWTPs sited in the Neversink watershed basin.

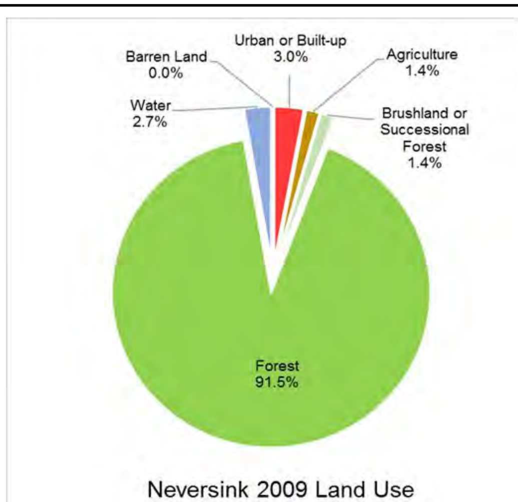

Figure 6.2 Land use in the Neversink watershed.

The land use breakdown for the Neversink watershed (Figure 6.2) is 91.5% forested, 3.0% urban, 1.4% brushland, 2.7% is water, and 1.4 % is in agricultural use. The Neversink watershed also has 0.9% of impervious surface. Therefore, the vast majority of this watershed is forested.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

6.3.2 Program Implementation in the Neversink Watershed

Since 1996, over 16 BMPs have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater and these BMPs were associated with over 400 acres of farmland in the Neversink basin (Figure 6.3). One environmental infrastructure project was constructed to control stormwater as well as a stream management project. Approximately 160 septic systems throughout the basin have been remediated during this period. Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place as described in in the Watershed Protection Program sections.

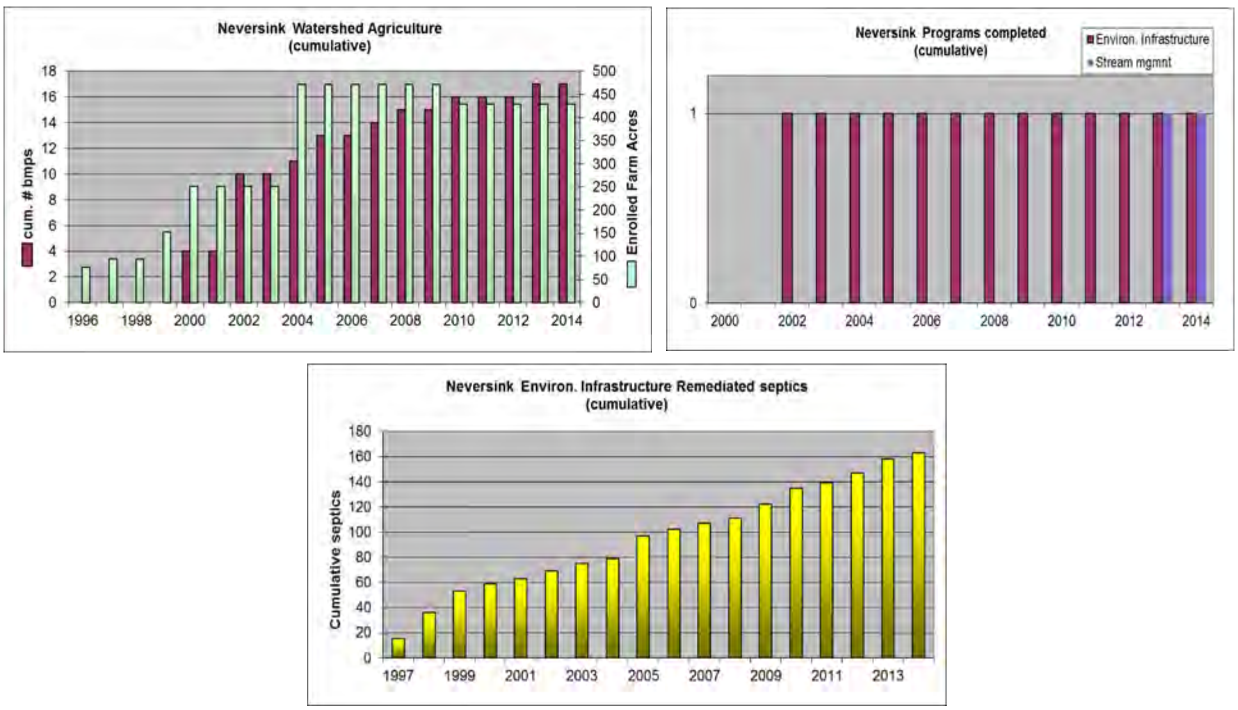

Figure 6.3 The history of watershed programs in the Neversink drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control, c) septic system remediation.

6.3.3 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 6.4. A comparison of the main inflow to the reservoir Neversink River (NCG), the reservoir (NN), and the outflow (NRR2CM) is shown. All values below the maximum detection limit for fecal

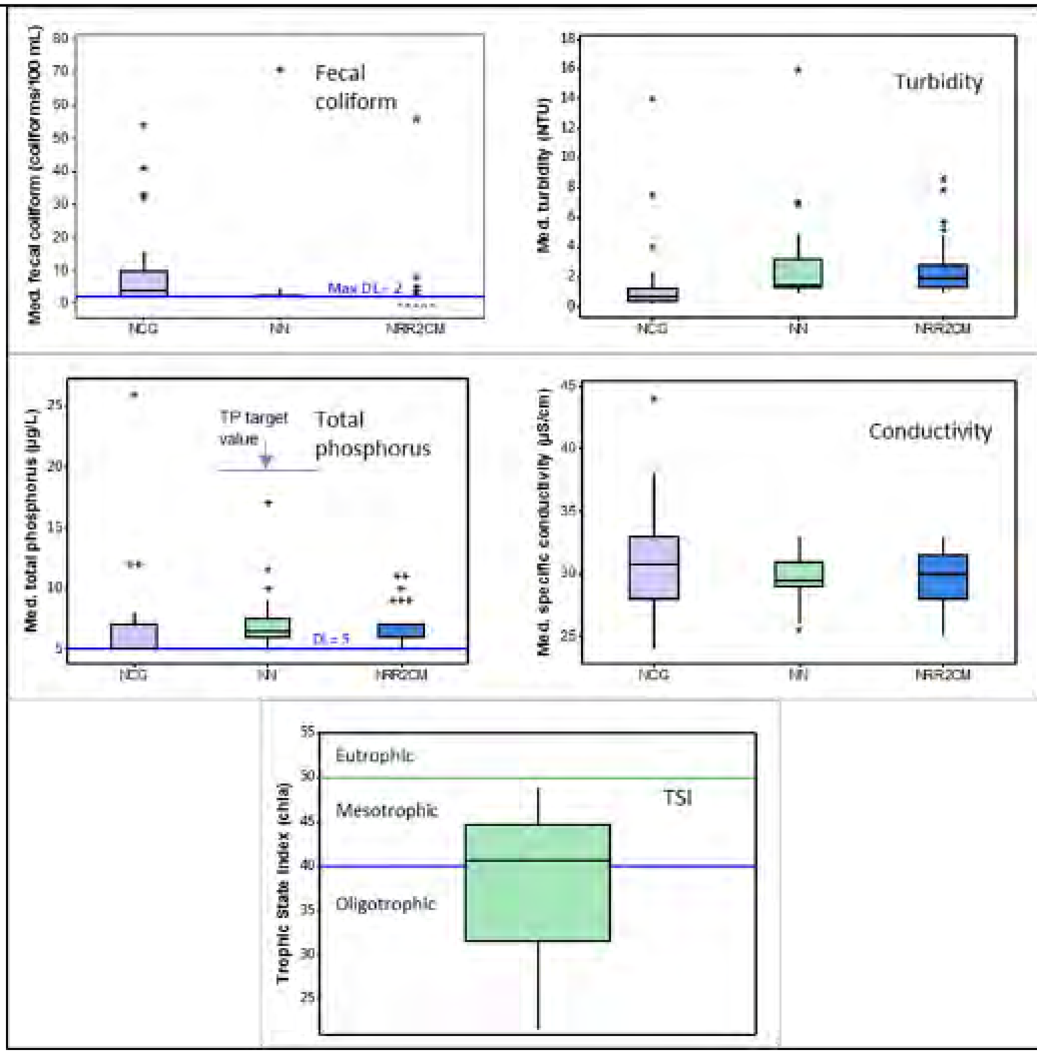

Figure 6.4 Water quality status boxplots using 2012-2014 monthly data for the Neversink basin main stream input at the Neversink River (NCG), Neversink Reservoir (NN), and the output at the Neversink gatehouse (NRR2CM).

coliform and total phosphorus were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2012-2014), fecal coliform bacteria remained well below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the river inflow. A rain event in September 2012 (2.34 inches recorded at DEP's rain gage at the Neversink Dam) was responsible for outlier median fecal coliform values at inflow, reservoir, and outflow sites.

Reservoir inflow fecal coliform levels were generally higher than the reservoir and outflow values. Turbidity in the Neversink basin is among the lowest in the entire DEP water supply watershed (reservoir median 1.5 NTU), but for the 2012-2014 assessment period there was a slight increase in the range and variability of turbidity at all sites as compared to the previous assessment period. Monthly median reservoir total phosphorus (TP) values did not exceed the target value of 20 µg L^{-1}. The TSI values for Neversink Reservoir ranged from oligotrophic to mesotrophic. Conductivity medians were typical of low-ionic strength waters with a monthly median conductivity of at or near 30 µS cm^{-1} for all sites.

In summary, water quality was good during the 2012-2014 status assessment period in the Neversink basin. All monthly median values were well below water quality status benchmark values.

Trends (Neversink)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. Water quality trend plots are presented in Figure 6.5 and results of the Seasonal Kendall trend analysis are provided in Table 6.1.

A strong upward turbidity trend was detected in the Neversink River at site NCG. The increase was largely due to large runoff events in 2010 and from tropical storms Irene and Lee in 2011. In addition, another large storm, the fourth highest peak flow on record, occurred from September 17-18, 2012, and was confined almost exclusively to the Neversink watershed. Although these more recent storms affected the reservoir and output, downward turbidity trends in the earlier part of the record offset the recent increase and no long-term trends were detected at these locations. Turbidity levels are generally higher in the reservoir and output than in the input indicating a possible additional source of turbidity unique to the reservoir. One potential source may be in-reservoir algal production. While algal particles generally produce very little turbidity, the background turbidity levels in the Neversink watershed are so low that even this small source is likely to exert some control over turbidity patterns in the reservoir. The discrepancy between the reservoir and input 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.

Long-term trends for fecal coliforms were not detected in the reservoir or output but a weak upward trend was indicated for the input. Fecal counts were consistently low especially in the reservoir and its output.

Table 6.1 Neversink basin trends from 1993-2014 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
NCG[3]	Input	Turbidity	263	0.15	***	0.01
Neversink	Reservoir	Turbidity	173	0.01	NS	
NRR2CM	Output	Turbidity	227	-0.04	NS	
NCG	Input	Fecal coliform	263	0.06	*	0.00
Neversink	Reservoir	Fecal coliform	173	-0.02	NS	
NRR2CM	Output	Fecal coliform	224	0.02	NS	
NCG[3]	Input	Total Phosphorus	263	0.17	***	0.08
Neversink	Reservoir	Total Phosphorus	174	0.11	***	0.00
NRR2CM	Output	Total Phosphorus	233	0.07	*	0.00
NCG[3]	Input	Conductivity	264	0.17	***	0.14
Neversink	Reservoir	Conductivity	173	0.02	NS	
NRR2CM	Output	Conductivity	228	-0.15	***	-0.07
Neversink	Reservoir	Trophic State Index	174	-0.02	NS	

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.
[3] Data were adjusted for flow prior to trend analysis - see Appendix C.

Strong long-term upward total phosphorus trends were observed in the reservoir and input and a weak increase was apparent in the output. However, the magnitude of the phosphorus increases for the reservoir and output were very small (<0.01 change yr^{-1}). The elevated input and reservoir concentrations in 1993 were caused by a large early spring rain event that followed two years (1991 and 1992) of extremely dry conditions in the watershed. From 1998-2011, the LOWESS curves indicate an increasing trend in the input, reservoir and output with the rate of change increasing, especially in the input, during the last three years of this period. The large runoff events during this time are probably the main drivers for the increase.

No conductivity trend was detected for the reservoir, but a statistically significant, small increase was detected for the input, and a highly significant, very small decrease was identified for the output. This seeming disparity can be explained by differences in sample frequency and lag time at these sample locations. The output was sampled 3-5 times per week and a monthly median of these results was used in the plots and for the trend analysis. In contrast, only monthly samples were available for the reservoir and input trend analysis. The greater sample frequency and the greater lag time induced by passage through the reservoir allows the output sample to better capture day to day fluctuations than the less frequently collected input and reservoir samples. The strong conductivity decrease in the output coincides with the relatively higher annual flows (and resulting dilution) from 2003-2011.

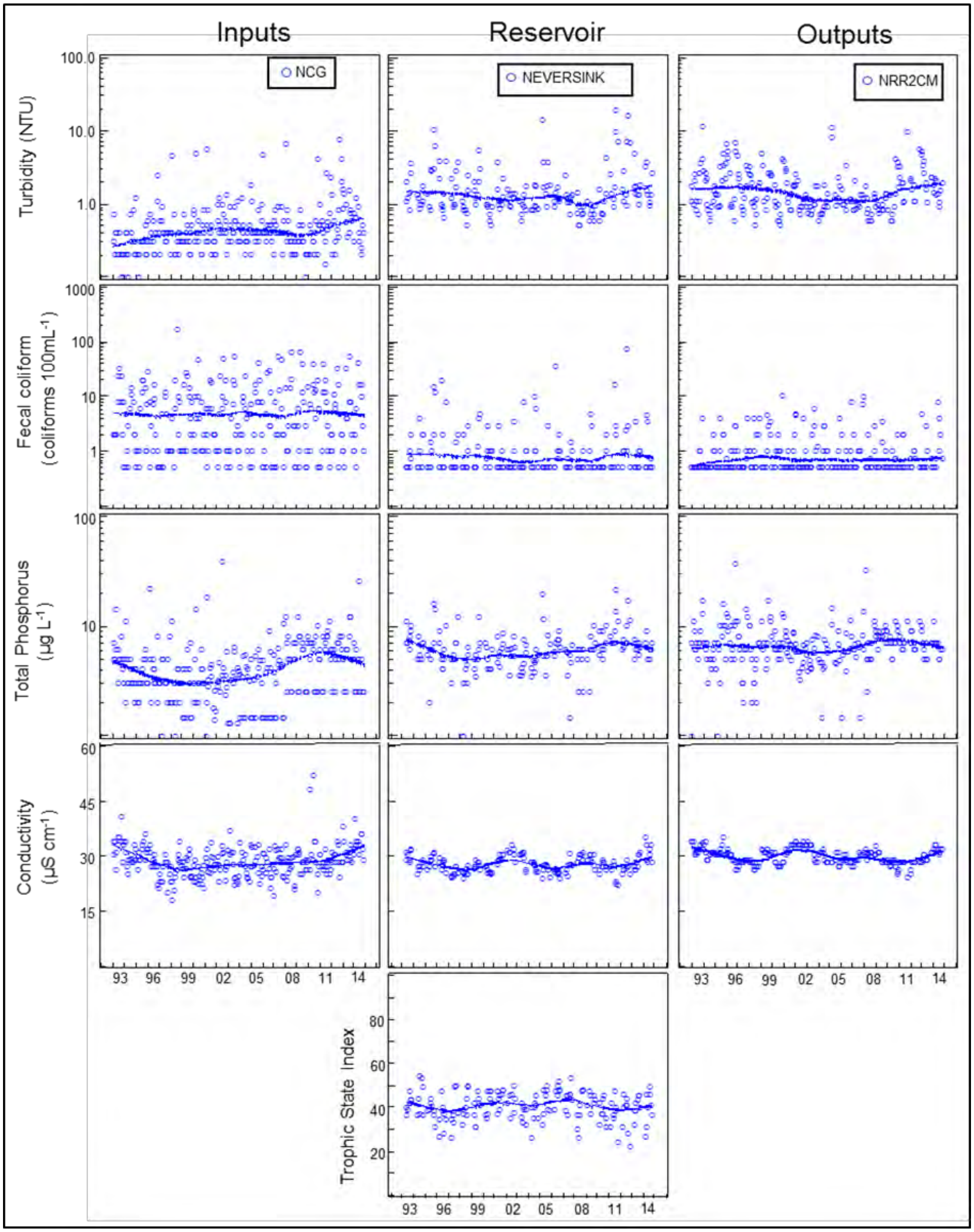

Figure 6.5 Water quality trends for the Neversink basin for the main stream input at the Neversink River (NCG), Neversink Reservoir, and the output at the Neversink gatehouse (NRR2CM).
For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix C.

In the 2009 FAD report, we reported a highly significant upward trend for the reservoir's TSI. Flooding events in 2010-2012, however, reduced water clarity and algal productivity declined enough to reverse the trend.

In summary, strong upward trends were detected for turbidity and total phosphorus and, strong upward trends were observed for conductivity and fecal coliforms in the Neversink Basin. A strong downward trend was detected for output conductivity and coincided with higher annual flows in the later portion of the study period. The turbidity and phosphorus increases are attributed to the recent record flooding events from 2010-2012. Reasons for the weak increase in input fecal coliforms were not apparent but could be related to recent storm activity.

6.4 The Pepacton Watershed

Pepacton Reservoir is located in Delaware County along the southern edge of the State's forever wild Catskill Park, 12 miles south of the Village of Delhi, and more than 100 miles northwest of NYC. 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 system by volume. Currently, Pepacton supplies 293 MGD or roughly 24.2% of the total average daily consumption.

Water withdrawn from the Pepacton Reservoir enters the East Delaware Tunnel and flows southeast for 25 miles into the Rondout Reservoir. There it mixes with water from the Cannonsville and Neversink Reservoirs, before heading south via the 85-mile long Delaware Aqueduct, which tunnels below the Hudson River to West Branch and Kensico Reservoirs. After mixing with Catskill system waters in the Kensico, it travels via aqueduct to the Hillview Reservoir and into the distribution system.

6.4.1 Land Use in the Pepacton Watershed

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. Presently there are six WWTPs sited in the Pepacton watershed producing an average cumulative flow of 0.315 MGD. As per the most recent SPDES permits, these plants are limited to a cumulative release of 0.665 MGD of flow. The Pepacton watershed, has a land use breakdown as follows: 77.7% is forested, 6.4% is urban, 6.3% is

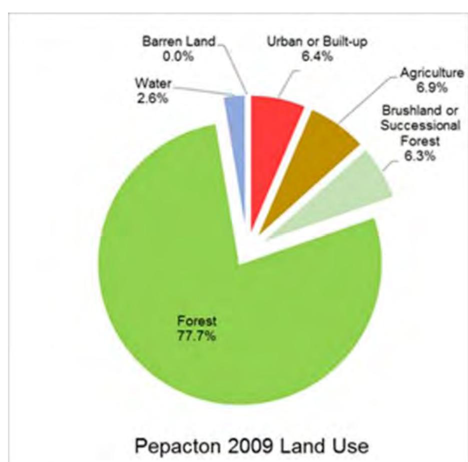

Figure 6.6 Land use in the Pepacton watershed.

brushland, 2.6% is water, and 6.9% is in agricultural use Figure 6.6. The Pepacton watershed also has 2.0% of impervious surface.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

6.4.2 Program Implementation in the Pepacton Watershed

Since 1996, over 450 BMPs have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater, and these BMPs were associated with approximately 8,600 acres of farmland (Figure 6.7). To date nearly 40 environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects. Nearly 900 septic systems throughout the basin have been remediated during this period. 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.

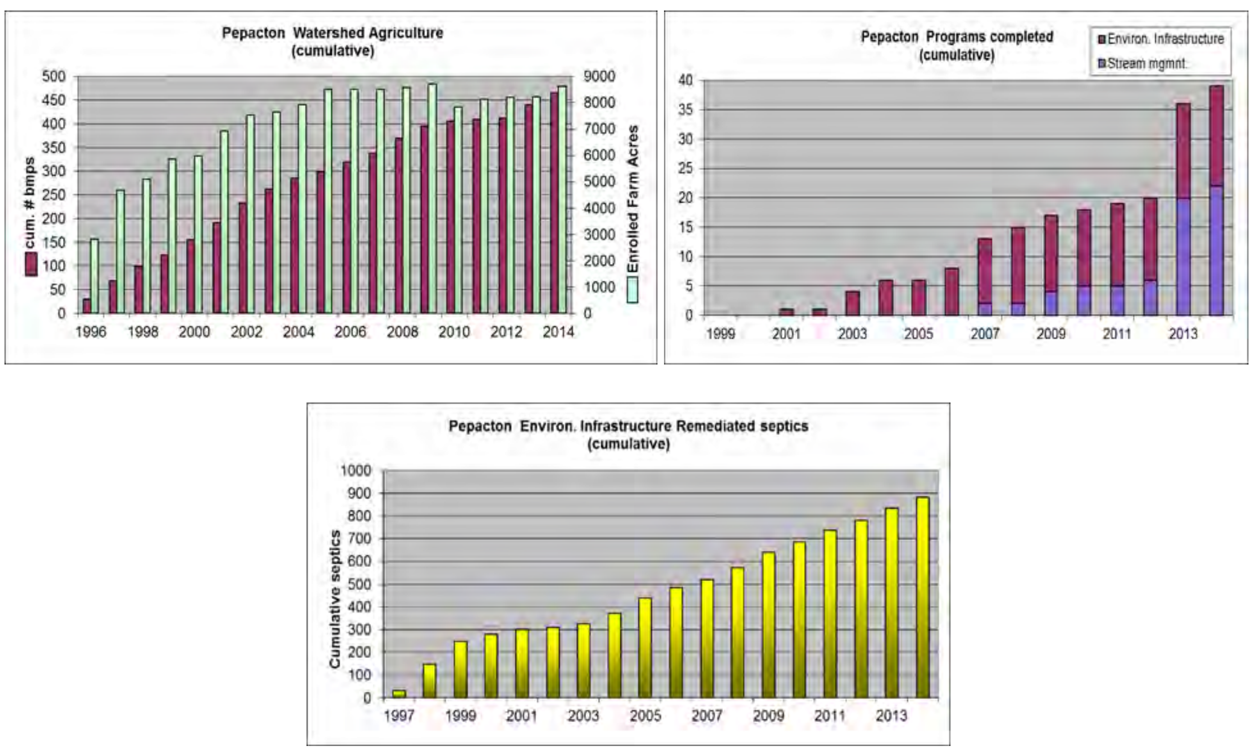

Figure 6.7 The history of watershed programs in the Pepacton drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control, including stream management projects, c) septic system remediation.

6.4.3 WWTPs and Phosphorus Load Reductions in the Pepacton Watershed

Inputs of phosphorus, as well as other pollutants, from WWTPs to Pepacton Reservoir continue to be reduced as a result of DEP's upgrade of all surface-discharging plants, including upgrade of DEP's Margaretville plant, and also through DEP's WWTP Compliance and Inspection Program. As illustrated in Figure 6.8 phosphorus (as TP) loads were considerably reduced from 1994 to 1999, and remained low in 2014. The combined flow showed an increase in 2009 due to the completion of two new plants – the Andes WTTP and the Fleischmanns WWTP.

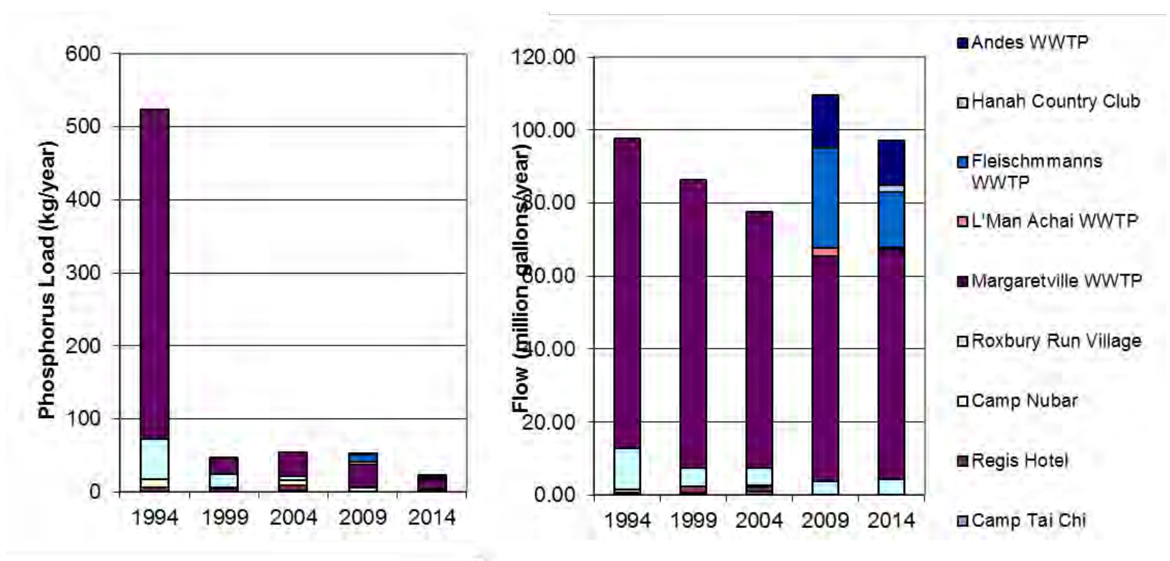

Figure 6.8 Wastewater treatment plant total phosphorus loads and flows in the Pepacton drainage basin, 1994 – 2014.

6.4.4 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 6.9. A comparison of the East Branch Delaware River (PMSB), the main inflow to the reservoir, the reservoir (EDP), and the outflow (PRR2CM) is shown. All values below the maximum detection limit for fecal coliform bacteria were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2012-2014), fecal coliform bacteria remained well below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the river inflow. Only one

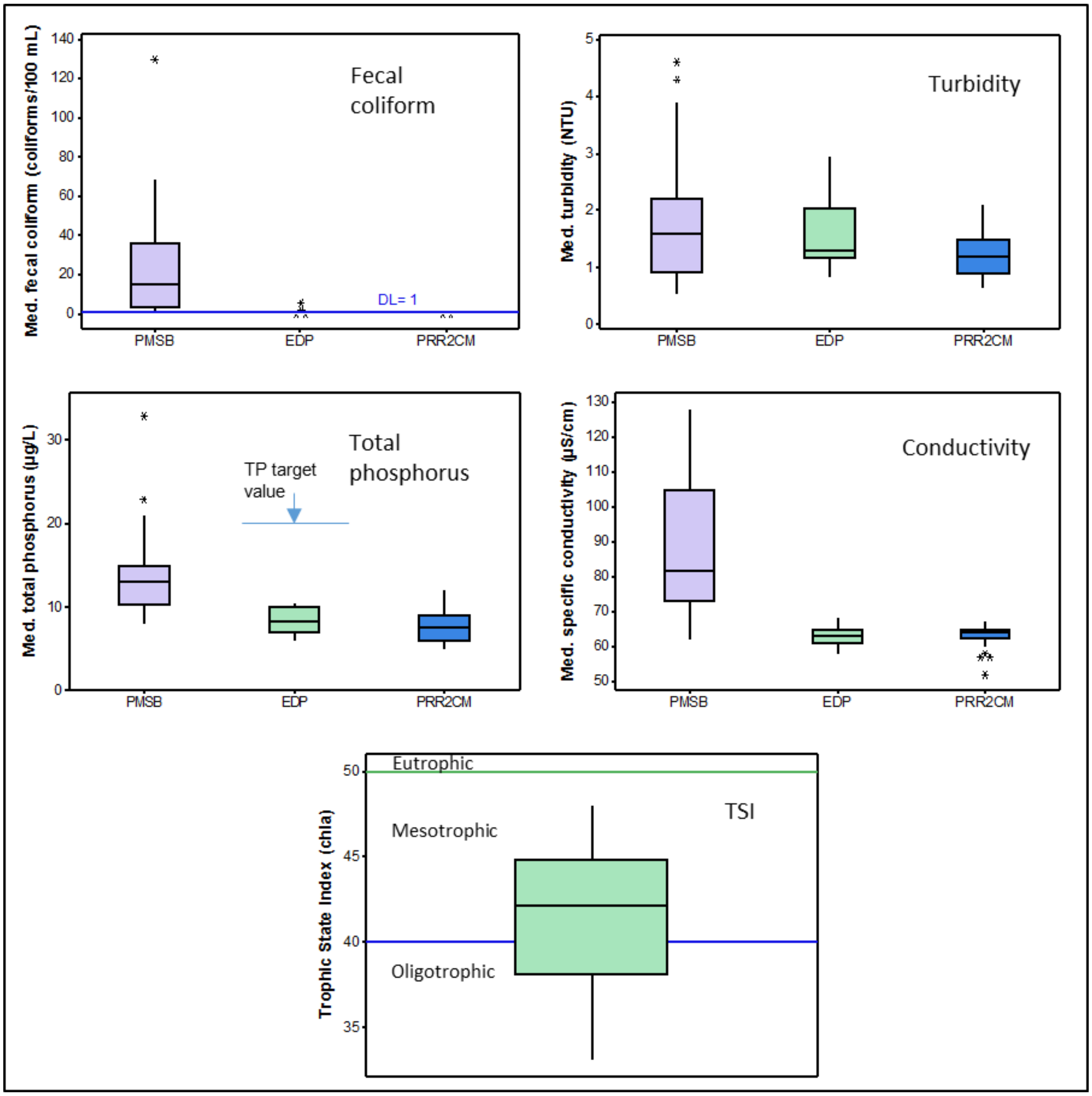

Figure 6.9 Water quality status boxplots using 2012-2014 monthly data for the Pepacton basin main stream input at the East Branch Delaware River (PMSB), Pepacton Reservoir (EDP), and the output at the Pepacton gatehouse (PRR2CM).

median outlier point was above the detection limit for the reservoir. Turbidity in the Pepacton Basin is typically low, as was the case for the 2012-2014 assessment period. Monthly median reservoir total phosphorus (TP) values were well below the target value of 20 µg L^{-1}. The TSI values for Pepacton Reservoir ranged from oligotrophic to mesotrophic, with a median of 45 in the mesotrophic range. Conductivity medians ranged from 81.5 µS cm^{-1} at the inflow to 64 µS cm^{-1} at the outflow.

In summary, water quality was good during the 2012-2014 status assessment period in the Pepacton basin. All monthly median values were well below water quality status benchmark values.

Trends (Pepacton)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. Water quality trend plots are presented in Figure 6.10 and results of the Seasonal Kendall trend analysis are provided in Table 6.2.

Table 6.2 Pepacton basin trends from 1993-2014 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
PMSB[3]	Input	Turbidity	264	-0.12	***	-0.00
Pepacton	Reservoir	Turbidity	171	-0.05	NS	
PRR2CM	Output	Turbidity	254	0.04	NS	
PMSB	Input	Fecal coliform	262	-0.11	***	-0.22
Pepacton	Reservoir	Fecal coliform	171	0.01	NS	
PRR2CM	Output	Fecal coliform	254	0.00	NS	
PMSB[3]	Input	Total Phosphorus	264	-0.27	***	-0.38
Pepacton	Reservoir	Total Phosphorus	170	-0.10	**	0.00
PRR2CM	Output	Total Phosphorus	255	0.01	NS	
PMSB[3]	Input	Conductivity	263	0.36	***	0.72
Pepacton	Reservoir	Conductivity	163	0.56	***	0.50
PRR2CM	Output	Conductivity	254	0.47	***	0.40
Pepacton	Reservoir	Trophic State Index	170	-0.21	***	-0.19

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.
[3] Data were adjusted for flow prior to trend analysis - see Appendix C.

Turbidity trends were not detected in the output or reservoir. However, a long-term downward trend was detected in the input. The change per year was very small (0.01 NTU) and appears to be driven by high values associated with a rain on snow event in January 1996. Note that the Pepacton basin was not as strongly affected (as other DEP water supply basins) by the flooding events of 2010-2011.

Trends were not detected for fecal coliforms in the reservoir or output. However, a strong downward trend was observed in the input which could be related to various watershed programs such as septic remediation and WWTP upgrades. Although downward trends were not detected in the reservoir the temporal plots (Figure 6.10) suggest strong coliform attenuation within the reservoir resulting in much lower coliform counts compared to the input.

A significant decline in TP (-0.40 $\mu g\ mL^{-1}\ yr^{-1}$) was observed in the input and a moderately strong, although very small (<0.01 $\mu g\ mL^{-1}\ yr^{-1}$) decline was detected in the reservoir. At the input site, phosphorus concentrations decreased from 1993-1999, especially 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, early 1996. Terrestrial and reservoir modeling suggest that land use changes (i.e., reduction in agricultural activity) may also have played a part in this reduction (DEP 2011a).

Strong upward trends in conductivity were detected in the input, reservoir, and output. Anthropogenic sources (e.g., road salt runoff) were a factor; chloride has steadily increased from a median of 4.4 mg L^{-1} in 1993-1994 to a median of 6.8 mg L^{-1} in 2013-2014 (DEP data, not presented here). Changes in precipitation patterns also contributed to the upward trend; for example, the concentration effect of the mid-2001-2002 drought is reflected in the noticeable rise in conductivity at that time. Relatively low flow from 2012-2014 could also be a factor.

A strong downward trend was detected for TSI in Pepacton Reservoir. The decrease may be due to more turbid conditions associated with storm events in 2010-2011 but decreases in phosphorus associated with watershed programs could also be a factor.

In summary, conductivity increases were apparent throughout the basin while downward trends were observed for turbidity, fecal coliforms, TP and TSI at select locations. The rise in conductivity can be explained by periods of low precipitation and the steady increase in chloride. Downward trends for fecal coliforms and especially TP and TSI could be linked to the watershed programs. However, more turbid conditions associated with flooding events in 2010-2011 may also be a factor contributing to the observed TSI decrease.

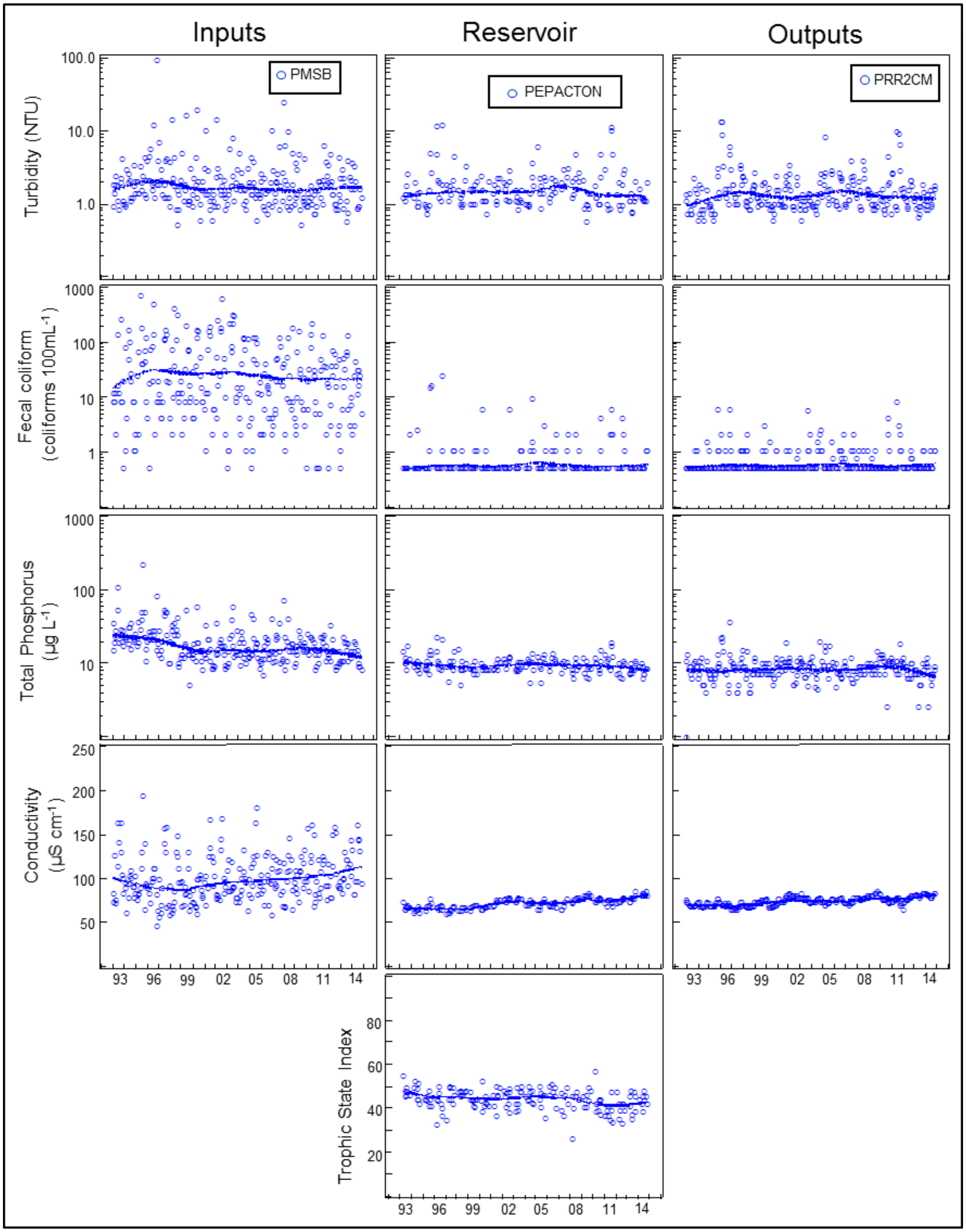

Figure 6.10 Water quality trend plots for the Pepacton basin for the main stream input at the East Delaware River (PMSB), Pepacton Reservoir, and the output at the Pepacton gatehouse (PRR2CM).

6.4.5 Biomonitoring in the Pepacton Watershed

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

The most recent status of macroinvertebrate communities in the Pepacton basin was evaluated by examining 2012-2014 data from sites located on the East Branch of the Delaware River. This stream is the primary inflow to Pepacton Reservoir, draining 45% of the basin. Two of the sites with data from these years (Sites 316 and 321) are routine, that is, they are sampled annually; the other (Site 306) is sampled on a rotating basis and was sampled only once during the 2012-2014 period.

Site 316 (PMSB) in Margaretville lies approximately five miles upstream of Pepacton Reservoir, Site 321 (EDRB) is about 13 miles upstream, and Site 306 is about 15 miles upstream. Site 316 was assessed as non-impaired in 2012 and slightly impaired in 2013 and 2014 (including a record low score of 6.80 in 2013), while Site 321 was assessed as slightly impaired in all three years. Site 306 was assessed as non-impaired in 2014, the only year it was sampled (Figure 6.11). Impact Source Determination (ISD), DEC’s procedure for identifying impacts that exert deleterious effects on a water body, indicated that nonpoint source nutrients were the likely source of impairment at both routine sites in 2013 and 2014. Trend analysis was based on the routine sites’ entire period of record, which in both cases began in 1996, and examined changes in both scores and assessment categories.

Long-term trends in biomonitoring scores at Sites 316 and 321 were examined using the non-parametric Mann Kendall trend test, which seeks to determine whether a given value—here, the Biological Assessment Profile (BAP) score—increases or decreases over time. A weak downward trend was detected at Site 316 ($p = 0.142$) and a strong one at Site 321 ($p = 0.006$) (Figure 6.12). These results reflect the increasing frequency of slightly

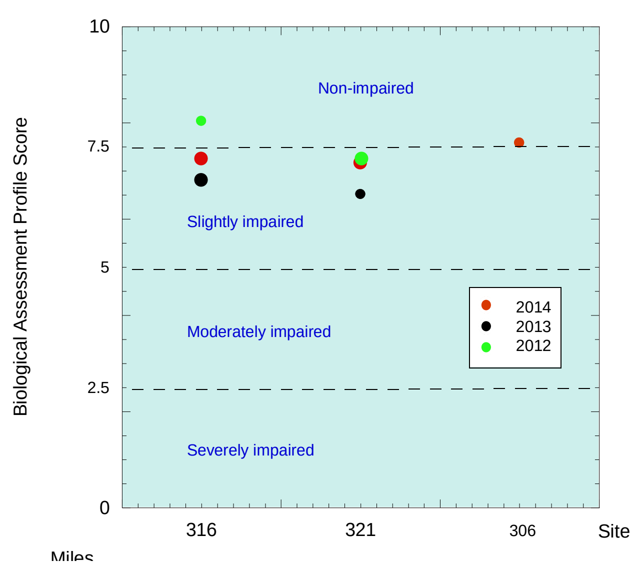

Figure 6.11 Biological Assessment Profile scores for East Branch Delaware River, 2012-2014.

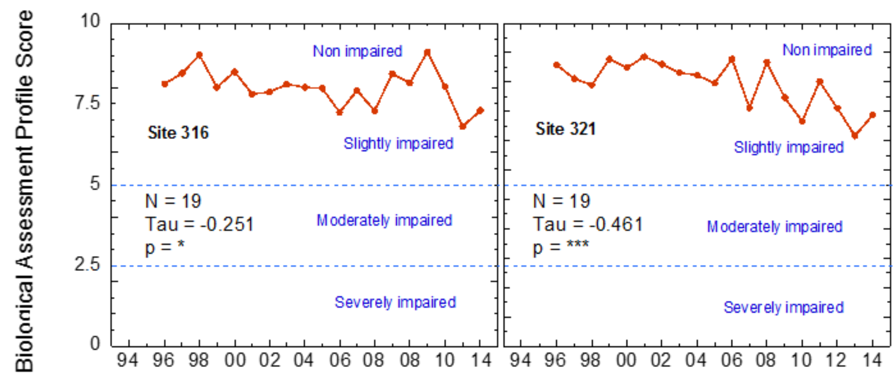

Figure 6.12 Biological Assessment Profile scores for East Branch Delaware River, 1996-2009.
Results of the Mann Kendall trend test are shown as follows: $0.20 > p > 0.10$ (*), $p \leq 0.05$ (***). N = number of observations, Tau = Mann Kendall test statistic.

impaired assessments at both sites over the last several years, following many years of non-impaired assessments. Thus, after 10 consecutive years of non-impaired assessments, four of the last nine results at Site 316, including the two most recent ones, have been slightly impaired. The change at Site 321 is even more pronounced: after 11 years of non-impaired assessments, five of the last eight, including the last three, have been slightly impaired. Although ISD indicates that nonpoint nutrients were the likely cause of impairment at Site 316 in 2013 and 2014, the results were inconclusive for the other two slightly impaired years (2006 and 2008). At Site 321, however, nonpoint nutrients were the likely cause of impairment in all years according to the ISD. The abundance of hydropsychid caddisflies at both sites in the years following Tropical Storms Irene and Lee, a phenomenon observed at many CAT/DEL sites, suggests that the slightly impaired results in those years may have been related to disturbances caused by those storms, since hydropsychids are known to favor enriched conditions. Whether or not elevated nutrient levels are implicated, however, remains unclear, since DEP data for the post-Irene/Lee years indicate that neither phosphorus nor nitrogen concentrations exceeded historical levels. The Roxbury Run WWTP lies upstream of Site 321, but elevated nutrient levels have not been detected in the plant's effluent. DEP will continue to monitor these sites in future years to see if they return to their non-impaired status.

6.5 The Cannonsville Watershed

The Cannonsville Reservoir is located at the western edge of Delaware County, southwest of the Village of Walton and about 120 miles northwest of NYC. 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 NYC and an additional one million upstate consumers.

The Cannonsville is one of four reservoirs in the Delaware system and the newest in NYC's water supply. Water drawn from the Cannonsville enters the West Delaware Tunnel and travels 44 miles to the upper end of the 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. At Kensico, it mixes with Catskill System water, then travels to the Hillview Reservoir in Yonkers, where it enters the water supply distribution system.

6.5.1 Land Use in the Cannonsville Watershed

The Cannonsville watershed's drainage basin is 455 square miles, the largest basin in the DEP's system, and includes parts of 17 towns, all in Delaware County: Andes, Bovina, Delhi, Deposit, Franklin, Hamden, Harpersfield, Jefferson, Kortright, Masonville, Meredith, Middletown, Roxbury, Sidney, Stamford, Tompkins and Walton. 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 WWTPs sited in the Cannonsville watershed producing a cumulative effluent average flow of 2.534 MGD. As per the most recent SPDES permits, the plants are limited to a cumulative release of 3.235 MGD of flow. 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 (Figure 6.13). The Cannonsville watershed also has 2.3% of impervious surface.

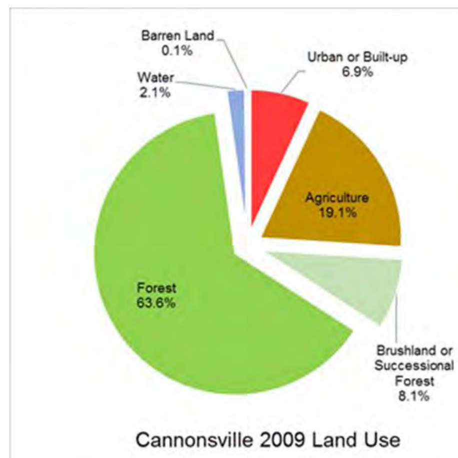

Figure 6.13 Land use in the Cannonsville watershed.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

A portion of water not taken for the City's supply is released from Cannonsville Dam at the reservoir's west end and flows into the lower West Branch of the Delaware River. Under a 1954 U.S. Supreme Court ruling, NYC 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. This process is overseen by the Delaware River Basin Commission (DRBC). The DEP also, in conjunction with the NYSDEC, releases water from Cannonsville and other Delaware system reservoirs to help maintain the fisheries of the lower West Branch Delaware River.

6.5.2 Program Implementation in the Cannonsville Watershed

Since 1996 approximately 2,500 BMPs have been implemented to control runoff of nutrients, turbidity, pathogens, and storm water and these BMPs were associated with nearly 40,000 acres of farmland (Figure 6.14). Over 60 environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects. Approximately 1,100 septic systems throughout the basin have been remediated during this period. 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.

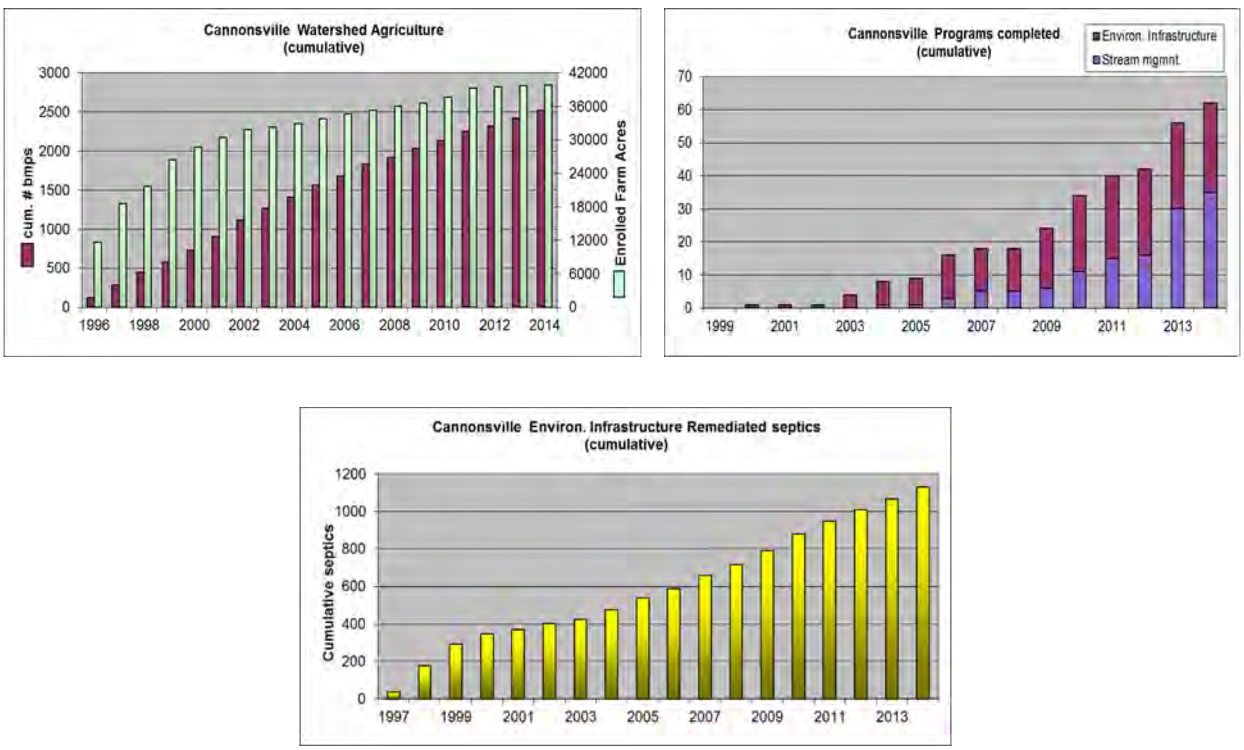

Figure 6.14 The history of watershed programs in the Cannonsville drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control including stream management projects, c) septic system remediation.

6.5.3 WWTPs and Phosphorus Load Reductions in the Cannonsville Watershed

Inputs of phosphorus, as well as other pollutants, from WWTPs to Cannonsville Reservoir continue to be reduced as a result of DEP's upgrade of all surface-discharging plants, and also through the efforts of DEP's WWTP Compliance and Inspection Program. As illustrated in Figure 6.15, phosphorus (as TP) loads were considerably reduced from 1994 to 2014. This was accomplished in large part through the intervention and assistance of DEP at Walton and at Walton's largest commercial contributor, Kraft. Permitted flows were increased at Walton and Delhi plants after 2009. The substantial additional reductions in phosphorus loads realized in 2004 can be attributed to final upgrades of several plants and diversion of another. Consequently, as of 2002 Cannonsville is no longer listed as a phosphorus-restricted basin.

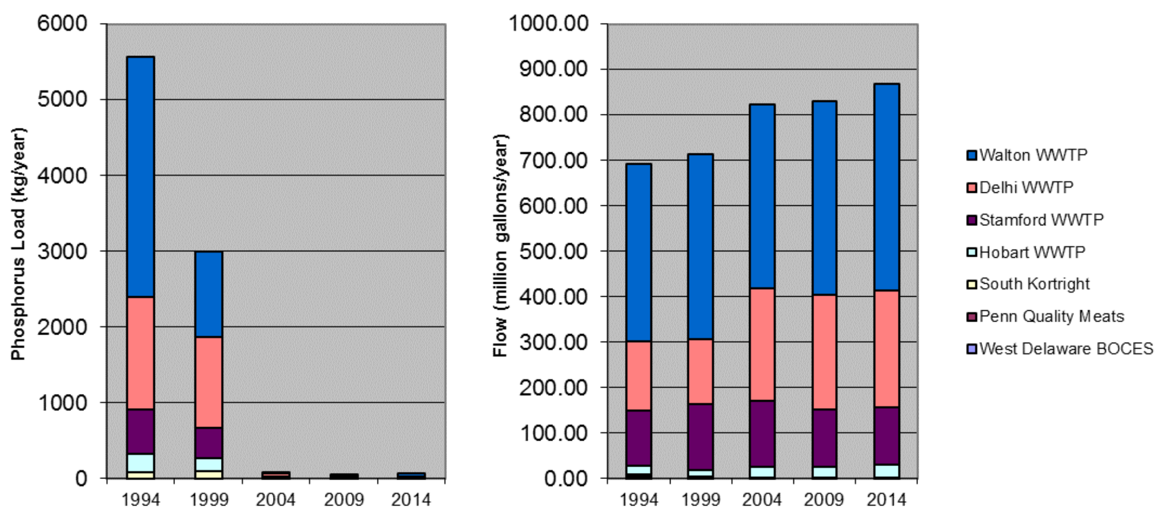

Figure 6.15 Wastewater treatment plant total phosphorus loads and total volume of WWTP effluent flow to flows in the Cannonsville Reservoir from drainage basin, 1994 to 2014.

6.5.4 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 6.16. A comparison of the main inflow, West Branch Delaware River (WDBN), the reservoir (WDC), and the outflow (WDTOCM) is shown. All values below the maximum detection limit

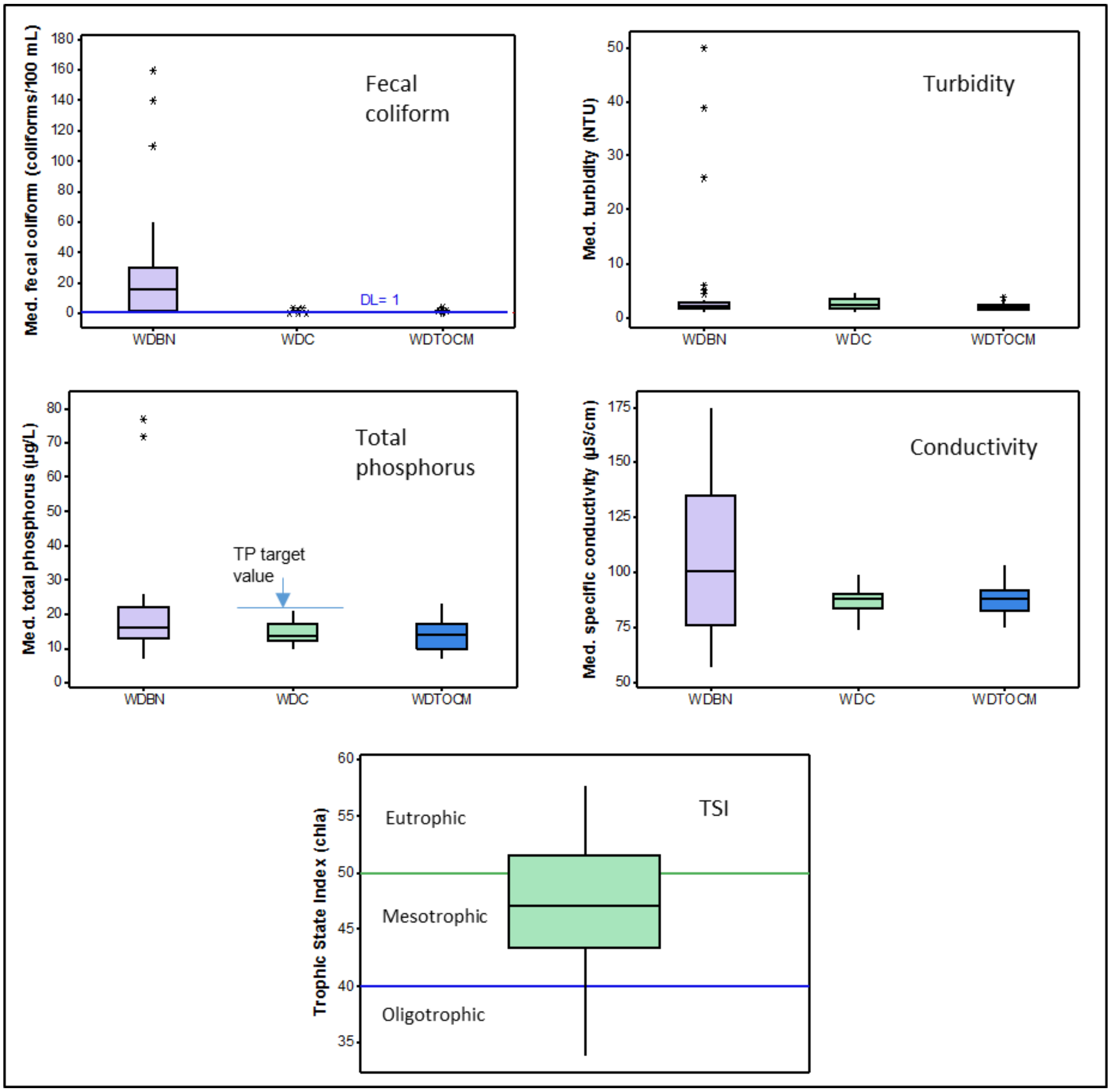

Figure 6.16 Water quality status boxplots using 2012-2014 monthly data for the Cannonsville basin main stream input at the West Branch Delaware River (WDBN), Cannonsville Reservoir (WDC), and the output at the West Delaware Tunnel Outlet (WDTOCM).

for fecal coliform were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2012-2014), fecal coliform bacteria remained well below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the stream inflow site.

Reservoir and outflow fecal coliform levels were at or below the detection limit. Turbidity was generally low, with a few exceptions for the river inflow. Median monthly total phosphorus (TP) for the reservoir median was 13.5 µg L^{-1}, well below the target value of 20 µg L^{-1}. The TSI values for Cannonsville Reservoir fell within the mesotrophic range primarily, with a median of 47. Conductivity medians were highest at the inflow (100.5 µS cm^{-1}) and slightly reduced in the reservoir and outflow (both with a median of 88 µS cm^{-1}).

In summary, water quality was good during the 2012-2014 status assessment period in the Cannonsville basin. Monthly medians did not exceed water quality benchmark values for any of the featured analytes.

Trends (Cannonsville)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. Water quality trend plots are presented in Figure 6.17 and results of the Seasonal Kendall trend analysis are provided in Table 6.3.

Table 6.3 Cannonsville basin trends for selected variables from 1993 to 2014.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
WDBN[3]	Input	Turbidity	264	-0.04	NS	
Cannonsville	Reservoir	Turbidity	174	-0.16	***	-0.03
WDTOCM	Output	Turbidity	195	-0.07	NS	
WDBN	Input	Fecal coliform	253	-0.15	***	-0.69
Cannonsville	Reservoir	Fecal coliform	173	0.02	NS	
WDTOCM	Output	Fecal coliform	190	-0.02	NS	
WDBN[3]	Input	Total Phosphorus	264	-0.39	***	-0.02
Cannonsville	Reservoir	Total Phosphorus	170	-0.34	***	-0.33
WDTOCM	Output	Total Phosphorus	199	-0.20	***	-0.21
WDBN[3]	Input	Conductivity	263	0.04	NS	
Cannonsville	Reservoir	Conductivity	170	0.22	***	0.81
WDTOCM	Output	Conductivity	195	0.41	***	0.58
Cannonsville	Reservoir	Trophic State Index	170	-0.22	***	-0.31

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.
[3] Data were adjusted for flow prior to trend analysis - see Appendix C.

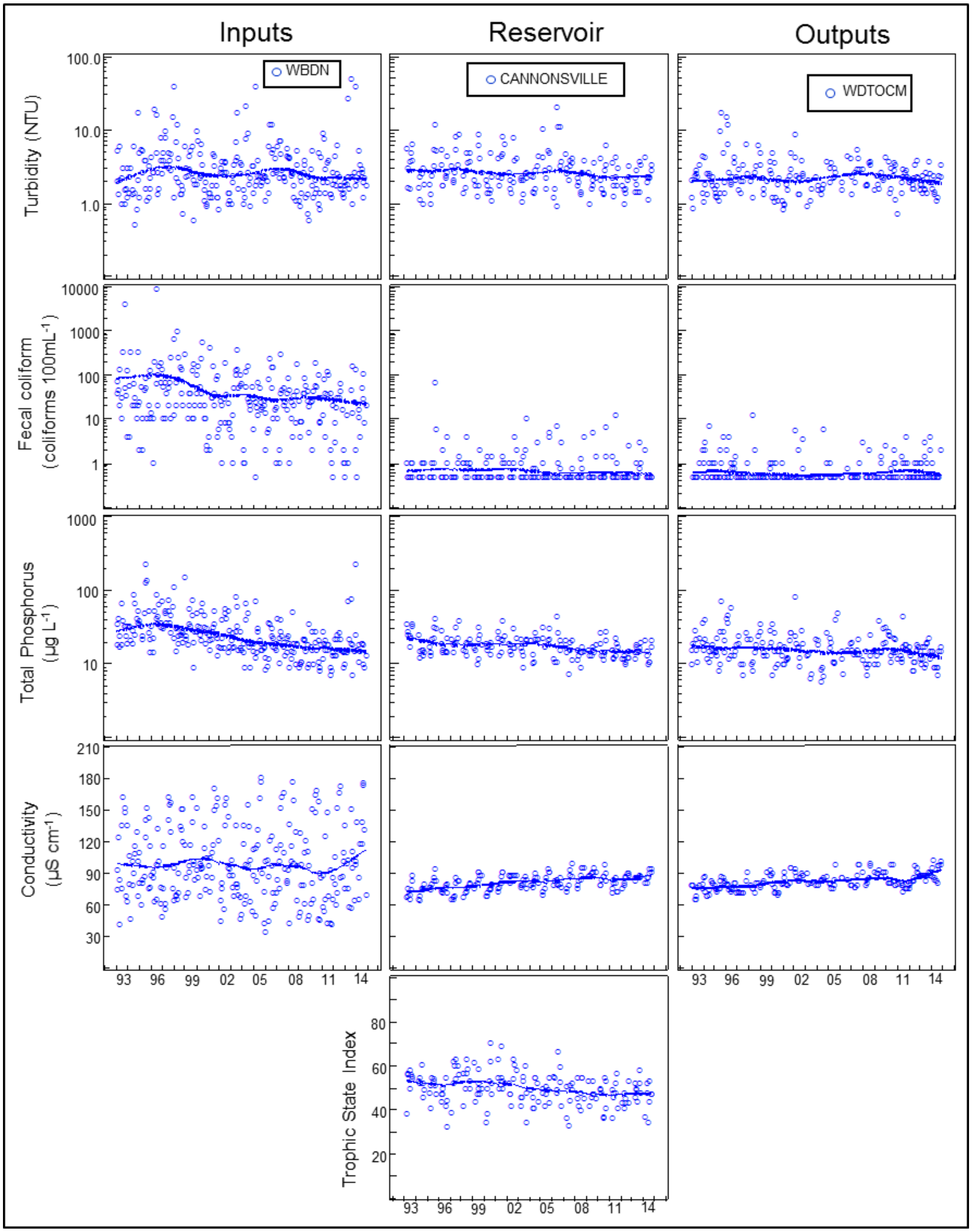

Figure 6.17 Water quality trend plots for the Cannonsville basin main stream input at the West Branch Delaware River (WDBN), Cannonsville Reservoir, and the output at the West Delaware Tunnel Outlet (WDTOCM).

Slight declines in turbidity were evident in the reservoir. Reasons for the decline are not clear. Recovery from flood events in late 1995 to early 1996, April 2005 and June 2006 is one possible factor. Periods of low inputs in years affected by droughts (2001-2002) or in years where large events (>2 inches) were scarce (2007-2009 and 2012-2014) are another. Extensive implementation of agricultural BMPs in the watershed is yet another factor. Downward trends were not detected in the input or in the output, possibly reflecting differences in sampling strategies compared to the reservoir. Both the input and output are sampled each month while the reservoir is only sampled during ice-free months, generally from April to November. In addition, the input data exhibit higher variability due to the low sampling frequency, making it difficult to detect trends.

Despite very high variability, a strong downward trend was detected for fecal coliforms in Cannonsville's main input. Since the data are dominated by many tied, low values resulting in a change per year estimated at zero. An alternative estimate of change can be used by comparing the median coliform concentrations for the first five years to the last five years of the period of record. The median concentration for the early period is 44 fecal coliforms 100 mL^{-1} versus 21 fecal coliforms 100 mL^{-1} for the later period yielding a decrease of 52%.

For TP concentrations, trend analysis results indicate significant decreases in the input, reservoir and output. The LOWESS curve indicates that phosphorus peaked at the input in 1996, and except for temporary increases in 1999 (Tropical Storm Floyd), June 2006 (seven inches of rain June 25-27) and in 2011 (Tropical Storm Irene and Tropical Storm Lee) it has been in decline through 2014. 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.

Increasing conductivity trends were not detected in the input presumably due to its high variability. However, the reservoir and the output experienced strong upward trends. The increases were not correlated with precipitation trends but did coincide with increases in chloride, suggesting an anthropogenic source (e.g., road salt). Median reservoir chloride in 1993-1994 was 6.2 mg L^{-1} versus 10.2 mg L^{-1} in 2013-2014.

Algal productivity seems to be decreasing in Cannonsville Reservoir as evidenced by the decline in TSI since 2002. The continuing decrease in phosphorus may be the driving factor, but poor water clarity from runoff events in May 2005 and especially June 2006.

Note that turbidity levels did not rise dramatically after Irene and Lee as this portion of the water supply system was not as heavily impacted.

In summary, downward trends were detected for turbidity, fecal coliforms and phosphorus while significant 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) and from periods characterized by few intensity runoff events (2007-2009) are another factor. Recovery from various flooding events may also contribute to the declines in phosphorus but load reductions from WWTPs and food manufacturing maybe the primary cause. Phosphorus reductions and low water clarity in 2005-2006 help to explain the decrease in trophic state. The conductivity increases are thought to be caused by increases from anthropogenic sources (e.g., road salt).

6.5.5 Biomonitoring in the Cannonsville Watershed

The NYC stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in DEP watershed streams. For methodology details, see Appendix C. The most recent status of macroinvertebrate communities in the Cannonsville basin was evaluated by examining 2012-2014 data from sites located on the West Branch of the Delaware River. This stream 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, that is, they are sampled annually; the other (Site 302) is sampled on a rotating basis and was sampled only once during the 2012-2014 period, in 2014.

Site 320 (WDBN) in Beerston lies approximately 1.5 miles upstream of Cannonsville Reservoir. Sites 304 (WSPB), 302, and 301 (WDHOA) are situated about 5, 23, and 42 miles, respectively, upstream of the reservoir. Sites 301 and 304 are located a short distance downstream of WWTPs. Site 320 was impaired in 2013, although the BAP sc impaired threshold. Sites 301 and 304, the two upstream routine sites, were slightly impaired in each year of the 2012-2014 period. Site 302 was slightly impaired in the one year it was sampled, although, like Site 320, its score, 7.46, was just below the non/slightly impaired threshold (Figure 6.18). Impact Source Determination (ISD), DEC’s procedure for identifying impacts that exert deleterious effects on a water body, indicated that nonpoint nutrients were the likely cause of impairment in all years at Site 301. The results at Site 304 were

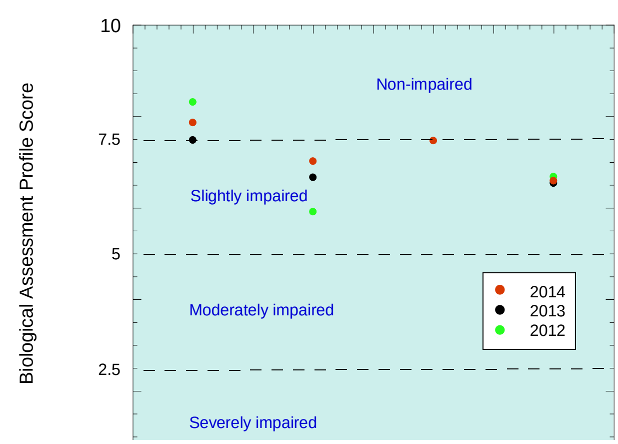

Figure 6.18 Biological Assessment Profile scores for West Branch Delaware River, 2012-2014.

mixed, however, being inconclusive with respect to 2012 and 2013 but indicating nonpoint nutrients as the likely source of impairment in 2014.

Several groups dominated the benthic communities at these sites in different years, contributing to the slightly impaired results (dominance by one taxon tends to depress the metrics used to calculate the BAP score). Hydropsychid caddisflies, which were abundant at many other CAT/DEL sites in the years following Tropical Storms Irene and Lee, were present in large numbers at Site 301 in 2013 and 2014, and at Sites 302 and 304, also in 2014. They were replaced as the dominant taxon, however, by elmid beetles at Site 301 in 2012, and, at Site 304, by psephenid beetles in 2012 and baetid mayflies in 2013.

Trend analysis was based on the entire period of record for sites whose record extended over a period of at least five years. All four sites fell into this category, with the period of record for the routine sites ranging from 19 to 21 years. Site 302 had a 5-year record. The analysis examined changes in both scores and assessment categories.

Long-term trends in biomonitoring scores were examined using the non-parametric Mann Kendall trend test, which seeks to determine whether a given value—here, the BAP score—increases or decreases over time. No significant trend was detected at Sites 301, 302 or 320, while a strong downward trend was observed at Site 304 ($p = 0.04$). (Figure 6.19).

At Sites 301 and 304, slightly impaired assessments have become the norm after many years of non-impaired assessments. Site 301 has been assessed as slightly impaired for the last five years, following 13 years when only three slightly impaired assessments were recorded. At Site 304, seven of the last nine assessments have been slightly impaired, following 15 years during which the site was rated slightly impaired only twice. ISD results suggest that the source of the impairment at Site 301 in 2010 and 2011was nonpoint nutrients, as it was during the 2012-2014 period. The results of the ISD analysis for years prior to 2012 at Site 304, however, are difficult to interpret, because, while they indicate impairment resulting from nonpoint nutrients in 2010, they also indicate natural (i.e., non-impaired) conditions from 2006 to 2008, when the site was assessed as slightly impaired.

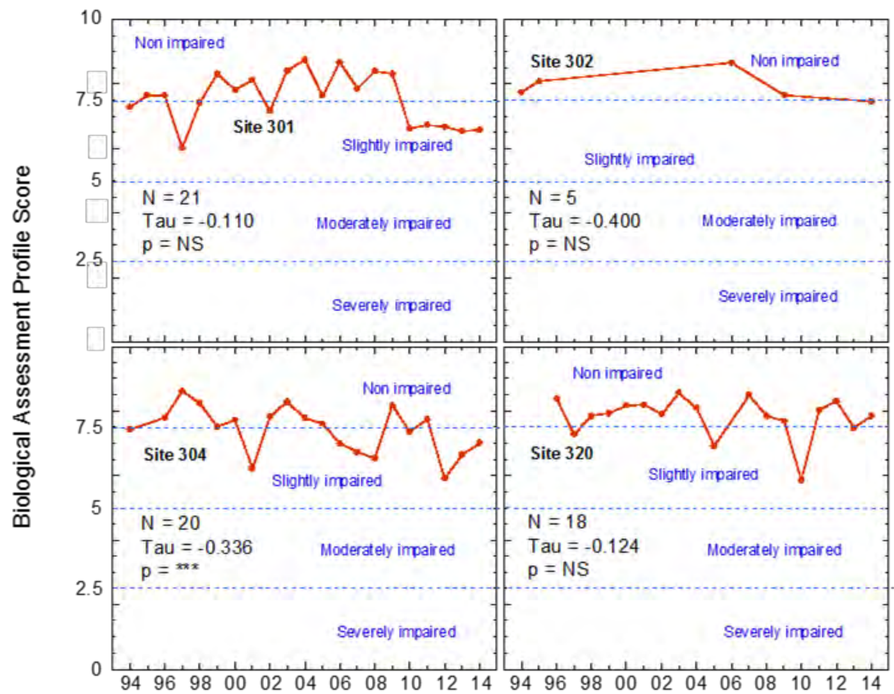

Figure 6.19 Biological Assessment Profile scores for West Branch Delaware River, 1994-2014.
Results of the Mann Kendall trend test are shown as follows: p ≥ 0.20 (NS—Not Significant), p ≤ 0.05 (***). N = number of observations, Tau = Mann Kendall test statistic.

6.6 The Rondout Watershed

The Rondout Reservoir straddles the Ulster/ Sullivan County border along the southern edge of the Catskill Park, approximately six miles northwest of the Village of Ellenville and more than 65 miles northwest of NYC. Placed into service in 1950, it was formed by the damming of Rondout Creek, which continues northeastward and eventually 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 NYC and an additional one million upstate consumers.

The Rondout is one of four reservoirs in the Delaware system. It serves as the central collecting reservoir for the Delaware system, receiving water from the Pepacton, Cannonsville and Neversink Reservoirs. Since the Delaware system supplies approximately 50% of NYC's water, the Rondout plays a critical role in the overall water supply system. The Rondout also receives water from its own watershed. Water from the Rondout drains southeast in the 85-mile long Delaware Aqueduct, which runs below the Hudson River to the West Branch and then the

Kensico Reservoir. After mixing with Catskill system water, it leaves Kensico and travels to the Hillview Reservoir and the distribution system.

6.6.1 Land Use in the Rondout Watershed

The Rondout's watershed area is 95 square miles and takes in parts of seven towns. Four main tributaries flow into Rondout, 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. Presently there is one WWTP sited in the Rondout watershed producing an average flow of 0.062 MGD. According to the most recent SPDES permit, the plant is limited to a release of 0.180 MGD.

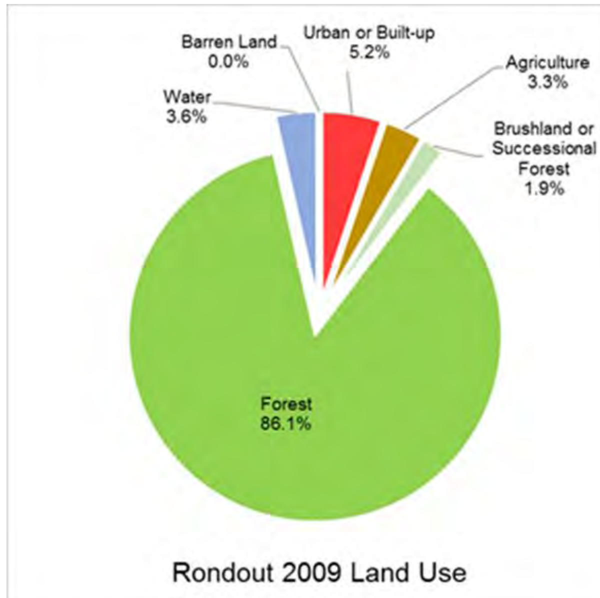

Figure 6.20 Land use in the Rondout watershed.

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 (Figure 6.20). The Rondout watershed also has 1.6% of impervious surface.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

6.6.2 Program Implementation in the Rondout Watershed

Since 1996 over 60 BMPs have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater and these BMPs were associated with more than 1,000 acres of farmland (Figure 6.21). 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 during this period. 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.

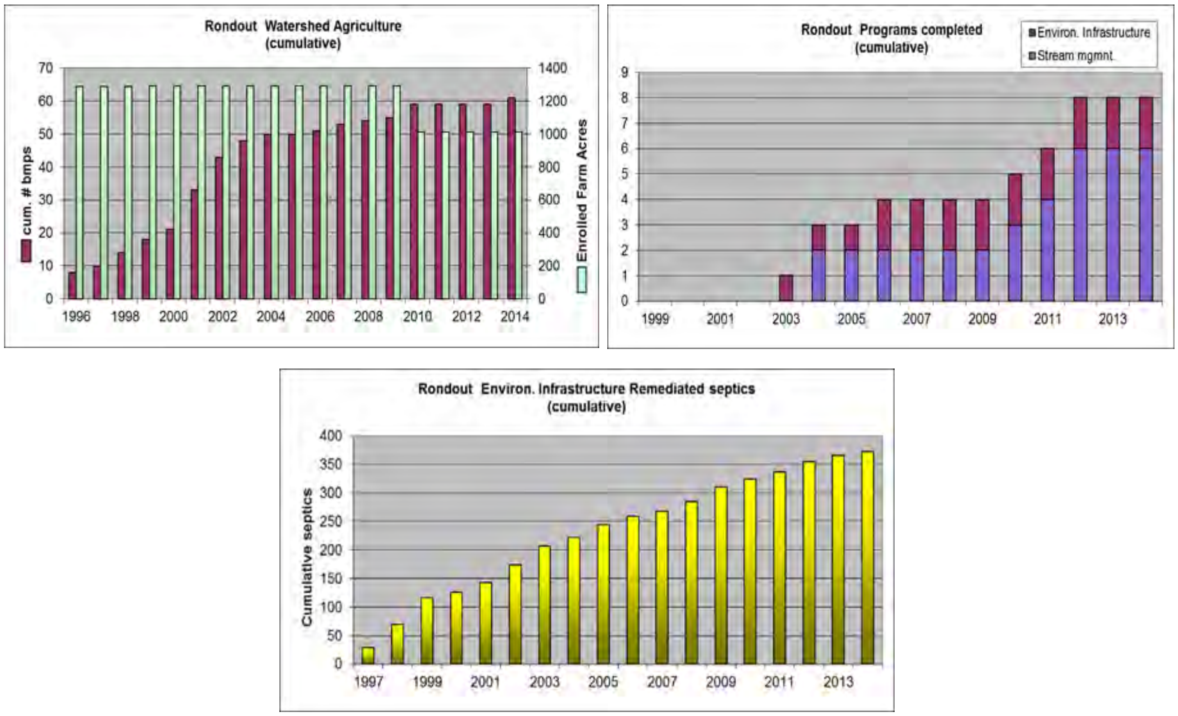

Figure 6.21 The history of watershed programs in the Rondout drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control including stream management projects, c) septic system remediation.

6.6.3 WWTPs and Phosphorus Load Reductions in the Rondout Watershed

Inputs of phosphorus, as well as other pollutants, to Rondout Reservoir have been considerably reduced as a result of the upgrade of DEP's Grahamsville plant, the only WWTP discharging in the Rondout Reservoir basin. As illustrated in Figure 6.22, phosphorus (as TP) loads were considerably reduced from 1994 to 1999, and remained low through 2014.

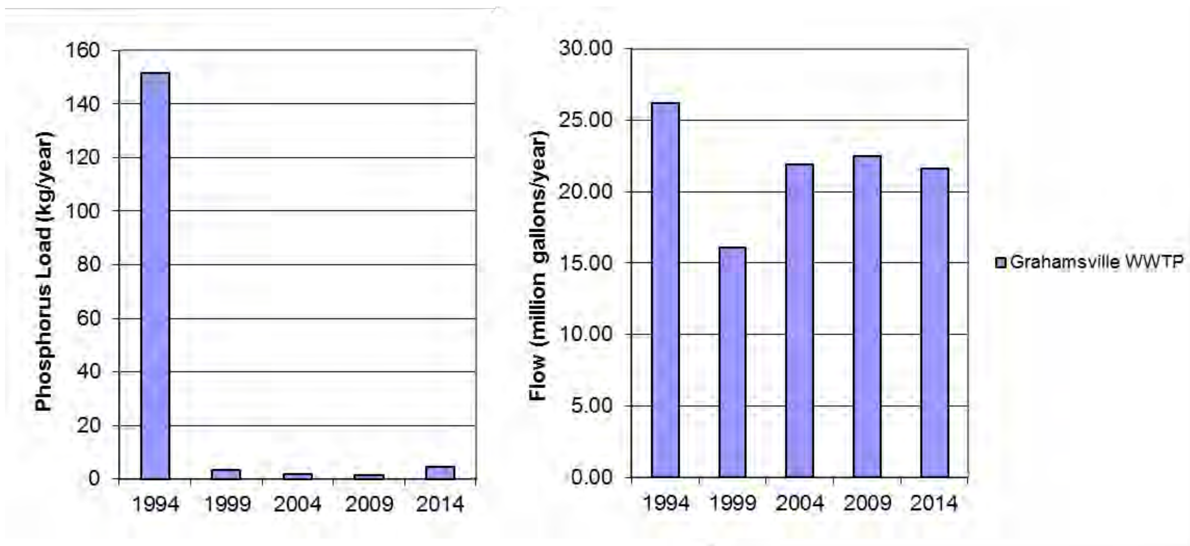

Figure 6.22 Wastewater treatment plant total phosphorus loads and flows in the Rondout drainage basin, 1994 – 2014.

6.6.4 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 6.23. Inputs 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. All values below the maximum detection limit for fecal coliform and total phosphorus were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2012-2014), fecal coliform bacteria remained well below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for all inflow sites. Only the principal river inflow, Rondout Creek (RDOA) had a median above the detection limit. Reservoir and outflow fecal coliform levels were low, with only a few outlier values above the detection limit. Turbidity was generally low at all sites. Median monthly total phosphorus (TP) for the reservoir median was 13.5 µg L^{-1}, well below the target value of 20 µg L^{-1}. The TSI values for Rondout Reservoir fell within the mesotrophic range primarily, with a median of 44. Conductivity medians were highest at the inflow from Cannonsville (88 µS cm^{-1}) and lower in the reservoir and outflow (with a median of 59 and 61 µS cm^{-1}, respectively).

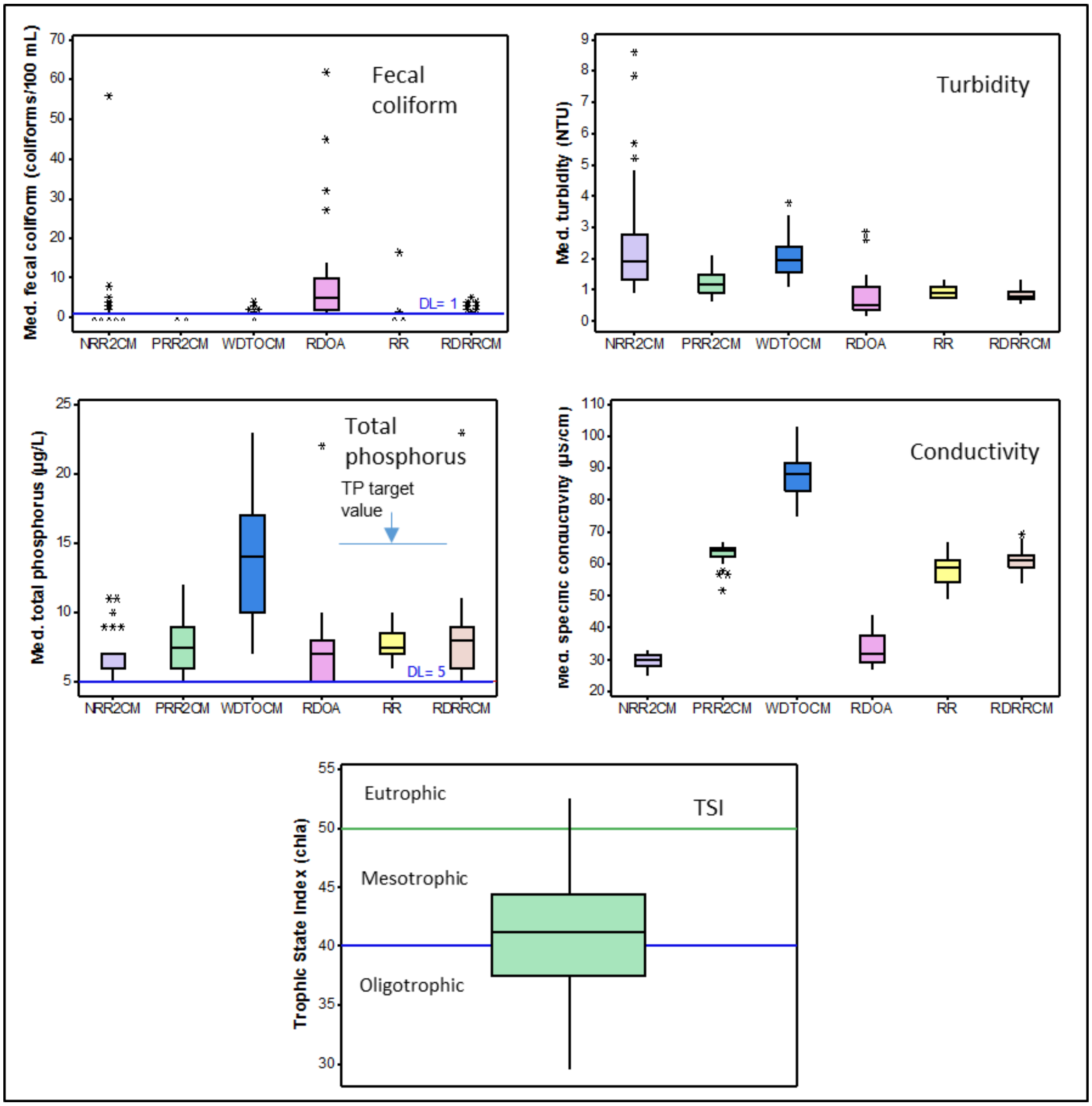

Figure 6.23 Water quality status boxplots using 2012-2014 monthly data for the Rondout basin inputs from Cannonsville (WDTOCM), Pepacton (PRR2CM), and Neversink (NRR2CM) Reservoirs and from the main stream input at Rondout Creek (RDOA); Rondout Reservoir (RR); and the output at the Rondout gatehouse (RDRRCM).

In summary, water quality was good during the 2012-2014 status assessment period in the Rondout basin. Monthly medians did not exceed water quality benchmark values for any of the featured analytes.

Trends (Rondout)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. Water quality trend plots are presented in Figure 6.24 and results of the Seasonal Kendall trend analysis are provided in Table 6.4.

Trend interpretation is difficult for Rondout Reservoir since it receives water from four major sources: diversions from Neversink, Cannonsville and Pepacton Reservoirs as well from a local stream, Rondout Creek (RDOA). No long-term turbidity trends were observed for any of the upstream reservoir inputs. However, a significant turbidity increase was detected for RDOA. Since RDOA only accounts for about 11% of the total flow to the reservoir, diversions from the upstream reservoirs offset the input from RDOA and an upward trend was not detected for the reservoir. In fact a strong downward trend was detected for the output although the rate of change was too small to be of any practical significance.

Fecal coliform trends were not apparent in inputs from Neversink, Pepacton and Cannonsville but a decreasing trend was observed for RDOA. Reasons for the decrease are not apparent, but because RDOA 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 the output but the generally low values compared to RDOA illustrate the reservoirs capacity to attenuate pathogens through processes such as die-off and sedimentation.

Trends in TP were not detected in Rondout Reservoir despite a significant decrease of -0.22 $\mu g\ L^{-1}\ yr^{-1}$ in inputs from Cannonsville Reservoir. 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). Upward trends were detected in the inputs from Neversink (NRR2CM) and Rondout Creek but estimates for these increases were very small (<0.01 and 0.07 $\mu g\ L^{-1}\ yr^{-1}$, respectively). Despite the lack of a trend in the reservoir, decreases were apparent in the output, RDRRCM, although like NRR2CM, with a <0.01 $\mu g\ L^{-1}\ yr^{-1}$rate of change. The absence of winter data collected from the reservoir may be masking a TP decline in Rondout.

An upward conductivity trend was detected in the reservoir coinciding with strong increases detected in some of its inputs (0.67 $\mu S\ cm^{-1}\ yr^{-1}$ for WDTOCM and 0.40 $\mu S\ cm^{-1}\ yr^{-1}$ for PRR2CM) and a weak small increase at RDOA. 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 2012-2014) base flow becomes a larger portion of the

Table 6.4 Rondout basin trends for selected analytes from 1993 to 2014.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
NRR2CM	Input	Turbidity	227	-0.04	NS	
PRR2CM	Input	Turbidity	254	0.04	NS	
WDTOCM	Input	Turbidity	195	-0.07	NS	
RDOA	Input	Turbidity	263	0.13	***	0.01
Rondout	Reservoir	Turbidity	172	-0.01	NS	
RDRRCM	Output	Turbidity	263	-0.10	***	0.00
NRR2CM	Input	Fecal coliform	224	0.02	NS	
PRR2CM	Input	Fecal coliform	254	0.00	NS	
WDTOCM	Input	Fecal coliform	190	-0.02	NS	
RDOA	Input	Fecal coliform	264	-0.09	***	0.00
Rondout	Reservoir	Fecal coliform	173	-0.02	NS	
RDRRCM	Output	Fecal coliform	263	-0.04	*	0.00
NRR2CM	Input	Total Phosphorus	233	0.07	*	0.00
PRR2CM	Input	Total Phosphorus	255	0.01	NS	
WDTOCM	Input	Total Phosphorus	199	-0.20	***	-0.21
RDOA	Input	Total Phosphorus	263	0.14	***	0.00
Rondout	Reservoir	Total Phosphorus	169	0.00	NS	
RDRRCM	Output	Total Phosphorus	260	-0.11	***	0.00
NRR2CM	Input	Conductivity	228	-0.15	***	-0.07
PRR2CM	Input	Conductivity	254	0.47	***	0.40
WDTOCM	Input	Conductivity	195	0.41	***	0.58
RDOA	Input	Conductivity	264	-0.03	NS	
Rondout	Reservoir	Conductivity	170	0.17	***	0.25
RDRRCM	Output	Conductivity	263	0.19	***	0.27
Rondout	Reservoir	Trophic State Index	169	-0.20	***	-0.22

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

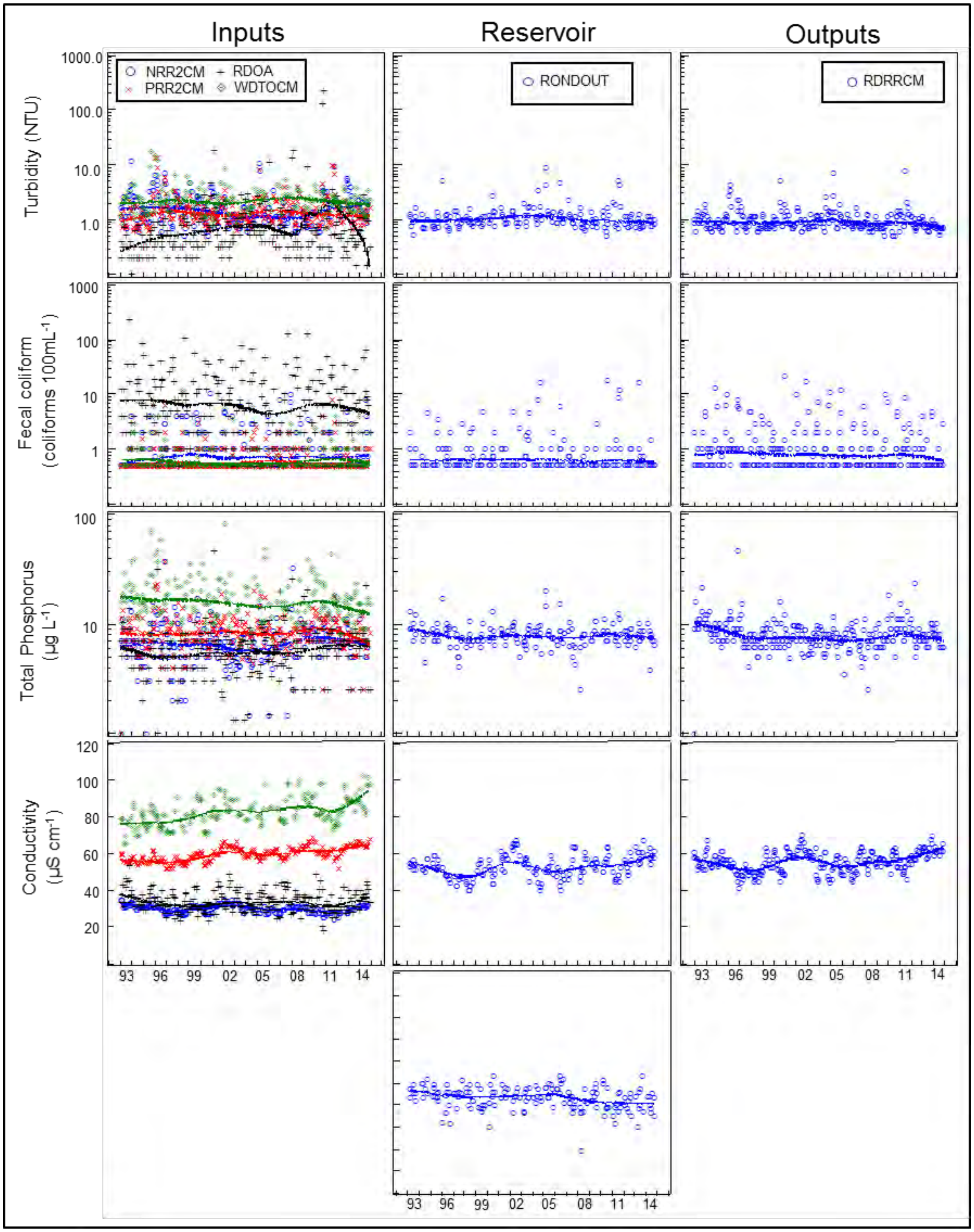

Figure 6.24 Water quality trend plots for the Rondout basin inputs from Cannonsville (WDTOCM), Pepacton (PRR2CM), and Neversink (NRR2CM) Reservoirs and the main stream input, Rondout Creek (RDOA); Rondout Reservoir; and the output at the Rondout gatehouse (RDRRCM).

inflow causing conductivity to increase. Increasing chloride from road salt could also be contributing to the observed conductivity increase. Reservoir chloride concentrations have increased from 4.8 mg L^{-1} in 1993-1994 to 7.3 mg L^{-1} in 2013-2014. Another factor that creates variation in reservoir conductivity is the relative amount of water delivered from each of the upstream impoundments. As the mix varies, so too will the mean conductivity of the reservoir.

A strong downward trend was detected in Rondout Reservoir's TSI. Diversions of lower TSI water due to turbid conditions from recent flooding from upstream reservoirs are one factor. Greater use of Cannonsville water from 2010-2013, which has experience long-term declines in TSI, may be another.

In summary, both upward and downward trends were detected for turbidity at various locations of the Rondout watershed. Downward trends were also detected for fecal coliforms and phosphorus while upward trends were indicated for conductivity. The increase in turbidity at RDOA was offset by inputs from upstream reservoirs resulting in a statistically significant turbidity decrease at the output. Reasons for the fecal coliform decline at RDOA are not known. Phosphorus declines at WDTOCM have been linked to a combination of wastewater treatment upgrades and other watershed improvement projects in the Cannonsville basin, as well as recovery following flooding events in 1995-1996. Increases in conductivity appear to be controlled by precipitation patterns and increased chloride inputs presumably from road deicers. Downward trends for TSI could be related to TSI improvement at Cannonsville Reservoir and to the diversion of turbidly related low TSI water form upstream reservoirs after recent flooding events in 2010-2011.

6.6.5 Biomonitoring in the Rondout Watershed

The NYC stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in DEP watershed streams. For methodology details, see Appendix C. The most recent status of macroinvertebrate communities in the Rondout Basin was evaluated by examining 2012-2014 data for a single site (310) located on Rondout Creek. 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 was sampled twice during the 2012-2014 period, receiving a slightly impaired assessment in 2012 and a non-impaired assessment in 2013 (Figure 6.25).

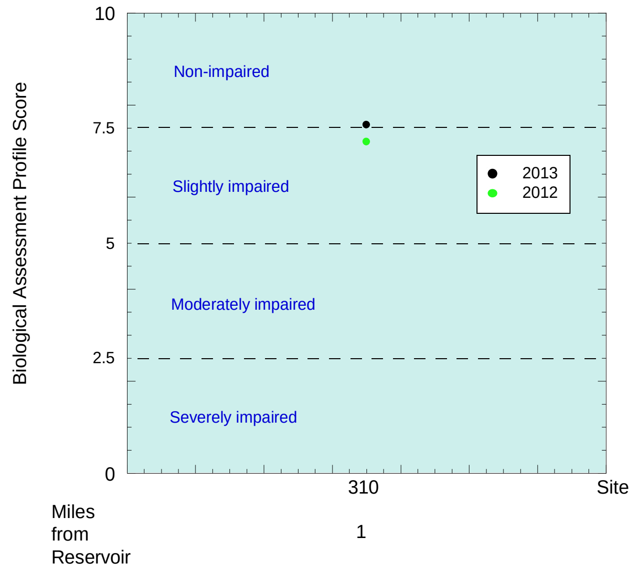

Figure 6.25 Biological Assessment Profile scores for Rondout Creek, 2012-2013.

Trend analysis was based on the site's entire period of record (1995 to 2013), during which time the site was sampled nine times. The analysis examined changes in both scores and assessment categories.

Long-term trends in biomonitoring scores were examined using the non-parametric Mann Kendall trend test, which seeks to determine whether a given value, here, the Biological Assessment Profile (BAP) score, increases or decreases over time. A weakly significant downward trend was observed (p = 0.11), driven by the slightly impaired scores in 2005, 2006, and 2012 (Figure 6.26). This in turn was largely attributable to the dominance of hydropsychid caddisflies in 2005 and 2012 and the paucity of individuals in the 2006 sample (87, which is below the threshold of 95 needed to pass DEP's biomonitoring QC protocols). Impact Source Determination, DEC's procedure for identifying impacts that exert deleterious effects on a water body, was inconclusive when applied to the surveyed sites.

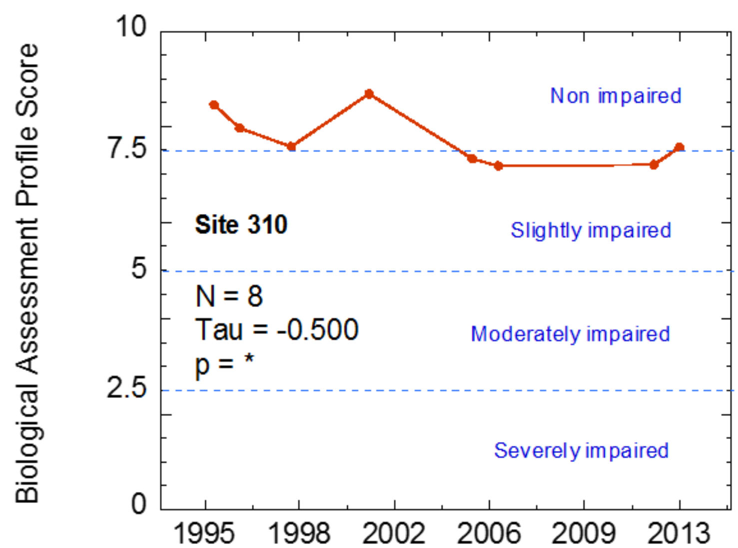

Figure 6.26 Biological Assessment Profile scores for Rondout Creek, 1995-2013.
Results of the Mann Kendall trend test are shown as follows: 0.20 > p > 0.10 (*), N = number of observations, Tau = Mann Kendall test statistic.

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. DEP will continue to monitor the site to obtain a clearer picture of what changes, if any, are occurring there.

6.6.6 Waterfowl Management Program: Rondout Reservoir

Rondout Reservoir is one of five reservoirs covered under the as needed criteria for waterfowl management. Although biweekly surveys were required from January 1, 2011 to March 13, 2013 by the Revised 2007 FAD, DEP performed surveys weekly on Rondout followed by a NYSDOH-approved change to only conduct surveys and bird dispersal activities on as needed basis. Migratory water bird populations at Rondout were similar to those recorded in previous years, showing seasonal increases from autumn through early spring. Higher levels of fecal coliform bacteria were reported during the late summer and early autumn of 2011 and coincided with Tropical Storms Irene and Lee that affected the northeastern United States. (Figure 6.27).

Wintering gulls persist until ice cover, at which time they migrate out of the area, not returning until they pass through on migration northward to the breeding grounds from mid-March to early April. The gulls generally begin their winter roosting near mid-reservoir in mid-October and move closer to the Rondout Effluent Chamber from December to early January.

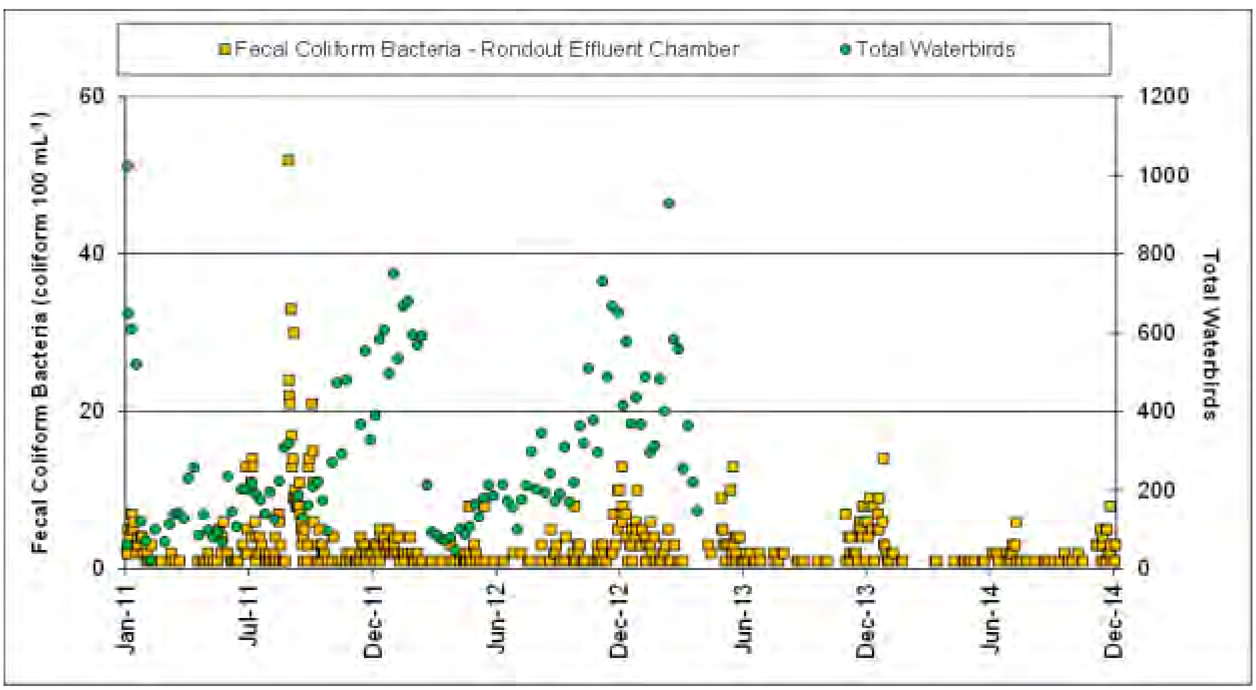

Figure 6.27 Fecal coliform bacteria (total coliform 100 mL^{-1}) versus total water birds at Rondout Reservoir, January 1, 2011 – December 31, 2014.

Additional unaided observations were conducted by DEP during routine daytime site visits. Based on the low numbers of birds reported, DEP determined it was not necessary to activate the as needed water bird dispersal program during the assessment period.

6.7 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 vs. total phosphorus are plotted in Figure 6.29. The majority of points lie above the standard OECD line. 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 OECD data used to calculate the regression. Field collection methods undoubtedly also differed between the studies. Nonetheless, all four reservoirs are well aligned showing an increase in biomass (as measured by chlorophyll *a*) with an increase in phosphorus levels. This indicates that phosphorus is controlling the level of algal standing crop and eutrophication can be controlled through phosphorus control.

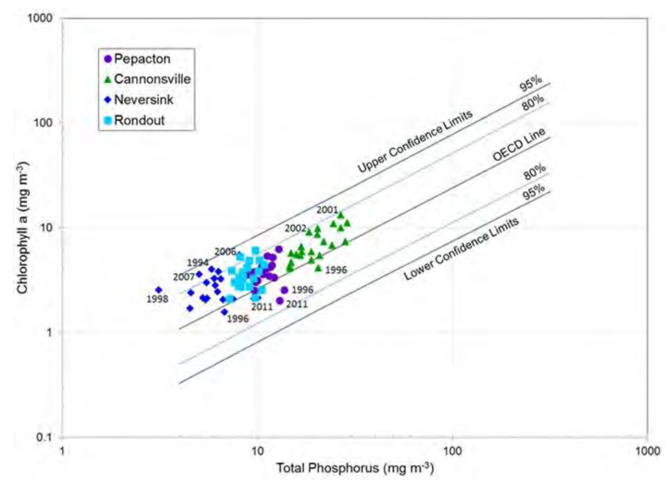

Figure 6.29 Chlorophyll vs. total phosphorus for Delaware System reservoirs.

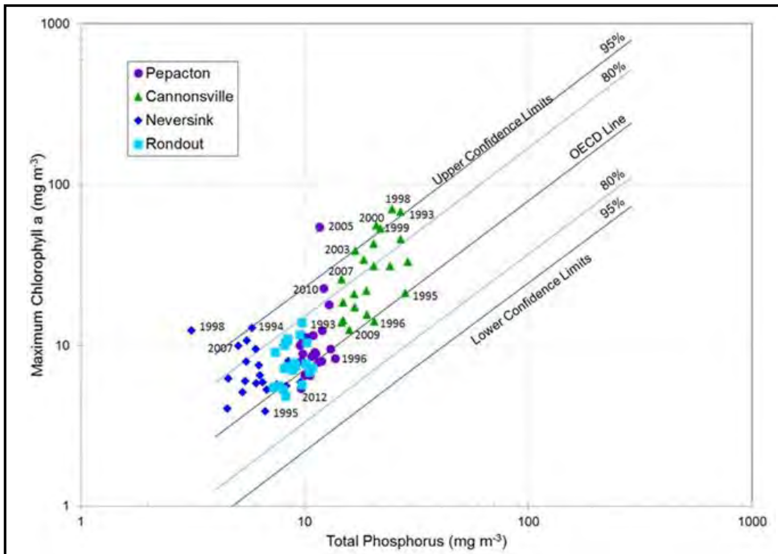

Figure 6.28 Maximum chlorophyll vs. total phosphorus in Delaware System reservoirs.

Maximum chlorophyll is plotted vs. total phosphorus in Figure 6.28. 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 in a given year than for annual mean chlorophyll, indicating that 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. Notably, 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. Secchi depth vs. total phosphorus is plotted in Figure 6.30. 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. Total phosphorus is associated with the substances that control the light climate in these reservoirs in a consistent way.

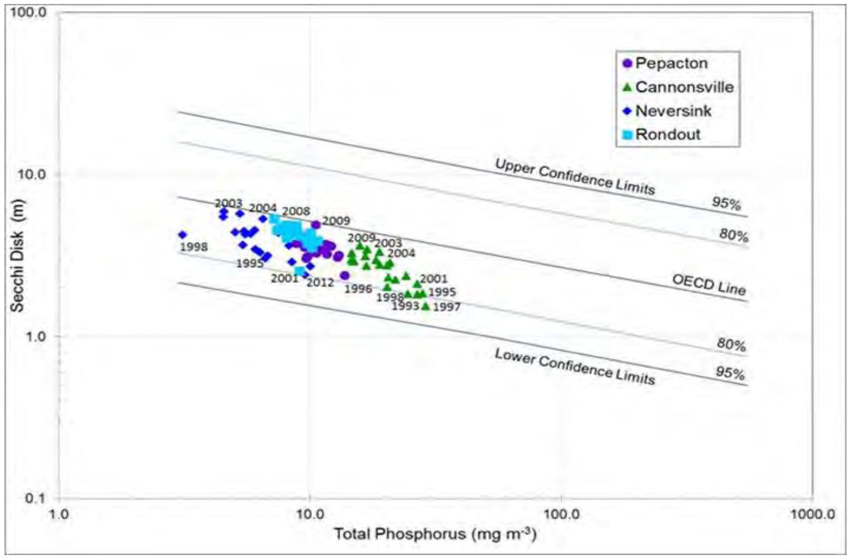

Figure 6.30 Secchi depth vs. total phosphorus for Delaware System reservoirs.

Secchi depth vs. chlorophyll is plotted in Figure 6.31. The observed Secchi depths are less than expected at the reported concentrations of

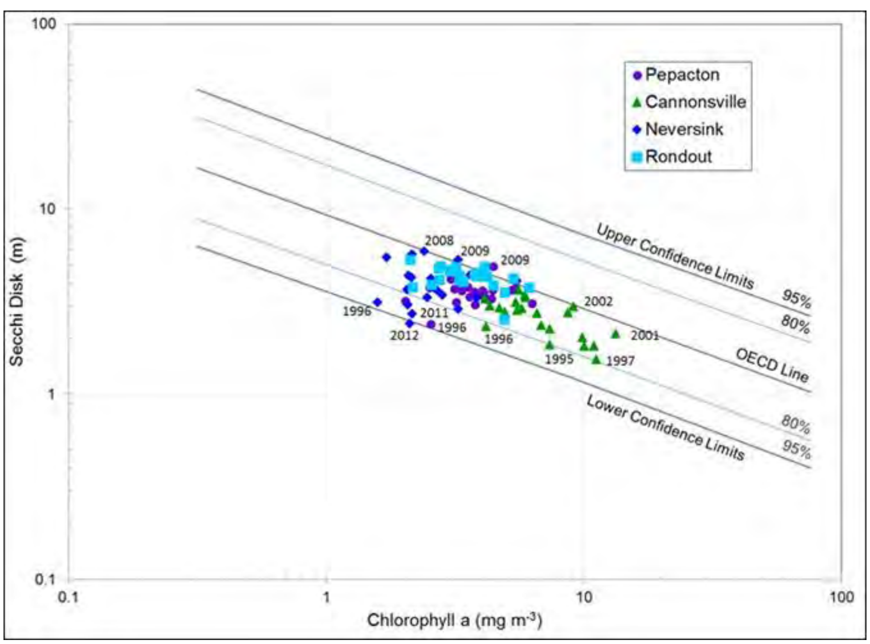

Figure 6.31 Secchi depth vs. chlorophyll in Delaware System reservoirs.

chlorophyll. The limitation of transparency is evidently influenced by factors in addition to algal biomass in all the Delaware System reservoirs.

Examining the changes in central tendencies over the past 25 years for geometric mean phosphorus (Figure 6.32), mean chlorophyll, maximum chlorophyll (Figure 6.33), and Secchi depth, it is very obvious that 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 dependent on extreme hydrological events and turbidity that can persist in the reservoirs for several months. (The full set of these plots is provided in Appendix C.)

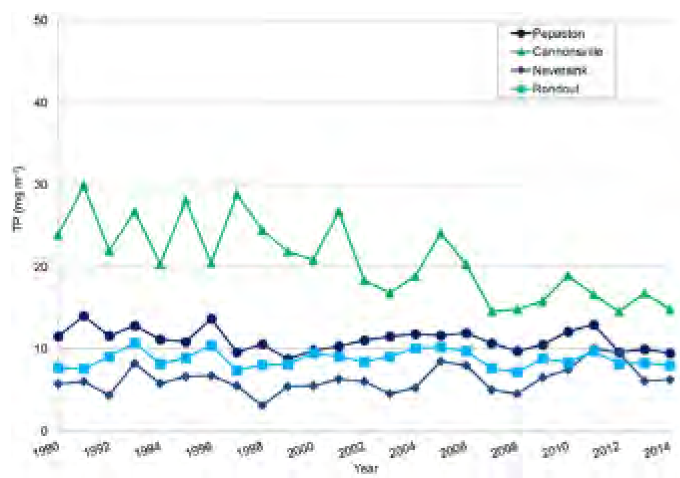

Figure 6.32 Annual geometric means for total phosphorous at Delaware reservoirs (1990 – 2014).

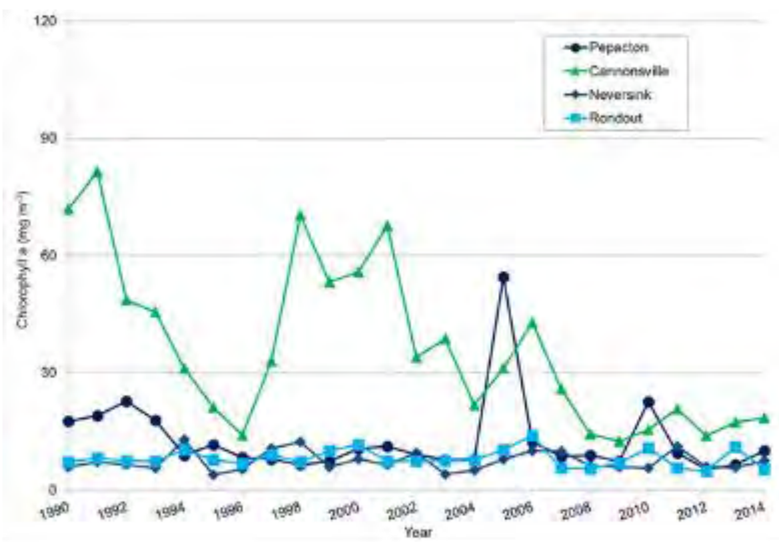

Figure 6.33 Annual maxima for chlorophyll *a* at Delaware reservoirs (1990 – 2014).

6.8 Delaware System Protozoa: Sources and Attenuation

6.8.1 Upstream Sites and Reservoir Outflows

From June 2002 to September 2015, DEP sampled for protozoa (*Giardia* and *Cryptosporidium*) in the Delaware System at two sites upstream of Pepacton Reservoir, two upstream of Cannonsville Reservoir, one upstream of Neversink Reservoir, and four upstream of 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 WDBN (West Branch Delaware River upstream of Delhi and West Branch Delaware River at Beerston). The PMSB site was dropped in 2010 to provide sampling resources for a protozoan study in the Schoharie basin. One tributary was studied for Neversink Reservoir, the Neversink River (NCG) from 2002 through 2008. The four inflows to Rondout Reservoir were the Pepacton, Cannonsville, and Neversink outflows, as they all enter Rondout; and the main stream input to Rondout Reservoir, Rondout Creek (RDOA).

When data from the sites upstream of Pepacton, Cannonsville, and Neversink are compared to their respective outflow data, it is clear that there are processes occurring in the reservoirs (e.g., settling, predation, UV exposure, die-off) that reduce the counts of protozoa found at the outflow monitoring station (Figure 6.34 and Figure 6.35). This is similar to the loss process observed in the Catskill System (Catskill System Protozoa: Sources and Attenuation 5.6). Since the three reservoirs providing aqueduct inflow to Rondout have already experienced protozoan attenuation, the difference between these inflows and Rondout's outflow is not as pronounced as the difference between the upstream samples and their respective reservoir outflows. For the 2002-September 2015 period, the upstream site in the Pepacton basin (PROXG) had the highest overall mean *Giardia* concentration (116.90 cysts $50L^{-1}$), followed by the Cannonsville stream site CDG1 (52.16 cysts $50L^{-1}$) and Neversink stream site NCG (37.41 cysts $50L^{-1}$) (Table 6.5). The four inflows to Rondout resulted in a much reduced mean concentration of 2.23 cysts $50L^{-1}$ at the reservoir outflow site.

Table 6.5 Mean concentrations for protozoans sampled at Delaware monitoring sites from 2002 – September 2015, according to USEPA method 1623HV or 1623.1 (40-60L samples only).

	Cryptosporidium (oocysts $50L^{-1}$)		*Giardia* (cysts $50L^{-1}$)	
	N	Mean	N	Mean
Cannonsville				
Cannonsville upstream (CDG1)	118	0.99	118	52.16
Cannonsville inflow (WDBN)	121	0.71	121	30.34
Cannonsville outflow (WDTOCM)	140	0.18	140	4.57
Pepacton				
Pepacton stream (PROXG)	139	1.16	139	116.90
Pepacton inflow (PMSB)	91	1.87	91	20.42
Pepacton outflow (PRR2CM)	156	0.06	156	1.33
Neversink				
Neversink inflow (NCG)	72	0.39	71	37.41
Neversink outflow (NRR2CM)	131	0.12	130	3.31
Rondout				
Cannonsville outflow (WDTOCM)	140	0.18	140	4.57
Pepacton outflow (PRR2CM)	156	0.06	156	1.33
Neversink outflow (NRR2CM)	131	0.12	130	3.31
Rondout Creek inflow (RDOA)	73	0.38	72	5.49
Rondout outflow (RDRRCM)	153	0.08	153	2.23

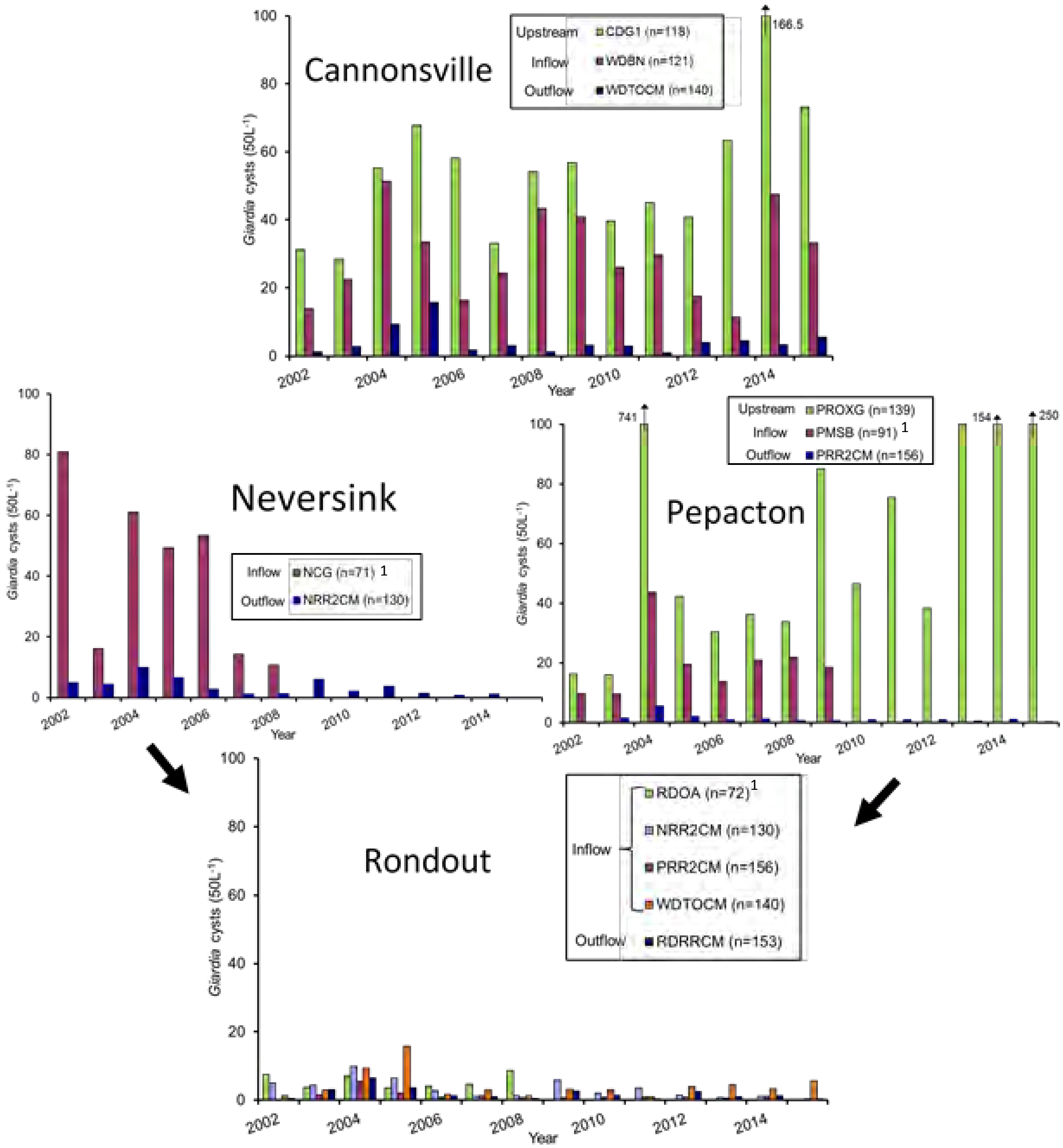

Figure 6.34 Annual mean concentrations of *Giardia* found at Delaware monitoring sites from June 2002 – September 2015, using Methods 1623HV and 1623.1 (40 – 60L samples only.)
Individual sample results were normalized to per 50L concentrations prior to averaging. [1]Sampling was discontinued at NCG and RDOA after 2008, and discontinued at PMSB after 2009.

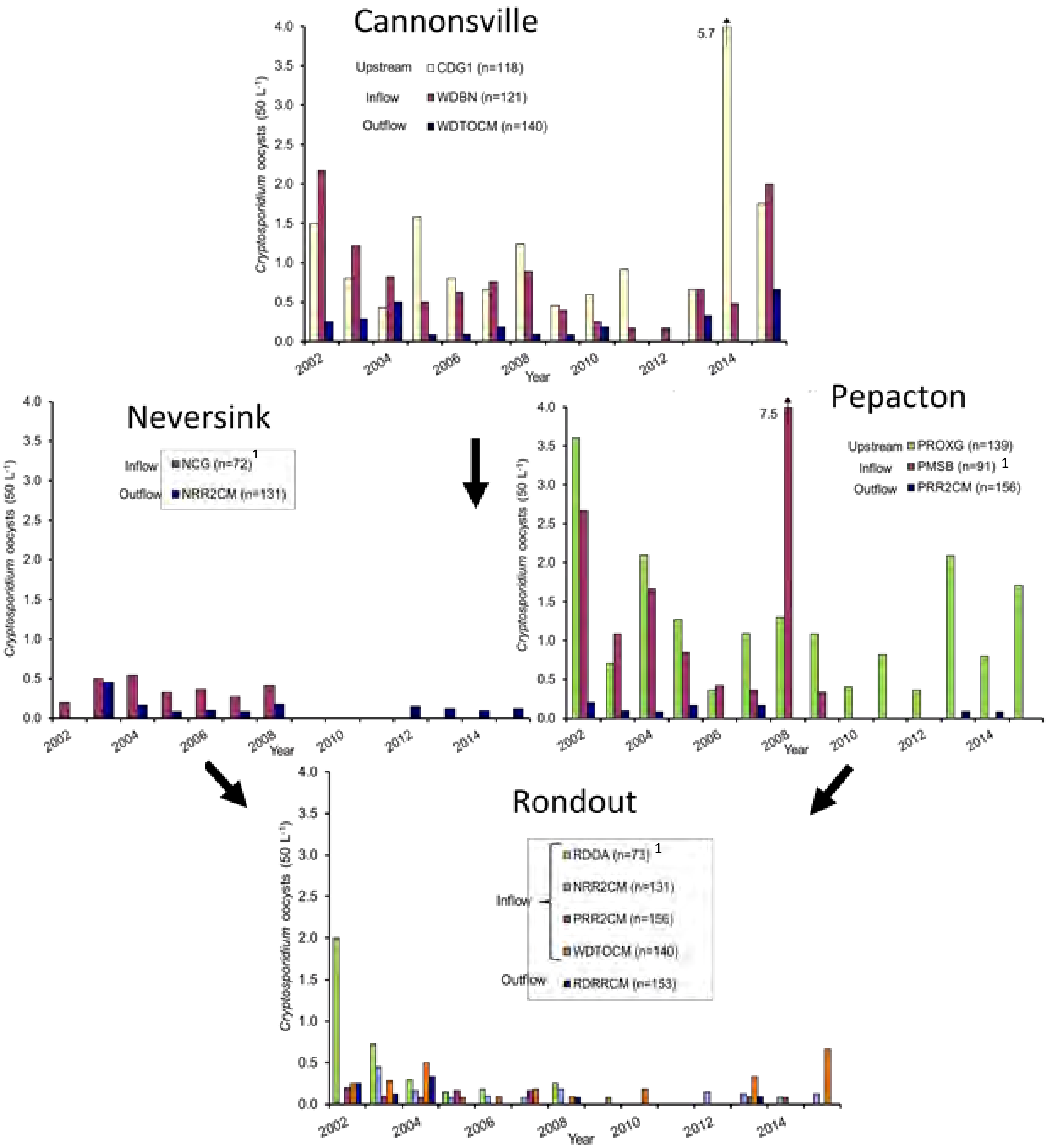

Figure 6.35 Annual mean concentrations of *Cryptosporidium* found at Delaware monitoring sites from June 2002 – September 2015, using Methods 1623HV and 1623.1 (40 – 60L samples only.)
Individual sample results were normalized to per 50L concentrations prior to averaging. [1]Sampling was discontinued at NCG and RDOA after 2008, and discontinued at PMSB after 2009.

Although much lower concentrations were observed, the pattern for *Cryptosporidium* detection was similar: annual mean concentrations were greater at the inflow sites compared to the outflows. Sites upstream of Pepacton Reservoir had the highest oocyst concentrations, followed by Cannonsville and then Neversink. From 2005 through September 2015, *Cryptosporidium* oocysts have been detected only twice in samples at Rondout Reservoir's outflow (September 2008 and December 2013), and both at a very low concentration (1 oocyst $50L^{-1}$).

6.8.2 Delaware WWTPs

DEP sampled eight WWTPs for protozoa in the Delaware System from 2002 to September 2015 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 plant operations, or other reasons. Overall, 266 samples were collected.

Detection of *Giardia* at the effluents of WWTPs in the Delaware System was 16.8% (32 out of 190 samples) from 2002 through 2010. From 2011 through September 2015, detections dropped to 1.3% (1 out 76 samples) and annual detections for all Delaware plants are graphed in Figure 6.36. Other than the RGMF site, all plants had at least one detection of *Giardia* during the period of study ranging in maxima from two to 68.3 cysts $50L^{-1}$ and Table 6.6 provides a

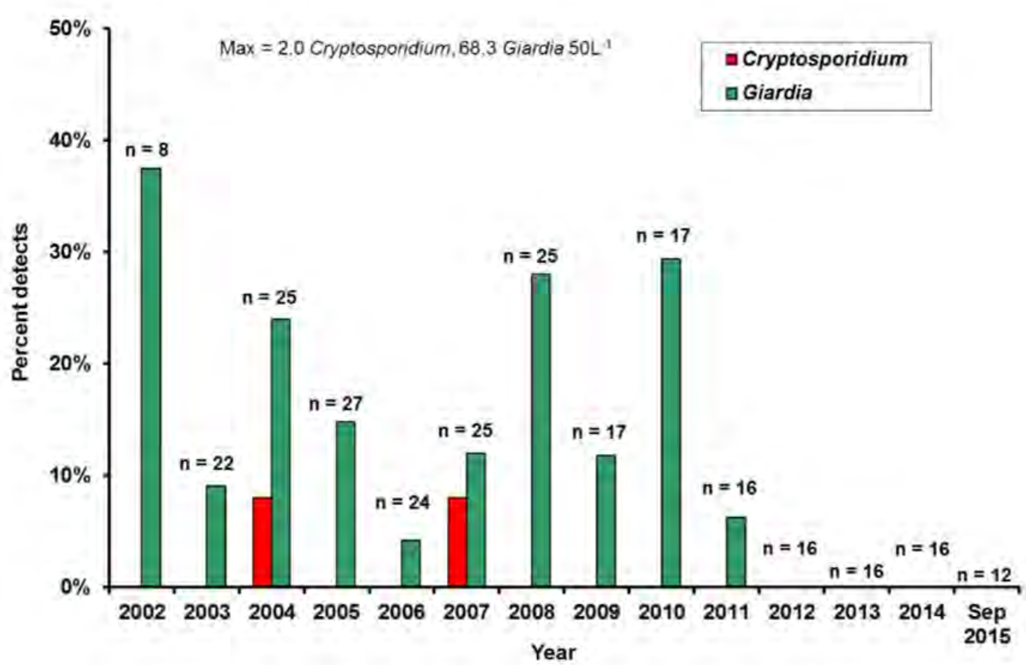

Figure 6.36 Protozoan detection frequency in effluents of upgraded Delaware System WWTPs, 2002 – September 2015.

Table 6.6 Delaware WWTPs with protozoan detects from 2002 to September 2015. NS = not sampled.

Basin	WWTP	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Sep 2015	Percent detection	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	0/3	4% n=28	2
	Fleischmanns (PFTP)	NS	NS	NS	NS	NS	NS	NS	2/4	1/4	0/4	0/4	0/4	0/4	0/3	11% n=27	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	4% n=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	0/3	19% n=52	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	8% n=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	55% n=31	39.0
	*Grahamsville (RGMF)	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	0/3	0% n=27	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	4% n=25	2.00
Cannonsville	Hobart (HTP)	0/1	0/4	1/4	0/4	0/4	0/4	0/4	NS	NS	NS	NS	NS	NS	NS	4% n=25	1.00
Rondout	*Grahamsville (RGC)	0/2	0/4	0/5	0/7	0/4	2/5	0/4	NS	NS	NS	NS	NS	NS	NS	6% n=31	2.00
	*Grahamsville (RGMF)	NS	NS	NS	NS	NS	NS	NS	0/4	0/4	0/4	0/4	0/4	0/4	0/3	0% n=27	0.00

*RGC site was changed to RGMF in February 2009 due to suspected wildlife contamination post filtration.

detailed breakdown of the detections by plant and year of detection, along with the percent detection and maximum concentrations. Note that the Grahamsville collection site was relocated from RGC to RGMF in 2009 due to the belief that wildlife had access to the water prior to it reaching the effluent and were possibly contaminating the final sample. Since the switch, all 27 samples collected at this site have been negative for protozoa suggesting that wildlife feces may have been a likely a factor in the past.

Cryptosporidium oocysts were detected in 2.1% of samples (four detections out of 190) from 2002 through 2010. Other than the RGMF site, all plants had at least one detection of *Cryptosporidium* during the period of study ranging in maxima from 1 to 2 oocysts $50L^{-1}$. There were no detections of oocysts in the 76 samples from 2011 through September 2015.

6.9 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 continues to be very good, which is a reflection in part of the ongoing investment in watershed protection. Monthly median fecal coliform counts were at or near detection limits for all reservoirs and their outflows with very few exceptions. During the 2012-2014 assessment period monthly median turbidity was low throughout the system, with a value around 1 NTU and corresponding median phosphorus value of 8 $\mu g\ L^{-1}$ for the outflow from Rondout Reservoir, the terminal reservoir in the Delaware System.

Long-term trend analysis for Delaware System basins for the assessment period of 1993-2014 showed continued improvement for some water quality parameters. Results varied between basins, and major storm events were a factor in the patterns of observed change. Neversink showed strong upward trends in turbidity and total phosphorus attributed to 2010-2011 storms. By contrast, turbidity trends for Pepacton and Cannonsville were downward. Downward trends in fecal coliform bacteria and total phosphorus were seen in some locations in Pepacton, Cannonsville, and Rondout basins and thought to reflect the water quality benefits of watershed protection programs. Overall, trends in TSI were downward. Upward trends in conductivity were seen in all basins and attributed to increases in chloride and changes in precipitation.

During the 2012-2014 period, biomonitoring was conducted at four sites on the primary stream input to Cannonsville Reservoir (West Branch Delaware River), three sites on the primary input to Pepacton Reservoir (East Branch Delaware River), and one site on the primary input to Rondout Reservoir (Rondout Creek). Most results indicated slightly impaired conditions, a decline from the generally optimal conditions noted during the previous assessment period (2007-2009). The two exceptions were the site on the West Branch Delaware River closest to Cannonsville Reservoir (Site 320), which was assessed as non-impaired in two of the three years of sampling, including the most recent one, and the site on Rondout Creek, which, while slightly impaired in 2012, was non-impaired in 2013, the most recent year it was sampled. The NYSDEC's Impact Source Determination (ISD) indicates the upstream site on the West Branch (Site 301) and the two downstream sites on the East Branch (Sites 316 and 321) fall into the category of the impact source class that is indicative of nonpoint nutrients. No trend was detected at three of the four sites in the Cannonsville basin with an extended period of record, while the fourth, Site 304, experienced a strong downward trend. Results of the ISD analysis at that site were inconclusive. In the Pepacton basin, both sites with an extended record experienced a downward trend, a weak one at Site 316, which lies a short distance upstream of the reservoir, and a strong one at Site 321, farther upstream. ISD indicated a community in the impact source class for nonpoint nutrients, although DEP has not detected elevated nutrient concentrations at that location. A weak downward trend was detected at the Rondout Creek site, but this may be at least partially attributable to the small sample size in 2006.

Waterfowl management in Rondout Reservoir has been conducted on an as needed basis. Water bird numbers reported from January 2011 to March 2013 have remained similar to those recorded in previous years. The winter migratory period coincided with a rise in fecal coliform counts in the reservoir. Higher levels of fecal coliform bacteria were reported during the late summer and early autumn of 2011 and coincided with Tropical Storms Irene and Lee that affected the northeastern United States. Gulls tend to linger on the reservoir up through reservoir icing and often shift their nightly roosting location from mid-reservoir to closer proximity to the Rondout Effluent Chamber. During the current assessment period, fecal coliform numbers did not increase to a level that triggered implementation an as needed water bird dispersal action.

Cryptosporidium and *Giardia* pathogen monitoring was conducted on the major inflows to all four reservoirs of the Delaware System. As with the Catskill System, reservoir outflow results for the 2011-September 2015 period were much reduced compared to those for inflow streams, indicating that reservoir processes such as die-off, sedimentation, and predation continued to be effective barriers throughout the entire 2002 through September 2015 period of record.

7. East of Hudson Catskill/Delaware Basins

7.1 The Scope of Water Quality Analyses

This chapter covers the water quality history of Kensico, West Branch, and Boyd Corners Reservoirs. A description of the approach and scope of the water quality analyses is given in Appendix C. In brief, the water quality analyses cover approximately 22 years of data to provide a long-term context for interpretation. This time span provides a view of these changes in the context of natural variation (such as floods and droughts) and allows sufficient time for program implementation to impact water quality. The water quality data used in this analysis begins in 1993, which represents conditions at the outset of filtration avoidance when many watershed protection programs were in their infancy. The data from this decade represents conditions with fewer watershed programs in place. The time period from about 2000 through 2014 represents a time when watershed protection programs have reached a high level of implementation.

7.2 The West Branch and Boyd Corners Watersheds

The West Branch Reservoir is located in Putnam County in the Towns of Kent and Carmel, approximately 35 miles from NYC. It was formed by the damming of the West Branch of the Croton River, which continues south to the 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 as part of the Croton water supply system.

The 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 the Boyd Corners Reservoir. The 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 DEP'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 where it mixes with Catskill system water before traveling to the Hillview Reservoir and into distribution.

7.2.1 Land Use in the West Branch and Boyd Corners Watersheds

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 (Figure 7.1). The West Branch watershed also has 4.4% of impervious surface.

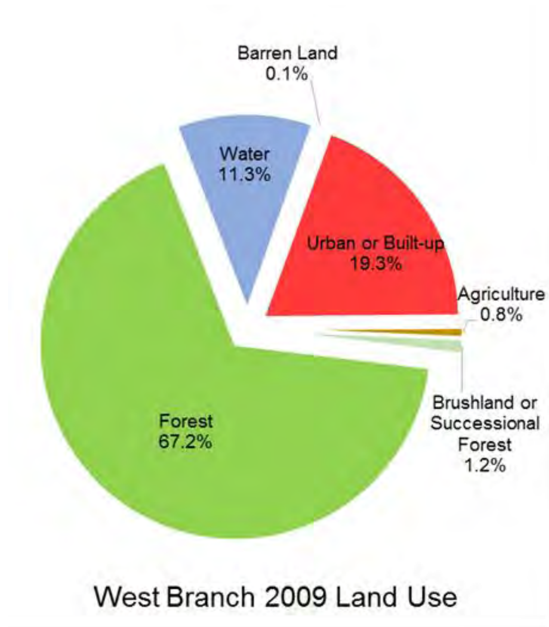

Figure 7.1 Land use in the West Branch basin.

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 (Figure 7.2). The Boyd Corners watershed also has 3.2% of impervious surface.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

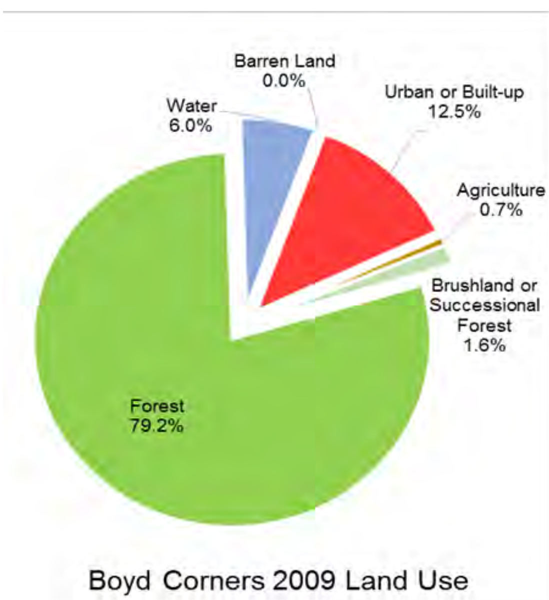

Figure 7.2 Land use in the Boyd Corners watershed.

7.2.2 Program Implementation in the West Branch and Boyd Corners Watersheds

By 2008, DEP had completed 38 stormwater retrofit/remediation projects in the West Branch and Boyd Corners Reservoir basins (Figure 7.3). Most of these projects were small and involved stream, bank and swale stabilization as well as culvert repair.

7.2.3 WWTPs and Phosphorus Load Reductions in the West Branch and Boyd Corners Watersheds

As shown in Figure 7.4 phosphorus loads (as TP) to West Branch Reservoir from the basin's only WWTP, Clear Pool Camp, have decreased since 2004, while

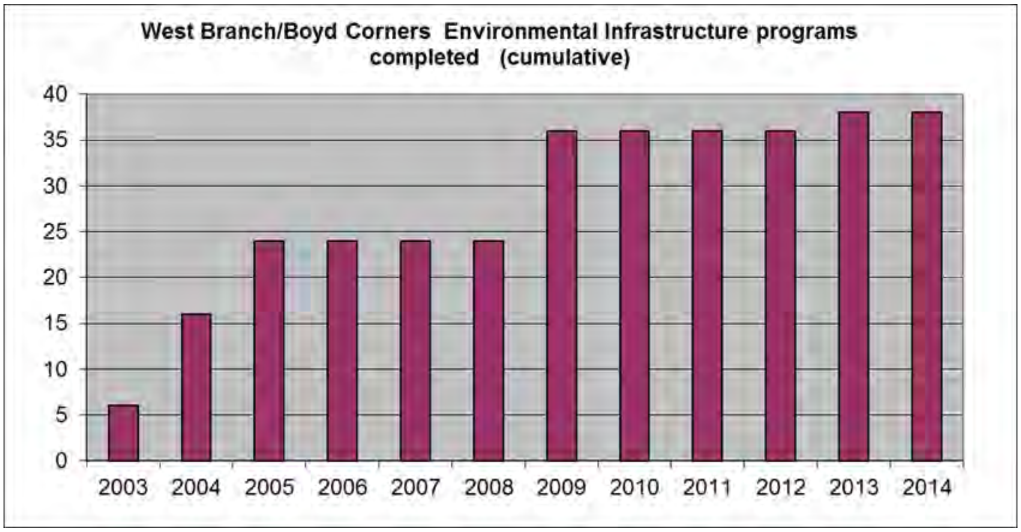

Figure 7.3 The history of watershed programs in the West Branch drainage basin: environmental infrastructure installations for stormwater control and stream management projects.

flows have declined since 1999. A plant upgrade was completed in 2005 as part of DEP's efforts to upgrade all surface-discharging WWTPs in the watershed. The upgrade significantly reduced the contribution of phosphorus and other pollutants to West Branch Reservoir.

7.2.4 Water Quality Status and Trends in the West Branch and Boyd's Corners Watersheds

Status (West Branch)

The West Branch Basin status evaluation is presented as a series of boxplots in Figure 7.5. The inputs include water diverted from Rondout Reservoir (DEL9), Boyd Corners release (BOYDR), and Horse Pound Brook (HORSEPD12). The reservoir is designated as CWB and the output is designated as WESTBRR. All values below the maximum detection limit for fecal coliform bacteria were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the status evaluation period (2012-2014), fecal coliform bacteria remained well below the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for all inflows with one exception in August 2014. The highest fecal coliform levels coming into the reservoir were from HORSEPD12, with a monthly median of 12 coliforms 100 mL^{-1} and one exceedance of the guidance value (11,000 coliforms 100 mL^{-1} on August 13, 2014). High turbidity (50 NTU) and total phosphorus (224 $\mu g\ L^{-1}$) occurred on the same date. Reservoir fecal coliform levels were

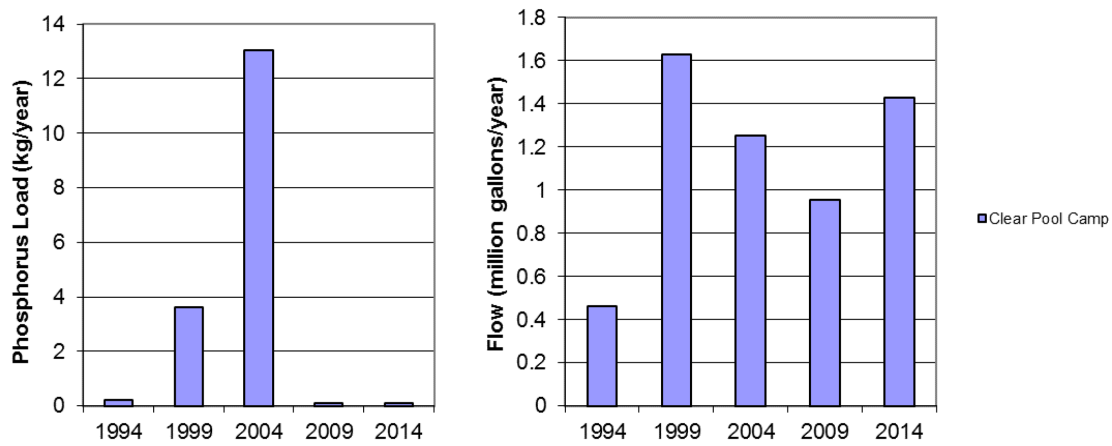

Figure 7.4 Wastewater treatment plant total phosphorus loads and flows in the West Branch/Boyd Corners drainage basins, 1994 – 2014.

low, with only two outlier points above the maximum detection limit for the reservoir. Turbidity in the West Branch Basin is typically low, as was the case for the 2012-2014 assessment period, with a few high values in the inflows associated with storm events that were attenuated in the reservoir (reservoir monthly median turbidity 1.45 NTU). Monthly median reservoir total phosphorus (TP) values were well below the target value of 15 µg L^{-1} with few exceptions at the time of fall turnover in 2012 and 2013 when median TP was 16 and 15.5 µg L^{-1}, respectively. The TSI values for West Branch Reservoir ranged from mesotrophic to eutrophic, with a median of 53.5 in the eutrophic range. Conductivity medians were higher from local inflows (BOYDR median 192 µS cm^{-1} and HORSEPD12 median 240 µS cm^{-1}, a reflection in part of bedrock geology, as well as impact from road deicers and to a lesser extent, water softener effluent (see below). Low-ionic strength water from Rondout Reservoir (DEL9) had a monthly median of 63 µS cm^{-1}. The resulting West Branch Reservoir monthly median conductivity was 126µS cm^{-1} for the evaluation period.

In summary, water quality was good during the 2012-2014 status assessment period in the West Branch Basin. All monthly median values were well below water quality status benchmark values. Only one monthly fecal coliform value for an influent stream (HORSEPD12) exceeded the NYSDEC Stream Guidance value on a date with high flows (peak flow of 0.59 m^3 sec^{-1} on August 13, 2014).

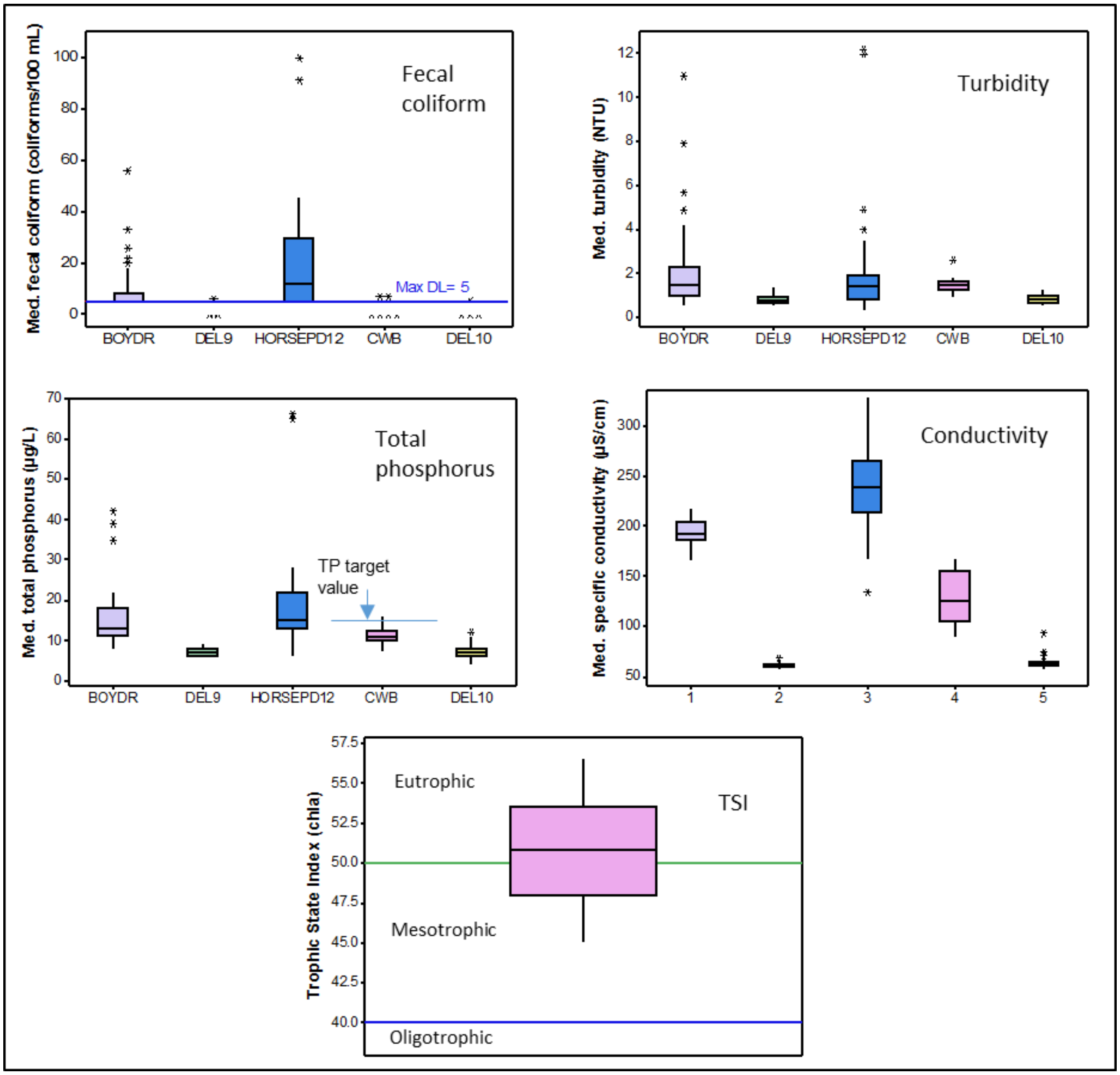

Figure 7.5 Water quality status boxplots using 2012-2014 monthly data for the West Branch basin for the inputs from Rondout Reservoir (DEL9), the main stream input at Boyd Corners Reservoir release (BOYDR), and Horse Pound Brook (HORSEPD12); West Branch Reservoir.

Trends (West Branch)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods and flow-adjustment is indicated, as appropriate, in the trend statistics table (Table 7.1). Water quality trend plots are presented in Figure 7.6 and results of the Seasonal Kendall trend analysis are provided in Table 7.1.

Table 7.1 West Branch inflow, reservoir, and outflow trends from 1993 to 2014.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
BOYDR	Input	Turbidity	258	-0.20	***	-0.04
DEL9	Input	Turbidity	261	-0.04	NS	
HORSEPD12	Input	Turbidity	238	-0.20	***	-0.05
West Branch	Reservoir	Turbidity	174	0.12	***	0.01
WESTBRR	Output	Turbidity	257	0.20	***	0.02
BOYDR	Input	Fecal coliform	238	0.04	NS	
DEL9	Input	Fecal coliform	261	-0.05	**	0.00
HORSEPD12	Input	Fecal coliform	235	-0.19	***	-1.00
West Branch	Reservoir	Fecal coliform	173	-0.10	***	0.00
WESTBRR	Output	Fecal coliform	237	-0.25	***	-0.13
BOYDR	Input	Total Phosphorus	253	0.02	NS	
DEL9	Input	Total Phosphorus	250	-0.19	***	-0.09
HORSEPD12	Input	Total Phosphorus	238	0.05	NS	
West Branch	Reservoir	Total Phosphorus	164	0.05	NS	
WESTBRR	Output	Total Phosphorus	253	0.09	***	0.06
BOYDR	Input	Conductivity	256	0.24	***	1.29
DEL9	Input	Conductivity	261	0.16	***	0.23
HORSEPD12	Input	Conductivity	235	0.39	***	4.55
West Branch	Reservoir	Conductivity	166	0.38	***	2.11
WESTBRR	Output	Conductivity	256	0.38	***	2.36
West Branch	Reservoir	Trophic State Index	164	0.43	***	0.47

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

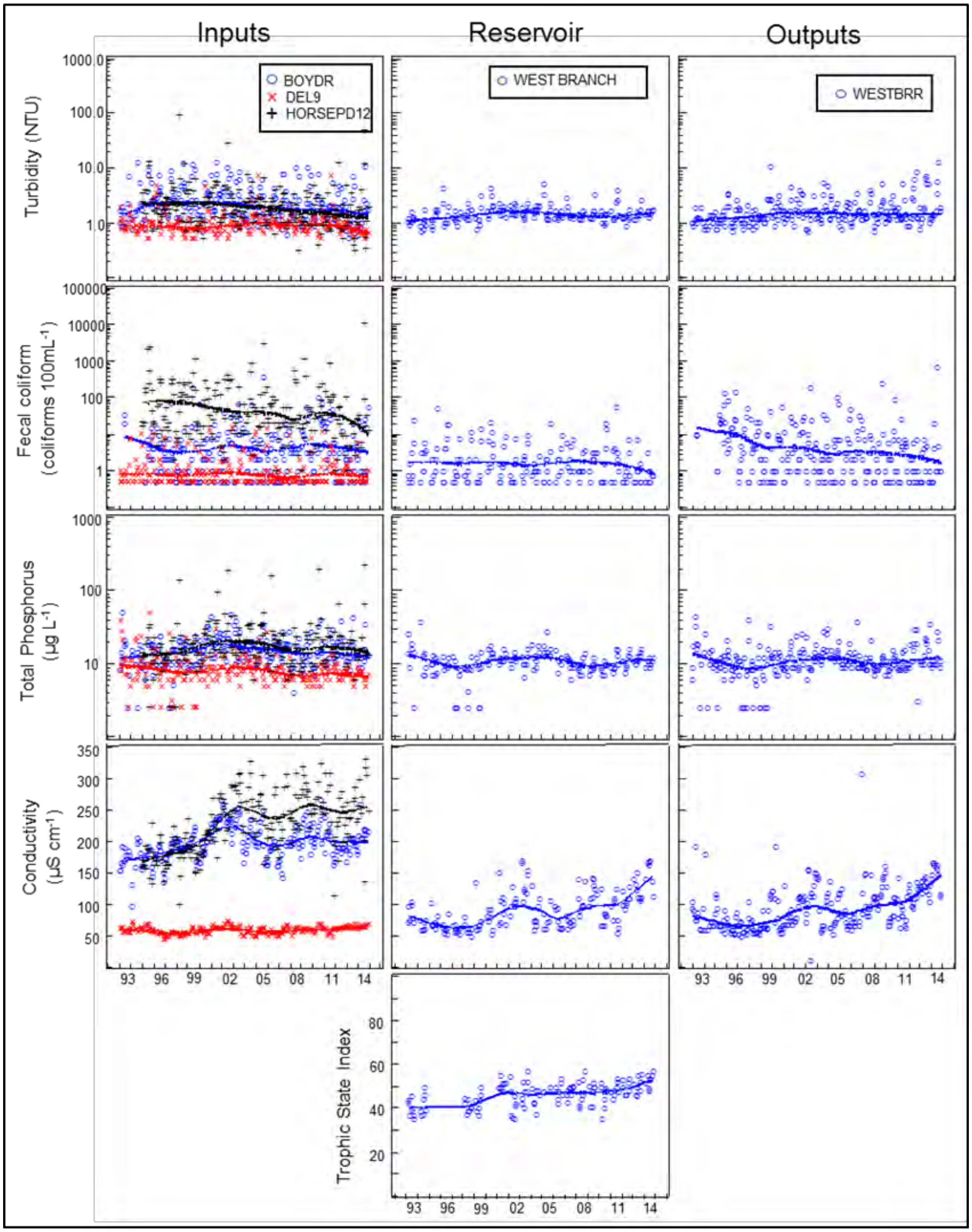

Figure 7.6 Water quality trend plots for the West Branch basin for the inputs from Rondout Reservoir (DEL9), the main stream input at Boyd Corners Reservoir release (BOYDR), and Horse Pound Brook (HORSEPD12); West Branch Reservoir (CWB); and the output at the West Branch release (WESTBRR).

The water comprising West Branch Reservoir is derived mainly from the Delaware System's Rondout Reservoir via the Delaware Aqueduct (DEL9) and from its primary local inputs, 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 inputs 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 slow 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 "bypass" mode increased to 16%. In "”bypass" mode, West Branch is totally isolated (no input, no outputs) from the Delaware Aqueduct and again local streams become the exclusive source of water to the reservoir. Local stream inputs 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 2010-2011 but increased to greater than 95% in 2012-2014.

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 inputs from local sources. During most of the last 17 years West Branch was operated in such a way that often increased the relative contributions of local (e.g., Croton Stream) inputs. 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 by-pass mode increased. Although days in float and bypass decreased in 2003, two prior years of drought had caused conductivity of the Croton inputs to increase dramatically, which caused reservoir and output 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 inputs and in the reservoir from 2004 to 2007. In 2008 and 2009, conductivity in the Croton inputs and in the reservoir (and output) 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 and to a lesser extent, water softener effluent (Heisig 2000).

Conductivity decreased in 2010-2011 due to more time in reservoir mode but rose dramatically from 2012-2014 as time in float mode increased above 95%.

Downward turbidity trends were detected in the Rondout Reservoir (DEL9) and Boyd Corners inputs, but an upward trend was apparent in the reservoir and output. This apparent anomaly is explained by the fact that, despite the decreases, turbidity in the local streams remained higher than Rondout, even as the relative contributions from Rondout dropped as a result of the operational changes. 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 inputs.

Downward fecal coliform trends were evident for the Horse Pound and DEL9 inputs, the reservoir and the output WESTBRR. Due to the preponderance of tied, low values in the record, the rate of decrease was estimated as zero for the reservoir and DEL9 input. Reasons for the fecal coliform downward trend at Horse Pound input and the West Branch Reservoir output are not clear at this time. Differences in sampling programs may explain why no trend was detected in the reservoir despite the strong downward trend in the output. Sampling at the output is more comprehensive, and is conducted in every month, while the reservoir data used in this analysis are from monthly surveys collected from April to November. The fecal counts observed in the output 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 input typically contributes much higher fecal counts than other inflows (Rondout Reservoir or Boyd Corners).

A downward TP trend was detected at the Rondout Reservoir input while all Croton inputs displayed no long-term trends. The greater usage of Croton inputs since 1998 and especially from 2012-2014 offset the decreasing TP from the Rondout Reservoir input; as a result, no trend was observed in the reservoir and an upward trend was detected in the reservoir output.

The increasing trend in TSI values can be ascribed to operational changes, which increased the contribution of local sources during the latter part of the data record.

In summary, conductivity increases were apparent in all inputs, in the reservoir, and in the output. Decreasing turbidity trends were detected in the Boyd Corners and Horse Pound inputs coincident with the completion of stormwater remediation projects, while an increasing trend was apparent in the reservoir and output due to operational influences. Fecal coliform exhibited a downward trend at the Horse Pound input and at the output. A decreasing TP trend was detected at the Rondout Reservoir input which coincides with watershed programs discussed in the Cannonsville and Rondout sections. However, an upward TP trend was apparent in the West Branch output. Productivity increases in the reservoir were detected as well. All trends (or lack thereof) in the reservoir are thought to be related to changes in reservoir operations. Local stream trends may be related to efforts to better manage stormwater runoff.

7.2.5 Biomonitoring in the West Branch and Boyd Corners Watersheds

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

The most recent status of macroinvertebrate communities in the West Branch Basin was evaluated by examining 2012-2014 data for a single site (146) on Horse Pound Brook. This stream is the primary inflow to West Branch Reservoir, draining 20% of the basin. The site is routine, that is, it is sampled annually, as opposed to non-routine sites, which are sampled on a rotating basis.

Site 146 (HORSEPD12) is located in Carmel, approximately two miles upstream of West Branch Reservoir. From 2012 to 2014, it was assessed as being slightly impaired, with scores that included the two lowest ever recorded at the site. (Figure 7.7). The slightly impaired assessments were largely attributable to the presence each year of one or two groups which dominated the community, which had the effect of depressing most of the metrics used to calculate the Biological Assessment profile (BAP) scores. Thus, beetles accounted for 28% of the community in 2012, beetles and hydropsychid caddisflies together accounted for 51% in 2013, and hydropsychids constituted 42% in 2014. While the increase in beetle and hydropsychid numbers is cause for con stoneflies, an indicator of excellent water quality, were present in all years, and that Hilshenhoff Biotic Index values remained high, indicating little or no organic pollution. Impact Source Determination, DEC’s procedure for identifying impacts that exert deleterious effects on a water body, was inconclusive for 2012 and 2013, but indicated that nonpoint source nutrients were the likely source of impairment in 2014.

Trend analysis was based on the site’s entire period of record (2004-2014), and examined changes in both scores and assessment categories.

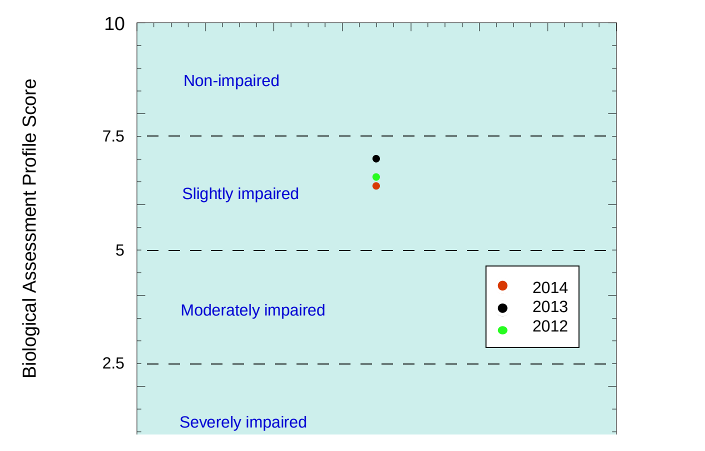

Figure 7.7 Biological Assessment Profile scores for Horse Pound Brook. 2012-2014.

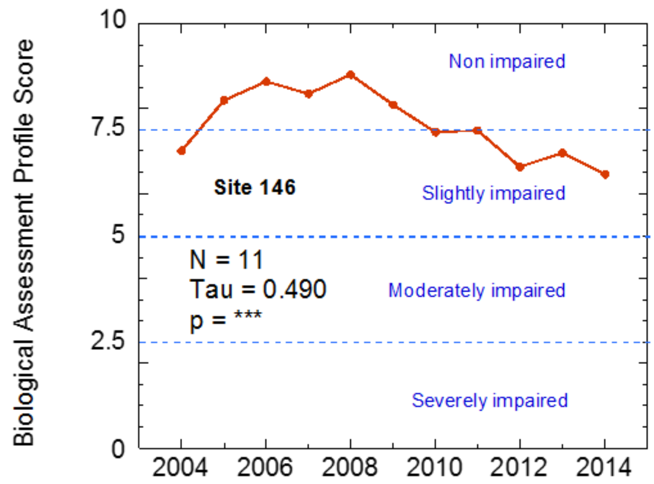

Figure 7.8 Biological Assessment Profile scores for Horse Pound Brook, 2004-2014. Results of the Mann Kendall trend test are shown as follows: *** = $p < 0.05$. N = number of observations, Tau = Mann Kendall test statistic.

The long-term trend in biomonitoring scores at Site 146 was examined using the non-parametric Mann Kendall trend test, which seeks to determine whether a given value, here, the Biological Assessment profile (BAP) score, increases or decreases over time. A strong significant downward trend was detected ($p = 0.04$), reflecting the sharply lower scores over the last three years and the shift from non-impaired to slightly impaired assessments (Figure 7.8). The underlying reason for these declines remains unclear, since no issues relating to development in the stream's watershed or to WWTP discharges have been identified. As noted in the section above, turbidity and fecal coliforms show a decreasing trend, while conductivity has increased. Results from 2004, which predate the non-impaired years of 2005 to 2009, further complicate the situation, since in that year large numbers of beetles and midges and the absence of mayflies produced scores comparable to those experienced between 2012 and 2014.

7.2.6 Waterfowl Management Program: West Branch Reservoir

West Branch Reservoir is one of five reservoirs covered under the as needed criteria for waterfowl management under the Revised 2007 FAD.

Water bird counts increased from mid-July through late-December in every year from 2011 to 2014 at site CWB1.5, near DEL10 (Figure 7.9). Elevated fecal coliform bacteria counts recorded in the late summer and early autumn of 2011 were associated with Tropical Storm Irene and Tropical Storm Lee. Seasonal increases in water birds, mostly ducks, generally begin annually in September and remain elevated up through ice-cover and may persist through early spring to the onset of spring migration. Additional unaided surveys were conducted during routine daytime site visits. DEP determined it was not necessary to activate the as needed water bird dispersal program during the assessment period.

7.3 The Kensico Watershed

The Kensico Reservoir is located in Westchester County, about 15 miles north of NYC. 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, which mix in the main basin before entering the Delaware Aqueduct at Shaft 18. The Catskill Aqueduct is currently off line until work is completed to pressurize the flow to the UV Plant. Kensico Reservoir holds 30.6 billion gallons at full capacity and was placed into service in 1915. As the final reservoir in the CAT/DEL system before water enters the distribution network, the Kensico Reservoir is subject to federal water quality standards for coliforms and turbidity under the SWTR.

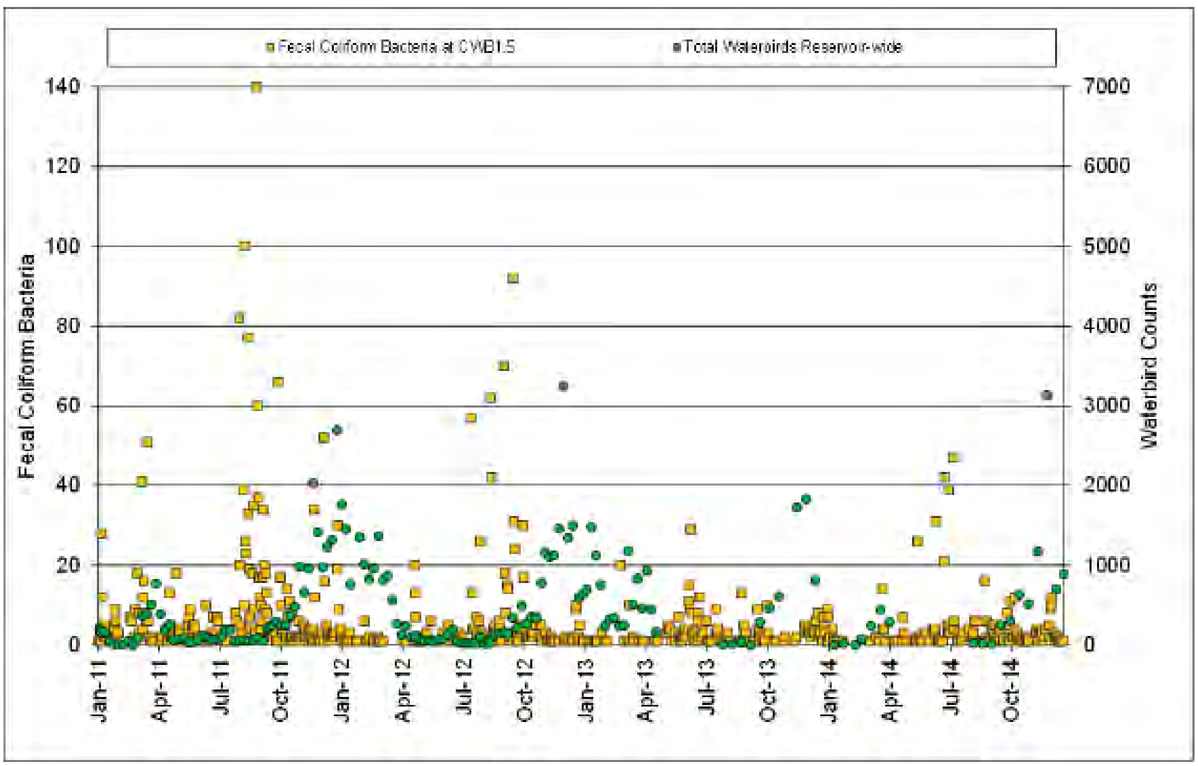

Figure 7.9 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total water birds at West Branch Reservoir, January 1, 2011 – December 31, 2014.

7.3.1 Land Use in the Kensico Watershed

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 (Figure 7.10). The Kensico watershed also has 7.6% of impervious surface.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

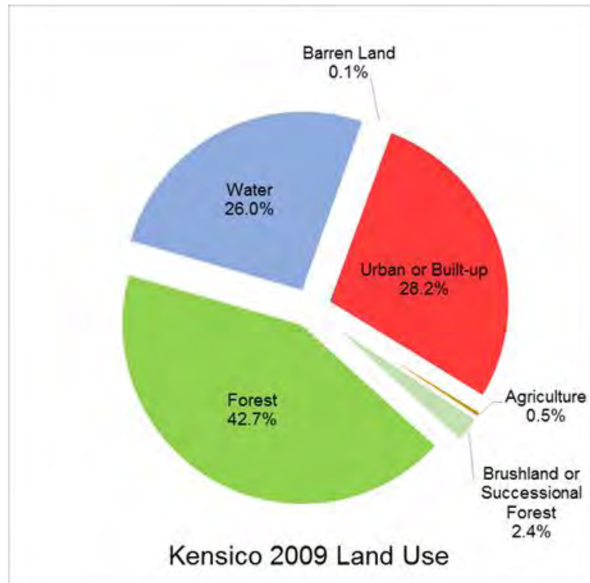

Figure 7.10 Land use in the Kensico watershed.

7.3.2 Program Implementation in the Kensico Watershed

DEP watershed protection programs have been effective in preserving the high quality of the water in the 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 focus 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 47 stormwater and erosion abatement facilities have been installed in the Kensico basin since 1997, significantly reducing in the possibility of turbidity and fecal coliforms entering the Reservoir (Figure 7.11). 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.

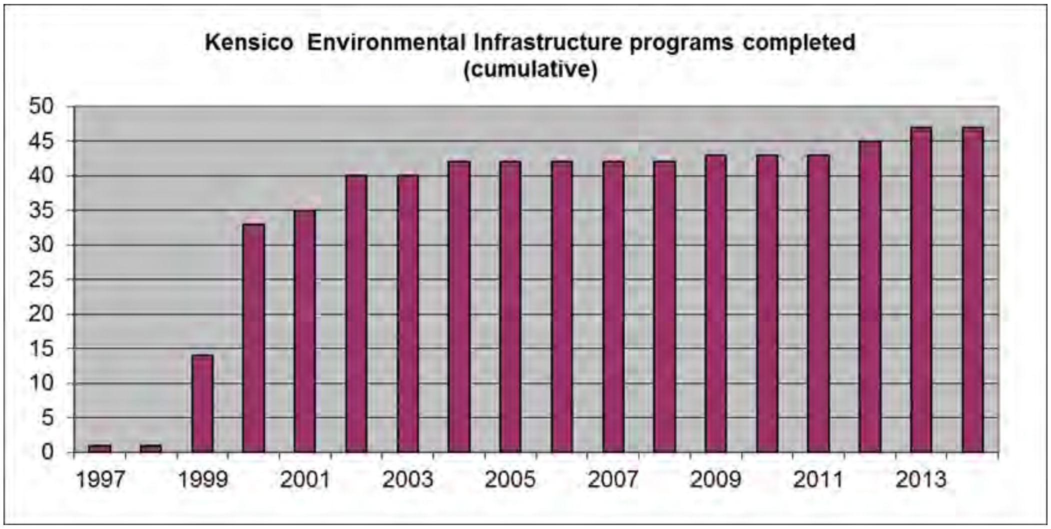

Figure 7.11 The history of watershed programs in the Kensico drainage basin - environmental infrastructure installations for stormwater control and stream management projects.

7.3.3 Water Quality Status and Trends in the Kensico Watershed

Status (Kensico)

The Kensico Basin status evaluation is presented as a series of boxplots in Figure 7.12. The inputs 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 outputs are designated as DEL18DT and CATLEFF. The output from the Catskill Aqueduct (CATLEFF) was taken out of operation in 2012, as previously noted, but results through September 2012 are included in Figure 7.12. All values below the maximum detection limit for fecal coliform bacteria were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2012-2014), fecal coliform levels were low in the Kensico Basin. Reservoir fecal coliform levels were well below the SWTR limit. Turbidity in the Kensico Basin is typically low, as was the case for the 2012-2014 assessment period, with a few high values associated with the inflow from the Catskill Aqueduct that were attenuated in the reservoir (reservoir monthly median turbidity 1.45 NTU). Monthly median reservoir

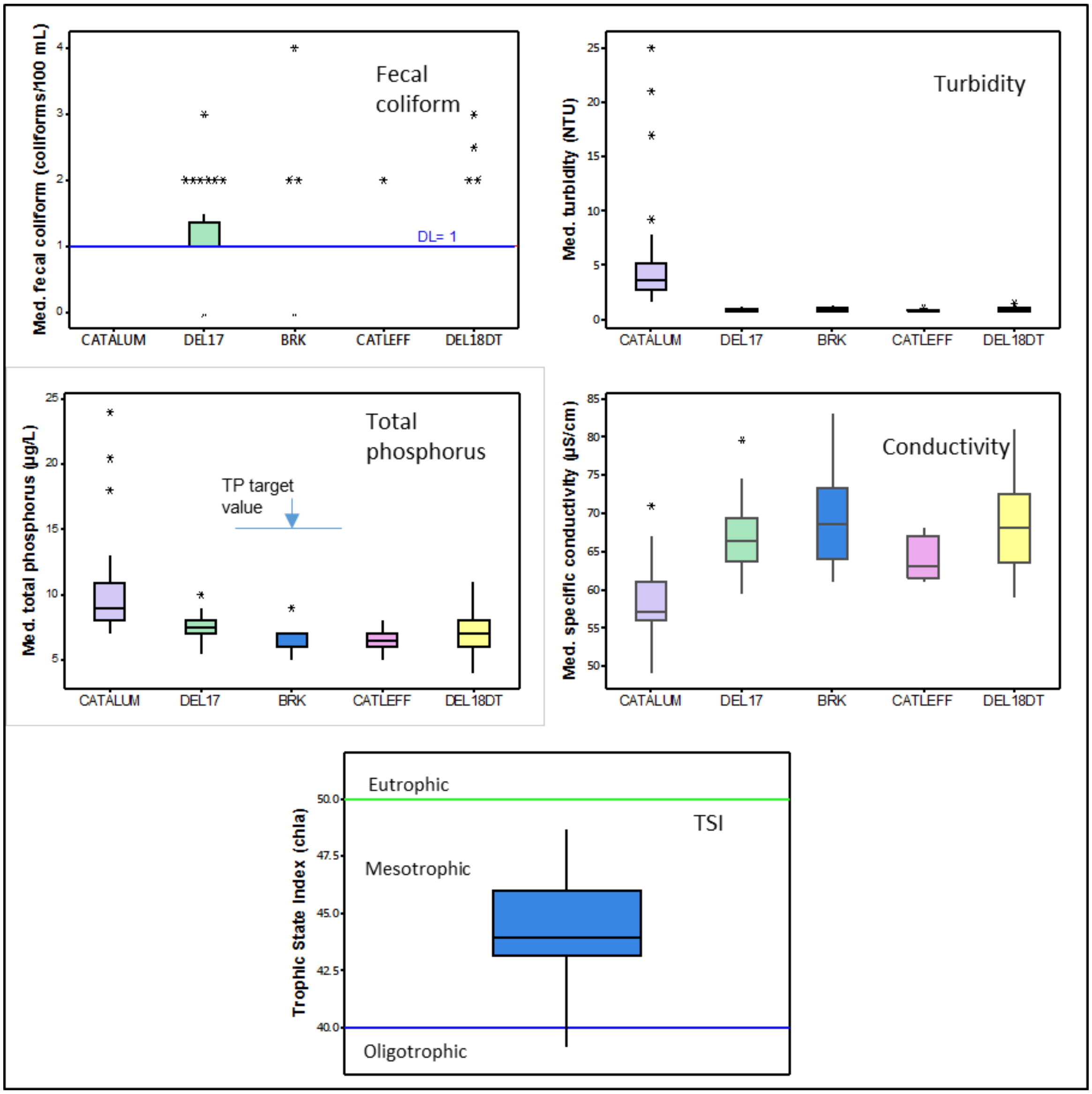

Figure 7.12 Water quality status boxplots using 2012-2014 monthly data for the Kensico basin inputs from the Delaware Aqueduct (DEL17) and the Catskill Aqueduct (CATALUM), Kensico Reservoir (BRK), and the outputs at the Kensico Reservoir gatehouses (DEL18DT and CATLEFF).

total phosphorus (TP) values were well below the target value of 15 µg L^{-1} with a median of 6 µg L^{-1}. The TSI values for Kensico Reservoir fell in the mesotrophic range, with a median of 46. Conductivity was highest in the reservoir with a median of 68.5 µS cm^{-1}.

In summary, water quality was good during the 2012-2014 status assessment period in the Kensico Basin. All monthly median values were well below water quality status benchmark values.

Trends (Kensico)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. Water quality trend plots are presented in Figure 7.13 and results of the Seasonal Kendall trend analysis are provided in Table 7.2. As previously noted, the UV plant was brought on-line in September 2012; as a result, all water leaving Kensico since late 2012 is through the Delaware output and is sampled at DEL18DT.

Reservoir operations are carefully managed to optimize water quality. For example, since Hurricane Sandy in 2012, Kensico Reservoir has been operated in float mode periodically when high winds are predicted. As discussed below, operational changes cause fluctuations in water quality, which can influence trend calculations and their interpretation.

No long-term turbidity trends were detected in Kensico Reservoir. Upward trends were detected in the Catskill Aqueduct input at CATALUM, the Delaware Aqueduct input at DEL17, and in the Delaware output at DEL18DT. The upward trend in the Catskill input is related to flooding events in 2005-2006 and again in 2010-2011, and may also reflect increased usage of water from the Ashokan West Basin as part of the strategy for Catskill turbidity control. Note that during times of excessive turbidity alum is applied just downstream of the Catskill input 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. Although an upward trend was detected for the Delaware input and output, the very small change, <0.01 NTU per year, is not of practical significance.

Significant downward trends were detected for fecal coliforms in both the inputs and outputs. Although the slope estimator test produced a slope of 0.00 at all sites (due to the preponderance of tied, low values), the Tau values from the Seasonal Kendall test were all negative, indicating a decrease (see Appendix C for a more detailed description of slope values of zero). Additional evidence of the decline is indicated by examination of the LOWESS curves at these sites. A dramatic decrease is observed at the Delaware input and probably represents recovery from the January 1996 flood event in the WOH watersheds. Because of the dominance of low values at the Catskill input, the change depicted by the LOWESS curve is much more subtle but the data do indicate a decrease in median counts over time. A downward trend was also detected for the reservoir, due in part to decreases observed in the major inputs. The low counts can also be attributed to the waterfowl management program in place at Kensico since 1993. 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,

Table 7.2 Kensico basin inflow, reservoir, and outflow trends from 1993 to 2014.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
CATALUM	Input	Turbidity	264	0.18	***	0.05
DEL17	Input	Turbidity	258	-0.08	**	0.00
Kensico	Reservoir	Turbidity	174	-0.04	NS	
CATLEFF	Output	Turbidity	237	0.01	NS	
DEL18DT	Output	Turbidity	264	0.09	***	0.00
CATALUM	Input	Fecal coliform	264	-0.10	***	0.00
DEL17	Input	Fecal coliform	258	-0.20	***	0.00
Kensico	Reservoir	Fecal coliform	174	-0.12	***	0.00
CATLEFF	Output	Fecal coliform	237	-0.09	***	0.00
DEL18DT	Output	Fecal coliform	264	-0.19	***	0.00
CATALUM	Input	Total Phosphorus	262	-0.09	***	-0.07
DEL17	Input	Total Phosphorus	258	-0.17	***	-0.10
Kensico	Reservoir	Total Phosphorus	165	-0.32	***	-0.17
CATLEFF	Output	Total Phosphorus	235	-0.21	***	-0.13
DEL18DT	Output	Total Phosphorus	262	-0.24	***	-0.11
CATALUM	Input	Conductivity	264	-0.03	NS	
DEL17	Input	Conductivity	258	0.13	***	0.22
Kensico	Reservoir	Conductivity	172	0.08	*	0.12
CATLEFF	Output	Conductivity	237	0.22	***	0.33
DEL18DT	Output	Conductivity	264	0.24	***	0.30
Kensico	Reservoir	Trophic State Index	165	0.12	**	0.10

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

with the highest monthly median counts reaching five fecal coliforms 100 mL^{-1} in most years. Elevated counts in 2003 coincided with a temporary lapse in the annual waterfowl management contract.

Strong downward TP trends were detected in both the inputs and outputs, as well as in the reservoir. Although none of these locations experienced downward trends through 2004 (DEP 2006a), phosphorus concentrations have generally dropped each year since then. WWTP upgrades in the Cannonsville, Ashokan and the Schoharie basins and the construction of a new plant in the Ashokan basin are the mostly likely explanation, although the ongoing implementation of agricultural BMPs and the septic system replacement in these upstate basins probably played a role as well.

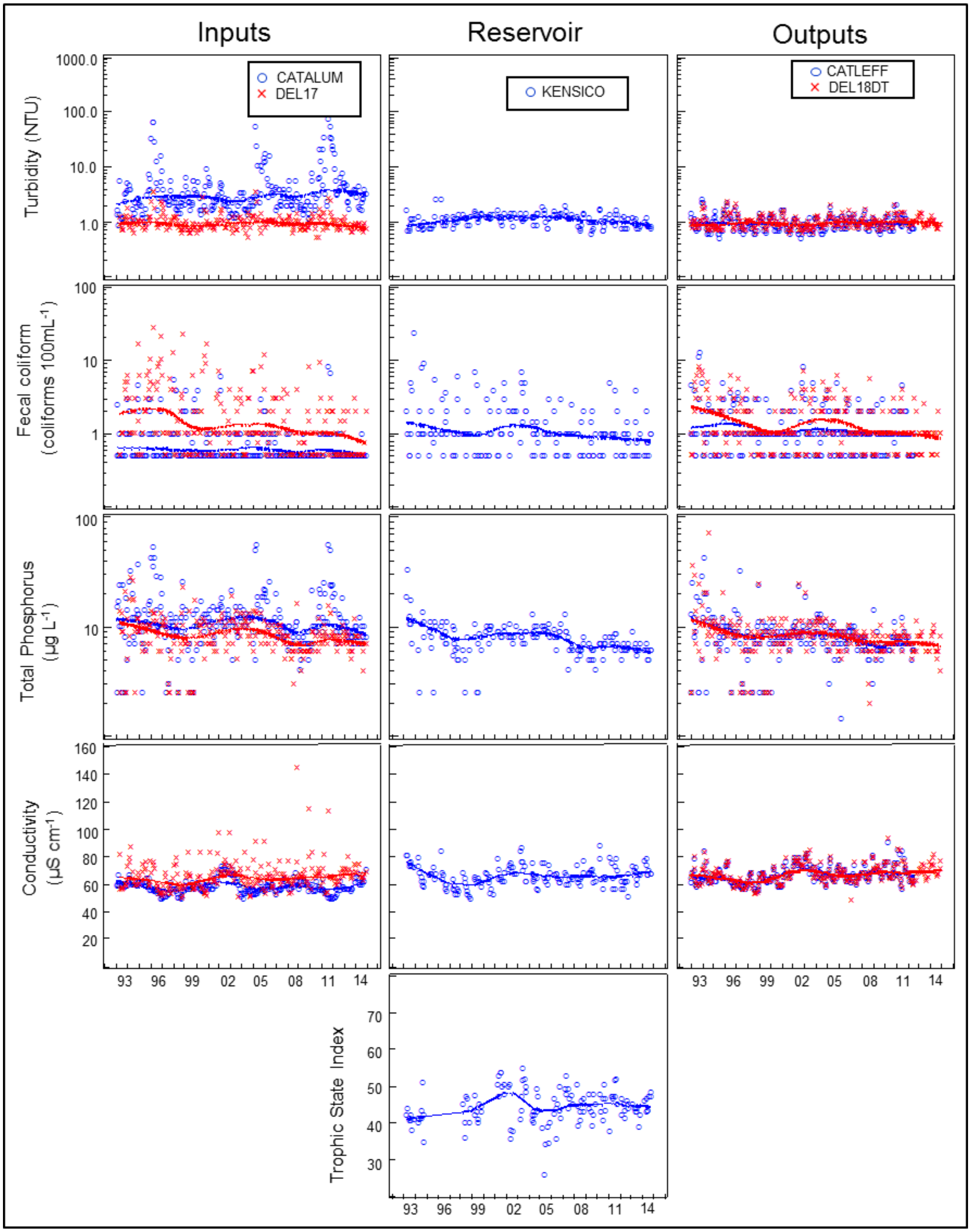

Figure 7.13 Water quality trend plots for the Kensico basin inputs from the Delaware Aqueduct (DEL17) and the Catskill Aqueduct (CATALUM), Kensico Reservoir (BRK), and the outputs at the Kensico Reservoir gatehouses (DEL18DT and CATLEFF).

A strong upward conductivity trend was found in the Delaware input, but no trends were apparent in the Catskill input. Increasing chloride trends in most Delaware System reservoirs may suggest greater usage of road deicers but these trends are hard to separate from conductivity changes due to the concentration/dilution effects of temporal changes in precipitation patterns. For example, a portion of the upward trend can be attributed to the effects of drought in 2001-2003. In addition, West Branch was operated for less time in float mode in 2005, 2007, 2010 and 2011, resulting in a greater contribution from local water sources with higher conductivity, by virtue of less time on float mode at West Branch. Strong upward conductivity trends were detected in both outputs with a moderately strong, smaller change indicated for the reservoir. The outputs are sampled daily and are more likely to capture highly conductive local stream inputs located near the effluent locations (e.g., Malcolm Brook) that may not be captured in the monthly reservoir samples used in this analysis. Winter time effects are also captured in the output trends but are not seen in the reservoir, which is generally not sampled during this time.

A small, statistically moderate increasing trend in TSI values was detected in the reservoir. The largest increase occurred in 2001, coinciding with the productivity increase (from increased clarity) noted for Ashokan Reservoir (DEP 2006a). High algal inputs continued from Ashokan through 2004, ending with a turbid runoff event in April 2005. 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. The small increase which occurred between 2005 and 2007 could not be attributed to inputs from Rondout or Ashokan Reservoirs. Their TSI levels did not increase during this period, so it is possible that the higher TSI observed in Kensico was due to a local increase in primary productivity. Since 2007, no trends have been observed in TSI values for Kensico Reservoir.

In summary, Kensico Reservoir and its Delaware input showed no or minimal long-term change in turbidity, but small increases were observed at the Catskill input and at the Delaware output. The Delaware output change of less than 0.01 NTU is considered inconsequential. The increase at the Catskill input reflects the flooding events of 2010-2011 but does not reflect the effects of alum which are administered downstream of this site. Fecal coliform counts were consistently low and appear to be decreasing due to decreasing counts from the Catskill and Delaware inputs, and as a result of the Waterfowl Management Program’s harassment activities. TP was in decline at all sites, and especially noticeable post 2004. WWTP upgrades in upstate watersheds are thought to be partly responsible. Upward conductivity trends were detected in the Delaware input and in both outputs as well. The 2001 drought, operational changes and local anthropogenic sources are likely causes for the noted increase. Productivity increases in Kensico Reservoir are likely due to increases in the Catskill System reservoirs through 2004.

7.3.4 Biomonitoring in the Kensico Watershed

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

In the Kensico basin, status and trends of macroinvertebrate communities were evaluated for Whippoorwill Creek, whose 1.5-square-mile sub-basin is the largest sub-basin in the Kensico Reservoir watershed. Site 117 (WHIP), which lies approximately 0.1 miles upstream of Kensico Reservoir, and Site 155, which is about 0.4 miles upstream, were the only sites sampled in the creek during the 2012-2014 period. The sampling effort that was conducted during that timeframe constituted the post-construction phase of a study to evaluate impacts to the benthic community from a stream bank stabilization project built between 2011 and 2012. The following discussion will focus on the results of that evaluation, in which Site 117 was the potentially affected downstream site and Site 155 the upstream control site. The sites' 2014 status, as well as a trend analysis for the more frequently sampled Site 117, will be discussed in the context of the evaluation.

In 2009, the year of pre-construction sampling, Site 155 was assessed as slightly impaired and Site 117 as moderately impaired. The latter was a downgrade from the originally-reported result, reflecting the influence of the Nutrient Biotic Index-Phosphorus metric, which was introduced by the NYSDEC in 2012. In 2014, the year of post-construction sampling, both sites assessed as slightly impaired (Figure 7.14), suggesting some improvement at the downstream site. That conclusion must be treated with caution, however, for a number of reasons. First, the moderately impaired assessment at Site 117 in 2009 was based on a BAP score (4.95) that is very close to the moderately impaired/slightly impaired threshold of 5. Because of the inherent interannual variability in BAP scores, DEP does not assign impairment to a particular category based on a single year's data when the score lies close to the threshold; instead, impairment is assigned only after the site has received two consecutive assessments at the same level of impairment. Consequently, Site 117's assessment as moderately

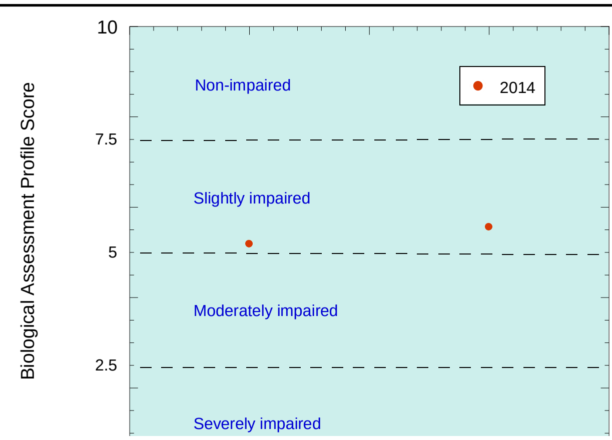

Figure 7.14 Biological Assessment Profile scores for Whippoorwill Creek, 2014.

impaired in 2009 must be considered tentative. Second, despite the moderately impaired rating, an analysis of BAP scores for Site 117's entire period of record using the nonparametric Mann-Kendall trend test detected no significant trend, either upward or downward, at the site (Figure 7.14). Finally, in both 2009 and 2014, the benthic communities at both sites were structurally and functionally similar. Given the equivocal nature of the results, DEP concluded that more data were needed to determine whether any change had in fact occurred at the downstream site. To achieve that, additional samples were collected at both sites in 2015. Results will be described in the next Water Quality Annual Report.

Over the course of its long-term record, Site 117 has experienced a continued increase in the percent composition of its hydropsychid caddisfly population. Percent composition varied between 3% and 19.4% from 1997 to 2005, rose to 25% in 2009, then spiked to 55.2% in 2014, the fourth highest hydropsychid percent composition recorded by DEP in 20 years of sampling in the EOH System. Numbers were also high at Site 155 (37.3% in 2009, 42.2% in 2014), but because there are no records for the site from before 2009, it is impossible to say if this represents an increase from prior years. The dramatic increase in hydropsychids at Site 117 mirrors conditions at Horse Pound Brook, whose hydropsychid population also expanded greatly in 2014 (see Section 7.2.5). Moreover, such untoward increases are not limited to the EOH FAD basins, as demonstrated by the situation at Anglefly Brook, a tributary to Muscoot Reservoir. There, the increase in hydropsychids has been ongoing since 2008, peaking at 72.9% in 2013 and 66.9% in 2014.

While it is true that hydropsychids are frequently abundant at disturbed sites and display occasional spikes at others, it is unusual to see such high relative abundance at sites that regularly assessed as non-impaired before such increases occurred (as in the case of Horse Pound Brook and Anglefly Brook), or to see increases of such magnitude at sites, like Whippoorwill Creek, where high numbers of hydropsychids had never previously been observed. It is not known if the increases in hydropsychids observed at these sites represent natural variability in the sites' macroinvertebrate communities or are of anthropogenic origin. To date, DEP has been unable to identify any pollution source that could account for these changes, but will continue to monitor the sites to see if declines in their hydropsychid populations occur in the future.

7.3.5 Waterfowl Management Program: Kensico and Hillview

Kensico Reservoir

Kensico Reservoir has been divided into eight bird zones to associate bird counts with water quality in samples collected at limnological sampling locations. Water bird numbers at Kensico Reservoir remained consistently low throughout the reporting period as a result of continued implementation of the Waterfowl Management Program.

Daily water bird observations were conducted at predawn hours (between 4:30 am and 8:00 am E.S.T.) and post dusk hours (between 5:00 pm and 10:00 pm E.S.T.) to determine overnight water bird roosting populations and to evaluate the success of the dispersal activities from the previous day (where applicable). Survey times vary seasonally reflecting available daylight hours. For successful bird observation data collection, ideal weather and atmospheric conditions were necessary. Precipitation events and fog prohibited data collection and resulted in short gaps of no data.

Fecal coliform bacteria levels at the keypoint water sampling locations (DEL18 and CATLEFF) remained in compliance with the SWTR during the assessment period from January 1, 2011 through December 31, 2014 (Figure 7.15) primarily from the implementation of the annual water bird management dispersal actions. The relatively low number of water samples with concentrations above 20 CFU 100 mL^{-1} limit helped keep the six-month running average well below the 10% regulatory limit with samples at DEL18 except for the impacts from two seasonal precipitation events in the late summer and early fall of 2011 from Tropical Storm Irene and Tropical Storm Lee. Despite the impacts from there two precipitation events DEP remained in compliance with the SWTR.

Prior to implementing a formal bird dispersal program, DEP began collecting bird census data in August of 1992. Bird counts reached several thousand during the migratory/wintering period (Figure 7.16) with high bird roosting counts recorded at the water intake coves at

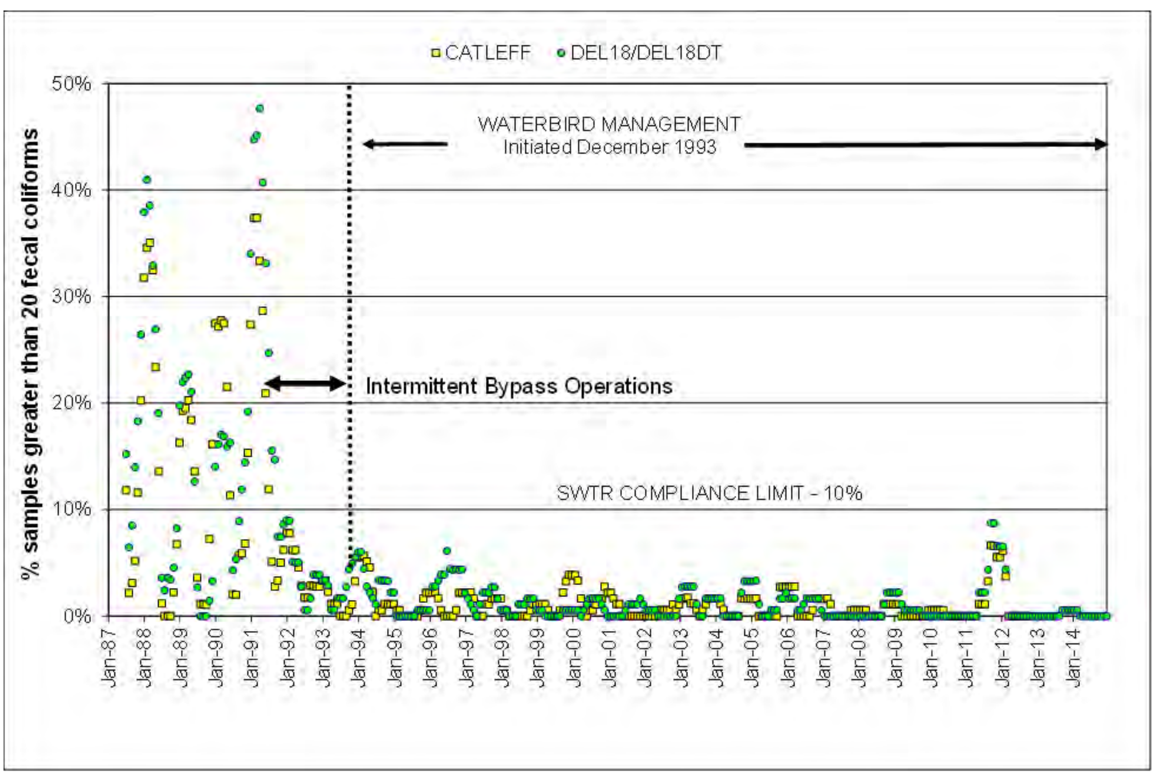

Figure 7.15 Kensico Reservoir SWTR compliance (fecal coliforms 100mL^{-1} at DEL18/DEL18DT and CATLEFF).

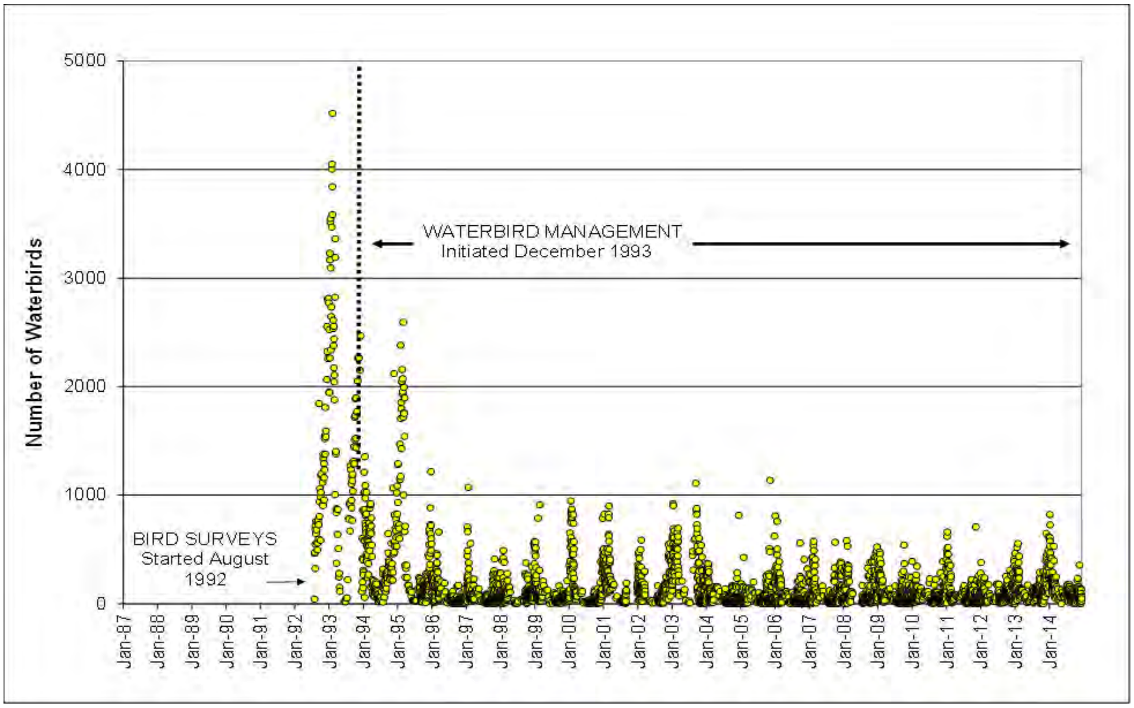

Figure 7.16 Kensico Reservoir water bird totals.

Kensico. Figure 7.16 shows a dramatic decline in bird counts simultaneous with the commencement of the bird dispersal efforts in December 1993, and this observation (or effect) continues through the present day.

The Waterfowl Management Program continued to maintain a high level of success from January 1, 2011 through December 31, 2014 managing water birds at Kensico Reservoir. Resident and migratory water bird populations were kept at low levels (Figure 7.16); a result of implementing bird dispersal activities. DEP's contract deployed a minimum of three motorboats combined with discharging pyrotechnics to disperse all water birds observed on the reservoir from August 1 through March 31 annually.

Figure 7.17 and Figure 7.18 compare the regulatory source water samples collected from Delaware Shaft 18 (DEL18/DEL18DT) and the Catskill Effluent (CATLEFF) with counts of overnight water birds. Since water birds roosting overnight represent the potential for fecal coliform bacteria contribution to the water supply, dispersal activities were only implemented from post sunrise to post sunset (about 1.5 hours). Overnight water bird counts were conducted

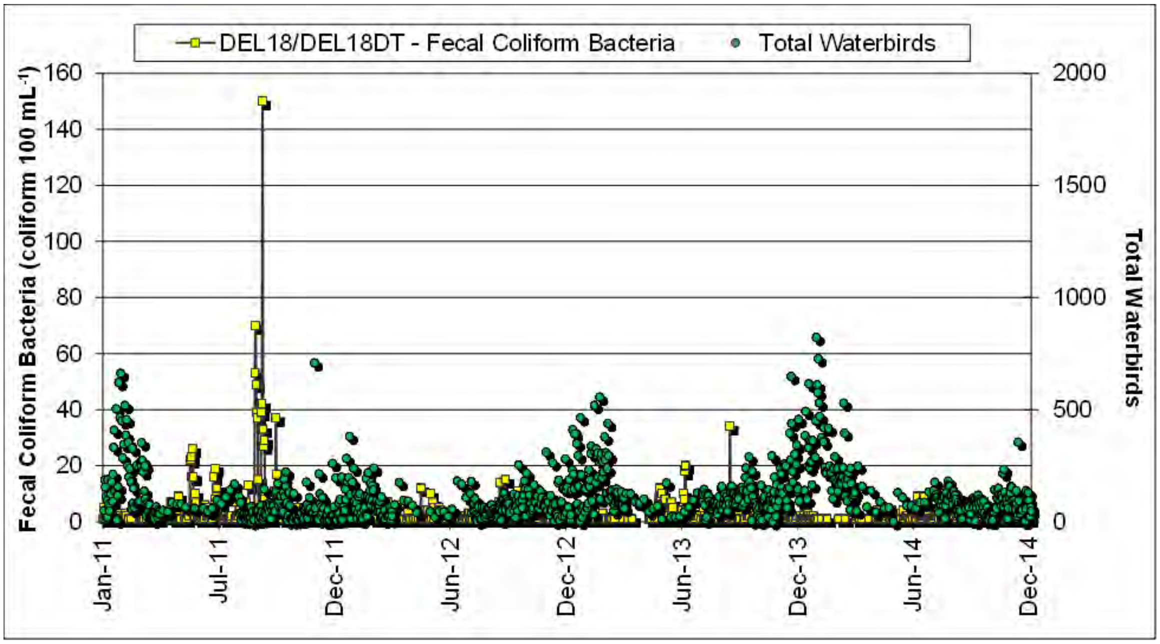

Figure 7.17 Kensico Reservoir fecal coliforms 100mL^{-1} at DEL18DT vs. total water birds (January 1, 2011 to July 31, 2015).

daily during the bird dispersal period from August 1 through March 31 and weekly from April 1 through July 31 and are represented in Figure 7.17.

Throughout this reporting period, a coliform-restricted assessment based on compliance of the SWTR for Kensico Reservoir, resulted in a determination that the basin status was non-restricted. The number of hits from compliance source water samples that exceeded 20 CFU 100 mL^{-1} for CATLEFF peaked at 12 for the months of September and October 2011, elevating the percentage of samples exceeding 20 CFU 100 mL^{-1} over the previous 6-month period to 6.6%. The number of samples exceeding 20 CFU 100 mL^{-1} remained at 0% for 11 of the 20 months the facility was on-line. The number of hits from compliance water samples that exceeded 20 CFU 100 mL^{-1} for DEL18/DEL18DT peaked at 16 for the months of September and October 2011, elevating the percentage of samples exceeding 20 CFU 100 mL^{-1} over the previous six month period to 8.7%. The highest number of monthly hits for each source water effluent corresponds with Tropical Storm Irene and Tropical Storm Lee that effected the northeastern United States that year. Total rainfall amounts associated with Tropical Storm Irene in late August 2011 was over seven inches of rain and a total of 6.2 inches of rain was recorded from Tropical Storm Lee in early September 2011.

The incidence of specific groups of water bird groups continues to follow trends for annual migration and over-wintering patterns. Water bird roosting locations during the winter period are generally determined by extent of ice-cover. During 2011-2014 the breakdown of

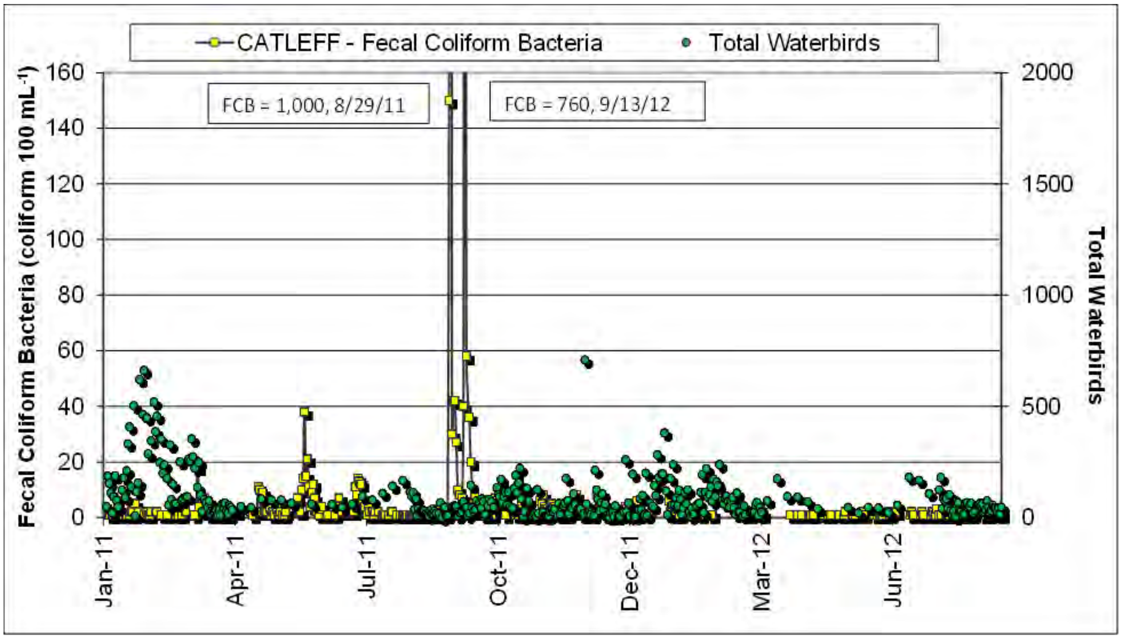

Figure 7.18 Kensico Reservoir fecal coliforms 100mL^{-1} at CATLEFF vs. total water birds (January 1, 2011 to September 12, 2012).

water bird groups was as follows: Canada Geese 44%, gulls 13%, and other water birds (ducks, grebes, loons, swans and cormorants) 43%. The DEP contractor used two Biondo Airboats for bird dispersal activities during the ice-cover period as the craft are designed to operate on ice or water interfaces.

The Westchester County Airport, located immediately east of the Rye Lake area continued to manage birds for air traffic safety. As part of the airport's Wildlife Hazard Management Plan (Airport Depredation Orders – Resident Canada Goose nest and egg depredation order, 50 CFR 12.50 and Control order for resident Canada Geese at airports and military airfields 50 CFR 12.49), Westchester County has contracted with USDA to remove all Canada Geese within a seven mile radius around the airport property which includes all of the Kensico Reservoir. During this reporting period, DEP allowed USDA officials under contract with the Westchester County Airport access to DEP property to determine if there were geese present during the annual goose molt period in the spring of 2011 through 2014. Results of the USDA survey indicated that geese were present on the Kensico Reservoir property in three of the four years reported. The USDA removed eight Canada Geese in 2013, zero in 2012, five in 2013 and three in 2014 from Kensico Reservoir property. Geese were live-trapped and removed from the reservoir property by USDA staff.

DEP's bird management activities have to prevent dispersal of water birds into the flight paths of arriving and departing aircraft at Westchester County Airport as the airport lies adjacent

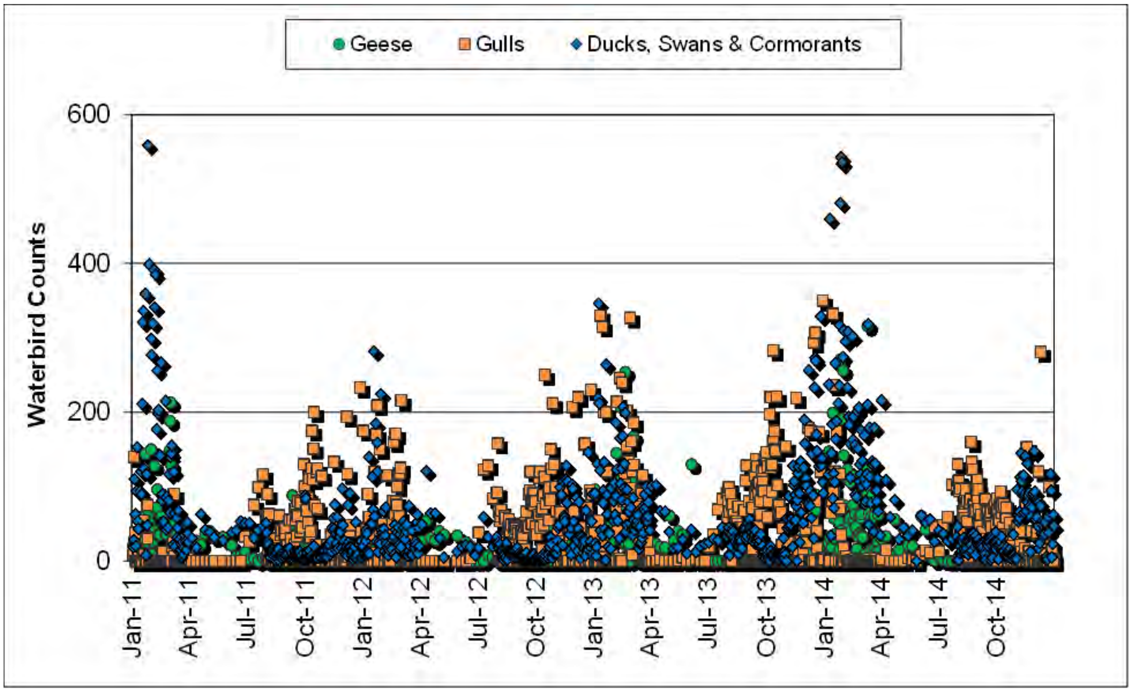

Figure 7.19 Kensico Reservoir total water birds by groups (January 1, 2011 to December 31, 2014).

to the eastern shoreline of Kensico Reservoir. Bird dispersal crews are instructed to abstain from discharging pyrotechnics with approaching aircraft to avoid potential airstrikes with birds and pilot confusion with the use of aerial low-grade explosives. DEP maintains routine communication with airport officials including its contractor on any changes in bird management activities conducted at the reservoir.

It is suspected that the increased spatial separation between birds and the water intake at Delaware Shaft 18 at Kensico is an important factor that helps reduce the threat of an increase in fecal coliform bacteria. As a result, bird dispersal activities were heavily concentrated in the vicinity Delaware of Shaft 18 and the lower main basin of Kensico. Overall, water bird numbers continue to be sufficiently managed at Kensico to maintain compliance with the federal SWTR for fecal coliform bacteria levels.

Alewives (*Alosa pseudoharengus*) and other baitfish transported through upstate aqueducts to Kensico were present during the autumn/winter period from 2011 to 2014. When present, the dead and dying Alewives typically attracted foraging gulls and diving ducks. DEP and its contractor continued to monitor fish concentrations and collected dead/dying baitfish as they entered Kensico Reservoir by way of the upstate aqueducts. The volume of fish observed, collected, and disposed of from Kensico CATIC (influent) is as follows: 2011-2012 was 115 lbs. in 2012-2013 was 800 lbs. in 2013-2014 was 41 lbs. and 2014-2015 was 36 pounds. The lower

Table 7.3 Kensico and Hillview Reservoir egg depredation 2011 to 2014.

Reservoir	Canada Geese/Mute Swan/Mallard Nests	Canada Geese/Mute Swan/Mallard Eggs Depredated	Canada Geese/Mute Swan/Mallard Depredation Success Rate
Kensico	78/3/NA	374/22/0	97%/100%/NA
Hillview	0/0/7	0/0/51	NA/NA/81%*

*A total of 27 Mallard ducklings hatched at Hillview Reservoir from 2011 to 2014 were live-trapped and successfully reared and released off reservoir property.

volume of fish observed seasonally reduced the amount of bird dispersal efforts necessary at the CATIC.

In the spring, Canada Geese and Mute Swan nests were identified along the reservoir shoreline and on islands at Kensico Reservoir. Table 7.3 lists the Canada Geese and Mute Swan egg-depredation actions and success rates from 2011 through 2014.

The ongoing implementation of the WMP has allowed DEP to maintain compliance with the SWTR standard for fecal coliform bacteria throughout this reporting period and dating back to 1993.

Hillview Reservoir

DEP initiated an in-depth program for waterbird management starting in 1993 followed by program enhancements with the 2007 FAD and again in 2011 under the Hillview Administrative Order. The DEP's Long-term Watershed Protection Program (July 2007 FAD) expanded the Waterfowl Management Program to include Hillview Reservoir on an as-needed basis similar to the 2002 FAD expansion for five additional reservoirs discussed above.

Hillview Reservoir is divided into two bird sampling geographic zones associated with the reservoirs two distinct basins and water quality sampling stations (Figure 7.20). Water bird population survey frequencies have varied through the years but generally had been conducted at a minimum on a weekly basis and in recent years on a daily basis. Bird deterrent and dispersal activities have also been employed since 1993 with a high level of success reducing and in most cases eliminating the presence of roosting water birds; particularly Canada Geese, Mute Swans, cormorants, gulls, and some ducks.

DEP and its contractor continued to use pyrotechnics, propane cannons, remote-control motorboats, and employed physical chasing techniques to the supplement overhead bird deterrent wire system to actively keep birds off the reservoir. Additional program enhancements were funded in association with a USEPA Administrative Order. In 2013, DEP installed an additional bird deterrent wire system along the reservoir's one-half mile long dividing wall railing to keep gulls and other species from landing and roosting. The newly installed railing wires have been

Figure 7.20 Hillview Reservoir basins.

largely successful in preventing gulls from attempting to land on the reservoir dividing wall and can be attributed to the reduced gull activity recorded during this reporting period.

A USEPA Administrative Order on Consent governing the covering of Hillview Reservoir (Docket No. SDWA-02-2010-8027 Catskill Delaware System) was signed on May 24, 2010. Under this order and beginning on August 1, 2011 DEP began implementing an enhanced wildlife management program at Hillview to further protect the water supply. New BMPs included increased bird census conducted daily from pre-dawn to post-dusk hours and dispersal from 5:00 am until post-dusk hours; mammal population monitoring and removal; Alewife (baitfish) monitoring and removal, animal sanitation inspections (facility and grounds inspections and clean-up of animal feces); swallow, starling, and sparrow management for egg and nest depredation; and monthly reporting on wildlife management activities at Hillview Reservoir.

Overnight and daytime water bird counts were conducted from January 1, 2011 through December 31, 2014 and are reported in Figure 7.21 and Figure 7.22. From January 2011 through December 2014 night-roosting guilds of birds comprised the following breakdown: Canada Geese 1%, gulls 11%, and ducks about 88%. Except for a low number of diving ducks (Ruddy Ducks, *Oxyura jamaicensis*) all water birds observed and reported on both nocturnal and diurnal surveys were dispersed from the reservoir using pyrotechnics, cannons, and physical chasing from 5:00 am until post-dusk times. Physical chasing of birds occurs from the time of personnel arrival starting as early as 5:00 am. DEP and its contractor crews were largely successful in dispersing the gulls, geese, cormorants, and some ducks once observed. Although diurnal counts

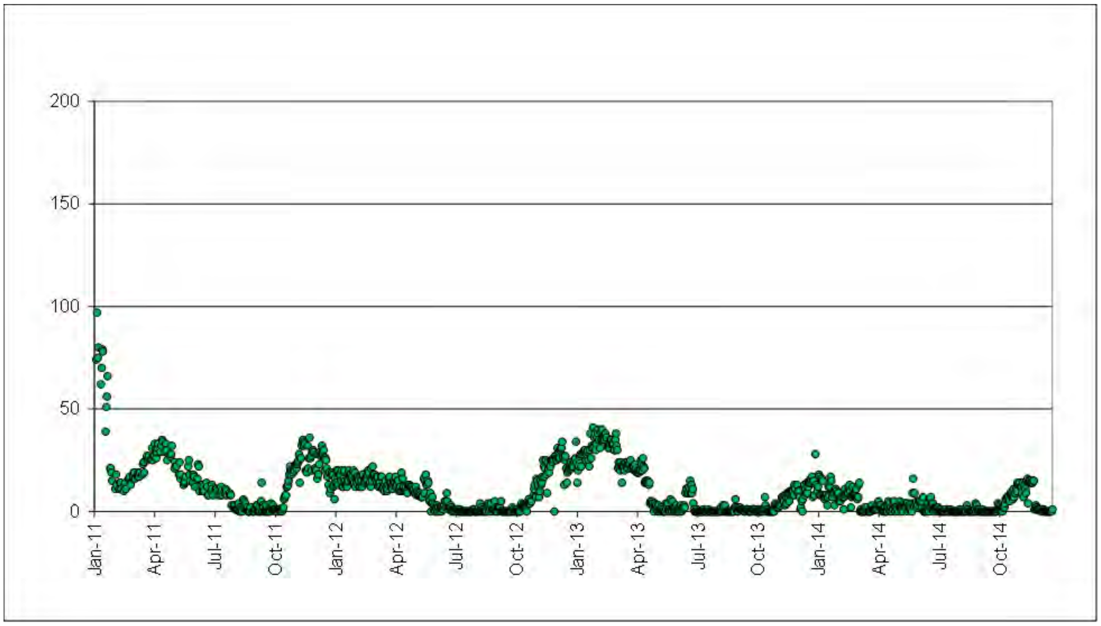

Figure 7.21 Hillview Reservoir total water birds nocturnal counts (July 1, 2011 to December 31, 2014).

generally appear to be higher than nocturnal counts, all birds observed roosting during the daytime period are immediately dispersed from or prevented from landing on the reservoir.

The diving ducks (Ruddy Ducks and Bufflehead (*Bucephala albeola*)) continue to remain unaffected by a variety of bird deterrent and dispersal measures employed by DEP to date. As a result, DEP utilized contract services with USDA Wildlife Services for lethal removal of ducks during this reporting period. The lethal duck removal program was initiated in April 2011 and is conducted on an as-needed basis. A total of 106 ducks were lethally removed by USDA during this reporting period. The majority of ducks removed were Ruddy Ducks with low numbers of Bufflehead, Lesser Scaup (*Aythya affinis*), and including four Canada Geese.

Overnight and daytime water bird counts on both basins remained very low and were almost exclusively from a relatively small resident duck population during the autumn and winter.

The behavior patterns of the water birds utilizing Hillview Reservoir are different from what is observed at Kensico Reservoir as Hillview is situated in a highly urbanized area and surrounded by large populations of breeding gulls throughout the NYC metropolitan area. This partially explains why gull activity is present year-around at Hillview. Since the installation of

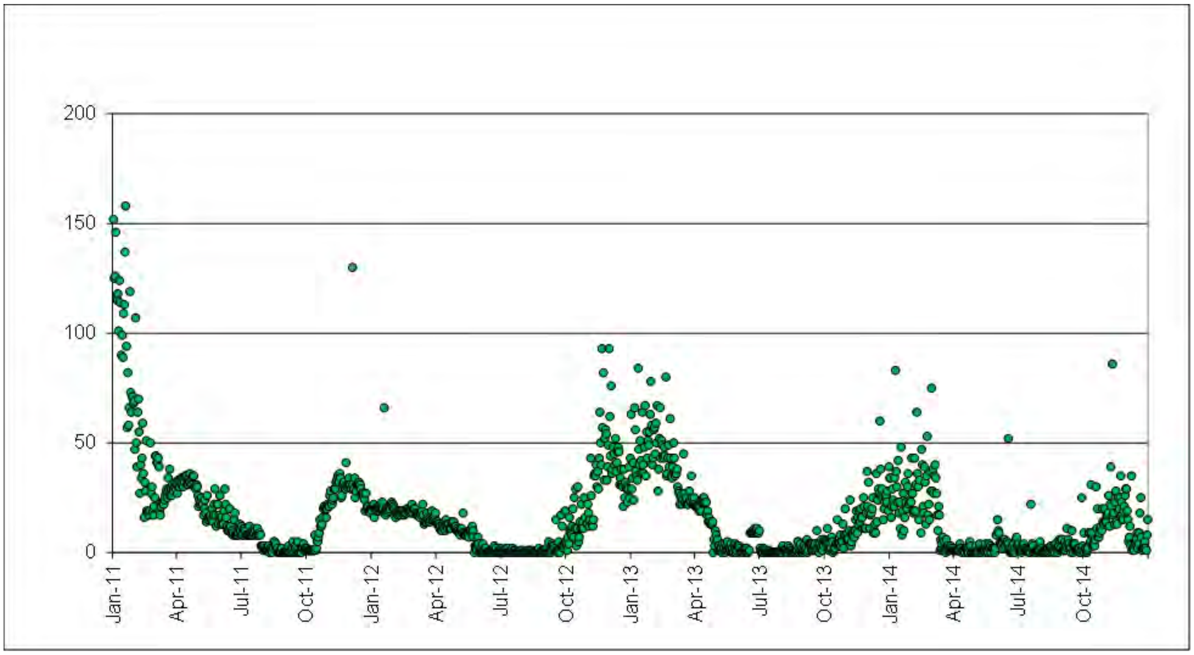

Figure 7.22 Hillview Reservoir total water birds diurnal counts (July 1, 2011 to December 31, 2014).

the bird deterrent wire system in 1994, small numbers of gulls and two species of ducks remain the target of active dispersal activity.

Water quality results for Hillview Reservoir are presented in this report as number of positive *E. coli* for each month of the reporting period at four water quality sampling locations Figure 7.23 and Figure 7.24. *E. coli* (grab samples) levels indicated a slight *E. coli* elevation during the following time periods: June to August 2011; July to August 2013 and May to July 2014 for water entering Hillview at water quality sampling locations Site 1 when compared with samples leaving the reservoir at sampling Site 3. Based on the relatively low number of water birds observed and the daily bird dispersal activities, it is unlikely that the water birds impacted the *E. coli* levels. There is however an annual increase in swallow and swift activity following the breeding season when adults and hatch-year birds are attracted to the reservoir for foraging from properties adjacent to Hillview. DEP employs an active swallow depredation program under a USFWS depredation permit to eliminate the nesting Barn Swallows and Cliff Swallows on the reservoir buildings.

Additional actions employed by DEP working in conjunction with assistance of NYSDEC and USDA Wildlife Services included implementing the following mitigative activities:

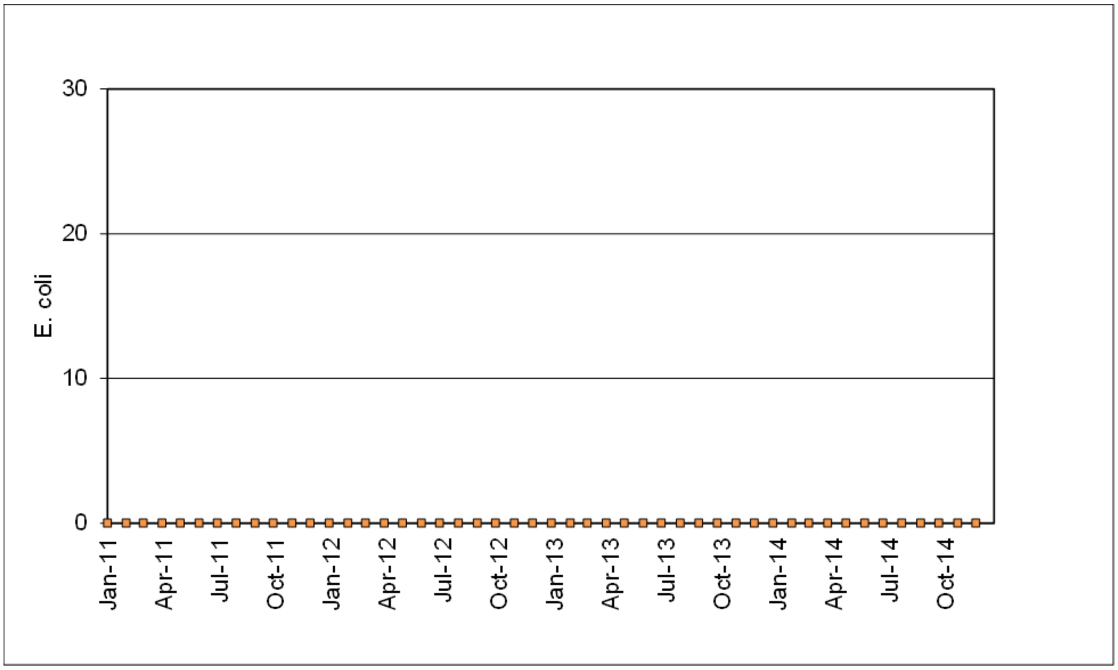

Figure 7.23 Hillview Reservoir number of positive *E. coli* (grab sample) at water sampling site 1 (January 1, 2011 to December 31, 2014).

- June 2011 – Present: USDA Wildlife Services Contract implemented to remove all resident ducks or other waterfowl that are unsuccessfully dispersed or removed by other non-lethal means implemented on an as-needed basis.
- August 2011 – Present: Under the USEPA Administrative Order and enhanced wildlife management program was implemented and includes the following:
    - Increased weekly survey shifts from 10 per week to 14 per week to allow daily, dawn to dusk coverage.
    - Daily sanitation surveys – observations and removal of animal fecal matter on the reservoir shaft buildings on the reservoir dividing wall.
    - Weekly small mammal trapping inside the reservoir perimeter fence.
    - Removal of Barn and Cliff Swallow nests on the reservoir shaft buildings and Osprey nests along the dividing wall bird wire stanchions. Nest removal activity is covered under United States Fish & Wildlife Service (USFWS) Depredation Permit.

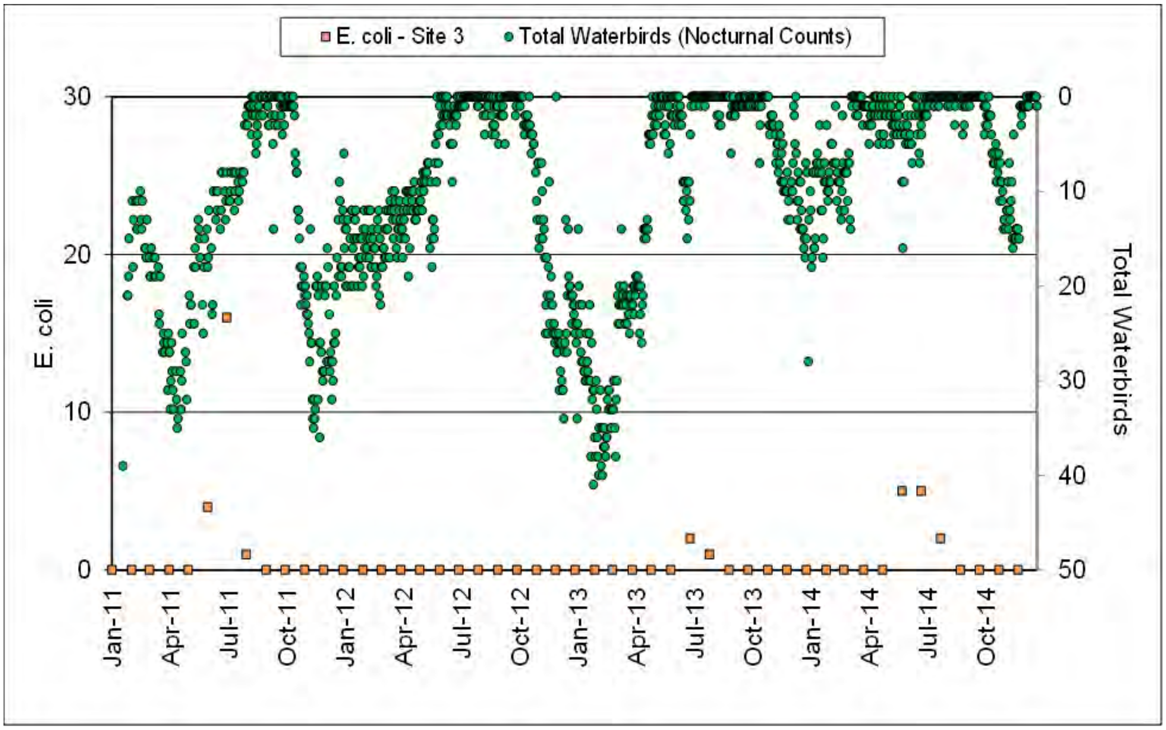

Figure 7.24 Hillview Reservoir number of positive *E. coli* (grab sample) versus total water birds at water sampling site 3 (January 1, 2011 to December 31, 2014).

  - Collection and disposal of Alewives from the Uptake 1 facility (water received from Kensico Reservoir). Removal of Alewives facilitates the elimination of water bird foraging activity and roosting at the reservoir.

- May 2012 – Present: Expanded access for USDA Wildlife Services Contract staff to improve duck depredation efficiency.
- January 2013 - Present: Received USFWS depredation permit for Cliff Swallows, Barn Swallows, and Mallard nest/egg/young removal during the breeding season.
- 2013 – Present: Completed installation and continued maintenance of avian deterrent wire system on reservoir dividing wall railing.
- July 2014 – Present: Expanded number of live mammal traps along reservoir perimeter.
- 2014 – Present: Installed additional motion activated cameras to document wildlife access at gate entrances to reservoir.

Mammal Trapping

DEP initiated a year-around mammal trapping program in August 2011 and currently focuses trapping efforts for raccoons and other small mammals each week of the year. Traps were generally set around the Downtake 1 Facility and Uptake 1 Facility perimeter catwalks and along the reservoir shoreline close to the shaft buildings. A variety of commercial and supermarket-type trapping baits have been used with variable success. Traps have been outfitted with catchment plates to avoid release of fecal material into the reservoir from trapped animals. All traps are secured with wires to the shoreline fence to prevent trap roll-overs. To date, mice (*Peromyscus spp.*) and raccoons (*Procyon lotor*) have been the most frequently trapped species. Other mammals trapped and subsequently depredated under NYSDEC approval include striped skunk (*Mephitis mephitis*), Virginia opossum (*Didelphis virginiana*), meadow vole (*Microtus pennsylvanicus*), eastern gray squirrel (*Sciurus carolinensis*), Norway rat (*Rattus norvegicus*), northern short-tailed shrew (*Blarina brevicauda*), house mouse (*Mus musculus*), and feral cat.

The success of the trapping program is displayed in Table 7.4. A total of 94 mammals from 10 species have been live-trapped inside the reservoir perimeter fence from 2011 to 2014 (Table 7.4). All trapped specimens were euthanized and subsequently composted at the DEP Animal Compost Facility located in Ulster County. A total of 5,519 mammal trapping nights have been set from 2011 to 2014. A single mammal trapping night consists of one trap baited for one night.

Trapping success also increased for striped skunks from zero in 2013 to nine in 2014, opossum from zero in 2013 to four in 2014, *Peromyscus spp*. decreased from 11 in 2013 to seven in 2014, and house mice from zero to 21 in 2014. The increase in trapping success may largely

Table 7.4 Trapping success summary for Hillview Reservoir (August 2011 to December 2014).

Species Trapped	2011 (August 1 to December 31)	2012	2013	2014	Trapping totals by species
Raccoon	8	5	6	6	25
Striped Skunk	0	1	0	7	8
Opossum	0	0	0	4	4
Mice (*Peromyscus* spp.)	7	0	11	7	25
Meadow Vole	0	0	4	0	4
Short-tailed Shrew	0	0	1	0	1
House Mouse	0	0	0	21	21
Norway Rat	0	0	0	1	1
Gray Squirrel	0	0	0	1	1
Feral Cat (relocated)	0	0	0	4	4
Annual Trapping totals by year	15	6	16	51	94

be attributed to a large increase in the number of traps set, in addition to setting at new trapping locations around the reservoir.

As part of the ongoing wildlife management initiatives, nighttime remote sensing cameras have been used to document the presence or absence of wildlife on the reservoir dividing wall and catwalks surrounding the shaft buildings at Hillview. The number of camera detections of wildlife appear to peak from August through October which represents many nights of repeated visits by a feral cat and Norway rat. The late winter period (March) coincides with the raccoon breeding cycles and young present. High counts of camera detection nights may also represent repeated photographs of the same individual. Raccoons are known to breed during the late winter period and have a 63-day gestation period which would suggest birthing in early spring. Raccoon home range can be two to four miles and extend to further distances during the autumn whereby the occurrence increase in the autumn may be attributed to these movements. The low camera detection and trapping success rate during the winter may be attributed to a lack in insect-type food that attracts them to the reservoir dividing wall, extended period of snow cover, and surface ice on the reservoir. The low detection rate of raccoons during the summer may be a result of alternate available feeding locations including berries, seeds and refuse found in the surrounding suburban neighborhoods and habitat.

7.4 Trophic Response of EOH CAT/DEL Basins

Chlorophyll versus total phosphorus in Kensico and West Branch Reservoirs is plotted in Figure 7.25. 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, and this is likely related to short water residence times. In 2001 and 2013 to 2014 chlorophyll annual means were high in both reservoirs. In 2005, two separate turbidity events which required alum treatment of the Catskill Aqueduct inflow to Kensico occurred in spring and fall, and these periods of

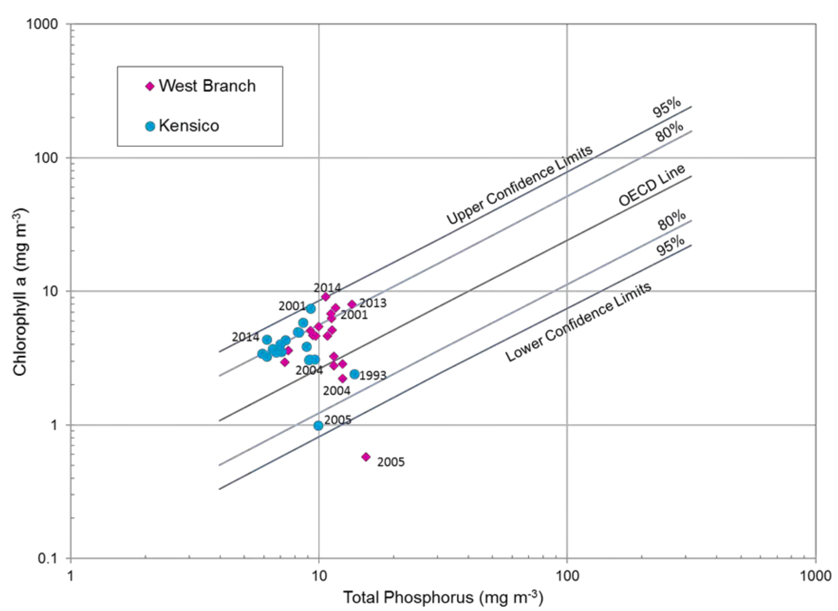

Figure 7.25 Chlorophyll vs. total phosphorus in West Branch and Kensico Reservoirs.

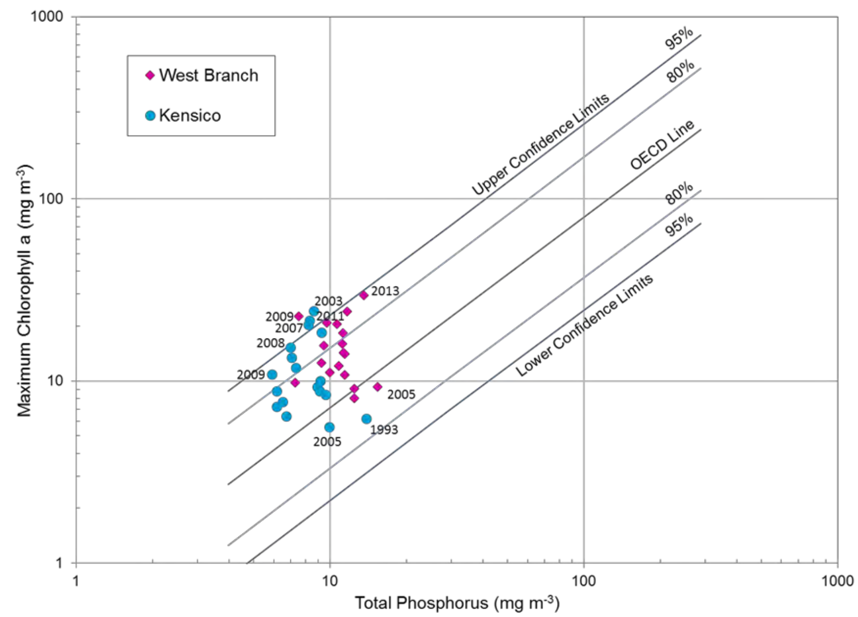

Figure 7.26 Maximum chlorophyll vs. total phosphorus in West Branch and Kensico Reservoirs.

elevated turbidity resulted in exceptionally low (<1 mg m^{-3}) chlorophyll means in both reservoirs.

The annual maximum values of chlorophyll versus total phosphorus is plotted for each year in Figure 7.26. In 2003, 2007 through 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.

Secchi depth versus total phosphorus annual mean values are plotted in Figure 7.27. 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 in the CAT/DEL System reservoirs.

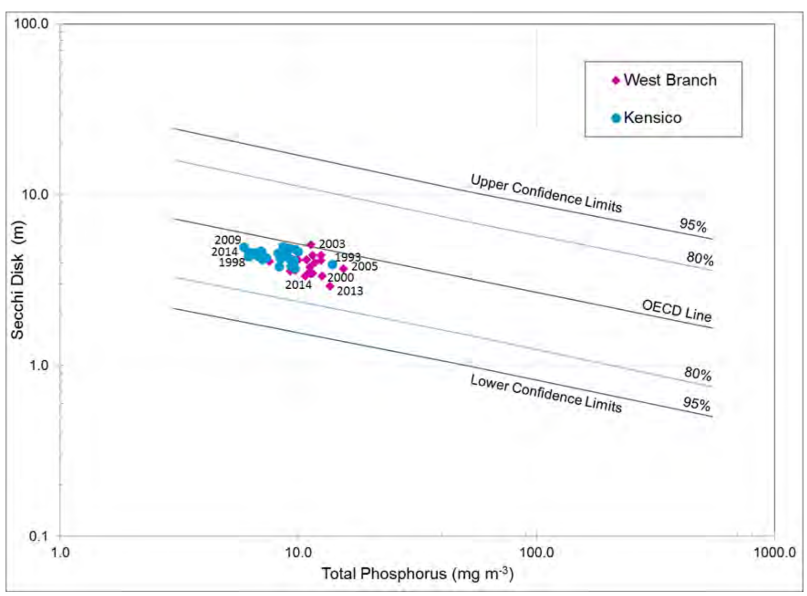

Figure 7.27 Secchi depth vs. total phosphorus in West Branch and Kensico Reservoirs.

Secchi depth versus chlorophyll is plotted in Figure 7.28. This plot demonstrates that transparency of the surface water is typically influenced by the chlorophyll levels. Interestingly, both reservoirs had other particulate matter other than chlorophyll limiting transparency particularly in 1993, and again in 2004 and 2005 when Hurricane Ivan and two tropical storms delivered heavy precipitation and flooding.

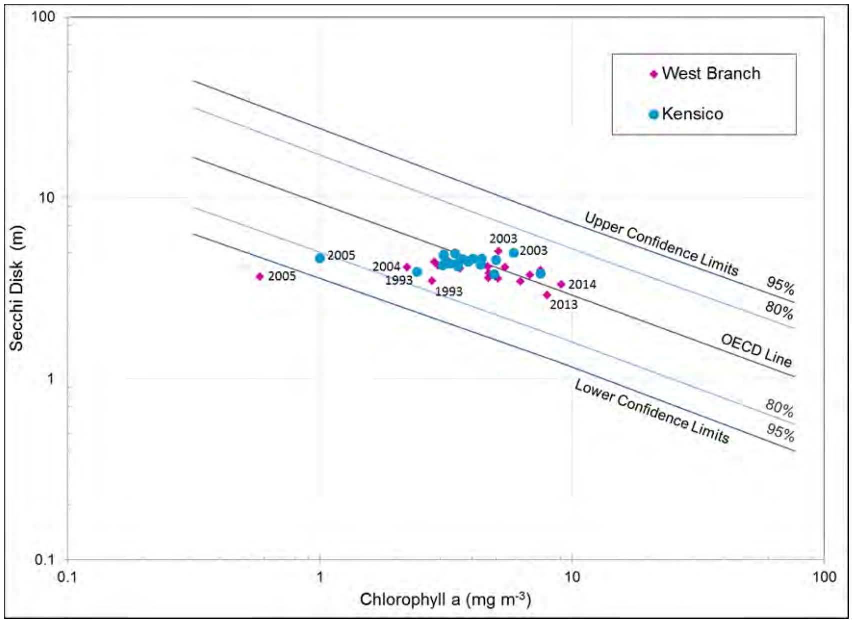

Figure 7.28 Secchi depth vs. chlorophyll in West Branch and Kensico Reservoirs.

7.5 EOH CAT/DEL Basin Protozoa: Sources and Attenuation

7.5.1 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, respectively) at least weekly since 2002. An exception is that the Catskill Aqueduct between Kensico Reservoir and the CAT/DEL UV Treatment Plant has been shut down since September 2012, when the CAT/DEL UV plant came online. As discussed previously, that portion of the aqueduct is not yet pressurized and as a result no samples have been collected at CATLEFF since that time. 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 1,623.1 (April 2015-present) have been used to collect and process samples, and a broad summary of the data acquired during this sampling period is provided here, with a focus on 2011 through September 2015.

Giardia

During this nearly 14-year period (January 2002-September 2015), 1,456 *Giardia* samples were collected at the Kensico inflows and 1,534 samples at the outflows. 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).

Giardia annual mean concentrations at the inflows and outflows of Kensico Reservoir were examined (Figure 7.29). The annual mean *Giardia* concentrations at the inflows to Kensico Reservoir have generally fluctuated between 0 and 2.5 cysts $50L^{-1}$ throughout the years with the exception of 2003 and 2004 when the Delaware inflow annual means were higher (maximum 4.5 cysts $50L^{-1}$) (Figure 7.29). This was a time of heavy rains and snowmelt, necessitating the addition of alum at the Catskill inflow, CATALUM, in April 2005. 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; however, alum addition could be a contributing factor to lower *Giardia* concentrations in the Catskill aqueduct when it is added. The *Giardia* outflow results were largely in the same range (0 to 2.5 cysts $50L^{-1}$) with the exception of, again, 2004 for both the Catskill and Delaware systems. It is not surprising, considering that the aqueduct inflows account for approximately 97% of Kensico's volume, that the years of highest *Giardia* are the same for both the inflow and the outflow locations (2003-2004). Also, as is expected, since the reservoir mixes the water from the two aqueduct inflows, the annual mean concentrations of *Giardia* leaving Kensico at either outflow

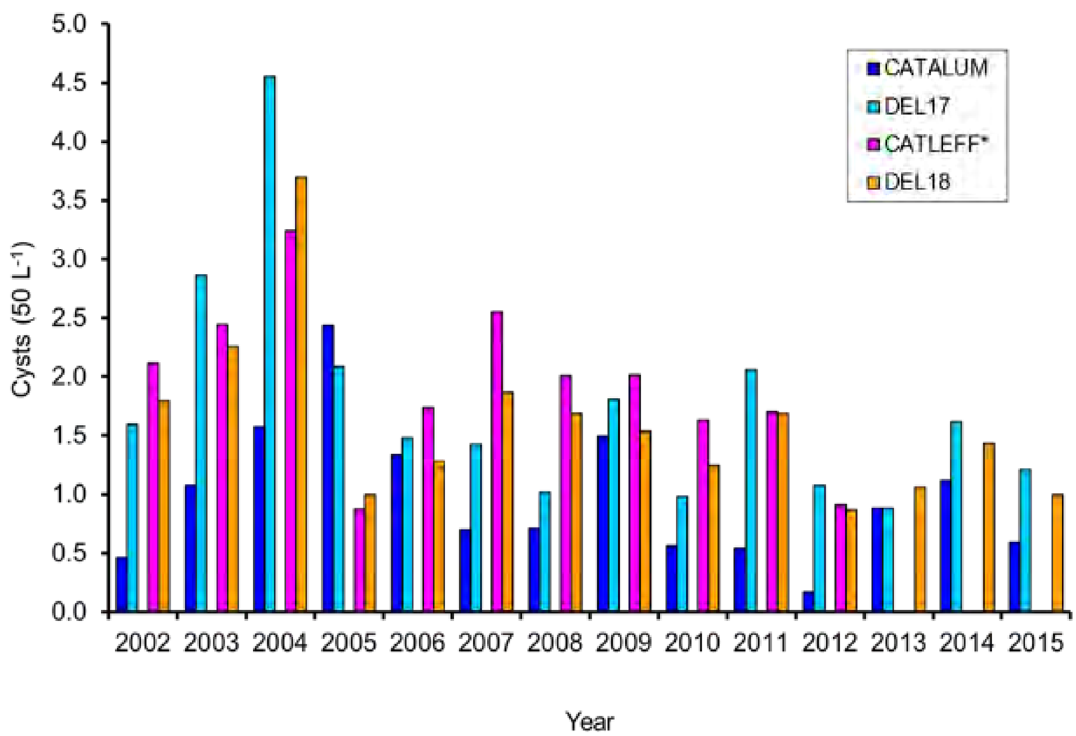

Figure 7.29 Kensico keypoint *Giardia* annual mean concentrations (cysts $50L^{-1}$) for 2002 through September 2015.
*Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued after September 2012.

have been very similar (Catskill 1.93 cysts $50L^{-1}$; Delaware 1.64 cysts $50L^{-1}$ for the period of record).

When the annual mean *Giardia* concentrations are examined overall and broken down over the last and current reporting periods, an interesting pattern can be seen (Figure 7.30). For all periods, the Catskill inflow has consistently contributed lower concentrations of *Giardia* cysts compared to Delaware; conversely, the Catskill outflow has had higher concentrations of *Giardia* compared to the Delaware outflow. The location of the Catskill outflow is most likely a factor that has contributed to this pattern as it is proximal to Malcolm Brook and other western shore streams that have been documented to contribute cysts, especially during storm events. As for the most recent reporting period, 2011-2015, the Catskill outflow has been closed for most of the time and therefore represents much less data, as portrayed by the single horizontal bar rather than a box (Figure 7.30, third panel). While it appears the data for this recent period may be slightly lower than the previous period, there are much less data and it is not statistically significantly different at this time. As additional data are collected to create the same size data base for the current period, a measurable and more confident downward trend in the data may emerge. Note that for the almost 14-year period, the inclusive mean *Giardia* concentration at the Kensico source water outflows was very low (1.79 cysts $50L^{-1}$).

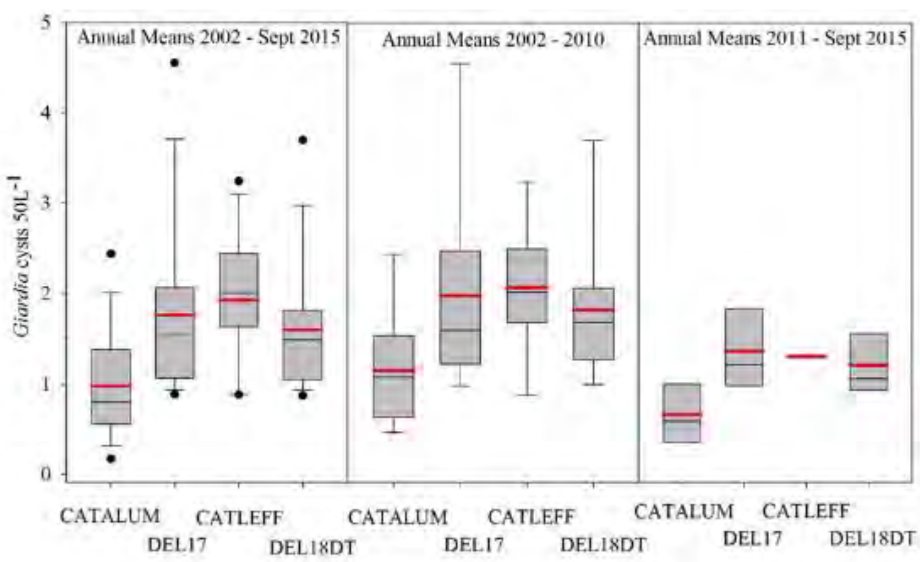

Figure 7.30 Boxplot of annual mean *Giardia* concentrations at the Kensico influents and effluents for all years monitored with methods 1623HV and 1623.1 (2002-September 2015). The red bar represents the mean of annual mean concentrations. *Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued after September 2012.

Cryptosporidium

The database available for *Cryptosporidium* analysis is very similar to *Giardia*, with 1,458 results for the inflows, and 1,535 results for the outflows. 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, only one of the organism's results is reported.

Cryptosporidium annual mean concentrations at the inflows and outflows of Kensico Reservoir were examined from January 2002 through September 2015 (Figure 7.31). The annual mean *Cryptosporidium* concentrations at the inflows to Kensico Reservoir ranged from 0 (no detects for 2011 and 2012 at CATALUM) to 0.29 oocysts $50L^{-1}$. The *Cryptosporidium* outflow mean result range was zero (no detects for 2012 and 2013 at DEL18DT) to 0.45 oocysts $50L^{-1}$. The difference in these ranges is very small and is within the range of variability expected by Method 1623 and 1623.1, so it is difficult to say if a true variance exists between the inflow and outflow concentrations when discussing annual means for *Cryptosporidium*. Not unlike *Giardia*, the lowest annual means for *Cryptosporidium* were in the 2011 to 2012 period; and the highest means, although still low, occurred during the period of 2003 to 2004. This co-occurrence of high and low concentrations in the same years supports the understanding that the transport mechanisms for both organisms are similar.

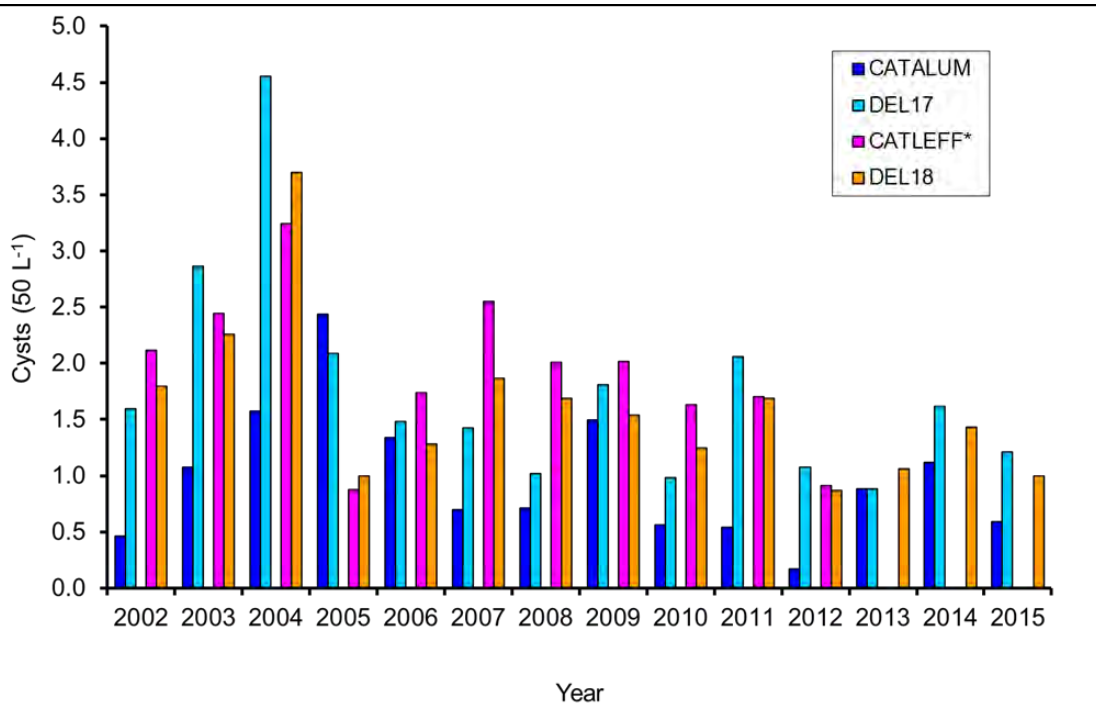

Figure 7.31 Kensico keypoint *Cryptosporidium* annual mean concentrations (oocysts $50L^{-1}$) for 2002 through September 2015.
*Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued after September 2012.

The data record for the DEP watershed continues to indicate that *Cryptosporidium* concentrations are much lower than those seen for *Giardia*, often by an order of magnitude or more. For the almost 14-year period, the mean *Cryptosporidium* concentration at the Kensico source water outflows was very low (0.18 oocysts $50L^{-1}$).

In addition to routine data analysis, DEP performs calculations consistent with the guidelines set forth in the LT2ESWTR (USEPA 2006). The Rule requires utilities to conduct monthly source water monitoring for *Cryptosporidium* and report data from two, two-year periods. The LT2 requires all unfiltered public water supplies to "provide at least 2-log (i.e., 99%) inactivation of *Cryptosporidium*." If the average source water concentration exceeds 0.01 oocysts L^{-1} based on the LT2 monitoring, "the unfiltered system must provide at least 3-log (i.e., 99.9%) 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. Results have been calculated here (Figure 7.32) using data from the most recent full two-year period (January 1, 2013-December 31, 2014), using all routine and non-routine samples.

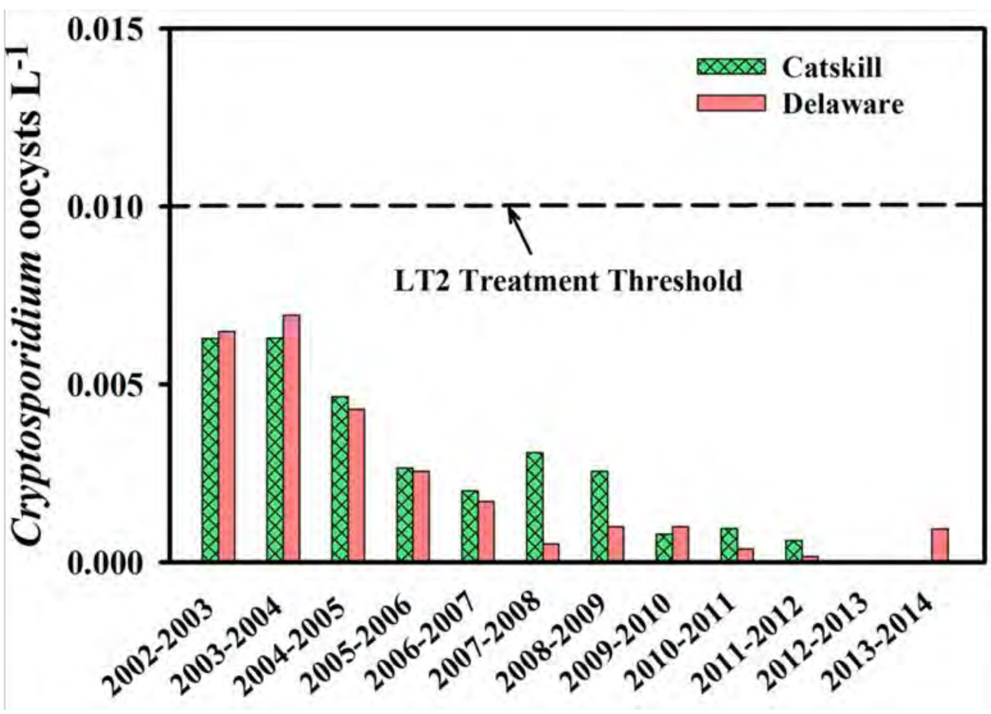

Figure 7.32 LT2 calculations for *Cryptosporidium* mean of monthly means. *Monitoring at the Catskill Lower Effluent Chamber site (CATLEFF) was discontinued after September 2012.

The 2013 - 2014 mean of monthly means for *Cryptosporidium* was 0.0009 oocysts L^{-1} for the Delaware effluent, well below the LT2 threshold level of 0.01 oocysts L^{-1}. This is consistent with DEP source water historical LT2 calculations, which have always remained below the threshold level.

Discussion

Interestingly, the year with the lowest *Giardia* and *Cryptosporidium* annual mean concentrations, for both inflow and outflows at Kensico Reservoir, was 2012, the year following Tropical Storm Irene and Tropical Storm Lee in September 2011. The combined inflow *Giardia* contribution in 2012 was a 14-year annual mean low of 0.62 cysts $50L^{-1}$, and the combined outflow concentration was also the lowest at 0.89 cysts $50L^{-1}$. The 2012 inflow *Cryptosporidium* mean concentration was 0.01 oocysts $50L^{-1}$, and the combined outflow was 0.02 oocysts $50L^{-1}$, also 14-year lows. It is reasonable to assume that operational and treatment decisions made during, and after the hurricane period resulted in a reduction of protozoa for the following year or more. It is also plausible that the storms were so strong that they flushed the system so thoroughly that a new, low baseline was established resulting in less available (oo)cysts for transport in the watershed after the storms. Both of these scenarios are possible explanations for observing less protozoa post storm activity.

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- 2014 period, the overall mean recoveries for *Giardia* were 44.0% and 47.6% for the Catskill and Delaware inflows respectively, and 46.6 and 48.4% for the outflows (Table 7.5). Similarly, the *Cryptosporidium* percent recovery at the inflows to Kensico Reservoir were 41.9% and 48.1% for Catskill and Delaware respectively, and 48.3% and 47.9% at the outflows. While the combined means of the inflows and outflows seem to suggest a slightly higher ability to recover *Giardia* and *Cryptosporidium* at the outflows, these percentages are well within the variability of the method and are not considered different. In fact, the similarity of these numbers over such a long period of time is an indication of the consistency of the water matrix, but 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.

Table 7.5 Summary statistics for Kensico keypoint annual mean MS recovery from 2002-2014.

2002-2014	*Cryptosporidium* CAT ALUM	*Cryptosporidium* DEL17	*Cryptosporidium* CAT LEFF	*Cryptosporidium* DEL18 DT	*Giardia* CAT ALUM	*Giardia* DEL17	*Giardia* CAT LEFF	*Giardia* DEL18 DT
n	13	13	11	13	13	13	11	13
Mean	41.85	48.08	48.27	47.92	44.00	47.62	46.64	48.38
Std Dev.	10.29	9.64	7.18	7.93	8.21	12.71	7.24	4.93
Min	17	33	36	29	31	16	37	41
Max	58	67	60	57	57	61	58	60

The MS annual mean data were examined for the periods of time 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 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, suggesting 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.

7.6 Water Quality Summary for the EOH CAT/DEL Basin System

DEP has continued enhancing watershed protection in the West Branch, Boyd Corners, and Kensico basins. Thirty-eight stormwater remediation projects were completed in the 2003-2009 period in the West Branch and Boyd Corners basins. In the Kensico basin, 47 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 water bird populations on and around Kensico Reservoir (see Section 7.3.5).

Water quality in West Branch and Kensico basins continued to be excellent during the 2012-2014 assessment period. Median and peak monthly median values were all well below established water quality benchmarks for fecal coliforms, turbidity, and total phosphorus. Decreasing trends in turbidity, fecal coliforms, and total phosphorus in the inputs to West Branch were attributed to improvements made through watershed protection programs. Likewise, for the Kensico basin, total phosphorus trends declined in the inputs, reservoir, and output. This decline was more pronounced after 2004 when significant improvements in wastewater treatment were made in the upstate watersheds. Conductivity trends were upward in both West Branch and Kensico basin. Increases in productivity were also found in both basins.

Biomonitoring results are available for the largest stream inputs to West Branch Reservoir (Horse Pound Brook) and Kensico Reservoir (Whippoorwill Creek). 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 aqueducts. Both sites on Whippoorwill Creek and the one site on Horse Pound Brook were slightly impaired in all years of sampling. High hydropsychid abundances contributed to this result at all sites. No trend was detected at the one site on Whippoorwill Creek with an extended period of record, while the Horse Pound Brook site experienced a strong downward trend, reflecting sharply lower scores over the last five years. No satisfactory explanation has been offered that would account for this decline.

The Waterfowl Management Program continued its long-term efforts to reduce water bird populations on and around Kensico Reservoir which helped eliminate a seasonal elevation in fecal coliform bacteria.

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 generally low at both the inflows and outflows, ranging between 0 and 2.5 cysts 50 L^{-1}, with the exception of 2004 when the maximum of 4.5 cysts 50 L^{-1} was the annual mean during a time of heavy rains and snowmelt. *Cryptosporidium* counts 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 nearly 14-year period of record, the mean *Cryptosporidium* oocyst concentration at the Kensico source water outflows was very low (0.18 oocysts).

8. East of Hudson Potential Delaware System Watersheds

8.1 The Scope of Water Quality Analyses

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 if this is ever needed. The water in these reservoirs therefore can be a supplement to Delaware water and undergoes similar scrutiny. The pump stations are rarely used. The Cross River pump station was last operated in 1995 during a drought. The Croton Falls pump station was last in use from December 5 to 28, 2009 to augment the supply while repairs were made to the Rondout to West Branch Tunnel. Both pump stations were original to the reservoir construction and needed rehabilitation. The Cross River pump station has been completed and has a capacity of 60 MGD from Cross River along with a projected increase for Croton Falls from 35 MGD currently to 180 MGD when the new pumping station goes online (expected in 2017). This has improved system reliability during drought or operational water shortages.

A description of the approach and scope of the water quality analyses is given in Appendix C. In brief, the water quality analyses cover approximately 22 years of data to provide a long-term context for interpretation. This time span provides a view of these changes in the context of natural variation (such as floods and droughts) and allows sufficient time for program implementation to impact water quality. The water quality data used in this analysis begins in 1993, which represents conditions at the outset of filtration avoidance when many watershed protection programs were in their infancy. The data from this decade represents conditions with fewer watershed programs in place. The time period from about 2000 through 2014 represents a time when watershed protection programs have reached a high level of implementation.

8.2 The Cross River Watershed

The Cross River Reservoir is located in northeastern Westchester County about 25 miles north of NYC. 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 New Croton Aqueduct, the water reaches Jerome Park Reservoir and the Croton Water Filtration Plant where it enters NYC's distribution system.

8.2.1 Land Use in the Cross River Watershed

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 approximately 0.079 MGD of flow. Under the most recent SPDES permits, the plants are limited to a combined release of 0.137 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 (Figure 8.1). The Cross River watershed also has 5.9% of impervious surface.

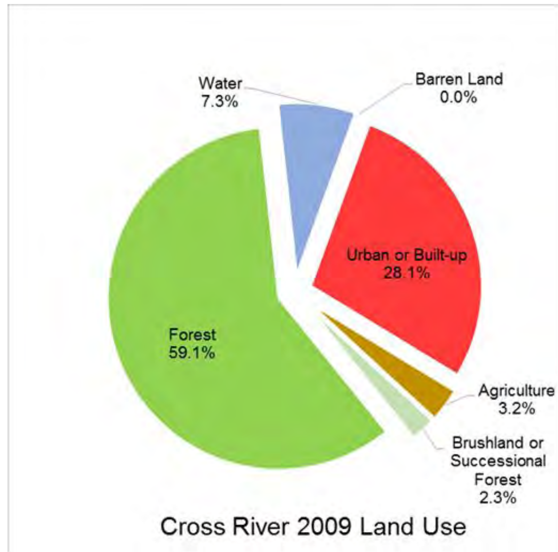

Figure 8.1 Land use in the Cross River watershed.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

8.2.2 Program Implementation in the Cross River Watershed

Three environmental infrastructure projects have been in place since 2013; these control storm water in the Cross River basin (Figure 8.2). Additional information on this and other

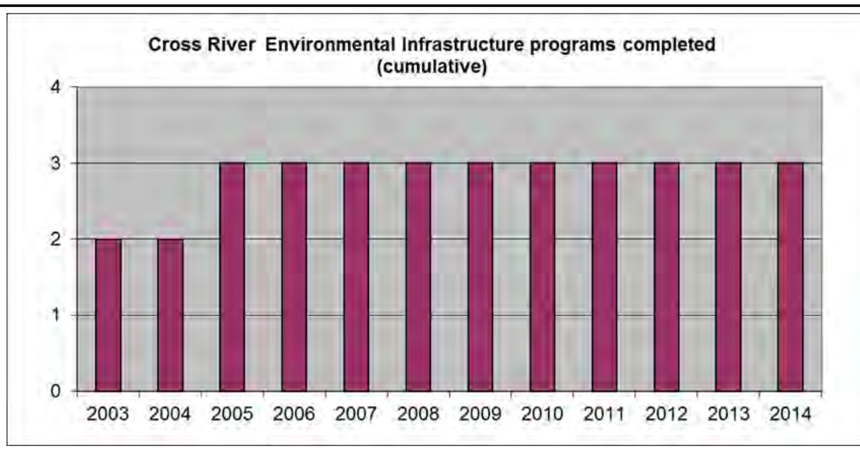

Figure 8.2 The history of watershed programs in the Cross River drainage basin. Environmental infrastructure installations for stormwater control and stream management projects.

programs occurring in the watershed are provided in Watershed Protection Program sections of this report.

8.2.3 WWTPs and Phosphorus Load Reductions in the Cross River Watershed

Upgrades to the WWTPs in the Cross River watershed started in 2008-09, and the phosphorus loads were markedly higher during the transition period compared to the decline shown in 2004 (Figure 8.3). The effect of the completed upgrades on phosphorus load is shown in the 2014 results.

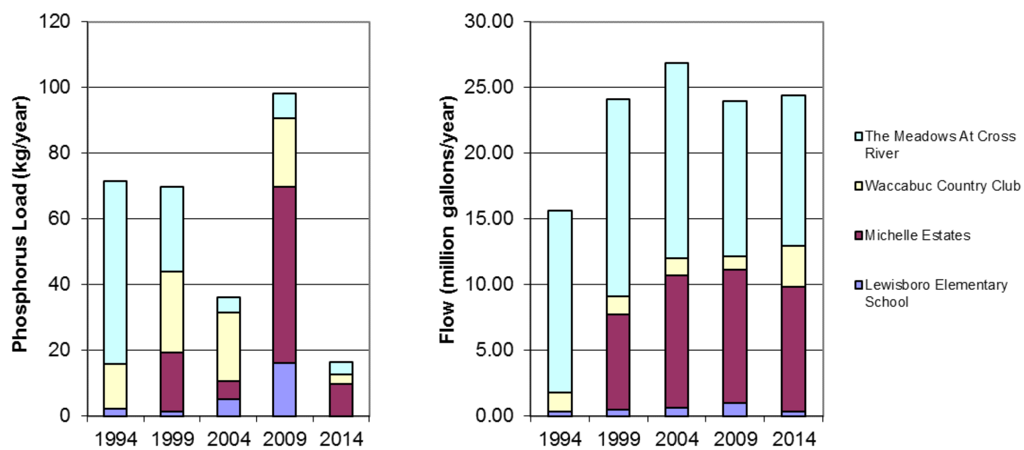

Figure 8.3 Total phosphorus loads and total volume of WWTP effluent flow to Cross River Reservoir from 1994 to 2009.

8.2.4 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 8.4. A comparison of the inflow (CROSS2), reservoir (CCR), and the outflow (CROSSRVVC) is shown. All values below the maximum detection limit for fecal coliform were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the status evaluation period (2012-2014), median monthly fecal coliform bacteria exceeded the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for four months (September 2012, July 2013, July and August 2014). The two highest values were associated with rain events and high flows (September 2012, mean daily flow 0.65 m^3 sec^{-1}) and July 2013, mean daily flow 0.48 m^3 sec^{-1}. Turbidity was generally low at all sites, with monthly medians

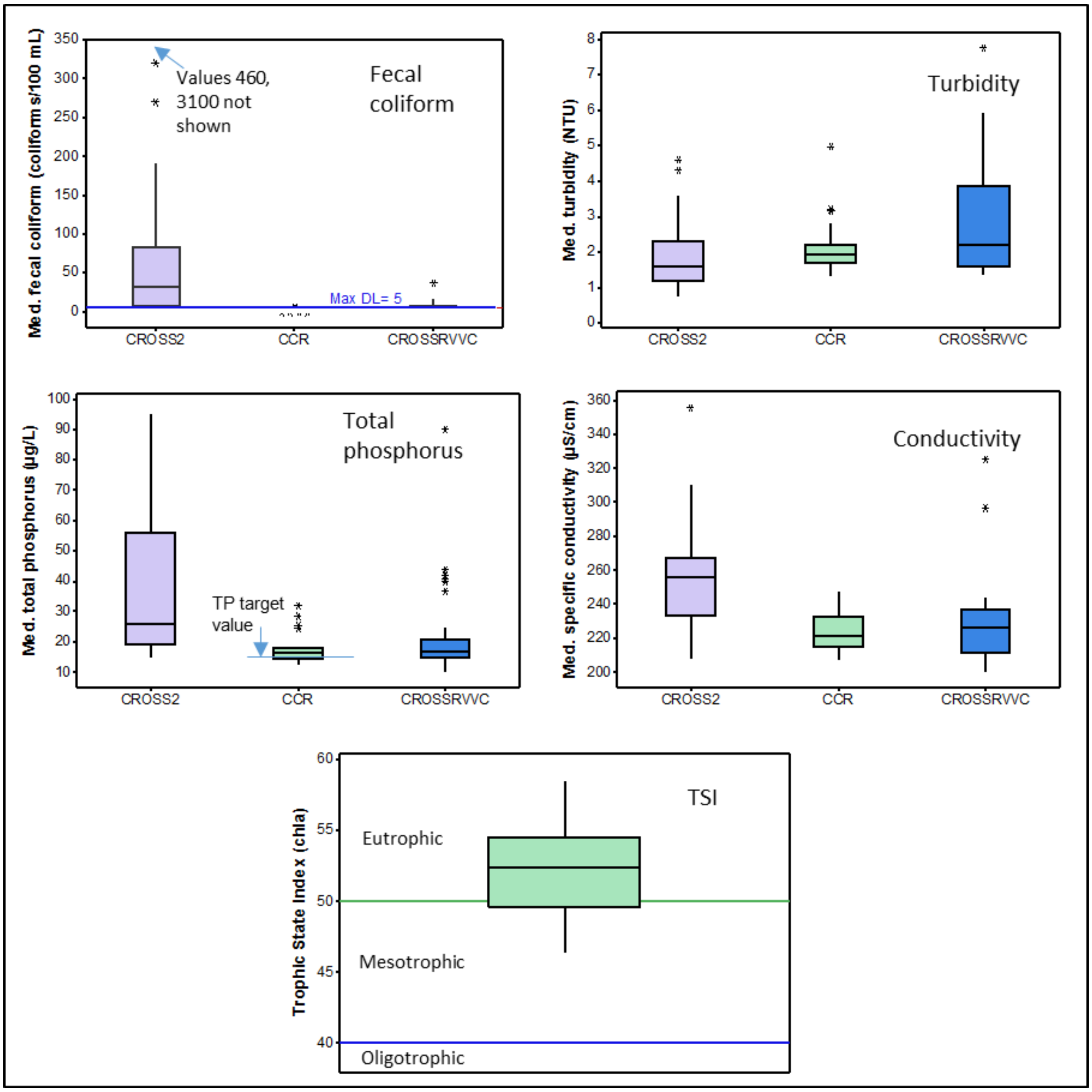

Figure 8.4 Water quality status boxplots using 2012-2014 monthly data for the Cross River basin main stream input at Cross River (CROSS2), Cross River Reservoir (CCR), and the output at the Cross River release (CROSSRVVC).

ranging from 1.6 NTU at the inflow, 1.9 NTU in the reservoir, and 2.2 NTU at the outflow. Median monthly total phosphorus (TP) for the reservoir was 16.5 µg L^{-1}, with several values above the target value of 15 µg L^{-1} for source waters. The TSI values for Cross River Reservoir fell within the eutrophic range primarily, with a median of 52. Conductivity was highest at the inflow (256 µS cm^{-1}) and slightly lower in the reservoir and outflow (with a median of 222 and 226 µS cm^{-1}, respectively).

In summary, water quality was generally good during the 2012-2014 status assessment period in the Cross River basin. TP is elevated enough to result in greater algal growth and a TSI value predominantly in the eutrophic range. The Cross River basin is classified as a phosphorus-restricted basin based on other analyses (DEP, 2015).

Trends (Cross River)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. Water quality trend plots are presented in Figure 8.5 and results of the Seasonal Kendall trend analysis are provided in Table 8.1.

No long-term turbidity trends were detected for the input or for the reservoir. The large increase in the output 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.

Table 8.1 Cross River basin (inflow, reservoir, and outflow) trend results for 1993 – 2014.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
CROSS2	Input	Turbidity	260	0.01	NS	
Cross River	Reservoir	Turbidity	158	-0.07	NS	
CROSSRVVC	Output	Turbidity	258	-0.09	**	-0.02
CROSS2	Input	Fecal coliform	262	-0.05	NS	
Cross River	Reservoir	Fecal coliform	156	-0.04	NS	
CROSSRVVC	Output	Fecal coliform	238	-0.09	***	0.00
CROSS2	Input	Total Phosphorus	260	0.17	***	0.33
Cross River	Reservoir	Total Phosphorus	150	0.00	NS	
CROSSRVVC	Output	Total Phosphorus	255	-0.01	NS	
CROSS2[3]	Input	Conductivity	227	0.07	*	0.05
Cross River	Reservoir	Conductivity	155	0.43	***	2.33
CROSSRVVC	Output	Conductivity	259	0.45	***	2.40
Cross River	Reservoir	Trophic State Index	150	0.22	***	0.25

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.
[3] Data were adjusted for flow prior to trend analysis - see Appendix C.

No long-term turbidity trends were detected for the input or for the reservoir. The large increase in the output 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.

Long-term fecal coliform trends were not detected in the reservoir or input, but a statistically significant change was detected at the output. The preponderance of low, tied values forced the change to be zero but the negative Seasonal Kendall Test statistic (Tau) suggests a downward trend as does the trend plot. Surprisingly, output fecal counts were much higher than those in the reservoir and are probably related to bird activity at the 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. Note that this sampling site was moved to a protected location within a shaft building in 2013, coinciding with the sudden drop in coliform counts shown in Figure 8.5.

An upward TP trend was detected in the input but no long-term trends were detected in the reservoir or in its output. The upward trend was driven by large storms in 2010-2011 and 2013-2014.

Strong upward conductivity trends were detected for the reservoir and output. After adjusting for flow, a weak, much smaller increase was observed for the input suggesting that changes in precipitation patterns were the major factor controlling conductivity in this basin. For example, drought conditions probably caused the large increase observed in 2001-2002 while the downturn from 2003-2006 was associated with very wet years. High values, unique to the output in 1997, were due to drawdown from dam repair work. Additional factors could be inputs of dissolved salts, primarily from development activity in the basin, road salt applications, and discharges from domestic water softeners. Short-term changes in precipitation patterns and drawdown were additional factors that affected the observed patterns.

A strong upward trend was detected for TSI especially evident from 2005 to 2014. Reasons for the upturn are not clear but increasing input TP concentrations associated with storm activity during the later years of this period may be one factor. 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 high levels related to dam repairs occurring early in the record. Long-term trends were not identified for fecal coliforms in the input or reservoir. A downward trend detected for the output may be related to a site change. An upward TP trend in the input was observed and coincided with the occurrence of storms in the later years of the record. Upward conductivity trends were detected for the input, reservoir, and output, caused by a combination of development activity in the basin, precipitation patterns, and reservoir drawdown in 1996-1997.

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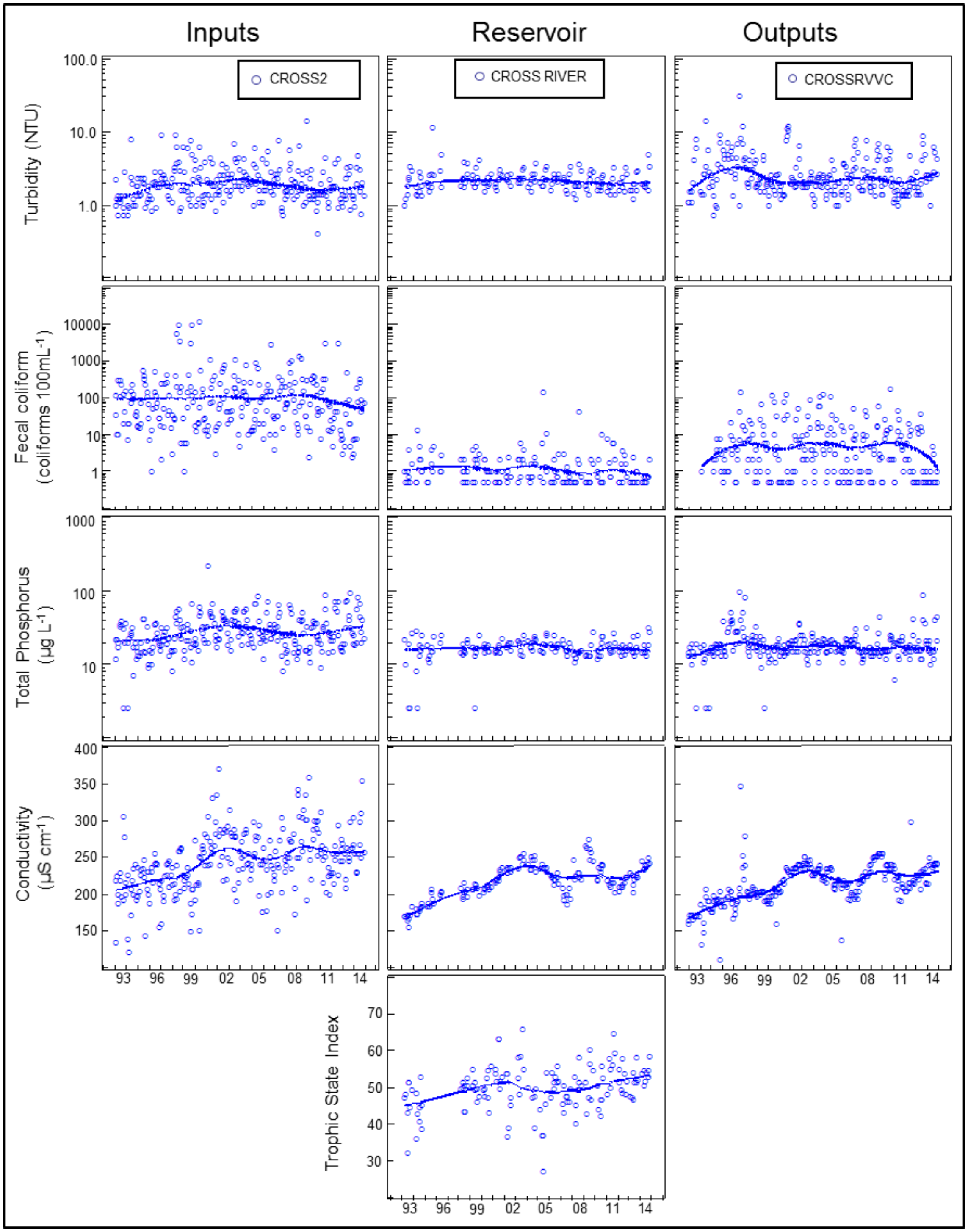

Figure 8.5 Water quality trend plots for the Cross River basin main stream input at Cross River (CROSS2), Cross River Reservoir, and the output at the Cross River release (CROSSRVVC).

An increasing TSI trend was detected and to some extent coincident with storm related TP increases.

8.2.5 Biomonitoring in the Cross River Watershed

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

The most recent status of macroinvertebrate communities in the Cross River Basin was evaluated by examining 2012-2014 data from a single site (123) on Cross River. This stream is the primary inflow to Cross River Reser

Site 123 is located near the haml Cross River Reservoir. The site was sampled once during the 2012-2014 period, in 2012, and was assessed as slightly impaired (Figure 8.6). Impact Source Determination, DEC's procedure for identifying impacts that exert deleterious effects on a water body, identified nonpoint nutrients as the likely cause.

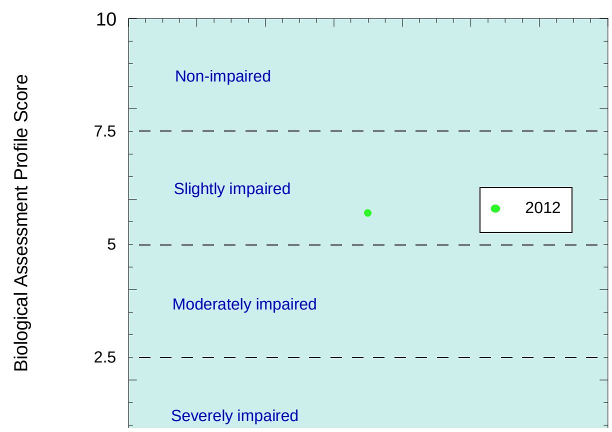

Figure 8.6 Biological Assessment Profile score for Cross River, 2012.

Because of the small sample size (four years of data), a statistical trends analysis was not considered appropriate for this site. The last three years (1999, 2000, and 2012) have all produced slightly impaired assessments, following a non-impaired assessment in 1998.

8.2.6 Waterfowl Management Program: Cross River Reservoir

The Revised 2007 FAD lists Cross River Reservoir as one of five reservoirs covered under the as needed criteria for waterfowl management. Cross River Reservoir is divided into three geographic bird sampling zones associated with reservoir water quality sampling locations. Water bird counts at Cross River were similar to those of the other reservoirs described in this report, increasing during the autumn, winter, and spring migration periods and dependent on the extent of ice cover. Canada Geese and ducks made up the majority of water birds on the reservoir throughout the years. Gulls are not commonly observed on the reservoir during the overnight roosting period, and based on the low numbers and only recorded on five of 64 surveys during

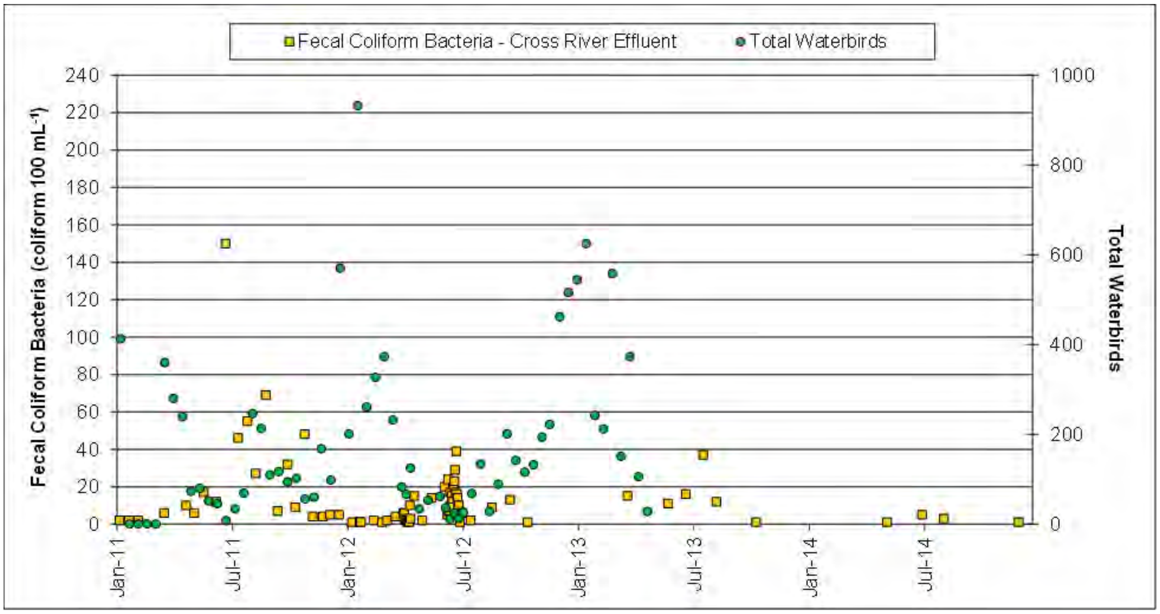

Figure 8.7 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total water birds at Cross River Reservoir, January 1, 2011 – December 31, 2014.

the biweekly water bird surveys from January 2011 to March 2013, do not pose a water quality threat. DEP determined it was unnecessary to activate the as needed bird dispersal actions at Cross River Reservoir during this reporting period.

Fecal coliform concentrations at the Cross River Reservoir water intake were reported elevated during the mid-summer period in 2011 through 2013 (Figure 8.7).

8.3 The Croton Falls Watershed

Located in Putnam County in the Towns of Carmel and Southeast, more than 30 miles north of NYC, the Croton Falls reservoir was formed by the damming of the West and Middle Branches 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 the Route 35 and Route 36 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.

8.3.1 Land Use in the Croton Falls Watershed

The Croton Falls drainage basin is 16 square miles and land use breakdown consists of: 50.2% forested, 36.9% urban, 1.8% brushland or successional forest, 10.7% water (Figure 8.8). There is no land in agricultural use. The Croton Falls watershed also has 10.6% of impervious surface.

There are five WWTPs in the Croton Falls watershed basin, which collectively release approximately 0.937 MGD of flow. Based on the most recent SPDES permits, the plants are limited to a combined release of 1.206 MGD of flow.

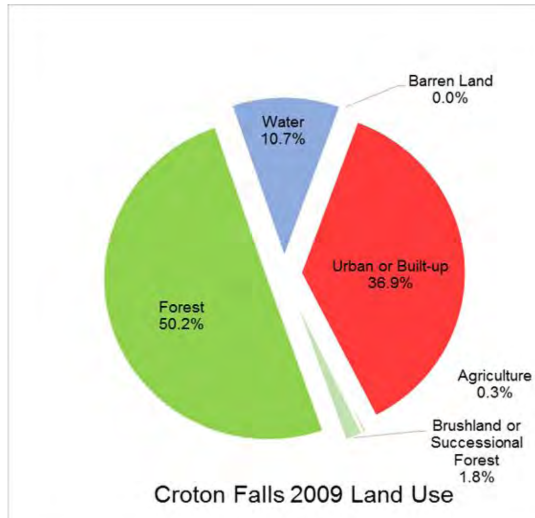

Figure 8.8 Land use in the Croton Falls watershed.

The land use data used in this report were derived from high-resolution LiDAR, leaf-on and leaf-off aerial imagery obtained in 2009, along with state-provided parcels and other datasets. The data were obtained for the entire DEP watershed and represent the most current data available.

8.3.2 Program Implementation in the Croton Falls Watershed

Since 2008, a total of 36 environmental infrastructure projects were completed, with the most recent project completed in 2014 to control stormwater in Croton Falls Reservoir (Figure 8.9). Additional information on this and other programs occurring in the watershed are provided in Watershed Protection Program sections of this report.

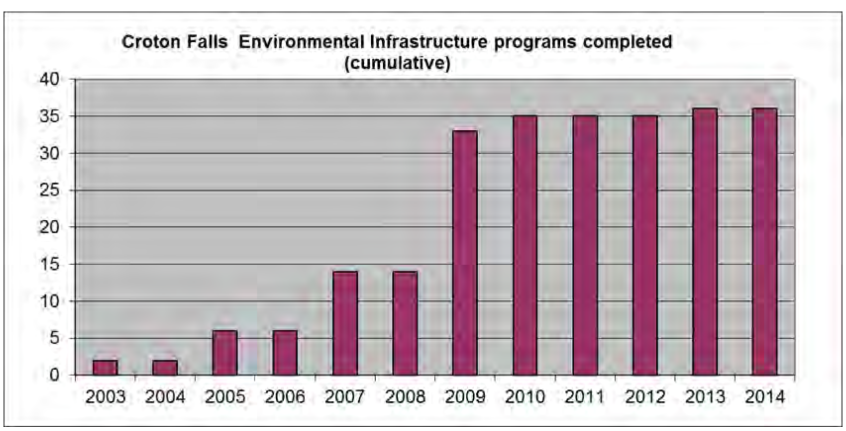

Figure 8.9 The history of watershed programs in the Croton Falls drainage basin. Environmental infrastructure installations for stormwater control and stream management projects.

8.3.3 Water Quality Status and Trends in the Croton Falls Watershed

Inputs of phosphorus and other pollutants from WWTPs continue to be reduced as a result of DEP's upgrade of all surface-discharging plants, including the upgrade of the City-owned Mahopac WWTP, and through DEP's Compliance and Inspection Program. As shown in Figure 8.10, phosphorus loads (as TP) declined considerably from 1994 to 2014. In recent years, wastewater for sites served by three plants is now diverted to the City-owned Mahopac WWTP. These include Fulmar Road Elementary School, Lake Plaza, and the Ralph Morando Building plants. Additionally, a new WWTP was permitted for Kent Manor Condominiums in July 2009.

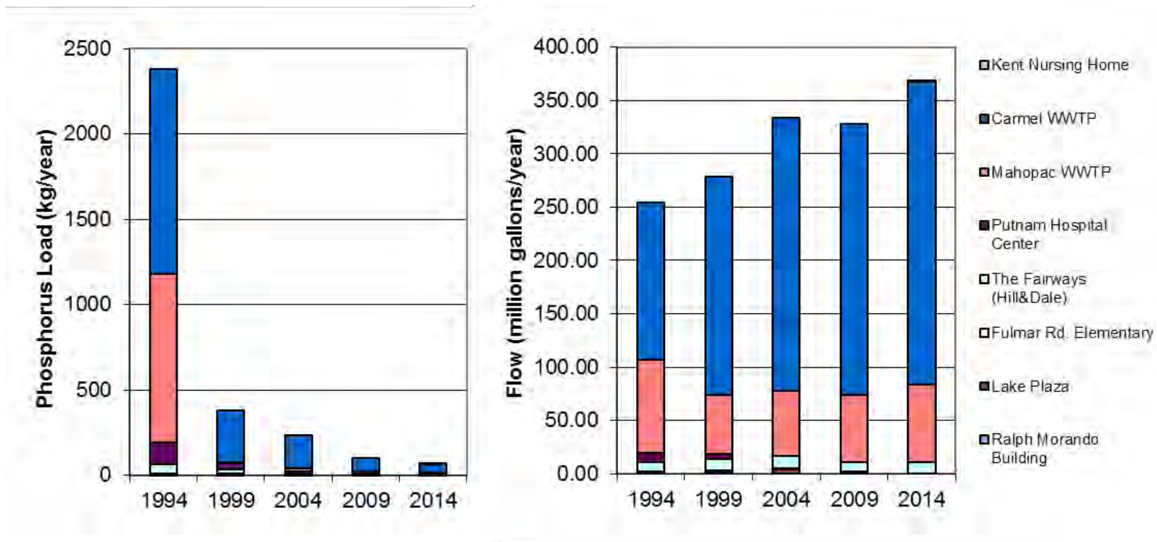

Figure 8.10 Wastewater treatment plant total phosphorus loads and flows in the Croton Falls drainage basin, 1994 – 2014.

Status (Croton Falls)

The Croton Falls basin status evaluation is presented as a series of boxplots in Figure 8.11. The two inputs to main (downstream) basin of Croton Falls Reservoir are the West Branch Reservoir Release (WESTBRR) and the middle basin of Croton Falls Reservoir (3_CCF). 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 1_CCF. The outflow site is designated as CROFALLSVC. All values below the maximum detection limit for fecal coliform were estimated according to statistical methods for censored data described by Helsel (2012). It is important to note that the reporting limit is shown as a horizontal (blue) line and values below are masked from view because the distribution below the reporting limit is unknown. For additional details on methodology and boxplot interpretation, see Appendix C.

For the evaluation period (2012-2014), median monthly fecal coliform bacteria did not exceed the NYSDEC Stream Guidance Value of 200 fecal coliforms 100 mL^{-1} for the inflow sites with the exception of one case (WESTBRR). Turbidity was generally low at all sites, with

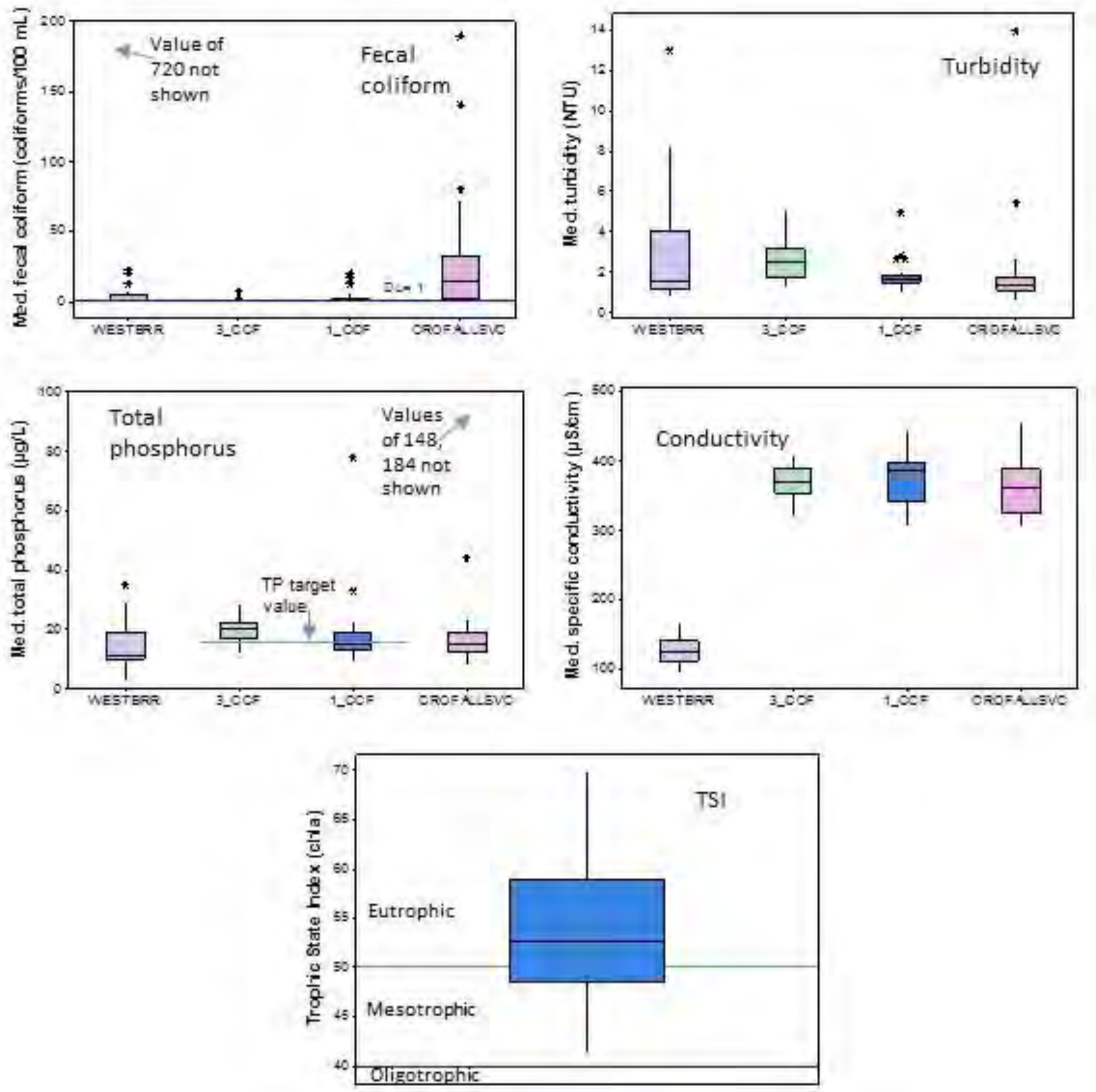

Figure 8.11 Water quality status boxplots using 2012-2014 monthly data for the Croton Falls basin inputs from the West Branch release (WESTBRR) and the middle basin of Croton Falls Reservoir (3_CCF), the main basin of the reservoir (1_CCF), and the output at the Croton Falls release (CROFALLSVC).

the highest monthly median of 2.5 NTU in the middle basin of the reservoir (3_CCF). Median monthly total phosphorus (TP) for the middle basin of the reservoir was 20 µg L^{-1}, and was 15 µg L^{-1} for the main basin of the reservoir. The TSI values for Croton Falls (main basin) was mainly in the eutrophic range, with a median of 53. Conductivity was highest in the main basin of the reservoir (388 µS cm^{-1}) and slightly lower in the middle basin of the reservoir and outflow (with a median of 372 and 361 µS cm^{-1}, respectively). The lowest conductivity was from the West Branch Reservoir Release (WESTBRR) with a median value of 125 µS cm^{-1}.

In summary, water quality was generally good during the 2012-2014 status assessment period in the Croton Falls basin. Elevated TP levels resulted in greater algal growth and a TSI value predominantly in the eutrophic range. The Croton Falls basin is classified as a phosphorus-restricted basin based on other analyses (DEP, 2015).

Trends (Croton Falls)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the monthly data, and second by performing the non-parametric Seasonal Kendall tests for trend significance and trend slope. The former seeks to place a best-fit smooth curve through the data and is insensitive to outliers. The latter addresses statistical significance of monotonic (unidirectional) change though the period of record. See Appendix C for a more detailed description of the data manipulation and statistical methods used. Water quality trend plots are presented in Figure 8.12 and results of the Seasonal Kendall trend analysis are provided in Table 8.2.

The hydrology of Croton Falls is very complex; the main basin of the reservoir receives inputs from its local watershed (represented in this analysis by the reservoir's middle basin), and from the West Branch Reservoir input (WESTBRR). The West Branch input 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.

No long-term turbidity trends were detected for the main basin, but very slight turbidity increases were detected for the West Branch and middle basin inputs as well as for the output. The turbidity increase in the West Branch input likely resulted from operational changes upstream at the West Branch Reservoir from 2000-2014. (For details, see Section. 7.2.). Additionally, the noticeable increase in turbidity in the output in 2014 coincides with a change in sampling site location.

Significant downward trends were detected for fecal coliforms in the West Branch input which also carried over to the main basin of the reservoir. The magnitude and trend of coliform counts at these locations are shown to track very well (Figure 8.12). Reasons for the fecal coliform downward trend in the upstream West Branch Reservoir watershed are not clear at this time. Differences in sampling programs may explain why no trend was detected in the output despite the strong downward trend in the reservoir. Sampling at the output is more comprehensive; it is conducted at higher frequency throughout the year while the reservoir data used in this analysis are from monthly surveys collected from April to November. The fecal counts observed in the output are generally higher than in the reservoir because the highest counts occur during winter months when the reservoir is not sampled.

Although TP improvements were not realized in the last FAD assessment, with the additional data collected since 2009 trend analysis now shows significant TP reductions the middle basin of Croton Falls Reservoir. The decreases were expected given the many upgrades to WWTPs in the Croton Falls basin and subsequent reductions in phosphorus loads (Figure 8.12). Statistically strong, albeit very small increases were detected in the West Branch input and in the Croton Falls output. These increases are likely related to operational changes upstream at the West Branch Reservoir and to the occurrence of high flow events in recent years.

Table 8.2 Croton Falls basin (inflows, reservoir, and outflow) trend results for 1993 – 2014.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
WESTBRR	Input	Turbidity	257	0.20	***	0.02
Croton Falls (middle basin)	Input	Turbidity	131	0.10	*	0.01
Croton Falls (main basin)	Reservoir	Turbidity	147	0.03	NS	
CROFALLSVC	Output	Turbidity	261	0.10	***	0.01
WESTBRR	Input	Fecal coliform	237	-0.25	***	-0.13
Croton Falls (middle basin)	Input	Fecal coliform	129	0.03	NS	
Croton Falls (main basin)	Reservoir	Fecal coliform	147	-0.24	***	-0.07
CROFALLSVC	Output	Fecal coliform	237	0.03	NS	
WESTBRR	Input	Total Phosphorus	253	0.09	***	0.06
Croton Falls (middle basin)	Input	Total Phosphorus	130	-0.24	***	-0.28
Croton Falls (main basin)	Reservoir	Total Phosphorus	146	-0.01	NS	
CROFALLSVC	Output	Total Phosphorus	257	0.12	***	0.10
WESTBRR	Input	Conductivity	256	0.38	***	2.36
Croton Falls (middle basin)	Input	Conductivity	128	0.45	***	4.00
Croton Falls (main basin)	Reservoir	Conductivity	145	0.52	***	5.94
CROFALLSVC	Output	Conductivity	259	0.55	***	6.73
Croton Falls (main basin)	Reservoir	Trophic State Index	146	0.06	NS	

[1] Tau refers to the Seasonal Kendall Test Tau statistic.
[2] The p-values for each trend test are symbolized as follows:
NS (Not Significant) = $p \geq 0.20$, * = $p < 0.20$, ** = $p < 0.10$, *** = $p < 0.05$.

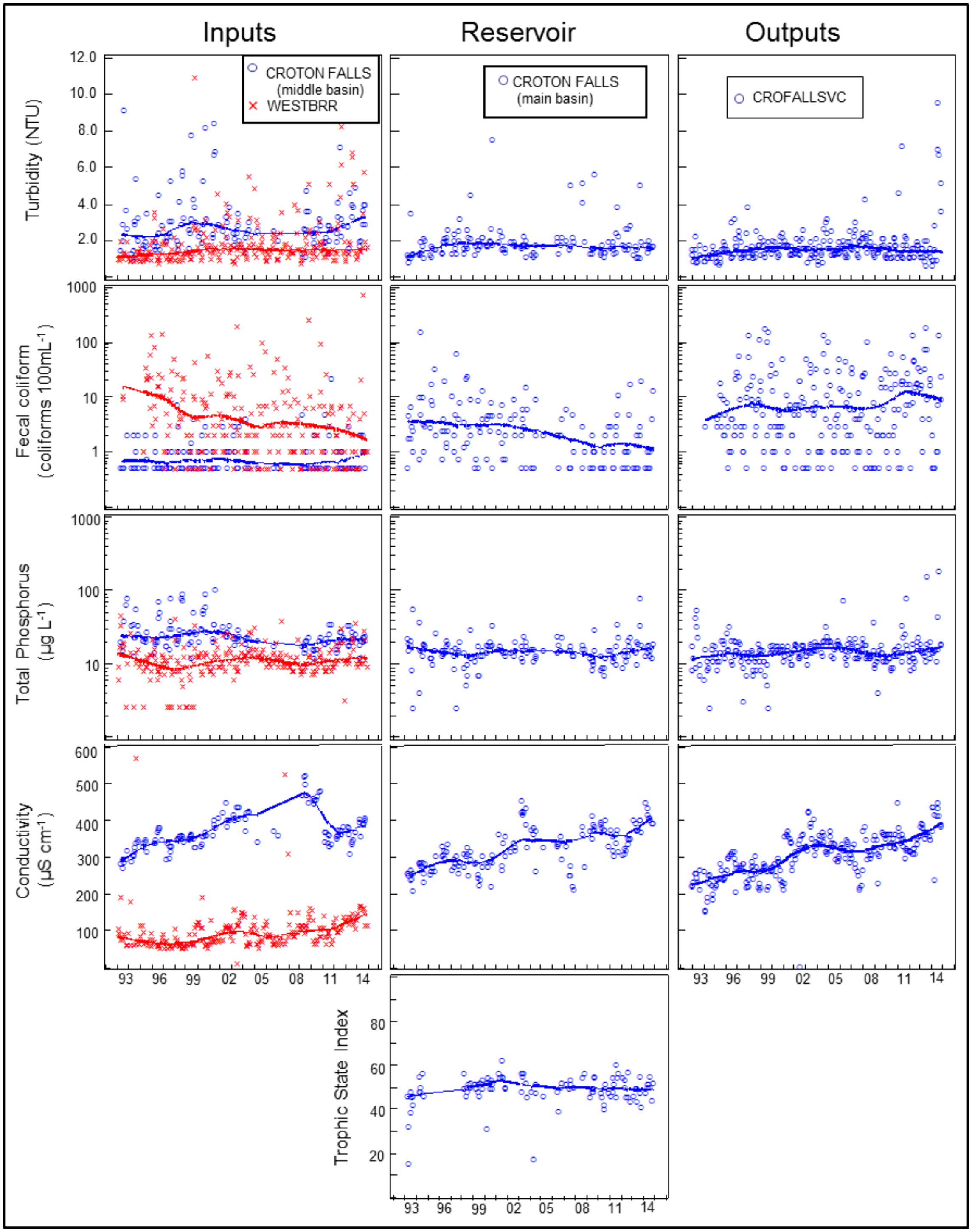

Figure 8.12 Water quality trend plots for the Croton Falls basin inputs from the West Branch release (WESTBRR) and the middle basin of Croton Falls Reservoir, the main basin of the reservoir, and the output at the Croton Falls release (CROFALLSVC).

As indicated by the LOWESS curve, conductivity in the output increased from approximately 220 µS cm^{-1} in 1993 to 400 µS cm^{-1} in 2014. Similar increases were apparent for the reservoir's main basin, and to a lesser extent, the middle basin input. It is not clear why the middle basin conductivity suddenly dropped from about 450 µS cm^{-1} to 350 µS cm^{-1} from 2009 to 2011, but the decrease maybe related to stormwater remediation activities in this sub-basin. Increasing conductivity in the Croton Falls basin is likely due to increases in development activity, principally road salt applications and discharges from domestic water softeners (Heisig 2000, Van Dreason 2011). A smaller increase was detected in the West Branch input. 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 7.2.4).

No trends were detected for TSI; the TSI trend plot suggests that algal populations have been relatively stable in Croton Falls Reservoir over the 1993-2014 period.

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 coincides with WWTP upgrades while the increase in turbidity, TP and conductivity at the West Branch input was due, in part, to Delaware Aqueduct operational changes. The conductivity increases observed elsewhere were likely due to development activity in the Croton Falls watershed.

8.3.4 Waterfowl Management Program: Croton Falls Reservoir

The Revised 2007 FAD lists Croton Falls Reservoir as one of five reservoirs covered under the as needed criteria for waterfowl management. Croton Falls Reservoir is divided into five geographic bird sampling zones associated with reservoir water quality sampling locations. As in previous years for which data are available, gulls and waterfowl (ducks) were the primary water bird groups counted throughout the reservoir from later summer through spring. Canada Geese were present throughout most of the year, showing increases in late spring and early summer following the post-nuptial molt and prior to the onset of autumn migration.

Fecal coliform bacteria elevations were reported from the impacts of Tropical Storm Irene and Tropical Storm Lee in the late summer and early autumn of 2011. Additional bacteria elevations were reported during the late autumn and early winter in 2011 and 2012 and may be associated with the onset of water bird migration and stopovers up through the reservoir icing when most bird activity normally decreases (Figure 8.13). DEP determined it was unnecessary to activate the as needed bird dispersal actions at Croton Falls Reservoir during this reporting period.

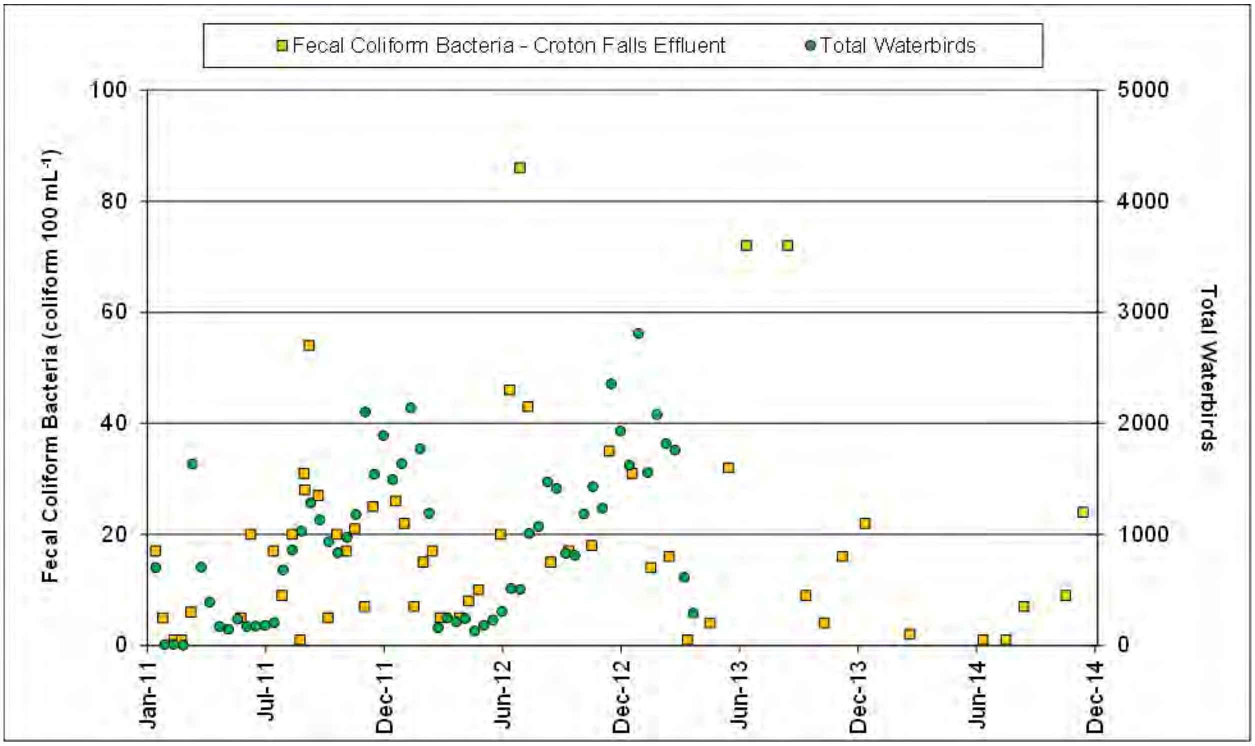

Figure 8.13 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total water birds at Croton Falls Reservoir, January 1, 2011 – December 31, 2014.

8.4 Trophic Response of Croton Falls and Cross River Reservoirs

A series of four plots were used to examine the trophic response of Cross River and Croton Falls Reservoirs. Chlorophyll vs. total phosphorus in the Cross River and Croton Falls Reservoirs is plotted in Figure 8.14. 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

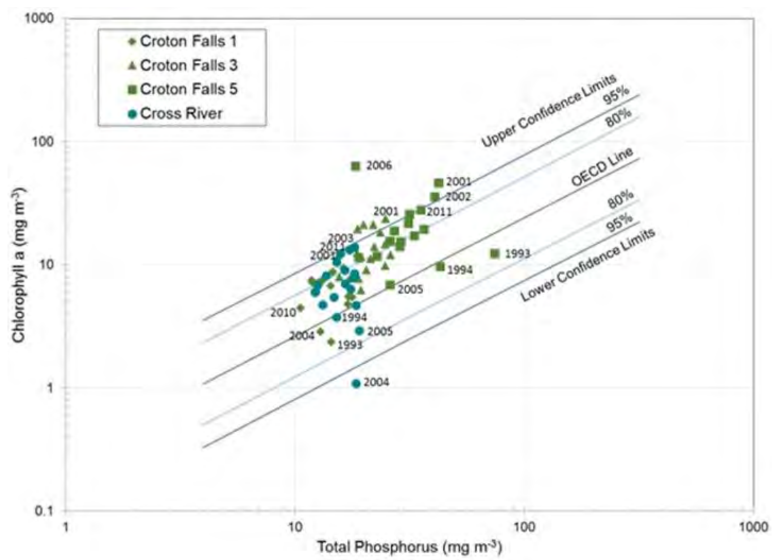

Figure 8.14 Chlorophyll vs. total phosphorus in Cross River and Croton Falls Reservoirs.

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, however the range of phosphorus is limited in Cross River and other factors influence the concentration standing crop (biomass) 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 concentration standing crops of algae tended to be high. These years include a drought during the 2001 to 2003 time period and the remaining years (2006 and 2011) were influenced by fall tropical storms in the preceding season and again in the fall of the years noted.

The annual maximum value of chlorophyll vs. total phosphorus is plotted for each year in Figure 8.15. Again 2001 through 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 concentration standing crops of algae. Cross River and Croton Falls react to precipitation events in approximately the same way.

Secchi depth vs. total phosphorus annual mean values are plotted in Figure 8.16. 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).

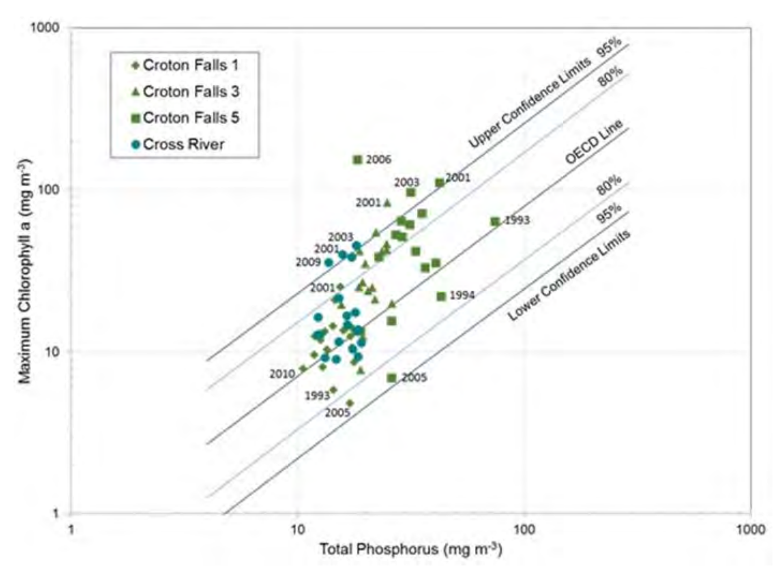

Figure 8.15 Maximum chlorophyll vs. total phosphorus in Cross River and Croton Falls Reservoirs.

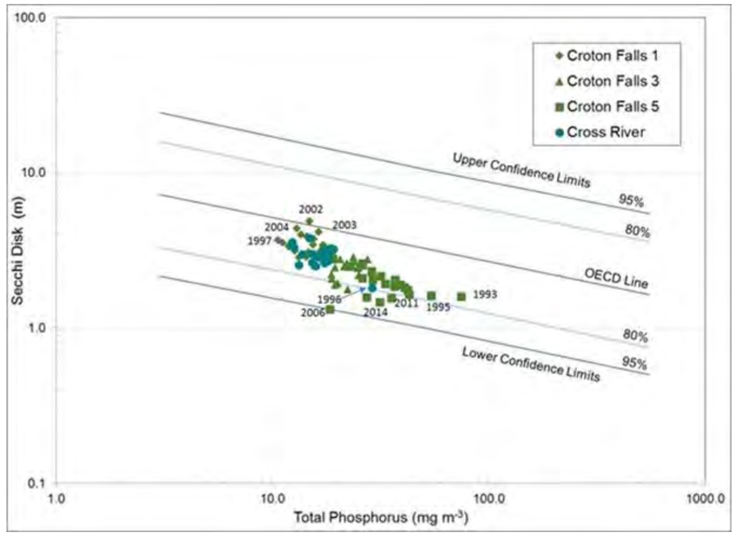

Figure 8.16 Secchi depth vs. total phosphorus in Cross River and Croton Reservoirs.

Secchi depth vs. chlorophyll is plotted in Figure 8.17. 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. 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 of 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 to 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.

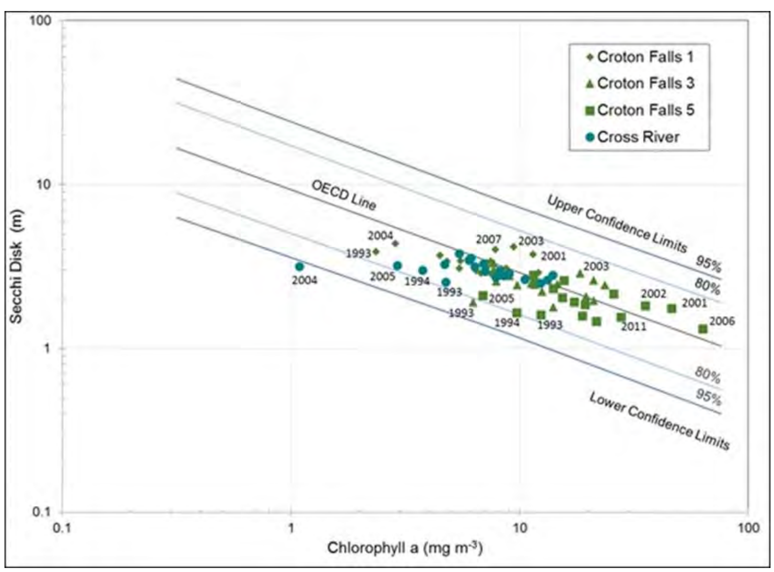

Figure 8.17 Secchi depth vs. chlorophyll in Cross River and Croton Falls Reservoirs.

8.5 Water Quality Summary for Cross River and Croton Falls Watersheds

Watershed protection improvements are ongoing in the Cross River and Croton Falls watersheds. Thirty-nine 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 DEP's Mahopac WWTP. Consequently, phosphorus loads in the Croton Falls basin have decreased from 2,400 kg year^{-1} in 1994 to less than 100 kg year^{-1} in 2014.

Water quality status for the assessment period (2012-2014) 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 and outflow from Croton Falls Reservoir. Total phosphorus monthly medians for the reservoirs were at or above the target value of 15 µg L^{-1} for source waters (median of 16.5 µg L^{-1} and 15 µg L^{-1} for Cross River and the main basin of Croton Falls, respectively). The median TSI was in the eutrophic range for both reservoirs and the basins remain listed as phosphorus-restricted.

Trends in turbidity were downward for the output from Cross River basin and attributed primarily to recovery from drawdown related to dam repairs. By contrast, the turbidity trend for Croton Falls was upward. Conductivity trends for both basins were upward and likely due to a combination of factors including development activity and precipitation patterns. Increases in the total phosphorus trend in the Cross River basin accompanied by an increasing trend in TSI coincided with storm events, particularly in recent years. A decline in the phosphorus trend in the middle basin of Croton Falls Reservoir were coincident with WWTP upgrades.

Biomonitoring was conducted at Cross River, the primary inflow to Cross River Reservoir. In 2012, the single year the site was sampled, the stream was assessed as slightly impaired. No trend analysis was performed because of the site's short (4-year) period of record.

Regarding trophic response in the Croton System reservoirs, chlorophyll and phosphorus annual mean concentrations are substantially higher than in the Catskill and Delaware reservoirs. Chlorophyll generally increases with phosphorus concentrations, however the range of phosphorus is limited in Cross River, so other factors have a major influence on the variation in concentration standing crop (biomass) of algae. Concentration standing crops of algae tend to be high in years of drought, but also in years when significant precipitation, such as that from tropical storms, occurs in the preceding season. As such, Cross River and Croton Falls react to precipitation highs and lows in approximately the same way. At Cross River, the most shallow Secchi depth and highest phosphorus level 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 general, transparency of these reservoirs is governed by algal growth, but stormwater can also diminish annual mean Secchi depth (transparency). Nearly all points approximately conform to the OECD relationship for Secchi depth vs chlorophyll and fall within the 80 % confidence intervals. Therefore phosphorus and stormwater reductions are good strategies to improve transparency and to minimize problems associated with eutrophication, (namely DBP-precursors, taste and odor, algal toxins, and turbidity).

9. Modeling Evaluation

9.1 Overview of the Modeling Program

DEP maintains an active program of model development and application in the areas of climate change analysis, watershed and terrestrial processes, reservoir transformation, fate and transport, and water supply system operation. These models are used to identify and predict the impact of ecosystem processes, climate change, land use changes, point source pollution abatement, improved agricultural practices, forestry management, requirements for dam releases to downstream channels, downstream flood control considerations, and water system operations on the quantity and quality of drinking water supplied to customers. Changing conditions in the watersheds present both ongoing and new challenges that DEP endeavors to plan for and respond to in order to deliver high quality drinking water. The models that have been evaluated and applied have covered the spectrum of model complexity, from simple empirical regression models for predicting stream turbidity, to complex numerical models that describe the three-dimensional variation in surface and subsurface conditions in watersheds, or the three dimensional variation of water quality in a reservoir. While early versions of water system operations models considered only storage and water quantity, water quality models are now being used to guide operations. DEP's modeling program is supported by a monitoring program of observations of meteorology, surface and subsurface hydrology, stream water quality, reservoir hydrodynamics and water quality, and aqueduct flows and water quality.

9.2 Ongoing Model Development and Testing

DEP has continued to explore new and alternative modeling approaches, identify and apply new models, modify and improve the framework of previously-applied models, and extend the period of calibration and/or verification of previously-applied models. This section describes these activities during the current five-year reporting period (2011-2015).

9.2.1 Streamflow Calibration in Cannonsville Watershed: Application of SWAT-WB

Early in the reporting period, DEP applied the SWAT-WB watershed model to the watershed of Cannonsville Reservoir. The USDA Soil and Watershed Assessment Tool (SWAT) is a widely accepted watershed hydrology and water quality model that is particularly strong in its representation of soil nutrient and plant growth processes, especially in agricultural watersheds. SWAT-WB is a version of SWAT that simulates runoff from variable source areas (VSAs) by the process of saturation excess runoff, which is considered a dominant runoff mechanism in the DEP watersheds. SWAT-WB incorporates a daily water balance for each Hydrologic Response Unit (HRU) to predict the partitioning of precipitation into runoff and percolation. HRUs are defined in SWAT as unique combinations of soil type, land cover, and slope class. Once the moisture is portioned, soil moisture routines are used to determine the degree of saturation-deficit for each soil profile for each day of simulation. To include the landscape features most important in runoff generation (e.g., upslope contributing area, soil depth, and slope) a topographic index was integrated with existing soils data to create a soil topographic index (STI), which is then used in the definition of an HRU. Values of STI are used to create wetness classes and represent a location's likelihood to saturate. This wetness class map is then combined with the soils map in the HRU definition process. This saturation-deficit is termed the available soil storage, and is a function of soil properties and watershed soil moisture status (White et al. 2011).

Model input parameters were developed using a DEM of the basin and a land use map for the Cannonsville watershed. The 19 sub-basins were delineated and further discretized into 554 HRUs based on spatial variations in land use and wetness class. The input meteorological conditions were observed temperature and precipitation data obtained from cooperator stations. The model was calibrated for streamflow at the watershed outlet (West Branch Delaware River) for the 1991-2000 interval. The calibrated streamflow was used to simulate a historical baseline prediction of streamflow using measured meteorological data for the period 1964-2008.

Twenty model coefficients parameters were calibrated. These coefficients control the hydrologic processes involved in streamflow generation including partitioning precipitation into infiltration and runoff, baseflow recession, and the rates of snowpack development and depletion. The overall objective of the calibration was to maximize the coefficient of determination and Nash-Sutcliffe efficiency, while minimizing bias. In addition, hydrology calibration was optimized so that the runoff and baseflow components of streamflow were simulated reasonably well compared to values derived from measured data using a baseflow separation technique. The mean monthly hydrographs of observed and simulated flow are shown in Figure 9.1. SWAT-WB has been found to perform well in simulating streamflow in Cannonsville watershed, where the saturation excess runoff process is dominant runoff generation mechanism.

Applications of SWAT and SWAT-WB are described below in sections 9.6.4, 9.8.1, and 9.8.2

Work began on SWAT-Hillslope, a version of the SWAT model modified for hillslope hydrologic processes. A dynamic perched aquifer and associated water table are added to SWAT using a statistical-dynamical approach, where the mean height of the perched water table is modeled as a time-varying dynamic process while the shape of the water table within a hillslope is modeled by a statistical relationship. As the perched water table rises and falls saturated areas correspondingly expand and contract, and saturation-excess overland flow is generated as precipitation and snowmelt that fails to infiltrate saturated soils. The perched aquifer is treated as a non-linear reservoir that can generate rapid subsurface stormflow as the water table rises, with return flow occurring at the saturated areas. The Greene-Ampt option in SWAT is used with direct precipitation and throughfall first tested against infiltration rate to produce infiltration-

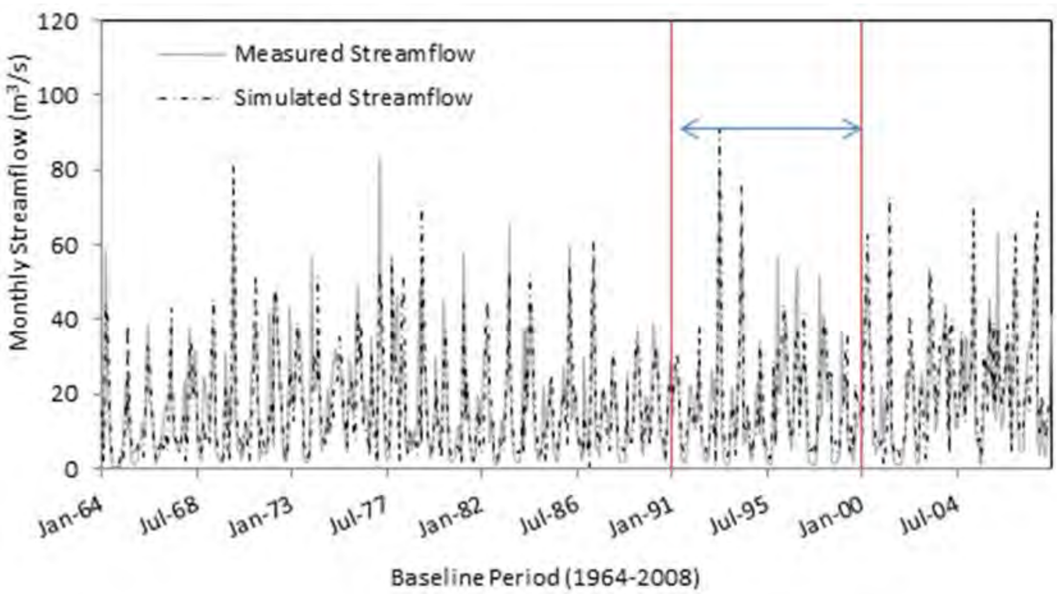

Figure 9.1 Predicted vs. measured monthly streamflow.

excess runoff, followed by infiltration of remainder, recharge of perched and deeper aquifers, VSA expansion, saturation-excess runoff and return flow. The two simulated surface runoff mechanisms, infiltration-excess and saturation-excess, effectively replace the Curve number method for generating runoff in SWAT. Tile drainage and plant water use are calculated based on the location of the perched water table relative to the root zone and tile drains, and soil biogeochemical calculations are adjusted to account for the effects of the perched aquifer intersecting the soil profile. Testing of SWAT-Hillslope for DEP watershed applications is underway. This model will allow us to estimate watershed loads under different hydrological conditions, test hypotheses about sensitive areas and hydrologic connectivities, and estimate the impacts of long-term land cover changes due to climate change. This information may therefore ultimately provide guidance in such decisions as the geographic placement of best management programs for greatest effect or development of watershed protection policies.

9.2.2 Influences of Channel Processes on Phosphorus Export

In the watershed of Cannonsville Reservoir, WWTPs and agriculture are major potential sources of phosphorus (P) entering the streams and reservoir. The downstream ecological impacts of P inputs are heavily dependent on the extent to which the phosphorus is physically retained and/or chemically and biologically processed. In-stream processing of P may account for the apparent disconnect between measures implemented to reduce P inputs and improvements in downstream water quality. Understanding net effects of P release and retention processes in watersheds is important for managing stream water quality and for targeting remediation and restoration measures. These processes are commonly quantified in water quality models to improve the accuracy of nutrient prediction. During the reporting period, a study was conducted to analyze channel P processes under different flow regimes. This analysis can also be used to examine the scale and variability of P retention and release, as an aid to watershed management and to include in-stream processing in existing water quality models.

A simple empirical approach for quantifying P delivery, the Extended-End Member Mixing Analysis (E-EMMA), was used to explore P net retention and release at the watershed outlet. This approach utilizes water quality monitoring and point source data to quantify the impacts of in-stream and watershed P processes on P delivery at the watershed scale. The point source data used for this study include effluent nutrients data from WWTPs and nutrients added in-stream by cattle before and after the implementation of watershed management programs in the Cannonsville watershed. Five years of data (1997, 2001, 2003, 2005 and 2008) were chosen to evaluate effects of P retention and release on delivery at the watershed outlet. These years were chosen to cover the full range of hydrological flows.

With E-EMMA, the relationship between P load and streamflow is established. It is assumed that there are two dominant and distinct sources of water, with different P concentrations, contributing to P loads at the watershed outlet: (1) a baseflow end-member source composed largely of wastewater effluent and/or groundwater, and (2) an eventflow end-member source composed of an integrated watershed-wide nonpoint source that, under the highest flows, is delivered directly to the watershed outlet. When the two water sources mix, a linear relationship between baseflow and eventflow P load end-members indicates that P was behaving conservatively. Conversely, a nonlinear mixing series indicates that P was behaving non-conservatively. Nonlinear behavior under low-flow conditions is assumed to result from in-stream processes, while nonlinear behavior under higher flows represents the net effects of in-stream and watershed retention/mobilization. By comparing an observed nonlinear relationship between stream P load and stream flow measurements to a theoretical linear conservative mixing series between the baseflow and eventflow end-member P loads, the net effects of P retention and release can be directly quantified. Dissolved and particulate P observations from the West Branch Delaware River at Walton were used to illustrate how E-EMMA can be used to estimate net losses and gains of P.

At annual scale, there was dissolved P retention with net annual retention (all flow regimes included) ranging from 31% in 1997 to 62% in 2005 (Table 9.1). However, there was net release of 20% in 2008 for dissolved P. Briefly summarizing the results for different flow regimes, there was net retention of dissolved P in low, dry, mid-range and moist flow regimes for all the five years. Dissolved P retention was greatest under the lowest and intermediate flows, which is strongly indicative of biological processing of P, particularly uptake by algae and/or sorption to sediments. There was no evidence of significant net release or remobilization dissolved P loads under low and intermediate flows relative to the linear conservative mixing. This indicates that remobilization of transient in-channel and watershed stores of P was small relative to P load retention under low and intermediate flows.

Table 9.1 Annual net phosphorus retention and release, West Branch Delaware River at Walton.

Year	Annual Net P Retention/Release	
	Dissolved P	Particulate P
1997	31%	19%*
2001	39%	47%
2003	36%	44%
2005	62%	>400%*
2008	20%*	21

* Net P release

The relationships between observed P load and discharge exhibited strong non-conservative behavior under the lowest and intermediate flows for both dissolved and particulate P. It is concluded that the curvilinear relationship reflects net P retention along the watershed and stream environment during mixing of the event-flow and baseflow. Further study is needed to gain better understanding of the balance of processes that determine the event-flow end-member load at intermediate to high flow conditions, especially in watersheds dominated by nonpoint export, such as differential erosion associated with events of different magnitudes, intensities, seasons, and pre-existing conditions; re-deposition and other processing active during overland flow; and in-stream processing.

9.2.3 A Hybrid Approach to Simulate Future East of Hudson Reservoir Inflows

Inflows from watersheds draining to EOH reservoirs are required to run simulations with the OASIS reservoir system model or OST, and when performing simulations to study possible impact of climate change on the DEP water supply. During Phase I of the Climate Change Integrated Modeling Project (CCIMP), the assumption was made to maintain EOH inflows at historical levels during future simulations. Though this assumption was reasonable considering that historically the EOH system contributes less than 10% of total water yield, a more comprehensive study, as planned for Phase II of CCIMP, will require simulated future EOH inflow. However, no models have been developed to simulate future individual EOH inflows. Modeling EOH inflows is not an easy task because the area is urbanized, with most streamflows regulated. A two-step hybrid approach was applied to simulate future inflows for each EOH reservoir. The methodology combines linear regression models that relate each individual reservoir inflow to the aggregated (total) inflow for the entire region and, the use of the Generalized Watershed Loading Functions (GWLF) watershed model to simulate a regional daily inflow time series. This hybrid approach combines a stochastic regression model and the GWLF watershed model. This approach can be summarized by the following three steps:

- An aggregate time series was developed consisting of an arithmetic sum of the individual OASIS EOH basin historical inflows. These historical inflow time series were previously estimated and embedded in the OASIS model.

- Individual regression models were developed for each OASIS EOH basin using the aggregate flow as the known or explanatory variable.
- Historical air temperature and precipitation time series representative for the region was used to calibrate the GWLF watershed model to the historical aggregate inflow. Soil radiation and relative humidity that are also required to run GWLF hydrology in addition to air temperature and precipitation were simulated internally in GWLF based on the latitude and longitude of the EOH watershed centroid and the inputs of air temperature and precipitation days.

The ordinary least squares (OLS) regression approach was applied to develop empirical inflow models for each individual EOH inflow. It is assumed that each individual inflow is linearly related to a total aggregate inflow of the entire OASIS EOH region. The models were developed using inflow data used in OST from October 1927 to December 2000. Except for the intercept for the East Branch of Bog Brook and Cross River basins, all regression parameters were found to be statistically significant at a 95% confidence level. The regression coefficients indicate that the individual regression models explain almost 100% of the data variance.

The GWLF model (Schneiderman et al. 2007) was calibrated to simulate historical total (aggregated) EOH inflow using air temperature and precipitation observed at Yorktown Heights. Solar radiation and relative humidity were generated internally in the GWLF model. The calibration period was 1966 through 2000; data from 2001 to 2008 were used for model verification. Delta change factors for a particular climate scenario (Section 9.7.1) were applied to historical aggregated time series to yield a simulated future regional inflow. The regression equation for each individual reservoir watershed was then applied to estimate the future inflow for an individual watershed.

9.2.4 Optimal Calibration of a One-dimensional Reservoir Models for Cannonsville and Pepacton Reservoirs

DEP has set up a one-dimensional hydrothermal and water quality model to simulate the thermal stratification, nutrients and phytoplankton in Cannonsville and Pepacton Reservoirs (UFI 2001). This model has three component submodels. The hydrothermal submodel simulates the vertical dynamics of thermal stratification and heat and mass transport, based on meteorological, hydrological and operational conditions. The nutrient submodel describes the transformation and fate of the nutrient loads to the reservoir, and distributes nutrients vertically through the water column based on vertical mixing coefficients derived from the hydrothermal submodel. For Cannonsville, the phytoplankton submodel is based on the PROTBAS (Markensten and Pierson 2007) approach which considers multiple phytoplankton classes, while for Pepacton the phytoplankton submodel uses a single representative phytoplankton class. In both models, phytoplankton biomass is predicted in terms of algal carbon and is a balance between growth (photosynthesis), and losses due to respiration, grazing, sedimentation and outflow, and chlorophyll *a* is calculated from algal carbon.

The objective of this study was to optimize the performance of these reservoir models by using an automated calibration using long-term measurement data. The model contains 52 coefficients whose value is known to be site-specific; the value of these coefficients must be determined to apply the model for management purposes. By conducting a sensitivity analysis (Huang and Liu 2008), it was found that, for the PROTBAS-based model applied to Cannonsville, 18 of these 52 coefficients were of great importance in determining simulated values temperature and water quality, while the Pepacton model was sensitive to 16 coefficients. This subset of coefficients (18 for Cannonsville, 16 for Pepacton) were adjusted in this model calibration exercise.

A hybrid genetic algorithm (HGA) consisting of a global search method combined with a local search method was used as an optimization algorithm to the value of these coefficients. The objective function for this optimization was to minimize the error in predicted values of temperature, dissolved oxygen, total phosphorus, and chlorophyll *a*. The model was calibrated against the measured data over the time period of 1986-1999, while model validation was performed using 2000-2004 data. As an example of the application of this procedure, the observed and predicted results for the validation period (2000-2004) for the epilimnion of Cannonsville is shown in Figure 9.2.

This automated procedure for calibration of reservoir water quality models offers an alternative to the more traditional manual approach, where individual, repetitive model runs are made, with the value of no more than a few coefficients changed from one run to the next.

9.2.5 Use of Gridded Meteorological Data in Watershed Model Applications

Spatially-distributed meteorological data for the DEP watersheds has recently become available from the National Weather Service, and DEP is now using these data in model applications. Spatially distributed data explicitly accounts for the considerable spatial variability

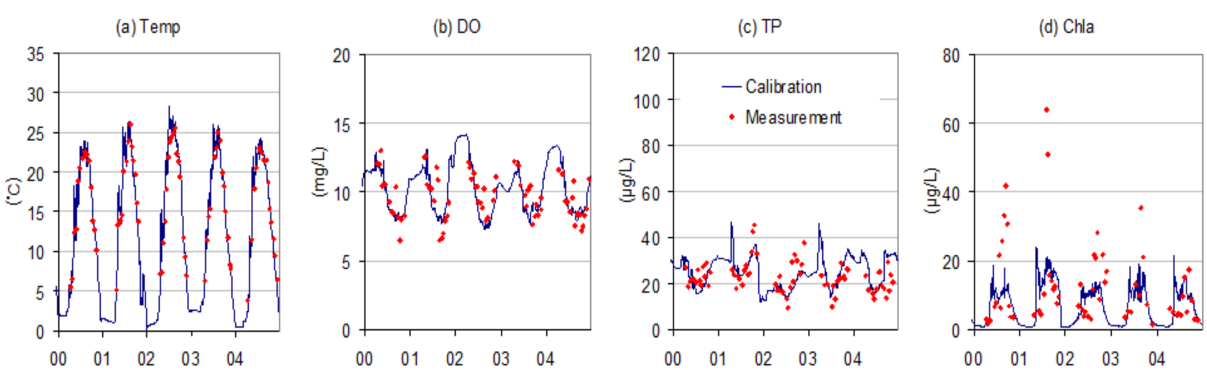

Figure 9.2 Model validation: simulated and observed temperature (Temp) and concentrations of dissolved oxygen (DO), total phosphorus (TP) and chlorophyll *a* (Chl*a*) in the epilimnion of Cannonsville Reservoir, 2000-2004.

in meteorology over a watershed due to orographic effects and variable storm types and paths, particularly in the mountainous terrain of the Catskills. Previously, model applications utilized meteorological estimates based on National Weather Service observer stations. However, the number of active stations has declined from 18 to eight since 2000. Deriving unbiased estimates of precipitation from this sparser network of data is increasingly problematic.

Gridded 4-km resolution daily precipitation and air temperature data are available from the Northeast Regional Climate Center (NRCC). The precipitation data is developed using radar-guided interpolation in which radar-based precipitation is adjusted on a daily time step using rain gauge observations to reduce spatially varying errors. Radar-based interpolation helps reduce model uncertainty by reducing interpolation errors independently from season or precipitation magnitude. Spatially distributed air temperatures are estimated by NRCC at grid points by interpolation from observation stations and application of an environmental lapse rate that adjusts for elevation effects on temperature.

The NRCC gridded data was evaluated by using the gridded data to drive GWLF watershed models of major gaged inflows to the WOH reservoirs, and comparing model performance with the GWLF models driven by data derived from observer station data for each of 10 gaged watersheds. Nash-Sutcliffe (NS) goodness of fit model statistics were computed for GWLF models driven by observer station met data, and for NRCC gridded met data. Statistics were computed for streamflow, surface runoff, and baseflow at daily and event time steps. The models driven by the NRCC gridded data substantially outperformed the observer station driven models in almost all cases at both daily and event time steps. These results support the use of the NRCC gridded met data for WOH watershed model applications.

9.2.6 Comparison of Snowpack Models for New York City Watersheds

The ability to simulate snow, snowpack development, and snowmelt on both basin and finer spatial scales is important for reservoir operational support, watershed management, and long-term planning of the DEP water supply. Snow is a substantial component of annual precipitation in mountainous regions around the world including the WOH watersheds. The pattern of snow accumulation and snowmelt has important implications for streamflow dynamics and for the management of water resources.

Snowpack models vary in complexity and resolution. Simple models utilize the daily lumped parameter temperature index approach, where the snowpack for a basin is a single storage of snow water equivalent (SWE) to which precipitation as snow is added and from which water as snowmelt is removed on a daily time step. A melt parameter that linearly relates snowmelt to air temperature is empirically determined. This approach has minimal data requirements and has been incorporated into widely used watershed water quality simulation models such as GWLF and SWAT. More complex snow models explicitly simulate an energy balance of snowpack and upper soil layers at sub-daily time-steps. With the added complexity comes increasing data requirements; depending on the objectives of the model application, sometimes the end effect does not justify the additional effort.

Three snowpack modeling approaches of varying complexity and spatial resolution were tested for their ability to simulate basin average SWE for the major DEP reservoir watersheds and the spatial variability of snowpack within a basin. The three modeling approaches are (1) the lumped-parameter temperature index approach from the GWLF watershed model, (2) a spatially distributed temperature index (SDTI) approach, (3) the 1-km gridded NOAA SNOw Data Assimilation System (SNODAS) model. Model testing included: (1) comparison of simulated basin average SWE to estimates based on snow survey data for each of the WOH reservoir watersheds, (2) comparison of the spatial distribution of SWE as simulated by the spatially distributed approaches (SDTI and SNODAS) to the collection of snow survey data locations across WOH watersheds, (3) comparison of the statistical distributions of SWE within selected reservoir watershed basins for the two spatially distributed approaches. These models were applied to the watersheds of the six CAT/DEL reservoirs.

Gridded 4-km resolution daily precipitation (both rain and snow), and air temperature data were obtained from NRCC (Section 9.2.5). The DEP snow survey is conducted biweekly during the winter months. Snow cores taken at 67 sites and analyzed for SWE for 2005-2011 were used. The basin average SWE was estimated by simple arithmetic average of the survey site measurements within the basin. For purposes of analyzing model performance in simulating snow survey site to site variability, the snow survey sites were characterized by elevation band (low: 250-450m, medium: 451-650m, and high: 651-850m); land use forest (evergreen, deciduous, and mixed); agriculture (row crop, pasture and hay); and commercial (high intensity commercial/industrial); and aspect (eight compass directions).

In addition, gridded SNODAS SWE and snowmelt were downloaded for this study from the National Operational Hydrologic Remote Sensing Center (NOHRSC) web site. SNODAS aims to achieve a physically consistent framework that integrates snow data from satellite, airborne platforms, and ground stations with model estimates of snow cover from the numerical weather prediction model. The two temperature index models were calibrated by adjusting the melt coefficient to maximize agreement between simulated and observed basin-average SWE for the calibration period. The six-year period of available snow survey data was split into a three-year calibration period (2005-2008) and three-year validation period (2008-2011).

Figure 9.3 shows the winter time series of average basin SWE for Schoharie and Neversink watersheds for the winter of 2008-2009. At Neversink the SNODAS product tracks well with the average survey data. For both watersheds GWLF and SDTI seem to track fairly closely. The only difference between these two models is the spatial resolution of the snowpack algorithm. This difference is most apparent at the end of the season when the SDTI model tends to continue to show SWE values for a few extra weeks in the spring. At Neversink, it is interesting to note that the timing of the spring melt for the SDTI model and the SNODAS match

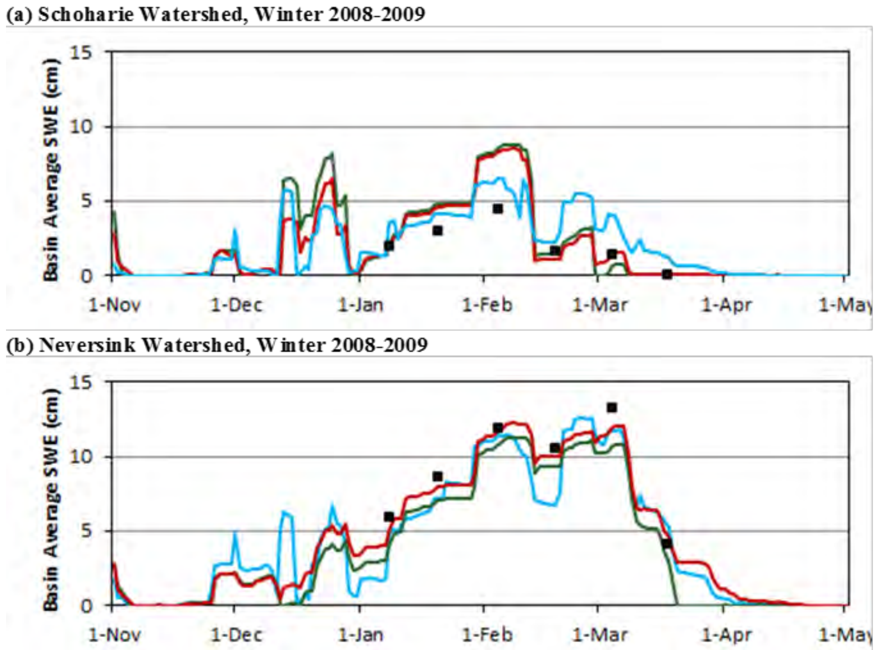

Figure 9.3 Example time series of basin average SWE with average of DEP snow survey measurements (black squares), SNODAS product (light blue), GWLF model results (green) and SDTI model results (red) for Schoharie and Neversink watershed for winter of 2008-2009.

quite well, suggesting that the spatial distributed component of the SDTI model is helpful in accounting for this elevation related process.

9.2.7 Trihalomethanes in the New York City Water Supply – Empirical Modeling and Tropical Storm Effects

Forms of chlorine commonly used to achieve disinfection in water supplies can combine with organic carbon to produce a number of disinfection byproducts (DBPs) including trihalomethanes (THMs) and haloacetic acids (HAAs), which are probable carcinogenic compounds. USEPA has set a maximum contaminant limit (MCL) of 80 μg L^{-1} for total trihalomethanes (TTHMs) and 60 μg L^{-1} for the sum of five haloacetic acids as site-specific running annual averages (USEPA, 2006). Formation of DBPs is influenced by a number of factors including disinfectant reaction time with natural organic matter (NOM), pH, temperature, types and amounts of NOMs, chlorine dose, and the presence of bromide ions (Hong et al. 2007).

An empirical model of TTHMs was developed and relative importance of the factors that affect the formation of THMs was quantified. Monthly water quality data from 24 locations from within the DEP distribution system during January 2009 through April 2012 were used. This dataset included 866 observations of TTHMs and other water quality parameters including pH, total organic carbon (TOC), and temperature. Water age estimates ranged from 26-95 hours for the 24 sites. Chlorine dose and bromide levels may also contribute to TTHM formation, but these were not considered because chlorine dose data were not available and brominated DBP concentrations were low. Model performance was validated independently using quarterly data for TTHMs and predictor variables (96 measured values) collected from April 2012 to March 2013 from the same 24 sites. Model performance was evaluated using coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE). Model accuracy was also tested using quarterly data for TTHMs and predictor variables (96 measured values) collected from April 2012 to March 2013 from the same 24 sites. A multiple nonlinear regression model was fitted with pH, temperature, time, and TOC as predictor variables as follows:

Equation 9.1

$$TTHMs = 0.0072\, pH^{2.60}\, Temp^{0.396}\, Time^{0.475}\, TOC^{1.397}$$

The model performed well ($R^2 = 0.75$) for both the calibration and validation periods (Mukunkdan and Van Dreason 2014). The average RMSE and MAE values were 7.89 µg L^{-1} and 6.16 µg L^{-1} respectively for the calibration period and 6.72 µg L^{-1} and 5.5 µg L^{-1} respectively for the validation period. Although the overall performance was acceptable it was noticed that the model generally over predicted the measured values by about 13% during the validation period (Figure 9.4). Relative importance of predictor variables estimated using sensitivity analysis were in the following order (most important first): (1) TOC, (2) water age (reaction time), (3) water temperature, and (4) pH.

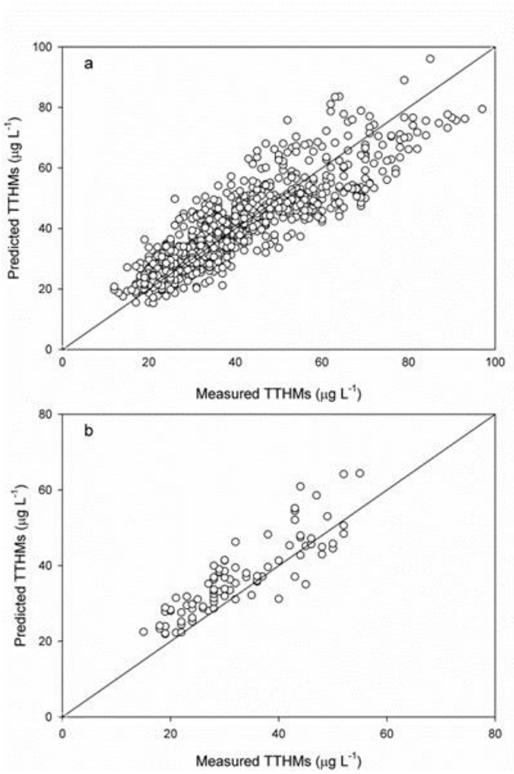

Figure 9.4 Predicted versus measured TTHM concentrations: (a) calibration, and (b) validation.

During 2011, Tropical Storm Irene (August 26-29) and Tropical Storm Lee (September 5-8) resulted in total rainfall ranging from 38 cm to 50 cm in the DEP water supply watersheds. In Esopus Creek, about 43% of the 2011 annual DOC load occurred within five days during Tropical Storm Irene. The TTHM levels in the water supply distribution system increased following the two storms, with 45% (17/38) of the samples recording values higher than MCL of 80 µg L^{-1} in October and November 2011. However, since compliance during this period was based on a system-wide running quarterly

Table 9.2 Comparison of median TTHM levels and water quality parameters between 2011 and 2009-2010 periods.
These values are for October and November from 10 sites where TTHM levels exceeded the regulatory limit in 2011.

Year	TTHM ($\mu g\ L^{-1}$)	TOC ($mg\ L^{-1}$)	pH	Temp (°C)
Oct.-Nov., 2011	85	2.03	7.48	18.3
Oct.-Nov., 2009, and Oct.-Nov., 2010	50	1.52	7.34	16.9
Difference	+35 (+70%)	+0.51(+33%)	+0.14 (+38%)	+1.4 (+8%)

average, the water supply was able to maintain compliance throughout 2011. Samples which exceeded the MCL in October and November of 2011 were mostly from 10 monitoring sites, eight of which were in Manhattan, one each in Queens and Staten Island.

The TOC increase (Table 9.2) would cause TTHMs to increase by 24 $\mu g\ L^{-1}$ based on the empirical model (Equation 9.1). Additionally, increases of 0.14 pH units and 1.4°C would increase TTHM by ~ 4.0 $\mu g\ L^{-1}$ and ~ 3.0 $\mu g\ L^{-1}$, respectively. The sum of these three components, 31 $\mu g\ L^{-1}$, was close to the observed TTHM increase of 35 $\mu g\ L^{-1}$. The predictive model based on easily measureable parameters such as presented here can be used to guide reservoir operations decisions.

9.2.8 Forest Ecosystem Modeling Project

Forests cover the majority of the 1,600 square mile drainage area of the WOH Water Supply System that supplies drinking water to NYC. As the predominant land cover type in the DEP watersheds, forest ecosystems play an important role in determining the water, nutrient, sediment, and pathogen inputs to the reservoir system by regulating evapotranspiration, storing nutrients, stabilizing soils, and attenuating surface runoff. The Forest Ecosystem Modeling Project aims to develop a comprehensive application of a spatially distributed forest ecosystem model for the DEP watersheds, to assess the effectiveness of forest management strategies and the potential effects of climate change on the DEP water supply.

DEP has begun testing the Regional Hydro-Ecologic Simulation System (RHESSys) model for the Biscuit Brook Watershed in the Neversink basin. RHESSys is a spatially distributed hydro-ecological model that simulates water, carbon and nutrient dynamics over spatial scales ranging from a small catchment (a few square hectares) to regional scales (i.e., multiple square kilometers). RHESSys simulates landscapes by using a DEM to delineate progressively nested basins (catchments), hillslopes (land areas draining into either side of, or the headwater of a stream segment), zones (micro-climatic zones), patches (portions of hillslopes having relatively uniform slope, aspect and soil characteristics) and strata (the vegetation types and vertical layers modeled within each Patch). RHESSys does not model individual plants, but rather the carbon content of various sinks that represent physiological vegetation compartments, where carbon content serves as a proxy for biomass. Likewise, RHESSys does not model individual tree canopies but rather uses a dual "Big-leaf" paradigm in which one leaf represents the shaded rate of photosynthesis and the other represents the unshaded rate of photosynthesis, and the result is mathematically scaled-up to forest canopy scale based on leaf area index (LAI), mean canopy height, sun angle, and day of the year.

Testing of two different hydrological modes of RHESSys have recently been initiated: Topmodel, which is a statistically based quasi-distributed approach utilizing a GIS-derived wetness index to redistribute hillslope moisture as a function of landscape steepness and specific catchment area (i.e., the total area draining through a particular landscape pixel); and explicit routing based on Distributed Hydrology Soil and Vegetation Model which calculates the actual surface and sub-surface movement of water between individual RHESSys landscape patches. The calibration process involves adjusting parameter values for soil moisture infiltration rate, decrease/increase in infiltration rate with soil depth, rate of movement of water from soil water to ground water and rate of movement of water from ground water to stream base flow.

9.2.9 Simulation of Ice Cover in Rondout and Ashokan Reservoirs

The presence of seasonal ice cover has dramatic impact on the interaction between reservoir surface waters and the atmosphere. Potential reductions in ice cover under future climate could produce changes in temperature and light levels, water circulation patterns and exposure of surface waters to UV radiation. Long-term simulations of ice conditions/duration are needed to understand the mechanics through which ice cover mediates the effects of climate on lake thermal structure and mixing, and how changing ice cover may ultimately influence phytoplankton succession and trophic status of a lake. In addition, ice cover affects the fate and transport of turbidity inputs occurring during extreme winter events.

The simple ice model (SIM) (Ashton 2011), based the steady-state 1-D heat conduction equation in the ice, predicts the occurrence of formation and breakup of ice cover, and ice thickness. The model is driven by daily or hourly air temperature and wind speed. This model was applied to Rondout and Ashokan reservoirs, using 19 years of observed formation and breakup, which were visually observed by DEP's wildlife research and police aviation groups. The simulated time of ice formation and breakup was often close to the observed dates of ice on and ice off, although ice break-up was predicted with a greater degree of certainty (results not shown here). Measurement of ice thickness in these two reservoirs was not made and thus not available for comparison with model prediction. Based on the model results, maximum ice thickness simulated in Ashokan Reservoir (~ 0.2 m – 0.3 m) greater than in Rondout Reservoir (~0.1 m – 0.2 m). The simple model tested here shows promise in allowing lake ice phenology to be simulated using readily available input data (air temperature and wind speed).

9.3 Update of Data to Support Modeling

DEP regularly updates its datasets to ensure that water quality and operational models are using the most recent and best available data. This section describes the efforts made during the reporting period to maintain current datasets for land use, watershed programs and time-series data that are used to support modeling.

9.3.1 Update Existing GIS Datasets

Water quality sampling locations change according to specific monitoring needs. As new locations are established, these locations have been added to the DEP GIS database. The addition of GIS locations complements the non-spatial sampling data stored in the LIMS. Events such as Tropical Storm Irene require the addition of new sampling locations to properly assess changes in water quality. In 2011, the largest number of new sites were EOH WWTP locations, and sampling sites on the lower Esopus Creek downstream of the Ashokan Reservoir. The DEP GIS databases were also updated with the locations of newly installed meteorological stations and snow pillows sites.

Soil types and other characteristics directly impact the degree of watershed and stream bank erosion and sediment transport, thereby affecting the turbidity of DEP reservoirs. The Soil Survey Geodatabase (SSURGO2), published by the USDA is a database that describes soil components and properties nationwide. In 2012, DEP databases were updated with the most recent data for all watershed counties. In addition to publishing data, the USDA has created a GIS data processing toolbox that enables end users to derive secondary soil information from the base soil data. Using this toolbox, DEP created data files for multiple properties, including soil porosity, field capacity, wilting point and root zone depth.

9.3.2 Time-series Data

Watershed (Table 9.3) and reservoir (Table 9.4) modeling require related, but distinct datasets for model calibration, validation and forecasting. Time series data, such as meteorological conditions and streamflow, are collected in near real time. These data are sourced from multiple entities, within DEP, NYS and federal agencies. To be usable by the modeling group, continuous datasets are aggregated and pre-processed to generate model input files. Certain water quality data, which had previously been collected externally, is now collected by DEP, and processed internally to calculate nutrient loads. While some of these data must be manually retrieved, options are currently being explored to streamline and automate the collection of relevant data and transformation into model input files.

Data collected during the reporting period of 2011-2015 will continue to support the development, testing, and application of predictive eco-hydrological models at the watershed scale as well as the reservoir water quality models. Use of the additional dataset to drive these models would enhance the robustness of the models as greater natural variability is incorporated in the inputs.

Table 9.3 Inventory of data used for watershed modeling.

Data Type	Data Source	Data Description	Dates*	Modeling Needs
Meteorology	Northeast Regional Climate Center	Daily Precipitation and Max/Min Temperature	Pre 1960-2015	Model Input
Wastewater Treatment Plants	DEP	Monthly WWTP Nutrient Loads	1990-2009	Model Input
Streamflow	USGS	Daily and Instantaneous Streamflow	Period of record available online via USGS	Hydrology Module Calibration / Nutrient and Sediment Loads
Water Quality	DEP	Routine and Storm Stream Monitoring	Period of record avail. via LIMS	Nutrient and Sediment Loads for Water Quality Calibration
	NYSDEC**	Stream Monitoring at West Branch Delaware River	1992-2010 w/ recent years avail. via LIMS	Nutrient and Sediment Loads for Water Quality Calibration

*Dates represent total span for all data sets combined. Individual station records vary. **Now part of the DEP Water Quality dataset.

Table 9.4 Inventory of data used for reservoir modeling.

Data Type	Data Source	Data Description	Dates*	Modeling Needs
Meteorology	DEP	Air Temp., Relative Humidity, Solar Radiation, PAR, Wind Speed, Wind Direction, and Precipitation	1994-June, 2010	Model Input
Key Point and Reservoir Operations	DEP	Tunnel Water Quality, Flow and Temp.; Reservoir Storage, Spill, Withdrawal, and Elevation	Period of record avail. via LIMS	Model Input
Streamflow	USGS	Daily and Instantaneous Streamflow	Period of record available online via USGS	Model Input
Stream Hydrology	DEP	Stream Water Quality, Flow and Temperature	Period of record avail. via LIMS	Model Input
Limnology	DEP	Reservoir Water Quality, and Temperature Profiles	Period of record avail. via LIMS	Model Input

*Dates represent total span for all data sets combined. Individual station records vary.

9.3.3 New Derived Datasets

In addition to datasets derived from updated SSURGO soil data, DEP leverages existing data to derive new information useful for modeling water quality. Existing drainage basin data is used for entire watersheds, but to focus analyses on smaller watersheds, elevation data are used. Examples are the watersheds draining to the USGS stream gages at Hollowtree Brook, Biscuit Brook, and Richardsville.

Stream power, a measure of the energy available in the stream channel, can be used to estimate sediment erosion and transport using various models. Using ArcGIS Modelbuilder, elevation data have been used to derive the stream power estimates for inclusion in the SWAT model, as described in Section 9.6.3. Models have been developed to calculate stream power for a variety of elevation resolution data ranging from 10 meter USGS DEM to 1 meter LiDAR data.

9.3.4 Acquisition of New Datasets

While leveraging existing datasets provides valuable additional information, new datasets are also being developed to fill information gaps. In 2012, the modeling group began testing and evaluating the use of 4km resolution gridded daily precipitation and temperature data provided by the NRCC. These data are near real-time interpolations of radar-based precipitation and air temperature point observations data, which provide a consistent spatial distribution of meteorological data.

Current bathymetry and hypsographic tables for DEP reservoirs are based on surveys completed in 1998. These existing data are low resolution, and cannot be used to accurately quantify sedimentation in the reservoirs. To better characterize the WOH reservoirs, DEP awarded a contract, to the USGS in 2012, to conduct high-resolution bathymetry surveys of Ashokan, Rondout, Neversink, Schoharie, Cannonsville and Pepacton Reservoirs. The project will be completed in 2016, and will result in triangulated irregular network surface models, 2 foot elevation contours and elevation-area-capacity hypsographic tables for each reservoir. To date, all data collection has been completed, and the data are being processed to generate rough draft bathymetry surfaces.

9.3.5 Watershed Atlas

DEP GIS staff provide support to the modeling unit by creating cartographic products. One such product created was the NYC Watershed Atlas. The Atlas provides an overview of each reservoir basin comprising the DEP water supply. Narrative descriptions and histories for each reservoir are accompanied with photographs, land-use summary tables and existing hypsographic charts of reservoir water storage. As the project evolved and new base datasets became available, the draft Atlas was updated with these new data, such as 1m resolution basin boundaries. The final draft of the Atlas was completed in December, 2014.

9.4 Modeling and Technical Support to the Catskill Turbidity Control Program

During the reporting period, DEP's multi-tiered water quality modeling program continued to provide modeling and technical support to the program to control turbidity in the Catskill system, and to operate the water supply so as to minimize the impact of turbidity events while considering longer-term system operating requirements. Given these objectives, the following modeling activities were undertaken: (1) development of models to predict turbidity at the mouth of Esopus Creek, (2) development of a W2 turbidity model for Rondout Reservoir, (3) upgrade of the W2 turbidity models for Schoharie, Ashokan, and Kensico reservoirs, (4) ongoing development of OST. The details are discussed below.

9.4.1 Advancements in Esopus Creek Turbidity Models

Automated high frequency monitoring of turbidity (Tn) in Esopus Creek can be used to accurately estimate Tn loads that are an important input to reservoir Tn models. Using these observations, empirical models have been developed and evaluated by DEP to allow estimation of Tn and turbidity loads at the Esopus Creek inflow to Ashokan Reservoir, based on quantities including streamflow, time of year or season, the length of the antecedent dry period prior to a runoff event, and other quantities.

In the early portion of the reporting period, an analysis of high-frequency Tn data from this location on Esopus Creek was conducted. Loads were calculated for 30 event days (where mean daily turbidity could be calculated) and 27 events (where event mean turbidity could be calculated) between November 19, 2003 and April 17, 2011 where both streamflow and turbidity data were available. A turbidity-discharge relationship was developed using data from days when the flow diversion from Schoharie Reservoir was less than 20% of the total Esopus Creek daily discharge, so that turbidity inputs to Esopus Creek from Schoharie were a very small component (<1%) of the event loads. A rating curve in the form of an ordinary least square (OLS) regression (Equation 9.2 and Figure 9.5) on log-transformed mean daily stream discharge (Q, $m^3\ s^{-1}$) and log-transformed flow-weighted mean daily turbidity (NTU) was developed:

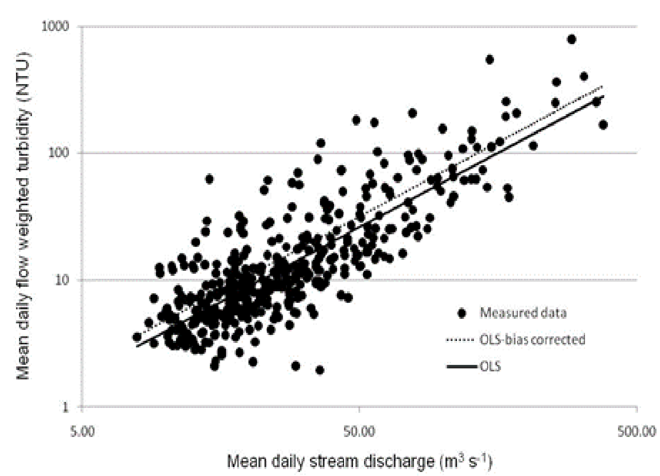

Figure 9.5 Discharge-turbidity relationship at Coldbrook outlet.

Equation 9.2

$$\log Tn = 1.17 \log Q - 0.575 \ (r^2 = 0.66)$$

A bias correction factor estimated based on the variance in the regression equation in the form $\beta = \exp(2.65\ \sigma^2)$, was multiplied by the OLS estimated turbidity value to reduce the expected under-prediction in loads due to retransformation bias.

Additional relationships to predict measures of turbidity or turbidity load were also explored. Rather than the daily average turbidity predicted by Equation 9.3, other measures of average turbidity during a runoff event were also explored. The event peak daily turbidity (EPDT), the maximum value of the flow-weighted 24-hour average turbidity during an event, and the event mean turbidity (EMT), the flow-weighted average turbidity for the entire event duration, were also considered. Regressions to predict EPDT were not improved relative to that given by Equation 9.3. However, a regression predicting EMT (units of NTU) gave the following result:

Equation 9.3

$$\log(EMT) = 1.84 \log(Q_E) + 0.0051\ ADD - 1.92$$
$$(r^2 = 0.89,\ p<0.0001)$$

Where Q_E is the mean discharge for the entire event (m^3sec^{-1}), and ADD is the duration of the antecedent dry period prior to the event (days).

Work conducted later in the reporting period indicated that an area for improvement of such empirical models is inclusion of serial correlation, or autocorrelation, in the observed turbidity time series. Daily average turbidity observations from Esopus Creek are serially correlated, as shown in (Figure 9.6). The residuals, or errors, in ordinary least square regression models are often highly correlated in time. Since the ordinary regression residuals are not independent for time series data, they contain information that can be used to improve the prediction. The autocorrelation function of the model residuals may show a strong serial

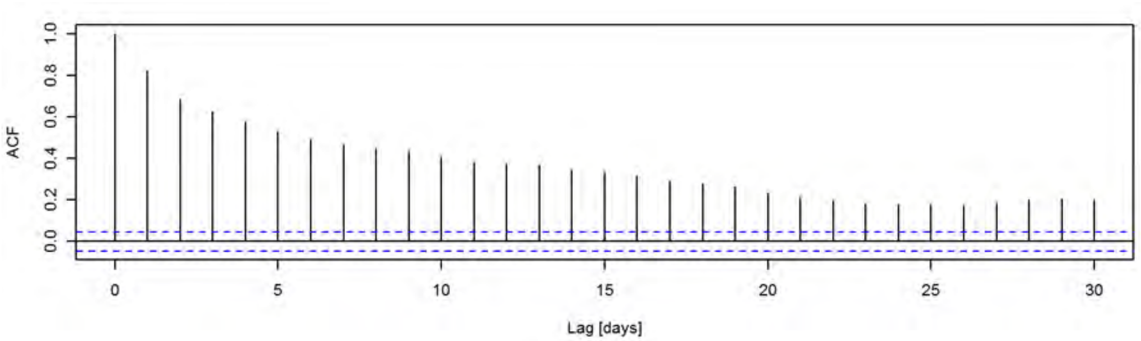

Figure 9.6 Autocorrelation function (ACF) of log-transformed turbidity observations from Esopus Creek. Statistically significant values show up above the upper blue dotted line.

correlation, violating the linear regression assumption that errors are uncorrelated. More importantly, including the effects of autocorrelation can avoid incorrect conclusions on significance of parameters, confidence limits for predicted values, and estimates of regression coefficients.

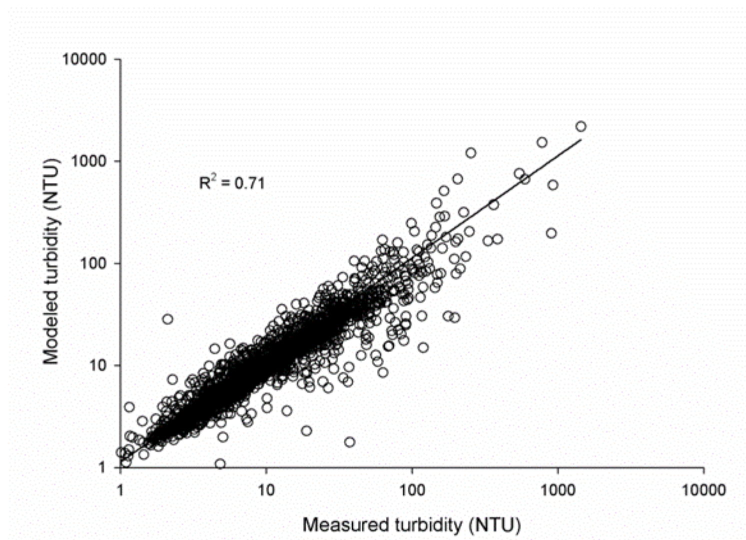

Figure 9.7 Scatter plot of predicted (from the time series model) and measured turbidity in Esopus Creek.

A comparison of observed turbidity with that predicted by this time series model is shown in Figure 9.7. The particular application of this time series model in predicting stream turbidity are: (1) short-term water quality forecasting for operational decision support, (2) interpolating missing values in a time series, (3) determining optimal baseflow sampling frequency for turbidity. Furthermore, improved turbidity predictions at the mouth of Esopus Creek will also improve the predictions of in-reservoir and Catskill Aqueduct turbidity levels.

9.4.2 Development of a Turbidity Model for Rondout Reservoir

Under normal runoff conditions, the Delaware System reservoirs are not impacted by elevated turbidity. However when extremely large storm events occur in the watershed, elevated turbidity may occur in these reservoirs. This was the case for Rondout Reservoir during Tropical Storm Irene (2011) and for Neversink Reservoir during a runoff event in 2012. In response to these events, DEP contracted with UFI to develop a turbidity model for Rondout Reservoir.

The turbidity model for Rondout Reservoir was based on the transport framework of CE-QUAL-W2 and the kinetic process framework of existing turbidity models for Schoharie, Ashokan, and Kensico reservoirs. The Rondout Reservoir model longitudinal segmentation is illustrated in Figure 9.8. Model drivers included inputs of discharge, water temperature and turbidity from the two major stream inputs, Rondout Creek and Chestnut Creek, and the three influent aqueducts from Neversink, Pepacton (East Delaware Tunnel) and Cannonsville (West

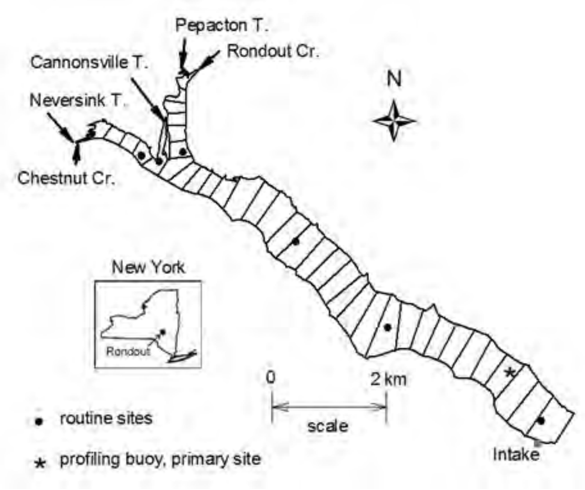

Figure 9.8 Map showing W2 model segmentation for Rondout Reservoir, inflow, outlet, and monitoring locations.

Delaware Tunnel) reservoirs. Meteorological data were obtained from the DEP meteorological stations available on or near Merriman Dam. In addition, as part of the model testing, data collected on an automated sampling buoy in the reservoir were also used (Figure 9.8).

Measurement of particle-size distribution (PSD) and particle composition were made samples from the inflows to and water column of Rondout. As in the models for Schoharie, Ashokan, and Kensico, turbidity causing particles were broken into three classes based on the relationship of light scattering to particle size. Based on these observations, the fraction of total turbidity in each of the 3 classes for the reservoir inflows was determined (Table 9.5). Particle coagulation was added to the turbidity model, allowing a fraction of the two smallest particle size classes to be transferred to the largest size class. To account for the configuration of the Rondout Reservoir outlet, the model code was modified to separately calculate the turbidity from each level of the outlet and from the spillway.

The model was tested for several historical runoff events. A large storm event on September 18-19, 2012 caused a plume of elevated turbidity. While the turbidity did not significantly impact the withdrawal water quality, spatial variations in reservoir turbidity were sufficient to test the turbidity model using short-term hindcasting simulations. Two hindcasting model runs were performed: Simulation of Aug 7 (prior to event) through Oct 11, 2012 (Figure 9.9); and Sept. 25 (after event) through Oct 11, 2012 (Figure 9.10). The model generally

Table 9.5 Contributions (%) to the total turbidity from the three size classes of particles for various sources of water.

Size Class (Size)	Cannonsville (West Delaware Tunnel)	Neversink (Neversink Tunnel)	Pepacton (East Delaware Tunnel)	Rondout Creek
Class I (1 μm)	15%	65%	45%	20%
Class II (3 μm)	50%	35%	45%	65%
Class III (10 μm)	35%	0%	10%	15%

performed well in these simulations. The Rondout W2 turbidity model is now in use for operational guidance during anticipated periods of elevated turbidity in the Delaware system.

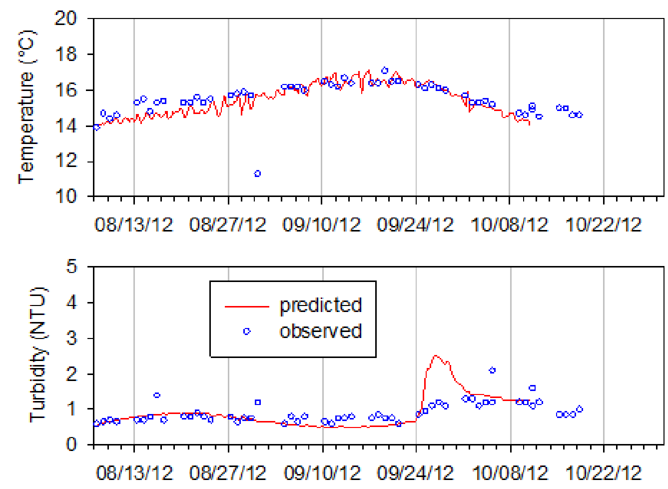

Figure 9.9 Rondout Reservoir model performance for Aug 7 – Oct. 11, 2012 (Gelda et al. 2013).

9.4.3 Upgrade of W2 Turbidity Models to Version 3.7

During the reporting period, as part of the development of OST for the Catskill System, the 2-D reservoir water quality models were upgraded. These existing W2 models for Schoharie, Ashokan and Kensico reservoirs were based on CE-QUAL-W2 version 3.2, and included UFI's turbidity submodel. These models were upgraded to version 3.7 of CE-QUAL-W2. The major benefits of the upgrading were: (1) easier code maintenance, (2) faster compilation and better control over optimization, (3) improved computational speed, (4) support for multiple processors, (5) additional choices for turbulent mixing algorithms. Three additional upgrades were made: (1) alternative segmentation schemes for Ashokan and Kensico reservoirs with a goal of reducing model runtime, (2) inclusion of the effect of solids and turbidity on water density, (3) adjustments to simulated withdrawal turbidity from Ashokan East basin due to short-circuiting.

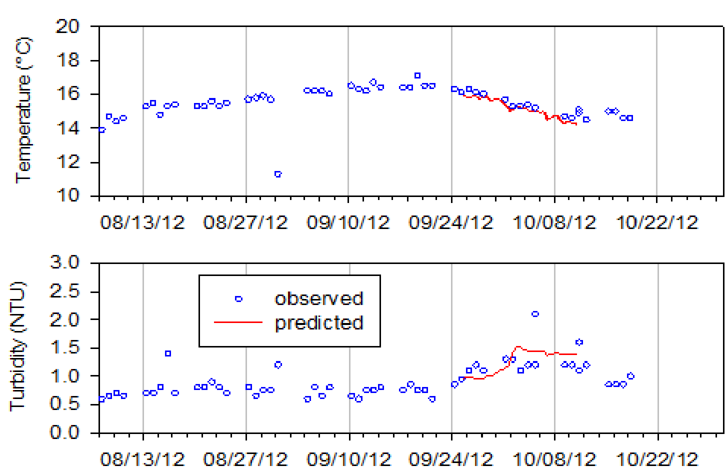

Figure 9.10 Rondout Reservoir model performance for Sept. 25 – Oct. 11, 2012 (Gelda et al. 2013).

The modified grid for Ashokan East basin considered 18 segments as compared to 39 segments in the original grid, with coarser resolution towards the eastern end and finer resolution near the dividing weir. With the alternative grid, the model runs 1.6 times faster than with the original grid. The overall improvement in the runtime, from using a coarser model grid and adopting version 3.7, was ~ 2.3 times.

The model predictions of turbidity with the two segmentation schemes were very similar. A coarser model grid for Kensico Reservoir with 24 active segments was adopted as compared to 46 active segments in the earlier grid. The new grid resulted in runtimes reduced by a factor of 3.3. Predictions of the withdrawal temperature and turbidity with the new coarser grid were virtually unchanged.

High concentrations of suspended solids are known to affect water density. For accurate simulation of hydrodynamics where such conditions exist, it is important to include the effect of solids on density. To address this, the W2 code was modified to include the effect of solids on density, where solids concentration was estimated from turbidity.

In the East Basin of Ashokan Reservoir, inflow from the West Basin enters the same W2 model segment from which the withdrawal from the East Basin occurs. There is evidence from observations and from model applications that the inflow to the East Basin may not always mix completely throughout this model segment before exiting the reservoir through the withdrawal structure, as assumed by the 2D model. This pattern of inflow to the East Basin has been described as short-circuiting. An approach was developed to correct for the short circuiting in the W2 model application as part of the OST. The method involved the application of a 3D hydrodynamic model near the gate house for selected events. The 3D model and W2 model results are compared to obtain an empirical post-processing correction for the W2 model. This approach accepts the 3D simulations as most accurate, based on its more complete representation of transport in both the lateral and longitudinal dimensions. Effectively, the 3D model simulations provided a basis to adjust the 2D model simulations to accommodate the effects of lateral short circuiting.

9.4.4 Operations Support Tool

OST is a software tool developed to help guide short-term reservoir operations as well as to evaluate long-term water resources planning decisions. It is comprised of a suite of CE-QUAL-W2 reservoir water quality models and OASIS reservoir systems model, linked with near real-time data acquisition, database and data visualization tools. The OASIS model includes the entire Delaware River Basin, the Catskill system, and the Croton system. W2 based turbidity models for Schoharie, Ashokan, and Kensico reservoirs are included in OST.

During the FAD assessment period, OST was further developed to include: (1) extension of the hydrologic and meteorological database through 2012, (2) acquisition of near real-time monitoring data, (3) improved prediction of Ashokan effluent turbidity by accounting for short-circuiting of flow over the dividing weir from the West Basin, (4) implementation of improved empirical loading prediction for Esopus Creek, (5) improvement in synchronization between DataMart (a database for OST developed by Hydrologics) and Aquarius (time series data acquisition and management software developed by Aquatic Informatics), (6) development of a tool to generate initial conditions file for Schoharie, Ashokan, and Kensico reservoirs, (7) improvement in OST graphical user interface and Dashboard to include processing and visualization of model output, (8) addition of animation software.

9.5 Application of Models to Support Operational Decisions

As described elsewhere in this section, DEP has developed a suite of mathematical water resources and water quality management models. This section presents selected examples of applications of such models. The models used were W2 reservoir turbidity models, watershed models (GWLF, SWAT), and system models (OASIS as part of OST).

Major runoff events in the CAT/DEL watersheds can impair water quality in receiving reservoirs. Model simulations to support operational decisions during these events were almost always related to elevated turbidity levels that occurred in Rondout, Schoharie, Ashokan, or Kensico reservoirs. The simulations usually followed a position analysis strategy that produced an ensemble of probable outcomes and allowed managers to make operations decisions in a probabilistic manner. Simulations were intended to answer questions such as: how should the operations be modified so that the need for adding alum in the Catskill Aqueduct at Kensico Reservoir is reduced or eliminated, what is the optimum turbidity loading to Kensico Reservoir, how should the West Basin of Ashokan Reservoir be drawn down, etc. Five selected modeling cases are presented below:

October 3, 2011: What is the best Catskill Aqueduct flow rate to minimize the movement of the turbid plume in Kensico?

Issue: Ashokan Reservoir had been impacted by Tropical Storm Irene and Tropical Storm Lee when another smaller runoff event caused high turbidity water to move across the dividing weir from Ashokan West Basin to the East Basin. This resulted in the East Basin withdrawal turbidity to rise to ~200 NTU. Furthermore, two plugs of high turbidity water had entered Kensico Reservoir during Sep. 29-Oct 1. Turbidity remained elevated in Rondout Reservoir resulting in influent turbidity at DEL17 of 3–4.5 NTU.

Modeling: Simulations were made to provide guidance on the Catskill Aqueduct flow rate (with or without stop shutters) to minimize the movement of the turbid plume in the Catskill arm of Kensico Reservoir to intake works. Two flow rates were tested: 50 MGD (minimum with stop shutters) and 275 MGD (minimum without stop shutters). In addition, the runs also investigated the potential use of alum on Delaware influent to Kensico Reservoir. The effective turbidity of Delaware influent treated with alum was unknown, so two potential inputs, 1 NTU and 2 NTU were tested. Runs using 4 NTU and 6 NTU input from Delaware were also performed to understand the effects of no alum use.

Results: All model simulations indicated a rapid increase in effluent turbidity as plume of turbidity in Kensico reservoir began to influence its effluent turbidity. Simulations with Catskill flow of 50 MGD showed less immediate increase in turbidity at effluents. For the longer term, the optimum mix of the CAT/DEL waters was dependent on the difference between alum treated Catskill influent turbidity and Delaware influent turbidity.

February 28, 2012: Is it necessary to continue alum use when turbidity had dropped in Ashokan East Basin after Tropical Storm Irene and Tropical Storm Lee?

Issue: Since the tropical events of the autumn of 2011, turbidity in Ashokan East Basin had dropped to about 20 NTU. Stop shutters and alum treatment continued to be implemented.

Modeling: As Ashokan East Basin turbidity continued to decrease, it might be possible within the next few months to end alum use. These Kensico Reservoir simulations were made to provide guidance as to what levels of turbidity could be tolerated as inputs to Kensico Reservoir from the Catskill aqueduct when alum treatment was ended. The tested flow rates were 150, 200 and 250 MGD in the Catskill Aqueduct with aqueduct turbidity of 12, 16 and 20 NTU.

Results: Results suggested that Kensico effluent turbidities would be 1.7–2.5 NTU for the case of influent turbidity of 12 NTU and 2.2–3.7 NTU for the case of influent turbidity of 20 NTU. Greater influent flow in the Catskill Aqueduct produced larger effluent turbidity.

September 28, 2012: What is the best strategy to minimize turbidity from Ashokan and Neversink during turbidity events?

Issue: A turbidity event on September 18, 2012 produced a large input of turbidity into Ashokan and Neversink reservoirs. In Ashokan Reservoir, the event did not fill the West Basin, but caused a plume of 200-300 NTU water just above the thermocline with values of >30 NTU at other depths. Since West Basin was not filled, the East Basin was only adversely affected to the extent that the dividing weir must stay partially open. In Neversink, a turbidity plume >300 NTU had formed; the Neversink diversion was offline; and the diversion was expected to remain offline for the foreseeable future.

Modeling: An OST simulation was made to provide an estimate of: (1) the period of time that it would take Ashokan Reservoir West Basin turbidity to reach the East Basin, (2) the extent to which the use of the Ashokan Release Channel will change the timing and magnitude of turbidity movement from West to East; (3) the effects of Release Channel use on potential Catskill Aqueduct flow reductions due to turbidity, (4) the effects of a temporary loss of the Neversink diversion on reservoir storage throughout the system.

Results: In these simulations, use of the release channel under the current protocols marginally delayed the movement of turbid water from the West Basin to the East Basin, however runs performed in October 2012 with more refined (and realistic) operations indicated greater delay and a decrease in the probability of West Basin turbidity moving to the East Basin. Reduction of Catskill Aqueduct flow could be used to reduce Kensico Reservoir turbidity inputs such that alum treatment might be avoided, however, this could require some drawdown in West Branch and Kensico Reservoirs. In about 12% of these simulations either another extreme storm event negatively impacted the Catskill System or a potentially large and unacceptable drawdown of West Branch and/or Kensico Reservoirs was simulated to occur. Later runs of the OST were performed to update these results in October 2012.

May 16, 2014: What would be the impact of an imminent runoff event at Ashokan and Schoharie reservoirs?

Issue: On May 14, 2014, Ashokan buoys indicated turbidity 2.5–5.5 NTU at site 4.2 near the gate house in the East Basin; 4.7–17.3 at site 1.4 in the West Basin; and 1.9–4.6 NTU at site 3.1 near the gate house in the West Basin. Turbidity in Schoharie Reservoir on May 13, 2014 was 9–18 NTU.

Modeling: OST was used to generate probabilistic forecast of turbidity in Schoharie and Ashokan reservoirs for the following 30 days.

Results: Ashokan Reservoir turbidity was not simulated to rise to extreme levels over the following 30 days. This was mainly due to the forecast consisting of only moderate and short-lived storm events. Ashokan West Basin turbidity was simulated to exceed 10 NTU in only one out of the 48 forecast traces simulated. Ashokan East Basin turbidity was not simulated to exceed 4 NTU in any of the forecast traces.

June 6, 2014: How would turbidity be affected in the Ashokan Reservoir for the summer if a recreational water release was implemented?

Issue: What would be the impact of a planned recreational water release, from Shandaken Tunnel into Esopus Creek, on the turbidity in Ashokan Reservoir?

Modeling: OST was used to generate probabilistic forecast of turbidity in Ashokan Reservoir through the end of August 2014.

Results: The effect of Shandaken Tunnel recreational releases was not apparent in the Ashokan Reservoir turbidity simulations. Ashokan East turbidity near the gate house was predicted to generally stay between 1–2 NTU for the period except for a few scenarios with peaks generated by higher Esopus watershed events during August. In most cases the turbidity plume located in the Ashokan West Basin was simulated to slowly decrease in magnitude and sink to deeper zones of the reservoir. The low magnitude turbidity plume located in the Ashokan East Basin was generally simulated to remain near thermocline depth.

9.6 Model Applications to Support Watershed Management and Long-term Planning

9.6.1 Introduction

As a component of DEP's modeling program, models and simulations are developed to support watershed management activities and improve long-term planning. Models have been used to inform planning for stream restoration projects by identifying areas likely to cause increased turbidity in the watershed. These models can be leveraged with high resolution supporting data such as elevation, soils and land-use to identify potential problem areas with limited monitoring data. More intensive fieldwork required for watershed management projects can then be focused on specific target areas suggested by the models for further investigation.

9.6.2 Pilot Study of Sediment Fingerprinting in the Esopus Creek Watershed

A project was conducted during the reporting period to characterize suspended sediment sources in the Esopus Creek watershed. Potential sediment sources to the creek include glacial and non-glacial fluvial sediments which are subject to channel erosion, and upland sediments that could be mobilized due to surface erosion. In this study a fingerprinting approach was used to track sediment movement within the watershed from various sources to the stream. The objective was to determine the relative contribution of sources to the total fine sediment load. The underlying principle is the difference in physical or chemical properties among the potential source materials are reflected in sediment samples collected from the watershed outlet.

Potential sediment sources were characterized for physical and chemical properties. Physical properties included the particle size distribution and the bulk density of each sediment source. Chemical properties included total carbon and stable isotopes of carbon and nitrogen ($\delta^{13}C$ and $\delta^{15}N$) in each sediment source. Stream sediment from the outlet of Esopus Creek at Coldbrook was collected along the rising limb of a storm hydrograph during an event on October 1, 2010. This event recorded the maximum event mean turbidity (1,402 NTU) based on the analysis of event turbidity loads between 2003 and 2011. For the preliminary analysis of sources, total C and $\delta^{15}N$ were found to be the useful tracers based on their composition in sources and stream sediment. The total C values in source samples were corrected for particle size and expressed in terms of clay content in order to ensure that source and stream sediments were comparable.

A mixing model approach was used to derive the proportion of stream sediment derived from each of the three potential sources. Results of mixing model indicate glacial sediment from stream channels as the most dominant source contributing about 91% of the stream sediment. Hillslope erosion contributed about 7% and non-glacial channel sediment contributed only about 2% of the total stream sediment. These results are consistent with previous evaluations of stream channel processes contributing up to 87% of total stream sediment loads in this watershed.

9.6.3 A Planning Level Tool to Identify Stream Channel Erosion Sites

A related study completed during the reporting period involved the application of a screening model to identify variations in the susceptibility of stream banks to erosion within the Esopus Creek watershed to determine potential sites of stream restoration projects for improving channel stability and water quality (Mukundan et al. 2012). Stream power based estimates of the susceptibility to channel erosion were compared to channel erosion sites identified using the bank erosion hazard index (BEHI) and rapid geomorphic assessment (RGA) indices. Calculations were performed for the Stony Clove Creek in the Esopus Creek watershed. The objective was to test a simple stream power based approach for ranking the relative susceptibility of channel reaches to degradation caused by fluvial erosion at the watershed scale. The analysis evaluated whether the relative contributions to sediment yield from different stream reaches calculated according to our stream power model are consistent with those given by rapid assessment methods.

Reach-scale variation in fluvial adjustments such as bank retreat is influenced by the stream power that can be defined as the energy available within the channel for overcoming channel resistance and sediment transport. Total stream power per unit channel length is effectively the rate of energy dissipation due to friction per unit channel length (units of watt meter^{-1}) Total stream power was calculated for each stream reach at bankfull discharge. Watershed delineation and determination of channel slope and geometry was done using a 10-m resolution DEM for the Stony Clove basin. To identify specific locations within a reach that may be susceptible to channel erosion due to excess shear stress from high stream power, a GIS tool was developed for mapping the longitudinal distribution of stream power along a stream channel.

Figure 9.11a shows the longitudinal variation in total stream power estimated along the main stem of Stony Clove Creek based on high resolution estimates of stream slope. Although an increasing trend in stream power was observed in the downstream direction, peaks were also observed. The most significant peak was observed near the 4,000 mark where the total stream power increased from near 2,000 to over 10,000 watt meter^{-1}. This increase was due to a combination of increased stream discharge as well as relative increase in channel slope at this location (Figure 9.11b and c). Such nonlinear increase in stream power may be used to identify potential areas of channel disturbances due to excess shear stress. Overlaying the generated stream power map with the high resolution aerial photographs allowed comparison of the predicted hotspots of channel instability with real channel features.

This type of stream power mapping has implications for stream management strategies such as identification and selection of best possible stream restoration practices at different sections along the stream network. For example, erosional sites identified in regions of relatively low stream power may be restored using vegetation that protects the stream bank whereas erosional sites identified in regions of high stream power may require more robust protection such as engineering structures. With extreme streamflow events being observed and predicted to increase in the future, stream power mapping provides an opportunity to predict stream locations that may be more sensitive to changes in storm discharge. Another potential use of stream power mapping is for distinguishing streams that are degrading, where stream power shows an increasing trend downstream, from aggrading streams where stream power decreases in the downstream direction.

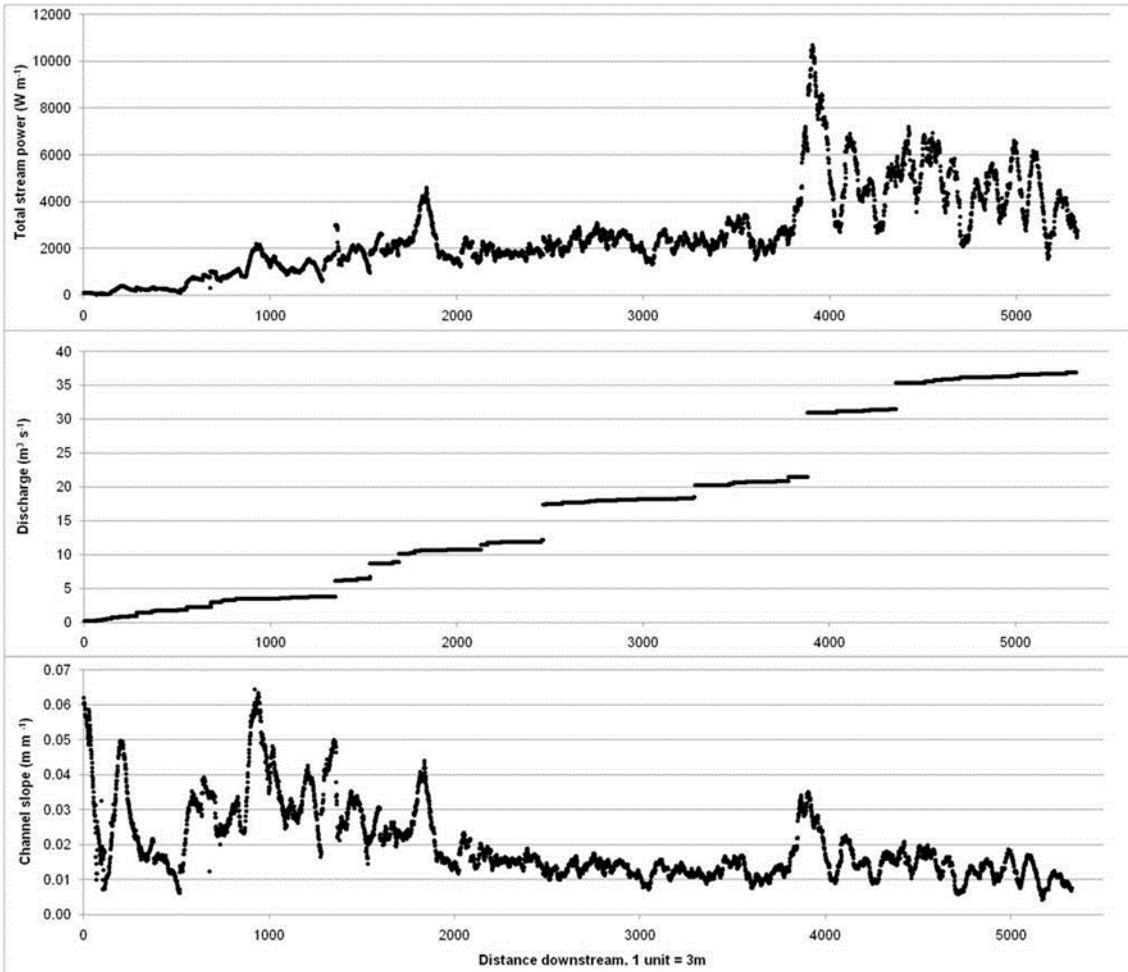

Figure 9.11 Longitudinal variation in properties for Stony Clove Creek: (a) total stream power; (b) bankfull discharge and (c) channel slope.

9.6.4 Simulating Spatial Sediment Loading in the Esopus Creek Watershed

Previous analyses of sediment sources in the upper Esopus Creek watershed indicated that the majority of suspended sediment originated from stream channels. While there is a general consensus on the dominant source of suspended sediment in the watershed, the spatial distribution of suspended sediment sources as well as the relative contribution by stream channels, uplands, and point sources is uncertain. During the reporting period, DEP and the USGS conducted a monitoring project to collect detailed spatial and temporal turbidity and suspended sediment data in the Esopus watershed. Completed in September 2012 one of the objectives of this project was to generate field data that can support water quality modeling analysis. DEP used information generated from this monitoring project to guide a spatially distributed model parameterization and modeling analysis. The objectives of this analysis were: (1) to use short-term monitoring data from multiple sites across the study watershed for parameterization and testing of a model for long-term simulation of sediment transport, (2) to simulate spatial variations in sediment entrainment within the Upper Esopus Creek watershed and its tributaries and predict sediment concentrations at the watershed outlet, (3) to quantify sediment yield at the watershed outlet.

The approach was to apply the SWAT model to estimate water, nutrient and sediment loading from a watershed. Using the ArcSWAT2012 GIS interface, the upper Esopus Creek (UEC) watershed was delineated into 89 sub-basins. In addition to streamflow and sediment data collected from monitoring stations in the watershed, data used to set up the SWAT model include 2001 satellite-based land use maps, SSURGO soils data, daily air temperature and precipitation, and other weather data. A three-step approach was used for model parameterization and calibration for spatially distributed sediment entrainment and transport simulation. In the first step, the model was calibrated for streamflow using observations from the USGS gage at Coldbrook. Second, channel parameters were adjusted for each major sub-basin individually to simulate sediment entrainment from the channel reaches. In the third step, channel transport capacity parameters were optimized using the SWAT automatic calibration tool, SWAT-CUP.

The period from June 2003 to December 2006 was the model calibration period for both streamflow and sediment concentration. The calibrated model was validated for streamflow and sediment concentration during the period from October 2008 to September 2010. The validated model was then used to provide a continuous simulation for the 1999 to 2010 under the wide range of hydrologic conditions observed during this period. The relative contribution of suspended sediment from the three sources in the UEC watershed based on long-term simulation of the calibrated model was 85% from stream channel processes, 11% from surface/upland erosion, and 4% point source.

Sediment yield from tributaries and the main stem of the Esopus Creek watershed predicted for 1999-2010 using the calibrated model are presented in Figure 9.12. The contribution of Stony Clove was estimated as 37% of the total sediment load; Woodland Creek (7%) contributed the next highest, followed by Beaverkill (5%). All other tributaries contributed less than 2% of the total sediment load at the outlet. In terms of a sediment load, this study, along with data collected by USGS, indicate that Stony Clove is a critical watershed for sediment reduction efforts. Two major stream restoration projects were completed in Stony Clove in 2012-2013; they included channel realignment, regrading and bank stabilization. This study shows that short-term detailed water quality monitoring programs complemented with watershed modeling efforts can help to quantify the sub-basin sources of suspended sediment and help to inform management options.

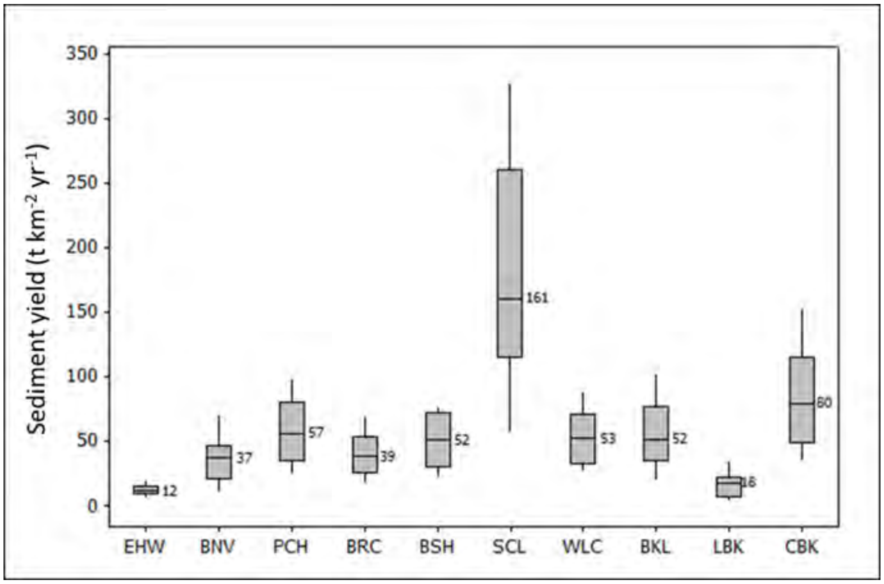

Figure 9.12 Simulated average annual suspended sediment yields from major sub-basins and outlet of the Esopus Creek at Coldbrook.
(EHW - Esopus headwaters; BNV – Bushnellsville; PCH - Peck Hollow; BRC – Birch Creek; BSH – Broadstreet Hollow; SCL – Stony Clove; WLC – Woodland Creek; BKL – Beaverkill; LBK – Little Beaverkill; CBK – Coldbrook)

9.7 Update of Future Climate Scenarios for Use as Model Inputs

9.7.1 Climate Change Integrated Modeling Project: Phase I

DEP's Climate Change Integrated Modeling Project (CCIMP) has the goal to evaluate the effects of future climate change on the quantity and quality of water in the DEP water supply. The project is an element of DEP's Climate Change Action Plan, established in 2008. Phase I of CCIMP was designed to address three major issues: (1) overall quantity of water in the entire water supply; (2) turbidity in the Catskill System of reservoirs, including Kensico; (3) eutrophication in Delaware System reservoirs. During Phase I, an initial estimate of climate change impacts was made using available global climate model (GCM) data sets and DEP's suite of watershed, reservoir and system operation models. Phase I of the CCIMP was completed in the fall of 2013, at which time a review workshop was held and the subsequent publication and distribution of a report detailing Phase I activities and a review of Phase I by a panel of experts.

In Phase I, considerable work was done on the application of the change factor approach, or delta change factor methodology, for describing and quantifying future climate conditions. The change factor approach is a method for downscaling of output from GCMs. Four GCMs were used by DEP in Phase I climate change work, identified by the acronyms which follow the GCM developers: National Center for Atmospheric Research (NCAR), Canadian Center for Climate Modeling and Analysis (CGCM3); European Center Hamburg Model (ECHAM); and Goddard Institute of Space Studies (GISS). GCMs typically have multiple simulations that cover a range of future atmospheric CO2 emissions scenarios. The future emission scenarios used with the GCM models are from the Special Report on Emission Scenarios (SRES) published in 2000. The SRES emission scenarios A2, A1B, and B1 represent future high, medium, and low greenhouse gas emissions.

Change factors are determined by comparing two time slices of a GCM simulation: a current conditions time slice and a future time slice. In Phase I work, time slices used in GCM predictions were 1981-2000 for current conditions, and 2046-2065 and/or 2081-2000 for future conditions. Individual changes factors are then determined as the difference (commonly used for air temperature) or ratio (commonly used for precipitation) of the two (current vs. future) predictions. This difference or ratio is then applied to an observed local meteorological dataset, creating a future climate time series that can be used to drive hydrologic and reservoir models.

Change factor values computed for future scenarios generally point to greater precipitation for most months and most scenarios. However, there are small decreases in precipitation in most months for some GCM simulations. For temperature, the change factors are positive for all months and more positive for 2081-2100 simulations. The change factors for wind speed tend to imply decreases in winter values, with many simulations indicating increases in spring and summer; however, most months have simulations with both increases and decreases in wind speed. Change factors for solar radiation show wide variability during each of the months, with no clear trend.

9.7.2 Climate Change Integrated Modeling Project: Phase II

Phase II of the CCIMP began in 2014 and is ongoing. The general goals were the same as Phase I, but in Phase II a more extensive set of GCM data will be used along with improved downscaling methods to develop a wider variety of future climate scenarios. DEP will also be making use of additional models and will subject all models to increased testing and scrutiny in respect to their climate change predictions.

In Phase II of CCIMP, an alternative approach is being developed to evaluate the impact of climate change. This approach begins with the development of stochastic weather generators (WGs). Weather generators are statistical models that produce long time series of weather variables (precipitation, temperature, etc.) that have statistical properties that are similar to those of existing records at a location of interest. There are different types of WGs, each having advantages and disadvantages. In Phase II work that has been completed, 12 parametric WGs, including all combinations of first, second, and third order Markov chain models, and four different probability distributions (exponential, gamma, skewed normal, and mixed exponential) have been evaluated, together with one semi-parametric WG based on k-nearest neighbor bootstrapping. Comparison of these alternatives suggest that the skewed normal and mixed exponential probability distributions combined with first order Markov chain models are most consistent with observations. The analysis of these alternatives has been completed only for precipitation. Future evaluations will include other meteorological variables including temperature and wind speed.

The stochastic weather generators are to be used in so-called bottom-up assessments of the impact of climate change. Bottom-up, or vulnerability-based approaches to climate change are a relatively new area of research. Bottom-up approaches will allow the exploration and identification of the vulnerability of the DEP water supply system to climate change over a wide range of plausible conditions.

9.8 Model Applications that Simulate the Impacts of Future Climate Change on Reservoir Water Quality and Quantity

Future climate change is expected to affect the ecology, hydrology, and water quality of the DEP watershed. The potential effects of climate change on the DEP water supply system can be simulated using site-specific mathematical models. During 2011-2015, DEP conducted the following studies to assess the effects of climate change on the portions of Catskill and Delaware watersheds: (1) stream flows in Cannonsville watershed, (2) sediment erosion and sediment yield in Cannonsville watershed, (3) thermal stratification in Cannonsville and Pepacton Reservoirs, (4) wintertime eutrophication in Cannonsville Reservoir, (5) wintertime turbidity in Esopus Creek, (6) wintertime turbidity in Ashokan Reservoir.

9.8.1 Streamflow Responses to Climate Change: Analysis of Hydrologic Indicators

During the reporting period, DEP conducted a study of the impacts of climate change on streamflow. The goals of this study were: (1) to examine how changes in precipitation and air temperature translate into changes in streamflow in the Cannonsville watershed using SWAT-WB, (2) to analyze baseline and future streamflow scenarios using the Indicators of Hydrologic Alterations (IHA) tool (Richter et al. 1996) to gain an overall indication of the extent of hydrological change from reference conditions. The potential effect of climate change on streamflow was assessed using scenarios derived from a group of GCMs that represent a range of future (2081-2100) climate conditions for the A1B scenario (representing rapid economic growth with balanced emphasis on all energy sources). Climate scenarios were downscaled using change factor methodology.

The general approach for hydrologic assessment consisted of defining a series of 33 hydrologic attributes that characterize intra-annual variability in streamflow conditions and then analyzing these variations to evaluate the impact of climate change on streamflow. The hydrologic attributes are based upon five characteristics of hydrologic regimes, known as Indicators of Hydrologic Alterations (IHA) (Richter et al. 1996). The IHA analysis statistically characterizes inter-annual variation in flow regimes and, because the methodology uses median daily streamflow, it is suitable for detecting the hydrological characteristics relevant to sustaining aquatic ecosystems. Seventeen of the 33 IHA parameters focus on the magnitude, duration, timing and frequency of extreme events, while the remaining 16 parameters are measures of the median of the magnitude of flows or the rate of change of water conditions. The steps used in hydrologic assessment are as follows:

- The streamflow time series (1964-2008) for baseline and nine climate change scenarios were defined; the baseline simulation was treated as pre-impact scenario and each climate change scenario as post-impact scenarios.
- The values for the ecologically relevant 33 parameters for each year in each time series were calculated.
- Inter-annual statistics such as measures of central tendency and dispersion were calculated for each time series for 33 parameters.
- The median and coefficient of variations for each parameter was then compared between simulated streamflow and streamflow as a result of climate change.

Changes in daily streamflow metrics were analyzed to identify changes in dynamics of streamflow in the Cannonsville watershed between the baseline simulation and the various climate change scenarios. When examining the hydrologic effects of climate change scenarios, the change in the hydrologic responses were calculated relative to the results from the calibrated baseline simulation, rather than the historic observations.

The hydrologic assessment showed an increase in median monthly streamflow for winter months. The highest increase in median daily flow was observed for January. An increase in winter flow can affect not only habitat suitable for winter flora and fauna, but can increase stream bank erosion and mass flux of pollutants. The streamflow decreased from April through September. The reduced flow during April and summer months can have adverse impacts on fish habitats and spawning. Annual mean streamflow increased for all the climate change scenarios. The results indicate that streamflow will become much more extreme with increases in both consecutive 7-day low flow (124% increase from baseline) and in 7-day high flow (3.5% increase from baseline) under future climate scenarios (Pradhanang et al. 2013) (Figure 9.13).

The timing of the maximum 1-day flow shifted from March 25 to March 19 while there was a forward shift in the timing of minimum flow as it shifted from early February to late October. This degree of shift would likely adversely affect the fall spawners such as brook trout due to reduced habitat availability resulting from extended low flow conditions. The pulsing behavior of the stream at the USGS gauge in Walton, NY shows a reduced (17.2%) number of low pulse events but an increase of 18.5% in high pulse events compared to the baseline scenario. The results showed an increase in both rise and fall rate of the hydrograph (e.g., steeper rising and receding limbs) resulting in increase in number of reversals.

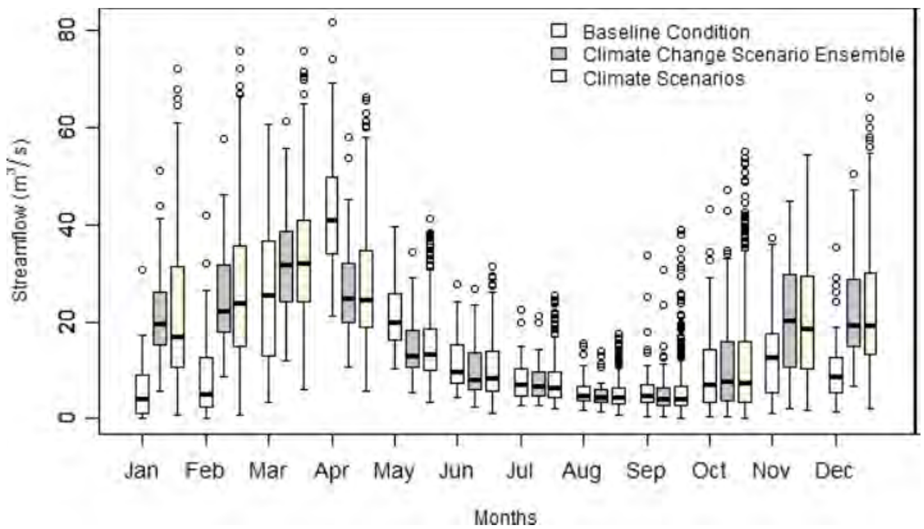

Figure 9.13 Monthly Median Streamflow (Group 1 Indicators) Box Plots for Baseline Scenario (hollow box), Average of Ensemble Climate Scenarios (gray box), and Climate Scenarios (bisque box).
Climate scenario boxplot contains all the data points (monthly medians) for eight climate models showing the range of streamflow simulations using eight climate models.

9.8.2 Modeling Sediment Source Areas and Future Climate Impact on Erosion and Sediment Yield in Cannonsville Watershed

In another study, DEP applied SWAT-WB to simulate sediment transport and quantify the potential impact of climate change on soil erosion and sediment yield in the watershed of Cannonsville Reservoir. An examination of historical data and results of model simulations for this region have shown an increasing trend in precipitation and streamflow over the past fifty years. The goal in this study was to examine how changes in precipitation and streamflow translate into changes in soil erosion and sediment transport in the Cannonsville watershed using a physically based model. The specific objectives were to identify the major sediment source areas within the Cannonsville watershed, and to quantify the impact of future climate on long-term sediment loads at the watershed outlet.

SWAT-WB was calibrated for streamflow and sediment yield at the watershed outlet for the 1991-1995 water years and validated for the 2000-2002 water years. Measured daily streamflow data was obtained from the USGS gauging station at the watershed outlet at Walton. Total suspended solids (TSS) was observed near the Walton station using a sampling protocol that allowed accurate estimation of both baseflow and storm event sediment loads. The calibrated streamflow and sediment models were used to simulate a historical baseline scenario (1965-

2008) of sediment yield using measured meteorological forcing. Both hydrology and sediment calibration used the goal of maximizing the coefficient of determination (R^2) and Nash-Sutcliffe efficiency, while minimizing percent bias. In addition, hydrology calibration was optimized so that the observed runoff and baseflow components of streamflow were captured.

The potential effect of climate change on soil erosion and sediment yield was evaluated using scenarios derived from GCMs that represent a range of future climate conditions, for the 2081-2100 future period, and using the A1B emission scenario. Climate scenarios were downscaled using the change factor methodology. Monthly change factors were used to adjust the same local meteorological data used for the baseline simulation to represent the future climate conditions. Use of long-term observed data in generating future climate scenarios ensured that the scenarios were representative of the observed climate patterns in the region. The predicted future trends in sediment yield at the watershed outlet indicate that during the October-February interval, sediment yield from the watershed increases, with decreases in the remainder of the year (Figure 9.14). These predictions should be viewed as qualitative trends, rather than as absolute numerical predictions, given the uncertainty in future climate predictions, particularly since potential changes in extreme events are not completely captured by GCMs and the downscaling method used. Results indicate a sharp increase in the annual rates of soil erosion although a similar result in sediment yield at the watershed outlet (Figure 9.14) was not evident.

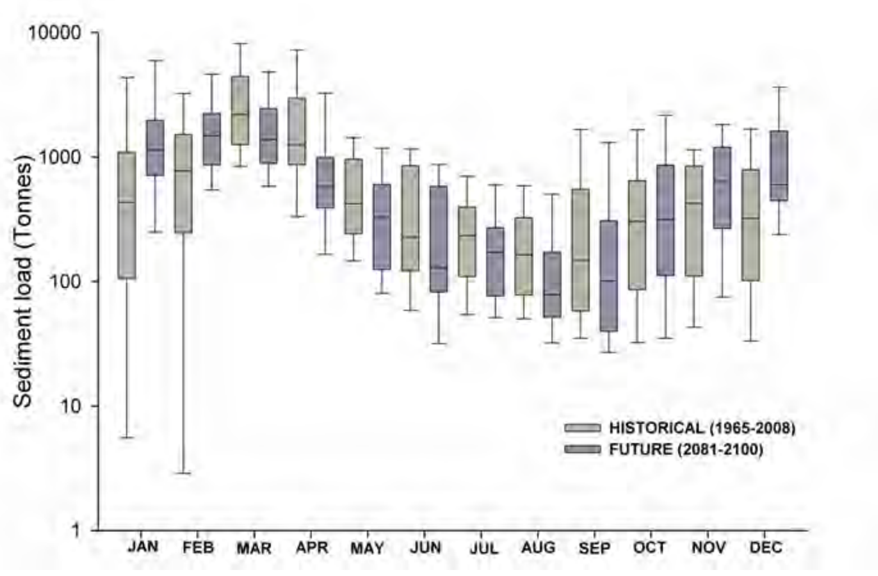

Figure 9.14 Boxplot of average monthly sediment yield from watershed outlet. Boxes represent the 25th and the 75th percentile and whiskers represent the 5th and 95th percentile values.

9.8.3 Impact of Climate Change on Thermal Stratification in Cannonsville and Pepacton Reservoirs

DEP has investigated the potential impact of climate change on the thermal structure and mixing regimes of the Cannonsville and Pepacton Reservoirs. This study used climate scenarios representative of current conditions (1980-2000) and two future time periods (2045-2065, 2080-2100). Future climate scenarios were derived by examining the differences between simulations of baseline and future time periods associated with three GCM models. Based on these differences, single monthly change factors were developed and applied to local records of meteorological data to produce future scenarios of air temperature, precipitation, humidity, solar radiation and wind speed. These data are used to drive the Generalized Watershed Loading Functions-Variable Source Area (GWLF-VSA) watershed model to simulate the future reservoir inflows. A one dimensional hydrothermal model was then applied to simulate the vertical water temperature over historical data sets and future scenarios for each reservoir. Stratification and mixing indices are derived from the simulated water temperature and observed wind speed under three different climate scenarios (A1B, A2 & B1). Both the watershed and reservoir hydrothermal models have been rigorously tested for these watersheds and reservoirs.

The impact of climate change on a number of measures of thermal stratification were determined. Figure 9.15 displays the impact on the date (Julian day) of the onset (formation) and loss of thermal stratification. On average the length of stratification in Cannonsville is projected to increase by seven days and 12 days for the A1B and A2 emission scenarios. Water temperature under these different climate scenarios was predicted to increase. There is a substantial projected increase in both surface and bottom temperatures under different future climate scenarios. For Pepacton, similar results suggest that the length of stratification will increase but by a greater extent of 16 and 21 days in the case of the A1B and A2 scenarios.

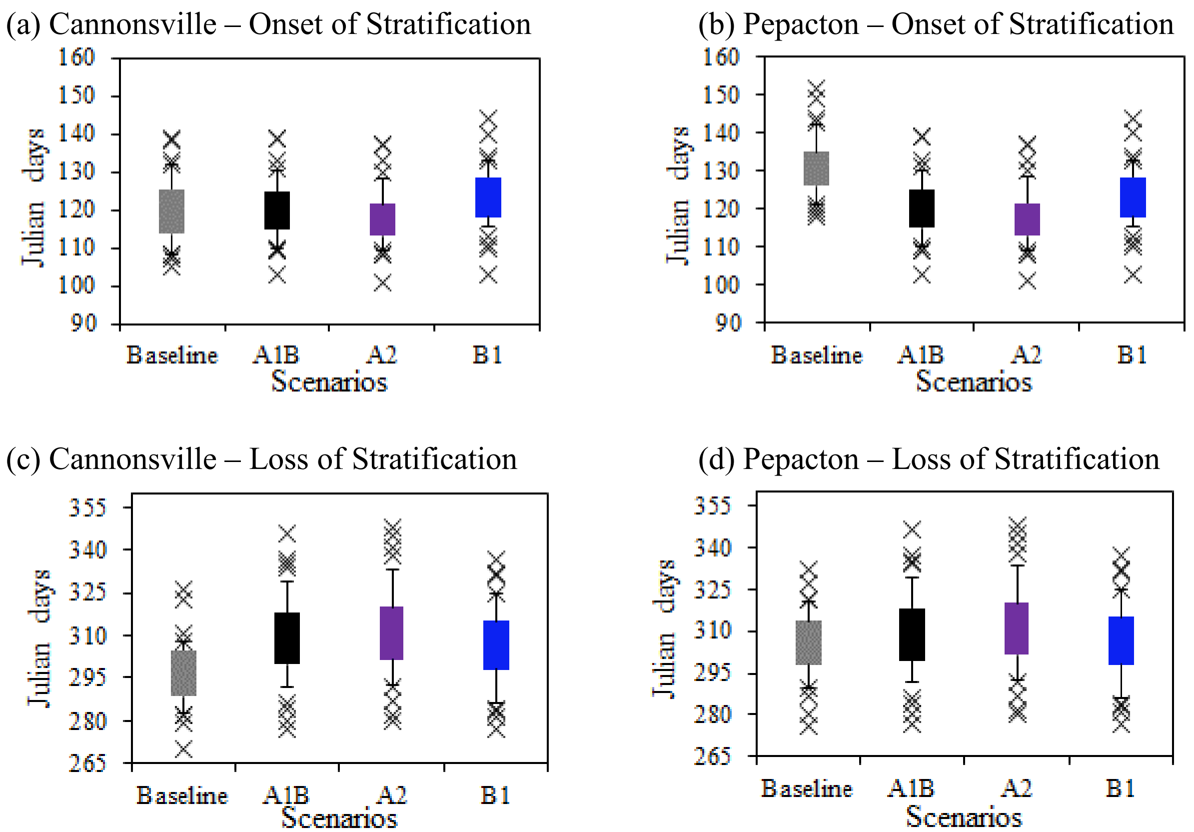

Figure 9.15 Boxplot showing range of Julian day of onset of stratification (a, b) and loss of stratification (c, d) for Cannonsville and Pepacton Reservoirs, for baseline and future climate scenarios.
Future scenarios represent time slice 2080-2100.

9.8.4 Effects of Winter Processes on Reservoir Eutrophication Simulations

Winter streamflow is historically an important component of the annual water budget in WOH reservoirs, and the ability to simulate the effects of changing levels of winter streamflow and nutrient loading on reservoir trophic status may be important for simulating present and future variations in reservoir trophic structure. This study examined: (1) the importance of winter nutrient loads to the annual nutrient load of Cannonsville Reservoir, and (2) the sensitivity of the DEP's reservoir eutrophication models to this variability.

The models used in this investigation were the GWLF VSA watershed model to simulate reservoir inflow and nutrient load, and two versions of a one dimensional reservoir water quality model that focuses on phytoplankton growth and eutrophication. GWLF VSA is used to predict watershed nutrient loading. The timing and magnitude of nutrient loading over any given year varies as a function of the daily variations in air temperature and precipitation that drive the model. Yearly variation in the meteorological inputs leads to yearly variation in hydrology and nutrient loading, including the proportion of the yearly nutrient load that occurs in the winter. Variations in winter nutrient loads can be examined under contemporary conditions driving the model with measured historical meteorological data, and under future conditions by driving the model with air temperature and precipitation data from future climate scenarios. For this study the models were driven by both historical data and future climate scenarios.

The two reservoir water quality models used by DEP are built upon the same one dimensional hydrothermal framework (Owens 1998), which simulates the reservoir thermal structure, and the rate of inflow, outflow, and vertical heat and mass transport. Both models simulate phytoplankton growth as a function of water temperature, light and nutrients. The UFI version 3.5 (UFI V3.5) water quality sub-model has a single phytoplankton component which has a maximum growth rate that varies as a function of temperature and a single rate of light limited growth that occurs below a fixed light threshold. The second model (PROTBAS, Markensten and Pierson 2007) considers eight algal functional groups, each of which has distinct allometric characteristics parameterized by the algal surface area, volume and axial length, characteristics that define need for silica and ability to fix nitrogen, and information related to rates of motility and sinking. Comparing these two models, UFI V3.5 has more detailed and realistic algorithms describing the transformations of nutrients and the effects of nutrient concentration on algal growth, while PROTBAS has a better description of the diversity of phytoplankton and the effects of phytoplankton characteristics on growth. Future climate scenarios were based on GCM predictions. Daily datasets were downloaded for present (baseline) conditions during the period 1960-2000, and three future emission scenarios (A1B, A2 and B1) during the 2045-2065 and 2081-2100 periods. All data were extrapolated to a common model grid and change factors were determined. For this study, GCM/emission scenarios were chosen which contained all the meteorological variables (air temperature, precipitation, solar radiation and wind speed) needed to drive both the watershed and reservoir models in the baseline and two future time periods.

Predictions show changes in the seasonality of stream discharge and phosphorus loading, as simulated by GWLF-VSA (Figure 9.16). Increased fall-winter precipitation, lower levels of snow accumulation and earlier snowmelt all result in increased winter (Nov-Feb) streamflow, and a somewhat decreased spring (Mar-Apr) runoff period. Predictions of mixed layer chlorophyll for the baseline and future conditions by both reservoir models are shown in Figure 9.17. Both models predict a lower peak chlorophyll occurring earlier in the spring under future conditions. Both models predict a lower peak chlorophyll occurring earlier in the spring under future conditions.

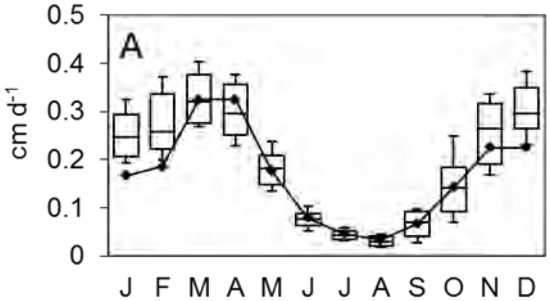

Figure 9.16 Simulated seasonal variation in (A) streamflow, and (B) TDP loading under baseline and future climate conditions.
The solid line shows the mean daily values for calculated for each month, based on the pooled data from all months in the baseline scenario. Boxplots show the variability of the 36 future climate scenarios.

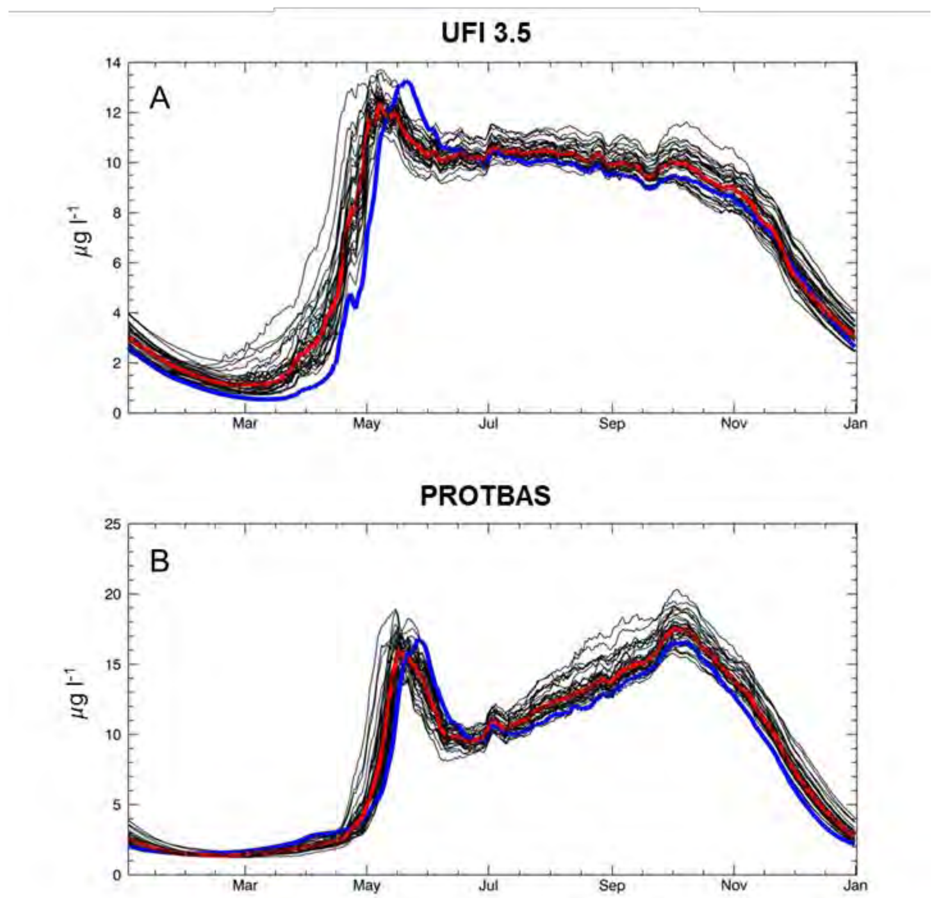

Figure 9.17 Seasonal variations in mixed layer chlorophyll concentration simulated with the UFI 3.5 (A) and PROTBAS (B) models.
Each line is the mean daily value of the data from all years in a given scenario.

9.8.5 Effect of Projected Changes in Winter Streamflow on Stream Turbidity in Esopus Creek

DEP has evaluated the sensitivity of stream turbidity to predicted changes in the seasonality of streamflow, with a focus on the winter period, using data from the Esopus Creek watershed. Analysis of the long term (1931-2010) record of measured streamflow data at the mouth of Esopus Creek at Ashokan Reservoir shows a majority of discharge events with a return period exceeding 1.5 year occur during the November – April interval. As a result, it is important to have a good understanding of potential changes in stream turbidity during this period.

The potential effect of climate change on stream turbidity was evaluated using baseline and future climate scenarios derived from five GCMs and three emission scenarios (A1B, A2 and B1) that represent a wide range of future climate conditions for the 2046-2065 and 2081-

2100 time slices, and a baseline scenario representing historical conditions. Projected values from the selected GCMs for the region surrounding the DEP water supply were extracted and interpolated to a common grid, and monthly change factors were calculated, which in turn were used to adjust the local meteorological data from 1927-2009 to generate future climate conditions associated with a given GCM. The calibrated GWLF model was used to simulate daily streamflow using daily time series of baseline and simulated future precipitation and air temperature. Daily streamflow turbidity was estimated by applying an empirical turbidity rating curve o the simulated streamflow.

Simulated long-term average daily stream turbidity for the baseline scenario showed a peak in April and this peak was maintained in future scenarios (Figure 9.18A and B). However, the height of the peak was reduced in the future time slices (2046-2065 and 2081-2100) due to the shift in timing of snowmelt runoff and the resulting increase in streamflow in earlier winter months. Moreover, a decrease in the amount of precipitation received as snow was predicted. The projected increase in ambient stream turbidity during January and February as a result of this shift in streamflow was up to 45% for the 2046-2065 period and up to 68% for the 2081-2100 period compared to baseline. Projected changes in average daily stream turbidity loads yielded similar results (Figure 9.18C and D). Maximum increase in winter turbidity loads is projected for the month of January and maximum decrease is projected in April. Figure 9.18E and F show the simulated long-term average annual cumulative turbidity load for baseline and future scenarios. The percent change in average annual cumulative turbidity load was only +3% and +5% for the 2046-2065 and 2081-2100 time slices and corresponds well with the projected average annual change in streamflow volumes (+4% and +6% respectively) for the same time period. This is interesting as analysis of climate change effects on turbidity loads at the annual time scale would yield no major effects even though there is a major seasonal effect in the winter due to a shift in the timing of snowmelt runoff. These predictions should be viewed as a general sensitivity analysis rather than absolute numerical predictions, considering the uncertainty in future climate projections, and in the streamflow versus turbidity relationship.

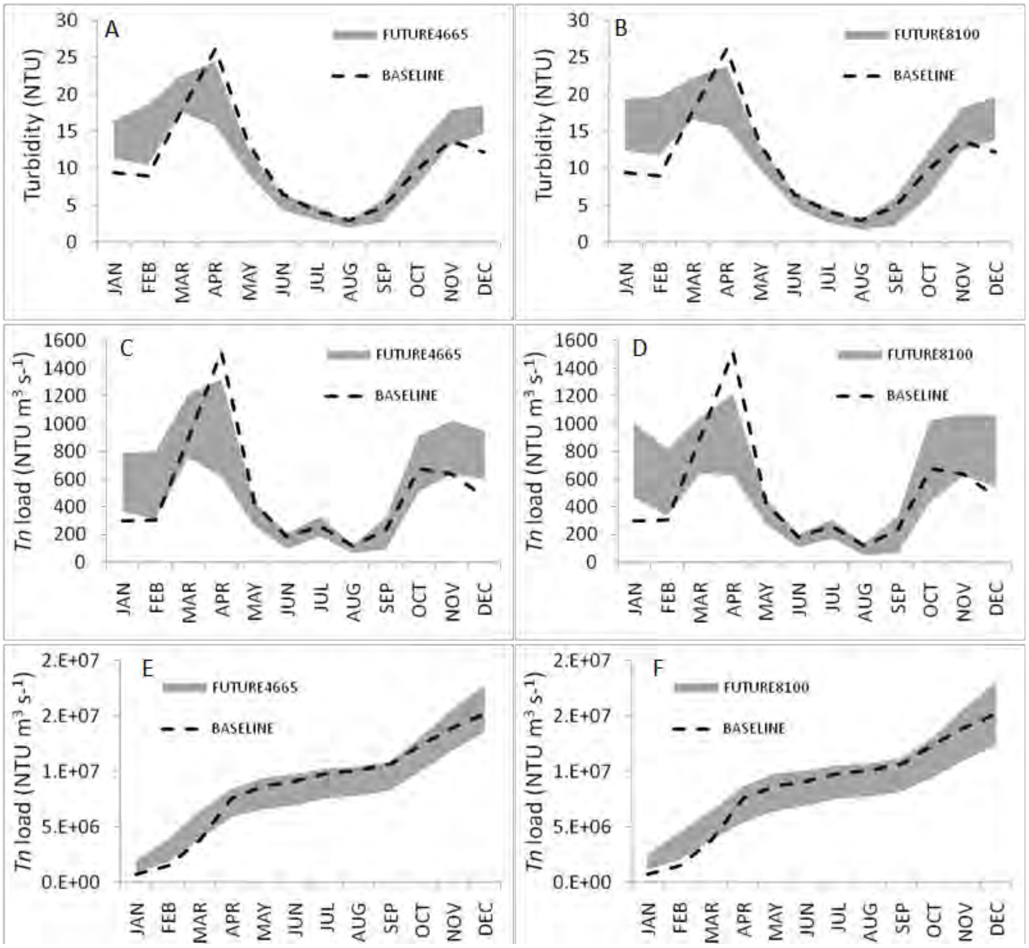

Figure 9.18 Comparison of baseline and future ambient stream turbidity for the 2046-2065 period (A) and 2081-2100 period (B); projected change in average ambient turbidity load by month for the 2046-2065 period (C) and 2081-2100 period (D) ; projected change in average annual cumulative turbidity loads (E and F).

9.8.6 Potential Effects of Climate Change on Winter Turbidity Levels in Ashokan Reservoir

A combined watershed and reservoir modeling study was conducted by DEP to estimate the impacts of climate change on winter turbidity levels in the water column of Ashokan Reservoir. Climate scenarios were developed from the output of three GCMs, which were combined with three future emission scenarios (A1B, A2, and B1). Scenarios of daily air temperature and precipitation were created by downscaling the different GCMs and scenarios for the Ashokan watershed determined by a change factor methodology. Change factors created by this method were applied to historical records of daily meteorological data to develop local future climate scenarios. Similar time series were used for reservoir modeling.

Inflows to the West Basin of Ashokan Reservoir are simulated on a daily time step using the GWLF-VSA model, which was calibrated using historical inputs to simulate streamflow from Esopus Creek at Coldbrook and Bush Kill, the major tributaries to the West Basin of Ashokan Reservoir. Inflow from the remaining ungaged area were estimated using Bush Kill estimates scaled by drainage area. An empirical rating curve was used to estimate inflow turbidity Tn based on simulated Esopus Creek flow, and total turbidity was partitioned into three particle sizes using criteria established by model calibration. Future values of Esopus Creek water temperature were estimated with an empirical expression based on air temperature. When running future climate scenarios, operational flows are obtained from OST simulations using similar climate change inflows. For the West Basin Ashokan Reservoir these include the Shandaken Tunnel flows, the gate flows in the dividing weir between the West and East Basins, and release channel withdrawals from the West Basin.

The higher winter reservoir turbidity and reduced summer reservoir turbidity (Figure 9.19A) under future climate scenarios are results of increased winter turbidity loading associated with increased future winter stream discharge and also to the variation in winter and summer settling rates (Figure 9.19B) of particles contributing to turbidity. Under future scenarios, the average annual streamflow is increased by 5% and 7%, which results in an annual increase in reservoir turbidity by 3% and 5% for the 2046-2065 and 2081-2100 time intervals, respectively. However, the average winter reservoir turbidity is increased by 11% and 17% as result of increase in winter streamflow by 12% and 20% for the 2046-2065 and 2081-2100 time intervals, respectively. The climate change scenarios clearly show a shift in timing of streamflow and turbidity loading to the reservoir from a peak in April to earlier in the winter (December-March). This shift in snowmelt driven events causes increased reservoir turbidity during December-March, and decreased turbidity in April-May as the peak events of April move to earlier in the year.

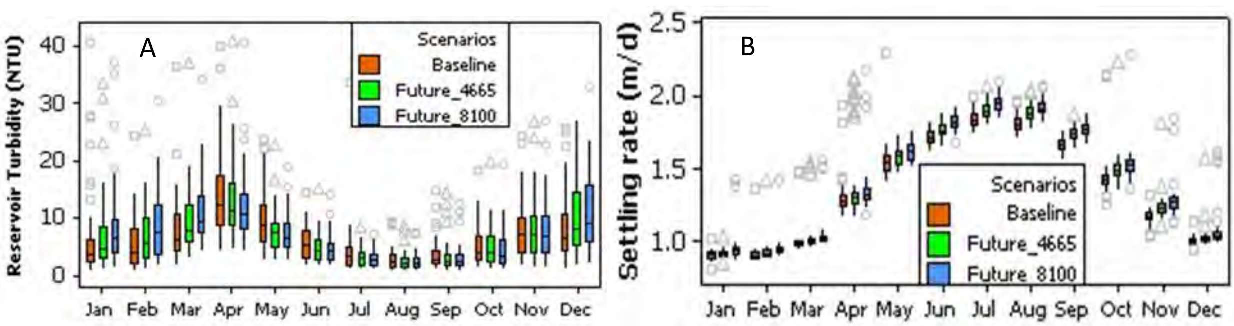

Figure 9.19 (A) Average monthly reservoir turbidity (NTU); (B) Average monthly settling velocity (m/day) for the baseline and simulated future period 2046-2065 and 2081-2100.

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

DEP was a collaborator in Water Research Foundation (WRF) Project 4262 – Vulnerability Assessment and Risk Management Tools for Climate Change. The goals of the project were to: (1) develop a risk assessment and management framework including methods for downscaling GCM data, watershed and water system planning tools to assimilate climate information, and a decision analysis framework to identify climate risk management strategies, (2) pilot test the framework for NYC and Colorado Springs. The collaborators include researchers from Stockholm Environment Institute, Rand Corporation, Hydrologics, Hazen and Sawyer, National Center for Atmospheric Research (NCAR), and DEP.

This project was completed in 2013 and the final report entitled "Developing Robust Strategies for Climate Change and Other Risks: A Water Utility Framework" was published in 2014 by the WRF. The project focused on climate change impacts related to turbidity and water availability, and made use of climate and streamflow scenarios developed as part of the CCIMP. Through an iterative modeling process, using the DEP OASIS and CE-Qual-W2 models, water supply vulnerability was examined in relationship to uncertainties in future climate, stream turbidity relationships, and water supply demand. The project confirmed that under present conditions dynamic system operations remain an effective turbidity control measure. The project also showed that system vulnerability is sensitive to changes in future water supply demand and the erosional processes controlling the turbidity inputs to the reservoirs (as captured in present models by turbidity vs. flow relationships).

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

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

9.9 Modeling Program Collaboration

DEP's water quality science and research program has been actively collaborating with various external agencies to share and enhance research, to automate observation of water quality and physical conditions in its reservoirs, and to develop tools and plans to meet climate challenges. DEP is a member of Water Utility Climate Alliance (WUCA) and is currently participating in the Piloting Utility Modeling Applications (PUMA) project. In addition, DEP staff have actively participated in Global Lake Ecological Observatory Network (GLEON) meetings. Further, a contract with the Research Foundation of the CUNYRF has provided support for model and data development by providing post-doctoral scientists who work with DEP water quality modeling staff, and supporting post-doctoral advisors. Descriptions of these external interactions to enhance DEP's modeling programs are provided below.

9.9.1 Water Utility Climate Alliance (WUCA)

DEP is one of ten large water utilities in the United States that form the Water Utility Climate Alliance. This group was formed to identify, understand, assess the impact of climate change, and to plan and implement programs to meet climate challenges. WUCA members are involved in enhancing climate change research and improving water management decision-making to ensure that water utilities will be positioned to respond to climate change and protect our water supplies. Two white papers recently released by the WUCA feature case studies of water utilities addressing the threat of climate change, including DEP. These white papers advance understanding of how the relatively new enterprise of climate change assessment and adaptation is developing.

DEP is also one of four WUCA utilities (New York, Tampa Bay, Seattle, and Portland) participating in the Piloting Utility Modeling Applications (PUMA) project. In this program, the four PUMA utilities have formed partnerships with scientific institutions to explore how to integrate climate considerations into their specific programs for water quality and quantity management. PUMA has convened workshops where water utility representatives and researchers meet to discuss and compare approaches for addressing the impact of climate change on water utilities. The four utilities pursued customized approaches based on specific utility needs and learned important lessons in conducting assessments that may be of interest to the wider adaptation community. In addition, these projects attempted to create a climate services environment in which utility managers worked collaboratively and iteratively with climate scientists to understand both utility concerns and the ability or limitations of today's climate science to respond to those concerns.

9.9.2 Global Lake Ecological Observatory Network (GLEON)

GLEON is a 10-year old organization that has been built around issues associated with the setup and deployment of robotic buoys for observing physical and water quality conditions in lakes and reservoirs, storage, processing, and analysis of the high-frequency data gathered by such buoys, and use of the data in modeling. DEP staff have attended recent annual GLEON meetings in Quebec and South Korea. DEP staff are also collaborating with other GLEON members in the intervals between meetings, including sharing of selected data. This participation has helped to ensure that DEP is getting the most out of its sizable investment in robotic monitoring in the reservoirs and tributary streams. DEP has made use of GLEON software tools in the analysis of robotic buoy data.

DEP is also applying the reservoir hydrothermal model GLM (General Lake Model) and associated water quality model FABM/AED. These models are open source software, and are thus open to use and revision by other researchers and professionals. These models are currently being applied to Cannonsville and Neversink Reservoirs by one of the CUNY post-doctoral researchers working in DEP's Water Quality Modeling Group.

9.9.3 CUNY Post-Doctoral Program

Through the reporting period, DEP has maintained a contract with the Research Foundation of the City University of New York (RF-CUNY) that provides support for model and data development by providing post-doctoral scientists who work with DEP water quality modeling staff, and supporting post-doctoral advisors. A significant portion of the research described here in Section 9 of this report has been conducted by the CUNY post-doctoral research staff.

In August, 2014, a new four-year contract was initiated between DEP and RF-CUNY. Under this contract, RF-CUNY has hired four full-time post-doctoral researchers who work in DEP's Water Quality Modeling office in Kingston, NY. Each of the researchers has an associated research advisor who receive part-time support under this contract. The research that has been initiated by these researchers continues to be a significant and critical component of DEP's modeling work. The post-doctoral program provides support in the form of providing model development and application expertise, modeling software, and data sets and in three project areas: (1) Evaluation of the effects of climate change on watershed processes and reservoir water quality as a part of CCIMP, (2) evaluation of FAD programs and land use changes on watershed processes and stream and reservoir water quality, (3) development of the modeling capability to simulate watershed loading of dissolved organic carbon (DOC), and reservoir and water supply concentrations of DOC and disinfection byproduct formation potential (DBPFP).

9.10 Modeling Program Published Papers

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Appendix A – Catskill and Delaware System UV Facility and Filtration Contingency Planning

Background

In 1993, USEPA issued two FADs for the Catskill and Delaware Systems 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 added deliverables for final design and the completion of a Final Environmental Impact Statement (FEIS), but included a provision allowing the DEP to seek relief from these deliverables if the remaining conditions of the FAD were being adequately addressed and the Catskill and Delaware Systems 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 move forward with design and construction of a UV disinfection facility for the CAT/DEL Systems, and produce biennial updates to the preliminary design for a CAT/DEL filtration plant.

The 2007 FAD requires the DEP to implement its program for the CAT/DEL UV disinfection facility in accordance with Section 2.6 of the DEP's 2006 Long-term Watershed Protection Program and the milestones contained therein, with the following clarifications:

- DEP will submit to USEPA and NYSDOH on a biennial basis a report updating the preliminary design of the CAT/DEL filtration facilities. This report will discuss the analysis and re-design work performed, and contain the issuance of necessary change pages to the final preliminary design, including revisions to drawings. This has been completed.
- DEP will supply NYSDOH, by August 31, 2010, with UV reactor validation and computer model results demonstrating that the UV disinfection units that will be installed are capable of delivering a minimum reduction equivalent dose of 40 mJ/cm^2, as required by condition "e" of the NYSDOH "Approval of Plans for Public Water Supply Improvement," dated January 30, 2006. This has been completed.
- DEP shall provide NYSDOH, within 10 days of a request from that agency, any additional information and data on this project, including bioassay results and dose or flow modeling,

that it may deem necessary in its review and evaluation of the UV reactor validation and the computer model results. This has been completed.

- DEP shall start up and operate the UV disinfection facility at a dose of 40 mJ/cm^2 unless NYSDOH approves alternative operational parameters. Over the past three years of operations, significant progress has been made in optimizing operations and maintenance of the CAT/DEL UV disinfection facility. DEP met the milestone for commencing full operation by October 2012.

Filtration Design Update

To maintain its dual track approach for meeting the goals of the Surface Water Treatment Rule of the Federal Safe Drinking Water Act, DEP continues to perform biennial updates of the preliminary designs for a CAT/DEL ozone/direct filtration facility that can be advanced to final design and construction in the event that filtration of the Catskill and Delaware Systems is deemed necessary.

In accordance with the terms for relief from completing final designs for a filtration facility, a preliminary design update was completed in September 2009 for a 2,110 MGD ozone/direct filtration facility for the CAT/DEL Systems. The design update was presented as a supplement to the 2003 Preliminary Design Update and incorporated all modifications previously presented in the 2005 design update. The changes included converting the previous design into a three-dimensional drawing platform. This change will facilitate additional coordination among the different design disciplines while resolving many conflicts before work begins onsite.

The update also includes refinement of the post-chemical treatment building. Additional detail was added to the building to fully incorporate the 2005 update that converted this to a mostly below-grade structure. The orientation and size of the structure were further influenced by changes to the Catskill Venturi Chamber in the 2007 update. The next update will be submitted in September 2011. This has been completed.

Ultraviolet Disinfection Facilities

DEP's UV disinfection facility was constructed along the eastern side of DEP's Eastview Parcel (Towns of Mount Pleasant and Greenburgh, Westchester County). At startup, water from the Delaware Aqueduct will enter the facility through the North Forebay and the treated water will be delivered to downstream consumers through the South Forebay/Delaware Aqueduct and Catskill Aqueduct. Provisions have been made for future connections from the Catskill Aqueduct once it is pressurized, as well as from the proposed Kensico City Tunnel and from the CAT/DEL water filtration facility, if built. The current design also provides design elements to facilitate connections for local consumers and for the delivery of finished water to the Kensico City Tunnel should it someday be constructed at this site.

Currently the Kensico Eastview Conveyance (KEC-2) project has begun which provides for a separate means of bringing Kensico reservoir water to the North Forebay. Soil borings are being scheduled for 2016. Depending on land acquisition and easements as well as geological review, the route of KEC-2 will be finalized.

Design of Ancillary Projects

Wetland Mitigation

The contract to perform wetland work, CAT210WL, was issued to Halmar International, LLC, in an order to commence in July 2009. The contract calls for the creation, restoration, stabilization, and maintenance of wetland areas in accordance with U.S. Army Corps of Engineers Protection of Waters permit requirements. The portion of the work to be performed in the Town of North Castle achieved substantial completion in accordance with the off-site work milestone listed in the permit. The work included clearing and excavating two parcels along Bear Gutter Creek that were then restored by constructing an inlet swale and planting various species of plants that will be compatible with the new environment. The work was monitored and maintained by Halmar for an additional two years as required by the contract. The wetlands at the Eastview site in the Town of Greenburgh and in the Town of Mount Pleasant are well established and will require continual maintenance and inspections to assure the USACE and town permits are satisfied. These permits are due to expire in fall of 2017.

Mount Pleasant Water Main

To meet certain requirements of the Mount Pleasant Site Plan Approval, DEP has constructed a pipeline between the Delaware Aqueduct on the Kensico campus and the Town's Commerce Street Pumping Station. The contract, CAT210WM, was issued to Northeast Remsco in November 2009. The contractor has installed 5,000 feet of pipe, a metering chamber, and a connection along the pipeline for Westchester County Water District 3. This contract achieved substantial completion in the fall of 2010. The testing and disinfection of the pipeline has been completed, and, as of October 2010, the Westchester County Department of Health has approved the as-built drawings. This has been completed.

Mount Pleasant UV

As part of the site plan permit approval agreement, DEP is required to provide the Town of Mount Pleasant with UV-treated water. The option of providing UV-treated water from the Eastview site was considered much more costly than local treatment and would have had substantial continuous operating costs. The design of the UV disinfection facility within the Commerce Street Pump Station for the Town of Mount Pleasant has been developed; this is identified as Contract CAT-341, Mount Pleasant UV Facility. The project involves the installation of a new UV disinfection system within the pump station so that the Town can meet the requirements of the LT2ESWTR. DEP is funding the design and construction of the UV disinfection upgrade, and the equipment will be turned over to the Town of Mount Pleasant upon completion of the project. During this time there has been constant coordination with the Town of Mount Pleasant to review the project and address concerns and comments. This has been completed.

Permitting

New York State Department of Transportation

The installation of the Catskill treated water conduits under Route 100C was completed in 2009. Continuous meetings and correspondence between representatives of the Towns of Mount Pleasant and Greenburgh and NYSDOT facilitated temporary partial road closures, allowing for timely performance of work. The contractor completed the installation of the stone veneer on the weir inlet structure/headwall on the north side of Route 100C. Once the work alongside the road was completed, the contractor realigned the traffic pattern on Route 100C, removing the lane shift. The final paving work was completed in October 2010 as requested by NYSDOT. This has been completed.

Greenburgh Work Permits

The contractor proceeded with site investigations related to a building permit to construct a small superstructure in the Town of Greenburgh that will provide access to the proposed treated water connection to the Catskill Aqueduct.

The Catskill Connection Chamber is now in full operation. A change order was issued to the contractor to install a gantry crane above the stop shutters so the Catskill aqueduct can be reactivated in a more expeditious manner if need during an emergency

SPDES Permits for Operations

The facility has a valid SPDES permit for operations. Permit number is NY0275151 effective January 1, 2012 through December 31, 2016. A permit modification was issued by NYSDEC on September 1, 2014 to account for geological effects of ground water being discharged (i.e. inherent hardness and mineral content of the groundwater).

Project Schedule

The project schedule is prescribed in both the FAD and in an Administrative Order on Consent (AO) between DEP and USEPA. Monthly reports are submitted in accordance with the AO and describe progress on the project and provide a mechanism for describing any known or anticipated non-compliant milestones. To date, the contractor's progress has allowed DEP to complete all AO Milestones in advance of the consent order date. The results of computer modeling and validation testing were submitted to NYSDOH in accordance with Milestone 7 in August 2010. Closeout of the AO is pending.

Facility Construction Contracts

All AO milestones were completed ahead of schedule. Various contractor and vendor warranties for structures and equipment are beginning to expire. DEP operations now maintains all equipment and structures.

UV Building

The UV building is operating as designed.

North Forebay

Improvements and repairs of the damaged motorized roller gates in the north forebay is pending. This work will be scheduled in a separate contract to be issued by DEP.

South Forebay

The South Forebay is operating as designed.

EDVC

The Energy Dissipating Valve Chamber (EDVC) is operating as designed.

Generator Building

The Generator building and equipment therein is operating as designed. DEP maintenance group is procuring a power monitoring system (PMS) simulator for the generator emergency power system to improve staff training and improve operations. The PMS simulator is scheduled for delivery in summer 2016.

Catskill Treated Water Line

The twin 108-inch-diameter treated water lines from the UV building to the Catskill Connection Chamber are operating as designed.

Pilot Studies

Dyed Microsphere Study

The validation of the UV facility was performed a second time to provide for a larger operating envelope. The facility began operations at the customary 40 mJ/cm^2 dosage. Since then, a dose reduction program was implemented in phases allowing for 2 log inactivation of *Cryptosporidium* at a lower operating dose. Final dose reduction phase will be implemented in 2016. Currently the reduction equivalent dose (RED) is 19.62 mJ/cm^2 saving energy and lowering associated air emissions.

Appendix B – Cross Connection Control Program

DEP administers a Cross Connection Control and Backflow Prevention Program (Program) to prevent contamination of the water supply from sources within the distribution system. Through the reporting period, the Program exceeded the milestones established by FAD for all of the report categories except two, where they are tracking close to the anticipated frequency[1]. The Program includes an inspection program, incident response, enforcement, and plan review elements. A notable change in the program in 2015 was an increase in enforcement staffing to expedite the violation process due to implementation of a digital Notice of Violation process implemented in 2014.

DEP is continuing the pilot to accept online applications for cross connection plan reviews through DEP's Water and Sewer Permitting System (WSPS). The online process streamlines the cross connection approval, as well as the water service and meter permit processes. The online WSPS cross connection filing experience allows users to file plans online for review; once the application is reviewed and approved, an electronic approval stamp will be used to identify plans that have been accepted. The pilot is ongoing.

Appendix Table B.1 Cross connection activities 2011-2015.

Year (Jan. - Dec.)	Respond to cross connection control complaints	Perform full inspection of potentially hazardous premises	Initiate enforcement for non-compliant hazardous premises	Backflow preventer plans approved	Backflow preventer plans accepted with self-certification	Review requests for exemption from cross connection control requirements	Notices of violation issued for failure to test annually
2011	2	5,187	4,060	7,625	19	445	57
2012	2	4,060	4,348	6,115	7	374	413
2013	0	5,257	2,436	5,235	10	370	1,382
2014	0	3,808	1,495	5,147	9	346	3,365
2015	0	3,679	1,182	4,881	4	368	4,449

1 All report categories with the exception of "Perform full inspection of potentially hazardous premises" have listed 'anticipated frequencies' because they are performed to some extent an as-needed basis. The 'Respond to cross connection control complaints' and 'Review Requests for Exemption' are tracking close to but below FAD anticipated frequencies. These two categories are counts of issues initiated by outside entities.

Appendix C – Water Quality Status and Trends Data Analysis

Scope of Water Quality Analyses

The scope of the water quality analyses encompass a longer time period than the five-year period described for program implementation (in Chapter 4). The time period of the water quality analyses extends from 1993 through 2014, which allows us to examine trends over the past 22 years. It provides a view of water quality changes in the context of natural variation caused by natural 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). The water quality data used in this analysis begins in the early 1990s, which represent conditions at the outset of Filtration Avoidance when many watershed protection programs were in their infancy. Sufficient time has now passed since programs have been in place that the major effects of programs on water quality should be apparent. Since many programs were implemented in the decade between 2000 and 2010, we are currently in a phase when we expect to 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 described for each reservoir system or basin to set the context for water quality interpretation.

Land use, a major determinant of water quality, is also described for each basin, including some highlights of watershed 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. BMPs for farming, stormwater control through environmental infrastructure, stream management, and septic remediation are among the programs that have reduced the loading of pollutants to the water supply. These figures are cumulative and show the progress of watershed protection over the past decades to give insight into what has been accomplished to date in terms of watershed improvements.

Given the general environmental conditions as noted above, 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, the trophic response of reservoirs, and pathogen assessment. Our objective was to look for central tendencies and trends in the water quality data over an extended time period during and after Watershed Protection Program implementation.

Water quality status and trends are described for selected analytes. Status is presented as boxplots of monthly medians for the 2012–2014 period and trends are evaluated for a 22-year period. The analytes chosen were those most important for the SWTR and meeting the requirements of the Revised 2007 FAD. Statistical techniques for the status and trend analysis were chosen to account for the influence of seasons on long-term trends. In addition, where applicable, stream sample concentrations were flow-adjusted for trend analysis to remove the influence of flow on analyte concentrations.

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 include:

- chlorophyll vs. total phosphorus,
- maximum chlorophyll vs. total phosphorus,
- Secchi depth vs. total phosphorus,
- Secchi depth vs. chlorophyll.

Annual geometric means of each analyte were plotted on the OECD standard lines that were developed from over 100 other northern temperate zone water bodies. Annual geometric means were used (as in the standard regressions) to best represent the central tendencies without undue influence of the few extreme high values typically recorded. These standard regressions provide a context to 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, DEP 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 22 years and selected case studies are presented to demonstrate the effectiveness of this program. Notably, terminal reservoirs (i.e., those with the potential to be 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.

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 DEP'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.

Sites

Site selected for water quality status and trends are listed in Appendix Table C.1 and shown pictorially in Appendix Figures C.1 and C.2. All reservoirs in the Catskill and Delaware Systems were evaluated, along with West Branch Reservoir, which acts as a balancing reservoir for water received from Rondout Reservoir; Kensico Reservoir, which is normally the main source reservoir for the entire system; and Cross River and Croton Falls Reservoirs because water from these reservoirs may, on occasion, be pumped into the Delaware Aqueduct prior to its entering Kensico Reservoir.

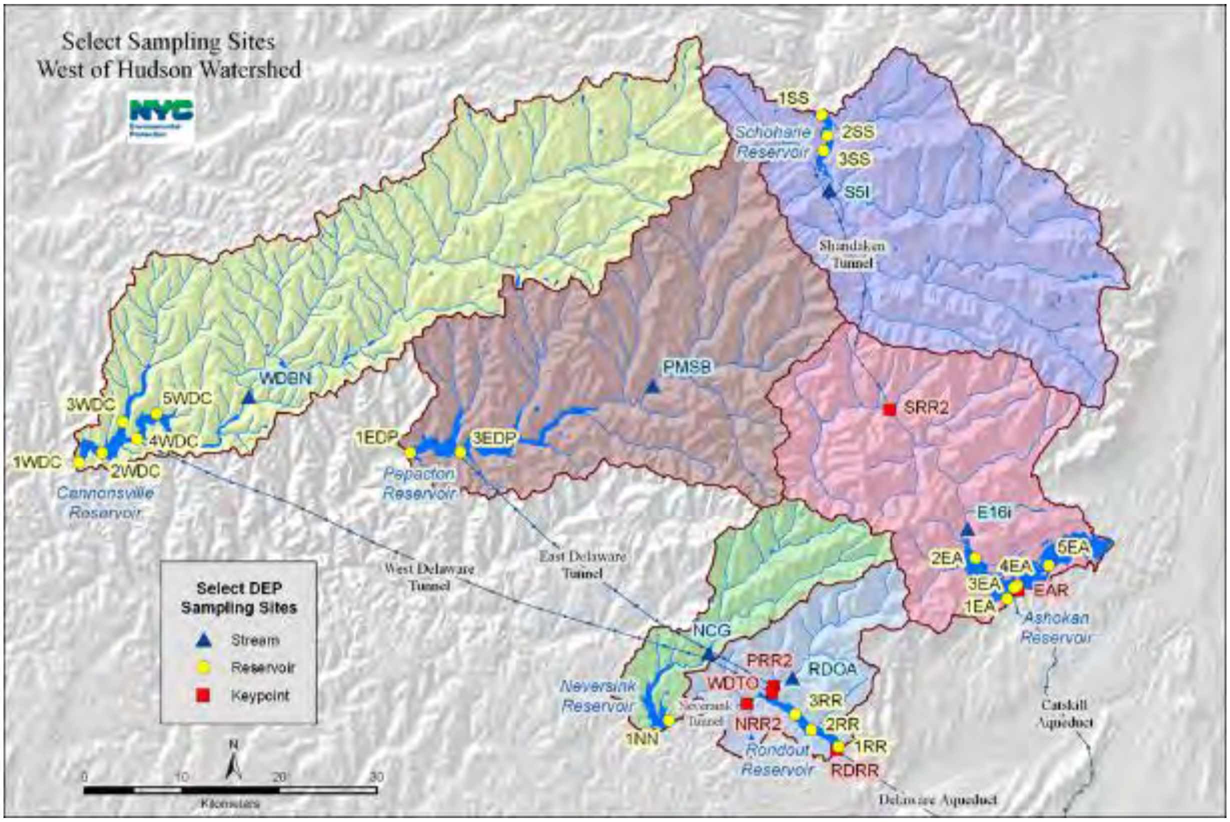
Appendix Table C.1 Inputs (streams and aqueduct keypoints), reservoirs, and outputs (aqueduct keypoints and releases) included in the water quality status and trends analysis.

System/District	Inputs[1]	Reservoirs[3]	Outputs[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
	WDBN[s]	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
	CATALUM[k], DEL17[k],	Kensico (BRK)[2]	CATLEFF, DEL18DT
	CROSS2[s]	Cross River (CCR)[2]	CROSSRVVC
	WESTBRR[s], CCF (middle basin)	Croton Falls (CCF-main basin)[2]	CROFALLSVC

[1] Current Keypoint site names are provided. In the last FAD summary and assessment report the last two letters were omitted for ease of use. The superscripts [s] and [k] refer to streams and keypoints, respectively; all outputs are keypoints except for WESTBRR, CROSSRVVC and CROFALLSVC which are releases.

[2] Indicates a source or potential source water.

[3] Reservoir designations represent an amalgam of multiple locations and depths (see text). Sites labeled 1 or 1.x are nearest the dam and are used interchangeably for purposes of analysis.

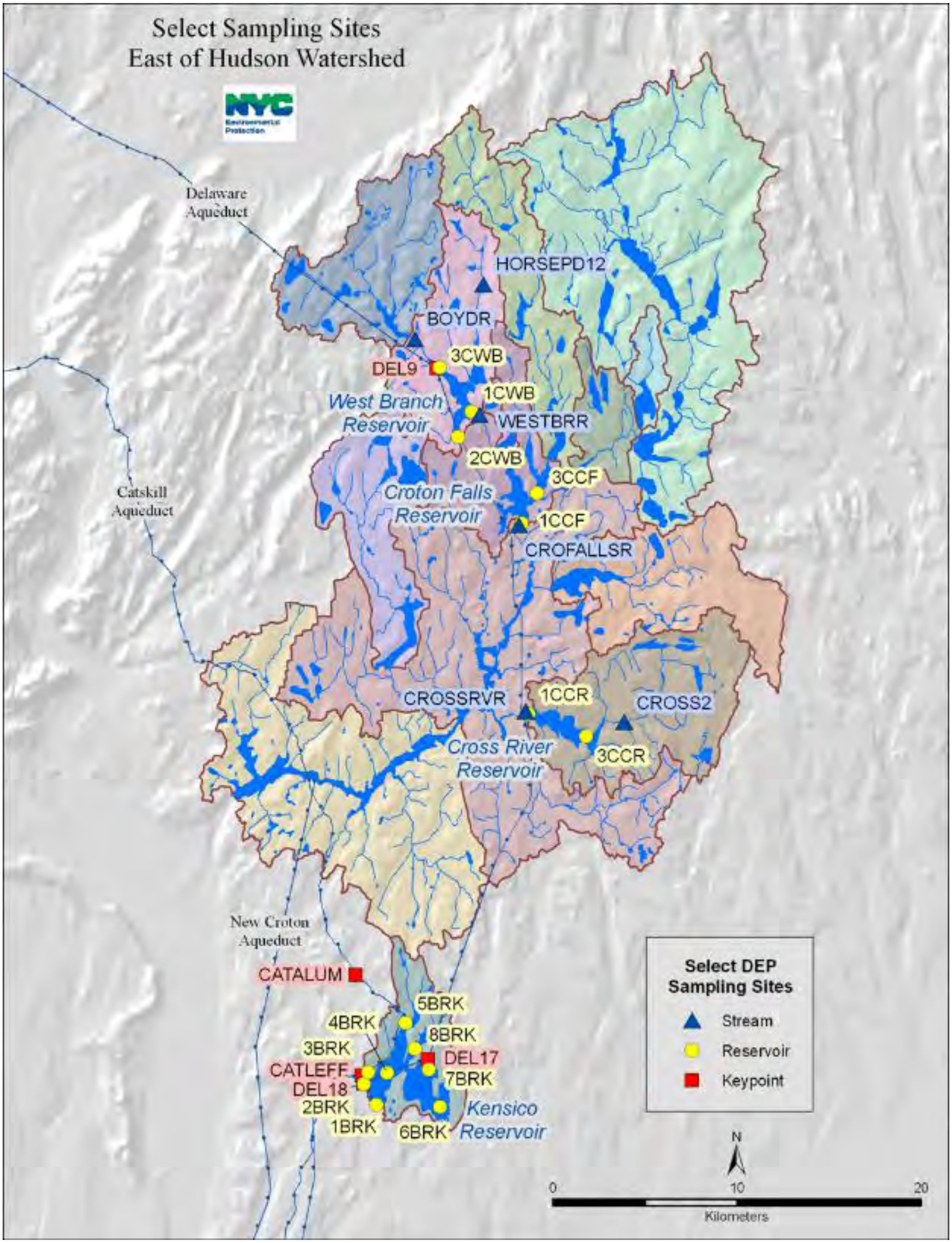


Appendix Figure C.1 Sampling sites for the WOH status and trends analysis.

The reservoir inputs comprise the main streams and, where appropriate, aqueducts. For all West-of-Hudson reservoirs and West Branch Reservoir, the stream sites selected are the furthest sites downstream on each of the main channels leading into the reservoirs. They are the main stream sites immediately upstream of the reservoirs and therefore represent the bulk of water entering the reservoirs from their respective watersheds. The keypoint outputs (effluents) from upstream reservoirs are also the keypoint inputs for Rondout, West Branch, and Kensico reservoirs. Reservoir outputs are normally keypoints except for West Branch, Cross River and Croton Falls where the outputs are the releases. The primary goal in site selection was to address the main inputs and outputs from the reservoirs considered.

Data collection

The reservoir, stream and release water quality data were obtained from the routine monitoring operations by the Directorate of Water Quality (DWQ) field groups. Reservoir samples used in this report are collected from April-November. Each reservoir is sampled from multiple depths at the dam, mid-reservoir, near major stream influent areas, and at other important sites, for instance near aqueducts. The full sampling programs are described in DEP (2009a). Keypoint samples are collected and analyzed by the DWQ laboratory operations staff.



Appendix Figure C.1 Sampling sites for the East of Hudson status and trend analysis.

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 three 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. As a result 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, but in reality 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 TSI (derived from chlorophyll *a* measurements). These are considered the most important water quality indicators for the City supply. Although ELAP-approved methods were used, several changes occurred during the period of record that could affect trend results. In 1999 the instrument used to measure turbidity was changed from the Hach Ratio X/ turbidimeter to the Hach 2100AN turbidimeter. In 2000, the instrument used to analyze chlorophyll *a* was switched from fluorometer to HPLC. Also in 2000, a more vigorous digestion was instituted for phosphorus analysis. Although a comparison of sample results using old and new methods for phosphorus and turbidity suggested that the new methods occasionally yielded higher values, more work is needed to determine an appropriate correction factor. Accordingly, the phosphorus and turbidity data in this report are the raw data using the current method of analysis. From 1993-2010 conductivity for stream samples was measured in-situ using multiprobes. Since 2009 conductivity samples have been collected and brought back to the lab for analysis. The effect has not been determined but initial comparisons indicate the effect to be minimal.

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 ($\mu g\ L^{-1}$).

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 rarely and only if they were far outside the normal range of historic data. Occasionally, when fecal 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.

Changes in sampling frequency during the period of record may produce a bias in the data, thereby obscuring or enhancing a trend. To create a balanced dataset we eliminated all special surveys and restricted data to those which were collected consistently each month throughout the 1993-2014 period. For example, extra water column sampling in the reservoirs, which began in 2002, was excluded. At stream sites, sample frequency has generally dropped from weekly to monthly in recent years. To maintain unbiased representation through the period of record, generally one survey per month was selected and used in our analysis. Since at least weekly turbidity samples were collected at stream site E16I for the entire period of record, here we used 4 turbidity samples per month. The sites used in this analysis are shown in Figure C.1 and Figure C.2.

In general, the median value from each full monthly survey was used in our status and trend analysis and in our plots of the data. To ensure consistent representation, if less than 75% of the normal monthly reservoir samples were not collected, a median was not calculated for that particular month. The approximate number of samples per month used to calculate monthly medians for each site is provided in Appendix Table C.2.

Status Methods

To assess 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 2012–2014 were used.

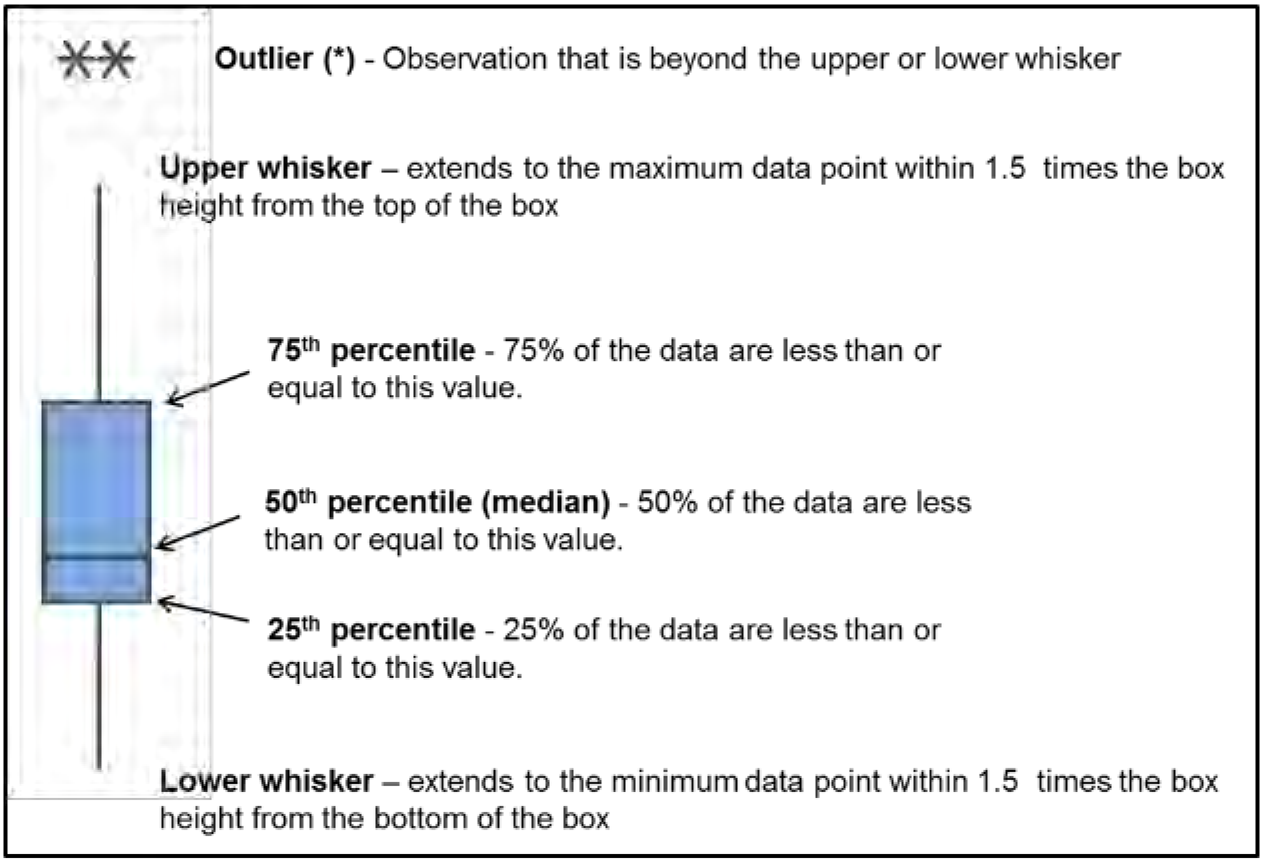
Turbidity and fecal coliform data for source water keypoints are compared to surface Water Treatment Rule standards (5 NTU of turbidity and 20 coliforms 100 mL^{-1} for fecal coliform). While these standards do not apply to source water reservoirs, they are included in the source water status plots for reference purposes. Similarly, a 200 coliforms 100 mL^{-1} reference line, based on a calculation developed for streams by the NYSDEC (6 NYCRR Part 703.4(b)), is included in the stream fecal coliform status plots. The TP benchmark in the status plots (15 μg L^{-1} for WOH impoundments and

Appendix Table C.2 Approximate number of samples collected per month from status and trend analysis sites, 1993-2014.

Site	Type	Fecal coliform	TP	Conductivity	Turbidity	Chlorophyll *a*
CATALUM	keypoint	30	1	30	30	0
CATLEFF	keypoint	31	1	31	31	0
DEL17	keypoint	30	1	30	30	0
DEL18DT	keypoint	31	1	31	31	0
DEL9	keypoint	5	1	5	5	0
EARCM	keypoint	27	1	27	27	0
NRR2CM	keypoint	20	1	20	20	0
PRR2CM	keypoint	20	1	20	20	0
RDRRCM	keypoint	25	1	25	25	0
SRR2CM	keypoint	5	1	4	5	0
WDTOCM	keypoint	18	1	18	18	0
BRK	reservoir	21	21	25	21	8
CCF (main)	reservoir	3	3	3	3	1
CCF (middle)	reservoir	1	2	3	2	1
CCR	reservoir	4	5	6	5	2
CWB	reservoir	7	7	7	7	3
EAE	reservoir	6	6	6	6	2
EAW	reservoir	10	10	10	10	3
EDP	reservoir	8	8	8	8	2
NN	reservoir	4	4	4	4	1
RR	reservoir	10	10	10	10	3
SS	reservoir	10	10	10	10	3
WDC	reservoir	15	15	15	15	5
BOYDR	stream	1	1	1	1	0
CROFALLSVC	stream	1	1	1	1	0
CROSS2	stream	1	1	1	1	0
CROSSRVVC	stream	1	1	1	1	0
E16I	stream	1	1	1	4	0
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
WDBN	stream	1	1	1	1	0
WESTBRR	stream	2	1	1	1	0

EOH source reservoirs; 20 µg L^{-1} for other EOH, non-source reservoirs) is based on phosphorus-restricted target values developed by DEP (DEP 2010a). TSI benchmarks (reservoirs with values <40 considered oligotrophic; those with values between 40 and 50, mesotrophic; values >50, eutrophic) were taken from Carlson 1977.

Box plots have been used as a visual aid to graphically display status using the Minitab® macro "cbox.mac" written by Dr. Dennis Helsel and available from the author's website at: www.practicalstats.com/nada. The cbox.mac macro is appropriate for data with nondetects, drawing a line at the highest reporting limit; this occurred typically for fecal coliform data and in a few cases, for total phosphorus. Percentiles below the highest reporting limit are estimated using the ROS method of Helsel and Cohn 1988. See Figure C.3 which provides a key for interpreting the box plots.



Appendix Figure C.2 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 ½ 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% of the data are used to perform the weighted least squares calculation for each data point. Through experimentation we found that 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 test was performed using a compiled Fortran program provided in Reckhow et al. 1993. 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).

For rivers and streams, the values of many water quality analytes are dependent on flow. Therefore data variability caused by flow has been removed where appropriate. This process is well described in (Smith et al. 1996). The required concentration/flow relationships were derived from a LOWESS procedure using SAS software using a 60% smoothing function. Trend analysis was performed on the flow-adjusted data as well as the raw data for rivers and streams. There is a major caveat here. (Helsel and Hirsch 1992) pointed out that there are potential pitfalls when using flow-adjusted values; specifically, such values should not be used where human activity has altered the probability distribution of river flow through changes in regulation, diversion or consumption during the period of trend analysis. For example, the flow of Esopus Creek at Boiceville is often greatly influenced by the contributions of the Shandaken Portal to the Esopus Creek. Hence, flow adjustment at this site would not be appropriate. Where flow adjustment was appropriate, the statistics have been presented and discussed in the text.

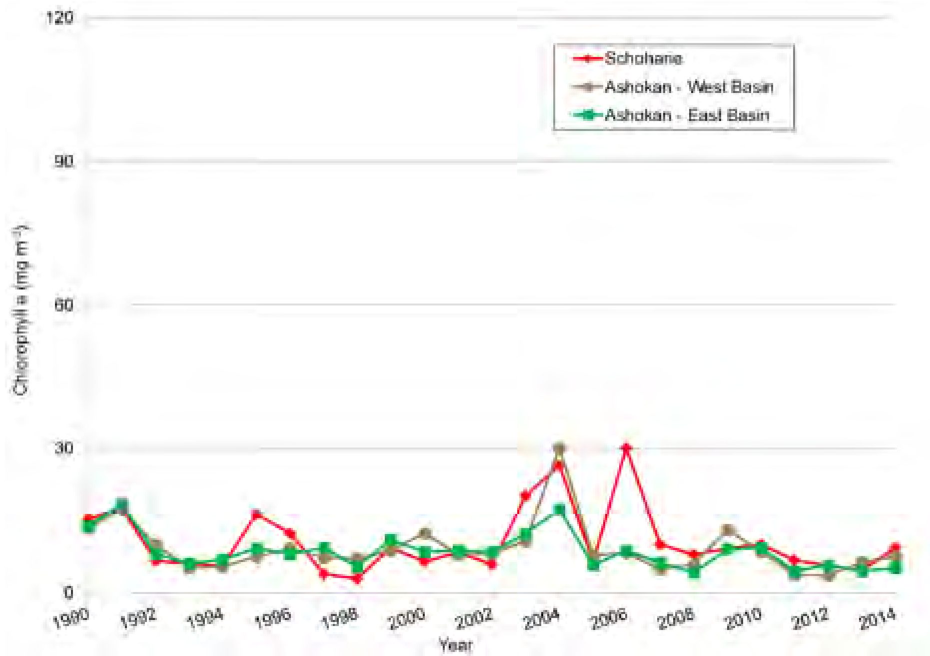
The SKSE technique is used to estimate trend magnitude (i.e., amount of change per year). In this technique, slope estimates are first computed for all possible data pairs of like months. The median of these slopes is then determined. This median is the Seasonal Kendall Slope Estimator. Note that it 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.

Biomonitoring Methods

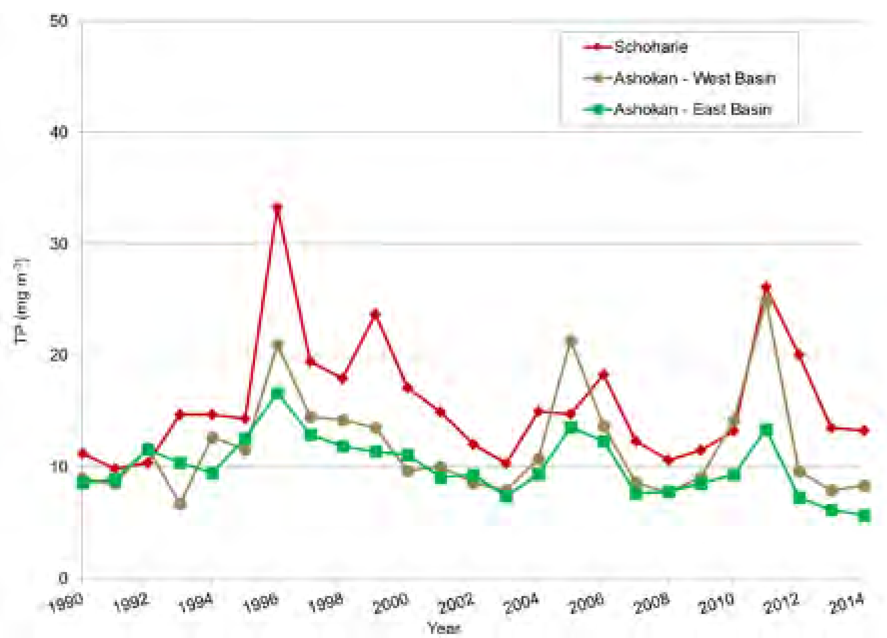
The DEP stream biomonitoring program uses protocols developed by the NYS Stream Biomonitoring Unit (SBU) to assess the health of stream macroinvertebrate communities in DEP watershed streams. Samples are collected annually between July and September using the "traveling kick" method, which consists of 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

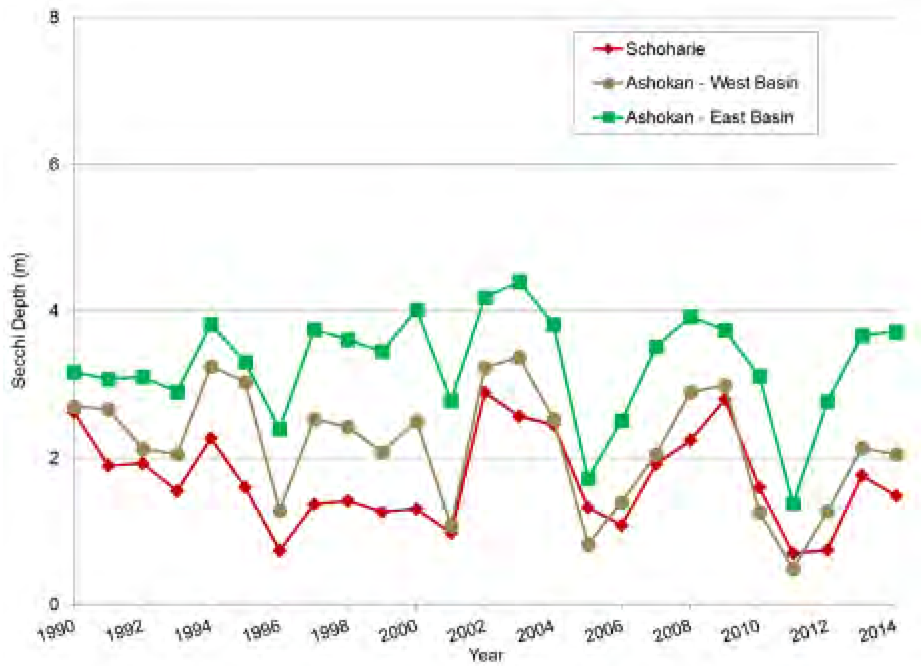
Appendix Figure C.4 Annual geometric means for chlorophyll *a* at Catskill reservoirs (1990 – 2014).



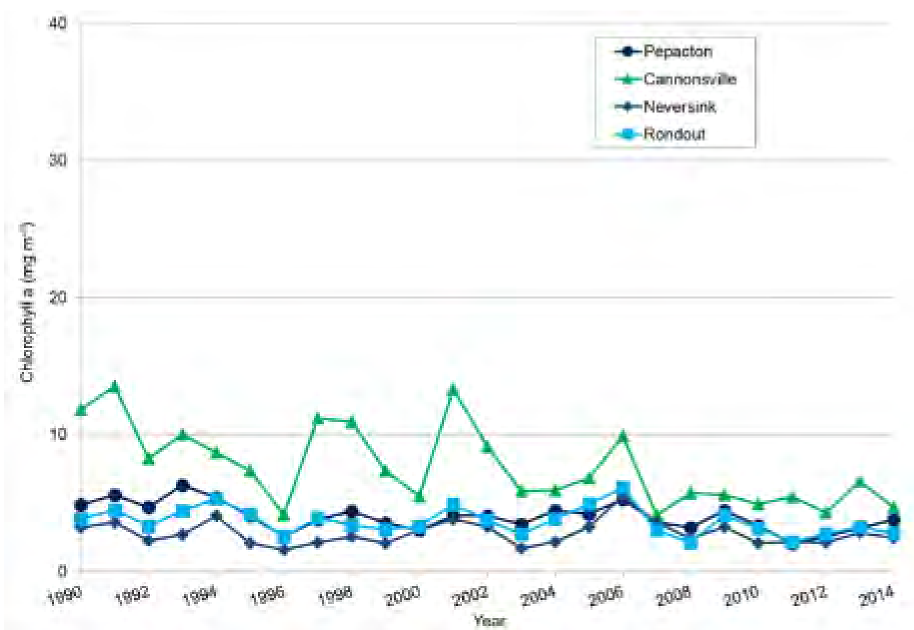
Appendix Figure C.5 Annual maxima for chlorophyll *a* at Catskill reservoirs (1990 – 2014).



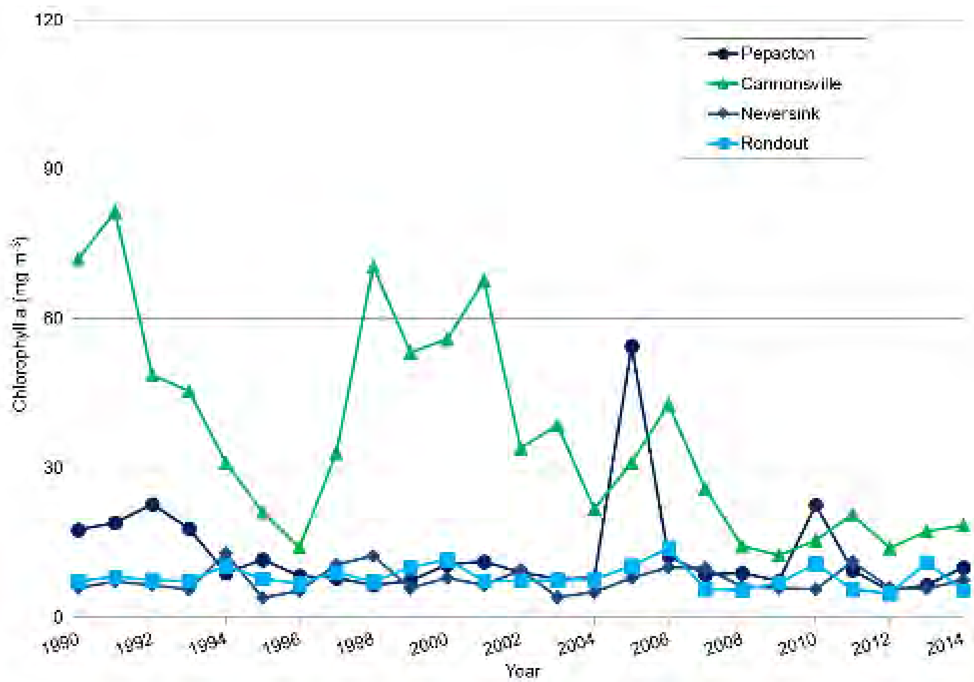
Appendix Figure C.6 Annual geometric means for total phosphorous at Catskill reservoirs (1990 – 2014).



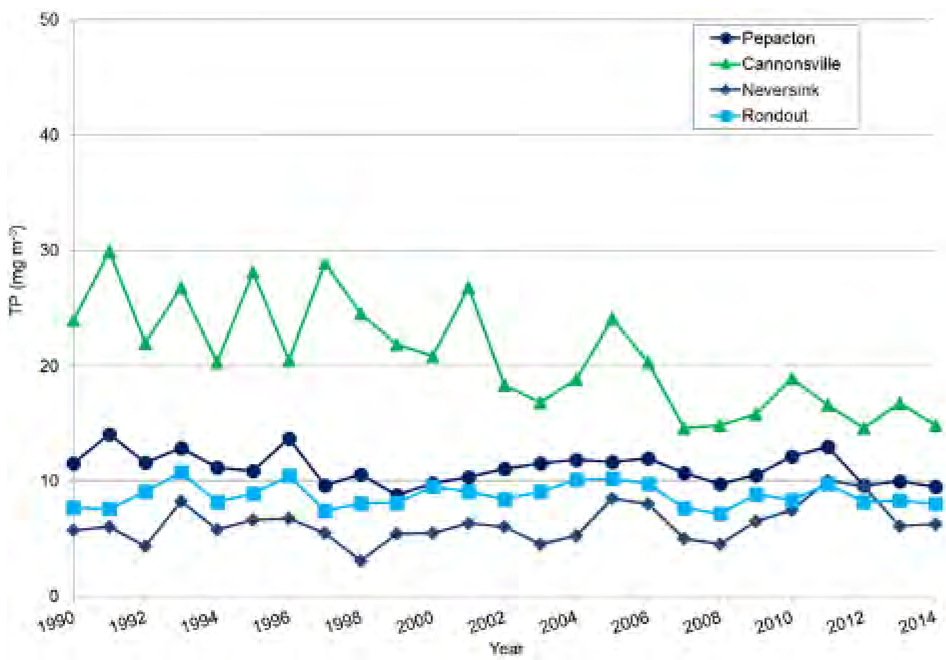
Appendix Figure C.7 Annual geometric means for Secchi depth at Catskill reservoirs (1990 – 2014).



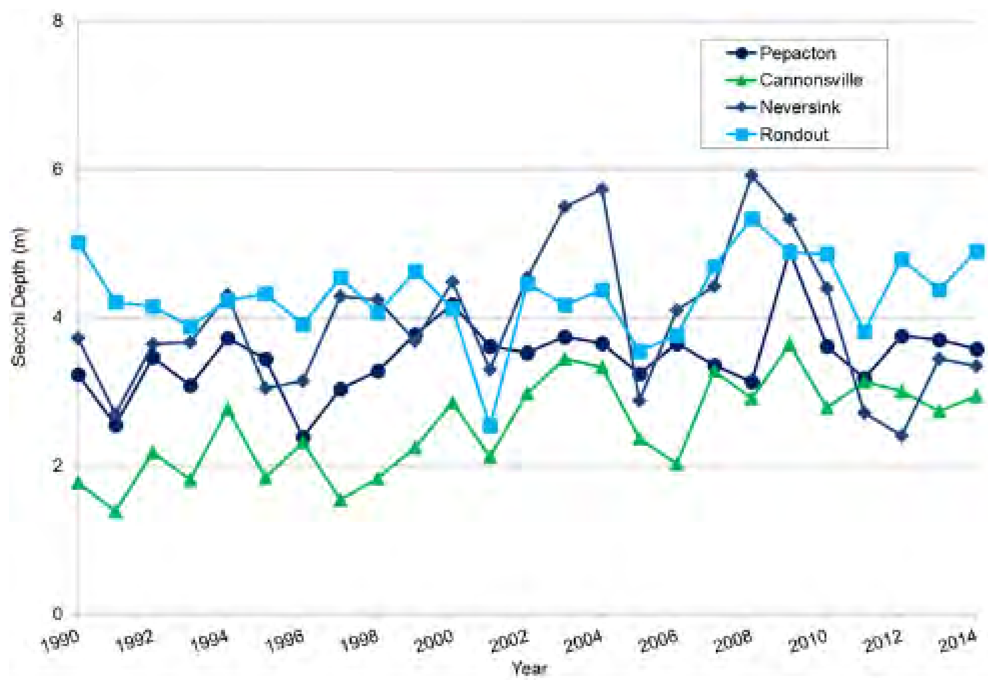
Appendix Figure C.8 Annual geometric means for chlorophyll *a* at Delaware reservoirs (1990 – 2014).



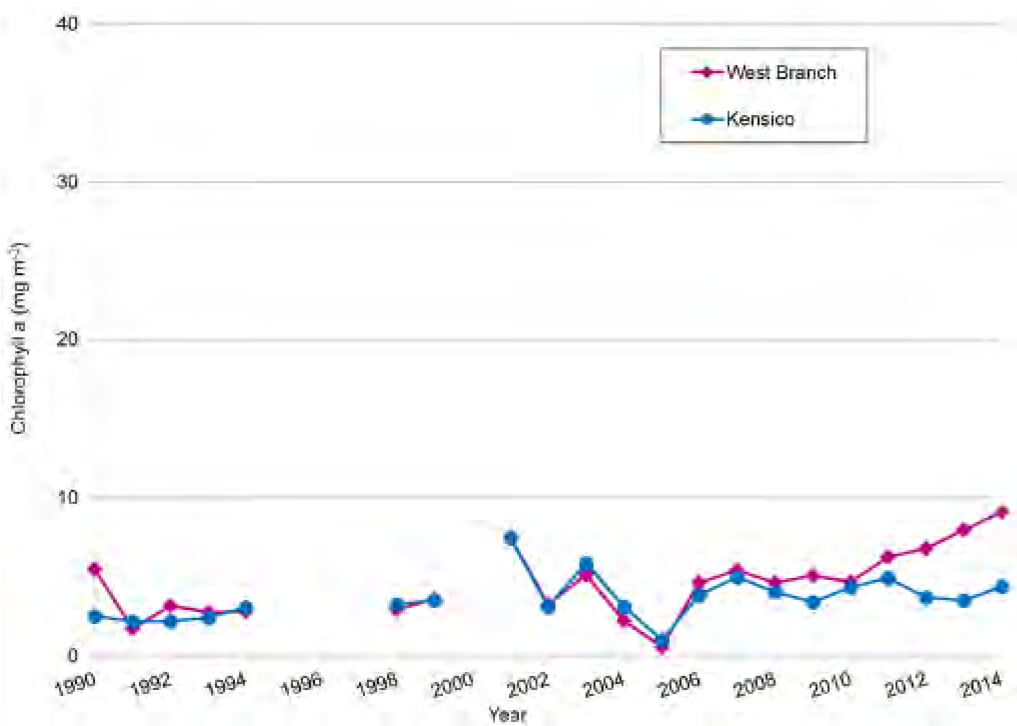
Appendix Figure C.9 Annual maxima for chlorophyll *a* at Delaware reservoirs (1990 – 2014).



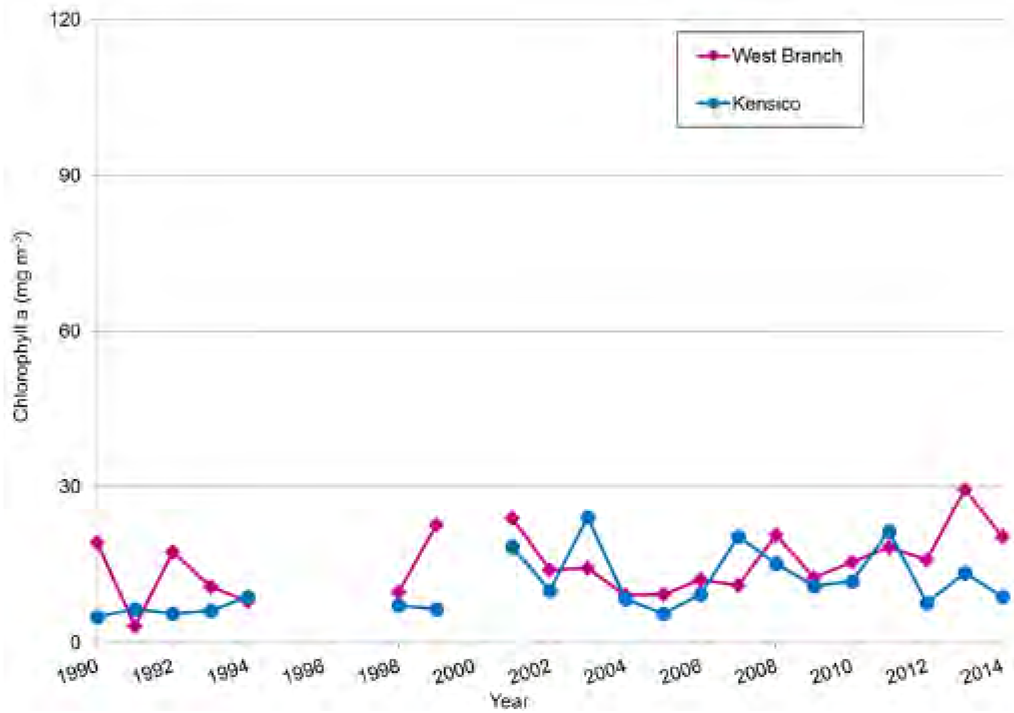
Appendix Figure C.10 Annual geometric means for total phosphorous at Delaware reservoirs (1990 – 2014).



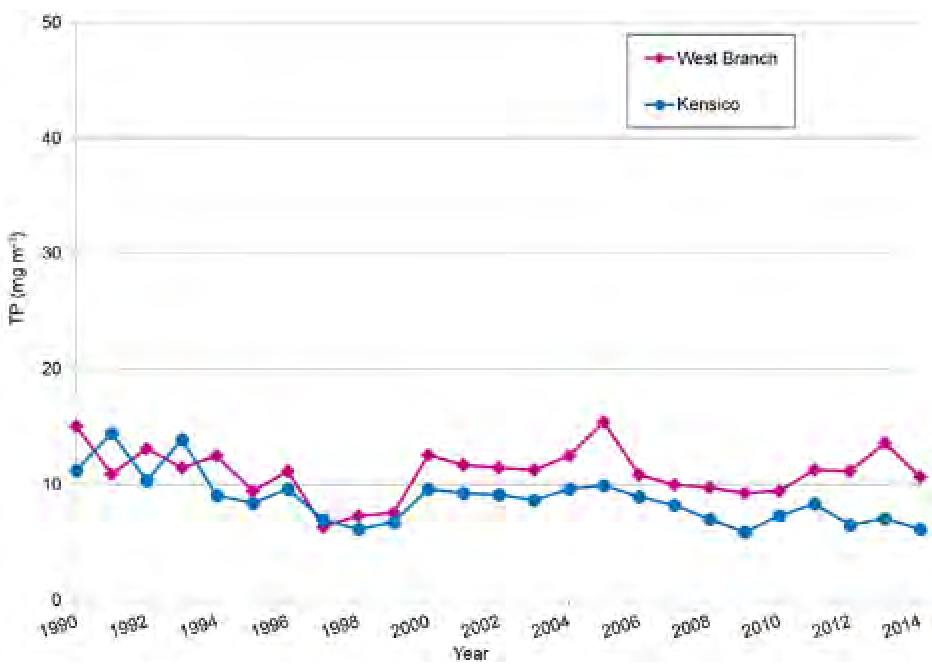
Appendix Figure C.11 Annual geometric means for Secchi depth at Delaware reservoirs (1990 – 2014).



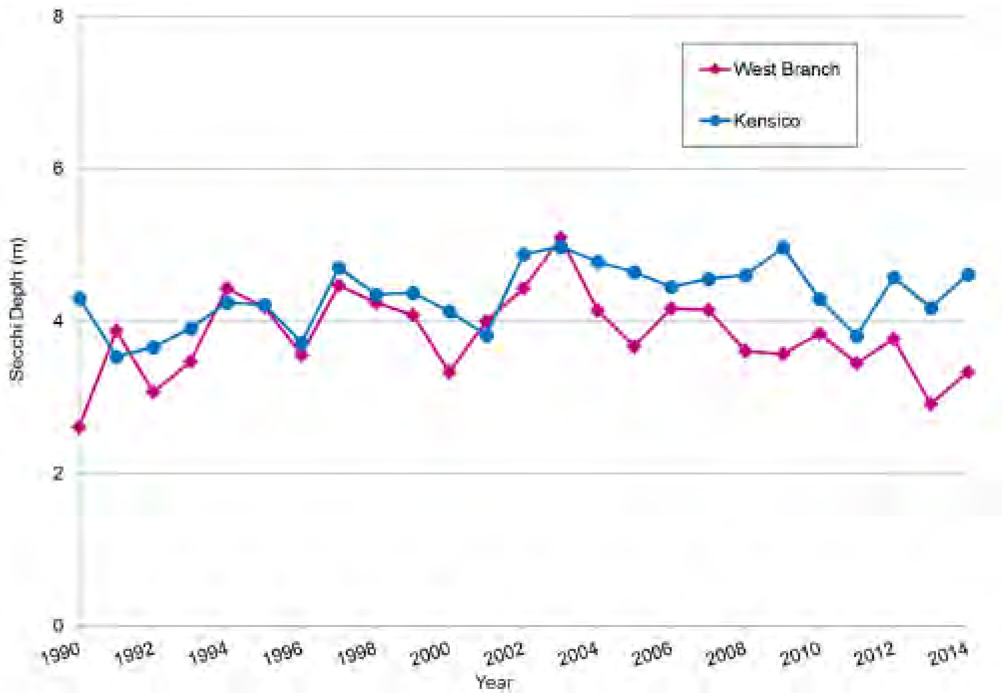
Appendix Figure C.12 Annual geometric means for chlorophyll *a* at West Branch and Kensico Reservoirs (1990 – 2014).



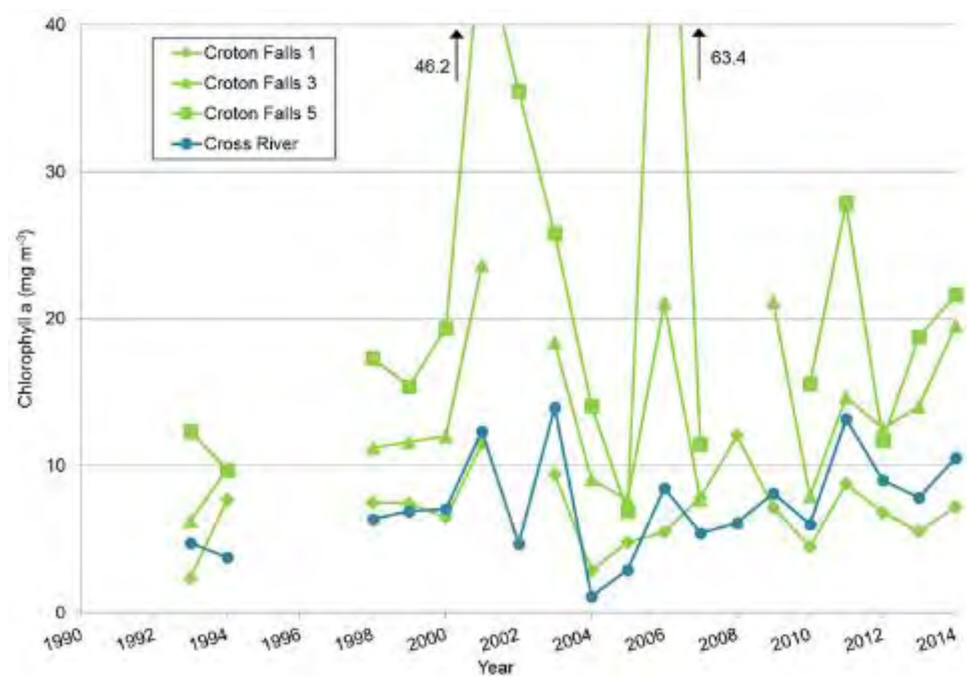
Appendix Figure C.13 Annual maxima for chlorophyll *a* at West Branch and Kensico Reservoirs (1990 – 2014).



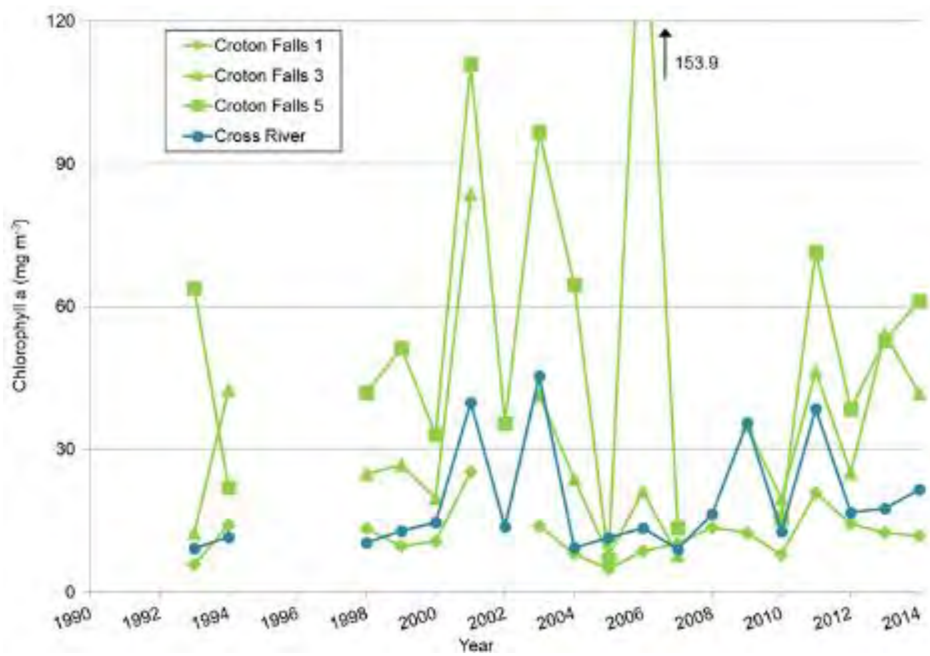
Appendix Figure C.14 Annual geometric mean for total phosphorous at West Branch and Kensico Reservoirs (1990 – 2014).



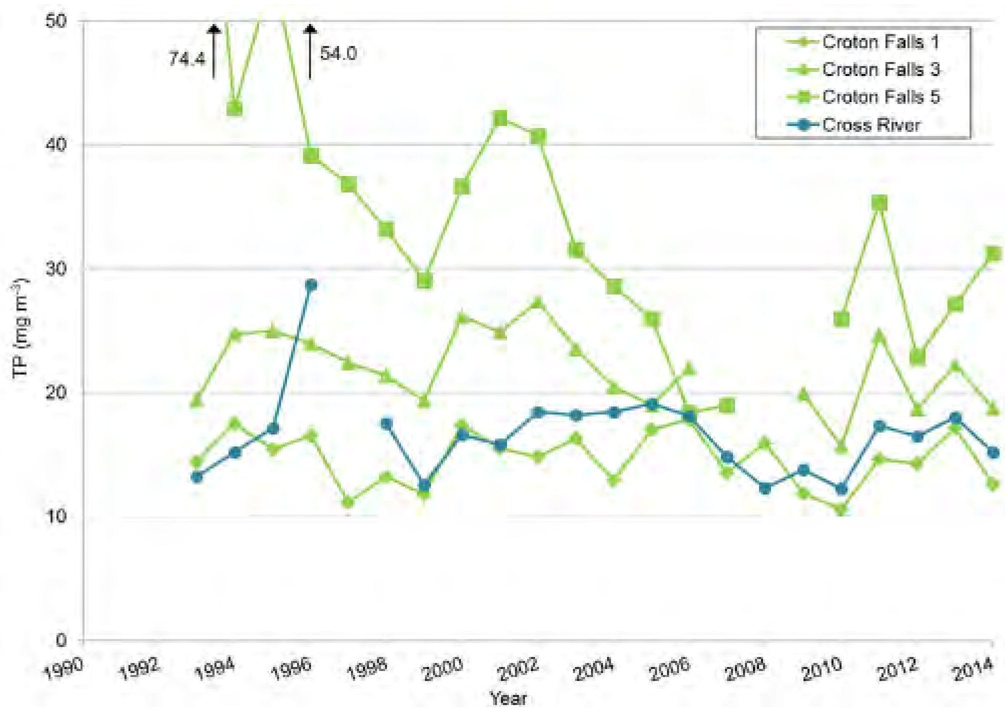
Appendix Figure C.15 Annual geometric mean for Secchi depth at West Branch and Kensico Reservoirs (1990 – 2014).



Appendix Figure C.16 Annual geometric means for chlorophyll *a* at Croton Falls and Cross River Reservoirs (1990 – 2014).



Appendix Figure C.17 Annual maxima for chlorophyll *a* at Croton Falls and Cross River Reservoirs (1990 – 2014).



Appendix Figure C.18 Annual geometric means for total phosphorous at Croton Falls and Cross River Reservoirs (1990 – 2014).

Appendix Figure C.19 Annual geometric means for Secchi depth at Croton Falls and Cross River Reservoirs (1990 – 2014).

Appendix D – Drought Management

For the years 2011-2015, 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, which remain in effect. These restrictions include a prohibition on watering sidewalks and lawns between November 1 and March 31 and illegally opening fire hydrants.

Appendix E – Rondout-West Branch Tunnel (2011-2015)

Efforts to evaluate the condition of, and to continue to develop dewatering and repair plans for, the RWBT have been ongoing from 2011 through 2015 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
- Finalized Design and Awarded Construction Contracts

Hydraulic Investigations of the RWBT

Investigations of the RWBT helped DEP assess the nature and degree of leakage stemming from the aqueduct in Roseton and Wawarsing, NY. Various efforts to study the nature and size of the leaks are described below.

- The Tunnel Monitoring Program- The object of this program is to determine if tunnel conditions are changing. On a routine basis DEP and consultants monitor tunnel flow rates, operational trends, and surface expressions to determine the quantity of the leak.
- The Tunnel Testing Program- DEP conducts hydrostatic tests and backflow tests on a routine basis. The hydro-static test involves shutting down the tunnel and isolating it from the reservoirs at each end. When this is done, the water level in the tunnel drops due to the leakage. This is measured, and an accurate leakage rate is calculated. 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 to feed the leak is measured as a negative number, and is interpreted as the net leakage. The leakage values obtained from both testing methods indicate that the RWBT leakage rate is stable. There have been one hydrostatic test and three backflow tests since 2011.
- Surface investigations in areas of Roseton and Wawarsing- Water is suspected to be leaking from the tunnel in these areas. The USGS performs monitoring of over 50 water wells throughout the Wawarsing area in an effort to better understand the thickness and lateral extent of the RWBT leak. Engineering teams catalogue surface leakage features on a monthly to weekly basis. During tunnel depressurizations, daily monitoring is performed.

AUV Inspection of the RWBT

Under the AUV program, an independent robotic vehicle completely photographs the interior surface of the RWBT in a single inspection lasting 12 hours. In 2014, DEP completed a third AUV inspection of the interior surface of the tunnel. (The previous inspections were performed in 2003 and 2009.) This latest inspection gathered 150,000 photographs of the tunnel.

The data will be incorporated into an updated tunnel condition report and an updated Tunnel Risk Assessment is expected to be made in 2017.

ROV Inspection of the RWBT in Wawarsing, NY

Under the ROV program, an independent robotic vehicle completely photographed the interior RWBT liner in Wawarsing in the vicinity of suspected leakage areas. Cracks in the liner were identified and exfiltration was documented during the inspection. The areas were carefully catalogued to instruct the grouting repair program to occur in 2022.

Risk Assessment

In 2011, a Technical Review Committee (TRC) was convened to review 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 unwatering was negligible, and tunnel inflows would be under 20 MGD. This information was used to inform the design of dewatering systems.

Tunnel and Shaft Rehabilitation Program

The Tunnel and Shaft Rehabilitation Program construction contract has been under way since 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.

The work was substantially complete in September 2014 and resulted in Shaft 6 RWBT unwatering pump station being operable and ready to unwater this section of the Delaware Aqueduct when required for inspection and repair of the tunnel. The Pump Station has been upgraded with new, larger submersible pumps that can handle additional inflows of water into the tunnel during the unwatering and repair activities.

Planning for a Roseton Bypass

Planning for a Roseton Bypass Tunnel began in 2009. An engineering consultant team was procured to investigate and plan a new section of tunnel specifically to bypass the worst leak areas in Roseton, NY. A bypass was designed in 2011-2012 and construction work on two access shafts began in 2013. The bypass tunnel will be approximately two and a half miles long and will connect to the existing RWBT above and below the known leakage zone in Roseton.

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.

The Catskill Aqueduct Repair and Rehabilitation design contract was given a notice to proceed on June 13, 2013. 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. During the RWBT connection period, the Catskill Aqueduct will be required to operate at maximum capacity for the full duration without fail.

Another measure to make up the loss of water from the Delaware system when the RWBT is out of service is enhance Demand Management. A series of projects have been implemented to reduce overall water demand in the City and upstate. Projects include toilet replacements with higher efficiency units, park spray shower enhancements, education programs, and enhanced leak detection.