New York City Department of Environmental Protection

2011 Watershed Protection Program Summary and Assessment

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Environmental Protection

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Acknowledgements

The New York City Department 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 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 15 years. Although the individual 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, with oversight by Paul Rush, P.E., Deputy Commissioner, and its Directorates of Operations, Water Quality, and Watershed Protection Programs and Planning. The support roles of Compliance and of Management Services and Budget, along with the Bureaus of Police and of Consumer and Intergovernmental Affairs, as well as the Office of Information Technology, are also acknowledged. Without the participation of these many groups, the extensive ability to conduct DEP's watershed programs and collect the information to produce this document would not be available.

More specifically, this document was produced in two major sections. The first major section describes program implementation and was authored by staff within the Watershed Protection Programs Directorate, with oversight by Dave Warne, Assistant Commissioner. The program managers and authors of the many programs include: Linda Beck, Larry Beckhardt, Brenda Drake, Jeff Graf, Paul Lenz, Laurie Machung, Mike Meyer, Bob Ravallo, Beth Reichheld, Terry Spies, John Schwartz, Dave Tobias, Jon Tuscanes, and Mike Usai.

The second half of this assessment consists of an extensive analysis of water quality data. The Water Quality Directorate is overseen by Steven Schindler, Director, and the water quality data for the analysis was provided by the staff of Watershed Water Quality Operations, overseen by Lori Emery, Chief WWQO. The analysis complements the program implementation information and evaluates program effectiveness. The Watershed Water Quality Science and Research Division provided this analysis, with oversight by Lorraine Janus, Ph. D., Chief WWQSR. Authors, scientists, editors, and publishing personnel who deserve special recognition for significant contributions include: Kerri Alderisio; Lorraine Janus, Ph. D.; David Lounsbury; Gerry Marzec; Jim Mayfield; Chris Nadareski; Christian Pace; Don Pierson, Ph.D.; Martin Rosenfeld; Anne Seeley; Elliot Schneiderman, Ph.D.; Rich Van Dreason; and Mark Zion. Additional support was provided by Ray Homolac, Don Kent, and David Quentin. A special note of thanks also goes to the WWQSR Publications and Reporting Unit, specifically, to Pat Girard for her supervision and significant technical work to bring all the pieces together as a polished document, and to Martin Rosenfeld for his masterful editing and proofreading of the entire document.

Executive Summary

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

The New York City Department of Environmental Protection (DEP) is responsible for operating, maintaining, and protecting the City's water supply and distribution system. This document, the 2011 Watershed Protection Program Summary and Assessment, has been prepared to comply with the U.S. Environmental Protection Agency (EPA) July 2007 Filtration Avoidance Determination (FAD) for the Catskill/Delaware Water Supply Systems. Unlike previous summary and assessment reports, which were prepared to support granting of a new FAD, this one represents a mid-term assessment at the halfway point of a 10-year FAD.

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 aggressive program to protect and enhance the quality of New York City's drinking water. DEP was able to demonstrate that the Catskill/Delaware supply met the objective criteria: (1) the source water met SWTR turbidity and fecal coliform standards, (2) there were no source-related violations of the Coliform Rule, and (3) there were no waterborne disease outbreaks in the City. The subjective criteria of the SWTR required DEP to demonstrate through ownership or agreements with landowners that it could control human activities in the watershed which might adversely impact the microbiological quality of the source water.

To demonstrate its eligibility for a filtration waiver, DEP advanced a program to assess and address water quality threats in the Catskill/Delaware System, which 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, and July 2007). 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. DEP has developed a comprehensive program to address each of these concerns.

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 nearly 16,000 samples from approximately 475 sites throughout the watershed—at aqueducts, reservoirs, streams, and wastewater treatment plants (WWTPs). The purpose of this intensive monitoring effort is to demonstrate compliance with all water quality standards, 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 programs and policies.

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 ones. Each element of the watershed protection effort is targeted at a specific objective that defines the spatial and temporal scales for water quality monitoring. Well-designed monitoring ensures the maintenance of the already high quality of the Catskill/Delaware waters. This effort yields benefits for the millions of water consumers, as well as the thousands of people who live, work, and recreate in the watershed and downstream communities.

Implementing the Watershed Protection Program and 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 stakeholder-driven watershed protection and partnership began when the City, the State, EPA, watershed counties, towns, and villages, and environmental and public interest groups signed the New York City Watershed Memorandum of Agreement (MOA). This unique coalition has come together with the dual goals of protecting water quality for generations to come and preserving the economic viability of watershed communities. The MOA established the institutional framework and relationships needed to implement the range of protection programs identified as necessary by the City, the State, and EPA, as well as the means to anticipate and resolve conflicts.

In July 2007, EPA, in consultation with the New York State Department of Health (DOH), issued a 10-year FAD that reflected over a decade of DEP research and the programmatic framework established in the 1997 MOA. The programs identified in the 2007 FAD reflect DEP's continued commitment to long-term watershed protection. Core ongoing programs depend on vital support from and cooperation with the City's watershed partners, with particular concentration on implementation of several key watershed protection initiatives: the Watershed Agricultural Program, the acquisition of watershed lands, the enforcement of improved watershed regulations, the Stream Management Program, and the continuation of environmental and economic partnership programs that target specific sources of pollution in the watershed. In addition, DEP continued its enhanced watershed protection efforts in the Kensico Reservoir basin and completed the upgrades of non-City-owned WWTPs. Key watershed protection program highlights are described in the sections below.

Watershed Agricultural Program

Since 1992, the Watershed Agricultural Program (WAP) has featured 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. By working through the Watershed Agricultural Council, the City funds development of farm pollution prevention plans and implementation of structural and non-structural best management practices (BMPs). To date, 254 large farm operations in the Catskill/Delaware watersheds have signed up for the WAP, representing 96% of identified large farms, and 98% of these have written their Whole Farm Plans. Ninety percent of all large farms have achieved "substantial implementation" of the practices called for in their plans. Implementation of 5,416 BMPs has been achieved on all participating farms at a cost of $37.6 million, not including planning, design, and administrative expenses. In 1998, the City augmented the program with the addition of a City-federal cost-sharing effort known as 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. To date, 2,030 acres of riparian buffers have been enrolled in CREP and nearly 11,000 head of cattle have been excluded from streams.

Land Acquisition

The program has completed its fourteenth year, during which time DEP has solicited at least once, and in most cases twice, the owners of 355,050 acres of land. Furthermore, since 2008, DEP has solicited the owners of approximately 90,000 acres of land not previously solicited. Watershed-wide, these solicitation efforts have resulted in the City securing 92,974 acres in fee simple or conservation easement, with another 21, 286 acres of farm easements secured by the Watershed Agricultural Council (WAC). Since 1997, the City's ownership interest in watershed real property has increased by 321%. In December 2010, New York State issued DEP a new Water Supply Permit, which not only allows continued land acquisition for the next 15 years, but also ensures continuation of the full range of watershed protection programs.

Watershed Regulations

Since 1997, DEP has reviewed thousands of applications for projects that proposed one or more regulated activities, performed regular compliance inspections at regulated wastewater facilities, and responded to violations of permit standards to enforce corrective actions. In April 2010, DEP revised the Watershed Rules and Regulations (WR&R) after a years-long public process, to reflect changes in federal and State law and address issues that have arisen during administration and enforcement of the WR&R over the previous 11 years.

Environmental and Economic Partnerships

The City, in conjunction with its partners, has continued to implement programs that have remediated more than 3,500 failing septic systems, upgraded 30 facilities that store winter road de-icing materials, and constructed stormwater BMPs in areas with previously uncontrolled stormwater runoff.

Wastewater Treatment Plant Upgrades

The five City-owned WWTPs in the Catskill/Delaware watershed—which account for 40% of the watershed's total WWTP flow—were upgraded to tertiary treatment in the late 1990s. There are 37 non-City-owned WWTPs in the Catskill/Delaware watershed (including one east of Hudson), which account for the remaining 60% of the watershed's WWTP flow. Upgrade work at all 37 of these WWTPs has been completed, either through construction of an onsite upgrade or through connection to another tertiary WWTP.

New Infrastructure Program

The New Sewage Treatment Infrastructure Program funds the study, design, and construction of new wastewater projects in seven communities identified in the 1997 MOA as having failing or likely to fail septic systems. Projects have been completed in six of the seven communities.

Stream Management Program

The Stream Management Program supports comprehensive planning, outreach, and education to foster a high level of riparian stewardship among municipalities, landowners, and community members throughout the Catskill/Delaware watershed. At its core, the program 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, the program has transitioned to implementation of stream management plan recommendations in order to demonstrate successful management techniques. In 2010, DEP and its stream management partners launched the Catskill Streams Buffer Initiative, which coordinates funding and outreach for an array of programs.

Protection of Kensico Reservoir

The City has implemented a variety of programs to ensure protection of Kensico Reservoir. Having completed 45 BMPs to manage and reduce stormwater pollution in the basin in the 1990s, recent effort has been focused on routine monitoring and maintenance of these facilities to ensure their effectiveness. DEP inspects and maintains the turbidity curtains that protect the Catskill Upper Effluent Chamber, and waterfowl management continues to be exceptionally effective in maintaining low levels of fecal coliform bacteria. DEP maintains 38 spill containment facilities around Kensico Reservoir to provide rapid response and clean up to reduce water quality impacts in the event of a spill.

Scope of Water Quality Analysis

Water quality analyses cover a longer time period than the five-year assessment period in order to capture changes in water quality in response to watershed protection programs in the context of natural variation (such as floods and droughts), which are not sufficiently represented in a five-year period. 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 analysis extends from 1993 through 2009, a 17-year period when new and intensified watershed protection programs have been implemented. This long-term data analysis allows for time lags between program implementation (causes) and water quality changes (effects). Sufficient time must pass after programs are in place in order to see the full effects of programs on water quality. Further improvements in water quality will evolve as the full effects of the programs are realized.

There are several important factors that govern water quality over the long term. Perhaps the two most important are climate, as a determinant of water residence times, and land use, as a determinant of substance loadings. Water residence times are important because they determine the response rates of reservoirs to watershed protection programs and their influence on material loadings. For example, the three basins of the Catskill System have characteristically different residence times. Schoharie consistently has the shortest water residence time (averaging about 40 days), the west basin of Ashokan averages about 80 days, and the east basin of Ashokan has the longest water residence time (averaging about 120 days). 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 Schoharie would adjust to e.g., new loading levels in about 4 months, whereas East Ashokan would take about a year's time to re-equilibrate to a new steady state. Thus, response rates to programs are largely dependent on hydrology.

Over the short term (i.e., less than a year), there are other influences that affect water quality. These account for the high degree of variation seen in the plots of water quality data over 17 years. Seasonal variations in precipitation and temperature affect runoff and stratification, which also affect water quality from week to week and from storm to storm. Since our objective was to look for trends in water quality data over the time period of program implementation, statistical techniques for the water quality trend analysis were chosen to minimize the influence of seasons on long-term trends. In addition, concentrations were flow-adjusted, where appropriate, in order to minimize the influence of short-term flow changes on trend detection. With this approach, DEP has examined the relationships between watershed protection and water quality changes.

The water quality analytes examined were those most important for the SWTR and meeting the requirements of the 2007 FAD. In addition, macroinvertebrate data provide insight into the ecological condition of streams and an index is calculated to track changes that can demonstrate water quality improvements. The impact of the waterfowl management program and its ability to control and reduce fecal coliform bacteria are demonstrated over the past five years. 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 distribution so it is by design that program intensity is higher in these basins than others. An analysis of pathogen transport through the system is also provided. This gives much insight into the benefit of NYC's sequential system of reservoirs and its ability to improve water quality as it travels towards distribution. Finally, a modeling analysis is used to estimate the relative effects of different watershed protection programs and the degree of implementation of those programs that results in water quality improvements. Modeling is also used to evaluate and guide operational options.

Water Quality Summary for the Catskill System

DEP has continued to enhance watershed protection in the Schoharie basin, and since 2004 three WWTPs have been constructed, in Hunter, Windham, and Prattsville. With this, the total phosphorus load decreased from 240 kg yr^{-1} in 2004 to < 50 kg yr^{-1} in 2009. In addition, more than 100 septic systems have been remediated since 2004, increasing total remediations to over 600 since the WWTP upgrade and septic rehabilitation programs began.

Water quality status in Schoharie Reservoir from 2007-2009 was good. Monthly median fecal counts and monthly median phosphorus concentrations never exceeded benchmarks and monthly mean turbidities only exceeded 10 NTUs on three occasions. Trophic status was mesotrophic.

Downward phosphorus trends were detected in the input, reservoir, and output and were attributed primarily to load reductions from WWTPs. Despite the decline in nutrients, the Trophic State Index showed an upward trend, presumably caused by improvements in water clarity. Increasing trends in fecal coliform counts appear to be associated with large runoff events and to the generally wet conditions in 2003-2005.

Biomonitoring results at Schoharie Creek indicated non-impairment for the three sites sampled during the 2007-2009 status evaluation period, while long-term trend analysis indicated improvement at one site and no change at the remaining two.

Three sites above Schoharie Reservoir are routinely monitored for *Cryptosporidium* and *Giardia*. *Cryptosporidium* oocysts have declined since 2007, coinciding with such watershed improvements as septic remediation and the construction of, or improvements to, WWTPs in the Schoharie basin. A reservoir output site is also monitored. Results at this site are typically lower than at the stream sites since reservoir processes (e.g., settling, predation, die-off) provide an effective reduction in protozoan numbers detected downstream.

Watershed protection efforts continue to benefit water quality in the Ashokan basin. Between 2004 and 2009, phosphorus loads from WWTPs were reduced from 50 kg yr^{-1} to approximately 25 kg yr^{-1}. The reduction in load was primarily the result of earlier WWTP improvements and more recent repair of numerous failing septic systems. Since 1996, over 900 septic systems have been remediated, with about 350 repairs occurring since 2005.

Water quality status in the West Basin of Ashokan Reservoir was good during the 2007-2009 status evaluation period. Monthly median fecal counts were predominantly at or just above detection limits, with one exception of 20 CFU 100 mL^{-1}. Monthly median turbidities were mostly below 5 NTU, with two exceptions related to storm events. Total phosphorus (TP) values were also low, with most monthly medians below 10 µg L^{-1}. The West Basin was usually mesotrophic, but could be considered oligotrophic more than 25% of the time.

Long-term water quality trend results were mixed. Phosphorus decreased, in part due to watershed programs, but turbidity, fecal coliforms, and conductivity all increased during the 1994-2009 period. A large spring runoff event in 2005 was largely responsible for these apparent upward trends.

Water quality status was better in the East Basin than in the West Basin. The highest monthly median fecal coliform count was 3 CFU 100 mL^{-1}. All other months had fecal coliform counts below 1 CFU 100 mL^{-1}. Most turbidity values were below 3 NTU, and phosphorus was generally below 10 µg L^{-1}. Similar to the West Basin, the trophic state in the East was in the mesotrophic to oligotrophic range.

Biomonitoring results generally indicated that the main input to the Ashokan basins, Esopus Creek, was in good health. Numerous mayflies occurred at most sites, indicative of good water quality, and all but one site were rated non-impaired. Long-term trend data are available at two sites. Results indicated improvement at one site and no change at the other.

Waterfowl management in Ashokan Reservoir has been conducted on an “as needed” basis. Since 2003, waterfowl numbers on Ashokan have decreased dramatically. This decrease is primarily attributable to closure of local landfills and a consequent shift in gull migratory patterns. During the current assessment period, fecal coliform numbers have been low enough to obviate the need for "as needed" management.

Four sites on the Esopus and one reservoir output sample have been routinely monitored for *Cryptosporidium* and *Giardia*. Reservoir output results were much lower than the incoming streams', indicating that reservoir processes (e.g., settling, predation, die-off) provide an effective barrier, resulting in a reduction of protozoan numbers detected downstream.

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.

Due in some measure to DEP's watershed protection efforts, the water quality status of all four Delaware System basins continues to be very good. Monthly median fecal coliform counts were at or near detection limits. Monthly median turbidity ranged from 1.0 NTU at Neversink and Rondout Reservoirs to about 2.0 NTU at Pepacton and Cannonsville. Monthly median phosphorus ranged from 6 $\mu g\ L^{-1}$ at Neversink to approximately 14 $\mu g\ L^{-1}$ at Cannonsville. No monthly medians greater than 10 $\mu g\ L^{-1}$ were observed during the 2007-2009 period at Neversink, Pepacton, or Rondout, indicating low nutrient levels.

Long-term (1993-2009) trend analysis results indicate continued improvement in some water quality parameters. Watersheds with very active remediation programs (e.g., Pepacton, Cannonsville, and Rondout) all experienced strong downward trends in TP. Downward fecal coliform trends were detected in the Cannonsville and Rondout basins as well. Notable improvements were also observed in the Trophic State Index at Cannonsville. Certainly, lower phosphorus loads were a factor, but poor water clarity from large storm events also contributed to limiting algal productivity in this reservoir. Minor trophic state fluctuations upward at Neversink appear to be related to a small increase in phosphorus and decrease in turbidity. Turbidity trends (both up and down) were small in magnitude and appeared to be related to precipitation patterns and, to a lesser extent, algal blooms. Most basins also experienced increases in conductivity coinciding with a consistent increase in chloride, and associated with changes in precipitation.

Biomonitoring is conducted at several sites located on the primary stream inputs to Pepacton and Cannonsville Reservoirs. Test results during the 2007-2009 period indicated optimal conditions for the benthic communities. Trend analysis on 14-16 years of data indicated improvement at two sites in the Cannonsville System, presumably related to WWTP upgrades (among other watershed improvements) and the resultant reduction in phosphorus loads. At Site 321 on the East Branch Delaware River in the Pepacton basin, all scores were in the optimal range and no trend was detected. At Site 316, also on the East Branch, all but one assessment was optimal.

Waterfowl management in Rondout Reservoir is conducted on an as needed basis. Waterfowl numbers have remained similar to those recorded in previous years. Gulls tend to remain and move toward the Rondout Effluent Chamber as ice cover progresses. During the current assessment period, fecal coliform numbers increased to a level that triggered implementation of the management program from December 22, 2005 to March 4, 2006. Shortly after waterfowl harassment began, fecal coliform counts dropped sharply.

Cryptosporidium and *Giardia* pathogen monitoring has been conducted on the major inputs to all four reservoirs of the Delaware System. As with the Catskill System, reservoir output results were much reduced compared to those for input streams, indicating that reservoir processes such as die-off, sedimentation, and predation were effective in limiting the transport of pathogens downstream.

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

DEP has continued to enhance watershed protection in the West Branch, Boyd Corners, and Kensico basins. In the West Branch and Boyd Corners basins, 37 stormwater remediation projects were completed in the 2003-2009 period, with five large projects scheduled for completion by 2011. In the Kensico basin, 41 projects have been completed since 1997, with five more to be finished in 2011. In 2009, a second turbidity curtain was installed in the Malcolm Brook cove to protect the water entering the Catskill Effluent Chamber from stormwater runoff. The Waterfowl Management Program continued its long-term efforts to reduce waterbird populations on and around Kensico Reservoir. In early 2007, bird harassment strategies similar to those used on Kensico were successfully employed on West Branch Reservoir as well.

Water quality status evaluations continued to be excellent during the 2007-2009 period in West Branch and Kensico Reservoirs. Median and highest values (of the monthly reservoir-wide medians) were all well below the established benchmarks. (Benchmarks were used for fecal coliforms (20 CFU 100 mL^{-1}), turbidity (5 NTU), and TP (15 µg L^{-1}).)

Trend analyses indicated some improvement, or maintenance of, excellent water quality in the West Branch and Kensico basins. Turbidity and fecal coliform decreases detected in the local stream inputs to West Branch may be due, in part, to the extensive stormwater management projects that have been completed in the West Branch and Boyd Corners watersheds. A downward trend in phosphorus at the input from Rondout Reservoir (DEL9) was noted, along with some declines in more recent years in the local stream inputs, in the reservoir, and in its output. Trophic state increases in West Branch Reservoir, and turbidity increases in both the reservoir and output, are likely due to changes in the operational mode in the latter half of the data record.

In the Kensico basin, downward trends were detected for both fecal coliforms and TP. The decrease in fecal coliform counts is due to lower inputs from the Catskill and Delaware Systems and to the successful ongoing local efforts to reduce bird populations on the reservoir. The decrease in phosphorus is explained by the net effects of the ongoing watershed protection programs in these systems. Slight upward trends in turbidity and in trophic state were coincident with improved water clarity prior to 2005 in the Catskill System.

Biomonitoring results are available on the largest local stream inputs to West Branch and Kensico. Notably, the influence of these local streams on reservoir water quality is very small because the largest inputs are from the Catskill and Delaware reservoirs via aqueducts. Results from the West Branch input—Horse Pound Creek—indicated optimal conditions for the macroinvertebrate community both in recent years and long-term. Whippoorwill Creek, the largest local input to Kensico, was rated slightly impaired. Although long-term trends were not statistically significant, a notable decline was observed in the most recent two years, presumably the result of an increase in sediment loading from eroding streambanks upstream of the sampling site. Stabilization of these streambanks is expected in the near future.

Since 2002, *Giardia* and *Cryptosporidium* pathogen monitoring has been conducted at least weekly at the Catskill and Delaware influents and effluents of Kensico Reservoir. *Giardia* counts at the effluent sites have been generally low, averaging 1.89 cysts 50 L^{-1}. Effluent counts were generally lower than influent counts, due to reservoir processes such as sedimentation, die-off, and predation. Instances of higher effluent counts are thought to be due to inputs from local streams, since storm-related inputs are known to have higher concentrations. *Cryptosporidium* counts were usually an order of magnitude lower than those for *Giardia*, making it impossible to discern statistical differences between influent and effluent counts.

Water Quality Summary for the Potential Delaware System Basins

Improvements are ongoing in the Cross River and Croton Falls watersheds. Thirty-two stormwater control projects, mostly in the Croton Falls basin, were completed by 2009. Upgrades to WWTPs in the Cross River basin were initiated in 2008-2009. Some upgrades have also occurred in the Croton Falls basin, including the diversion of three WWTPs to the NYC-owned Mahopac WWTP. Consequently, phosphorus loads in the Croton Falls basin have decreased from 2,400 kg yr^{-1} in 1994 to about 100 kg yr^{-1} in 2009.

Long-term (1993-2009) trend analysis results did not indicate consistent changes in the key water quality indicators. In the Croton Falls basin, turbidity and phosphorus increases coincided with increases in precipitation, while increases in conductivity were associated with development activity in the watershed. A strong downward trend in fecal coliform was apparent in the West Branch release, which is the primary input for Croton Falls. In Cross River Reservoir, conductivity, turbidity, and phosphorus increases were also apparent. A decrease was detected in fecal coliform counts, but the statistical strength of the trend was weak and the magnitude small.

Recent status results indicate that the main basin of Croton Falls Reservoir is eutrophic, with monthly phosphorus concentrations exceeding 15 µg L^{-1} 50% of the time. Monthly median turbidity was 2 NTU, but on several occasions exceeded 5 NTU. Cross River water quality status was somewhat better: trophic state was usually in the mesotrophic range, monthly turbidity did not exceed 4 NTU, and phosphorus levels were slightly lower than those observed at Croton Falls. Elevated conductivities in both basins are indicative of development pressure. Given these conditions, it is more likely that Cross River would be chosen as a supplementary water source in the rare situations when pump stations are operated, although either source is generally acceptable.

Summary of Program Effects Estimated by Models

The effects of non-point source management, point source upgrades, and land use change on eutrophication in the Cannonsville and Pepacton Reservoirs were evaluated using DEP's Eutrophication Modeling System. Output from the Generalized Watershed Loading Function (GWLF) model provided loading estimates to evaluate watershed programs implemented as part of the MOA. Four watershed management programs were evaluated: Watershed Agricultural Program, Urban Stormwater Retrofit Program, Septic Rehabilitation and Replacement Program, and WWTP Upgrade Program. In addition, a significant decline in agricultural land use and agricultural activity that occurred from the early 1990s to the late 2000s independent of deliberate watershed management was evaluated.

Calibrated and validated GWLF models for Cannonsville and Pepacton were used to estimate nutrient loads for a series of scenarios, each of which represents a combination of land use, non-point source management, and point source conditions. A *BASELINE* scenario represents conditions existing in the 1990s prior to implementation of FAD programs. Two FAD evaluation scenarios represent conditions of the early 2000s (*FADPERIOD1*) and late 2000s (*FADPERIOD2*), before and during which substantial implementation of FAD programs occurred. Nutrient reduction factors due to watershed management programs were applied to represent watershed management effects in each of the scenario periods.

Changes in nutrient loading due to the combined effects of land use change and FAD programs were examined by comparing the *FADPERIOD* scenarios to the *BASELINE*. There was a ~49% reduction in dissolved phosphorus (P) loads from Cannonsville watershed from the *BASELINE* to *FADPERIOD1* and an additional ~7% reduction from *FADPERIOD1* to *FADPERIOD2*. For the Pepacton watershed, dissolved P export was reduced by ~23% from *BASELINE* to *FADPERIOD1* and an additional ~3% from *FADPERIOD1* to *FADPERIOD2*. The large reductions seen between the *BASELINE* and *FADPERIOD1* correspond to a combination of high rates of new program implementation and a substantial reduction in agricultural activity during that period. Continued but slower declines in P loads from *FADPERIOD1* to *FADPERIOD2* occurred as FAD programs became more focused on maintenance and improvement than on new program development, and the reduction in agricultural activity continued.

The relative effects of land use change versus watershed management on load reductions were examined by comparison of the *BASELINE* scenario to all scenarios examined during *FADPERIOD2*. Land use change (decline in agriculture) and watershed management both produced substantial reductions in P loading. Loading reductions due to land use change alone were ~18% for dissolved P in Cannonsville, and ~10% for dissolved P in Pepacton. The combination of land use change and watershed management produced reductions of ~55% for dissolved P in Cannonsville and ~26% for dissolved P in Pepacton. WWTP upgrades and the implementation of agricultural BMPs by the Watershed Agricultural Program provided most of the loading reductions, with minor reductions from septic system remediation and urban stormwater management.

The effects of land use change, non-point BMPs, and point source management on the trophic status of Cannonsville and Pepacton Reservoirs were evaluated by driving reservoir water quality models with the different nutrient loading scenarios simulated using GWLF. Simulated loading reductions due to combined land use change and watershed management between *BASELINE* and *FADPERIOD1* resulted in a ~34% reduction in the May-October epilimnetic chlorophyll concentrations, and a ~30% reduction in the May-October epilimnetic TP concentrations in Cannonsville Reservoir. For Pepacton Reservoir, the same reductions in concentration were ~15% and ~9% for chlorophyll and TP, respectively. As was the case for the input loads simulated with GWLF, reductions in reservoir concentrations during *FADPERIOD2* were lower. Between *FADPERIOD1* and *FADPERIOD2* there was a further reduction of ~5% in May-October epilimnetic chlorophyll concentrations and a ~3% further reduction in May-October epilimnetic TP concentrations. For Pepacton Reservoir, the additional reductions in concentration simulated as occurring between *FADPERIOD1* and *FADPERIOD2* were ~3% and ~2% for chlorophyll and TP.

Land use and FAD program-specific effects on reservoir trophic status were examined by comparison of *BASELINE* with *FADPERIOD2*. For Cannonsville Reservoir, lower watershed loads due to land use change only (decline in farming) resulted in reductions of ~9% for in-lake growing season chlorophyll and ~8% for TP. Greater reductions were predicted when the FAD programs were considered in addition to land use change (~39% for chlorophyll and ~32% for TP). The response of Pepacton Reservoir (which exhibited less eutrophication under *BASELINE* conditions) was similar, but the magnitudes of the reductions were less, suggesting that reservoirs with higher eutrophic conditions tend to benefit proportionately more from watershed load reductions.

Examination of daily, as well as long-term, mean reservoir chlorophyll levels suggests that the occurrence of extreme “bloom-like” epilimnetic chlorophyll concentrations are also affected by differing nutrient loading scenarios, and that the implementation of watershed management programs had an even greater impact on reducing the frequency of extreme epilimnetic chlorophyll concentrations than in reducing long-term mean concentrations.

A case study for the winter of 2010 was used to demonstrate the use of the DEP modeling system to inform reservoir operational decisions under the Catskill Turbidity Control Program. A series of events during the winter of 2010, which included a large event in late January, an unusually heavy snow pack in early March, and a series of significant events in March as the large snow pack melted, led to a prolonged period of elevated turbidity in Ashokan Reservoir. Throughout this period, a number of operational steps were employed to maintain high water quality in Kensico effluents without alum usage. These steps included the use of the Ashokan waste channel, the use of stop shutters in the Catskill Aqueduct to reduce flow to Kensico Reservoir, and the use of modeling-based determinations of the optimal Catskill and Delaware Aqueduct flow rates into Kensico Reservoir. Modeling activities helped to inform the timing and level of these operational decisions. This set of events demonstrates the potential usefulness of DEP’s water quality models in reservoir operation decision support during turbidity events. A hindcasting simulation was used to examine the effectiveness of the chosen turbidity control operations that were, in part, based on modeling forecasts. This simulation of the actual conditions during the turbidity event were compared to three scenarios simulated using the LinkRes reservoir model for Ashokan and Kensico Reservoirs. The scenarios examined the beneficial effects of using the waste channel, and of using stop shutters to reduce Catskill Aqueduct flow by systematically removing the use of these control measures and comparing simulated turbidity levels to those obtained from the hindcast scenario.

The results indicated that, for this particular event, use of the stop shutters to reduce Catskill System turbidity loads had the greatest impact on Kensico effluent turbidity. Use of stop shutters allowed simulated Kensico effluent turbidity to remain generally below 2 NTU. Simulations further suggest that if stop shutters had not been used the Kensico effluent turbidity would have rapidly increased in response to turbidity increases in the Ashokan East Basin and that Kensico effluent turbidity levels would have approached 3 NTU. Use of the waste channel led to a marginal improvement of Kensico effluent turbidity and to some decreased spill volume out of Ashokan Reservoir. It is important to note that the results for this case study may not hold true for other situations, such as: cases when turbidity in Ashokan Reservoir may be more persistent; cases where it would be possible to close the dividing weir gate to more effectively isolate the turbid West Basin water from the East Basin aqueduct effluents; or cases where extended periods of reduced Catskill Aqueduct flow may not be possible due to water quantity concerns.

The case study demonstrates the effectiveness of DEP's efforts to mitigate the effects of elevated turbidity in the Catskill System on the quality of water entering the distribution system from Kensico Reservoir. Despite turbidity inputs to Ashokan Reservoir of over 1,000 NTU and West Basin turbidity levels of over 200 NTU, the Kensico effluent turbidity levels never exceeded 2 NTU and chemical treatment of the water entering Kensico was not required during this event. This result was achieved by effective use of the Ashokan waste channel to minimize the spill of highly turbid water between the West and East Basin of Ashokan Reservoir, and by reducing the flow of water in the Catskill Aqueduct.

1. Introduction

1.1 Purpose of this Report

This report has been drafted to comply with Section 5.1 of the July 2007 Filtration Avoidance Determination (FAD), which requires that the City submit a Comprehensive Water Quality/ Program Evaluation Report to the United States Environmental Protection Agency (EPA) by March 31, 2011. The purpose of this report is to summarize the achievements of the programs that comprise the City's overall watershed protection program; to review water quality status and trends in the Catskill/Delaware basins; and, where possible, to demonstrate the link between program activities and changes in water quality.

The report is divided into two main sections: Chapter 2 provides short summaries of the accomplishments of each of the watershed protection programs for the past five years, and Chapters 3 through 7 use monitoring results and modeling to assess current and future water quality and to evaluate the effectiveness of some of those programs.

This document should be viewed as a companion to the regular reports DEP has produced detailing program progress and water quality over the past five years. For specific details about the implementation of watershed protection programs, refer to the Annual Reports prepared pursuant to the FAD for the years 2007 through 2009. 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 (www.dep.nyc.gov) contains periodic updates on certain programs and other details.

1.2 Water Supply System

The New York City water supply system consists of three surface water sources (the Croton, the Catskill, and the Delaware) and a system of wells in Queens (the Jamaica system). 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. The system supplies drinking water to almost half the population of the State of New York—over eight million people in New York City 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 2010 averaged less than 1.1 billion gallons a day.

The New York City Department of Environmental Protection (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 and Assessment, Consumer and Intergovernmental 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 New York City Department of Health and Mental Hygiene assist in certain drinking water programs and staff from the New York City Law Department provide important 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 150 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. Approximately 10% of the City's average daily water demand is supplied by the Croton, although in times of drought the Croton System may supply significantly more water.

The City is in the process of constructing a water treatment plant to filter the Croton Supply. While the Croton System continues to meet all current health-based regulatory standards for a surface water supply, it does experience periodic violations of the aesthetic standards for color, taste, and odor. In addition, DEP does not believe that the Croton System will be able to meet stricter disinfection by-product rules recently promulgated. The Croton water treatment plant is expected to resolve these concerns.

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 twentieth century, and Ashokan Reservoir went into service in 1915. Water leaves Schoharie Reservoir via the 18-mile Shandaken Tunnel, which empties into Esopus Creek at Allaben and then travels 22 miles to Ashokan Reservoir. Water leaves Ashokan via the 75-mile-long Catskill Aqueduct, which travels to Kensico Reservoir in Westchester County. The Catskill System supplies, on average, 40% of the City's daily water supply.

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

In the late 1980s, the City decided to apply for filtration avoidance for the Catskill/ Delaware System under the terms of the Surface Water Treatment Rule (see 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 Catskill/Delaware water. This program has been recognized internationally as a model for watershed protection and has allowed the City to secure a series of waivers from the filtration requirements of the Surface Water Treatment Rule.

1.3 Regulatory Context

The Safe Drinking Water Act (SDWA) amendments of 1986 required EPA to develop criteria under which filtration would be required for public surface water supplies. In 1989, EPA promulgated the Surface Water Treatment Rule (SWTR), which requires all public water supply systems supplied by unfiltered surface water sources to either provide filtration or meet a series of water quality, operational, and watershed control criteria. These criteria are referred to as the filtration avoidance criteria.

As noted, the filtration avoidance criteria are comprised of three main areas:

- 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.

These requirements were reinforced through the 1996 amendments to the SDWA. EPA amended the SWTR on December 16, 1998, with the Interim Enhanced Surface Water Treatment

Rule (IESWTR), which is codified in Subpart P of 40 CFR Part 141. The IESWTR requires unfiltered systems to meet additional provisions to remain unfiltered, including compliance with more stringent disinfection by-product maximum contaminant levels and the requirement to address *Cryptosporidium* in their watershed control programs.

1.4 Historical Context

The City first applied for a waiver for the Catskill/Delaware System from the filtration requirements of the SWTR in 1991. This first application was filed with the New York State Department of Health (DOH), because at the time the City and DOH believed that DOH had primacy for all systems in New York State. DOH granted a one-year filtration waiver. Subsequently, it was determined that EPA had retained primacy for the SWTR for the Catskill/Delaware Systems. In mid-1992, DEP submitted a 13-volume application to EPA, describing in detail the City's plans for protecting the Catskill/Delaware supply. On January 19, 1993, EPA 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. EPA also imposed substantial reporting requirements on the City, to monitor the City's progress.

DEP submitted a second application for avoidance to EPA 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, EPA 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, EPA issued a second conditional determination, containing 150 conditions related primarily to enhanced watershed protection and monitoring programs. EPA also required that the City proceed with design of a filtration facility for the Catskill/Delaware supply, so that no time would be lost should EPA decide that filtration was necessary in the future.

Two critical pieces of the watershed protection program that DEP described in September 1993, and that EPA 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; EPA; 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 Memorandum of Agreement (MOA). The MOA supplemented the City's existing watershed protection program with approximately $350 million in additional funding for economic-environmental partnership programs with upstate communities, including a water quality investment program, a regional economic development fund, and a regional advisory forum for water quality initiatives and watershed concerns. The State issued a land acquisition permit, which allows the City to purchase land in the watershed, and approved a revision to the City Watershed Rules and Regulations governing certain aspects of land use in the watershed. The City also secured a 5-year waiver from the filtration requirements for the Catskill/Delaware System. The City agreed to fund these programs, including significant funding to be used to maintain the character and economic viability of watershed communities.

In December 2006, the City submitted to EPA a rigorous, science-based assessment of Catskill/Delaware water quality and an enhanced, comprehensive long-term plan for watershed protection efforts. DEP has conducted an assessment of current water quality and the effectiveness of certain aspects of its watershed protection program. 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 a revised FAD, issued by EPA in July 2007. Significantly, the 2007 FAD was the first FAD to cover a full 10-year period, signaling the growing confidence of all parties that source water protection has become a sustainable alternative to filtration for the City's Catskill/Delaware supply.

1.5 Report Details

This report primarily focuses on program activities undertaken since 2006 and continuing through the end of 2010. However, since most of the programs discussed were initiated prior to 2006, 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 2001and 2006 assessments of DEP's FAD programs. Here DEP presents an analysis covering 17 years of data collection and program implementation. These data include results collected through the end of 2009. Due to the time needed to compile, review, and verify data, it was not possible to incorporate monitoring results from 2010. Long-term data are critical in the evaluation of programs that cover large geographical areas and are implemented over long periods of time, so analyses will become better defined as the data record becomes longer. The approach DEP has used is to evaluate water quality in terms of status, trends, case studies, and modeling. The status of waterbodies is based on three recent years of data (i.e., 2007 through 2009) and these are compared to regulatory benchmark values. The trends are based on 17 years of data (i.e., 1993 through 2009). Five important analytes were selected, including fecal coliforms, turbidity, phosphorus, conductivity, and trophic status. Case studies were done for selected monitoring sites that had sufficient proximity and sampling intensity to demonstrate program effects. Modeling was conducted to attribute program effects to programs on a watershed-wide basis and to evaluate program effectiveness under potential future conditions. All analyses togeth er provide a context to understand program effects.

2. Watershed Management Programs

2.1 Institutional Alliances

While DEP is responsible for the collection, monitoring, treatment, and delivery of high quality water to the City, it relies heavily on the work of partner organizations to carry out watershed protection efforts. Numerous towns, counties, state and federal agencies, not-for-profit organizations, and private businesses have participated in and helped implement watershed protection programs. Without local input and involvement, the City's programs would not be as successful as they are today.

The Watershed Memorandum of Agreement (MOA) explicitly acknowledges the importance of cooperative partnerships to the success of the City's watershed protection efforts:

> …the goals of drinking water protection and economic vitality within Watershed communities are not inconsistent and it is the intention of the parties to enter into a new era of partnership to cooperate in the development and implementation of a Watershed protection program that maintains and enhances the quality of the New York City drinking water supply system and the economic vitality and social character of the Watershed communities...

Indeed, two of the three major sections of the MOA establish voluntary protection programs—the protection and partnership programs and the Land Acquisition Program. These and other partnership programs arise from the recognition that the actions of private landowners—the farmers, homeowners, and businesspeople who own 65% of the land in the watershed—directly affect the quality of the City's water supply. For this reason, the City has supported strategies to encourage landowners to manage their land in a manner that will protect and improve water quality. Because of its position in the watershed as a large outside municipality, however, DEP is not always the best positioned organization to implement these programs. In addition, watershed municipalities, agencies and organizations can be more responsive to local concerns and are able to act quickly to resolve issues as they occur. For these reasons, the City has contracted with numerous municipalities and not-for-profit organizations to implement many of its watershed protection programs. These partnerships have maximized the success of the programs and at the same time improved DEP's relations with municipalities and individuals in the watershed.

Since the last assessment of the watershed protection program in 2006, already-established organizations have matured and more organizations have developed and taken hold in the NYC Watershed. The collective efforts of these organizations have greatly contributed to the implementation of the City's watershed protection program.

DEP's major partner organizations involved in FAD implementation—the Watershed Agricultural Council (WAC), the Catskill Watershed Corporation (CWC), and DEP's partners in the Stream Management Program—continued to refine and enhance programming in the last five-year period. These organizations have strengthened both administratively and financially and provide excellent leadership in the watershed.

WAC

During the period 2006 to 2010, WAC continued to mature and evolve as a local not-for-profit organization with a focus on strengthening and improving its overall governance structure and recruiting a new executive leadership team (Executive Director, Finance Director, Agricultural Program Manager, Forestry Program Manager, Easement Program Manager, and Database Administrator). As a first step, WAC conducted a comprehensive decision making consultancy project that resulted in a more focused and streamlined internal decision making process, with many programmatic decisions being delegated to WAC committees or WAC staff. This project also resulted in a major reorganization of WAC policies and the development of detailed staff guidelines and standard operating procedures to further help guide and clarify internal decisions. As part of this effort, the WAC board also adopted a series of new policies that address public input and transparency issues. Also during the reporting period, WAC conducted an internal controls risk assessment audit which strengthened and clarified its finance department. WAC is currently conducting a similar audit to assess human resource functions and issues, in addition to launching a renewal of its Five-Year Strategic Plan with input from the WAC Advisory Committee. Finally, WAC has undertaken the development of a conservation easement stewardship endowment fund, as well as a comprehensive database management system that will serve the entire organization; the latter will greatly improve WAC's ability to monitor, track, report, and utilize program accomplishments and other data in a more effective and proactive manner.

CWC

CWC successfully integrated new programming into its portfolio of services, including Stormwater Technical Assistance, a Business Septic Repair Program, and an Institutional Sand and Salt Storage Program. The CWC Septic Repair Program has had unprecedented levels of participation in recent years as it has continued to grow. CWC has also assumed full management of the Catskill Fund for the Future, including those program elements that were previously handled by the NYS Environmental Facilities Corporation (EFC). CWC continues to effectively manage its finances and grow its technical and administrative capabilities. It has also successfully addressed several sensitive community issues and serves as a valuable forum for productive discussion on topics important to watershed communities and partners.

Stream Management Program Partners

Since 2007, the partnerships in the Stream Management Program have substantially expanded and strengthened for the purpose of implementing the programmatic, policy, and project recommendations outlined in the stream corridor management plans. Under the leadership of the county Soil and Water Conservation Districts (SWCDs), Cornell Cooperative Extension (CCE) of Ulster County, and the Delaware County Planning Department (DCPD), locally-driven funding programs have been developed and deployed in the Schoharie, Ashokan, and Delaware watersheds. The Districts, CCE Ulster, and DCPD oversaw an ambitious effort to encourage each watershed municipality to adopt its respective stream management plan(s), the Stream Stewardship Principles, and a Memorandum of Understanding to work collaboratively with the respective SWCD to solve stream-related challenges. Further, the Districts, CCE Ulster, and DCPD formalized advisory boards comprised of municipal leaders and key stakeholders, and these boards and their subcommittees are now overseeing the implementation of the stream management plan recommendations. Projects range from stream, floodplain, and riparian buffer restoration to improve water quality and reduce erosion, to addressing hydraulic constrictions that exacerbate localized flooding, to planning for enhanced recreational access to rivers, to school curriculum enhancements to teach students the principles of stream ecology and how streams respond to management decisions. This progress since 2007 reflects a tremendous commitment to advancing stream stewardship in the West of Hudson watershed region that simply could not be achieved without local leadership and initiative.

Beyond the efforts and participation of the board members and staff of these organizations, private landowners throughout the watershed continue to come forward and participate in watershed protection opportunities. Whether it is by maintaining a septic system, cooperating with efforts to address an eroding streambank, selling land or a conservation easement to the City or WAC, or attending a public education program, private landowners are participating in voluntary programming in increasing numbers. This unprecedented level of participation shows that the programs are working.

All of these activities mean local expertise is being developed throughout the watershed to ensure that future land management activities are conducted in the best way possible to protect and improve water quality. While the activity and record of accomplishment is very significant, it is the local expertise, economic value of these programs, and understanding of the local benefits that will serve the New York City water supply well into the future.

2.2 Land Acquisition

Background

The 2007 FAD established the following requirements through 2017:

- A commitment of $241 million of new funding, bringing the total amount available for land acquisition in the Catskill/Delaware Systems from 1997 to 2017 to $541 million. Seventy-two and one-half million dollars in new funding was required to be sequestered prior to December 31, 2008, $90 million prior to December 31, 2011, and $78.5 million prior to December 31, 2014.
- Development and implementation of a plan to substantially increase the use of land trusts and other non-government organizations to identify and help the City acquire eligible lands. In addition, DEP will provide $6 million in funding to the Watershed Agricultural Council (WAC) to undertake a pilot program for the acquisition of conservation easements, by WAC, on forested portions of non-agricultural properties.
- An agreement by the City to provide an additional $500,000 for local consultation on proposed acquisitions of land by the City under its Land Acquisition Program (LAP).
- A strategic review that will help establish the shape of the program, for the second five years of this FAD and for a further five years after this FAD.

2.2.1 Status of Deliverables

Funding

Seventy-two and one-half million dollars was sequestered as required prior to December 31, 2008.

Land Trusts

The City issued a "Land Trust Strategy" in November 2007 with the goal of "substantially increasing the use of land trusts to help the City acquire eligible lands." It has since been determined that the majority of proposals in the Strategy cannot be feasibly implemented, through no lack of dedication by both the City and land trust community. However, the City has continued to work with land trusts to conclude a number of specific land transactions, has funded and/or become a sponsor of several land trust educational events directed at landowners in the watershed, and is currently engaged in negotiations with land trusts and local communities West of Hudson (WOH) to develop the following programs:

- A riparian buffer protection program, pursuant to the 2010 Water Supply Permit;
- A program through which land trusts would acquire large properties with dwellings (the City is prohibited from acquiring dwellings WOH) and sell vacant land directly to the City. The program would be targeted to landowners who are not willing to undertake subdivision in order to retain their dwelling. The process is expected to involve acquisition of the entire property by the land trust followed by subdivision, after which the land trust would convey the dwelling to a private buyer and the vacant parcel to the City.

Pilot Forest Easement Program

The 2007 FAD mandated that DEP fund a $6 million program through which WAC would acquire easements on "forested portions of non-agricultural" property. Negotiations began in earnest in late 2007 and continued through 2010, but the two organizations have been unable, to date, to find the common ground needed to advance the program. DEP's own conservation easement program provides ample opportunity and has demonstrated success in providing opportunities for willing sellers to protect their forest resources.

Solicitation and Resolicitation

The entire Catskill/Delaware watershed, which includes all WOH basins as well as the West Branch/Boyd Corners and Kensico basins East of Hudson, comprises 1,023,496 acres (excluding reservoirs). Of these, approximately 215,894 acres (21.1%) are owned outright by other public agencies or land trusts, and provide a strong level of protection. As of 1997, 35,578 acres (3.5%) of land (excluding reservoirs) were owned by New York City. Of the remaining privately-held land, the City was required to solicit the owners of 355,050 acres during the first eight years of the program. This original solicitation deliverable was met as of December 2004. Pursuant to the 2007 FAD, the City issued a 2008-2010 Solicitation Plan, which called for the solicitation of approximately 90,000 acres of "new" land through 2010, which DEP has completed. During the term of the program to date, resolicitation of most acres previously solicited has continued, in particular within the highest priority areas, and has led to considerable success. As of December 31, 2010, watershed-wide solicitation and resolicitation efforts resulted in the City securing 92,139 acres in fee simple or conservation easement, with another 21,236 acres of farm easements secured by WAC[1]. Since 1997, LAP has thus increased the City's ownership interest in real property within the watershed by 319%.

Local Consultation Funds

An additional $500,000 was allocated in 2007 to the Local Consultation Fund, managed by the Catskill Watershed Corporation, as directed by the 2007 FAD.

Long-Term Strategic Plan

In September 2009, DEP issued a Long-Term Land Strategic Plan for the period 2012-2022, as directed by the 2007 FAD.

Additional Program Areas

MOA "Supplementary" Fund

The City has consulted on several occasions with EPA and the New York State Department of Health (DOH) regarding the potential use of the $50 million supplementary fund. In 2004 and 2006, the City was directed to allocate $7 million and $20 million of the fund,

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1. Unless otherwise noted, all acreage figures (and percentages derived from acreage figures) in this section utilize a GIS-based figure that excludes any land acquired outside the Catskill/Delaware watershed. For example, if LAP acquired a 100-acre property and 3 acres of that property lies outside the watershed (or in the Croton System) this report tallies that acquisition as 97 acres. Overall, LAP acquired 114,235 acres in Catskill/Delaware transactions through the end of 2010, of which 860 acres, or 0.8%, were outside the watershed boundary or in the Croton System.

respectively, to the Farm Easement Program managed by WAC. In 2008, DOH directed the City to allocate the remaining $23 million to WAC in support of this program. This commitment is expected to be assigned in the context of a revised program contract before the current contract expires in September 2012. (See report on WAC Farm Easement Program below.)

Program Improvements

- Many properties require subdivision of residential improvements that are retained by sellers who wish to convey vacant land to the City. Since 2008 the City has implemented an incentive reimbursement of up to $5,000 to such landowners to pay for related subdivision costs. This incentive has resulted in a noticeable increase in fee simple subdivision contracts.
- During the first several years of program operation, the standard purchase contract term for fee simple, non-subdivision projects was 18 months, which was shortened to 14 months beginning in 2003. The contract term for acquisitions involving subdivisions and conservation easements remains at 18 months. There are procedural constraints that make shorter contract terms impractical, although DEP does close many contracts within a shorter time frame when the landowner's obligations are completed in a timely fashion.

Fee Simple Acquisitions by DEP

Between January 2006 and December 2010, DEP signed 370 fee simple projects totaling 24,981 acres. Through 2010, DEP had secured 1,059 fee simple contracts totaling 70,148 acres. This represents 62% of the 113,375 acres (a figure which includes WAC farm conservation easements) secured through the overall LAP.

Conservation Easements

DEP's Conservation Easement (CE) Program. Between January 2006 and December 2010, DEP signed 79 CEs totaling 11,904 acres. Through 2010, DEP secured 144 CEs totaling 21,991 acres. This represents 19% of the 113,375 acres (a figure which includes WAC farm CEs) secured through the overall LAP.

WAC's Farm Easement Program. Between January 2006 and December 2010, WAC signed purchase contracts on 47 farm easements totaling 7,993 acres. Through 2010, WAC secured 115 farm easements totaling 21,236 acres, or 19% of the 113,375 acres secured through the overall LAP.

The WAC Farm Easement Program—including the costs of virtually all easement acquisitions, program overhead, and stewardship costs—has been supported by the following funds from DEP:

- $20 million in 1999 (including $10 million for "agricultural" and $10 million for "non-agricultural" land on farms) from the original $250 million LAP fund;
- $7 million in 2006 (from the $50 million Supplementary Fund outlined in MOA section 74);
- $20 million in 2007 (from the Supplementary Fund); and

- The remaining $23 million from the Supplementary Fund, which DOH directed DEP, in a letter dated April 30, 2008, to allocate to WAC; these funds have been budgeted. Time delays due to negotiating certain elements of the program contract have led to a postponement of the new program contract. However, there has been no interruption in WAC's program, because the existing contract has been extended through September 14, 2012, before which time a new contract adding the $23 million will be finalized. Existing unspent funds are deemed sufficient by both WAC and DEP to carry the program through this period.

Upon allocation of the new funds, the total committed to the WAC Farm CE Program will be $70 million.

Riparian Buffers: Catskill/Delaware Watershed Only

Prior to 1997, the City controlled 1,946 acres of riparian buffers (defined here as land within 100 feet of streambanks), or 2.6% of buffers in the watershed. Under LAP from 1997 through 2005, the City protected an additional 3,516 acres of buffers under fee simple acquisition and 1,011 acres under CEs; WAC protected 950 acres of buffers within farm easements during this period. (It should be noted that WAC's model farm CE substantially protects riparian buffer strips within 25 feet of streambanks, areas which are protected from, and act as buffers to, intensive farm practices; the remaining 75 feet of buffer land within a farm CE may be actively farmed, but only in adherence to a Whole Farm Plan, which is intended to balance farming and water quality protection.) Through 2005, the City acquired 9.7% of riparian buffers in the watershed. From 2006 through 2010, the City acquired another 1,677 acres of riparian buffers in fee simple and 740 acres under easement, while WAC secured an additional 876 acres of riparian buffers under farm CEs—in all another 4.3% of riparian buffers in the watershed. Thus, including lands owned by the City before 1997, the City now protects over 16% of the 100-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 24,922 acres of identified 100-foot stream buffers are protected, or 32.7% of the 76,300 acres of the 100-foot stream buffers identified in the Catskill/Delaware watershed. (For more on stream buffers, see Section 2.6.)

Wetlands: Catskill/Delaware Watershed Only

Of the 1,023,496 acres that comprise the Catskill/Delaware watershed, 43,539 acres (4.15%) are identified as wetland or inundated aquatic habitat (i.e., lakes and streams). Of these, 2,576 acres (6.0%) have been protected by LAP (including farm CEs) as of the end of 2010. Wetlands represent roughly 2.3% of lands protected by LAP. For more on DEP's wetland protection programs, see Section 2.9.

2.2.2 Basin Status Reports

Schoharie

The Schoharie basin contains 200,895 acres, excluding the reservoir ("basin land area"), and all land within the basin has been categorized as either Priority 3 or 4. As of 1997, the City owned 1,038 acres of reservoir buffer land, or 0.5% of basin land area, with another 37,985 acres (18.9%) protected by non-City entities[1]. Since 1997 the City has protected 22,629 acres in fee or easement, a figure which includes WAC farm CEs. This newly-acquired land represents 11.3% of the basin and a more than twenty-fold increase in the amount of City-controlled land in this basin since 1997. Total land protected by City and non-City entities is roughly 61,958 acres, or 30.7% of the basin. Figure 2.1 illustrates lands protected by program area, while Figure 2.2 illustrates the extent of change of City ownership within the basin due to program acquisitions.

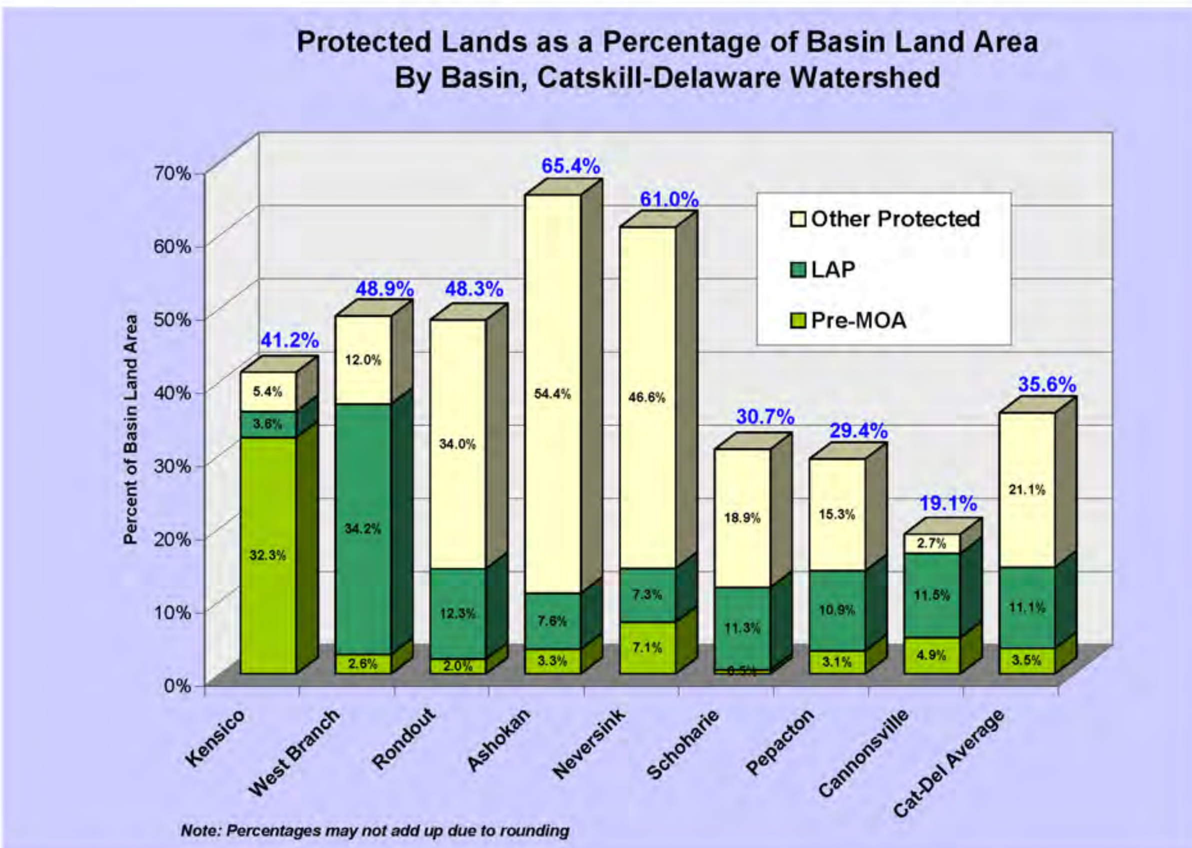

Figure 2.1 Protected lands as a percentage of basin land area, Catskill/Delaware watershed.

1. Information on land protected by non-City entities is derived from county tax data and/or other non-verified independent sources.

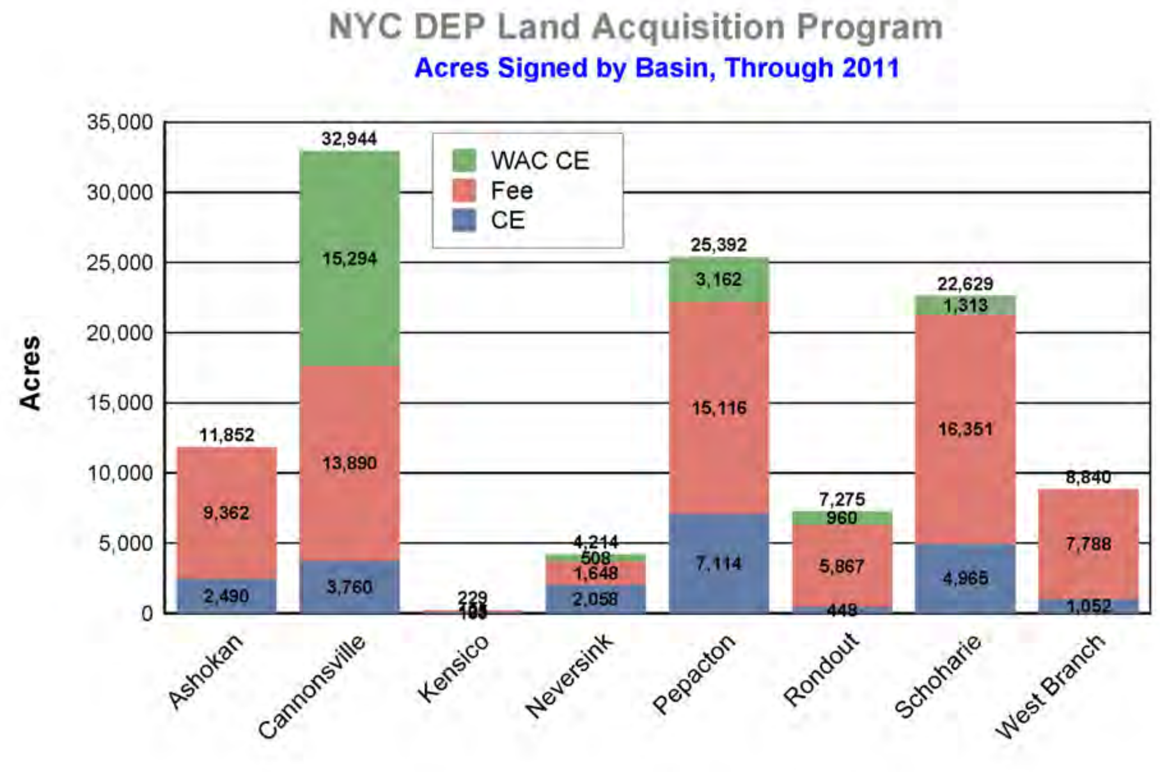

Figure 2.2 Acres signed by basin through 2010.

Ashokan

The Ashokan basin land area is 155,299 acres, all categorized as either Priority 1 or 2. As of 1997, the City owned 5,202 acres of reservoir buffer land, or 3.3% of the basin, with another 84,523 acres (54.4%) protected by non-City entities. Since that time the City has protected 11,852 acres in fee or easement. This land represents 7.6% of the basin land area and a 228% increase in the amount of City-controlled land in this basin since 1997. Total land protected by City and non-City entities is over 100,000 acres, or 65.4% of the basin land area.

Neversink

The Neversink basin land area contains 57,410 acres, all categorized as Priority 4, with the exception of 0.2% in Priority 1A. As of 1997, the City owned 4,050 acres of reservoir buffer land, or 7.1% of the basin, with another 26,778 acres (46.6%) protected by non-City entities. Since that time the City has protected 4,214 acres in fee or easement, a figure which includes WAC farm CEs. This land represents 7.3% of the basin land area and a 104% increase in the amount of City-controlled land in this basin since 1997. Total land protected by City and non-City entities is 35,042 acres, or 61.1% of basin land area.

Pepacton

The Pepacton basin land area contains 232,276 acres, categorized variously as Priority 1, 3, or 4. As of 1997, the City owned 7,286 acres of reservoir buffer land, or 3.1% of the basin land area, with another 35,499 acres (15.3%) protected by non-City entities. Since that time the City has protected 25,392 acres in fee or easement, a figure which includes WAC farm CEs. This land represents 10.9% of the basin land area and an increase of over 349% in the amount of City-controlled land in this basin since 1997. Total land protected by City and non-City entities is 68,177 acres, or 29.4% of the basin land area.

Cannonsville

The Cannonsville basin land area contains 286,377 acres, categorized variously as Priority 1, 3, or 4. As of 1997, the City owned 14,065 acres of reservoir buffer land, or 4.9% of the basin, with another 7,602 acres (2.7%) protected by non-City entities. Since that time the City has protected 32,994 acres in fee or easement, a figure which includes WAC farm CEs. This land represents 11.5% of the basin land area and an increase of over 230% in the amount of City-controlled land in this basin since 1997. Total land protected by City and non-City entities is 54,611 acres, or 19.1% of the basin land area.

Rondout

The Rondout basin land area contains 59,003 acres, all categorized as Priority 1A or 1B. As of 1997, the City owned 1,192 acres of reservoir buffer land, or 2.0% of the basin, with another 20,058 acres (34.0%) protected by non-City entities. Since that time the City has protected 7,275 acres in fee or easement. This land represents 12.3% of the basin land area and more than a six-fold increase in the amount of City-controlled land in this basin since 1997. Total land protected by City and non-City entities is 28,525 acres, or 48.3% of the basin land area.

West Branch/Boyd Corners

The West Branch and Boyd Corners basin land areas contain 25,830 acres, all categorized as Priority 1A or 1B. As of 1997, the City owned 680 acres of reservoir buffer land, or 2.6% of the basin land area, with another 3,150 acres (12.0%) protected by non-City entities. Since that time the City has protected 8,840 acres in fee or easement. This land represents 34.2% of the basin land area and a thirteen-fold increase in the amount of City-controlled land in this basin since 1997. Total land protected by City and non-City entities is 12,625 acres, or 48.9% of the basin land area.

Kensico

The Kensico basin land area contains 6,406 acres, all categorized as Priority 1A or 1B. As of 1997, the City owned 2,066 acres of reservoir buffer land, or 32.1% of the basin land area, and another 344 acres (5.4%) were protected by non-City entities. Since that time the City has protected 229 acres in fee or easement, representing 3.6% of the basin and bringing total land under City control to 35.8% of the basin land area since 1997. Total land protected by City and non-City entities is 2,640 acres, or 41.2% of the basin land area.

Croton System Acquisitions

With virtually all of the $38.5 million allocated to it having been spent or committed, DEP's acquisition program in the Croton System as envisioned by the MOA is complete. Twenty-five properties (1,650 acres) have been acquired using these funds, with one additional property (269 acres) remaining under contract yet to close. In addition, approximately 788 acres of Croton acquisitions were made—some by non-City entities—using City funding from sources external to LAP's dedicated "Croton" funds. The total number of acres secured in the Croton System through all DEP funding sources is thus 2,707 (including the purchase contract yet to close).

Catskill/Delaware Watershed Summary: City Has Tripled Number of Acres Protected by Ownership Interests

Figures 2.1 and 2.3 provide different graphical perspectives on land acquired and/or otherwise protected throughout the water supply system. Figure 2.1 illustrates the percentage of each basin's land area that has been protected, by program area, while Figure 2.3 shows the pattern of acres signed to contract annually, indicating acreage within each of the three LAP program areas. As of 1997, the City owned and controlled 3.5% of watershed lands (not including reservoirs). Since 1997, an additional 113,375 acres (11.1%) have been secured by DEP, including WAC farm CEs; therefore, including pre-MOA land, the City now controls 14.6% of land (Figure 2.1). Tax map data and other sources indicate that at least another 21.1% is owned and controlled by non-City (non-WAC) public agencies and land trusts, bringing total protected land to over 35% of the watershed, up from about 23% 10 years ago. Through the City's land acquisition efforts to date, therefore, there has been a tripling of City-controlled land in the watershed, or a 45% increase in all protected lands (regardless of owner) since 1997.

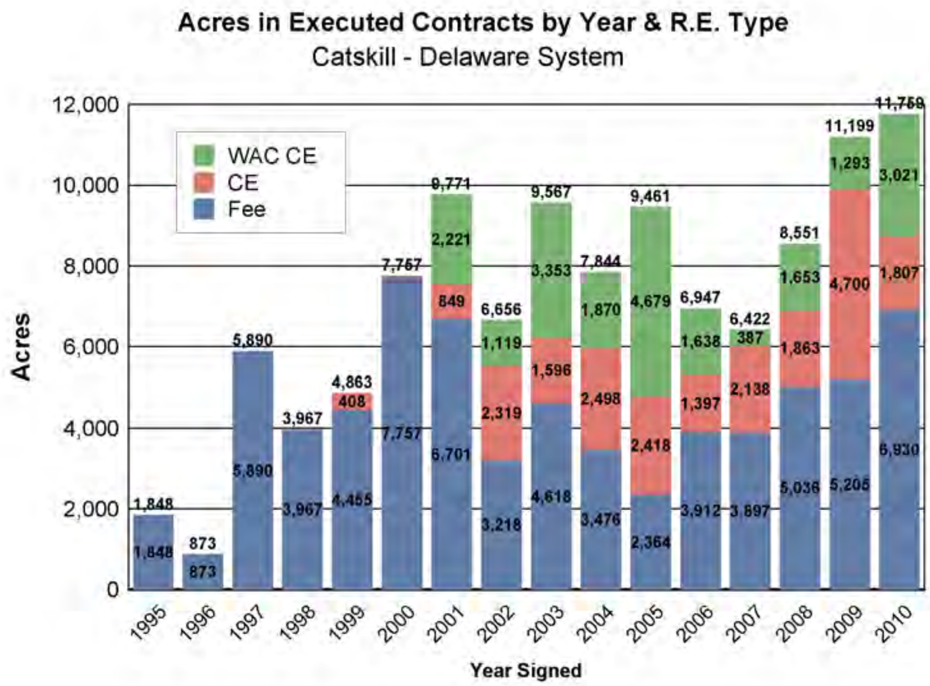

Figure 2.3 Acres in executed contracts by year and real estate type, Catskill/ Delaware watershed.

Table 2.1 displays total and average annual statistics for acres and deals signed to contract during the two assessment periods. As between those periods, the number of acres and deals acquired by DEP in fee simple, and the acres/deals acquired under easement by WAC, are not distinctly different, while the average annual deals and acres under easement acquired by DEP do appear to be substantially lower during the first assessment period. This is likely due, however, to the inclusion of the early program period (1997-2000), when the easement program was being designed, prior to full implementation. One conclusion from this review is that the program has remained stable and strong over time, although on the whole it is difficult to make meaningful comparisons between these two “arbitrary” assessment periods with respect to the Land Acquisition Program. Figure 2.3 may depict a more coherent story with regard to program successes over time, since, from that figure, it is possible to recognize the impacts of larger market forces. These forces (the job market, property taxes, stock market, construction costs, etc.) that shape real estate demand and values are probably the most important factors influencing landowner responses to LAP solicitations.

Table 2.1: Program accomplishments by assessment period.

Acres/Deals Signed to Contract	1997*-2005	2006-2010	Grand Totals
Acres Signed to Contract			
DEP Fee Land	45,167	24,981	70,148
DEP Easements	10,087	11,904	21,991
WAC Farm Easements	13,243	7,993	21,236
Totals	68,497	44,878	113,375
DEP Fee Annual Average	5,018	4,996	5,011
DEP CE Annual Average	1,121	2,381	1,571
WAC Annual Average	1,471	1,599	1,517
Total Annual Average	7,611	8,976	8,098
Assessment period, in years	9	5	14
Deals signed to contract			
DEP Fee Land	689	370	1,059
DEP Easements	65	79	144
WAC Farm Easements	68	47	115
Totals	822	496	1,318
DEP Fee Annual Average	77	74	76
DEP CE Annual Average	7	16	10
WAC Annual Average	8	9	8
Total Annual Average	91	99	94
Assessment period, in years	9	5	14

* 1997 figures include option agreements signed in 1995 and 1996.

2.3 Land Management

Background

As the City's portfolio of lands has grown, management of these lands has taken on greater importance. DEP's land management approach has four major areas of concentration:

- Property Management
- Forest Management
- Natural Resources
- Land Uses on City Lands

2.3.1 Property Management

The success of the Land Acquisition Program is outlined in Section 2.2 of this report. As a result, management responsibilities have become quite significant.

Monitoring

DEP revised its fee-monitoring policy (DEP 2010a) in 2010. The revised policy assigns two classes of priority to City-owned water supply land: high and standard. High priority properties were selected based on a ranking system that assigned points for uses and activities occurring on the land, including: (1) area is open for high-intensity recreational use, (2) there are permits in effect allowing high-intensity land use activities on the land, (3) property includes areas of special concern or security risks (e.g., aqueducts, dams, intakes), and (4) property had an incident of trespass or encroachment in the last two years. Roughly 25% of the portfolio is designated as high priority. All other properties were designated as standard priority properties. The priority of a property may be changed depending on conditions and field observations by DEP staff.

High priority properties receive greater attention from DEP staff, including an annual inspection. These inspections may cover the entire property or those areas with the greatest use or potential for encroachments. Standard priority properties will receive an inspection every five years at a minimum. All properties may receive site visits at any time depending on reports of suspicious activity by staff or the public, after natural disasters, and to follow up on issues that have been reported previously.

Boundary Line Maintenance

All properties receive a Boundary Inspection and Maintenance visit every five years. During these visits, all external property boundaries are walked and inspected. Blazes and signs are refreshed and boundary monumentation replaced as needed.

Figure 2.4 DEP staff inspecting and posting property.

Encroachments

With large land holdings come increased chances of encroachments and trespass. Through consistent and thorough inspections and boundary line maintenance, encroachments can be discovered sooner, thereby increasing the chances of an easy resolution. If encroachments have been in existence for many years, they become much more difficult to resolve. DEP has to strike a balance between dealing with minor encroachments (e.g., small vegetable gardens, mowing, fences), which present no water quality issues, and major encroachments (e.g., a house, septic field, car dump), which may be a water quality issue. Resource limitations make prioritizing encroachments a necessity. For minor encroachments, DEP staff primarily seeks discontinuation of the encroachment.

The number of possible encroachments and trespass increases with greater numbers of adjacent landowners. Figure 2.5 illustrates a typical City-owned East of Hudson property with many adjacent neighbors.

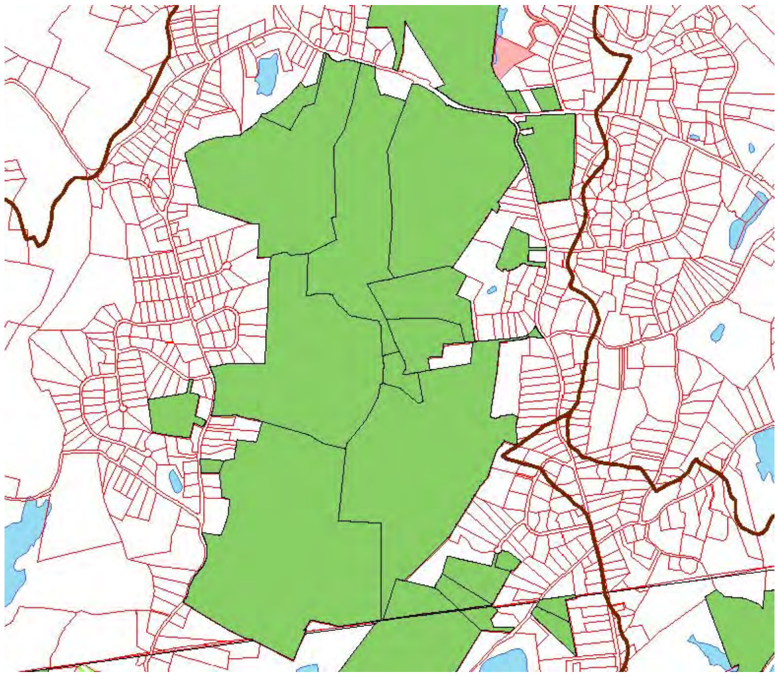

Figure 2.5 City-owned property with adjacent neighbors.

In 2010, DEP finalized a protocol for addressing criminal encroachments such as trespass, vandalism, and timber theft. Previously, DEP had no formal protocol for coordination among DEP Police, DEP Legal, and other DEP directorates. One of the first cases to utilize this process resulted in the restoration of damaged City property.

Conservation Easements

As reported in Section 2.2, since 2006 the portfolio of conservation easements has risen substantially. The preferred method of acquiring land for water supply protection has always been to purchase fee-simple lands. However, the conservation easement has played a key role in securing protection when landowners did not want to sell land in fee. Over the years, DEP has incorporated greater reserved rights to its easement agreement to make it more attractive to landowners but still offer a high level of protection for water quality.

Annual Inspections

DEP inspects easements twice per year. In 2010, DEP revised its Conservation Easement Monitoring Policy (DEP 2010b) to provide greater flexibility in the types of easement inspections. For example, aerial inspections now play a greater role in the inspection process. Land trusts across the country, particularly ones with large holdings, have performed aerial inspections for years with great success. Aerial inspections completed during leaf-off conditions but before snow cover can be used to discover potential violations such as road building or unapproved timber harvesting. If a potential violation is discovered, the policy requires an on-site visit be conducted. Focused and partial inspections are performed annually to look at areas of the property where potential violations are greatest, such as along outparcel or building envelopes, along stream corridors, or where DEP-approved activities as required by the easement have taken place. In all cases, a complete inspection is required every five years in which the entire property is traversed, including all property boundary lines.

To date, the number of violations has been minimal. Only one violation has resulted in DEP initiating legal action and that case was settled by the landowner restoring the disturbed site. The incident occurred when the landowner excavated and constructed a riding arena in part of a wetland, thereby violating two provisions of the easement.

Posting

Security of watershed lands is important and taken very seriously. Signs are posted on acquired lands within 90 days of the closing date and are consistent with the recreation designation, including “entry by permit” or “Public Access Areas.” For those properties for which there is no public access, “posted” signs are installed. Additional signs may be installed depending on the message DEP wishes to convey. This could include “no trespassing”, “no dumping”, “no vehicles allowed”, “public access temporarily closed”, as well as others. DEP also developed signs for outreach purposes, notifying the public of ongoing agricultural, forestry, invasive species eradication, and planting projects. In 2008, DEP finalized its sign design manual, which calls for consistent and well-developed messages. DEP is now installing these signs on newly-acquired properties as well as replacing older signs with the new ones.

2.3.2 Forest Management

Forest Land Cover

Forests in the watershed provide important ecological functions, such as forest regeneration, protection of soil, filtration of water, attenuation of runoff, and nutrient buffering. Lands protected as forests also prevent major land conversion such as development and land clearing, which can have major impacts on water quality. Carefully planned forest management can help the City to maintain and improve the watershed forest’s ability to enhance nutrient uptake, resist and recover from catastrophic events, improve ecological integrity, create and maintain recreational opportunities, reduce liability exposure from forest safety hazards, and provide economic benefit to the City and watershed communities.

Forest Management Projects

Forest management and restoration projects on City water supply land are performed for the following reasons:

- The DEP Rapid Forest Inventory conducted in 2003, assessing the overall condition of DEP forests, indicated that the majority of the forests range in age from 65 to 85 years old, with few acres in young growth. Young trees are necessary to maximize the uptake of nutrients and to replace aging and dying trees.
- A continuous, healthy, and vigorous forest cover over time supports ecological functions such as regeneration, protection of soil, filtration of water, and nutrient buffering.
- The City's forest stands are aging and, if left alone, will decline over wide geographic areas in the next 30 to 50 years.

Forest management projects protect public health, maintain ecosystem integrity, provide community benefits, and increase understanding of watershed functions. Table 2.2 lists the number of forestry projects over the last five years.

Table 2.2: Number of annual forest management projects, 2006-2010.

Year projects completed	Number of projects	Total acres of all project areas
2006	3	111
2007	4	193
2008	1	165
2009	3	230
2010	1	70

Forest Management Plan

Comprehensive forest management planning enhances the protection of the ecological systems that provide the City's drinking water by enabling landscape-level decision making. Watershed forest management planning is necessary to support DEP in its management of its water supply lands. The initial part of the planning process is a comprehensive inventory of forest resources.

The 2007 FAD requires DEP to "develop and submit a forest management plan" by November 30, 2011. Significant progress was made towards this deliverable between 2007 and 2010. In 2007 and 2008, DEP, in consultation with the United States Forest Service (USFS), completed the development of parameters needed for a comprehensive forest inventory and the draft components of a forest management plan of all City-owned lands. In 2008 DEP developed a contract with the USFS which was finalized in the spring of 2009; work began on the forest inventory that summer. The Watershed Forest Management Plan will include analysis, summary, and presentation of the forest inventory data, and related land and natural resource information. The plan will provide directives for practical, sustainable, science-based management of City-owned watershed forest lands, with the overall goals of protecting public health through source water protection, maintaining or enhancing ecological integrity, and providing economic benefits to watershed communities.

The selection of forest inventory analysis software was completed and analysis of data was initiated in 2008 and 2009. Inventory was completed on all City-owned lands in the Ashokan and Kensico basins and a portion of the Neversink basin in 2009. During 2010, the USFS finished inventory on all City-owned lands in the remaining basins; in that year also, data were being submitted to DEP for review and processing. Altogether, approximately 9,675 inventory plots were completed in 2009 and 2010. Table 2.3 lists approximately how many plots were completed in the various basins.

Table 2.3: Approximate number of plots completed per basin, 2009-2010.

Basin	Number of Plots	Basin	Number of Plots
Amawalk	72	Lake Gilead	10
Ashokan	1,212	Lake Gleneida	7
Bog Brook	19	Middle Branch	18
Boyd Corners	428	Muscoot	350
Cannonsville	2,230	Neversink	511
Cross River	52	New Croton	288
Croton Falls	151	Pepacton	1,646
Diverting	44	Rondout	675
East Branch	58	Schoharie	1,315
Kensico	196	Titicus	29
		West Branch	364

Preliminary data is already proving useful. For example, during the fall of 2010, DEP used the data to identify forest stands with a high concentration of ash trees. Emerald Ash Borer was discovered at several locations in Ulster County, one site being one-half mile from Ashokan Reservoir. Using a GIS analysis, areas with high concentration of ash can be overlaid with DEP facilities and roads as well as reservoir shorelines and watercourses, to begin to anticipate possible impacts.

Another major goal of the plan is to facilitate and standardize the environmental reviews of individual forest management projects through the State Environmental Quality Review Act (SEQRA) process. Once the forest management plan is complete, the environmental review of all forest management projects will be planned and conducted within the bounds of the plan. As part of the plan, DEP developed a comprehensive set of conservation practices that will ensure projects are properly planned and carried out in a manner that eliminates adverse environmental impacts.

2.3.3 Natural Resources

Invasive Species

In response to the growing threat of invasive species to water quality, water supply infrastructure, and the watershed, DEP formed an Invasive Species Working Group (ISWG) in 2008. The ISWG mission is to develop a comprehensive invasive species management plan that includes threat identification and prioritization, prevention, early detection and rapid response, management, and restoration. In 2009 and 2010, the ISWG made significant progress in its first goal of developing a risk assessment process to evaluate invasive species threats to the water supply and watershed lands. Invasive species threats and potential impacts to water supply and watershed lands have been identified and ranked, and a preliminary list of priority species to be assessed was developed.

The working group evaluated several risk assessment methods and selected the NYS Invasiveness Ranking Method (Jordan et al. 2008). Because this method does not specifically address water quality and human health impacts, the ISWG developed a qualitative risk assessment module for water supply and human health impacts to identify those species that are potential threats to water quality. Those species identified by the module as potential threats are further assessed with the NYS Method and ranked based on the likelihood of establishment and spread in the watershed. Species on the priority list are currently being run through the analyses as a first step in identifying and prioritizing threats. Species newly identified as potentially invasive in the watershed will also be assessed and priorities shifted based on those assessments. Invasive species surveys, early detection/rapid response plans, and long-term management plans will be developed based on the water supply risk assessment process.

In addition to establishing the ISWG, between 2007 and 2010 DEP was involved with invasive species survey and management through the DEC Terrestrial Eradication Grant, jointly awarded to DEP and the Eastern Chapter of The Nature Conservancy. The purpose of the grant was to eradicate Pale Swallow-wort and Black Swallow-wort on City land near Pepacton Reservoir.

Additionally, the grant required that surveys be undertaken for Asian Longhorned Beetle in private campgrounds in the Catskills; this was accomplished in 2009, with additional follow-up in 2010. DEP also continues to manage City lands for invasive species including Giant Hogweed, Japanese Barberry, Chinese Wisteria, and Japanese Stiltgrass. After *Didymosphenia*, commonly known as “rock snot”, was discovered in Esopus Creek in 2009, DEP adopted a cleaning protocol for its aquatic field equipment and boots to reduce the risk of DEP staff spreading this invasive and potentially deleterious diatom.

2.3.4 Land Uses on City Lands

Recreational Use

DEP has taken significant steps towards increasing the acreage of its lands available to the public. Additionally, DEP has eliminated administrative requirements to make it easier for people to use City lands. DEP welcomes the opportunity to share its water supply lands with the public in a manner that does not negatively impact water quality.

In 2007, DEP revised its "Rules for Recreational Use of Water Supply Lands and Waters" to allow for Public Access Areas (PAAs) on its West of Hudson watershed lands. PAAs do not require users to have a DEP access permit and allow users to hunt, hike, fish, and trap. Figure 2.6 shows the amount of land now open for recreation, including PAAs.

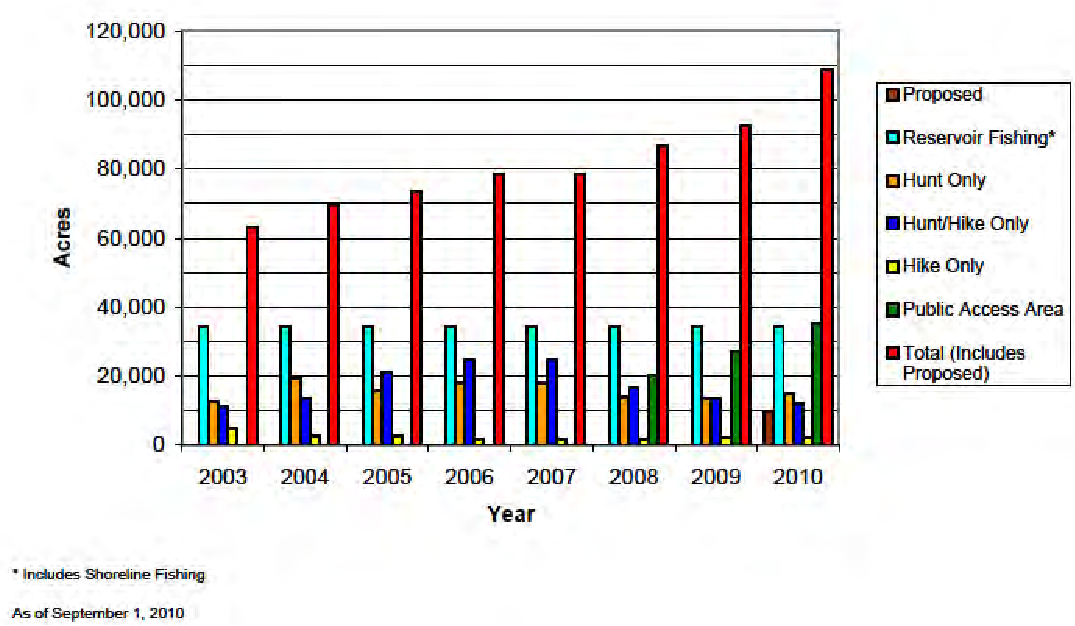

Figure 2.6 Amount of City land, both East and West of Hudson, now open for recreation.

In 2009, DEP again revised its rules for recreation and eliminated the DEP Hunt Tag requirement. Eliminating this requirement and increasing PAA designations are expected to increase the number of deer hunters on City land. Deer hunting is one of the most successful tools land managers have to control adverse deer impacts on forested lands.

Cannonsville Pilot Boating Program

The 2009 revised Recreation Rules incorporated a provision for recreational boating. This is a program in addition to the long-standing "fishing by boat" that DEP has always allowed on all its reservoirs and controlled lakes. The recreational boating program would allow participants to use canoes, kayaks, rowboats, sailboats, and sculls. In 2009, DEP began the three-year Cannonsville Pilot Boating Program, under which a large portion of the reservoir was opened for boating, provided all vessels were steam cleaned. Vendors were selected and financed through the Catskill Watershed Corporation to steam clean boats. Users are allowed to apply for two types of recreational boat tags, temporary (1-7 days) or seasonal (good for the boating season (Memorial Day through Columbus Day)). In 2009, over 400 boat tags were issued and there were no major safety or water quality issues. In 2010, the western portion of the reservoir was opened for boating to expand the use area. The number of boaters utilizing the program in 2010 was similar to the number using it in 2009 and again, there were no major safety or water quality issues.

Agricultural Use

In 2004, DEP began allowing limited agricultural uses of its watershed lands for harvesting hay and tapping sugar maple trees. In 2006, in response to requests from the agricultural community, DEP expanded agricultural uses to include the planting and harvesting of row crops and livestock grazing. Project guidelines were established which incorporated many best management practices outlined in components of the Watershed Agricultural Council's Whole Farm Plans; anyone performing agricultural uses on City land must agree to follow these practices. Once DEP identifies an eligible piece of land for agriculture or receives a request from the public, DEP puts out requests for proposals. Farmers then submit a plan to DEP for how they feel the land can best be utilized for farming while protecting water quality. The majority of farmers now using City lands are also enrolled in the Watershed Agricultural Program. At the end of 2010, DEP had over 50 active agriculture projects covering over 1,500 acres of City land.

Land Use Permits

The City issues revocable land use permits to utilities, municipalities, non-profits, and, in a limited number of instances, individuals and commercial users. Land use permits are typically issued to entities as a last resort, that is, when private land is not available. In January 2006, there were 1,014 active permits and as of December 2010 there were 1,128, an increase of 114 and an average of 23 new permits per year. In 2006, DEP refined its review process for land use permit applications to include e-mail notification to a wide array of DEP staff. This ensures a more thorough review and conditioning of the permit. DEP conditions its permits so that potential water quality impacts are eliminated or significantly reduced.

2.4 Watershed Agricultural Program

The Watershed Agricultural Program (WAP), one of DEP's oldest watershed protection programs, is a voluntary pollution prevention partnership administered locally by the Watershed Agricultural Council (WAC) in cooperation with local, state, and federal partner agencies/ organizations. The WAP strives to protect water quality from agricultural pollution through the development of Whole Farm Plans and the implementation of best management practices (BMPs).

The 2007 FAD contains a number of enhancements to the WAP, including the development of a programmatic strategy for replacing aging/failing BMPs; continued expansion/ availability of the Nutrient Management Credit Program to approximately 80 farms in the Cannonsville Reservoir basin; formal evaluations of the Conservation Reserve Enhancement Program (CREP), Small Farms Program, and Delaware County Precision Feed Management Program; and a new revised metric (originally introduced in the 2002 FAD) that requires that 90% of all large farms in the West of Hudson watershed have "substantially implemented" Whole Farm Plans by September 30, 2010. The 2007 FAD also requires DEP to conduct a review of current WAP evaluation criteria with input from the WAC Advisory Committee. Please refer to the review (DEP 2010c) for additional detailed information.

Excluding the WAC Agricultural Easement and Forestry Programs, DEP has committed more than $116 million to the WAP during the period September 1992 through October 2012, which includes a new contract with WAC that commenced on January 1, 2009. In addition, DEP and WAC have leveraged more than $20 million in federal, state, and private funding to support the WAP through grants, appropriations, technical assistance, and donations. This includes a $2 million federal grant that WAC applied for and received in 2009 through the USDA Agricultural Watershed Enhancement Program (AWEP) to support several large BMP implementation projects during a four-year period.

Given the WAP's nearly two-decade track record, it is important to recognize that the universe of watershed farms has changed dramatically since the early 1990s, with the number of large commercial farms declining (especially dairy farms) and essentially being replaced with smaller-scale farming operations. Specifically, at least 25% of all large commercial farms in the West of Hudson watershed have become inactive since then despite major improvements being made to the farm through participation in the WAP.

2.4.1 Whole Farm Planning

Through 2010, and excluding the designation of sub-farms, 254 of the 265 known large farms in the Catskill/Delaware (West of Hudson) watersheds have signed up for the WAP (96% participation) and 248 of these participants (98%) have Whole Farm Plans. Six additional farms that recently signed up are in the process of developing a Whole Farm Plan. In September 2010, the WAP achieved a major FAD milestone by having 90% of all West of Hudson large farms meeting the definition of "substantially implemented" Whole Farm Plans at least once. Please refer to DEP's report (DEP 2010d) for additional information on this topic.

WAC has been inventorying all small farms (earning between $1,000 and $10,000 per year) since October 2000 using the New York State Agricultural Environmental Management (AEM) Guide. In June 2009, DEP submitted a Small Farms Assessment FAD report that contained a number of recommendations for prioritizing small farm planning efforts in the future, including a proposal to lower the current FAD goal. Through 2010, WAP staff have completed Tier I questionnaires for 310 small farms (representing the current known universe of small farms), of which 85 have Whole Farm Plans (27%). The 2007 FAD requires the WAP to develop 10 new Whole Farm Plans for small farms annually.

2.4.2 BMP Implementation

Since 1993, the WAP has supported the construction and implementation of more than 5,416 agricultural BMPs on West of Hudson large and small farms at a total direct cost of more than $37.6 million (excluding WAP staff costs and administrative expenses). These figures are comprised of approximately 796 BMPs implemented on small farms at a cost of $3.2 million, and approximately 4,620 BMPs implemented on large farms at a cost of $34.4 million. Although most BMPs are recommended to address multiple Whole Farm Plan pollutant categories, it is worth noting that BMPs that have been implemented in the greatest numbers—such as nutrient management plans, livestock fencing, manure spreading equipment, and barnyard water management systems—are specifically designed to reduce risk from the highest priority pollutant categories (parasites and nutrients).

BMP Repair and Replacement Strategy

During 2008, all of the WAP partners collaboratively developed a BMP Repair and Replacement Strategy, as required pursuant to the 2007 FAD. The strategy describes a process for: (1) identifying and evaluating aging/failing BMPs that are still needed for water quality protection on active watershed farms, (2) incorporating BMP repair or replacement into the existing Whole Farm Plan revision process, and (3) prioritizing BMPs for repair or replacement. Since the strategy was developed, more than 75 BMPs have been repaired or replaced at a cost exceeding $784,500. As the WAP moves forward into a new phase of Whole Farm Plan operation and maintenance, however, there will increasingly be large numbers of BMPs in need of reinvestment as they reach their life spans.

BMP Prioritization Methodology

In September 2010, the WAP achieved the 90% "substantially implemented" FAD metric which was originally codified in the 2002 FAD to ensure that Whole Farm Plans are implemented in a timely manner. During the past eight years, therefore, the WAP has prioritized BMP implementation based on the need to achieve substantial implementation, as opposed to prioritizing BMPs based on water quality issues or changing conditions on farms. Given the recent achievement of 90% substantial implementation, all of the WAP partners developed and proposed a BMP Prioritization Methodology that will provide a new framework for scheduling and implementing BMPs in a manner that provides the greatest protection to water quality. The proposed new BMP Prioritization Methodology was presented to the WAC Advisory Committee in October 2010 and subsequently submitted by DEP as part of the December 2010 WAP Evaluation FAD Report (DEP 2010c). Preliminary feedback from the WAC Advisory Committee thus far indicates that the new BMP Prioritization Methodology is being embraced as an acceptable alternative to the "substantially implemented" FAD metric.

2.4.3 Annual Status Reviews

One important element of the WAP is the annual status review that became part of the Whole Farm Planning process in 1998. Conducting an annual status review allows WAP staff to ensure that implemented BMPs are working as designed while assessing farms for any new water quality issues. Annual status reviews also provide an opportunity to assess farmer acceptance and satisfaction levels with their Whole Farm Plans and BMPs, and to verify whether inactive farms are indeed still inactive. The 2007 FAD requires that annual status reviews be completed on all large farms with "substantially implemented" Whole Farm Plans. Excluding sub-farms, the WAP conducted 249 annual status reviews in 2009 and 300 annual status reviews in 2010. As the WAP moves into the future, annual status reviews will continue to be a high priority.

2.4.4 Nutrient Management Plans

Nutrient Management Plans (NMPs) are designed to manage the amount, source, placement, form, and timing of the application of nutrients from fertilizer, manure, and other organic sources. Through 2010, 174 active large farms and 60 small farms in the West of Hudson watershed were following NMPs, which in total represents 15,903 animal units. It is worth noting that for the past several years more than 90% of all active large farms with an NMP have maintained their plans in a current state (i.e., they were developed within the past three years).

Nutrient Management Credit Program

Since 2000, WAC has offered financial incentives to farmers (mainly in the Cannonsville Reservoir basin) who properly follow their NMPs. Currently there are 80 farms in the Cannonsville basin and four other farms that participate in the Nutrient Management Credit Program. Participants are required to attend a nutrient management course and must keep daily manure spreading records that are reviewed annually by WAP staff to determine if the NMP is being followed correctly. Farmers receive a monetary credit that can be used to purchase manure management equipment. In 2010, WAC applied for and received federal funding through AWEP to expand the Nutrient Management Credit Program to 8-10 new farms each year for the next three years. In addition, farms with manure storage facilities that are required to spread manure more than two miles from their farmsteads are eligible to receive additional incentives through WAC's Enhanced Nutrient Management Credit Program.

2.4.5 East of Hudson Agricultural Program

Through 2010, the WAP has approved 56 Whole Farm Plans for East of Hudson watershed farms; 42 of these plans have commenced BMP implementation. These figures include six horse farms that are located within the Catskill/Delaware Systems: two farms in the Boyd Corners Reservoir basin, three farms in the West Branch Reservoir basin, and one farm in the Kensico Reservoir basin. A total of 414 BMPs have been implemented on East of Hudson farms at a cost exceeding $3 million. The 2007 FAD currently requires the WAP to develop 6-10 new Whole Farm Plans on East of Hudson farms annually.

2.4.6 Conservation Reserve Enhancement Program

The Conservation Reserve Enhancement Program (CREP) has been a successful part of the WAP since 1998. In December 2009, DEP submitted a CREP Evaluation FAD Report that included a field assessment of CREP tree and shrub plantings and recommended potential modifications to the CREP agreement signed by New York City, New York State, and the USDA that might lead to program improvements and enhanced CREP enrollment of cropland. During 2010, DEP worked with the USDA and local CREP partners to explore and assess the feasibility of implementing the potential modifications, but it was decided that time and costs outweighed the benefits.

Through 2010, 149 watershed landowners (both small and large farms) have signed 194 CREP contracts representing 2,029.8 acres of riparian buffers (348.5 acres of which were contracted during the FAD assessment period 2006-2010). In total, CREP has excluded nearly 11,000 head of livestock (mainly dairy and beef cows) from Catskill/Delaware watershed streams. Through CREP, the WAP has a goal of enrolling 100 new riparian forest buffer acres annually.

2.4.7 Farmer Education Program

The WAP actively provides participating farmers with a range of educational opportunities such as workshops, classroom instruction, farm tours, and other training that address an array of topics related to Whole Farm Plans (e.g., nutrient and pathogen management) and the operation and maintenance of BMPs. Since 2002, the WAP has conducted at least 120 farmer education programs that were attended by at least 2,860 participants, of which more than half were watershed farmers. Other participants included non-watershed farmers, agri-service professionals, agency staff, students, and others. Given the number of Whole Farm Plans developed by the WAP to date, ongoing support of a Farmer Education Program that attracts a high level of farmer participation and interest should continue to be a high priority for the WAP as the program moves forward in the future.

2.5 Stream Management Program

2.5.1 Introduction

The Stream Management Program's (SMP) goal is the protection and/or restoration of stream system stability and ecological integrity by providing for the long-term stewardship of streams and floodplains. In the West of Hudson watershed, 65% of land ownership is in private hands. The independent and uncoordinated activities of landowners and municipalities in a mountain setting will determine the long-term viability of Catskill stream integrity and water quality. The activities that pose potential threats to water quality are those that damage the physical structure of the channel or its riparian buffer and floodplain, including the construction and management of roads, bridges, and culverts, uninformed in-stream practices such as gravel removal or ill-informed stream stabilization, poor siting of residences and businesses, and damaging activities in riparian and floodplain areas.

Under the 2007 FAD, DEP formally initiated the transition from a planning and demonstration phase into an implementation phase that is locally led and serving the purpose of enhanced implementation of stream management plan recommendations. This transition is largely complete. Ambitious efforts during the assessment period by DEP and its partners to make the transition included:

- Completing all outstanding stream management plans and their related Action Plans;
- Establishing a set of new contracts between DEP and local partners—Soil and Water Conservation Districts (SWCDs) and Ulster County Cooperative Extension—for delivering the enhanced and locally driven implementation of stream management plans;
- Substantially strengthening and extending the existing network of partnering agencies of West of Hudson watershed towns which adopted the plans, signed cooperative agreements with their local stream program, and serve as advisors on councils;
- Developing and launching the Schoharie, Ashokan, and Delaware Basin Stream Management Implementation Grant Programs (SMIPs), and strengthening DEP's capacity to meet the demands of the implementation effort;
- Designing and constructing a total of 61 projects demonstrating techniques for achieving multiple objectives and addressing 5.93 miles of stream corridor. When combined with the Catskill Streams Buffer Initiative projects described below, this brings the total number of projects implemented by the SMP since its inception in 1996 to 106, addressing 13.88 miles of stream length and planting 262.7 acres;
- Strongly enhancing communications for the basin stream management programs and stakeholders by establishing field offices throughout the watershed and establishing the interagency website www.CatskillStreams.org as a central place for communications and distribution of materials related to stream management in the West of Hudson watershed;
- Organizing and rolling out a new program, the Catskill Streams Buffer Initiative (CSBI), providing technical and financial assistance to non-farming riparian landowners. A total of 34 CSBI projects were completed, addressing 3.5 miles of stream length and planting 28.6 acres (see Section 2.6.2).

This report details the SMP's progress towards achieving its goals and objectives in the areas of planning, project and policy implementation, stream restoration and other projects, and floodplain mapping.

2.5.2 Stream Management Plans

Planning

Stream management plans have been finalized for the last two remaining West of Hudson basins, Neversink and Rondout. The Neversink and Rondout watersheds are unique in that they are relatively less disturbed watersheds with a large percentage of their mainstems owned by the state and in park status. The development of these plans benefits from staff experience gained in the earlier efforts in other basins: protocols for assessment, strategies for community engagement, plan format, and institutional arrangements for programming plan implementation.

Other plans completed during the assessment period include Upper Esopus Creek, East Branch Delaware River, Schoharie Creek, and East Kill. Assessment and planning were also extended to the tributary streams of several mainstems covered by these plans, including Woodland Valley in the Esopus, the Manor Kill in Schoharie, and Trout Creek in the West Branch of the Delaware River watershed. This expansion enables the partnering agencies to address system instability in the headwaters as part of an effort to prevent additional problems downstream. All plans are available for review by the public at http://www.CatskillStreams.org/Stream_Management_Plans.html.

Plan Adoption

With completion of these deliverables, DEP has finalized plans for 92% of the West of Hudson watershed and has advanced implementation of plan recommendations in most basins. Adoption of the plans by local municipalities required a significant public outreach effort that resulted in greater understanding of the contents of the plans and a commitment by both the community and local partner to support its implementation. In each basin, the partnering agency met with municipal leaders, presented the plan, and asked that the municipality formally adopt the plan and stream stewardship principles (http://www.CatskillStreams.org/pdfs/Prin_stream_stew.pdf). Municipalities were encouraged to sign a memorandum of agreement with the partnering agency for future stream management collaboration. Of the 38 municipalities covered by the plans, all but one municipality (Colchester) adopted their plan and signed an agreement. Adoption cleared the path for the implementation of the plans and the initiation of the locally implemented SMIPs.

Implementation

In all of the basins, the stream management planning process was guided by a Project Advisory Committee or Council (PAC) comprised of key stakeholders. After completing the plan, DEP and its partners worked with the PAC to establish and implement a local funding program for each basin. DEP, partnering agencies, and the PAC have developed program rules and an application process, and undertaken the outreach needed to solicit grant applications. Funds were provided to the partnering agencies under DEP contracts early in the assessment period, and are awarded to projects and programs that help implement recommendations or are consistent with the recommendations. Tables 2.4 and 2.5 summarize the progress to date in administering the SMIPs.

Table 2.4: Summary of locally implemented SMIP progress.

Basin	Amount Budgeted	Amount Appropriated through 2010	Number of Grants Approved
Delaware	$2,000,000	$524,325.00	10
Schoharie	$2,000,000	$728,749.50	25
Ashokan	$2,000,000	$648,412.00	21

Although many of the rules and processes are similar, the grant programs in each basin operate independently of each other. This independence has fostered local creativity and boosted local buy-in. Despite the significant workload associated with the organization and outreach needed for the program launch, the staff in each partnering agency has welcomed the increased community contact and additional public input into the program. The grant program has also resulted in the delegation of additional project management responsibilities to the partnering agencies. A link to more information on these grants is www.CatskillStreams.org/grants.

Table 2.5: Number of locally implemented SMIP grants by type and basin.

Type of Grant	Schoharie	Delaware	Ashokan	Total
Restoration	2	4	1	7
Stormwater	1	2	2	5
Recreation	3	1	0	4
Education	10	0	8	18
Planning	3	0	1	4
Infrastructure	5	3	2	10
Research and Monitoring	1	0	7	8

Implementation of the stream management plans also involves initiatives beyond the scope of the grants program. Efforts to improve floodplain management, flood response, and riparian buffer protection are active in many of the planning basins and are fulfilling the recommendations of the various plans with the full support of the partnering agencies and the PACs.

2.5.3 Partnership and Education

Over the past five years, the SMP has significantly improved the effectiveness of its Education and Outreach (E&O) efforts by making them both *more comprehensive* –identifying and programming for all key target audiences who impact stream management– and *more tightly integrated* with all other program elements, from the development and implementation of stream management plans, to the construction of stream restoration projects, to the roll-out of the CSBI, to the technical support provided through extension of applied research results to state-of-the-art management practices and policies. All of these efforts have benefited from the development of the multi-agency CatskillStreams.org website, where most of the E&O documents described below are archived, E&O activities are promoted, and application materials for various programs can be found. Since its creation in 2007, the number of website "hits" has grown yearly, exceeding half a million in the past 12 months, and providing a strong indicator that E&O programming is needed.

In 2006, the SMP coordinated a NOAA Project Design and Evaluation workshop for DEP and partner agency staff, which provided instruction in developing logic models for defining program needs, goals, and objectives. As a result of iterative meetings with DEP's basin-level partners in 2007, a comprehensive E&O Strategy was developed for the SMP. The objectives of the overall strategy are to ensure that (1) the E&O content in the annual Action Plans of DEP's partners reflect common E&O goals between DEP and its partners and, where possible, specify associated learning objectives; (2) these basin-level plans are coordinated such that messages are consistent and efficiencies of scale are achieved in the development of programming; and (3) programming gaps are identified and filled, so that the training, education, and outreach needs of all key audiences who influence the management and stewardship of streams are ultimately addressed. Each of DEP's basin partner teams has hired or designated E&O staff, and quarterly inter-basin E&O planning meetings ensure that the E&O Strategy is implemented. Among the highest E&O priorities for the SMP is the need for coordinated emergency flood response and training for those working in streams following floods, when waterways become clogged with wood, gravel, and items from floodplains (such as fuel tanks, equipment, vehicles, and structures), and the need for training to assist communities in implementing their existing floodplain ordinances. The following examples highlight just a few of the many E&O accomplishments that occurred during the assessment period:

- Delaware County (DC) SWCD developed the Post Flood Emergency Stream Intervention Contractor Training Program, providing 131 highway department staff and contractors a three-day "hands-on" training program on the importance of appropriate channel clearing methods and how to appropriately dimension reaches that require some clearing.
- DCSWCD, in coordination with the NYS Association of Floodplain and Stormwater Managers, hosted the 2010 Spring NYS Floodplain Management conference, enabling 35 West of Hudson floodplain managers and code enforcement officers to receive training and four participants to take and pass the four-hour exam to become Certified Floodplain Managers.
- In the Schoharie basin, through its annual Schoharie Watershed Summit (2007-2010), Greene

County (GC) SWCD provided training for 260 town planning, zoning, and code enforcement officers in appropriate stream management policies and practices, including the National Flood Insurance Program, and in effective application of floodplain maps and ordinances.

2.5.4 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. A final goal is to provide a set of locally-based demonstration projects that illustrate the various methods that can be used to construct stream projects that achieve multiple objectives by applying concepts of stream morphology. Figure 2.7 displays the 61 projects accomplished during the assessment period.

Figure 2.7 New York City DEP - Stream Management Program planning basins and stream restoration sites.

The April 2006 SMP Evaluation Report provided a comprehensive evaluation of projects that had been completed at that time. The report included a recommendation that the program broaden its focus from reach-scale projects to smaller-scale best management practices (BMPs) that apply the principles of natural channel design (NCD) to hydraulic constrictions along stream corridors. Hydraulic constrictions are created by undersized culverts and bridges and create instability up and downstream. Addressing hydraulic constrictions is a recommendation in most stream management plans, is well supported by stakeholder groups, can provide water quality benefits, and need not always require a reach-scale solution. To this end, since 2006 the program and its partners have begun tackling hydraulic constrictions to demonstrate more sustainable solutions with and for highway managers. In the long term, this will reduce channel instability and its associated erosion, mitigate flooding under certain conditions, and reduce maintenance costs. Demonstrating this need, in June 2010, the Delaware County PAC received five applications for culvert-related hydraulic constrictions as part of its first SMIP grant round.

DEP and county partners continue to advocate and extend training in the NCD approach to restoring stability and proper ecological functioning on all projects regardless of their size. NCD was incorporated wherever possible into projects during the assessment period, ranging from full channel stream restoration to stormwater and infrastructure (culverts), to ensure multiple objectives are achieved.

Between January 1, 2006 and December 31, 2010, DEP and/or SWCDs constructed 12 full channel restorations, 5 stormwater and infrastructure projects, 66 riparian restorations, 4 post-flood response projects and 8 streambank stabilizations. Tables 2.6 through 2.10 summarize many of the specific projects completed. In addition, Figures 2.8 through 2.13 show before and after photos of selected projects.

Table 2.6: Full channel stream restoration projects completed during the assessment period.

Reservoir Basin	Project Name	Completion Date	Area Affected (Acres)	Project Length (feet)
Schoharie	Sugar Maples	October 2009	1.4	550
Schoharie	Conine	October 2007	8.1	1,650
Schoharie	Ashland Connector	October 2006	26.0	3,400
Schoharie	RAH Stables	October 2006	4.0	1,600
Schoharie	Long Road	October 2009	19.5	3,000
Schoharie	Tannersville Bike Path	September 2007	0.15	400
Schoharie	Gooseberry Creek	September 2007	0.15	400
EB Delaware	Margaretville Fairgrounds	April 2008	1.0	900
WB Delaware	Palmatier Farm	September 2006	0.20	100
WB Delaware	Lowenthiel Farm	June 2010	4.5	1,400
WB Delaware	Rama Farm	October 2007	1.75	1,100
WB Delaware	County Route 22	October 2009	0.60	900

Table 2.7: Stormwater and infrastructure projects completed during the assessment period.

Reservoir Basin	Project Name	Completion Date	Area Affected (Acres)
Schoharie	Sugar Maples—stormwater	November 2008	4.7
Schoharie	Windham Mountain	September 2010	39
Schoharie	Hunter Foundation	August 2010	1.2
Schoharie	Hunter Highway	October 2006	0.93
Schoharie	Lexington Culvert Replacement	October 2008	0.06

Table 2.8: Pre-CSBI riparian restoration projects completed during the assessment period.

Reservoir Basin	Project Name	Completion Date	Area Affected (Acres)	Project Length (feet)
Schoharie	Sugar Maples	October 2008	0.3	800
Schoharie	Kastanis Project	June 2009	7.1	2,929
Schoharie	Curtain Planting	September 2007	0.1	80
Schoharie	Conesville Town Hall	September 2008	0.32	235
WB Delaware	Akins	November 2009	0.28	250
Schoharie	Carr Road	October 2008	5.2	2,300
Schoharie	Deming Road	June 2009	1.5	998

Table 2.9: Post-flood response projects completed during the assessment period.

Reservoir Basin	Project Name	Completion Date	Area Affected (Acres)	Project Length (feet)
Esopus	Brown Road	November 2010	2.5	600
EB Delaware	Plattekill Training	October 2009	1.7	400
WB Delaware	West Brook Delaware	October 2009	0.5	1,100
WB Delaware	Launt Hollow Training	October 2009	1.0	1,500

Table 2.10: Streambank stabilization projects completed during the assessment period.

Reservoir Basin	Project Name	Completion Date	Area Affected (Acres)	Project Length (feet)
Esopus	Fawn Hill	November 2010	0.05	80
Schoharie	Schoharie Avenue	September 2008	0.12	180
Schoharie	Wright	September 2010	3.7	3,127
Schoharie	Oakwood	October 2009	0.11	138
Schoharie	Windham Country Club	October 2009	0.14	105
EB Delaware	Tuttle Farm	October 2007	0.25	150
WB Delaware	Terrace Avenue	November 2008	1.0	850
WB Delaware	South Street	June 2010	0.15	550

Figure 2.8 Long Road before stream restoration project.

Figure 2.9 Long Road after stream restoration project.

Figure 2.10 Before restoration of an undersized and failing culvert in Lexington.

Figure 2.11 After restoration of an undersized and failing culvert in Lexington.

Figure 2.12 Terrace Avenue before streambank stabilization.

Figure 2.13 Terrace Avenue after streambank stabilization.

2.5.5 Floodplain Mapping

DEP entered into a $7,000,000 contract with FEMA to produce revised flood studies and flood insurance rate maps (FIRMs) for areas in the West of Hudson watershed. This effort will deliver the tools and skills watershed communities and resource managers need to improve floodplain protection. Using DEP funds, FEMA is in the process of contracting with an engineering consultant for the development of the FIRMs and with DEC for the community outreach effort needed to support map adoption and use by the communities. Map Steering Committees, and groups of key informants and technical support staff organized by DEC and SMP's contractual partners, will provide regular input into the process and will help prepare communities for the map adoption. Training for municipal floodplain administrators, code officers, surveyors, engineers, highway officials, and stream managers is ongoing and is expected to continue beyond the completion of map adoption. Unlike other floodplain mapping efforts across the nation, this process is focused on making a concerted effort to include communities and their floodplain management officials early in the process to ensure they can fully utilize the new digital maps to protect their community and water resources.

2.6 Riparian Buffer Protection Program

In 2004, DEP reported that the state of riparian buffers was generally healthy. The report and subsequent meetings with watershed stakeholders identified the need for a riparian-focused program available to landowners who may not qualify for the existing watershed programs. The 2007 FAD formalized these discussions by adding Section 4.7 (Riparian Buffer Protection Program) to develop the Catskill Streams Buffer Initiative (CSBI), targeting landowners in this programmatic gap. DEP and its watershed partners have made substantial progress on the Riparian Buffer Protection Program during the 2006-2010 assessment period.

2.6.1 Acquisition and Management of Riparian Buffers on City-Owned or Controlled Lands

Acquisition

Acquisition of sensitive buffer lands is one of the tools used by DEP. Since 2006, DEP has increased the amount of buffer land protected through acquisition from 2.6% to more than 16%. See Section 2.2.1 of this report for further details.

Management

When DEP reviews requests from outside parties to engage in land use activities or institute projects on City lands, it always carefully considers riparian buffers. For example, DEP allows agricultural use of City-owned land and requires a minimum of a 25-foot buffer. Proposals that offer a greater buffer than 25 feet are given extra points in their ratings. When DEP receives requests for land use permits, input is sought from the Stream Management Program. DEP reviews proposed projects for their potential impacts to the buffer and provides "conditions" and suggestions on how to avoid or mitigate these impacts.

2.6.2 Catskill Streams Buffer Initiative

The CSBI was developed, launched, and implemented during the last four years. The CSBI has been well received and is progressing well.

Development and Coordination

To support development of the CSBI, originally called the Streamside Assistance Program, DEP hosted several meetings with watershed partners to gather their ideas, thoughts, and concerns about offering a new riparian buffer program. The county Soil and Water Conservation Districts (SWCDs) and branches of Cornell Cooperative Extension (CCE), as well as the Watershed Agricultural Council (WAC), the Catskill Watershed Corporation, The Nature Conservancy, and Catskill Center for Conservation and Development, all provided insight into goals and objectives for the CSBI. Additionally, these partners reviewed and commented on program guidelines. Experts in the eastern United States were also consulted to share strengths and weaknesses of their riparian buffer programs. The final program guidelines were completed in December 2008. The investment in development has led to a popular program that partner agencies are comfortable recommending to landowners who may not qualify for existing watershed programs.

Native Plant Materials

Plantings are an essential ingredient of natural streambank stability, but an equally important component of DEP's overall stream management mission is to restore ecosystem integrity. Providing Catskill native plant material is thus one of the unique aspects of the CSBI. To do this, plant selection, propagation, and grow-out have and will continue to be carefully considered. These efforts have led to local genotype planting stock available not only to the CSBI, but also to other stream restoration projects initiated by DEP and its partners. CSBI coordinators have established plant material holding areas to allow access to stock on an as needed basis.

Plant Selection (New York Natural Heritage)

Identifying native natural riparian plant communities as reference areas can inform planting plans and ensure they support the overall program mission. During stream management planning in the West Kill sub-basin, DEP supported a partnership between Greene County (GC) SWCD and the New York Natural Heritage Program to identify riparian reference areas along the West Kill and help GCSWCD identify target plant communities and specific species for restoration efforts. Natural Heritage has successfully completed this work, which in the short term has assisted with better selection of species to use in future riparian projects. Since completion, Ulster County SWCD has contracted with Natural Heritage to conduct similar work in the Ashokan watershed. This new study will allow Natural Heritage to produce results specific to the Ashokan basin.

Plant Supply (Greenbelt)

After conducting a comprehensive solicitation of plant-related services to over 200 nurseries throughout the northeast, DEP identified New York City Parks and Recreation's Greenbelt Native Plant Nursery as the best entity to work with to collect, clean, and store Catskill native plant seed, and to propagate this seed for the CSBI. To date, DEP and its partners have received over 50,000 herbaceous plugs, 17,500 tree and shrub tubelings, and 10,000 gallon-sized trees and shrubs. An existing agreement with Greenbelt Nursery will provide an additional 20,000 herbaceous plugs and 15,000 gallon-sized trees and shrubs. All of this material originates from the Catskill Mountains, providing locally-native stock that is adapted to regional conditions, giving it a competitive edge for survival, and providing a range of ecological values beyond streambank stability.

RPM Ecosystems, Inc.

Because Greenbelt Nursery is unable to support the grow-out of restoration-sized (one- and two-gallon containers) trees and shrubs in the volume needed, DEP reached out to the private sector to supply additional native plant material for the CSBI. DEP competitively awarded a contract to RPM Ecosystems to pick up tubeling-sized material from Greenbelt and transfer it into larger containers for later use. RPM also provides its own stock (from sources within a 200-mile radius of the Catskills) for planting restoration projects. To date, DEP has received 5,000 trees and shrubs from RPM, with the delivery of an additional 32,000 plants provided for under existing contracts.

Planting Design (Vegetation mapping and monitoring)

In support of stream management plans, DEP and its partners have conducted stream feature inventories and riparian vegetation mapping. Stream management plans now cover 92% of the West of Hudson watershed. Although the inventories and mapping were done as part of a larger effort, the results inform CSBI coordinators about project prioritization and design. Stream managers who have walked each mile of a particular stream have identified potential planting locations, willow supply areas, invasive species locations, and potential riparian reference reaches, among other features. With knowledge of vegetative communities identified in the riparian maps, which now cover 198 miles of stream, CSBI coordinators can target specific property owners whose land may expand an existing forest, wetland, or previous stream restoration project.

Implementation

Five CSBI coordinators at partnering SWCDs, along with one DEP coordinator, provide the base for implementing the program. Landowners reach out to their local coordinator, a plan is developed for the property, and if landowners concur, they are invited to apply for funds and/or technical assistance to implement the project. Applications are invited once each year.

Program Roll-out

After developing a marketing strategy and supporting materials (e.g., logo, program brochure, program application), DEP unveiled the CSBI in January 2010 through a West of Hudson watershed press release. The program materials reference www.CatskillStreams.org/CSBI to guide landowners through the process, and provide appropriate contacts and ready access to application materials.

Riparian Corridor Management Plans

Riparian Corridor Management Plans (RCMPs) provide landowners with a detailed analysis of their property in relation to the broader watershed and to their streamside neighbors. The plans reference stream management plans where they have been completed and document landowner priorities and goals. After analyzing historic information and landowner concerns, CSBI coordinators propose a suite of recommendations that range from best management practices (BMPs) landowners can do themselves to more substantial practices that require SWCD assistance. To date, CSBI coordinators have completed 44 RCMPs.

Projects

The first grant round for CSBI was launched in February 2010. Several pilot projects had been completed or advanced prior to the official launch of the grant program. Thirty-nine applications were received for the initial grant round, of which 24 were approved, 4 are pending approval, and 11 were rejected. The primary reason for rejecting applications was that streambank erosion on the site or the practice itself was beyond the scope of the CSBI.

To date, coordinators have completed 34 pilot and full CSBI projects ("full" is defined as those that are part of the CSBI grant program). Figure 2.14 illustrates approximate project locations for CSBI pilot and full projects**.** These 34 projects enhanced riparian vegetation on 28.6 acres and over 3.9 miles of streambank length. This includes the installation of 8,866 trees and shrubs, 7,782 herbaceous plugs, and 2,695 live willow stakes.

Riparian planting activities have also taken place on 31 additional projects in the assessment period; these are described in Section 2.5.4. These projects represent a combination of volunteer planting projects and riparian plantings coupled wit^h stream restoration and emergency protection projects. For the 2006-2010 assessment period, DEP, with its program partners, enhanced riparian vegetation by planting more than 31,000 trees and shrubs, 20,000 herbaceous plugs, 4,000 feet of willow fascines, and 24,000 willow stakes at 65 project sites.

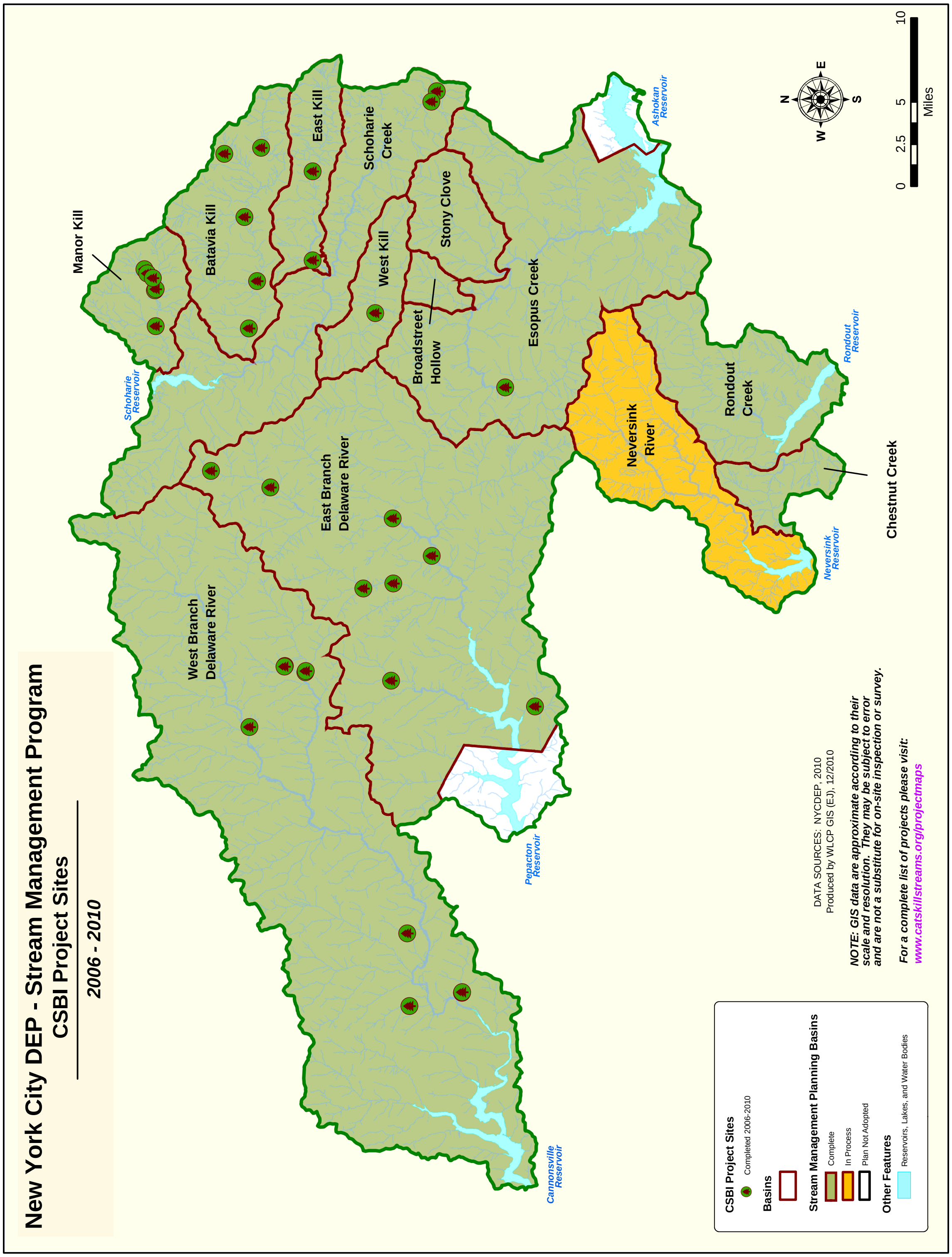

Figure 2.14 CSBI project sites, 2006-2010.

Through a partnership with the State University of New York Research Foundation on behalf of SUNY Delhi, a crew of summer interns provides much of the labor needed to install the various plantings across the West of Hudson watershed. In addition to the aforementioned projects, in 2010 the crew treated over 5,300 square meters of Japanese knotweed, an invasive plant that threatens the viability of riparian plantings. The crew also assisted CSBI coordinators with loading and unloading material, site preparation, weed mat installation, transplanting, plant material center creation, and maintenance and vegetation monitoring of 30 plots. To date, this partnership has offered 10 young adults the opportunity to gain first-hand experience of water quality improvement and monitoring projects, while providing DEP and its partners with enthusiastic labor to complete riparian-related work.

Evaluation

A variety of mechanisms are in place to evaluate the effectiveness of the CSBI. The mechanisms correspond to the program aspect being monitored; for example, outreach tool versus plant survival. An evaluation plan has been developed that directly ties into the tactics recommended in the CSBI marketing strategy. DEP has developed a database specifically for the CSBI that will assist with reporting numbers of applicants, projects, and plant material installed, among others. This database will also help track landowner participation in the variety of outreach tools described in Section 2.6.3, as well as progress towards project implementation.

2.6.3 Riparian Buffer Education and Outreach

Providing assistance with installing BMPs for riparian buffer protection or enhancement is ineffective without the accompanying outreach that explains the importance and rationale behind these activities. The marketing strategy for the CSBI provides an organized approach to engage the public in learning about riparian buffers, with a long-term goal of promoting positive riparian stewardship. For more detail please see the December 2009 FAD deliverable, “Enhanced Education, Outreach and Marketing Strategy for Riparian Landowners.”

DEP has engaged the public in a variety of forums between 2006 and 2010 to support the goal of the CSBI as well as the overarching agency mission. Overall, approximately 35 targeted activities reached over 1,600 individuals living or working in the West of Hudson watershed. Activities ranged from volunteer planting, tree identification, poetry reading, and riparian workshops for students, families, and streamside landowners, to willow identification, seed collection, and expert presentations for stream management personnel and watershed professionals.

2.6.4 Watershed Forestry Program

The Watershed Forestry Program is administered by WAC using a combination of City and federal funding sources to promote and support well-managed working forests as a beneficial land use for watershed protection. The program provides financial incentives and technical assistance to loggers, foresters, and landowners to encourage the protection and restoration of riparian buffers through long-term forest stewardship.

Riparian Planning

Since 2002, the Watershed Forestry Program has continued to require the delineation of riparian areas in all WAC forest management plans as well as specific streamside protection recommendations for these delineated areas. During the current assessment period, 276 riparian plans were completed covering 7,896 riparian acres. These figures include 301 new WAC plans and 14 existing (older) WAC plans that were updated to meet current WAC plan specifications. It is worth noting that for all WAC plans and plan updates completed to date, 38% contain a riparian plan, covering 10,740 riparian acres. When only those plans completed since 2002 are counted (the year riparian planning became part of all WAC plan specifications), this percentage increases to 42%.

Forestry BMP Program

In 2007, the Watershed Forestry Program expanded its various best management practices (BMPs) programs to include a greater emphasis on stream crossings. Part of this expansion was the purchase of new stream crossing BMPs, such as plastic arch culverts and additional portable bridges that are available for loan to interested loggers or landowners. A second part of this expansion involves cost-sharing the proper layout and construction of timber harvest roads as they approach streams, which includes the availability of new BMPs (rubber tire land mats) used to stabilize the approaches. During the current assessment period, WAC supported the completion of 19 stream crossing projects (associated with a timber harvest) in addition to loaning out 27 portable bridges and 11 arch culverts to keep logging equipment out of streams.

Education and Training

During the current assessment period, the Watershed Forestry Program continued to implement a wide range of forestry education and professional training programs for landowners, loggers, foresters, school groups, and other target audiences. One of the primary aims of these programs is to teach audiences about the importance of riparian buffers.

2.6.5 Watershed Agricultural Program

The Watershed Agricultural Program (WAP) is administered by WAC in cooperation with local, state, and federal partner agencies/organizations. The WAP develops and implements Whole Farm Plans that protect water quality from agricultural pollution, with particular emphasis on waterborne pathogens, nutrients, and sediment. With respect to riparian buffers, the WAP helps farmers to keep their livestock out of streams while managing their croplands and pasture-lands in a manner that reduces streamside disturbances and other potential impacts.

As part of the Whole Farm Planning process, WAP planners work with farmers to identify and assess water quality concerns on their farms. One of the most important concerns related to riparian buffers is when livestock have unlimited access to watercourses, which can result in eroded streambanks, denuded riparian vegetation, and animal waste being deposited directly into streams. Early in the WAP's history, planners had a difficult time encouraging farmers to retire their riparian areas from production, exclude their livestock from streams, and establish riparian buffers. However, in 1998 the Conservation Reserve Enhancement Program was initiated to provide additional incentives for riparian protection.

Conservation Reserve Enhancement Program

The Conservation Reserve Enhancement Program (CREP) allows farmers to enter into 10-15 year contracts with the USDA to retire environmentally sensitive agricultural lands from production and to establish forested riparian buffers and filter strips adjacent to streams and other water bodies. The USDA pays the farmer an enhanced rental rate of $115 per acre per year as well as 50% of the cost of all BMPs associated with establishing riparian buffers and/or permanent vegetative cover. WAC then utilizes DEP funds committed to the WAP to pay the remaining 50% of BMP costs as well as technical assistance and program administration costs. Without the financial incentives provided by the USDA, farmers would generally not be able to retire sensitive riparian areas and/or establish riparian buffers.

The USDA standard for riparian forest buffer width varies between 35 and 180 feet. To date, the majority of CREP buffers implemented have been on pastureland, which requires additional BMPs to ensure the success of the buffer. These BMPs may include tree and shrub planting, fencing to exclude livestock from streams and buffers, establishment of alternative water supplies, and installation of stream crossings. Excluding livestock from riparian buffers eliminates the direct deposition of manure into streams and protects streambanks from erosion caused by heavy hoof traffic. Establishing trees and shrubs in buffer areas helps to trap and filter sediment, nutrients, and pathogens from adjacent agricultural lands. Farmers agree to maintain all BMPs implemented through CREP for the full term of their CREP contract.

To date, 149 watershed landowners (both small and large farms) have signed 191 CREP contracts representing 2,029.8 acres of riparian buffers, of which 348.5 acres were contracted during the assessment period (2006-2010). Of the 191 CREP contracts, 183 are complete, with all associated BMPs implemented. It is estimated that CREP riparian buffers have excluded more than 11,000 head of livestock (mainly dairy and beef cows).

Finally, it is worth noting that establishing riparian buffers through CREP is a major component of the WAP Small Farms Program. Of the 85 Whole Farm Plans developed on small farms to date (through 2010), 36 (42%) include CREP buffers. Pursuant to the 2007 FAD, the WAP has a goal of developing 10 new Whole Farm Plans on small farms every year. Small farms that are eligible for CREP are given higher priority by the WAP planners when they select which farms will be planned in the following year.

2.7 Environmental Infrastructure Programs

2.7.1 WWTP Regulatory and SPDES Upgrade Program

As part of the 1997 Watershed Memorandum of Agreement (MOA), the City agreed to fund the eligible costs of designing, permitting, and constructing upgrades of all non-City-owned wastewater treatment plants (WWTPs) in the watershed. For the purposes of this program, “upgrades” means equipment and methods of operation that are required solely by the Watershed Rules and Regulations (WR&R), and not by federal or state law. The City further agreed to pay the annual costs of operation and maintenance of the upgraded facilities.

The task of coordinating these complex projects with 37 different West of Hudson (WOH) owners (the total includes one facility located in the West Branch Reservoir basin East of Hudson (EOH)) and an additional 69 EOH owners is an enormous one. Virtually all of the WWTP owners are restaurateurs, hoteliers, camp operators, homeowners’ associations, school administrators, managers of recreational facilities and the like, not professional WWTP operators and construction specialists. DEP has proceeded diligently with this vast undertaking and provided step-by-step guidance on a host of legal, engineering, contracting, and regulatory issues.

DEP contracted with the New York State Environmental Facilities Corporation (EFC) to assist with the administration of the program. EFC’s technical expertise and long history of assisting in wastewater infrastructure projects throughout the state made it the perfect partner for the upgrade program. DEP’s contract with EFC identifies a wide range of tasks EFC must perform to ensure that upgrades at the various WWTPs are achieved. The tasks include, but are not limited to, various program start-up tasks, contracting with each WWTP owner, technical assistance to each WWTP owner, change order administration, construction oversight at each WWTP, funds management (including invoice review and reconciliation), and project management assistance and fiscal reporting to DEP.

The upgrade of WWTPs is divided into two distinct programs: regulatory upgrades and SPDES upgrades (WOH only). Although the two programs are separate, the Upgrade Agreement between the EFC and the WWTP owner encompasses both programs.

The Regulatory Upgrade Program is designed to assist each WWTP meet the requirements of the WR&R and provides for the design and installation of highly advanced state-of-the-art treatment of WWTP effluent. Treatment technologies required by the Regulatory Upgrade Program and funded by DEP include, but are not limited to, phosphorus removal, sand filtration, backup power, backup disinfection, microfiltration (or DEP-approved equivalent), flow metering, and alarm telemetering.

The SPDES Upgrade Program is designed to assist each WWTP achieve and maintain compliance with its current SPDES permit. Equipment that is unreliable or reaching the end of its useful life is eligible for replacement under this program. Initial funding available under the program was $4.6 million; a separate paragraph of the program dedicates an additional $400,000 to Infiltration and Inflow (I/I) projects. One million dollars was added in 2008 as agreed to in the 2007 FAD renewal.

Over the past five years, remarkable progress has been made toward achieving the goals of the WWTP Upgrade Program. In fact, work on the WOH projects has been completed, either through construction of an on-site upgrade or through connection to another tertiary WWTP (see Table 2.11). These facilities account for 100% of the SPDES-permitted flow from non-City-owned WWTPs WOH.

Table 2.11: WWTP Upgrade Program status.

WWTP	Drainage Basin	Permit Flow (MGD)	Status
Catskill District			
Batavia Kill Recreation Area	Schoharie	0.0050	Completed
Black Bear Enterprises (aka Mountainside Inn)	Ashokan	0.0031	Completed
Camp Timberlake	Ashokan	0.0340	Completed
Camp Loyaltown	Schoharie	0.0210	Completed
Camp Oh Neh Tah	Schoharie	0.0075	Completed
Colonel's Chair Estates	Schoharie	0.0300	Completed
Crystal Pond	Schoharie	0.0360	Completed
Elka Park	Schoharie	0.0100	Completed
Forester Motor Lodge	Schoharie	0.0039	Completed
Frog House Restaurant	Schoharie	0.0018	Completed
Golden Acres	Schoharie	0.0092	Completed
Harriman Lodge	Schoharie	0.0200	Completed
Hunter Highlands Wpc	Schoharie	0.0400	Completed
Latvian Church Camp	Schoharie	0.0070	Completed
Liftside	Schoharie	0.0810	Completed
Mountainview Estates (#001)	Schoharie	0.0070	Completed
Mountainview Estates (#002)	Schoharie	0.0060	Completed
Olive Woods (aka Woodstock Percussion/Rotron)	Ashokan	0.0127	Completed
Onteora Jr./Sr. High School	Ashokan	0.0270	Completed
Rondevoo Restaurant	Schoharie	0.0010	Completed
Thompson House, Inc.	Schoharie	0.0050	Completed
Whistle Tree Development	Schoharie	0.0125	Completed
Windham Mountain (aka Snowtime/Ski Windham)	Schoharie	0.1200	Completed
Delaware District			
Camp Nubar	Pepacton	0.0125	Completed
Camp L'man Achai	Pepacton	0.0075	Completed
Delaware BOCES	Cannonsville	0.0100	Completed
Delhi (Village of)	Cannonsville	0.5150	Completed

Table 2.11: (Continued) WWTP Upgrade Program status.

WWTP	Drainage Basin	Permit Flow (MGD)	Status
Hobart (Village of)	Cannonsville	0.1600	Completed
Regis Hotel	Pepacton	0.0096	Completed
Roxbury Run Village	Pepacton	0.0350	Completed
SEVA Institute (#002 and #003)	Cannonsville	0.0078	Completed
South Kortright Center for Boys (aka Allen Residential)	Cannonsville	0.0200	Completed
Stamford (Village of)	Cannonsville	0.5000	Completed
Ultradairy/Morningstar	Cannonsville	0.2000	Completed
Walton (Village of)	Cannonsville	1.1700	Completed
Worcester Creameries (aka MSF Dairy)	Pepacton	0.0360	Completed
East of Hudson District			
Clear Pool Camp, Inc.	West Branch	0.0200	Completed

The City continues to pay for O&M on those WWTPs that constructed an on-site upgrade. Those WWTPs that were decommissioned and converted to either a subsurface disposal system or connected to another tertiary WWTP are not eligible for WWTP O&M payments.

2.7.2 Septic System Rehabilitation and Replacement Program

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

DEP allocated $13.6 million in 1997 and $15 million in 2002 for the septic program. As part of its 2007 FAD commitment, DEP agreed to allocate an additional $26 million, which brings total City funding commitments to $54.6 million for the program since 1997.

CWC's septic program rules in effect today reflect an inspection and remediation program implemented in a prioritized fashion according to potential impact to the City'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), and P6 (150 to 200 feet). 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:

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

In 2000, CWC began implementing the inspection and remediation program within the Priority 1A area (sub-basins within 60-day travel time to distribution that are near intakes). CWC staff continued to inspect and identify failures in the Priority 1A area in 2001. Early in 2002, CWC expanded the program to the Priority 1B area (sub-basins within 60-day travel time to distribution that are not near intakes). In 2003, the program expanded outside the 60-day travel time areas to address septic systems located within 50 feet of a watercourse or within 500 feet of a reservoir or reservoir stem (P3). The program expanded again in 2004, this time to homeowners between 50 feet and 100 feet of a watercourse (P4). Through 2005 a total of 2,128 septic systems had been repaired, replaced, or managed under the septic program.

During 2006, 252 septic systems were remediated, as CWC continued to implement the program by priority areas. The program expanded in 2007 to address septic systems between 100 feet to 150 feet of a watercourse (P5). Two hundred seventy-two septic systems were remediated in that year. In 2008, 259 septic systems were repaired, replaced, or managed, as CWC expanded the program to include septic systems between 150 feet and 200 feet of a watercourse. During 2009, CWC repaired, replaced, or managed 363 septic systems. That represents the most remediations in a single year in the program's history. In 2010, 335 septic systems were remediated under the program.

Table 2.12: Number of septic system remediations from 2006 to 2010.

Year	Septic System Remediations
2006	252
2007	272
2008	259
2009	363
2010	335

From 1997 through December 2010, 3,562 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. In the future, the septic program will continue to be implemented in a prioritized fashion, based upon the potential impact to the City's water supply.

2.7.3 New Sewage Treatment Infrastructure Program

The New Sewage Treatment Infrastructure Program (NIP) funds the study, design, and construction of new wastewater projects in seven communities: Andes, Roxbury, Hunter, Windham, Fleischmanns, Phoenicia, and Prattsville. NIP projects have been successfully completed in six of the seven communities (Table 2.13).

As per the 1997 Watershed MOA, NIP was funded at $75 million. As per the 2002 FAD, DEP added $12,150,000 to the program to allow block grant allocations to be awarded to Phoenicia and Prattsville. In December 2006, DEP executed a Change Order to NIP in the amount of $6,211,000 to provide the additional funding to revise the block grant for Phoenicia to $17,211,000. The revised block grant amount was based upon construction bids received for the proposed WWTP and collection system.

In 2007, DEP executed a Change Order to NIP in the amount of $1,500,000 to allow for the design and construction of a sewage collection system for the Hubbell Corners Supplemental Service Area (Roxbury NIP project).

NIP funding now totals $104,075,016.

Table 2.13: Status of new sewage treatment infrastructure projects.

Municipality	Permitted Flow (gpd)	Septics Displaced	Status
Hunter	338,400	434	Completed 2005
Fleischmanns	160,000	295	Completed 2007
Windham	373,800	394	Completed 2005
Andes	62,000	133	Completed 2005
Roxbury	100,000	315	Completed 2005
Phoenicia	185,000		In design review phase
Prattsville	86,000	185	Completed 2007

Table 2.14: New sewage treatment infrastructure projects completed, 2006-2010.

Municipality	Project	Septics Displaced	Flow (gpd)	Completed Date
Fleischmanns	Activated Sludge WWTP	295	160,000	2007
Roxbury (Hubbell Corners)	Sewer System	29	10,000	2010
Prattsville	Sequencing Batch Reactors WWTP	185	86,000	2007

Project summaries for each community follow:

Hunter

Conventional collection system to an activated sludge WWTP with continuous backwash upflow dual sand filtration.

Fleischmanns

Conventional collection system to an activated sludge WWTP with continuous backwash upflow dual sand filtration.

Windham

Conventional collection system to activated sludge WWTP with continuous backwash upflow dual sand filtration. The Town has approximately $2.5 million left in its block grant and is constructing additional sewer extensions within the approved service area.

Andes

Conventional collection system (+ Gladstone Hollow Road – small diameter variable grade pipe – 16 properties) to sequencing batch reactor WWTP with microfiltration.

Roxbury

Conventional collection system to pump station/force main to Grand Gorge WWTP. A conventional collection system serving the Hubbell Corners Supplemental Service Area was completed in 2010.

Phoenicia

The Town of Shandaken executed a contract with CWC in September 2010 to manage the project and has begun the design review phase of the project. The contract specifies a 1-year review phase, followed by a 1-year design phase, a 6-month bid phase, and a 2-year construction phase.

Prattsville

Conventional collection system to sequencing batch reactor WWTP with microfiltration.

Overall, NIP is providing centralized wastewater solutions in communities where there is a potential threat to water quality posed by failing and likely-to-fail septic systems. Wastewater projects in six of the seven communities are complete. This is a voluntary program and the City has extended a number of time extensions to the Town of Shandaken in support of the Town's efforts to implement a wastewater project in Phoenicia. The City hopes that Phoenicia residents will avail themselves of this opportunity.

2.7.4 Sewer Extension Program

The purpose of the Sewer Extension Program is to protect the quality of the City's water supply by connecting existing residences and businesses to central sewer systems in areas where on-site septic systems are either failing or are likely to fail. The 1997 MOA established the Sewer

Extension Program for the design and construction of sewer extensions to service areas of City-owned WWTPs in the WOH watershed. City-owned WWTPs in the watershed where sewer extensions were planned include: Grahamsville (Town of Neversink), Margaretville (Village of Margaretville/Town of Middletown), Pine Hill (Town of Shandaken), Tannersville (Town of Hunter), and Grand Gorge (Town of Roxbury).

During the past five years, DEP achieved several significant milestones in the implementation of these projects. Construction was completed on three extension projects, while two other projects are nearing the completion of the planning and design phase.

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

Town of Hunter – Haines Falls (Tannersville WWTP)

Construction was completed in December 2006. The project included five separate extensions totaling approximately 13,000 linear feet and included extending sewer service to the Haines Falls area of the Town. The extensions brought on line approximately 100 residences and businesses that previously treated and disposed of wastewater on-site. All told, approximately 39,500 gallons per day of new wastewater flow were added to DEP's existing Tannersville sewer system.

Town of Hunter – Showers Road (Tannersville WWTP)

With the anticipated completion of the project's design in early 2011, this sewer extension project will also be transitioning from the planning and design phase to the construction phase. The planned extension, which totals approximately 2,320 linear feet, will result in approximately 20 new house connections and an additional wastewater flow of 8,400 gallons per day into DEP's existing Tannersville Sewer System.

The project's review under the State Environmental Quality Review Act (SEQRA) was completed in 2010. In addition, all of the necessary easements have been procured and the Town's existing Sewer Use Law (SUL) has been modified to make reference to the planned extension.

Town of Neversink (Grahamsville WWTP)

The Town of Neversink Sewer Extension Project was completed in December 2009. This project included four separate extension areas totaling approximately 27,800 linear feet. Over 120 homes and businesses were brought on line, which added approximately 36,500 gallons per day in wastewater flows to DEP's existing Grahamsville sewer system.

Town of Roxbury (Grand Gorge WWTP)

Construction was completed on the Grand Gorge Sewer Extension Project in October 2010. This extension, which is situated along NYS Rt. 23 west of the Hamlet of Grand Gorge from Settlement Road to Bruce Porn Road, totaled approximately 5,100 linear feet.

Approximately 20 homes were brought on line, which added approximately 5,220 gallons per day in additional wastewater flows to DEP's existing Grand Gorge sewer system.

Town of Shandaken (Pine Hill WWTP)

With completion of the project's design in late 2010, the Pine Hill Sewer Extension Project is currently transitioning from the planning and design phase to the construction phase. The extension, which totals approximately 2,600 linear feet, will be located immediately adjacent to the Pine Hill WWTP along NYS Rt. 28. When completed, it will bring approximately 30 residences and businesses on line and will add approximately 5,700 gallons per day in added wastewater flows to DEP's existing Pine Hill sewer system.

To date, the project's design plans and specifications, as well as compliance with SEQRA, have been completed. It is anticipated that the Town of Shandaken Town Board will adopt a new SUL in early 2011, which is required pursuant to the MOA in order to proceed to construction. In addition, nearly all the easements necessary to construct the laterals that will be required to complete the project have been obtained.

Margaretville/Middletown (Margaretville WWTP)

Planning and design for the Margaretville/Middletown Sewer Extension Project has recommenced following suspension of activities lasting several years, during which time local officials took steps to procure high priority easements for the sewer mains. The planned extension project will involve three separate sewer extensions which collectively total approximately 7,400 linear feet. When completed, approximately 65 residences will be brought on line, resulting in approximately 16,900 gallons per day of additional wastewater flow into DEP's Margaretville sewer system.

Work that remains before the project reaches the construction phase includes complying with SEQRA, obtaining additional easements for constructing laterals on private properties, finalizing the project's design plans and specifications, and modifying the Village and Town's existing SULs. The 30% design for the system was completed in late 2010.

2.7.5 Community Wastewater Management Program

The Community Wastewater Management Program (CWMP) provides funding for the design and construction of community wastewater systems, including related sewer 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 West of Hudson communities.

Established under the 2002 FAD, the CWMP initially addressed wastewater needs in five communities: Bloomville, Boiceville, Hamden, DeLancey, and Bovina. In 2006, a sixth community, Ashland, was added to the program. Through the 2007 FAD, DEP provided funding for three additional communities: Trout Creek, Lexington, and South Kortright.

From 2006 to 2010, community septic systems were completed in Bovina (2006), Hamden (2009), and Bloomville (2009); a Septic Maintenance District was completed for the Hamlet of DeLancey (2007); and a WWTP was constructed for the Hamlet of Boiceville (2010) (Table 2.15). In addition, Preliminary Engineer's Reports for wastewater projects for the Hamlets of Trout Creek, Lexington, and South Kortright have been completed.

Table 2.15: CWMP projects completed, 2006-2010.

Community	Project	Flow (gpd)	Septics Displaced	Completed Date
Bloomville	Community Septic w/Sand Filter	30,000	89	2009
Boiceville	Sequencing Batch Reactor WWTP	75,000	105	2010
Hamden	Community Septic w/Sand Filter	26,000	59	2009
DeLancey	Septic Maintenance District	NA	57	2007
Bovina	Community Septic System	25,000	74	2006

CWMP projects are under way in the following communities:

<u>Ashland</u>. Recirculating sand filter WWTP with small diameter gravity sewers. Construction of the WWTP and installation of the collection system began in April 2010.

<u>Lexington</u>. DEP approved the recommended project as per the Preliminary Engineer's Report in June 2010. The proposed project is a small diameter gravity sewer system to a sand filter to subsurface disposal and a septic maintenance district for the Lexington Hotel. A $9.1 million block grant has been approved for the project. CWC presented the findings of the Preliminary Engineer's Report for Lexington to the community at a Town Board meeting in December 2010. The next step is for the Town to pass a resolution to proceed to the preconstruction (design) phase of the project. The Town must acknowledge in writing its desire to continue with the pre-construction phase of the project.

<u>Trout Creek</u>. DEP approved the recommended project as per the Preliminary Engineer's Report in June 2010. The recommended project is a small diameter gravity sewer system to two subsurface disposal sites. A $6.5 million block grant has been approved for the project. CWC presented the findings of the Preliminary Engineer's Report for Trout Creek to the community at a Town Board meeting in November 2010. The Tompkins Town Board passed a resolution to move into the preconstruction (design) phase of the project in November 2010. The Town must acknowledge in writing its desire to continue with the pre-construction phase of the project.

<u>South Kortright</u>. DEP approved the recommended project as per the Preliminary Engineer's Report in June 2010. The recommended project is a conventional sewer system with sewage pumped to the Hobart WWTP via the Allen Residential Center pump station. A $4.9 million block grant has been approved for the project. CWC expects to present the findings of the Preliminary Engineer's Report for South Kortright to the community in the first quarter of 2011.

The Town must acknowledge in writing its desire to continue with the pre-construction phase of the project.

The CWMP is providing centralized (community septic systems) and decentralized (septic maintenance districts) wastewater solutions in communities where there is a perceived potential threat to water quality posed by failing and likely-to-fail septic systems.

2.7.6 Septic Maintenance Program

Because the City's WOH watersheds are sparsely developed, many communities rely on individual septic systems to treat and dispose of sanitary waste. Proper septic maintenance is important in prolonging the life 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 $1.5 million Septic System Maintenance Program, administered by CWC, is a voluntary program open to homeowners 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. Participation in the program has been steady since its inception (Table 2.16).

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 his/her 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 homeowner 50% of eligible costs for pump-outs and maintenance. Another component of the program is the development and dissemination of septic system maintenance educational materials.

Table 2.16: Septic Maintenance Program participation, 2006-2010.

Year	Activity
2006	86 septic pump-outs
2007	63 septic pump-outs
2008	69 septic pump-outs
2009	84 septic pump-outs
2010	130 septic pump-outs

Since 2004, 575 homeowners have been paid 50% of eligible costs for septic system pump-outs and maintenance.

2.7.7 Stormwater Programs

Stormwater Retrofit Program

The Stormwater Retrofit Program is administered jointly by CWC and DEP. Since its inception, the total program budget has risen to $21,791,800, which includes $16,298,050 for capital expenditures, $2,993,750 for maintenance activities, and $2,500,000 to conduct community-wide stormwater infrastructure assessment and planning initiatives.

CWC maintains an open application timetable for construction grant project applications, evaluating each application as it is submitted, but gives funding preference to construction grant project applications where a planning and assessment contract has already been successfully completed or where a NIP project or CWMP project is in process.

Planning and assessment projects provide a basis for future capital construction projects. During the period 2006 through 2010, 10 planning and assessment projects totaling more than $400,000 were reviewed and approved for funding.

During the period 2006 through December 2010, 34 stormwater retrofit project applications were completed for a total of nearly $7.5 million disbursed (Table 2.17). Projects focused on street drainage, stormwater separation, and highway maintenance activities.

Table 2.17: Completed stormwater retrofit construction projects, 2006-2010.

Applicant	Project Description	Grant Amount
Ashokan		
Town of Hurley	Collection, conveyance, sedimentation	$235,320.80
Town of Olive	Collection, conveyance, sedimentation	$581,400.00
Town of Shandaken	Equipment—brine tanks	$24,436.00
Ulster County	Maintenance equipment—vacuum truck	$275,000.00
Cannonsville		
Village of Delhi	Collection, conveyance, sedimentation	$513,657.00
Delaware County	Collection, conveyance, sedimentation	$1,546,488.20
Delaware County	Sedimentation (deep sump catch basins/CDS)	$280,500.00
Town of Hamden	Collection, conveyance, sedimentation	$974,200.00
Town of Kortright	Collection, conveyance, sedimentation	$473,078.30
Town of Walton	Collection, conveyance, sedimentation	$29,500.00
Village of Delhi	Maintenance equipment—street sweeper	$137,020.00
Delaware County	Maintenance equipment—ice control system	$8,483.00
Pepacton		
Town of Halcott	Collection, conveyance, sedimentation	$75,000.00
Village of Margaretville	Channel improvements (culvert replacement)	$286,875.00
Town of Roxbury	Collection, conveyance, sedimentation	$52,031.00
Village of Margaretville	Stormwater separation (household stormwater laterals)	$444,225.00
Village of Margaretville	I&I monitoring	$74,655.00

Table 2.17: (Continued) Completed stormwater retrofit construction projects, 2006-2010.

Applicant	Project Description	Grant Amount
Rondout		
Town of Wawarsing	Channel improvements	$41,510.00
Schoharie		
Town of Hunter	Collection, conveyance, sedimentation	$56,100.00
Greene County	Maintenance equipment—street sweeper	$180,000.00
Town of Roxbury	Collection, conveyance, sedimentation	$52,000.00
Town of Windham	Collection, conveyance, sedimentation	$25,834.37
Town of Prattsville	Collection, conveyance, sedimentation	$454,000.00
Village of Hunter	Collection, conveyance, sedimentation	$259,998.00
Town of Hunter	Equipment—brine tanks	$16,084.55

Future Stormwater Controls Program

State and federal regulations require the construction of stormwater BMPs as part of stormwater pollution prevention plans and individual residential stormwater plans. Additional requirements are imposed by the New York City watershed regulations. For construction begun after May 1, 1997, the Future Stormwater Controls Program pays for costs arising solely as a result of complying with City regulations, over and above those incurred as a result of state and federal requirements.

Two separate programs have been developed to offset these additional compliance costs incurred as a result of the implementation of the City'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% of eligible costs. Another program, Future Stormwater Controls Paid for by the City, reimburses low-income housing projects and single-family homeowners 100% and small businesses 50% of eligible costs.

Through 2010, CWC paid out over $3.6 million for eligible incremental costs for stormwater controls required by the City's watershed regulations. Pursuant to the terms of the MOA, CWC has also transferred $14,176,724 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. Between 2006 and 2010, 34 Local Technical Assistance projects were approved for funding (Table 2.18).

Table 2.18: Local Technical Assistance projects approved, 2006-2010.

Applicant	Project	Funding
2006		
Delaware County	Delaware County Highway Maintenance Plan	$50,000
Town of Jewett	Jewett Infrastructure Study	$30,000
Village of Margaretville	Margaretville Comprehensive Plan	$34,947
Village of Tannersville	Tannersville Highway Maintenance Plan	$32,000
Village of Walton	Walton Floodplain Analysis	$50,000
Town of Windham	Windham Generic Environmental Impact Statement (GEIS)	$50,000
2007		
Delaware County	Delaware County Highway Maintenance Plan	$50,000
Delaware County	Third Brook Flood Study	$50,000
Village of Fleischmanns	Village of Fleischmanns Comprehensive Plan	$25,000
Town of Jewett	Ground Water/Land Use	$44,620
Town of Middletown	Town of Middletown Comprehensive Plan	$25,000
Town of Roxbury	Town of Roxbury Comprehensive Plan & GEIS	$84,000
Town of Conesville	Manorville Watershed GEIS	$66,000
Town of Windham	Windham GEIS	$162,611
Town of Hunter	Hunter Corridor GEIS	$144,389
2008		
Town of Halcott	Town of Halcott Zoning Update	$25,000
Town of Denning	Town of Denning Comprehensive Plan	$45,000
Town & Village of Delhi	Town & Village of Delhi Comprehensive Plan	$50,000
Town of Hunter	Hunter Corridor GEIS	$30,000
Town of Roxbury	Town of Roxbury GEIS	$9,200
Town of Windham	Windham GEIS	$78,843
2009		
Village of Fleischmanns	Village of Fleischmanns Zoning Law Update	$20,000
Town of Stamford	Town of Stamford Comprehensive Plan	$25,000
Ulster County	Main Street Strategic Toolbox	$50,000
Town of Olive	Route 28 Corridor Management Plan	$50,000
Village of Fleischmanns	Village Park Planning Project	$14,170
Town of Middletown	Regional Economic Revitalization Plan	$40,830
Town of Woodstock	Woodstock Habitat Mapping	$50,000
2010		
Village of Hunter	Village of Hunter Zoning Update & Subdivision Regulations	$50,000
Town of Hunter	NYC Watershed Riparian Buffer Program	$48,000

Environmental Protection

Table 2.18: (Continued) Local Technical Assistance projects approved, 2006-2010.

Applicant	Project	Funding
Town of Olive	Town of Olive Comprehensive Plan	$50,000
Town of Roxbury	Inventory and Comprehensive Plan Update	$25,000
Greene Co. Soil & Water	Mountaintop Better Site Design Plan	$50,000
Town of Denning	Land Use Codes Update	$27,000
W. Mountain Properties	Hobart Quickway stormwater measures	$101,160

2.8 Waterfowl Management Program

The management of waterbird populations at Kensico Reservoir is essential to meet the requirements of EPA's Surface Water Treatment Rule (SWTR). DEP's Waterfowl Management Program (WMP) was established to research the relationship between wildlife, particularly waterbirds that inhabit the reservoirs (geese, gulls, cormorants, swans, ducks, and other duck-like birds), and fecal coliform bacteria concentrations in surface water prior to disinfection. Following several years of waterbird population monitoring, DEP identified birds as a significant source of fecal coliform in Kensico Reservoir. In addition, it was determined that migratory populations of waterbirds utilize NYC reservoirs as temporary staging areas and wintering grounds and therefore significantly contribute to increases in fecal coliform loadings during the autumn and winter, primarily from direct fecal deposition in the reservoirs. These 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 1993-2010) have documented that, in water samples collected near roosting locations at several NYC reservoirs, fecal coliform increases have occurred concurrently with increases in waterbird populations.

In response, DEP implemented the use of standard bird management techniques approved by the United States Department of Agriculture (USDA), the New York State Department of Environmental Conservation (DEC) and the United States Fish and Wildlife Service to reduce or eliminate the waterbird populations inhabiting the reservoir system. In combination with these standard deterrence techniques, an additional measure is used to manage local breeding populations of Canada geese (*Branta canadensis*), double-crested cormorants (*Phalocrocorax auritis*), and mute swans (*Cygnus olor*): identification of nesting locations and subsequent depredation of eggs and nests. Since the implementation of these measures, there has been a dramatic reduction in both roosting bird populations and fecal coliform levels, which has helped DEP maintain high quality water in compliance with the SWTR. While developed for Kensico Reservoir in 1992, the WMP was expanded to include five additional reservoirs (West Branch, Rondout, Ashokan, Croton Falls, and Cross River) for waterbird management on an "as needed" basis under the November 2002 Filtration Avoidance Determination (FAD). The City's 2006 Long-Term Watershed Protection Plan expanded the WMP on an "as needed" basis to include avian harassment and deterrent measures at Hillview Reservoir in Yonkers, NY. To ensure that

DEP's program activities remained in compliance with all federal, state, and local laws, an environmental impact statement was completed for Kensico in 1996 and another one in the spring of 2004 for the five additional reservoirs. Bird mitigation actions conducted at Hillview Reservoir have been identified as Type II Actions under 6 NYCRR Part 617.5(c)(29), and as such do not require an environmental impact statement or any other determination or procedure.

Implementation of the WMP is described in the sections that follow. The water quality results of the program are described in Chapters 3-6, in the discussion of each reservoir basin in which the program was implemented.

2.8.1 Waterbird Census

New York City reservoirs lie in the Atlantic Flyway, an important migratory pathway for many groups of birds, including waterbirds. The reservoirs offer important areas of open water used by these birds for night roosting and winter stopovers. DEP initiated waterbird surveys to track the number of waterbirds on the reservoirs throughout the year because of the well-established relationship between elevated waterbird counts and increased levels of fecal coliform bacteria in raw water samples. Since it is well documented that night-roosting birds are primary contributors of bacteria to the water supply, night census data are presented throughout this report, in addition to daytime data. Defecation rates of birds are known to be somewhat lower nocturnally than diurnally.

Currently, reservoir bird surveys are conducted throughout the calendar year. A breakdown of the survey schedule by reservoir from January 2006 to March 31, 2010 is presented in Table 2.19.

Table 2.19: Frequency of bird observation surveys by reservoir, 2006-2010.

Reservoir	Bird Survey Schedule
Kensico	Pre-dawn to post-dusk daily, August 1-March 31; Pre-dawn and post-dusk weekly, April 1-July 31
West Branch	Pre-dawn, midday, and post-dusk weekly. Increased to daily "as needed".
Rondout	Pre-dawn, midday, and post-dusk weekly. Increased to daily "as needed".
Ashokan	Pre-dawn, midday, and post-dusk weekly. Increased to daily "as needed".
Croton Falls	Pre-dawn, midday, and post-dusk bi-weekly. Increased to daily "as needed".
Cross River	Pre-dawn, midday, and post-dusk bi-weekly. Increased to daily "as needed".
Hillview	Pre-dawn to post-dusk 3 days/week and daylight hours only 4 days/week.

2.8.2 Waterbird Mitigation

Bird harassment

A list of bird dispersal activities conducted since 1993 is presented in Table 2.20. During the assessment period, as in years past, waterbird dispersal techniques were employed at Kensico and Hillview Reservoirs, with motorboats, Husky Airboats, noisemakers (pyrotechnics), and bird distress tapes being used at the former, and pyrotechnics and propane cannons at the latter. 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. Dispersal techniques were conducted by HDR (Henningson, Durham, and Richardson, P.C., of Nyack, New York) under a WMP contract. Beginning daily at 8 am and continuing until approximately 1.5 hours past sunset, bird hazing activities were conducted reservoir-wide, targeting all species except those designated as endangered or threatened by the federal government or New York State. Bird harassment in the five "as needed" reservoirs is also presented in Table 2.20.

Table 2.20: Reservoir Bird Mitigation, 1993-2010.

Reservoir	Dates of Bird Harassment/Deterrence	Bird Harassment & Deterrence Measures Used
Kensico	December 1993-present	Bird Harassment—motorboats, Husky Airboats, pyrotechnics, bird distress tapes Deterrence—waterbird reproductive depredation, shoreline meadow management and fencing, alewife collections
West Branch*	January 11-March 28, 2007	Bird Harassment—motorboats and pyrotechnics Deterrence—waterbird reproductive depredation
Rondout*	December 2002-January 2003 December 2003-January 2004 December 2005-March 2006	Bird Harassment—pyrotechnics, red-beam lasers, bird distress tapes Deterrence—waterbird reproductive depredation
Ashokan*	None required during the reporting period	Deterrence—waterbird reproductive depredation
Croton Falls*	January 2002 None required during the reporting period	Bird Harassment—motorboats, pyrotechnics, red-beam lasers, bird distress tapes Deterrence—waterbird reproductive depredation
Cross River*	None required during the reporting period	Deterrence—waterbird reproductive depredation
Hillview	Year-round continuous or "as needed" (July 1993-March 31, 2010)	Bird Harassment—pyrotechnics Deterrence—bird deterrent wire system

*Indicates reservoir mitigation only occurs "as needed" under the 2002 FAD, Section 4.1.

Bird deterrence

Egg depredation

DEP conducts annual springtime breeding surveys and egg depredation for Canada geese and mute swans within NYC reservoir property to suppress reproductive success, which in turn eliminates population recruitment and breaks site fidelity of nesting adults. Preliminary surveys of 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 to assure egg destruction eliminates any 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 goose nests are typically destroyed late in the breeding season to encourage the birds to relocate off reservoir property during the annual post-nuptial molt, when the birds are rendered flightless for a few weeks.

Meadow vegetation and shoreline fencing maintenance, which contribute to the success of bird depredation activities, are also performed, principally in the meadows adjacent to Shaft 18, where geese typically nest. Table 2.21 outlines the number of nests located as well as the number of eggs depredated between 2006 and 2010.

All depredation activity was conducted under the terms of U.S. Fish & Wildlife and DEC permits for Canada geese, and under DEC permit for mute swans. Additionally, DEP, in conjunction with DEC, continued an annual Canada goose banding project in Westchester, Putnam, and Ulster Counties to track local goose movements throughout the NYC watersheds. Band identifications help identify local breeding, feeding, and loafing areas, which in turn may aid in implementing best management practices (i.e., elimination of feeding areas may eliminate presence on reservoirs).

Table 2.21: Egg depredation summary for Canada geese and mute swans, 2006-2010.

Reservoir	Year	Surveys	Canada Goose Nests (eggs depredated)	Mute Swan Nests (eggs depredated)	Depredation Success Rate for Canada Geese/Mute Swans (number surviving young)
Kensico	2006	7	39 (186)	1 (6)	100% (0 goslings)/100% (0 cygnets)
	2007	7	36 (138)	1 (5)	98% (3 goslings)/100% (0 cygnets)
	2008	5	50 (159)	1 (12)	94% (10 goslings)/75% (4 cygnets)
	2009	5	38 (192)	1 (12)	99% (2 goslings)/100% (0 cygnets)
	2010	5	36 (170)	0 (0)	98% (4 goslings)/NA
	Totals		199 (845)	4 (35)	98% (19 goslings)/ 89% (4 cygnets)
West Branch	2006	7	8 (21)	0 (0)	81% (5 goslings)/NA
	2007	5	6 (21)	0 (0)	95% (1 gosling)/NA
	2008	4	14 (45)	0 (0)	100% (0 goslings)/NA
	2009	4	13 (55)	0 (0)	98% (1 gosling)/NA
	2010	4	12 (42)	0 (0)	100% (0 goslings)/NA
	Totals		53 (184)	0 (0)	96% (7 goslings)/ NA

Table 2.21: (Continued) Egg depredation summary for Canada geese and mute swans, 2006-2010.

Reservoir	Year	Surveys	Canada Goose Nests (eggs depredated)	Mute Swan Nests (eggs depredated)	Depredation Success Rate for Canada Geese/Mute Swans (number surviving young)
Rondout	2006	1	2 (9)	0 (0)	60% (6 goslings)/NA
	2007	1	2 (2)	0 (0)	25% (6 goslings)/NA
	2008	1	NA (0)	0 (0)	0% (19 goslings)/NA
	2009	1	7 (39)	0 (0)	83% (8 goslings)/NA
	2010	5	2 (11)	0 (0)	34% (21 goslings)/NA
	Totals		13 (61)	0 (0)	50% (60 goslings)/ NA
Ashokan	2006	2	7 (35)	0 (0)	74% (12 goslings)/NA
	2007	2	4 (23)	0 (0)	85% (4 goslings)/NA
	2008	4	5 (30)	0 (0)	65% (16 goslings)/NA
	2009	4	7 (30)	0 (0)	58% (22 goslings)/NA
	2010	4	4 (19)	0 (0)	37% (32 goslings)/NA
	Totals		27 (137)	0 (0)	61% (86 goslings)/ NA
Croton Falls	2006	7	6 (9)	0 (0)	100% (0 goslings)/NA
	2007	4	5 (18)	0 (0)	100% (0 goslings)/NA
	2008	5	6 (25)	0 (0)	100% (0 goslings)/NA
	2009	5	5 (38)	0 (0)	88% (5 goslings)/NA
	2010	4	6 (24)	0 (0)	83% (5 goslings)/NA
	Totals		28 (114)	0 (0)	92% (10 goslings)/ NA
Cross River	2006	4	15 (69)	0 (0)	100% (0 goslings)/NA
	2007	4	12 (41)	0 (0)	100% (0 goslings)/NA
	2008	4	7 (25)	0 (0)	100% (0 goslings)/NA
	2009	4	5 (38)	0 (0)	100% (0 goslings)/NA
	2010	4	7 (33)	0 (0)	100% (0 goslings)/NA
	Totals		46 (206)	0 (0)	100% (0 goslings)/NA
Hillview	2006	91	0 (0)	0 (0)	NA/NA
	2007	91	0 (0)	0 (0)	NA/NA
	2008	91	0 (0)	0 (0)	NA/NA
	2009	91	0 (0)	0 (0)	NA/NA
	2010	91	0 (0)	0 (0)	NA/NA
	Totals		0 (0)	0 (0)	NA/NA

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 structure (CATIC) to remove the dead fish that collected at the boom. Table 2.22 presents an estimate of the amount of alewives collected during each bird hazing season (August 1 through March 31) from 2005 to 2010. 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 2.22: Alewife collections, 2005-2010.

Season (August 1-March 31)	Collection Days per Season	Estimated Amount (lbs.)
2005-2006	22	5,125
2006-2007	1	25
2007-2008	13	1,630
2008-2009	8	1,205
2009-2010	1	125

2.9 Wetlands Protection Program

In 1996, DEP set forth a Wetlands Protection Strategy to preserve wetlands and their valuable water quality functions in the New York City Watershed. The strategy was enhanced in 2001 and 2007 to reflect advances in wetlands mapping and research that support DEP's protection programs. In addition to non-regulatory protection programs, DEP reviews wetland permits received under federal, state, and municipal regulations within the watershed to ensure that impacts to wetland water quality functions are avoided, minimized, and mitigated to the extent practicable. DEP also comments on any proposed changes to such regulations to maintain or improve protection levels in the watershed.

2.9.1 Wetlands Mapping and Research

The National Wetlands Inventory (NWI) is central to DEP's wetlands mapping and research program. The NWI provides information on the extent, distribution, and characteristics of wetlands to support DEP's watershed protection programs. The NWI was most recently updated for the entire watershed in the prior reporting period. During that period, the NWI provided the foundation for an assessment of wetland trends for the Croton watershed for three time periods spanning 1968 to 2004 and a watershed-scale wetland functional assessment. During the current assessment period, the NWI provided baseline data for an assessment of wetland trends in the Catskill and Delaware watersheds from the mid-1980s to 2004. DEP also continued to collect and analyze data from reference wetlands located throughout the Catskill and Delaware watersheds.

West of Hudson Wetland Status and Trends Analysis

In 2008, an assessment of wetland trends was completed for the West of Hudson watershed covering the mid-1980s to 1994 and 1994 to 2004, through a contract with the U.S.

Fish and Wildlife Service (USFWS). To assess wetland gains, losses, and cover type changes, the USFWS superimposed imagery from the time periods of interest to detect and record changes in a geospatial wetland database. Summary statistics were then provided by reservoir basin. Vegetated wetlands and ponds were analyzed separately, as ponds may not provide the same suite of functions as vegetated wetlands. DEP completed an extensive quality assurance review of the spatial databases produced for this project.

Based on this analysis, the USFWS detected a net loss of approximately 96 acres of vegetated wetlands from the mid-1980s to 1994 and a net gain of approximately four acres from 1994 to 2004. The slight net gain can be attributed to the succession of ponds to vegetated wetlands in the Ashokan and Pepacton basins, which offset 14 acres of vegetated wetland loss. Pond construction was the leading cause of vegetated wetland loss in all time periods. Most of the vegetated wetland loss between the mid-1980s and 1994 occurred in the Schoharie, Cannonsville, and Pepacton basins, where 64, 29, and 12 acres of vegetated wetlands were converted to ponds, respectively. There was a net gain in pond acreage during both time periods, with approximately 515 acres gained between the mid-1980s and 1994, and 110 acres gained between 1994 and 2004. The majority of the pond gain occurred in the Cannonsville, Pepacton, and Schoharie Reservoir basins (Figures 2.15a and 2.15b, Tables 2.23 and 2.24).

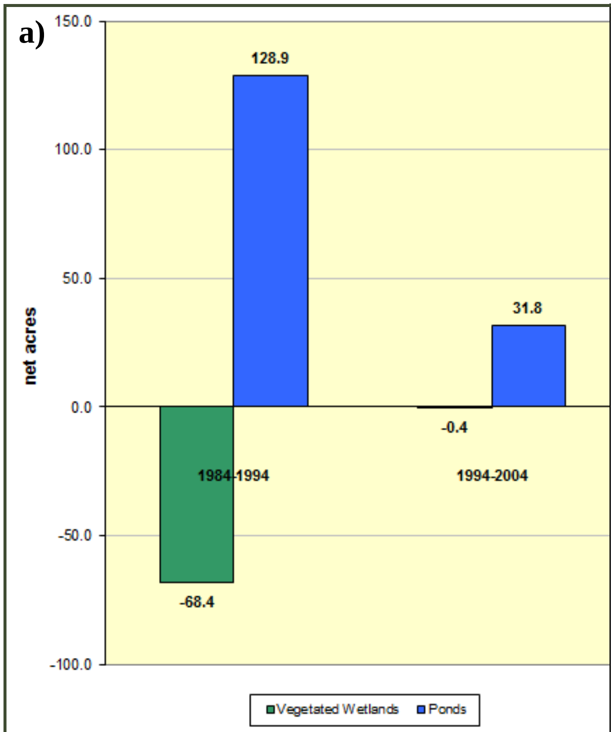

Figure 2.15a Wetland trends (mid-1980s to mid-1990s) for individual reservoir basins in the Catskill watershed. Units are in acres.

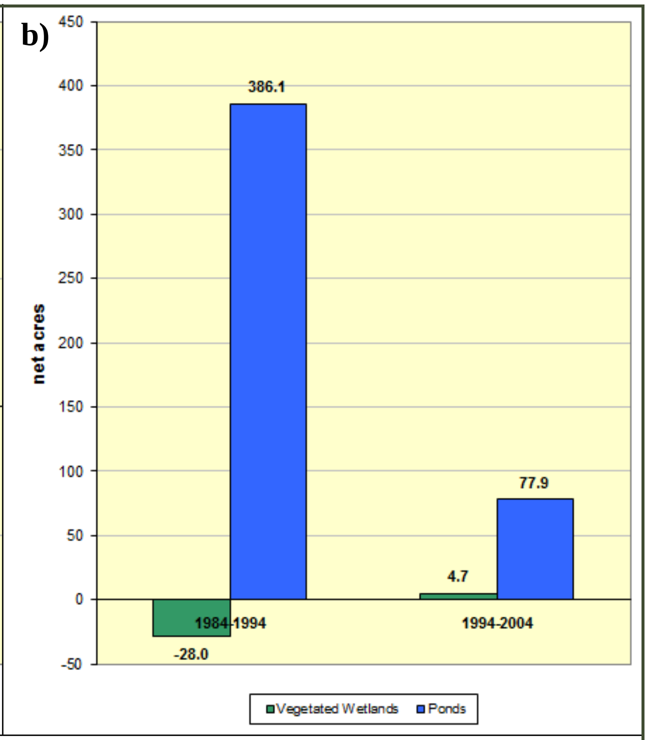

Figure 2.15b Wetland trends (mid-1980s to mid-1990s) for individual reservoir basins in the Delaware watershed. Units are in acres.

Table 2.23: Wetland trends (mid-1980s to mid-1990s) for individual reservoir basins in the West of Hudson watershed. Units are in acres.

	Vegetated Wetlands			Ponds		
	Loss	Gain	Net	Loss	Gain	Net
Ashokan	0.27	0.31	+0.04	13.23	12.37	-.845
Cannonsville	31.23	10.71	-20.52	0.71	247.23	+246.52
Neversink	--	--	--	--	4.07	+4.07
Pepacton	13.31	5.87	-7.44	0.72	128.96	+128.24
Rondout	--	--	--	--	6.97	+6.97
Schoharie	82.5	14.03	-68.47	8.07	137.72	+129.65
Total Change	127.3	30.9	-96.4	22.7	537.3	+514.6

Table 2.24: Wetland trends (mid-1990s to 2004) for individual reservoir basins in the West of Hudson watershed. Units are in acres.

	Vegetated Wetlands			Ponds		
	Loss	Gain	Net	Loss	Gain	Net
Ashokan	--	5.57	+5.57	5.57	3.22	-2.35
Cannonsville	5.21	2.24	-2.97	1.97	51.98	+50.01
Neversink	--	--	--	--	--	--
Pepacton	1.14	9.03	+7.89	9.03	33.24	+24.21
Rondout	0.22	--	-0.22	--	3.65	+3.65
Schoharie	7.89	1.90	-5.99	0.06	34.19	+34.13
Total Change	14.46	18.74	+4.28	16.63	126.28	+109.65

Because the trends analysis is based on photography from three time periods ranging in both quality and scale (from 1:24,000 to 1:58,000), there are likely undetected losses and gains of smaller or drier wetland types that are difficult to detect from aerial photography. Nonetheless, this analysis provides a useful estimate of the extent and causes of wetland loss. The decrease in the rate of vegetated wetland loss and significant gain in pond acreage is consistent with national trends. The decreased rate of loss may be attributable to the cumulative effectiveness of regulatory and voluntary protection programs at federal, state, and municipal levels. The functional impacts of an increase in pond acreage on a watershed scale, often at the expense of vegetated wetlands, are not well documented.

Reference Wetlands Monitoring Program

DEP has a reference wetlands monitoring program in place to provide information on the water table, water quality, vegetation, and soil characteristics of wetlands throughout the watershed. Monitoring was initiated in 1999 at six reference wetlands in the West Branch and Boyd Corners Reservoir basins. DEP expanded its reference wetlands monitoring program in 2004 to include 22 sites located throughout the Catskill and Delaware watersheds. Much of the West of Hudson wetlands monitoring was completed during the previous assessment period (2004 and 2005 growing seasons) and consisted of routine and stormwater quality sampling, along with vegetation, soils, and water table monitoring. During the current assessment period, DEP completed a detailed quality assurance review and analysis of hydrologic, water quality, vegetation, and soils data collected from these sites in 2004 and 2005.

Figure 2.16 Automated monitoring well installed near the inflow of a lotic headwater red maple swamp along an unnamed tributary to Ashokan Reservoir.

DEP continues to collect data from automated monitoring wells at the Catskill and Delaware study sites to obtain a long-term record of reference hydrologic conditions for lotic and terrene wetland types. DEP installed 35 automated monitoring wells which capture water table levels at six-hour intervals. This long-term record is used to assess baseline reference hydrologic conditions and functions, and to interpret previously collected soils, vegetation, and water quality data; it can also be used to assess long-term trends in wetland hydrology (Figure 2.16).

Information gained from the wetlands mapping and monitoring programs supports DEP's various protection strategies. Reference wetland conditions provide standards for wetland assessment and mitigation site design that guide DEP's review of applications received under federal, state, and municipal wetland regulations, Watershed Rules and Regulations (WR&R), State Environmental Quality Review Act (SEQRA), and DEP construction and land management proposals. DEP's wetland mapping and monitoring programs collectively provide site- and watershed-scale information on the extent, characteristics, functions, and trends of wetlands that can be applied to prioritize wetlands for strengthened protection through regulatory and voluntary programs.

2.9.2 Wetlands Regulatory Program

Activities during the current assessment period include DEP's review of federal, state, and municipal permit applications in the watershed, review of numerous proposed legislative or regulatory changes affecting wetlands, and the final adoption of revisions to New York State freshwater wetland maps for Putnam and Dutchess Counties. DEP also coordinated with external agencies to revise procedures for the review of Article 15 and 24 permit applications within the watershed.

In addition to reviewing federal, state, and municipal wetland permit applications, DEP reviews proposals subject to review under the SEQRA and the WR&R. As the level of protection afforded to wetlands varies among regulatory authorities, reviewing applications pending before multiple agencies helps to ensure that all activities that potentially threaten the water quality functions of wetlands in the watershed are carefully reviewed by DEP. Project proposals within the watershed are reviewed by staff to assess the potential impact on water quality. Measures to avoid, minimize, or mitigate impacts on the water quality protection functions of wetlands are often recommended.

Army Corps of Engineers Applications

The United States Army Corps of Engineers (ACOE) forwards Individual Permit Applications under Section 404 of the Clean Water Act to DEP for review and comment. DEP reviews Individual Permit Applications to ensure adverse impacts to federal wetlands and water quality are avoided or minimized, and that unavoidable impacts are appropriately mitigated. DEP reviewed nine ACOE wetland applications from 2006-2010.

New York State Applications

DEP continued to review permit applications pending before DEC under Article 24 of the Environmental Conservation Law. DEP reviews permit applications to recommend measures to protect water quality and minimize disturbance to wetlands and their regulated adjacent areas. DEP reviewed 67 permit applications pending before DEC from 2006-2010.

Municipal Applications

DEP reviews proposals involving wetlands before municipal regulatory bodies to assess potential impacts to wetlands and water quality in the East of Hudson watershed. DEP reviewed 65 local wetland applications in New York State and Connecticut between 2006 and 2010.

SEQRA

As either an involved agency or interested party, DEP reviews SEQRA documents for land use proposals in the watershed to ensure that impacts to wetlands are avoided to the extent practicable. SEQRA review in many cases helps to minimize wetland impacts prior to the federal, state, and municipal wetland permitting process.

New York City Watershed Rules and Regulations

The WR&R provide another level of wetland protection. DEP reviews applications to conduct regulated activities to ensure they do not involve actions proscribed by the WR&R, such as the creation of impervious surfaces or installation of septic systems within limiting distances to DEC-mapped wetlands. DEP also regulates other activities that may adversely affect wetlands, such as discharges of stormwater and wastewater from new developments.

NYS State Freshwater Wetland Map Amendments

DEC's revision of the freshwater wetland maps for the East of Hudson watershed was completed during this assessment period. At DEP's request, DEC completed field work from 2002 to 2004 to assess the boundaries of existing regulated wetlands, locate additional wetlands that meet the state regulatory threshold of 12.4 acres, and identify smaller wetlands of Unusual Local Importance (ULIs) that are adjacent to the reservoirs. Final maps, adding approximately 2,400 acres of regulated wetlands, were accepted for Westchester County in 2004. Final maps, adding approximately 4,500 acres of wetlands, were adopted for Putnam and Dutchess Counties in April 2006. These amendments increased the extent of wetlands subject to review under both the WR&R and the NYS Freshwater Wetlands Law by nearly 7,000 acres East of Hudson.

Legislative Reviews

DEP reviews and issues comments on proposed regulatory revisions that affect wetland protection in the watershed. Comments often draw on information gained from the wetland mapping and monitoring programs. In 2006, DEP provided extensive technical input to the City's preparation of an amicus brief for two U.S. Supreme Court cases regarding the scope of wetlands jurisdiction under the Clean Water Act. Data from the wetlands monitoring program and from the USFWS Wetland Characterization and Functional Assessment mapping projects were used to demonstrate the extent of headwater wetlands in portions of the New York City Watershed and their nexus to the protection of navigable waters. DEP commented on this issue again in 2008 when EPA and ACOE issued a proposed "Guidance Regarding Clean Water Act Jurisdiction after *Rapanos*".

In 2006, DEP provided extensive review and comment on the Nationwide Permits that were subsequently issued by the ACOE in March 2007. DEP also reviewed the Regional Conditions for the Nationwide Permit Program that were proposed by the New York District of ACOE. In 2007, DEP commented on proposed changes to the State Water Quality Certifications, which were made due to revisions to the ACOE's Nationwide Permits. DEP also contributed to the City's comments on the "Rule regarding Compensatory Mitigation for Losses of Aquatic Resources," as proposed by EPA and ACOE in 2006.

2.9.3 Wetland Partnerships and Outreach

Land Acquisition

DEP protects wetlands through fee acquisition and conservation easements. As of December 31, 2010, DEP had protected 2,238 acres, or 14.7% of wetlands in the Catskill and Delaware Systems (Table 2.25).

Table 2.25: Wetlands acquired or protected by the NYC Land Acquisition Program (LAP) in the Catskill/Delaware and Croton Systems as of December 31, 2010[1].

Description	Acres	% of Total Watershed Acreage	% of Total Land Acquired	% of Total Wetland Type in System
For Catskill/Delaware				
Total acreage of entire watershed	1,049,484			
Total acreage of wetlands (both NWI and DEC-regulated) in entire watershed (excluding inundated aquatic habitats[2])	15,200	1.45%		
Total acreage of inundated aquatic habitats in entire watershed	28,339	2.70%		
Total acreage of wetlands and inundated aquatic habitats in entire watershed	43,539	4.15%		
Total lands under contract or closed by DEP as of 12/31/10[1,3]	112,683	10.74%		
Within total lands under contract or closed:				
Total acreage of wetlands (both NWI and DEC-regulated, excluding inundated aquatic habitats[2])	2,414		2.14%	15.88%
Total acreage of inundated aquatic habitats[2]	162		0.14%	0.57%
Total acreage of wetlands and inundated aquatic habitats[2]	2,576		2.29%	5.92%
For Croton				
Total acreage of entire watershed	212,161			
Total acreage of wetlands (both NWI and DEC-regulated) in entire watershed (excluding inundated aquatic habitats[2])	20,028	9.44%		
Total acreage of inundated aquatic habitats in entire watershed	10,693	5.04%		
Total acreage of wetlands and inundated aquatic habitats in entire watershed	30,721	14.48%		
Total lands under contract or closed by DEP as of 12/31/10[1,3]	2,269	1.07%		

Table 2.25: (Continued)Wetlands acquired or protected by the NYC Land Acquisition Program (LAP) in the Catskill/Delaware and Croton Systems as of December 31, 2010[1].

Description	Acres	% of Total Watershed Acreage	% of Total Land Acquired	% of Total Wetland Type in System
Within lands under contract or closed:				
Total acreage of wetlands (both NWI and DEC-regulated, excluding inundated aquatic habitats[2])	127		5.60%	0.63%
Total acreage of inundated aquatic habitats[2]	2		0.07%	0.02%
Total acreage of wetlands and inundated aquatic habitats[2]	129		5.67%	0.42%

[1]Acres are calculated directly from areas of GIS polygons and therefore may not match exactly other acreage totals submitted by DEP.

[2]Categories considered inundated aquatic habitats include reservoirs or large lakes, unconsolidated bottom, and riverbeds or streambeds, but exclude uplands and unconsolidated shore. Categories considered wetlands exclude the inundated aquatic habitats classes as well as all upland and unconsolidated shore.

[3]Includes fee, conservation easements, and farm easements. Excludes non-LAP and pre-MOA land.

Outreach

DEP updated and produced the educational pamphlet, "Wetlands in the Watersheds of the New York City Water Supply System". The document was originally produced in 1996 and revised in 2009 to summarize the findings of the most recent NWI update, wetland status and trends analyses, and wetland characterization and functional assessment mapping projects, as well as DEP's wetland monitoring and protection programs. The pamphlet also contains general information on the definition, characteristics, and functions of wetlands, and on regulatory and voluntary wetlands protection methods. DEP distributed the pamphlet to all watershed towns, and continues to distribute it to the general public at various forums.

DEP presented findings of its wetland mapping and research projects at numerous meetings and workshops, including the New York State Wetlands Forum and the Watershed Science and Technical Conference. DEP also reconvened the New York State Interagency Wetlands Group in 2009 and partnered with the Ulster County Cornell Cooperative Extension to provide training to Ashokan Youth Stewards from the Onteora School District.

2.10 Watershed Forestry Program

The Watershed Forestry Program is a partnership between DEP, the Watershed Agricultural Council (WAC), and the USDA Forest Service (USFS) that promotes and supports well-managed working forests as a beneficial land use for watershed protection. WAC utilizes core DEP contract funds to secure multi-year matching grants from the USFS to administer the following major program tasks: (1) forest management planning and stewardship, (2) best management practice (BMP) implementation, (3) logger and forester training, (4) model forest program, (5) forestry education program, and (6) wood products marketing and utilization.

The 2007 FAD requires DEP to continue implementing the Watershed Forestry Program as detailed in the City's 2006 Long-Term Watershed Protection Program and to report annually on program accomplishments. In January 2009, DEP entered into a new contract with WAC to implement the Watershed Forestry Program through October 2012 utilizing a long-term budget plan that combines City and federal funding sources to support all major program tasks.

2.10.1 Forest Management Planning and Stewardship

During the current FAD assessment period, the Watershed Forestry Program continued to provide cost-sharing and technical assistance to private landowners to encourage their adoption of long-term forest management plans written by trained professional foresters. The Program also continued to evaluate the implementation status of five-year-old forest management plans in an effort to better understand landowner behaviors, attitudes, and practices as they relate to forest stewardship. It is important to recognize that the Watershed Forestry Program has been supporting the development of forest management plans since 1997, which means that increasing numbers of plans are reaching their 10-year milestones every year. Although long-term forest management planning remains a fundamental cornerstone of the Watershed Forestry Program, supporting the voluntary implementation of these plans with various stewardship incentives is gradually becoming a greater programmatic focus.

To date, more than 914 landowners have completed forest management plans covering approximately 163,513 watershed acres, of which more than 128,121 acres are estimated forest land. These figures include 74 East of Hudson watershed plans covering 14,524 total acres (11,965 forested acres). Since 2001, riparian planning has continued to be an integral component of the WAC forest management plan specifications, with consulting foresters developing specific forest management recommendations for riparian area protection. To date, 343 riparian plans have been completed covering 10,740 riparian acres. These riparian plans represent 38% of all WAC plans completed to date and 73% of all WAC plans completed from 2006-2010.

Since 2002, DEP and WAC have annually evaluated five-year-old WAC forest management plans to assess their implementation status. This evaluation includes landowner surveys, on-site property visits, and a comprehensive database analysis to assess landowner participation in other stewardship programs. Cumulative results from all 265 landowner surveys completed to date (a 49% response rate) indicate that 91% of respondents still own their land, 86% are satisfied with their plans, 73% have referenced their plans, 82% feel that having a plan has improved their stewardship, and 53% have retained the services of their foresters. Approximately 66% of respondents whose plan recommended forestry activities reported they completed these activities, while approximately 58% of respondents whose plan recommended water quality BMPs reported they implemented the BMPs. For those respondents who conducted a timber sale during the previous five-year period, 88% used a professional forester and 94% used a certified logger. Evaluating the implementation status of forest management plans and better understanding the needs and motivations of private forest landowners will continue to be key programmatic priorities in the future.

Since 2005, the Watershed Forestry Program has supported a new Management Assistance Program (MAP) that is designed to assist watershed landowners with implementing specific practices recommended in their WAC plans. Eligible practices include: timber stand improvement, tree planting, riparian improvements, wildlife improvements, and invasive species control projects. The MAP was originally pilot-tested from 2005-2008 and was successfully expanded in 2009 following submission of a FAD evaluation report in December 2008. To date, 233 MAP projects have been completed by 135 different landowners. These completed MAP projects include: 132 timber stand improvements, 28 tree plantings, 4 riparian improvements, 44 wildlife improvements, and 25 invasive species control projects. The MAP will continue to be a priority of the Watershed Forestry Program in the future.

2.10.2 BMP Implementation

During the current FAD assessment period, the Watershed Forestry Program continued to provide cost sharing, technical assistance, and other incentives to loggers and landowners to promote their implementation of forestry BMPs. Over the years, WAC developed a number of BMP programs to support the installation of portable bridges, the proper construction of new timber harvest roads, the remediation of existing forest roads having erosion problems, and the use of non-traditional erosion control technology such as geotextile fabric. In 2007, the forestry BMP programs were expanded again to include a greater emphasis on stream crossings.

Currently, WAC owns 10 portable bridges and five plastic arch culverts that are available for temporary loan for crossing watershed streams during timber harvests, along with 12 sets of rubber tire land mats that are used to stabilize the approaches to streams. WAC also initiated a new stream-crossing cost-sharing component as part of its forestry road BMP program to ensure that stream crossings needed during or after timber harvest operations are properly planned, designed, and implemented with appropriate BMPs. As part of this new stream crossing initiative, WAC forestry staff now utilize a new BMP Monitoring Protocol that was originally developed by the USFS to assess and evaluate site conditions and water quality impacts both before and after each stream crossing project is completed.

To date, the Watershed Forestry Program has supported the completion of 71 portable bridge projects and 277 road BMP projects, the latter of which includes 19 stream crossings. The 277 road BMP projects can further be characterized as either remediation projects (65 projects, or 23%) or new timber harvest road projects (212 projects, or 77%), depending on whether the forest roads were already present or freshly installed as part of a timber harvest. Given the importance of forestry BMPs to water quality protection, the Watershed Forestry Program will continue to support an active BMP implementation program for loggers, landowners, and foresters.

2.10.3 Logger and Forester Training

During the current FAD assessment period, the Watershed Forestry Program continued to sponsor annual training workshops for private consulting foresters while promoting voluntary participation in the statewide Trained Logger Certification (TLC) program administered by New York Logger Training, Inc. To become fully certified through the TLC program, loggers must complete three courses: forest ecology and silviculture, first aid and CPR, and chainsaw safety. To further recruit and train watershed loggers, the Watershed Forestry Program also sponsors several continuing education courses every year that focus on topics such as invasive species, skidder bridges, hazard trees, and new technology for the field.

Currently, 51 private consulting foresters are trained and approved to write WAC forest management plans for watershed landowners, of which at least half provide services in the East of Hudson watershed. According to the New York Logger Training database, 112 individuals working in the Catskill/Lower Hudson region were fully certified through the TLC program as of December 1, 2010, representing a 187% increase from 2005. It is worth noting that, of the six regions into which New York Logger Training has divided New York State, the Catskill/Lower Hudson region has the second highest number of fully certified loggers, trailing only the Eastern Adirondacks region.

2.10.4 Model Forest Program

During the current FAD assessment period, the Watershed Forestry Program continued to support and coordinate a watershed model forest program that integrates scientific research, practical field demonstrations, forestry education, and public outreach at three unique sites that are geographically distributed throughout the watershed. The Lennox Model Forest is located in Delaware County, the Frost Valley Model Forest is located in Sullivan County, and the recently established Siuslaw Model Forest is located in Greene County. All three model forests are utilized year-round by their respective host organizations and various Watershed Forestry Program partners to conduct education and training programs for landowners, loggers, foresters, school groups, and other target audiences from both the watershed and New York City.

The 2007 FAD requires the Watershed Forestry Program to establish a working model forest in the East of Hudson watershed. Previous efforts to install a model forest at the New York State-owned Nimham Mountain property in Putnam County proved unsuccessful, so for the past few years WAC and DEP have explored alternative East of Hudson sites that potentially align with model forest selection criteria. In 2009, WAC developed a model forest promotional packet that was distributed to more than a dozen East of Hudson environmental education centers and forestry organizations to solicit their interest in hosting a watershed model forest. Three applicants responded, and in March 2010 the Watershed Forestry Program selected Clearpool Environmental Education Camp in Putnam County. After a series of productive meetings with the Clearpool staff and board members, there appears to be significant support from all parties to move forward with a model forest, so the effort is now focused on signing a host agreement and developing a public outreach strategy that cultivates broad community support. Establishing a working model forest at the Clearpool facility will continue to be a priority of the Watershed Forestry Program in the near future.

2.10.5 Forestry Education Program

During the current FAD assessment period, the Watershed Forestry Program continued to support and refine a range of educational programs targeting forest landowners, municipal officials, and urban/rural school-based audiences. Educating landowners in particular about the role and importance of well-managed working forests and engaging these landowners in long-term stewardship activities remains a top priority of the Watershed Forestry Program. Primary topics of interest include riparian buffer protection and management, invasive species control, forest health and sustainability, and forestry economic viability.

In 2009, the Watershed Forestry Program developed a forest landowner education strategy that assessed efforts to date and recommended a framework for moving forward using a targeted and measurable approach. The strategy estimated that the Watershed Forestry Program directly sponsored and/or supported approximately 94 landowner education events during 1997-2009 that were attended by at least 2,430 individuals. Early in the Program's history, many of these events were large indoor conferences and workshops that required substantial investments of staff time and resources to plan and execute. In recent years, the Program has moved towards localized, targeted events that include a field component to reinforce classroom instruction. As per the new landowner education strategy, future forestry events will continue to be localized and targeted, with an increased emphasis on peer-to-peer learning and educating landowners more fully about the need to develop and implement long-term forest management plans.

In terms of school-based educational efforts, the Watershed Forestry Program has devoted significant resources over the past few years towards strengthening and streamlining several complementary programs that are now organized under the programmatic umbrella of WAC's Urban/Rural Education Initiative. As a first step, DEP and WAC incorporated the Catskill Stream and Watershed Education Program—which was previously implemented by DEP's Stream Management Program through a contract with the Catskill Center for Conservation and Development—into the Watershed Forestry Program. Through a single contract with WAC, the Catskill Center now oversees the annual Watershed Forestry Institute for Teachers, Green Connections School Partnership Program, and the Catskill Stream and Watershed Education Program (CSWEP). The complementary Watershed Forestry Bus Tour Program is implemented by a private educational consultant who works closely with the Catskill Center to ensure inter-program synergies through enhanced coordination and collaboration.

Another positive development during the past few years has been the enhanced collaboration between the Watershed Forestry Program, the Catskill Watershed Corporation's Public Education Grants Program, and Trout Unlimited's Trout in the Classroom Program. The annual Trout in the Classroom teacher training workshop has grown into a major watershed event that attracts nearly 200 participants who learn about the full range of watershed education programs available to school-based audiences. In addition, annual student trout releases in the watershed now include an active forestry education field component, and many classrooms now participate in multiple watershed education programs.

2.10.6 Wood Products Marketing and Utilization

During the current FAD assessment period, the Watershed Forestry Program continued to support and implement forestry economic development projects with a focus on strengthening the viability of the wood products industry and promoting the marketing and utilization of local wood products. In general, these types of activities are funded almost exclusively through generous matching grants from the USFS, which utilizes the Watershed Forestry Program as an incubator for projects with regional or national significance. This programmatic partnership is critical to the continued success of the Watershed Forestry Program's efforts to protect water quality and support rural economic viability.

Between 2001 and 2008, WAC distributed more than $2.5 million in USFS Economic Action Program funding via 83 grants to local wood-using businesses. These economic grants were used for new product development, advertising and marketing, staff training, professional development, apprenticeships, new equipment purchases, computer technology upgrades, long-term business plans, facility expansions and improvements, and other activities related to forest products manufacturing and wood utilization. A preliminary evaluation of the Economic Action Program that was completed in 2006 revealed that the USFS grants were critical to the survival and expansion of several major employers in the watershed despite contrary national trends.

In 2007, the Watershed Forestry Program launched the Catskill WoodNet website (www.catskillwoodnet.org) as part of a comprehensive marketing campaign for locally produced wood products. WAC has also sponsored a series of wood marketing workshops and related training sessions during the past few years that were attended by several hundred participants, in addition to promoting Catskill wood products at numerous local, regional, and national expos. More than 80 local businesses are currently members of the Catskill WoodNet marketing campaign, which is closely aligned with the regional "Buy Local" branding efforts of the WAC Pure Catskills campaign for farms, restaurants, farmers markets, and other local food businesses.

More recently, the Watershed Forestry Program has pursued a new forestry economic development project using grant funding provided by the USFS. The project involves a series of pre-feasibility studies to assess the potential for using woody biomass heating technology at several large facilities located throughout the watershed region. This project will be ongoing, as the Watershed Forestry Program explores and supports new initiatives that improve the economic viability of forest land and the wood products industry.

2.11 Education and Outreach

DEP implements the City's Long-term Watershed Protection Strategy through active stakeholder collaboration, broad community outreach, and targeted educational programs for both upstate watershed residents and downstate water consumers. DEP works closely with the Catskill Watershed Corporation (CWC), Cornell Cooperative Extension (CCE), Soil and Water Conservation Districts (SWCDs), the Watershed Agricultural Council (WAC), and numerous other partners to educate constituents and raise public awareness about the water supply system, source water protection, water conservation, and environmental stewardship.

The 2007 FAD requires DEP to report on the educational efforts of the Watershed Agricultural and Forestry Programs, Stream Management Program, and CWC Public Education Program, in addition to other school-based education efforts, general community outreach, and partnerships with regulatory and local government officials. The FAD also requires DEP to collaborate with local municipal officials on education, outreach, and training programs that promote land use planning, stream corridor protection, and stormwater management.

Since 2007, in order to present a more cohesive watershed education and outreach program, DEP has reported on annual education/outreach accomplishments based on the primary audiences targeted by them. In 2009, these audience categories were streamlined into the following categories: (1) New York City water consumers; (2) watershed residents, landowners, and homeowners; (3) school groups and youth audiences; (4) local government officials, professionals, and business groups; and (5) recreational groups and other public audiences.

2.11.1 New York City Water Consumers

During the current assessment period, DEP utilized both its official website (nyc.gov/dep) and nyctapwater.org to provide New York City water consumers and other audiences with a wealth of information about the water supply system, watershed protection, water conservation, and drinking water quality. The official website was begun in 2002 pursuant to a FAD deliverable, and was completely reorganized and re-launched in 2010 (particularly with respect to its watershed protection component) with updated information more easily accessed by website visitors.

Since 2007, DEP has supported an aggressive marketing campaign designed to promote New York City tap water. This campaign includes refillable water bottles, tap water decals and other promotional items, and portable "water-on-the-go" stations that provide official tap water at special events throughout the City. In 2008, DEP joined the Groundswell Community Mural Project to create a four-story mural entitled "Water is the Life of New York City" that stands adjacent to a DEP shaft site in Brooklyn. The mural was featured on the cover of DEP's 2008 New York City Water Supply and Quality Report, which represents one of DEP's most prominent and widely distributed annual publications relating to the water supply system.

Also since 2007, DEP has supported Hydrant Education Action Teams (HEAT) comprised of 60-80 high school and college students who canvass New York City neighborhoods during the summer disseminating information about the effects of illegally-opened fire hydrants on water pressure in the City's distribution system. DEP also developed a pilot Rain Barrel Giveaway Program for homeowners in the Jamaica Bay Watershed (Queens) to promote water conservation and reduce stormwater runoff.

Collaborating with in-City partners is integral to the success of DEP's education and outreach efforts. During the assessment period, DEP collaborated extensively with the Queens Museum of Art (QMA) to complete the restoration of the unique 27-piece watershed relief model and to conduct numerous professional development workshops to educate QMA staff about the City's water supply. DEP also sponsored/supported several water-related exhibitions and/or public lectures throughout the City at locations such as the Museum of the City of New York, American Museum of Natural History, New York Public Library, Brooklyn Public Library, and the Newtown Creek Wastewater Treatment Plant in Brooklyn, where DEP opened a self-guided Nature Walk in 2007 and a Visitor Center in 2010.

Every year, DEP maintains an educational presence at several highly visible Greenmarkets throughout the City to increase public knowledge about the water supply and water conservation. DEP also participated in the following special events held throughout New York City during the assessment period: Farm Aid (2007), World Water Week/NYC Tap Project Water Walk (2008 and 2009), and NYC Winter Jam (2009).

2.11.2 Watershed Residents, Landowners, and Homeowners

Pursuant to the City's Long-Term Watershed Protection Strategy, watershed residents, landowners, and homeowners are generally targeted through specific DEP-supported programs such as the Watershed Agricultural Program, Watershed Forestry Program, Stream Management Program, and various CWC programs. Below is a summary of key education/outreach highlights that were accomplished by these programs during the assessment period.

The Watershed Agricultural Program educates hundreds of farmers each year regarding Whole Farm Plans, nutrient management plans, best management practices, and various agribusiness topics. WAC traditionally partners with Delaware County CCE to conduct a series of farmer education programs such as the annual Catskill Regional Dairy, Livestock, and Grazing Conference; annual Farm to Market Conference; various producer group meetings and farm tours; in-classroom training workshops; and annual farmer recognition events. For more than a decade, the Watershed Agricultural Program has also co-sponsored the annual Clean Sweep Chemical Disposal Day for Delaware County residents, farmers, and small businesses.

The Watershed Forestry Program educates forest landowners in both the Croton and Catskill/Delaware watersheds about sustainable forest management and stewardship, primarily in collaboration with a watershed model forest host organization. Common landowner programs include a multi-part forestry education course (Friday Forestry School); model forest tours and workshops; and various newsletters, brochures, and press/magazine articles. In 2009, WAC developed a Forest Landowner Education Strategy to further guide these activities in the future.

The Stream Management Program educates streamside landowners about water quality and riparian buffer protection, primarily through local partnerships with CCE and SWCDs, but also through public presentations, volunteer planting efforts, watershed advisory committees, and the CatskillStreams.org website, which was launched in 2006 along with a new publication for riparian landowners, "Living Streamside in the Catskill Region". Other highlights include the publication of a newsletter by Ulster CCE (Esopus Creek News), sponsorship of a 2007 "Paint the Stream" community mural project in Phoenicia, installation of a kiosk at the Esopus Creek Demonstration Site in 2008, and the sponsorship of three new annual events: the Batavia Kill Stream Celebration, Schoharie Watershed Summit, and Schoharie Watershed Bus Tour.

During the assessment period, CWC sponsored three homeowner education workshops every year covering septic system maintenance. CWC also informed watershed residents about its various watershed programs and other timely issues through regular press releases, a print newsletter (The Advocate), the CWC website (cwconline.org), and appearances at special events. In 2008, CWC developed and posted on its website a comprehensive packet of information materials concerning oil and gas drilling in the Marcellus Shale, which was intended to serve as an educational resource for interested watershed residents.

In the East of Hudson watershed, DEP worked with Putnam and Westchester municipalities to educate landowners about the pollution impacts from lawn fertilizers, in part through the publication and distribution of more than 25,000 copies of a phosphorus reduction brochure in 2007. DEP also continued to support the Kensico Environmental Enhancement Program (KEEP), which educates Kensico residents about watershed protection issues.

Finally, DEP partnered with the Catskill Institute for the Environment (CIE) in 2007 to sponsor the symposium, "Rural Life in the Catskills: A Forum on Food, Water and Wood for the Future," that attracted more than 100 people. DEP also partnered with CIE during 2009 and 2010 to co-sponsor a series of public lectures at regional colleges that were attended by hundreds of participants. These lectures were organized under the banner "Vision for 2020" and addressed topics such as changing demographics in the Catskills, climate change, and invasive species.

2.11.3 School Groups and Youth Audiences

School-based programs, especially upstate and downstate school partnership programs, represent an important component of DEP's Long-Term Watershed Protection Strategy, in large part because they teach and prepare the next generation of water consumers and watershed residents to be good stewards of the New York City water supply. During the assessment period, DEP continued to support and implement a number of school-based educational programs while exploring new initiatives and strengthening collaborations.

In 2006, DEP facilitated the creation of a Watershed Environmental Education Alliance (WEEA) comprised of more than 40 environmental education centers, organizations, and agencies that develop, support, and implement school-based education programs relating to the New York City water supply system. With DEP support, WEEA developed a comprehensive watershed field trip guide ("New York City Watershed Environmental Education Resource Directory") for school teachers and educators that was published in 2007, updated in 2008, and is currently posted on the official DEP website and numerous partner agency websites.

In 2007, DEP joined the Stroud Water Research Center, Catskill Center, Riverkeeper, Catskill Mountainkeeper, New York Harbor School, Sidney Central School, CWC, WAC, and other partners to plan and execute the first-ever "Mountaintop to Tap" Watershed Trek for six New York City students and six watershed students. During the course of three weeks in July, these 12 students followed the path of the New York City water supply from Belleayre Mountain to Central Park using as little motorized transportation as possible. The students hiked, camped, floated down Esopus Creek on tubes, rowed down the Hudson River in wooden boats, conducted water quality monitoring experiments, and participated in outdoor interpretive education activities taught by local professionals and community leaders. The entire trek was filmed by a documentary camera crew and a 35-minute film was produced using CWC public education funds. A traveling exhibit comprised of student art work, photographs, and journal entries was displayed in New York City and the watershed during 2008-2009.

Within New York City, DEP sponsors the annual Water Conservation Art and Poetry Contest, which involves hundreds of fourth, fifth, and sixth grade students from all five boroughs and attracts more than 900 people to the annual awards ceremony. Throughout the school year, DEP conducts numerous classroom presentations; participates in the Science Council of New York City (SCONYC) annual teacher conference, annual Environmental Expo, and Operation Explore; coordinates in-City school field trips to water-related places such as the Staten Island Bluebelt, High Bridge, Central Park Reservoir, Old Croton Aqueduct, and Newtown Creek; and collaborates with dozens of in-City partners to conduct professional development programs for school teachers and environmental educators. Examples of key DEP partners include the Department of Education, Bronx River Alliance, Intrepid Museum, South Street Seaport Museum, Council on the Environment, New York Hall of Science, New York Public Art Fund, Environmental Education Advisory Council, and New York City ReLeaf.

DEP continues to host and supervise the New York City coordinator of the Trout Unlimited Trout in the Classroom education program that has grown in both size and scope over the past several years. In 2009, approximately 220 schools in New York City and the Catskill/Delaware and Croton watersheds participated in the Trout in the Classroom Program, which represents a nearly 40% increase since 2006. The annual Trout in the Classroom workshop held every October routinely attracts nearly 200 school teachers.

Pursuant to the 2007 FAD, the CWC Public Education Grants Program funds watershed education projects for both New York City and West of Hudson watershed audiences. During the period 2006-2010, CWC awarded 144 education grants totaling $734,377. To date, CWC has awarded more than 340 grants totaling over $1.7 million. Many of these grants support school-based education programs. In 2007, CWC compiled and distributed a packet of watershed educational materials to more than 60 teachers from New York City and West of Hudson watershed schools. These packets included CDs, DVDs, books, teacher guides, and other education materials produced over the years using CWC public education funds.

During the assessment period, the Watershed Forestry Program continued to implement a comprehensive urban/rural school-based education program that traditionally includes the annual Watershed Forestry Institute for Teachers (20 teachers per year), Green Connections School Partnership Program (about six schools per year), and the Watershed Forestry Bus Tour Program (about 20 bus tours per year). In 2008, DEP and WAC agreed to integrate the Catskill Stream and Watershed Education Program (CSWEP) into the school-based efforts of the Watershed Forestry Program in order to achieve greater efficiencies. CSWEP was previously funded and implemented through DEP's Stream Management Program in collaboration with the Catskill Center, which for the past few years has also implemented the Watershed Forestry Institute for Teachers and Green Connections Program.

2.11.4 Local Government Officials, Professionals, and Business Groups

Pursuant to the 2007 FAD, DEP works with local officials through collaborative education and training opportunities that promote land use planning, stream corridor protection, and stormwater management. One prominent venue for reaching this audience is the annual Watershed Science and Technical Conference that is organized and sponsored by the Watershed Protection and Partnership Council, New York Water Environment Association, DEP, WAC, CWC, US Geological Survey, and the NYS Departments of State, Health, and Environmental Conservation. Another prominent venue is the annual Catskills Local Government Day, which is organized and sponsored by the CWC and attracts over 100 participants every year.

In 2007, DEP and CWC collaborated with other partners to sponsor a 10-year anniversary dinner to commemorate the signing of the New York City Watershed Memorandum of Agreement. Approximately 80 people attended this event, primarily local government officials and watershed community leaders. In tandem with this milestone, CWC produced a video ("Of Streams and Dreams") which highlights its history and programs. Approximately 800 DVDs were produced and distributed to watershed municipalities and other partners.

Since 2007, DEP's Stream Management Program has partnered with the CWC and Greene County SWCD to sponsor the annual Schoharie Watershed Summit that attracts more than 120 highway department employees, planning board members, and other municipal leaders each year. Training topics have included stream and stormwater management, septic systems, wetland protection and regulations, floodplain mapping, and land use planning. DEP's Stream Management Program also works closely with basin-level project advisory committees composed of municipal officials, technical professionals, and other local representatives, regarding the adoption and implementation of stream management plans. Through these collaborations, DEP supports numerous municipal training programs covering topics such as the Shandaken SPDES permit, culvert management, erosion and sedimentation control, post-flood emergency stream restoration work, and applied river morphology.

The Watershed Forestry Program educates local officials and other municipal audiences about the importance of well-managed working forests, especially in the East of Hudson watershed where local ordinances may conflict with forest management. Since 2006, DEP has facilitated increased collaboration between WAC, New York ReLeaf, and the New York State Urban and Community Forestry Council to sponsor and support a series of urban forestry workshops and conferences that attract hundreds of local officials and citizen volunteer groups. In 2007, WAC initiated a forestry training program for East of Hudson municipal officials which resulted in nearly a dozen presentations for town planning boards. Finally, every year both WAC and DEP participate in New York State Forestry Awareness Day in Albany, which educates more than a hundred local officials and state legislators about forestry issues.

Since at least 2006, DEP has participated in both the Catskill Regional Invasive Species Partnership (CRISP) and the Lower Hudson Partnership for Regional Invasive Species Management (PRISM) along with numerous local, state, and federal partners. Through these partnerships, DEP has supported a series of training and outreach activities for agency officials and forestry professionals, in addition to working with The Nature Conservancy to coordinate survey and outreach efforts at more than a dozen private campgrounds in the Catskill region.

During the assessment period, DEP has also reached out to multiple stakeholders—including realtors, land trusts, landowner associations, and local officials—to educate them about the Land Acquisition Program and watershed conservation easements. Highlights include the New York State Land Trust Rally and National Land Trust Rally (both sponsored by the Land Trust Alliance), the Ulster County Land Trust Conference, the Northeast Land Trust Rally, and numerous local roundtables and educational workshops held throughout the watershed.

Finally, the Watershed Agricultural Program continues to promote a "buy local" food campaign through the Pure Catskills marketing website (buypurecatskills.com) and "Guide to Farm Fresh Products" (over 30,000 copies printed annually), while the Watershed Forestry Program promotes local wood products through the Catskill WoodNet marketing website (catskillwoodnet.org). These campaigns collectively boast more than 400 member businesses.

2.11.5 Recreational Groups and Other Public Audiences

Given that numerous City-owned watershed properties are open for recreation, there is a need to educate and inform watershed recreationalists and other public audiences about DEP's watershed recreation rules and natural resource programs. Over the years, DEP has conducted interpretive hikes, tree and wetland planting projects, reservoir clean-up projects, fishing demonstrations, and other activities on City-owned lands. In 2009, DEP converted its "Watershed Recreation" newsletter into an online publication, updated the Recreational Rules booklet and "Wetlands in the Watershed of the New York City Water Supply System" booklet, and worked with Delaware County to develop a new brochure to promote the Cannonsville Reservoir Recreational Boating Pilot Program.

Finally, every year DEP participates in dozens of community outreach events throughout the watershed where thousands of people receive information. Highlights include: Bedford Environmental Summit, Chappaqua Community Day, Cobleskill Sunshine Fair, Delaware County Fair, FOL-DE-ROL Fair, Grahamsville Little World's Fair, Great Swamp Celebration, Greene County Environmental Awareness Day, Hudson River Day, Hunter Mountain Culture Festival, Lewisboro Library Fair, Mahopac Street Festival, Margaretville Cauliflower Festival, Muscoot Fair, Putnam County 4-H Fair, Rondout Valley Job Fair, Teatown Eagle Fest, Teatown Lake Fall Festival, Ulster County Fair, Ulster County Environmental Awareness Day, Westchester County 4-H Fair, Westchester Earth Day, World Fishing and Outdoor Expo, Woodstock "Go Green" Day, Yorktown Community Day, and Yorktown Grange Fair.

2.12 Regulatory Review and Enforcement

The most recent revisions to the Rules and Regulations for the Protection from Contamination, Degradation, and Pollution of the New York City Water Supply and its Sources (Watershed Rules & Regulations (WR&R)) became effective on April 4, 2010. These most recent revisions to the WR&R reflect changes in federal and state law since 1997 and address issues that have arisen during administration and enforcement of the WR&R over the past 11 years. These changes include:

- Stormwater plans. Revisions to incorporate the New York State Department of Environmental Conservation (DEC) SPDES General Permit for Stormwater Discharges from Construction Activity, Permit No. GP-0-10-001. The WR&R also continue to require the water quality protection standards that DEP has determined are appropriate for stormwater pollution prevention plans in the watershed.
- Variance within 60-day travel time. New provision authorizing DEP to grant a variance for a new or expanded surface-discharging wastewater treatment plant (WWTP) within the 60-day travel time, in the Croton System only, under specific, limited circumstances.
- Phosphorus-restricted basins. Revision to the definition of "Phosphorus-restricted basin" to incorporate, with respect to basins of source water reservoirs only, a phosphorus concentration standard of 15 $\mu g\ L^{-1}$, consistent with the Phase II Total Maximum Daily Loads for Phosphorus for New York City's Drinking Water Reservoirs proposed by DEC and approved by EPA.
- In addition, the proposed amendments include more recent versions of publications cited in the WR&R, updating certain technical terminology and modifying or changing the order of certain text to improve clarity and intelligibility.

The control of sewage collection and treatment, stormwater discharges, impervious surfaces, and erosion and sediment practices continue to form the major components of DEP's regulatory program. In general, the WR&R require that applicants sponsoring projects that involve such a regulated activity meet stringent standards, and obtain DEP review and approval of that activity. In addition, DEP enforces applicable environmental regulations including the federal Clean Water Act, the NYS Environmental Conservation Law, the NYS Public Health Law, and the NYS Environmental Quality Review Act (SEQRA), among others. DEP's regulatory efforts are focused on three major areas: review and approval of projects within the watershed, regulatory compliance and inspection, and environmental enforcement.

Since DEP has specific review and approval authority granted by state law, it is considered an "Involved Agency" under SEQRA for projects where DEP approval is required, and must review and issue findings statements regarding projects that have potential environmental impacts in the watershed. A special SEQRA Division has been created within DEP to consolidate and track SEQRA activities within the watershed.

2.12.1 Project Review

Each project proposed in the watershed is reviewed by DEP to ensure compliance with the WR&R, as well as federal, state, and local laws. Projects that require DEP review and approval include all WWTPs, subsurface sewage treatment systems (SSTSs), sewer connections exceeding certain flow criteria (SCs), preparation of specific stormwater pollution prevention plans (SPPPs), and the construction of certain impervious surfaces. In addition, DEP reviews and issues permits or approvals for individual residential stormwater plans (IRSPs) and for impervious surfaces associated with stream crossings, piping, or diversions (CPDPs). DEP also ensures that during and after construction, projects that require SPPPs or IRSPs install and maintain adequate sediment and erosion controls and include the necessary post-construction Stormwater Management Practices (SMPs). DEP also reviews applications that have been sent to DEC for special permits involving mining operations, timber harvesting, stream crossings, and wetland activity. These applications are forwarded to DEP for review and comment as provided for in the DEP/DEC Memorandum of Understanding.

In March 2007, DEP rolled out a new organizational structure for the Bureau of Water Supply. These organizational changes modified the duties of some Regulatory Review staff, such as increasing the number of supervisors while reducing the number of direct report staff. These changes allowed for consistency between DEP offices and regions for regulatory reviews.

During 2008, Westchester County Department of Health and DEP revised the existing 2005 Delegation Agreement to include the review and approval of remediated SSTSs. The Westchester County Delegation Agreement is consistent with the Putnam County Delegation Agreement for the review and approval of remediated septic systems. The only other county delegation agreement is Ulster County for the review and approval of new SSTSs.

In 2009, DEP introduced a new, more extensive database that is particularly useful in creating reports, analyzing data, copying files, storing information, and, with its GIS component, locating projects in the watersheds and allowing staff to create site maps for initial site visits and evaluate soils data on nearby projects. The GIS layer provides a location for all regulatory projects reviewed by DEP.

Since the promulgation of the WR&R in 1997, DEP has seen several trends in the number and type of applications received.[1] Since a peak in 1999, the number of new SSTS applications East of Hudson has been declining steadily. West of Hudson, the numbers increased until 2005 and have declined steadily since then (Figure 2.17). Conversely, SSTS remediation applications have been increasing since 2001 West of Hudson, after a sharp decline between 1998 and 2001. East of Hudson, the numbers of SSTS remediations were relatively few and steady until 2005; since then, however, they have been trending upward (Figure 2.18). This is because, in 2005, the Putnam County Delegation Agreement was modified to include the review of remediated septic systems, and in 2008, the Westchester County Delegation Agreement was revised for the same purpose. As a result, the numbers of SSTS remediation applications is expected to remain higher than pre-2007 numbers (Figure 2.18). The numbers of SSTS remediation applications West of Hudson is also expected to trend upward due to the existence of the Catskill Watershed Corporation Septic Repair Program.

1. To be able to properly show the trends in the number of applications reviewed by DEP, the total number of applications received in the entire NYC watershed is included, not just the basins regulated by the FAD (Ashokan, Boyd Corners, Cannonsville, Cross River, Croton Falls, Kensico, Neversink, Pepacton, Rondout, Schoharie, West Branch).

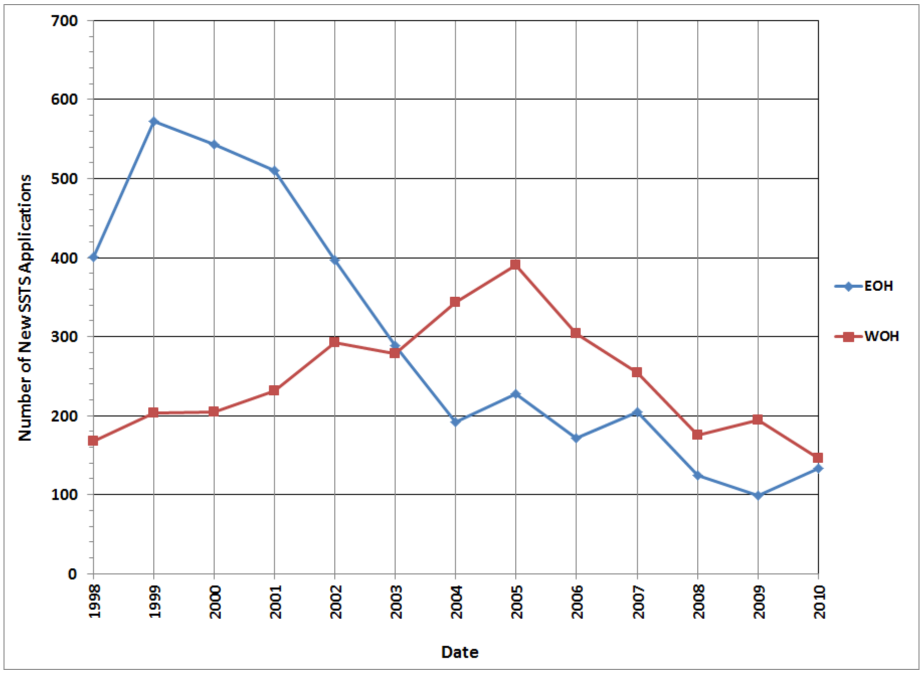

Figure 2.17 Total new septic applications received in the NYC watershed since the WR&R became effective (1997).

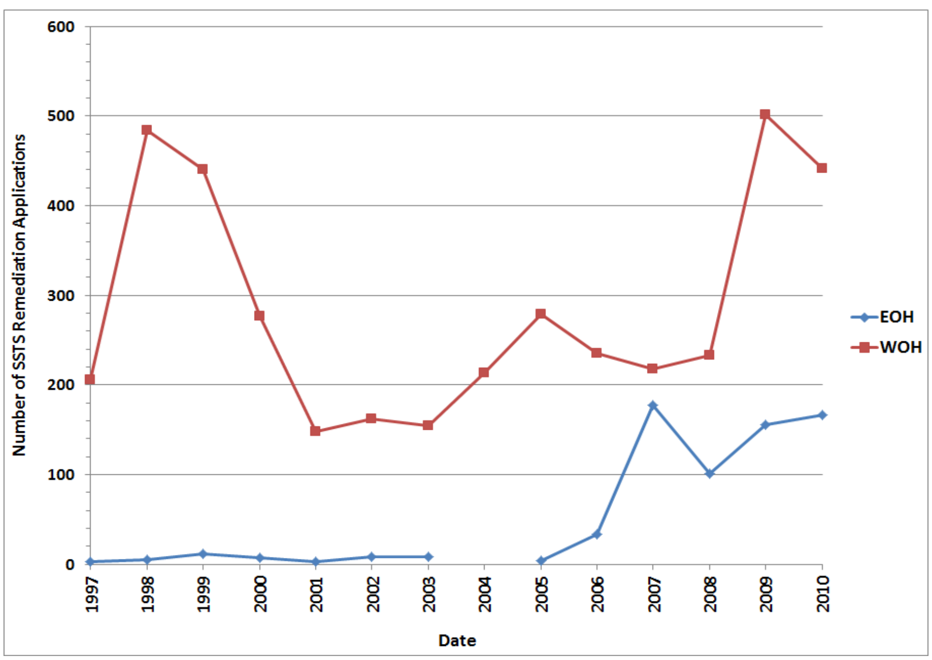

Figure 2.18 Total septic remediation applications received in the NYC watershed since the WR&R became effective (1997).

For New SPPP applications, the East of Hudson numbers have remained relatively steady, with a fluctuation of 10-15% or less from year to year since 1998 (Figure 2.19). The one exception occurred during 2007 and 2008, when the numbers declined nearly 30% per year. This was followed by a 66% increase in 2009 and a large 30+% decrease in 2010. New SPPP applications West of Hudson can be described as a slow, steady upward trend since 1997, with large decreases in 2007 followed by an increase in 2008 and a large increase in 2009. The sharp drop in 2010 may be related to the slowdown in the housing market and the economy which occurred during that time.

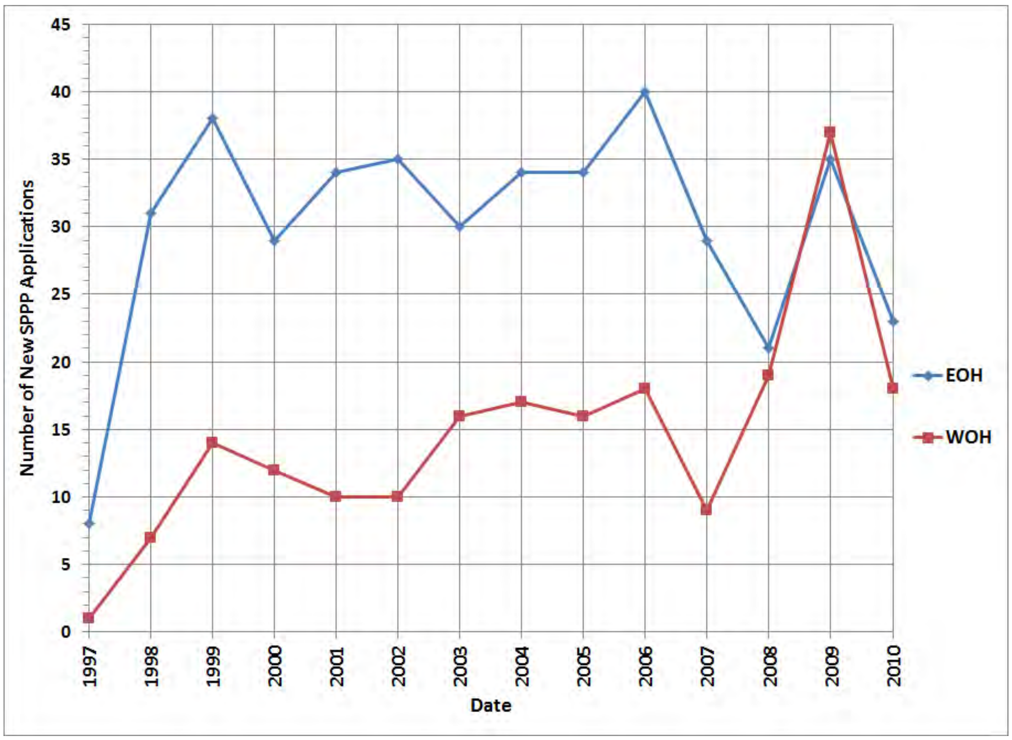

Figure 2.19 Total stormwater pollution plan applications received in the NYC watershed since the WR&R became effective (1997).

Specific data regarding applications received for regulated activities is available in the Quarterly and Annual FAD Reports submitted by DEP.

2.12.2 Regulatory Compliance and Inspection

At each surface-discharging WWTP that operates on a year-round basis, DEP conducts one inspection during each calendar quarter. At a minimum, two inspections per year are conducted at seasonal surface-discharging facilities during the facility's operating season. 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.

Including New Infrastructure Program facilities, there are, within the FAD basins, 36 WWTPs West of Hudson and 9 WWTPs East of Hudson that are inspected on a regular schedule. In addition to regular inspections, DEP conducts follow-up inspections when necessary. If it is determined at the initial inspection 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. If chronic violations of SPDES parameters are occurring, DEP, in conjunction with DEC and local health departments, will issue a Notice of Violation and will 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 (WECC) meetings with DEC.

WWTPs in the watershed continue to show improvement in complying with their SPDES permits, due in large part to DEP's Compliance and Inspection Program (CIP). Many facilities have been remediated or have made improvements to reduce the risks of non-compliant discharges. These have been initiated by DEP through the inspection program and/or by DEC in cooperation with DEP. Additionally, many problematic and outdated facilities which exceeded their permits on a regular basis have been connected to another upgraded facility, upgraded as a stand-alone facility, converted to subsurface discharge, or totally abandoned. As a result, the number of failing WWTPs has decreased greatly.

One example of enforcement involved a compliance conference held in November 2006 for the Oorah Catskill Retreat WWTP (SPDES# NY - 0069957), which is a summer camp. Although this facility was upgraded in 2006, it was plagued by excessive hydraulic loads due to expanded usage in subsequent years. The existing SPDES permit was for 9,200 gallons per day (gpd). Between 2006 and 2008, the facility received sewage flows around 18,000 gpd during the camp season. An executed DEC Consent Order was issued on July 12, 2007. Between November 2008 and May 2009, the WWTP underwent a complete SEQRA review to expand its sewage flow from 9,200 gpd to 18,000 gpd. The facility received a SPDES permit modification from DEC to operate during the 2009 season with an interim flow limitation of 15,000 gpd while SEQRA was completed and modifications were made to expand the facility's capacity to 18,000 gpd. During the 2009 camp season, the WWTP received approximately 21,000 gpd of sewage. In order to avoid any violations related to excess flow beyond the 15,000 gpd interim SPDES permit flow limit, the facility instituted a pump and haul procedure to remove approximately 6,000 gpd of raw wastewater from the facility's septic tanks. On December 9, 2009, DEP issued an approval to install an additional continuous microfiltration unit, an additional ultraviolet disinfection chamber, and three pressurized sand filters. These improvements satisfied the requirements to expand the WWTP to the new SPDES final effluent flow limitation of 18,000 gpd. Installation of the upgraded components was completed prior to the start of the 2010 camp season.

In October 2009, DEP also discovered a failed SSTS at the Oorah facility—not connected to the Oorah WWTP—that received wastewater from a staff housing complex. DEC held a Compliance Conference for the SSTS in November 2009. Because the WWTP at the facility was already exceeding its flow limits, the schedule of compliance indicated that the facility must investigate and determine if the failed SSTS could be remediated in accordance with current codes and standards. On May 21, 2010, the SSTS was approved and construction has since been completed and accepted by DEP.

In another example demonstrating the benefits of the CIP, a sewage overflow was discovered on April 20, 2010, at the Crystal Pond Lift Station in the Town of Windham. When the lift station pumps were energized, air bubbles and more sewage surfaced, confirming that the source was a force main leak. There was a large area of dried sewage around the pool, implying this condition may have existed for some time. Several additional problems were observed at the time of the inspection, including sinkholes roughly 8' deep where the old WWTP equipment and buildings were recently decommissioned; unsecured control panels, main breakers, and disconnects; and the fact that the rear door of the building was wide open. The owners and all relevant regulatory agencies were notified of the discovery. The facility contractor, who was originally charged with the task of constructing the lift station, returned to make all necessary repairs to minimize the impact of this event. DEC initiated an Order on Consent requiring the facility to submit a long-term operating plan establishing inspection procedures, site security, contact list and notification procedures, and alarm testing. The order was executed, with payable fines submitted to DEC on July 23, 2010. The facility now employs a local wastewater treatment operating company to oversee the station.

In addition to its rigorous inspection program, DEP coordinates enforcement activities with DEC through the quarterly WECC meetings. At these meetings the status of watershed WWTPs is discussed, and steps are taken to ensure that adequate enforcement activities are pursued to achieve compliance. Staff members from EPA, the New York State Department of Health, and the Attorney General's Office also participate in the WECC.

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

2.13 Kensico Water Quality Control Program

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

Kensico basin. By doing so, DEP ensures the continued success of past protection efforts while promoting the development of new source water protection initiatives.

2.13.1 Stormwater Management and Erosion Abatement Facilities

Best Management Practice (BMP) Construction, Operation, and Maintenance

In the early 1990s, DEP developed a Stormwater Management Program for the Kensico basin that was based upon an evaluation of watershed conditions, including:

- Subbasin-level digital mapping of key parameters, including topography, soils, land use, natural resources, and impervious surfaces;
- Monitoring and modeling stream quality and hydrology;
- Ranking potential sites and retrofit types using selection criteria that included opportunities to minimize adverse environmental impacts, maintenance requirements, suitability of existing conditions (soils, hydrology, topography, and property ownership), conforming to physical and property ownership site constraints, ensuring public benefit, and maximizing measurable water quality benefits.

The evaluation concluded that stormwater loads of fecal coliform bacteria and turbidity delivered to Kensico Reservoir could be reduced by installing a series of stormwater management and erosion abatement facilities. Forty-five such facilities were subsequently constructed based on that evaluation (Figure 2.20).

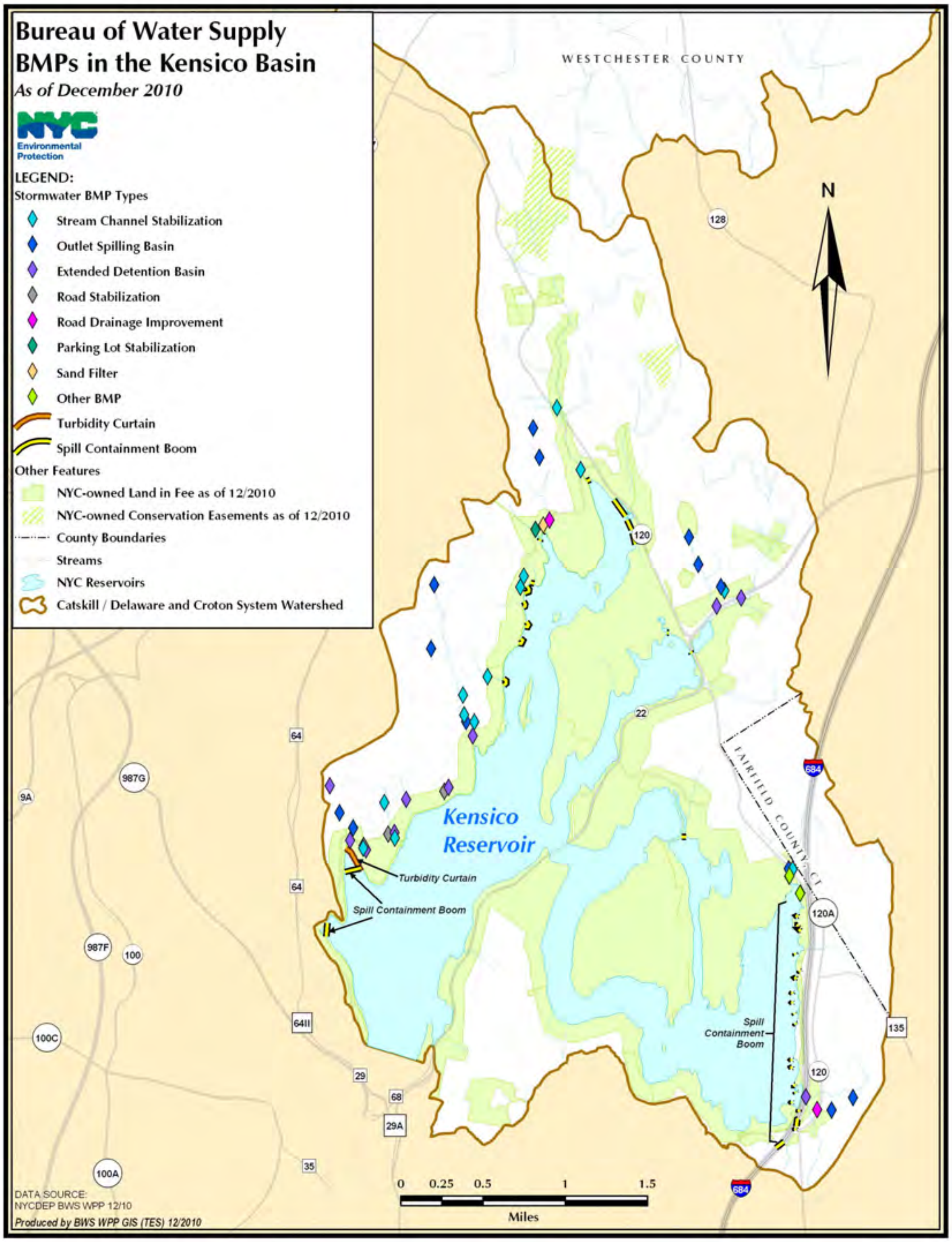

Figure 2.20 BMPs in the Kensico basin as of December 2010.

The facilities are routinely inspected and maintained as needed throughout the year. Maintenance and inspections are completed in accordance with the Operation and Maintenance

Guidelines (DEP 2000, revised 2003). Maintenance under these guidelines is performed by a contractor through renewal of a three-year operation and maintenance contract.

Repairs and maintenance activities during 2006-2010 consisted of erosion repair; access road repair; fence repair; grass cutting; removal and disposal of dead trees and unwanted vegetation; cleaning out catch basins; removal and disposal of sediment from forebays, main basins, and upstream from weirs; road stabilization and erosion or washout repair; adding stone and reshaping roads; and log check dam repair.

To ensure the facilities are inspected and maintained properly, DEP commissioned the development of a unique computer software application. This Computer Assisted Facilities Management (CAFM) application uses a GIS interface to integrate internal GIS and facility data. The program displays the pertinent infrastructure such as stormwater and erosion abatement facilities, stormwater and sanitary infrastructure, and spill containment facilities, as well as land features such as streams, aerial imagery, and parcel boundaries.

BMP Monitoring

In 2010, in fulfillment of a FAD requirement, DEP reported on the findings of the stormwater BMP monitoring program. DEP conducted sampling at selected Kensico BMPs from 2000 to 2007. The goal of the monitoring was to quantify the fecal coliform, total suspended solids, and total phosphorus load reductions that could be attributed to four extended detention basins and one sand filter constructed within Kensico catchments. The five BMPs selected for the study were BMP 12, BMP 13, BMP 37, BMP 57, and BMP 74.

The results of the study suggest that BMPs provide a reduction in total suspended sediment, turbidity, fecal coliform, and total phosphorus load, and hence provide an improvement to water quality compared to what would be observed were BMPs not present. The BMPs were not specifically designed to remove fecal coliforms because it had been assumed that removal of suspended solids would result in a reduction in fecal coliform concentrations. Nevertheless, the loading results do indicate some degree of reduction, depending on initial load, size, and intensity of the storm, provided it is a storm within the design of the BMP.

Spill Containment Facilities

DEP installed and now maintains spill containment facilities around Kensico Reservoir (Figure 2.20). The facilities improve spill response, cleanup, and recovery, thereby minimizing water quality impacts in the event of a spill. During the current assessment period, DEP continued to maintain the 38 spill containment facilities installed at the outlets of 26 storm drains along I-684 and Route 120.

Although no spills have been reported on I-684 or the roads surrounding Kensico since the spill containment facilities were installed, the facilities have functioned as designed. DEP has also located temporary spill containment booms at the end of the boat ramp that can encircle the ramp in the event of a spill. No spills or discharges have occurred at the ramp, nor has boom deployment been required.

Turbidity Curtain

Since its installation in 1995, the turbidity curtain between the Catskill Upper Effluent Chamber and Malcolm and Young Brooks has effectively deflected discharges from the two watercourses away from the effluent chamber. The turbidity curtain has been expanded twice since the original installation to improve the functionality of the flow deflection, and is now 1,100 feet long.

Along with the existing 1,100-foot-long turbidity curtain, a new 1,000-foot-long turbidity curtain was installed as a backup in August 2009. This primary and secondary turbidity curtain system has effectively deflected discharges from the two watercourses away from the effluent chamber.

One to two dive inspections were performed each year from 2006 to 2010 by DEP to monitor the extended turbidity curtain. The following maintenance work was completed based on the dive inspections:

- All underwater curtain sections of the primary turbidity curtain that had been secured with plastic ties were replaced with stainless steel ties.
- All anchor connections were secured with stainless steel chain.
- All curtain tears were patched with stainless steel nuts, bolts, and rubber washers.
- The first 11 curtain sections were replaced in November 2009 and the remaining 10 sections were replaced in June 2010.

2.13.2 Kensico Remediation Programs

Kensico Action Plan

Kensico Action Plan Development

In early 2006, DEP initiated development of the Kensico Action Plan in an effort to build on the successful watershed management and protection strategies already existing within the Kensico basin. DEP submitted the final Kensico Action Plan in August 2007. Key steps taken to develop the Kensico Action Plan include:

- Completion of a user friendly library of data and background material on the development of the Kensico Reservoir BMPs;
- Delineation and re-mapping of the Kensico watershed using the most recently available photogrammetric base maps;
- Modeling the Kensico catchments, using the most recent GIS data and sub-basin mapping. This modeling exercise estimated the relative volumes, rates, and quality of stormwater discharging from the various Kensico sub-basins;

- Completion of a review of the results of the sanitary sewer mapping and video infrastructure inspection program;
- Preparation of four stormwater remediation plans;
- Completion of three water quality risk assessments;
- Assessment of the sediment accumulations in the approach channels to Shaft 18 and CAT-UEC.

The four stormwater remediation plans consisted of the following proposals:

1. 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. The construction of catch basins to intercept this flow and redirect it to BMP 13 was proposed to enhance the performance of both basins.
2. Pipeline system for N7 sub-basin. A riprap-lined channel in the N7 catchment area receives flow from upgradient impervious surfaces and is not properly stabilized. Stream velocities, compounded by the steepness of the slope, have contributed to the erosion of this channel. The proposed project would pipe portions of this channel in order to reduce erosive velocities, restabilize the area above the pipe, and install centrifugal sediment traps at the base of the slope.
3. Extended detention basin for the N12 sub-basin. The construction of an extended detention basin in this catchment was proposed to treat stormwater runoff. The extended detention basin will be constructed off-line, allowing baseflows from the stream to by-pass the structure. Only stormwater runoff will be treated by this design.
4. Whippoorwill Creek stream stabilization. Several areas of the Whippoorwill Creek stream corridor were identified where streambank erosion contributed to the sediment load to Kensico Reservoir. Several tools were proposed to re-direct streamflow away from these banks, forcing the stream energy to the center of the stream. This design is expected to reduce the sediment load to Kensico Reservoir without the construction of a large-scale basin.

The three water quality risk assessments consisted of the following:

1. Westchester County Airport. This review assessed the water quality risks to the reservoir associated with the operation of the Westchester County Airport. The report found that the airport had previously re-plumbed stormwater from airport surfaces so that it would be discharged outside of the Kensico Reservoir watershed. In addition, fuel and de-icing storage facilities are located outside of the Kensico watershed. The report found that the airport's compliance programs are adequate to ensure that releases of petroleum and hazardous materials from the airport will be addressed properly.
2. Swiss Re Corporate Park. Swiss Re is one of the largest commercial office parks within the Kensico Reservoir watershed. A review of the Swiss Re property found no chemical transport from the property to Kensico Reservoir. In fact, several environmental initiatives have been implemented by the facility, including the elimination of "non-green" cleaning agents, non-organic fertilizers, and all herbicides.
3. Turf management chemicals in the N5 sub-basin. Previous DEP water quality data found that the N5 sub-basin had detectable levels of common herbicides in runoff. A risk assessment

was conducted to determine the source and risk associated with these chemicals. The assessment included the development and implementation of a survey to homeowners and landscapers in the area. Data from this survey were used to quantify chemical treatment within the watershed. These data were then applied to a model to evaluate potential herbicide loading and its impact on water quality within Kensico Reservoir. The modeling work found that less than 0.1% of the applied herbicides are transported to Kensico Reservoir, and the observed concentrations are well below federal water quality criteria.

The Kensico Action Plan also included an evaluation of the potential need for further effluent chamber dredging following removal of sediment from the intake channels at the Catskill Upper Effluent Chamber (CATUEC) and Shaft 18 in May 1999. Based on the results of the sub-bottom profiling, DEP determined there was no need to dredge the channel into Shaft 18 or CATUEC.

Kensico Action Plan Implementation

Following completion of the Kensico Action Plan in August 2007, DEP evaluated the four proposed stormwater remediation practices and determined, in December 2007, to implement them all.

Since completion of the Kensico Action Plan, DEP has completed design and prepared the necessary bid specifications for the stormwater remediation practices. The first bid opening occurred in January 2009, but the project needed to be re-bid due to inadequate bids. DEP re-bid the four projects in April 2009 and selected a contractor. The selected contractor withdrew his bid in July 2009. DEP bid the contract again in August 2010 and anticipates awarding the contract for construction in early 2011.

DEP secured all the necessary town permits in 2009. Applications for Army Corps of Engineers permits were submitted in October 2009, but those permits have yet to be issued. Approval of these permits will complete the permitting process.

West Lake Sewer Trunk Line

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 Westchester County to mitigate risks posed by the line while maintaining the collection system's location and gravity flow.

Sanitary Sewer Remote Monitoring System

DEP has proposed a sanitary sewer remote monitoring system for the West Lake Sewer Trunk Line, the purpose of which would be to provide real-time detection of conditions associated with changes in water levels in the collection system which would indicate problems such as leaks, system breaks, overflows, blockages and power outages. This, in turn, would facilitate a quick response to such problems. During the assessment period, DEP, the WCDEF Director of Maintenance, and Westchester County legal counsel established a project scope of work and a draft inter-municipal agreement (IMA). The IMA contains language that requires WCDEF to provide the contracting services for installation, monitoring, and maintenance of the remote monitoring system. The IMA also establishes a procurement process to reimburse Westchester County for capital expenses and ongoing maintenance costs for the remote monitoring system.

Sewer Line Visual Inspection

DEP conducts an annual visual inspection of the trunk line to assess the condition of exposed infrastructure, including manholes, for irregularities. The full inspection was performed annually during the assessment period. Partial inspections were conducted throughout the year in association with ongoing routine maintenance of Kensico stormwater BMPs in the vicinity of the line. No defects or abnormalities were noted.

Video Inspection of Sanitary Sewers

DEP established a program under which select portions of the sanitary sewer system located within the Kensico basin could be inspected on a recurrent basis. The effort will be completed under the same contract as was entered into for the inspection and cleaning of the sanitary infrastructure contained within the EOH Cat/Del reservoir basins. The targeted area—a 2,000-foot section of the sewer system in the Town of Harrison—was identified during the prior video inspection of sanitary infrastructure in the Kensico basin. DEP notified the Town of Harrison of these concerns. DEP re-inspected the 2,000 feet of sewer main in 2010 and will have the results in early 2011. DEP will inform the Town of Harrison if there are any further concerns, so the Town can perform any necessary repairs to its sewer system.

Septic Repair 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 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 in three priority phases, with those properties located closest to Kensico Reservoir and watercourses given higher priority (Figure 2.21).

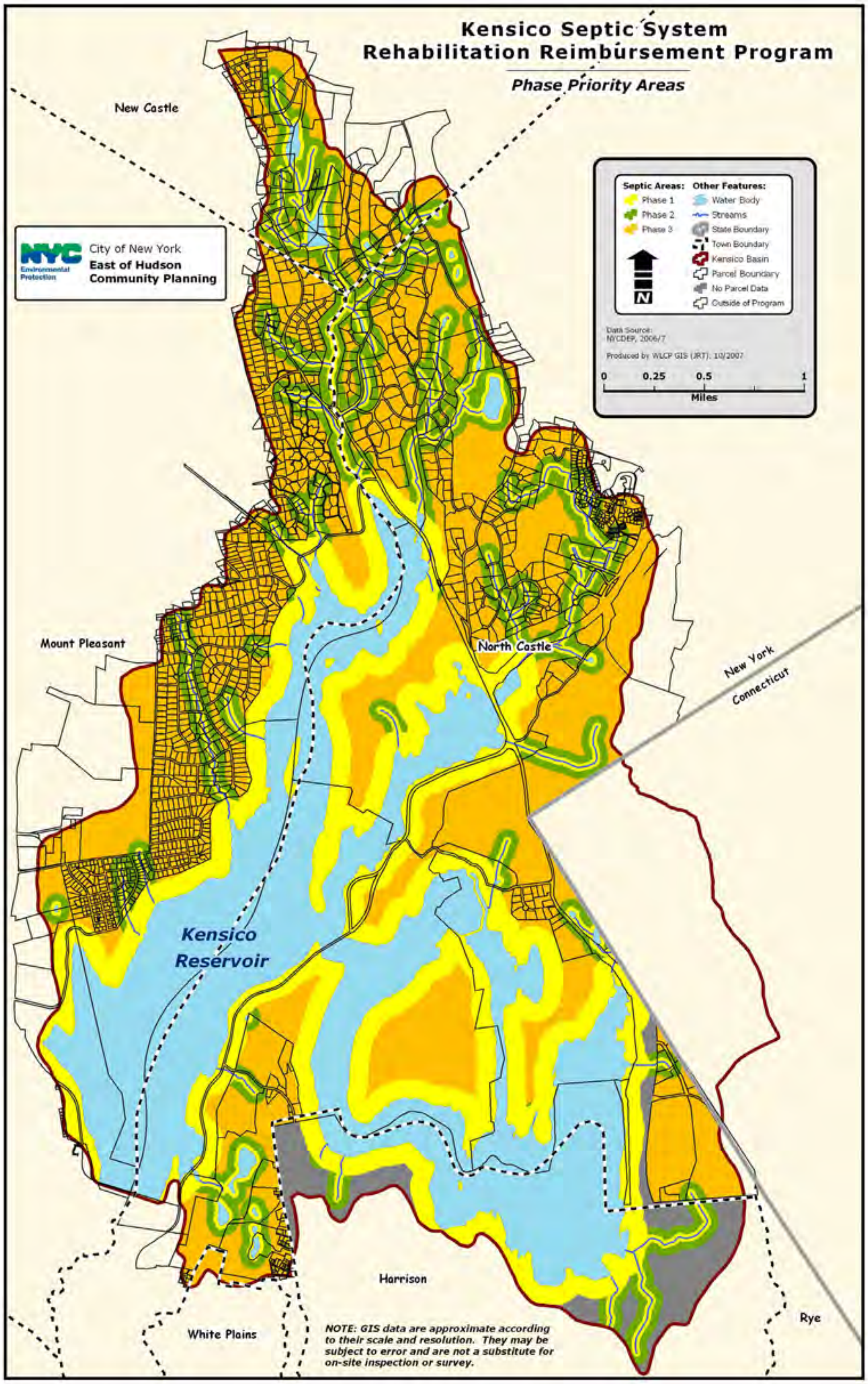

Figure 2.21 Kensico Septic System Rehabilitation Reimbursement Program.

In 2007, DEP drafted the program's terms and conditions, which were modeled on the septic repair program implemented by the Catskill Watershed Corporation in the West of Hudson watershed. In 2008, DEP entered into an agreement with the New York State Environmental Facilities Corporation (EFC) to assist in implementing the program. Starting in April 2009, EFC began sending initial notification letters to residents in the Kensico Reservoir watershed, alerting them to their eligibility for funding and providing a brief program overview. The mailing also included response cards which provided DEP with additional information on the status of residents' on-site wastewater systems.

Notification letters were sent to 672 properties thought to be served by on-site sewage treatment systems. EFC received 142 responses, either through telephone inquiries or return of the enclosed response cards. Using data received from the mailed responses, DEP updated its database of parcels that are served by a municipal sewer system rather than an on-site wastewater system. Five systems were found to be in failure. Four of them have been rehabilitated or connected to an existing sewage collection system. The remaining system is currently in the design stage.

Turbidity Reduction

The Catskill Upper Effluent Chamber (CATUEC) is situated along the shore of a cove in the southwest section of Kensico Reservoir. The shoreline of this cove trends north to south, so that CATUEC faces east into the cove. The cove extends south and east into the main basin of the reservoir. Water from Kensico Reservoir enters CATUEC and is transported to the Catskill Lower Effluent Chamber (CATLEC) where Kensico Reservoir's Catskill Lower Effluent Chamber monitoring site (CATLEFF) is located. When wind velocities are sufficient to create wave action on the shoreline in the cove near CATUEC, sediment in this area may become re-suspended and entrained into the Kensico Reservoir effluent that enters CATUEC, resulting in a short-term rise in turbidity values measured at CATLEFF.

Based on the assessment of these wind events, DEP has decided to implement a shoreline stabilization project south of the chamber to mitigate the erosion and possible re-suspension of near-shore materials that may contribute to turbidity at CATUEC during the events. After review of various alternatives, DEP determined that riprap would be the best material for stabilization and that a coffer dam would be the best way to dewater the work area adjacent to the shoreline during installation. The final design was completed in 2008.

During 2009 and 2010, DEP spent significant time securing the necessary permits for the installation of the project. The Site Plan Approval package and Stormwater Pollution Prevention Plans (SPPP) were submitted to the Town of Mt. Pleasant in August 2009. The Town permitting approvals were completed in 2010 following the SEQR Negative Declaration. The ACOE permit application and Conceptual Wetland Mitigation Plan were submitted in the second half of 2009. The ACOE permit was secured in 2010.

Non-DEP Projects

DEP also monitors projects within the Kensico basin that are being implemented by other parties. Among the projects that are monitored are projects along the Route 120 corridor and at the Westchester County Airport.

Route 120

DEP continued to monitor the activities associated with the New York State Department of Transportation (DOT) plans for work along Route 120 and I-684 in the Kensico basin. DEP staff attended the New York State Route 120 Advisory Committee Meeting held in Armonk in April 2006, along with representatives from the Natural Resources Defense Council, Riverkeeper, Friends of Jerome Park Reservoir, and the Gaia Institute, as well as DOT consultants. In August 2007, DEP received a project notification from the New York State Department of Health with a report and plans. Between 2008 and early 2010, there was limited activity on the DOT proposal for resurfacing I-684 and constructing 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. This project, which is a portion of the overall corridor project known as Routes 120 and 22/Exits 2 and 3 on I-684/Old Post Road, has been delayed due to a pending permit requirement from Connecticut.

Westchester County Airport

The Westchester County Airport is located east of Kensico Reservoir in close proximity to Rye Lake. As such, DEP continues to review any activities that are being proposed at the airport. Two projects are still pending. At this time, DEP has not identified serious problems with the proposals. The activities include the following:

- The relocation of the north perimeter road away from the northern end of Runways 16 and 34, and the removal of a portion of the existing north perimeter road. The north perimeter road will be relocated to increase safety at the north end of the runway, pursuant to FAA runway safety requirements. This project received DEP approval in October 2009. Construction is nearly completed, with DEP finding no issues during construction.
- Proposed improvements to the existing terminal area aircraft deicing system and related improvements. This proposal was initially part of a larger overall Airport Layout Plan modification, now being considered a separate project as requested by the Westchester County Planning Department. The SEQRA review was initiated in 2007, with a request for Lead Agency by the Westchester County Planning Department. A public meeting was held in November 2007. There has been no new activity since the end of 2007. A delay in obtaining federal grants to fund this project and the relocation of the deicing tank are contributing to project delays.

2.14 East of Hudson Non-Point Source Pollution Control Program

The East of Hudson Nonpoint Source Pollution Control Program is a comprehensive effort to address nonpoint pollutant sources in the four East of Hudson Catskill/Delaware watersheds (West Branch, Boyd Corners, Croton Falls, and Cross River)[1]. The program supplements DEP's existing regulatory efforts and nonpoint source management initiatives. The program generates data on the watershed and its infrastructure and uses that information to evaluate, eliminate, and remediate existing nonpoint pollutant sources, maintain system infrastructure, and evaluate DEP's programs.

2.14.1 Wastewater-Related Nonpoint Source Pollution Management Programs

Nonpoint sources of wastewater may include exfiltration or other releases from defective sewer lines, failing septic systems, and illicit connections to the stormwater collection system. The four target watersheds contain 12 wastewater treatment plant discharges and a system of sewer infrastructure within several sewer districts. Outside of the existing sewer districts, wastewater is treated by subsurface sewage treatment systems (SSTSs).

Wastewater Infrastructure Mapping and Inspection Program

As part of its efforts to reduce potential pollutant loading from wastewater sources, DEP developed a program for the inspection and mapping of the sanitary infrastructure in the East of Hudson Catskill/Delaware basins. The inspection program includes identifying defects and assessing those that may result in exfiltration of effluent to surface water. Digitized data that were collected during the inspections include sewer pipe size, estimated age, composition, and precise location; manhole location, size, and estimated age; pump station locations, size, and flow capacity; interceptor sewer location, size, and estimated age; and other pertinent data concerning cross and illicit connections.

DEP began infrastructure inspections in 2004. During the course of the inspection it was discovered that the number of structures and length of pipe were substantially more than initially estimated. The work to inspect and digitally map the remaining sewer pipe and structures will be completed under a contract that DEP awarded to Fred A. Cook, Inc. DEP issued an order to commence work in July 2009 and it is anticipated that the work will be completed in the first half of 2011. Once the inspection and mapping are complete, DEP will coordinate the remediation of any identified failures with the responsible entity.

Septic Program East of Hudson

DEP provides ongoing support to Westchester County and Putnam County in their efforts to reduce the potential impacts of improperly functioning or maintained SSTSs. Within Westchester County, DEP supports the County Health Department in its efforts to train and license septic contractors as well as develop a Septic System Management Program database. Funding to continue the contractor training, contractor licensing, and septic repair database was

1. West Branch and Boyd Corners are East of Hudson watersheds that are part of the Catskill/Delaware System. Croton Falls and Cross River are hydrologically part of the Croton System but are included here because DEP's water system allows diversion of these flows into the Catskill/Delaware System, although this is an event that rarely occurs.

provided through East of Hudson Water Quality Investment Program (WQIP) funds, as provided for in Section 140 of the 1997 New York City Watershed Memorandum of Agreement. To date, the County has developed a preliminary database of sewage service status and is currently conferring with local municipalities in order to increase the accuracy of the database. The County has also developed a database to track various septic program activities such as tank pump-outs, repairs, remediations, and new applications.

Within Putnam County, DEP worked with Putnam County Septic Repair Program (SRP) staff to target repairs in priority areas as well as provide septic education information to residents. The SRP includes several phases of implementation that target priority areas within the Catskill/Delaware watersheds located East of Hudson. Since the start of the SRP, Putnam County has allocated over $4.5 million in WQIP funds for ongoing SRP implementation. Through December 2010, approximately 161 septic systems have been repaired or remediated.

DEC also issued Phase II MS4 permit requirements in 2008 and 2010, which call for specific measures to reduce the impacts of improperly functioning SSTSs. In particular, East of Hudson municipalities are required to "develop, implement and enforce a program that requires property owners to inspect, repair and/or replace failing septic systems that are tributary to the small MS4." As part of the inspection program, homeowners are required to inspect their systems once every five years. As East of Hudson MS4s implement these Phase II requirements, DEP will evaluate its existing activities in order to avoid duplicative or conflicting efforts.

2.14.2 Stormwater-Related Nonpoint Source Pollution Management Programs

Stormwater Retrofit and Remediation

In an effort to further reduce pollutant loading from stormwater runoff, DEP is working on multiple nonpoint source reduction projects within the East of Hudson Catskill/Delaware basins. These projects, which include large retrofit and remediation projects as well as remediation of smaller erosion sites (Figure 2.22), are in addition to the other large remediation projects that DEP has previously completed. DEP is currently gathering new information through mapping that will further enhance pollutant reduction initiatives.

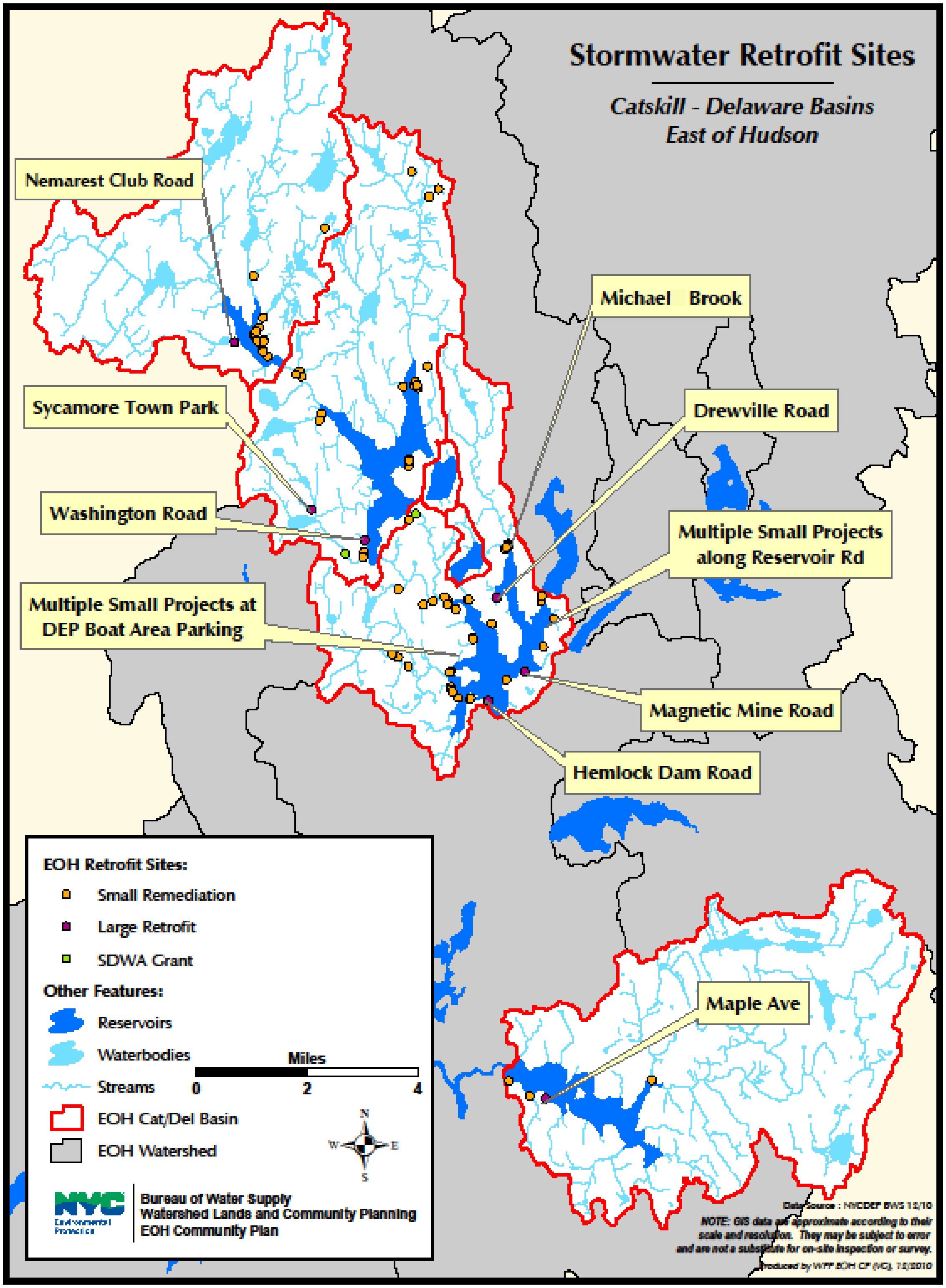

Figure 2.22 Stormwater retrofit sites, Catskill-Delaware basins, East of Hudson.

Stormwater Retrofit Projects

Hemlock Dam Road and Magnetic Mine Road are unpaved roads in the Town of Carmel that drain toward Croton Falls Reservoir. DEP identified possible roadway and drainage improvements that could be made to reduce erosion potential and turbidity in the Croton Falls basin. The project involves making roadway improvements as well as improving the functionality of the existing stormwater conveyance system along the roadways.

a)

b)

Figure 2.23 Project site following completion of retrofits.

Design for the work and preparation for the construction specifications was initiated in 2007. In January 2009, DEP awarded the construction contract for the reconstruction of both Hemlock Dam Road and Magnetic Mine/Lower Mine Road. During construction, a private landowner approached the City and claimed that he owned land parcels on both sides of Lower Mine Road in the Town of Southeast within DEP's project limits. A Stop Work Order (within the area of the private property) was issued to the contractor until confirmation of ownership and right-of-way could be determined. The decision resolving these issues found that a portion of the work initially envisioned for the project was indeed on private property; as a result, that work was not completed. DEP did, however, complete the work to install culverts, swales, riprap outfalls, and erosion control materials in 2010 (Figures 2.23a-b).

Stormwater Remediation Projects

DEP is implementing five large stormwater remediation projects that are located on both City-owned and private land. Designs for these projects are complete and DEP is in the process of finalizing the permitting requirements before bidding the construction contracts.

Remediation Projects on City-Owned Property

Maple Ave., Town of Bedford, Westchester County. The Maple Avenue site was chosen to replace the original site (CR-1) along a stretch of Maple Avenue that occasionally experienced accelerated erosion and sedimentation during periods of high precipitation. DEP worked with town officials in an attempt to find a suitable solution. However, given that local residents chose to maintain the road as unpaved as an expression of rural community character, a cost-effective solution was not possible. Therefore, DEP chose another site along Maple Avenue that will have a similar water quality benefit for Cross River Reservoir.

The Maple Avenue site consists of two roadside ditches carrying a significant amount of suspended solids that discharge into Cross River Reservoir. In order to prevent the continued buildup of sediment along the hillside and water's edge, a sediment and gravel collection system is being 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. 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. The survey and preliminary design work for this project were initiated in December 2008 and are now complete.

Michael Brook, Town of Carmel, Putnam County. DEP will repair a severely eroded drainage ditch along Hughson Road that drains directly into Croton Falls Reservoir. Numerous trees and other debris that have accumulated at the juncture of Croton Falls Reservoir and Michael Brook will be relocated outside the watercourse of Michael Brook.

Drewville Road, Town of Carmel, Putnam County. This site replaced the original Joseph Court site (WB-1) in the Town of Kent. Construction at that site would have required acquisition of an access agreement to cross through and demolish private property. Additionally, town surveying documents were inaccurate in depicting the location of several wells and septic locations. Due to these site constraints and access issues, DEP proposed to replace the original project with the Drewville Road project in 2008.

The Drewville Road site consists of a roadside drainage ditch that drains to Croton Falls Reservoir and has eroded in several locations and is undermining the adjacent rock wall. The ditch will be improved to minimize erosion and repair areas where the wall is being undermined, and a micropool extended detention basin will be installed. The basin was designed to maintain the existing conveyance way, with provision made for established wetland-dependent species along the existing flow path.

Remediation Projects on Privately-Owned Property

DEP initiated a number of projects on privately-owned property aimed at improving stormwater quality in their respective basins.

Sycamore Park, Long Pond Road/Crane Road, Town of Carmel, Putnam County. DEP will remove gravel parking areas within the wetland buffer zone and replace with porous grass paving. This will stabilize parking areas within the wetland buffer and remove the source of gravel migration into the wetlands. Landscape improvements and barriers will be installed to prevent parking from encroaching into the wetlands. Drainage improvements and swales will be constructed to contain runoff from the paved road and parking areas beyond the wetland buffer. Debris buildup within the current culvert located under the access road and draining directly to the wetlands will be removed and the culvert outfall will be reconstructed outside of the wetland. Stormwater treatment practices to be installed include two biofiltration areas to collect and treat runoff from the paved areas, as well as a vegetated drainage swale to provide additional water quality treatment. Site plans have been reviewed by the Town of Carmel Recreation Department and their comments have been incorporated into final design drawings.

Nemarest Club, Town of Kent, Putnam County. Improvements to this site include replacing the existing partially collapsed culvert with a larger span concrete structure capable of conveying the 100-year storm and minimizing sediment runoff from the damaged roadway entering Boyd Corners Reservoir. Specifically, DEP will (1) replace a defective and undersized road culvert where the stream crosses under a dirt road, (2) relocate large rocks that are currently in-channel near the road crossing, (3) install forebays adjacent to the culvert, and (4) replace guiderails along the culvert crossing.

Stormwater Remediation Small Projects

The Small Stormwater Remediation Projects Program involves the identification and remediation of smaller erosion sites in the four East of Hudson Catskill/Delaware basins. Typical erosion abatement includes embankment stabilization, headwall repair, road drainage improvements, installation of stabilized outlet controls, and renovating dirt/gravel parking areas.

DEP remediated seven of the proposed 30 sites during the 2007 construction season prior to contractor default in March 2008. Cassidy Excavating, Inc., became the prime contractor under the replacement contract, which was registered in April 2009. Construction commenced in April 2009 and by October 2009, Cassidy Excavating had completed construction of the 23 outstanding sites. Sites completed are shown in Table 2.26.

Table 2.26: Completed small stormwater remediation projects.

Site No.	Reservoir Basin	Town	Street Name	Location	Description of Work
CF1-05	Croton Falls	Carmel	Crafts Road	Putnam County Bikeway	Watercourse erosion repair
CF2-05	Croton Falls	Carmel	Hemlock Dam Road	West side of Croton Falls Road	Forebay construction, channel stabilization
CF3-05	Croton Falls	Carmel	Hemlock Dam Road	Southeast of Croton Falls Road	Headwall and endwall repair, embankment and channel stabilization
CF4-05b CF4-05a	Croton Falls	Carmel	Croton Falls Road	Stebbins, between Stebbins and Pigott Roads	Embankment and channel stabilization
CF 3-07	Croton Falls	Carmel	Stoneleigh Avenue	Magnetic Mine Road	Channel erosion stabilization, pipe outlet stilling basin
CF3-10	Croton Falls	Carmel	Croton Falls Road	Boat Area #6	Repair of eroded swales
CF5-05	Croton Falls	Carmel	Stoneleigh Avenue	Vista on the Lake	Replacement of asphalt swale with water quality swale, repair of eroded swale
CF1-09	Croton Falls	Carmel	West Shore Drive	Intersection of Stebbins Road	Outfall channel stabilization, sediment stilling trap, stabilized roadway perimeter
CF2-09	Croton Falls	Carmel	Hughson Road	Intersection of Stoneleigh Avenue	Stabilization of roadside drainage channel
WB1-09	West Branch	Carmel	Belden Road	Intersection of Route 301 (@ Verizon pole #D8792)	Installation of deep sump catch basins, replacement of roadway cross culvert
WB2-09	West Branch	Carmel	Belden Road	Intersection of Route 301 (@ wastewater pump station)	Installation of deep sump catch basins, replacement of roadway cross culvert
CF3-09	Croton Falls	Carmel	Rock Mill Road	Intersection of Drewville Road	Installation of drainage network and deep sump catch basins, stabilization of existing outfalls

Environmental Protection

Table 2.26: (Continued) Completed small stormwater remediation projects.

Site No.	Reservoir Basin	Town	Street Name	Location	Description of Work
CF4-09	Croton Falls	Carmel	Seminary Hill Road	Intersection of Drewville Road	Installation of deep sump catch basins, stabilization of existing outfalls
CF5-09	Croton Falls	Carmel	Drewville Road	Between Weber Hill Road and Cherry Hill Road	Stabilization of roadside drainage channel, addition of stone check dams
CF6-09	Croton Falls	Carmel	West Shore Drive	@ 245 West Shore Drive	Installation of deep sump catch basin, outfall channel stabilization
CF7-09	Croton Falls	Carmel	West Shore Drive	Intersection of Croton Falls Road	Installation of deep sump catch basin, outfall channel stabilization
CF8-09	Croton Falls	Carmel	Croton Falls Road	Intersection of Union Valley Road (North)	Installation of deep sump catch basin, outfall channel stabilization
CF9-09	Croton Falls	Carmel	Croton Falls Road	Intersection of Union Valley Road (South)	Installation of deep sump catch basin, outfall channel stabilization
CF10-09	Croton Falls	Carmel	Cherry Hill Road	Intersection of Drewville Road	Installation of sediment tank/deep sump catch basins, stabilization of parking area with pervious pavers
CF11-09	Croton Falls	Carmel	West Shore Drive	¼ mile north of Farview Road	Installation of pipe and fill material within eroded gorge, outfall stabilization
CF12-09	Croton Falls	Carmel	Reservoir Road	Unpaved portion—intersection of Lower Mine Road	Installation of drainage network and deep sump catch basins, stabilization of existing outfalls

Table 2.26: (Continued) Completed small stormwater remediation projects.

Site No.	Reservoir Basin	Town	Street Name	Location	Description of Work
CF13-09	Croton Falls	Carmel	Reservoir Road	Paved portion—intersection of Drewville Road	Installation of drainage network and deep sump catch basins, stabilization of existing outfalls
WB3-09	West Branch	Kent	Farmers Mills Road	Intersection of Route 52	Stabilization of roadside drainage channel
WB4-09	West Branch	Kent	Meadow Court	Intersection of Farmers Mills Road	Installation of deep sump catch basins and pipe network within eroded channels, outfall stabilization
WB5-09	West Branch	Kent	Church Hill Road	Intersection of Daffodil Lane	Construction of sediment stilling basin and stabilized outfall
BC1-09	Boyd Corners	Kent	Gypsy Trail Road	Intersection of Kent Acres Road	Replacement of headwall, outfall stabilization
BC2-09	Boyd Corners	Kent	East Boyd's Road	@ 202 East Boyd's Road	Installation of deep sump catch basins, outfall stabilization
BC3-09	Boyd Corners	Kent	East Boyd's Road	@ 236 East Boyd's Road	Installation of deep sump catch basins, outfall stabilization
BC4-09	Boyd Corners	Kent	322 East Boyd's Road	@ 322 East Boyd's Road	Installation of deep sump catch basins, outfall stabilization
BC5-09	Boyd Corners	Kent	326 East Boyd's Road	@ 326 East Boyd's Road	Installation of deep sump catch basins, replacement of roadway cross culvert

Many of the 23 sites completed in 2009 included a component to capture sediment from adjacent impervious roadways, such as deep sump catch basins and stone stilling sumps. As an example, the site CF10-09 configuration consists of a modified septic tank and a series of deep sump catch basins to capture runoff from a significant section of town roadway. In addition, an unnamed intermittent stream was disconnected from the existing roadway drainage system, the road embankment was stabilized, and a fisherman parking area was upgraded with pervious pavers.

In April 2010, in accordance with operation and maintenance protocols, DEP's contractor was directed to remove approximately 13 cubic yards of sediment from the CF10-9 best management practice (BMP) (combined total from the tank and deep sump catch basins). Prior to the small projects remediation work that was performed under this program, sediment and road salt would have directly entered the West Branch Croton River. This portion of the river is a protected waterway that supports native trout and empties into Croton Falls Reservoir only a short distance from the BMP.

DEP completed an evaluation and assessment of the Small Projects Program in 2009 and provided an update in 2010. Based on the evaluation's review of earlier program successes, several of the projects that were installed in 2009 were intentionally configured in a similar manner to CF10-09, the intention being to capture sediment loads prior to discharge to water surface features. Based on inspections and initial maintenance activity, the 2009 sites, including those intended to stabilize existing drainage channels, have performed as intended.

Facility Inspection and Maintenance

The facility inspection and maintenance program was developed in order to ensure that previously constructed remediation facilities continue to function as designed. New facilities continue to be brought on line and are added to the routine inspection program. The program currently includes 75 stormwater management and erosion abatement facilities in the East of Hudson watershed. Maintenance during the first year of a facility's life is promptly completed under the warranty in the facility's construction contract and under DEP's BMP Operation and Maintenance Program contract thereafter. Inspection and maintenance follow procedures identified in the Operation and Maintenance Guidelines (DEP 2000, revised 2003), which has been incorporated into the operation and maintenance contract; facility types not described in this document were incorporated into the operation and maintenance contract with explicit maintenance instructions.

DEP updated the scope of the next three-year maintenance contract and the new contract was in place in August 2008. Repairs and maintenance activities during 2006-2010 consist of such items as: erosion repair; access road repair; fence repair; grass cutting; removal and disposal of dead trees and unwanted vegetation; cleaning out catch basins; removal and disposal of sediment from forebays, main basins, and upstream from weirs; road stabilization and erosion or washout repair; adding stone and reshaping roads; and log check dam repair.

Stormwater Infrastructure Mapping and Inspection Program

Having already completed the contract to map Croton Falls, Cross River, and portions of the West Branch and Boyd Corners Reservoir basins, DEP implemented a program to digitally map and video inspect stormwater infrastructure in the remaining portion of the West Branch and Boyd Corners basins. In 2008, DEP completed all of the mapping, which included some 130,000 linear feet of stormwater infrastructure.

In 2009, digital mapping from the program was added to DEP's GIS system. DEP has notified the relevant municipalities that the mapping and inspection information is available to them so they can effectively plan for their compliance with the Phase II MS4 permit requirements.

Inspection and Illicit Connection Investigation

The video inspections of stormwater infrastructure revealed areas with deformation, breakage, and/or clogging (Table 2.27). DEP notified the responsible municipality or county agency so that appropriate steps could be taken to eliminate all illicit inputs and remediate other sources as appropriate. Follow-up by DEP with local municipalities and/or county agencies indicated there were no illicit connections; instead, roof and footing drains, among others, were identified as the source of the inputs.

Table 2.27: Stormwater tap-ins and potential illicit connections.

Section No.	From MH	To MH	Pipe Length (ft.)	Street	Town	Observation
28	WB011CB14	WB011CB16	223	Robin Drive	Carmel	At 14 - Tap break-in
29	WB011CB14	WB011CB12	239	Robin Drive	Carmel	At 96 - Tap break-in
79	WBP10CB17	WBP10OU3	300	Horsepound Road	Carmel	At 45 - Tap break-in
88	WBP10CB4	WBP10CB6	225	Joseph Court	Carmel	At 214 - Tap break-in
209	WBH20CB14	WBI20CB8	212	Pennebrook Lane	Carmel	At 50 - Tap break-in
						At 82 - Tap break-in
257	WBJ18CB2	WBJ18CB4	74	Abin Road	Carmel	At 60 - Tap break-in
						At 66 - Tap break-in
306	WBF15CB21	WBF15CB13	36	Chestnut Ridge Road	Carmel	At 32 - Tap break-in
308	WBF15CB13	WBF15CB11	96	Chestnut Ridge Road	Carmel	At 96 - Tap break-in
377	WBG16CB5	WBG16CB3	201	Brittany Lane	Carmel	At 200 - Tap factory made
477	WBL12CB1	WBL12OU2	136	Gypsy Trail Road	Kent	At 46 - Tap break-in
517	WBD18CB-1	WBD18OU-3	108.01	Old Long Pond Road	Kent	At 24 -Tap break-in
639	WBI15OU-1	WBI15CB-2	54.05	Carolyn Road E.	Carmel	At 40 - Tap break-in
640	WBP10CB-15	WBP10OU-2	281.88	Horse Pound Road	Kent	At 154 - Tap break-in
640	WBP10CB-15	WBP10OU-2	281.88	Horse Pound Road	Kent	At 163 - Tap break-in

Table 2.27: (Continued) Stormwater tap-ins and potential illicit connections.

Section No.	From MH	To MH	Pipe Length (ft.)	Street	Town	Observation
642	WBD18CB1	WBD18OU3	107	Old Long Pond Road	Carmel	At 24 - Tap break-in
672	BCGO6CB4	BCGO6CB3	253	Peekskill Hollow Road	Kent	At 176 - Tap break-in
714	HPJ12CB-1	HPJ12CB-18	164.16	Anna Court	Kent	At 124 - Tap break-in
714	HPJ12CB-1	HPJ12CB-18	164.16	Anna Court	Kent	At 160 - Tap factory made
716	HPJ12CB-2	HPJ12CB-19	315.01	Anna Court	Kent	At 150 - Tap break-in
716	HPJ12CB-2	HPJ12CB-19	315.01	Anna Court	Kent	At 214 - Tap break-in
734	HPJ12CB-14	HPK12CB-4	131.33	Barret Hill Road	Kent	At 94 - Tap break-in
772	HPBO2CB6	HPBO2CB4	145	White Pond Road	East Fishkill	At 54 - Tap break-in
777	HPCO2CB2	HPCO2CB3	159	Milltown Road	East Fishkill	At 86 - Tap break-in
788	HPEO5CB4	HPEO4IN5	90	Kent Shore Drive	Kent	At 44 - Tap break-in
788	HPEO5CB4	HPEO4IN5	90	Kent Shore Drive	Kent	At 89 - Tap break-in
817	HPK12CB9	HPK12OU2	200	Anna Street	Kent	At 144 - Tap break-in
819	HPK12CB8	HPK12CB15	106	Anna Street	Kent	At 54 - Tap break-in
823	HPK12CB14	HPK12OU3	253	Anna Street	Kent	At 133 - Tap break-in
937	LBE05CB-24	LBE05CB-13	226.02	Leetown Road	East Fishkill	At 119 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 32 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 36 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 40 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 44 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 58 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 63 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 73 - Tap break-in
958	HPFO4CB1	HPFO4OU3	145	Kent Lake Avenue	Kent	At 80 - Tap break-in
1043	LBE07CB-2	LBE07CB-3	112.71	Leetown Road	East Fishkill	At 14 - Tap break-in
1084	LBG02CB-11	LBG03CB-5	201	Shaker Lane	East Fishkill	At 31 - Tap break-in
1084	LBG02CB-11	LBG03CB-5	201	Shaker Lane	East Fishkill	At 110 - Tap break-in
1089	LBI01CB-7	LBI01OU-1	191.19	Overhill Road	East Fishkill	At 101 - Tap break-in
1089	LBI01CB-7	LBI01OU-1	191.19	Overhill Road	East Fishkill	At 121 - Tap break-in
1142	BBCO3CB1	BBCO3OU1	77	Kentview Drive	Kent	At 52 - Tap break-in
1142	BBCO3CB1	BBCO3OU1	77	Kentview Drive	Kent	At 67 - Tap break-in
1142	BBCO3CB1	BBCO3OU1	77	Kentview Drive	Kent	At 76 - Tap break-in
1211	LBF03CB-3	LBF03OU-2	132.03	Leetown Road	East Fishkill	At 42 - Tap break-in

Table 2.27: (Continued) Stormwater tap-ins and potential illicit connections.

Section No.	From MH	To MH	Pipe Length (ft.)	Street	Town	Observation
1211	LBF03CB-3	LBF03OU-2	132.03	Leetown Road	East Fishkill	At 62 - Tap break-in
1226	BBDO7CB6	BBDO7CB7	151	Chief Nimham Circle	Kent	At 24 - Tap break-in
1226	BBDO7CB6	BBDO7CB7	151	Chief Nimham Circle	Kent	At 85 - Tap break-in
1226	BBDO7CB6	BBDO7CB7	151	Chief Nimham Circle	Kent	At 104 - Tap break-in
1256	SLI05CB-1	SLI05CB-4	370.06	Route 301	Kent	At 269 - Tap break-in
1289	LBD13CB2	LBD13IN4	253	Seven Hills Lake Drive	Kent	At 230 - Tap break-in
1308	SLC07CB-15	SLC07CB-12	460.05	Taconic State Parkway	Kent	At 227 - Tap break-in

Stormwater Infrastructure Capacity Evaluation

With the completion of the digital mapping and inspection program, DEP completed a study to evaluate the adequacy of infrastructure in the four East of Hudson Catskill/Delaware basins that were mapped and catalogued. The study considered the adequacy of existing piping, swales, and drainage structures to safely convey stormwater to receiving waters and potential improvements that may enhance water quality. Pertinent, complete information has been shared with the agencies responsible for maintenance of the drainage systems. The consultant evaluated and organized the available data, performed the infrastructure analysis, developed and applied prioritization criteria, and provided a final report that includes recommendations concerning appropriate corrective measures where necessary.

Stormwater Prioritization Assessment—DEP Properties

Using information gathered from DEP's implementation of retrofit and remediation projects, DEP has developed prioritization criteria for potential future stormwater projects that could be located on City-owned property. Data that were used to create the prioritization included the East of Hudson stormwater infrastructure mapping, GIS data layers, and the prioritization determination developed through the Croton Watershed Strategy. The final report was submitted in March 2009 and the anticipated implementation timeframe was submitted in September 2009.

Funding Program—Croton Falls/Cross River

As part of the 2007 FAD, DEP established a grant program to reduce stormwater pollution in the Cross River, Croton Falls, and upstream hydrologically-connected reservoirs. In 2008, DEP and DEC submitted a joint proposal to reallocate a portion of the $4.5 million in funds allocated to the Croton Falls/Cross River Funding Program toward the support of a Regional Stormwater Entity (RSE) in the East of Hudson watershed. DEP, DEC, and the New York State Department of State met with East of Hudson MS4s to begin discussions on the formation of an RSE and potential uses of these funds. In response, East of Hudson municipalities, through the use of inter-municipal agreements, formed three separate regional entities, one representing the municipalities in each of the three East of Hudson counties.

In 2009, the regional coalitions in Westchester, Putnam, and Dutchess Counties completed studies of potential stormwater retrofit locations. The Westchester study also included possible RSE structures to strengthen the inter-municipal model under which they are currently operating. Concurrently, DEP worked with partners in the East of Hudson watershed to finalize the Croton Falls/Cross River Funding Program rules and draft an Inter-municipal Agreement that would allow for the allocation of grant monies pursuant to the program.

In November 2009, DEP sent notification letters to each municipality in the East of Hudson watershed notifying them of the availability of funding under the program. The responses alerted DEP to various local concerns with regard to the timing and conditions of program implementation. DEP re-issued its funding notification to the municipalities in June 2010 and included an updated copy of the rules. While the notification set an application deadline of December 31, 2010, DEP now anticipates that applications will be received in the first half of 2011.

2.14.3 Other Activities

Croton Watershed Strategy

The primary goal of the Croton Watershed Strategy project was to develop an integrated watershed management plan for the Croton System which would allow DEP to optimize management efforts and focus limited resources on critical areas to achieve maximum water quality benefit. The results were compiled in a series of documents and released in March 2003 as a FAD deliverable (DEP 2003).

The watershed assessment examined both existing and full build-out conditions in the watershed for 74 sub-basins. The methodology focused on impairment from point and nonpoint watershed sources with regard to four critical indicator variables: total phosphorus, total suspended solids, pathogens, and toxic chemicals. The assessment did not model actual concentrations of water quality variables, but rather identified a sub-basin’s relative potential to impair water quality compared to other sub-basins. The sub-basin results were used to develop basin-specific management recommendations and watershed-wide prioritizations.

The Croton Watershed Strategy results have been used as guidance in several DEP management programs and State Environmental Quality Review Act (SEQRA) reviews of new development projects. The Strategy was also used in response to a request from Putnam County to assist in prioritizing a phased approach for its Septic Repair Program.

2.15 Pilot Phosphorus Offset Program

The Watershed Rules and Regulations prohibit the construction of new or expanded wastewater treatment plants with surface discharges in phosphorus-restricted reservoir basins of the watershed. In 1997, as part of the 1997 Watershed Memorandum of Agreement (MOA), DEP initiated the Phosphorus Offset Pilot Program to test the feasibility of an offset-based regulatory structure in phosphorus-restricted basins. The MOA stipulated a five-year pilot program with the option of one five-year extension, which the City exercised due to a lower than expected demand. In March 2007, DEP released a programmatic review of the pilot program which did not recommend that the pilot program become permanent. The assessment determined that the offset program was complicated and expensive to implement for both the oversight agency and the participants. Not only was it difficult and time-consuming for applicants to identify approvable offsets, but the careful monitoring and reporting necessary to establish the offset as real and ongoing was at times very deficient, requiring a substantial degree of agency oversight and the risk that water quality could easily be adversely impacted.

Even though the pilot program expired in 2007, there remain three approved participants—one which is fully built and conducting compliance monitoring (Brewster Highlands) and two which have all their approvals but have not been built and are awaiting better market conditions (Campus at Fields Corners and Kent Manor). Both Campus at Fields Corners and Kent Manor conducted pre-development monitoring for two to three years and have currently suspended monitoring until such time as the project is reactivated.

2.16 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 streambanks, mobilize stream beds, 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 turbidity standards at the Kensico effluent. Periodically, however, the City has had to use chemical treatment to control high turbidity levels.

Over the past five years, DEP has executed a comprehensive program to identify and implement operational strategies and infrastructure improvements that improve the system’s resilience during naturally-occurring turbidity events and reduce the frequency of alum treatment events.

2.16.1 Catskill Turbidity Control Study Phases

DEP initiated the Catskill Turbidity Control Study to provide a comprehensive analysis of engineering and structural alternatives to reduce turbidity levels in the Catskill System and reduce the frequency of alum treatment events. DEP engaged the Gannett Fleming/Hazen and Sawyer Joint Venture (JV) to support this effort, along with JV subconsultants Upstate Freshwater Institute and HydroLogics, Inc. The study has been conducted in three phases.

Phase I

The Phase I study, completed in December 2004, provided a preliminary screening-level assessment of turbidity control alternatives at Schoharie and Ashokan Reservoirs, and identified potentially feasible, effective, and cost-effective measures for subsequent detailed evaluation.

Phase II

The Phase II study, completed in September 2006, consisted of a detailed conceptual design, cost estimation, and performance evaluation of three alternatives for improving turbidity and temperature in diversions from Schoharie Reservoir: a Multi-Level Intake, In-Reservoir Baffle, and Modification of Reservoir Operations. The performance evaluation relied on development and application of an integrated modeling framework that linked the OASIS water supply model of the entire NYC reservoir system and Delaware Basin with the W2 water quality model of Schoharie Reservoir. Schoharie water quality model development was supported by detailed routine and event-based in-reservoir and in-stream monitoring efforts and process studies, as detailed in annual FAD reports.

DEP selected Modification of Reservoir Operations as the most feasible, effective, and cost-effective alternative for improving turbidity and temperature control at Schoharie Reservoir, and proposed in the December 2006 Phase II Implementation Plan to develop a system-wide Operations Support Tool (OST) to support implementation of this alternative. The Modification of Reservoir Operations/OST plan was conditionally approved by regulatory agencies in August 2008, pending completion of additional sensitivity analyses. These analyses plus an array of model updates were presented in the July 2009 report, Phase II Implementation Plan: Updates and Supporting Analyses. DEP is currently proceeding with implementation of Modified Reservoir Operations and development of the OST, as described in more detail below.

Phase III

The Phase III study, completed in December 2007, focused on alternatives at Ashokan Reservoir that could reduce turbidity levels entering Kensico Reservoir, including a West Basin Outlet Structure, Dividing Weir Crest Gates, East Basin Diversion Wall, Upper Gate Chamber Modifications, a new East Basin Intake, and Catskill Aqueduct Improvements/Modified Operations. The performance evaluation relied on an updated version of the OASIS-W2 model, which included water quality models of Kensico Reservoir and the West and East Basins of Ashokan Reservoir. Ashokan and Kensico water quality model development was supported by detailed routine and event-based in-reservoir and in-stream monitoring efforts and process studies, as detailed in annual FAD reports.

The Phase III evaluation indicated that, when turbidity levels rise, taking the Catskill System offline (or operating the Catskill Aqueduct at the minimum flow rate needed to satisfy demands) is the most effective way to reduce the turbidity load transferred from Ashokan to Kensico and reduce the frequency of alum treatment events. Releasing water from the West Basin via the Waste Channel prior to and during a storm event was also found to provide significant reductions in turbidity loading to the East Basin, and hence to Kensico Reservoir.

DEP selected Catskill Aqueduct Improvements and Modified Operations as the most feasible, effective, and cost-effective alternative for reducing turbidity levels entering Kensico Reservoir, and proposed implementation of this alternative in the July 2008 Phase III Implementation Plan. The Phase III Implementation Plan also presented the results of extensive model sensitivity and uncertainty testing undertaken by DEP.

2.16.2 Implementation of Catskill Turbidity Control Alternatives

DEP is proceeding with implementation of turbidity control measures at Schoharie and Ashokan Reservoirs consistent with the Phase II and Phase III Implementation Plans, respectively.

Operations Support Tool

The core element of the Phase II and Phase III plans is Modification of Reservoir Operations, which relies on the development of the system-wide OST. The OST (Figure 2.24) is based on the OASIS-W2 linked model framework developed under the Phase II and Phase III studies, but includes links to real-time hydrologic and in-reservoir water quality data, forecasting routines, and numerous other enhancements designed to allow operators to evaluate the pros and cons of alternative operating policies. While the OST will provide DEP with operations guidance throughout the system, the core focus is on supporting reservoir release and diversion decisions at Schoharie and Ashokan Reservoirs that improve turbidity control and reduce the need for alum treatment.

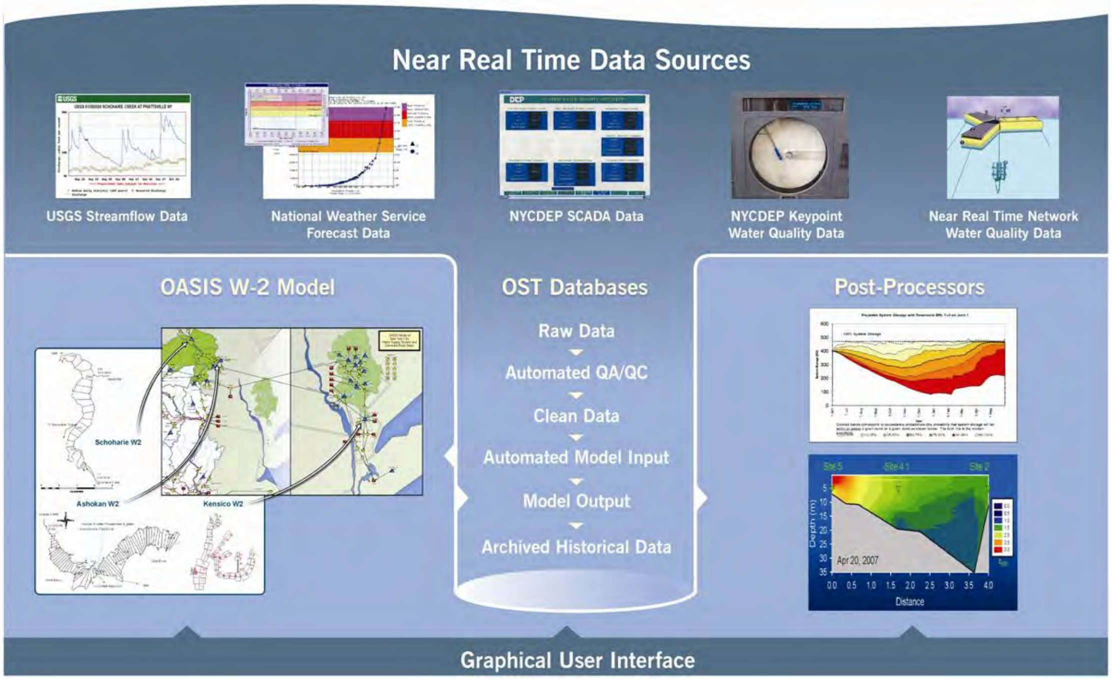

Figure 2.24 Major components of the Operations Support Tool.

In 2008 DEP issued a Request for Proposals for the OST and selected a consultant team to develop it. The contract was finalized in early 2009, and work on the project began in November 2009.

The OST development effort has prioritized the delivery of interim versions of the OST designed to incrementally build DEP's analytical and decision support capabilities throughout the project. Interim versions of the OST were deployed in June and August 2010. These deployments focused on automated acquisition of hydrologic data, development of statistical inflow forecast routines, programming modifications to allow linked OASIS-W2 simulations in a look-ahead or "Position Analysis" mode, development of post-processing and visualization tools to support operating decisions, and training of DEP staff in use of the tools.

The interim versions of the OST deployed to date have been applied to support evaluation of alternative long-term operating rules, to assess the impact of alternative operations on the probability of system refill, to support Gilboa Dam construction planning, and to guide operating decisions at Ashokan subsequent to the October 1, 2010 storm event. DEP's response to this event has included implementation of practices identified in the Phase III Implementation, including drawdown of the West Basin via operation of the Waste Channel.

Additional OST deployments are slated for December 2010 and June 2011. A final beta-version of the OST will be deployed in October 2012, followed by one year of testing, technical support, customization, and training of DEP operations staff. Deployment of the final OST is scheduled for October 2013.

Shaft 4 Connection

The Phase III study demonstrated that reducing diversions from the Catskill System during elevated turbidity conditions is the most effective way to reduce the turbidity load entering Kensico Reservoir and reduce the frequency and duration of alum treatment events. Completion of the Croton water treatment plant in 2012 will substantially bolster DEP's ability to take the Catskill System off-line during turbidity events.

DEP's ability to readily reduce diversions from the Catskill System during turbidity events could also be improved by a connection between Shaft 4 of the Delaware Aqueduct and the Catskill Aqueduct. The Shaft 4 connection would allow DEP to minimize or eliminate Catskill diversions during turbidity events, while still maintaining sufficient flow in the Catskill Aqueduct to provide service to outside communities. Preliminary design of the Shaft 4 connection and a Value Engineering (VE) workshop were completed in 2010. Design of the preferred VE option is expected to be complete by October 2011. Construction registration is expected in June 2012.

Catskill Aqueduct Improvements

In addition to the shaft connection, two potential Catskill Aqueduct improvement options were identified in the Phase III study as alternative measures for maintaining service to outside communities at low Catskill Aqueduct flow rates. These options included improvements to stop shutter facilities and modifications to taps servicing outside communities. Further evaluation of these alternatives was initiated in 2010. Major activities to date have included detailed field inspections and an assessment of stop shutter facilities and preliminary design of improvement options.

Waste Channel Operation/West Basin Drawdown

Releasing water from the West Basin during or in anticipation of a turbidity event was found to be effective at reducing turbidity levels entering Kensico Reservoir and the frequency and duration of alum treatment events. Operation of the existing Ashokan Waste Channel is currently practiced on a provisional basis within applicable flow constraints. Major elements of DEP's efforts to fully implement this alternative include:

Ashokan Field Campus (AFC) demolition/restoration: Operation of the Waste Channel is currently constrained by flooding impacts on the Ashokan Field Campus. DEP acquired low-lying portions of the AFC in March 2008, and is proceeding with a demolition/restoration effort under a design contract. Design for the demolition of the AFC is planned for September 2011, and construction is expected to commence in September 2012.

Valve Improvements at the Ashokan Lower Gate Chamber: Improvements at the Ashokan Lower Gate House were substantially complete in September 2010. Four new 48-inch control valves are operating, which replace original equipment in this facility. Additionally, a new overhead crane was installed under a separate contract which facilitated the installation of the new valves. Further improvements to the electrical distribution and improved lighting were completed. With the newly installed valves, operational control can also be achieved remotely from the Water Supply Control Center.

2.17 Monitoring, Modeling, and GIS

Monitoring

DEP conducts extensive water quality monitoring throughout the watershed. The 2009 Watershed Water Quality Monitoring Plan (WWQMP), which was delivered to DOH, EPA, and DEC in October 2008 (DEP 2009a), describes the monitoring plan. 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 New York City 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 New York City watershed. This includes the requirements of the Surface Water Treatment Rule and its subsequent extensions, as well as the New York City Watershed Rules and Regulations (WR&R), 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 EPA, New York State Department of Health (DOH), and DEP regulations.

As New York City'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, EPA has specified many requirements in the 2007 FAD that must be met to protect public health. These objectives form the basis for the City'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. As watershed protection programs develop and analytical techniques for key parameters change, it is necessary to reassess the monitoring program to ensure that it continues to support DEP's watershed management program. The periodic reassessment of the City's monitoring program is achieved by critical review and revision of the monitoring plan approximately every five years. The City 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 2006a), also produced approximately every five years. (For the current five-year water quality assessment, see Chapters 3-6.)

The 2007 FAD also requires that DEP's watershed-wide monitoring program meet the needs of the Long-Term Watershed Protection Program (DEP 2006b). The goals of this program are to:

- provide an up-to-date, objective-based monitoring plan for the routine watershed water quality monitoring programs, including aqueducts, streams, reservoirs, and pathogens;
- provide routine water quality results for aqueduct, stream, reservoir, and pathogen programs to assess compliance; provide comparisons with established benchmarks; and describe ongoing research activities;
- provide mid-term results from routine watershed (e.g., stream and wastewater treatment plant) pathogen monitoring;
- use water quality data to evaluate the source and fate of pollutants, and the effectiveness of watershed protection efforts in controlling pollutants;
- provide a comprehensive evaluation of watershed water quality status and trends to support assessment of the effectiveness of watershed protection programs.

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 the City's water supply, as one of the few large unfiltered systems in the nation, far into the future.

The surveillance monitoring plan 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 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 manmade 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 DOH'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., 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. Pursuant to the City's Long-Term Watershed Protection Program (DEP 2006b) and as a FAD requirement (Section 5.1 Watershed Monitoring Program), DEP produces a Watershed Water Quality Annual Report which is submitted to EPA 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 2009, the limnology and hydrology information provided in the annual report was supported by an extensive monitoring effort. Monitoring was conducted at approximately 204 routinely-sampled reservoir and stream sites, resulting in almost 4,500 samples and over 61,000 analyses. Protozoan sampling consisted of 615 routine samples that were analyzed for *Giardia*, *Cryptosporidium*, turbidity, pH, and temperature at 45 sampling sites (including keypoints). In addition, 316 samples were collected for human enteric virus examination. Biomonitoring samples were collected at 38 sites.

Additional water quality information is submitted to EPA in March as part of FAD Section 4.10, Kensico Water Quality Control Program. DEP submits a Kensico Programs Annual Report, which includes a section that analyzes monitoring data from the Kensico watershed and provides an update on the status and application of the Kensico reservoir model. This report contains information such as fecal coliform bacteria and turbidity results obtained at various keypoint, stream, and reservoir locations. Additionally, the document reports observations from the assessment of Kensico BMPs, sampling for toxic substances, and applications of the Kensico water quality model to guide operations. A Kensico Programs Semi-Annual Report is submitted in July that provides a brief discussion of material events in Kensico Program implementation.

The monitoring plan has been designed to meet the broad range of DEP's regulatory obligations and informational needs. These requirements include: compliance with all federal, state, and local regulations to ensure safety of the water supply for public health; watershed protection and improvement to meet the terms of the 2007 FAD; the need for current and future predictions of watershed conditions and reservoir water quality to ensure that operational decisions and policies are fully supported over the long term; and that ongoing surveillance of the water supply will continue to ensure delivery of the best water quality to consumers.

Modeling

DEP has developed an Integrated Modeling System consisting of linked watershed, reservoir, and supply system models for evaluating the effects of land use, watershed management, climate change, reservoir infrastructure and operations, and system demand on water quantity and quality of the NYC Water Supply System. The system is modular and flexible, and is used to address a variety of water supply issues that naturally arise from operating a complex water supply system under changing conditions (Figure 2.25).

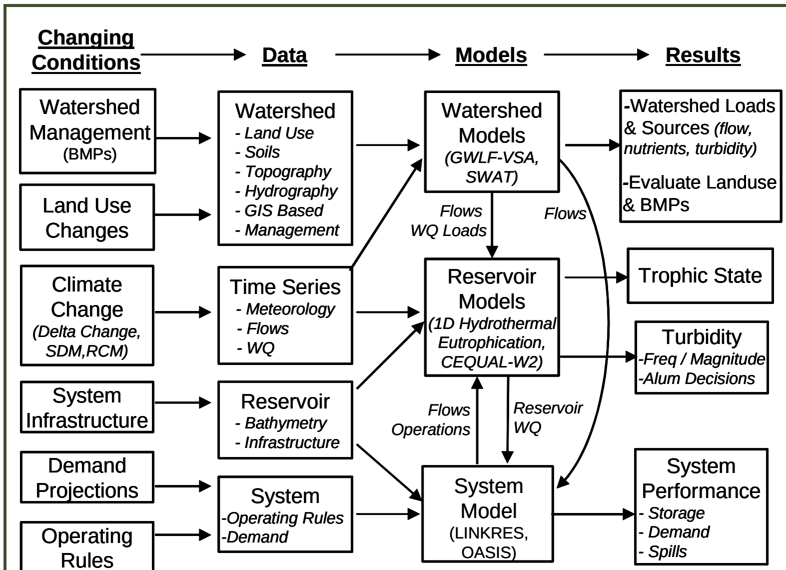

Figure 2.25 DEP's Integrated Modeling System.

An important and ongoing application of the modeling system is to evaluate the status, causes, and control of eutrophication in the Delaware System reservoirs (Cannonsville and Pepacton). This involves simulating flows and nutrient loads for various land use and watershed management scenarios using watershed models, and then simulating the hydrothermal and trophic response of the reservoir by running the watershed model output through a reservoir eutrophication model. An application of this sort was done in 2006 (DEP 2006c) using the GWLF-VSA models linked to 1-D Eutrophication Models for Cannonsville and Pepacton Reservoirs. In 2010 the SWAT watershed model (Neitsch et al. 2005), which explicitly simulates agricultural management practices and soil nutrient dynamics in much more detail than GWLF, was used in conjunction with updated watershed management and stream water quality data for more comprehensive analyses.

A second major application of the modeling system is to evaluate alternative strategies for operating the Catskill System to minimize turbidity during and after storm events. This involves using the LINKRES System Model, which simulates the reservoir system as a series of linked CE-QUAL-W2 2-D reservoir water quality models, to simulate turbidity in the reservoirs and tunnels under various operational strategies. LINKRES, originally developed by Upstate Freshwater Institute (DEP 2004), has been adapted for positional analysis applications, in which an operational strategy is repeated for multiple meteorological scenarios taken from historical records, producing a probabilistic forecast that accounts for historical meteorological variability. LINKRES with positional analysis is used in particular to evaluate the use of the Ashokan Waste Channel, as proposed in the Catskill Turbidity Control Study (DEP 2007), to mitigate turbidity fluxes from Ashokan West to East Basins during storm events, and to evaluate various Catskill versus Delaware System mixing strategies to minimize turbidity in Kensico Reservoir. The NYC OASIS Supply System Model (HydroLogics, Inc. 2007), which also simulates the reservoirs as a system but has the distinct advantage of utilizing a formalized set of operating rules to simulate system operations (as opposed to LINKRES applications system operations, which must be pre-specified), is now beginning to be used for these types of model applications as well.

DEP’s Climate Change Research Program uses the Integrated Modeling System to evaluate the potential effects of climate change on water supply quantity and quality. This involves developing climate change scenarios by downscaling Global Climate Model (GCM) output for the NYC watershed region; running the scenarios through the watershed, reservoir, and system models; and comparing model results to baseline (current climate) conditions to estimate the effects of climate change. Multiple GCMs are utilized in scenario development to bracket the inherent variability in these models, resulting in a probabilistic analysis of future projections. Phase 1 of the Climate Change Research Program utilized existing models and a simple downscaling procedure in a preliminary evaluation of effects of climate change on eutrophication in Cannonsville Reservoir, turbidity in Schoharie Reservoir, and water quantity in the West of Hudson system assuming static demand (DEP 2009b). Phase 2 of the research program currently under way will link more robust GCM downscaling methods with improved models and updated data for a more comprehensive analysis.

These modeling system applications strongly depend upon the ongoing data development efforts of the GIS and monitoring programs. Stream, reservoir and aqueduct, and meteorological data are all needed to develop, calibrate, and validate models. Stream monitoring includes flow monitoring and targeted water quality sampling to support watershed and reservoir model development, testing, and applications. Reservoir monitoring provides flow and reservoir operations data to support reservoir water balance calculations, and reservoir water quality data to support testing the eutrophication model. The meteorological data collection effort provides critical input necessary to meet both watershed and reservoir modeling goals.

Modeling system development and applications are currently supported by postdoctoral research projects in collaboration with the City University of New York. These projects include statistical downscaling and evaluation of GCMs for the NYC watershed region; evaluation of NYC water supply performance using NYC-OASIS Supply System Model and system indicators; SWAT-WB model development and testing for NYC watersheds; improved sediment loading predictions for Catskill System reservoirs using multivariate analysis; application of the RHESSYS Forest Ecosystem Model to NYC watershed forests; and calibration and testing of 1-D eutrophication models and 2-D turbidity models for NYC reservoirs. These projects support the continued improvement and expanded capabilities of the modeling system.

Geographic Information System

DEP's upstate Geographic Information System (GIS) was used during the assessment period to manage the City'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 supported numerous FAD and Memorandum of Agreement watershed management applications as described in annual reports to EPA. The reports describe progress in applying the GIS to watershed management, completing new data layers, incorporating data layers into the modeling database, disseminating data to stakeholders and the public upon request, and improving GIS infrastructure.

The GIS program was and continues to be managed cooperatively by the Bureau's Watershed Protection and Planning Directorate (WPP) and the Water Quality Directorate. In addition to providing GIS project support, GIS staff managed the centralized GIS infrastructure, laboratory, and database content, including developing capital and expense budgets, as well as capital proposals to address future GIS needs. DEP's Office of Information Technology (OIT) provided much of the technical support for hardware, software, and database administration. GIS resources were utilized by Bureau of Water Supply (BWS) staff at offices throughout the watershed, directly and via the Watershed Lands Information System (WaLIS).

GIS staff routinely:

- acquired, updated, or developed new GIS data and metadata;

- performed GIS analysis and research;
- produced maps and statistical reports;
- fulfilled requests for Bureau-specific data from other agencies and watershed stakeholders;
- trained and supported other DEP staff, interns, and local government agents in the use of Global Positioning Systems (GPS) for project-specific data gathering efforts;
- provided support in the acquisition, management, and analysis of remotely-sensed data such as satellite or aerial imagery for watershed-wide land use and topographical (terrain) mapping.

Progress in GIS Watershed Management Applications

During the evaluation period, the GIS program provided technical support and data development, including extensive GPS fieldwork, for a variety of protection programs and modeling applications in the following areas:

- State Environmental Quality Review Act (SEQRA) review and regulatory mapping
- stormwater infrastructure mapping and inspection
- evaluation of environmental site constraints for new development
- land acquisition prioritization
- open space mapping
- water supply infrastructure mapping
- municipal sewer infrastructure mapping
- septic repair prioritization and mapping
- forestry management
- water quality compliance monitoring
- reservoir morphometry (bathymetry)
- land cover and impervious surface mapping and tracking
- stream assessment and riparian vegetation classification
- wetland trend assessment
- invasive species mapping and assessment
- modeling evaluation of watershed management programs
- land use, soil, and meteorological inputs for modeling
- climate change impact assessment

Completion of New Data Layers

Over the past five years, volumes of new feature classes and tables were created and placed in the GIS library, and several existing feature classes were updated or overhauled. This included the acquisition of high-resolution aerial data and their derived products. Mission-critical datasets to various DEP programs that were continuously developed or updated included annual digital tax parcel updates for all watershed counties, NYC-owned land or interests, NYS-owned land, DEP water supply facilities, stream reaches and restoration projects, septic repairs, engineering project locations, regulatory hydrological buffers, and United States Geological Survey (USGS) and DEP stream monitoring gages and sites.

In 2009-2010, DEP collaborated with the New York State Office of Cyber Security and Critical Infrastructure Coordination (NYS CSCIC) to collect wall-to-wall aerial data products over all NYC watersheds and aqueducts, as part of NYS CSCIC's Digital Orthoimagery Program. This program enables participating state municipalities to leverage their resources through cooperative data acquisition activities using cost-sharing and economies of scale. DEP's datasets encompass an area of approximately 2,700 square miles, and include 1-meter Light Detection and Ranging (LiDAR)-based topography, 1-foot Leaf-off 4-band orthoimagery, and 1-foot Leaf-on 4-band orthoimagery. Aerial data were collected in spring and summer 2009 and delivered in summer 2010. Additional data products, such as enhanced hydrological stream networks, drainage delineations, a high resolution level 4 land use and land cover dataset, and impervious surface data set, will be derived from this aerial collection in 2010-2011.

GIS staff of the water quality modeling unit continued to develop and improve spatial data necessary for modeling applications. As new or updated NRCS SSURGO2 soil data became available for the watershed counties, they were downloaded, processed, and added to the GIS library. These data are used in conjunction with the Soil Data Viewer extension for ArcGIS to create derivative layers of soil physical properties. Given updated, watershed-wide soil information, it was possible to complete the task of deriving rasters of Topographic Index and Enhanced (Soil) Topographic Index, key inputs for GWLF-VSA (Variable Source Area) modeling. Similarly, updates of the National Hydrography Dataset (NHD) for the Hydrologic Unit Codes that comprise the watershed were processed and incorporated into the GIS library.

A point feature class of DEP water quality monitoring sites was created to replace four existing datasets (stream, reservoir, keypoint, and pathogen monitoring sites). In the ArcSDE geodatabase, the feature class is linked to SQL tables containing attribute data of the Laboratory Information Management System (LIMS) and of the Site Assessment and Management Inventory (SAMI) database. Datasets of meteorological, snow, and USGS stream gages were also improved. These point locations are important for defining modeling areas of interest, deriving spatial data inputs using the GWLF-VSA Inputs Tool, and assessing time-series data availability for each study area. New and updated data for modeling were placed either in the ArcSDE geodatabase or in the coverage library, where a portion of modeling data continues to reside.

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 GIS data to CDs as required for data sharing. Stakeholders and communities that are on a schedule to receive semi-annual data updates, such as newly-acquired lands, were sent data via email or CD as they became available. In 2009, staff created a detailed GIS data catalog that inventories all of the BWS's current QAed GIS holdings. The catalog describes each GIS dataset and whether it is shareable, proprietary, or confidential/sensitive. A separate "shareable to public" catalog has also been created as a subset which can be distributed to data requestors, such as stakeholders or consultants working on a DEP project who need to know what data exists. This inventory also satisfies a DEP-wide requirement for cataloging and providing inventory of GIS data to OIT and NYC's Office of Emergency Management.

GIS Infrastructure Improvement

GIS infrastructure was substantially upgraded throughout the evaluation period in several areas, including geodatabase structure, hardware, software, and enterprise database applications.

DEP completed the migration of the GIS library from an aging Unix/Oracle platform to an OIT-standard Windows 64-bit/SQL Server platform. In addition to improving performance for users of native-GIS software such as ArcGIS, this migration simplified the manner in which the GIS is integrated into other database management systems such as WaLIS, a function of the fact that SQL Server is the common database platform. This platform is also more easily supported by in-house OIT, which is now managing the SDE Geodatabase as well as providing ESRI software management enterprise-wide. In 2010, new Windows-based servers were procured to replace older ones from 2006 no longer under maintenance. This will also provide much-needed additional server storage space to accommodate new large aerial datasets, as well as a growing body of WaLIS database attachments. GIS-capable workstations for 24 advanced GIS users, including data developers, were procured in 2007, and most of these will be upgraded again in late 2010 to keep up with changing software and operating system technology requirements.

The GIS database administrator managed the GIS library throughout the latter part of the assessment period by creating and updating geodatasets, maintaining file geodatabase copies of the library, and supporting spatial data development for WaLIS. During the past year, the GIS database administrator installed and configured a production instance of ESRI Image Server for the storage and dissemination of raster datasets, particularly orthoimagery. This marks a significant improvement in the GIS library, because Image Server reduces raster preprocessing, increases scalability, and boosts client performance. Several ArcSDE raster datasets have already been migrated to Image Server. Moving forward, all new raster acquisitions will be hosted in Image Server.

Since early 2006, the GIS program has taken on the role of managing the complete redesign, cleanup, and broader implementation of WaLIS throughout DEP. WaLIS is a custom database application, developed in-house in Kingston through contracted support, that manages information about the watershed lands and resources owned by NYC and its neighbors. It is a labor-saving system that uses GIS data analyses, relational database management, document management, and workflow and reporting capabilities to primarily support WPP Watershed Lands and Community Planning and Regulatory Review and Engineering, with GIS data serving as the common data element to their distributed databases.

WaLIS saves a significant amount of staff time within each supported group by reducing the amount of time spent analyzing data, tracking/auditing information, and generating reports through manual means. WaLIS's map preparation tools provide a way for DEP users of various skill levels to explore data and print quality maps, including aerial views, of watershed lands and resources, as well as review the data and history of each area. WaLIS was upgraded in 2008 to provide the user with an easier-to-use system, improve maintenance and support capability by switching to OIT-compliant technologies, enhance mapping capability, and implement DEP-wide enterprise security standards. The GIS program continued to develop, upgrade, and maintain WaLIS with the development of version 4.1, released in April 2010. The GIS program has finished the full integration into WaLIS of previously stand-alone applications such as the Land Acquisition Tracking System (LATS), Property Tax Payments (TAXIS), Engineering Project Review, and the Land Use Permits databases. WaLIS currently operates on the workstations of approximately 220 registered DEP users.

The GIS has evolved over the past five years into a mature enterprise solution that is widely accessible through native GIS software and through its integration into other database applications. The GIS provides visualization and analysis tools that assist in the design, implementation, and evaluation of water quality monitoring and watershed protection programs in a unique spatial and temporal context. With this foundation in place, it will continue to be a useful tool in four primary areas:

- Inventory and tracking of water supply lands and facilities
- Analysis of land use and terrain to map development, agriculture, forest, and hydrography
- Estimating the effects of watershed management programs on long-term water quality
- Supporting watershed and reservoir modeling of water quantity and quality, and modeling of system operation

2.18 Waterborne Disease Risk Assessment

New York City's Waterborne Disease Risk Assessment Program (WDRAP) was established to: (a) obtain data on the rates of giardiasis and cryptosporidiosis, along with demographic and risk factor information on case-patients; (b) provide a system to track diarrheal illness to ensure rapid detection of any outbreaks; and (c) attempt to determine the contribution (if any) of tap water consumption to gastrointestinal disease. The program is jointly administered by the Bureau of Communicable Diseases (BCD) of the New York City Department of Health and Mental Hygiene (DOHMH) and DEP's Bureau of Water Supply (BWS). WDRAP was initiated in 1993 and consists of active disease surveillance and syndromic surveillance as its major and ongoing components. In addition, some outreach/education activities are undertaken.

2.18.1 Active Surveillance

Active 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. Giardiasis and cryptosporidiosis rates in NYC have been on a general downward trend over the years of this surveillance program. A review of the data collected shows an 83% decrease in cryptosporidiosis cases in New York City from 1995 to 2009. NYC cryptosporidiosis rates have been comparable to national rates, although they have recently trended down while national rates have increased. In NYC there has been a 67% decrease in giardiasis cases since 1994. Rates of giardiasis nationally have also declined.

Attempts are made to interview all patients with cryptosporidiosis regarding commonly reported potential risk exposures, tap water consumption, and HIV/AIDS status. However, it must be noted that the determination of an association between exposure to possible risk factors for cryptosporidiosis and acquisition of cryptosporidiosis cannot be made without reference to a suitable control population (i.e., non-*Cryptosporidium*-infected controls). As exposure data for a control population are not available, such determinations of association cannot be made. Though no conclusions about association can be reached, in an attempt to assess if there are any patterns of interest, data have been compared between patients who are immunocompromised due to HIV/AIDS and patients who are immunocompetent. Looking at four potential risk categories using the chi-square test to compare data since 2001, the following results were observed. Patients who were immunocompetent were significantly more likely to report international travel in all years (p<0 .01), and to report exposure to recreational water in all years except 2003, 2006, and 2007 (2001-2002, p<0.01; 2003, p=0.17; 2004, p<0.05; 2005, p<0.01; 2006, p=0.24; 2007, p=0.06; 2008, p<0.05; 2009, p<0.01). There was no statistically significant difference between these two groups in the proportion of cases reporting animal contact in 2001 to 2009, or reporting high-risk sex in 2001 to 2005, 2007, and 2009. In 2006 and 2008, the proportion of cases reporting high-risk sex was significantly higher among persons with HIV/AIDS than among immunocompetent persons (p<0.01). (Note that "high-risk sex" in this context refers to practices which facilitate fecal-oral transmission, which is different than other more commonly-used meanings of the phrase.) Information about sexual practices is gathered via phone interview and may not be reliable. These data indicate that immunocompetent case-patients are more likely to travel internationally and have recreational water exposure than immunocompromised case-patients. International travel and exposure to recreational water may be more likely risk factors for the acquisition of cryptosporidiosis in the immunocompetent group. However, as noted above, the extent to which these risk factors may have been associated with cryptosporidiosis cannot be determined without comparison to a control population.

Two general programmatic modifications in NYC's giardiasis and cryptosporidiosis active surveillance programs have occurred during the period of this assessment report:

- On April 26, 2010, questionnaires administered to case-patients concerning potential exposures to *Cryptosporidium* were revised to focus on exposures 14 days rather than 30 days before onset. This change was made after reviewing the current literature regarding the incubation period for cryptosporidiosis, and after consulting with personnel at the New York State Department of Health (DOH) Regional Epidemiology Program and at the Centers for Disease Control and Prevention's (CDC's) Waterborne Disease Prevention Branch.

- Since 2008, data collected from WDRAP have been reported to EPA twice a year in an annual and semi-annual report, rather than three times a year with an annual and two semi-annual reports as was done previously. (For reference, for years 1993-2002, the reporting frequency was quarterly plus an annual report.) The semi-annual reports primarily contain case rates and demographic findings and use preliminary data, while the annual report contains final rates, demographics, and information from cryptosporidiosis case investigations.

2.18.2 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. The systems WDRAP is currently using are described below.

Clinical Laboratory Monitoring

The number of stool specimens submitted to clinical laboratories for bacterial and parasitic testing provides information on gastrointestinal illness trends in the population. Participating laboratories transmit data by fax or by telephone report to DOHMH indicating the number of stool specimens examined per day for (a) bacterial culture and sensitivity, (b) ova and parasites, and (c) *Cryptosporidium.* One of the two laboratories in the system recently closed so now one large laboratory provides data for this system. The stool analysis work that had been conducted by the lab which closed is now directed to the other lab participating in NYC's Clinical Lab monitoring program. Therefore, NYC does not believe that there has been a significant reduction in results reported to DOHMH as a result of the closure. In August 2004, DOHMH started implementation of a computer model to establish statistical cut-offs for significant increases in clinical laboratory submissions.

Medication Monitoring

The tracking of sales of anti-diarrheal medications is a potentially useful source of information about the level of diarrheal illness in the community. NYC began tracking anti-diarrheal drug sales as a public health indicator in 1995. Modifications to NYC's anti-diarrheal surveillance program have been made over the years. Currently NYC utilizes two separate systems to monitor sales of anti-diarrheal medications: the ADM (anti-diarrheal medications) system and the OTC (over-the-counter) system. Both systems involve the tracking of over-the-counter or non-prescription anti-diarrheal medications.

The ADM System

NYC's ADM system, established in 1996, utilizes volume-of-sales information of non-prescription anti-diarrheal medications obtained weekly from a major drugstore chain. Until March 2010, the program was operated as follows. Weekly sales volume data reports for loperamide and non-loperamide anti-diarrheal medications from electronic store scanners were sent to DEP, where the data were entered into a database, sorted into drug formulation categories, graphed, and visually compared to historic data. Sales volume data were examined citywide, by borough, and by basic drug formulation category. Information was also obtained on promotional sales of ADM products and promotional data were considered in interpreting the sales volume. In 2008, a quality control issue was discovered with regard to the promotional sales data. A corrective action report was prepared on this matter and modified procedures were implemented. In March 2010, DEP implemented its enhanced ADM system as a pilot program. The enhanced program includes the following features:

- ADM data are received in digital format on a daily basis, and are analyzed and reported out on a five days/week schedule.
- More data are included (more anti-diarrheal products, and from more stores).
- Data are run through CDC's Early Aberration Reporting System (EARS) for analysis of signals, looking at citywide and borough-specific sales. EARS uses three aberration detection methods, which are based on a one-sided positive cumulative sums calculation.
- Data are also received on health and beauty product sales volume and are used to "normalize" the analysis (e.g., to help account for changing store traffic on different days of the week).
- Data on promotional sales vs. non-promotional sales are provided directly by the data provider.

The OTC System

The second of the currently operating drug monitoring systems, the OTC system, was started in 2002 by DOHMH. This system involves the monitoring of anti-diarrheal medication sales at a second large store chain. The goal was to develop a system that would provide more timely and detailed data than the ADM system in place at the time. The OTC system also collects data on other medicines, for broader bioterrorism and emerging infectious disease surveillance purposes. Routine daily analyses began in mid-December 2002. Drugs are categorized into key syndromes, and trends are analyzed for citywide increases in sales of non-prescription anti-diarrheal medications. The gastrointestinal category includes generic and brand name loperamide-containing agents and bismuth subsalicylate agents.

In addition to the OTC system, DOHMH received daily data from a third tracking program, the National Retail Data Monitor (NRDM), during the period May 2003-November 2007. This system, based at the University of Pittsburgh, gathers retail pharmacy data from national chains for use in public health surveillance. DOHMH stopped receiving NRDM data in November 2007 as a result of DOH's decision to discontinue a state-wide license to procure and disseminate the data to health departments. DOHMH concurred with this decision, since the data were primarily used as an adjunct to NYC's other systems and because the discontinuation of this data flow would have little impact on syndromic surveillance activities. The last date of complete and analyzable NRDM data received at DOHMH was November 12, 2007. DOH and EPA were formally notified of the program's discontinuance on November 16, 2007.

Hospital Emergency Department Monitoring

New York City initiated monitoring of hospital emergency department (ED) visits as a public health surveillance system in 2001. Currently, DOHMH receives electronic data from 49 of NYC's 54 EDs, reporting approximately 10,000 visits per day, roughly 95% of all ED visits citywide. Hospitals transmit electronic files each morning containing chief complaint and demographic information for patient visits during the previous 24 hours. Patients are classified into syndrome categories, and daily analyses are conducted to detect any unusual patterns or signals. The two syndromes used to track gastrointestinal illness are vomiting syndrome and diarrhea syndrome. Temporal citywide analyses assess whether the frequency of ED visits for the syndrome has increased in the last one, two, or three days compared to the previous 14 days. Spatial analyses scan the data for geographic clustering in syndrome visits on the most recent day compared to the previous 14 days. Clustering is examined by both hospital location and residential zip code. There have been no recent changes to this system.

Nursing Home Sentinel Surveillance

The nursing home surveillance system began in March 1997 and was modified in August 2002. When a participating nursing home notes an outbreak of gastrointestinal illness that is legally reportable to DOH, the nursing home must also notify designated WDRAP team members working in the DOHMH. When an outbreak occurs, specimens are collected for testing for bacterial culture and sensitivity, ova and parasites, *Cryptosporidium*, and viruses. DOHMH staff facilitates transportation of the specimens to the City's Public Health Laboratory. Beginning in April, 2010, specimens collected as part of this protocol have also been tested for *Clostridium difficile* toxin. This change addressed a need expressed by infection control practitioners in the nursing homes, and was intended to help ensure compliance with the sentinel nursing home protocol. From 2002 to 2005, nine nursing homes participated in sentinel surveillance. In 2006 one nursing home did not respond to requests for continued participation. Since then, eight nursing homes have been participating in sentinel surveillance. Otherwise, there have been no significant changes to the system since 2002.

Summary

As described in previous WDRAP reports, data from syndromic surveillance systems have proven useful in demonstrating annual citywide seasonal trends of norovirus and rotavirus. Knowledge of these trends provides a baseline of data which should improve the City's ability to detect aberrations.

2.18.3 Activation of *Cryptosporidium* Action Plan in Response to Pathogen Finding

In mid-November 2008, unusually high counts of *Cryptosporidium* and *Giardia* were found in a sample collected from the New Croton Reservoir raw water effluent by the DEP Pathogen Laboratory. Although it was quickly suspected (and later corroborated) that the elevated sample results were due to a laboratory error, a modified version of NYC's *Cryptosporidium* Action Plan (CAP) was activated. The City's surveillance systems showed no evidence of increased illness in relation to the incident.

2.18.4 Outreach/Education

Outreach and education activities continued during the current assessment period. Outreach is primarily conducted by DOHMH BCD staff, including presentations to clinicians and others at public health/medical schools on the topic of parasitic diseases. DEP BWS staff have also provided public health school presentations covering WDRAP topics. In 2008, staff members in DOHMH BCD and DOHMH Public Health Engineering partnered with the CDC to develop health promotional materials for the City's swimming pool users and operators. This effort was undertaken in response to increasing numbers of recreational water outbreaks in the United States caused by *Cryptosporidium*.

2.18.5 Conclusions

During the current assessment period (2006-2010), the only major change in WDRAP was a series of enhancements to the ADM monitoring program in 2010. All other changes have been minor and some of them—such as the number of hospitals in the emergency department system and the number of laboratories in the clinical laboratory system—are a result of the consolidation of the health care system in New York City, with hospitals and laboratories closing and merging. Also during the assessment period, there was no evidence of an outbreak of waterborne disease in the City. WDRAP program implementation continues, and reports continue to be prepared and submitted as per the FAD schedule.

3. The Catskill System

3.1 Introduction

Water quality analyses cover a longer time period than the five-year period described for program implementation in Chapter 2. Therefore, several decades of data were used to provide long-term context for interpretation. Selection of this extensive time period was done in order to use a sufficiently long time to capture changes in water quality in response to watershed protection programs. Doing so provides a view of these changes in the context of natural variation (such as floods and droughts), which are not sufficiently represented in a five-year period. The water quality data used in this analysis begin in 1993, which represents conditions at the outset of filtration avoidance when many watershed protection programs were in their infancy. The data from this time represent conditions with fewer watershed safeguards in place. The time period of the analysis extends through 2009, which allows DEP to examine trends over the past 17 years, as new and intensified watershed protection programs have been implemented. Another reason for using long-term data is the fact that there are time lags between program implementation (causes) and water quality changes (effects). Sufficient time must pass after programs are in place in order to see the full effects of programs on water quality. Therefore, further improvements in water quality will evolve as the full effects of the programs develop and stabilize.

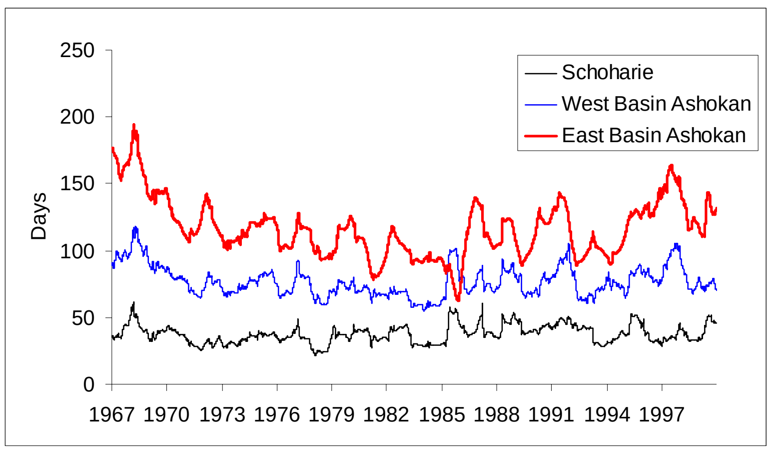

Figure 3.1 Catskill System reservoir water residence times over a 30-year time period (1967 through 1997).

There are several important factors that govern water quality over the long term. Perhaps the two most important are climate, as a determinant of 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 three basins in the Catskill System over a 30-year period (1967 to 1997) are depicted in Figure 3.1. Overall, water residence time is determined by the relationship of hydraulic load to basin volume, so reservoirs with large catchment areas and high hydraulic loads relative to their volume (such as Schoharie) have short water residence times (or high flushing rates). The three basins of the Catskill System have characteristically different residence times. Schoharie consistently has the shortest water residence time (averaging about 40 days), whereas the east basin of Ashokan has the longest water residence time (averaging about

110 days). 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 Schoharie would adjust to new loading levels, for example, in about four months, whereas East Ashokan would take about a year's time to re-equilibrate to a new steady state.

Water residence times of these four reservoirs vary, as illustrated in Figure 3.1. The Schoharie is one of two reservoirs in the City's Catskill System, and the northernmost reservoir in the entire water supply system. For a reservoir of its size, Schoharie has a very large watershed and consequently a short water residence time, i.e., a high flushing rate (Figure 3.1). Water typically flows through the reservoir in one to two months. It was designed to collect water from a large area and divert it into the Shandaken Tunnel, where it travels southeast 18 miles and enters Esopus Creek at the Shandaken Portal in Ulster County. It then flows another 11 miles down the Esopus into Ashokan Reservoir for longer-term storage and settling. When it leaves Ashokan, it is carried southeast under the Hudson River via the 92-mile Catskill Aqueduct. It ordinarily makes its way to Kensico Reservoir in Westchester for further settling and mixing with Delaware System water, before moving down aqueducts to Hillview Reservoir in Yonkers and entering New York City's water supply distribution system.

Over the short term (i.e., less than a year), there are other influences that affect water quality. These account for the high degree of variation seen in the plots of water quality data over 17 years. Seasonal variations in precipitation and temperature affect runoff and stratification, which also affect water quality from week to week and storm to storm. Since DEP's objective was to look for trends in the water quality data over the time period of program implementation, statistical techniques for the water quality trend analysis were chosen to minimize the influence of seasons on long-term trends. In addition, concentrations were flow-adjusted, as appropriate, in order to minimize the influence of short-term flow changes on trend detection. With this approach, DEP has examined the relationships between watershed protection and water quality changes.

Some summary information on program implementation in each basin follows the land use description. This serves as a brief reminder 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 Chapter 2. Cumulative figures are provided to show the progress of watershed protection over the past decade and to give insight into what has been accomplished in terms of watershed improvements. Best management practices for farming, stormwater control through environmental infrastructure, stream management, and septic remediation are among the programs that have reduced the loading of pollutants to the water supply. One other activity depicted is boating permits, as an indication of reservoir use by the public. This has been fairly stable over the past decade.

Water quality status and trends are then described. Status is presented as a three-year monthly median and trends are evaluated for a 17-year period. The analytes chosen were those most important for the Surface Water Treatment Rule and meeting the requirements of the 2007 Filtration Avoidance Determination. Macroinvertebrate data provide insight into the ecological condition of streams and form the basis for an index to track changes that can demonstrate water quality improvements. The impact of the waterfowl management program and its ability to control and reduce fecal coliform bacteria over the past five years are demonstrated. 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 distribution, so it is by design that program intensity is higher in these basins than others. Finally, an analysis of pathogen transport through the system is presented. This provides much insight into the benefit of NYC's sequential system of reservoirs and its ability to improve water quality as water travels towards distribution.

3.2 The Schoharie Basin

Schoharie Reservoir is located at the intersection of Schoharie, Delaware, and Greene Counties, about 36 miles southwest of Albany and roughly 110 miles from New York City. Placed into service in 1926, it was formed by damming Schoharie Creek, which continues north and eventually drains into the Mohawk River, which flows into the Hudson north of Albany. The reservoir consists of one basin, almost 6 miles in length, and holds 17.6 billion gallons at full capacity.

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. Presently, there are 12 wastewater treatment plants (WWTPs) sited in the Schoharie watershed, producing approximately 0.715 million gallons per day (MGD) of flow. As per the most recent SPDES permits, the plants are limited to a collective release of 2.2 MGD of flow.

Of the 202,017 acres of land in the Schoharie watershed, 172,055 acres (85.2%) are forested, 9,404 acres (4.7%) are urban or built-up land, 11,080 acres (5.5%) are brushland or successional land, and 92 acres (0.0%) are classified as barren land. Wetlands comprise 3,295 acres (1.6%) of the watershed, while 1,659 acres (0.8%) are water. The remaining 4,432 acres (2.2%) are in agricultural use (Figure 3.2). (Note that agricultural land use differs between this pie chart and the subsequent bar chart because the agricultural program includes grassland and brushland used as farmland.)

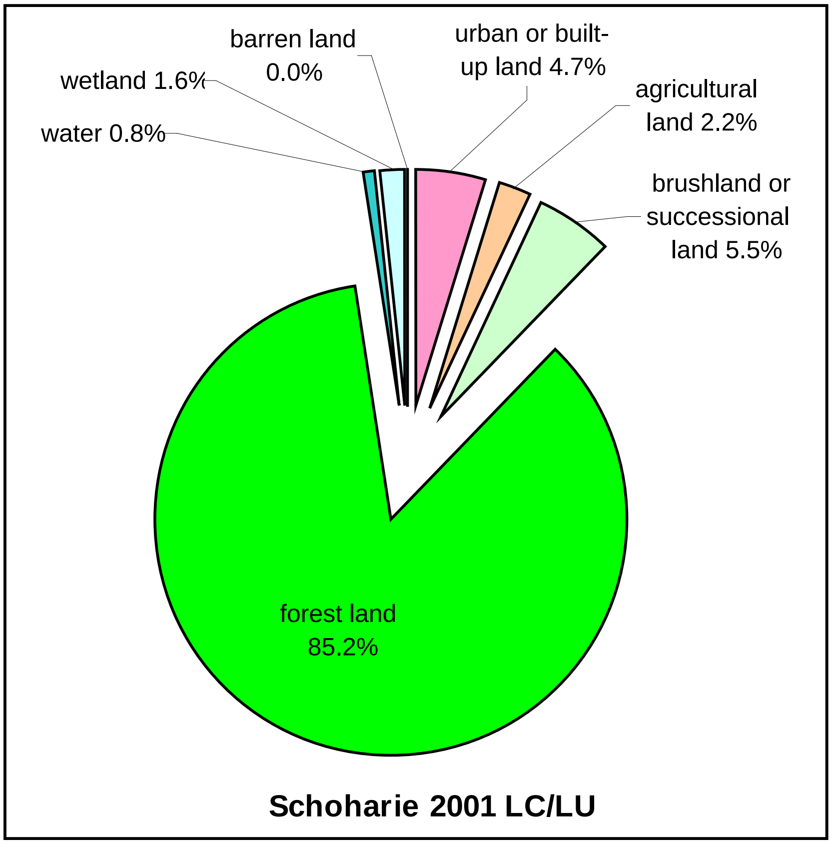

Figure 3.2 Land use in the Schoharie drainage basin based on 2001 data.

3.2.1 Program Implementation (Schoharie Basin)

Since 1996 over 250 best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater (Figure 3.3a). These BMPs are associated with over 8,000 acres of farmland (i.e., more than 4% of the drainage basin area). Over the last decade, nearly 50 additional environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects (Figure 3.3b). More than 600 septic systems throughout the basin have been remediated during this time period (Figure 3.3c). Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Chapter 2 of this report.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Schoharie has remained at about 200 in recent years, which is somewhat higher than in the early part of the decade, when the average was approximately 160 boats (Figure 3.3d).

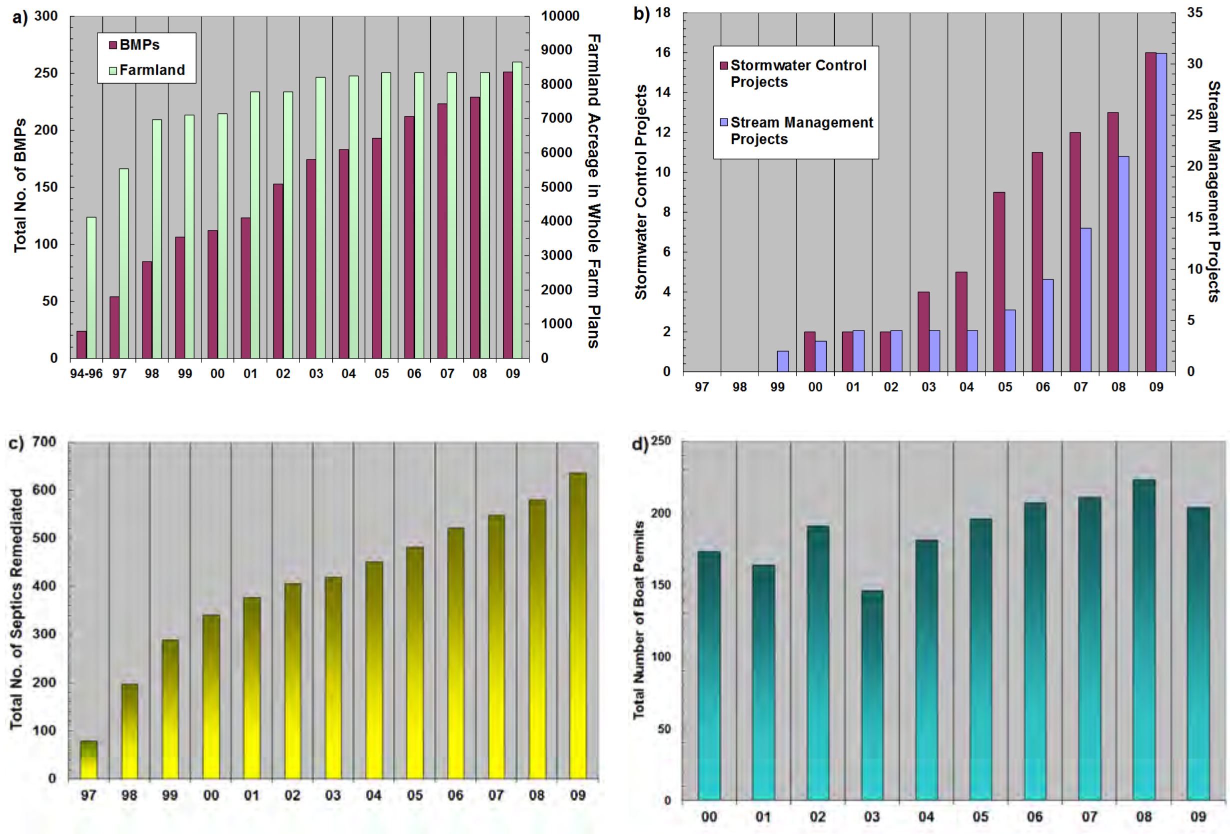

Figure 3.3 History of watershed programs in the Schoharie drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control and stream management projects, c) septic system remediation, d) number of boat permits issued.

Note: Bars in plots (a)-(c) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the Schoharie Basin

Inputs of phosphorus, as well as other pollutants, from WWTPs to Schoharie Reservoir continue to be reduced as a result of DEP's effort to upgrade all surface-discharging WWTPs, including upgrades of the City-owned plants at Tannersville and Grand Gorge, and the addition of new infrastructure plants at Windham and Prattsville. The intervention and involvement of DEP's WWTP Compliance and Inspection Program (Section 2.12.2) also assures the role of these plants in reducing nutrient loadings.

As illustrated in Figure 3.4, phosphorus loads (as total phosphorus) declined considerably from 1994 to 2009, 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 and Prattsville, constructed as part of DEP's New Infrastructure Program (NIP) (see

Section 2.7.3). The increase in flow seen between 2004 and 2009 reflects the completion of these plants. Note, however, that even with these additions, total phosphorus loads reached an all-time low in 2009.

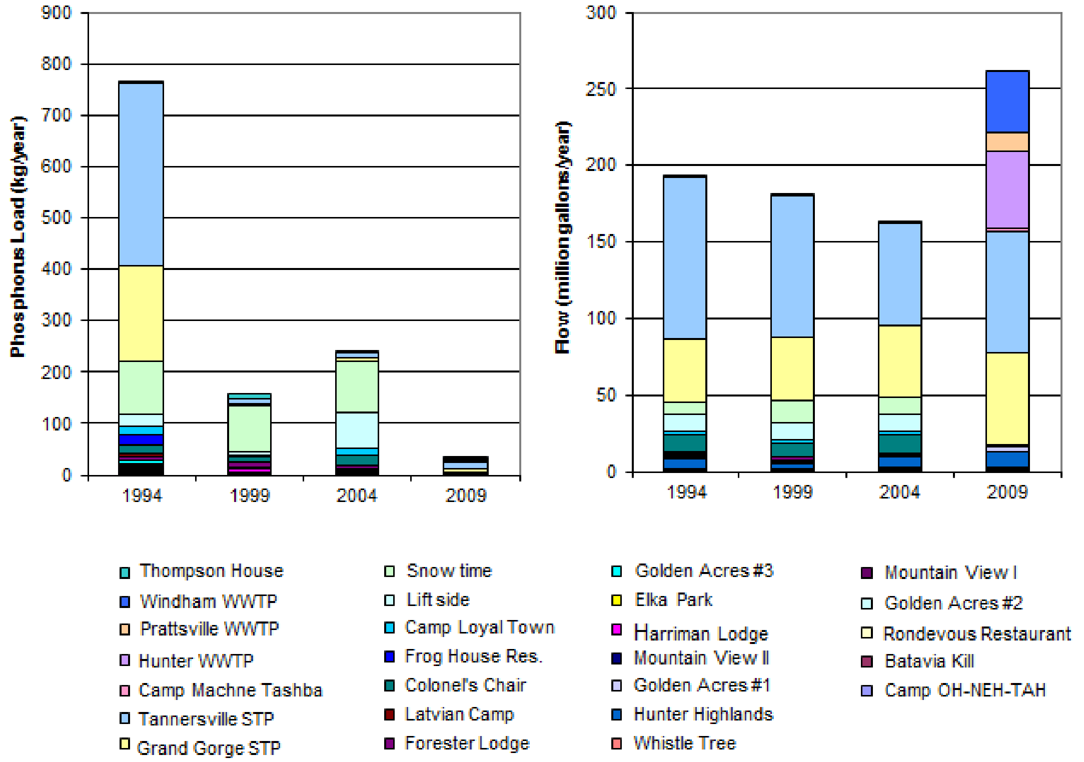

Figure 3.4 Wastewater treatment plant total phosphorus loads and flows in the Schoharie drainage basin, 1994-2009.

3.2.2 Water Quality Status and Trends (Schoharie Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 3.5. Two time periods are assessed for each site: i) the full period of record, and ii) a three-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deterioration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

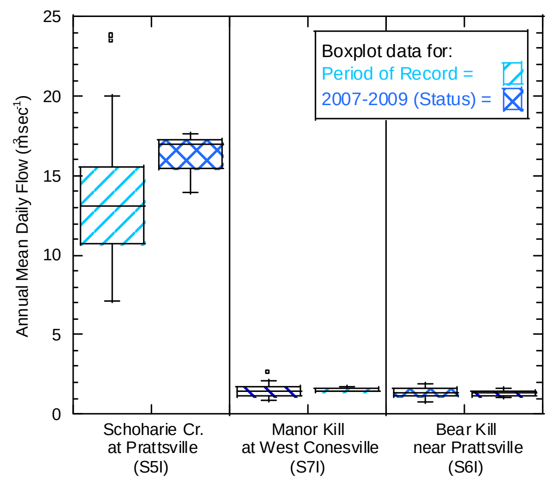

Figure 3.5 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the Schoharie watershed.

Schoharie Creek at Prattsville is the primary inflow to Schoharie Reservoir. It drains 75% of the basin (Table 3.1). The status period's mean annual daily flow median was about 4 $m^3 sec^{-1}$ greater than the long-term median. Therefore, flows in the status period were higher than usual.

Table 3.1: DEP sample site descriptions for the Schoharie watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
S5I	Schoharie Creek at Prattsville	74.9%	November 1902-present
S7I	Manor Kill at West Conesville	10.3%	July 1986-present
S6I	Bear Kill near Prattsville	8.3%	October 1998-present

Status (Schoharie Basin)

The Schoharie basin status evaluation is presented as a series of boxplots in Figure 3.6. The input is Schoharie Creek (S5I), the reservoir is designated as SS, and the output is designated as SRR2. All values below the maximum detection limit line for fecal coliform and total phosphorus (blue lines) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

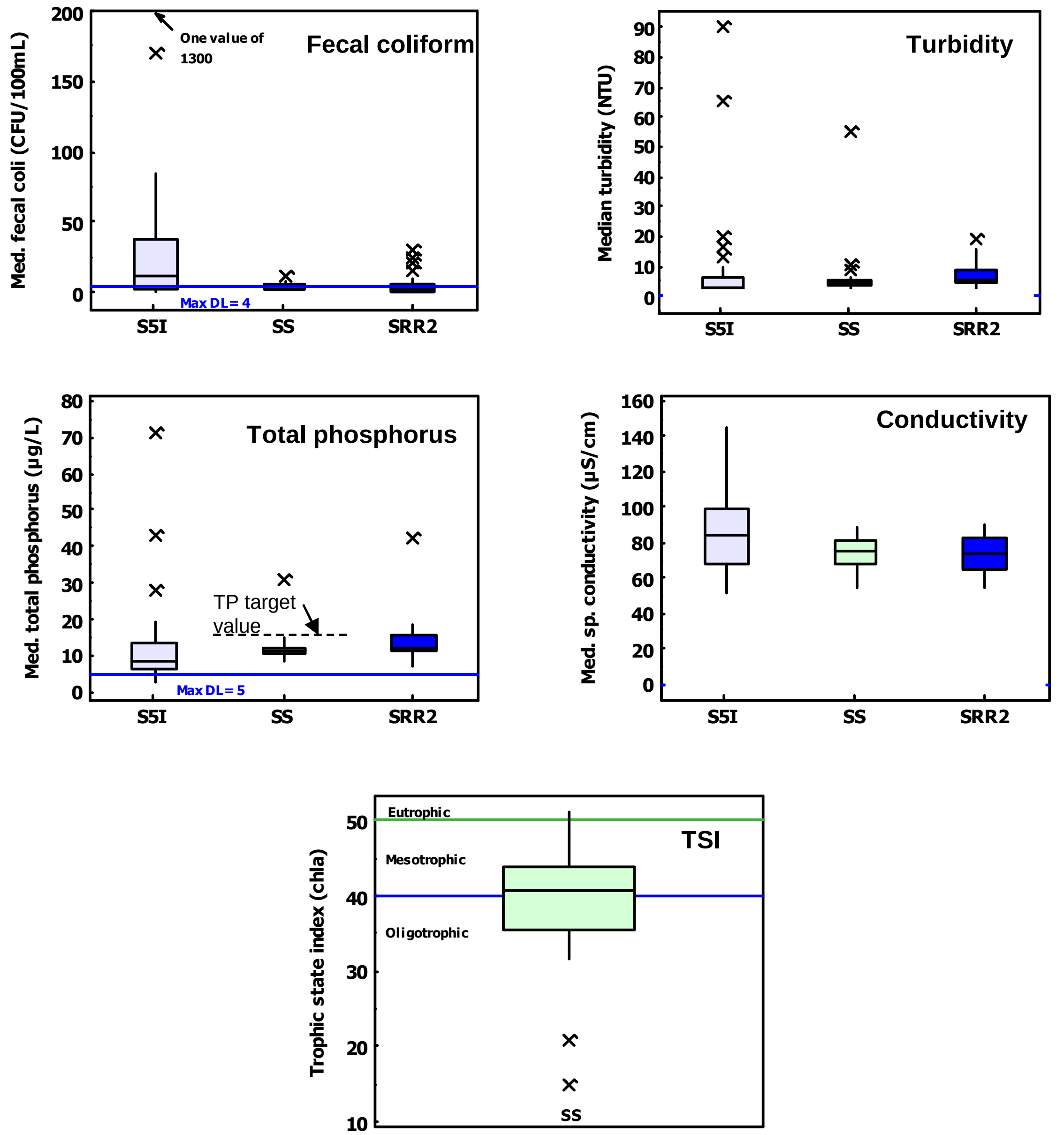

Figure 3.6 Water quality status boxplots using 2007-2009 monthly data for the Schoharie basin main stream input at Schoharie Creek (S5I), Schoharie Reservoir (SS), and the output at the Shandaken Portal (SRR2).

In general, one would expect input stream levels of fecal coliform bacteria to be higher than the corresponding reservoir or output levels, and that is demonstrated in the boxplots. All but one point for the input stream to Schoharie Reservoir were well below the DEC Stream Guidance Value of 200 CFU 100 mL^{-1} during the 2007-2009 analysis period. The reservoir-wide values and the values for the output for fecal coliform during this same time period were much lower than the stream. Due to the large number of data points below the detection limit, non-detect statistics were used to obtain the boxplots. In Schoharie's case, values below the maximum detection limit of 4 CFU 100 mL^{-1} were estimated by the statistics.

Turbidity values were broadly similar among the input, reservoir, and output. The similarities in the boxplots can be attributed to particulates, which cause turbidity in the basin and do not settle quickly. Consequently, attenuation through the system is low. As can be expected, there were some occurrences of higher values in the input stream, S5I.

Total phosphorus (TP) concentrations show a broadly similar pattern to turbidity, because TP is associated with the same clay particulates that cause turbidity. Reservoir-wide TP values were generally well below the phosphorus-restricted target value of 15 μg L^{-1} with a few exceptions.

The Trophic State Index (TSI) values for Schoharie Reservoir primarily ranged from oligotrophic to mesotrophic for the three-year period. In general, light penetration is a limiting factor for primary production in this reservoir due to suspended particulates.

There was greater variability in the conductivity in the input stream than either the reservoir or the output of the reservoir. During times of drought, the conductivity in the input stream generally increases; in addition, higher conductivities typically occur in late summer and early fall during periods of lower stream flow. Low conductivities generally occur during storm events. Depending upon the corresponding reservoir elevation, the effects from the stream may be diminished by dilution in the reservoir.

In summary, water quality was good during the 2007-2009 status assessment period in the Schoharie basin. The data for the selected variables show that there were few times when the monthly values exceeded established benchmarks.

Trends (Schoharie Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 3.2).

Water quality trend plots are presented in Figure 3.7 and results of the Seasonal Kendall trend analysis are provided in Table 3.2.

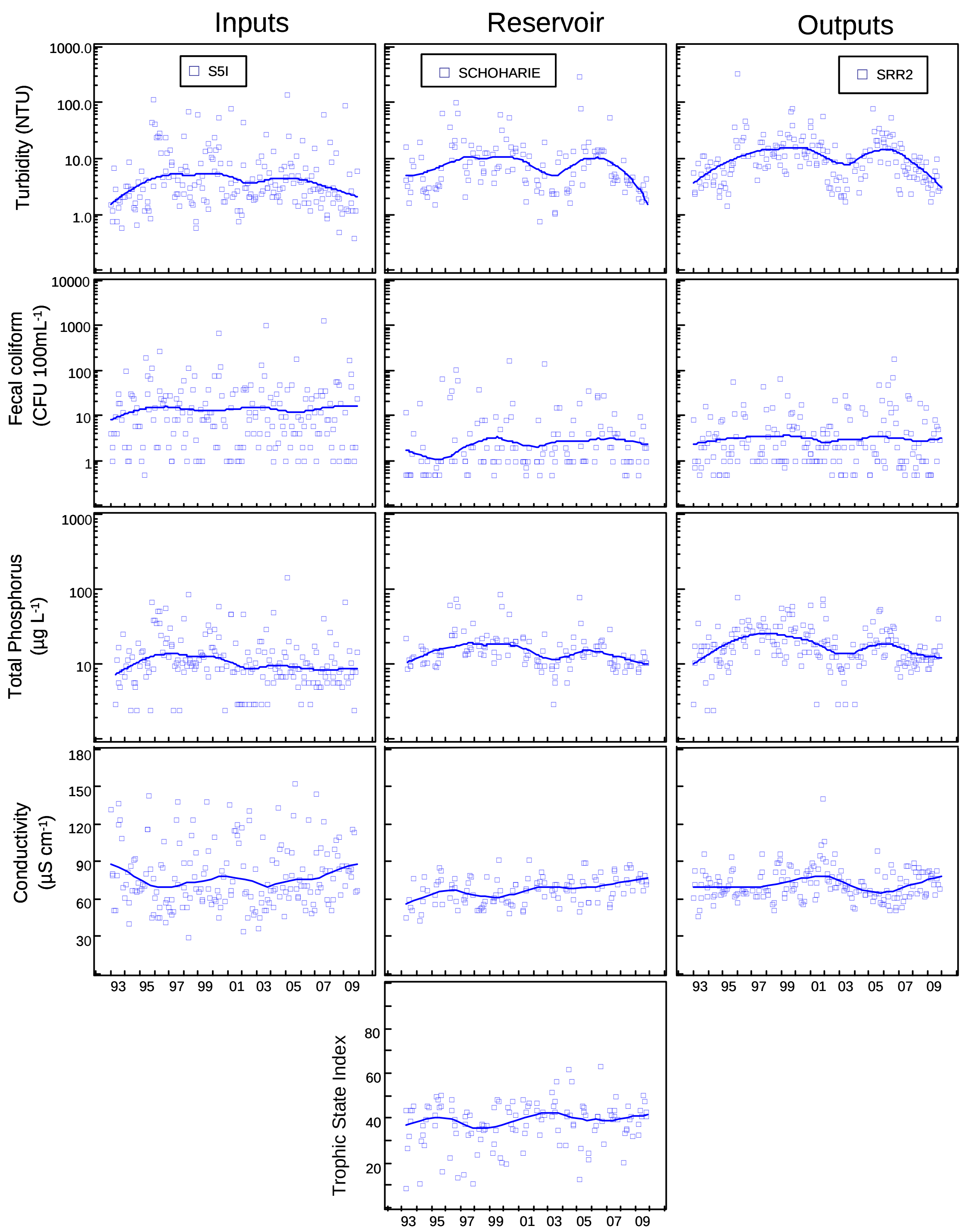

Figure 3.7 Water quality trend plots for the Schoharie basin main stream input at Schoharie Creek (S5I), Schoharie Reservoir, and the output at the Shandaken Portal (SRR2). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 3.2: Schoharie basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
S5I [3]	Input	Turbidity	197	-0.12	***	-0.10
Schoharie	Reservoir	Turbidity	133	-0.09	*	-0.10
SRR2	Output	Turbidity	184	-0.05	NS	
S5I[4]	Input	Fecal coliform	193	-0.01	NS	
Schoharie[4]	Reservoir	Fecal coliform	133	0.05	*	0.00
SRR2[4]	Output	Fecal coliform	181	0.10	*	0.00
S5I [4]	Input	Total phosphorus	191	-0.16	***	0.00
Schoharie	Reservoir	Total phosphorus	127	-0.21	***	-0.38
SRR2	Output	Total phosphorus	184	-0.12	***	-0.25
S5I [3]	Input	Conductivity	193	0.30	***	1.00
Schoharie	Reservoir	Conductivity	125	0.25	***	0.75
SRR2	Output	Conductivity	183	0.02	NS	
Schoharie	Reservoir	Trophic State Index	131	0.17	***	0.40

[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 3.

[4]Data in this row required the use of statistical methods for “non-detect” values.

Downward turbidity trends of 0.10 NTU yr^{-1} were detected in Schoharie Reservoir and in its major input, Schoharie Creek (S5I). Due to the large number of values less than the detection limit, non-detect statistics were used to assess the trends (Helsel 2005). Several notable short-term turbidity trends, common to the input, reservoir, and output, were indicated by the LOWESS curves. Upward turbidity trends in 1995-1997 and 2003-2005 were associated with flood events. The downward trend from 2000-2003 was likely caused by recovery from the floods and by low turbidity loads associated with drought from mid-2001 to 2002. An especially steep decline in turbidity was also apparent from 2006-2009. Several overlapping factors were responsible. In part the decline can be explained as recovery from a large spring runoff event in 2005. Additional factors include mild winter snowmelts coupled with relatively few high intensity rainfall events during the last three years of the data record (2007-2009).

Unlike turbidity, strong long-term phosphorus declines were apparent in the input, reservoir, and output of the Schoharie watershed. In this case, short-term declines, again associated with recovery and drought, plus WWTP upgrades with resultant smaller TP loads delivered to the streams, were sufficient to offset the short-term increases associated with above average runoff in the mid-to-late 1990s and in 2003-2005.

An increasing trend was detected for fecal coliforms in the reservoir. Although the change per year was estimated as zero, the Tau value was positive, indicating an upward trend. As shown by the LOWESS curve, the sharpest increase, from 1995 to 1999, was driven largely by a 1995-1996 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: two dry years followed by three wet years.

Small long-term increases in conductivity were detected in the reservoir (0.75 µS cm^{-1} yr^{-1}) and input (1.0 µS cm^{-1} yr^{-1}). A decrease in annual precipitation since 2003 is one factor but road deicers may have played a role since the chloride concentration increased from 5.2 in 1993-1994 to 9.9 mg L^{-1} in 2008-2009. Trends were not detected in the output. The increase detected in the reservoir was not observed in the output because unlike the reservoir, the output is sampled during winter and reflects dilution from winter melts in 2003-2006.

Productivity was found to increase in the reservoir, with an upward trend of 0.4 yr^{-1} being detected for TSI values. The increase in productivity can be attributed to improvements in water clarity. Turbidity in the reservoir has decreased, especially in recent years, allowing enough additional light to support increased algal growth.

In summary, downward trends were detected for turbidity and TP, while upward trends were detected for conductivity and trophic state. The decline in turbidity is attributable to the mid-2001-2002 drought and to the low frequency of runoff events from 2007-2009. The decline in phosphorus is attributable to recovery from high loads produced by flood events in the mid-to-late 1990s and the spring of 2005. The decline is also due to load reductions associated with the mid-2001-2002 drought, the lack of runoff events from 2007-2009, and WWTP upgrades. The conductivity increase in the reservoir and input may be attributable to decreased total annual precipitation since 2003. Improvements in water clarity explain the upward trend in trophic state.

Biomonitoring Status and Trends (Schoharie Basin)

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. For methodology details, see Appendix 3.

The most recent status of macroinvertebrate communities in the Schoharie basin was evaluated by examining 2007-2009 data from sites located on Schoharie Creek. This stream is the primary inflow to Schoharie Reservoir, draining 75% of the basin. The three sites with data from these years are all routine, that is, they are sampled annually, as opposed to non-routine sites, which are sampled on a rotating basis.

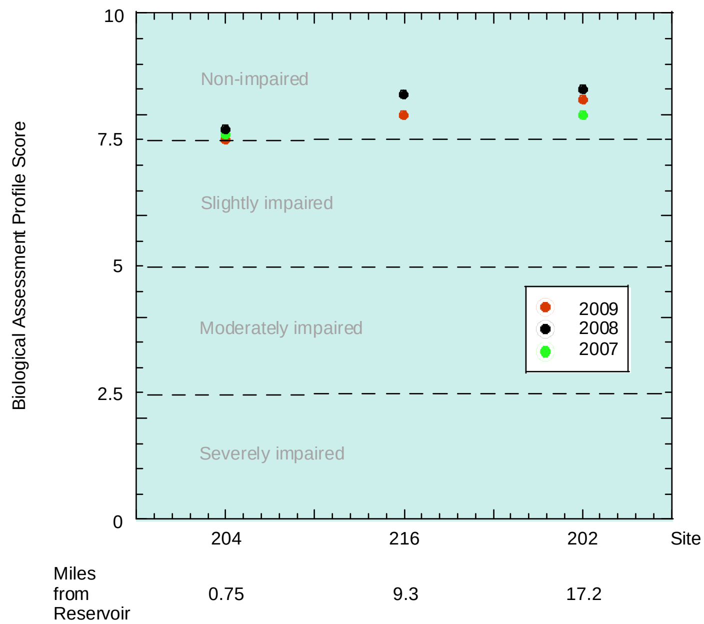

Figure 3.8 Biomonitoring status scores for Schoharie Creek, 2007-2009.

Site 204 (S5I) is located in Prattsville, approximately three-quarters of a mile upstream of Schoharie Reservoir. Site 216 is about 9 miles upstream of the reservoir, and Site 202 is about 17 miles upstream. From 2007-2009, all sites were assessed as being non-impaired (Figure 3.8), indicating the presence of optimal conditions for the benthic community. Sites were dominated in most years by ephemerellid, heptageniid, and leptophlebiid mayflies, three particularly sensitive mayfly taxa. Scores at Site 204 were lower than at the other two 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 the lower scores. Moreover, analysis of the data from all the surveyed sites using the NYS Stream Biomonitoring Unit's Impact Source Determination procedures detected no impacts to any site along the creek, including Site 204.

Trend analysis was based on these sites' entire period of record (which ranged from 14 to 16 years in length), and examined changes in both scores and assessment categories.

Long-term trends in biomonitoring scores at the three sites on Schoharie Creek 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. No significant trend was detected at Sites 202 or 204, but at Site 216 a weak upward trend (p = 0.19) was observed (Figure 3.9). This may be related to the stream stabilization BMP constructed at the site in 1997, although the paucity of pre-construction data makes it difficult to test this hypothesis.

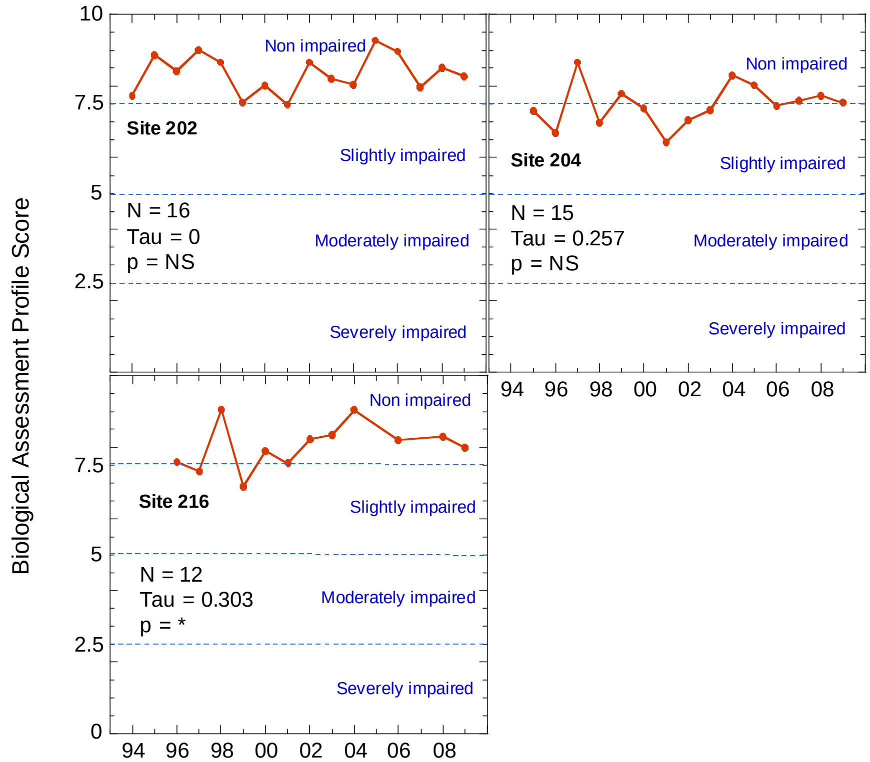

Figure 3.9 Biomonitoring trend plots for Schoharie Creek, 1994-2009. Results of the Mann Kendall trend test are shown as follows: NS (Not Significant) = $p \geq 0.20$, * = $0.20 > p > 0.10$. N = number of observations, Tau = Mann Kendall test statistic.

Site 202 has been assessed as non-impaired in almost every year since 1994, the one exception being 2002, when its 7.49 score was a fraction below the non-impaired/slightly impaired threshold. Site 216 has been non-impaired in every year since it was first sampled in 1996, except for 1997 and 1999, when it received slightly impaired ratings. The 1997 result is probably explained by the fact that the sample was collected shortly after the site had been dewatered in preparation for construction of the BMP, allowing little time for the benthic community to recolonize. Site 204, by contrast, has not had a consistent record of non-impairment. While five of the last six assessments at the site have been non-impaired, slightly impaired assessments were recorded in six of the previous nine years, possibly indicating a change from a community that consistently rates slightly impaired to one that rates non-impaired. Additional monitoring, however, will be required to determine if such a change has taken place, because the slight shifts to either side of the non-impaired/slightly impaired threshold that have produced this result could be attributable to natural variability in assessment scores, rather than any actual improvement in the benthic community.

3.3 The West and East Ashokan Basins

Ashokan Reservoir is located in Ulster County, about 13 miles west of Kingston and 73 miles north of New York City. 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. On average over the past few years, Ashokan supplied 500 million gallons per day (MGD), or roughly 42% of the total average daily consumption, to New York City and an additional one million upstate consumers.

Ashokan is one of two reservoirs in the City's Catskill water supply system, and is located 27 miles downstream of the other one, Schoharie Reservoir. Water flows into Ashokan via the Shandaken Tunnel and Esopus Creek. Under normal operating conditions, water enters Ashokan's West Basin and, after a settling period, is withdrawn from its East Basin. Water residence time in the West Basin averages two to four months, while residence time in the East Basin is typically about twice as long (Figure 3.1). It is carried southeast under the Hudson River via the 92-mile Catskill Aqueduct, which has a maximum depth of 1,114 feet. It ordinarily enters Kensico Reservoir in Westchester, where further settling and mixing with Delaware System water takes place, and then travels south in two aqueducts before entering the water supply distribution system at Hillview Reservoir in Yonkers.

The Ashokan watershed's drainage basin is 255 square miles and includes parts of 11 towns. Bush Kill and Esopus Creek 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. Presently there are four wastewater treatment plants (WWTPs) sited in the Ashokan watershed, producing approximately 0.215 MGD of flow. As per the most recent SPDES permits, the plants are limited to a collective release of 0.621 MGD of flow.

Of the 163,392 acres of land in the Ashokan watershed, 146,773 acres (89.8%) are forested, 4,479 acres (2.7%) are urban or built-up land, 1,409 acres (0.9%) are brushland or successional land, and 33 acres (0.0%) are classified as barren land. Wetlands comprise 2,056 acres (1.3%) of the watershed, while 8,375 acres (5.1%) are water. The remaining 267 acres (0.2%) are in agricultural use (Figure 3.10).

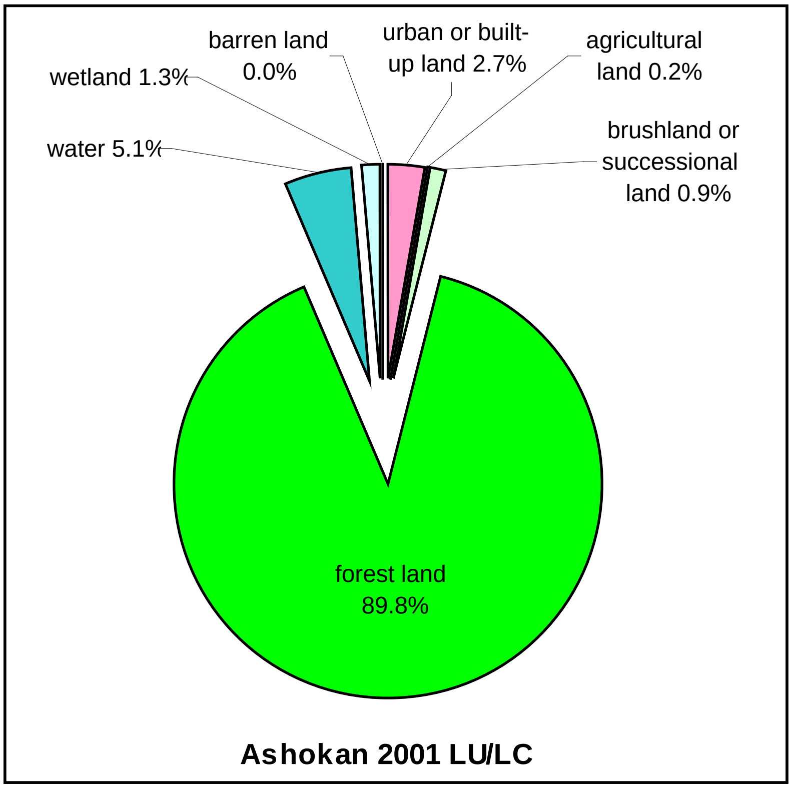

Figure 3.10 Land use in the Ashokan drainage basin based on 2001 data.

3.3.1 Program Implementation (Ashokan West and East Basin)

Since 1996, four best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater (Figure 3.11a). These BMPs are associated with approximately 60 acres of farmland. Over the last decade, approximately six environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects (Figure 3.11b). Approximately 900 septic systems throughout the basin have been remediated during this time period (Figure 3.11c). Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Chapter 2 of this report.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Ashokan has remained at about 1,800 in recent years, which is only slightly higher than in the early part of the decade, when the average was approximately 1,600 boats (Figure 3.11d).

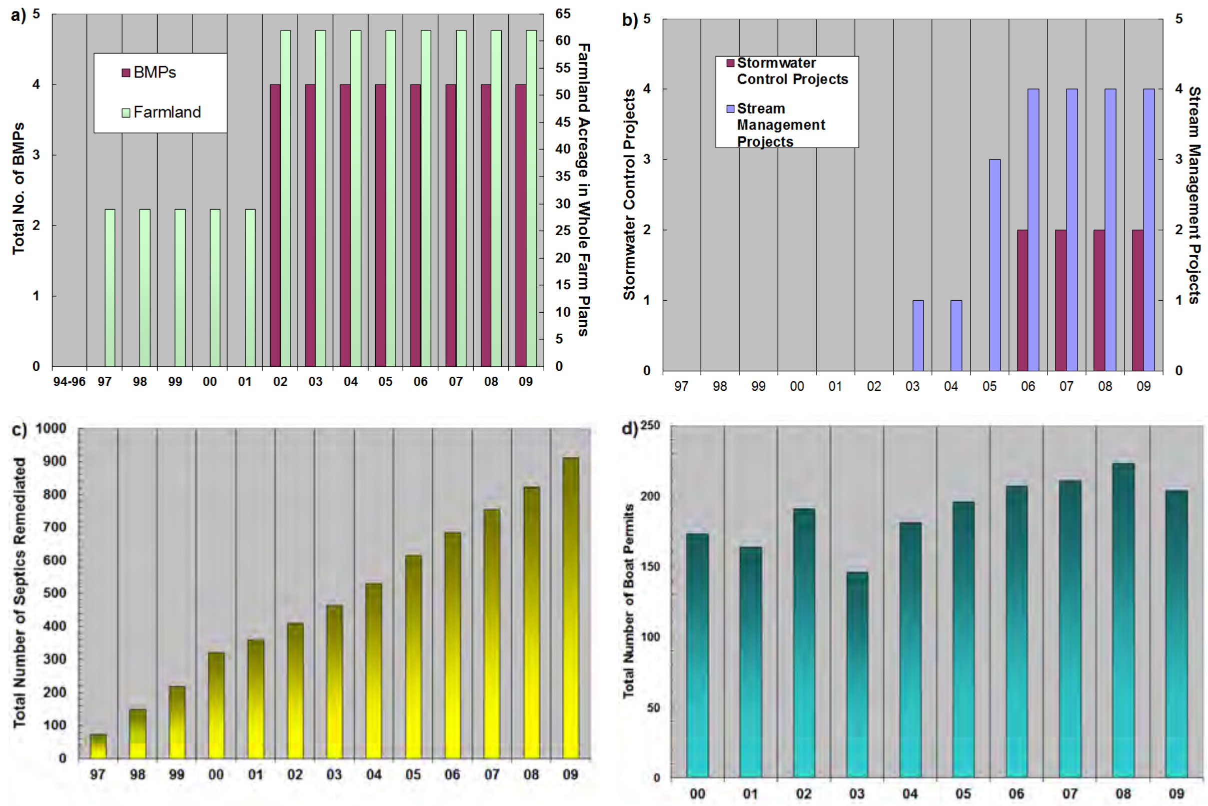

Figure 3.11 History of watershed programs in the Ashokan drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control and stream management projects, c) septic system remediation, d) number of boat permits issued.

Note: Bars in plots (a)-(c) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the West Ashokan Basin

Inputs of phosphorus, as well as other pollutants, from WWTPs to Ashokan Reservoir continue to be reduced as a result of DEP's effort to upgrade all surface-discharging plants, including upgrade of the City-owned Pine Hill plant, and also through the intervention and involvement of DEP's WWTP Compliance and Inspection Program (Section 2.12.2). As illustrated in Figure 3.12, phosphorus loads (as total phosphorus) declined considerably from 1994 to 1999 and remained low into 2009. Overall, the phosphorus loads to Ashokan Reservoir were reduced from 220 kg yr^{-1} in 1994 to less than 30 kg yr^{-1} in 2009. The reduction was largely due to the upgrade of the largest plant, Pine Hill, and improvements at Onteora Central School. 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. A new infrastructure plant was completed in Boiceville in 2010, and data for that plant will be available for the next evaluation.

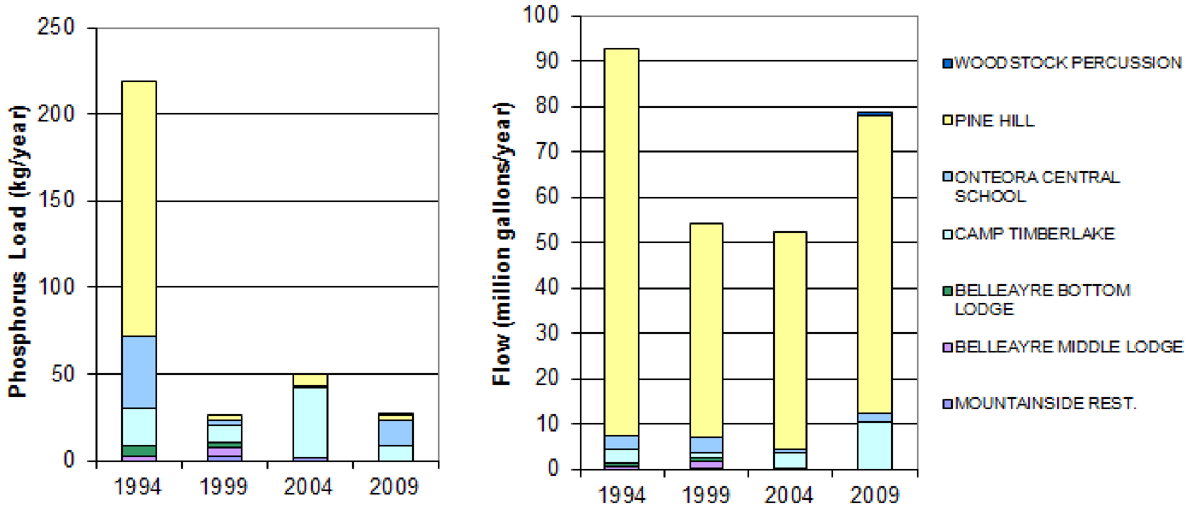

Figure 3.12 Wastewater treatment plant total phosphorus loads and flows in the Ashokan drainage basin, 1994-2009.

3.3.2 Water Quality Status and Trends (Ashokan West and East Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 3.13. Two time periods are assessed for each site: i) the full period of record, and ii) a three-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deterioration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

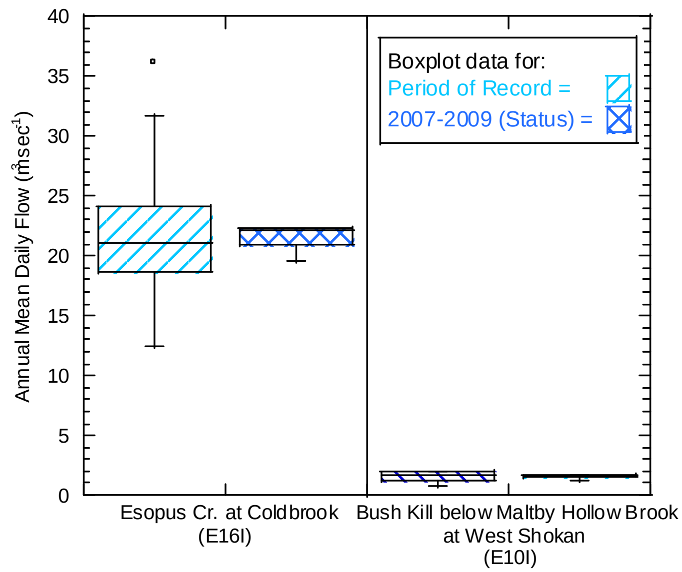

Figure 3.13 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the Ashokan watershed.

Esopus Creek at Coldbrook is the primary inflow to Ashokan Reservoir. It drains 75% of the basin (Table 3.3). The status period's mean annual daily flow median was similar to the long-term median. It should be noted that flows at Coldbrook are greatly influenced by the discharge from the upstream Shandaken Portal and as a consequence do not represent the natural regime.

Table 3.3: DEP sample site descriptions for the Ashokan watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
E16I	Esopus Creek at Coldbrook	74.7%	October 1931-present
E10I	Bush Kill below Maltby Hollow Brook at West Shokan	7.3%	August 2000-present

Status (West Basin)

Ashokan's West Basin status evaluation is presented as a series of boxplots in Figure 3.14. Only the input stream (E16I) and the reservoir basin (EAW) are included because water is rarely withdrawn directly from this basin. The output goes directly into the East Basin of Ashokan. All values below the maximum detection limit line for fecal coliform and total phosphorus (blue lines) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

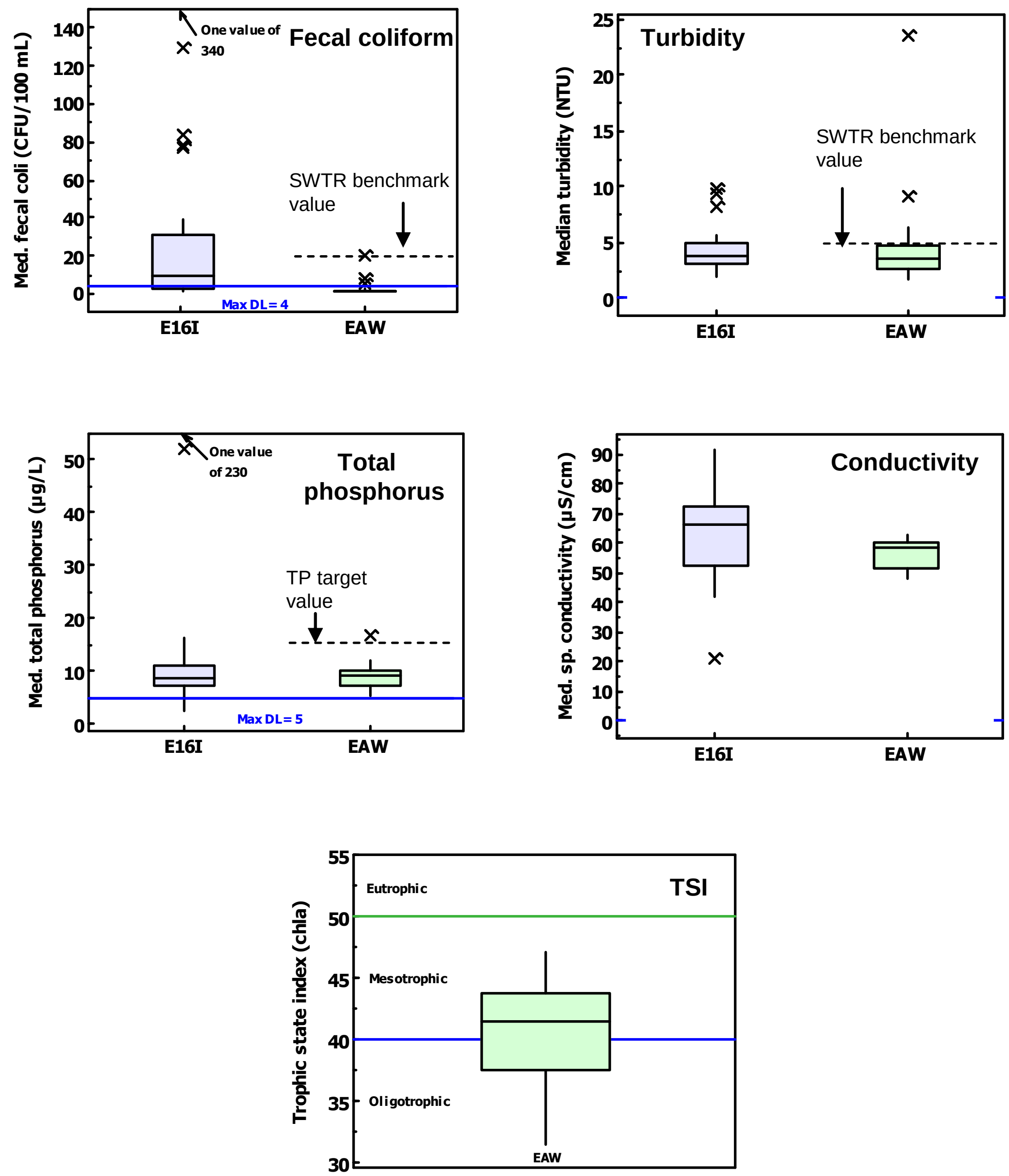

Figure 3.14 Water quality status boxplots using 2007-2009 monthly data for the Ashokan West Basin main stream input at Esopus Creek (E16I) and the Ashokan Reservoir West Basin (EAW).

All but one monthly value for fecal coliform in the input stream were below the DEC Stream Guidance Value of 200 CFU 100 mL^{-1} during the 2007-2009 analysis period. The reservoir-wide values during this period were much lower than the stream's, with only one excursion above the 20 CFU 100 mL^{-1} Surface Water Treatment Rule (SWTR) benchmark used for source waters. Non-detect statistics were required to analyze the data since the majority of reservoir values were below the detection limit.

The turbidity values were generally similar in both the reservoir and the input stream. Almost all of the monthly turbidity values for the Esopus and the West Basin were below the 5 NTU SWTR benchmark value for source waters. This reference line is included for the West Basin because as a terminal reservoir, Ashokan can become source water if Kensico Reservoir is by-passed.

Total phosphorus (TP) values were also similar in both the reservoir and the input stream, and were well below the phosphorus-restricted target value of 15 $\mu g\ L^{-1}$.

The Trophic State Index (TSI) value for Ashokan's West Basin was primarily within the mesotrophic range for the three-year period. As with Schoharie Reservoir, light penetration can be a limiting factor for primary production in this reservoir due to suspended particulates. The TSI values in the oligotrophic range probably occurred during times of diminished productivity caused by turbidity.

Variability in conductivity was greater in Esopus Creek than in the reservoir. In general, the reservoir has a large volume that attenuates the influence of the incoming stream.

In summary, water quality was good during the 2007-2009 status assessment period in the West Basin of Ashokan Reservoir. The data for the selected variables show that there were very few times when the monthly values exceeded established benchmarks.

Trends (West Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 3.4).

Water quality trend plots are presented in Figure 3.15 and results of the Seasonal Kendall trend analysis are provided in Table 3.4.

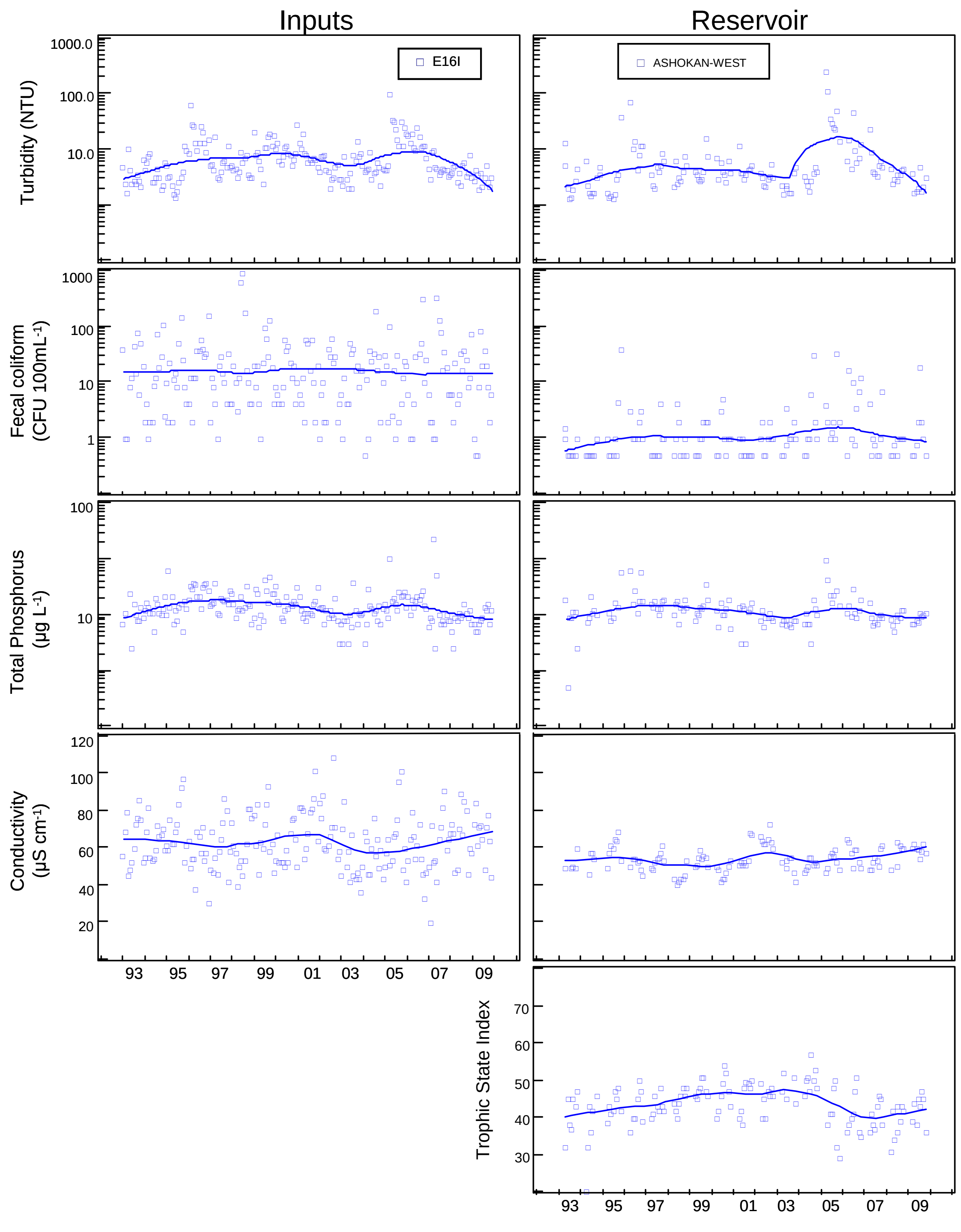

Figure 3.15 Water quality trend plots for the Ashokan West Basin for the main stream input at Esopus Creek (E16I) and the Ashokan Reservoir West Basin. For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 3.4: Ashokan West Basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
E16I	Input	Turbidity	202	-0.00	NS	
Ashokan-west	Reservoir	Turbidity	136	0.09	*	0.05
E16I[3]	Input	Fecal coliform	202	-0.01	NS	
Ashokan-west[3]	Reservoir	Fecal coliform	134	0.10	*	0.00
E16I	Input	Total phosphorus	202	-0.18	***	-0.33
Ashokan-west	Reservoir	Total phosphorus	129	-0.19	***	-0.25
E16I	Input	Conductivity	204	0.01	NS	
Ashokan-west	Reservoir	Conductivity	124	0.12	**	0.25
Ashokan-west	Reservoir	Trophic State Index	130	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 in this row required the use of statistical methods for "non-detect" values.

Although long-term turbidity trends were not detected in the main input to the West Basin of Ashokan Reservoir, a weak upward trend was detected for the reservoir. Examination of the turbidity plots reveals that the upward trend was driven by extremely high turbidity values in the spring of 2005 and in May/June 2006. On April 1-3, 2005, a three-day rain-on-snow event produced extensive runoff and flooding in the Catskill and Delaware System watersheds. The Ashokan Reservoir watershed received the highest amount of rainfall, with 103 mm (4.05 inches) over the three-day period. Four days prior to this event the area received a significant two-day rainfall event which swelled watershed streams and saturated the ground. Stream levels did not have time to recover from this first event before the April 1-3 rain occurred. Since 2005, turbidity levels have steadily decreased, reaching typical levels by 2008-2009.

A long-term upward fecal coliform trend was also detected in the reservoir and, like turbidity, appears to have been initiated by the April 2005 flood event and prolonged by the May-June runoff events in 2006 (Figure 3.15). The upward trend may be temporary, however, as fecal counts since then have steadily decreased. Statistically significant trends were not detected in the input.

Except for temporary increases associated with major runoff events in January 1996, April 2005, and May-June 2006, TP concentrations in the input and in the reservoir have declined over the long-term record. One factor in this decline was the low contribution from the input during the drought that lasted from mid-2001–2002. Lower inputs were also achieved through the implementation of watershed programs, in particular the upgrade to the Pine Hill WWTP.

An upward conductivity trend was detected in Ashokan's West Basin but not in its primary input, where conductivity is much more variable. The long-term upward trend in the reservoir was driven largely by a short-term increase from 2004-2009, a period of declining precipitation in the watershed. Drought conditions in 2001 were responsible for the temporary increase observed in the input and reservoir.

Long-term trends were not detected for TSI. Although TSI consistently increased from 1993-2004, the trend suddenly reversed in April 2005, coinciding with that month's flooding event. Under the conditions of diminished water clarity caused by the turbid floodwater, algae were unable to thrive, as reflected by the decrease in TSI. Since 2006, algal productivity has increased but through 2009 had not reached pre-flood levels.

In summary, downward trends were evident for TP. The decrease in phosphorus is due to low loading periods in 2001-2002, recovery from high loading periods (floods in mid-to-late 1990s and 2005), and WWTP upgrades. Upward trends were detected for turbidity, fecal coliform, and conductivity. The increase in turbidity and fecal coliform is attributable to a large spring runoff event in 2005. Conductivity increases coincided with a decline in precipitation over the last six years of the data record.

Status (East Basin)

Ashokan's East Basin status evaluation is presented as a series of boxplots in Figure 3.16. Only the reservoir (EAE) and the output (EAR) are included because water from the West Basin flows directly to the East Basin. All values below the maximum detection limit line for fecal coliform (blue line) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

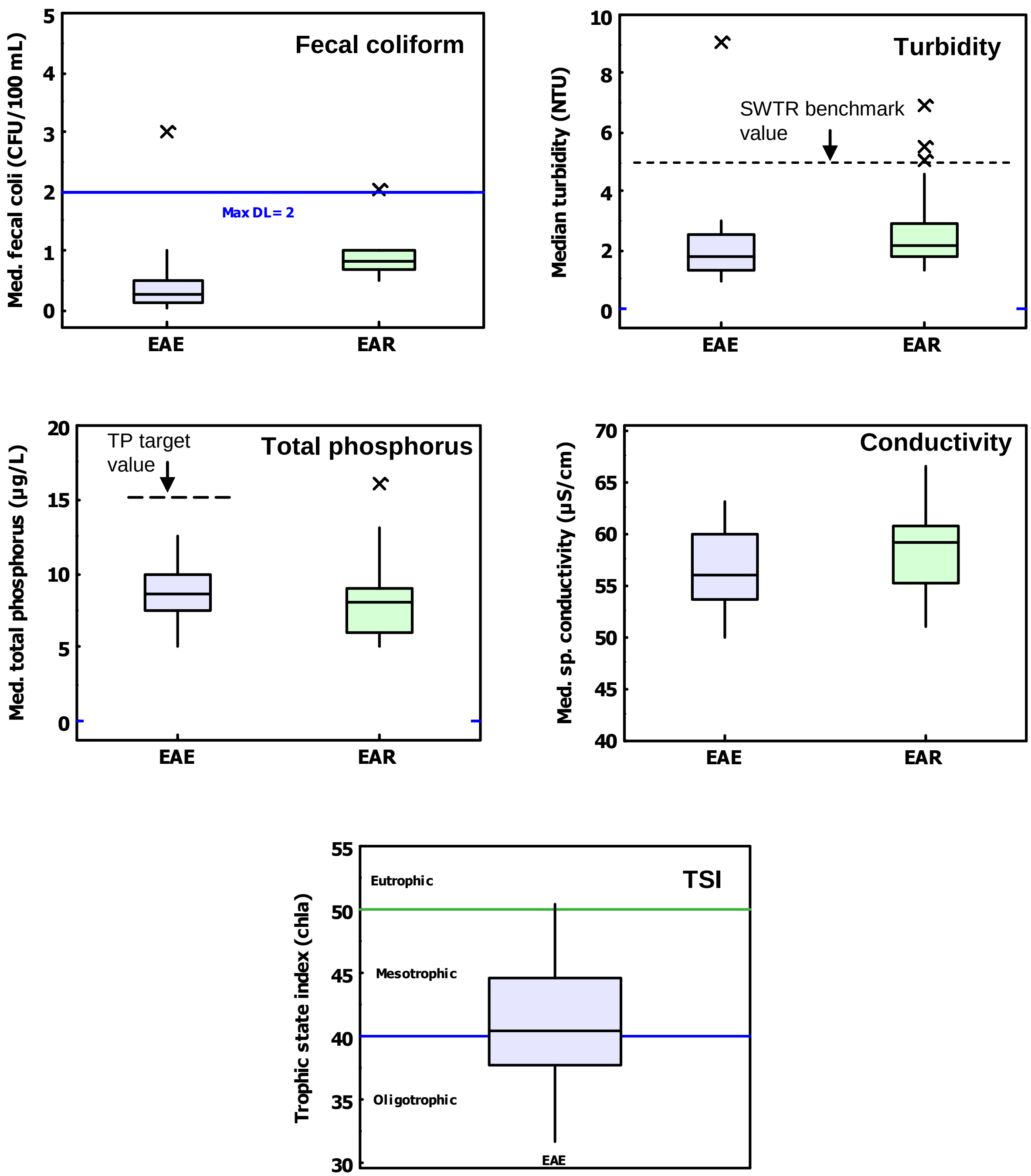

Figure 3.16 Water quality status boxplots using 2007-2009 monthly data for the Ashokan Reservoir East Basin (EAE) and the output at the Ashokan gatehouse (EAR).

Fecal coliform values were very low for both the reservoir and the output. The majority of the monthly median values were below the detection limit, requiring the use of non-detect statistical methods. None of the monthly median values exceeded the 20 CFU 100 mL^{-1} SWTR benchmark used for source waters.

The turbidity values were broadly similar in the reservoir and the output from the East Basin. Monthly median values were well below the 5 NTU SWTR benchmark value for source waters. This reference line is included for the East Basin because Ashokan can become source water if Kensico Reservoir is by-passed. The output had a median and some values that were slightly higher than the reservoir, primarily because of the location of the effluent structure relative to the incoming water from the West Basin. Wind and mixing patterns can cause turbidity levels to increase at EAR, in contrast to the rest of the East Basin where turbidity levels tend to be the lowest in the impoundment.

TP values in the East Basin and the output were also generally similar. Only one individual monthly value was above the phosphorus-restricted target value of 15 µg L^{-1} in the reservoir.

The TSI values for Ashokan's East Basin ranged between the oligotrophic and mesotrophic categories for the three-year period. Light penetration can be a limiting factor for primary production in this reservoir due to suspended particulates, but to a much lesser degree than in either the West Basin or Schoharie Reservoir.

The variability in reservoir conductivity was similar to the output's, while the output had a slightly higher median conductivity as compared to the reservoir. The overall range, however, was only 15 µS cm^{-1} at both sites.

In summary, water quality was generally good during the 2007-2009 status assessment period in the East Basin of Ashokan Reservoir. The data for the selected variables show that medians were well below the established benchmarks.

Trends (East Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 3.5).

Water quality trend plots are presented in Figure 3.17 and results of the Seasonal Kendall trend analysis are provided in Table 3.5. The West Basin, the East Basin's primary source of water, is discussed in the preceding section (Trends (West Basin)).

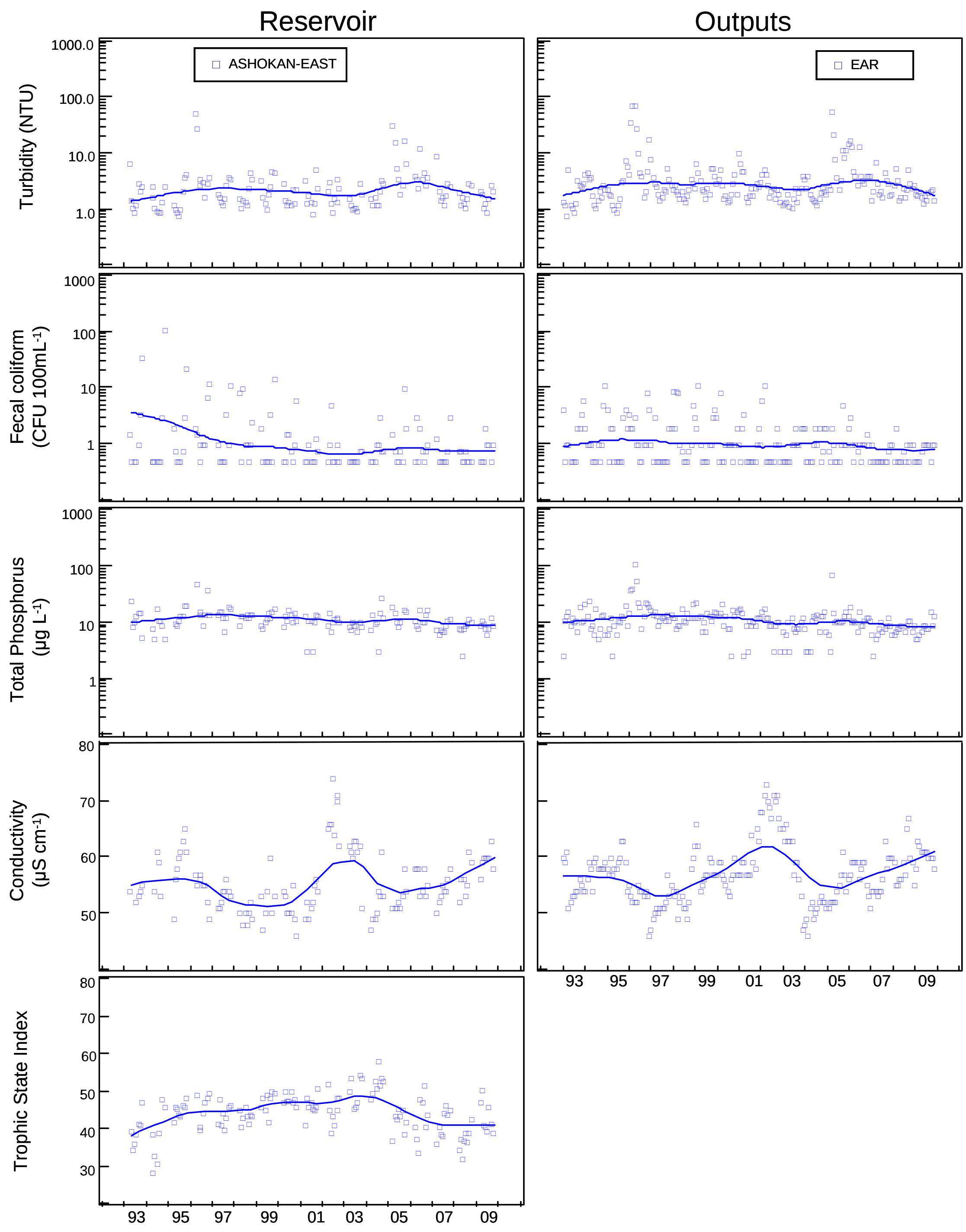

Figure 3.17 Water quality trend plots for the Ashokan Reservoir East Basin and the output at the Ashokan gatehouse (EAR). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 3.5: Ashokan East Basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
Ashokan-East	Reservoir	Turbidity	136	0.05	NS	
EAR	Output	Turbidity	204	0.04	NS	
Ashokan-East[3]	Reservoir	Fecal coliform	135	-0.17	***	0.00
EAR[3]	Output	Fecal coliform	204	-0.17	***	0.00
Ashokan-East	Reservoir	Total phosphorus	131	-0.31	***	-0.29
EAR	Output	Total phosphorus	203	-0.22	***	-0.25
Ashokan-East	Reservoir	Conductivity	126	0.11	**	0.17
EAR	Output	Conductivity	204	0.15	***	0.19
Ashokan-East	Reservoir	Trophic State Index	133	0.00	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 in this row required the use of statistical methods for "non-detect" values.

Turbidity trends were not detected in the reservoir or in its output, EAR. The LOWESS curves show the increase of turbidity during the January 1996, April 2005, and May/June 2006 storm events.

Strong downward fecal coliform trends were detected in both the reservoir and the output. Although the change per year was estimated as zero, the sign of the Tau statistic was negative, indicating a downward trend. The Sen Slope Estimator used to estimate change per year in this report may not be appropriate for data that are dominated by many tied, low values (e.g., fecal coliform counts). A better estimate of change may be derived from using the LOWESS curve. In Figure 3.17 the reservoir LOWESS curve starts at about 3 CFU and by around 2001 stays at 1 or less, a downward change of approximately 67%. 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 2010e).

Declining trends were detected for TP, indicating continued recovery from flooding events in the mid-to-late 1990s, and perhaps also indicating low phosphorus loads during the drought that lasted from mid-2001 to 2002. Another portion of the decline can be attributed to upstream WWTP upgrades (including those in the Schoharie watershed), resulting in smaller loads of TP being delivered to the streams.

Long-term upward conductivity trends were detected in the reservoir and its output. In this basin, conductivity has a strong negative correlation with precipitation. The long-term increasing trend is due to low precipitation amounts in the latter half of the data record, especially in the drought years lasting from mid-2001–2002 and since 2006. The LOWESS curves clearly illustrate the variability induced by drought and storms.

Long-term trends were not detected for TSI. Although TSI consistently increased from 1993-2004, this increasing trend was offset by a sharp decrease caused by the major flooding event in April 2005. Since 2006, algal productivity has increased, but through 2009 had not reached pre-flood levels.

In summary, downward trends were evident for TP and fecal coliforms and upward trends for conductivity. The decrease in phosphorus is due to recovery from high loading periods and WWTP upgrades. The decrease in fecal coliforms is likely the result of declining bird populations brought about by landfill closures, while the increase in conductivity is associated with several short-term declines in precipitation.

Biomonitoring Status and Trends (Ashokan Basin)

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. For methodology details, see Appendix 3.

The most recent status of macroinvertebrate communities in the Ashokan basin was evaluated by examining 2007-2009 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 are routine, that is, they are sampled annually; the other four are sampled on a rotating basis and were sampled only once during the 2007-2009 period.

Site 213 (E16I) in Boiceville lies approximately three-quarters of a mile upstream of Ashokan Reservoir. Sites 255, 227, 215 (E5), 256, and 260 (AEHG), are situated roughly 4, 9, 13, 17, and 29 miles, respectively, upstream of the reservoir. From 2007-2009, all sites but Site 260 were assessed as being non-impaired, with little variation in scores among sites or years (Figure 3.18). Mayflies, indicative of good water quality, were numerous at most sites, especially Sites 215, 255, 256, and, in 2009, 227. At Site 260, high oligochaete numbers (61% of the total) depressed all four metric scores, resulting in a Biological Assessment Profile (BAP) score of 5.1, only marginally above the non-impaired/slightly impaired threshold. It is unlikely, however, that this score reflects suboptimal water quality, given that half the taxa present in the subsample were extremely sensitive organisms, with an average tolerance value of 1. (Tolerance values range from 0-10, 0 being the most sensitive.)

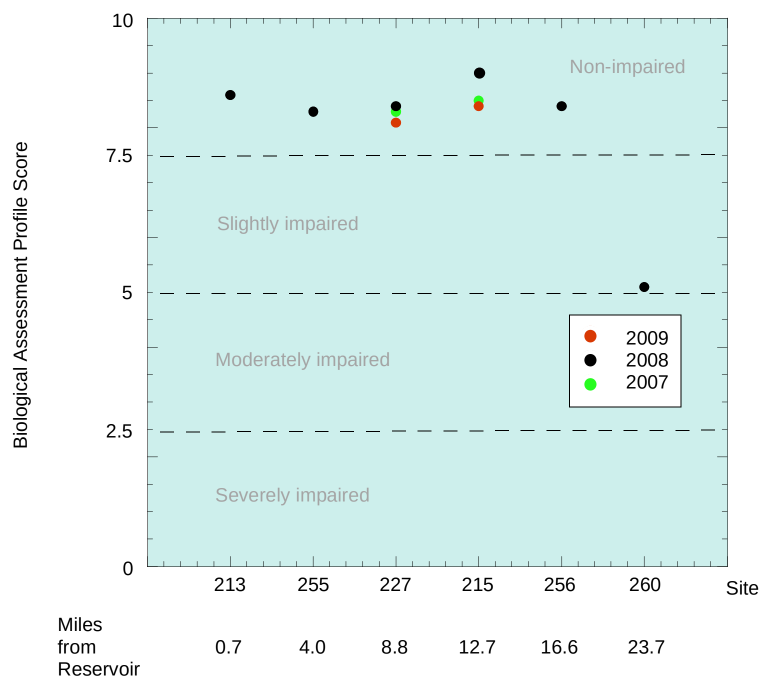

Figure 3.18 Biological Assessment Profile scores for Esopus Creek, 2007-2009.

Trend analysis was based on the routine sites' entire period of record (which ranged from 11 to 14 years in length), and examined changes in both scores and assessment categories.

Long-term trends in biomonitoring scores at the two routine sites on Esopus Creek (215 and 227) 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 Site 215, while at Site 227, a weak upward trend (p = 0.12) was observed (Figure 3.19). Assessments also remained stable, with non-impaired scores prevailing in most years. Slightly impaired assessments occurred at Site 215 in 2003 and 2005, and at Site 227 in 1999, 2003, and 2006.

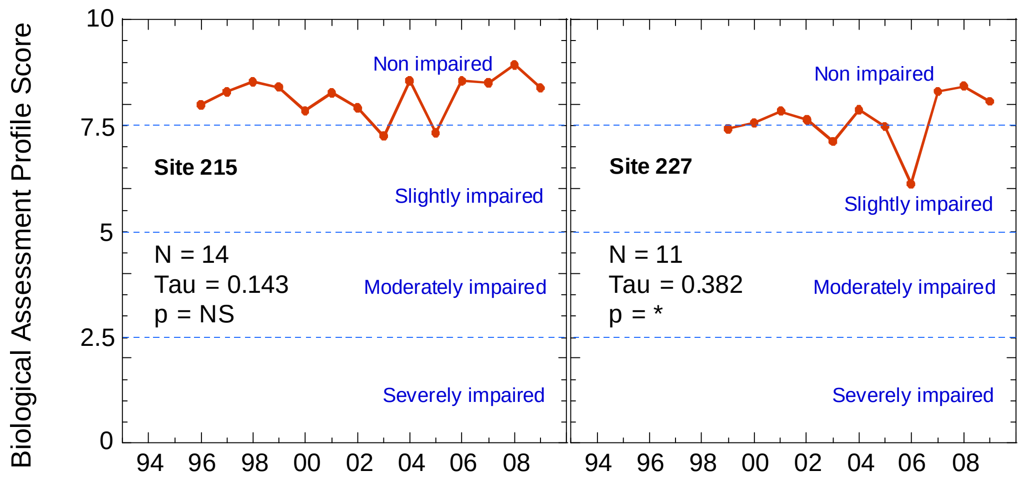

Figure 3.19 Biomonitoring trend plots for Esopus Creek, 1996-2009. Results of the Mann Kendall trend test are shown as follows: NS (Not Significant) = $p \geq 0.20$, * = $0.20 > p > 0.10$. N = number of observations, Tau = Mann Kendall test statistic.

3.3.3 Waterfowl Management Program: Ashokan Reservoir

Waterfowl management in Ashokan Reservoir is conducted on an "as needed" basis as per the 2002 FAD. The reservoir is divided into two main basins, each with a water intake chamber located near a dividing weir. Waterbird populations peaked above 10,000 birds in the mid-1990s, but dropped precipitously thereafter to 1,000 birds or less (mostly less) in recent years. 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 waterbird roosting area, where high numbers of gulls, ducks, and geese have been recorded seasonally (Figure 3.20). 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.

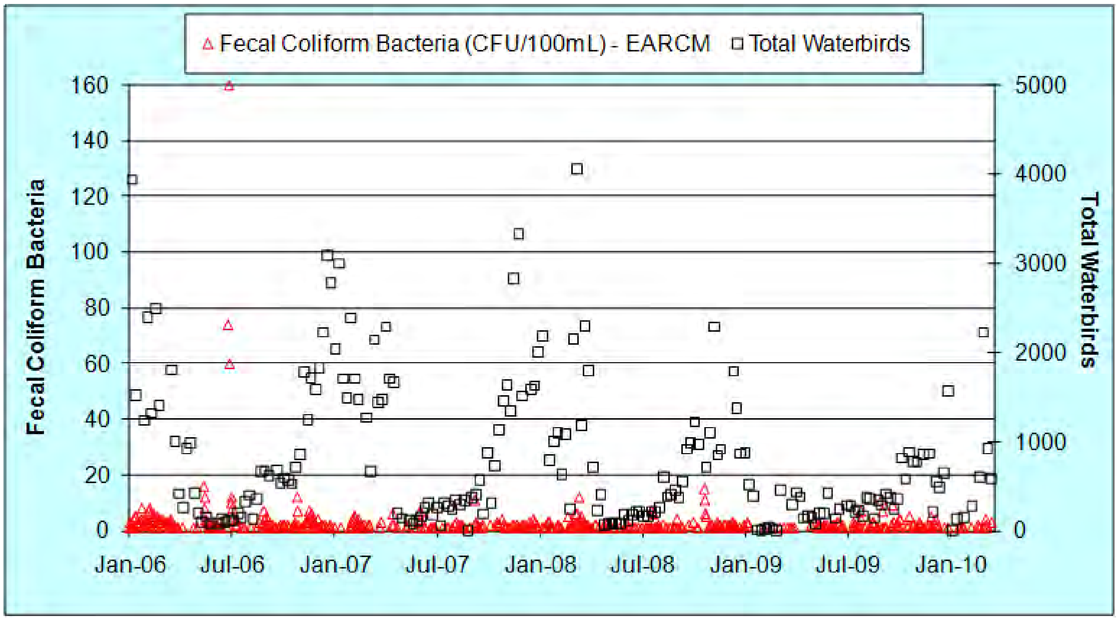

Figure 3.20 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total waterbirds at Ashokan Reservoir East Basin Effluent (EARCM), January 1, 2006-March 31, 2010.

3.4 Catskill System Protozoa: Sources and Attenuation

3.4.1 Upstream Sites and Reservoir Effluents

In the Catskill System, DEP has sampled for protozoa (*Giardia* and *Cryptosporidium*) at three sites upstream of the Schoharie Reservoir basin and four upstream of the Ashokan Reservoir basin, from June 2002 to October 2010. The three sites monitored above Schoharie Reservoir were S7I (Manor Kill), S4 (Schoharie Creek at Lexington, upstream of S5I), and S5I (Schoharie Creek at Prattsville). The four sites monitored in the Ashokan basin were ABCG (Birch Creek), E5 (Esopus Creek, upstream of the Shandaken Tunnel), SRR2CM (Shandaken Tunnel outlet), and E16I (Esopus Creek just before entering Ashokan Reservoir).

When data from the reservoir input sites are compared to that of the reservoir effluents—SRR2CM (Schoharie effluent) and CATALUM (downstream of the Ashokan effluent in a closed aqueduct)—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 effluents (Figures 3.21 and 3.22). Thus, 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 effluents are consistently far less than the combined mean of the upstream sites in each basin. Moreover, as the water flows downstream from the Schoharie basin through the Ashokan basin, additional reductions in protozoa are noted. Over the approximate eight-year sampling period, the three Schoharie upstream sites demonstrated a higher annual mean concentration of *Giardia* cysts (53.26 cysts 50 L^{-1}) when compared to the four Ashokan upstream sites (13.69 cysts 50 L^{-1}).

Similarly, although at much lower concentrations, the *Cryptosporidium* annual mean concentrations were lower at the two reservoir effluents than at the sites upstream of the reservoir. In the Schoharie basin there appears to be a notable trend of decreasing oocyst concentrations at the upstream sites, especially after 2007. This may be the result of watershed programs and improvements and upgrades to wastewater treatment plants (WWTPs) during the same time period. While there appears to be a similar pattern with respect to the annual mean oocyst concentrations in the Ashokan basin, it is less prominent, perhaps due to the overall lower concentrations of oocysts in that basin. In any event, it is clear that the reservoirs in both Catskill System basins provide for a significant reduction in protozoan concentrations at the effluents compared to the concentrations at the upstream sites.

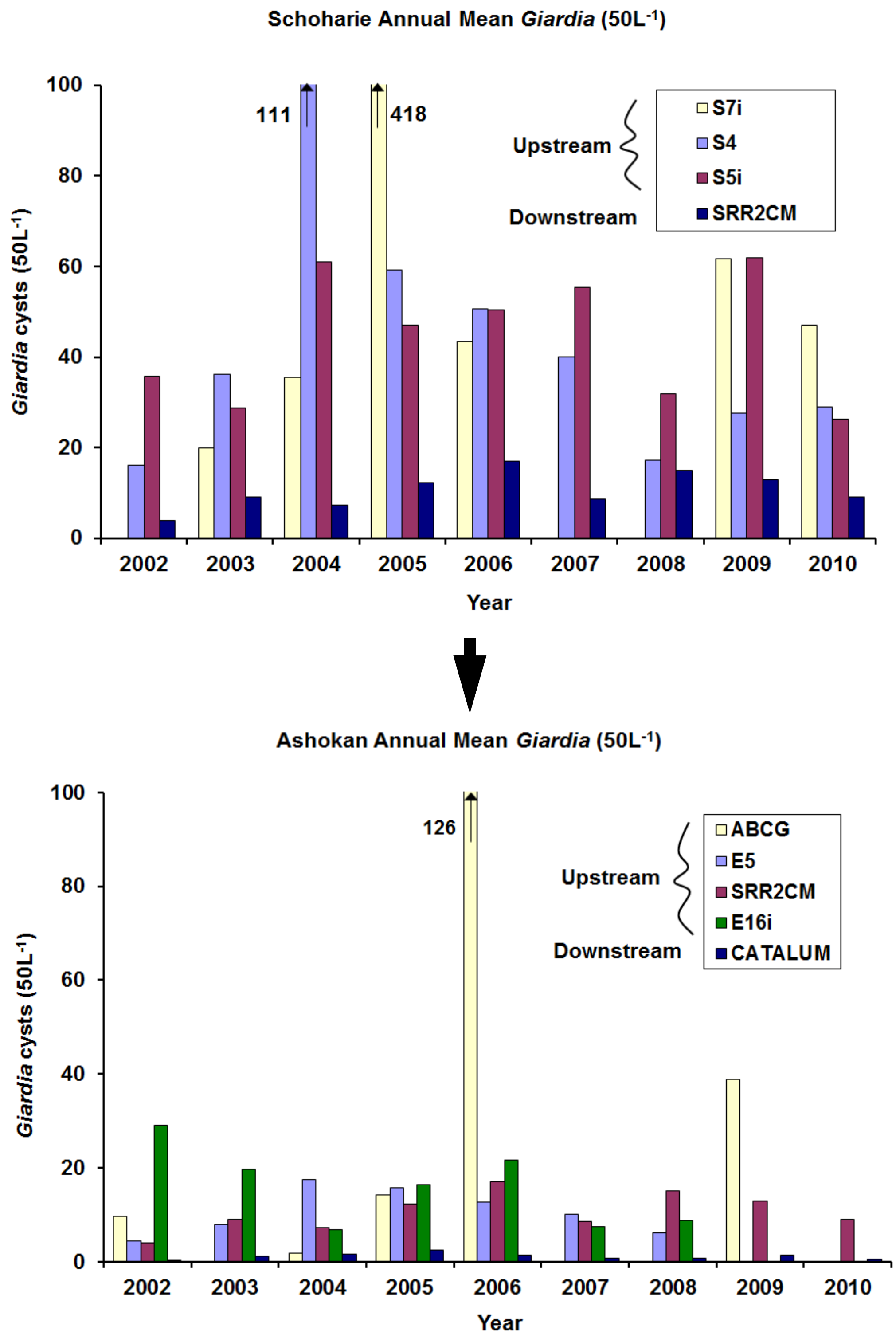

Figure 3.21 *Giardia* cyst reduction as water travels through each reservoir, and from upstream (Schoharie) to downstream (Ashokan).

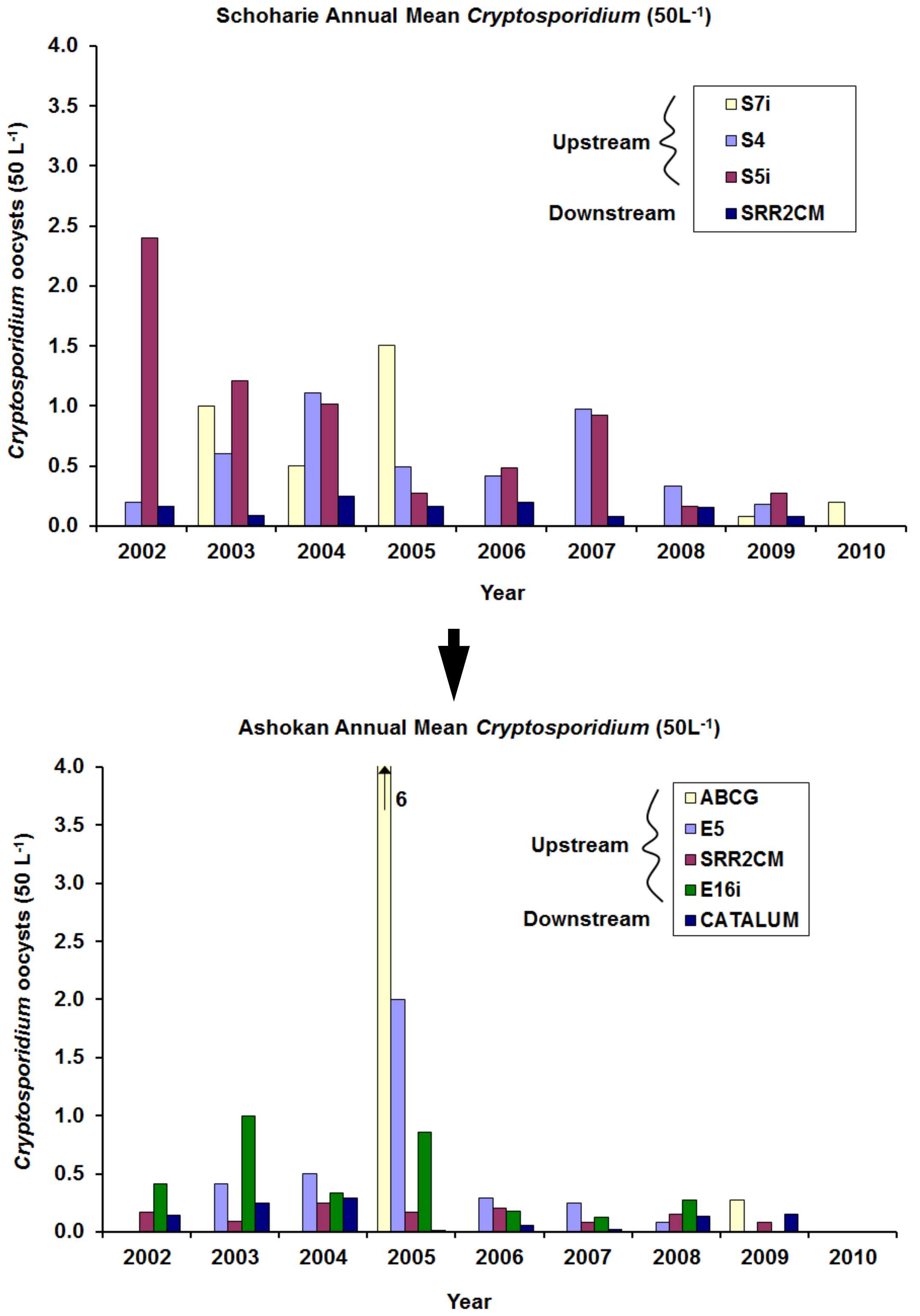

Figure 3.22 *Cryptosporidium* oocyst reduction as water travels through each reservoir, and from upstream (Schoharie) to downstream (Ashokan).

3.4.2 WWTPs

DEP sampled seven WWTPs for protozoa in the Catskill System from 2002 to October 2010 in order to monitor long-term performance of WWTP upgrades. Some sites have been discontinued, while others have been added as the upgrades have occurred. All routine samples have been collected quarterly. In some cases, extra samples were collected as a follow-up to an unusual result; in some other cases, samples were not collected due to plant operations or for other reasons. Overall, 157 samples were collected.

Detection of *Giardia* in the effluents of WWTPs in the Catskill System was 6.36% during this period (10 detections out of 157 samples), while *Cryptosporidium* was detected 1.91% of the time (3 detections out of 157). Annual detections for all Catskill plants are graphed in Figure 3.23. *Cryptosporidium* was detected in 2002 and 2004 only, while *Giardia* detection at the WWTP effluents has fluctuated throughout the years. Table 3.6 provides a more detailed breakdown of the positive detections by identifying the plant and year of detection, along with the percent detection and maximum concentrations. Note that the Hunter Highlands collection site was changed from HHE to HHBD in 2009 due to the belief that wildlife had access to the water prior to its reaching the effluent and were contaminating the final sample. Since the switch, all seven samples collected at this site have been negative for protozoa.

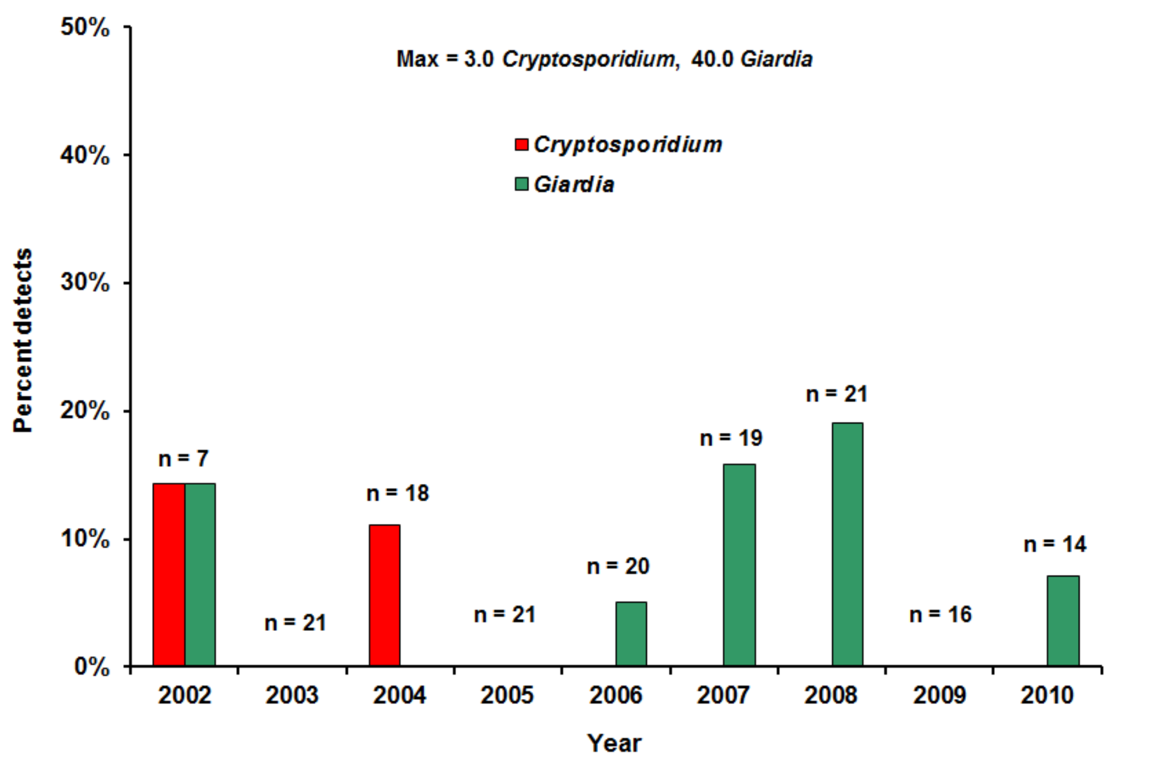

Figure 3.23 Protozoan detection frequency in Catskill WWTP effluent, 2002-2010.

Table 3.6: Catskill WWTPs with protozoan detects, 2002-October 2010. NS = not sampled.

Basin	WWTP	2002	2003	2004	2005	2006	2007	2008	2009	Oct. 2010	Percent detection	Max Conc. (50 L^{-1})
Giardia												
Schoharie	Hunter Highlands (HHE)*	NS	0/5	0/3	0/4	1/5	2/4	3/5	NS	NS	23% n = 26	7.0
	Hunter Highlands (HHBD)*	NS	NS	NS	NS	NS	NS	NS	0/4	0/3	0% n = 7	0.0
	Hunter (HTP)	0/1	0/4	0/4	0/4	0/4	0/3	0/4	0/4	1/4	3% n = 32	2.0
	Grand Gorge (SGE)	0/2	0/4	0/4	0/4	0/3	1/4	0/4	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	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	4% n = 26	3.0
	Hunter Highlands (HHBD)*	NS	NS	NS	NS	NS	NS	NS	0/4	0/3	0% n = 7	0.0
	Hunter (HTP)	0/1	0/4	1/4	0/4	0/4	0/3	0/4	0/4	0/4	3% n = 32	1.0
Ashokan	Pine Hill (EPE)	1/2	0/4	0/3	0/5	0/4	0/4	0/4	NS	NS	4% n = 26	1.0

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

3.5 Water Quality Summary for the Catskill System

DEP has continued to enhance watershed protection in the Schoharie basin. Since 2004, three large wastewater treatment plants (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 600 since the WWTP upgrade and septic rehabilitation programs began.

Water quality status in Schoharie Reservoir from 2007-2009 was good. Monthly median fecal counts and monthly median phosphorus concentrations never exceeded benchmarks and monthly turbidities only exceeded 10 NTUs on three occasions. Trophic status was mesotrophic.

Downward phosphorus trends were detected in the input, reservoir, and output and were attributed primarily to load reductions from WWTPs. Despite the decline in nutrients, the Trophic State Index showed an upward trend, presumably caused by improvements in water clarity. Increasing trends in fecal coliform counts appear to be associated with large runoff events and to the generally wet conditions in 2003-2005.

Biomonitoring results were also positive. Three sites on Schoharie Creek were rated non-impaired for the 2007-2009 status period, while long-term trend analysis indicated improvement at one site and no change at the remaining two.

Three sites above Schoharie Reservoir are routinely monitored for *Cryptosporidium* and *Giardia*. Oocysts have declined since 2007, coinciding with such watershed improvements as septic remediation and the construction of improvements to WWTPs in the Schoharie basin. A reservoir output site is also monitored. Results at this site are typically lower than at the stream sites since reservoir processes (e.g., settling, predation, die-off) provide an effective barrier to protozoan survival, resulting in a reduction of protozoan numbers downstream.

Watershed protection efforts continue to benefit water quality in the Ashokan basin. Between the last report in 2004 and 2009, phosphorus loads from WWTPs were reduced from 50 kg year^{-1} to about 25 kg year^{-1}. The reduction in load was primarily the result of improvements to the Pine Hill and Camp Timberlake WWTPs. Numerous failing septic systems have also been repaired. Since 1996, over 900 septic systems have been remediated, with about 350 repairs occurring since 2005.

Water quality status in the West Basin of Ashokan Reservoir was good during the 2007-2009 period. Monthly median fecal counts were predominantly at or just above detection limits, with one excursion of 20 CFU 100 mL^{-1}. Monthly median turbidities were mostly below 5 NTU, with two exceptions related to storm events. Total phosphorus values were also low, with most monthly medians below 10 µg L^{-1}. The distribution of monthly trophic state values indicates that the West Basin was usually mesotrophic but could be considered oligotrophic more than 25% of the time.

Long-term water quality trend results were mixed. Phosphorus decreased, in part due to watershed programs, but turbidity, fecal coliforms, and conductivity all increased during the 1994-2009 period. A large spring runoff event in 2005 was largely responsible for the upward trends in turbidity and fecal coliforms.

Water quality status was even better in the East Basin. The highest monthly median fecal coliform count was 3 CFU 100 mL^{-1}. All other months had fecal coliform counts below 1 CFU 100 mL^{-1}. Most turbidity values were below 3 NTU, and phosphorus was generally below 10 µg L^{-1}. Similar to the West Basin, the trophic state in the East was in the mesotrophic-oligotrophic range.

Biomonitoring results generally indicated that the main input to the Ashokan basins, Esopus Creek, was in good health. Numerous mayflies occurred at most sites, indicative of good water quality, and all but one site were rated non-impaired. Long-term trend data are available at two sites. Results indicated improvement at one site and no change at the other.

Waterfowl management in Ashokan Reservoir has been conducted on an “as needed basis”. Since 2003, waterfowl numbers on Ashokan have decreased dramatically. This decrease is primarily attributable to closure of local landfills and a consequent shift in gull migratory patterns. During the current assessment period, fecal coliform numbers have been low enough to obviate the need for as needed management.

Four sites on the Esopus and one reservoir output sample have been routinely monitored for *Cryptosporidium* and *Giardia*. Reservoir output results were much lower than the incoming streams’, indicating that reservoir processes (e.g., settling, predation, die-off) provide an effective barrier to protozoan survival, resulting in a reduction of protozoan numbers downstream.

NYC Environmental Protection

4. The Delaware System

4.1 Introduction

Water quality analyses cover a longer time period than the five-year period described for program implementation in Chapter 2. Therefore, several decades of data were used to provide long-term context for interpretation. Selection of this extensive time period was done in order to use a sufficiently long time to capture changes in water quality in response to watershed protection programs. Doing so provides a view of these changes in the context of natural variation (such as floods and droughts), which are not sufficiently represented in a five-year period. The water quality data used in this analysis begin in 1993, which represents conditions at the outset of filtration avoidance when many watershed protection programs were in their infancy. The data from this time represent conditions with fewer watershed safeguards in place. The time period of the analysis extends through 2009, which allows DEP to examine trends over the past 17 years as new and intensified watershed protection programs have been implemented. Another reason for using long-term data is the fact that there are time lags between program implementation (causes) and water quality changes (effects). Sufficient time must pass after programs are in place in order to see the full effects of programs on water quality. Therefore, further improvements in water quality will evolve as the full effects of the programs develop and stabilize.

There are several important factors that govern water quality over the long term. Perhaps the two most important are climate, as a determinant of 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 30-year period (1967 to 1997) are depicted in Figure 4.1. Overall, water residence time is determined by the relationship of hydraulic load to basin volume, so reservoirs with large catchment areas and high hydraulic loads relative to their volume have short water residence times (or high flushing rates). The four basins of the Delaware System have characteristically different residence times. Rondout consistently has the shortest and most stable water residence time on account of the high hydraulic load that is consistently delivered by the three upstream reservoirs; it averages about one to two months. On the other end of the spectrum,

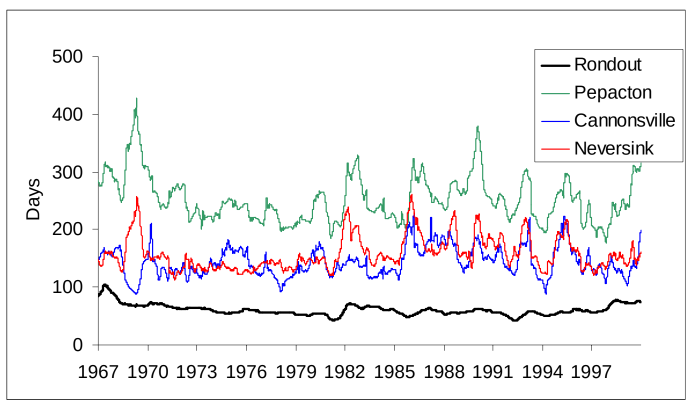

Figure 4.1 Water residence times of reservoirs in the Delaware System over a 30-year time period (1967 through 1997).

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 new loading levels, for example, in about six months, whereas Pepacton would take more than two years to re-equilibrate to a new steady state.

Water residence times of these four reservoirs vary, as illustrated in Figure 4.1. The downstream reservoir, Rondout, has the most consistent residence time, averaging three months, since it receives its supply from the other three upstream reservoirs and is maintained in a relatively full condition. Cannonsville and Neversink have water residence times of similar duration that fluctuate around five months. Pepacton Reservoir, the largest capacity reservoir of all 19 reservoirs, has a water residence time that fluctuates around nine months. Operational management of the flows into Rondout clearly eliminates much of the variability that occurs in the three upstream reservoirs.

Over the short term (i.e., less than a year), there are other influences that affect water quality. These account for the high degree of variation seen in the plots of water quality data over 17 years. Seasonal variations in precipitation and temperature affect runoff and stratification, which also affect water quality from week to week and storm to storm. Since DEP's objective was to look for trends in the water quality data over the time period of program implementation, statistical techniques for the water quality trend analysis were chosen to minimize the influence of seasons on long-term trends. In addition, concentrations were flow-adjusted in order to minimize the influence of short-term flow changes on trend detection. With this approach, DEP has examined the relationships between watershed protection and water quality changes.

Some summary information on program implementation in each basin follows the land use description. This serves as a brief reminder 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 Chapter 2. Cumulative figures are provided to show the progress of watershed protection over the past decade and to give insight into what has been accomplished in terms of watershed improvements. Best management practices for farming, stormwater control through environmental infrastructure, stream management, and septic remediation are among the programs that have reduced the loading of pollutants to the water supply. One other activity depicted is boating permits, as an indication of reservoir use by the public. This has been fairly stable over the past decade, with the largest increase in permits occurring in the Pepacton basin.

Water quality status and trends are then described. Status is presented as a three-year average and trends are evaluated for a 17-year period. The analytes chosen were those most important for the Surface Water Treatment Rule and meeting the requirements of the 2007 Filtration Avoidance Determination. Macroinvertebrate data provide insight into the ecological condition of streams and form the basis for an index to track changes that can demonstrate water quality improvements. The impact of the waterfowl management program and its ability to control and reduce fecal coliform bacteria over the past five years are demonstrated. 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 distribution, so it is by design that program intensity is higher in these basins than others. Finally, an analysis of pathogen transport through the system is presented. This provides much insight into the benefit of NYC's sequential system of reservoirs and its ability to improve water quality as water travels towards distribution.

4.2 The Neversink Basin

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

The Neversink is one of four reservoirs in the Delaware water supply system, the newest of the City's three systems. The water withdrawn from the reservoir travels six miles in the Neversink Tunnel to 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 entering the two aqueducts that carry Catskill/Delaware water to Hillview Reservoir in Yonkers, at the City's northern boundary, where it enters the water supply distribution system.

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 wastewater treatment plants sited in the Neversink watershed basin.

Of the 58,891 acres of land in the Neversink watershed, 54,619 acres (92.7%) are forested, 1,073 acres (1.8%) are urban or built-up land, and 894 acres (1.5%) are brushland or successional land. Wetlands comprise 680 acres (1.2%) of the watershed, while 1,522 acres (2.6%) are water. The remaining 103 acres (0.2%) are in agricultural use (Figure 4.2). (Note that agricultural land use differs between this pie chart and the subsequent bar chart because the agricultural program includes grassland and brushland used as farmland.) Thus, the vast majority of this watershed is forested.

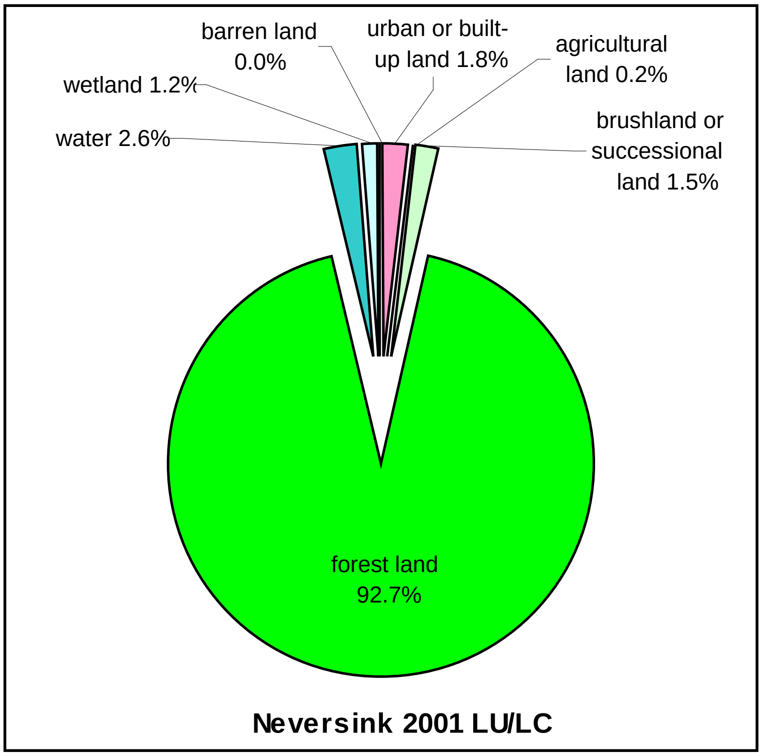

Figure 4.2 Land use in the Neversink drainage basin based on 2001 data.

4.2.1 Program Implementation (Neversink Basin)

Since 1996, 12 best management practices (BMPs) have been implemented to control run-off of nutrients, turbidity, pathogens, and stormwater (Figure 4.3a). These BMPs are associated with approximately 470 acres of farmland. One environmental infrastructure project was constructed to control stormwater (Figure 4.3b). Approximately 120 septic systems throughout the basin have been remediated during this time period (Figure 4.3c). Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Chapter 2 of this report.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Neversink has increased from about 125 in the early part of the decade to approximately 220 (Figure 4.3d) in the most recent years.

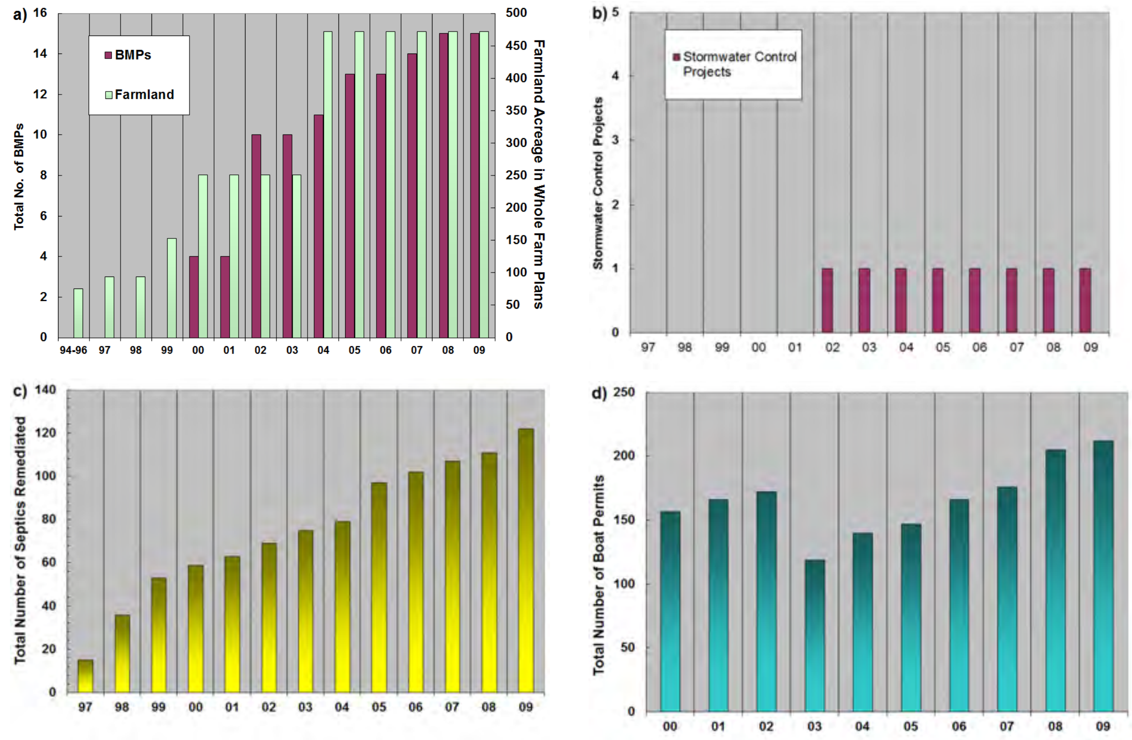

Figure 4.3 History of watershed programs in the Neversink drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control, c) septic system remediation, d) number of boat permits issued.

Note: Bars in plots (a)-(c) represent cumulative totals.

4.2.2 Water Quality Status and Trends (Neversink Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 4.4. Two time periods are assessed for each site: i) the full period of record, and ii) a three-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deteri-

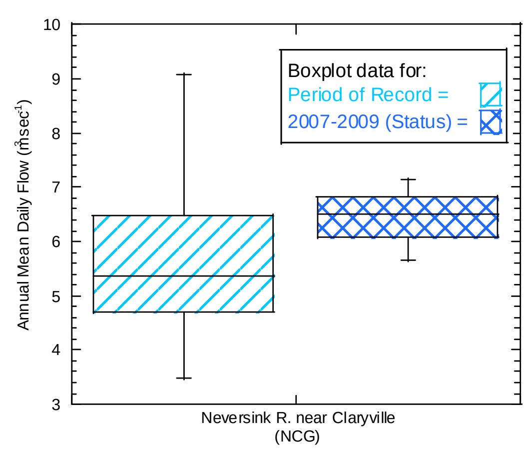

Figure 4.4 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the Neversink watershed.

oration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

The Neversink River near Claryville is the primary inflow to Neversink Reservoir. It drains 72% of the basin (Table 4.1). The status period's mean annual daily flow median was about 1.1 m^3 sec^{-1} greater than the long-term median and the overall distribution was slightly biased to higher flows. Therefore, flows in the status period were somewhat higher than usual.

Table 4.1: DEP sample site descriptions for the Neversink watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
NCG	Neversink River near Claryville	72.4%	July 1951-present, November 1937-May 1949

Status (Neversink Basin)

The Neversink basin status evaluation is presented as a series of boxplots in Figure 4.5. The input stream is the Neversink River (NCG), the reservoir is designated as NN, and the output is designated as NRR2. All values below the maximum detection limit line for fecal coliform and total phosphorus (blue lines) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

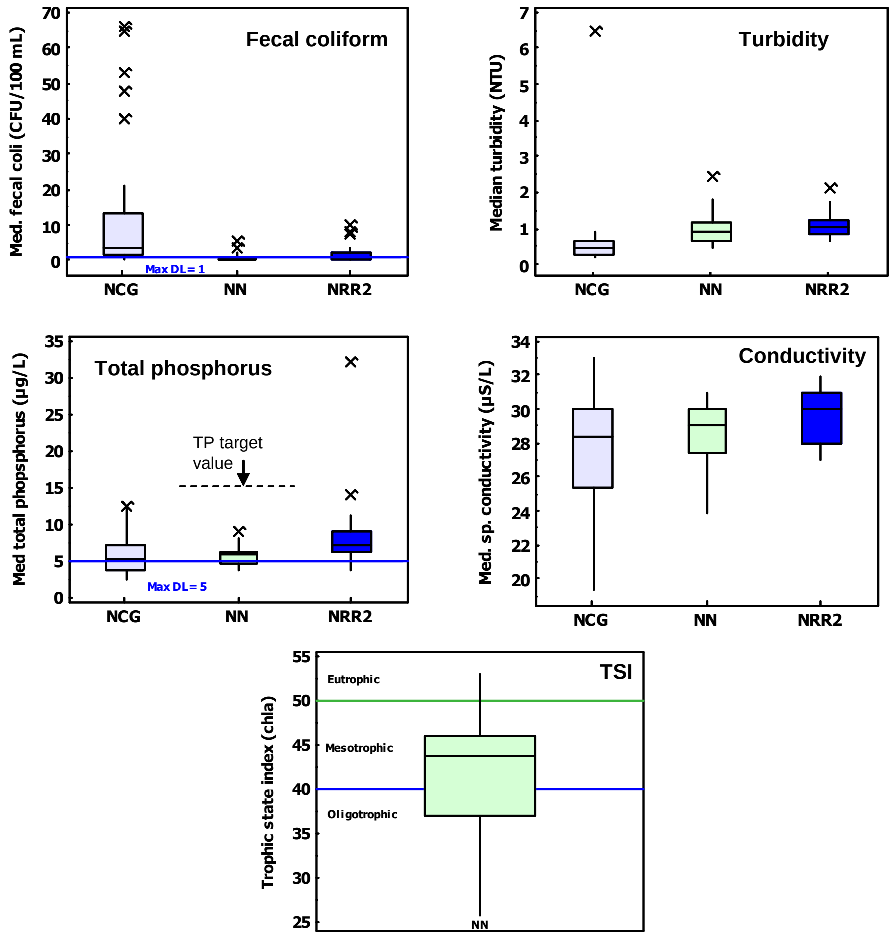

Figure 4.5 Water quality status boxplots using 2007-2009 monthly data for the Neversink basin main stream input at the Neversink River (NCG), Neversink Reservoir (NN), and the output at the Neversink gatehouse (NRR2).

Fecal coliform values were very low throughout the basin and all values for the input stream were well below the DEC Stream Guidance Value of 200 CFU 100 mL^{-1} during the 2007-2009 analysis period. Many of the values were at or below the detection limit in the reservoir, which required the use of non-detect statistics to estimate the distribution for the boxplots. There was a notable decrease in the median and variability of fecal coliform values as water traveled from the input through the reservoir and to the output.

The turbidity values of the input stream were lower than those for both the reservoir and the output. Because the output is sampled five days per week and the input only once per month, turbidity loadings from storms are far more likely to be captured in the output samples. With respect to the higher reservoir turbidity values, note that although both the input stream and reservoir data are monthly, multiple sites and depths are sampled in the reservoir. In addition, the residence time of the reservoir is much longer than the stream's. Together, the additional samples and longer residence time increase the chances of capturing turbidity loading in the reservoir. Reservoir operations may also have played a role in increasing turbidity. Outflows were reduced, starting in June 2007, after which turbidity increased from algal blooms, presumably caused by the increased water and nutrient residence times.

Total phosphorus (TP) values for the input had more variability than those for the reservoir, and the medians were similar. Both sites generally had lower TP values than the output. As mentioned for turbidity, this may be the result of missed storm events with fixed-frequency stream monitoring, or increased TP associated with primary productivity in the reservoir. None of the values in the reservoir were above the phosphorus-restricted target value of 15 $\mu g\ L^{-1}$ in the reservoir.

The Trophic State Index (TSI) values for Neversink Reservoir primarily ranged from oligotrophic to mesotrophic for the three-year period. This classification is typical for Neversink, which has the lowest primary productivity in the NYC water supply system.

There was slightly more variability in conductivity in the input as compared to the reservoir and output. Similarly, conductivity medians rose from upstream to downstream. Variations in sample collection frequency and times, and use of different instruments, may have played a role in these minor differences between the sites.

In summary, water quality was very good during the 2007-2009 status assessment period used to evaluate status in the Neversink basin. The data for the selected variables show that there were no values that exceeded the established benchmarks.

Trends (Neversink Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 4.2).

Water quality trend plots are presented in Figure 4.6 and results of the Seasonal Kendall trend analysis are provided in Table 4.2.

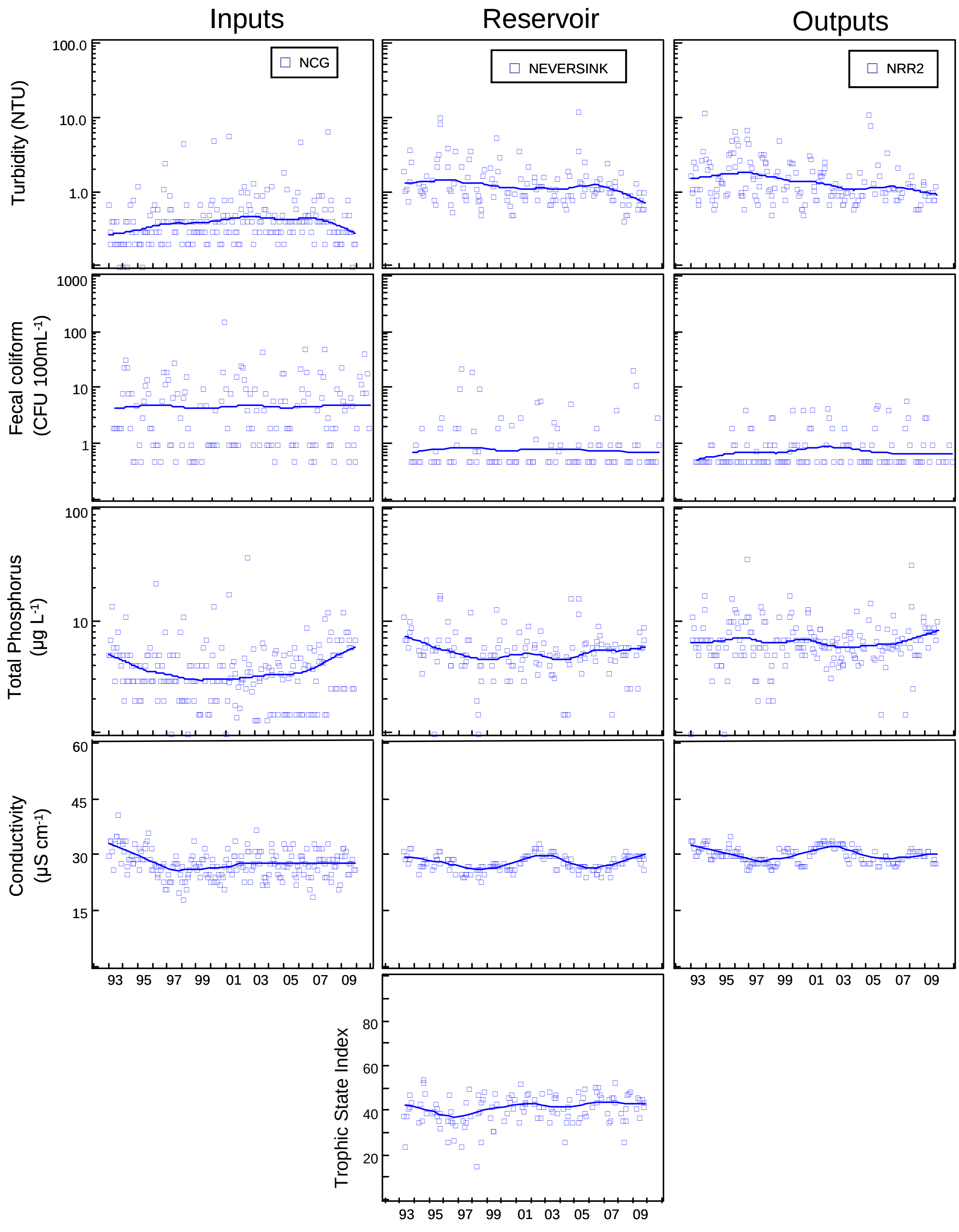

Figure 4.6 Water quality trends for the Neversink basin for the main stream input at the Neversink River (NCG), Neversink Reservoir, and the output at the Neversink gatehouse (NRR2). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 4.2: Neversink basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
NCG	Input	Turbidity	203	0.14	***	0.00
Neversink	Reservoir	Turbidity	133	-0.27	***	-0.03
NRR2	Output	Turbidity	162	-0.24	***	-0.03
NCG[3]	Input	Fecal coliform	200	0.04	NS	
Neversink[3]	Reservoir	Fecal coliform	132	-0.01	NS	
NRR2[3]	Output	Fecal coliform	157	0.10	*	0.00
NCG[3]	Input	Total phosphorus	204	0.05	NS	
Neversink[3]	Reservoir	Total phosphorus	134	-0.04	NS	
NRR2	Output	Total phosphorus	188	-0.00	NS	
NCG	Input	Conductivity	204	-0.08	*	-0.07
Neversink	Reservoir	Conductivity	133	0.03	NS	
NRR2	Output	Conductivity	162	-0.09	*	0.00
Neversink	Reservoir	Trophic State Index	126	0.17	***	0.33

[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 in this row required the use of statistical methods for “non-detect” values.

Declines in turbidity were detected in the reservoir (0.03 NTU yr^{-1}) and in its output (0.03 NTU yr^{-1}), representing recovery from flood events in the mid-to-late 1990s as well as low turbidity loads during the drought period of mid-2001–2002. Due to the large number of values less than the detection limit, non-detect statistics were used to assess the trends (Helsel 2005). In contrast, an upward trend, based on the positive Tau value, was detected for the main input, NCG. Adjusting the data to account for flow did not appreciably affect the trend results. It is possible that turbidity patterns in Neversink Reservoir are not predominantly a function of this input. Moreover, 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 Neversink basin. Fecal counts were consistently low, especially in the reservoir and its output.

Long-term TP trends were also not observed in the Neversink basin. The elevated input and reservoir concentrations in 1993 were caused by a large early spring rain event that followed two years of extremely dry conditions in the watershed (1991 and 1992). Since 1998, 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 the data record. Reasons for the increase are not clear and will continue to be investigated.

Very slight conductivity decreases were detected for the input and output. The decrease in the input is largely driven by elevated conductivity during the first three years of the data record. Reasons for the high conductivity during this time are not apparent. The increase observed in 2002, best illustrated in the reservoir and output data, can be ascribed to the dry conditions prevalent in that year.

A highly significant upward trend was detected in the TSI values of the reservoir. The steepest increase represents recovery from a large flooding event in January 1996. Higher TSI values observed from 2006 through 2009, correspond to an increase in phosphorus and water clarity (as suggested by a decrease in turbidity) during this period.

In summary, downward trends were detected for turbidity and, to a lesser degree, conductivity, in the Neversink basin. The turbidity decline is attributable to recovery from flood-induced turbidity highs in the mid-to-late 1990s, low turbidity loads during the mid-2001–2002 drought period, and a decrease in runoff-generating events from 2007-2009. Reasons for the slight decrease in input and output conductivity are not clear. Although trends were not detected for phosphorus, the input, reservoir, and output all experienced increases during the latter half of the data record for reasons not yet apparent. In this basin, water quality trends are governed by natural, rather than anthropogenic, events.

4.3 The Pepacton Basin

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 New York City. The reservoir was formed by damming the East Branch of the Delaware River, which continues west to join the lower Delaware River. Placed into service in 1955, Pepacton consists of one basin, approximately 15 miles in length. The reservoir holds 140.2 billion gallons at full capacity, which makes it the largest reservoir in the City system by volume. Currently, Pepacton supplies 293 million gallons per day (MGD), or roughly 24.2% of the total average daily consumption, to New York City and an additional one million upstate consumers.

Pepacton is one of four reservoirs in the City's Delaware water supply system. Water withdrawn from Pepacton Reservoir enters the East Delaware Aqueduct and flows southeast for 25 miles into Rondout Reservoir. There it mixes with water from 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 Kensico, it travels via aqueduct to Hillview Reservoir and into the distribution system.

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: the East Branch Delaware River contributes 44% of the flow, Platte Kill provides 9.5%, and Tremper Kill and Mill Brook provide 9% and 7%, respectively. Presently there are six wastewater treatment plants (WWTPs) sited in the Pepacton watershed, producing approximately 0.315 MGD of flow. As per the most recent SPDES permits, the plants are limited to a collective release of 0.665 MGD of flow.

Of the 237,459 acres of land in the Pepacton watershed, 195,406 acres (82.3%) are forested, 10,222 acres (4.3%) are urban or built-up land, 18,204 acres (7.7%) are brushland or successional land, and 14 acres (0.0%) are classified as barren land. Wetlands comprise 1,838 acres (0.8%) of the watershed, while 5,733 acres (2.4%) are water. The remaining 6,042 acres (2.5%) are in agricultural use (Figure 4.7). (Note that agricultural land use differs between this pie chart and the subsequent bar chart because the agricultural program includes grassland and brushland used as farmland.)

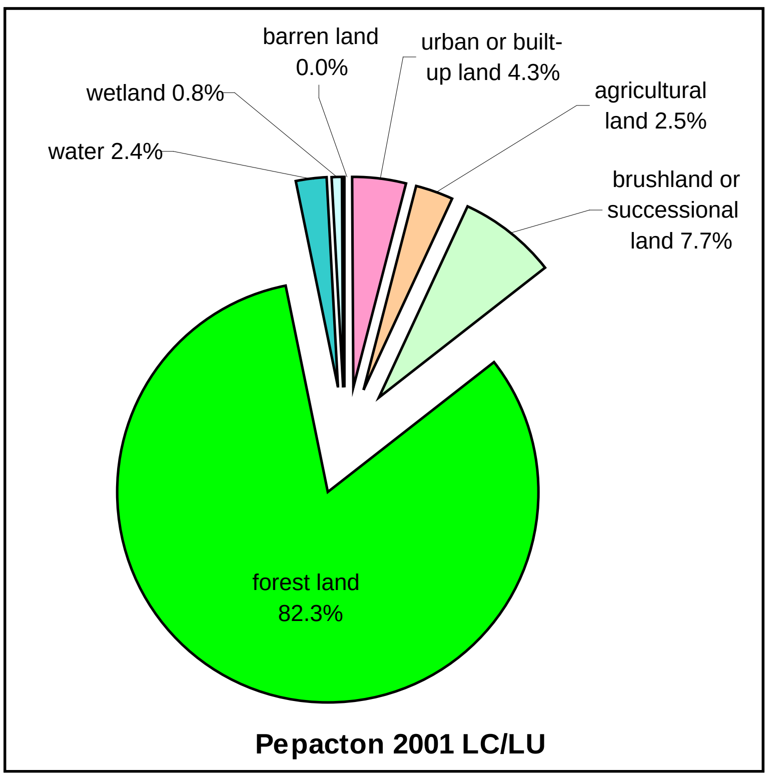

Figure 4.7 Land use in the Pepacton drainage basin based on 2001 data.

4.3.1 Program Implementation (Pepacton Basin)

Since 1996 nearly 400 best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater (Figure 4.8a). These BMPs are associated with approximately 9,000 acres of farmland. Over the last decade, nearly 18 additional environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects (Figure 4.8b). More than 640 septic systems throughout the basin have been remediated during this time period (Figure 4.8c). Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Chapter 2 of this report.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Pepacton has increased from 1,550 in the early part of the last decade to over 1,800 in 2010 (Figure 4.8d).

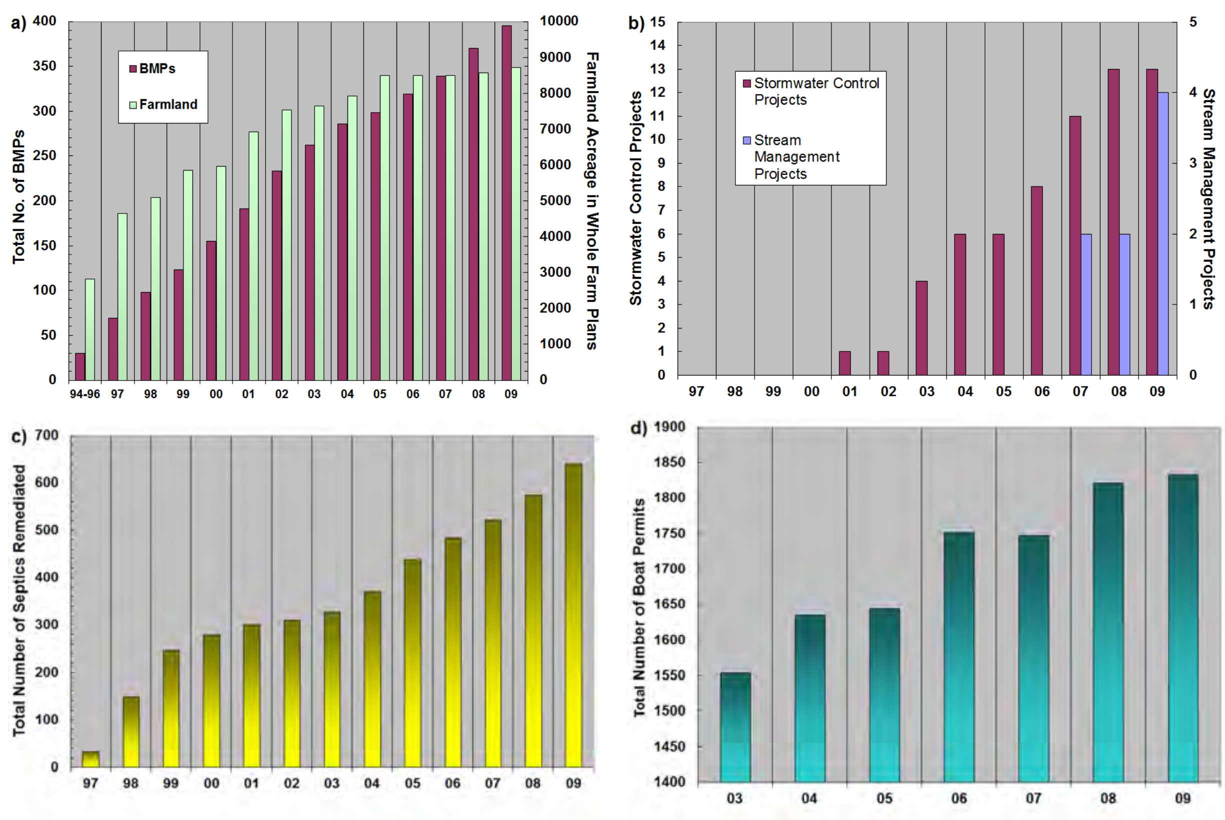

Figure 4.8 History of watershed programs in the Pepacton drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control, including stream management projects, c) septic system remediation, d) number of boat permits issued.

Note: Bars in plots (a)-(c) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the Pepacton Basin

Inputs of phosphorus, as well as other pollutants, from wastewater treatment plants (WWTPs) to Pepacton Reservoir continue to be reduced as a result of DEP's effort to upgrade all surface-discharging plants, including upgrade of the City-owned Margaretville plant, and also through the intervention and involvement of DEP's WWTP Compliance and Inspection Program (Section 2.12.2). As illustrated in Figure 4.9, phosphorus loads (as total phosphorus) declined considerably from 1994 to 1999, and remained low in 2009. The combined flow from all Pepacton WWTPs shows an increase in 2009 due to the completion of two new plants, the Andes WWTP and the Fleischmanns WWTP.

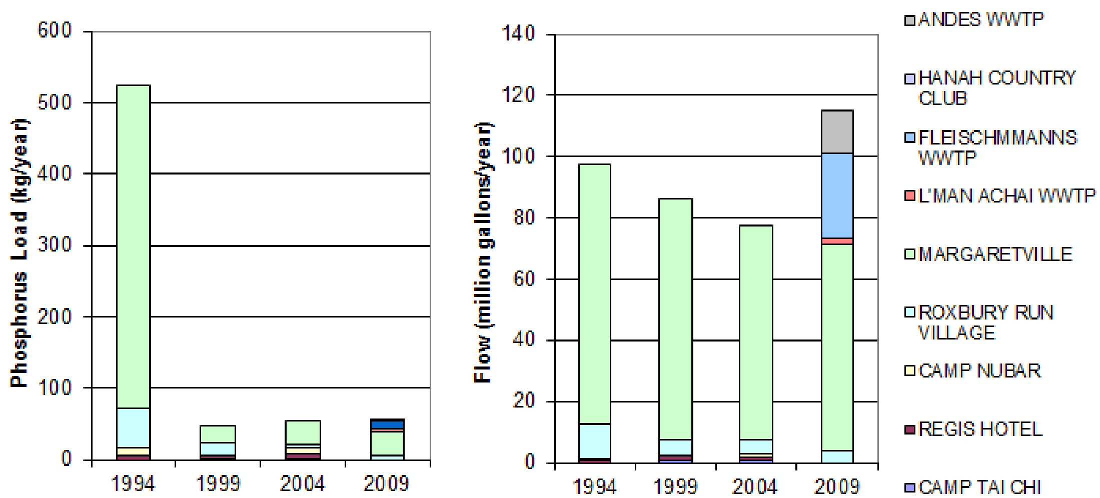

Figure 4.9 Wastewater treatment plant total phosphorus loads and flows in the Pepacton drainage basin, 1994-2009.

4.3.2 Water Quality Status and Trends (Pepacton Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 4.10. Two time periods are assessed for each site: i) the full period of record, and ii) a three-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deterioration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

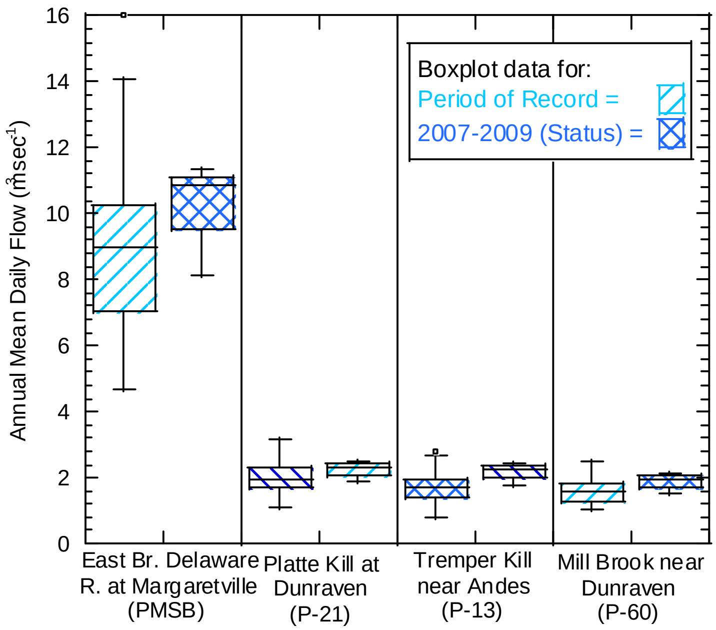

Figure 4.10 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the Pepacton watershed.

The East Branch of the Delaware River at Margaretville is the primary inflow to Pepacton Reservoir. It drains 45% of the basin (Table 4.3). The status period's mean annual daily flow median was about 1.8 m^3 sec^{-1} greater than the long-term median, and the overall distribution was slightly biased to higher flows. The other tributaries to Pepacton Reservoir had similar flow characteristics. Therefore, flows in the status period were higher than usual.

Table 4.3: DEP sample site descriptions for the Pepacton watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
PMSB	East Branch Delaware River at Margaretville	44.5%	February 1937-present
P-21	Platte Kill at Dunraven	9.4%	December 1996-present, Oct 1941-Sept. 1962
P-13	Tremper Kill near Andes	8.8%	February 1937-present
P-60	Mill Brook near Dunraven	6.7%	February 1937-present

Status (Pepacton Basin)

The Pepacton basin status evaluation is presented as a series of boxplots in Figure 4.11. The input stream is the East Branch Delaware River (PMSB), the reservoir is designated as EDP, and the output is designated as PRR2. All values below the maximum detection limit line for fecal coliform (blue line) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

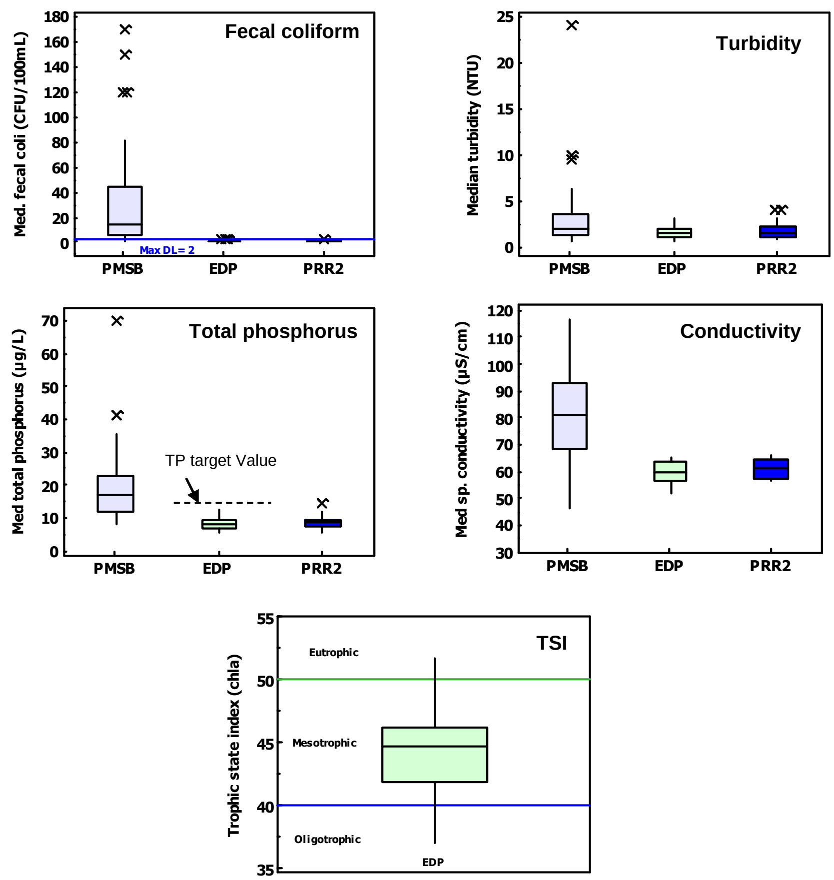

Figure 4.11 Water quality status boxplots using 2007-2009 monthly data for the Pepacton basin main stream input at the East Branch Delaware River (PMSB), Pepacton Reservoir (EDP), and the output at the Pepacton gatehouse (PRR2).

Fecal coliform values dropped significantly between the input and the reservoir. None of the input stream values exceeded the DEC Stream Guidance Value of 200 CFU 100 mL^{-1} during the 2007-2009 analysis period. In the reservoir and the output, all of the values were at or below the detection limit, making it necessary to use non-detect statistics to estimate the distribution of the boxplots. These data suggest that there was a significant attenuation of fecal coliform levels in water detained in the reservoir.

The turbidity values also show attenuation through the system. Both the variability and the medians decreased from the input through the reservoir and to the output. The median value at the output was 1.3 NTU for the status period. The attenuation of turbidity along a longitudinal transect, as occurred here, is expected, since the particulates associated with turbidity settle with time.

Total phosphorus (TP) values resembled the pattern found with turbidity. The medians and variability were lower for the output and the reservoir as compared to the input stream. None of the values for the reservoir were above the phosphorus-restricted target value of 15 µg L^{-1}.

Most of the Trophic State Index (TSI) values for Pepacton Reservoir were well within the mesotrophic range.

There was more variability in the input stream's conductivity than in the reservoir's or the output's. Stream conditions can be expected to fluctuate more than the reservoir's, so this pattern was anticipated.

In summary, water quality was very good during the 2007-2009 status assessment period in the Pepacton basin. The data for the selected variables show that medians for fecal coliform were well below the established benchmarks.

Trends (Pepacton Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 4.4).

Water quality trend plots are presented in Figure 4.12 and results of the Seasonal Kendall trend analysis are provided in Table 4.4.

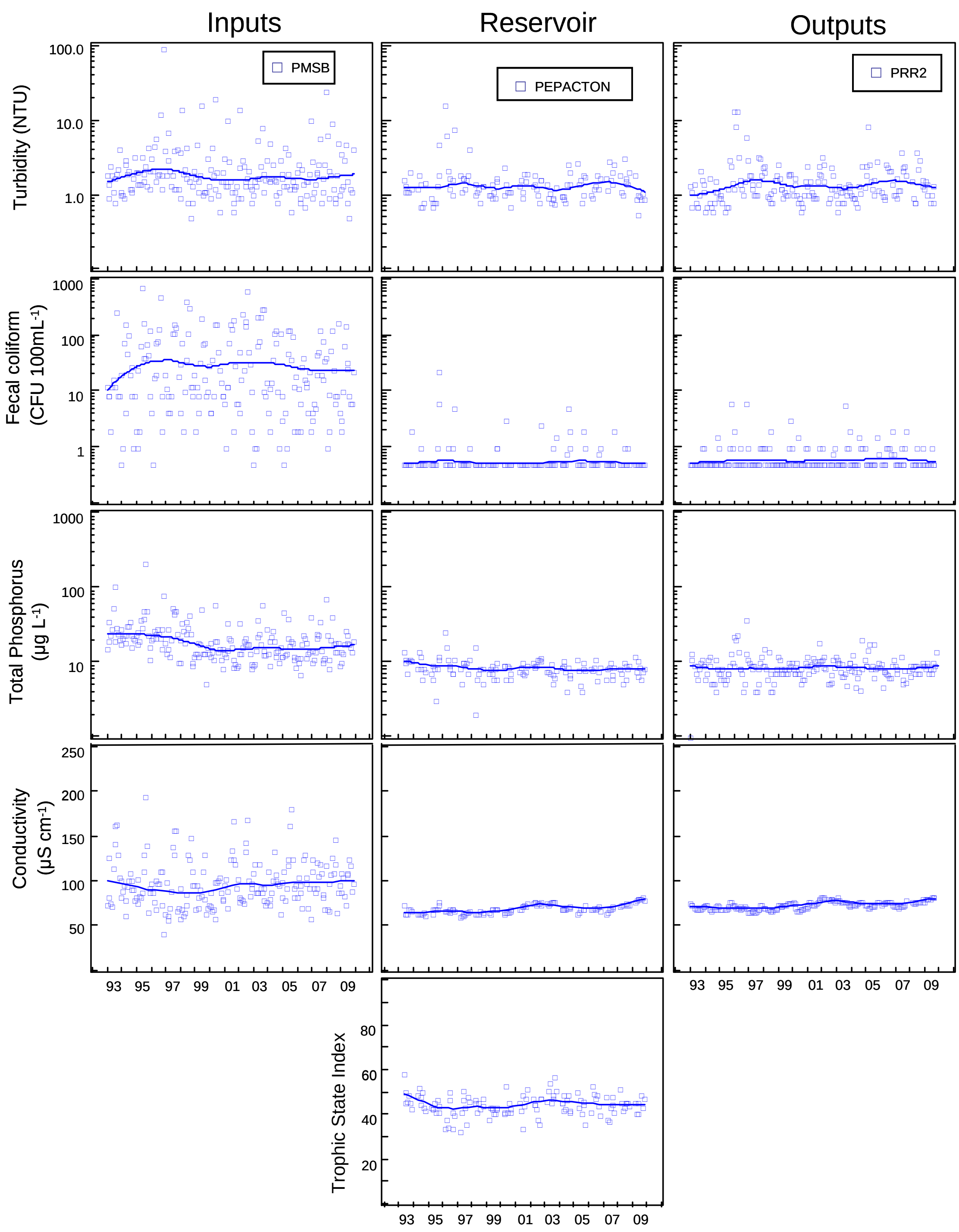

Figure 4.12 Water quality trend plots for the Pepacton basin for the main stream input at the East Delaware River (PMSB), Pepacton Reservoir, and the output at the Pepacton gatehouse (PRR2). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 4.4: Pepacton basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
PMSB	Input	Turbidity	204	-0.05	NS	
Pepacton	Reservoir	Turbidity	129	-0.02	NS	
PRR2	Output	Turbidity	183	0.09	**	0.01
PMSB[3]	Input	Fecal coliform	200	-0.05	NS	
Pepacton[3]	Reservoir	Fecal coliform	128	-0.08	NS	
PRR2[3]	Output	Fecal coliform	180	0.01	NS	
PMSB	Input	Total phosphorus	204	-0.27	***	-0.55
Pepacton	Reservoir	Total phosphorus	129	-0.12	**	0.00
PRR2	Output	Total phosphorus	195	0.05	NS	
PMSB[4]	Input	Conductivity	203	0.29	***	0.70
Pepacton	Reservoir	Conductivity	122	0.47	***	0.50
PRR2	Output	Conductivity	183	0.41	***	0.43
Pepacton	Reservoir	Trophic State Index	128	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 in this row required the use of statistical methods for "non-detect" values.

[4]Data were adjusted for flow prior to trend analysis—see Appendix 3.

Turbidity trends were not detected in the input or reservoir. However, a long-term upward trend was detected in the output. The change per year was very small (0.01 NTU) and appears to have been driven by low values during the first three years of the data record.

Trends were not detected for fecal coliforms. The large number of values below the detection limit in the reservoir and the output necessitated the use of non-detect statistics. At the input, trend difficult was difficult because of the low sampling frequency (1/month) and extremely high variability exhibited by the data (Figure 4.12). Elevated values in the reservoir were generally associated with runoff events.

A significant decline in TP (0.55 µg mL^{-1} yr^{-1}) was observed in the input. Downward trends were weak in the reservoir and nonexistent in the output. At the input site, phosphorus concentrations declined from 1993-1999, especially from 1996-1999, a period that coincided with upgrades to the Margaretville WWTP (completed in 1999). Part of the decline can also be attributed to recovery from flooding events in late 1995 and early 1996. Terrestrial and reservoir modeling suggest that land use changes may also have played a part in this reduction.

Small, statistically significant upward trends in conductivity were detected in the input (0.70 µS cm^{-1} yr^{-1}), reservoir (0.50 µS cm^{-1} yr^{-1}), and output (0.43 µS cm^{-1} yr^{-1}). Anthropogenic sources (e.g., road salt runoff) were a factor; chloride steadily increased from a median of 4.2 mg L^{-1} in 1993-1994 to a median of 6.9 mg L^{-1} in 2008-2009 (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.

Trends were not detected for TSI, indicating that algal activity has been steady during the period of record. The sharp decline in TSI in the early 1990s corresponds to the decrease in TP observed during those years in the input, and to a lesser degree in the reservoir.

In summary, a downward phosphorus trend was detected at the input and in the reservoir and upward conductivity trends occurred at the input, the reservoir, and the output. Treatment plant upgrades and recovery from flooding events are thought to be the main factors controlling the phosphorus decrease. Periods of low precipitation and a steady increase in chloride explain the rise in conductivity.

Biomonitoring Status and Trends (Pepacton Basin)

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. For methodology details, see Appendix 3.

The most recent status of macroinvertebrate communities in the Pepacton basin was evaluated by examining 2007-2009 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. The two sites with data from these years are both routine, that is, they are sampled annually, as opposed to non-routine sites, which are sampled on a rotating basis.

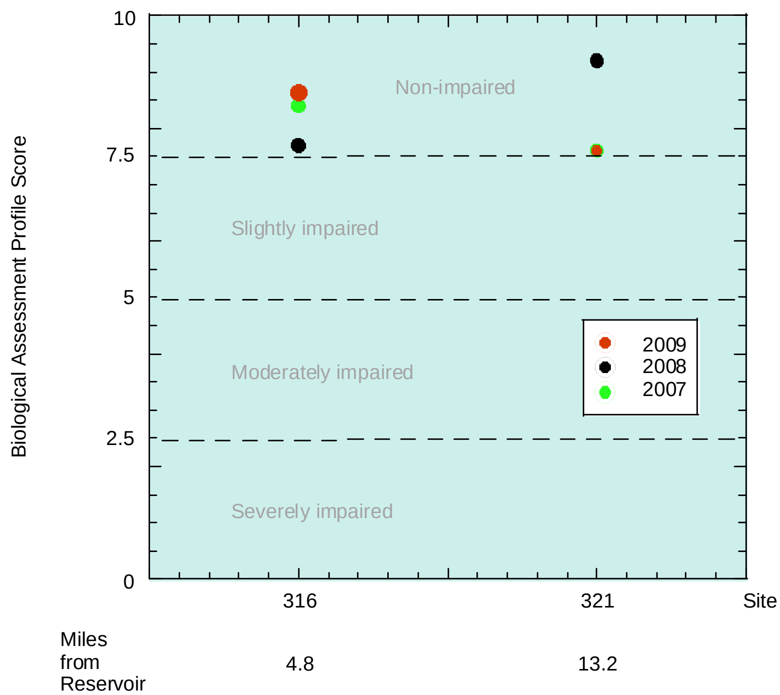

Figure 4.13 Biomonitoring status scores for the East Branch Delaware River, 2007-2009.

Site 316 (PMSB) in Margaretville lies approximately five miles upstream of Pepacton Reservoir; Site 321 (EDRB) is about 13 miles upstream. From 2007-2009, both sites were assessed as being non-impaired (Figure 4.13), indicating the presence of optimal conditions for the benthic community.

Trend analysis was based on the 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. No significant trend was detected at Site 321, where all assessments since 1996 have been non-impaired. At Site 316, even though all but one of the assessments have been non-impaired, a weak downward trend ($p = 0.19$) was observed (Figure 4.14). This result must be viewed with caution, however, since it is largely driven by a single high score in 1998 (9.4). Moreover, two of the most recent scores (in 2007 and 2009) were the highest recorded at the site since 2000. Equally significant, the 2009 community was dominated by the very sensitive mayfly *Ephemerella* (tolerance value = 1), which comprised one-quarter of the entire subsample in that year.

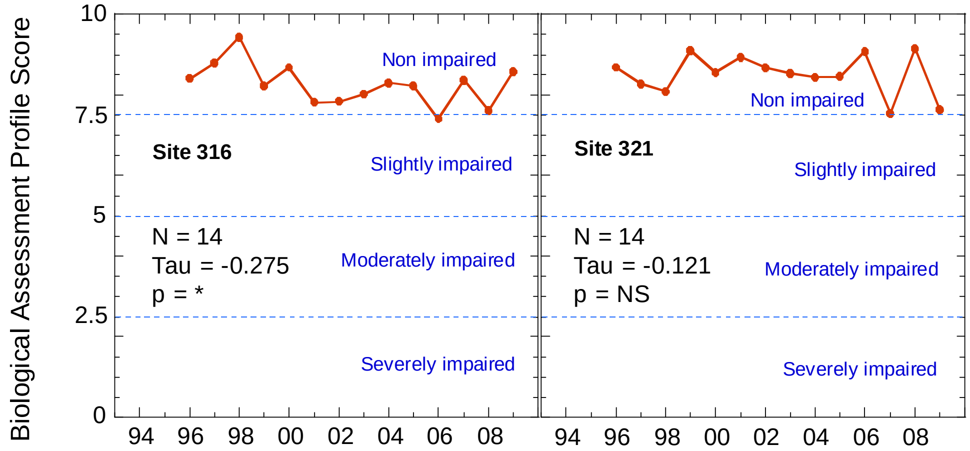

Figure 4.14 Biomonitoring trend plots for the East Branch Delaware River, 1996-2009. Results of the Mann Kendall trend test are shown as follows: NS (Not Significant) = $p \geq 0.20$, * = $0.20 > p > 0.10$. N = number of observations, Tau = Mann Kendall test statistic.

4.4 The Cannonsville Basin

Cannonsville Reservoir is located at the western edge of Delaware County, southwest of the Village of Walton and about 120 miles northwest of New York City. Placed into service in 1964, it holds 95.7 billion gallons at full capacity. Currently, Cannonsville supplies 86 million gallons per day (MGD), or roughly 7.1% of the total average daily consumption, to New York City and an additional one million upstate consumers.

Cannonsville is one of four reservoirs in the City's Delaware System and the newest in New York City's water supply. Water drawn from Cannonsville enters the West Delaware Tunnel and travels 44 miles to the upper end of Rondout Reservoir. From there, it is carried in the 85-mile-long Delaware Aqueduct under the Hudson River to West Branch and Kensico Reservoirs. At Kensico, it mixes with Catskill System water, then passes through two aqueducts to Hillview Reservoir in Yonkers, where it enters the water supply distribution system.

The Cannonsville watershed's drainage basin is 455 square miles, the largest basin in the City's system, and includes parts of 17 towns, all in Delaware County: Andes, Bovina, Delhi, Deposit, Franklin, Hamden, Harpersfield, Jefferson, Kortright, Masonville, Meredith, Middletown, Roxbury, Sidney, Stamford, Tompkins, and Walton. Trout Creek and the West Branch Delaware River are the two primary tributaries flowing into Cannonsville, the former providing approximately 4.5% and the latter approximately 77% of the flow. Presently there are five wastewater treatment plants (WWTPs) sited in the Cannonsville watershed, producing an average flow of 2.534 MGD. As per the most recent SPDES permits, the plants are limited to a collective release of 3.235 MGD of flow.

Of the 291,031 acres of land in the Cannonsville watershed, 200,217 acres (68.8%) are forested, 19,520 acres (6.7%) are urban or built-up land, 32,941 acres (11.3%) are brushland or successional land, and 61 acres (0.0%) are classified as barren land. Wetlands comprise 3,570 acres (1.2%) of the watershed, while 5,182 acres (1.8%) are water. The remaining 29,540 acres (10.2%) are in agricultural use (Figure 4.15). (Note that agricultural land use differs between this pie chart and the subsequent bar chart because the agricultural program includes grassland and brushland used as farmland.)

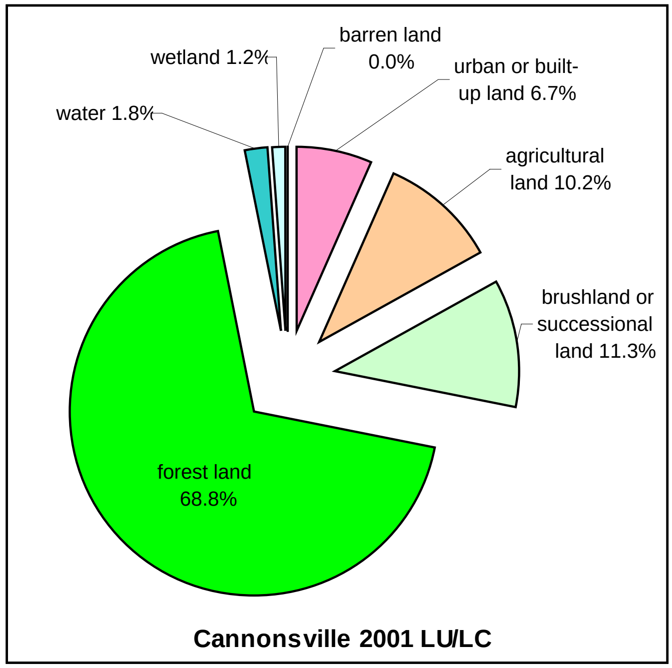

Figure 4.15 Land use in the Cannonsville drainage basin based on 2001 data.

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 Delaware River. Under a 1954 U.S. Supreme Court ruling, New York City can take up to 800 million gallons a day from the Delaware River, provided it releases enough water to ensure adequate flow in the lower Delaware for New Jersey and other downstream users. This process is overseen by the Delaware River Basin Commission. In conjunction with DEC, the City also releases water from Cannonsville and other Delaware System reservoirs to help maintain the fisheries of the lower West Branch Delaware River.

4.4.1 Program Implementation (Cannonsville Basin)

Since 1996, over 2,000 best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater (Figure 4.16a). These BMPs are associated with more than 36,500 acres of farmland. Over the last decade, 24 additional environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects (Figure 4.16b). Nearly 800 septic systems throughout the basin have been remediated during this time period (Figure 4.16c). Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Chapter 2 of this report.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Cannonsville has increased from 300 boats in the early part of the last decade to over 470 boats in 2010 (Figure 4.16d).

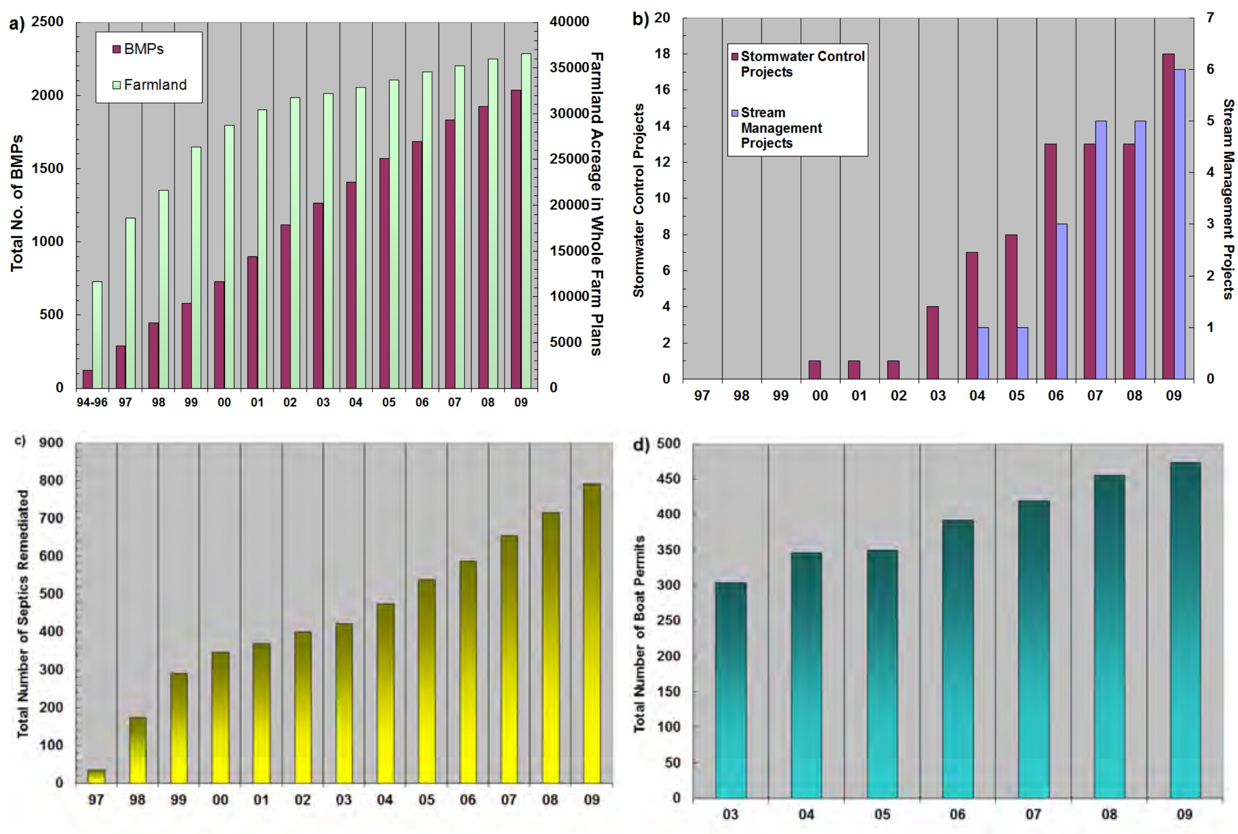

Figure 4.16 History of watershed programs in the Cannonsville drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control and stream management projects, c) septic system remediation, d) number of boat permits issued.

Note: Bars in plots (a)-(c) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the Cannonsville Basin

Inputs of phosphorus, as well as other pollutants, from WWTPs to Cannonsville Reservoir continue to be reduced as a result of DEP's effort to upgrade all surface-discharging plants, and also through the efforts of DEP's WWTP Compliance and Inspection Program (Section 2.12.2). As illustrated in Figure 4.17, phosphorus loads (as total phosphorus) declined considerably from 1994-2004. This was accomplished in large part through the intervention and assistance of DEP at Walton and at Walton's largest commercial contributor, Kraft. The substantial additional reductions in phosphorus loads realized in 2004 can be attributed to final upgrades of several plants and the diversion of another. As a result, as of 2002 Cannonsville is no longer listed as a phosphorus-restricted basin.

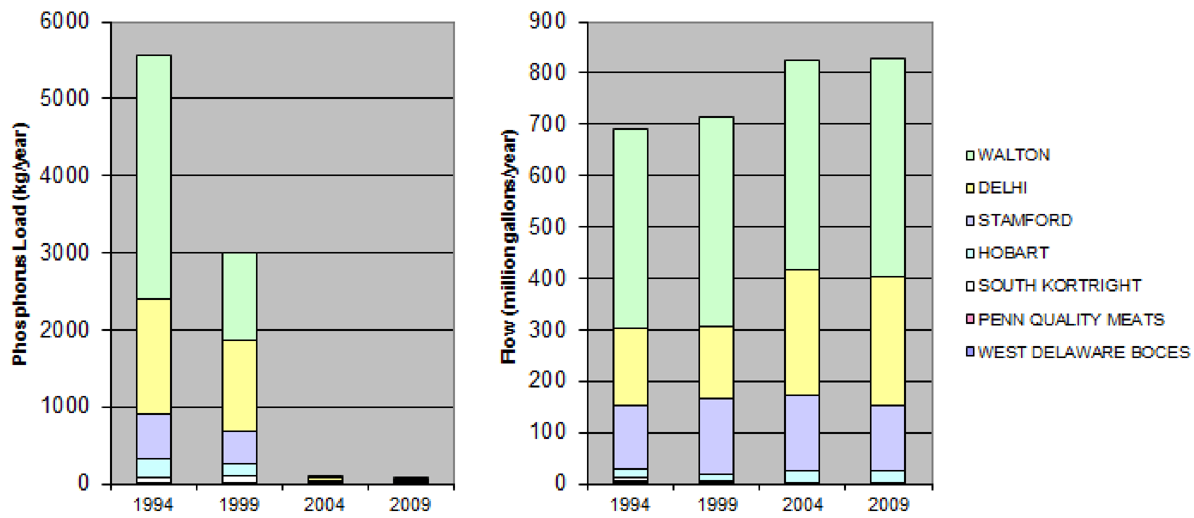

Figure 4.17 Wastewater treatment plant total phosphorus loads and flows in the Cannonsville drainage basin, 1994-2009.

Case Study
Evaluation of Bloomville's Conversion from Septic Systems to a Community Septic System

Septic systems typically require a certain amount of space to effectively treat wastewater. In hamlets or subdivisions where density may constrain the capacity of septic systems, the water quality in adjacent receiving waters may suffer degradation. In such cases, the Filtration Avoidance Determination recommends conversion of septic systems to sewers and WWTPs, or the construction of community septic systems, in order to protect receiving waters. Because of Bloomville's small population density, the community septic system option was chosen for this hamlet, which is located in Delaware County. The system was completed in the summer of 2009 with 78 sanitary connections (Figure 4.18).

Figure 4.18 Bloomville sand filter building.

To determine the water quality effects of the new system, sites were monitored on Wright Brook above and below the system both before and after construction. The upstream and downstream sites were designated CWBA and CWBB, respectively. Baseline sampling began in March 2009 and post-construction samples will be collected through 2011. This summary covers the data collected for the first year, ending in December 2009, and includes 10 monthly samples for each site. March-August samples are considered pre-construction, while September-December are post-construction. All samples were analyzed for total nitrogen, nitrate, ammonia, total phosphorus (TP), specific conductivity, dissolved organic carbon, and dissolved oxygen.

Results from the first year were plotted and are presented in Figure 4.19. Ammonia data were not plotted because the majority of the samples yielded values at or below the detection limit of 0.02 mg L^{-1}.

Examination of the plotted data shows that, both before and after construction, chloride and specific conductivity values were higher at sampling sites below the new system, except for specific conductivity on October 5, 2009 at CWBB. Sites below the system yielded higher fecal coliform counts in the majority of the samples prior to the system's completion. The same was also true for TP, total nitrogen, and nitrate-nitrite, within a margin of variability. However, for dissolved oxygen and dissolved organic carbon, the sites above and below the system did not differ greatly, and when there was a difference, it could be positive or negative (i.e., sometimes the above site had the higher value, sometimes the below site).

Continuation of the Wright Brook sampling through 2011 will allow DEP to make more meaningful comparisons between the upstream and downstream sites, which will in turn provide a clearer understanding of the water quality effects of the new community septic system.

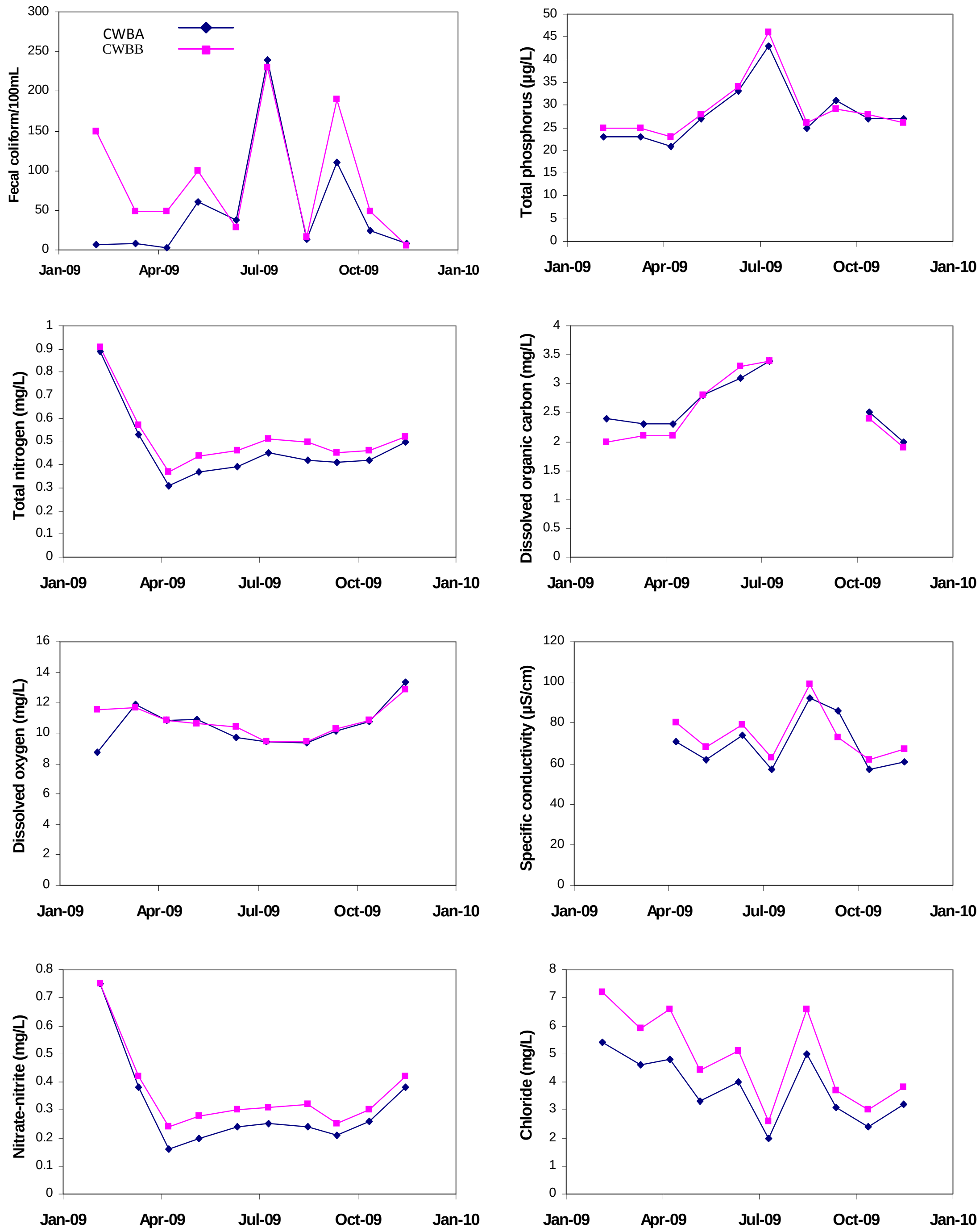

Figure 4.19 Water quality analytes for Wright Brook septic conversion project. Sites are Wright Brook Above (CWBA) and Wright Brook Below (CWBB). Sites are upstream and downstream of the Bloomville community septic system.

4.4.2 Water Quality Status and Trends (Cannonsville Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 4.20. Two time periods are assessed for each site: i) the full period of record, and ii) a three-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deterioration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

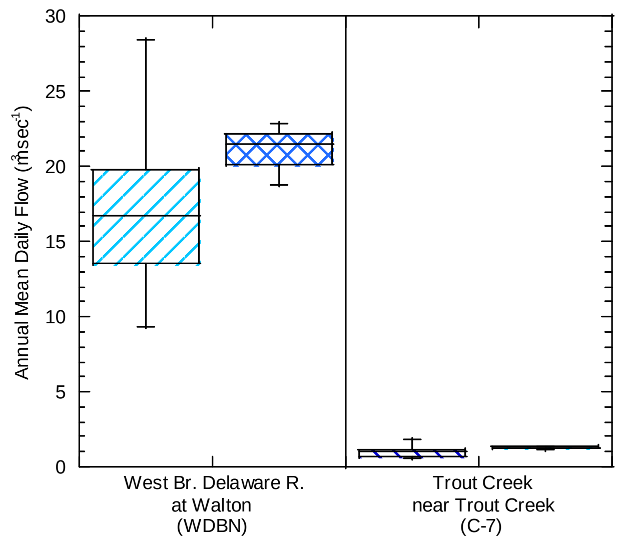

Figure 4.20 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the Cannonsville watershed.

The West Branch of the Delaware River at Walton is the primary inflow to Cannonsville Reservoir. It drains 77% of the basin (Table 4.5). The status period's mean annual daily flow median was about 4 $m^3 sec^{-1}$ greater than the long-term median and the overall distribution was somewhat biased to higher flows. Therefore, flows in the status period were somewhat higher than usual.

Table 4.5: DEP sample site descriptions for the Cannonsville watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
WDBN	West Branch Delaware River at Walton	77.4%	October 1950-present
C-7	Trout Creek near Trout Creek	4.5%	December 1996-present, June 1952-June 1967

Status (Cannonsville Basin)

The Cannonsville basin status evaluation is presented as a series of boxplots in Figure 4.21. The input stream is the West Branch Delaware River (WDBN), the reservoir is designated as WDC, and the output is designated as WDTO. All values below the maximum detection limit line for fecal coliform (blue line) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

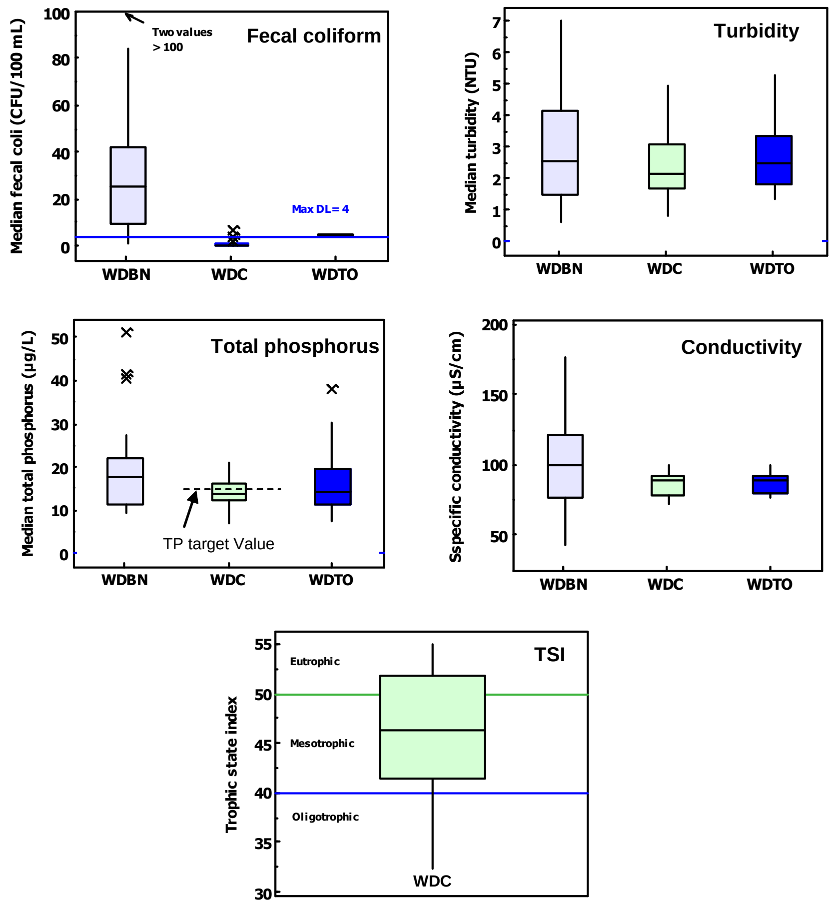

Figure 4.21 Water quality status boxplots using 2007-2009 monthly data for the Cannonsville basin main stream input at the West Branch Delaware River (WDBN), Cannonsville Reservoir (WDC), and the output at the West Delaware Tunnel Outlet (WDTO).

Fecal coliform values dropped sharply between the input and the reservoir. This is the result of settling and die-off of the coliform bacteria. In the reservoir and the output, the majority of the values were at or below the detection limit, which required the use of non-detect statistics to estimate the distribution of the boxplots.

The turbidity values demonstrated that attenuation occurs between the input and the reservoir. Both the variability and the medians decreased as water traveled downstream from the input through the reservoir. The output's variability was similar to the reservoir's, with slightly higher median turbidity during the status period.

TP values resembled the pattern found with turbidity. The medians and variability were lower for the reservoir than for the input stream. Although the median for the output was similar to the reservoir's, the variability was greater in the output. The boxplot for the reservoir demonstrates that the majority of the TP values in Cannonsville were below the phosphorus-restricted target value of 15 $\mu g\ L^{-1}$.

Trophic State Index (TSI) values ranged from mesotrophic to eutrophic, with the majority of the values falling in the mesotrophic range. Cannonsville typically has the highest trophic status among the Catskill and Delaware reservoirs, although this has changed as phosphorus concentrations have declined (see Trends section below).

Conductivity was more variable in the input stream than in the reservoir or the output, but the medians were broadly similar. During drought, conductivity in the input stream generally increases, while low conductivities generally occur during storm events and wet years. These factors account for the greater variability of the input stream.

In summary, water quality was generally good during the 2007-2009 status assessment period in the Cannonsville basin. The data for the selected variables show that medians were well below the established benchmarks for the parameters presented.

Trends (Cannonsville Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 4.6).

Water quality trend plots are presented in Figure 4.22 and results of the Seasonal Kendall trend analysis are provided in Table 4.6.

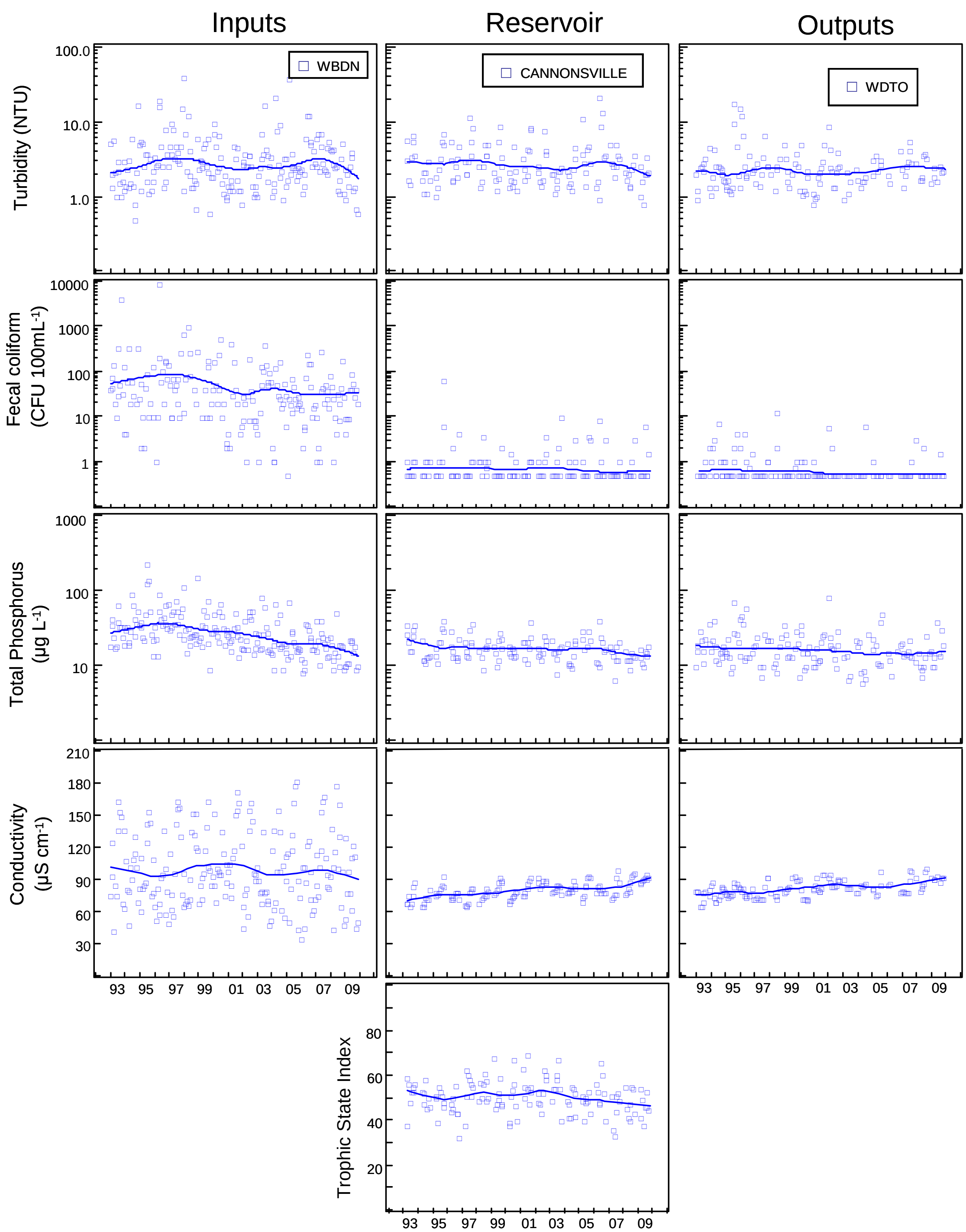

Figure 4.22 Water quality trend plots for the Cannonsville basin main stream input at the West Branch Delaware River (WDBN), Cannonsville Reservoir, and the output at the West Delaware Tunnel Outlet (WDTO). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 4.6: Cannonsville basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
WDBN	Input	Turbidity	204	0.00	NS	
Cannonsville	Reservoir	Turbidity	135	-0.12	**	-0.03
WDTO	Output	Turbidity	131	0.02	NS	
WDBN[3]	Input	Fecal coliform	184	-0.15	***	0
Cannonsville[3]	Reservoir	Fecal coliform	134	0.07	NS	
WDTO[3]	Output	Fecal coliform	127	-0.11	*	0
WDBN	Input	Total phosphorus	204	-0.44	***	-1.41
Cannonsville	Reservoir	Total phosphorus	131	-0.26	***	-0.33
WDTO	Output	Total phosphorus	144	-0.12	**	-0.22
WDBN [4]	Input	Conductivity	203	0.29	***	1.20
Cannonsville	Reservoir	Conductivity	131	0.42	***	0.86
WDTO	Output	Conductivity	131	0.43	***	0.86
Cannonsville	Reservoir	Trophic State Index	134	-0.12	**	-0.20

[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 in this row required the use of statistical methods for "non-detect" values.

[4]Data were adjusted for flow prior to trend analysis—see Appendix 3.

Slight declines in turbidity were evident in the reservoir. Reasons for the decline are not clear. Recovery from flooding events in late 1995-early 1996, April 2005, and June 2006 is one factor. Periods of low inputs in years affected by droughts (2001-2003) or in years dominated by low intensity rain events (2007-2009) are another. 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.

A strong downward trend was detected for fecal coliforms in Cannonsville's main input. Unfortunately, the data are dominated by many low, tied values, resulting in a change per year estimated at zero. A more "reasonable" estimate probably results from comparing the central tendency of the data in the 1993-2001 period (approximately 75 CFU 100 mL^{-1}) to the 2002-2009 period (approximately 40 CFU 100 mL^{-1}); this yields a percent decrease of 47%. A downward trend was also detected in the reservoir's output. Although most values were at or near the detection limit, there was clearly a decrease in the number of detected values with time.

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 minor temporary increases in 1999 (Tropical Storm Floyd) and June 2006 (7 inches of rain from June 25-27), has been in decline through 2009. 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 load reductions from a food production plant located in Walton.

Increasing conductivity trends were detected in the input, output, and reservoir. The increases were not correlated with precipitation trends but did coincide with increases in chloride, suggesting an anthropogenic source. Median reservoir chloride in 1993-1994 was 6.2 mg L^{-1}, versus 11.2 mg L^{-1} in 2008-2009.

Algal productivity seems to be decreasing in the 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 June 2006 may also contribute to the decline.

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 years (2001-2003) and during 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, although load reductions from WWTPs and food manufacturing are probably 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).

Biomonitoring Status and Trends (Cannonsville Basin)

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. For methodology details, see Appendix 3.

The most recent status of macroinvertebrate communities in the Cannonsville basin was evaluated by examining 2007-2009 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 are routine; the other is sampled on a rotating basis and was sampled only once during the 2007-2009 period.

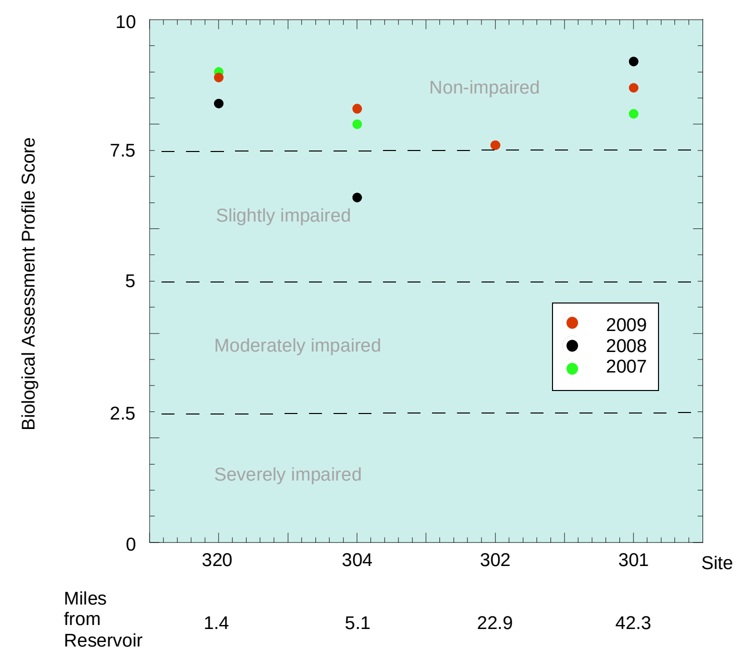

Figure 4.23 Biomonitoring status scores for the West Branch Delaware River, 2007-2009.

Site 320 (WDBN) in Beerston lies approximately 1 ½ 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. From 2007-2009, all sites were assessed as being non-impaired with the single exception of Site 304, which was slightly impaired in 2008 (Figure 4.23). These results indicate the presence of optimal conditions for the benthic community in the West Branch Delaware River.

Trend analysis was based on the routine sites' entire period of record (which ranged from 14 to 16 years in length), and examined changes in both scores and assessment categories.

Long-term trends in biomonitoring scores at routine Sites 301, 304, and 320 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. Moderate to strong upward trends were detected at Sites 320 ($p = 0.06$) and 301 ($p = 0.02$), respectively, while a weak downward trend was observed at Site 304 ($p = 0.17$) (Figure 4.24). The improvement at the first two sites may be related to the decline in phosphorus concentrations that have occurred in recent years in the West Branch Delaware River basin, a trend probably attributable, at least in part, to WWTP upgrades and the Whole Farm Program. The contrary conclusion suggested by the weak downward trend at Site 304 should be viewed with caution, given the high p value and the fact that the 2009 BAP score of 8.30 was the highest at the site since 2003, and fifth highest overall since sampling began there in 1994.

With few exceptions, sites have maintained a non-impaired rating throughout the 16-year period of record. Of the 44 samples collected since 1994, 89% have been assessed as being non-impaired, with the remaining 11% (5) in the slightly impaired range.

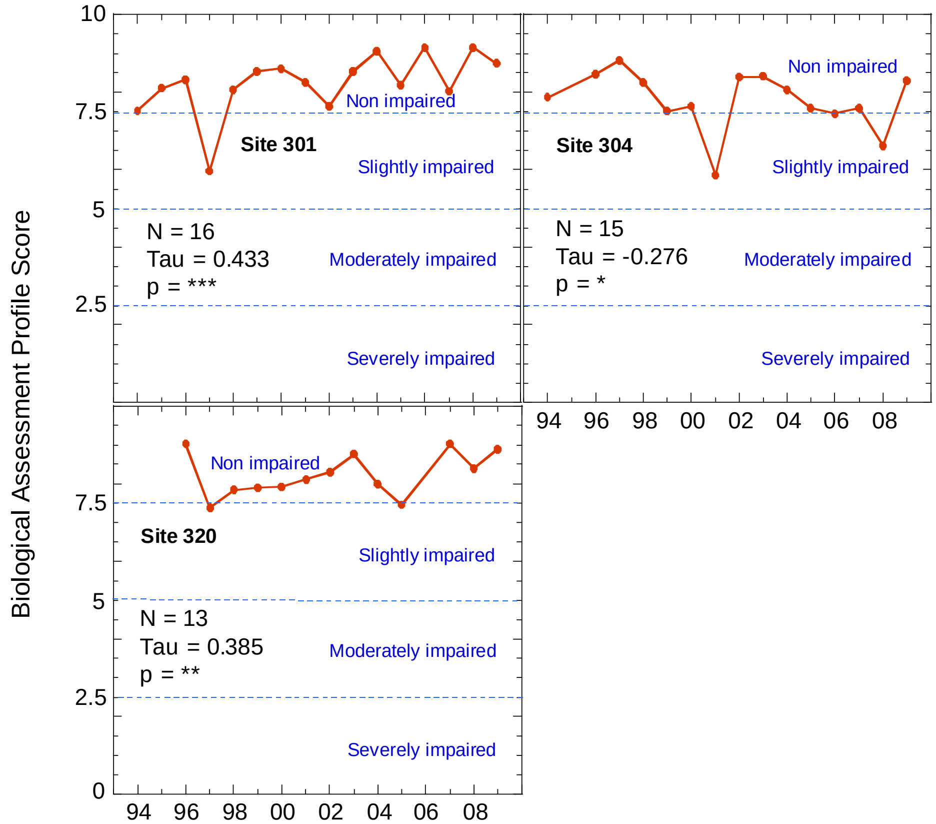

Figure 4.24 Biomonitoring trend plots for the West Branch Delaware River, 1994-2009. Results of the Mann Kendall trend test are shown as follows: * = 0.20 > p > 0.10, ** = 0.10 ≥ p > 0.05, *** = p ≤ 0.05. N = number of observations, Tau = Mann Kendall test statistic.

4.5 The Rondout Basin

Rondout Reservoir straddles the Ulster/Sullivan County border along the southern edge of the state's forever wild Catskill Park, approximately six miles northwest of the Village of Ellenville and more than 65 miles northwest of New York City. Placed into service in 1950, it was formed by damming 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 million gallons per day (MGD), or roughly 13.2% of the total average daily consumption to New York City and an additional one million upstate consumers.

Rondout is one of four reservoirs in the City's Delaware System. It serves as the central collecting reservoir for that system, receiving water from Pepacton, Cannonsville, and Neversink Reservoirs. Since the Delaware System supplies approximately 50% of New York City's water, Rondout plays a critical role in the City's overall water supply system. Rondout also receives water from its own watershed. Water from Rondout drains southeast into the 85-mile-long Delaware Aqueduct, which runs below the Hudson River to West Branch and then to Kensico Reservoir. After mixing with Catskill System water, it leaves Kensico through aqueducts to reach Hillview Reservoir and the distribution system.

Rondout's watershed drainage basin is 95 square miles and takes in parts of seven towns. Four main tributaries flow into Rondout, with Rondout Creek supplying 40% of the flow and Chestnut Creek 22%. Sugarloaf Brook delivers another 8.4% and Sawkill Brook an additional 6.6% of flow. Presently there is one wastewater treatment plant (WWTP) sited in the Rondout watershed, producing approximately 0.062 MGD of flow. As per the most recent SPDES permit, the plant is limited to a release of 0.180 MGD.

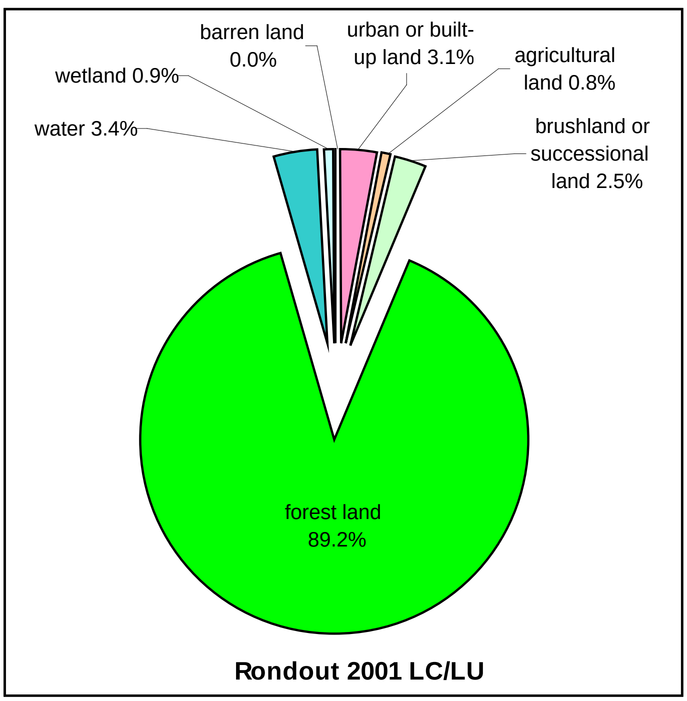

Figure 4.25 Land use in the Rondout drainage basin based on 2001 data.

Of the 61,026 acres of land in the Rondout watershed, 54,462 acres (89.2%) are forested, 1,911 acres (3.1%) are urban or built-up land, and 1,506 acres (2.5%) are brushland or successional land. Wetlands comprise 544 acres (0.9%) of the watershed, while 2,102 acres (3.4%) are water. The remaining 501 acres (0.8%) are in agricultural use (Figure 4.25). (Note that agricultural land use differs between this pie chart and the subsequent bar chart because the agricultural program includes grassland and brushland used as farmland.)

4.5.1 Program Implementation (Rondout Basin)

Since 1996, over 55 best management practices (BMPs) have been implemented to control runoff of nutrients, turbidity, pathogens, and stormwater (Figure 4.26a). These BMPs are associated with more than 1,200 acres of farmland. Over the last decade, four additional environmental infrastructure projects have been constructed, consisting of both stormwater control facilities and stream management projects (Figure 4.26b). Over 300 septic systems throughout the basin have been remediated during this time period (Figure 4.26c). Other protection programs related to forestry, wetlands, and waterfowl control for pathogen risk reduction are also in place, as described in Chapter 2 of this report.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Rondout has increased from an average of about 750 in the early part of the last decade to about 830 in recent years (Figure 4.26d).

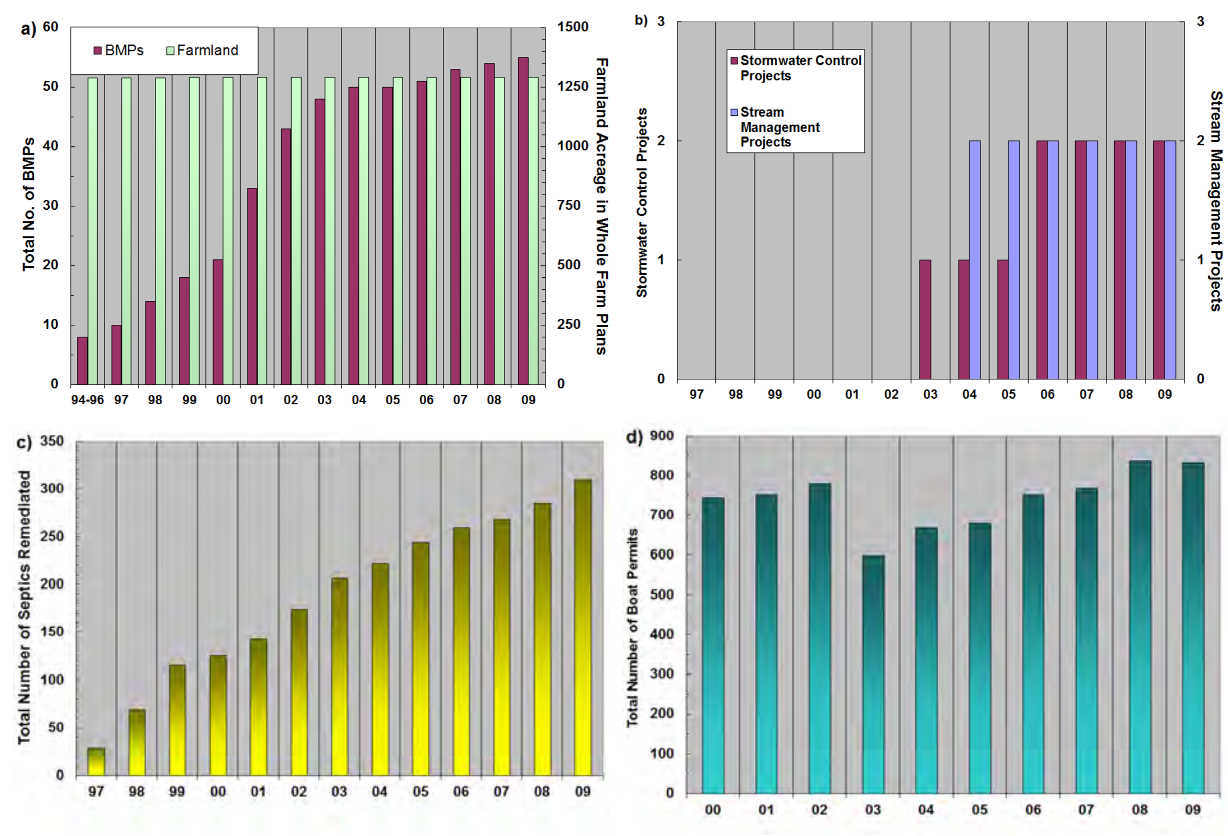

Figure 4.26 History of watershed programs in the Rondout drainage basin: a) BMP installations on farmland, b) environmental infrastructure installations for stormwater control and stream management projects, c) septic system remediation, d) number of boat permits issued.

Note: Bars in plots (a)-(c) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the Rondout Basin

Inputs of phosphorus, as well as other pollutants, to Rondout Reservoir have been considerably reduced as a result of the upgrade of the City-owned Grahamsville plant, the only WWTP discharging into the Rondout Reservoir basin. As illustrated in Figure 4.27, phosphorus loads (as total phosphorus) declined considerably from 1994 to 1999, and remained low through 2009.

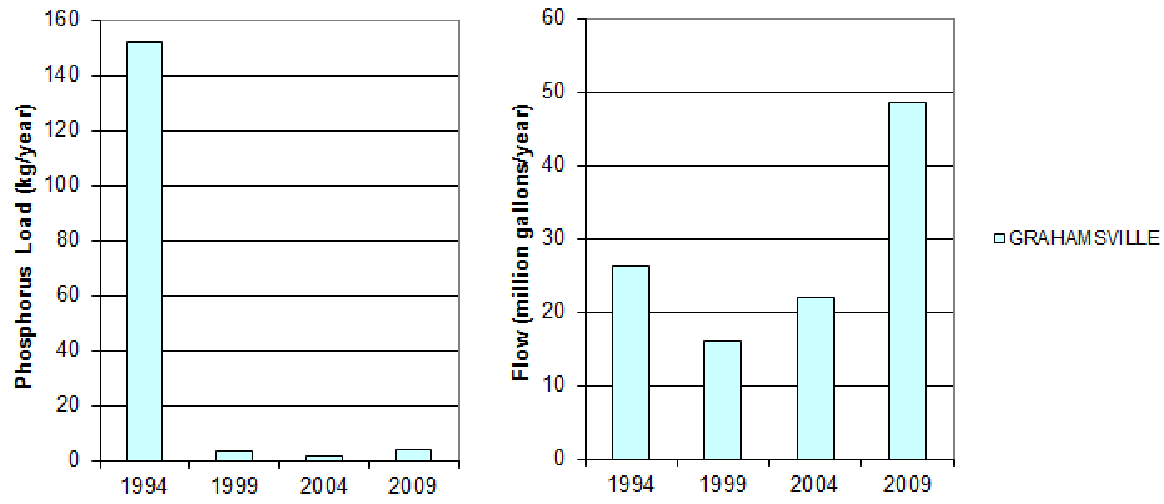

Figure 4.27 Wastewater treatment plant total phosphorus loads and flows in the Rondout drainage basin, 1994-2009.

4.5.2 Water Quality Status and Trends (Rondout Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 4.28. Two time periods are assessed for each site: i) the full period of record, and ii) a three-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deterioration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

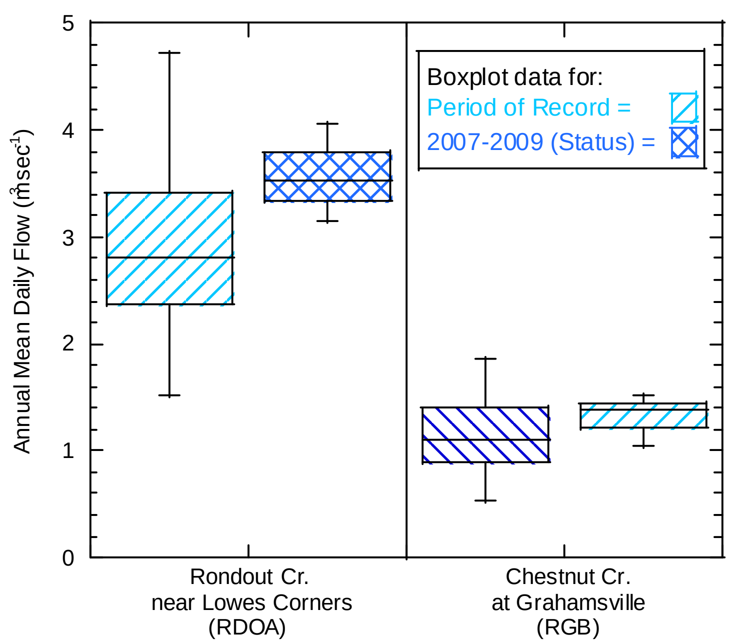

Figure 4.28 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the Rondout watershed.

Rondout Creek near Lowes Corners is the primary stream inflow to Rondout Reservoir. It drains 40% of the basin (Table 4.7). The status period's mean annual daily flow median was about 0.7 m^3 sec^{-1} greater than the long-term median, and the overall distribution was slightly biased to higher flows. Therefore, flows in the status period were higher than usual.

Table 4.7: DEP sample site descriptions for the Rondout watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
RDOA	Rondout Creek near Lowes Corners	40.3%	February 1937-present
RGB	Chestnut Creek at Grahamsville	22.1%	October 1998-present, Oct. 1938-March 1987

Status (Rondout Basin)

The Rondout basin status evaluation is presented as a series of boxplots in Figure 4.29. All values below the maximum detection limit line for fecal coliform and total phosphorus (blue lines) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

Environmental Protection

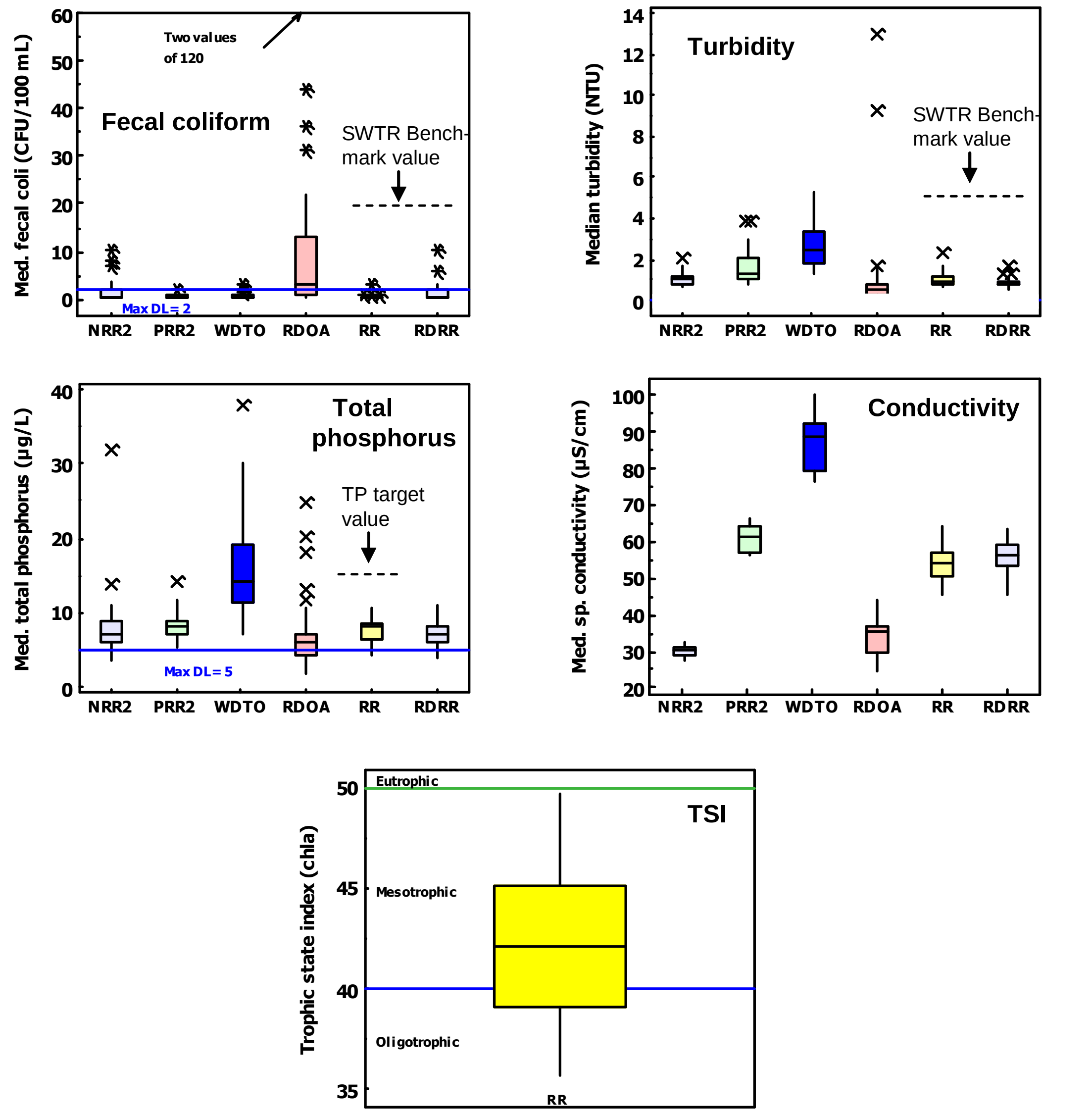

Figure 4.29 Water quality status boxplots using 2007-2009 monthly data for the Rondout basin inputs from Cannonsville (WDTO), Pepacton (EDTO), and Neversink (NRR2) Reservoirs and from the main stream input at Rondout Creek (RDOA); Rondout Reservoir (RR); and the output at the Rondout gatehouse (RDRR).

The inputs include water diverted from Neversink Reservoir (NRR2), Pepacton Reservoir (PRR2), Cannonsville Reservoir (WDTO), and Rondout Creek (RDOA). The reservoir is designated as RR and the output is designated as RDRR.

Fecal coliform values were mostly below the detection limit for the three reservoir inputs and higher for the stream input from Rondout Creek. None of the values exceeded the 200 CFU 100 mL^{-1} DEC Stream Guidance Value. The reservoir and the output had a majority of coliform values below the detection limit, and therefore, well below the Surface Water Treatment Rule (SWTR) benchmark of 20 CFU 100 mL^{-1} used for source waters. Rondout Reservoir can be source water when Kensico and West Branch Reservoirs are by-passed.

The turbidity values were lowest for the NRR2 input, and increased going from PRR2 to WDTO. WDTO had the most variability of the reservoir inputs, probably due to turbidity contributed by primary production in Cannonsville Reservoir. Another potential source is turbidity caused by a nepheloid layer at the bottom of the reservoir during times of anoxia. High flows during these conditions can entrain this turbid water. Interestingly, the boxplot for the stream input, RDOA, was lower than those of the other inputs, with the exception of a couple of outliers. One would expect higher values of turbidity in the stream due to less settling. None of the values for the reservoir or the output from Rondout were above the 5 NTU SWTR benchmark value for source waters.

Total phosphorus (TP) values varied among the inputs. WDTO had the highest median and the most variability, while RDOA had the lowest median. RDOA and some other sites had values below the detection limit, which required the use of non-detect statistics to determine the distribution of the data. The reservoir and its output had similar TP values. None of the values in the reservoir were above the phosphorus-restricted target value of 15 μg L^{-1}.

The Trophic State Index (TSI) indicated that Rondout was primarily mesotrophic over the three-year study period, and at times oligotrophic.

Conductivity varied widely among the inputs, reflecting the differing water quality of each of these sources. The Cannonsville input had the highest conductivity in the Delaware System compared to the Neversink, which had the lowest. RDOA also had low conductivity levels, but this stream source contributes only a small percentage to the total inflow. Operational changes that result in the mixing of these sources determine the conductivity in the reservoir.

In summary, water quality was very good during the 2007-2009 status assessment period in the Rondout basin. The data for the selected variables show that none of them had values that exceeded the established benchmarks.

Trends (Rondout Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 4.8).

Water quality trend plots are presented in Figure 4.30 and results of the Seasonal Kendall trend analysis are provided in Table 4.8.

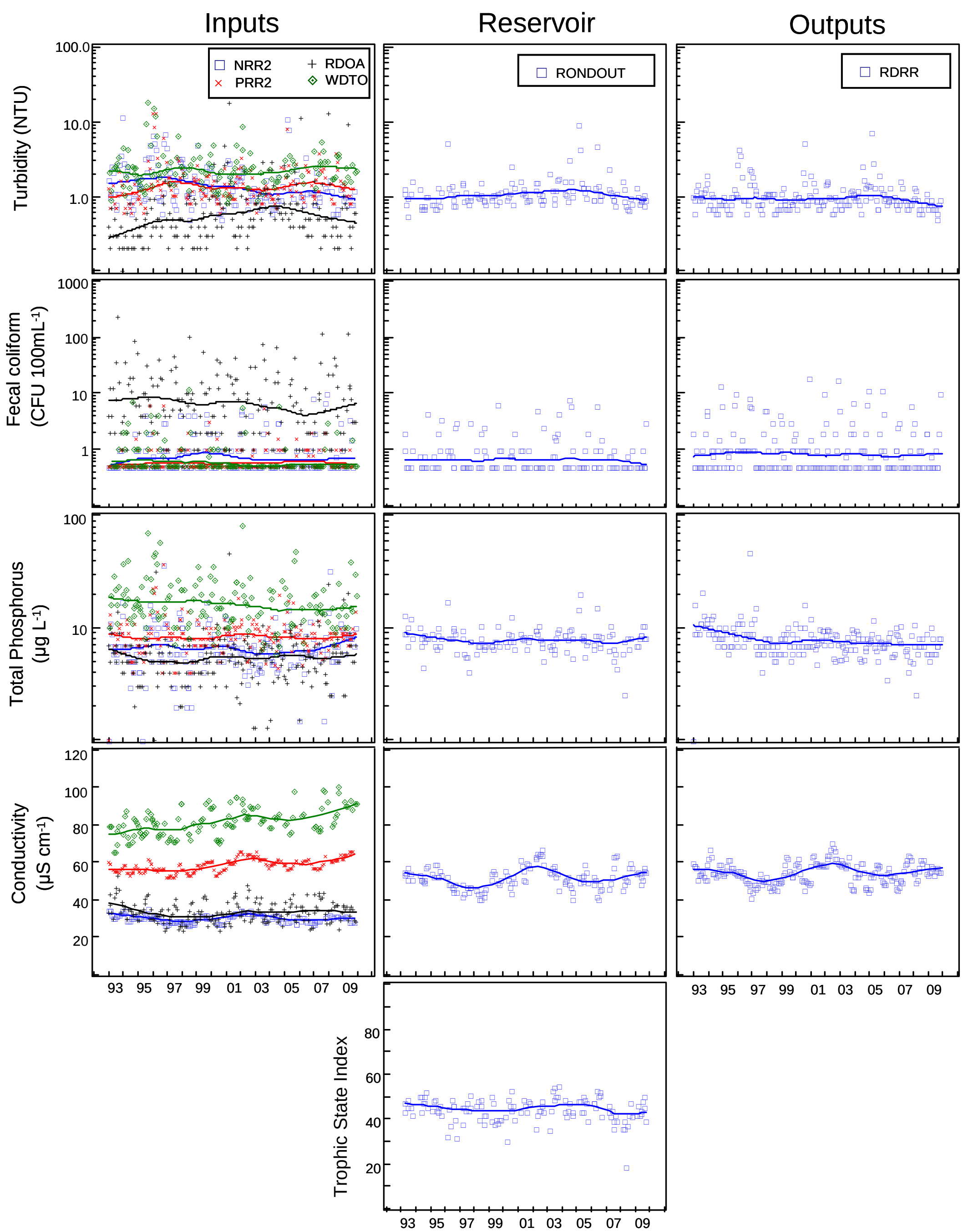

Figure 4.30 Water quality trend plots for the Rondout basin inputs from Cannonsville (WDTO), Pepacton (EDTO), and Neversink (NRR2) Reservoirs and the main stream input, Rondout Creek (RDOA); Rondout Reservoir; and the output at the Rondout gatehouse (RDRR). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 4.8: Rondout basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
NRR2	Input	Turbidity	162	-0.24	***	-0.03
PRR2	Input	Turbidity	183	0.09	**	0.01
WDTO	Input	Turbidity	131	0.02	NS	
RDOA	Input	Turbidity	203	0.20	***	0.01
Rondout	Reservoir	Turbidity	134	0.10	*	0.00
RDRR	Output	Turbidity	203	-0.07	*	0.00
NRR2[3]	Input	Fecal coliform	157	0.10	NS	
PRR2[3]	Input	Fecal coliform	180	0.01	NS	
WDTO[3]	Input	Fecal coliform	127	-0.11	*	0.00
RDOA[3]	Input	Fecal coliform	202	-0.12	***	0.00
Rondout[3]	Reservoir	Fecal coliform	135	-0.03	NS	
RDRR[3]	Output	Fecal coliform	203	-0.07	*	0.00
NRR2	Input	Total phosphorus	188	-0.00	NS	
PRR2	Input	Total phosphorus	195	0.05	NS	
WDTO	Input	Total phosphorus	144	-0.12	**	-0.22
RDOA[4]	Input	Total phosphorus	204	0.11	***	0.10
Rondout	Reservoir	Total phosphorus	131	-0.06	NS	
RDRR	Output	Total phosphorus	201	-0.24	***	-0.13
NRR2	Input	Conductivity	162	-0.09	*	0.00
PRR2	Input	Conductivity	183	0.41	***	0.43
WDTO	Input	Conductivity	131	0.43	***	0.86
RDOA[4]	Input	Conductivity	204	0.19	***	0.20
Rondout	Reservoir	Conductivity	132	0.06	NS	
RDRR	Output	Conductivity	203	0.04	NS	
Rondout	Reservoir	Trophic State Index	130	-0.07	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 in this row required the use of statistical methods for “non-detect” values.

[4]Data were adjusted for flow prior to trend analysis—see Appendix 3.

A very small turbidity increase (0.01 NTU per year) was detected in Rondout Reservoir despite a much greater turbidity decrease of 0.03 NTU per year observed in one of its major inputs, NRR2. The NRR2 decrease was offset by very small upward increases of 0.01 NTU per year detected in both the input from Pepacton (PRR2) and the largest stream input, Rondout Creek (RDOA). On average, this input accounts for about 11% of the total flow into the reservoir. Note that the turbidity input from Rondout Creek has been steadily decreasing in recent years (since 2004) despite an increasing trend in precipitation during the 2004-2009 period. The last remaining input, WDTO, showed no long-term trends for turbidity. Despite the slight increase observed in the reservoir, a minor turbidity decrease was detected in the output. This seeming disparity is explained by differences in sampling frequencies. Reservoir data used in this report are derived from one survey per month from April-November, while the output was sampled five days per week in all months of the year.

Fecal coliform trends were not apparent in inputs from Neversink (NRR2) and Pepacton (PRR2), but downward trends were detected in inputs from Cannonsville (WDTO) and Rondout Creek (RDOA). Reasons are not apparent for the decrease at RDOA, but the multiple WWTP upgrades that went into effect from 1994-2002 in the Cannonsville watershed may explain the WDTO reductions, which occurred during the same time period. Whatever the reason, reductions at WDTO and RDOA are evidence of improvement, since the highest fecal counts typically occur at these inputs. The reservoir itself showed no trend, but as with turbidity, a downward trend for fecal coliforms occurred at the output.

Trends in TP were not detected in the reservoir despite a significant decrease of 0.22 µg L^{-1} per year in inputs from Cannonsville Reservoir (WDTO). The decrease at WDTO is especially significant since this input generally has the highest phosphorus concentrations. Trends were not apparent in the other inputs except for a weak upward trend at RDOA. The increase at RDOA and a recent short-term phosphorus increase at Neversink (NRR2) may be offsetting the decrease from Cannonsville. The absence of winter data collected from the reservoir may be masking a TP decline in Rondout. Despite the lack of a trend in the reservoir, decreases were apparent in the output, most likely as a result of WWTP upgrades and because of other watershed programs within the Cannonsville basin.

Conductivity trends were not detected in the reservoir despite increases detected in some of its inputs (0.86 µS cm^{-1} yr^{-1} for WDTO, 0.43 µS cm^{-1} yr^{-1} for PRR2 and 0.1 µS cm^{-1} yr^{-1} for RDOA). Conductivity trends appear to be controlled by precipitation patterns. In wet years (e.g., 2003, 2004), dilution causes conductivity to decrease. During drier periods (e.g., 1998-2001), base flow becomes a larger portion of the inflow, causing conductivity to increase. Since chlorides are a component of conductivity, an upward trend in conductivity for the reservoir might be expected, given an increase in chloride mean concentrations from 1993-2004. However, short-term variations in precipitation can mask a potential long-term trend in conductivity, as demonstrated by the variations in the LOWESS plot for reservoir conductivity. 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.

Trends were not detected in the reservoir's TSI, suggesting that algal productivity was relatively stable during the period of record.

In summary, both upward and downward trends were detected for turbidity in the various sites at Rondout Reservoir. Downward trends were detected for fecal coliforms and phosphorus, while upward trends were indicated for conductivity in most of Rondout's inputs. The increase in reservoir turbidity is related to input increases from Pepacton and Rondout Creek, which offset the turbidity decrease from Neversink. The fecal coliform decline in the input from Cannonsville Reservoir coincides with multiple WWTP upgrades that occurred in that watershed from 1994-2002. Reasons for the decline in fecal coliform at Rondout Creek are not known. Phosphorus declines may be linked to a combination of WWTP upgrades, other watershed improvement projects in the Cannonsville basin, and 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. No trends were detected for TSI.

4.5.3 Waterfowl Management Program: Rondout Reservoir

Like West Branch, Rondout Reservoir is one of five reservoirs covered under the "as needed" criteria for waterfowl management. Although only biweekly surveys are required by the 2007 FAD, DEP performed surveys weekly on Rondout during the 2006-2010 assessment period, with additional surveys added during the early winter period when bird numbers and fecal coliform counts increase. Migratory waterbird populations at Rondout were similar to those recorded in previous years, showing seasonal increases from autumn through early spring (Figure 4.31).

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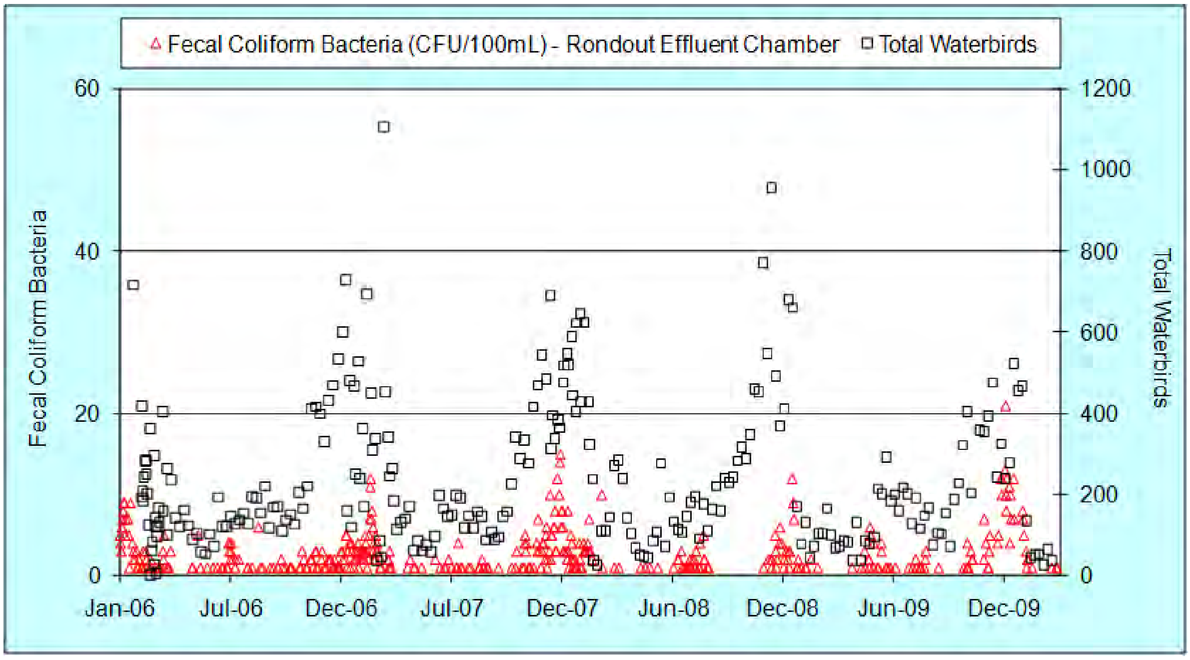

Figure 4.31 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total waterbirds at Rondout Reservoir, January 1, 2006-March 31, 2010.

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. This pattern resulted in an "as needed" action from December 22, 2005 through March 4, 2006.

Case Study: Rondout Reservoir Waterfowl Management Program "As Needed" Action (December 22, 2005 to March 4, 2006)

During the autumn of 2005, elevated fecal coliform counts were detected at the Rondout Effluent Chamber (REC) along with increased waterbird activity in Bird Zone 1. These conditions triggered an "as needed" action to harass waterbirds away from the REC. Fecal coliform levels at the reservoir effluent sampling site (RDRRCM) increased from 11 CFU 100 mL^{-1} on December 15, 2005 to 27 CFU 100 mL^{-1} on December 16, 2005 and remained elevated through December 24, 2005. DEP initiated bird harassment measures using pyrotechnics on December 22, 2005 and continued this effort through March 4, 2006. The primary goal was to eliminate bird activity in Bird Zone 1, and this was accomplished by December 24, 2005. Bird counts remained near zero through early March 2006. Figure 4.32 depicts the relationship between fecal coliform at RDRRCM and waterbirds in Bird Zone 1. Overall, the mitigation efforts conducted during this period were successful at minimizing bird activity in Zone 1 and significantly reduced the fecal coliform levels at the REC.

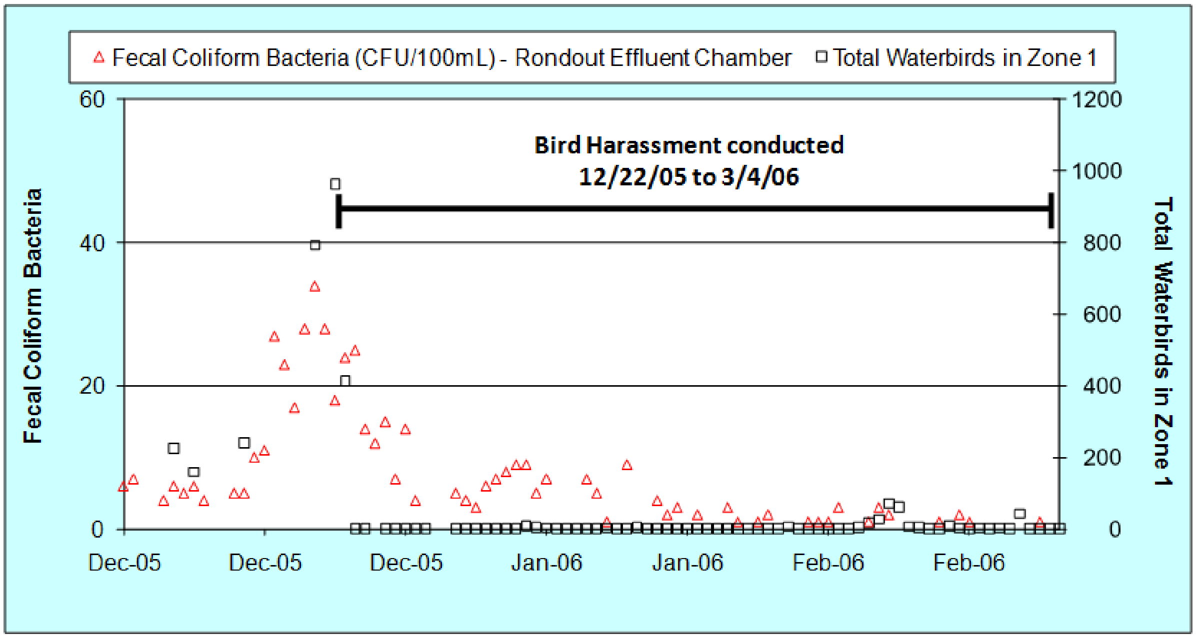

Figure 4.32 Fecal coliform bacteria (CFU 100 mL^{-1}) at RDRRCM and waterbirds in Zone 1, December 2005-March 2006.

4.6 Delaware System Protozoa: Sources and Attenuation

4.6.1 Upstream sites and Reservoir Effluents

From June 2002 to October 2010, 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 wastewater treatment plant (WWTP)); those upstream of Cannonsville Reservoir were CDG1 and WDBN (West Branch Delaware River upstream of Delhi and West Branch Delaware River at Beerston). One tributary was studied for Neversink Reservoir, the Neversink River (NCG). The four inputs to Rondout Reservoir were the Pepacton, Cannonsville, and Neversink effluents, since they all enter Rondout, and one stream, Rondout Creek (RDOA).

When data from the sites upstream of Pepacton, Cannonsville, and Neversink are compared to these reservoirs' effluent data, it becomes 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 effluents (Figures 4.33 and 4.34). This is a situation similar to the one observed in the Catskill System (Section 3.4.1). Since the three reservoirs all contribute to Rondout, the difference between the inputs to Rondout and Rondout's effluent is not as pronounced as the difference between the three reservoirs' inputs and their effluents, because the protozoa have already been reduced by passing through these reservoirs.

For the 2002-2008 period, the upstream sites in the Pepacton basin had the highest overall mean *Giardia* concentration (73.20 cysts 50 L^{-1}), followed by the Cannonsville (46.38 cysts 50 L^{-1}) and Neversink (36.83 cysts 50 L^{-1}) sites. The four inputs to Rondout resulted in a much reduced mean concentration of 4.02 cysts 50 L^{-1} at the reservoir outflow site.

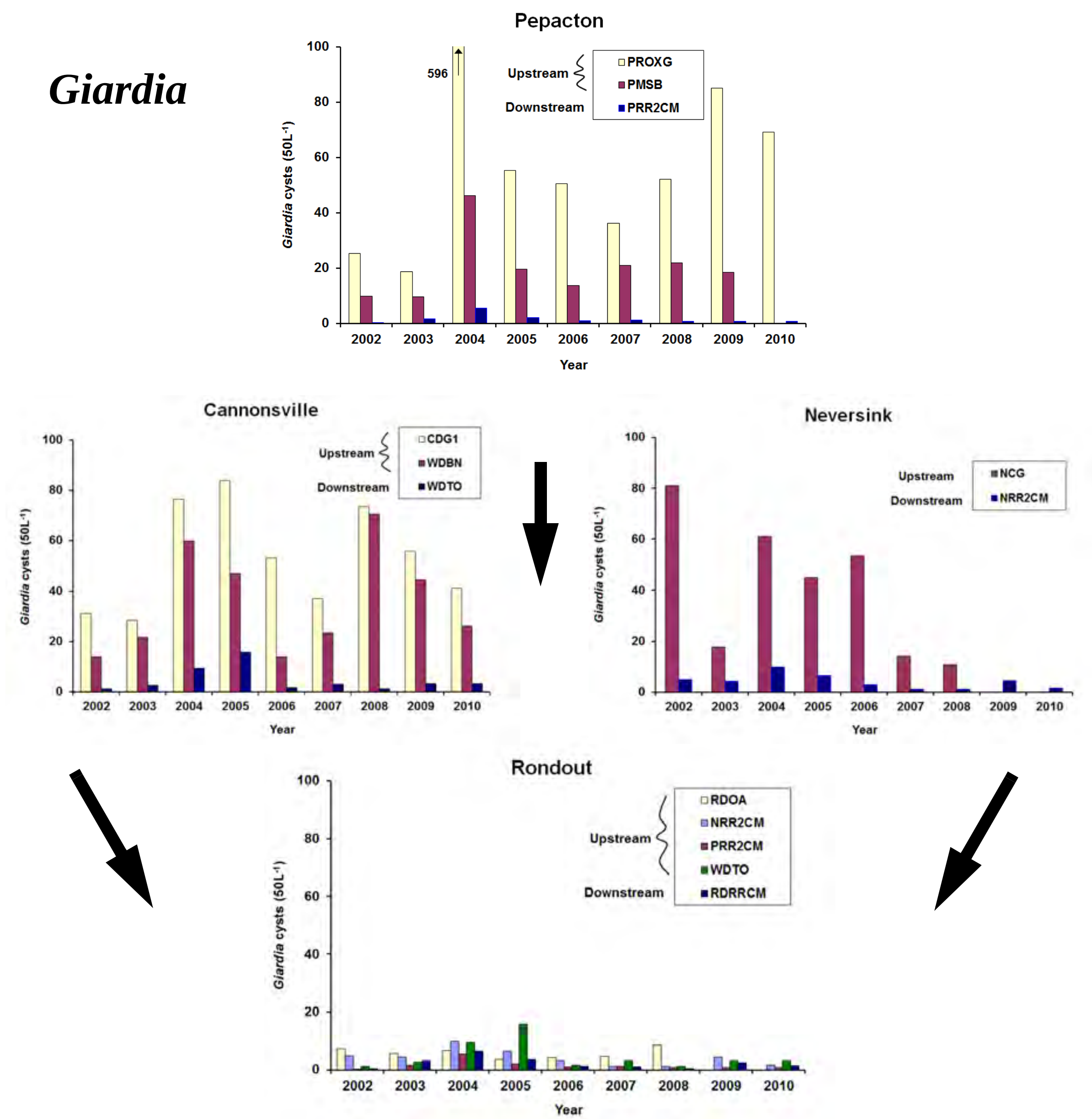

Figure 4.33 Reduction of *Giardia* cysts as water flows through each reservoir and downstream.

Although much lower concentrations were involved, the situation for *Cryptosporidium* was similar: annual mean concentrations were less at the upstream reservoir effluents than at their input sites. Sites upstream of Pepacton Reservoir had the highest oocyst concentrations, followed by Cannonsville and then Neversink. As expected, Rondout Reservoir had the lowest levels of *Cryptosporidium* both entering and leaving the reservoir, with the lowest concentrations occurring in 2009 and 2010 (as of October).

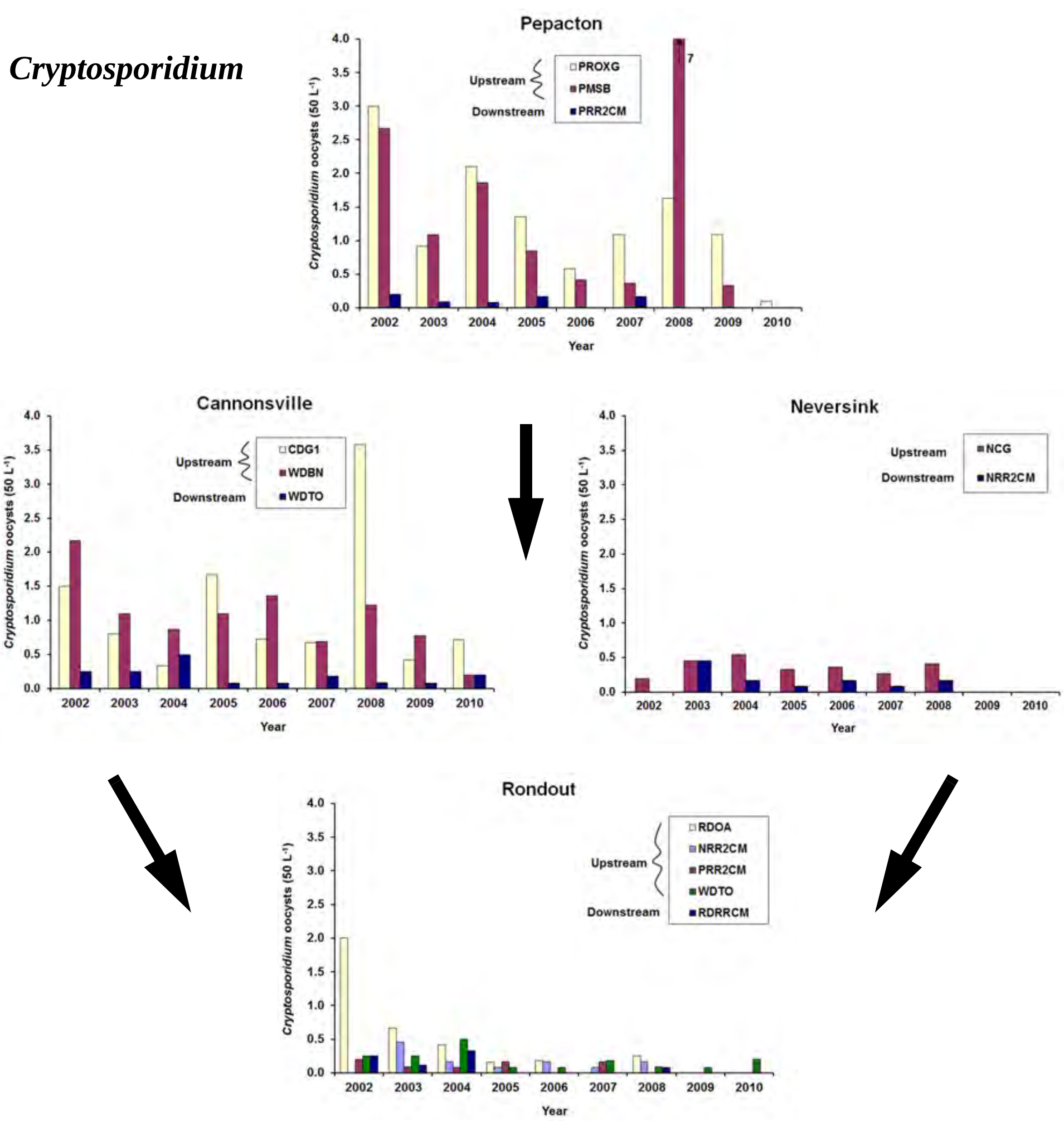

Figure 4.34 Reduction of *Cryptosporidium* oocysts as water flows through each reservoir and downstream.

WWTPs

DEP sampled seven WWTPs for protozoa in the Delaware System from 2002 to October 2010 in order to monitor long-term performance of treatment plant upgrades. Some sites have been discontinued, while others have been added as the upgrades have occurred. All routine samples have been collected quarterly. In some cases, extra samples were collected as a follow-up to an unusual result; in some other cases, samples were not collected due to plant operations, or for other reasons. Overall, 161 samples were collected.

Detection of *Giardia* in the effluents of WWTPs in the Delaware System was 19.25% during this period (31 detections out of 161 samples), while *Cryptosporidium* samples were detected 1.86% of the time (3 detections out of 161). Annual detections for all Delaware plants are graphed in Figure 4.35. *Cryptosporidium* was detected in 2004 and 2007 only, but note that these sites have not been sampled since 2007, while *Giardia* detection at the WWTP effluents has fluctuated throughout the years. Table 4.9 provides a more detailed breakdown of the detections, by identifying the plant and year of detection, along with the percent detection and maximum concentrations. Note that the Grahamsville collection site was changed from RGC to RGMF in 2009 due to the belief that wildlife had access to the water prior to its reaching the effluent and were contaminating the final sample. Since the switch, all seven samples collected at this site have been negative for protozoa.

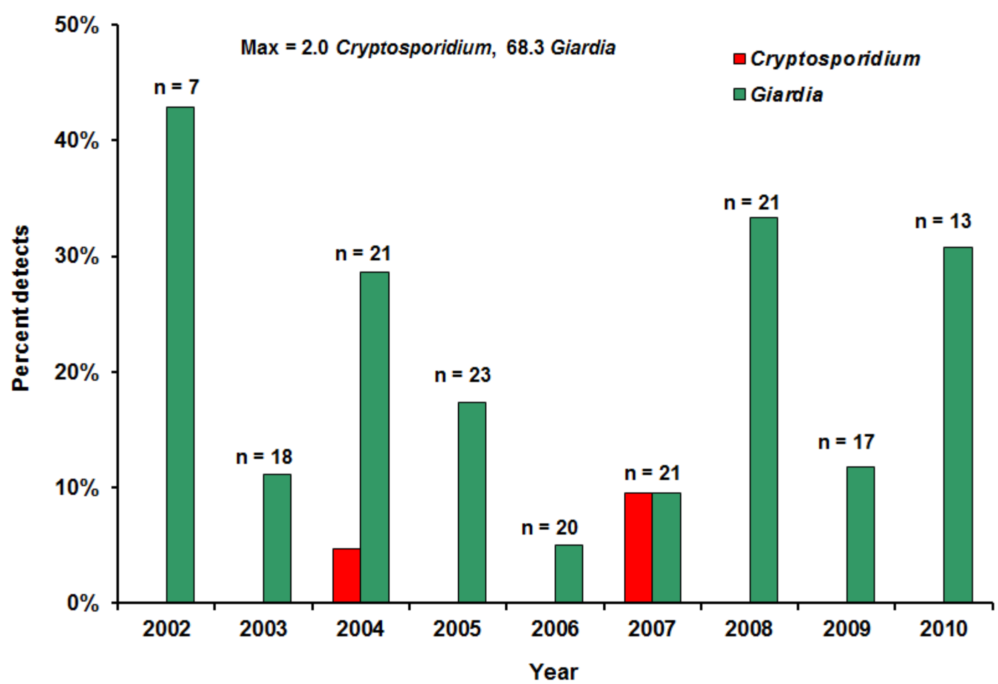

Figure 4.35 Protozoan detection frequency in effluents of upgraded Delaware System WWTPs, 2002 to October 2010.

Table 4.9: Delaware WWTPs with protozoan detects, 2002-2010. NS = not sampled.

Basin	WWTP	2002	2003	2004	2005	2006	2007	2008	2009	Oct 2010	Percent detection	Max Conc. (50 L^{-1})
Giardia												
Pepacton	Fleischmanns (PFTP)	NS	NS	NS	NS	NS	NS	NS	2/4	1/3	43% n=7	7.0
Cannonsville	Delhi (DTP)	1/1	0/4	0/4	0/4	0/4	0/4	0/4	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	3/4	28% n=32	4.0
	Walton (WSP)	1/1	0/4	0/4	0/4	0/4	0/4	1/5	NS	NS	8% n=26	68.3
Rondout	*Grahamsville (RGC)	1/2	2/4	5/5	2/7	0/4	2/5	4/4	NS	NS	53% n=30	39.0
	*Grahamsville (RGMF)	NS	NS	NS	NS	NS	NS	NS	0/4	0/3	0% n=7	0.0
Cryptosporidium												
Pepacton	Margaretville (MSC)	0/2	0/3	1/4	0/4	0/4	0/4	0/4	NS	NS	4% n=25	2.00
Rondout	*Grahamsville (RGC)	0/2	0/4	0/5	0/7	0/4	2/5	0/4	NS	NS	6% n=31	2.00
	*Grahamsville (RGMF)	NS	NS	NS	NS	NS	NS	NS	0/4	0/3	0% n=7	0.00

*RGC site was changed to RGMF in February 2009 due to suspected wildlife contamination post-filtration.

4.7 Water Quality Summary for the Delaware System

Exceptional improvements in watershed protection have been implemented throughout the Delaware System. Seventeen wastewater treatment plants (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.

Due in some measure to DEP's watershed protection efforts, the water quality status of all four Delaware System basins continues to be very good. Monthly median fecal coliform counts were at or near detection limits. Monthly turbidity ranged from 1.0 NTU at Neversink and Rondout Reservoirs to about 2.0 NTU at Pepacton and Cannonsville. Monthly median phosphorus ranged from 6 µg L^{-1} at Neversink to approximately 14 µg L^{-1} at Cannonsville. In fact, no monthly medians greater than 10 µg L^{-1} were observed during the 2007-2009 period at Neversink, Pepacton, or Rondout.

Long-term (1993-2009) trend analysis results indicate continued improvement in some water quality parameters. Watersheds with very active remediation programs (i.e., Pepacton, Cannonsville, and Rondout) all experienced strong downward trends, as opposed to the Neversink basin, which has a relatively minor program and showed no long-term trend in phosphorus concentrations. Downward fecal coliform trends were detected in the Cannonsville and Rondout basins as well. Notable improvements were also observed in the Trophic State Index at Cannonsville. Certainly, lower phosphorus loads were a factor, but poor water clarity from large storm events also helped to limit algal productivity in this reservoir. Trophic state increases at Neversink appear to correspond to an increase in phosphorus and water clarity in the latter part of the analysis. Turbidity trends (both up and down) were small in magnitude and appeared to be related to precipitation patterns and, to a lesser extent, algal blooms. Most basins also experienced increases in conductivity coinciding with a consistent increase in chloride, but also associated with changes in precipitation patterns.

Biomonitoring is conducted at several sites located on the primary stream inputs to Pepacton and Cannonsville Reservoirs. Test results during the 2007-2009 period indicated optimal conditions for the benthic communities. Trend analysis on 14-16 years of data indicated improvement at two sites in the Cannonsville System, presumably related to WWTP upgrades (among other watershed improvements) and the resultant reduction in phosphorus loads. At Site 321 in the Pepacton basin, all scores were in the optimal range and no trend was detected. At Site 316, all but one assessment was optimal, but a single very high score recorded early in the period of record was apparently enough to produce a weak downward trend.

Waterfowl management in Rondout Reservoir has been conducted on an “as needed” basis. Waterfowl numbers have remained similar to those recorded in previous years. The winter migratory period coincided with a rise in fecal coliform counts in the reservoir, and the weekly monitoring regime was increased in frequency during these times. Gulls tend to remain and move toward the Rondout Effluent Chamber as ice cover progresses. During the current assessment period, fecal coliform numbers increased to a level that triggered implementation of the management program from December 22, 2005 to March 4, 2006. Shortly after waterfowl harassment began, fecal coliform counts dropped sharply.

Cryptosporidium and *Giardia* pathogen monitoring has been conducted on the major inputs to all four reservoirs of the Delaware System. As with the Catskill System, reservoir output results were much reduced compared to those for input streams, indicating that reservoir processes such as die-off, sedimentation, and predation were effective barriers.

5. East of Hudson Catskill/Delaware Basins

5.1 Introduction

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. For this reason, an overview of water residence time and some land use features are provided in the introductory section for each basin 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. Overall, water residence time is determined by the relationship of hydraulic load (from precipitation) to basin volume, so reservoirs with large catchment areas and high hydraulic loads relative to their volume have short water residence times. In general, the evolution of a basin to a new steady state in response to a change in nutrient load (e.g., as a result of a watershed protection program) is reached in approximately three times the duration of its water residence time. (This time estimate for a new equilibrium varies according to sedimentation and internal loading rates of the analyte in question.) Notably, the operational mode of a reservoir may strongly influence its response rate. For example, the operational mode (i.e., float or flow-through) at West Branch can change the response from a month to more than a year, depending on flows. At Kensico, water residence time is short (i.e., about one month), so the response to new loading levels would be expected to take about three months to reach a new equilibrium. Ultimately, some reservoirs will respond more quickly to watershed protection measures than others and water residence times give insight into relative response rates.

Watershed protection programs have been developed to reduce the negative impacts of the major environmental influences, i.e., climate extremes and pollutants related to land use. In view of the importance of watershed protection programs as determinants of water quality, summary information on program implementation in each basin is provided (following the land use overview). This serves as an indication of the relative activity of some programs in the basin in question. These brief descriptions should not be taken as comprehensive; full watershed program descriptions are covered in Chapter 2. Best management practices for farming, stormwater control (through “environmental infrastructure”), stream management, and septic remediation are among the programs that have reduced the loadings of pollutants to the water supply. Finally, the number of boating permits issued is presented graphically as an indication of reservoir use by the public. Cumulative figures are provided to show the progress of watershed protection over the past decade and to give insight into the course of progress in watershed protection as it relates to water quality trends over the same time period.

Water quality over the long term has been examined from a number of perspectives. Status and trends are described, with status presented as a three-year average and trends evaluated over a 17-year period. The analytes chosen were those most important for meeting the requirements of the Surface Water Treatment Rule and the 2007 Filtration Avoidance Determination. Macroinvertebrate data provide insight into the ecological condition of streams and form the basis for an index to track changes that can demonstrate water quality improvements. The impact of the waterfowl management program and its ability to control and reduce fecal coliform bacteria over the past five years are demonstrated. 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 water quality surveillance and program implementation. Program implementation is prioritized to provide greatest protection near distribution, so it is by design that program intensity is higher in these basins than others. Finally, an analysis of pathogen transport through the system is presented. This provides much insight into the benefit of NYC's sequential system of reservoirs and its ability to improve water quality as water travels towards distribution.

Water quality analyses were based on several decades of data rather than the five-year period described for program implementation in Chapter 2. Selection of this extensive time period provides a long-term context for interpretation and makes it possible to capture the changes in water quality that have occurred in response to watershed protection programs. It also provides a view of these changes in the context of natural variation (such as floods and droughts), which are not sufficiently represented in a five-year period. The water quality data used in these analyses begin in 1993, and as such represent conditions at the outset of filtration avoidance when many watershed protection programs were in their infancy, and when fewer watershed safeguards were in place. The time period of the analyses extends through 2009, which allows DEP to examine trends over the past 17 years, as new and intensified watershed protection programs have been implemented. Another reason for using long-term data is that, because there are time lags between program implementation (causes) and water quality changes (effects), sufficient time must pass after programs are in place to see the full effects of programs on water quality. Improvements in water quality continue to evolve as the full effects of the programs develop and stabilize.

Over the short term (i.e., less than a year), there are other influences that affect water quality. These account for the high degree of variation seen in the plots of water quality data over the 17-year analysis period. Seasonal variations in precipitation and temperature affect runoff and stratification, which also affect water quality from week to week and storm to storm. Since DEP's objective was to look for trends in the water quality data over the time period of program implementation, statistical techniques for the water quality trend analysis were chosen to account for the seasonal variation in data used to evaluate long-term trends. In addition, concentrations were flow-adjusted in order to minimize the influence of short-term flow changes on trend detection. With this approach, DEP has been able to examine long-term water quality trends over the period of watershed protection implementation.

5.2 The West Branch Basin

West Branch Reservoir is located in Putnam County approximately 35 miles north of New York City. It was formed by damming the West Branch of the Croton River, which continues south to Croton Falls Reservoir. West Branch 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 City's Croton water supply system.

West Branch functions primarily as part of the Delaware System, serving as a supplementary settling basin for water which arrives from Rondout Reservoir via the Delaware Aqueduct. West Branch Reservoir also receives water from its own small watershed and Boyd Corners Reservoir. In addition, West Branch is connected to adjacent Lake Gleneida, one of the three controlled lakes that are part of the City's water supply. Water from West Branch ordinarily flows via the Delaware Aqueduct into Kensico Reservoir, where it mixes with Catskill System water before entering Hillview Reservoir and the water supply distribution system.

The West Branch watershed's drainage basin is 20 square miles, or 12,735 acres. Land use in the West Branch watershed is as follows: 8,767 acres (68.8%) are forested, 1,535 acres (12.1%) are urban or built-up in nature, 398 acres (3.1%) are brushland or successional land, and 12.7 acres (0.1%) are classified as barren land. Wetlands comprise 734 acres (5.8%) of the watershed, while 1,232 acres (9.7%) are water. The remaining 56.55 acres (0.4%) are in agricultural use (Figure 5.1a).

Boyd Corners Reservoir is located just upstream of West Branch Reservoir. It consists of one basin, 1.5 miles in length, and holds 1.7 billion gallons at full capacity. First placed into service in 1873, the dam, spillway and outlet works were rebuilt in 1990 as part of the City's dam rehabilitation program for the 19 reservoirs in its water supply system. Originally constructed as part of the Croton System, Boyd Corners today serves mainly as part of the Delaware System.

The Boyd Corners watershed's drainage basin is 22 square miles, or 14,310 acres. Land use in the Boyd Corners watershed is as follows: 10,577 acres (73.9%) are forested, 1,234 acres (8.6%) are urban or built-up in nature, and 517 acres (3.6%) are brushland or successional land. Wetlands comprise 1,271 acres (8.9%) of the watershed, while 658 acres (4.6%) are water. The remaining 53.4 acres (0.4%) are in agricultural use (Figure 5.1b).

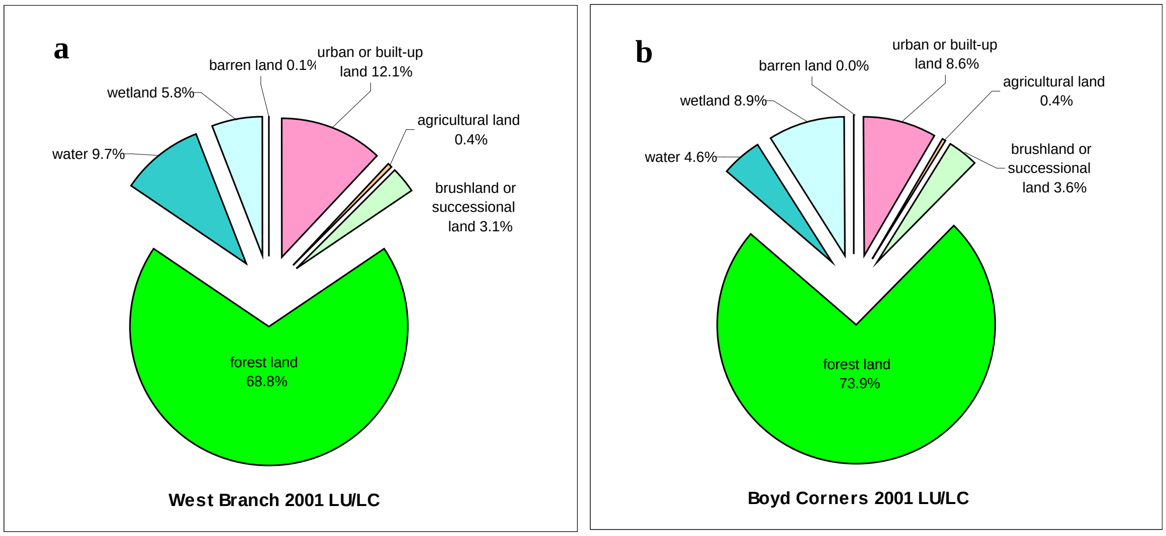

Figure 5.1 Land use in the (a) West Branch and (b) Boyd Corners drainage basins based on 2001 data.

5.2.1 Program Implementation (West Branch/Boyd Corners Basins)

Since 2003, DEP has completed 37 stormwater retrofit/remediation projects in the West Branch and Boyd Corners Reservoir basins (Figure 5.2a). Most of these projects were small and involved stream, bank, and swale stabilization, and culvert repair. Two large projects are targeted for completion in 2011.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on West Branch Reservoir has increased from an average of about 350 in the early part of the last decade to about 450 boats in recent years (Figure 5.2b).

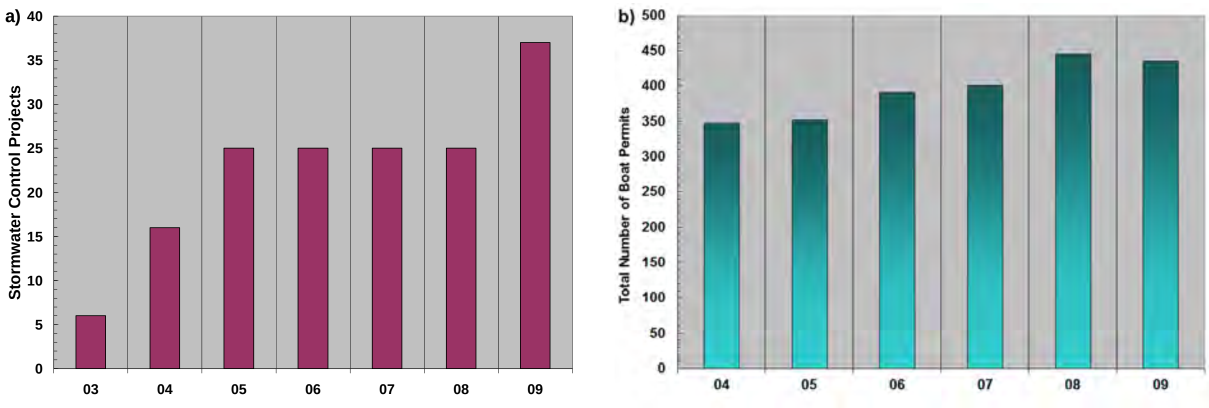

Figure 5.2 History of watershed programs in the West Branch/Boyd Corners drainage basin: a) environmental infrastructure installations for stormwater control, b) number of boat permits issued.

Note: Bars in plot (a) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the West Branch Basin

As illustrated in Figure 5.3, phosphorus loads (as total phosphorus) to West Branch Reservoir from the basin's only wastewater treatment plant (WWTP), Clear Pool Camp, have decreased since 2004, while flows have declined since 1999. The plant upgrade was completed in 2005 as part of DEP's effort to upgrade all surface-discharging WWTPs. This has significantly reduced the plant's inputs of phosphorus, as well as other pollutants, to West Branch Reservoir. It should be noted that loads and flows from this plant are extremely small.

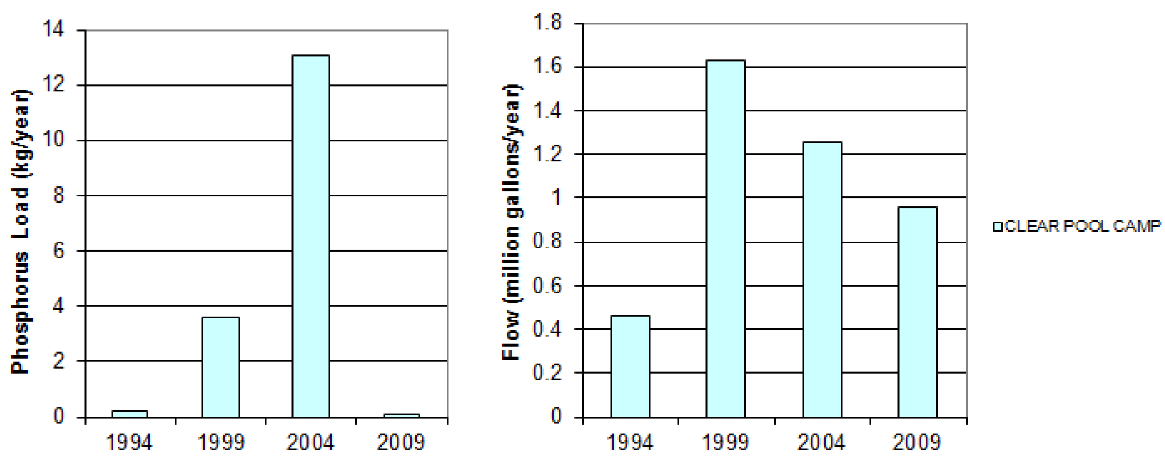

Figure 5.3 Wastewater treatment plant total phosphorus loads and flows in the West Branch drainage basin, 1994-2009.

5.2.2 Water Quality Status and Trends (West Branch Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 5.4. Two time periods are assessed for each site: i) the full period of record, and ii) a 3-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deterioration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

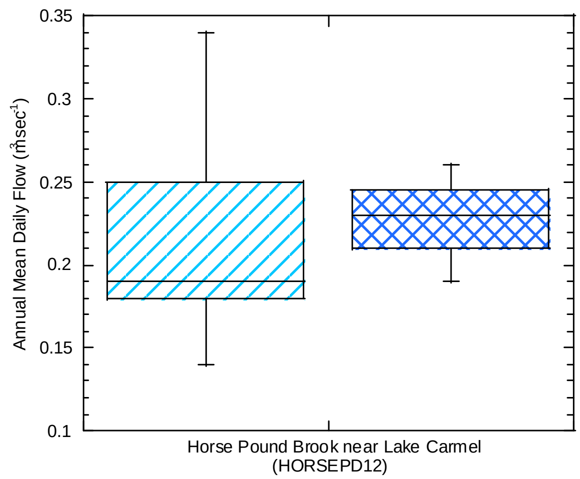

Figure 5.4 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the West Branch watershed.

Horse Pound Brook near Lake Carmel is the primary stream inflow to West Branch Reservoir. It drains 20% of the basin (Table 5.1). The status period's mean annual daily flow median was very similar to the long-term median, although the overall distribution was slightly biased to higher flows..

Table 5.1: DEP sample site descriptions for the West Branch watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
HORSEPD12	Horse Pound Brook near Lake Carmel	19.6%	August 1996-present

Status (West Branch Basin)

The West Branch basin's status evaluation is presented as a series of boxplots in Figure 5.5. 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 line for fecal coliform (blue line) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

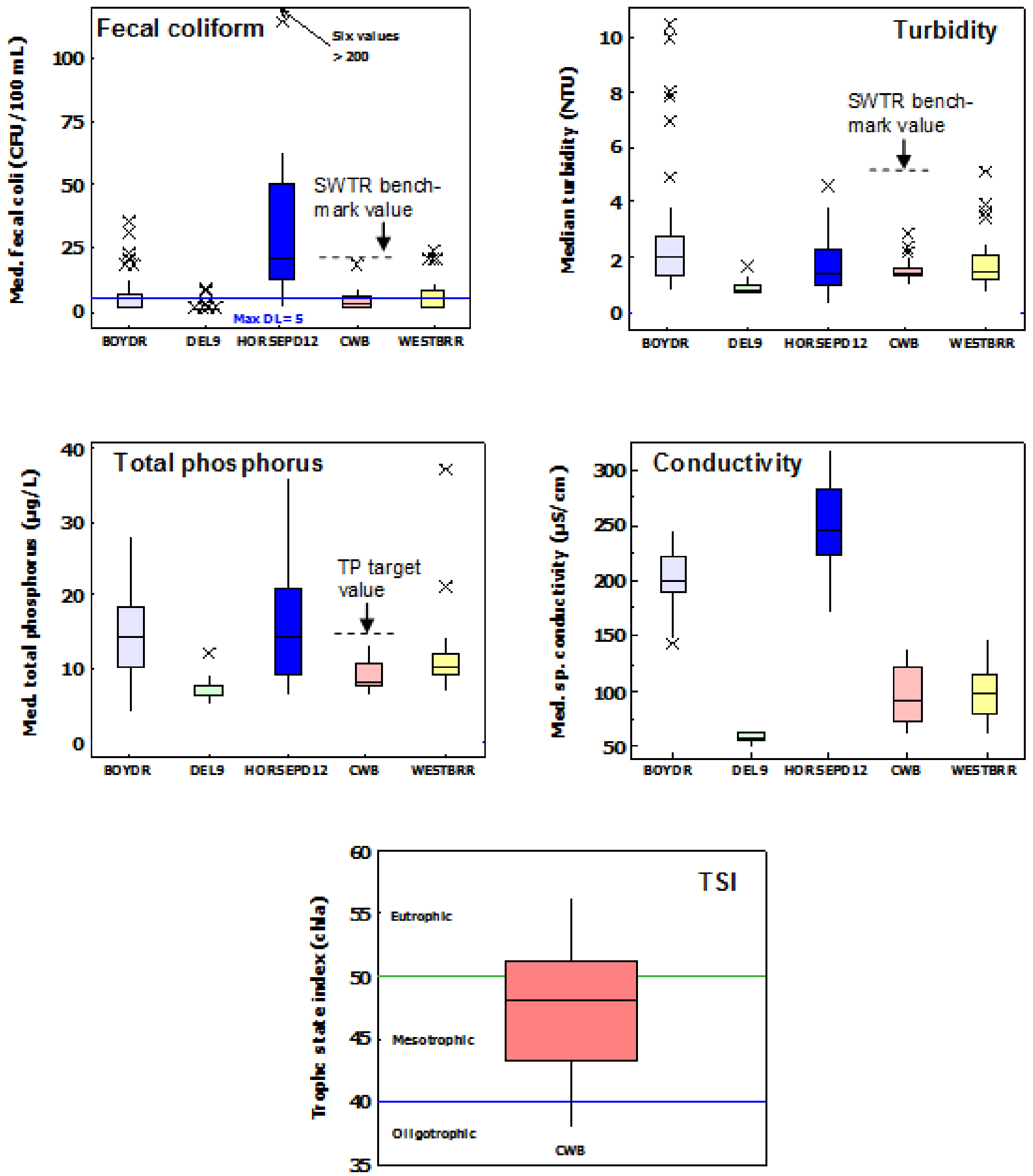

Figure 5.5 Water quality status boxplots using 2007-2009 monthly data for the West Branch basin for the inputs from Rondout Reservoir (DEL9), the main stream input at Boyd Corners Reservoir release (BOYDR), and Horse Pound Brook (HORSEPD12); West Branch Reservoir (CWB); and the output at the West Branch release (WESTBRR).

Fecal coliform values for the input sites were the lowest for Rondout Reservoir and highest for Horse Pound Brook. Horse Pound Brook is a local stream, and this situation illustrates the difference between water quality from Rondout Reservoir and the local watershed. Differences in land use between the Croton and Catskill/Delaware watersheds account for the higher concentrations of constituents typically found in Croton water. The flow from Boyd Corners had fecal coliform levels between the other two inputs. The reservoir and the output had median coliform values (2 and 4 CFU 100 mL^{-1}, respectively) that were well below the Surface Water Treatment Rule (SWTR) benchmark of 20 CFU 100 mL^{-1} used for source waters. All sites had values below the detection limit, which required the use of non-detect statistics, as indicated above.

Turbidity values were higher in the two local watershed inputs (i.e., Boyd Corners and Horse Pound Brook) than the input from Rondout Reservoir. Boyd Corners had the widest variability among the inputs. Both the reservoir and the output had low median turbidity values. The reservoir values tended to be slightly lower than the output because water is released from the bottom near the dam, where water can be hypoxic for part of the year. (Low oxygen levels cause the release of material from the sediments which can create turbidity.) None of the values for the reservoir or the output were above 5 NTU, the SWTR benchmark value for source waters.

Total phosphorus (TP) values for the local (i.e., Croton stream) inputs were also higher than the input from Rondout. The highest variability was found in Horse Pound Brook. The reservoir and the output had broadly similar TP values, and the median for the reservoir (8 µg L^{-1}) was well below the phosphorus-restricted target value of 15 µg L^{-1}.

The Trophic Status Index (TSI) value for West Branch Reservoir was well within the mesotrophic range for the three-year period. As compared to the TSI plot for Rondout Reservoir, however, the West Branch TSI was higher, as a result of operational changes during the three-year period. These changes can affect the TSI at West Branch by changing the proportion of local watershed and Rondout Reservoir inputs.

As with the other analytes, conductivity varied among the inputs. Horse Pound Brook had the highest, which is typical of values found in the Croton System. Both local watershed inputs (Horse Pound Brook and Boyd Corners) were significantly higher than the Rondout input. Boyd Corners had conductivity similar to that found in the reservoir.

Water quality was good in the West Branch basin during the 2007-2009 status assessment period. It is important to bear in mind, however, that operational changes largely determine the characteristics of the reservoir, which is driven by the inflow from Rondout Reservoir (via the Delaware Aqueduct at DEL9). The data for the selected variables show that medians were all well below the established benchmarks for fecal coliforms, turbidity, and TP.

Trends (West Branch)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 5.2).

Water quality trend plots are presented in Figure 5.6 and results of the Seasonal Kendall trend analysis are provided in Table 5.2.

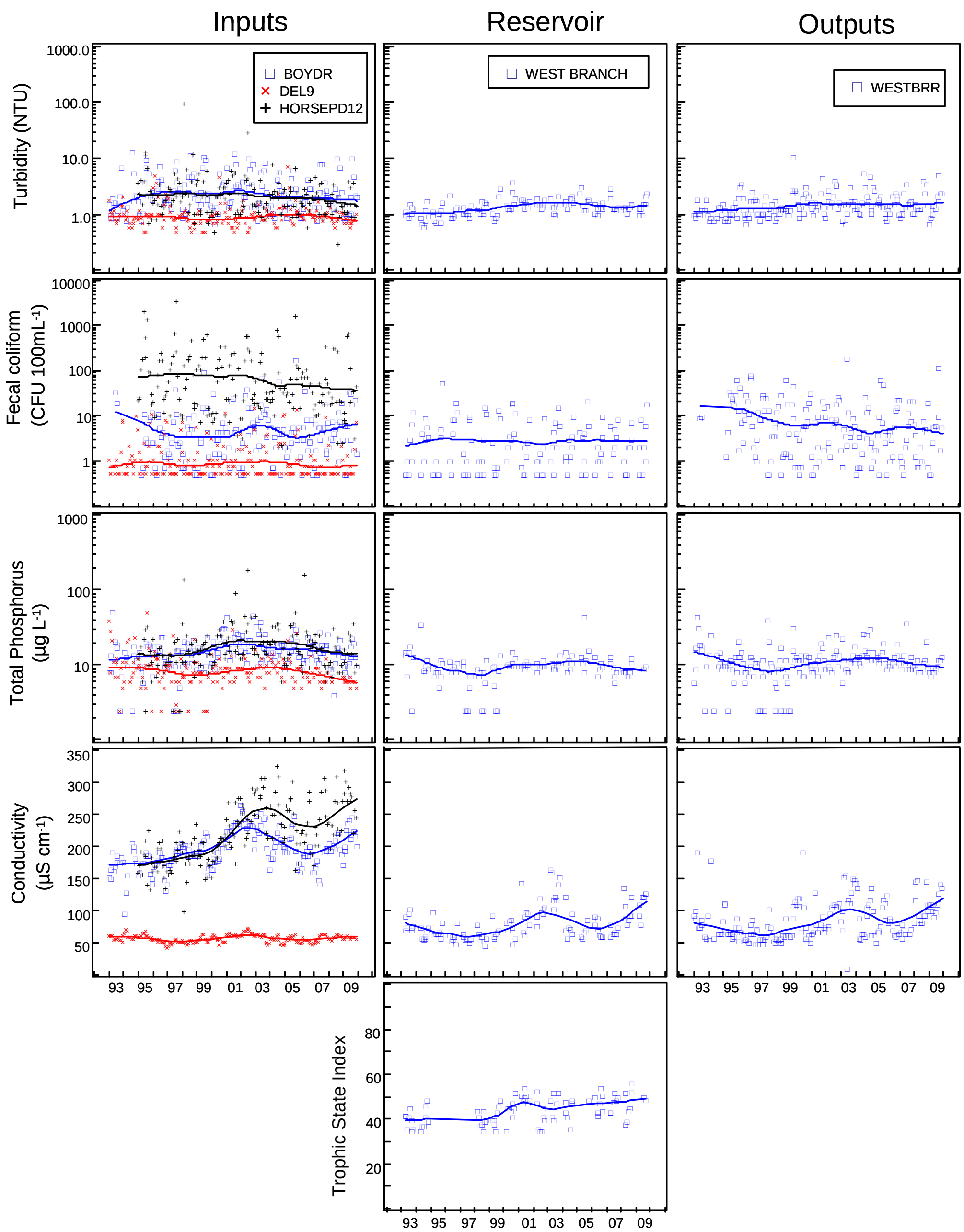

Figure 5.6 Water quality trend plots for the West Branch basin for the inputs from Rondout Reservoir (DEL9), the main stream input at Boyd Corners Reservoir release (BOYDR), and Horse Pound Brook (HORSEPD12); West Branch Reservoir (CWB); and the output at the West Branch release (WESTBRR). For each site, 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 3.

Table 5.2: West Branch basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
BOYDR	Input	Turbidity	199	-0.09	**	-0.02
DEL9	Input	Turbidity	202	-0.01	NS	
HORSEPD12	Input	Turbidity	179	-0.15	***	-0.04
West Branch	Reservoir	Turbidity	131	0.31	***	0.03
WESTBRR	Output	Turbidity	197	0.19	***	0.03
BOYDR[3]	Input	Fecal coliform	178	0.07	NS	
DEL9[3]	Input	Fecal coliform	202	-0.09	*	0.00
HORSEPD12[3]	Input	Fecal coliform	178	-0.11	***	0.00
West Branch[3]	Reservoir	Fecal coliform	130	0.03	NS	
WESTBRR[3]	Output	Fecal coliform	177	-0.17	***	0.00
BOYDR	Input	Total phosphorus	195	0.06	NS	
DEL9	Input	Total phosphorus	190	-0.14	***	-0.11
HORSEPD12	Input	Total phosphorus	179	0.05	NS	
West Branch	Reservoir	Total phosphorus	115	0.08	NS	
WESTBRR	Output	Total phosphorus	193	0.06	NS	
BOYDR	Input	Conductivity	195	0.34	***	2.33
DEL9	Input	Conductivity	202	0.01	NS	
HORSEPD12	Input	Conductivity	175	0.47	***	6.67
West Branch	Reservoir	Conductivity	121	0.25	***	1.45
WESTBRR	Output	Conductivity	193	0.28	***	2.00
West Branch	Reservoir	Trophic State Index	93	0.30	***	0.50

[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 in this row required the use of statistical methods for “non-detect” values.

Under normal operating conditions, West Branch Reservoir receives the majority of its water from Rondout Reservoir via the Delaware Aqueduct (DEL9), so water quality patterns are similar to those found in Rondout. Exceptions occur when operational changes decrease or eliminate the input from Rondout, allowing local inputs—Boyd Corners Reservoir release and Horse Pound Brook—to have greater influence over the reservoir’s water quality. 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. Due to the large number of values less than the detection limit, non-detect statistics were used to assess the trends (Helsel 2005).

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 roughly 50% reservoir/50% “float” mode, and in 2001 and 2002 it was 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 and a higher proportion of water from local streams. During 2003, time in reservoir mode was increased to about 44%, time in float mode was reduced to 40%, and time in “by-pass” mode increased to 16%. In by-pass 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 by-pass mode 71% of the time.

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 the last 12 years, West Branch was operated in a way that often increased the relative contributions of local 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 local 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 local inputs and in the reservoir from 2004-2007. In 2008 and 2009, conductivity in the local 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. The primary sources of the chlorides are road deicers and water softener effluent (Heisig 2000).

Downward turbidity trends were detected in the local inputs, but an upward trend was observed 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 in Rondout, even as the relative contributions from Rondout dropped as a result of the operational changes. Numerous stormwater remediation projects have been completed in both the West Branch and Boyd Corners watersheds and have probably contributed to the downward turbidity trends observed in the local inputs.

Downward fecal coliform trends were evident for the Horse Pound and Rondout Reservoir inputs and in the output, but no trend was detected in the reservoir. The decrease at Horse Pound and the output may be due, in part, to stormwater remediation projects in the watershed. 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; it is conducted twice every month, while the reservoir data used in this analysis are from monthly surveys collected from April to November. The coliform 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 coliform counts than the other inflows (Rondout Reservoir or Boyd Corners).

A downward TP trend was detected at the Rondout Reservoir input but was offset by the absence of a trend in the local inputs; as a result, no trend was observed in the reservoir and output. Since 2002, however, phosphorus declines have been evident in local stream inputs to West Branch, coinciding with stormwater improvements. Several large stormwater projects are expected to be completed by 2011, suggesting that the downward trend will continue.

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 both local inputs, in the reservoir, and in the output, but no trend was detected at the Rondout Reservoir input. 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. Horse Pound also displayed a decrease in fecal coliforms, as did the Rondout Reservoir input and the output. Fecal coliform trends were not apparent at Boyd Corners or in the reservoir, but strong decreases occurred at Horse Pound and the output. A decreasing TP trend was detected at the Rondout Reservoir input. 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 are likely related to efforts to better manage stormwater runoff.

Biomonitoring Status and Trends (West Branch Basin)

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. For methodology details, see Appendix 3.

The most recent status of macroinvertebrate communities in the West Branch Basin was evaluated by examining 2007-2009 data for a single site (146) on Horse Pound Brook. This stream is the primary stream 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 2007-2009, it was assessed as being non-impaired, with little variation in scores between years (Figure 5.7). This is reflected in the taxonomic composition of the community, which remained little changed during this period. Mayflies, stoneflies, and caddisflies, generally considered the most sensitive macroinvertebrate groups, together comprised between one-third and one-half the community, with beetles and dipterans accounting for most of the rest. These results indicate the presence of optimal conditions for the benthic community at this site.

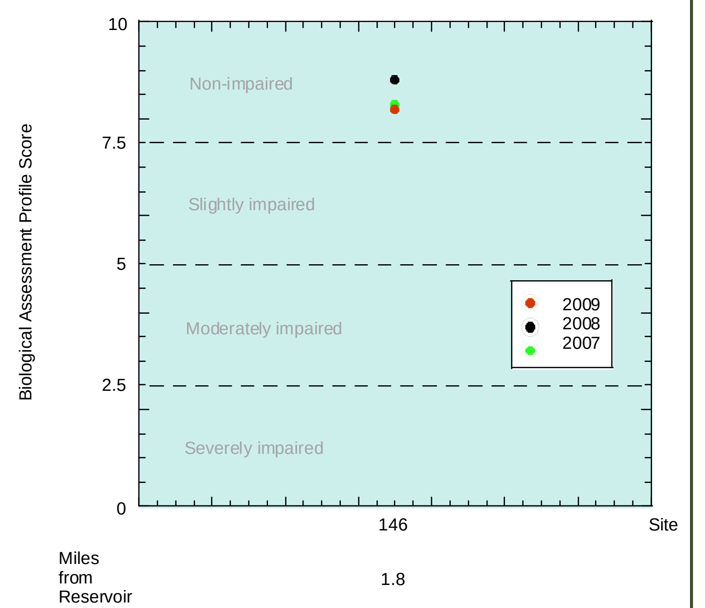

Figure 5.7 Biomonitoring status scores for Horse Pound Brook, 2007-2009.

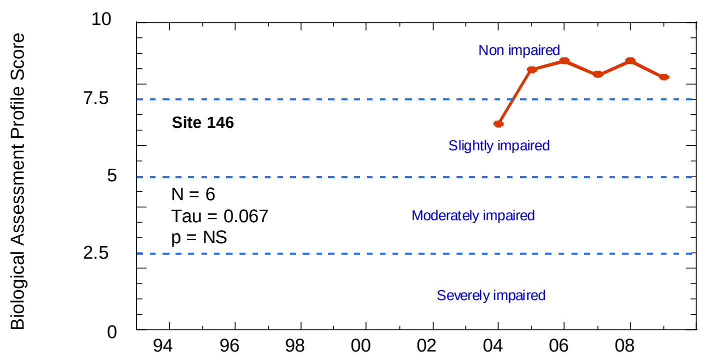

Figure 5.8 Biomonitoring trend plot for Horse Pound Brook, 2004-2009. Results of the Mann Kendall trend test are shown as follows: NS (Not Significant) = $p \geq 0.20$. N = number of observations, Tau = Mann Kendall test statistic.

Trend analysis was based on the site's entire period of record (2004-2009), and examined changes in both scores and assessment categories.

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. No significant trend was detected. Assessments also remained stable, with five consecutive years of non-impaired scores following a slightly impaired assessment in 2004 (Figure 5.8).

5.2.3 Waterfowl Management Program: West Branch Reservoir

West Branch Reservoir is one of five reservoirs covered under the "as needed" criteria for waterfowl management. West Branch receives water from Rondout Reservoir and may be operated in full flow-through, float, or bypass mode, depending on water quality and operational needs. From 2006 to 2010 it was only necessary to conduct bird harassment activities once—in early 2007—based on the criteria established for "as needed" actions (bird counts, fecal coliform bacteria levels, reservoir operations). A full description of this action is described in the case study below.

Bird counts increased from mid-July through late December in every year from 2006-2010 at site CWB1.5 (near DEL10), and this increase was accompanied by a corresponding rise in fecal coliform counts (Figure 5.9). The elevated bird counts were largely a function of increased gull roosting activity.

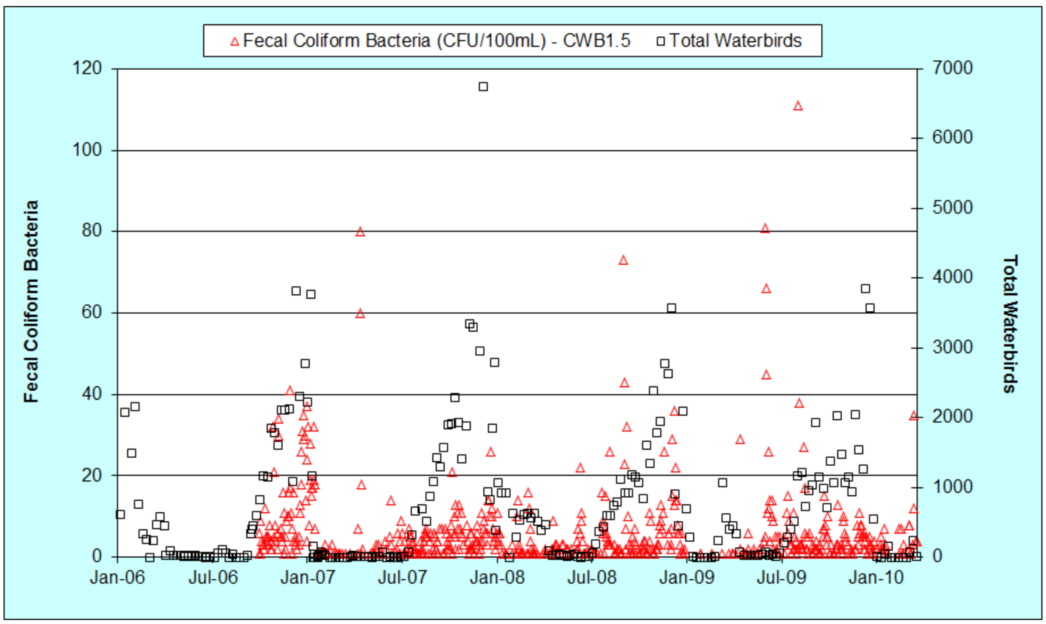

Figure 5.9 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total water-birds at West Branch Reservoir, January 1, 2006-March 31, 2010.

Case Study: West Branch Reservoir Waterfowl Management Program "As Needed" Action (January 11, 2007 to March 27, 2007)

West Branch Reservoir is an integral component of the City's Delaware System. The reservoir receives water from Rondout Reservoir and discharges it to Kensico Reservoir. DEP can also operate West Branch in float or bypass mode, the latter delivering water directly from Rondout to Kensico Reservoir. From November 2006 into January 2007 fecal coliform counts increased at the in-reservoir keypoint sampling site CWB1.5, which is located approximately 500 feet in front of the water intake at Delaware Shaft 10. Since it was necessary to operate West Branch in reservoir mode to maintain the elevation of Kensico Reservoir, DEP initiated an "as needed" bird harassment program to improve West Branch water quality. The "as needed" program was conducted from January 11 through March 27, 2007, under DEP contract. A combination of motorboats, Husky Airboats, and pyrotechnics was used to chase birds from three of four bird zones (Bird Zones 1, 2, and 3) in the main basin of West Branch Reservoir. Fecal coliforms rose above 20 CFU 100 mL^{-1} on January 3, 2007, and ranged from 8 to 37 CFU 100 mL^{-1} through the start of bird harassment on January 11, 2007. There was a marked improvement in water quality within seven days of bird harassment, as fecal coliform counts dropped to 7 CFU 100 mL^{-1} by January 19, 2007 and to 1 CFU 100 mL^{-1} on January 20, 2007 (Figure 5.10). Bird harassment activities continued through the end of March to ensure satisfactory water quality. Reservoir icing was first observed on January 21, 2007 on about 5% of the surface, extending to most of the reservoir by January 31, 2007. After ice cover, pyrotechnics were launched from shoreline locations, since motorboat activity was no longer possible. Overall, the mitigation efforts conducted during this period were successful in minimizing bird activity and reducing the fecal coliform levels at West Branch Reservoir.

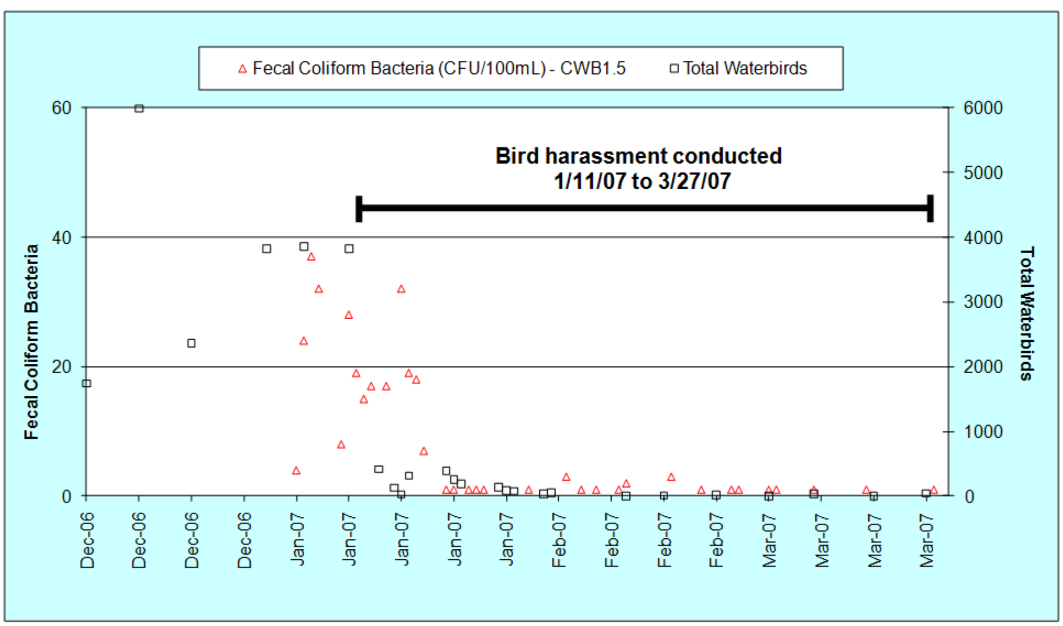

Figure 5.10 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total waterbirds at keypoint sampling site CWB 1.5, September 8, 2006-March 27, 2007.

5.3 The Kensico Basin

Kensico Reservoir is located in Westchester County, about 15 miles north of New York City. Although formed by the damming of the Bronx River, it receives most of its water from the City's West of Hudson reservoirs through the Catskill and Delaware Aqueducts. Kensico consists of a western main basin and an eastern Rye Lake portion, with water passing freely between the two. It holds 30.6 billion gallons at full capacity and was placed into service in 1915.

The major function of Kensico Reservoir is to receive water from all six Catskill/Delaware System reservoirs via two aqueducts, and to make those waters available for the daily demands of New York City. Kensico is the last reservoir for all Catskill/Delaware System waters before they flow into Hillview Reservoir and distribution. Under normal operations, waters from the Catskill and Delaware Aqueducts flow under the Hudson River and mix once they enter Kensico Reservoir. Kensico also has its own small watershed, which supplies just 2% or less of the total water volume entering the reservoir. As the final reservoir in the Catskill/Delaware System before water enters the distribution network, Kensico is subject to federal water quality standards for coliforms and turbidity.

The Kensico watershed's drainage basin is 13 square miles, or 8,469 acres. The land use breakdown for the watershed is as follows: 4,177 acres (49.3%) are forested, 1,309 acres (15.5%) are urban or built-up in nature, and 301 acres (3.6%) are brushland or successional land. Wetlands comprise 403 acres (4.8%) of the watershed, while 1,993 acres (23.5%) are water. The remaining 287 acres (3.4%) are in agricultural use (Figure 5.11).

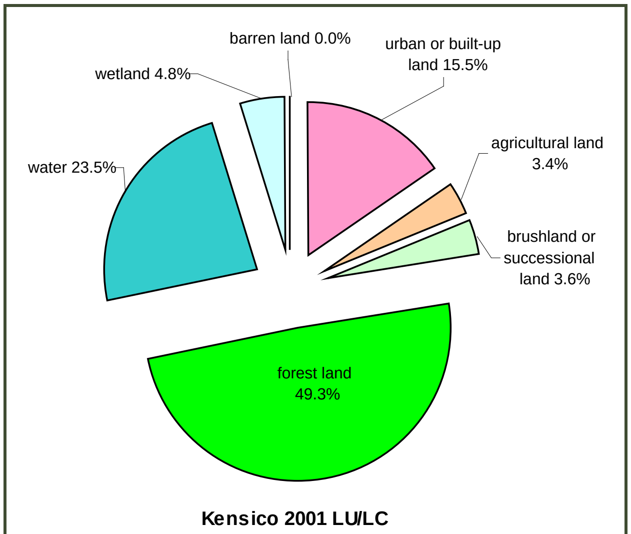

Figure 5.11 Land use in the Kensico drainage basin based on 2001 data.

5.3.1 Program Implementation (Kensico Basin)

DEP watershed protection programs have been effective in preserving the high quality of water in Kensico Reservoir. Approximately 97-99% of the water in the reservoir is delivered via the Catskill or Delaware Aqueduct. Kensico was one of the earliest focuses 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.

Forty-one stormwater and stream management projects have been installed in the Kensico basin since 1997, significantly reducing the possibility of turbidity and fecal coliforms entering the reservoir (Figure 5.12a). Five other stormwater control projects are currently under way and are scheduled for completion in 2011. To further reduce turbidity entering Kensico from two streams near the Catskill Effluent Chamber, DEP installed a back-up turbidity curtain that was completed in 2009.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Kensico Reservoir peaked at 1,103 in 2008 (Figure 5.12b).

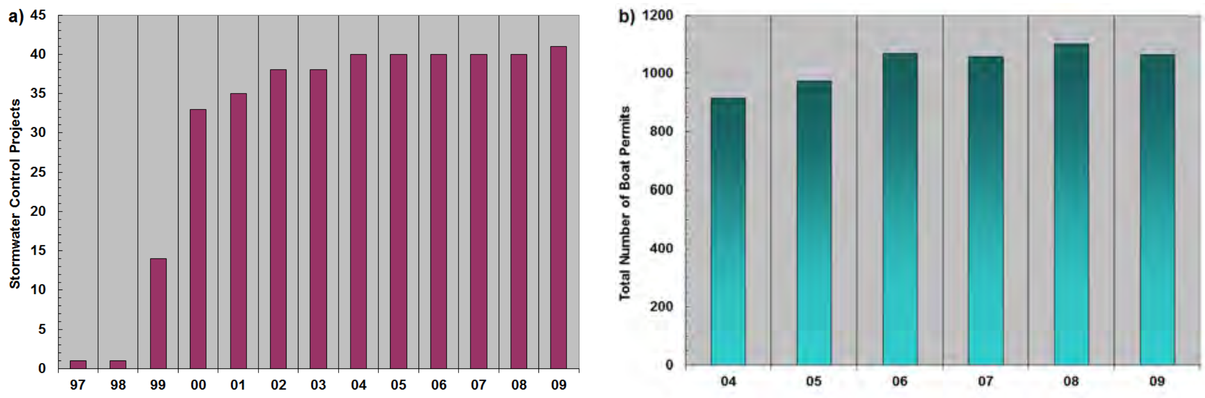

Figure 5.12 History of watershed programs in the Kensico drainage basin: a) environmental infrastructure installations for stormwater control and stream management projects, b) number of boat permits issued.

Note: Bars in plot (a) represent cumulative totals.

5.3.2 Water Quality Status and Trends (Kensico Basin)

Status (Kensico Basin)

The Kensico basin’s status evaluation is presented as a series of boxplots in Figure 5.13. The inputs are Rondout Reservoir via West Branch (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 from Kensico Reservoir are designated as DEL18 and CATLEFF. All values below the maximum detection limit line for fecal coliform (blue line) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

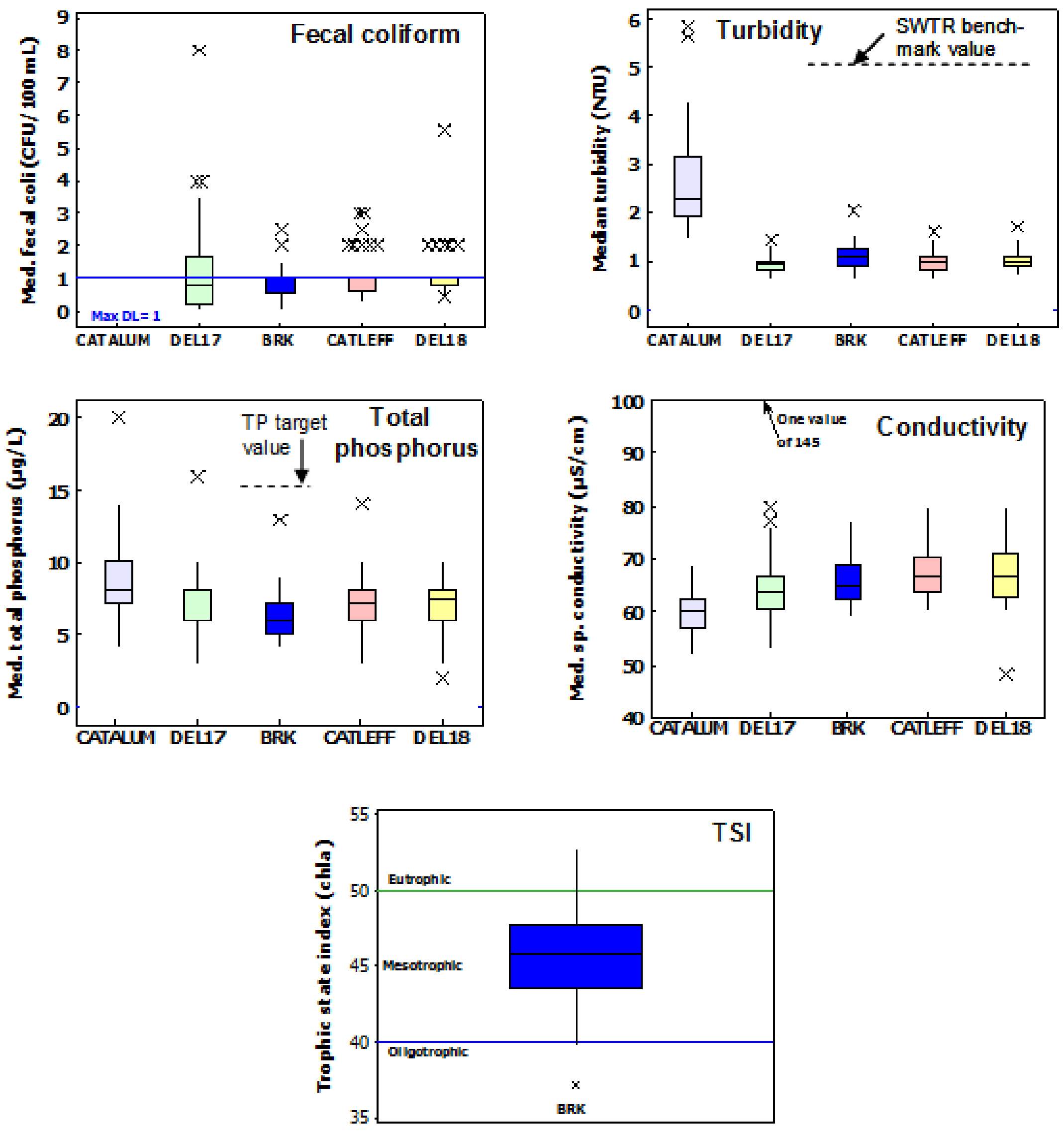

Figure 5.13 Water quality status boxplots using 2007-2009 monthly data for the Kensico basin inputs from the Delaware Aqueduct (DEL17) and the Catskill Aqueduct (CATALUM), Kensico Reservoir (BRK), and the outputs at the Kensico Reservoir gatehouses (DEL18 and CATLEFF).

Fecal coliform values were low for all sites, requiring the use of non-detect statistics to quantify the distribution of the data. The Catskill Aqueduct monthly median values never exceeded 1 CFU 100 mL^{-1}, so all the data fell within the maximum detection limit line in Figure 5.13. The Delaware Aqueduct also had low fecal coliform values, but had more variability over the three-year period. The reservoir and the two outputs had coliform values that were well below the Surface Water Treatment Rule (SWTR) benchmark of 20 CFU 100 mL^{-1} used for source waters. Only minor differences occurred between the reservoir and the outputs.

Turbidity values were lower in the Delaware Aqueduct than the Catskill Aqueduct. The latter provides water from Ashokan Reservoir, which is impacted by turbidity events in the Catskills. Kensico Reservoir can attenuate the various sources of turbidity to some degree, and for that reason lower median turbidity can be found in the outputs than in the reservoir or inputs. None of the values shown for the reservoir or the outputs exceeded the 5 NTU SWTR benchmark, and median values were well below it.

Total phosphorus (TP) values exhibited a pattern similar to turbidity. The Catskill Aqueduct had the highest values and variability of the two inputs, a product of the association between TP and particulates. In the reservoir, the median TP value (6 µg L^{-1}) was well below the phosphorus-restricted target value of 15 µg L^{-1}.

The Trophic State Index (TSI) values for Kensico Reservoir were well within the mesotrophic range for the three-year period. The trophic index was driven by the major inputs from Ashokan and Rondout Reservoirs.

Conductivity median and variability in the Delaware Aqueduct were higher than those found in the Catskill Aqueduct. The Delaware Aqueduct showed more variation in conductivity due to the periodic use of more Croton System water from West Branch Reservoir. Kensico Reservoir and its two outputs had similar median conductivity values and similar variability.

In summary, water quality was excellent during the 2007-2009 status assessment period in the Kensico basin. The data for the selected variables show that none of the monthly values exceeded the established benchmarks in the reservoir or the outputs, and that median values were well below the benchmarks.

Trends (Kensico Basin)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 5.3).

Water quality trend plots are presented in Figure 5.14 and results of the Seasonal Kendall trend analysis are provided in Table 5.3.

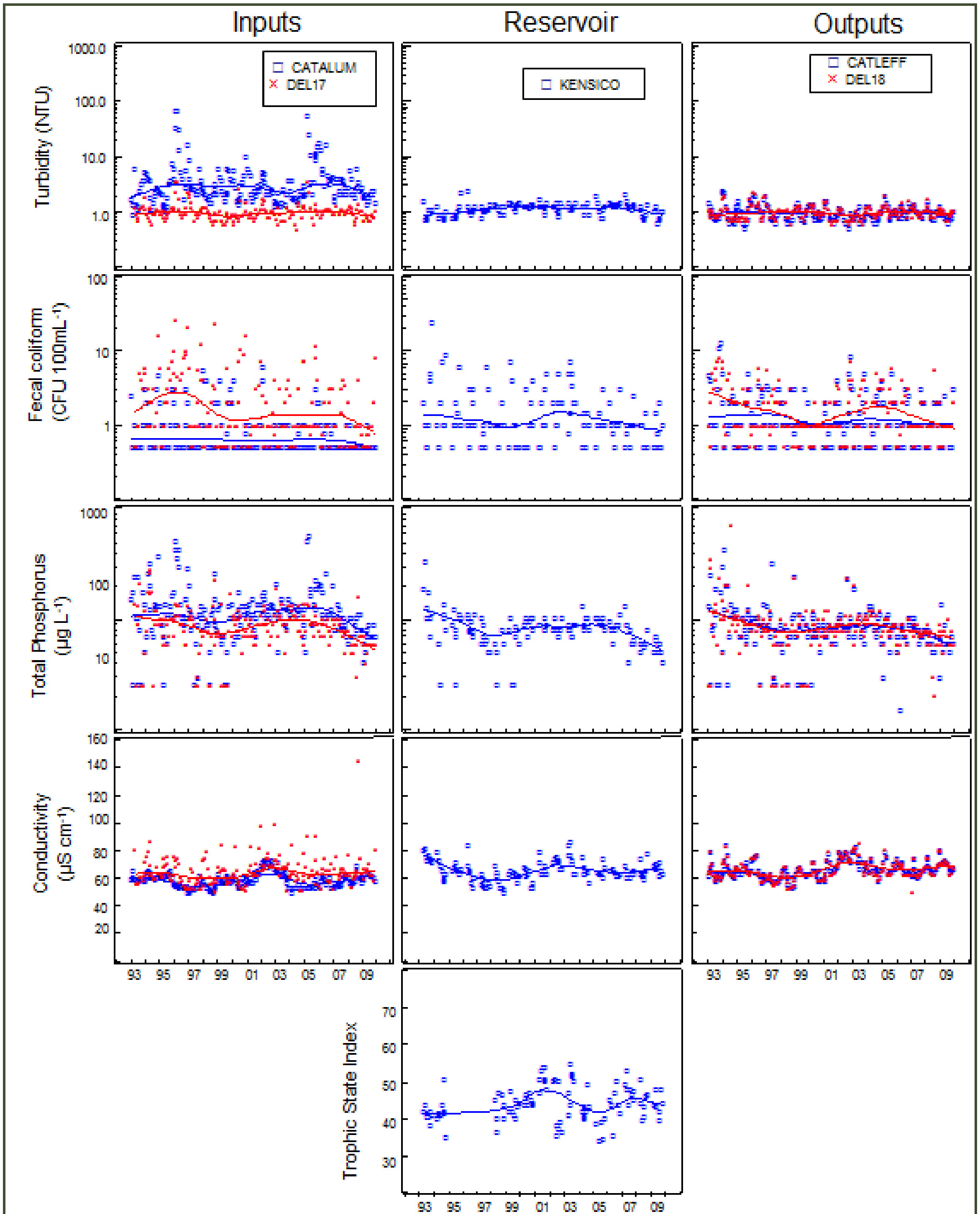

Figure 5.14 Water quality trend plots for the Kensico basin inputs from the Delaware Aqueduct (DEL17) and the Catskill Aqueduct (CATALUM), Kensico Reservoir (BRK), and the outputs at the Kensico Reservoir gatehouses (DEL18 and CATLEFF). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 5.3: Kensico basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
CATALUM	Input	Turbidity	204	0.03	NS	
DEL17	Input	Turbidity	198	-0.08	*	0.00
Kensico	Reservoir	Turbidity	132	0.13	***	0.01
CATLEFF	Output	Turbidity	204	-0.05	NS	
DEL18	Output	Turbidity	204	0.03	NS	
CATALUM[3]	Input	Fecal coliform	204	-0.17	***	0.00
DEL17[3]	Input	Fecal coliform	198	-0.19	***	0.00
Kensico[3]	Reservoir	Fecal coliform	122	-0.11	**	0.00
CATLEFF[3]	Output	Fecal coliform	204	-0.10	**	0.00
DEL18[3]	Output	Fecal coliform	204	-0.13	***	0.00
CATALUM	Input	Total phosphorus	202	-0.11	***	-0.14
DEL17	Input	Total phosphorus	198	-0.14	***	-0.11
Kensico	Reservoir	Total phosphorus	122	-0.21	***	-0.17
CATLEFF	Output	Total phosphorus	203	-0.17	***	-0.13
DEL18	Output	Total phosphorus	202	-0.18	***	-0.13
CATALUM	Input	Conductivity	204	0.04	NS	
DEL17	Input	Conductivity	198	0.07	*	0.14
Kensico	Reservoir	Conductivity	129	-0.01	NS	
CATLEFF	Output	Conductivity	204	0.21	***	0.33
DEL18	Output	Conductivity	204	0.18	***	0.27
Kensico	Reservoir	Trophic State Index	104	0.12	*	0.13

[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 in this row required the use of statistical methods for “non-detect” values.

A very slight increase in turbidity (0.01 NTU yr^{-1}) was detected in Kensico Reservoir; however, this was not apparent in the major inputs, which show either no statistically significant trend (the Catskill Aqueduct) or a slight downward trend (the Delaware Aqueduct). The small increase may be the result of operations that increased the diversion from the Catskill System (which is generally more turbid than the Delaware System) in 1998, 1999, 2006, and 2008. Trends were not detected in either output.

Significant downward trends were detected for fecal coliform in both the inputs and outputs. Non-detect statistical analysis was used for all fecal coliform trends due to the large number of values less than the detection limit. Although the slope estimator test produced a slope of zero 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. Additional evidence of the decline is indicated by examination of the LOWESS curves at these sites. A dramatic decrease was observed at the Delaware Aqueduct and probably represents recovery from the January 1996 flooding event in the West of Hudson watershed. Because of the dominance of low values at the Catskill Aqueduct, 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 CFU 100 mL^{-1}. Since then, most of the monthly median counts have been 1 CFU 100 mL^{-1} or less than the detection limit, with the highest monthly median counts reaching 5 CFU 100 mL^{-1} in most years. Elevated counts in 2003 coincided with a temporary lapse in the annual waterfowl management contract.

Strong downward phosphorus 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 consistently dropped each year since then. Wastewater treatment plant (WWTP) upgrades in the Cannonsville, Ashokan, and Schoharie basins are the most likely explanation, although the ongoing implementation of agricultural BMPs in these upstate basins, as well as septic system replacements, have probably played a role as well.

A slight, weakly significant, upward conductivity trend was found in the Delaware Aqueduct, but no trends were apparent in the Catskill Aqueduct. A portion of the upward trend is attributable to the effects of drought in 2001-2003. An increase in the blend of more conductive Croton water (via Boyd Corners into West Branch Reservoir) during the latter half of the data record also helps to explain the increase observed at the Delaware Aqueduct. Surprisingly, strong upward conductivity trends were detected in both outputs but not in the reservoir itself. The outputs are sampled daily and are thus 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 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 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 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.

In summary, the Catskill Aqueduct input showed no change in turbidity, but a weak, small decrease was detected at the Delaware Aqueduct input. A small upward trend was apparent in the reservoir but no trends were detected in either output. The reservoir increase may be attributable to operational changes in the late 1990s and in 2006 and 2008. Fecal coliform counts were consistently low and appear to be decreasing, due to decreasing counts from the Catskill and Delaware Aqueducts, and as a result of the Waterfowl Management Program's harassment activities. TP was in decline at all sites, especially after 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. The 2001 drought, operational changes, and local anthropogenic sources are likely causes for the increase. Productivity increases in Kensico Reservoir are likely due to increases in the Catskill System reservoirs through 2004.

Biomonitoring Status and Trends (Kensico Basin)

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit to assess the health of stream macroinvertebrate communities in NYC watershed streams. For methodology details, see Appendix 3.

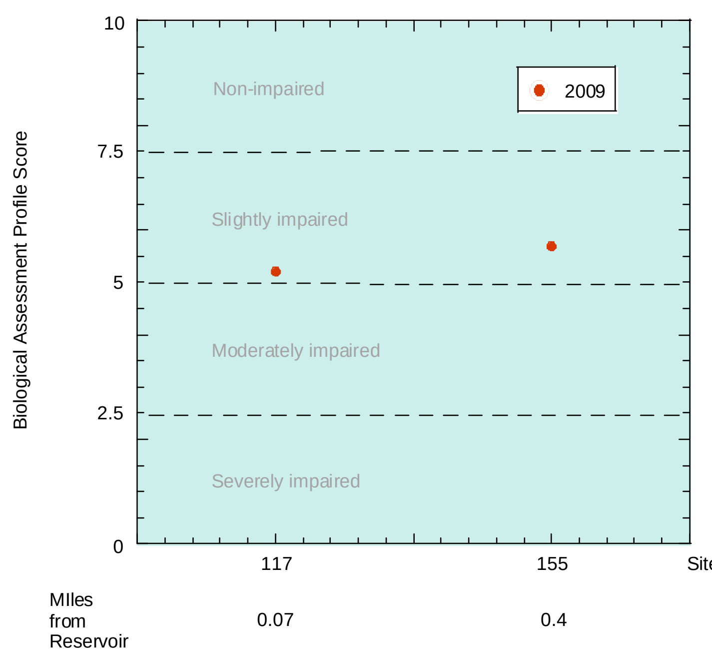

Figure 5.15 Biomonitoring status scores for Whippoorwill Creek, 2009.

The most recent status of macroinvertebrate communities in the Kensico basin was evaluated by examining 2009 data from two sites located on Whippoorwill Creek (Figure 5.15). (2009 was the only year within the three-year status period for which biomonitoring data from Whippoorwill Creek were available.) At 1.5 square miles, the Whippoorwill Creek sub-basin is the largest sub-basin in the Kensico Reservoir watershed. Both sites are non-routine, that is, they are sampled on a rotating basis.

Site 117 (WHIP) in North Castle lies approximately 0.1 miles upstream of Kensico Reservoir; Site 155 is about 0.4 miles upstream. Both sites were rated as slightly impaired in 2009, typical of streams in highly developed Westchester County. Slight impairment indicates the presence of suboptimal conditions for the benthic community.

Trend analysis was based on the entire period of record for Site 117, the one Whippoorwill Creek site for which at least five years of data are available (1997, 1998, 2001, 2005, 2009). The analysis examined changes in both scores and assessment categories.

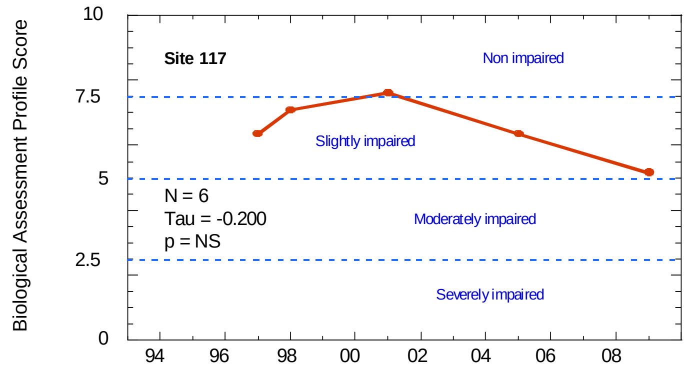

Figure 5.16 Biomonitoring trend plot for Whippoorwill Creek, 1997-2009. Results of the Mann Kendall trend test are shown as follows: NS (Not Significant) = $p \geq 0.20$. N = number of observations, Tau = Mann Kendall test statistic.

The long-term trend in biomonitoring scores at Site 117 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. No significant trend was detected, nor was there any change in assessment during the 1997-2009 period (slightly impaired in all years) (Figure 5.16). Scores, however, have declined substantially in the last two years of sampling, reaching a low of 5.2 in 2009, only marginally above the slightly impaired/moderately impaired threshold. Eroding streambanks introduce significant quantities of suspended solids into this stream, which is likely a major factor in the declining scores. As particulates settle, the embeddedness of rocky substrates increases, reducing the available area for macroinvertebrate colonization. Suspended sediment is scheduled to be addressed in the near future by installation of stream stabilization structures upstream of this site.

5.3.3 Waterfowl Management Program

Kensico Reservoir

Fecal coliform bacteria levels at the keypoint water sampling locations (DEL18 and CATLEFF) were consistently low and remained in compliance with the SWTR during the assessment period (Figures 5.17 and 5.18). The relatively low number of water samples with concentrations above the 20 CFU 100 mL^{-1} limit helped keep the six-month running average well below the 10% regulatory limit, with samples at DEL18 ranging from 0% to 2.2% and samples at CATLEFF from 0% to 1.6%.

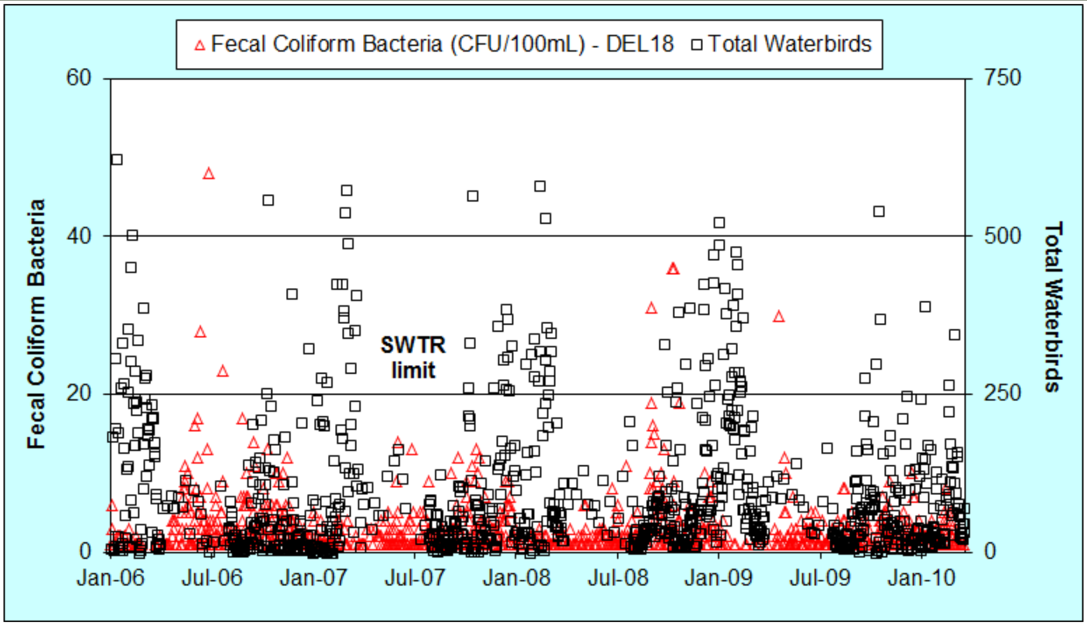

Figure 5.17 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total waterbirds at Kensico Reservoir DEL18, January 1, 2006-March 31, 2010.

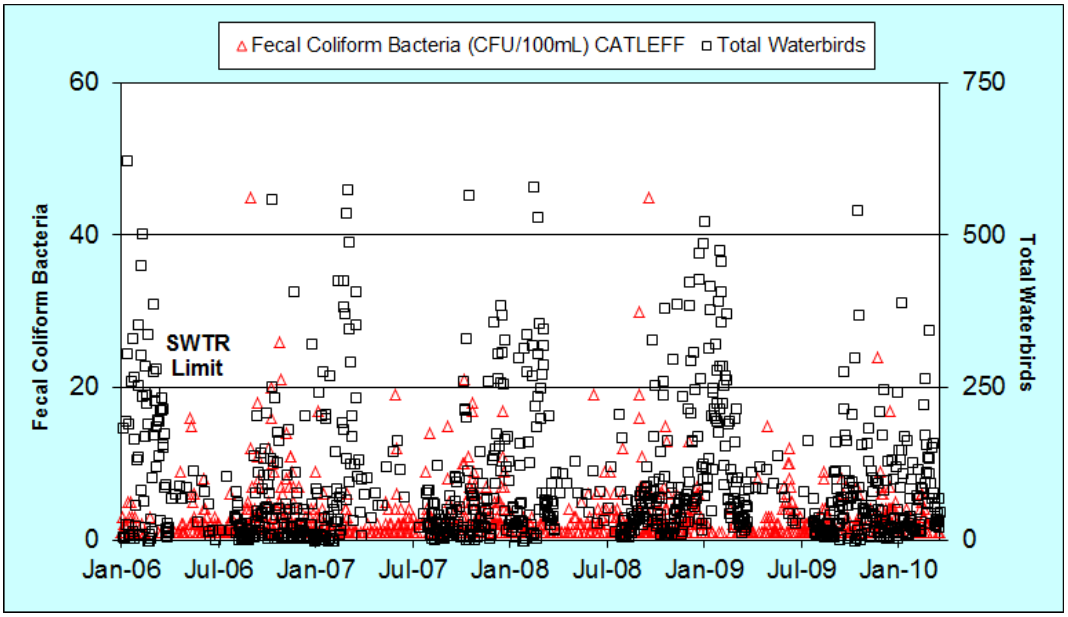

Figure 5.18 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total waterbirds at Kensico Reservoir CATLEFF, January 1, 2006-March 31, 2010.

Overall, waterbird numbers continue to be low throughout Kensico, a direct result of the ongoing bird harassment work. Since the inception of the Waterfowl Management Program in 1993, waterbird populations at Kensico have been kept at levels which allow DEP to maintain full compliance with the SWTR (Figures 5.19 and 5.20). There is a distinct seasonality in Canada goose numbers, which generally rise from April to June during the breeding season and drop off by mid-June, a direct result of DEP's egg/nest depredation efforts. In August, bird harassment is implemented to maintain relatively low goose numbers through March. Geese generally respond to the bird hazing activities and readily disperse from the reservoir. Early nesting and non-breeding gulls tend to begin local migrations as early as July and continue to rise in number each autumn and winter, requiring a continuous hazing effort. Ducks, swans, and duck-like birds (loons, grebes, and coots) tend to increase in numbers during the autumn and winter migration period and will often maintain openings in the ice cover for overnight roosting. Cormorants are typically present from spring through autumn but do not nest.

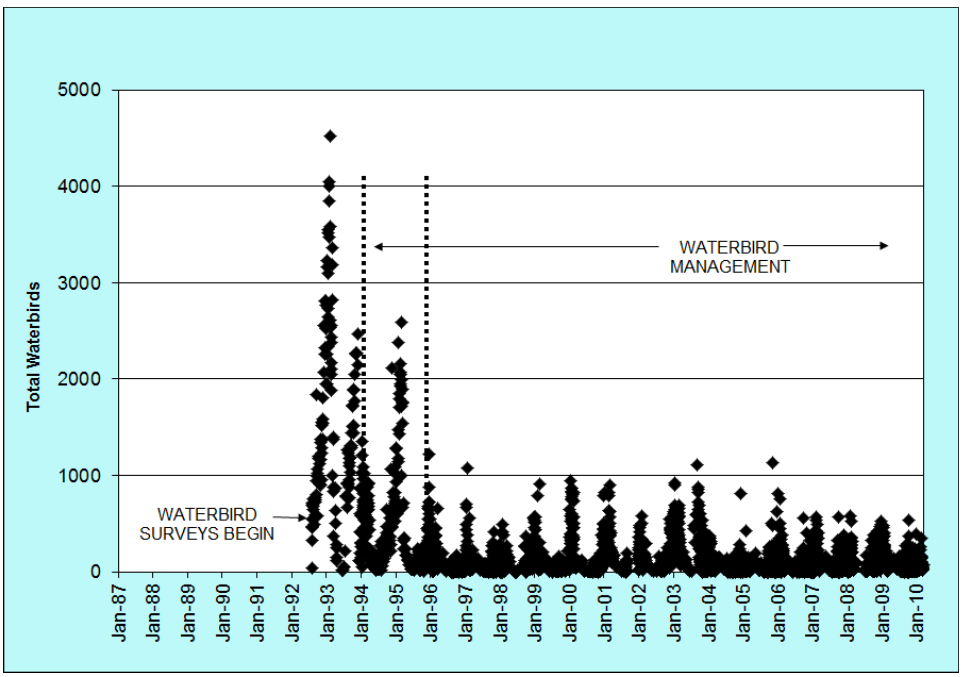

Figure 5.19 Waterbird counts at Kensico Reservoir, August 1992-March 31, 2010.

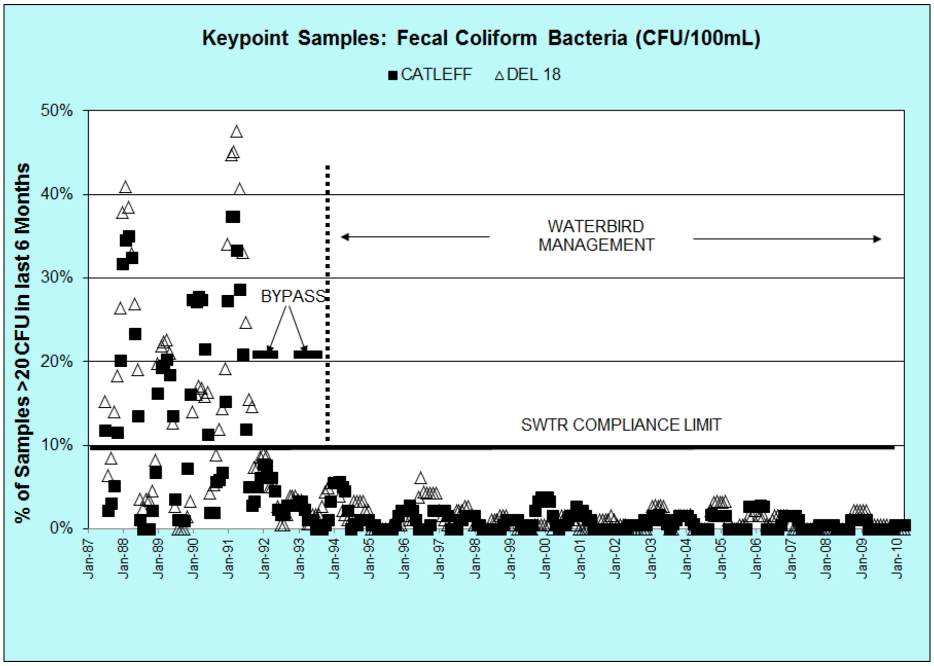

Figure 5.20 Fecal coliform bacteria (% of samples > 20 CFU 100 mL^{-1} in previous 6 months) at Kensico Reservoir keypoint sampling locations (CATLEFF and DEL18).

Hillview Reservoir

Bird monitoring and deterrence

In 1993, DEP initiated a formal bird management program at Hillview to monitor bird counts throughout the year and develop a bird deterrence/harassment program. Hillview is divided into two geographic bird sampling zones associated with the reservoir's two distinct basins and water quality sampling stations. The frequency of monitoring in the reservoir has varied through the years, but, at a minimum, has generally been conducted on a weekly basis and most recently on a daily basis. Bird deterrent and harassment activities have been employed since 1993 with a high level of success, reducing and in most cases eliminating the presence of roosting waterbirds, particularly geese, cormorants, and gulls.

Prior to 1993, DEP used noisemakers infrequently to eliminate birds at Hillview, but in the summer of 1993, with the startup of the new bird management program, pyrotechnics and propane-operated cannons began to be used to chase the birds off the water and from adjacent shaft buildings. In July 1994, a bird deterrent wire system was partially installed, which formed an aerial grid above the surface of the water to prevent birds such as swans, cormorants, geese, gulls, and ducks from landing. The wire grid was mostly complete by the spring of 1995 and consisted of a combination of high-test monofilament, Kevlar wire, and twine, which was strung along the shoreline fences for a distance of nearly 1,200 feet. In 2007, an upgraded version of the wire deterrent system, using 15-foot stanchions with reel tensioning devices at the base, was completed. DEP and its contractor continue to use pyrotechnics to supplement the wire system to minimize bird counts at Hillview. In the early winter of 2008, DEP made enhancements to the program by installing remote-operated propane cannons along the reservoir's dividing wall to keep gulls from roosting on the railings. The cannons were supplemented by installation of Daddi-long-legs (bird deterrent wires) placed on the tops of the 15-foot stanchions to prevent birds from roosting.

Bird totals recorded in 1993 and 1994 were elevated during both night and daytime periods, reaching roosting counts of over 1,250 birds. Overnight counts have been conducted since 1993, whereas regular daytime counts were only initiated in the summer of 2004, with infrequent data collection before then. Prior to bird wire mitigation in 1994, gulls comprised more than 70% of the night-roosting species on the reservoir (Figure 5.21).

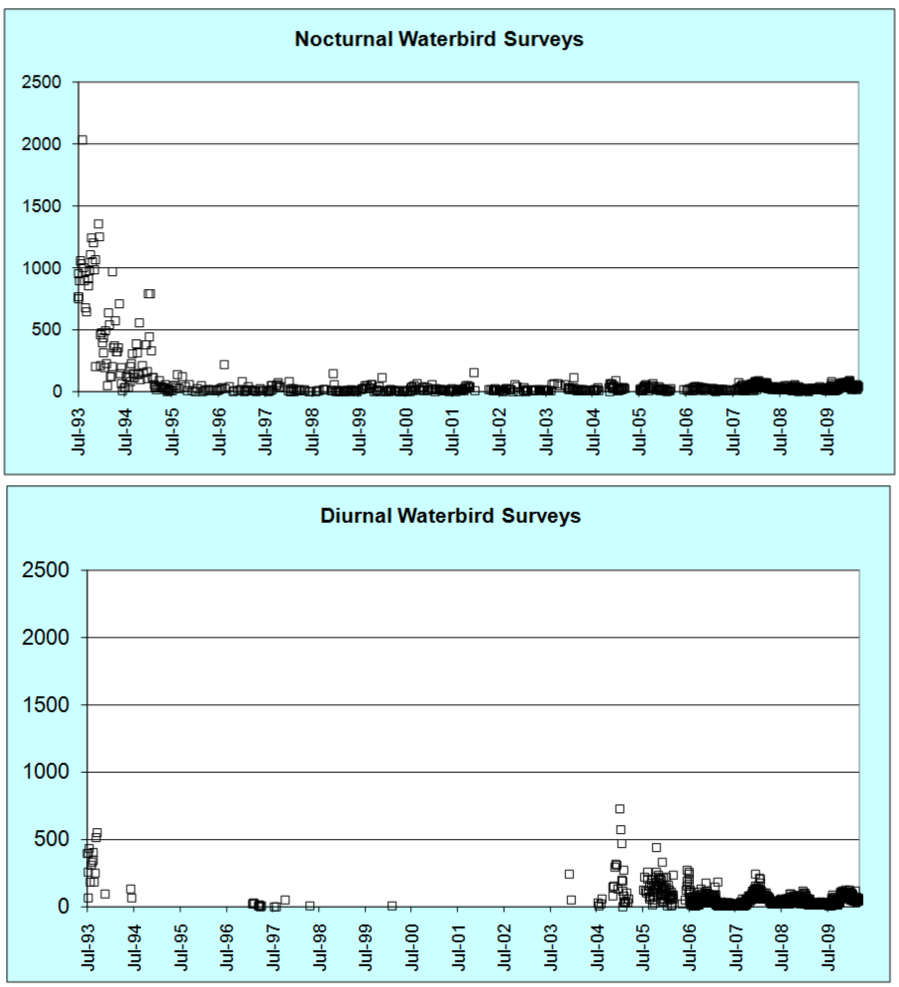

Figure 5.21 Nocturnal waterbird surveys (top) and diurnal waterbird surveys (bottom) at Hillview Reservoir, January 4, 2006-March 31, 2010.

The behavior patterns of the waterbirds at Hillview are different from those at the other upstate reservoirs because Hillview is situated in a highly urbanized area with large populations of breeding gulls, many of which are attracted to the reservoir. This partially explains why gull activity can be a year-round challenge at Hillview. Since the installation of the bird deterrent wire system in 1994, the number of gulls has greatly declined, but small numbers persist, and these, along with two species of ducks, remain the target of active harassment activity. Gulls continue to land along the dividing wall separating the two water basins and both mallards and ruddy ducks occasionally fly in under the wires.

The ruddy ducks in particular have proved to be a challenge, despite a decline of nearly 50% in 2008, apparently due to starvation. The Hillview basins are concrete and may not provide the ducks with a sufficient supply of aquatic invertebrates, their principal food source. Working in conjunction with DEC and USDA Wildlife Services, DEP has engaged in a number of actions since 2008 aimed at removing the surviving birds:

- September 2008 and February 2009. Use of remote control motorboat for harassment
- December 2008 to present. Use of canoes, kayaks, and electric motored Jon-boats for harassment
- September 2009. Deployment of gill nets and use of electric motored Jon-boats to attempt to capture ducks

DEP will continue to assess the feasibility of trapping efforts in the late summer when the ducks undergo a molt and are temporarily rendered flightless; these efforts will include the nighttime spotlighting technique as well as gill net deployment. If live-trapping efforts are successful, the small flock of ruddy ducks will be relocated to a northern New York location that has been designated by DEC. Daily monitoring and bird harassment activities will continue, under DEP contract, in order to supplement the new bird wire grid system. DEP continues to evaluate additional options for the removal of the ruddy ducks, including lethal action.

Additional deterrence measures at Hillview will include bird exclusion netting to cover water intake openings on the reservoir shaft buildings to prevent smaller bird species such as barn and cliff swallows from nesting and defecating in the water.

Relationship between E. coli and waterbirds

A comparison of the diurnal and nocturnal waterbird counts and *E. coli* numbers at Hillview sampling site 3, from 2006 through 2009, is displayed in Figures 5.23 and 5.22. (Sampling is conducted for *E. coli* at Hillview, as opposed to the fecal coliform sampling that occurs at upstate reservoirs.) There is no apparent relationship between waterbirds and *E. coli* at Hillview Reservoir. This is probably attributable to the fact that, although waterbird populations periodically rise on both a seasonal and daily basis at Hillview, the daily bird harassment program immediately disperses the birds after counts are made, so that the actual residence time of the birds on the reservoir is not significant.

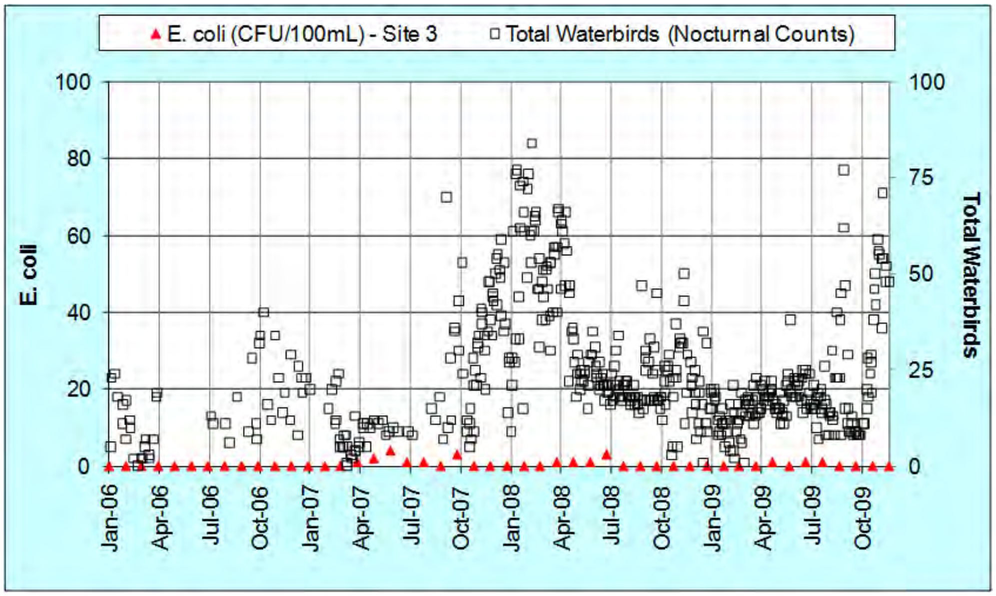

Figure 5.22 *E. coli* versus total waterbirds (nocturnal counts) at Hillview Reservoir sampling site 3, 2006-2009.

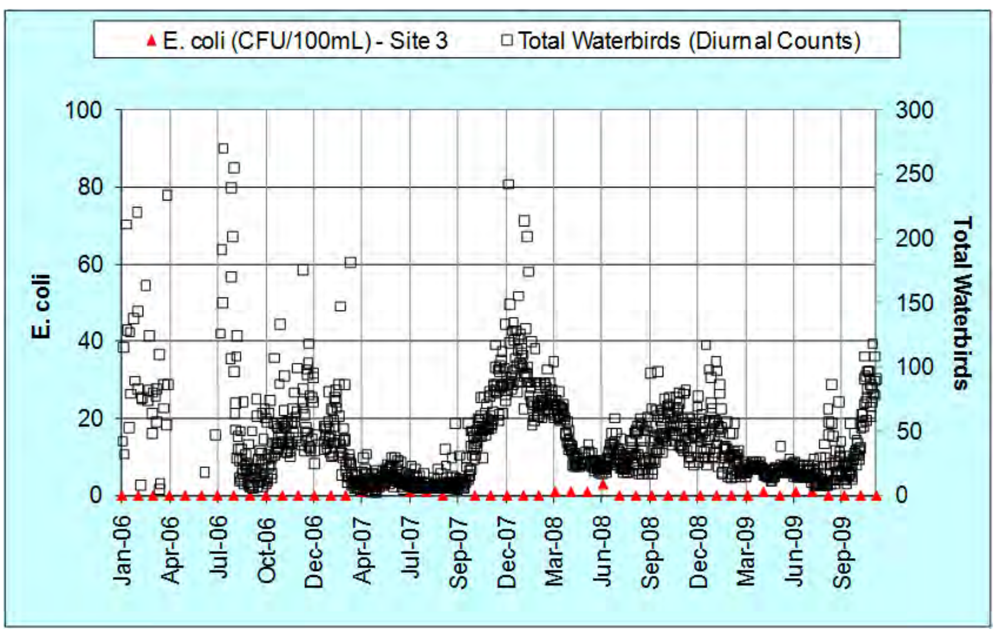

Figure 5.23 *E. coli* versus total waterbirds (diurnal counts) at Hillview Reservoir sampling site 3, 2006-2009.

5.4 Kensico Reservoir Protozoans

Reservoir Influents and Effluents

DEP has sampled for protozoa (*Giardia* and *Cryptosporidium*) at least weekly since 2002 at the two source water influent sites located upstream of Kensico Reservoir (CATALUM and DEL17), and at the two effluent sites as the water enters the Catskill and Delaware Aqueducts (CATLEFF and DEL18, respectively). One method (USEPA Method 1623HV, 50 L) has been used consistently from 2002 to the present, and a broad summary of the data acquired through this sampling is provided here.

Giardia

For the nearly nine-year period (January 2002-October 2010), NYCDEP has results for 909 *Giardia* samples at the influents (annual sample size ranges from 52 to 60), and 1,099 samples at the effluents (annual sample size ranges from 52 to 100). The effluents have been sampled more often over the years since they represent the final source water prior to treatment. Additional samples are collected at the effluents when DEP adds chemicals (alum) to reduce elevated turbidity. Additional samples were also collected when DEP first experienced increased *Giardia* counts during colder months compared to the warmer months of the year. After several years of increased sampling during the colder months it was established that the increase is a seasonal phenomenon.

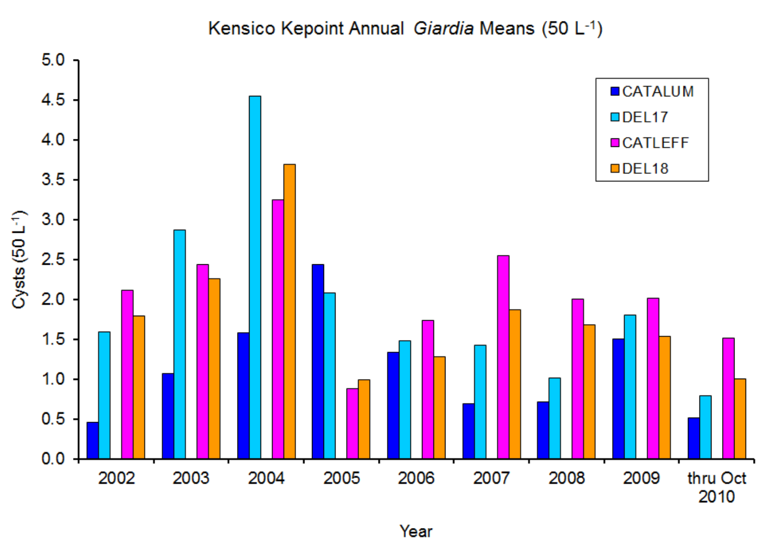

Figure 5.24 Kensico keypoint annual *Giardia* means (50 L^{-1}).

Giardia annual mean concentrations have fluctuated through the years; however, the highest mean influent and effluent values both occurred in 2004 (Figure 5.24). This was a year of heavy rains and snowmelt, necessitating the addition of alum at CATALUM in April 2005. Based on annual means, the three-year *Giardia* influent mean for 2003-2005 was higher (2.43 cysts 50 L^{-1}) than the more recent 2006-2009 period (1.25 cysts 50 L^{-1}).

The reservoir acts as a sink for a certain percentage of the cysts (and oocysts) that enter at the influents, which contribute approximately 97-99% of Kensico's volume (Pace and Alderisio 2009). The Kensico watershed has tributaries that also contribute to the reservoir, but their contribution is much smaller. The most significant contribution from these streams occurs during storm events, when stream flow volume to the reservoir increases from approximately 1% to 4% (Pace and Alderisio 2009). As a result, the annual mean concentration of *Giardia* at the Kensico effluents is sometimes greater than at the influents, most likely during years when there are fewer protozoan inputs from the influents (e.g., 2006-2009, possibly 2010). When fewer cysts enter the reservoir, there are fewer to be removed as they travel through it, producing less of a difference between the influent and effluent means.

Moreover, Kensico has a baseline local contribution of *Giardia* from its own watershed (especially during local storms) that may not be subjected to the same removal opportunities as cysts entering at the influents. This is because the influents, being at the far side of the reservoir, are much further from the effluents than some of the streams, whose inputs thus receive less exposure to reservoir processes. For example, from 2003-2005, the mean *Giardia* influent input was 2.43 cysts 50 L^{-1}, while the mean effluent concentration during the same period was 2.25, suggesting no real change in cysts as they passed through the reservoir during this three-year period. Conversely, from 2006-2009, the mean influent input (1.25 cysts 50 L^{-1}) was lower than the effluent mean (1.84 cysts 50 L^{-1}). This suggests a possible increase of cysts at the effluent. The difference between influent and effluent concentrations may represent the background level of *Giardia* expected from the local watershed. Notably, the 2006-2009 effluent mean is still lower than the effluent mean of the previous period (1.84 vs. 2.25).

In summary, during periods when the contribution of *Giardia* at the influents is minimal, there is less reduction of cysts from influent to effluent, and a baseline level of *Giardia* from the local Kensico watershed can be expected to affect the effluent mean. When the influent contribution of cysts is elevated above background levels, reservoir processes appear to provide a greater reduction of cysts between the influent and effluent; however, the effluent mean may still be above average. Note that for the entire eight-year period, the mean *Giardia* count at the Kensico effluents was very low (1.89 cysts 50 L^{-1}).

Cryptosporidium

The sample numbers available for *Cryptosporidium* were very similar to *Giardia*, with 911 results for the influents (annual sample size range 52 to 60), and 1,100 results for the effluents (annual sample size range 52 to 101). These numbers are slightly different than those for *Giardia* because in some cases either the *Giardia* or *Cryptosporidium* cysts were not successfully stained during the analysis. In such rare situations, only the result for the stained protozoan is reported.

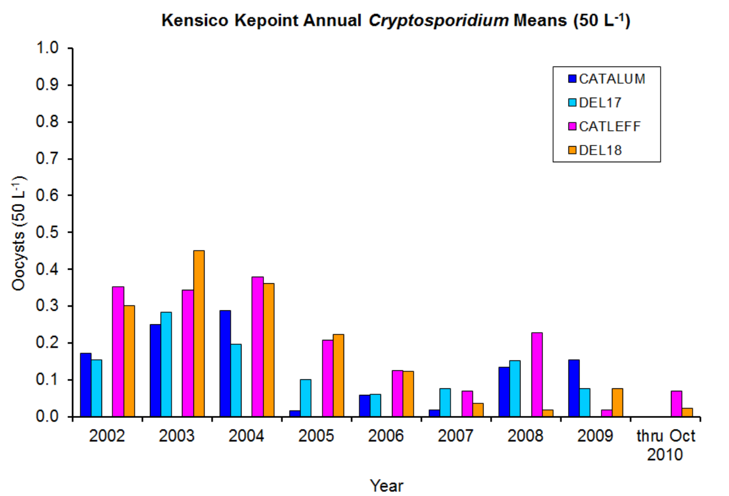

Figure 5.25 Kensico keypoint annual *Cryptosporidium* means (50 L^{-1}).

As has been noted in the data record in the NYC watershed, *Cryptosporidium* concentrations are much lower than those seen for *Giardia*, often by an order of magnitude or more. As a result, it is usually more difficult to detect changes in the data with a high level of confidence. Annual mean concentrations of *Cryptosporidium* at the influents of Kensico Reservoir since 2002 ranged from 0 (no detects for 2010 as of October 31) to 0.29 oocysts 50 L^{-1} (Figure 5.25). Effluent annual mean concentrations ranged from 0.02 to 0.45 oocysts 50 L^{-1}. While these means may suggest differences between the influents and effluents, the differences are within the range of variability expected by Method 1623, so it is difficult to say that a true difference exists. One thing the data do appear to indicate is a general decrease in both influent and effluent means in 2005 and 2006 compared to previous years. This may be a result of the 292 days of alum treatment in 2005-2006: cysts and oocysts may have settled out with the turbidity.

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

DEP has continued enhancing watershed protection in the West Branch, Boyd Corners, and Kensico basins. Thirty-seven stormwater remediation projects were completed in the 2003-2009 period in the West Branch and Boyd Corners basins, with five large projects scheduled for completion by 2011. In the Kensico basin, 41 projects have been completed since 1997, with five more to be finished in 2011. In 2009, a second turbidity curtain was installed in the Malcolm Brook cove to protect the water entering the Catskill Effluent Chamber from stormwater runoff. The Waterfowl Management Program continued its long-term efforts to reduce waterbird populations on and around Kensico Reservoir. In early 2007, bird harassment strategies similar to those used at Kensico were successfully employed at West Branch Reservoir as well.

Water quality continued to be excellent during the 2007-2009 analysis period in West Branch and Kensico Reservoirs. Median and highest values (of the monthly reservoir-wide medians) were all well below the established benchmarks for fecal coliforms (20 CFU 100 mL^{-1}), turbidity (5 NTU), and total phosphorus (15 µg L^{-1}).

Trend analysis results indicated some improvement or at least maintenance of the excellent water quality in the West Branch and Kensico basins. Turbidity and fecal coliform decreases detected in the local stream inputs to West Branch may be due, in part, to the extensive stormwater management projects that have been completed in the West Branch and Boyd Corners watersheds. With the exception of a downward trend in the DEL9 input, long-term phosphorus trends were not detected in the West Branch basin. However, promising declines in more recent years were evident in the local inputs, in the reservoir, and in its output. Trophic state increases in West Branch reservoir and turbidity increases in both the reservoir and output are likely related to operational changes in the latter half of the data record.

In the Kensico basin, downward trends were detected for both fecal coliforms and total phosphorus. The decrease in fecal coliform counts is due to lower inputs from the Catskill and Delaware Systems and to the successful ongoing local efforts to reduce bird populations on the reservoir. The decrease in phosphorus is explained by the net effects of the ongoing watershed protection programs in these systems. Upward trends in turbidity and in trophic state were detected. The turbidity increase appears to be operationally-related, while the increase in trophic state coincides with improved water clarity in the Catskill System prior to 2005.

Biomonitoring results are available on the largest local stream inputs to West Branch and Kensico. 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. Results from the West Branch input—Horse Pound Creek—indicated optimal conditions for the macroinvertebrate communities both in recent years and long-term. Whippoorwill Creek, the largest local input to Kensico, was rated slightly impaired. Although long-term trends were not statistically significant, a decline was observed in the most recent two years, presumably the result of an increase in sediment loading from eroding streambanks upstream of the sampling site. Stabilization of these streambanks is expected in the near future.

Since 2002, *Giardia* and *Cryptosporidium* pathogen monitoring has been conducted at least weekly at the Catskill and Delaware influents and effluents of Kensico Reservoir. *Giardia* counts at the effluent sites have been generally low, averaging 1.89 cysts 50 L^{-1}. Effluent counts were generally lower than influent counts, due to reservoir processes such as sedimentation, die-off, and predation. Instances of higher effluent counts are thought to be due to local stream inputs, especially when those inputs are storm-related. *Cryptosporidium* counts were usually an order of magnitude lower than those for *Giardia*, making it impossible to discern statistical differences between influent and effluent counts. A notable decrease in *Cryptosporidium* was evident in all influent and effluent sites after 2004.

6. East of Hudson Potential Delaware System Basins

6.1 Introduction

Water quality analyses cover a longer time period than the five-year period described for program implementation in Chapter 2. Therefore, several decades of data were used to provide long-term context for interpretation. Selection of this extensive time period was done in order to use a sufficiently long time to capture changes in water quality in response to watershed protection programs. Doing so provides a view of these changes in the context of natural variation (such as floods and droughts), which are not sufficiently represented in a five-year period. 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 time represent conditions with fewer watershed safeguards in place. The time period of the analysis extends through 2009, which allows DEP to examine trends over the past 17 years, as new and intensified watershed protection programs have been implemented. Another reason for using long-term data is the fact that there are time lags between program implementation (causes) and water quality changes (effects). Sufficient time must pass after programs are in place in order to see the full effects of programs on water quality. Therefore, further improvements in water quality will evolve as the full effects of the programs develop and stabilize.

Over the short term (i.e., less than a year), there are other influences that affect water quality. These account for the high degree of variation seen in the plots of water quality data over 17 years. Seasonal variations in precipitation and temperature affect runoff and stratification, which also affect water quality from week to week and storm to storm. Since DEP's objective was to look for trends in the water quality data over the time period of program implementation, statistical techniques for the water quality trend analysis were chosen to minimize the influence of seasons on long-term trends. In addition, concentrations were flow-adjusted in order to minimize the influence of short-term flow changes on trend detection. With this approach, DEP has examined the relationships between watershed protection and water quality changes.

Summary information on stormwater program implementation, boating permits issued, wastewater treatment plant phosphorus reductions, and waterfowl management in each basin is provided. This serves as a brief reminder 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 Chapter 2. Cumulative figures are provided to show the progress of watershed protection over the past decade and to give insight into what has been accomplished in terms of watershed improvements. Notably, the basins covered in this chapter (Cross River and Croton Falls) are not routinely used as part of the Catskill/Delaware System. Water from these basins only enters the unfiltered supply in the rare event that pump stations are operated, an event which is not allowed to proceed until water quality has been tested and approved as meeting the same standards as those applying to an unfiltered supply. Even then, the contribution to the total supply is only a small fraction of daily consumption.

Water quality status and trends are then described. Status is presented as a three-year average and trends are evaluated for a 17-year period. The analytes chosen were those most important for meeting the requirements of the Surface Water Treatment Rule and the 2007 Filtration Avoidance Determination.

6.2 Cross River Basin

Cross River Reservoir is located in northeastern Westchester County about 25 miles north of New York City. It was formed by damming 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. It holds 10.3 billion gallons at full capacity.

Cross River is one of 12 reservoirs in the City's Croton System. Water from the reservoir flows into Cross River and Muscoot Reservoir, and from there flows to New Croton Reservoir. After travelling through the 24-mile New Croton Aqueduct, the water reaches Jerome Park Reservoir in the Bronx, where it enters New York City's distribution system.

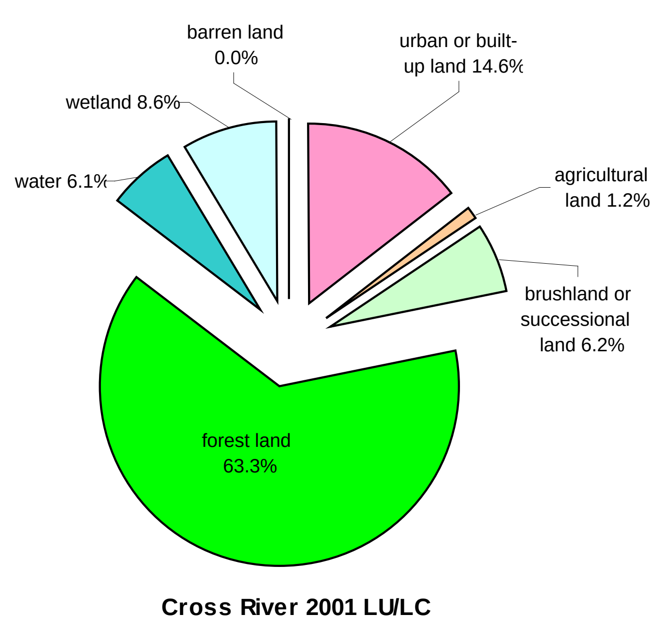

Figure 6.1 Land use in the Cross River drainage basin based on 2001 data.

The Cross River watershed's drainage basin is 30 square miles, mostly in Westchester County, with a small part in Fairfield County, CT. Currently there are four wastewater treatment plants (WWTPs) located in the Cross River drainage basin, which collectively produce approximately 0.079 million gallons per day (MGD) of flow. Under the most recent SPDES permits, the plants are limited to a combined release of 0.137 MGD of flow.

Of the 19,191 acres of land in the Cross River watershed, 12,137 acres (63.3%) are forested, 2,811 acres (14.6%) are urban or built-up in nature, and 1,185 acres (6.2%) are brushland or successional land. Wetlands comprise 1,650 acres (8.6%) of the watershed, while 1,174 acres (6.1%) are water. The remaining 234 acres (1.2%) are in agricultural use (Figure 6.1).

Cross River Reservoir has a pump station that enables DEP to pump water into the lower portion of the Delaware Aqueduct. The pump station, located on Reservoir Road, near Katonah, is rarely needed and was last operated in 1995 during a drought. A new pump station is being designed to increase capacity, and when constructed will give DEP the ability to pump up to 60 MGD from Cross River Reservoir. This will improve system reliability during times of drought or other water shortages.

6.2.1 Program Implementation (Cross River Basin)

Three environmental infrastructure projects have been constructed since 2003 to control stormwater in the Cross River basin (Figure 6.2a). Chapter 2 of this report provides additional information on this and other programs occurring in the watershed.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Cross River has varied since 2004 (Figure 6.2b).

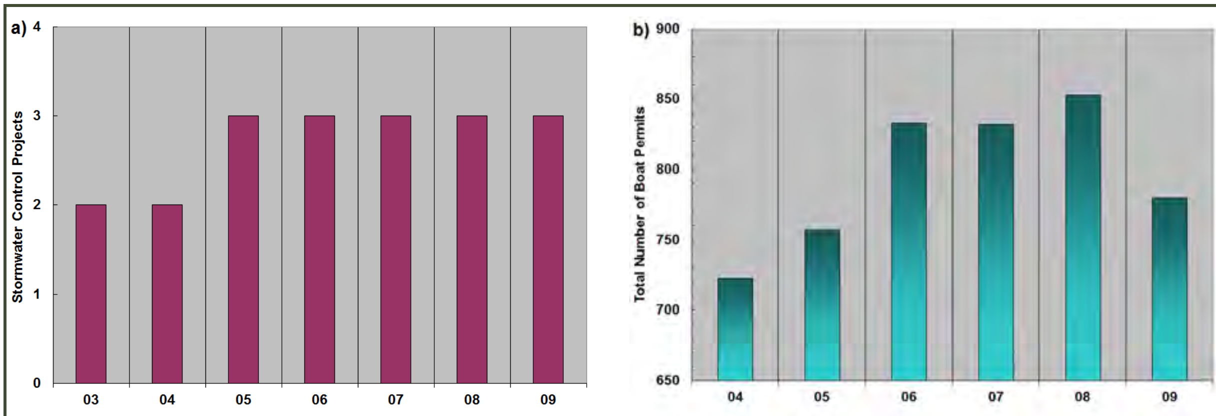

Figure 6.2 History of watershed programs in the Cross River drainage basin: a) environmental infrastructure installations for stormwater control, b) number of boat permits issued.

Note: Bars in plot (a) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the Cross River Basin

The WWTPs in the Cross River watershed were undergoing upgrades in 2008-2009, and phosphorus loads were anomalous compared to the decline shown in 2004 (Figure 6.3). DEP continues to upgrade all surface-discharging WWTPs and anticipates much lower loads in the future as these upgrades are completed.

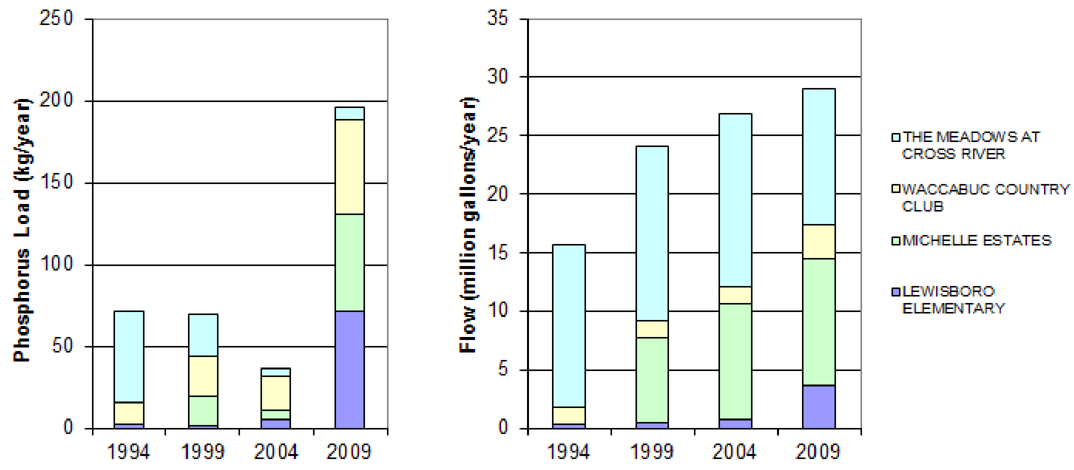

Figure 6.3 Wastewater treatment plant total phosphorus loads and flows in the Cross River drainage basin, 1994-2009.

6.2.2 Water Quality Status and Trends (Cross River Basin)

Water quality is dependent on the flow characteristics of streams, and subsequently the flushing rates of the receiving reservoirs. In order to gain perspective on the flow characteristics for the different time periods assessed in the water quality descriptions, flow distributions are presented in Figure 6.4. Two time periods are assessed for each site: i) the full period of record, and ii) a three-year period (2007-2009) representing the most recent status of water quality. High flows typically transport greater material loads from the landscape than small flows, and exceptionally high flows typically lead to deterioration of water quality. Moderate flushing rates are usually associated with high water quality, whereas low flushing rates (such as those that occur during times of drought) may be associated with low water quality.

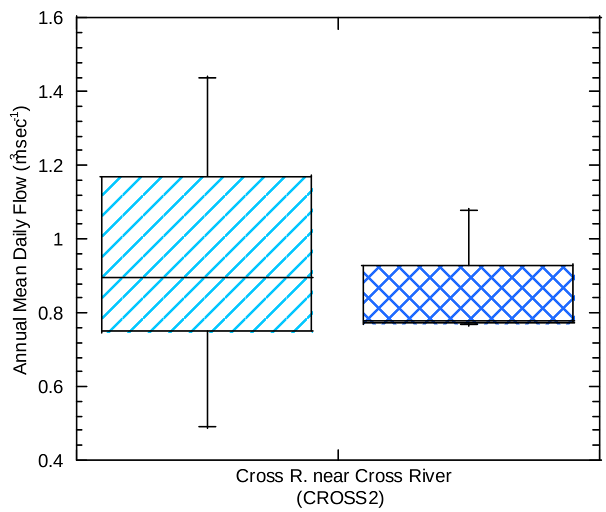

Figure 6.4 Boxplots of annual mean daily flows for the period of record and for 2007-2009 at USGS sampling sites in the Cross River watershed.

Cross River near the hamlet of Cross River is the primary inflow to Cross River Reservoir. It drains 57% of the basin (Table 6.1). The status period's mean annual daily flow median was about 0.2 $m^3 sec^{-1}$ lower than the long-term median, and the overall distribution was slightly biased to lower flows. Therefore, flows in the status period were somewhat lower than usual.

Table 6.1: DEP sample site description for the Cross River watershed.

DEP Site Code	Site Description	Sample Site Drainage Area as Percent of Reservoir Drainage Area	Period of Record
CROSS2	Cross River near Cross River	57.0%	Dec. 1995-present

Status (Cross River Basin)

The Cross River basin status evaluation is presented as a series of boxplots in Figure 6.5. The input is Cross River (CROSS2), the reservoir is designated as CCR, and the output is designated as CROSSRVR. All values below the maximum detection limit line for fecal coliform were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

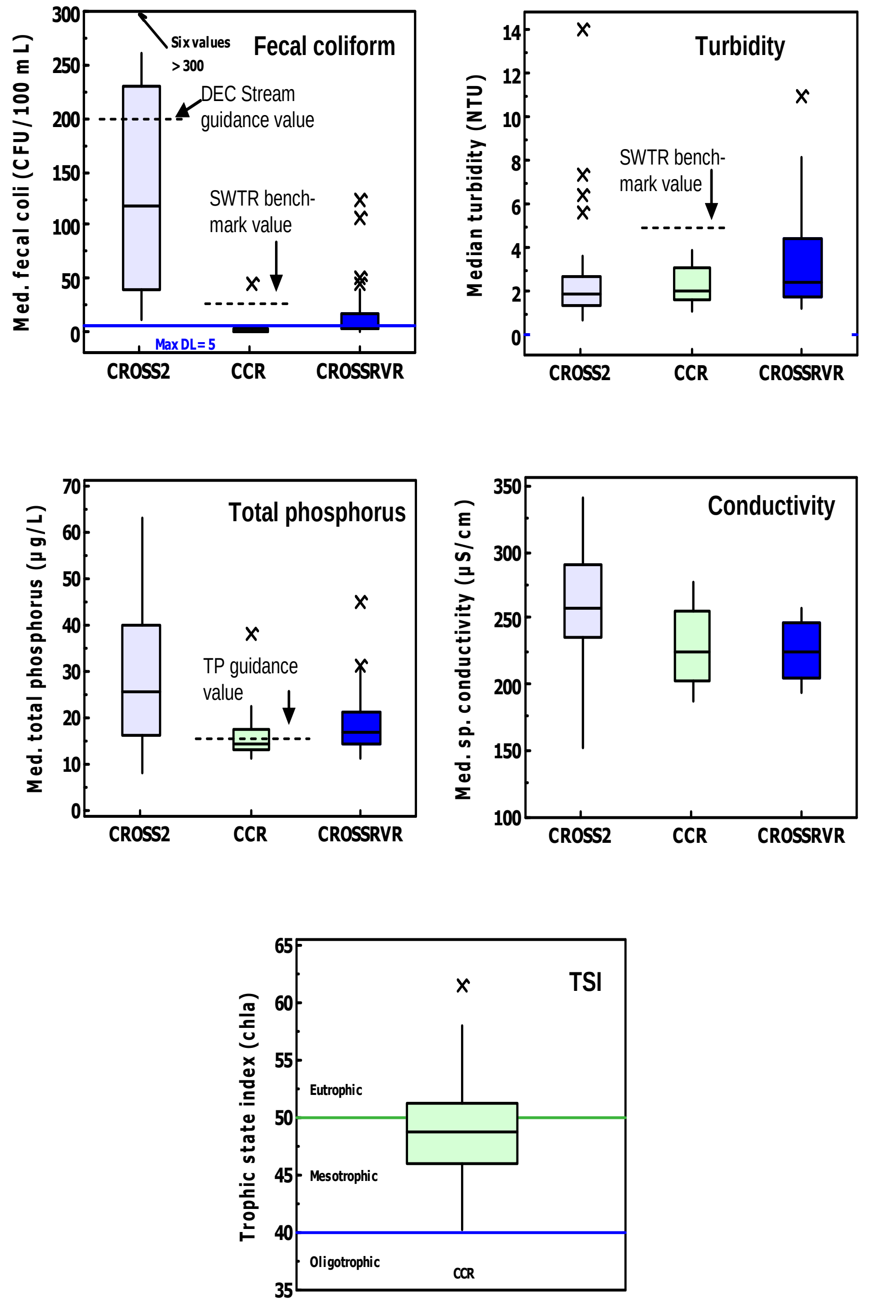

Figure 6.5 Water quality status boxplots using 2007-2009 monthly data for the Cross River basin main stream input at Cross River (CROSS2), Cross River Reservoir (CCR), and the output at the Cross River release (CROSSRVR).

Fecal coliform counts were highest in the input stream. This site exhibited wide variability in coliform values, with part of its boxplot extending beyond the 200 CFU 100 mL^{-1} DEC Stream Guidance Value. The fecal coliform values in the reservoir were at or below the maximum detection limit of 5 CFU 100 mL^{-1}. Only one value exceeded the Surface Water Treatment Rule (SWTR) guidance value for source waters of 20 CFU 100 mL^{-1}. Coliform levels in the output were higher and more variable than in the reservoir, possibly due to the more frequent sampling of the output.

The turbidity values for the input, reservoir, and output were broadly similar. The input had the widest variability, while the median for all three sites was similar. The output had wider variability than the reservoir, again possibly due to more frequent sampling. None of the monthly values for the reservoir exceeded the 5 NTU SWTR benchmark for source water, and only a few values exceeded this threshold in the output.

Total phosphorus (TP) median values and variability decreased between the input stream and the reservoir. However, there was a slight increase in the median and the variability of TP between the reservoir and the output. Since there are times when the release may be drawn from anoxic hypolimnetic water, fluctuations in TP may be greater in the release water than in the reservoir as a whole. (Anoxic waters provide reducing conditions that solubilize particulate TP.) With a median of 14 µg L^{-1}, the majority of the monthly values in the reservoir were below the phosphorus-restricted target value of 15 µg L^{-1}.

The Trophic State Index (TSI) values for Cross River Reservoir ranged between mesotrophic and eutrophic for the three-year period.

The conductivity in the reservoir and output were generally lower than in the input. The output and the reservoir had similar distributions of conductivity values during the three-year period. The high variability of input stream values is due to the effects of flow on concentrations.

In summary, water quality was generally good during the 2007-2009 status assessment period in the Cross River basin. Fecal coliform and turbidity exceeded their respective SWTR guidance values on only a few occasions. TP in the reservoir was below the established benchmark of 15 µg L^{-1} in more than half of the samples taken during these three years.

Trends (Cross River)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 6.2).

Water quality trend plots are presented in Figure 6.6 and results of the Seasonal Kendall trend analysis are provided in Table 6.2.

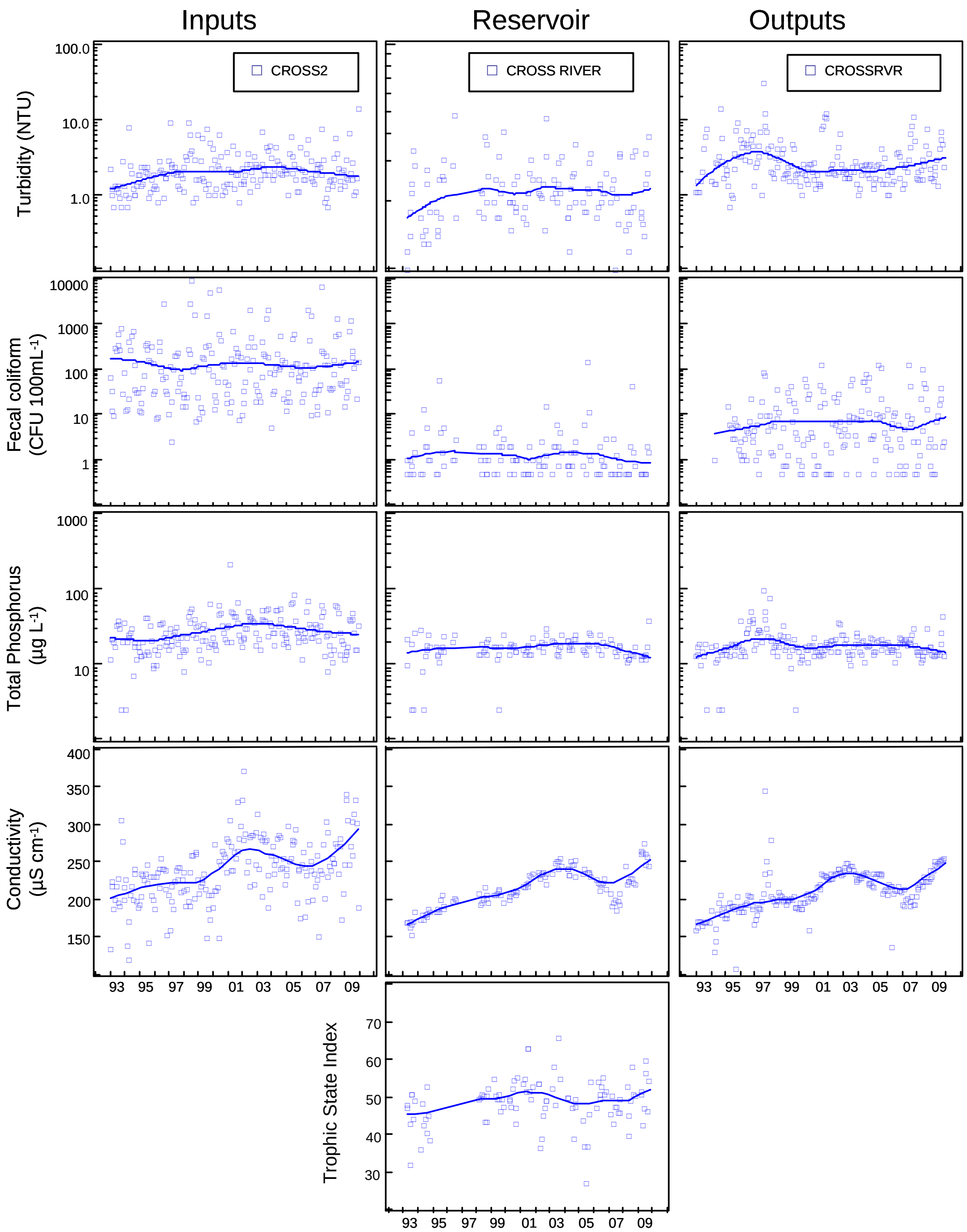

Figure 6.6 Water quality trend plots for the Cross River basin main stream input at Cross River (CROSS2), Cross River Reservoir, and the output at the Cross River release (CROSSRVR). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 6.2: Cross River basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
CROSS2	Input	Turbidity	201	0.17	***	0.04
Cross River	Reservoir	Turbidity	123	0.03	NS	
CROSSRVR	Output	Turbidity	198	-0.06	NS	
CROSS2[3]	Input	Fecal coliform	203	0.03	NS	
Cross River[3]	Reservoir	Fecal coliform	122	-0.11	*	0.00
CROSSRV[3]	Output	Fecal coliform	177	0.03	NS	
CROSS2	Input	Total phosphorus	200	0.20	***	0.57
Cross River	Reservoir	Total phosphorus	114	-0.03	NS	
CROSSRVR	Output	Total phosphorus	195	-0.04	NS	
CROSS2	Input	Conductivity	203	0.35	***	3.92
Cross River	Reservoir	Conductivity	120	0.60	***	4.65
CROSSRVR	Output	Conductivity	199	0.51	***	3.57
Cross River	Reservoir	Trophic State Index	107	0.09	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 in this row required the use of statistical methods for "non-detect" values.

Long-term trends of increasing turbidity and phosphorus were detected for the input, driven largely by numerous runoff events (i.e., snowmelt and rainstorms) between 1997 and 2003. However, concentrations peaked in 2003 and have steadily decreased since then. Long-term turbidity and phosphorus trends were not apparent in the reservoir or output. The large increase displayed in the output from 1995-1997 was due to drawdown of the reservoir to perform repairs to the dam. Note that the reservoir was not sampled in 1996-1997 because of the drawdown and lack of boat access. Due to the large number of values less than the detection limit, non-detect statistics were used to assess the trends (Helsel 2005).

A slight yet statistically significant downward trend was detected for fecal coliforms in the reservoir, but trends were not apparent in the input or output. The reservoir's estimated change per year was zero, but the Tau statistic was negative (and small), indicating that the decreasing trend was weak. Although cumulative precipitation quantities have been average to above average, a decrease in the number of large runoff events during the last three years may explain the trend. Surprisingly, output fecal counts were much higher than those in the reservoir and are probably related to bird activity at the sample 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.

Strong upward conductivity trends were detected for the reservoir, input, and output. Inputs of dissolved salts, primarily from development activity in the basin, road salt applications, and discharges from domestic water softeners, is the most important factor influencing this trend. Short-term changes in precipitation patterns and drawdown were additional factors that affected the observed patterns. Drought conditions 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 for dam repair work.

No long-term trend was detected for TSI. The relative high value in 2001 appears to be a temporary response to refilling the reservoir in 1998 and drought in 2001. The decrease in 2005 was possibly caused by high rainfall and dilution.

In summary, although there were very slight upward turbidity and phosphorus trends for the input to Cross River Reservoir, reservoir levels have declined for both analytes since 2002. A weak downturn in fecal coliform was detected in the reservoir, coinciding with a general lack of major runoff events during the last three years of the data 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. Productivity trends were not apparent but a short-term increase through 2001 was probably in response to the drawdown for dam rehabilitation.

6.2.3 Waterfowl management Program: Cross River Reservoir

Water from Cross River Reservoir can be diverted into the Delaware System for emergency and dependability use. As a result, the 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. Waterbird 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 birds on the reservoir throughout the year. Gulls are not commonly observed on the reservoir during the overnight roosting period, and based on the low numbers recorded during the biweekly waterbird surveys, do not pose a water quality threat.

Fecal coliform concentrations at the Cross River Reservoir water intake were reported elevated nine times during the assessment period, with one sample on August 19, 2009, recorded as “TNTC” (too numerous to count) (Figure 6.7). Applying the established “as needed” criteria, however, DEP determined it was not necessary to activate the waterbird dispersal program during the assessment period.

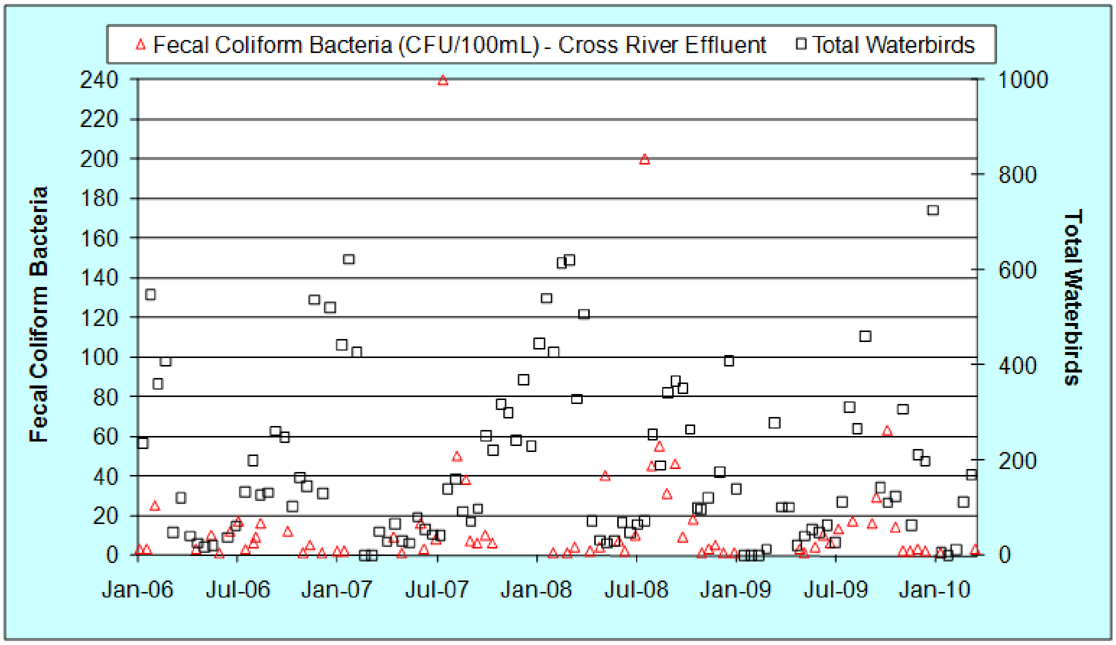

Figure 6.7 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total waterbirds at Cross River Reservoir, January 1, 2006-March 31, 2010.

6.3 Croton Falls Basin

Croton Falls Reservoir was formed by damming the West and Middle Branches of the Croton River, which drain to the south and into Muscoot Reservoir. Upstream reservoirs include Diverting, Middle Branch, East Branch, and Bog Brook. Croton Falls Reservoir is located in Putnam County about 35 miles north of New York City and east of the Hudson River. 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.

The Croton Falls watershed's drainage basin is 16 square miles and includes portions of the Towns of Carmel and Southeast. Currently, there are five wastewater treatment plants (WWTPs) in the Croton Falls watershed basin, which collectively release approximately 0.937 million gallons per day (MGD) of flow. As per the most recent SPDES permits, the plants are limited to a combined release of 1.206 MGD of flow.

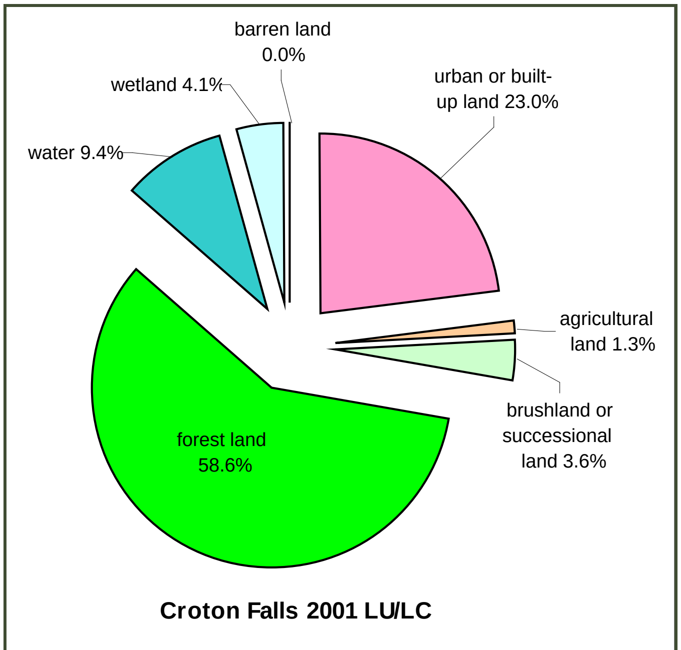

Figure 6.8 Land use in the Croton Falls drainage basin based on 2001 data.

Of the 10,228 acres of land in the Croton Falls watershed, 5,996 acres (58.6%) are forested, 2,353 acres (23.0%) are urban or built-up in nature, and 366 acres (3.6%) are brushland or successional land. Wetlands comprise 418 acres (4.1%) of the watershed, while 958 acres (9.4%) are water. The remaining 137 acres (1.3%) are in agricultural use (Figure 6.8).

Croton Falls Reservoir has a pump station, located on Hemlock Road in Carmel, that allows DEP to divert water from the reservoir into the Delaware Aqueduct under emergency or drought conditions. When operating at full capacity, the pump station can divert 60-70 MGD into the Delaware Aqueduct at Shaft 11 on Butlerville Road in Carmel. Croton Falls Reservoir can be considered source water when the pump station is operational and the Delaware Aqueduct is by-passing Kensico, hence the designation of Croton Falls as a “potential” source water. The pump station was last used from December 5-28, 2009, to augment the supply while repairs were made to the Rondout-to-West Branch Tunnel. A new electric pump station, currently under construction, will give DEP the capacity to pump up to 180 MGD.

6.3.1 Program Implementation (Croton Falls Basin)

Since 2003, 32 environmental infrastructure projects have been completed to control stormwater in the Croton Falls watershed (Figure 6.9a). Two additional large remediation projects are under way and are scheduled to be completed in 2011. Chapter 2 of this report provides details on this and other programs occurring in the watershed.

Although not directly quantifiable in terms of impact on water quality, boat permits can be viewed as a relative measure of human activity in the basin. The number of permits issued for boats on Croton Falls Reservoir has varied in the recent past, with a median of about 730 permits issued (Figure 6.9b).

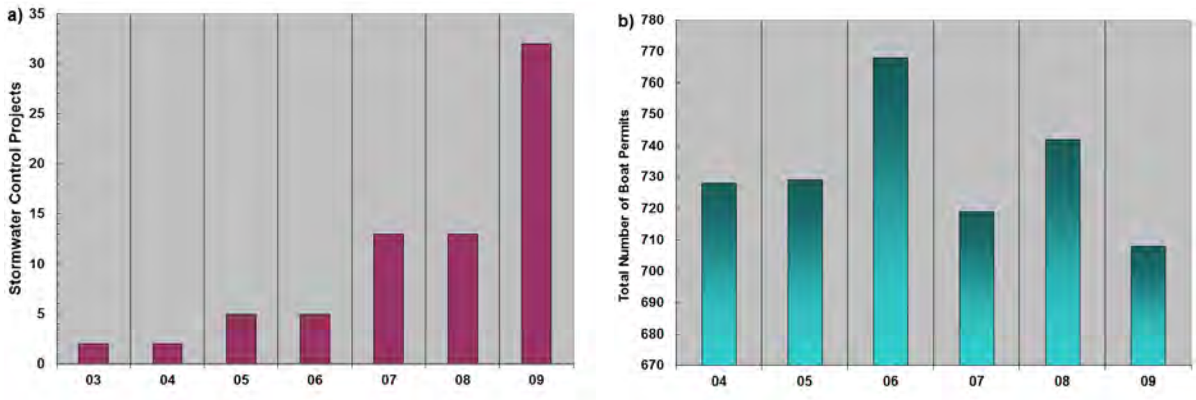

Figure 6.9 History of watershed programs in the Croton Falls drainage basin: a) environmental infrastructure installations for stormwater control, b) number of boat permits issued.

Note: Bars in plot (a) represent cumulative totals.

Wastewater Treatment Plants and Phosphorus Load Reductions in the Croton Falls Basin

Inputs of phosphorus, as well as other pollutants, from WWTPs to Croton Falls Reservoir continue to be reduced as a result of DEP's effort to upgrade all surface-discharging WWTPs, including upgrade of the City-owned Mahopac plant and through the intervention and involvement of DEP's WWTP Compliance and Inspection Program (Section 2.12.2). As illustrated in Figure 6.10, phosphorus loads (as total phosphorus) declined considerably from 1994 to 2009. Within the past five years, upgrades to divert the flows of three plants to the Mahopac WWTP (which is owned by the City) have either started or been completed. These include Fulmar Road Elementary School, Lake Plaza, and the Ralph Morando Building plants.

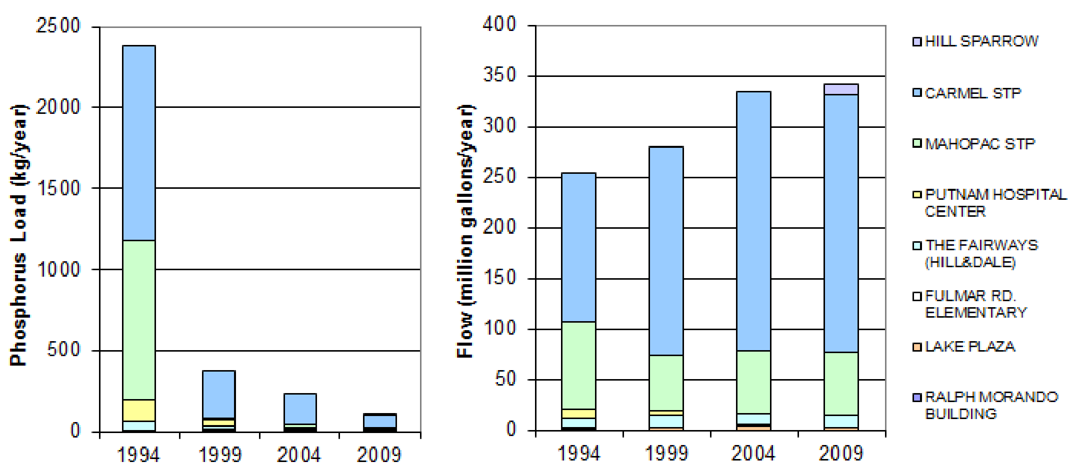

Figure 6.10 Wastewater treatment plant total phosphorus loads and flows in the Croton Falls drainage basin, 1994-2009.

6.3.2 Water Quality Status and Trends (Croton Falls Basin)

Status (Croton Falls Basin)

The Croton Falls basin status evaluation is presented as a series of boxplots in Figure 6.11. The two inputs to Croton Falls are the West Branch Reservoir release (WESTBRR) and the middle basin of Croton Falls Reservoir (CCF3). The middle basin receives water from Michael Brook and Middle Branch Reservoir. The reservoir is designated as CCF, sampled in the main basin, and the output is designated as CROFALLSR. All values below the maximum detection limit line for fecal coliform (blue line) were estimated according to non-detect methods described by Helsel (2005). For methodology details and boxplot interpretation, see Appendix 3.

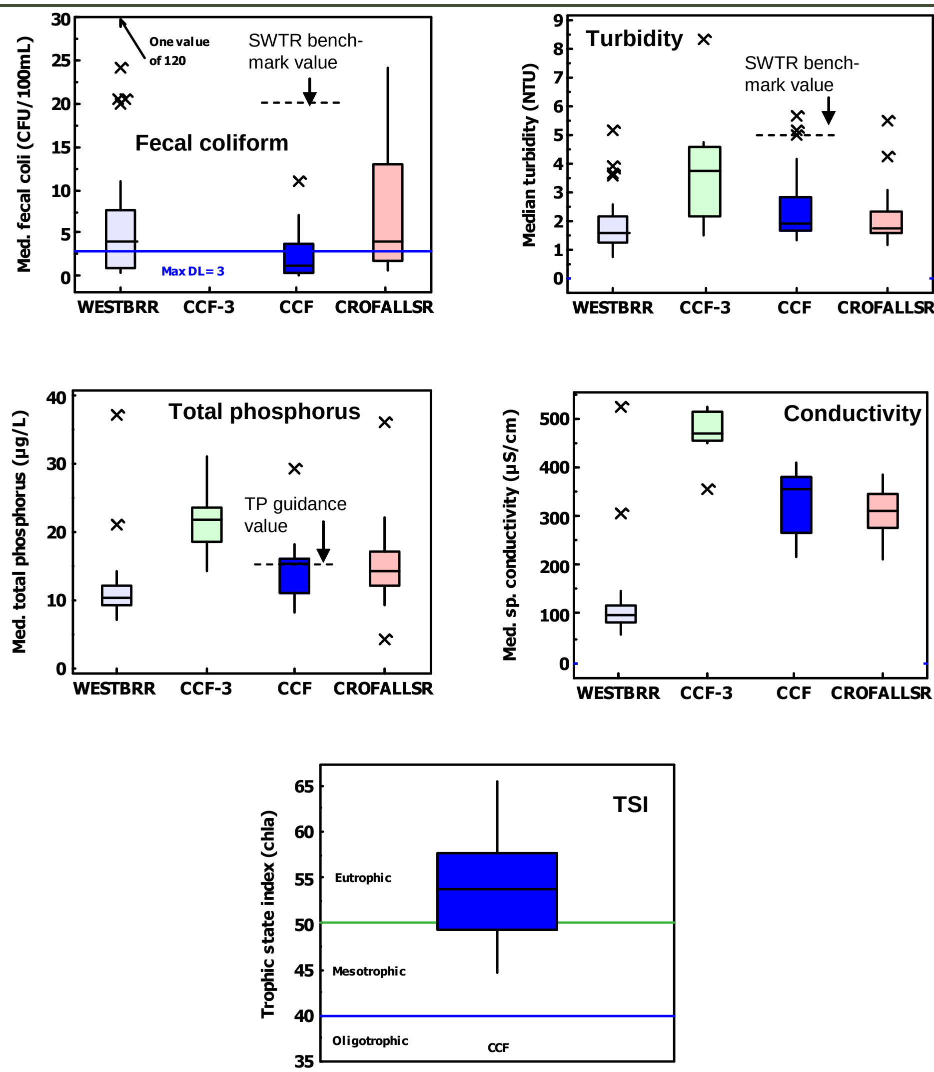

Figure 6.11 Water quality status boxplots using 2007-2009 monthly data for the Croton Falls basin inputs from the West Branch release (WESTBRR) and the middle basin of Croton Falls Reservoir (CCF3), the main basin of the reservoir (CCF), and the output at the Croton Falls release (CROFALLSR).

Fecal coliform values in the West Branch input varied, but were primarily <10 CFU 100 mL^{-1}. The middle basin input did not have enough detectable data to estimate a distribution; only eight data points were available for the analysis period, and six of these were non-detects. The reservoir did not exceed the Surface Water Treatment Rule (SWTR) benchmark of 20 CFU 100 mL^{-1} used for source waters. Coliform levels in the output were higher and more variable than in the reservoir. One explanation for this difference is that the output is sampled during the winter, while the reservoir is not, so if the higher values occur during the winter, they will be observed in the output samples, but not in samples from the reservoir. Despite the slightly higher levels of fecal coliform in the output, none of the values exceeded the 200 CFU 100 mL^{-1} DEC Stream Guidance Value.

Turbidity values were lower in the West Branch input and had less variability than values in the middle basin input. Croton Falls Reservoir only exceeded the SWTR benchmark value of 5 NTU a few times during the three-year evaluation period. The output had turbidity values very similar to the reservoir's.

Total phosphorus (TP) levels were similar to the pattern found for turbidity. The West Branch input had lower values than the middle basin input. Since TP levels can vary dramatically between the sources, the median values for the reservoir fell between those of the two inputs. The reservoir and the output were broadly similar in their distributions. The median value in the reservoir was equivalent to the target value of 15 µg L^{-1} for phosphorus-restricted basins.

Most of the Trophic State Index (TSI) values for Croton Falls Reservoir were within the eutrophic range for the three-year evaluation period, with only a small percentage falling below the TSI threshold of 50 for eutrophic waters.

Conductivity also reflected the differences between the inputs, with the West Branch input's median value of 99 µS cm^{-1} substantially lower than the middle basin input's 469 µS cm^{-1}. The higher conductivity in the middle basin input reflects Croton System sources, including Middle Branch Reservoir, which typically has the highest conductivity values in the system. The reservoir had values within the range of the two inputs. The output had less variability and a lower median than the reservoir during the three-year evaluation period.

In summary, water quality was acceptable during the 2007-2009 evaluation period in the Croton Falls basin. The data show that the median TP value from the reservoir was equivalent to the benchmark for terminal basin phosphorus-restriction, and only a few values were higher than the SWTR benchmark for turbidity. Median fecal coliform levels were well below the SWTR benchmark. Although the trophic status was moderate to high, the reservoir generally provided water of acceptable quality.

Trends (Croton Falls)

Trends are examined in two ways, first by fitting a smoothing function (LOWESS) through all the raw data, and second, by performing the non-parametric Seasonal Kendall tests for trend 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 through the period of record. See Appendix 3 for a more detailed description of the data manipulation and statistical methods used. The use of non-detect statistical methods is indicated, as appropriate, in the trend statistics table (Table 6.3).

Water quality trend plots are presented in Figure 6.12 and results of the Seasonal Kendall trend analysis are provided in Table 6.3. Note that trend results are not available for the reservoir's middle and main basins (i.e., the middle basin input and reservoir sites, respectively). This is because only a limited number of samples were collected after 2004, when reservoir access became restricted due to dam rehabilitation.

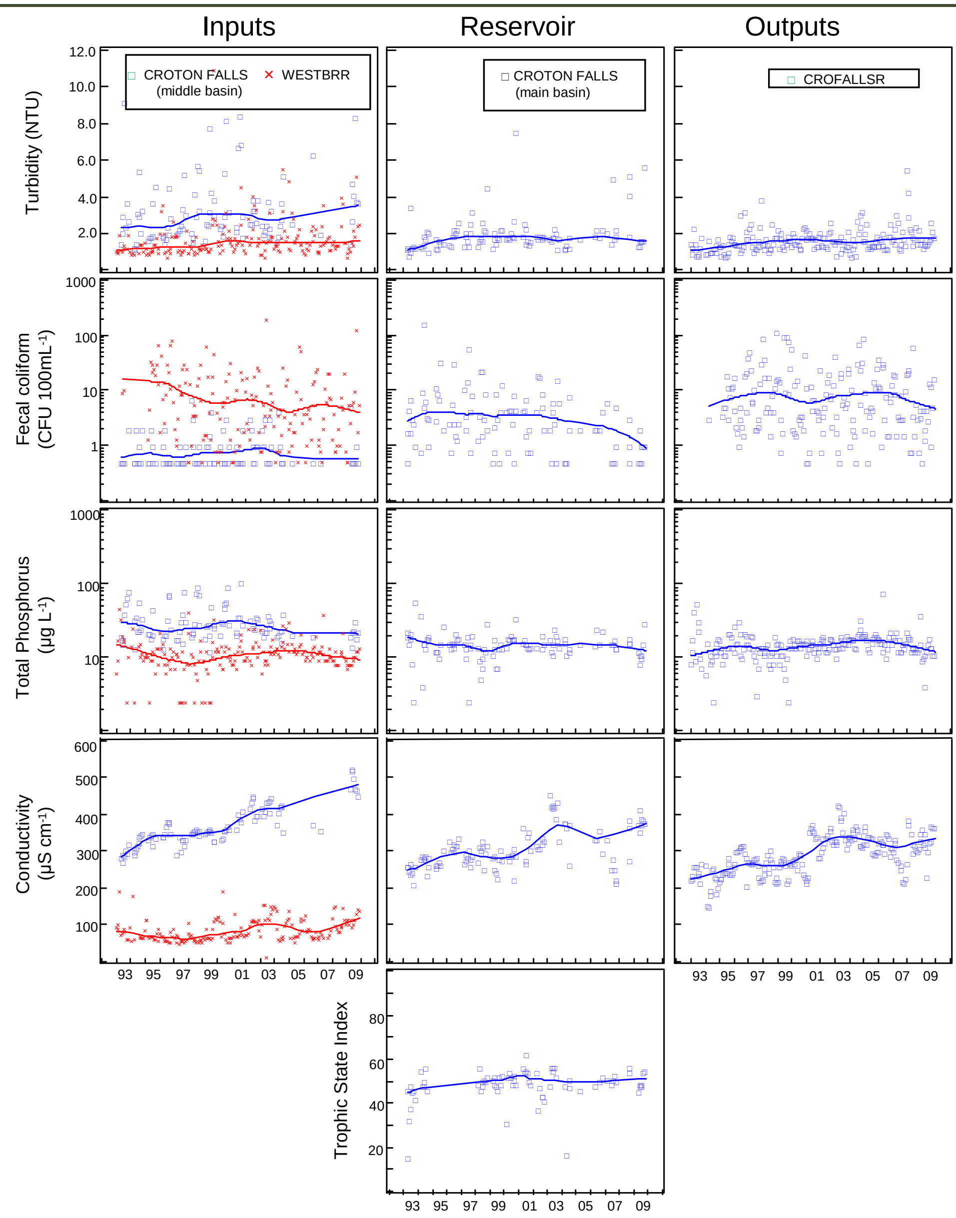

Figure 6.12 Water quality trend plots for the Croton Falls basin inputs from the West Branch release (WESTBRR) and the middle basin of Croton Falls Reservoir (CCF3), the main basin of the reservoir (CCF), and the output at the Croton Falls release (CROFALLSR). For each site, the central tendency of the data over time is represented by a LOWESS curve with a smooth factor of 30%. For methodology details, see Appendix 3.

Table 6.3: Croton Falls basin trends from 1993-2009 for selected analytes.

Site	Description	Analyte	N	Tau[1]	*p*-value[2]	Change yr^{-1}
WESTBRR	Input	Turbidity	197	0.19	***	0.03
CCF3[3] (middle basin)	Input	Turbidity	99	NA	NA	
Croton Falls[3] (main basin)	Reservoir	Turbidity	109	NA	NA	
CROFALLSR	Output	Turbidity	201	0.23	***	0.03
WESTBRR[4]	Input	Fecal coliform	177	-0.17	***	0.00
CCF3[3] (middle basin)	Input	Fecal coliform	96	NA	NA	
Croton Falls[3] (main basin)	Reservoir	Fecal coliform	109	NA	NA	
CROFALLSR[4]	Output	Fecal coliform	176	-0.07	NS	
WESTBRR	Input	Total phosphorus	193	0.06	NS	
CCF3[3] (middle basin)	Input	Total phosphorus	94	NA	NA	
Croton Falls[3] (main basin)	Reservoir	Total phosphorus	106	NA	NA	
CROFALLSR	Output	Total phosphorus	197	0.15	***	0.17
WESTBRR	Input	Conductivity	193	0.28	***	2.00
CCF3[3] (middle basin)	Input	Conductivity	94	NA	NA	
Croton Falls[3] (main basin)	Reservoir	Conductivity	106	NA	NA	
CROFALLSR	Output	Conductivity	197	0.46	***	7.00
Croton Falls	Reservoir	Trophic State Index	79	NA	NA	

[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]Trend analysis not performed because of the limited data available due to restricted reservoir access after 2004.

[4]Data in this row required the use of statistical methods for “non-detect” values.

Very slight increasing trends in turbidity were detected in the West Branch input and in the output. The turbidity increase in the input likely resulted from operational changes upstream at West Branch Reservoir from 2000-2009. (For details, see Section 5.2.2.) The slight upward trend at the output was largely driven by the higher turbidities that coincided with the “wet” years of 2004-2006 and the winter of 2008. Although data were insufficient from the middle basin input to conduct trend analysis, the LOWESS curve from this location suggests an increasing trend there as well. Taken together, these trends, despite not being fully captured in the reservoir samples because of the dam rehabilitation work, do suggest the presence of an upward trend in the reservoir.

A significant downward trend was detected for fecal coliform in the West Branch input. This result was unexpected, because an operational change that began in 1999 increased the influence of local inputs and in so doing tended to increase coliform counts in the reservoir. Reasons for the observed decrease are not clear. Six large stormwater remediation projects were completed in the West Branch basin by 2003 (and many more by 2009) and may have played a role. The LOWESS curve for the reservoir trend plot suggests a decrease at the reservoir also, but that may be misleading, since the relative lack of data collected during the 2004-2006 period probably caused the curve to be overly dominated by low counts in 2007-2009. This observation is confirmed by examining the data from the output. Complete data were available from this site, and indicate that coliform counts actually trended higher during the 2004-2006 period of limited reservoir sampling. Considering the entire 1993-2009 period, however, no trends for fecal coliform were apparent at the output. Given the consistent sampling there, the lack of a trend at the output is probably a better indicator of water quality change in the reservoir than any conclusions based on the limited data from the reservoir itself.

Despite many upgrades to WWTPs in the Croton Falls watershed and subsequent reductions in phosphorus loads (Figure 6.10), long-term phosphorus declines were not detected in the Croton Falls basin. In fact, an overall increase of 0.17 µg L^{-1} yr^{-1} was detected in the output. The increasing trend appears to be driven by above average precipitation in 2003-2006. Phosphorus levels have since declined, coinciding with a reduction in the number of runoff events in more recent years.

As indicated by the LOWESS curve, conductivity in the output increased from approximately 220 µS cm^{-1} in 1993 to 330 µS cm^{-1} in 2009. Similar increases were apparent in the LOWESS curves for the middle basin input and the reservoir. 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). 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 5.2.2).

From the limited data available, the trophic state trend plot suggests that algal populations have been relatively stable in Croton Falls Reservoir over the 1993-2009 period.

In summary, upward trends were detected for turbidity, TP, and conductivity in the Croton Falls basin, while a downward trend was detected for fecal coliform. Despite the fecal coliform decrease, long-term coliform levels in the reservoir remained stable, as indicated by trend results from the reservoir output. The increase in turbidity and TP was due, in part, to Delaware Aqueduct operational changes, but mostly to above average precipitation in the latter part of the data record. The conductivity increase was likely related to development activity in the watershed. No explanation is yet available to explain the strong decreasing trend for fecal coliform at the West Branch input.

6.3.3 Waterfowl Management Program: Croton Falls Reservoir

The 2007 FAD lists Croton Falls Reservoir as one of five reservoirs covered under the "as needed" criteria for waterfowl management, since water from the reservoir can be diverted into the Delaware System for emergency and dependability use. 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 bird groups counted throughout the reservoir from late summer through spring. Geese were present throughout most of the year, showing increases in late summer/autumn following the post-nuptial molt and onset of autumn migration.

There were 18 elevated fecal coliform samples recorded at the Croton Falls water intake during the assessment period. There does appear to be a relationship between increased bird activity and elevated fecal coliform levels (Figure 6.13), but applying the established "as needed" criteria, DEP determined it was not necessary to activate the waterbird dispersal program during the assessment period. Additional surveys were conducted from October through December in 2008 and 2009, however, to support operation of the Croton Falls Hydraulic Pump Station.

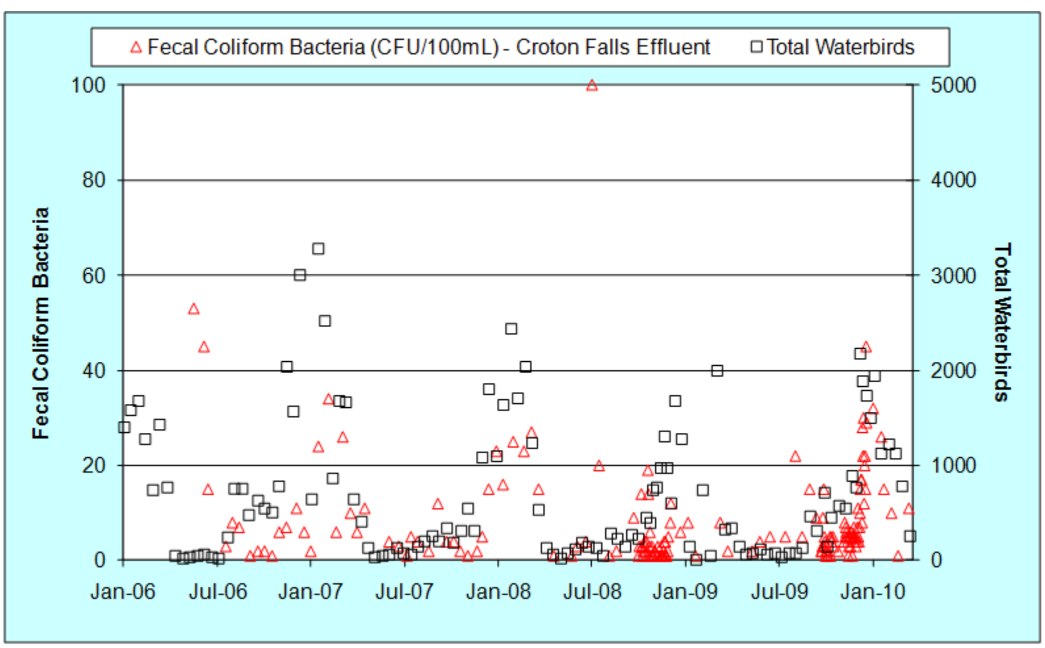

Figure 6.13 Fecal coliform bacteria (CFU 100 mL^{-1}) versus total waterbirds at Croton Falls Reservoir, January 1, 2006-March 31, 2010.

6.4 Water Quality Summary for the Potential Delaware System Basins

Improvements are ongoing in the Cross River and Croton Falls watersheds. Thirty-two stormwater control projects, mostly in the Croton Falls basin, were completed by 2009. Upgrades to WWTPs in the Cross River basin were initiated in 2008-2009. Some upgrades have also occurred in the Croton Falls basin, including the diversion of three WWTPs to the NYC-owned Mahopac WWTP. Consequently, phosphorus loads in the Croton Falls basin have decreased from 2,400 kg year^{-1} in 1994 to about 100 kg year^{-1} in 2009.

Notwithstanding the structural improvements to the local basins, long-term (1993-2009) trend analysis results did not indicate much improvement in the key water quality indicators. In the Croton Falls basin, turbidity and phosphorus increases coincided with increases in precipitation, while increases in conductivity were associated with development activity in the watershed. One encouraging trend was found—a strong downward trend in fecal coliform in the primary Croton Falls input, WESTBRR—but the cause was not apparent. Conductivity, turbidity, and phosphorus increases were also apparent in the Cross River basin. A decrease was detected in fecal coliform counts but the statistical strength of the trend was weak and the magnitude small.

Recent status results indicate that the main basin of Croton Falls Reservoir is eutrophic, with monthly phosphorus concentrations exceeding 15 µg L^{-1} 50% of the time. Monthly median turbidity was 2 NTU, but on several occasions exceeded 5 NTU. Cross River water quality status was somewhat better: trophic state was usually in the mesotrophic range, monthly turbidity did not exceed 4 NTU, and phosphorus levels were slightly lower than those observed at Croton Falls. Given these conditions, it is more likely that Cross River would be chosen as a supplementary water source in the rare situations when pump stations are operated, although either source is generally acceptable. Elevated conductivities in both basins are indicative of development pressure.

7. Modeling Evaluation

7.1 Modeling Evaluation of Program Effects in Cannonsville and Pepacton Watersheds

The effects of land use change and best management practices (BMPs) implemented by watershed management programs can be evaluated using models. Modeling integrates watershed and reservoir data collected through DEP's extensive monitoring programs along with algorithms describing the processes governing the transport and fate of nutrients to obtain water quality predictions. Through model application, inferences are made about the simultaneous effects of population growth, land use change, and watershed management programs designed to improve water quality. Model application allows DEP to make a quantitative comparison of the effects of individual programs so that the most effective ones for controlling eutrophication can be identified.

DEP has developed a eutrophication modeling system, consisting of the Generalized Watershed Loading Function (GWLF) watershed model linked to a reservoir receiving water model, to evaluate the relationship of nutrient loading changes to reservoir trophic state changes. GWLF model simulations generate time series of loads for a variety of scenarios representing pre- and post-FAD land use and watershed management conditions. These scenario loading time series are then used for input to the reservoir model. Output from the reservoir model includes probability frequency distributions for water quality parameters that describe the trophic state of the reservoir for different watershed scenarios.

The eutrophication modeling system was applied to evaluate land use change and watershed management that occurred in the Cannonsville and Pepacton watersheds from 1990 through 2009. Changes in agricultural activity and human population in these two basins during the period were evaluated as a land use change that occurred independent of watershed management. Watershed management programs (and associated BMPs) that were evaluated include:

- Watershed Agricultural Program (WAP)
- Urban Stormwater Retrofit Program
- Septic Remediation and Replacement Program
- Wastewater Treatment Plant (WWTP) Upgrade Program

Scenario results were compared to nutrient data for the Cannonsville watershed collected in 2000-2009 (after land use changes and BMP implementation occurred) to test the validity of the scenario predictions.

7.1.1 Eutrophication Modeling System

GWLF Watershed Model

The GWLF watershed loading model is a lumped-parameter model that simulates daily water, nutrients, and sediment loads from non-point and point sources. GWLF was originally developed at Cornell University by Dr. Douglas Haith and associates (Haith and Shoemaker 1987, Haith et al. 1992) as "an engineering compromise between the empiricism of export coefficients and the complexity of chemical simulation models". GWLF treats the watershed as a system of different land areas (Hydrologic Response Units or HRUs) that produce runoff, and a single groundwater reservoir that supplies baseflow. Dissolved and suspended substances (e.g., nutrients and sediment) in streamflow are estimated at the watershed outlet by loading functions that empirically relate substance concentrations in runoff and baseflow to watershed and HRU-specific characteristics.

GWLF has been modified for NYC watershed conditions. Saturation-excess runoff on Variable Source Areas (VSAs), which is considered the primary source of surface runoff in NYC watersheds, has been incorporated in the model (Schneiderman et al. 2002, 2007). The revised model simulates runoff volumes using the Natural Resource Conservation Service (NRCS) Curve Number (CN) Method, similar to the standard GWLF model, but spatially distributes the runoff response according to a soil wetness index. The spatial distribution of runoff by soil wetness index provides a more realistic identification of runoff generating areas in the NYC watersheds, with important consequences for simulation of pollutants that are typically transported by runoff.

Phosphorus (P) loading functions for agricultural land uses were revised by explicitly tracking dissolved P losses from surface applied manures and fertilizers, based on the work of Easton et al. (2009). Surface applied manure in particular may be a dominant source of dissolved P from agriculture (Gerard-Marchant et al. 2005), and the management of manure application is a primary component of nutrient management planning. P loss from the plant/soil complex is still estimated by export concentration coefficient, but derived from soil test P data where available. These enhanced agricultural P loading functions permit a more rigorous evaluation of nutrient management and agricultural P sources.Other model modifications include use of the Priestley-Taylor method for estimating potential evapotranspiration and incorporation of a sediment rating curve into the sediment yield algorithm (DEP 2005, 2006d). GWLF models have been calibrated and validated for the Cannonsville and Pepacton watersheds with available land use, soils, meteorology, streamflow, and water quality monitoring data using methods described in DEP (2006c; 2006a).

GWLF generates the following daily time series which subsequently can be input to the reservoir receiving water model:

- streamflow
- dissolved P and nitrogen (N) from non-point and point sources

- particulate P from non-point and point sources
- dissolved organic carbon (C) from non-point sources,
- total suspended solids (TSS)

Loads in surface runoff from different land uses, in sub-surface flows, from septic systems, and from point sources are explicitly tracked in GWLF and summed to provide total loads delivered to the reservoir. The explicit tracking of loads from different sources is the key to evaluating the effects of watershed management on nutrient loading. Non-point source watershed management entails application of BMPs which typically focus on removing nutrients from specific sources. A significant and growing literature exists which documents nutrient removal rates for BMPs applied to specific nutrient sources. Applying BMP efficiency data and implementation rates to loading estimates from different sources provides a means for quantifying nutrient reductions from BMPs on a watershed scale.

The effects of BMPs on nutrient loads are applied in the model by land use-specific BMP reduction factors which adjust dissolved nutrient time series as generated by the model. Loading reductions for agricultural BMPs that influence manure application rates are calculated in the model as a response to reductions in surface applied nutrient loading rates. Loading reductions due to septic system upgrades are implemented in GWLF by revising the percentages of failing systems and unsewered population sizes which are input to the model. Loading reductions due to WWTP upgrades are implemented in GWLF by revising the daily WWTP effluent loading estimates that are input to the model.

Reservoir Water Quality Model

DEP has developed one dimensional (1D) reservoir water quality models for all West of Hudson (WOH) reservoirs. These models provide a quantitative framework that can be used to evaluate watershed management programs and to predict water quality features related to eutrophication. These models consist of three components:

1. a hydrothermal sub-model
2. nutrient sub-models
3. a phytoplankton sub-model

The hydrothermal model simulates the vertical dynamics of reservoir thermal stratification and related hydrodynamics/transport regimes, based on changes in such critical (state) variables as meteorological, hydrological, and operational conditions. The hydrothermal models define the physical/mass transport frameworks within which the reservoir water quality models operate.

The nutrient sub-model describes the transformation and fate of the nutrient loads (total dissolved P, total dissolved N, and particulate P) that are simulated to enter the reservoir by the GWLF model. The reservoir model distributes nutrients vertically through the water column based on vertical mixing coefficients derived from the hydrothermal sub-model, and the nutrient inputs are partitioned into different forms based on model coefficients. Nutrient transformations occur within the model, which affect the form and bioavailability of the nutrient. Nutrients input to the reservoir will ultimately either be taken up by the phytoplankton, or lost from the reservoir in outflows or by sedimentation.

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. Growth is a function of light, temperature, and nutrients. P is the nutrient that predominately limits growth in the Cannonsville and Pepacton Reservoirs. Thus, the most important and manageable input condition or factor affecting primary production and phytoplankton biomass addressed with these models is the external P loads. Chlorophyll, the most widely used measure of phytoplankton biomass, is calculated from the algal carbon based on system-specific stoichiometric relationships.

Since DEP initially used the eutrophication modeling system to evaluate FAD watershed management programs (DEP 2001) the Cannonsville water quality model has been modified to better account for the effects of sediment resuspension on P availability (UFI 2003). The upgraded model includes an inorganic particle sub-model, and adds inorganic suspended solids as a model state variable. This sub-model has three components: (1) a wave sub-model that simulates waves and associated energy from wind conditions and reservoir morphometry, (2) a sediment resuspension sub-model that simulates fluxes of resuspended sediment from the near-shore zone associated with wave energy delivered and sediment characteristics, and (3) a sediment mass balance model that simulates the mass or thickness of sediments available for resuspension. In accordance with the improved capability to simulate sediment resuspension, the P sub-model has been modified to accommodate the effects of P sorption/desorption associated with resuspended inorganic material. Mass balance calculations are conducted on a new state variable in this sub-model, total reactive P, that includes both soluble reactive and particulate reactive (subject to sorption/desorption transformations) components. The effect of resuspended particulate material on light attenuation is also included in the upgraded model.

The reservoir component of the eutrophication modeling system used for the simulations in this report are the 1D eutrophication models developed for the Pepacton and Cannonsville Reservoirs. For Cannonsville this is the model that mechanistically describes the effects of resuspension on P and light availability as summarized above. For Pepacton the same model is used as in the last FAD program evaluation (DEP 2006a). In this version of the model, resuspension is simulated empirically based on a relationship between reservoir water elevation and resuspended particulate P. Both of these versions of the 1D reservoir model have been extensively calibrated and model performance has been verified using datasets independent of that used for calibration (UFI 2001, 2003).

Eutrophication Modeling System Simulation Strategy

This study examines the effects of changes in land use that occurred in the Cannonsville and Pepacton Reservoir watersheds, and the effects of the FAD programs implemented in these watersheds on the quality of water within these reservoirs. As these changes are expected and/or designed to influence nutrient delivery, the predicted effect is on reservoir trophic status. There are always difficulties associated with assessing the effects of long-term changes in nutrient delivery on reservoir water quality, because reservoir water quality can vary greatly from year to year as a result of natural variations in climate and the manifestation of climatic variations on nutrient delivery and phytoplankton growth. Through the use of modeling it is possible to separate the effects of FAD program-induced changes in nutrient delivery from the year-to-year variations due to climate, in a way that cannot be achieved by analyzing actual water quality measurements.

The strategy used here is to make multiple runs of the linked watershed and reservoir water quality models using a long-term 39-year record (1966-2004) of daily meteorological and operational data. For each model run, parameters are fixed to represent a particular scenario of watershed land use, population and management conditions. A model run driven by the long-term meteorological record describes how the watershed responds to the meteorological variability of the long-term record given the particular set of watershed conditions represented by the scenario. Comparison of different scenarios addresses how changes in watershed conditions affects model output (e.g., nutrient loading) within the context of long-term meteorological variability.

The watershed model produces a time series of simulated streamflow and nutrient loads to the reservoir. Simulated reservoir loads are combined with historical meteorology and reservoir operations as input to the 1D reservoir water quality model. The reservoir model, in turn, produces a time series of reservoir water quality results (Figure 7.1). Simulations run in this manner predict changes in reservoir trophic status over a range of recorded meteorological variability.

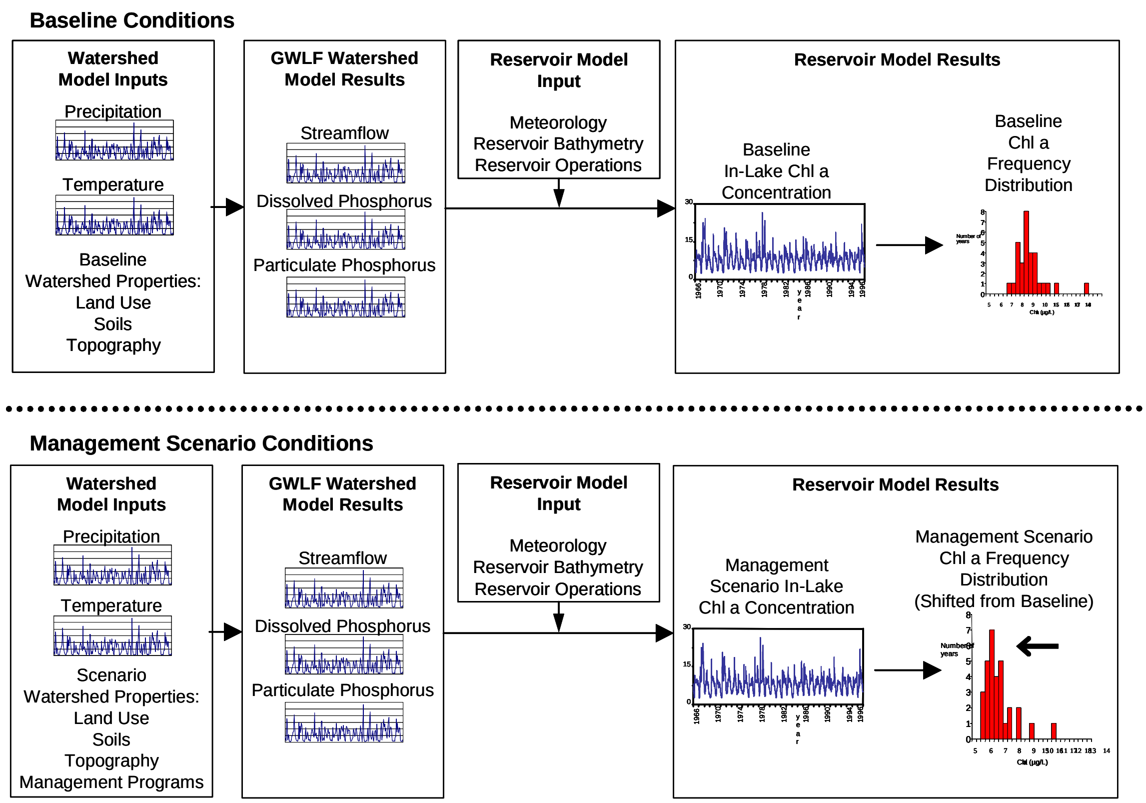

Figure 7.1 Schematic Eutrophication Modeling System.

7.1.2 Modeling Scenarios

Model scenarios were run and compared to analyze the separate and combined effects of land use and watershed management programs on levels of nutrient loading and the trophic status of Cannonsville and Pepacton Reservoirs. Scenarios were developed with different combinations of land use and watershed management, representing baseline conditions existing prior to implementation of watershed management programs (1990s) and for two FAD evaluation periods before and during which substantial implementation of FAD programs occurred: (1) the early 2000s (the period of the previous FAD), and (2) the late 2000s (the period of the current FAD). Six scenarios were analyzed and are listed in Table 7.1

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Table 7.1: Modeling scenarios.

Scenario	Description
BASELINE	1990s land use and population conditions representative of conditions prior to implementation of watershed management
FADPERIOD1	Early-2000s land use, population, NPS BMPs and PS upgrades
FADPERIOD2	Late-2000s land use, population, NPS BMPs and PS upgrades
FADPERIOD2-LU	Late-2000s land use and population, but NPS BMPs and PSs unchanged from *BASELINE*
FADPERIOD2-LU-BMP	Late-2000s land use, population, and NPS BMPs, but PSs unchanged from *BASELINE*
FADPERIOD2-LU-PS	Late-2000s land use, population, and PS upgrades, but NPS BMPs unchanged from *BASELINE*

The *BASELINE* scenario represents watershed conditions prior to or at the initial stages of implementation of point source (PS) upgrades and non-point source (NPS) BMPs. *BASELINE* land use is based on land use data derived from analysis of 2001 remotely-sensed imagery (DEP 2006d), with agricultural areas increased to account for additional farms that were active prior to 1993. Average farm animal density is from estimates made in 1997, and human population density estimates are from 1990 census data.

Since the 1990s there has been a decline in active farmland area and in farm animal density, and an increase in census population. Changes in farm activity have taken a number of forms, including the ending of operations for some farms and, for other farms, changes in operations, such as a switch from dairy production to heifers. These changes are independent of, and treated separately from, the effects of any land use changes associated with watershed management.

Land use areas and population estimates are given in Tables 7.2 and 7.3 for Cannonsville and Pepacton. The *FADPERIOD1* scenario uses land use areas from analysis of 2001 remotely-sensed imagery (DEP 2006d), average farm animal density from 2003 based on WAP data, and human population density from 2000 census data. The *FADPERIOD2* scenario also uses human population estimates from the 2000 census data (because more current data are not yet available) and land use is again based on the 2001 remote sensing imagery, but in this case adjustments to agricultural land use areas and farm animal density are based on farm data for 2009.

Comparison of *BASELINE* to *FADPERIOD1* and *FADPERIOD2* scenarios gives the cumulative effects of changes in land use, population, and watershed management for the previous and current FAD evaluation periods, respectively.

Three additional scenarios were made to examine the separate effects of land use change, NPS BMPs, and PS upgrades on nutrient reductions between *BASELINE* and *FADPERIOD2*. In the *FADPERIOD2-LU* scenario, only land use change is included, while watershed management is unchanged from the baseline. The *FADPERIOD2-LU-BMP* and *FADPERIOD2-LU-PS* scenarios also include NPS-BMPs or PS upgrades, respectively. Comparisons of *BASELINE* with *FADPERIOD2*, *FADPERIOD2-LU*, *FADPERIOD2-LU-BMP*, and *FADPERIOD2-LU-PS* address relative effects of land use change versus watershed management and NPS versus PS management on nutrient loads.

Table 7.2: Land use areas (ha) and population estimates for Cannonsville watershed scenarios.

Land Use Category	*BASELINE*	*FADPERIOD1*		*FADPERIOD2*	
		LU	LU-BMP	LU	LU-BMP
Deciduous Forest	63,961	65,785	66,328	66,323	66,866
Coniferous Forest	11,324	11,324	11,324	11,324	11,324
Mixed Forest	4,398	4,398	4,398	4,398	4,398
Brushland	6,328	6,328	6,328	6,328	6,328
Cropland	4,874	4,579	4,436	3,898	3,755
Hayland	5,267	4,480	4,589	4,478	4,588
Pasture	5,754	5,013	4,504	5,159	4,650
Barnyard	42	42	42	42	42
Non-Agricultural Turf	8,701	8,701	8,701	8,701	8,701
Residential Pervious	1,837	1,837	1,837	1,837	1,837
Residential Impervious	564	564	564	564	564
Commercial/Industrial Pervious	219	219	219	219	219
Commercial/Industrial Impervious	171	171	171	171	171
Rural Roads	649	649	649	649	649
Wetland	869	869	869	869	869
Water	844	844	844	844	844
Population Estimates					
Winter Unsewered Population	9674	10562		10562	
Summer Unsewered Population	13527	14771		14771	

Table 7.3: Land use areas (ha) and population estimates for Pepacton watershed scenarios.

Land Use Category	*BASELINE*	*FADPERIOD1*		*FADPERIOD2*	
		LU	LU-BMP	LU	LU-BMP
Deciduous Forest	62,978	63,212	63,277	63,190	63,255
Coniferous Forest	11,285	11,285	11,285	11,285	11,285
Mixed Forest	4,385	4,385	4,385	4,385	4,385
Brushland	5,354	5,354	5,354	5,354	5,354
Cropland	538	507	492	455	439
Hayland	1,273	1,205	1,215	1,303	1,313
Pasture	1,213	1,078	1,019	1,055	995
Barnyard	12	12	12	12	12
Non-Agricultural Turf	3,551	3,551	3,551	3,551	3,551
Residential Pervious	1,318	1,318	1,318	1,318	1,318
Residential Impervious	348	348	348	348	348
Commercial/Industrial Pervious	98	98	98	98	98
Commercial/Industrial Impervious	64	64	64	64	64
Rural Roads	455	455	455	455	455
Wetland	433	433	433	433	433
Water	613	613	613	613	613
Population Estimates					
Winter Unsewered Population	5821	6766		6766	
Summer Unsewered Population	8149	8149		8149	

Table 7.4: Livestock counts for WOH watersheds based on WAP Program data (DEP 2010c).

		1997		2005		2009	
Animal Type	Animal Units per Animal*	No. of Animals	Animal Units	No. of Animals	Animal Units	No. of Animals	Animal Units
Mature Dairy	1.2	12,636	15,163	7,607	9,128	6,002	7,202
Dairy Heifers	0.7	8,758	6,131	6,971	4,880	5,648	3,954
Veal	0.2	790	158	823	165	0	0
Beef	1.0	1,566	1,566	2,254	2,254	2,490	2,490
Sheep	0.1	569	57	594	59	421	42
Goats	0.1	78	8	251	25	230	23
Pigs	0.3	68	20	272	82	289	87
Horses	1.0	565	565	940	940	512	512
Chickens	0.004	2,655	11	5,709	23	1,565	6
Pheasants	0.005	250	1	0	0	40	0
Rabbits	0.018	25	0	100	2	95	2
Emus	0.15	0	0	22	3	0	0
Ostrich	0.15	18	3	27	4	0	0
Llama	0.15	55	8	4	1	29	4
Deer	0.15	375	56	135	20	157	24
Total			23,747		17,586		14,346

*Minnesota Department of Agriculture (2006).

The *FADPERIOD1* and *FADPERIOD2* scenarios include adjustments made to agricultural runoff nutrient concentrations due to a reduction of livestock density in the watershed. Since the early 1990s the number of animal units using the farmed area has decreased, thus creating fewer animals per farmed hectare (ha). Based on data from the WAP, the number of animal units for WOH watersheds has decreased by more than 50% from 1997 to 2009 (Table 7.4). P concentrations in runoff from agricultural land areas where manure is applied are calculated in the model as a function of water extractable P in surface applied manure. Manure application rates are estimated from animal unit data, P content of manure, and manure spreading schedule data from the farm program.

BMP Scenarios (Non-Point Source Management)

Agricultural BMPs

Eight agricultural BMPs which are applied regularly in farm plans developed by the WAP were considered: Conservation Tillage, Contour Strip Cropping, Crop Rotation, Grass Filter Strips, Nutrient Management Plans, Barnyard Runoff Management, Livestock Exclusion Fencing, and Riparian Forest Buffers. These are briefly described in Table 7.5.

The effects of nutrient management plans are simulated by adjusting manure spreading patterns; the model then simulates P concentrations based on manure P application rates. Barnyard runoff management primarily involves replacement of P-enriched barnyard soils with a concrete pad which is then scraped clean on a weekly basis. This is modeled by reducing the average runoff P concentration coefficient for barnyard soils. Livestock exclusion fencing is evaluated by estimating P contributions directly to streams as a function of in-field animal density and access to stream, based on empirical studies of P contributions from pastured dairy cattle to streams in the Cannonsville watershed (James et al. 2007).

The remaining agricultural BMPs are evaluated by applying P reduction factors that account for the cumulative effects of BMPs on P loads from different agricultural land uses. Dissolved P removal rates for these BMPs (Table 7.6) were estimated based on literature review by the USDA Pasture Systems Lab BMP database project (Gitau et al. 2005). BMP reduction factors were calculated for dissolved P by land use (Tables 7.7 and 7.8). For each agricultural land use (cropland, hayland, pasture, and barnyard), a BMP-specific P reduction factor was calculated by multiplying the mean BMP P removal rate by the BMP implementation rate (the fraction of the total watershed land use affected by a BMP). BMP implementation rates were determined by analysis of data from the WAP. The total reduction factor for an individual land use was determined by compounding the effects of the individual BMPs applied. Compounding is used because it is assumed that multiple BMPs are applied to the same fields. A similar approach was followed by Palace et al. (1998) for analyzing agricultural non-point BMPs for the Chesapeake Bay watershed using the HSPF model.

In addition to BMP effects, which operate by effectively reducing loads from particular land uses, several agricultural BMPs—Riparian Forest Buffers and Conversion of Cropland to Hayland—also effectively change the distribution of land use areas in the watershed. Land use area changes for Cannonsville amounted to a reduction in cropland and pasture of 143 ha and 509 ha, respectively, with a corresponding increase in hayland and forest of 110 ha and 543 ha due to BMP implementation through 2009. For Pepacton, cropland decreased by 16 ha, pasture decreased by 59 ha, hayland increased by 10 ha, and forest increased by 65 ha due to BMP implementation through 2009.

Table 7.5: Agricultural BMPs employed by the Watershed Agricultural Program.

BMP	BMP Description
Barnyard Runoff Management	Exclusion of naturally-occurring runoff from the barnyard. Disposal of collected barnyard runoff to minimize pollution potential
Conservation Tillage	Tillage and planting system that leaves a minimum of 30% of the soil surface covered with plant residue after the operation (e.g., reduced-till, no-till)
Contour Strip Crop	Alternating strips of a row crop with a small grain or forage, planted on the contour
Crop Rotation	A planned sequence of annual and/or perennial crops
Exclusion Fencing	Fencing to exclude livestock from streams and hydrologically sensitive areas
Grass Filter Strips	A strip of perennial grasses, planted across the slope, established adjacent to areas of high pollutant potential
Nutrient Management Plan	Managing the rate, timing, and placement of fertilizers, manures, and other nutrient sources to encourage maximum nutrient recycling and minimize nutrient runoff and leaching
Riparian Forest Buffers	An area of trees, shrubs, and grasses located adjacent to ponds, lakes, and streams that filters out pollutants from runoff

Table 7.6: Dissolved phosphorus removal rates for selected agricultural BMPs.

	Dissolved Phosphorus Removal Rate		
BMP	mean	min	max
Conservation Tillage	-167%	-889%	73%
Contour Strip Crop	45%	20%	93%
Crop Rotation	50%	30%	75%
Grass Filter Strips	26%	-56%	59%
Riparian Forest Buffers	62%	28%	99%

Table 7.7: Dissolved phosphorus reduction factors for agricultural BMPs in Cannonsville watershed, F*ADPERIOD1 and F*ADPERIOD2.

Agricultural BMPs	DP Removal Rate	Fraction of Land Use Affected by BMP			Total Reduction Factor for Land Use		
		Cropland	Hayland	Pasture	Cropland	Hayland	Pasture
FADPERIOD1:							
Conservation Tillage	-167%	0.1%	--	--	-0.2%	--	--
Contour Strip Crop	45%	5.0%	--	--	2.3%	--	--

Table 7.7: (Continued) Dissolved phosphorus reduction factors for agricultural BMPs in Cannonsville watershed, F*ADPERIOD1 and F*ADPERIOD2.

Agricultural BMPs	DP Removal Rate	Fraction of Land Use Affected by BMP			Total Reduction Factor for Land Use		
		Cropland	Hayland	Pasture	Cropland	Hayland	Pasture
Crop Rotation	50%	47.2%	--	--	23.6%	--	--
Grass Filter Strip	26%	0.1%	--	--	0.0%	--	--
Riparian Forest Buffers	62%	1.9%	0.1%	28.4%	1.2%	0.1%	17.6%
Total	-	--	--	--	26.1%	0.1%	17.6%
FADPERIOD2:							
Conservation Tillage	-167%	0.2%	--	--	-0.3%	--	--
Contour Strip Crop	45%	5.9%	--	--	2.6%	--	--
Crop Rotation	50%	55.2%	--	--	27.6%	--	--
Grass Filter Strip	26%	0.1%	--	--	0.0%	--	--
Riparian Forest Buffers	62%	2.3%	0.1%	27.5%	1.4%	0.1%	17.1%
Total	-	--	--	--	30.3%	0.1%	17.1%

Table 7.8: Dissolved phosphorus reduction factors for agricultural BMPs in Pepacton watershed, *FADPERIOD1* and *FADPERIOD2*.

Agricultural BMPs	DP Removal Rate	Fraction of Land Use Affected by BMP			Total Reduction Factor for Land Use		
		Cropland	Hayland	Pasture	Cropland	Hayland	Pasture
FADPERIOD1:							
Conservation Tillage	-167%	--	--	--	--	--	--
Contour Strip Crop	45%	5.0%	--	--	2.2%	--	--
Crop Rotation	50%	79.3%	--	--	39.6%	--	--
Grass Filter Strip	26%	--	--	--	--	--	--
Riparian Forest Buffers	62%	--	1.4%	15.6%	--	0.8%	9.7%
Total	-	--	--	--	41.0%	0.8%	9.7%
FADPERIOD2:							
Conservation Tillage	-167%	--	--	--	--	--	--
Contour Strip Crop	45%	5.6%	--	--	2.5%	--	--
Crop Rotation	50%	88.4%	--	--	44.2%	--	--
Grass Filter Strip	26%	--	--	--	--	--	--
Riparian Forest Buffers	62%	2.9%	1.3%	16.0%	--	0.8%	9.9%
Total	-	--	--	--	45.6%	0.8%	9.9%

Urban Stormwater BMPs

Five urban BMPs used as part of the Stormwater Retrofit Program were considered: Ponding System, Infiltration System, Water Quality Inlet/Catch Basin, Manufactured Devices, and Grass Swales. Dissolved and particulate P removal rates for the urban stormwater BMPs considered (Table 7.9) were estimated based on literature data (EPA 2002, Schueler 1987).

P reduction factors for urban land uses due to BMPs implemented by the Stormwater Retrofit Program were calculated, similarly as for agricultural land uses, as the product of removal rate and implementation rate (Tables 7.10 and 7.11). Implementation rates (percentages of urban land uses to which BMPs are applied) were determined by analysis of data on existing or planned stormwater retrofit projects. Assuming that only one of the five urban BMPs is applied to any one urban development project, the combined effect of all urban BMPs applied to each land use type was calculated as a weighted average of the load reductions for the individual BMPs. The use of additive reductions here is in contrast to the compounding effect used with the agricultural BMPs, for which it is assumed that multiple BMPs can be applied on the same farm fields.

Table 7.9: Dissolved phosphorus removal rates for urban stormwater BMPs.

BMP	BMP Description	Dissolved Phosphorus Removal Rate
Ponding System	Retention pond. Treatment mechanism: particle sedimentation. Peak flow reduction	66%
Infiltration System	Infiltration trench/basin. Treatment mechanism: percolation/infiltration.	85%
Water Quality Inlet/Catch Basin	Treatment mechanism: particle settling	5%
Manufactured Devices	Vortechnics, CDS, or other proprietary device. Treatment mechanism: mechanical separation	40%
Grass Swale	Treatment mechanism: Filtering action of grass, deposition in low velocity areas and infiltration into soil.	38%

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Table 7.10: Dissolved phosphorus reduction factors for urban BMPs in Cannonsville watershed, *FADPERIOD1* and *FADPERIOD2*.

Urban Stormwater BMPs	DP Removal Rate	Fraction of Land Use Affected by BMP				Total Reduction Factor for Land Use			
		Res. Imperv.	Res. Pervious	Com./Ind. Imperv.	Com./Ind. Pervious	Res. Imperv.	Res. Pervious	Com./Ind. Imperv.	Com./Ind. Pervious
FADPERIOD1:									
Ponding System	66%	0.4%	1.8%	0.3%	--	0.3%	1.2%	0.2%	--
Infiltration System	85%	4.9%	3.1%	0.7%	0.7%	4.2%	2.6%	0.6%	0.6%
Water Quality Inlet/Catch Basin	5%	2.3%	0.5%	1.3%	--	0.1%	0.0%	0.1%	--
Manufactured Devices	40%	2.7%	2.4%	3.1%	2.9%	1.1%	0.9%	1.2%	1.2%
Grass Swale	38%	--	--	--	--	--	--	--	--
Total	-	--	--	--	--	5.7%	4.8%	2.1%	1.8%
FADPERIOD2:									
Ponding System	66%	0.7%	3.0%	0.5%	--	0.5%	2.0%	0.3%	--
Infiltration System	85%	8.4%	5.3%	1.2%	1.2%	7.1%	4.5%	1.0%	1.0%
Water Quality Inlet/Catch Basin	5%	3.8%	0.9%	2.1%	--	0.2%	0.0%	0.1%	--
Manufactured Devices	40%	4.6%	4.0%	5.2%	4.9%	1.8%	1.6%	2.1%	2.0%
Grass Swale	38%	--	--	--	--	--	--	--	--
Total	-	--	--	--	--	9.6%	8.1%	3.5%	3.0%

Table 7.11: Dissolved phosphorus reduction factors for urban BMPs in Pepacton Watershed, *FADPERIOD1* and *FADPERIOD2*.

Urban Stormwater BMPs	DP Removal Rate	Fraction of Land Use Affected by BMP				Total Reduction Factor for Land Use			
		Res. Imperv.	Res. Pervious	Com./Ind. Imperv.	Com./Ind. Pervious	Res. Imperv.	Res. Per-vious	Com./Ind. Imperv.	Com./Ind. Pervious
FADPERIOD1:									
Ponding System	66%	--	--	--	--	--	--	--	--
Infiltration System	85%	--	--	--	--	--	--	--	--
Water Quality Inlet/Catch Basin	5%	0.3%	1.1%	0.5%	0.4%	0.0%	0.1%	0.0%	0.0%
Manufactured Devices	40%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Grass Swale	38%	0.2%	0.1%	--	--	0.1%	0.0%	0.0%	0.0%
Total	-	--	--	--	--	0.1%	0.1%	0.0%	0.0%
FADPERIOD2:									
Ponding System	66%	--	--	--	--	--	--	--	--

Table 7.11: (Continued) Dissolved phosphorus reduction factors for urban BMPs in Pepacton Watershed, *FADPERIOD1* and *FADPERIOD2*.

Urban Stormwater BMPs	DP Removal Rate	Fraction of Land Use Affected by BMP				Total Reduction Factor for Land Use			
		Res. Imperv.	Res. Pervious	Com./Ind. Imperv.	Com./Ind. Pervious	Res. Imperv.	Res. Pervious	Com./Ind. Imperv.	Com./Ind. Pervious
Infiltration System	85%	--	--	--	--	--	--	--	--
Water Quality Inlet/Catch Basin	5%	0.7%	2.6%	1.1%	0.8%	0.0%	0.1%	0.1%	0.0%
Manufactured Devices	40%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Grass Swale	38%	0.5%	0.2%	--	--	0.2%	0.1%	0.0%	0.0%
Total	-	--	--	--	--	0.2%	0.2%	0.1%	0.1%

Septic Systems

The GWLF model simulates nutrient loads from septic systems as a function of the percentage of the unsewered population served by normally functioning versus three types of failing systems: ponded, short-circuited, and direct discharge (Haith et al. 1992). Septic System Rehabilitation and Remediation Program effects are modeled by adjusting the fractions of failing systems. Under *BASELINE* conditions, the Delaware County Soil and Water Conservation District (Day 2001) estimates that approximately 50% of previously installed septic systems could be expected to fail, based on soil suitability and design criteria analysis. A GIS analysis of dwelling locations relative to waterbodies suggests that 42% of septic systems in Cannonsville and 39% of septic systems in Pepacton are located within 300 feet of a waterbody. Assuming that failing systems beyond 300 feet of a waterbody are too far away to significantly add to the stream nutrient load, the effective *BASELINE* septic failure rates for the Cannonsville and Pepacton watersheds are 20.8% and 19.6%, respectively. To estimate the percentages of the three types of failing systems, it was assumed that 80% of the failing systems are ponded failures, 10% are short-circuited, and 10% are direct discharge (professional judgment, DEP Engineering staff). The resultant percentages of the current unsewered population served by normal versus failing systems are given in Table 7.12 and are used in the *BASELINE* scenario. These percentages hold for the wet seasons (April through mid-June, mid-September through mid-November). During other times of the year, ponded systems are assumed to effectively function normally, and the percentages of failures are reduced accordingly.

The effects of the Septic System Rehabilitation and Replacement Program on nutrient loads under BMP scenarios is based on a GIS analysis of the number of septic system rehabilitation and replacement projects within the 300-foot waterbody buffer for each of the evaluation periods. The results of the GIS analysis are listed in Table 7.12 with a reduced percentage of systems categorized under the failing types.

The failure percentages of the systems are combined with the unsewered population in each watershed to obtain total septic system loads. Unsewered population estimates were based on 1990 census data for the *BASELINE* scenario and 2000 census data for the *FADPERIOD1* and *FADPERIOD2* scenarios. Based on the census data, year-round unsewered population increased in Cannonsville by 9% and in Pepaction by 16%.

Table 7.12: Model input septic system failures rates for *BASELINE*, *FADPERIOD1*, and *FADPERIOD2*. Reductions in percent of systems ponded, short-circuited, or direct discharge are due to septic program implementation.

	Cannonsville			Pepacton		
Septic Type	*BASELINE*	*FADPERIOD1*	*FADPERIOD2*	*BASELINE*	*FADPERIOD1*	*FADPERIOD2*
Normal	79.2%	82.6%	84.4%	80.4%	82.3%	83.9%
Ponded	16.6%	13.9%	12.5%	15.7%	14.1%	12.9%
Short-circuited	2.1%	1.8%	1.6%	2.0%	1.8%	1.6%
Direct discharge	2.1%	1.8%	1.6%	2.0%	1.8%	1.6%

PS Scenarios (PS Management)

Waste Water Treatment Plants

WWTP P loads for the *BASELINE* scenario were estimated from WWTP effluent monitoring data. The average daily loads for calendar years 1993-1995 for all WWTPs in each watershed were calculated and summed to give the cumulative average daily WWTP load under *BASELINE* conditions. For Cannonsville, total P loads from WWTPs were partitioned into 60% dissolved versus 40% particulate P for the Walton WWTP, and 92% dissolved versus 8% particulate for the other WWTPs, based on WWTP monitoring data (P. Bishop, NYS DEC, pers. comm.). For Pepacton, total P loads from WWTPs were partitioned into 85% dissolved versus 15% particulate (DEP 2006c). *BASELINE* daily WWTP loads as input into the GWLF model are given in Table 7.13

Nutrient loads from upgraded WWTPs were estimated from average monthly loads for WWTP's for calendar years 2003-2005 for the PS00 scenarios and for calendar years 2007-2009 for the PS09 scenarios. Partitioning of total phosphorus loads to dissolved versus particulate phosphorus was assumed the same as for *BASELINE* conditions. The final load reductions due to WWTP upgrades are given in Table 7.13.

Table 7.13: Reductions in PS loads due to WWTP upgrades in Cannonsville and Pepacton watersheds.

	BASELINE	*FADPERIOD1*		*FADPERIOD2*	
	Load (kg day^{-1})	Load (kg day^{-1})	% Reduction	Load (kg day^{-1})	% Reduction
Cannonsville	9.30	0.65	93.0%	0.12	98.7%
Pepacton	1.05	0.15	85.9%	0.14	87.0%

7.1.3 Watershed Modeling Results

GWLF Estimates of Loading Reductions Due to Land Use Change and Watershed Management

Figures 7.2 and 7.3 depict the 39-year annual time series of simulated dissolved phosphorus loads from the Cannonsville and Pepacton watersheds for the *BASELINE* versus *FADPERIOD1* and *FADPERIOD2* scenarios. The reduction in loads depicted in these graphs represents the combined effects of NPS BMPs, WWTP upgrades, and the land use changes that occurred between baseline and the two post-implementation scenarios.

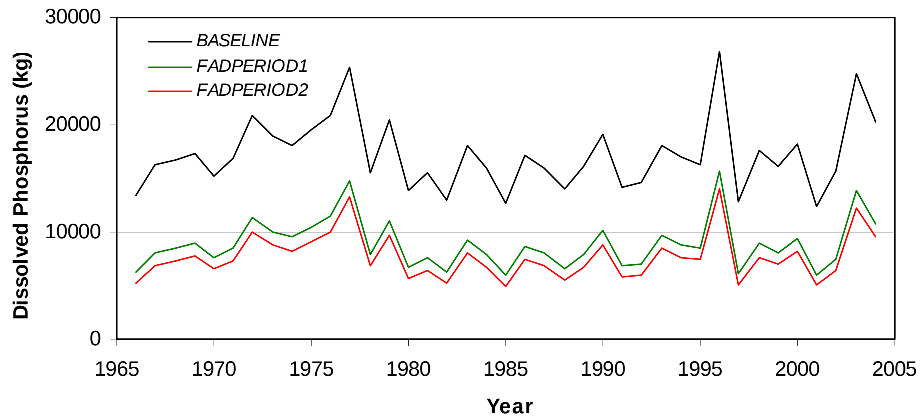


Figure 7.2 A 39-year annual time series of simulated dissolved phosphorus loads (kg yr^{-1}) from the Cannonsville Reservoir watershed for *BASELINE*, *FADPERIOD1*, and *FADPERIOD2* scenarios.

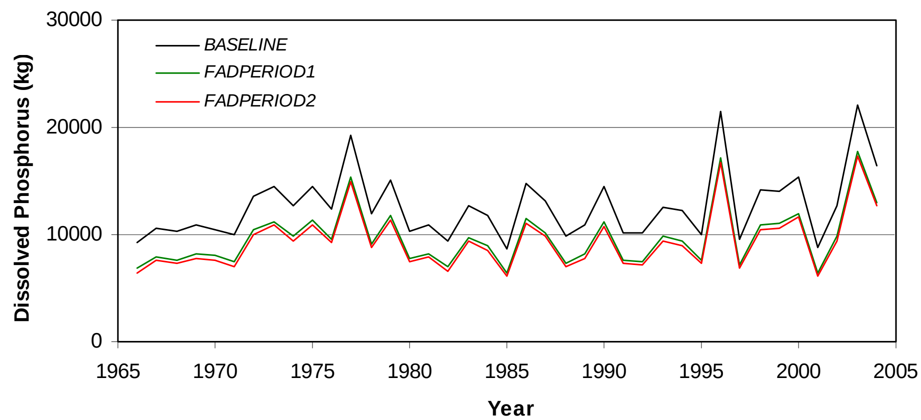


Figure 7.3 A 39-year annual time series of simulated dissolved phosphorus loads (kg yr^{-1}) from the Pepacton Reservoir watershed for *BASELINE*, *FADPERIOD1*, and *FADPERIOD2* scenarios.

Figure 7.4 shows the relative contributions of major sources of dissolved P loads for the two watersheds for the *BASELINE* period. For Cannonsville, average annual dissolved P loads are mostly attributable to agricultural runoff (51.0%), WWTPs (17.0%), and NPS nutrients transported collectively in baseflow (including direct P loading from agricultural animals in the proximity of water courses) (17.2%); other watershed sources contribute significantly less (urban runoff (3.9%), non-agricultural turf (3.7%), forest/brushland (4.5%), septic systems (2.6%)). In Pepacton, the dominant dissolved P loading sources are agricultural runoff (42.7%), forest/brushland runoff (15.0%), and baseflow (21.3%). WWTPs are not as dominant in Pepacton, contributing only 3.0% of the annual load. The other sources in Pepacton include septic systems (2.3%), urban runoff (9.2%), and non-agricultural turf (6.4%).

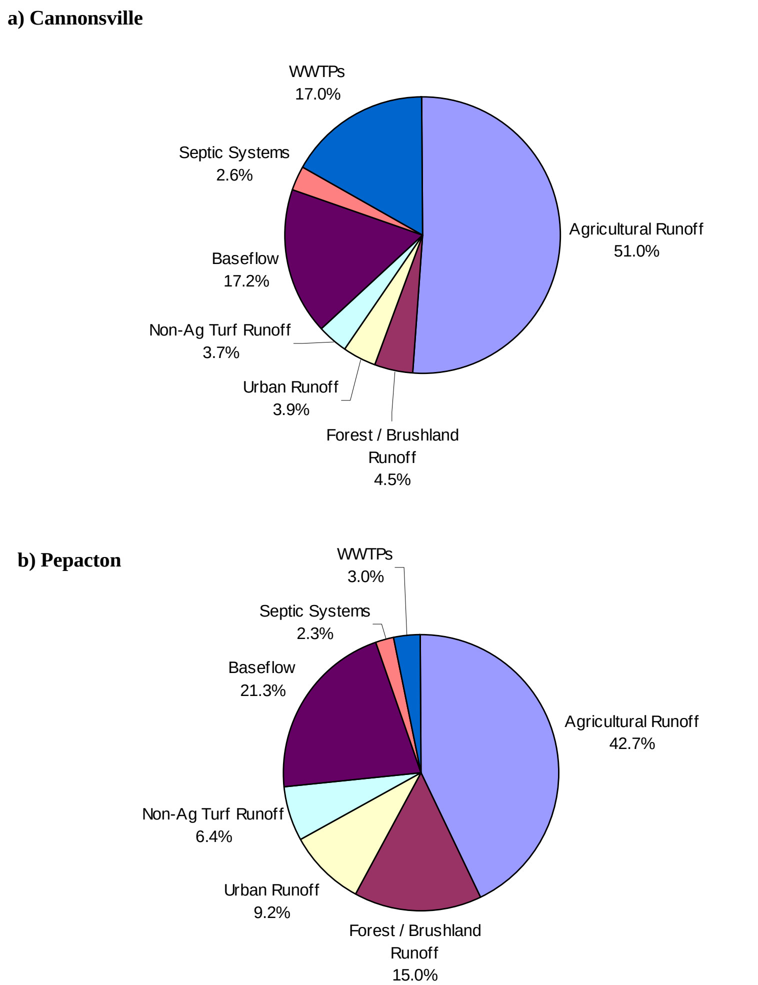
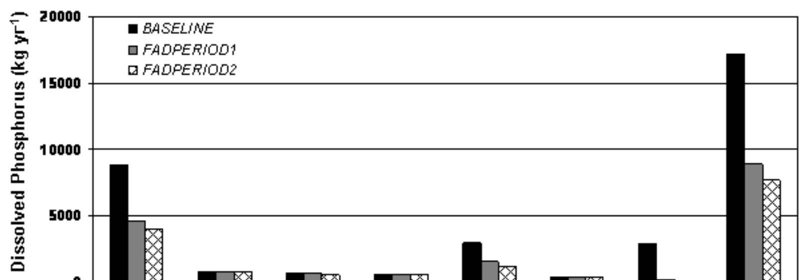


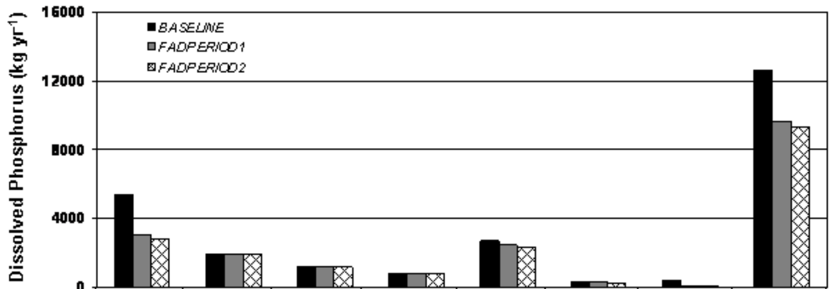
Figure 7.4 Relative *BASELINE* contributions of each land use category to total dissolved P loads for (a) Cannonsville Reservoir watershed and (b) Pepacton Reservoir watershed.

Average annual dissolved P loadings for *BASELINE*, *FADPERIOD1*, and *FADPERIOD2* scenarios with corresponding percent reductions broken down by land use are depicted in Figures 7.5 and 7.6. Percent load reductions are given for the land use category (change in load relative to baseline load for the specific land use) and for the entire watershed (change in load relative to total watershed load). Overall dissolved P reductions from the combination of land use change, watershed management programs, and WWTP upgrades were considerable. Watershed reductions of 48.5% and 55.4% occurred from the 1990s to *FADPERIOD1* and *FADPERIOD2*, respectively. Of the total 55.4% reduction due to land use change and management programs for Cannonsville from *BASELINE* to *FADPERIOD2*, 27.7% comes from agricultural runoff, 16.8% from WWTP improvements, 10.3% from reductions in loads during baseflow periods, and minor reductions from septic systems and urban runoff. For Pepacton, the total load reduction of 26.2% from *BASELINE* to *FADPERIOD2* consists of a 20.7% reduction from agricultural runoff, 2.7% from reductions in load during baseflow periods, a 2.6% reduction from WWTPs, and lesser reductions from septic systems and urban runoff.



	Agricultural Runoff	Forest / Brushland Runoff	Urban Runoff	Non-Ag Turf Runoff	Baseflow	Septic Systems	WWTPs	Total
Loads (kg/yr):								
BASELINE	8,797	772	677	644	2,966	450	2,927	17,234
FADPERIOD1	4,643	780	656	641	1,551	409	205	8,884
FADPERIOD2	4,020	780	641	639	1,200	377	38	7,694
% Reduction for Source:								
FADPERIOD1	47.2%	-1.0%	3.2%	0.4%	47.7%	9.1%	93.0%	
FADPERIOD2	54.3%	-1.0%	5.4%	0.7%	59.6%	16.2%	98.7%	
% Reduction for Total Load:								
FADPERIOD1	24.1%	0.0%	0.1%	0.0%	8.2%	0.2%	15.8%	48.5%
FADPERIOD2	27.7%	0.0%	0.2%	0.0%	10.3%	0.4%	16.8%	55.4%

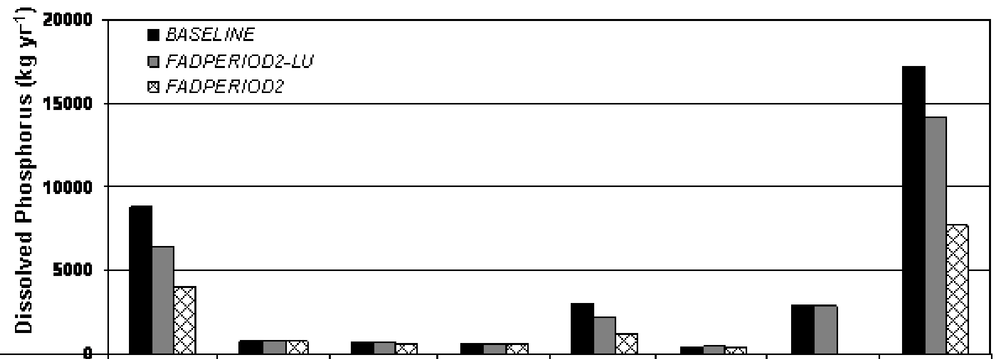
Figure 7.5 Dissolved phosphorus loadings (kg yr^{-1}) for *BASELINE* (black), *FADPERIOD1* (gray), and *FADPERIOD2* (cross-hatch) scenarios, with corresponding percent reductions broken down by land use for the Cannonsville Reservoir watershed.



	Agricultural Runoff	Forest / Brushland Runoff	Urban Runoff	Non-Ag Turf Runoff	Baseflow	Septic Systems	WWTPs	Total
Loads (kg/yr):								
BASELINE	5,394	1,892	1,167	805	2,692	288	382	12,618
FADPERIOD1	3,024	1,895	1,166	804	2,450	299	54	9,692
FADPERIOD2	2,782	1,894	1,166	804	2,352	273	50	9,321
% Reduction for Source:								
FADPERIOD1	43.9%	-0.2%	0.1%	0.0%	9.0%	-4.0%	85.9%	
FADPERIOD2	48.4%	-0.1%	0.0%	0.1%	12.6%	4.9%	87.0%	
% Reduction for Total Load:								
FADPERIOD1	18.8%	0.0%	0.0%	0.0%	1.9%	-0.1%	2.6%	23.2%
FADPERIOD2	20.7%	0.0%	0.0%	0.0%	2.7%	0.1%	2.6%	26.1%

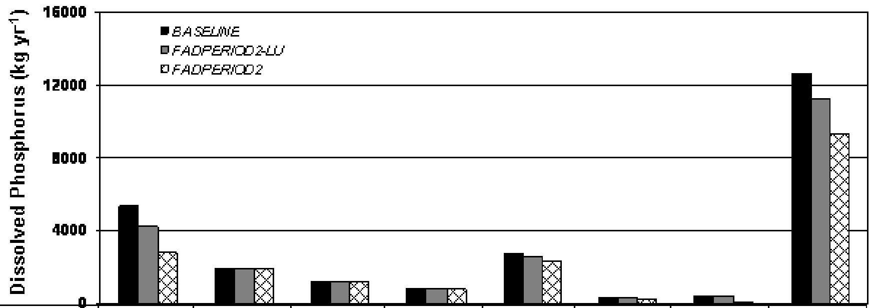
Figure 7.6 Dissolved phosphorus loadings (kg yr^{-1}) for *BASELINE* (black), *FADPERIOD1* (gray), and *FADPERIOD2* (cross-hatch) scenarios, with corresponding percent reductions broken down by land use for the Pepacton Reservoir watershed.

The relative effects of land use change versus watershed management on load reductions were examined by comparing *BASELINE*, *FADPERIOD2*, and *FADPERIOD2-LU* scenarios (Figures 7.7 and 7.8). Comparison of *BASELINE* and *FADPERIOD2-LU* scenarios shows the effects of land use change only. Comparison of these scenarios with the *FADPERIOD2* scenario shows the additional reductions due to non-point BMPs and PS upgrades. The effect of land use change only (independent of watershed management) was quite significant. For Cannonsville, annual dissolved P in agricultural runoff was reduced by 27.0% simply due to less farming, including fewer farmed hectares and lower density of animal units in the watershed. An additional 37.4% reduction was achieved by adding the effects of agricultural BMPs. Compounding these two reductions produces the final 54.3% total reduction in annual loads from agricultural runoff. Therefore, for agricultural runoff, almost half of the expected dissolved P reductions are due to changes in the level of agricultural activity, independent of watershed management activities. Baseflow dissolved P load reductions due to land use change were also considerable (24.9%). For Pepacton, reductions in agricultural runoff loads due to the combination of land use changes and management programs were similar (48.4%) to Cannonsville.



	Agricultural Runoff	Forest / Brushland Runoff	Urban Runoff	Non-Ag Turf Runoff	Baseflow	Septic Systems	WWTPs	Total
Loads (kg/yr):								
BASELINE	8,797	772	677	644	2,966	450	2,927	17,234
FADPERIOD2-LU	6,421	778	676	640	2,228	491	2,928	14,162
FADPERIOD2	4,020	780	641	639	1,200	377	38	7,694
% Reduction for Source:								
due to Land Use/Farm Change	27.0%	-0.7%	0.2%	0.6%	24.9%	-9.2%	0.0%	17.8%
due to Management Programs	37.4%	-0.3%	5.2%	0.1%	46.2%	23.3%	98.7%	45.7%
Combined	54.3%	-1.0%	5.4%	0.7%	59.6%	16.2%	98.7%	55.4%
% Reduction for Total Load:								
due to Land Use/Farm Change	13.8%	0.0%	0.0%	0.0%	4.3%	-0.2%	0.0%	17.8%
due to Management Programs	17.0%	0.0%	0.3%	0.0%	7.3%	0.8%	20.4%	45.7%
Combined	27.7%	0.0%	0.2%	0.0%	10.3%	0.4%	16.8%	55.4%

Figure 7.7 Dissolved phosphorus loadings (kg yr^{-1}) for *BASELINE* (black), *FADPERIOD2-LU* (gray), and *FADPERIOD2* (cross-hatch) scenarios, with corresponding percent reductions broken down by land use for the Cannonsville Reservoir watershed.



	Agricultural Runoff	Forest / Brushland Runoff	Urban Runoff	Non-Ag Turf Runoff	Baseflow	Septic Systems	WWTPs	Total
Loads (kg/yr):								
BASELINE	5,394	1,892	1,167	805	2,692	288	382	12,618
FADPERIOD2-LU	4,205	1,893	1,166	804	2,528	333	382	11,312
FADPERIOD2	2,782	1,894	1,166	804	2,352	273	50	9,321
% Reduction for Source:								
due to Land Use/Farm Change	22.0%	-0.1%	0.0%	0.1%	6.1%	-15.9%	0.0%	10.4%
due to Management Programs	33.8%	-0.1%	0.0%	0.0%	7.0%	17.9%	87.0%	17.6%
Combined	48.4%	-0.1%	0.0%	0.1%	12.6%	4.9%	87.0%	26.1%
% Reduction for Total Load:								
due to Land Use/Farm Change	9.4%	0.0%	0.0%	0.0%	1.3%	-0.4%	0.0%	10.4%
due to Management Programs	12.6%	0.0%	0.0%	0.0%	1.6%	0.5%	2.9%	17.6%
Combined	20.7%	0.0%	0.0%	0.0%	2.7%	0.1%	2.6%	26.1%

Figure 7.8 Dissolved phosphorus loadings (kg yr^{-1}) for *BASELINE* (black), *FADPERIOD2-LU* (gray), and *FADPERIOD2* (cross-hatch) scenarios, with corresponding percent reductions broken down by land use for the Pepacton Reservoir watershed.

For septic systems, the effects of land use change (population increase) and management programs (septic rehabilitation and replacement) work in opposite directions. In Cannonsville, increases in population from the 1990 census to the 2000 census, without implementation of septic programs, would have produced an increase of 9.2% in annual dissolved P load from septic systems. The implementation of the septic program is predicted to reduce septic system loads by 23.3%. When the effects of increased population and watershed management programs are combined the total reduction for septic systems is 16.2%. Results for Pepacton were similar, with population increase causing a 15.9% increase and management programs producing a 17.9% decrease, netting a combined 4.9% decrease in septic loads. Note in both cases the combined load reduction is not simply the sum of the two effects because the effects are compounded, not additive.

Figures 7.9 and 7.10 show the seasonal variability in average dissolved P loading for each land use type for the *BASELINE*, *FADPERIOD1*, and *FADPERIOD2* scenarios for Cannonsville and Pepacton, respectively. Dissolved P loads associated with agricultural runoff, urban runoff, forest/brushland runoff, managed turf, and baseflow all follow the seasonal pattern of streamflow, peaking in spring and reaching a low in summer. Dissolved P loads in agricultural runoff display the most pronounced seasonality, with elevated spring loading. Septic system loads peak during the spring and again in autumn. WWTP loads and reductions are more or less constant throughout the year. Given that loading reductions from other sources are less during the summer low flow months, the constant WWTP reductions have greater impact on the total dissolved P reduction during these months.

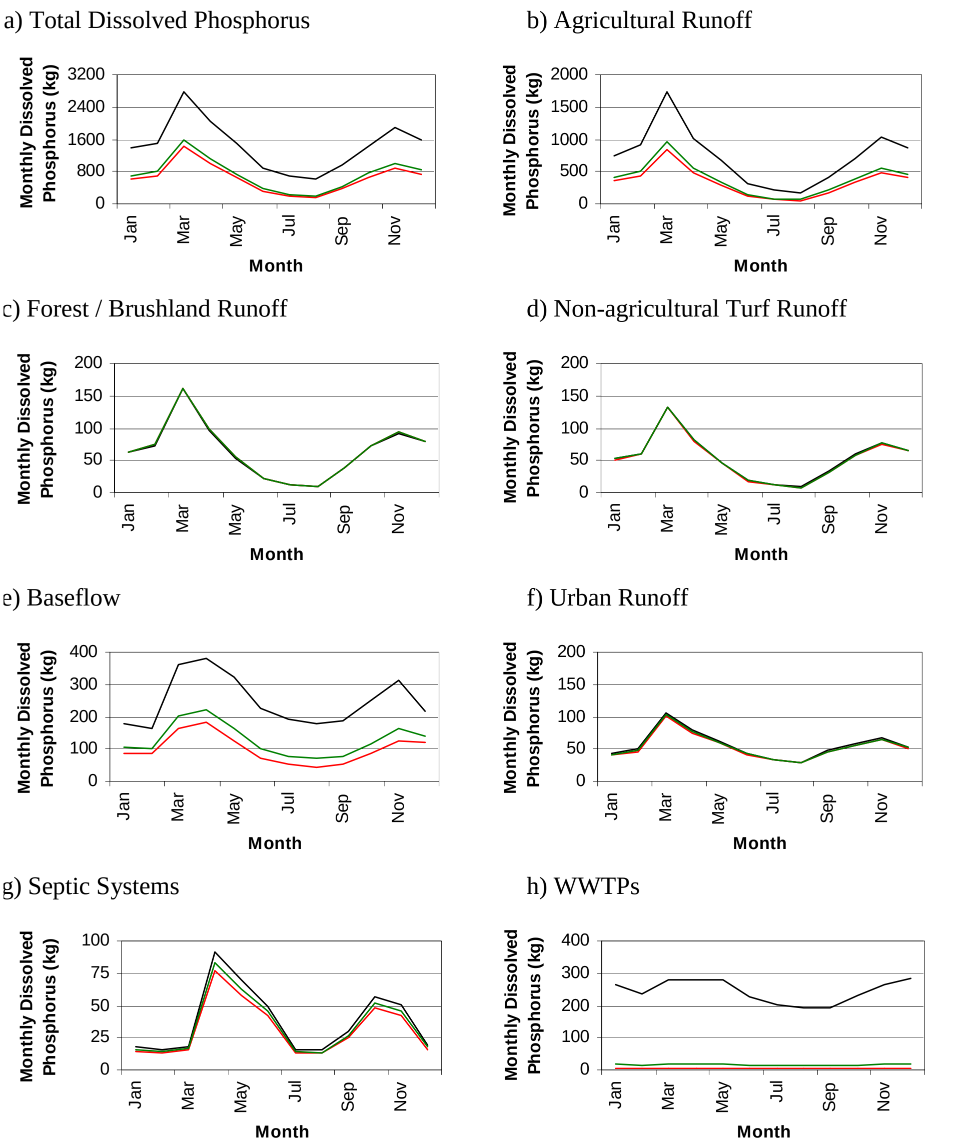


Figure 7.9 Average monthly dissolved phosphorus loads (kg month^{-1}) for Cannonsville *BASELINE* (black line), *FADPERIOD1* (green line), and *FADPERIOD2* (red line) scenarios attributable to: (a) all categories together, (b) agricultural runoff, (c) forest/brushland runoff, (d) non-agricultural turf runoff, (e) baseflow, (f) urban runoff, (g) septic systems, and (h) WWTPs.

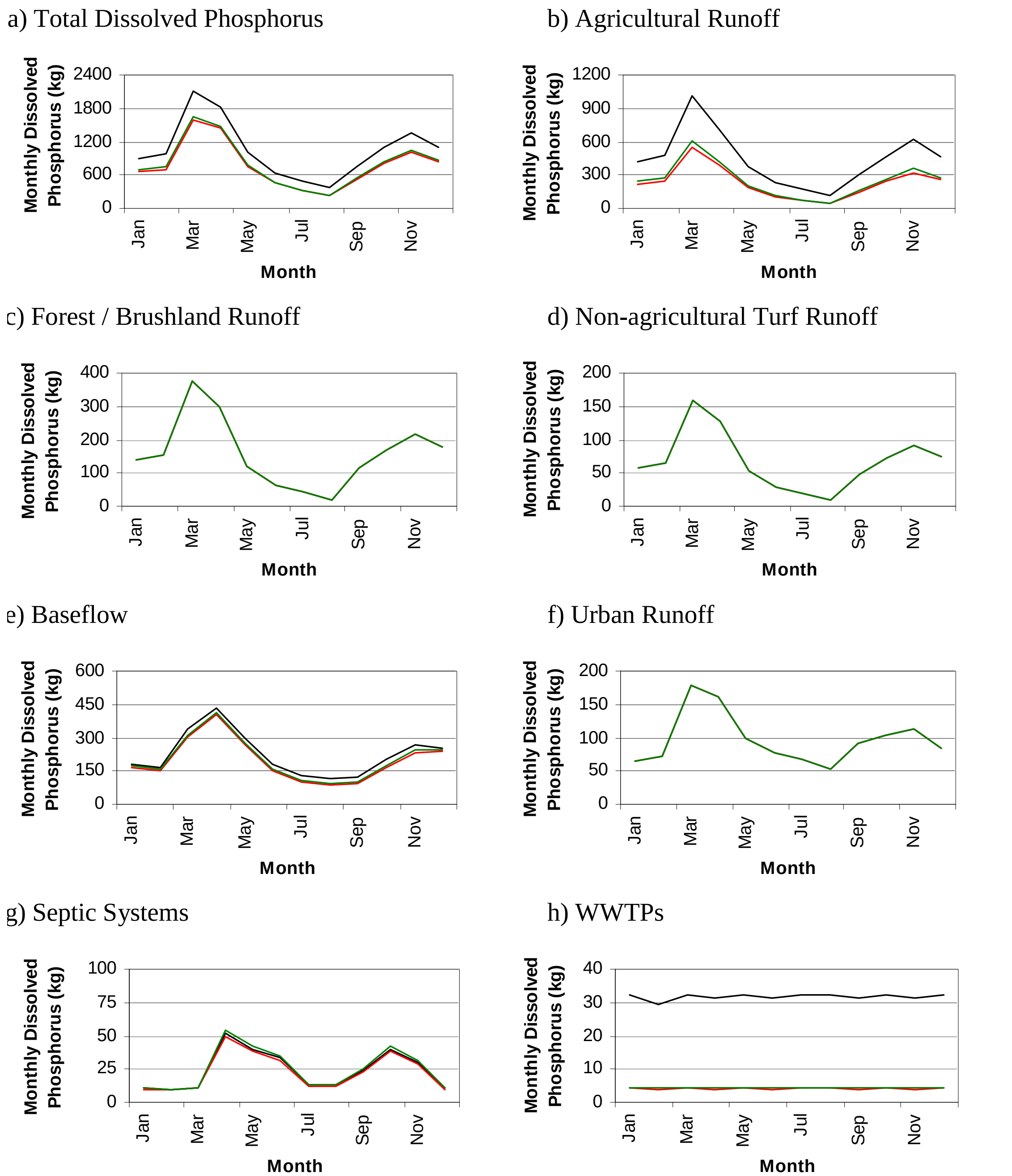


Figure 7.10 Average monthly dissolved phosphorus loads (kg month^{-1}) for Pepacton *BASELINE* (black line), *FADPERIOD1* (green line), and *FADPERIOD2* (red line) scenarios attributable to: (a) all categories together, (b) agricultural runoff, (c) forest/brushland runoff, (d) non-agricultural turf runoff, (e) baseflow, (f) urban runoff, (g) septic systems, and (h) WWTPs.

GWLF Model Scenario Predictions vs. Observed Trends in Cannonsville Phosphorus Loads

Analysis of water quality data collected by NYSDEC along the West Branch of the Delaware River at Beerston between 1992 and 2008 reveals a considerable reduction in P loads to Cannonsville Reservoir. The average annual dissolved P concentration in streamflow at Beerston has dropped from 0.029 mg L^{-1} for the period 1992-1999 (not including the January 1996 extreme event) to 0.016 mg L^{-1} for 2000-2008, a 45% reduction. In contrast, annual particulate P concentrations, and annual streamflow, have not declined (Figure 7.11).

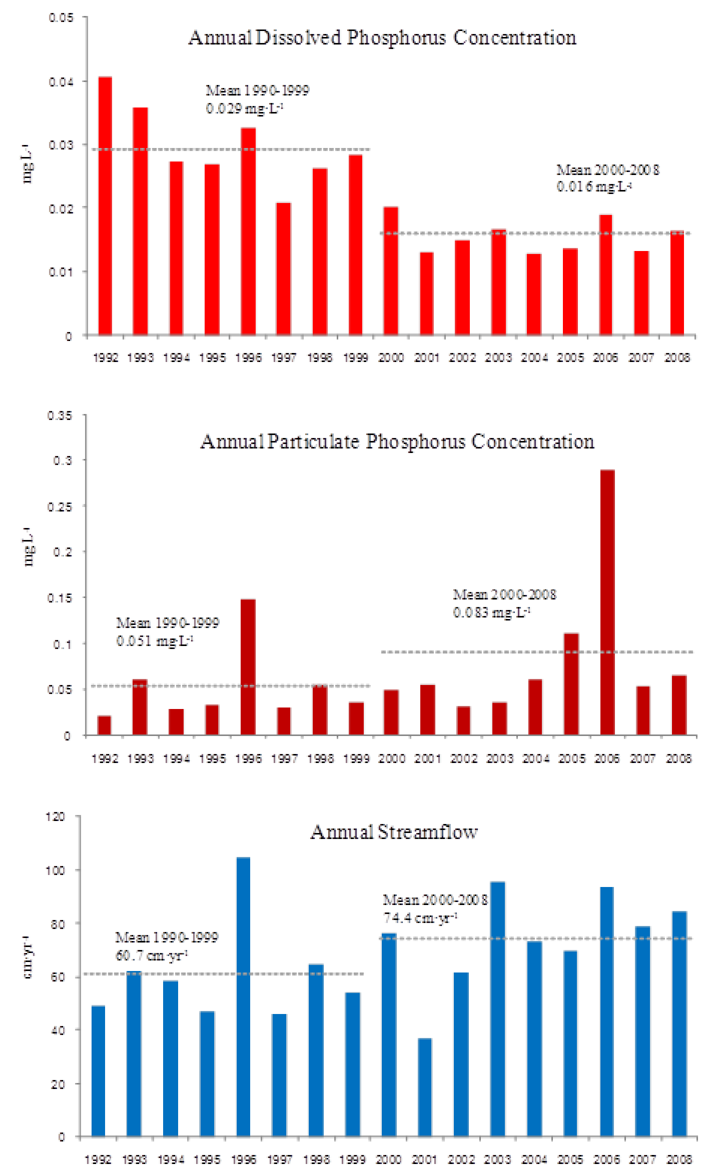


Figure 7.11 Observed annual dissolved and particulate phosphorus concentrations (mg L^{-1}) at Beerston and observed annual streamflow (cm yr^{-1}) at Walton, 1992-2008.

The combination of water quality monitoring data collected since 1991 along with data on watershed management program implementation and land use change provides an opportunity to test the watershed model scenario simulations and to increase confidence in the model predictions. In typical model applications a model is calibrated and validated using data collected for a set period and subsequently used to predict future scenarios under varying watershed conditions, but additional data is rarely available for testing the prediction scenarios. The GWLF model was previously calibrated and validated for the period 1992-1999, which approximates *BASELINE* conditions. Here we compare observed data for 2000-2009 with model scenario predictions representing recent land use changes and watershed management program implementation.

Three Beerston watershed scenarios were developed to predict loads at Beerston for comparison with observed data for 2000-2009. A *BeerstonBaseline* scenario coincides with the calibration period, and assumes no changes in land use or watershed management. A *BeerstonLU* scenario assumes land use change as specified for *FADPERIOD1* and *FADPERIOD2* (Table 7.2), but watershed management is unchanged from *BeerstonBaseline* conditions. A *BeerstonLUBMP* scenario adds BMP implementation for the two *FADPERIOD*s to the land use changes. For both the *BeerstonLU* and *BeerstonLUBMP* scenarios the *FADPERIOD1* model parameters were applied for simulation years 2000-2005 and the *FADPERIOD2* parameters were applied for simulation years 2006-2009, so that the simulated changes in land use and NPS BMPs correspond to the land use and BMP implementation data for these two periods. Observed WWTP loads for Beerston were used for all three scenarios. Differences between predictions and observed data in this analysis can thus only be attributable to NPSs and/or land use changes.

Figure 7.12 depicts observed versus model scenario predictions of cumulative dissolved P at Beerston for 2000-2009. The *BeerstonBaseline* scenario markedly overestimates (~50%) dissolved P loads. This is expected given the observed reduction in dissolved P concentrations from 1992-2009 (Figure 7.11). The *BeerstonLU* scenario shows that land use change alone accounts for a considerable fraction of the observed reductions in dissolved P loads, but loads are still overestimated (~27%). When the effects of land use change and NPS BMPs are combined (*BeerstonLUBMP* scenario), the predicted cumulative dissolved P loads match the observed loads fairly well (~9% underestimate). These results substantiate the ability of the model to simulate dissolved P under the changing land use and NPS management conditions as they occurred in the 2000s.

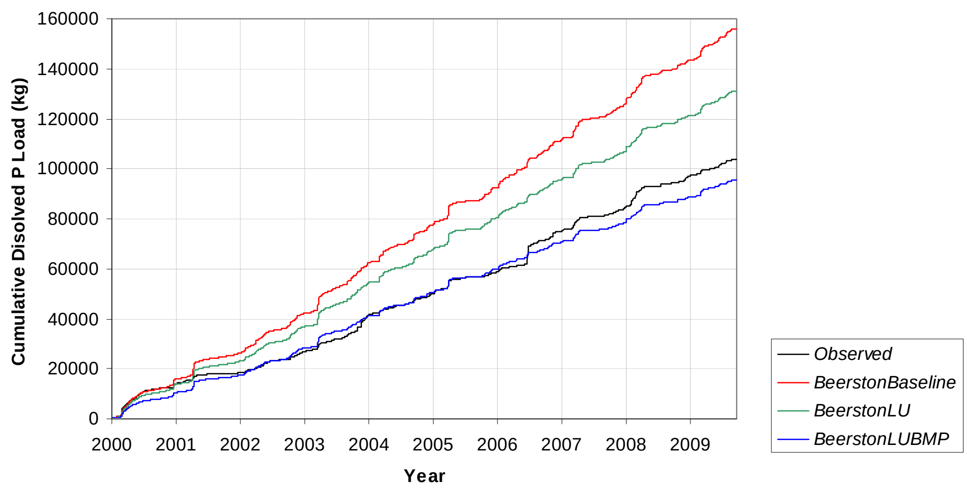


Figure 7.12 Observed vs. model scenario predictions of cumulative dissolved phosphorus at Beerston, 2000-2009.

Summary of GWLF Model Run Results

The effects of NPS management, PS upgrades, and land use change on nutrient export from the Cannonsville and Pepacton watersheds were evaluated. Output from the GWLF watershed model provided loading estimates to evaluate watershed programs. Four watershed management programs were evaluated: Point Source WWTP Upgrades, Watershed Agricultural Program, Urban Storm water Program and Regulations, and Septic System Rehabilitation Program. In addition, a significant decline in agricultural land use (~15% reduction in agricultural land area) and agricultural activity (~43% reduction in farm animal units) that occurred from the early 1990s to the late 2000s independent of deliberate watershed management was evaluated.

Calibrated and validated GWLF models for Cannonsville and Pepacton were used to estimate nutrient loads for a series of scenarios, each of which represents a combination of land use, NPS management, and PS conditions. A *BASELINE* scenario represents conditions existing in the 1990s prior to implementation of FAD programs. Two FAD evaluation scenarios represent conditions of the early 2000s (*FADPERIOD1*) and late 2000s (*FADPERIOD2*), before and during which substantial implementation of FAD programs occurred. Nutrient reduction factors due to watershed management programs-based BMP nutrient removal and implementation data were applied to represent watershed management effects in each *FADPERIOD* scenario.

Changes in nutrient loading due to the combined effects of land use change and FAD programs were examined by comparing the FAD period scenarios to the *BASELINE*. There was a ~49% reduction in dissolved P loads from the Cannonsville watershed from the *BASELINE* to *FADPERIOD1*, and an additional ~7% reduction from *FADPERIOD1* to *FADPERIOD2*. For the Pepacton watershed, dissolved P export was reduced by ~23% from *BASELINE* to *FADPERIOD1* and an additional ~3% from *FADPERIOD1* to *FADPERIOD2*. The large reductions seen between the *BASELINE* and *FADPERIOD1* correspond to a combination of high rates of new program implementation and a substantial reduction in agricultural activity during that period. Continued but slower declines in P loads from *FADPERIOD1* to *FADPERIOD2* occurred as FAD programs became more focused on maintenance and improvement than on new program development, and the reduction in agricultural activity continued.

The relative effects of land use change versus watershed management on load reductions were examined by comparing the *BASELINE* to the *FADPERIOD2* and *FADPERIOD2-LU* scenarios. Land use change (decline in agriculture) and watershed management both produced substantial reductions in P loading. Loading reductions due to land use change alone were ~18% for dissolved P in Cannonsville, and ~10% for dissolved P in Pepacton. The combination of land use change and watershed management produced reductions of ~55% for dissolved P in Cannonsville, and ~26% for dissolved P in Pepacton. PS WWTP upgrades and the implementation of agricultural BMPs by the WAP provided most of the loading reductions, with minor reductions from septic system remediation and urban stormwater management.

Loading reductions exhibit seasonal patterns. Dissolved P reductions due to agricultural BMPs are greatest in spring and lowest in summer, following the seasonal pattern of streamflow. In contrast, reductions due to WWTPs do not exhibit a seasonal pattern, causing the relative reduction due to WWTP upgrades to be greater during the summer and least during spring. Particulate P reductions also exhibit strong seasonality, following the seasonal pattern of streamflow. These seasonal patterns are significant when considering the effects of loading reductions on eutrophication in the reservoirs, as in-lake algal growth is sensitive to the timing of nutrient inputs.

Comparison of model scenario results with observed loading data for the West Branch Delaware River at Beerston corroborates the scenario predictions for dissolved P loading from the Cannonsville watershed. A close match was found between observed annual dissolved P loads at Beerston and simulated loads for the two FAD periods when reductions due to both land use change and FAD programs are included. Neither land use change (observed decline in agriculture) nor watershed management programs considered alone provides reductions that match observed dissolved P reductions between the *BASELINE* and the FAD periods.

Watershed loading scenario results are subsequently input to reservoir models to evaluate the effects of loading changes on reservoir water quality.

7.1.4 Reservoir Modeling Results

Trophic status is commonly measured in terms of phytoplankton chlorophyll concentration or total P concentration, and it is the model output of these two variables that is examined here. Furthermore, water quality issues related to eutrophication almost always occur during thermal stratification, and in the epilimnion (upper mixed layer) of the reservoir as illustrated by Figure 7.13. For this reason, chlorophyll and total P are examined between May and October, using data contained within the epilimnion. Yearly May-October averaging was also used since similar averages (based on measured data) are used by DEP to monitor reservoir water quality, and are compared to critical threshold concentrations in the Total Maximum Daily Loads (TMDL) estimation procedure.

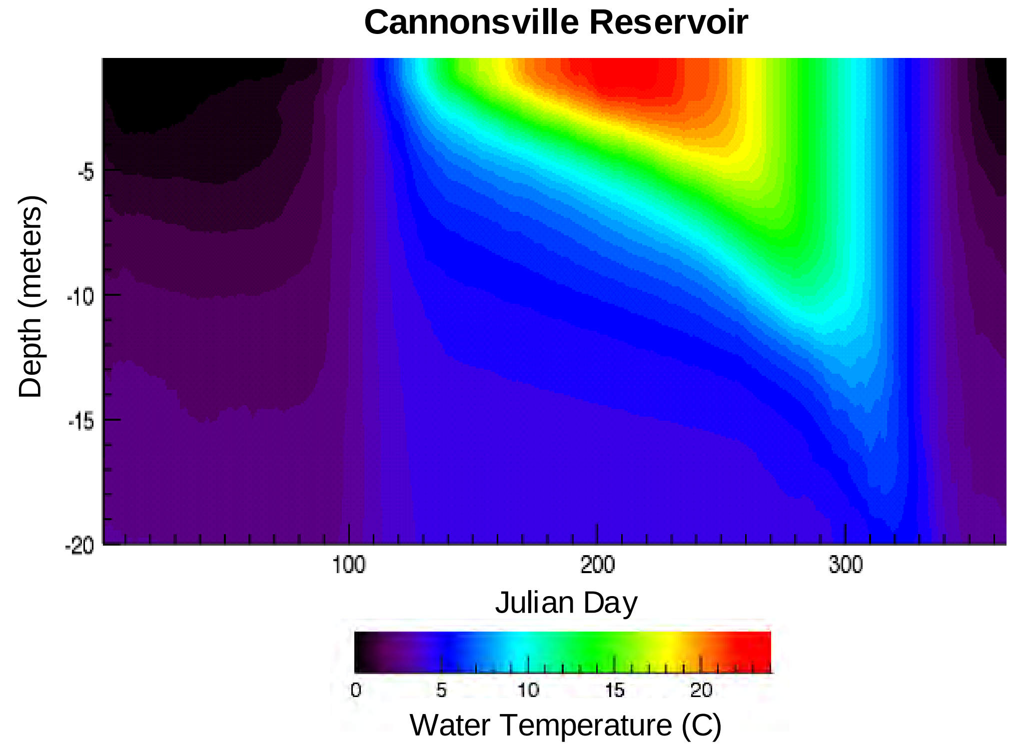


Figure 7.13 Water temperature isopleth diagram for Cannonsville Reservoir. The isopleths are based on mean profiles for each Julian day (1-365) that were calculated using data from all the simulation years (n=39). Simulated water temperature is the same for all nutrient loading scenarios. Thermal stratification is generally considered to exist between 1 May (Julian Day 121) and 31 October (Julian Day 304). The same general pattern of thermal stratification is also found in Pepacton Reservoir.

Model output from the different simulation scenarios can be interpreted in terms of the probability of occurrence of a given chlorophyll or total P concentration (Figures 7.14 and 7.15). Measures of central tendency associated with these derived probability distributions give an overall estimate of the effects of the programs, while the range of variability provides a realistic description of the variations in water quality that will be experienced under any given nutrient loading scenario. Differences between the scenarios represent the effects of changes in land use and the cumulative effects of land use change coupled with differing combinations of FAD management programs.

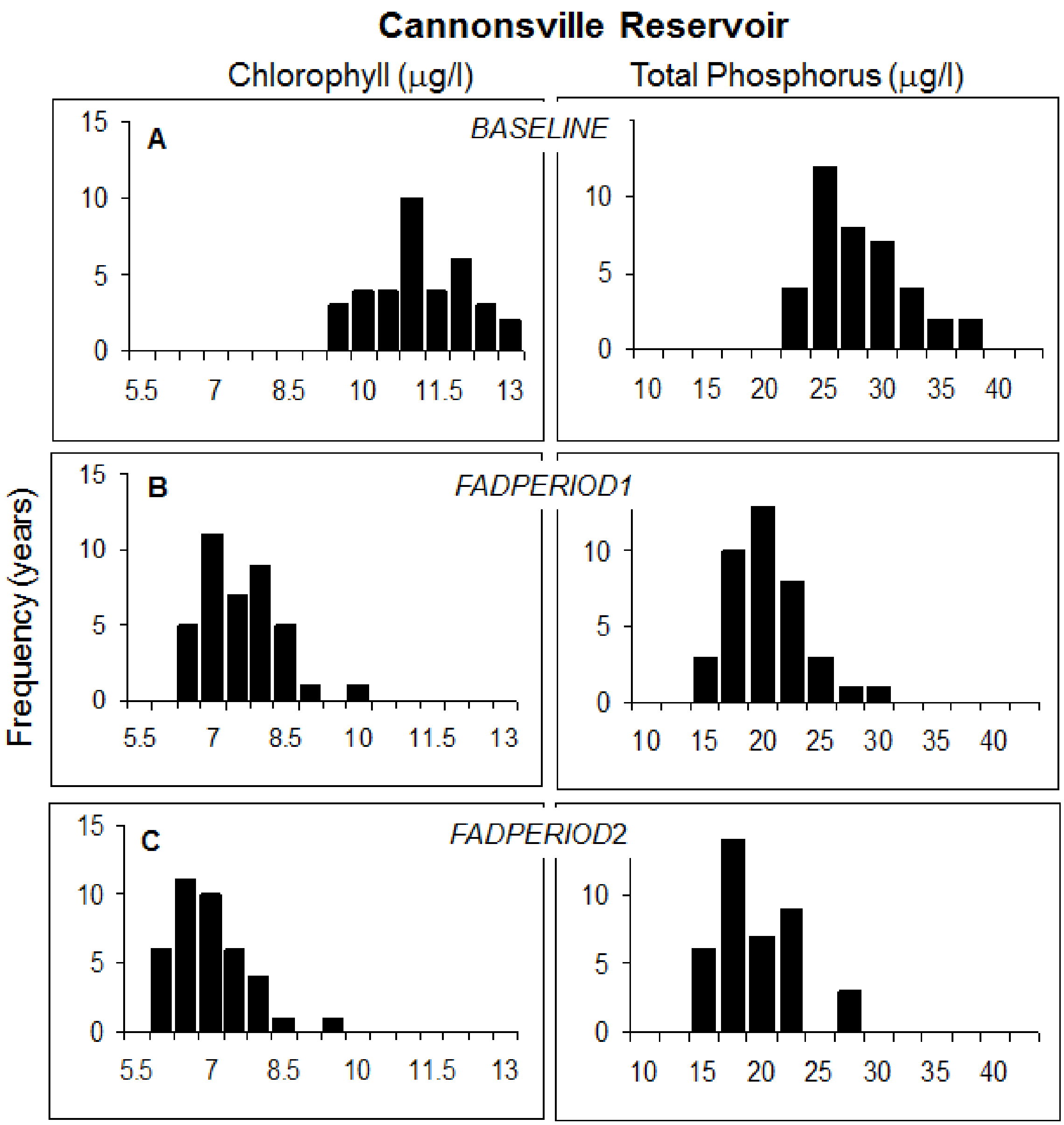


Figure 7.14 Frequency distributions of mean summer (May-October) epilimnetic chlorophyll and total phosphorus concentrations in Cannonsville Reservoir, showing progressive improvement in reservoir water quality as a result of FAD programs. A) Frequency distribution of the expected variations in concentrations under *BASELINE* conditions when no FAD programs were in place. B) Frequency distributions showing the combined effects of land use change and FAD programs for simulations of *FADPERIOD1*. C) Frequency distributions showing changes in water quality for simulations using *FADPERIOD2* conditions.

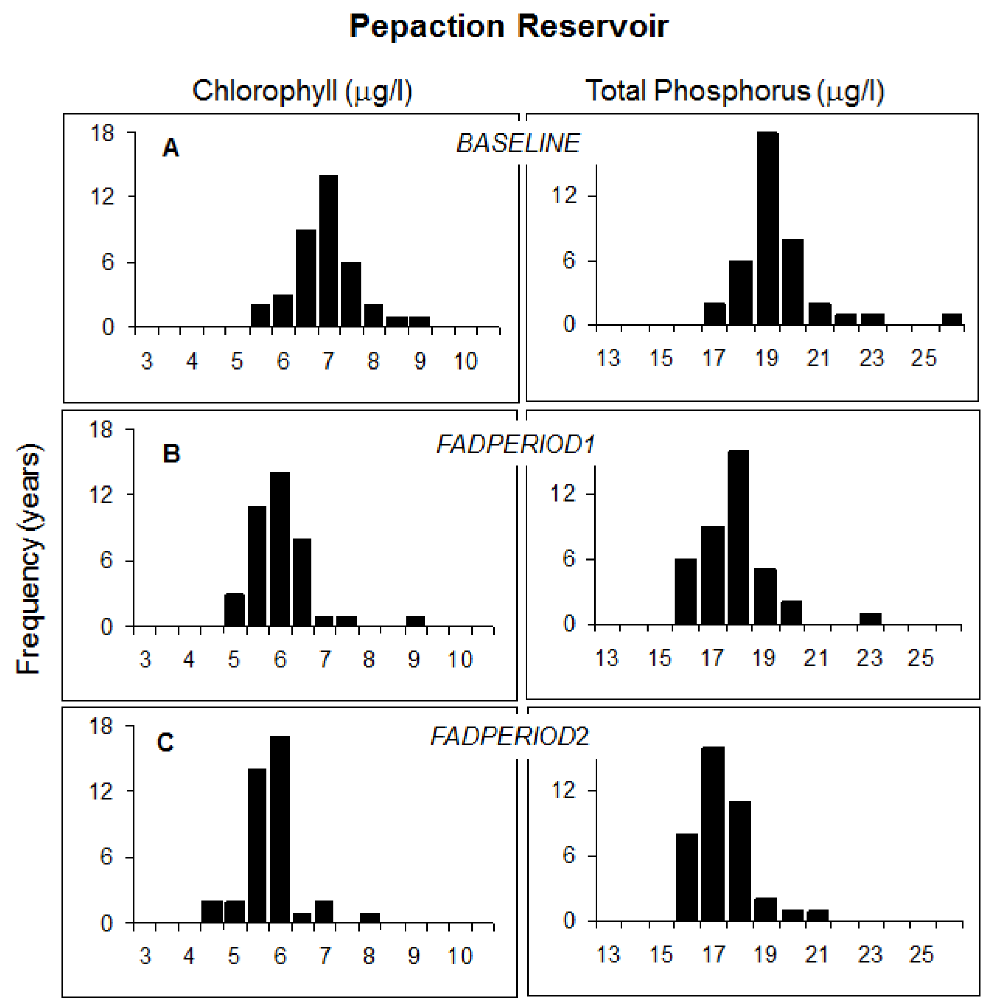


Figure 7.15 Frequency distributions of mean summer (May-October) epilimnetic chlorophyll and total phosphorus concentrations in Pepacton Reservoir under A) *BASELINE*, B) *FADPERIOD1*, and C) *FADPERIOD2* conditions

Progressive Effects of FAD Implementation, 2000-2009

The data in Table 7.14 summarize the changes in mean May-October chlorophyll and total P concentrations simulated for *BASELINE* conditions, as occurring during *FADPERIOD1* and *FADPERIOD2*. The means in Table 7.14 are calculated using data from all 39 simulation years, while the variability associated with the individual years of meteorological data can be seen in the histograms of yearly mean May-October concentrations (Figures 7.14-7.17). The program-specific scenarios in Table 7.14 are not additive. For example, both the *FADPERIOD2-LU-BMP* and *FADPERIOD2-LU-PS* scenarios are impacted by land use change and their sum is therefore greater than the total program effects represented by the *FADPERIOD2* scenario. The response of the reservoir to changes in external nutrient loading is also not expected to be linear, and would not support an additive relationship between FAD program implementation and reservoir response.

Table 7.14: Long-term epilimnetic mean values of chlorophyll and total phosphorus calculated between May-October for each of the five scenarios. Numbers in parentheses are the percent change of the scenario mean from the *BASELINE* mean. Extreme Chlorophyll values are those that exceed a threshold defined by the 95th percentile of the *BASELINE* scenario.

	Mean May-Oct. Chlorophyll (μg L^{-1})	Extreme Chlorophyll Values	Mean May-Oct. Total P (μg L^{-1})
Cannonsville Reservoir			
Changes in reservoir trophic status over time			
BASELINE	11.09	713	26.74
FADPERIOD1	7.32 (-34.0%)	110 (-84.6%)	19.02 (-29.8%)
FADPERIOD2	6.77 (-38.9%)	84 (-88.2%)	18.07 (-32.4%)
Program-specific effects during most recent FAD evaluation period			
BASELINE	11.09	713	26.74
FADPERIOD2-LU	10.07 (-9.2%)	437 (-38.7%)	24.51 (-8.3%)
FADPERIOD2-LU-BMP	8.22 (-25.8%)	143 (-79.9%)	21.26 (-20.5%)
FADPERIOD2-LU-PS	8.56 (-22.8%)	185 (-74.1%)	21.33 (-20.2%)
FADPERIOD2	6.77 (-38.9%)	84 (-88.2%)	18.07 (-32.4%)
Pepacton Reservoir			
Changes in reservoir trophic status over time			
BASELINE	6.80	713	18.99
FADPERIOD1	5.77 (-15.2%)	226 (-68.3%)	17.31 (-8.9%)
FADPERIOD2	5.57 (-18.2%)	172 (-75.9%)	16.93 (-10.9%)
Program-specific effects during most recent FAD evaluation period			
BASELINE	6.80	713	18.99
FADPERIOD2-LU	6.44 (-5.4%)	454 (-36.3%)	18.39 (-3.2%)
FADPERIOD2-LU-BMP	5.67 (-16.7%)	184 (-74.2%)	17.08 (-10.1%)
FADPERIOD2-LU-PS	6.28 (-7.6%)	395 (-44.6%)	18.10 (-4.7%)
FADPERIOD2	5.57 (-18.2%)	172 (-75.9%)	16.93 (-10.9%)

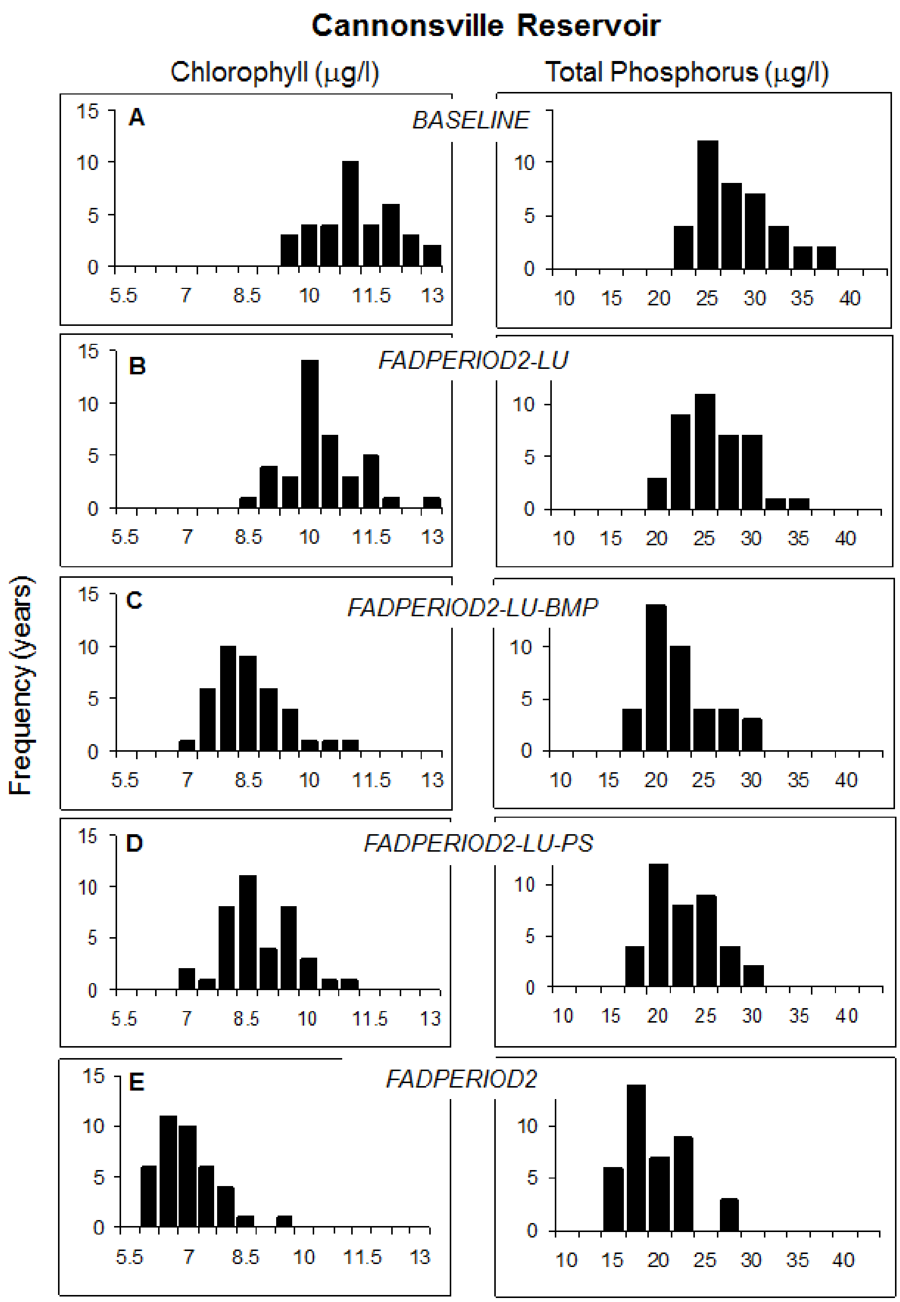


Figure 7.16 Frequency distributions of mean summer (May-October) epilimnetic chlorophyll and total phosphorus concentrations in Cannonsville Reservoir. A) Frequency distributions under *BASELINE* conditions. B) *FADPERIOD2-LU*—changes in frequency distributions as a result of changing land use . C) *FADPERIOD2-LU-BMP*—changes in frequency distributions as a result of the cumulative effects of land use change and watershed BMPs. D) *FADPERIOD2-LU-PS*—changes as a result of land use change and reduction in point source nutrient loads. E) *FADPERIOD2*—cumulative effects of land use change, BMPs, and point source reductions.

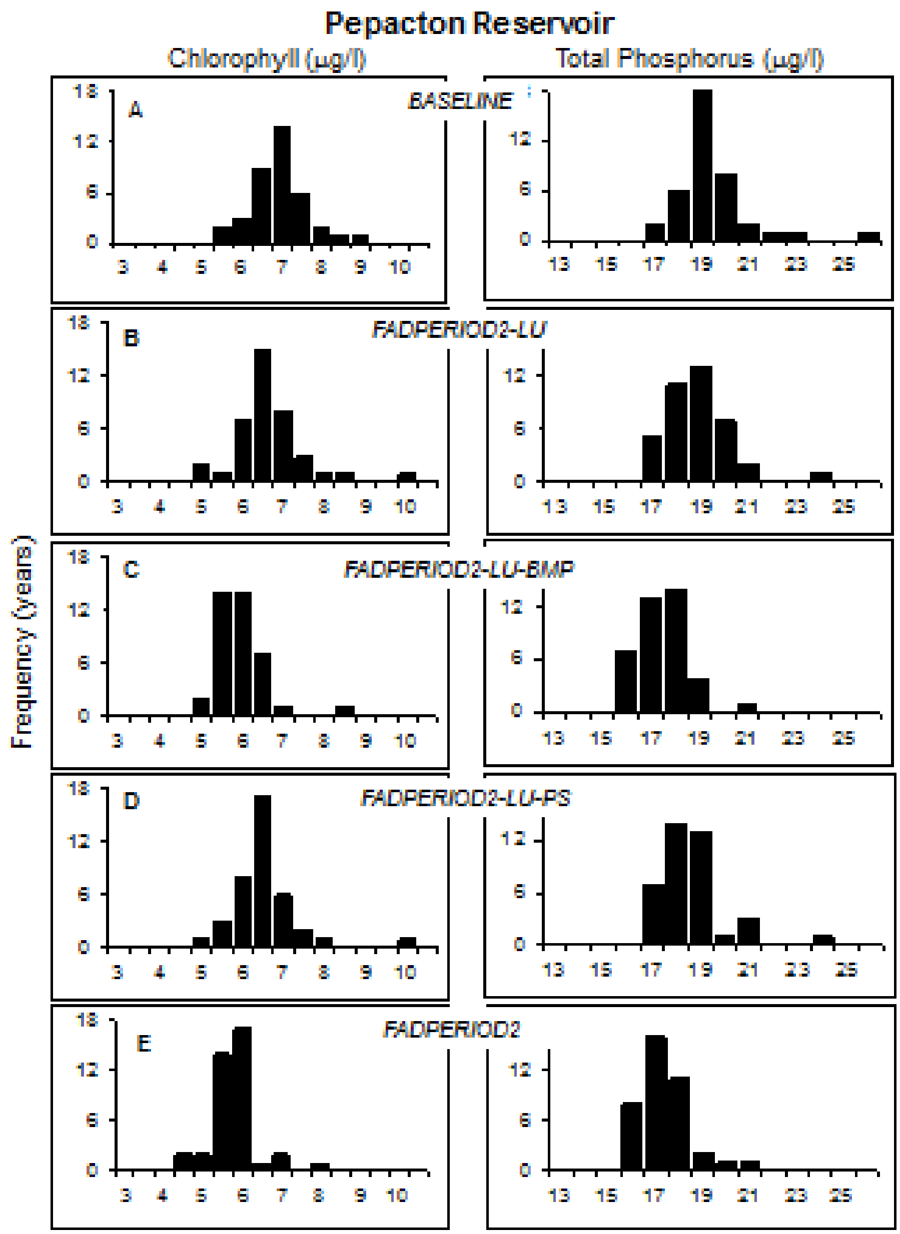


Figure 7.17 Frequency distributions of mean summer (May-October) epilimnetic chlorophyll and total phosphorus concentrations in Pepacton Reservoir that demonstrate the effects of changing land use and FAD program implementation. Frequency distributions under A) *BASELINE*, B) *FADPERIOD2-LU*, C) *FADPERIOD2-LU-BMP*, D) *FADPERIOD2-LU-PS*, and E) the cumulative effect of all *FADPERIOD2* conditions.

For both Cannonsville and Pepacton Reservoirs, the greatest reduction in reservoir chlorophyll and total P occurred between *BASELINE* and *FADPERIOD1*, as a result of land use change and the FAD programs that were by and large implemented during this time period. In Cannonsville Reservoir, a 34% reduction in May-October epilimnetic chlorophyll concentrations, and a nearly 30% decrease in total P concentrations occurred between *BASELINE* and *FADPERIOD1* conditions. Histograms showing the yearly variations in these two key parameters show the same trend with the median values decreasing significantly between *BASELINE* and *FADPERIOD1*, with a subsequent shift in the histogram to overall lower concentrations. The histograms also show the importance of climatic variability in affecting the general trends; although the overall mean in Table 7.14 clearly represents the trend in declining concentrations, the yearly variations in concentrations are as great as the changes seen in the three periods in Figures 7.14 and 7.15. Only through the use of an analysis that explicitly considers the effects of climatic variability is it possible to correctly represent the conditions and the variability in the conditions that would be expected as a result of the FAD programs (Figures 7.14 and 7.15) Reductions between *FADPERIOD1* and *FADPERIOD2* continued but were less pronounced since the bulk of the FAD implementation occurred between *BASELINE* and *FADPERIOD1*, especially capital intensive programs such as WWTP and septic upgrades. The greatest recruitment of farms into the WAP, and therefore the greatest implementation of agricultural NPS BMPs also occurred between *BASELINE* and *FADPERIOD1*. In Cannonsville Reservoir there was approximately an additional 5% reduction in epilimnetic chlorophyll and a further 4% reduction in total P between *FADPERIOD1* and *FADPERIOD2*. These small changes result from some additional program implementation and also reflect continual improvements in the programs that were already in place. The relatively small changes in reservoir trophic status between *FADPERIOD1 and FADPERIOD2* is an indication that the large benefits of the programs seen between the *BASELINE* and *FADPERIOD1*scenarios remain in effect, and that the maintenance and gradual improvements in the programs both perpetuate improvements already achieved and yield small but measurable improvements in reservoir water quality.

Similar trends were seen for Pepacton Reservoir, although concentrations in this reservoir were lower from the start due to lower levels of nutrient loading (Section 7.1.3). As a result, improvements in watershed management and changes in land use had proportionally less effect than that seen in the Cannonsville Reservoir watershed. Changes in land use and watershed management have a more pronounced effect on Cannonsville, since this reservoir was the most eutrophic under *BASELINE* conditions, and since there is a greater proportion of land use in the Cannonsville watershed that was impacted by the watershed management programs.

Effects of Land Use Change and FAD Implementation, 2006-2009

The effects of land use change and different classes of FAD programs are evaluated in more detail by comparing the *BASELINE* simulation with the land use and program-specific simulations that represent conditions during *FADPERIOD2*. Figures 7.16 and 7.17 examine the effects of land use change and of specific programs. *FADPERIOD2* effects are also shown in

Table 7.14. To better visualize the mean effects of the different programs, particularly over the May to October averaging period, mean chlorophyll isopleths are plotted for Cannonsville Reservoir (Figure 7.18) for the same scenarios of land use change and FAD program implementation as examined using the histograms in Figure 7.16.

Comparison of the histograms for the *BASELINE* and late 2000s land use change scenarios (Figures 7.16 and 7.17) suggests that changes in land use alone will result in a noticeable shift to lower total P and chlorophyll concentrations, which corresponds to a ~9% reduction in the long-term mean chlorophyll concentration and a ~8% reduction in the long-term mean total P concentration in the Cannonsville watershed (Table 7.14). A similar but smaller shift in chlorophyll (~5%) and total P (~3%) occurred in Pepacton Reservoir as a result of land use changes. Land use changes, as previously discussed, are pronounced due to the changing demographics in the these two reservoir watersheds, particularly the Cannonsville watershed, which has led to a reduction in agricultural activity and the intensity of agricultural practices on the remaining agricultural land.

The next two sets of histograms (parts C and D of Figures 7.16 and 7.17) show the cumulative effects of land use-derived changes and the changes associated with either the implementation of watershed BMPs (*FADPERIOD2-LU-BMP*) or point source upgrades (*FADPERIOD2-LU-PS*). When comparing data derived from these different modeling scenarios it can be seen that the combination of land use change with either of PS or BMP programs is predicted to have a similar beneficial effect on reservoir water quality, reducing Cannonsville Reservoir chlorophyll concentrations by a further 12-15% and mean total P concentrations by an additional 13-16% (Table 7.14). Of the two programs, non-point BMP nutrient reductions led to a slightly greater decrease in the long-term mean Cannonsville chlorophyll concentration, which is also evident as shifts shown by the frequency distributions in Figure 7.16. The response to changes in nutrient loading associated with the *LU-BMP* and *LU-PS* scenarios, simulated to occur in Pepacton, is again similar to that described above for Cannonsville, but is less distinct and of a smaller magnitude. For Pepacton, both the *FADPERIOD2-LU-BMP* and *FADPERIOD2-LU-PS* scenarios had a beneficial effect on reservoir water quality, reducing reservoir concentrations of chlorophyll by ~ 5%-17% and total P by ~ 3%-10%. In the case of Pepacton, greater benefit was simulated to result from the combined effects of land use change and the BMP programs than from land use change and reductions in PS nutrient loads.

The bottom panel (E) of the histograms (Figures 7.16 and 7.17) shows the cumulative effect of both land use change and watershed management programs on reservoir water quality. Both in terms of chlorophyll and total P there are significant shifts in the frequency distributions for both reservoirs, as the cumulative effects of land use change and watershed management progressively reduce nutrient loading to the reservoir. The long-term scenario means (Table 7.14) show that there is a roughly 32-39% reduction in P and chlorophyll in Cannonsville Reservoir, and that about one-third of this can be attributed to the effect of land use change. This model prediction represents a significant improvement in water quality, which can be largely attributed to DEP's watershed management programs. Furthermore, comparing panels A and E of Figures 7.16 and 7.17 shows that the variability in the final *FADPERIOD2* scenario frequency distributions is also reduced relative to the *BASELINE* scenario, so that the year-to-year variations in chlorophyll and total P become less. This will lead not only to improved water quality, but also to lower and more predictable variations in water quality, which will in turn lead to a reservoir that is more easily managed.

The data for Pepacton Reservoir shows much the same pattern as that discussed for Cannonsville Reservoir above. Here the long-term mean reductions are less, suggesting an overall reduction between the *BASELINE* and *FADPERIOD2* scenarios of approximately 18% for chlorophyll and 11% for total P (Table 7.14). The relative shifts in the chlorophyll and total P frequency distributions between simulations scenarios (Figure 7.17) or the relative differences in the long-term mean concentrations simulated for each scenario (Table 7.14) are similar to Cannonsville; however, the absolute magnitude of the differences is less. This is due to the fact that Cannonsville was the most eutrophic reservoir in the WOH system, and consequently, the FAD watershed programs have had a proportionally greater effect there. Secondly, Cannonsville is also the reservoir watershed which had the most agricultural land use of any WOH reservoir. Implementation of agricultural BMP programs and reduction in agricultural activity therefore, has had the greatest effect on this reservoir.

The seasonal effects of the nutrient reductions summarized in Table 7.14 can also be visualized in two dimensions using isopleth diagrams of chlorophyll concentration. This is shown for Cannonsville Reservoir in Figure 7.18, which plots depth versus time chlorophyll isopleths for the upper 20 meters of the reservoir water column. The vertical variations in the daily data are averaged across the 39 simulation years for each Julian day. Figure 7.18 clearly shows the importance of thermal stratification (Figure 7.13) in influencing the seasonal pattern and vertical distribution of chlorophyll. This figure also clearly supports the rationale for using May-October epilimnetic chlorophyll in assessments of reservoir trophic status. When comparing the different scenarios to *BASELINE* conditions it can be seen that the reductions shown by Table 7.14 lead to progressive reductions in the chlorophyll concentrations simulated throughout the mixed layer. There is, however, a relatively greater reduction in the magnitude of the fall bloom as compared with the spring bloom. This is the result of the spring bloom coinciding with seasonally high levels of nutrient loading and also being confined to the relatively shallow mixed layer. Nutrients entering the epilimnion will therefore result in higher concentrations, in an environment with shallow mixing, higher light exposure, and therefore more favorable growth conditions.

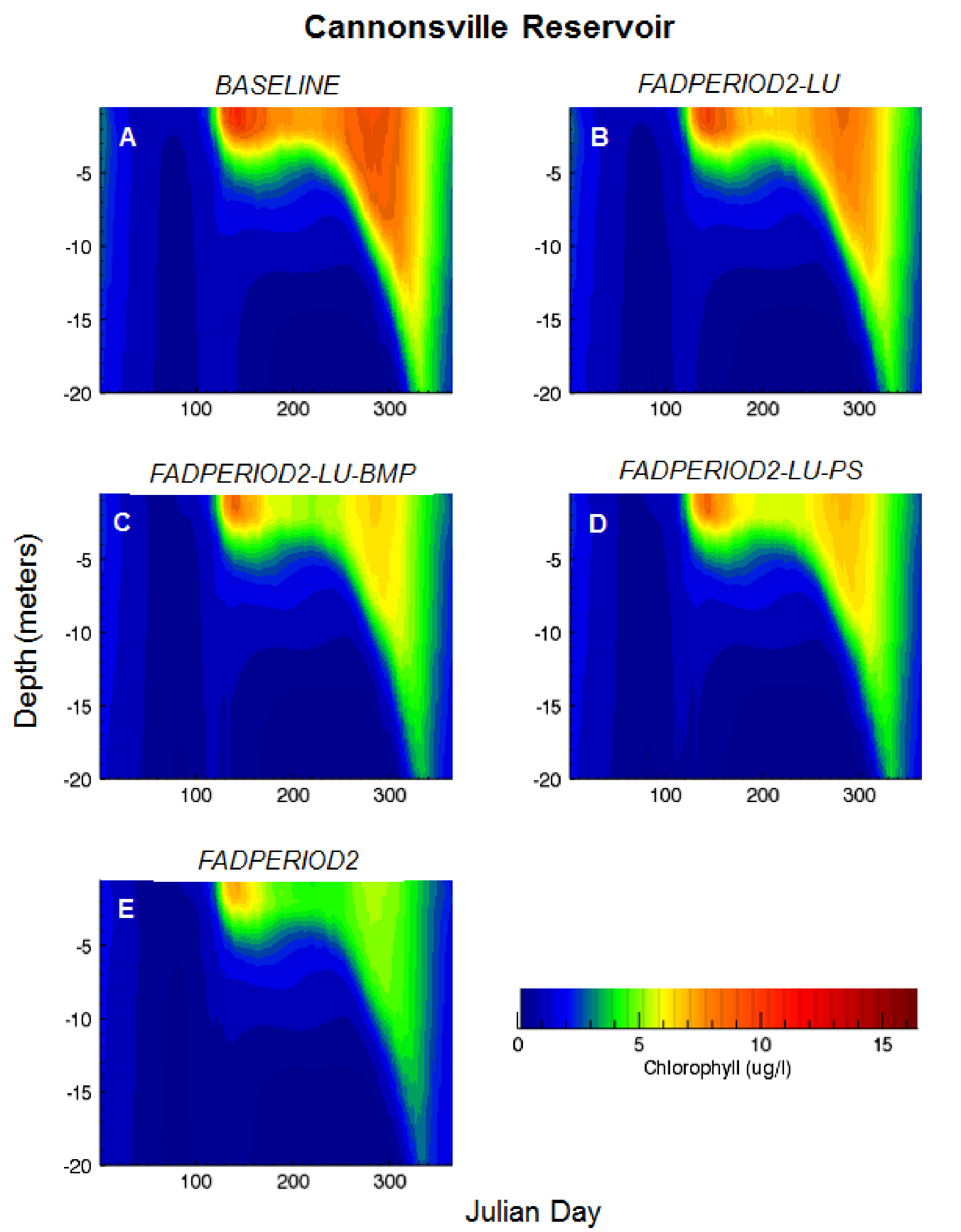


Figure 7.18 Isopleth diagrams showing the vertical distribution of Cannonsville Reservoir chlorophyll concentrations that would be expected to occur under the five nutrient loading scenarios examined: A) *BASELINE*, B) *FADPERIOD2-LU*, C) *FADPERIOD2-LU-BMP*, D) *FADPERIOD2-LU-PS*, and E) all *FADPERIOD2* programs. The isopleths are based on mean profiles for each Julian day (1-365) that were calculated using data from all the simulation years (n=39).

Effects of Land Use Change and FAD Programs on Extreme Chlorophyll

In addition to examining variations in epilimnetic chlorophyll averaged over the summer period of each year, variations in daily epilimnetic chlorophyll concentrations were also examined. Daily data show the influence of the different nutrient loading scenarios on shorter term increases in chlorophyll a concentration (i.e. “algal blooms”). These events can lead to significant water quality problems, but will not be well measured by long term averages. In Figure 7.19 daily values of epilimnetic chlorophyll are plotted for the entire 39 year time period that was used to represent meteorological variability in our simulations. The upper panel shows the range and seasonal variations in concentrations simulated as occurring under the *BASELINE* scenario, while the bottom panel shows the concentrations simulated as occurring as a consequence of all *FADPERIOD2* watershed program implementation and landuse change. The medians of the daily scenario data are shown by the blue line and the actual value is also labeled on the graphs. A threshold value is plotted as a red line that is the 95 percentile level associated with the frequency distributions of the daily data from the *BASELINE* simulation. We took this value as a reasonable reservoir specific threshold to define levels of epilimnetic chlorophyll that were unusually high for that reservoir. Values exceeding the threshold are an extreme or “bloom like” occurrence for the reservoir in question. However, since the threshold defining the extreme chlorophyll concentrations is scaled to the long term distribution of chlorophyll in that reservoir the extreme concentrations do not necessarily represent an actual water quality concern. The same threshold is used for all scenarios associated with each reservoir, and the number of daily epilimnetic chlorophyll concentrations exceeding the threshold is also labeled on the examples shown Figure 7.19, as well as shown for all scenarios in Table 7.14.

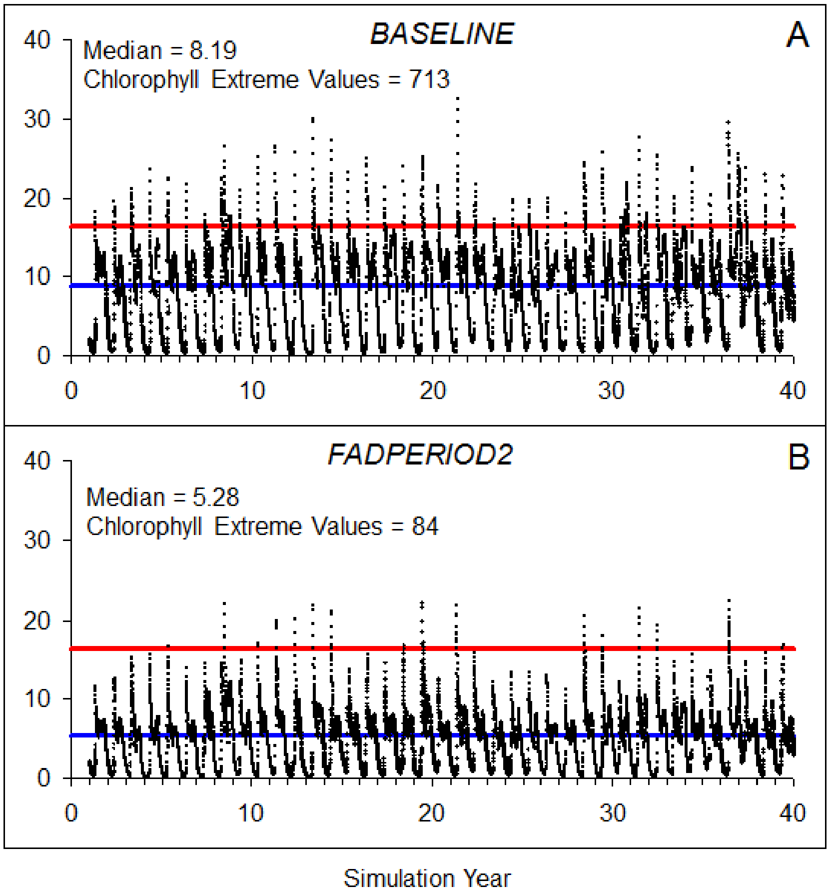


Figure 7.19 Plots of daily epilimnetic chlorophyll concentration simulated during the entire 39-year simulation period used in this study. The examples are from reservoir model simulations driven by the same meteorological and reservoir operation data, but with nutrient loads from the GWLF model for scenarios representing A) *BASELINE* and B) *FADPERIOD2* conditions. The blue line shows the median of all the daily values and the red line shows a threshold defined by the 95th percentile of the distribution of daily data in the *BASELINE* scenario. Values above this threshold are considered to be extreme or bloom-like concentrations.

These data show that the effects of changes in watershed land use and the implementation of watershed nutrient reduction programs not only reduce the long-term mean values of epilimnetic chlorophyll, but also lead to important improvements in water quality by dramatically reducing the frequency of extreme chlorophyll values. When examining the progressive improvements in Cannonsville Reservoir water quality that occurred during the two FAD periods (Table 7.14), 34%-39% reductions in long-term mean values of epilimnetic chlorophyll are simulated to occur. Reductions in the extreme chlorophyll values are much more significant, with an 85%-89% decrease in occurrence. This is an important finding, since it is extreme events rather than long-term averages which actually influence the usability of the reservoirs as sources of drinking water. Most regulations (e.g., TMDL calculations) implicitly assume a linkage between the occurrence of extreme events and long-term mean concentrations. Here this is explicitly demonstrated.

When examining the effects of land use changes and watershed program implementation during *FADPERIOD2* (Table 7.14), it can also be seen that the cumulative effects of these changes had a proportionally greater impact on the extreme as opposed to the mean epilimnetic chlorophyll levels. The effects of land use changes alone led to a nearly 40% reduction in the occurrence of extreme chlorophyll values. Comparison of the *FADPERIOD2-LU-BMP* and *FADPERIOD2-LU-PS* scenarios shows that both the NPS BMP programs and PS reduction programs have a similar effect in reducing extreme chlorophyll concentrations. In Cannonsville, both programs when combined with land use changes led to a 74%-80% reduction in the number of extreme chlorophyll values.

Pepacton Reservoir shows similar trends to those described for Cannonsville Reservoir (Table 7.14). Even though the reductions in mean concentrations between the *BASELINE* and the two *FADPERIOD* scenarios are lower in Pepacton, the reductions in the frequency of extreme concentrations are of a similar magnitude in both reservoirs. This is to some extent the result of the reservoir-specific threshold being a function of the distribution of concentrations in that reservoir. However, it is significant that factors leading to long-term reductions in nutrient loading and long-term seasonal changes in P and chlorophyll have the beneficial effect of decreasing the extremes of the overall distribution of epilimnetic chlorophyll more than the mean of the distribution. This suggests that the impact of land use changes and the FAD programs will have an important impact in reducing higher concentrations, which could be a more critical water quality concern than the seasonal average.

7.1.5 Summary of Program Effects Estimated by Models

The effects of NPS management, PS upgrades, and land use change on eutrophication in Cannonsville and Pepacton Reservoirs were evaluated using DEP's Eutrophication Modeling System. Output from the GWLF watershed model provided loading estimates to evaluate watershed programs implemented as part of the Watershed Memorandum of Agreement. Four watershed management programs were evaluated: Point Source WWTP Upgrades, Watershed Agricultural Program, Urban StormWater Program and Regulations, and the Septic System Rehabilitation Program. In addition, a significant decline in agricultural land use and agricultural activity that occurred from the early 1990s to the late 2000s independent of deliberate watershed management was evaluated.

Calibrated and validated GWLF models for Cannonsville and Pepacton were used to estimate nutrient loads for a series of scenarios, each of which represents a combination of land use, NPS management and PS conditions. A *BASELINE* scenario represents conditions existing in the 1990s prior to implementation of FAD programs. Two FAD evaluation scenarios represent conditions of the early 2000s (*FADPERIOD1*) and late 2000s (*FADPERIOD2*), before and during which substantial implementation of FAD programs occurred. Nutrient reduction factors due to watershed management programs were applied to represent watershed management effects in each *FADPERIOD* scenario.

Changes in nutrient loading due to the combined effects of land use change and FAD programs were examined by comparing the *FADPERIOD* scenarios to the *BASELINE*. There was a ~49% reduction in dissolved P loads from the Cannonsville watershed from the *BASELINE* to *FADPERIOD1* and an additional ~7% reduction from *FADPERIOD1* to *FADPERIOD2*. For the Pepacton watershed, dissolved P export was reduced by ~23% from *BASELINE* to *FADPERIOD1* and an additional ~3% from *FADPERIOD1* to *FADPERIOD 2*. The large reductions seen between the *BASELINE* and *FADPERIOD1* correspond to a combination of high rates of new program implementation and substantial reduction in agricultural activity during that period. Continued but slower declines in P loads from *FADPERIOD1* to *FADPERIOD2* occurred as FAD programs became more focused on maintenance and improvement than on new program development, and the reduction in agricultural activity continued.

The relative effects of land use change versus watershed management on load reductions were examined by comparing the *BASELINE* scenario to all scenarios examined during *FADPERIOD2*. Land use change (decline in agriculture) and watershed management both produced substantial reductions in P loading. Loading reductions due to land use change alone were ~18% for dissolved P in Cannonsville, and ~10% for dissolved P in Pepacton. The combination of land use change and watershed management produced reductions of ~55% for dissolved P in Cannonsville and ~26% for dissolved P in Pepacton. PS WWTP upgrades and the implementation of agricultural BMPs by the WAP provided most of the loading reductions, with minor reductions from septic system remediation and urban stormwater management.

The effects of land use change, non-point BMPs, and PS management on the trophic status of Cannonsville and Pepacton Reservoirs were evaluated by driving reservoir water quality models with the different nutrient loading scenarios simulated using GWLF. Simulated loading reductions due to combined land use change and watershed management between *BASELINE* and *FADPERIOD1* resulted in a ~34% reduction in the May-October epilimnetic chlorophyll concentrations, and a ~30% reduction in the May-October epilimnetic total P concentrations in Cannonsville Reservoir. For Pepacton Reservoir, the same reductions in concentration were ~15% and ~9% for chlorophyll and total P, respectively. As was the case for the input loads simulated with GWLF, reductions in reservoir concentrations between *FADPERIOD1* and *FADPERIOD2* were lower. Between *FADPERIOD1* and *FADPERIOD2* there was a further reduction of ~5% in May-October epilimnetic chlorophyll concentrations and a ~3% further reduction in May-October epilimnetic total P concentrations. For Pepacton Reservoir, the additional reductions in concentration simulated as occurring between *FADPERIOD1* and *FADPERIOD2* were smaller, being ~3% for chlorophyll and ~2% for total P.

Land use and FAD program-specific effects on reservoir trophic status were examined by comparing the *BASELINE* scenario to all scenarios examined during *FADPERIOD2*. For Cannonsville Reservoir, lower watershed loads due to land use change only (decline in farming) resulted in reductions of ~9% for in-lake growing season chlorophyll and ~8% for total P. Greater reductions were predicted when the FAD programs were considered in addition to land use change (~39% for chlorophyll and ~32% for total P). The response of Pepacton Reservoir (which exhibited less eutrophication under *BASELINE* conditions) was similar, but the magnitudes of the reductions were less, suggesting that reservoirs with higher eutrophic conditions tend to benefit proportionately more from watershed load reductions.

Examination of daily, as well as long-term, mean reservoir chlorophyll levels suggests that the occurrence of extreme "bloom-like" epilimnetic chlorophyll concentrations are also affected by differing nutrient loading scenarios, and that the implementation of watershed management programs had an even greater impact on reducing the frequency of extreme epilimnetic chlorophyll concentrations than in reducing long-term mean concentrations.

7.2 Evaluation of Catskill Turbidity Control Through Use of Operations and Models

An integral component of the Catskill Turbidity Control Program involves the development and use of an Operational Support Tool (OST). The OST is a suite of data acquisition and database tools, linked reservoir water quality and water supply system models, and data visualization tools. An important use of the OST will be to develop and analyze scenarios which show the effects of different operational decisions during the occurrence of high flow/turbidity events on system storage and water quality. Although the full OST is not yet completed, some components of the system are already available and have been used to aid in operating decisions.

This section describes a case study of the use of the core modeling components of the OST to support operational decisions for the Catskill System during the winter and early spring of 2010. The case study shows that the use of model-based turbidity forecasting can help reservoir operators develop more informed decisions to mitigate the potential impacts of high turbidity levels in one part of the NYC water supply system, thereby minimizing the need for chemical treatment of the turbid water. Use of models during the case study event is described in three stages.

1. How modeling-based forecasts were used to inform operational decisions during the winter-spring 2010 turbidity event is described.
2. How well the models performed is evaluated by running a hindcast simulation where the models are driven using the actual flows and turbidity levels recorded during the event. Simulated reservoir turbidity levels are compared with measured data collected during the event.
3. The effectiveness of reservoir operations in mitigating turbidity impacts is evaluated by comparing the effects of the implemented operations (as described by the hindcast simulation) with the results of alternative scenarios based on other possible operational strategies.

7.2.1 Description of System

The model runs described in this section relate to decisions made for the Catskill System, specifically for Ashokan Reservoir and Kensico Reservoir. For Ashokan Reservoir, turbidity events are potentially mitigated through the operation of the Ashokan waste channel and the use of stop shutters to reduce Catskill Aqueduct flow from the Ashokan East Basin to Kensico Reservoir.

The Ashokan waste channel can be used to discharge water from the reservoir's West Basin directly into Esopus Creek downstream of the reservoir. Waste channel discharge can be used to create a storage void in the West Basin, and thereby reduce the probability of spill from the West Basin to the East Basin when a large event occurs. This reduction in spill can be an important means of turbidity control since water that spills during these events tends to have high levels of turbidity, and since water flowing across the dividing weir tends to impact the turbidity levels in the water withdrawal by the Catskill Aqueduct.

Stop shutters in the Catskill Aqueduct are used to reduce flow in the aqueduct while keeping the water levels in the aqueduct high enough to maintain service to upstate communities that draw water from the upper levels of the aqueduct. Stop shutters allow aqueduct flow reductions during periods of elevated turbidity in the Ashokan East Basin. Without the stop shutters the aqueduct flow would need to be greater to meet the needs of the upstate communities, which, in turn, would greatly increase turbidity inputs to Kensico Reservoir.

Kensico Reservoir simulations were run to determine the optimal ratios of Catskill System and Delaware System inputs to the reservoir, given the turbidity levels in each system. These simulations were used to guide the choice of aqueduct input flows to Kensico, in order to ensure that Kensico effluent turbidity remained below the 5 NTU regulatory limit.

7.2.2 Model Descriptions

Reservoir, watershed, and system models were used for the simulations described in this section. For all of the simulations, LinkRes and its component 2D CEQUAL W2 reservoir model (Cole and Buchak 1995, DEP 2004) were used to simulate turbidity values within the reservoir and aqueduct withdrawals. The CEQUAL W2 model has been set up and tested for the Ashokan West Basin, the Ashokan East Basin, and Kensico Reservoir. For the first set of simulations, the OASIS system model (HydroLogics, Inc. 2007, DEP 2007) as set up for the New York City supply was used to simulate aqueduct flows. Finally, for the simulation of March 12, the GWLF-VSA watershed model (Schneiderman et al. 2002, 2007; DEP 2006c) was used to forecast flows given an initial snow pack and a short-term forecast of meteorology.

A "positional analysis" strategy was followed for these model runs. Under this strategy, the initial conditions of the reservoir and watershed are used as the starting point for the model simulations. Then the model is run for a three-month period (the forecast period) into the future, using as inputs the meteorology, flows, and derived turbidity loads for the same three-month period for each year in the historical record: 1948-2004 for Ashokan model runs and 1987-2004 for Kensico model runs. With this method, each year represents a separate realization (or trace) of the simulated model outcomes. Taken in total, all of the traces can then be used to develop a statistical probability of potential simulated reservoir storage levels and turbidity. Figure 7.20 illustrates an example of the positional analysis strategy. The top panel shows a time series of model results for turbidity for each of the 57 traces representing the historical variability of climate from 1948-2004. Taken as a whole, probability distributions can then be derived from the results of these time series. The cumulative probability plot in the lower panel shows the fraction of traces that exceed a certain turbidity level during the forecast period. For example, a turbidity of 10 NTU is exceeded in 39% of the runs illustrated in the upper panel.

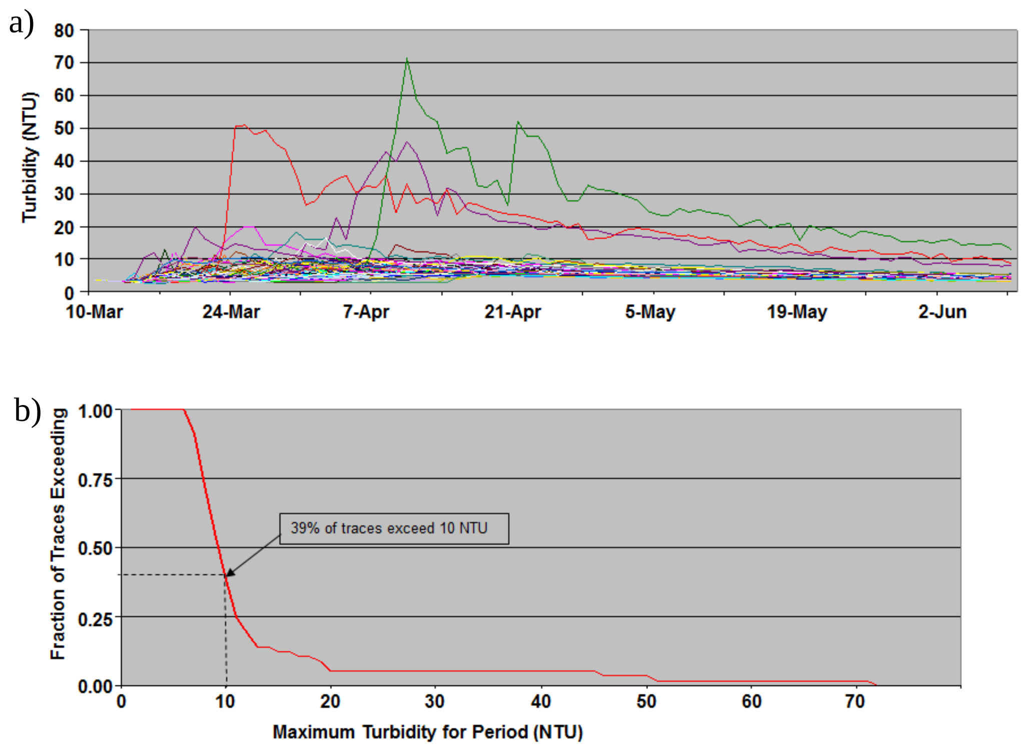


Figure 7.20 Example of positional analysis strategy. Upper panel (a) shows example results of a positional analysis simulation with 57 traces representing the variability in historical meteorology and inflows over the period 1948-2004. Lower panel (b) shows a cumulative probability distribution of maximum trace turbidity derived from the result in the upper panel (a). Panel (b) reflects the fraction of simulation traces that exceed a certain turbidity.

7.2.3 Modeling-Based Turbidity Forecasts

During the winter of 2010 there were a series of storm events that resulted in elevated turbidity in Ashokan Reservoir that could have potentially caused the turbidity in the water withdrawn from Kensico Reservoir to exceed the regulatory limit of 5 NTU. Figure 7.21 shows the time series of flows and turbidity, based on provisional data collected by USGS and Upstate Freshwater Institute (UFI), for Esopus Creek at Coldbrook, the major tributary input to Ashokan Reservoir. Winter and early spring 2010 were characterized by a significant combined rain and snowmelt event in late January, a calm February, and a large snowfall in the beginning of March, followed by a series of combined rain and snowmelt events in mid- to late March (Figure 7.21). As these events unfolded, conditions within the water supply system changed, and DEP's understanding of the potential consequences of the ongoing event on reservoir water quality evolved, requiring additional simulations to help inform operational decisions. A summary of the model simulations, the conditions that brought them about, and forecasting goals are given in Table 7.15.

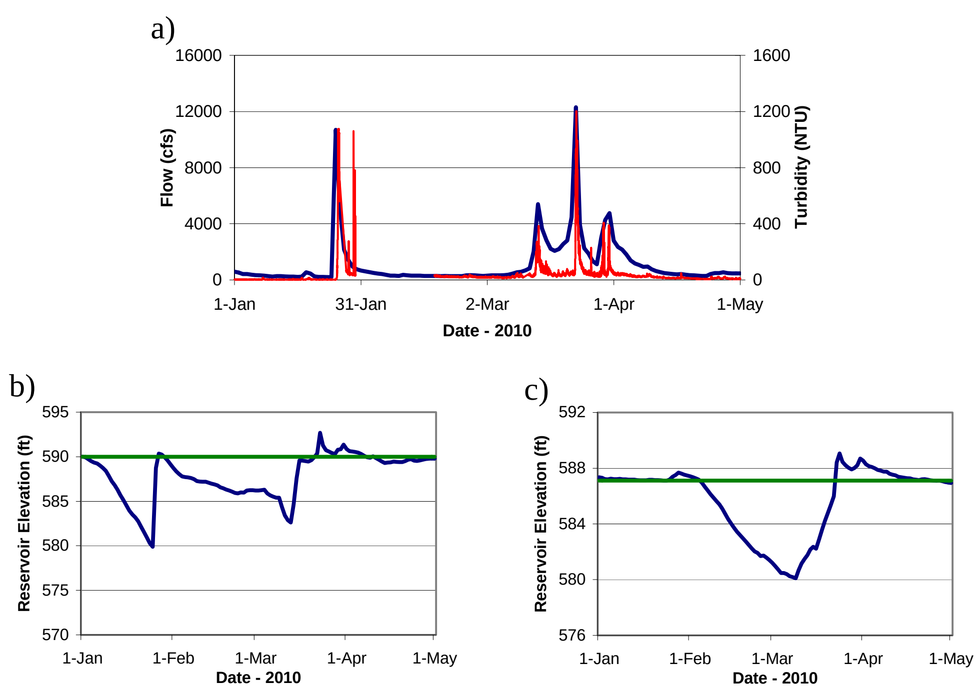


Figure 7.21 Esopus Creek and Ashokan Reservoir conditions during January-April of 2010. The top panel (a) shows the discharge (blue) and turbidity (red) measured in Esopus Creek at Coldbrook near its entry into Ashokan Reservoir. Panel (b) shows the storage elevation of the Ashokan Reservoir West Basin, with the elevation of the crest of the dividing weir in green. Panel (c) shows the storage elevation of the Ashokan Reservoir East Basin, with the spillway elevation in green. All data plotted here are provisional.

Table 7.15: Reservoir, system, and watershed model simulations used to inform operational decisions for maintaining water quality during the winter of 2010.

Date	Background	Simulation Description
Feb 26	West Basin turbidity was elevated due to storm event in late January, and there was a concern that if another large storm event were to occur, the West Basin would spill to the East Basin, creating elevated East Basin turbidity.	Ashokan Reservoir and OASIS simulations were run to examine the effects of operating the Ashokan waste channel on the risks of higher turbidity water spilling from the West Basin to the East Basin and on the resulting turbidity in the Catskill Aqueduct withdrawal from the East Basin.
March 10	A large snow event in the beginning of March added to the already developed snowpack, creating a risk of a potentially large streamflow event when the snow melted. Due to this concern a series of reservoir model simulations were performed to better understand the risks and to plan for possible scenarios.	Kensico Reservoir simulations were run to ascertain the sensitivity of Kensico effluent turbidity levels to the turbidity coming from the Catskill Aqueduct at a Catskill Aqueduct flow rate of 300 MGD. Catskill Aqueduct turbidity levels in the sensitivity simulations were 8, 10, and 15 NTU.
March 12	See March 10 above.	Ashokan Reservoir and GWLF watershed model simulations were performed to understand the risks of East Basin turbidity rising to different levels. Initial conditions of the GWLF runs included measurements of snowpack water equivalent and the simulations incorporated forecasts of an impending rain and snowmelt event into model input. These Ashokan runs were then placed into context with the Kensico sensitivity simulation results performed on March 10.
March 17	A rain and snowmelt event entered, but did not fill, the West Basin of Ashokan Reservoir. Due to the concern of more storms and rising East Basin turbidity, a further understanding of the impact of potentially elevated Catskill turbidity entering Kensico Reservoir was necessary.	Kensico Reservoir simulations were run to examine the impact of decreasing the Catskill Aqueduct flow rate to 300 MGD, 200 MGD, or 100 MGD assuming that the Catskill Aqueduct turbidity levels would range between 15-35 NTU.

Table 7.15: (Continued) Reservoir, system, and watershed model simulations used to inform operational decisions for maintaining water quality during the winter of 2010.

Date	Background	Simulation Description
March 25	A large rain and snowmelt event occurred on March 22, filling both the West and East Basin of Ashokan Reservoir. The storm also elevated East Basin turbidity. Stop shutters were installed in the Catskill Aqueduct to permit reduced flows from Catskill into Kensico Reservoir.	Kensico Reservoir simulations were run to examine the impact of decreasing the Catskill Aqueduct flow rate to 200 MGD, 150 MGD, 100 MGD, or 50 MGD assuming that Catskill Aqueduct turbidity levels would range between 30-50 NTU.
March 31	The large rain and snowmelt events that occurred in late March also had a small effect on turbidity entering Kensico from the Delaware Aqueduct. Further simulations were necessary to understand the effects of small increases in Delaware Aqueduct turbidity on the previous Catskill sensitivities for Kensico Reservoir.	Kensico Reservoir simulations were run to examine the impact of decreasing the Catskill Aqueduct flow rate to 100 MGD or 50 MGD assuming that Catskill Aqueduct turbidity levels would range between 20-50 NTU and Delaware Aqueduct turbidity would range between 2-3 NTU.
April 15	By this time, Catskill Aqueduct turbidity levels were following a declining trend. Further simulations were performed to better understand the impact of increasing Catskill Aqueduct flows into Kensico Reservoir.	Kensico Reservoir simulations were run to examine the impact of increasing the Catskill Aqueduct flow rate to 200 MGD, 300 MGD, or 400 MGD assuming that Catskill Aqueduct turbidity levels would range between 8-20 NTU.

February 26, 2010 Simulations

In January, the combined effects of snowmelt and rain caused Esopus Creek flow and turbidity to rise. As a consequence of the elevated turbidity loading to the West Basin of the Ashokan Reservoir, turbidity levels increased. The turbidity in the East Basin also began to rise as water spilled from the full West Basin to the East Basin until both basins were full (Figure 7.21b). If another large storm event were to occur, the West Basin would again spill to the East Basin, further increasing East Basin turbidity, and therefore the turbidity loads input to Kensico Reservoir via the Catskill Aqueduct. A series of CEQUAL-W2 reservoir model simulations and OASIS system model simulations were run for the Ashokan Reservoir to understand how the use of the Ashokan waste channel might reduce the risk of higher turbidity water in the West Basin spilling over the dividing weir and entering the East Basin. Two issues were investigated: (1) the timing of any potential spill of water from the West Basin to the East Basin and (2) the timing and level of future turbidity in the East Basin.

Two sets of positional analyses were performed to forecast the effects of waste channel use on probability of spill from the West to East Basins of Ashokan Reservoir. These simulations used historical inflows from 1948-2004 to produce 57 traces for analysis. Initial conditions were based on reservoir levels and water quality of February 2, the date of the most recent limnological survey that could be used for model initialization. Flow in the Catskill Aqueduct, withdrawing from the East Basin, was set to 470 MGD based on the operating conditions at the time of the simulations. The flow in the gate at the dividing weir was set to zero assuming that the only flow from the West Basin to the East Basin would be over the top of the dividing weir. The difference in the two sets of simulations was that one set did not operate the Ashokan waste channel, while the second set had the waste channel operating at 350 MGD.

Figure 7.22 shows the cumulative probability distribution for the simulated first date of spill from the West Basin to the East Basin. The red line shows the distribution of spill dates for the waste channel not operating and the blue line shows the case for the waste channel operating at 350 MGD. Not surprisingly, with the waste channel not operating, the West Basin, under almost all historical traces, quickly fills and spills water into the East Basin. With the waste channel operating, the date on which the West Basin spills varies widely, with about 35% of the traces spilling by March 15, 69% of the traces spilling by April 7, and about 85% of the traces spilling by the end of the forecast period at the beginning of May.

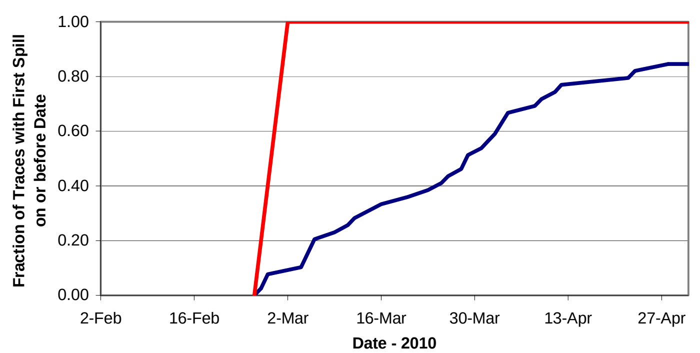


Figure 7.22 Results of OASIS positional analysis showing the fraction of traces that spill water over the dividing weir from the West Basin to the East Basin in the case of no Ashokan waste channel operation (red) and with waste channel operation of 350 MGD (blue).

The effects of the changes on the probability of West Basin to East Basin spill are also evident in the simulated East Basin withdrawal turbidity. Figure 7.23 shows the time series of the 57 traces of Ashokan East Basin effluent turbidity for each scenario. For cases where a major event takes place, the turbidity in the East Basin is impacted significantly in both the waste-channel-off and the waste-channel-on scenarios. However, in the majority of traces when a major event does not occur, the waste channel has a strong effect on the Catskill withdrawal turbidity, with values of about 2-8 NTU being forecast to occur with use of the waste channel and values of about 10 NTU forecast when the waste channel was off. The cumulative probability plot in Figure 7.24

shows the fraction of traces with East Basin effluent turbidity that exceed 10 NTU on or before a given day for the three-month simulation period. The simulations indicate that on or before March 30, about 70% of the traces had Catskill withdrawal turbidity above 10 NTU with the waste channel off, while only about 15% of the traces exceeded the same threshold with the waste channel on. Similarly, on or before May 1, over 95% of the traces exceeded 10 NTU in the waste-channel-off case, and slightly less than 35% of the traces exceeded 10 NTU with the waste channel operating.

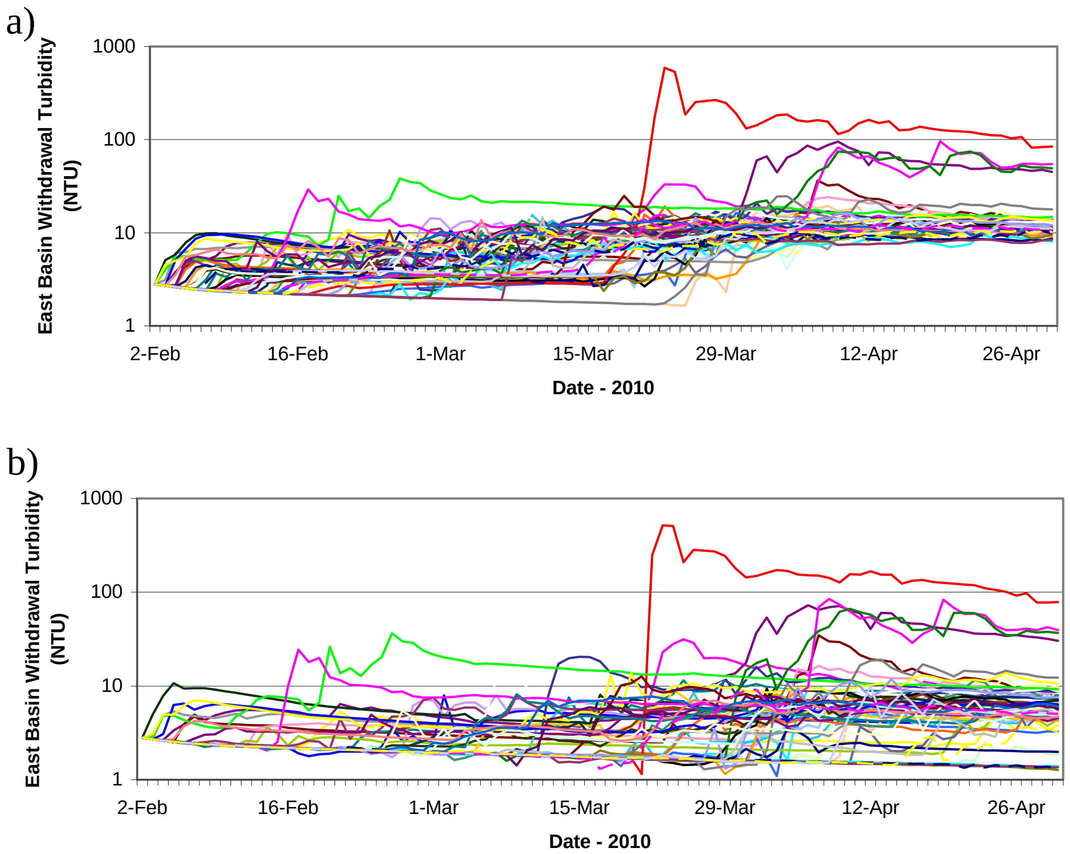


Figure 7.23 CEQUAL-W2 simulation traces of Catskill Aqueduct withdrawal turbidity from the East Basin with (a) waste channel off, (b) waste channel flow set to 350 MGD.

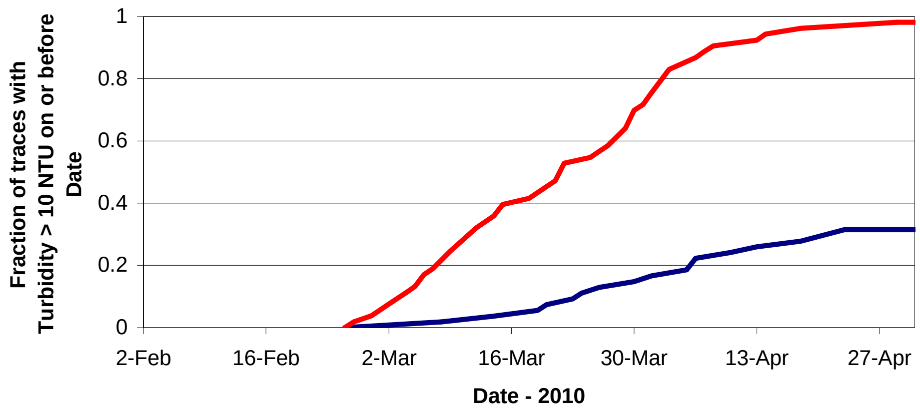


Figure 7.24 Cumulative probability function showing the fraction of simulation traces with turbidity greater than 10 NTU in the Catskill Aqueduct withdrawal from the Ashokan East Basin with the waste channel off (red) and with the waste channel operating at 350 MGD (blue).

These simulations illustrated that operation of the Ashokan waste channel had the potential to significantly delay the spill of West Basin water to the East Basin, which, in turn, greatly reduced the probability that East Basin turbidity would exceed 10 NTU. The use of the waste channel reduced turbidity in all historical traces, even though turbidity associated with extreme events was not as strongly reduced as for storms occurring in more typical years. Based on this set of model forecasts it was recommended that the waste channel be used to draw down the level of water stored in the Ashokan West Basin during the winter of 2010.

March 10-12, 2010 Simulations

After a period of relative calm during February, a large snow event in the beginning of March created a risk of a potentially large streamflow event. The snow pack in the Ashokan watershed became unusually large, with 31 billion gallons (BG) of snow water equivalent estimated by a snow survey conducted on March 1, compared to an historical average of about 11 BG. This level of water storage in snow within the watershed created a risk of a potentially large streamflow event when the snow melted. Due to this concern a series of Ashokan and Kensico Reservoir model simulations were performed to better understand the risks and to plan for possible mitigation measures. Kensico Reservoir simulations were used to define turbidity levels in the Catskill Aqueduct that may create a concern for Kensico Reservoir effluents. Ashokan Reservoir simulations were performed to quantify the risks of East Basin turbidity rising to levels of concern as defined by the Kensico simulations. The Ashokan runs were driven by GWLF simulations that accounted for the unusually high snow water equivalent at the onset of the simulations. Forecasts of an impending rain and snowmelt event were incorporated into a positional analysis that made use of historical flow and meteorological data.

To examine the effects of the potential turbidity inputs to Kensico Reservoir under current aqueduct flows, a set of turbidity simulations for Kensico Reservoir was used. These were also run in a positional analysis framework, using meteorological forcings and aqueduct input water temperatures for the years 1987-2004 (18 traces) to represent historical variability in the model forcings. The simulations were run for a three-month forecast period from March 10-June 10. Initial conditions in the reservoir were based on robotic monitoring information collected on March 9. Aqueduct flow inputs to Kensico were set to 300 MGD from Catskill and 800 MGD from Delaware and flow outputs from Kensico were set to 400 MGD and 700 MGD via Catskill and Delaware Aqueducts, respectively. For all runs the input turbidity from the Delaware Aqueduct was set to 1 NTU based on conditions at the time. Kensico effluent sensitivity was tested by performing three sets of simulations with input Catskill turbidity of 8, 10, and 15 NTU. These simulations assume that the inputs and outputs are constant for the three-month forecast period.

Figure 7.25 shows the results for the three input turbidity scenarios. The plots show the median and range of Kensico Reservoir effluent turbidity via the Catskill Aqueduct for the 18 traces. Delaware Aqueduct effluents from Kensico were of a similar magnitude and showed similar trends in turbidity, and are therefore not shown. Effluent turbidity was predicted to rise to about 2-3 NTU with a sustained Catskill Aqueduct input of 8 NTU, while the effluent turbidity prediction was about 3-5 NTU with sustained Catskill input of 15 NTU. These results indicated that inputs of greater than 10 NTU from the Catskill Aqueduct would cause the effluent turbidity levels to come close to or exceed the 5 NTU regulatory limit for the Kensico effluent.

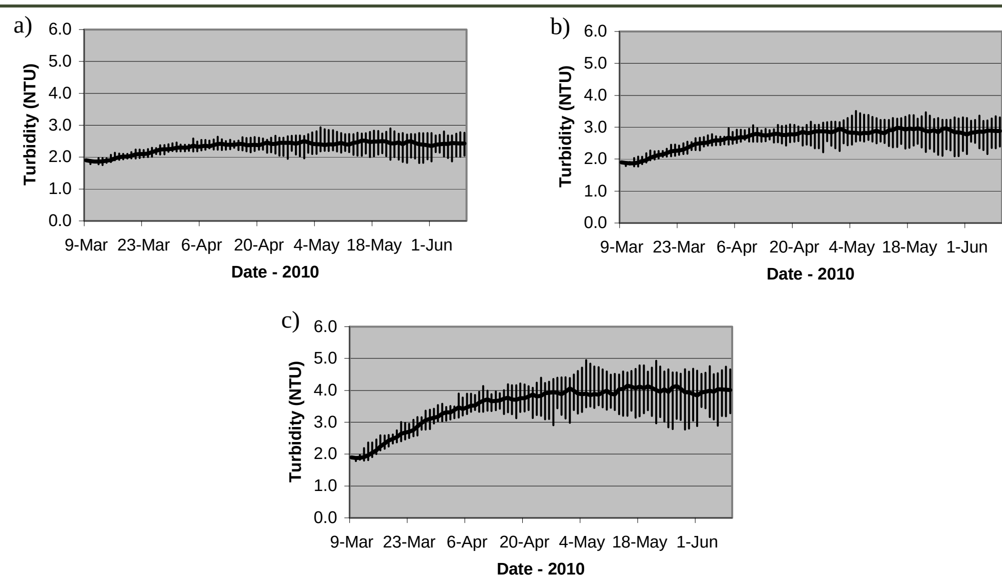


Figure 7.25 Results of CEQUAL-W2 simulations from March 10, 2010, for Kensico Reservoir effluent turbidity, with influent Catskill turbidity of (a) 8 NTU, (b) 10 NTU, and (c) 15 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the error bars show the range of values for all traces.

A positional analysis of Ashokan Reservoir was performed to further understand the risks of Catskill Aqueduct turbidity exceeding levels of concern indicated by the Kensico simulations. At the start of the simulations, the parameter in the GWLF-VSA model specifying the snow pack snow water equivalent was set to the Ashokan basin average determined from a recent snow survey. During the first three days of the simulation, short-term forecast meteorology was used to drive the model, while for the remaining three-month forecast period historical meteorology for 1948-2004 was used as input to generate 57 traces of input streamflow. These streamflow and derived turbidity forecasts from GWLF became the input to the Ashokan Reservoir CEQUAL-W2 model, which was used to determine the potential effects of variations in input turbidity on the turbidity in the Catskill Aqueduct withdrawal from the East Basin. Assumptions for these simulations included the waste channel operating at 400 MGD, the Catskill Aqueduct withdrawal was operating at 300 MGD, and the gate at the dividing weir was closed so flow from the West Basin to the East Basin could only go over the dividing weir crest. As with other simulations of this type, the operating conditions are assumed to be constant for the entire three-month forecast period.

The results for the forecast Catskill Aqueduct withdrawal turbidity from Ashokan are shown in Figure 7.20. The top panel of the figure shows the results for the 57 forecast traces of the positional analysis. The lower panel shows the cumulative probability function derived from these traces, showing the fraction of traces with turbidity exceeding 10 NTU during the forecast period. For the forecast period, roughly 39% of the traces had turbidity exceeding 10 NTU and 12% of the traces had turbidity exceeding 15 NTU.

These two sets of simulations forecast that there was about a 39% probability, given current operations and watershed and reservoir conditions, that the turbidity entering the Catskill Aqueduct at Ashokan might exceed 10 NTU, a level indicated by Kensico simulations to be a threshold of concern.

March 17, 2010 Simulations

As a number of storm events combining rain with melt of the large snow pack began to impact Ashokan Reservoir, further Kensico Reservoir sensitivity runs were performed to inform operational decisions, as conditions in the reservoir and watershed evolved. The use of the waste channel earlier in the winter mitigated the effects of the first storm in March by preventing spill over the dividing weir from the West Basin to the East Basin. In mid-March, after the first storm, a set of Kensico Reservoir simulations were performed to define Ashokan effluent turbidity levels beyond which Catskill Aqueduct flow would need to be reduced through the use of stop shutters.

Sensitivity simulations for Kensico Reservoir were done again in the positional analysis framework using meteorological forcings and aqueduct input water temperatures for the years 1987-2004 (18 traces) to represent historical variability in the model forcings. The simulations were run for a three-month forecast period from March 15-June 15. Initial conditions in the reservoir were based on robotic monitoring information collected on March 15. Aqueduct flow outputs from Kensico were set to 400 MGD and 700 MGD via Catskill and Delaware Aqueducts, respectively. For all runs the input turbidity from the Delaware Aqueduct was set to 1 NTU based on conditions at the time. To test various inflow and turbidity combinations input from the Catskill Aqueduct to Kensico Reservoir, flows were set to 100, 200, and 300 MGD and input turbidities were set to 15, 25, and 35 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow of the two aqueducts equaled 1,100 MGD. Each of the simulations assumes that these inputs and outputs are constant for the three-month forecast period.

Figure 7.26 shows the results for the scenarios with 300 MGD input from the Catskill System. The plots show the median and the range of effluent turbidity for the 18 traces. For the case of 15 NTU input from the Catskill System, the Kensico effluent turbidity would rise dangerously close to 5 NTU. Figure 7.27 shows the results for the 100 MGD Catskill input scenarios. In this case, the reduced input flow from the Catskill Aqueduct results in a reduced Kensico effluent turbidity of about 2-2.5 NTU with a 15 NTU input from Catskill, and a Kensico effluent turbidity of about 2.5-4 NTU with a 35 NTU input from Catskill. These runs indicated that if turbidity in the East Basin of Ashokan Reservoir were to increase beyond 15 NTU, use of stop shutters to reduce Catskill Aqueduct flow to below 300 MGD would be necessary.

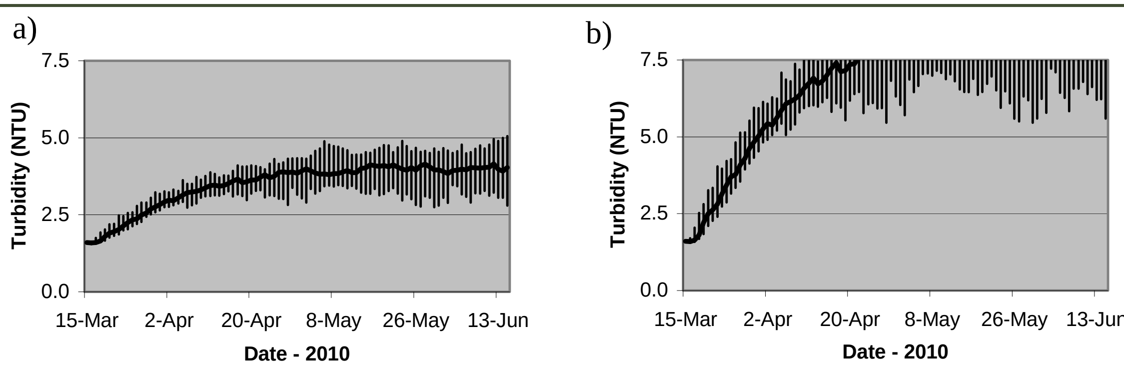


Figure 7.26 Results of CEQUAL-W2 simulations from March 17, 2010, for effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 300 MGD and influent Catskill turbidity of (a) 15 NTU and (b) 35 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the vertical bars show the range of values for all traces.

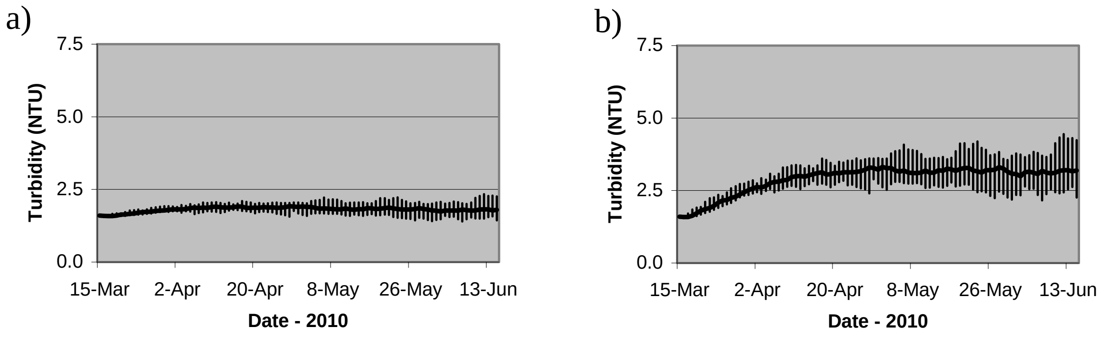


Figure 7.27 Results of CEQUAL-W2 simulations from March 17, 2010, for effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 100 MGD and influent Catskill turbidity of (a) 15 NTU and (b) 35 NTU.

March 25, 2010 Simulations

A large storm event on March 22 filled Ashokan Reservoir and water began to spill from the West Basin to the East Basin. East Basin turbidity began to rise and stop shutters were employed to reduce Catskill Aqueduct flow to Kensico Reservoir. A series of Kensico sensitivity simulations were run to better define acceptable levels of reduced flow in the Catskill Aqueduct. The positional analysis framework used in previous Kensico simulations was used again for these scenarios. The simulations were run for a three-month forecast period from March 25-June 25. Initial conditions in the reservoir were based on robotic monitoring information collected on March 25. Aqueduct flow outputs from Kensico were set to 400 MGD and 700 MGD via the Catskill and Delaware Aqueducts, respectively. For all runs, the input turbidity from the Delaware Aqueduct was set to 1.5 NTU based on conditions at the time. To test various inflow and turbidity combinations from the Catskill Aqueduct to Kensico Reservoir, flows were set to 50, 100, 150, and 200 MGD and input turbidities were set to 30, 40, and 50 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow of the two aqueducts equaled 1,100 MGD. Each of the simulations assumes that these inputs and outputs are constant for the three-month forecast period.

Figure 7.28 shows the results for the minimum flow scenarios, which used a 50 MGD input from the Catskill System. The plots show the median and the range effluent turbidity for the 18 traces. For the case of a 30 NTU input from the Catskill System, the Kensico effluent turbidity was predicted to rise to about 2.5 NTU, while for the case of a 50 NTU Catskill input, the Kensico effluent turbidity was predicted to rise to about 2.5-3.5 NTU. Figure 7.29 shows the other extreme of the inflow scenarios, with the Catskill input fixed at 200 MGD. As expected, in this case the high turbidity from the Catskill Aqueduct has a more detrimental effect on the simulated Kensico effluent turbidity, with levels rising to over 5 NTU for all the input scenarios. The full set of forecast runs indicated that if Catskill influent turbidity was in the 30-50 NTU range for a sustained period of time, the Catskill Aqueduct flow into Kensico should be reduced to 50-100 MGD.

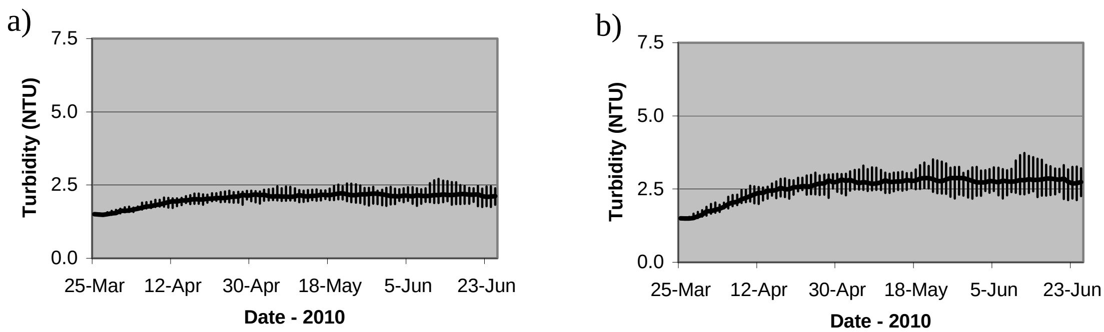


Figure 7.28 Results of CEQUAL-W2 simulations from March 25, 2010, for effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 50 MGD and influent Catskill turbidity of (a) 30 NTU and (b) 50 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the error bars show the range of values for all traces.

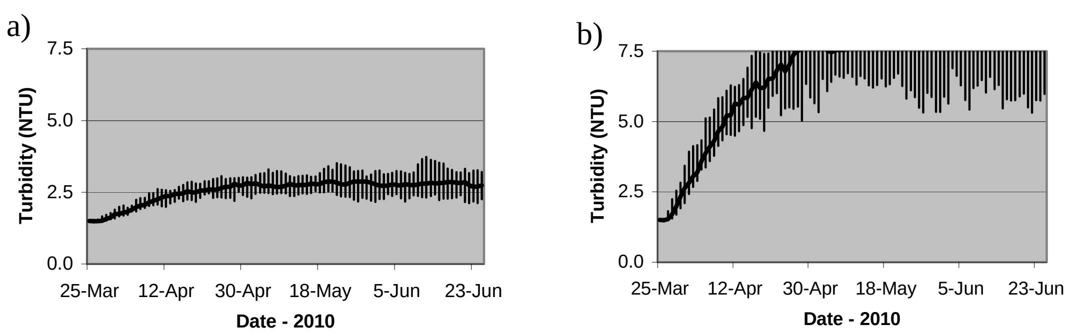


Figure 7.29 Results of CEQUAL-W2 simulations from March 25, 2010 for effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 200 MGD and influent Catskill turbidity of (a) 30 NTU and (b) 50 NTU.

March 31, 2010 Simulations

A final large rain and snowmelt event occurred on March 31, which necessitated further Kensico simulations with higher turbidity inputs from the Delaware Aqueduct than were used in previous runs. These runs built on the simulations of March 25, only in this case, turbidity levels in the Delaware Aqueduct input to Kensico Reservoir were increased and the sensitivity of Kensico effluent turbidity to Delaware input turbidity levels of 2 NTU and 3 NTU were examined. As an example of the results from these simulations, Figure 7.30 shows the plots of simulated Kensico effluent turbidity for the scenarios with the lowest and highest input turbidity loads. For the lowest turbidity loads, the Kensico effluent was simulated to rise to about 2-3 NTU, while for the highest turbidity loading, the Kensico effluent was simulated to rise to about 2.5-4 NTU, a level that is close to the acceptable threshold. Based on these runs, it was predicted that with a Delaware input turbidity of 2 NTU, a Catskill input turbidity of about 50 NTU could be tolerated at a flow rate of 50 MGD, while with a Delaware input turbidity of 3 NTU, a Catskill turbidity of no more than 40 NTU could be tolerated. These runs highlight the importance of low turbidity Delaware System water in maintaining low turbidity at the Kensico effluent during Catskill turbidity events, and that the system is fairly resilient as long as large flow reductions of a turbid Catskill System are possible and can be combined with low turbidity inputs from the Delaware System.

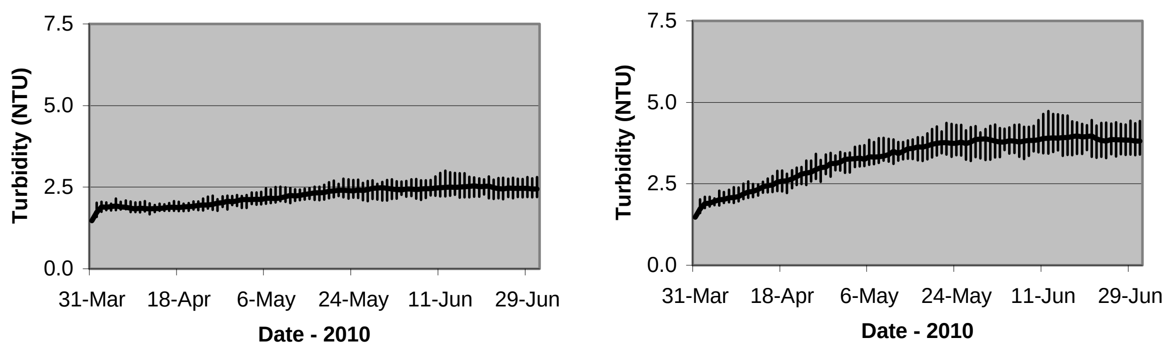


Figure 7.30 Results of CEQUAL-W2 simulations from March 31, 2010, for effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 50 MGD and Delaware Aqueduct inflow of 1,050 MGD. Influent turbidity is (a) 30 NTU for Catskill and 2 NTU for Delaware, and (b) 50 NTU for Catskill and 3 NTU for Delaware.

April 15, 2010 Simulations

In mid-April, once turbidity in the East Basin declined as a result of reduced inputs and particle settling, additional Kensico Reservoir sensitivity simulations were performed to forecast the effects of increased Catskill Aqueduct flow. These simulations were used to help inform decisions about the timing of stop shutter removal and the level of increased flow that could be used after stop shutter removal.

Kensico positional analysis simulation was used again for these scenarios. The simulations were run for a three-month forecast period from April 15-July 15. Initial conditions in the reservoir were based on robotic monitoring information collected on April 12. Aqueduct flow outputs from Kensico were set to 400 MGD and 700 MGD via the Catskill and Delaware Aqueducts, respectively. For all runs, the input turbidity from the Delaware Aqueduct was set to 1.5 NTU based on conditions at the time. To test various inflow and turbidity combinations input from the Catskill Aqueduct to Kensico Reservoir, flows were set to 200, 300, and 400 MGD and input turbidities were set to 8, 10, 15, and 20 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow of the two aqueducts equaled 1,100 MGD. Each of the simulations assumes that these inputs and outputs are constant for the three-month forecast period.

The results (not shown) indicated that at Catskill Aqueduct turbidity levels of 8 NTU, Catskill Aqueduct flows up to 400 MGD would lead to Kensico effluent turbidity of 2.5-3.5 NTU. At Catskill Aqueduct turbidity levels of 10 NTU, Catskill Aqueduct flows of up to 300 MGD would lead to acceptable Kensico effluent turbidity. If sustained input turbidity levels exceeded 15 NTU, the simulations suggested that flow levels below that possible in the absence of stop shutters would be needed. It was therefore recommended that the stop shutters not be removed until turbidity levels fell below 15 NTU.

7.2.4 Hindcasting Scenario

A hindcasting scenario is used to represent conditions within the Catskill System that closely match the historical conditions during the winter and early spring of 2010. This historical simulation serves two purposes: (1) to verify the performance of the reservoir water quality models by comparing simulated and measured reservoir and aqueduct turbidity levels, and (2) to establish a baseline model run that represents the actual operations and conditions during the 2010 turbidity event which can then be compared to scenarios describing alternative reservoir operations.

A coupled Ashokan West, Ashokan East, and Kensico Reservoir simulation was run between January 15 and April 30, 2010, using LinkRes and its component model 2D reservoir model CEQUAL W2 (Cole and Buchak 1995, DEP 2004). Historical flows, input turbidity, meteorology, and operations data were used as model inputs during the entire simulation period. Initial conditions for the reservoirs in all runs reflect robotic monitoring information collected on Jan 11, 2010. Initial reservoir temperatures were assumed to be isothermal and 0.5 and 1.0 degrees Celsius for Ashokan West and Ashokan East, respectively. Initial ice thickness was set to 0.05 m for Ashokan and 0.0 m for Kensico Reservoirs. An input temperature profile was developed to represent slightly stratified conditions in Kensico Reservoir.

The major input flow to Ashokan Reservoir is Esopus Creek. Figure 7.21 shows the time series of flows and turbidity, based on provisional data collected by USGS and UFI, for Esopus Creek at Coldbrook. For the historical scenario, provisional flow inputs from Esopus Creek were slightly adjusted in order to obtain an appropriate water balance in the Ashokan West Basin. As the reservoirs are run in a linked format, the operational flows from one reservoir to another are specified by the modeling system. Therefore the output of the Ashokan West simulation becomes input to the Ashokan East model, and the output of Ashokan East becomes input to the Kensico model. The major input to Kensico from the Delaware System was specified based on measured aqueduct flow, turbidity, and water temperature.

Figure 7.31 shows a comparison between simulated and measured water surface elevation for Ashokan and Kensico Reservoirs. The modeled water surface elevations match the observed values closely, showing that the water balance of each reservoir is correctly simulated.

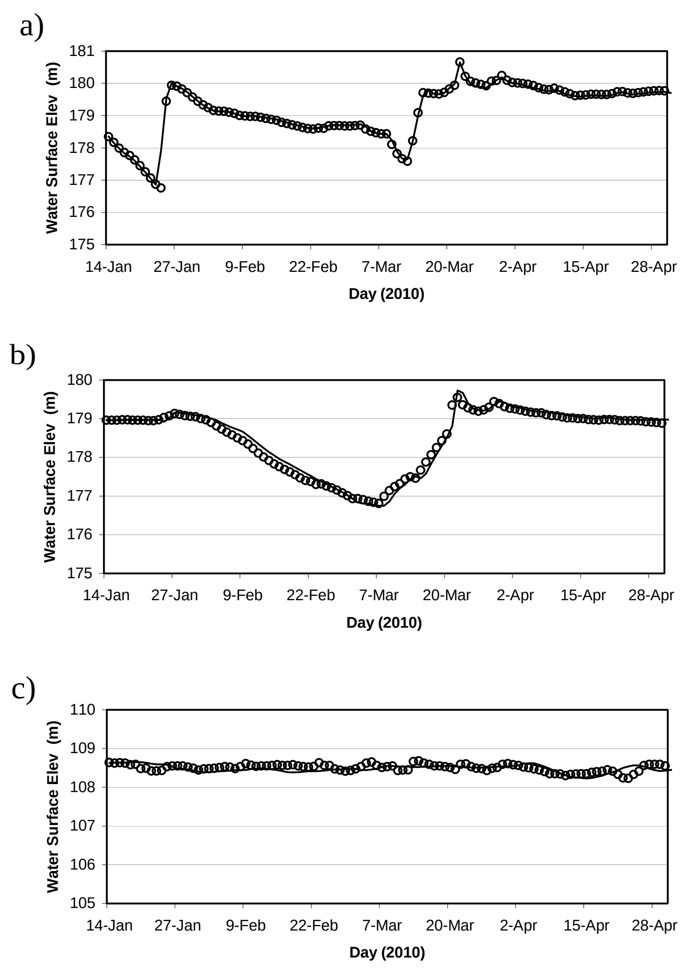


Figure 7.31 Hindcast water surface elevation (line) compared to measured provisional data (points) for (a) Ashokan Reservoir West Basin, (b) Ashokan Reservoir East Basin, and (c) Kensico Reservoir.

Figure 7.32a shows that the model simulated and measured turbidity in the Ashokan West Basin. The data points show measurements taken at the elevation taps located in the West Basin gatehouse. The measurements of turbidity were made at three different vertical locations (surface, middle, and bottom) by sampling water from the gatehouse elevation taps. These observed values are the measure of turbidity in the West Basin during winter, when a more traditional limnological survey is difficult due to ice cover. During the January 2010 event, surface turbidity observations increased rapidly to over 200 NTU. The rise in turbidity at the middle and lower levels was less extreme, with the middle level rising to about 50 NTU and the bottom rising at a slow rate to about 13 NTU. The line on the graph shows the simulated turbidity of the flow from the West Basin to the East Basin through the dividing weir gate, which is at a depth of about 12 meters. The simulated dividing weir gate turbidity is generally representative of a mix of the three measured values. However, during January, when turbidity was stratified with a surface maximum, model simulation of the flow through the dividing weir gate best matches turbidity measurements made at the mid-level elevation tap (Figure 7.32a). After the January event, the West Basin turbidity began to decline, with turbidity at all levels ranging from 10-13 NTU on March 6. During the next large event in mid-March, West Basin turbidity again rose quickly to about 100 NTU and steadily decreased to about 14-22 NTU at the end of April. The model-simulated turbidity in the dividing weir gate continued to reasonably predict these turbidity values for the full period from February-April 2010.

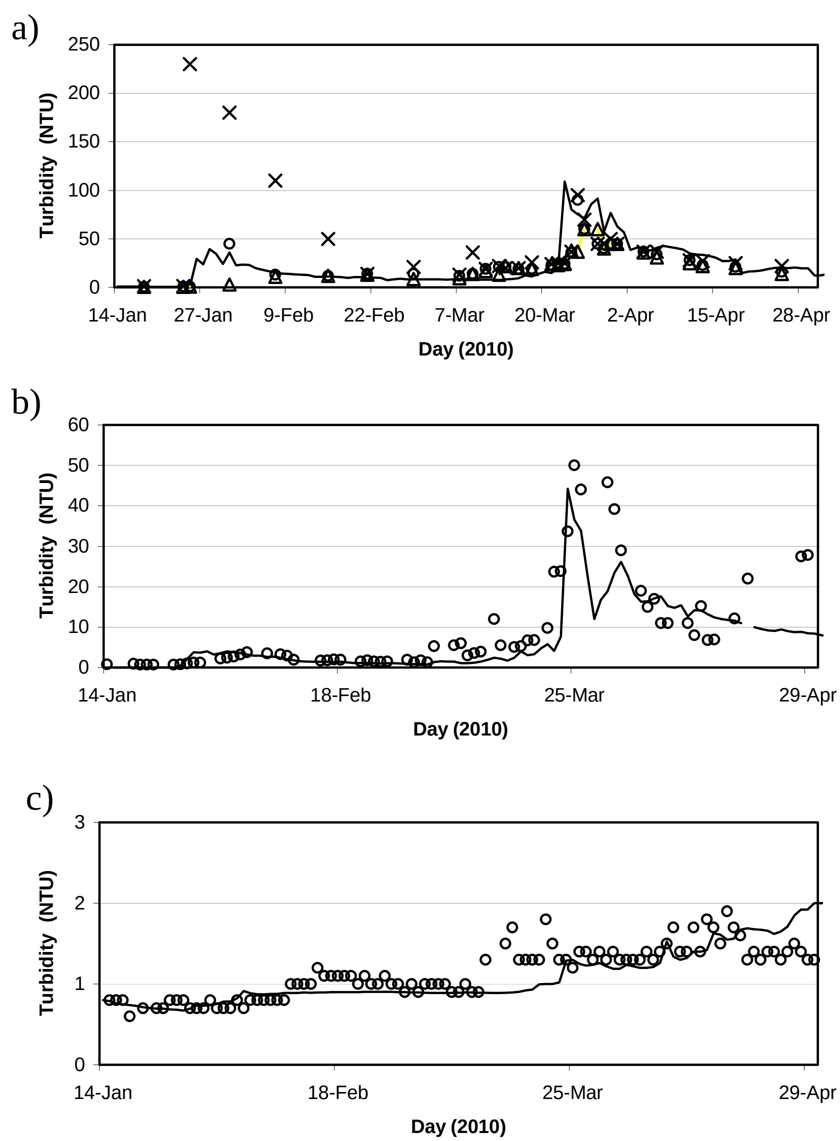


Figure 7.32 Observed and simulated turbidity in Catskill System reservoirs: a) West Basin Ashokan Reservoir. The observed turbidity is obtained at elevation taps at the West Basin gatehouse at three depths: surface (triangles), middle (circles), and bottom (x). The solid line shows the model simulated turbidity in the flow of the dividing weir gate, which is generally representative of a combination of the three observed values. b) Observed (dots) versus simulated (line) turbidity from the East Basin withdrawal to the Catskill Aqueduct. c) Kensico Reservoir Catskill effluent observed turbidity (dots) versus modeled turbidity (line).

For Ashokan East Basin, the turbidity as measured in the Catskill Aqueduct effluent is compared to the model-simulated result for the same effluent (Figure 7.32b). For the January event, very little water spilled from the West Basin into the East Basin, and therefore the turbidity increase in the East Basin withdrawal was only about 4 NTU. The simulated withdrawal turbidity also exhibited a slight increase during the January 2010 event, followed by a long-term decrease in turbidity through the beginning of March. In mid-March, large flows moved from the West Basin to the East Basin due to a series of storms during March filling the West Basin. The spill from the West Basin to the East Basin led to elevated turbidity levels in the East Basin withdrawal, with turbidity in the withdrawal climbing to about 50 NTU. Turbidity remained elevated for about one week and then decreased to less than 10 NTU during the following two weeks. The model simulation of this mid-March and early April period also simulated the peak turbidity well, although the simulated turbidity tended to initially decrease somewhat more rapidly when compared to the observed turbidity. The longer two-week decline in turbidity was simulated quite accurately by the model.

Turbidity results for the Catskill Aqueduct effluent from Kensico Reservoir are shown in Figure 7.32c. During the simulation period the observed turbidity in the Kensico Reservoir effluent increased somewhat from about 0.7 NTU in January to about 2.0 NTU at the end of April. Model simulation of this turbidity increase was quite accurate in both magnitude and rate of increase. These results demonstrate that the model is representing the historical conditions relatively well. These data also demonstrate that DEP was able to effectively manage the elevated Ashokan Reservoir turbidity and maintain the quality of water withdrawn from Kensico Reservoir by using operational control measures.

7.2.5 Effects of Alternative Operational Decisions During Winter and Early Spring 2010

This section presents a retrospective analysis of the influence of operational decisions on reservoir water quality during the winter and early spring events of 2010. In this analysis the actual operational decisions and the resulting reservoir turbidity levels defined by the hindcasting analysis described above are compared to three alternative operating scenarios:

1. No use of the waste channel, with all other conditions remaining the same as in the hindcasting scenario (Figure 7.33a; NoWC alternative).
2. No use of stop shutters, which results in the Catskill Aqueduct flow being maintained at the minimum possible level of 275 MGD from the East Basin of Ashokan to Kensico through the Catskill Aqueduct (Figure 7.33b). As part of this scenario Delaware Aqueduct flow into Kensico Reservoir is adjusted accordingly to preserve the total inflow to Kensico equal to that of the historical scenario. All other conditions including use of the waste channel are the same as in the hindcasting scenario (NoSS alternative).
3. Applying both (1) and (2) so that neither the Ashokan waste channel nor the Catskill Aqueduct stop shutters were used (NoWC+SS alternative).

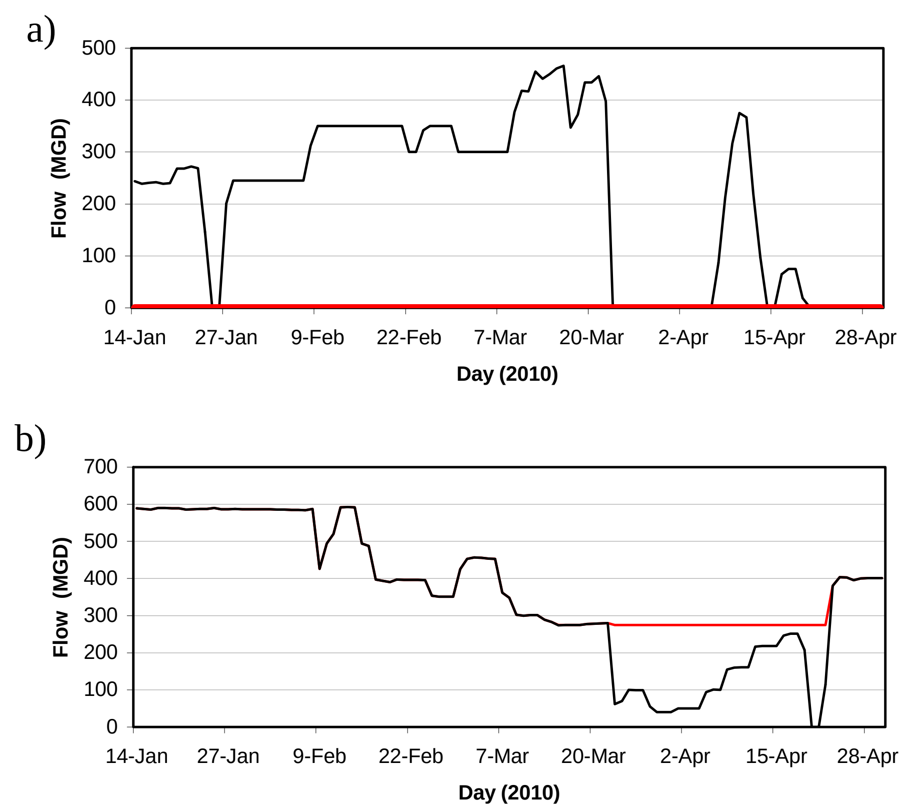


Figure 7.33 Flow time series for (a) waste channel and (b) Catskill Aqueduct withdrawal from Ashokan Reservoir for historical scenario (black line) and alternative scenarios (red line). For (a), alternative NoWC is shown; for (b), alternative NoSS is shown.

These scenarios are based on the fact that during the winter and early spring of 2010, the waste channel was used to minimize spill from the Ashokan West Basin to the East Basin and/or stop shutters were employed to reduce flows in the Catskill Aqueduct. Historically, these two measures were rarely used together to mitigate the effects of Catskill System turbidity or to reduce the use of alum treatment. The impact of each of the above alternative scenarios is investigated below by comparing the spill volume and spill turbidity from Ashokan West to Ashokan East and out of Ashokan East, as well as the turbidity levels at the Catskill and Delaware effluents from Kensico and the turbidity at the dividing gate.

NoWC Alternative

During this period, the effects of not using the waste channel caused a series of small flows over the dividing weir to occur from Ashokan West Basin to the East Basin (Figure 7.34a) during smaller events between February 7 and March 9. These flows did not occur under the hindcasting scenario. For the large mid-March events the NoWC alternative leads to flow over the dividing weir to begin about one week earlier compared to the hindcasting scenario. The increased flow over the dividing weir only slightly impacts the turbidity in the Catskill Aqueduct withdrawal from Ashokan Reservoir (Figure 7.35b) and the spill out of Ashokan East Basin (Figure 7.34b). When this input is simulated through Kensico Reservoir, the simulated peak turbidity for the study period in the Kensico effluent only increases about 0.2 NTU from the level indicated by the historical scenario (Figure 7.35c).

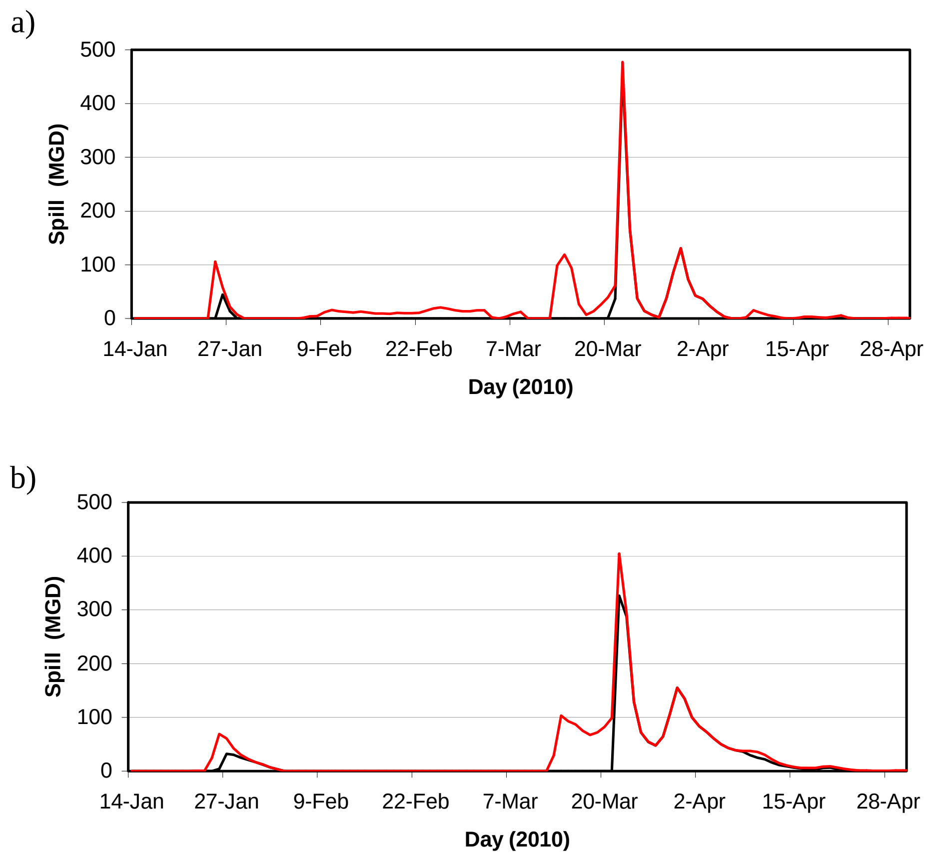


Figure 7.34 Simulated flows for the historical and three alternative scenarios: (a) flow over dividing weir from Ashokan Reservoir West Basin to East Basin and (b) spill from Ashokan Reservoir East Basin to Lower Esopus Creek. Historical and NoSS scenarios are black line; NoWC and NoWC+SS scenarios are red line.

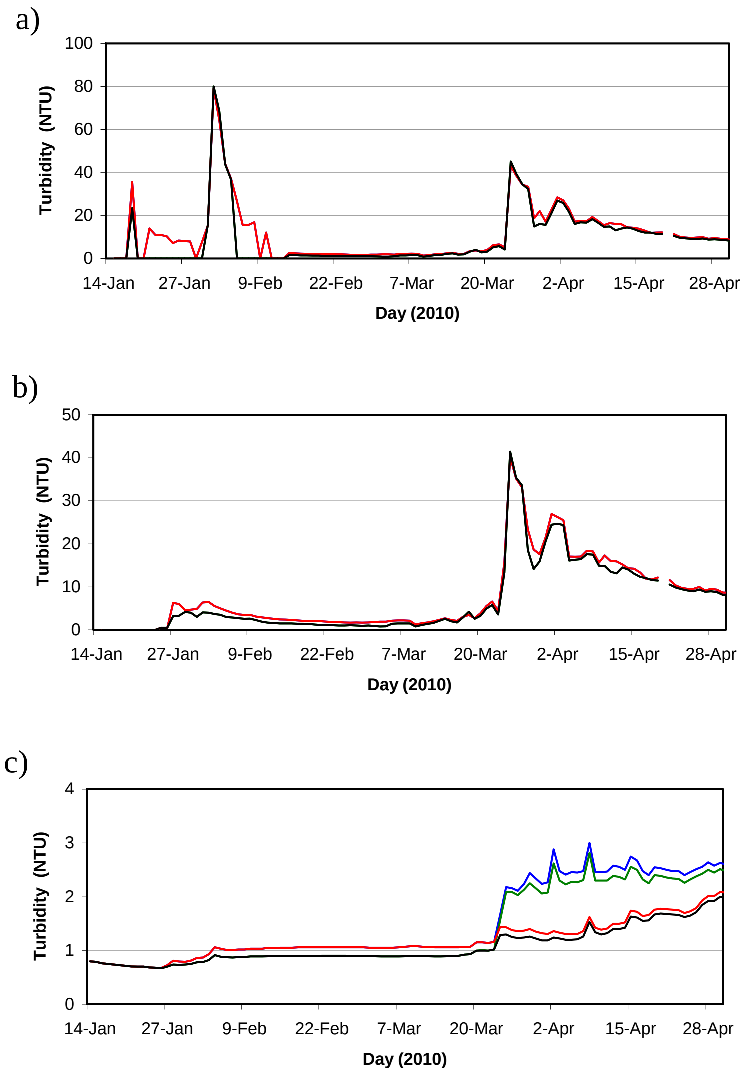


Figure 7.35 Simulated turbidity for the historical and three alternative scenarios for (a) flow over dividing weir from Ashokan Reservoir West Basin to East Basin, (b) aqueduct withdrawal from Ashokan Reservoir East Basin, and (c) Catskill Aqueduct effluent of Kensico Reservoir. Historical scenario is black line, NoWC scenario is red line, NoSS scenario is green line, NoWC+SS scenario is blue line.

NoSS Alternative

One of the most effective methods to mitigate the effects of turbidity in the Catskill System is to reduce the use of Catskill water while increasing the use of water from the Delaware System. Given the diversity of the NYC water supply, selective use of water is an important regulator of water quality.

The use of the stop shutters reduced the turbidity load (flow multiplied by turbidity) to Kensico Reservoir by limiting the flow from the Catskill Aqueduct during high turbidity periods. Figure 7.36 shows the turbidity load from the Catskill Aqueduct into Kensico Reservoir for the hindcasting and alternative scenarios. The NoSS scenario (green line) causes a large spike of turbidity to enter Kensico Reservoir after the mid-March storm event. This spike in turbidity load has a strong effect on Kensico effluent turbidity, with a rapid increase in simulated turbidity at the Kensico Reservoir effluent from 0.9 NTU to 2.2 NTU (Figure 7.35c). This effluent turbidity continues to rise into April with spikes of simulated turbidity near 3 NTU. These results indicate a significantly increased risk of elevated turbidity in the Kensico effluent if use of the stop shutters had not been implemented.

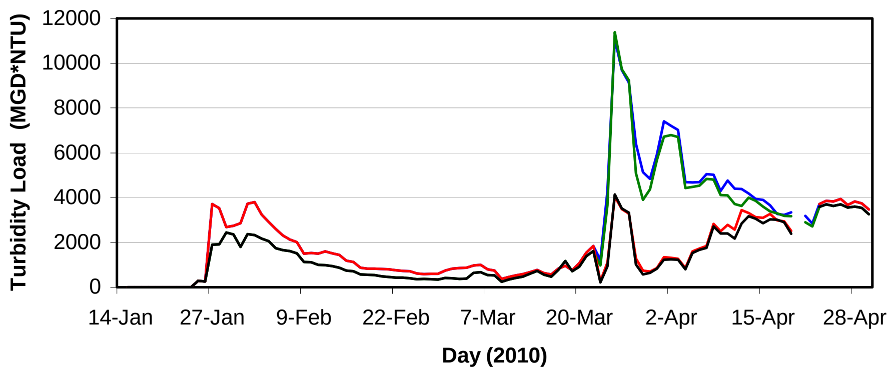


Figure 7.36 Simulated turbidity load (flow * turbidity) from Ashokan Reservoir into Kensico Reservoir via the Catskill Aqueduct for the historical and three alternative scenarios. Historical scenario is black line, NoWC scenario is red line, NoSS scenario is green line, NoWC+SS scenario is blue line.

Although stop shutters had an important role in reducing turbidity for this event, the NoSS scenario indicated that not using stop shutters had no impact on the spills out of Ashokan Reservoir (Figure 7.34).

NoWC+SS Alternative

This alternative is a combination of the previous two scenarios. Results here show the combined effect of not using the waste channel or the stop shutters. As would be expected there is a cumulative increase in turbidity levels that is approximately the sum of the individual reductions associated with each turbidity control measure. For this event, the dividing weir gate was open, so that while the waste channel reduced the volume of turbid West Basin water reaching the East Basin, its use did not isolate the two reservoir basins. Use of the waste channel also reduced the spill over the dividing weir, as a result of which water was not able to enter the Catskill Aqueduct effluent as quickly as if the spill had been greater. The effects of the waste channel operations were therefore beneficial but led to relatively small reductions in turbidity at the Kensico effluents. A far greater improvement in Kensico effluent turbidity was achieved by reducing the turbidity load to the reservoir through the use of stop shutters.

7.2.6 Summary

A series of events during the winter of 2010, which included a large event in late January, an unusually heavy snow pack in early March, and a series of significant events in March as the large snow pack melted, led to a prolonged period of elevated turbidity in Ashokan Reservoir. Throughout this period, a number of operational steps were employed to maintain high water quality in Kensico effluents without alum usage. These steps included the use of the Ashokan waste channel, the use of stop shutters in the Catskill Aqueduct to reduce flow to Kensico Reservoir, and the use of modeling-based determinations of the optimal Catskill and Delaware Aqueduct flow rates into Kensico Reservoir. The modeling activities described herein helped to inform the timing and level of these operational decisions. This set of events demonstrates the potential usefulness of DEP's water quality models in reservoir operation decision support during turbidity events.

A hindcasting simulation was used to examine the effectiveness of the chosen turbidity control operations that were, in part, based on modeling forecasts. This simulation of the actual conditions during the turbidity event were compared to three scenarios simulated using the LinkRes reservoir model for Ashokan and Kensico Reservoirs. The scenarios examined the beneficial effects of using the waste channel, and of using stop shutters to reduce Catskill Aqueduct flow by systematically removing the use of these control measures and comparing simulated turbidity levels to those obtained from the hindcast scenario.

The results indicate that, for this particular event, use of the stop shutters to reduce Catskill System turbidity loads had the greatest impact on Kensico effluent turbidity. Use of stop shutters allowed simulated Kensico effluent turbidity to remain generally below 2 NTU. Simulations further suggest that if stop shutters had not been used, the Kensico effluent turbidity would have rapidly increased in response to turbidity increases in the Ashokan East Basin, and Kensico effluent turbidity levels would have approached 3 NTU. Use of the waste channel led to a marginal improvement of Kensico effluent turbidity and to some decreased spill volume out of Ashokan Reservoir. It is important to note that the results for this case study may not hold true for other situations, for example, when turbidity in Ashokan Reservoir may be more persistent; when it would be possible to close the dividing weir gate to more effectively isolate the turbid West Basin water from the East Basin aqueduct effluents; or when extended periods of reduced Catskill Aqueduct flow may not be possible due to water quantity concerns and the need to refill the water supply system.

The results presented in this section demonstrate the effectiveness of DEP's efforts to mitigate the effects of elevated turbidity in the Catskill System on the quality of water entering the distribution system from Kensico Reservoir. Despite turbidity inputs to Ashokan Reservoir of over 1,000 NTU (Figure 7.21) and West Basin turbidity levels of over 200 NTU (Figure 7.32a), the Kensico effluent turbidity levels never exceeded 2 NTU (Figure 7.32c) and chemical treatment of the water entering Kensico was never required. This result was achieved by effective use of the Ashokan waste channel to minimize the spill of turbid water between the West and East Basins of Ashokan Reservoir, and by reducing the flow of water in the Catskill Aqueduct.

Model-based decision support played an important role in optimizing the use of these turbidity control measures (Section 7.2.3). The modeling described here can be seen as a precursor to what will be routinely available following the completion of the OST. This result suggests that use of the OST to inform reservoir operations will greatly aid in reducing the impact of elevated Catskill turbidity on overall quantity and quality of water in the NYC water supply.

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Environmental Protection

Appendix 1 - Catskill and Delaware System UV Facility and Filtration Contingency Planning

Background

In 1993, EPA issued two Filtration Avoidance Determinations (FADs) for the Catskill and Delaware Systems that required the City to proceed with conceptual and preliminary design of a water filtration facility that could be built in the event that filtration was someday 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 City 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 City applied for and later received relief from the final design deliverable and related environmental impact statement activities, including the release of a Draft Environmental Impact Statement (DEIS) and the completion of an FEIS. As conditions for relief, the City 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 Catskill/Delaware filtration planning process, the 2002 FAD required the City to move forward with design and construction of a UV disinfection facility for the Catskill/Delaware Systems, and produce biennial updates to the preliminary design for a Catskill/Delaware filtration plant.

The 2007 FAD requires the City to implement its program for the Catskill/Delaware UV disinfection facility in accordance with Section 2.6 of the City's 2006 Long-Term Watershed Protection Program and the milestones contained therein, with the following clarifications:

- DEP will submit to EPA and NYSDOH on a biennial basis a report updating the preliminary design of the Catskill/Delaware filtration facilities. This report will discuss the analysis and redesign work performed, and contain the issuance of necessary change pages to the final preliminary design, including revisions to drawings.
- 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.
- DEP shall also provide NYSDOH, within 10 days of a request from that agency, with 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 computer model results.

- 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 five years, significant progress has been made in construction of the Catskill/Delaware UV disinfection facility, and DEP is on track to meet 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 Catskill/Delaware 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 million gallons per day ozone/direct filtration facility for the Catskill/Delaware 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.

Ultraviolet Disinfection Facilities

DEP's UV disinfection facility is currently being constructed along the eastern side of the City-owned 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 Catskill/Delaware 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.

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 will be monitored and maintained by Halmar for an additional two years as required by the contract. The on-site portion of work is scheduled to begin in the Fall of 2010. The contractor will clear a portion of the Eastview site in the Town of Greenburgh followed by clearing a portion of the site in the Town of Mount Pleasant.

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.

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 Long-Term 2 Enhanced Surface Water Treatment Rule (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. Currently the contract is pending NYC legal review and should be advertised in late 2010.

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.

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.

SPDES Permits for Operations

The SPDES Application for Operation was sent to DEC on August 27, 2010.

Project Schedule

The project schedule is prescribed in both the FAD and in an Administrative Order on Consent (AO) between DEP and EPA. 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 Milestones 3-6 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.

Facility Construction Contracts

Progress has been steady, allowing the completion of AO milestones ahead of schedule. Work on the buildings related to the facility continued. These buildings include the North and South Forebays, the Energy Dissipating Valve Chamber (EDVC), Generator Building, Shaft 19 structure, and the Catskill Flowmeter Chamber.

UV Building

The general contractor (CAT-210G) continued with major concrete placement, large diameter pipe installation, and welding operations. To date, the contractors have completed installation of the 144-inch pipe in the UV building and completed installation of the structural steel, including the standing seam barrel roof. The contract has proceeded with cement lining the interior of the 144-inch-diameter raw water, treated water, and future connections. The monorail hoisting system within the UV building has been installed. This system will be used to install and remove large pieces of equipment, including the UV units. In the UV building, the first complete "train" of 48-inch-diameter butterfly valves, UV disinfection unit, 48-inch magnetic flowmeter, and control panel was installed. The manufacture and shipment of key pieces of equipment continued throughout 2010. As of October 2010, all 56 UV units had been manufactured and shipped.

North Forebay

The contractor continued setting roller gate guides and placing concrete infill around the guides in the North Forebay. These gates will be used to isolate source water if additional aqueducts connect to the facility in the future. At this time, the concrete structure for the North Forebay is approximately 80% complete.

South Forebay

In the South Forebay, activities included placement of structural concrete and completion of the Delaware Valve and Flowmeter Chamber. Additional work has included placement of the Delaware control weir. At this time, the concrete structure of the South Forebay is approximately 81% complete.

EDVC

In the EDVC building, work continued on concrete placement for the north upper walls and shoring for the construction of the intermediate level beams, as well as installation of the monorail system and 32 knife gate valves. Testing of the energy dissipating valves has commenced. These 16 valves will provide the flow control through the facility.

Generator Building

The contractor has installed reinforced concrete encased duct banks below the proposed generator building and has placed concrete for the outer walls of the building. At this time, the structure is approximately 70% complete.

Catskill Treated Water Line

The excavation and installation of the twin 108-inch-diameter treated water lines from the UV building to the Catskill Connection Chamber south of Route 100C continued.

Due to delays related to the Kensico aerator remediation, the stockpile of soil has exceeded the original design. This has led to the installation of additional sediment control basins to limit runoff during heavy rain events, as part of an ongoing stormwater pollution prevention plan.

Pilot Studies

Dyed Microsphere Study

A study to analyze the level of inactivation was performed at the Hydroqual Facility in Johnstown, NY. Dyed microspheres were added to the water to simulate *Cryptosporidium.* The microspheres were analyzed before and after disinfection to measure the actual rate of inactivation. This study has provided additional information that will aid in the determination of the appropriate UV dose during operation.The data have been analyzed and are currently being used in conjunction with the modeling results to develop standard operating procedures. According to the study, a lower dosage of UV treatment will be equal to or more effective than the customary 40 mJ/cm^2 dosage. Operation at a lower dose is subject to NYSDOH approval but could reduce energy consumption and associated air emissions.

Appendix 2 - Cross Connection Control Program

Cross connections in a drinking water distribution system are a potential source of contamination. Cross connections can be caused by improper or direct connections, excessive back pressure on the system, back siphonage, and other reasons. It is important to eliminate areas where such conditions exist to eliminate the possibility for cross connection contamination. DEP's Cross Connection Control Program has as its primary objective the avoidance of any potential for backflow from within premises to the public water supply system. To accomplish this objective, property owners are required to install backflow prevention containment devices in water service lines for premises that pose a potential hazard. After installation, backflow prevention containment devices are required to be tested by a certified tester at least once a year.

Since the promulgation of the revised FAD in 2007, DEP's Bureau of Water and Sewer Operations has achieved or exceeded all of the FAD goals outlined in this document. The implementation of DEP's Cross Connection Control Enforcement procedures, which began in 2002, has accelerated the rate of achievement of compliance for "Hazardous" premises. The revised enforcement procedures involved the issuance of letters, Commissioner's Orders, Notices of Violations, Environmental Control Board hearings, Cease and Desist Orders, and ultimately the termination of water service. There are currently 15 locations where water service is planned for termination due to the failure to install an approved backflow prevention device.

One notable change to the program since its inception was the creation of a contract that was used to obtain a consultant to perform the balance of inspections for "High Hazard" premises. In 1998 a list was generated in the initial stages of the program that contained over 20,000 facilities which were identified as possible "High Hazard" locations based on several parameters (e.g., facility type, commercial/residential, facility size). After these 20,000 facilities were identified, DEP inspectors proceeded to weed out which facilities warranted further, more detailed full inspections based on an accelerated preliminary inspection. As the program became further developed, DEP recognized that these quick preliminary inspections served little value, as it was increasingly difficult to assess whether a facility required a more in-depth full inspection based on a curbside assessment. This prompted DEP to phase out the preliminary inspection step, and opt for routine performance of a complete full inspection of any potential "High Hazard" location on the list. By concentrating efforts on "High Hazard" inspections and enforcement, DEP believed that the most hazardous premises would come into compliance in a more effective and timely manner. The original list of over 20,000 is expected to be completed by the end of the year, thanks, in part, to the help of the consultant, who plans on performing the balance of the inspections. Of the original 22,765 locations classified as potentially "High Hazard" premises, over 21,000 have already been inspected. This list will be exhausted by the end of the calendar year 2010. This "one-time" contract cost just under $600,000. Any new construction of potentially hazardous businesses will be identified when the property applies for its water connection, since a backflow device or exemption is a required condition for permit.

Environmental Protection

Currently, there are 14,276 locations in the database that have a device installed. Another 16,491 locations have been directed to install a backflow prevention device. In the first half of 2010, 640 violations were issued for failure to install or test a device when required. In 2009, 766 violations were issued for failure to install, and 568 were issued for failure to test, the device. The compliance status of these 22,765 premises is as follows:

1. Compliance Achieved	7,992	35.0%
2. Compliance Initiated	7,910	34.8%

A water quality anomaly incident that occurred in southeast Queens in 2007 demonstrated the need to identify a more up to date list of businesses; this task was contracted out and became known as the "Appleseed" List. This list emphasized car washes, dry cleaners, laundromats, and auto repair shops in the area in question, and therefore a majority of the addresses investigated around that time were for the southeast portion of Queens. In addition to this list, other lists have been compiled in-house and through consultants, and there are currently over 65,000 locations in the Cross Connection database. This database contains addresses that already have devices and those that are slated to be inspected.

In addition to the heightened inspection component, DEP has expanded its effort with respect to enforcement of the annual test report requirement for installed cross connection control containment devices. Property owners who fail to submit test reports annually are issued a Notice of Violation. This new protocol has resulted in a significant increase in the number of test reports received. This, compounded by a sharp decrease in support staff for the program, has resulted in a backlog of nearly 2,000 reports that need to be checked and logged into the system for compliance. Also in 2009, changes to the plumbing code requiring a double check on all sprinkler services has resulted in additional plans to review. Starting July 1, 2010, the Department began charging a fee for reviewing plans, and for processing requests for exemption. The application fee is now $350 per service line for backflow prevention device plan reviews, and $100 for a request for exemption.

Appendix 3 - Water Quality Status and Trends Data Analysis

Sites

Sites selected for water quality status and trends analysis are listed in Appendix Table 3.1 and shown pictorially in Appendix Figures 3.1 and 3.2. 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.

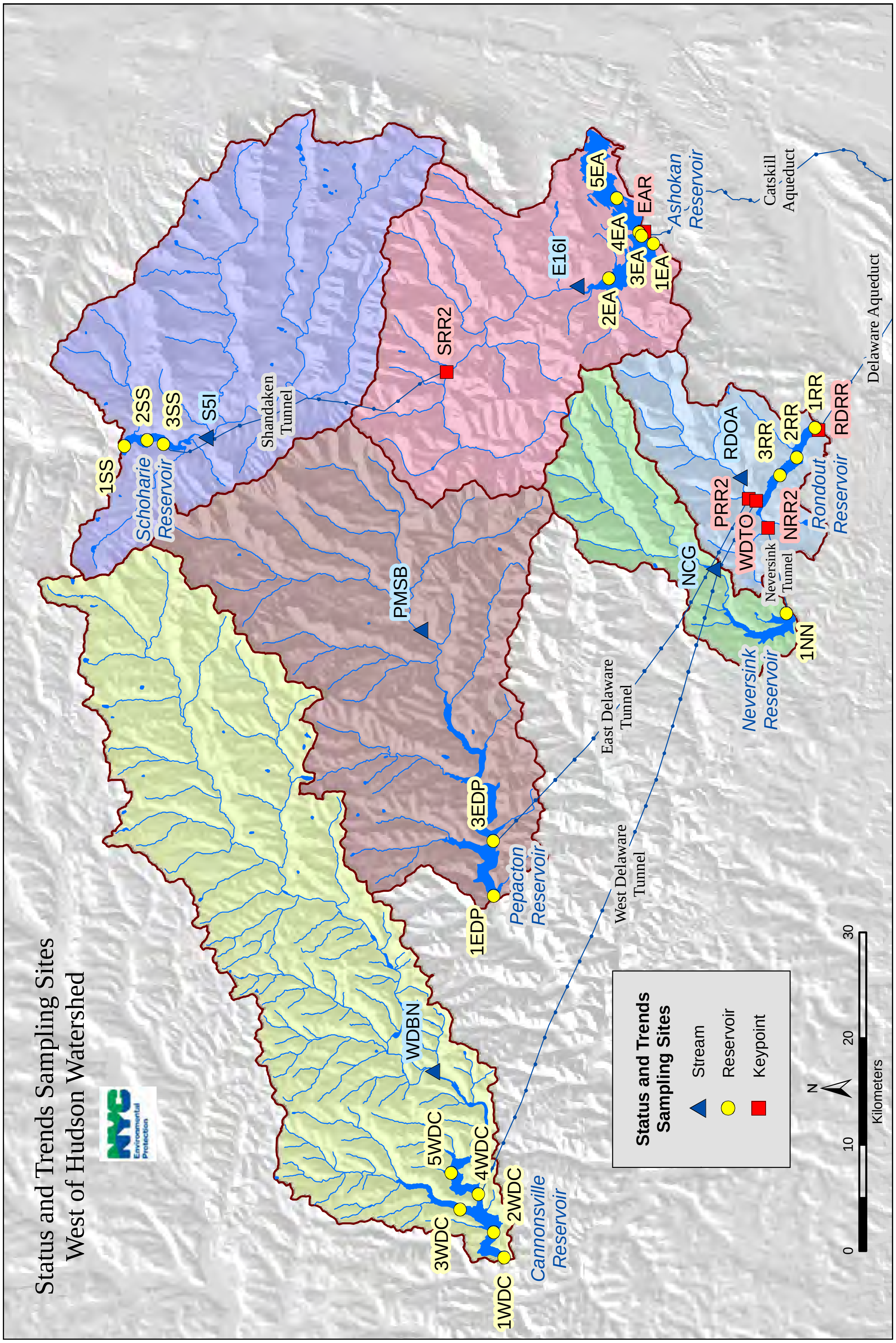
Appendix Table 3.1: Inputs (streams and aqueduct keypoints), reservoirs, and outputs (aqueduct keypoints and releases) included in the water quality status and trends analysis.

System/District	Inputs[1]	Reservoirs[3]	Outputs[1]
Catskill	S5I[s]	Schoharie (SS)	SRR2
	E16I[s]	Ashokan (West—EAW)[2]	—
	—	Ashokan (East—EAE)[2]	EAR
Delaware	NCG[s]	Neversink (NN)	NRR2
	PMSB[s]	Pepacton (EDP)	PRR2
	WDBN[s]	Cannonsville (WDC)	WDTO
	NRR2[k], PRR2[k], WDTO[k], RDOA[s]	Rondout (RR)[2]	RDRR
East of Hudson	DEL9[k], BOYDR[s], HORSEPD12[s]	West Branch (CWB)[2]	WESTBRR
	CATALUM[k], DEL17[k],	Kensico (BRK)[2]	CATLEFF, DEL18
	CROSS2[s]	Cross River (CCR)[2]	CROSSRVR
	WESTBRR[s], CCF (middle basin)	Croton Falls (CCF-main basin)[2]	CROFALLSR

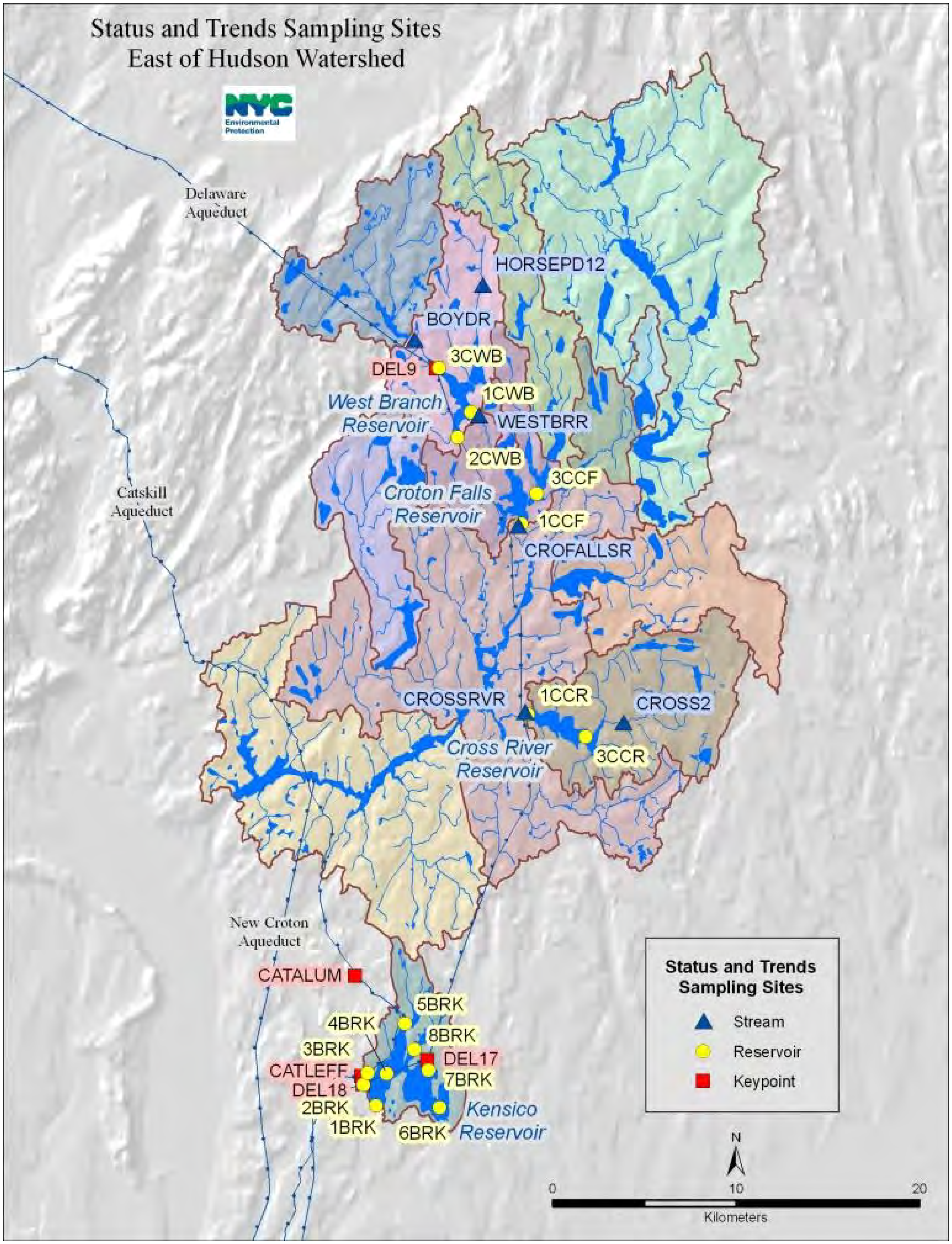
[1] Keypoint site codes omit the last two letters of the code, CM (Continuous Monitoring). These letters were added to the code for West of Hudson keypoints within the last several years of the study period. The superscripts "s" and "k" refer to streams and keypoints, respectively; all outputs are keypoints except for WESTBRR, CROSSRVR, and CROFALLSR, which are releases.

[2] Indicates a source or potential source water.

[3] Reservoir designations represent at amalgam of locations and depths (see text).



Appendix Figure 3.1 Sampling sites for the West of Hudson status and trends analysis.



Appendix Figure 3.2 Sampling sites for the East of Hudson status and trends analysis.

The reservoir inputs comprise the main streams and in some cases, depending on the basin, aqueducts. For all West of Hudson (WOH) 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 performed by the Directorate of Water Quality (DWQ) field groups. Reservoir samples used in this report were 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 example, near aqueducts. The full sampling programs are described in DEP (2009a). Keypoint samples are collected and analyzed by the DWQ laboratory operations staff.

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 over time for the collection of reservoir surface samples that may affect trend results. From 1993-2001, surface samples were composited from the air-water interface down to the depth of the 1% light level. In 2002, these integrated surface samples were replaced by a 3-meter discrete sample collected using a Van Dorn sampler. The depth of integration also changed. From 1993-1998 the 1% light depth was based on an initial light measurement made in the air above the water surface. From 1999-2001 the location of the initial light measurement was corrected to begin just below the air-water interface. As a result of this change, the depth of the photic zone increased by 10-20%. For the purpose of this report, it was 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 were turbidity, fecal coliform, total phosphorus (TP), and conductivity, plus reservoir trophic state index (derived from chlorophyll *a* measurements). These are considered the most important water quality indicators for the City 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 yielded higher values, more work is needed to determine an appropriate correction factor. Accordingly, the phosphorus and turbidity data presented in this report are the raw data obtained using the current method of analysis.

Trophic State Index (TSI) was calculated from the chlorophyll *a* concentration using the following equation (Carlson 1977):

$$TSI = 9.81 \times \ln(\text{chlor } a) + 30.6$$

where chlor *a* = chlorophyll *a* concentration ($\mu g\ L^{-1}$).

Only samples collected from the photic zone (either integrated samples taken from the surface to the 1% light level, or discrete samples taken at 3 m 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 comparing each point to an expected range of values based on similar location, season, and, in the case of reservoirs, depth. Suspect data were flagged and the original records reviewed to determine if a transcription error had occurred. All discovered transcription errors were corrected. Remaining outliers were removed only if they were far outside the normal range of historic data. Occasionally, when fecal counts were predicted to be high (in response to a runoff event) large dilutions (>10:1) were used in the laboratory to analyze fecal coliform data. If fecals were not observed in the diluted sample, it was judged that dilution had rendered the sample unreliable and the results were set 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, all special surveys were eliminated and data were restricted to those which were collected consistently each month throughout the 1993-2009 period. For reservoirs, this required the elimination of some shallower riverine sites, which could not be sampled consistently during summer drawdown periods. Additional reservoir sample eliminations included sites 2 and 3 from Neversink and sites 2, 4, and 5 from Pepacton. These sites were not consistently sampled in 2009 due to a shortage of field staff. Extra water column sampling, which occurred in 2002, was also 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, one survey per month was selected and used in the analysis.

In general, the traditional median value from each full monthly survey was used in the status and trend analysis and in the plots of the data. To ensure consistent representation, if less than 75% of the normal monthly sample load was not available, a median was not calculated for that particular month, and the month was set to missing. A summary of the number of consistently collected samples used to calculate monthly medians for each site is provided in Appendix Table 3.2.

Appendix Table 3.2: Number of samples collected per month from status and trend analysis sites, 1993-2009.

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
DEL18	keypoint	31	1	31	31	0
DEL9	keypoint	5	1	5	5	0
EAR	keypoint	27	1	27	27	0
NRR2	keypoint	20	1	20	20	0
PRR2	keypoint	20	1	20	20	0
RDRR	keypoint	25	1	25	25	0
SRR2	keypoint	5	1	4	5	0
WDTO	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	2	1	1	1	0
CROFALLSR	stream	2	1	1	1	0
CROSS2	stream	2	1	1	1	0
CROSSRVR	stream	2	1	1	1	0
E16I	stream	1	1	1	1	0
HORSEPD12	stream	2	1	1	1	0
NCG	stream	2	1	1	1	0
PMSB	stream	1	1	1	1	0
RDOA	stream	1	1	1	1	0

Appendix Table 3.2: (Continued) Number of samples collected per month from status and trend analysis sites, 1993-2009.

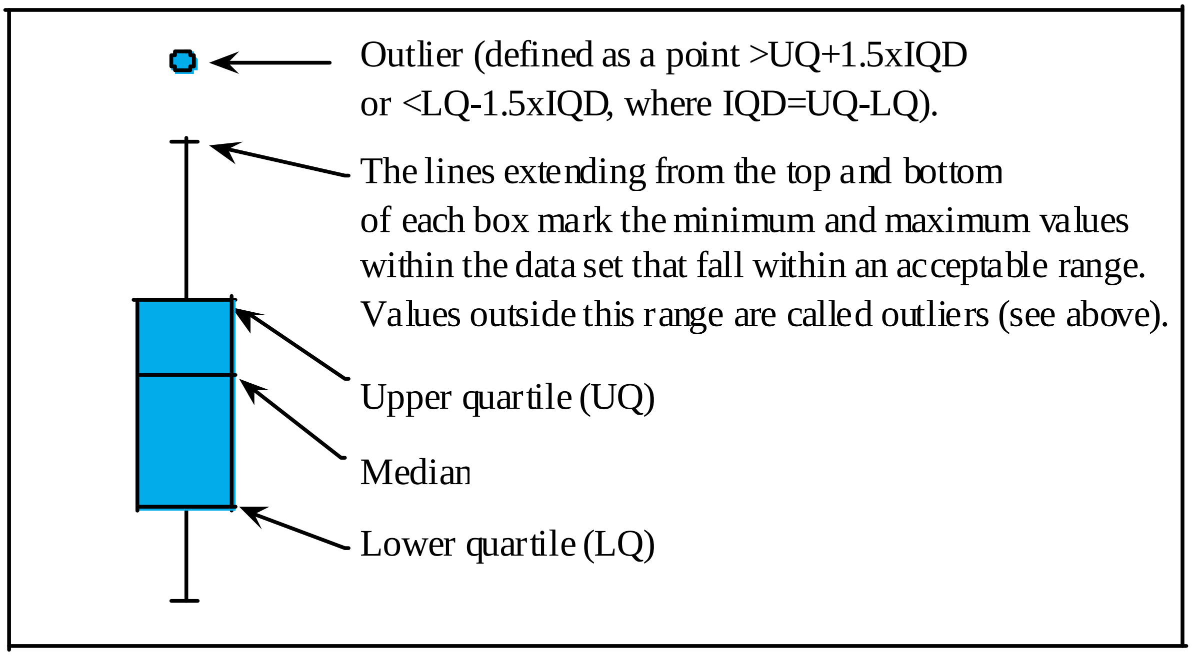
Site	Type	Fecal coliform	TP	Conductivity	Turbidity	Chlorophyll *a*
S5I	stream	1	1	1	1	0
WDBN	stream	1	1	1	1	0
WESTBRR	stream	2	1	1	1	0

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 also. A three-year time period was considered appropriate and monthly medians from the years 2007-2009 were used. If more than 50% of the month's data was left-censored, the median was set to the instrument detection limit.

Turbidity and fecal coliform data for source water keypoints are compared to Surface Water Treatment Rule standards (5 NTU for turbidity and 20 coliform forming units (CFU) 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 CFU 100 mL^{-1} reference line, based on a calculation developed for streams by the New York State Department of Environmental Conservation (6 NYCRR Part 703.4(b)), is included in the stream fecal coliform status plots. The TP benchmark in the status plots (15 mg L^{-1} for WOH impoundments and East of Hudson (EOH) source reservoirs; 20 mg L^{-1} for other EOH, non-source reservoirs) is based on phosphorus-restricted "target values" developed by DEP (DEP 2010f). TSI benchmarks (reservoirs with values <40 considered oligotrophic; those with values between 40 and 50, mesotrophic; values >50, eutrophic) were taken from Carlson (1977).

Boxplots 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. Percentiles below the highest reporting limit are estimated using the ROS method of Helsel and Cohn (1988). See Appendix Figure 3.3, which provides a key for interpreting the boxplots.



Appendix Figure 3.3 Description of the boxplot statistics (Minitab^{TM}) 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 when a high percentage of the data was left-censored (Helsel 2005).

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 was left-censored, the median was set to one-half the instrument detection limit. The non-parametric LOWESS technique was chosen because, unlike parametric methods such as linear regression, it provides a robust description of the data without presupposing 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 9.1 (SAS 2002-3). 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 DEP's analysis, a smooth factor of 0.3 was chosen, which means that 30% of the data was used to perform the weighted least squares calculation for each data point. Through experimentation, it was 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 removed they are from the data group. Selecting one iteration corresponds to no re-weighting. Given the prevalence of extreme values commonly observed in coliform data, the selection of 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 discernible effect on the LOWESS fit. For ease of presentation in the report, therefore, LOWESS curves for all analytes were determined using three iterations.

For non-censored data, the occurrence of long-term monotonic trends was tested for statistical significance using the non-parametric SK test. 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 "NS" does not mean 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 30% smoothing function. Trend analysis was performed on the flow-adjusted data as well as on 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 Tunnel to 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 SKSE. 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.

A variation of the SK and SKSE tests was used in cases where the data record contained large amounts of left-censored data. In these cases, the Minitab® macro "ckend.mac" was used to determine the statistical significance of trend and the "ATS.mac" macro was used to fit the data with the Akritas-Theil-Sen line, a nonparametric regression based on Kendall's Tau. The slope of the Akritas-Theil-Sen line represents the change per year as reported in the text. These techniques are recommended and fully described in Helsel (2005). The macros used in this analysis are available from the author's website, **www.practicalstats.com/nada**.

In practice one can rarely, if ever, say there is no trend. All one can say is that there has been a failure to detect a trend at a certain level of confidence. In fact, there is nearly *always* a trend and the null hypothesis of no trend is nearly always false to begin with! Note also that *p*-values produced with data having different *n* values are not comparable (McBride 2005).

Biomonitoring Methods

The New York City stream biomonitoring program uses protocols developed by the New York State Stream Biomonitoring Unit (SBU) to assess the health of stream macroinvertebrate communities in NYC watershed streams. Samples are collected annually between July and September using the "traveling kick" method, which consists of disturbing the stream bottom of a riffle habitat area and holding a net downstream to catch macroinvertebrates released into the water column by this disturbance. A subsample of approximately 100 organisms is taken from each sample and the macroinvertebrates in it are identified and enumerated. From these data, a series of four metrics is generated which yield four independent numeric 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)); and 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). These metrics, in turn, are converted to a common scale and averaged, producing a Biological Assessment Profile (BAP) score from 0-10, with a score of 7.5-10 corresponding to a rating of non-impaired; 5-7.5, slightly impaired; 2.5-5, moderately impaired; and 0-2.5, severely impaired. Routine sites, generally situated on mainstems close to a reservoir, are sampled annually; other sites are sampled on a rotating basis.

Environmental Protection

Appendix 4 - Drought Management

For the years 2006-2010, it was not necessary to invoke any of the components of the City's Drought Management Plan, as precipitation, runoff, and storage levels all remained 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 the City's reservoirs to be drained. This probability is estimated during dry periods in consultation with the New York State Drought Management Task Force and the New York State 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 the City'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.

Environmental Protection

Appendix 5 - Rondout-West Branch Tunnel

Efforts to evaluate the condition of, and to develop dewatering and repair plans for, the Rondout-West Branch Tunnel (RWBT) have been ongoing from 2006 through 2010 and involve the following components:

- Hydraulic investigations of the RWBT
- Autonomous Underwater Vehicle (AUV) inspection of the RWBT
- Risk assessment
- Tunnel and Shaft Rehabilitation Program
- Planning for a Roseton bypass

Hydraulic Investigations of the RWBT

Investigations of the RWBT helped DEP assess the nature and degree of leakage stemming from the aqueduct. Various efforts to study the nature and size of the leak 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 monitors 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. The hydrostatic 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. These tests indicate that the tunnel is stable. There have been 6 hydrostatic tests and 14 backflow tests since 2006.
- Surface investigations in areas of Roseton and Wawarsing. Water is suspected to be leaking from the tunnel in these areas. Engineering teams catalogue surface leakage features on a monthly to weekly basis. During tunnel depressurizations, daily monitoring is performed.

Autonomous Underwater Vehicle (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 2009, DEP completed a second AUV inspection of the interior surface of the tunnel. (The first inspection was performed in 2003.) This latest inspection gathered 150,000 photographs of the tunnel.

The data were incorporated into a tunnel condition report and a 2010 update to the Tunnel Risk Assessment.

Risk Assessment

In 2010, a revised risk assessment of the RWBT was prepared. Data from 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, were gathered. The tunnel engineers calculated a risk of tunnel collapse under a number of operating conditions. The governing condition (a tunnel liner collapse in the Roseton vicinity with the tunnel in operation) showed the risk of tunnel collapse remains from 0.1% to 1.0% per year for a 5-year period. This is substantially the same as the 2004/5 Risk Assessment.

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.

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. Work on the conceptual plan for the tunnel is currently under way. The tunnel is expected to be approximately three miles long and connect to the existing RWBT above and below the leakage area in Roseton.