NYC Environmental Protection

New York City
Department of Environmental Protection

2010 Watershed Water Quality Annual Report

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Caswell F. Holloway, Commissioner
Paul Rush, P.E., Deputy Commissioner

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Acknowledgements

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Executive Summary

This report provides summary information for 2010 for the watersheds, streams, and reservoirs that are the sources of New York City's drinking water, as well as information on operations and the use of water quality models for management of the water supply. In order to ensure high quality drinking water, DEP conducts extensive water quality monitoring that encompasses all areas of the watershed, including sites at water supply intakes on the aqueducts (known as keypoints), streams, and reservoirs. Watershed monitoring meets the sampling needs for regulatory compliance and operational requirements and also forms the basis for DEP's ongoing assessment of watershed conditions, changes in water quality, and ultimately for developing any modifications to the policies, strategies, and management of the watershed protection programs.

The NYC water supply system is dependent on precipitation and subsequent runoff to supply the reservoirs in each of the three watershed systems, Catskill, Delaware, and Croton. Total precipitation in the watershed in 2010 was 49 mm (1.9 inches) below the long-term annual average. However, two large storms, one in late September-early October and the other at the end of November, led to water quality issues and very high flows in Esopus Creek. Overall, in 2010 the annual runoff was above the normal historical values for the West of Hudson reservoirs and near normal for the East of Hudson reservoirs. The runoff led to above average system-wide usable storage levels in the reservoir system during the early part of the year. Levels stayed near normal with some fluctuation until falling below normal in late summer. The large storm event at the end of September, along with other events, kept capacity well above normal for the remainder of the year.

In 2010, watershed water quality was assessed using data collected at keypoint, reservoir, and stream sites. The keypoint data demonstrated that the NYC source waters were well within the Surface Water Treatment Rule limits for fecal coliform and turbidity.

Many variables were assessed for the reservoirs. Turbidity data were generally higher than historical data in the Catskill System. Cannonsville was more affected by storm events than the other Delaware basins. Most of the Croton reservoirs had lower median turbidity levels than in the past. Coliform-restricted calculations showed that all the source waters except West Branch were non-restricted with respect to fecal coliform. Total coliform exceeded the assessment standards in some basins. Phosphorus-restricted calculations continued to show that all the Delaware basins were non-restricted. Ashokan-West Basin was restricted but improving, since the high values of 2005 were not included in the current five year assessment (2006–2010). All Croton reservoirs except for Boyd Corners were phosphorus-restricted. Trophic status results based on chlorophyll *a* were mixed. Comparison of terminal reservoir water quality data to water quality benchmarks was also performed.

Stream sample data were evaluated for turbidity, total phosphorus, and fecal coliform. Turbidity medians for the major inflowing streams were near or below normal for the year. Total phosphorus results were mixed for the Catskill and Delaware basins. The Croton System streams generally had total phosphorus medians lower than historical levels, with the exception of Muscoot and East Branch Reservoirs. Fecal coliform median values were all near or below historical levels. In a comparison to stream benchmarks, results for the three districts varied, depending on the analyte. Stream biomonitoring results showed that the majority of sites were non-impaired in the Catskill and Delaware basins, while in the Croton System, all 12 sites were slightly impaired.

In 2010, DEP collected 598 samples for protozoan analysis, and 300 samples for human enteric virus monitoring. Most samples were collected at keypoint locations and streams, with additional samples collected at upstate reservoir releases and wastewater treatment plants. As reported in past years, *Giardia* cysts are more frequently detected and found at higher concentrations than *Cryptosporidium* oocysts throughout the entire watershed, and human enteric viruses are not commonly detected. Moreover, *Giardia* continues to appear in higher concentrations in the colder months of the year. From January 1, 2009 through December 31, 2010, DEP source water *Cryptosporidium* mean values were well below the LT2 treatment threshold for unfiltered water supplies (0.010 oocysts L^{-1}). Mean cyst and oocyst concentrations $50L^{-1}$ were lower in upstate reservoir effluent samples than in the 10 WOH stream sites that feed those reservoirs, suggesting a reduction as water passes through the reservoirs. Similarly, the mean concentrations at the effluents of Kensico Reservoir were also less than the combined mean cyst and oocyst concentrations entering the reservoir at the eight perennial streams. While there were a few detections of *Giardia* cysts at wastewater treatment plants in 2010, no *Cryptosporidium* oocysts were detected.

Modeling was used to support operational decisions, evaluate watershed management programs and to further understand potential impacts of climate change on the water supply system. For operational decision support, reservoir and water system models were used during periods of elevated turbidity in the Catskill System to inform aqueduct flow decisions to ensure that water quality standards are met while minimizing the use of alum.

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 watershed and reservoir models. Model results suggested that large reductions in phosphorus loading during the initial phases of the FAD were due to a combination of high rates of new program implementation and substantial reduction in agricultural activity during that period. Continued but slower declines in phosphorus loads continued during the most recent FAD period as programs became more focused on maintenance and improvement than on new program development, and as the reduction in agricultural activity continued.

DEP is also using its suite of simulation models to investigate the effects of climate change on the New York City Water Supply. Preliminary investigations focused on estimating future climate projections using four climate models, looking 65 years and 100 years into the future. The most consistent finding of this preliminary work is a shift in winter streamflow timing, with more flow occurring during the mid-winter period and slightly reduced flow during the traditional early spring snowmelt period.

1. Introduction to Watershed Monitoring

This report provides summary information about the watersheds, streams, and reservoirs that are the sources of New York City's drinking water. It is an annual report that provides the public, regulators, and other stakeholders with a general overview of the City's water resources, their condition during 2010, and compliance with regulatory standards. It also provides information on operations and the use of water quality models for management of the water supply. It is complementary to the "New York City 2010 Drinking Water Supply and Quality Report," which is distributed to consumers annually to provide information about the quality of the City's tap water. More detailed reports on some of the topics described herein can be found in other DEP publications, accessible through the DEP website at http://www.nyc.gov/dep/.

The New York City water supply system (Figure 1.1) supplies drinking water to almost half the population of the State of New York, which includes over eight million people in New York City and one million people in upstate counties, plus millions of commuters and tourists. New York City's Catskill/Delaware System is one of the largest unfiltered surface water supplies in the world. (The Croton System, which can supply on average 10% of the City's demand, is expected to be filtered by 2013.) The water is supplied from a network of 19 reservoirs and 3 controlled lakes that contain a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The total watershed area for the system is approximately 5,100 square kilometers (1,972 square miles), extending over 200 kilometers (125 miles) north and west of New York City.

1.1 Monitoring Objectives

In order to ensure high quality drinking water, DEP conducts extensive water quality monitoring that encompasses all areas of the watershed, including sites at water supply intakes on the aqueducts (known as keypoints), streams, and reservoirs. A key component of monitoring is the extensive sampling of terminal reservoirs. These reservoirs are potential "source waters" that can be routed directly into the distribution system, and are therefore subject to more stringent standards. They include Kensico, West Branch, New Croton, Ashokan (West and East Basins), and Rondout Reservoirs. The watershed monitoring program meets the sampling needs for regulatory compliance requirements and also forms the basis for DEP's ongoing assessment of watershed conditions, changes in water quality, and ultimately for developing any modifications to the policies, strategies, and management of the watershed protection programs. The watershed monitoring plan is documented in detail in the Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a), which establishes an objective-based water quality monitoring network. The plan covers four major areas that require ongoing attention— Compliance, Filtration Avoidance Determination (FAD) Program Evaluation, Modeling Support, and Surveillance Monitoring—with many specific objectives within these major areas.

Figure 1.1 The New York City Water Supply System watersheds.

Monitoring design must consider several elements, including choice of sites, analytes, analytical methodology and detection limits, and sampling frequency. Statistical features of the water quality database were used to guide development of the WWQMP sampling design in terms of streamlined monitoring site plans and appropriate collection frequencies.

1.1.1 Compliance Sampling

The objectives of this sampling 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 (SWTR) and its subsequent extensions, other regulations issued by the United States Environmental Protection Agency (USEPA), the New York City Watershed Rules and Regulations (WR&R) (2010), the Croton Consent Decree (CCD), Administrative Orders (AO), State Pollution Discharge Elimination System (SPDES) permits, and regulations issued by the New York State Department of Health (NYSDOH).

1.1.2 Filtration Avoidance and Watershed Protection Program Evaluation

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 as specified in the SWTR. USEPA has specified many requirements in the 2007 FAD that must be met to maintain a filtration waiver. These requirements are met through the City's ongoing assessment of watershed conditions, tracking of changes in water quality, and ultimately any modifications that are made to the strategies, management, and policies in the long-term watershed protection plan (DEP 2006a). DEP's water quality monitoring data are essential to evaluate watershed programs. Program effects on water quality are reported in the Watershed Protection Summary and Assessment reports, produced every five years (most recently in March 2011). The 2007 FAD also requires that DEP's watershed-wide monitoring program meet the needs of the long-term watershed protection plan (DEP 2006b), which has goals that specifically require results from a rigorous monitoring effort. 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.

1.1.3 Water Quality Modeling

Modeling data are used to meet the long-term goals for water supply policy and protection and to provide guidance for short-term operational strategies when unusual water quality events occur. There are several types of data needed to generate models: stream, reservoir, aqueduct, and meteorological data. 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. The water balance and reservoir water quality data are necessary both as model inputs and to continue to test, apply, and further develop DEP's one- and two-dimensional modeling tools. The meteorological data collection effort provides critical input necessary to meet both watershed and reservoir modeling goals.

The modeling requirements of the FAD include:

- Implementation of watershed and reservoir model improvements based on ongoing data analyses and research results
- Ongoing testing of DEP's watershed and reservoir models
- Updating of data necessary for model runs, including land use, watershed program implementation data, and time series of meteorological, stream flow, and water chemistry data
- Development of data analysis tools supporting modeling projects
- Applications of DEP models to support watershed management, reservoir operations, climate change analysis, and long-term planning

The modeling goals of FAD projects could not be accomplished without appropriate data.

1.1.4 Water Supply Surveillance

The WWQMP contains several specific objectives related to surveillance monitoring, i.e., monitoring to support management and operational decisions. The heart of surveillance monitoring is the network of sampling points at 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, such as trace metals, volatile organic compounds, and pesticides, while 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. Surveillance is conducted to track the water quality of the reservoirs, so that managers can be made aware of developing problems and pursue appropriate actions.

1.2 Water Quality Sampling

Water quality of the reservoirs, streams, and aqueducts is monitored throughout the watershed in order to protect the water supply and provide the highest quality drinking water to the City. A summary of the number of samples and analyses that were processed in 2010 by the four upstate laboratories, and the number of sites that were sampled, is provided below in Table 1.1. The sampling effort for the distribution system is also listed for completeness; however, those results are presented elsewhere, as noted earlier.

Table 1.1: Water quality sampling summary for 2010.

District/Laboratory	Number of Samples	Number of Analyses	Number of Sites
Catskill/Kingston	3,447	67,486	133
Delaware/Grahamsville	3,294	44,859	124
EOH/Kensico	11,259	101,934	131
EOH/Brewster	1,229	10,970	66
Watershed	19,229	225,249	454
Distribution	33,000	375,800	1,000
Total	52,229	601,049	1,454

1.3 Operations in 2010 to Control Ashokan Reservoir Turbidity

In 2010, DEP implemented operational turbidity control strategies at Ashokan Reservoir that were developed under the Catskill Turbidity Control Program. Two of the operational strategies deployed were waste channel releases and West Basin drawdowns. These techniques were implemented in 2010 on an interim basis, and it is expected that long-term operating procedures will be developed in consultation with DEC, with input from other stakeholders, and that they will be guided by the near-real-time monitoring and forecasting capabilities of the Operations Support Tool (OST) currently being developed by DEP.

In 2010, DEP implemented three separate waste channel release events. The first release event was from January 24, 2010 to March 22, 2010, a 74-day release, with the intent to: 1) lower the level of water in the West Basin of the reservoir to help accommodate the anticipated spring runoff, and 2) help prevent this turbid runoff from spilling over the dividing weir into the East Basin of the reservoir. This release event was terminated when the reservoir began to spill water to the lower Esopus Creek. Waste channel releases were initiated a second time on April 7, 2010, once the spill volume had been reduced. (In order to restrict releases that could contribute to downstream flooding, DEP does not operate the waste channel when the flow at the USGS gage at Mount Marion is greater than 2,140 MGD (about 85% of Flood Action Stage) and is predicted to rise.) The release operation lasted until April 19, 2010. The final operation of the waste channel began on October 7, 2010, following a major rainfall event in the watershed. This was followed by another significant event in December. The release lasted 118 days, ending on February 1, 2011. It was intended to protect water quality by preventing turbid water in the West Basin of the reservoir from spilling over the dividing weir and entering the East Basin where the intake is located. These modified release operations helped to control turbidity in Ashokan Reservoir; however, the two major runoff events in October and December overwhelmed the system, and by February 2011 turbidity levels in Kensico Reservoir had become elevated to a level where alum treatment was required.

In addition to waste channel releases, DEP also implemented a West Basin drawdown during the summer of 2010 by transferring water to the East Basin and selectively withdrawing water from the West Basin into the Catskill Aqueduct when water quality conditions allowed. From August 10, 2010 to September 7, 2010 DEP withdrew water from the West Basin into the Catskill Aqueduct to be delivered to Kensico Reservoir. This drawdown operation resulted in reducing the West Basin elevation to 566 feet, about 34 feet below its spillway. The drawdown was successful in providing a water quality benefit by allowing Ashokan Reservoir to capture much of the turbid runoff from the significant storm events that occurred in October and December of 2010.

2. Water Quantity

2.1 The Source of NYC's Drinking Water

New York City's water is supplied by a system consisting of 19 reservoirs and 3 controlled lakes with a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The system's watershed drains approximately 5,100 square kilometers (1,972 square miles) (Figure 1.1). The system is dependent on precipitation (rainfall and snowmelt) and subsequent runoff to supply the reservoirs in each of three watershed systems, Catskill, Delaware, and Croton. The first two are located West of Hudson (WOH), while the Croton System is located East of Hudson (EOH). As the water drains from the watershed, it is carried via streams and rivers to the reservoirs. The water is then moved via a series of aqueducts to terminal reservoirs before the water is piped to the distribution system. In addition to supplying the reservoirs with water, precipitation and surface water runoff also directly affect the nature of the reservoirs. The hydrologic inputs to and outputs from the reservoirs control the nutrient and turbidity loads and hydraulic residence time, which in turn directly influence the reservoirs' water quality and productivity.

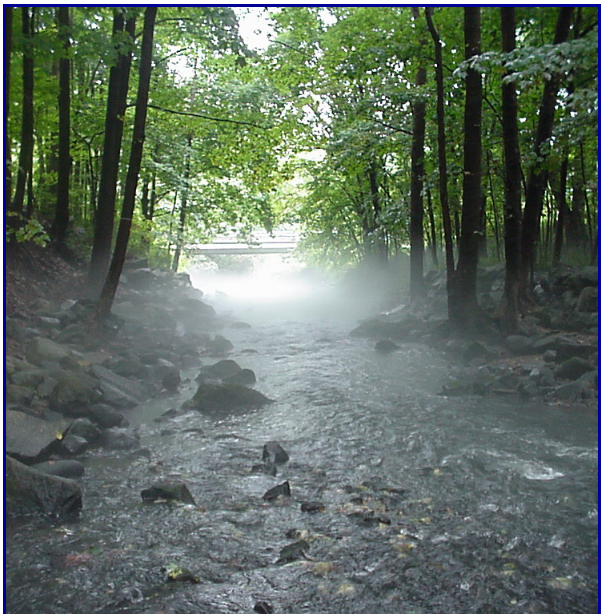

Figure 2.1 Titicus Reservoir Release.

Photo by Martin Rosenfeld

2.2 2010 Watershed Precipitation

Figure 2.2 West Kill.

Photo by David Burns

The average precipitation for each watershed was determined from daily readings collected from a network of precipitation gages located in or near each watershed. The total monthly precipitation is the sum of the daily average precipitation values calculated for each reservoir watershed. The 2010 monthly precipitation total for each watershed is plotted along with the historical monthly average in Figure 2.3.

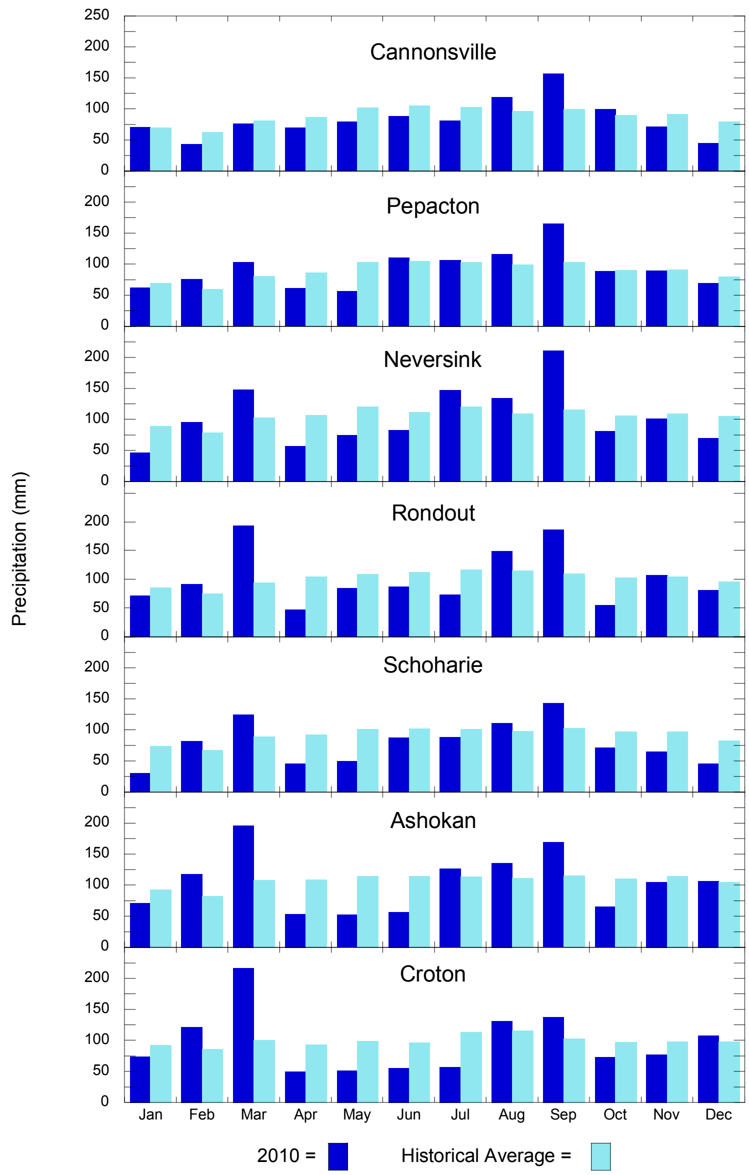

Figure 2.3 Monthly rainfall totals for NYC watersheds, 2010 and historical values.

The total monthly precipitation figures show that in general precipitation was below normal for January in all watersheds, except Cannonsville. Precipitation in February and March was above normal, except for Cannonsville. April through June had below average precipitation, except for the Pepacton watershed in June, which was slightly above average. Precipitation totals were mixed in July and above average in all watersheds for August and September. In October and November precipitation was below normal in all watersheds, except for Cannonsville and Pepacton in October and Ashokan and Croton in December. Overall, the total precipitation in the watershed for 2010 was 1,097 mm (43.2 inches), which was 49 mm (1.9 inches) below normal.

There were two significant events in 2010 which led to water quality issues. From September 26 through October 1, 2010, the Catskill watershed received a significant storm event, with some areas of the watershed receiving more than 178-229 mm (7-9 inches) of rainfall. Esopus Creek at Coldbrook had a peak discharge of 12,350 $m^3 s^{-1}$ (43,600 cfs), which has a recurrence interval of about 15 years (i.e., a peak of that magnitude has a 6.7% probability of being equaled or exceeded in any given year). On November 30, 2010, the Catskill watershed received a second significant storm event. The average rainfall during this event in the Ashokan watershed was more than114 mm (4.5 inches) and Esopus Creek at Coldbrook had a peak discharge of almost 11,330 $m^3 s^{-1}$ (40,000 cfs). (This peak had a 12-year recurrence interval, which equals an 8.2% probability of being equaled or exceeded in any given year.) These two events had peak discharges so large that each would rank in the top 10 of annual peak flows recorded in the 78-year history of the USGS gage on Esopus Creek at Coldbrook. Having two such high runoff events within two months of one another was very unusual.

The National Climatic Data Center's (NCDC) 2010 Annual Climate Summary (http://www.ncdc.noaa.gov/sotc/national/2010/13) reports that the 2010 spring period (March-May) was the warmest on record (1985-2010) for New York, and that the summer period (June-August) was the fifth warmest. It was also a relatively wet summer (fifteenth wettest out of the last 116 years). Overall for New York, it was the sixth warmest year on record and the sixteenth wettest since 1895.

2.3 2010 Watershed Runoff

Runoff is defined as the part of the total rainfall and snowmelt input to a basin that leaves by drainage to a stream channel. The runoff from the watershed can be affected by meteorological factors such as type of precipitation (e.g., rain, snow, and sleet), rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the drainage basin, direction of storm movement, antecedent precipitation and resulting soil moisture, and temperature. The physical characteristics of the watersheds also affect runoff. These include land use; vegetation; soil type; drainage area; basin shape; elevation; slope; topography; direction of orientation; drainage network patterns; and ponds, lakes, reservoirs, sinks, and other features of the basin which prevent or alter runoff. The annual runoff coefficient is a useful statistic to compare the runoff between watersheds. It is calculated by dividing the annual flow volume by the drainage basin area, yielding a depth that would cover the drainage area would be covered if all the runoff for the year were uniformly distributed over the basin. This statistic allows comparisons to be made of the hydrologic conditions in watersheds of varying sizes.

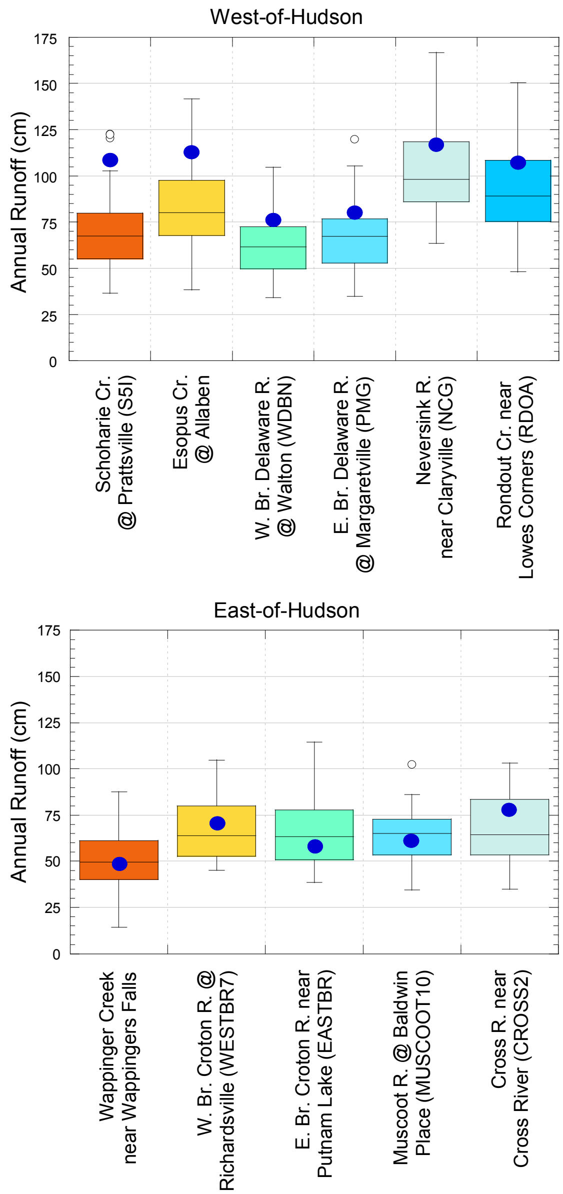

Figure 2.4 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds, with the values for 2010 displayed as a dot. The Wappinger Creek near Wappingers Falls site is not located in the EOH watershed, but was used because it has a long-term record that fairly well reflects the EOH hydrological conditions.

Selected USGS stations were used to characterize annual runoff in the different NYC watersheds (Figure 2.8). The annual runoff in 2010 from the WOH watersheds was somewhat above the normal range, with the four Delaware System basins at about the 75th percentile while the two Catskill watersheds were above the 75th percentile. In the EOH watersheds, the 2010 annual runoff was generally near the watersheds' historical medians (50th percentile) (Figure 2.4). The EOH stations have a 14-year period of record, except for the Wappinger Creek site (82-year period of record). On the other hand, the period of record for the WOH stations ranges from 46 years at the Esopus Creek Allaben station to 107 years at the Schoharie Creek Prattsville gage.

2.4 Use of Rainfall Data in the Design of Stormwater Pollution Prevention Plans

DEP is responsible for regulatory oversight of land development activities in the watershed via the review and approval of applications submitted in accordance with Section 18-39 of the New York City Watershed Rules and Regulations (2010). Section 18-39 established DEP's authority to regulate the management and treatment of stormwater runoff, established standards for the delineation and protection of watercourses, and codified prohibitions regarding the construction of impervious surfaces. This is the section under which Stormwater Pollution Prevention Plans (SPPPs) are submitted, as well as applications for Individual Residential Stormwater Permits (IRSPs) and Stream Crossing, Piping and Diversion Permits (CPDPs). Residential-, commercial-, institutional-, and transportation-related activities are among the land uses requiring DEP review under this section.

The SPPPs require specific hydrologic modeling and analyses of site runoff conditions prior to and after proposed construction and development activities. Stormwater computer models rely on historical records that include the most current rainfall data to define the magnitude of a number of storm events, namely the 1-year, 10-year, and 100-year/24-hour events, and the 90% rainfall event, in order to size stormwater management practices and to gauge a variety of runoff conditions and predict downstream impacts. The 1-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 100% chance of occurring in any given year, while the 10-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 10% chance of occurring in any given year. The 100-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 1% chance of occurring in any given year. Figures 2.5 through 2.8 are isohyetal maps that present the most current estimates of these precipitation return periods for New York. Where construction activities require DEP review and approval of an SPPP in accordance with the New York City Watershed Regulations, these maps are used in the design of stormwater management practices. They are available in Chapter 4 of the New York State Stormwater Management Design Manual (issued Aug. 2010) or online at http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf.

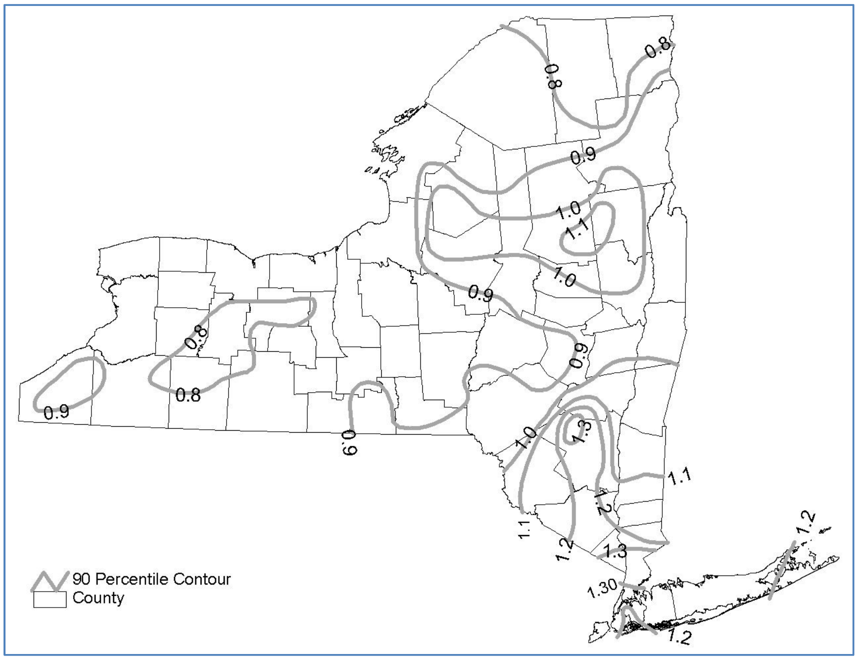

Figure 2.5 Ninety percent rainfall in New York State (DEC 2010).

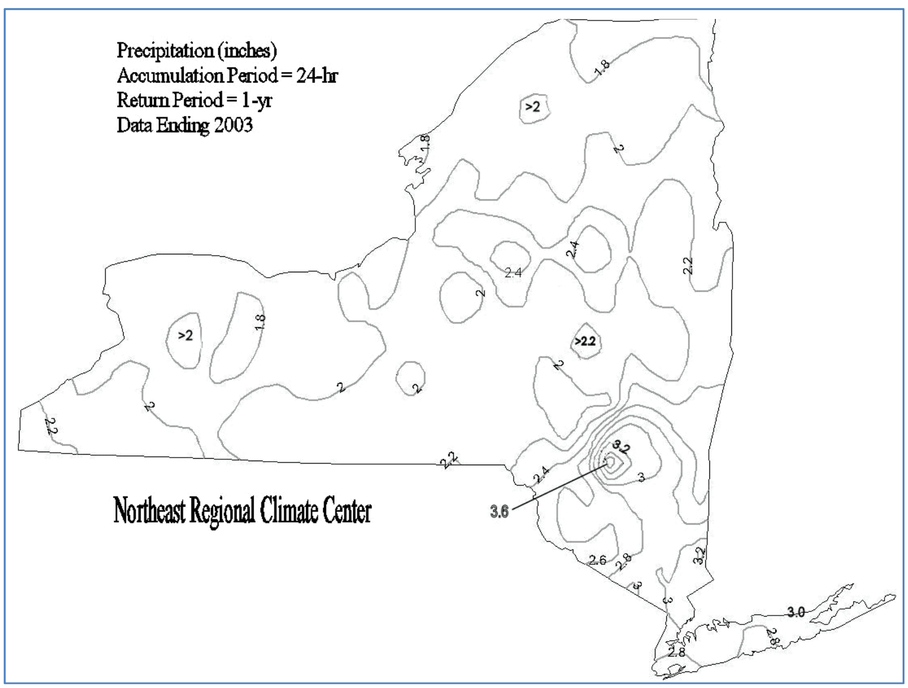

Figure 2.6 One-year design storm (DEC 2010).

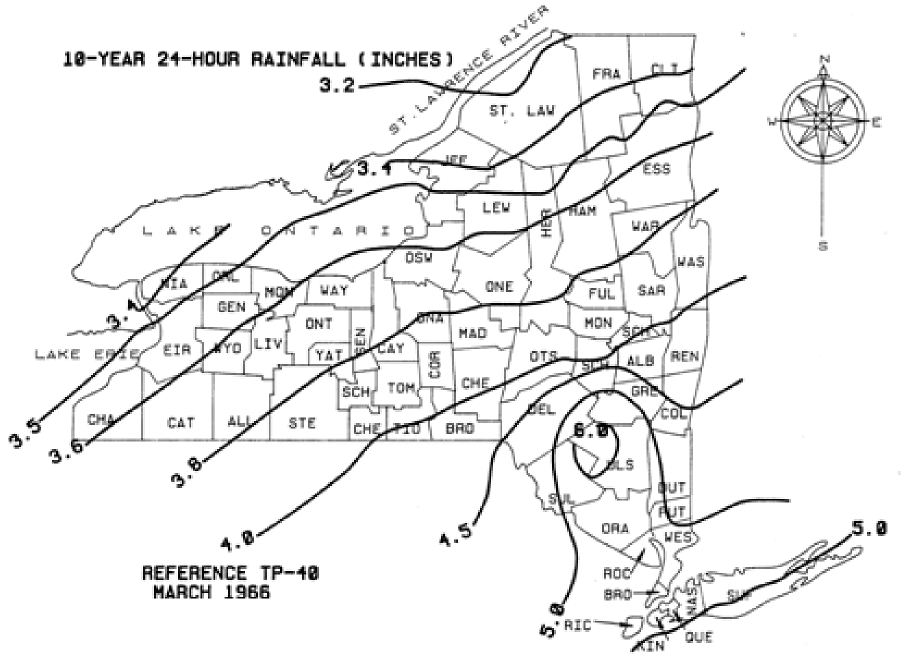

Figure 2.7 10-year design storm (DEC 2010).

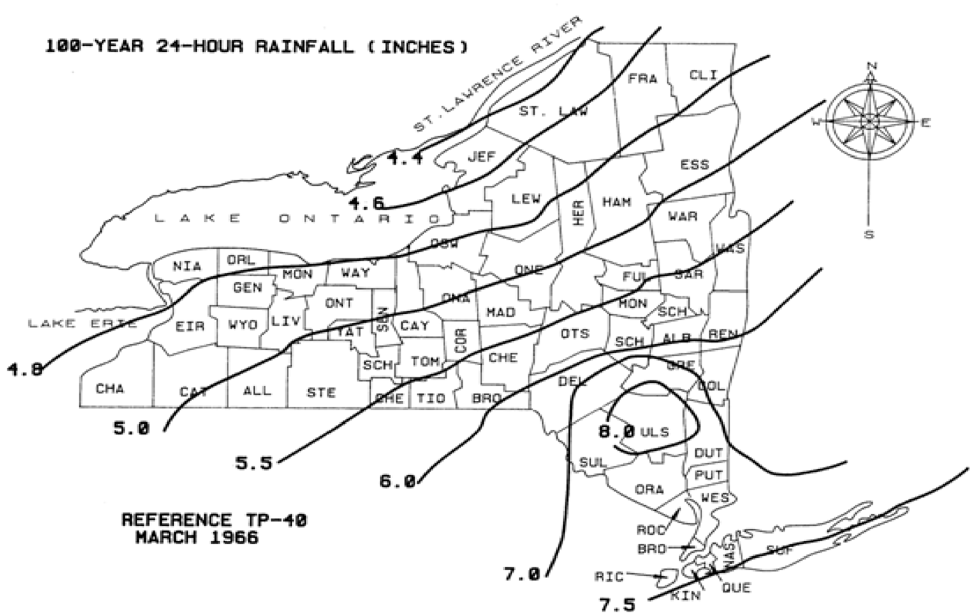

Figure 2.8 100-year design storm (DEC 2010).

2.5 Reservoir Usable Storage Conditions in 2010

DEP has established typical or "normal" system-wide usable storage levels for each calendar day. These levels are based on historical storage values, which are a function of system demand, conservation releases, and reservoir inflows. Ongoing daily monitoring of these factors allows DEP to compare the present system-wide storage against what is considered typical for any given day of the year. In 2010 the actual system-wide storage began the year above normal levels (Figure 2.9), but fell to near normal by the end of February due to below average precipitation (see Section 2.2). Several large rain events (more than one inch) in March caused a sharp increase in storage. Levels dropped quickly in April, and stayed slightly above normal in May and June before gradually falling below normal storage near the end of September. Storage quickly recovered by October 1, due primarily to a very large rain event from September 29-30. Because of this storm, and several small events in December, storage remained well above normal levels for the remainder of the year.

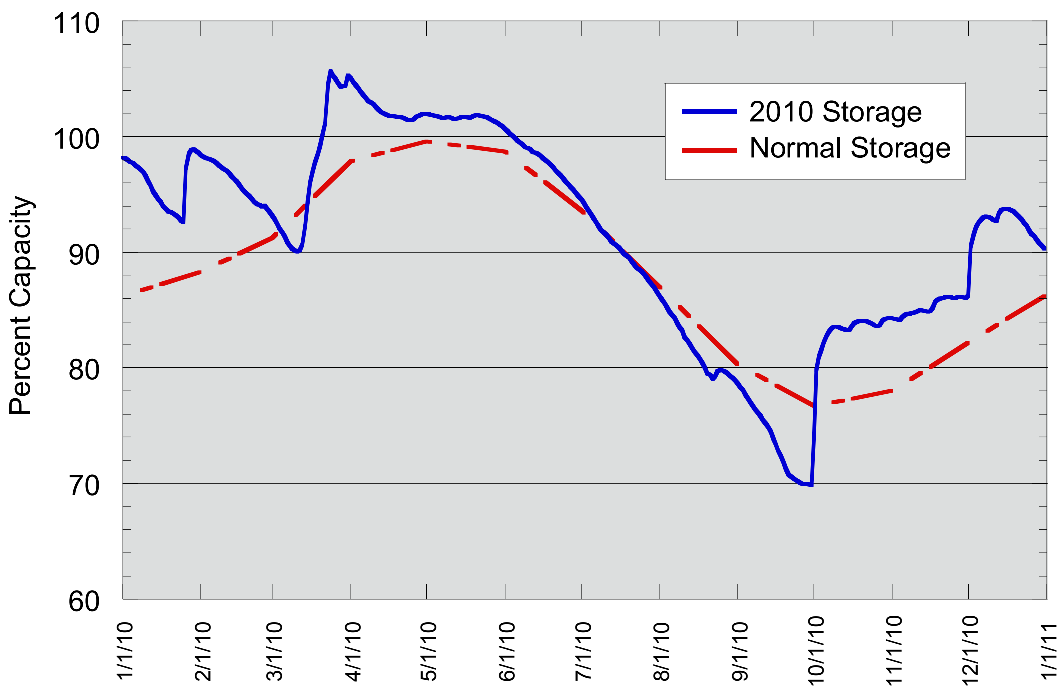

Figure 2.9 2010 system-wide usable storage compared to historical storage. Storage of greater than 100% is possible when the reservoirs are spilling or when the water surface elevation is greater than the spillway elevation.

3. Water Quality

3.1 Keypoint Compliance with the Surface Water Treatment Rule

The Surface Water Treatment Rule (SWTR) (40 CFR §141.71(a)(1)) requires that water at a point just prior to disinfection not exceed the thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the water supply systems at "keypoints" (entry points from the reservoirs to the aqueducts) just prior to disinfection (the Croton System at CROGH, the Catskill System at CATLEFF, and the Delaware System at DEL18). Table 3.1 and Figure 3.1 depict fecal coliform and turbidity data, respectively, for 2010. The turbidity graphs include horizontal lines marking the SWTR limit.

Table 3.1: Fecal coliform at the keypoints compared to the SWTR limit for 2010 (percent daily samples > 20 CFU $100mL^{-1}$ in the previous six months).

Month	Croton %	Catskill %	Delaware %
Jan	0.0	0.6	0.0
Feb	0.0	0.6	0.0
Mar	0.0	0.6	0.0
Apr	0.0	0.6	0.0
May	0.0	0.6	0.0
Jun	0.0	0.0	0.0
Jul	0.0	0.0	0.0
Aug	0.0	0.0	0.0
Sep	0.0	0.0	0.0
Oct	0.0	0.0	0.0
Nov	0.0	0.0	0.0
Dec	0.0	0.0	0.0

As indicated in Table 3.1 , the fecal coliform counts at all three keypoints consistently met the SWTR standard that no more than 10% of daily samples contain > 20 CFU $100mL^{-1}$. The 2010 calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were far below this limit. Median fecal coliform counts (CFU $100mL^{-1}$) in raw water samples taken at these sites were < 1, 1, and 1 CFU $100mL^{-1}$, while maxima were 19, 19, and 14 CFU $100mL^{-1}$, respectively.

The SWTR limit for turbidity is 5 NTU. As indicated in Figure 3.1, all three effluent waters, measured at 4-hour intervals, were consistently well below this limit in 2010. When New Croton Reservoir is not on-line, a daily sample may be collected from a representative location such as CROGH, CRO1T, CRO1B, CRO1D, CRO143E, and CRO183E. These different samples are noted in Figure 3.1. A high value in early December 2010 coincided with a storm that occurred while New Croton Reservoir was off line. For CROGH, CATLEFF, and DEL18, all median turbidity values were the same, at 0.9 NTU, while maximum values were 4.8, 2.9, and 1.9 NTU, respectively. (Note: The plot shows a high value at DEL18 in 2010 that was collected as a drop sample on March 10, 2011. Gate operations caused conditions that resulted in a sample that was deemed not representative of source water quality.)

These findings highlight the continued success of the management of the NYC watershed as well as effective operational strategies in maintaining high quality drinking water.

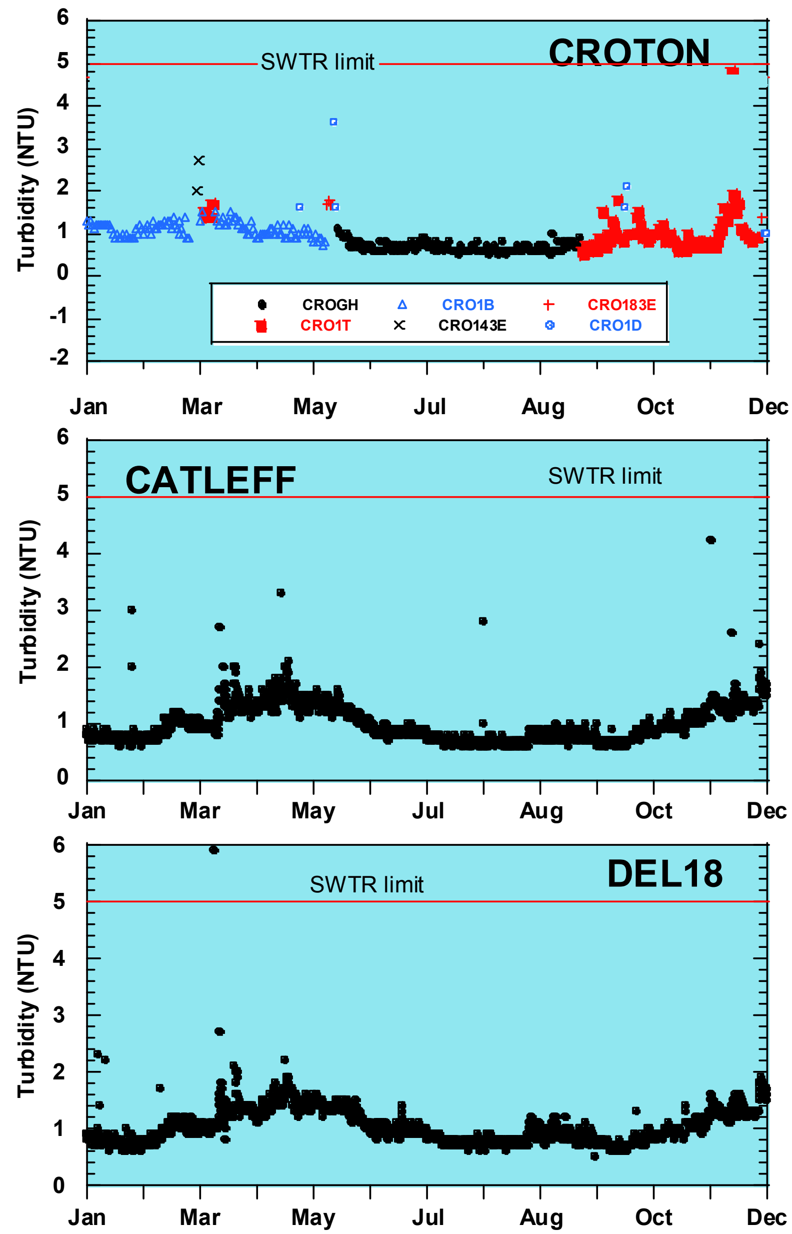

Figure 3.1 Turbidity at keypoints compared to the SWTR limit, 1992-2010. CROGH panel provides data for all potential keypoint samples.

3.2 Reservoir Turbidity Patterns in 2010

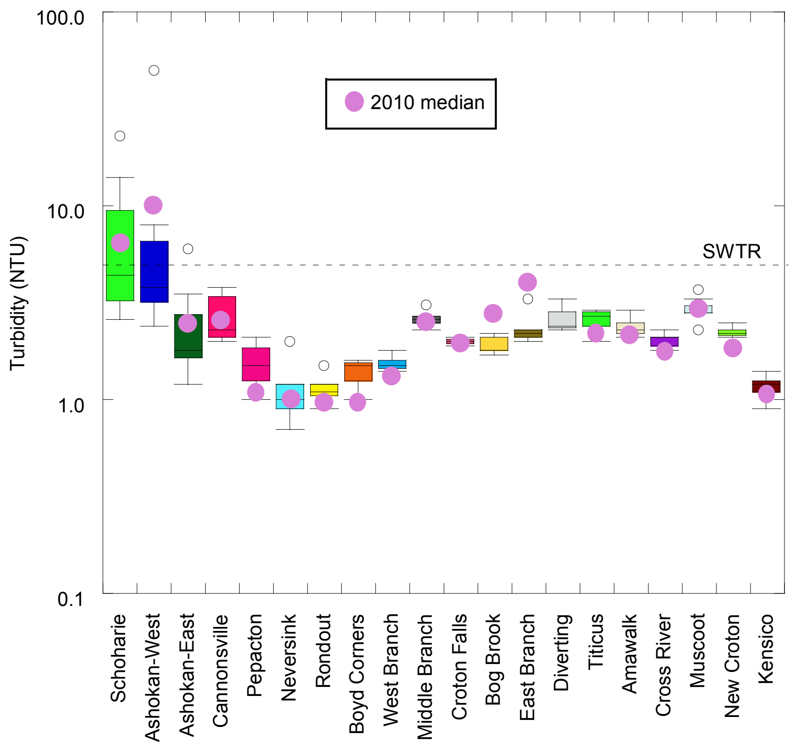

Figure 3.2 Annual median turbidity in NYC water supply reservoirs (2010 vs. 2003-2009). The dashed line at 5 NTU refers to the SWTR criterion that considers 2 consecutive days > 5NTU a violation in *source water* reservoirs. A boxplot key is found in Appendix A.

Note: In general, data were obtained from multiple sites, multiple depths, and at routine sampling frequencies (once per month from April through November).

Turbidity in reservoirs is mainly caused by inorganic (e.g., clay, silt) particulates suspended in the water column and, to a lesser extent, by organic (e.g., plankton) constituents. Turbidity may be derived from the watershed by erosional processes (storm runoff in particular) or generated within the reservoir itself (e.g., internal plankton development, sediment re-suspension).

Turbidity in the Catskill System reservoirs was higher than normal in 2010 (Figure 3.2). Winter runoff events produced very high turbidities through May. These events were mitigated somewhat by the diversion of water out of Ashokan-West Basin to the lower Esopus via the waste channel. The use of stop shutters was also critical to avoiding alum use. Turbidity levels became elevated again, beginning in late summer, due to very large rain events on August 22 and September 30.

In the Delaware System, winter runoff and the September rain event caused turbidity to be higher than normal in Cannonsville Reservoir (although much lower compared to the Catskill reservoirs). However, winter runoff and the August rain event appeared to have no effect on turbidity levels in the remaining reservoirs of the Delaware System. Consequently, the median turbidity levels in 2010 at Pepacton, Neversink, Rondout, and West Branch were less than historical levels.

Turbidity at Kensico, the terminal reservoir for the Catskill and Delaware Systems, was down slightly for the year, largely due to more reliance on the Delaware System during periods when the Catskill System was affected by turbidity.

Lower than normal turbidities were observed in most of the Croton System reservoirs in 2010. The largest decrease (40%) occurred at Boyd Corners, while lesser decreases ranging from 4 to 19% occurred in eight other Croton reservoirs. A small turbidity increase of 4% occurred at Muscoot, while large increases were observed at Kirk Lake (131%), East Branch (86%), and Bog Brook (56%). Because turbidity samples were only collected from Kirk on two occasions, once in May and another two days after the large August rain event, the annual median turbidity reported for that lake should be viewed with caution. The turbidity increase at East Branch and Bog Brook is related to the frequent drainage of these reservoirs in 2010 to support downstream construction at Diverting and Croton Falls dams. Water level fluctuations tend to increase re-suspension of reservoir sediments. Exposed shoreline sediments are also susceptible to erosion from rain events. The largest turbidity increases at Bog Brook and East Branch followed the large rain events in August and September when the reservoirs were at their lowest elevations.

3.3 Coliform-Restricted Basin Assessments in 2010

Coliform bacteria are used by water suppliers as indicators of pathogen contamination. To protect the City's water supply, the New York City Watershed Rules and Regulations restrict potential sources of coliforms in threatened water bodies (2010). These regulations require the City to perform an annual review of its reservoir basins to decide which, if any, should be given "coliform-restricted" determinations.

Coliform-restricted determinations are governed by four sections of the regulations: 18-48(a)(1), 18-48(d)(1), 18-48(c)(1), and 18-48(d)(2). Section 18-48(c)(1) applies to "terminal basins," those that serve, or potentially serve, as source water reservoirs (Kensico, West Branch, New Croton, Ashokan, and Rondout). The coliform-restricted assessments of these basins are based on compliance with federally-imposed limits on fecal coliforms collected from waters within 500 feet of the reservoir's aqueduct effluent chamber. Section 18-48(a)(1) applies to all reservoirs and Lakes Gilead and Gleneida ("non-terminal basins") and specifies that coliform-restricted assessments of these basins be based on compliance with NYS ambient water quality standard limits on total coliform bacteria (6 NYCRR Parts 701 and 703).

3.3.1 Terminal Basin Assessments

In 2010, assessments were made for all five terminal basins, and only West Branch received a restricted assessment (Table 3.2). Currently, coliform-restricted assessments for terminal basins are made using data from a minimum of five samples each week over two consecutive six-month periods. If 10% or more of the effluent samples measured have values ≥ 20 CFU $100mL^{-1}$, and the source of the coliforms is determined to be anthropogenic (Section 18-48(d)(2)), the associated basin is deemed a coliform-restricted basin. Since other microbial tests for identification of potential sources were not performed on these samples, the results for West Branch are only presented as an initial assessment for 2010.

Table 3.2: Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2010.

Reservoir Basin	Effluent Keypoint	2010 Assessment
Kensico	CATLEFF and DEL18	Non-restricted
New Croton	CROGH	Non-restricted[1]
Ashokan	EARCM	Non-restricted
Rondout	RDRRCM	Non-restricted
West Branch	CWB1.5	Restricted[2] (24% >20 CFU $100mL^{-1}$)

[1]Data from sites CRO1B and CRO1T were also used for analysis.
[2]Fecal coliform source not definitively anthropogenic.

3.3.2 Non-Terminal Basin Assessments

Section 18-48(a)(1) requires that non-terminal basins be assessed according to 6 NYCRR Part 703 for total coliform. These New York State regulations are specific to the class of the reservoir. A minimum of five samples must be collected per month in each basin. Both the median value and >20% of the total coliform counts for a given month need to exceed the values ascribed to the reservoir class to exceed the standard. Table 3.3 provides a summary of the coliform-restricted calculation results for the non-terminal reservoirs. A detailed listing of these calculations is provided in Appendix B.

Table 3.3: Coliform-restricted calculations as per Section 18-48(a)(1) for non-terminal reservoirs in 2010.

Reservoir Basin	Class[1]	Standard Monthly median/ >20% (CFU $100mL^{-1}$)	Number of months that exceeded the standard/ months of data	Months not evaluated due to TNTC data[2]
Amawalk	A	2400/5000	0/7	2/7
Bog Brook	AA	50/240	2/8	
Boyd Corners	AA	50/240	1/7	
Croton Falls	A/AA	50/240	2/7	1/7
Cross River	A/AA	50/240	1/8	
Diverting	AA	50/240	2/4	
East Branch	AA	50/240	4/7	1/7
Gilead	A	2400/5000	0/8	
Gleneida	AA	50/240	0/7	
Kirk	B	2400/5000	0/7	1/7

Table 3.3: (Continued) Coliform-restricted calculations as per Section 18-48(a)(1) for non-terminal reservoirs in 2010.

Reservoir Basin	Class[1]	Standard Monthly median/ >20% (CFU $100mL^{-1}$)	Number of months that exceeded the standard/ months of data	Months not evaluated due to TNTC data[2]
Muscoot	A	2400/5000	0/8	
Middle Branch	A	2400/5000	0/8	
Titicus	AA	50/240	1/8	1/8
Pepacton	A/AA	50/240	0/8	
Neversink	A	50/240	0/8	1/8
Schoharie	A	50/240	7/8	1/8
Cannonsville	A/AA	50/240	2/8	3/8

[1]The reservoir class is defined by 6 NYCRR Subpart C. For those reservoirs that have dual designations, the higher standard was applied.

[2]TNTC data refers to coliform plates that were Too Numerous To Count. Determination of the montly median or individual sample exceedance of the standard was not possible.

Five reservoirs never exceeded the Part 703 standard for total coliform in 2010: Lake Gilead, Lake Gleneida, Muscoot, Middle Branch, and Pepacton. Three reservoirs—Amawalk, Kirk Lake, and Neversink— may not have exceeded the standards for the year, but the inclusion of data that was Too Numerous To Count (TNTC) prohibited the calculation of some of the monthly statistics. (Too Numerous to Count is standard microbiological terminology to describe plates containing too many colonies to enumerate.) Schoharie Reservoir exceeded the standard for seven out of eight months. TNTC data precluded the calculation for the eighth month. The remaining reservoirs exceeded the standard for one to four months during the sampling season.

Total coliforms originate from a variety of natural and anthropogenic (man-made) sources. However, Section 18-48(d)(1) states that the source of the total coliforms must be proven to be anthropogenic before a reservoir can receive coliform-restricted status. Since other microbial tests for identification of potential sources were not performed on these samples, the results in Table 3.3 are only presented as an initial assessment of total coliform for the non-terminal basins in 2010.

3.4 Reservoir Total and Fecal Coliform Patterns in 2010

Total coliform and fecal coliform bacteria are regulated at raw water intakes by the SWTR at levels of 100 CFU 100mL^{-1} and 20 CFU 100mL^{-1}, respectively. Both are important as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals; total coliforms include both fecal coliforms and other coliforms that typically originate in water, soil, and sediments.

Total and fecal coliform results are presented in Figure 3.3, 3.4 and Table 3.4. Note that data used to construct the boxplots are annual 75th percentiles rather than medians. Generally, more than 50% of coliform data is below the detection limit. Using annual medians, the resulting boxplot is compressed at the bottom of the y-axis. By using the 75th percentile, the data are "spread out", making it easier to discern differences among reservoirs.

Historically, the highest total coliform counts occur in the Catskill System reservoirs (Figure 3.3) and counts continued to be high in 2010. Because coliforms commonly adhere to soil particles, and soils are very susceptible to erosion in these watersheds, an equal volume of runoff tends to produce much higher coliform counts in the Catskill System reservoirs than in other watersheds. Some coliform species increase around July, peak in September, and remain elevated into the fall. In 2010, however, total coliforms were also unusually high in the spring due to the numerous runoff events that occurred during the winter through March. The highest counts of the year (>10,000 CFU 100 mL^{-1} in Ashokan-West) occurred in October and were associated with a large rain event on September 30.

Despite less erodible soils, Muscoot and Diverting Reservoirs and Kirk Lake have had historically high total coliform levels. Muscoot and Kirk are much shallower than the other Croton System reservoirs and are susceptible to wind derived re-suspension events, which distribute bacteria and detritus into the water column. The shallow depths are also conducive to warm temperatures, which allow many types of coliforms to survive. Although Diverting is deeper, flow-through is generally rapid, which may influence total coliform levels by re-suspending bottom sediments. Note that due to dam repairs, the elevation of Diverting has been lowered in recent years, which also facilitates re-suspension.

Even though the broad y-axis scale of Figure 3.3 makes it difficult to discern, 2010 total coliform counts decreased from 15 to 73% in 8 of 14 Croton reservoirs and lakes compared to their historical levels. Counts at Middle Branch, Titicus, and Cross River were unchanged. Several increases were also apparent, most notably at East Branch and nearby Bog Brook, up 288% and 107%, respectively. Lesser increases were apparent at New Croton (23%) and Amawalk (20%). With the exception of one large rain event on August 22 (3.8 inches), the increase in total coliform counts was not related to runoff events.

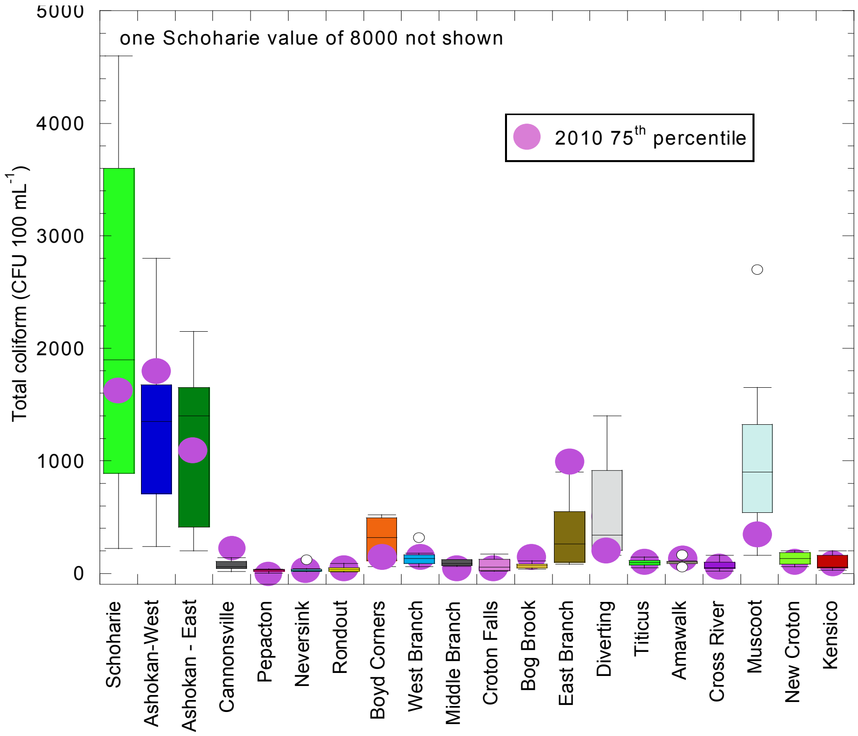

Figure 3.3 Annual 75th percentile total coliform in NYC water supply reservoirs (2010 vs. 2003-2009). A boxplot key is found in Appendix A.

Note: In general, data were obtained from multiple sites, multiple depths, and at routine sampling frequencies (once per month from April through November).

In the Delaware System, declines in total coliforms were observed at Rondout (41%), Pepacton (27%), and West Branch (38%), while Neversink was unchanged from historical levels. The lone increase occurred at Cannonsville (53%), where counts were high throughout the year and not generally associated with rain events.

Reservoir fecal coliform data are summarized in Figure 3.4. The controlled lakes of the Croton System are summarized in Table 3.4. In 2010, with the exception of West Branch and Schoharie, fecal counts in the Catskill and Delaware Systems were low and unchanged compared to historical levels. High counts in Schoharie were associated with spring runoff and a large rain event of 4.1 inches that occurred on September 30. West Branch coliforms were high from September to November, and were likely transported to the reservoir during large rain events on

August 22 and September 29-30. Fecal coliform counts continued to be very low at Kensico, the terminal reservoir for the Catskill and Delaware Systems, presumably due to the ongoing success of the waterfowl management program.

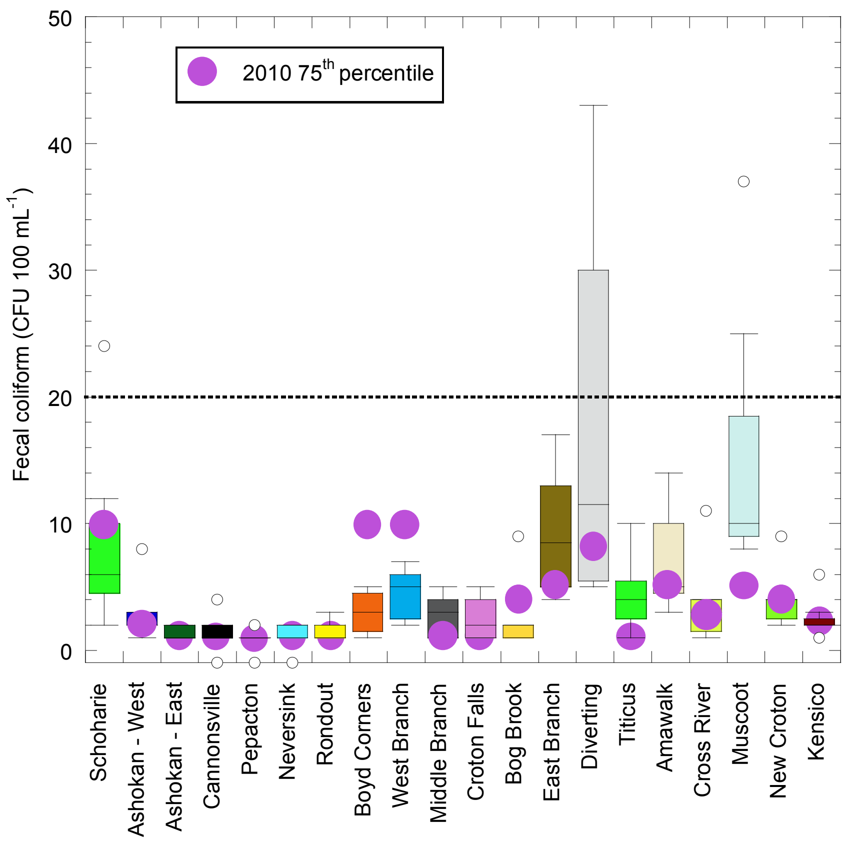

Figure 3.4 Annual 75th percentile of fecal coliform in NYC water supply reservoirs (2010 vs. 2003-2009). The dashed line represents the SDWA standard for *source waters,* and is presented as a reference. A boxplot key is found in Appendix A.

Note: In general, data were obtained from multiple sites, multiple depths, and at routine sampling frequencies (once per month from April through November).

Table 3.4: Summary statistics for coliform in NYC controlled lakes (CFU $100mL^{-1}$)

Lake	Historical total coliform (75^{th} percentile 2003-2009)	Current total coliform (75^{th} percentile 2010)	Historical fecal coliform (75^{th} percentile 2003-2009)	Current fecal coliform (75^{th} percentile 2010)
Gilead	51	14	4	2
Gleneida	34	29	1	1
Kirk	190	100	5	10

Fecal coliform counts were generally lower than usual in the Croton System in 2010. Large decreases were observed at Croton Falls (50%), Diverting (30%), East Branch (41%), Gilead (50%), Muscoot (50%), Middle Branch (67%), and Titicus (75%). Reasons for the low counts are not clear. Counts at New Croton, Amawalk, Cross River, and Gleneida did not differ from historical levels. Notable increases were only apparent at Boyd Corners (233%), Kirk Lake (120%), and Bog Brook (100%). High counts at these reservoirs were mostly associated with the large rain events in late August and late September.

3.5 Phosphorus-Restricted Basin Assessments in 2010

Phosphorus-restricted basin status is presented in Table 3.5 and was derived from two consecutive assessments (2005-2009 and 2006-2010) using the methodology stated in Appendix C. Appendix Table C.1 in Appendix C lists the annual growing season geometric mean phosphorus concentrations for NYC reservoirs. Reservoir basins whose geometric mean phosphorus concentrations exceed the benchmarks in the New York City Watershed Rules and Regulations (2010) for both assessments are classified as restricted. Figure 3.5 graphically depicts the phosphorus restriction status of the NYC reservoirs and the 2010 geometric mean phosphorus concentrations. As of April 4, 2010, the New York City Watershed Rules and Regulations were amended to lower, from 20 to 15 $\mu g\ L^{-1}$, the acceptable geometric mean for total phosphorus (TP) for reservoirs that serve, or potentially serve, as source waters (DEP 2010a). These reservoirs are Ashokan-East Basin, Ashokan-West Basin, Cross River, Croton Falls, Kensico, New Croton, Rondout, and West Branch. The assessments for these reservoirs were calculated using the new, lower, TP limit.

Table 3.5: Phosphorus-restricted reservoir basin status for 2010.

Reservoir Basin	05-09 Assessment (mean + S.E.) (µg L^{-1})	06-10 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus Restricted Status
Delaware System			
Cannonsville	17.8	17.0	Non-Restricted
Pepacton	9.6	9.8	Non-Restricted
Neversink	6.7	6.3	Non-Restricted
Catskill System			
Schoharie	15.9	13.7	Non-Restricted
Croton System			
Amawalk	22.5	21.6	Restricted
Bog Brook	22.2	25.7	Restricted
Boyd Corners	15.3	14.1	Non-Restricted
Diverting	Insufficient data	Insufficient data	Restricted
East Branch	26.9	28.7	Restricted
Middle Branch	27.8	25.9	Restricted
Muscoot	27.2	27.7	Restricted
Titicus	24.9	25.3	Restricted
Lake Gleneida	Insufficient data	25.2	Restricted
Lake Gilead	35.0	33.9	Restricted
Kirk Lake	30.7	30.1	Restricted
Source Reservoirs			
Ashokan-East	9.8	9.4	Non-Restricted
Ashokan-West	15.7	10.7	Restricted
Cross River	17.7	16.9	Restricted
Croton Falls	17.7	16.7	Restricted
Kensico	8.0	7.0	Non-Restricted
New Croton	17.6	17.0	Restricted
Rondout	8.0	8.0	Non-Restricted
West Branch	11.8	9.8	Non-Restricted

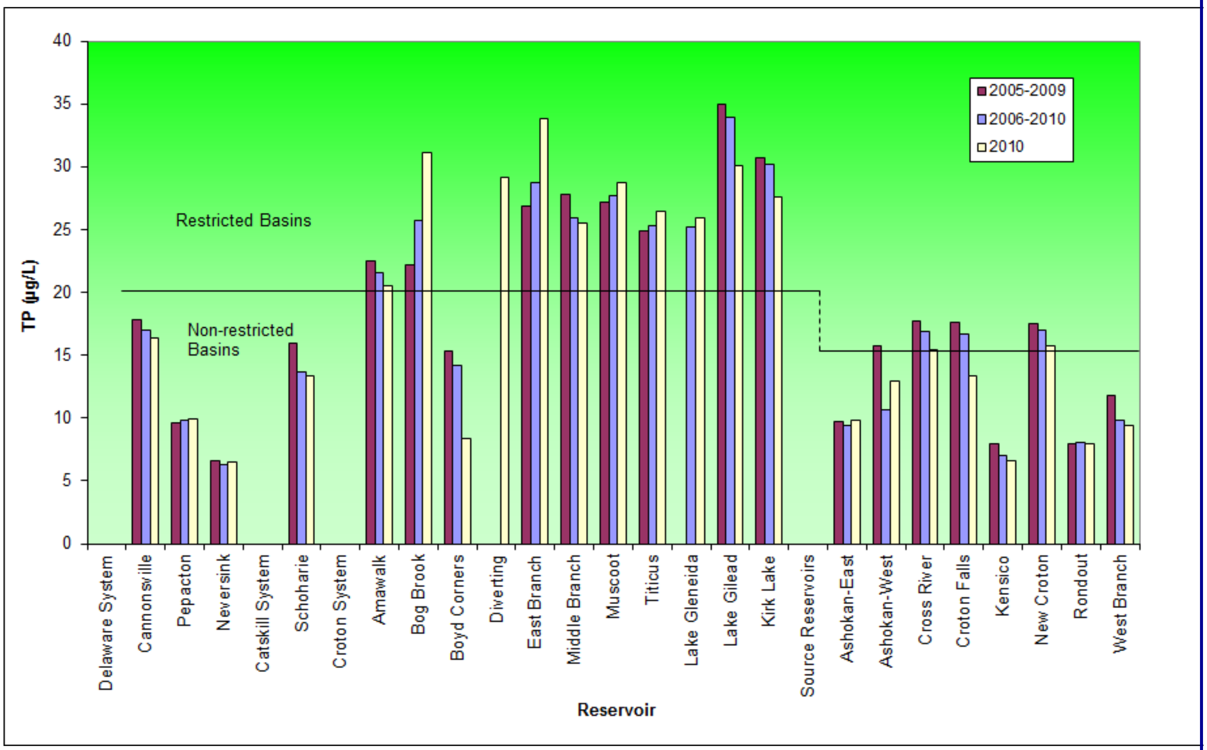

Figure 3.5 Phosphorus-restricted basin assessments, with the current year (2010) geometric mean phosphorus concentration displayed for comparison.

Note: The horizontal solid lines at 20 µg L^{-1} and 15 µg L^{-1} represent the NYC Watershed Rules and Regulations standard for non-source waters and source waters, respectively.

Some notes and highlights regarding phosphorus-restricted basin status in 2010:

- Delaware System reservoirs remained non-restricted with respect to TP. Figure 3.5 shows that, for Cannonsville, the 2010 geometric mean was lower than the mean for the two five-year assessment periods. The 2010 mean was similar to the two assessment periods for both Pepacton and Neversink Reservoirs.
- Croton System reservoirs remained phosphorus-restricted, with the exception of Boyd Corners, which remained non-restricted.
- Geometric means of the TP concentrations for 2010 were generally higher than in previous years (Appendix C), the exceptions being Boyd Corners, Lake Gilead, and Kirk Lake. Bog Brook and East Branch values were higher than usual in 2010 due to low water levels and minimal flushingin order to accommodate a construction project of the East Branch dam and spillway.
- Due to a limited number of surveys, Diverting Reservoir had insufficient data to evaluate either the 2005-2009 or 2006-2010 assessments.

- Source waters were held to the new limit of 15 µg L^{-1}, which placed four reservoirs into the phosphorus-restricted category: Ashokan-West Basin, Cross River, Croton Falls, and New Croton Reservoirs. Croton Falls was also generally lower than in previous years.
- Kensico, Ashokan-East Basin, Rondout, and West Branch Reservoirs were well below the 15 µg L^{-1} threshold.
- Ashokan-West continues on phosphorus restriction due to abnormally high mean TP during 2005, causing the 2004-2008 and 2005-2009 assessments to be elevated. The 2006-2009 assessment no longer includes this high value and reflects a more normal level. If the 2007-2011 assessment is also below 15 µg L^{-1}, Ashokan-West will no longer be restricted at that time.

3.6 Reservoir Total Phosphorus Patterns in 2010

Precipitation and runoff generated by precipitation are important mechanisms by which phosphorus is transported from local watersheds into streams and reservoirs. Primary sources of phosphorus include human and animal waste, fertilizer runoff, and internal recycling from reservoir sediments.

Phosphorus in the Catskill System reservoirs was higher than normal in 2010 (Figure 3.6). Winter runoff events produced high suspended solids loading and associated TP through May. These events were mitigated somewhat by shutting down the Schoharie diversion, allowing the reservoir to spill to the Schoharie Creek, and by diversion of water out of Ashokan-West to the lower Esopus via the waste channel. The use of stop shutters was also critical to avoiding alum use. TP concentrations became elevated again, beginning in late summer, due to very large rain events on August 22 and September 30.

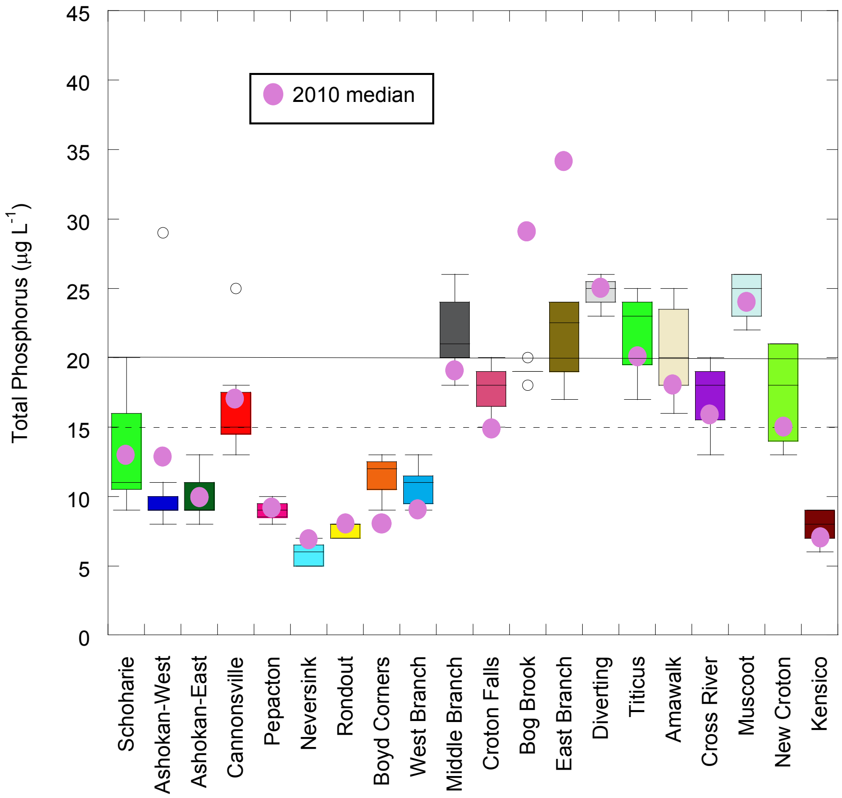

Figure 3.6 Annual median total phosphorus in NYC water supply reservoirs (2010 vs. 2003-2009). A boxplot key is found in Appendix A.

Note: The horizontal dashed line at 15 µg L^{-1} refers to the NYC TMDL guidance value for source waters. The horizontal solid line at 20 µg L^{-1} refers to the NYS DEC ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs).

In the Delaware System phosphorus results were mixed in 2010 (Figure 3.6). While phosphorus was unchanged compared to historical concentrations at Rondout and Pepacton, increases of 13% and 17% were observed at Cannonsville and Neversink, respectively. Winter runoff and March rain events caused April and May phosphorus concentrations to increase above normal in all Delaware basins. All basins were again impacted by a large storm on September 30. The overall increase at Neversink and to a lesser extent at Cannonsville appears to be related to the proximity of sampling dates to summer rain events.

West Branch Reservoir is a blend of Rondout water from the Delaware System and Boyd Corners water from the Croton System. Phosphorus concentrations at Rondout were normal and well below average at Boyd Corners, resulting in below average phosphorus in West Branch in 2010.

Phosphorus in Kensico Reservoir, which receives water from Rondout, West Branch, and Ashokan, decreased slightly in 2010 compared to historical concentrations, largely due to the low phosphorus concentrations and high input from Rondout.

Compared to the Catskill and Delaware Systems, the Croton watershed has a greater abundance of phosphorus sources; there are 60 wastewater treatment plants (WWTPs), numerous septic systems, and extensive paved surfaces scattered throughout the watershed. Because of this more extensive development and geologic differences, TP concentrations in the Croton System reservoirs (Figure 3.6) and controlled lakes (Table 3.6) are normally much higher than in the reservoirs of the Catskill and Delaware Systems.

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

Lake	Median Total Phosphorus (2003-2009)	Median Total Phosphorus (2010)
Gilead	20	18
Gleneida	18	17
Kirk	28	27

Efforts to reduce phosphorus loads in the Croton watershed are ongoing. Many WWTPs have been upgraded; others are at some intermediate stage of upgrade. Septic repair and pump out programs continue in Putnam and Westchester counties, as well as the implementation of farm (usually equestrian-based) BMPs. Stormwater remediation projects are ongoing in the Boyd Corners, West Branch, Croton Falls, and Cross River watersheds. Although eutrophication is still prevalent in the Croton System, in 2010 phosphorus concentrations were low relative to past concentrations for most reservoirs and lakes, perhaps reflecting management efforts to control phosphorus. In two reservoirs, Bog Brook and East Branch, phosphorus increased substantially in 2010. The increase is related to the operational lowering of these reservoirs to facilitate downstream repairs at Diverting and Croton Falls. The largest increases followed the large rain events in August and September when Bog Brook and East Branch were at their lowest elevations.

3.7 Terminal Reservoir Comparisons to Benchmarks in 2010

The NYC reservoirs and water supply system are subject to the federal SWTR standards, NYS ambient water quality standards, and DEP's own guidelines. In this section, the 2010 sampling data, encompassing a variety of physical, biological, and chemical analytes for the terminal reservoirs, are evaluated by comparing the results to the water quality benchmarks listed in Table 3.7. These benchmarks, in turn, are based on the applicable federal, state, and DEP standards or guidelines, also listed in Table 3.7. Note that the standards in this table are not necessarily applicable to the individual samples and medians described herein (e.g., SWTR limits for turbidity and fecal coliform apply only to the point of entry to the system). It should also be noted that different values apply to Croton reservoirs versus West of Hudson reservoirs. Placing the data in the context of these benchmarks assists in understanding the robustness of the water system and water quality issues.

Table 3.7: Reservoir and controlled lake benchmarks as listed in the Watershed Rules and Regulations.

Analyte	Croton System		Catskill and Delaware Systems		
	Annual Mean	Single Sample Maximum	Annual Mean	Single Sample Maximum	Basis
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.00		≥40.00		(a)
Ammonia-N (mg L^{-1})	0.05	0.10	0.05	0.10	(a)
Dissolved chloride (mg L^{-1})	30.00	40.00	8.00	12.00	(a)
Chlorophyll *a* (mg L^{-1})	0.010	0.015	0.007	0.012	(a)
Color (Pt-Co units)		15		15	(b)
Dominant genus (SAU)		1000		1000	(c)
Fecal coliform (CFU 100mL^{-1})		20		20	(d)
Nitrite+nitrate (mg L^{-1})	0.30	0.50	0.30	0.50	(a)
pH (units)		6.5-8.5		6.5-8.5	(b)
Phytoplankton (SAU)		2000		2000	(c)
Dissolved sodium (mg L^{-1})	15.00	20.00	3.00	16.00	(a)
Soluble reactive phosphorus (μg L^{-1})		15		15	(c)
Sulfate (mg L^{-1})	15.00	25.00	10.00	15.00	(a)
Total dissolved solids (μg L^{-1})	150.00	175.00	40.00	50.00	(a)
Total organic carbon (mg L^{-1})	6.00	7.00	3.00	4.00	(a)
Total dissolved phosphorus (μg L^{-1})		15		15	(c)
Total phosphorus (μg L^{-1})		15		15	(c)
Total suspended solids (μg L^{-1})	5.00	8.00	5.00	8.00	(a)
Turbidity (NTU)		5		5	(d)

(a) NYC Rules and Regulations (Appendix 18-B) – based on 1990 water quality results.
(b) NYSDOH Drinking Water Secondary Standard.
(c) DEP Internal standard/goal.
(d) NYSDOH Drinking Water Primary Standard.
Note that additional benchmarks may be developed.

Comparison of the terminal reservoir results to these benchmarks is presented in Appendix D, which lists results not only for the terminal reservoirs, but for non-terminal reservoirs and the controlled lakes as well.

Highlights of the benchmark comparisons are as follows. Summer algal blooms caused 12% of the pH samples in New Croton to exceed the water quality benchmark of 8.5. The pH readings in WOH reservoirs were generally circumneutral. As a result of naturally low alkalinity, however, readings dropped below the benchmark of 6.5 for 26% of the Ashokan-East Basin samples and up to 29% of the Rondout samples. The pH values in Kensico were outside the benchmark range for 12% of the samples.

All chloride samples in New Croton exceeded the benchmarks of the 40 mg L^{-1} single sample maximum and the annual mean standard of 30 mg L^{-1}. Both Kensico and West Branch exceeded the WOH annual mean benchmark for chloride, but only Kensico did not exceed the single sample standard. All chloride samples were much lower than the health standard of 250 mg L^{-1}.

Turbidity levels in West Branch Reservoir never exceeded the single sample maximum of 5 NTU. Rondout, New Croton, and Kensico turbidity exceeded 5 NTU for 1%, 2%, and 3% of the samples, respectively. Twenty-four percent of the Ashokan-East Basin samples exceeded this criterion, while 75% exceeded it in the West Basin.

In Kensico and Rondout, only 1% of the samples exceeded the TP single sample maximum of 15 µg L^{-1} in 2010. Exceedances at the other terminal reservoirs ranged from 13% in Ashokan-East Basin to 52% in New Croton. Nitrate samples were below the single sample maximum and the annual mean benchmarks for all reservoirs except New Croton. This reservoir was 11% above the benchmark, but did not exceed the annual mean. Ammonia values were very low and benchmarks were not exceeded either in the Ashokan basins or in Rondout.

In 2010, phytoplankton counts in Kensico and Rondout Reservoirs were below the 2000 ASU benchmark. In the remaining terminal reservoirs, between 2% and 6% of samples exceeded this benchmark or the single genus benchmark of 1000 ASU. The Croton System typically has greater nutrient inputs than the WOH reservoirs, which results in higher phytoplankton counts and chlorophyll *a* levels. I n New Croton, both the single sample maximum and the annual mean benchmark for chlorophyll *a* were exceeded, while only the single sample standard was exceeded in West Branch. No other terminal reservoirs exceeded the criteria for chlorophyll *a*.

Color readings for 96% of the samples collected in New Croton were above the secondary (aesthetic) color benchmark of 15 units, followed by 44% in West Branch, up to 36% in Ashokan-West Basin, and 13% in Kensico. The high rate of color exceedance in the West Basin was largely due to turbidity increases associated with spring runoff and late summer rain events.

Fecal coliform counts were the lowest in Kensico, where only 1% of the samples exceeded the single sample maximum of 20 CFU 100mL^{-1}. Single sample maximum exceedances in the remaining terminal basins ranged from 3% in Rondout and Ashokan-East Basin to 8% in West Branch.

3.8 Reservoir Trophic Status in 2010

The trophic state index (TSI) is commonly used to describe the productivity of lakes and reservoirs. Three trophic state categories—oligotrophic, mesotrophic, and eutrophic—are used to separate and describe water quality conditions. Oligotrophic waters are low in nutrients, low in algal growth, and tend to have high water clarity. Eutrophic waters, on the other hand, are high in nutrients, high in algal growth, and low in water clarity. Mesotrophic waters are intermediate. The indices developed by Carlson (1977, 1979) use commonly measured variables (chlorophyll *a*, TP, Secchi transparency) to delineate the trophic state of a body of water. TSI based on chlorophyll *a* concentration is calculated as:

$$TSI = 9.81 \text{ x } (\ln (CHLA)) + 30.6$$

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

The Carlson TSI ranges from approximately 0 to 100 (there are no upper or lower bounds), and is scaled so that values under 40 indicate oligotrophy, values between 40 and 50 indicate mesotrophy, and values greater than 50 indicate eutrophy. Trophic indices are generally calculated from data collected in the photic zone of the reservoir during the growing season (the DEP definition of "growing season" is May through October), when the relationship between the variables is most highly correlated. DEP water supply managers prefer reservoirs of a lower trophic state, because such reservoirs typically reduce the need for chemical treatments and produce better water quality at the tap; eutrophic waters, by contrast, may be aesthetically unpleasant from a taste and odor perspective.

Historical (2003-2009) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.7. The 2010 annual median TSI appears in the figure as a circle containing an "x". This analysis generally shows a split between West of Hudson reservoirs, which usually fall into the mesotrophic category, and East of Hudson reservoirs, which are typically classified as eutrophic. The exceptions to these generalizations are Cannonsville, which is usually considered eutrophic; West Branch, which is considered mesotrophic due to incoming water from Rondout Reservoir; and Kensico, which is considered mesotrophic due to inputs from Rondout (usually via West Branch) and from the East Basin of Ashokan.

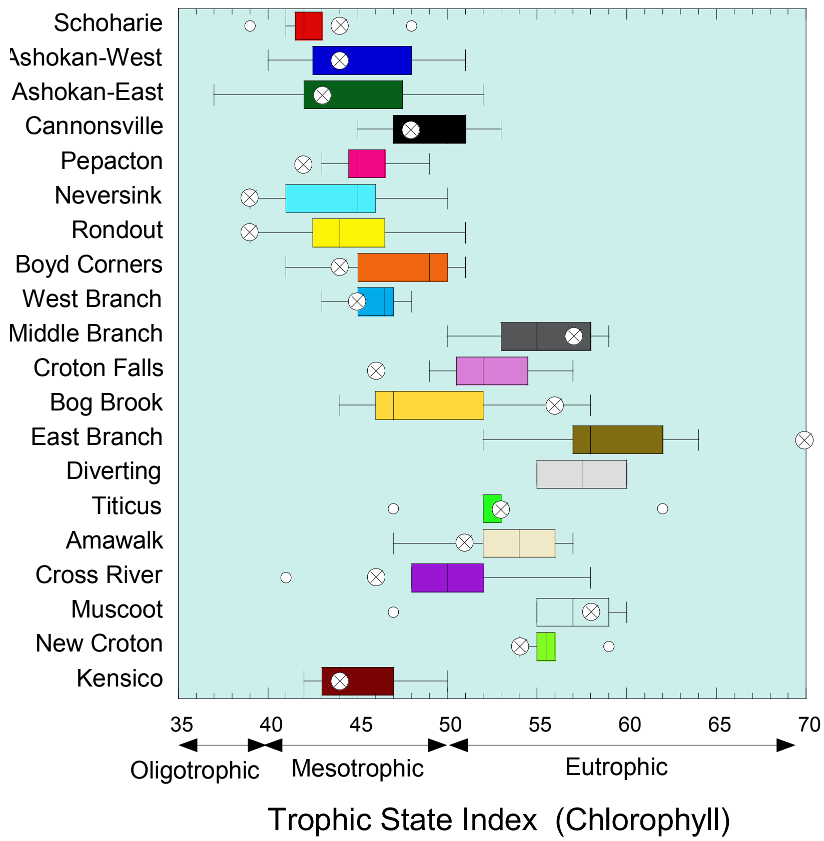

Figure 3.7 Annual median trophic state index in NYC water supply reservoirs (2010 vs. 2003-2009). A boxplot key is found in Appendix A.

Note: In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per from month May through October. TSI is based on chlorophyll *a* concentrations.

TSI was slightly elevated at Schoharie in 2010 as compared to previous years, but remained well within the mesotrophic range. Both Ashokan basins had TSI values in 2010 that were at, or near, the long-term medians.

In the Delaware System, the 2010 TSI levels for Pepacton, Neversink, and Rondout Reservoirs were below their 2003-2009 range, and both Neversink and Rondout were in the oligotrophic range. Cannonsville had a median TSI of 48, which was below the long-term median of 50. The relatively low precipitation from April to June 2010 may have been responsible for lower productivity in these impoundments.

TSI at West Branch was below the long-term median in 2010. Although most of the water in West Branch comes from Rondout, the TSI was more similar to Boyd Corners, indicating that the local watershed played an important role in determining the trophic state of West Branch during that year. Kensico Reservoir, the terminal reservoir for the Catskill and Delaware Systems, had a median TSI in 2010 that was similar to the median TSI in Ashokan-East Basin and West Branch Reservoirs. All were within the mesotrophic range.

TSI patterns were not consistent for the Croton System reservoirs in 2010. Bog Brook and East Branch Reservoirs showed the biggest increases over the long-term median. Water levels were lowered in both reservoirs on numerous occasions to support contract work at Diverting and Croton Falls. Decreased elevation may have been responsible for algal blooms in August and September. Middle Branch, Muscoot, and the controlled lakes Gilead, Gleneida, and Kirk (not shown on the plot) were up slightly for the year, while Titicus remained unchanged compared to 2003-2009 levels. Several decreases in TSI were also apparent in 2010, coinciding with similar declines in phosphorus (see Section 3.6). The largest decrease occurred at Croton Falls, with lesser declines observed at Boyd Corners, Cross River, Amawalk and New Croton. Note that TSI results were not available for Diverting Reservoir, since contract work precluded sufficient sampling of the reservoir in 2010.

3.9 Water Quality in the Major Inflow Streams in 2010

The stream sites discussed in this section are listed in Table 3.8 and shown pictorially in Figure 3.8. The stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill and Delaware reservoirs and into five of the Croton reservoirs. This means they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds (except for New Croton, where the major inflow is from the Muscoot Reservoir release). Kisco River and Hunter Brook are tributaries to New Croton Reservoir and represent water quality conditions in the New Croton watershed.

Table 3.8: Site codes and site descriptions for the major inflow streams.

Site Code	Site Description
S5I	Schoharie Creek at Prattsville, above Schoharie Reservoir
E16I	Esopus Creek at Boiceville bridge, above Ashokan Reservoir
WDBN	West Branch Delaware River at Beerston, above Cannonsville Reservoir
PMSB	East Branch Delaware River below Margaretville WWTP, above Pepacton Reservoir
NCG	Neversink River near Claryville, above Neversink Reservoir
RDOA	Rondout Creek at Lowes Corners, above Rondout Reservoir
WESTBR7	West Branch Croton River, above Boyd Corners Reservoir
EASTBR	East Branch Croton River, above East Branch Reservoir
MUSCOOT10	Muscoot River, above Amawalk Reservoir

Table 3.8: (Continued) Site codes and site descriptions for the major inflow streams.

Site Code	Site Description
CROSS2	Cross River, above Cross River Reservoir
KISCO3	Kisco River, input to New Croton Reservoir
HUNTER1	Hunter Brook, input to New Croton Reservoir

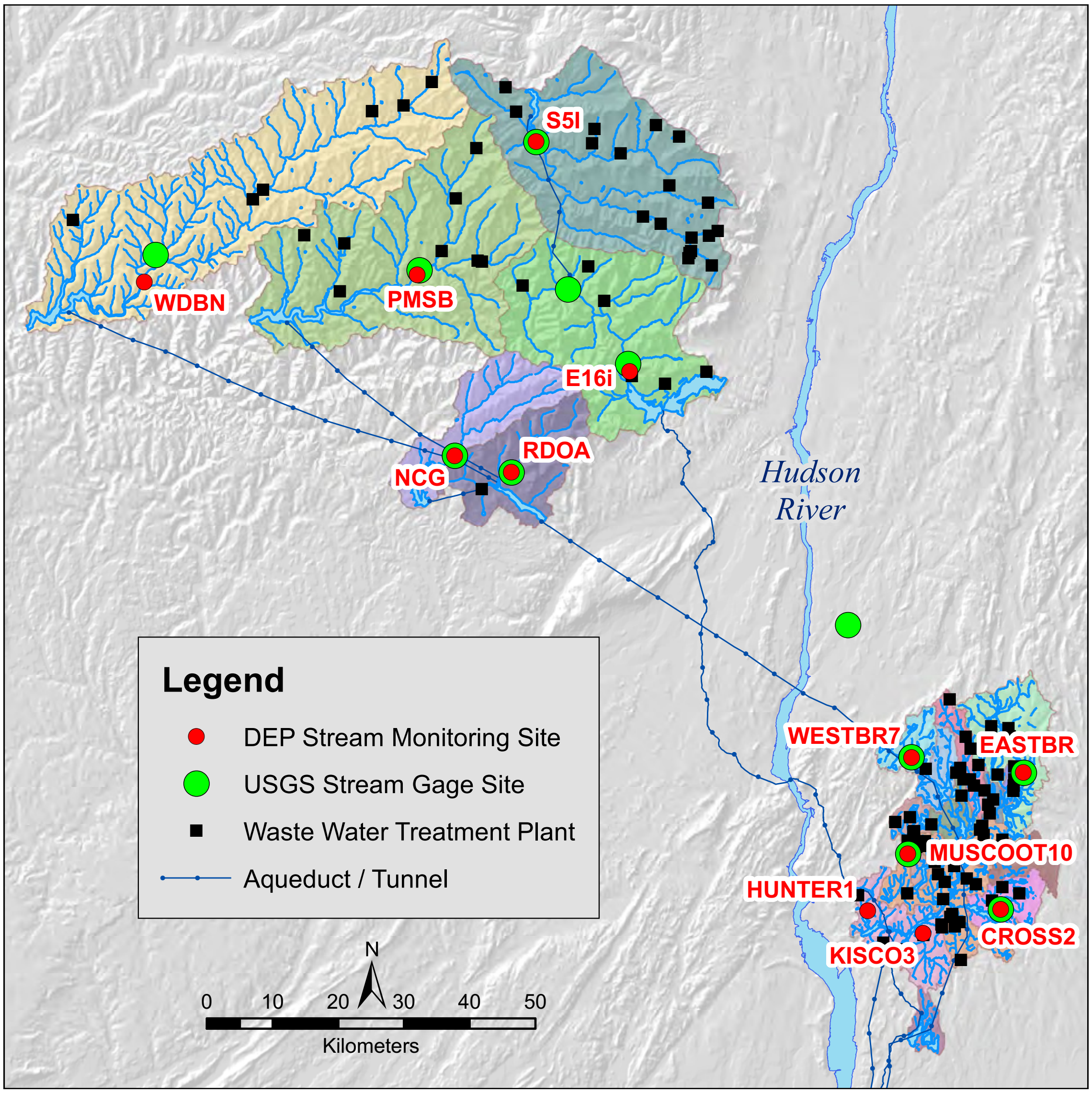

Figure 3.8 Locations of major inflow stream sampling sites and USGS stations used to calculate runoff values (see Section 2.3).

Water quality in these streams was assessed by examining those analytes considered to be the most important for the City's water supply. For streams, these are turbidity (values may not exceed SWTR limits at the distribution points), total phosphorus (nutrient/eutrophication issues), and fecal coliform bacteria (values may not exceed SWTR limits at the distribution points).

The results presented in Figure 3.9 are based on grab samples generally collected once a month in 2010 (twice a month for coliforms for the East of Hudson (EOH) sites). The figures compare the 2010 median values against historical median annual values for the previous 10 years (2000-2009).

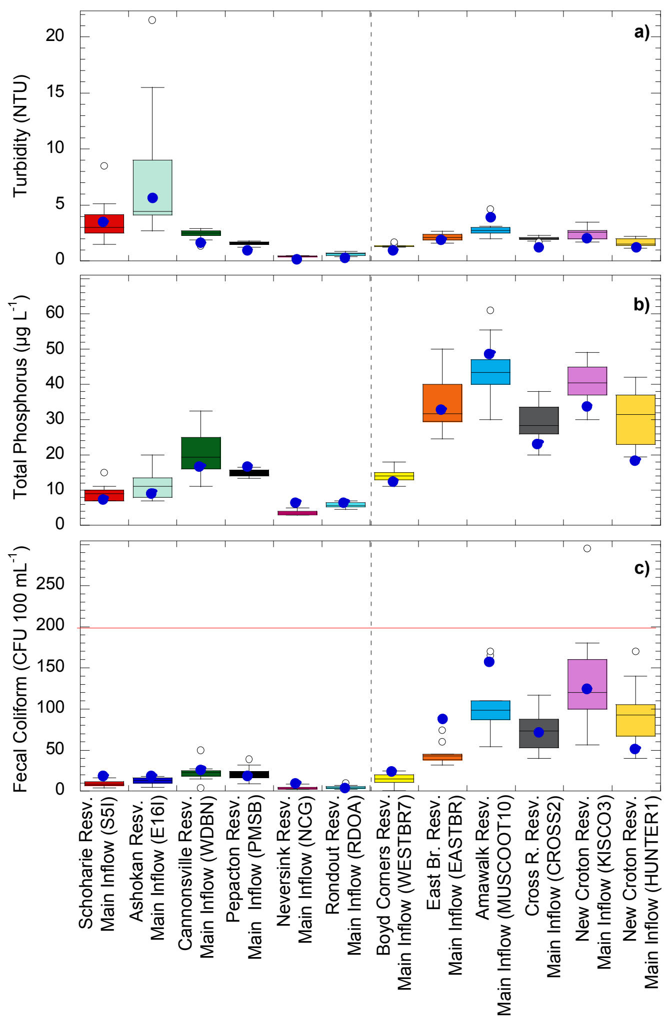

Figure 3.9 Boxplot of annual medians (2000-2009) for a) turbidity, b) total phosphorus, and c) fecal coliform for selected stream (reservoir inflow) sites, with the value for 2010 displayed as a dot. A boxplot key is found in Appendix A.

Note: The dotted line separates WOH streams (left) from EOH streams (right).

Turbidity

The turbidity levels for 2010 were generally near or below “normal” values. Only the Muscoot River above the Amawalk Reservoir had an annual turbidity median above the top whisker of the boxplot.

Total Phosphorus

In the Catskill and Delaware Systems, the 2010 median TP concentrations were below or near typical historical values for Ashokan, Schoharie, and Cannonsville and somewhat above the historical TP medians for Pepacton, Neversink, and Rondout. This pattern was also observed in 2009. The 2010 TP medians in the Croton System were all generally less than historical values, except for East Branch, which was near normal, and the Muscoot River above Amawalk Reservoir, which was slightly above the 75th percentile when compared to the last 10 years of annual medians.

Fecal Coliform Bacteria

The 2010 median fecal coliform bacteria levels in the Catskill, Delaware, and Croton Systems were generally near or below typical historical levels, except for Schoharie Creek, East Branch, and Muscoot River above Amawalk Reservoir, which were all somewhat above their historical median for 2010. A fecal coliform benchmark of 200 CFU 100mL^{-1} is shown as a solid line in Figure 3.9. This benchmark relates to the New York State Department of Environmental Conservation water standard (expressed as a monthly geometric mean of five samples, the standard being <200 CFU 100mL^{-1}) for fecal coliform (6 NYCRR §703.4b). The 2010 median values for all streams shown here lie below this value.

3.10 Stream Comparisons to Benchmarks in 2010

Selected water quality benchmarks have been established for streams in the New York City Watershed Rules and Regulations (2010). In this section stream status is evaluated by comparing 2010 results from 41 streams to these benchmarks, which are listed in Table 3.9.

Table 3.9: Stream water quality benchmarks as listed in the Watershed Rules and Regulations.

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

[1] Organic nitrogen is currently not analyzed. However, results for total nitrogen are provided in Appendix E.

[2] Total dissolved solids was estimated by multiplying specific conductivity by 0.65 (van der Leeden 1990).

[3] Dissolved organic carbon was used in this analysis since TOC is no longer analyzed.

Comparison of stream results to these benchmarks is presented in Appendix E along with site descriptions, which appear next to the site codes.

It is advantageous to maintain alkalinity levels above 10 mg L^{-1} to ensure the effective use of alum during turbidity events. The Catskill streams of the Schoharie, Cannonsville, and Pepacton basins generally met these criteria. Excursions slightly below 10 mg L^{-1} occasionally occurred during the winter and in the case of Mill Brook (Pepacton basin), again in the spring. In contrast, excursions below 10 mg L^{-1} were common in the streams of the Ashokan, Rondout, and Neversink basins. Such low buffering capacity is typical of the surficial materials in this region of the Catskills. The Croton System streams have much higher natural buffering capacity and no samples were below the benchmark of 40 mg L^{-1} in 2010.

None of the Catskill or Delaware streams exceeded the single sample chloride benchmark of 50 mg L^{-1} in 2010. However, the annual mean benchmark of 10 mg L^{-1} was exceeded in eight of the 22 streams monitored in these two systems. Only the three streams of the Ashokan basin met the annual benchmark. The highest annual mean, 34.8 mg L^{-1}, occurred at Kramer Brook above Neversink Reservoir. The two other monitored streams in the Neversink watershed averaged between 3 and 5 mg L^{-1}. The Kramer Brook watershed is very small (less than1 square mile), is bordered by a state highway, and contains pockets of development, all of which may contribute to the relatively high chloride levels. Other high annual means occurred at Bear Kill Creek (19.6 mg L^{-1}), a tributary to Schoharie Reservoir; at Trout Creek (15.7 mg L^{-1}) and Loomis Brook (15.9 mg L^{-1}), both tributaries to Cannonsville Reservoir; and at Chestnut Creek (15.1 mg L^{-1}), a tributary to Rondout Reservoir. In the Croton System, the single sample chloride benchmark of 100 mg L^{-1} was commonly exceeded on the Muscoot River (MUSCOOT10) above Amawalk Reservoir, on Michael Brook (MIKE2) above Croton Falls Reservoir, and on the Long Pond outflow (LONGPD1) above West Branch Reservoir. In all, 15 of the 17 monitored Croton streams exceeded the annual mean benchmark of 35 mg L^{-1}, collectively averaging 74 mg L^{-1} in 2010. Given the common occurrence of chloride and sodium, it was not surprising that sodium benchmarks were exceeded in much the same pattern as chloride. Potential sources of sodium chloride include road salt, septic system leachate, water softening brine waste, and/or wastewater treatment effluent.

TDS (total dissolved solids) is a measure of the ionic content of water. Since TDS is not analyzed directly by DEP, specific conductivity was used to estimate TDS by multiplying specific conductivity by 0.65 (van der Leeden 1990). In 2010, 16 of 23 Catskill/Delaware streams had at least one exceedance of the single sample maximum of 50 mg L^{-1}. Thirteen of the 16 also exceeded the annual mean benchmark of 40 mg L^{-1}. Only streams with very low chloride concentrations (<6.5 mg L^{-1}) could consistently meet the TDS benchmarks. In the Croton System only Boyd Corners release, WESTBR7 (above Boyd Corners Reservoir), and the West Branch Reservoir release met the annual benchmark of 150 mg L^{-1} and, in most cases, the single sample maximum criterion of 175 mg L^{-1}. Like the Catskill/Delaware streams, these Croton streams had relatively low chloride concentrations. TDS excursions in all systems are most likely associated with any of the following sources: elevated salt concentrations from road salt, water softening brine waste, septic system leachate, and/or wastewater treatment effluent.

When present in excess, nitrogen, especially in the bioavailable forms of nitrate and ammonia, is one of the important nutrients that can contribute to excessive algal growth in the reservoirs. The single sample nitrate benchmark of 1.5 mg L^{-1} was exceeded in two Croton streams: Michael Brook, located upstream of Croton Falls Reservoir, and the Muscoot River at MUSCOOT10. The benchmark was exceeded in 6 of 12 monthly samples and was especially high in January (2.8 mg L^{-1}), February (2.5 mg L^{-1}), and August (3.3 mg L^{-1}). Three Croton streams exceeded the annual benchmark of 0.35 mg L^{-1} for 2010: the Kisco River, 0.66 mg L^{-1} at KISCO3; the Muscoot River, 0.80 mg L^{-1} at MUSCOOT10; and Michael Brook, 2.6 mg L^{-1} at MIKE2. Two streams in the Delaware System and one in the Catskill System exceeded the annual nitrate benchmark of 0.4 mg L^{-1}. The 2010 averages for the Delaware streams, Kramer Brook and the West Branch of the Delaware River at Beerston, were 0.48 and 0.50 mg L^{-1}, respectively. The Catskill stream, Bear Creek, a tributary to Schoharie Creek, averaged 0.46 mg L^{-1} in 2010.

The Delaware River and Bear Creek sites are downstream of WWTPs, the probable source of the elevated nitrate, although agricultural runoff may also play a role. At Kramer Brook, failing septics are a potential source.

None of the Croton streams exceeded the mean annual ammonia benchmark of 0.1 mg L^{-1} or the single sample maximum of 0.2 mg L^{-1} in 2010. Only Kramer Brook exceeded the mean annual benchmark of 0.05 mg L^{-1} for the Catskill and Delaware Systems. The average for that stream was driven by one very high result of 1.25 mg L^{-1} in March (which also exceeded the single sample maximum of 0.20 mg L^{-1}); all other monthly samples were at or near the detection limit of 0.02 mg L^{-1}.

In 2010, the Croton System single sample maximum benchmark of 25 mg L^{-1} for sulfate was exceeded at Michael Brook, Gypsy Trail Brook, Horse Pound Brook, the Muscoot River at MUSCOOT10, and the Kisco River at KISCO3. The annual mean sulfate benchmark of 15 mg L^{-1} was also surpassed in four of these streams, with averages of 31.2 mg L^{-1} at Gypsy Trail Brook, 25.1 mg L^{-1} at Michael Brook, 25.0 mg L^{-1} at KISCO3 on the Kisco River, and 16.7 mg L^{-1} at MUSCOOT10 on the Muscoot River. With the exception of Gypsy Trail Brook, the probable sources of the excess sulfate are the WWTPs located upstream. Neither the single sample nor annual mean benchmarks for sulfate were surpassed in the Catskill and Delaware streams in 2010.

Dissolved organic carbon (DOC) was used in this analysis instead of total organic carbon since the latter is no longer analyzed as part of DEP's watershed water quality monitoring program. Previous work has shown that DOC constitutes the majority of the organic carbon in stream and reservoir samples. The DOC benchmarks for single sample (25 mg L^{-1}) and annual mean (9.0 mg L^{-1}) were not surpassed by any stream in 2010. The Catskill/Delaware annual mean DOC ranged from 1.0 to 2.6 mg L^{-1}, well below the annual mean benchmark. Due to a greater percentage of wetlands in their watersheds, Croton streams typically had higher DOC concentrations, with annual means ranging from 2.1 to 5.1 mg L^{-1}.

3.11 Stream Biomonitoring

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994. (For methodology details, see DEP 2011a.) In 2010, DEP sampled 36 sites in 26 streams throughout the City's water supply watershed, 12 in the Croton System, 10 in Catskill, and 14 in Delaware. (For site locations, see Appendix F). Scores in Croton were generally lower than in Catskill and Delaware, which is consistent with the long-term means for these sites (Figures 3.10 and 3.11).

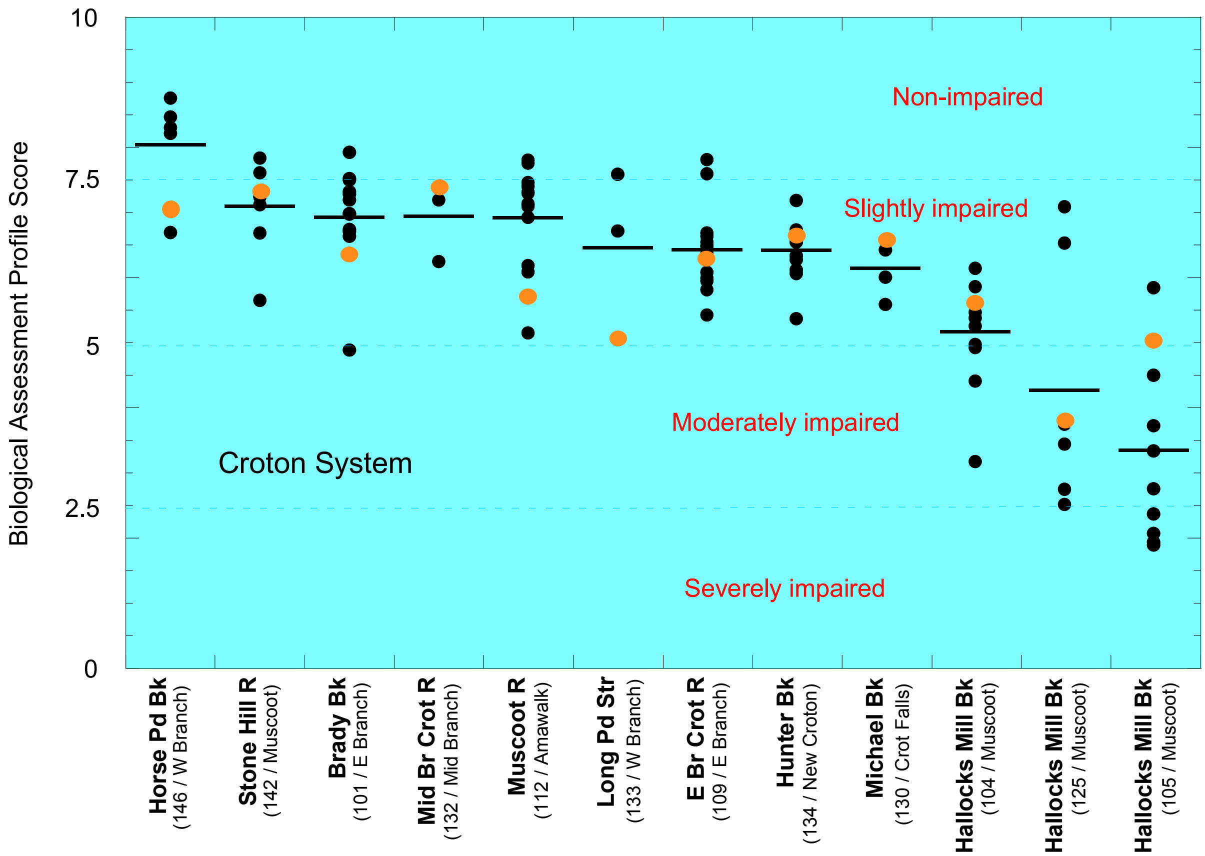

Figure 3.10 Biological Assessment Profile scores for East of Hudson biomonitoring sites sampled in 2010, arranged by mean score from highest to lowest. ● = 2010 score; ● = pre-2010 score. The site's number and watershed are indicated in parentheses following the site name.

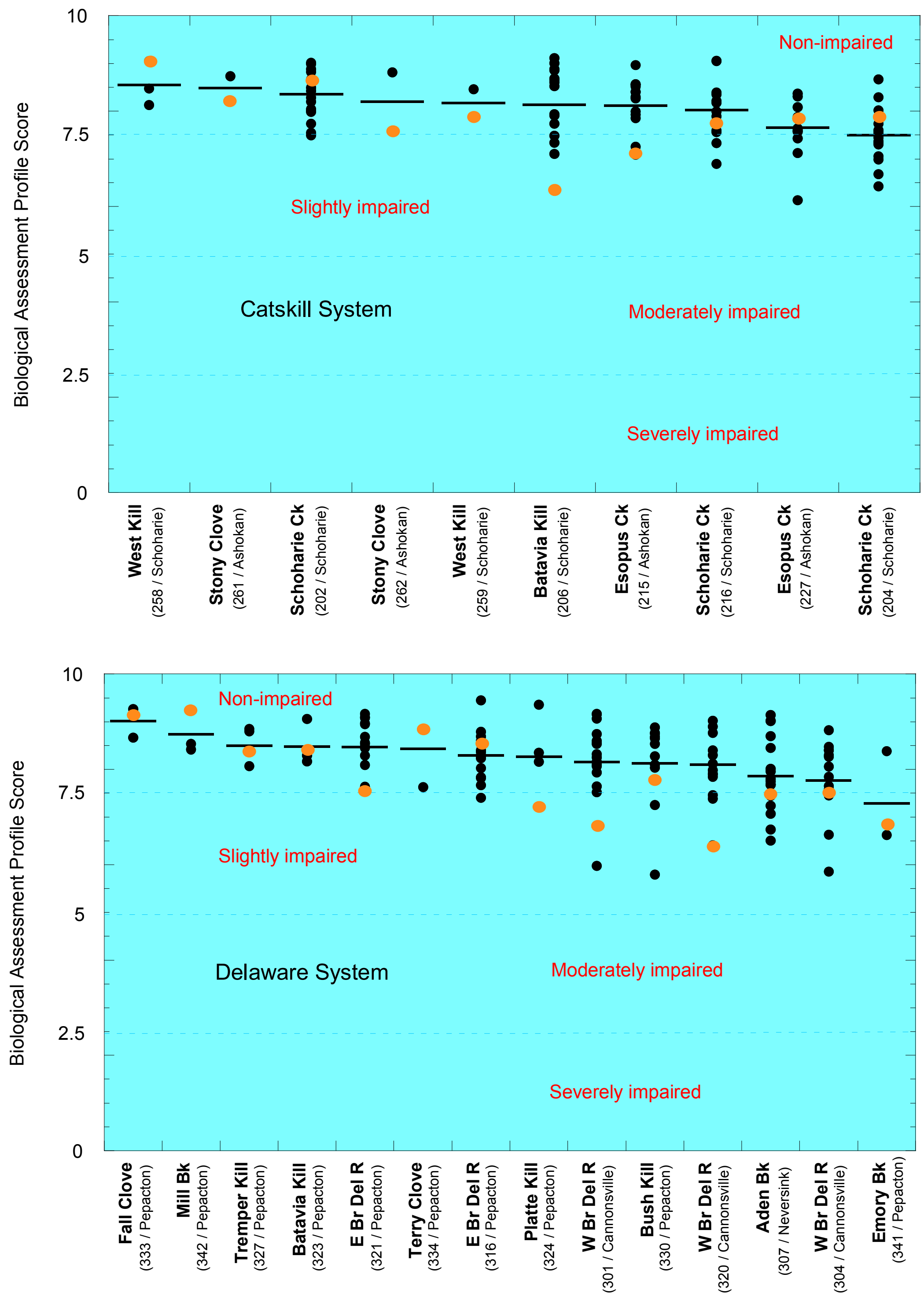

Figure 3.11 Biological Assessment Profile scores for West of Hudson biomonitoring sites sampled in 2010, arranged by mean score from highest to lowest. ● = 2010 score; ● = pre-2010 score. The site's number and watershed are indicated in parentheses following the site name.

All 12 sites sampled East of Hudson were rated slightly impaired; for 9 of them, Biological Assessment Profile (BAP) scores were near or above the site's long-term mean. The low scores at the three remaining sites—on the Muscoot River (Site 112), Long Pond Stream (Site 133), and Horse Pound Brook (Site 146)—were associated with very high numbers of beetles, which depressed all four metrics at the first site and three at the other two. Future sampling will be needed to determine whether the increase in beetle abundance is temporary, reflecting natural variation in these streams, or if it indicates the presence of an as yet undetected disturbance.

In the Catskill System, 6 of the 10 sampled sites were rated non-impaired, while the remaining four received an assessment of slightly impaired. Two of the four had BAP scores near or above their long-term means, but the others—Batavia Kill upstream of Prattsville (Site 206) and Esopus Creek at Allaben (Site 215)—received the lowest scores ever observed at these sites. The low score at Site 215 was driven largely by the high abundance of ephemerellid mayflies and hydropsychid caddisflies, together comprising roughly 50% of the sample. Dominance on this scale tends to depress the total taxa, EPT, and PMA metrics, which is in fact what occurred here. (See DEC 2009 for a description of metrics used in biomonitoring.) However, given that ephemerellids are extremely intolerant of pollution, and that increases in hydropsychids appears to be a cyclical event at this site (occurring previously in 2001 and 2005), it is unlikely that the low score is reflective of declining water quality conditions. In the Batavia Kill, however, the 2010 score represents the fourth consecutive year of decline, a function of the dominance of filter-feeding caddisflies that began at this site in 2007 and has continued since (mean percent composition of filter feeders 1995-2006—16.9%; 2007-2010—48.9%). The cause of this increase is not clear. Applying the New York State Stream Biomonitoring Unit's Impact Source Determination (ISD) protocols (DEC 2009) to the data, nonpoint nutrients appears to be the most likely reason, but that conclusion is inconsistent with actual chemical data collected at the site, which indicate a decline in nutrients during this period. The DEC's NBI-P index (DEC 2009) yields another result that contrasts with the ISD findings, namely, that conditions at Site 206 between 2007-2010 ranged from oligotrophic to mesotrophic. DEP will continue to monitor the stream to try to identify the disturbance responsible for this decline.

Of the 14 sites sampled in the Delaware System, 9 were rated non-impaired, while the remaining 5—Platte Kill (Site 324), West Branch Delaware River at Hobart (Site 301) and at Beerston (Site 320), Emory Brook (Site 341), and Aden Brook (Site 307)—received an assessment of slightly impaired. The Aden Brook BAP score, 7.47, was barely below the non-impaired/slightly impaired threshold of 7.5. At the Platte Kill and Beerston sites, the dominance of tanytarsine midges (35% of each community) caused the scores to drop substantially from the previous year, 8.16 to 7.22 at the former site and 8.62 to 7.28 at the latter. The high midge numbers suggests an increase at these sites in the presence of fine particulate organic matter, the preferred food of these organisms.

3.11.1 WWTP Upgrade Biomonitoring

The dramatic improvement to the benthic macroinvertebrate community observed downstream of the Yorktown Heights WWTP in 2008 and 2009 presented strong evidence of the effectiveness of the plant's 2007 upgrade. (See DEP 2009b and 2010b for details.) In 2010, DEP resampled the stream to determine whether these improvements continued to be reflected in the benthic community at the two sampled sites—Site 105, directly below the outfall, and Site 125, approximately 1.3 miles below it.

The results suggested a retreat from the gains achieved in previous years. Assessments dropped to moderately impaired at both sites, following slightly impaired scores in 2009. Note, however, that the lower rating at Site 105, while disappointing, reflected only small changes from the previous year. In 2009, the Biological Assessment Profile (BAP) score was 5.85; in 2010 it had fallen to 4.92, just shy of the slightly impaired/moderately impaired threshold of 5. EPT numbers were also down, but not greatly—3 from the previous year's 5—and, counting one additional taxon present in the sample but not in the subsample, 4 EPT were present at the site, only one less than in 2009. (See DEC 2009 for a description of EPT and other metrics used to calculate the BAP.) Given the inherent variability of scores from year to year, the small changes exhibited by the 2010 data more likely reflect a stable, but naturally varying, community than a return to pre-upgrade conditions.

At Site 125, however, the decline was a good deal steeper. The BAP score dropped from 7.1 in 2009 to 3.81; the total taxa count fell from 23 to 10 and the number of EPT from 9 to 3; and the percent model affinity (PMA) score, after reaching 71.6 in 2009, fell to 33.9. While a cursory review of these data does indeed suggest a return to conditions prevailing prior to the upgrade, closer examination suggests otherwise. Virtually all of the decline can be traced to a single factor, the dominance of filter-feeding hydropsychid caddisflies, which accounted for fully two-thirds of the subsample. Dominance by a single group always depresses at least three of the four metrics used to calculate the BAP score—total taxa, EPT, and PMA. Moreover, great increases in hydropsychid abundance, which have been observed at other sites before (e.g., Site 215 on Esopus Creek, see p. 43), are often temporary, with numbers frequently returning to former levels within a year or two.

Temporary or not, it is unclear whether the steep rise in hydropsychid numbers in 2010 was the result of a natural event or continued anthropogenic impacts. Physicochemical conditions at Site 125 remain similar to what they were in past years and to conditions at Site 105, while levels of ammonia in the plant's discharge (the primary source of impact to the stream before the upgrade) remain similar to those recorded in 2008 and 2009. It is unlikely that the community at Site 125 was affected by some disturbance upstream of the plant's discharge, since no significant change has been observed either at the biomonitoring site above the outfall (Site 104) or at Site 105 (which, as noted previously, appears to be relatively stable). Continued sampling will be required to determine if scores at Site 125 return to the level attained in 2008-2009, or if the 2010 decline indicates that, at least with respect to the macroinvertebrate community, conditions have not fundamentally altered since the upgrade was accomplished.

4. Pathogens

4.1 Introduction

DEP conducts compliance and surveillance monitoring for protozoan pathogens and human enteric viruses (HEV) throughout the 1,972-square-mile NYC watershed. DEP staff collected and analyzed a total of 598 samples for protozoan analysis during 2010, and 300 samples for HEV analysis. Source water samples (Kensico and New Croton keypoints) comprised the greatest portion of the 2010 sampling effort, accounting for 43.5% of the samples, followed by stream samples, which were 35.5% of the sample load. Upstate reservoir effluents and wastewater treatment plants made up the remaining 21.0% of samples (Figure 4.1).

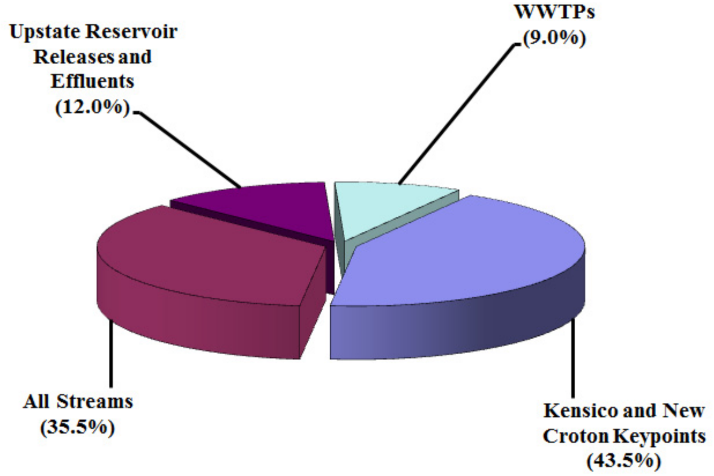

Figure 4.1 DEP protozoan sample type distribution for 2010 (includes routine and enhanced monitoring samples).

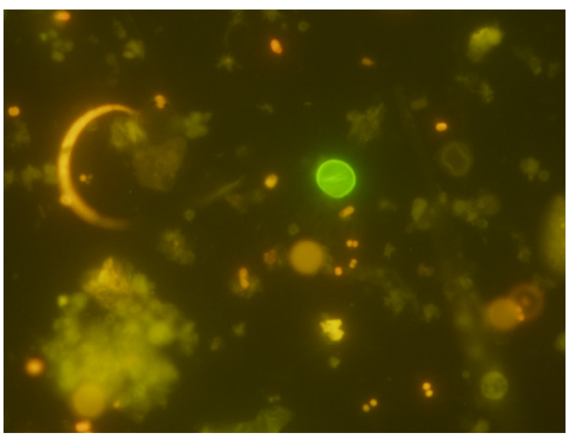

Figure 4.2 Slide of *Cryptosporidium* under microscope.

Under routine reservoir operation, the two influents and the two effluents of Kensico Reservoir, and the one effluent of New Croton Reservoir, are considered the five keypoint source water sampling sites for the NYC water supply. Filtration avoidance compliance requires weekly sampling at these five sites for *Cryptosporidium*, *Giardia*, and HEV's. All 52 protozoan samples were collected and analyzed this year; however, one set of HEV samples was not analyzed because temperature sample acceptance criteria were not met upon arrival at the laboratory. Therefore, the total HEV samples for the keypoints this year is 51. The effluent results are reported weekly on DEP's website (http://www.nyc.gov/html/dep/html/drinking_water/pathogen.shtml), monthly in the Croton Consent Decree (CCD) and Filtration Avoidance Determination (FAD) reports, and semi-annually and annually in the FAD reports (DEP 2011b).

4.2 Source Water

4.2.1 Results

Catskill Aqueduct

In 2010, both *Cryptosporidium* oocyst concentration and detection frequency at CATALUM (Catskill influent to Kensico Reservoir) were low, with a mean of 0.04 oocysts $50L^{-1}$ and only 1 detection out of 52 samples (1.9%) (Table 4.1). *Cryptosporidium* results at CATLEFF (Catskill effluent of Kensico Reservoir) were also low, with a mean of 0.06 oocysts $50L^{-1}$ and 3 detections out of 52 samples (5.8%) for the year.

Table 4.1: Summary of *Giardia*, *Cryptosporidium*, and HEV compliance monitoring data at the five DEP keypoints for 2010 (protozoa, n=52; HEV, n=51, except n=52 for the Catskill Influent and Effluent).

	Keypoint Location	# of positive samples	Mean**	Max
Cryptosporidium oocysts $50L^{-1}$	Catskill Influent	1	0.04	2
	Catskill Effluent	3	0.06	1
	Delaware Influent	1	0.02	1
	Delaware Effluent	1	0.02	1
	New Croton Effluent*	5	0.10	1
Giardia cysts $50L^{-1}$	Catskill Influent	18	0.56	4
	Catskill Effluent	36	1.63	8
	Delaware Influent	25	0.98	8
	Delaware Effluent	32	1.25	5
	New Croton Effluent *	30	1.23	9
Human Enteric Virus $100L^{-1}$	Catskill Influent	4	0.19	4.46
	Catskill Effluent	1	0.04	2.11
	Delaware Influent	6	0.21	4.46
	Delaware Effluent	2	0.04	1.03
	New Croton Effluent*	2	0.08	3.25

*Includes alternate sites sampled to best represent CROGH during “off-line” status.

**Samples greater or less than 50L are calculated to per L concentrations and then re-calculated to 50L for determination of means. Zero values are substituted for non-detect values when calculating means.

The mean *Giardia* cyst concentration at CATALUM was 0.56 cysts $50L^{-1}$, with 18 detections out of the 52 weekly samples (34.6%) (Table 4.1). Mean *Giardia* concentrations at CATLEFF were higher than those at CATALUM, with a mean of 1.63 cysts $50L^{-1}$ and 36 detections (69.2%). These higher values at the effluent of the reservoir indicate a contribution of *Giardia* from the local watershed prior to water leaving the reservoir. Based on previous work in the Kensico basin, the most likely source of these cysts is wildlife feces.

Concentration and detection frequency of HEVs at CATALUM were low in 2010, with a mean concentration of 0.19 MPN $100L^{-1}$ and 4 detections out of 52 samples (7.7%) (Table 4.1). As in previous years, 2010 HEV results were lower at CATLEFF than at CATALUM, at 0.04 MPN $100L^{-1}$ and 1 detection (1.9%) for the year, suggesting a reduction of viruses as water passes through the reservoir.

Delaware Aqueduct

Both *Cryptosporidium* oocyst concentration and detection frequency at DEL17 (Delaware influent to Kensico Reservoir) were very low, with a mean of 0.02 oocysts $50L^{-1}$ and 1 positive sample out of 52 (1.9%) (Table 4.1). *Cryptosporidium* values at DEL18 (Delaware effluent of Kensico Reservoir) were the same as the influent's.

Giardia cyst mean concentration at DEL17 was 0.98 cysts $50L^{-1}$, with 25 positive samples out of the 52 collected (48.1%) (Table 4.1). Mean *Giardia* concentration and detection frequency at DEL18 were slightly higher, with mean concentration of 1.25 cysts $50L^{-1}$ and 32 positive samples (61.5%) for 2010.

HEV concentration and detection frequency at DEL17 were 0.21 MPN $100L^{-1}$ and 6 positive samples out of 51 (11.8%), respectively (Table 4.1). The HEV data for DEL18 were lower than that of DEL17 during 2010, with a mean concentration of 0.04 MPN $100L^{-1}$ and 2 positive samples (3.9%).

New Croton Aqueduct

Protozoan sample data at CROGH (New Croton Reservoir effluent) for 2010 indicated that the mean *Cryptosporidium* concentration was 0.10 oocysts $50L^{-1}$ and that 5 out of 52 samples were positive (9.6%) (Table 4.1). CROGH had a mean *Giardia* concentration of 1.23 cysts $50L^{-1}$ and 30 positive samples (57.7%). Results for HEV sampling at CROGH were once again low, with a mean of 0.08 MPN $100L^{-1}$ and 2 out of 51 positive samples (3.9%) for the year.

As in previous years, a seasonal variation could be detected for *Giardia* at all influent and effluent sites in 2010, with winter and spring having higher concentrations and more frequent occurrences than summer and fall (Figure 4.3). While there may also be some seasonality associated with *Cryptosporidium* occurrence, there were not enough oocysts detected in the source water to be statistically confident in this hypothesis. In general, *Giardia* occurrences were much more frequent and at higher concentrations than *Cryptosporidium* at the source water sites, which is common for the NYC watershed.

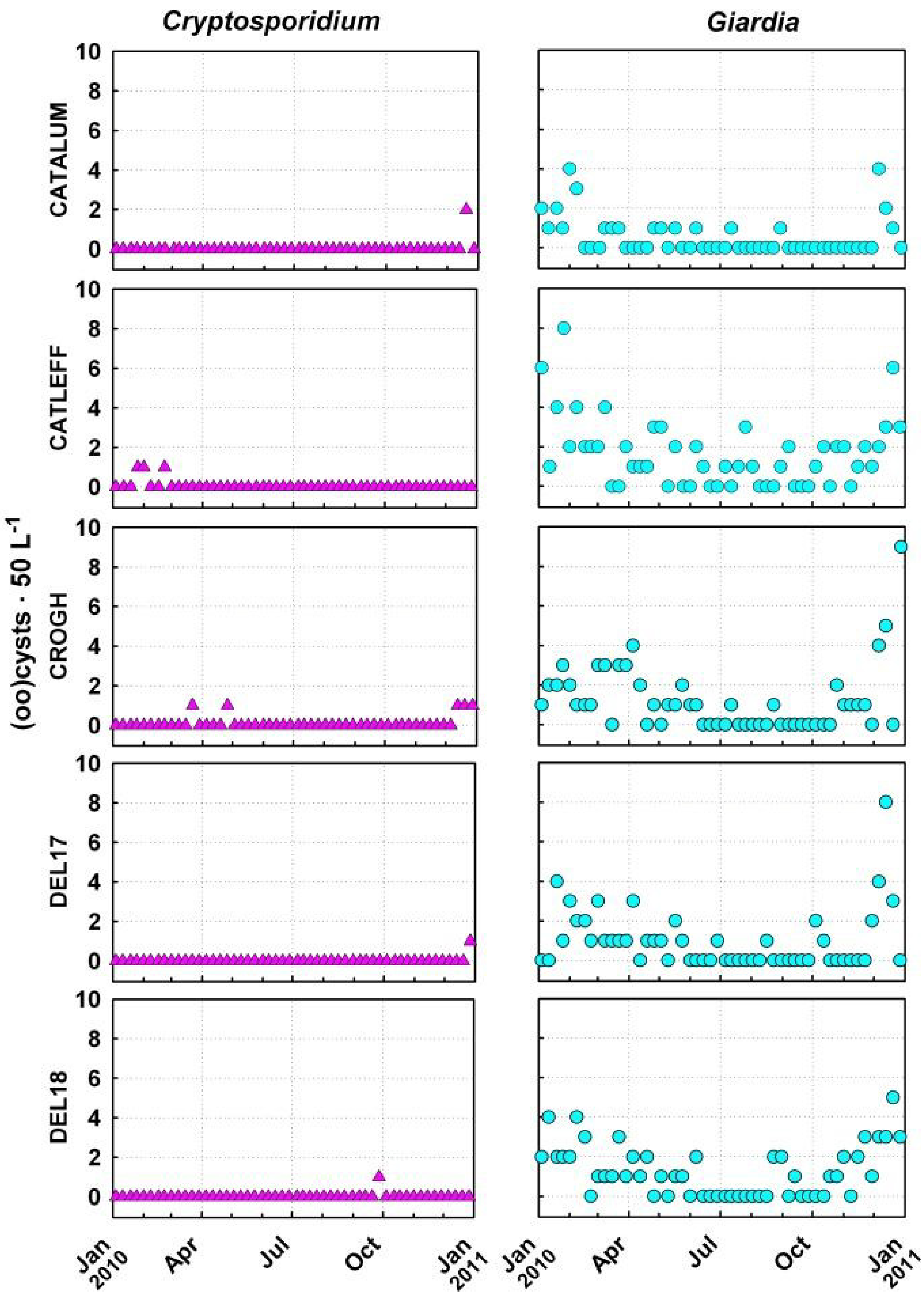

Figure 4.3 Routine weekly source water keypoint monitoring results for 2010.

4.2.2 2010 Source Water Compared to Historical Data

Water quality can vary at the source water sites depending on several factors in each site's watershed, such as stormwater runoff, environmental impacts from land use, and the effects of other ecological processes, such as algal blooms. Each source water site has been sampled weekly since October 2001, using USEPA Method 1623HV. This gives DEP a large dataset, with several years of samples for the detection of seasonal patterns and long-term changes in protozoan concentrations.

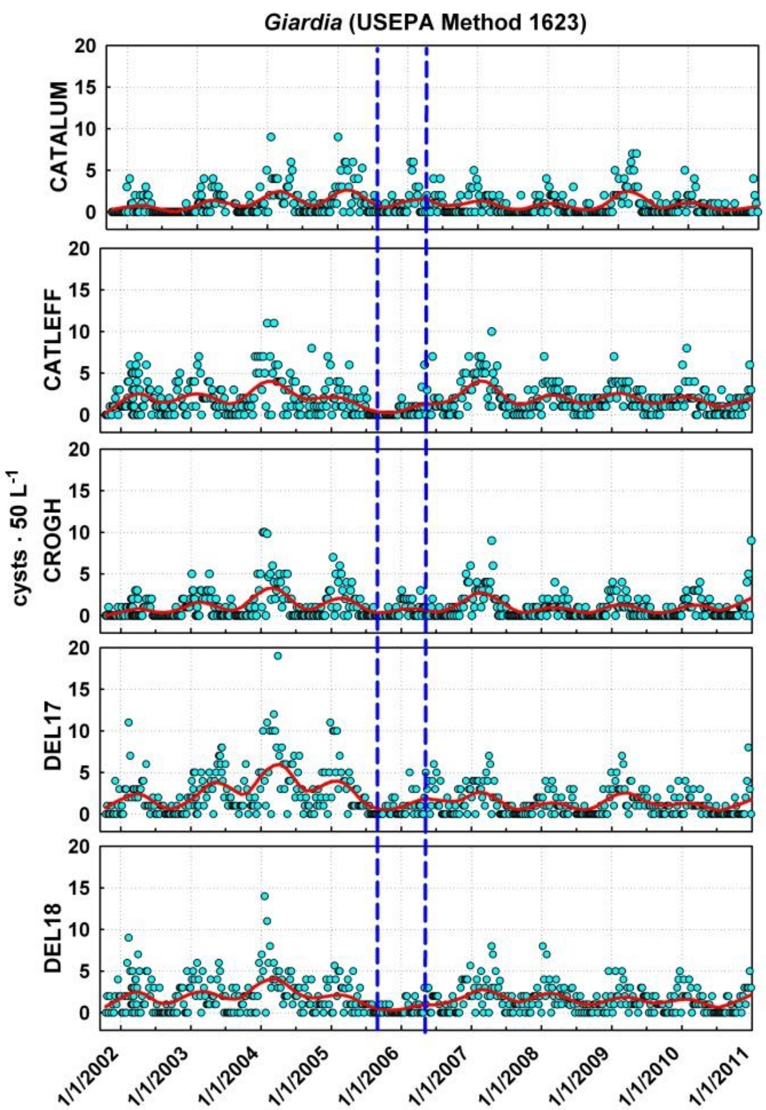

Figure 4.4 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2010. The area between the blue dotted lines indicates the period during which DEP temporarily switched to a different EPA-approved stain.

Pathogen sample data collected in 2010 indicate that concentrations of *Giardia* and *Cryptosporidium* remained relatively low for most of the source water sites compared to data collected from 2001 to 2009. *Cryptosporidium* detections were notably less frequent at source water sites in 2010, with just a few detects (11) during the year, most at concentrations of 1 oocyst $50L^{-1}$. *Giardia* results appear consistent with past years, again showing the seasonal variation of higher values in the colder months (Figure 4.4).

4.2.3 2010 Source Water Compared to Regulatory Levels

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA 2006) requires that utilities conduct monthly source water monitoring for *Cryptosporidium* over a two-year period, though a more frequent sampling schedule may be used. The LT2 requires all unfiltered public water supplies to "provide at least 2-log (i.e., 99 percent) inactivation of *Cryptosporidium*." If the average source water level exceeds 0.01 oocysts L^{-1} based on the LT2 monitoring, "the unfiltered system must provide at least 3-log (i.e., 99.9 percent) inactivation of *Cryptosporidium.*" The value is derived by calculating the mean monthly results over the course of two years, and then taking a mean of those monthly means. For perspective, results have been calculated here using data from the most recent two-year period (January 1, 2009-December 31, 2010), including all routine and non-routine samples (Table 4.2).

Table 4.2: Number and type of samples used to calculate the LT2 bin classification set under the LT2 from January 1, 2009 to December 31, 2010.

Aqueduct	# of routine samples, 2009-2010	# of non-routine samples, 2009-2010	Total n
Croton	104	0	104
Catskill	104	0	104
Delaware	104	0	104

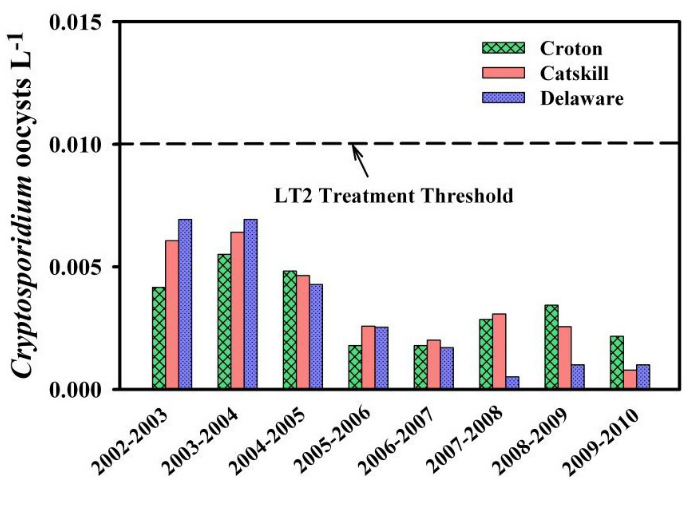

Figure 4.5 LT2 calculated means for *Cryptosporidium* since the start of Method 1623 at DEP's three source waters (2002-2010): Croton, Catskill, and Delaware Systems.

Since 2002, the three source water locations for the NYC water supply have yielded two-year running LT2 means well below 0.01 oocysts L^{-1}, the level requiring additional treatment (Figure 4.4). For the 2009-2010 period, the means were as follows: 0.0022 oocysts L^{-1} at the Croton effluent, 0.0008 oocysts L^{-1} at the Catskill effluent, and 0.0010 oocysts L^{-1} at the Delaware effluent. Compared to the previous LT2 period (2008-2009), the 2009-2010 period showed no change in the LT2 mean for the Delaware System, while the Croton and Catskill means were slightly lower. These slight decreases are likely due to natural variability of oocyst load and weather patterns within the watershed in the studied timeframe.

4.3 Upstate Reservoir Effluents

DEP samples the effluents of upstate reservoirs to help determine potential sources of protozoa and to help ensure the quality of water entering downstream reservoirs. The effluents of the six WOH reservoirs are sampled at least monthly, with the Ashokan effluent being sampled weekly (at CATALUM, the aluminum sulfate plant on the Catskill Aqueduct). Additionally, Muscoot Reservoir is sampled monthly as the major input to New Croton Reservoir and as specified by the CCD.

Of 124 protozoan samples representing the effluents of upstate reservoirs for 2010, only three samples (2.4%) were positive for *Cryptosporidium* (Table 4.3), compared to 10 positive samples in 2009. The site that contributed the most to this decrease was CATALUM, which had 6 fewer detections in 2010 than in 2009. *Cryptosporidium* levels remained low at upstate effluent sites, with a mean of less than 0.20 oocysts $50L^{-1}$. The three detections for the year occurred at three different sites, and these results act as outliers in the dataset by moving the mean only slightly above zero (Figure 4.6).

Table 4.3: Upstate reservoir effluent protozoan results summary for 2010.

		Cryptosporidium				*Giardia*			
Site	n*	Mean ($50L^{-1}$)	% Detects	Max/Vol.	Max (L^{-1})	Mean ($50L^{-1}$)	% Detects	Max/Vol.	Max (L^{-1})
CATALUM (Ashokan)	52	0.04	1.9%	2 (50.0 L)	0.04	0.56	34.6%	4 (50.0 L)	0.08
MUSCOOTR	12	0.00	0.0%	0	0.00	6.50	58.3%	55 (50.0 L)	1.10
NRR2CM (Neversink)	12	0.00	0.0%	0	0.00	2.04	75.0%	5 (50.0 L)	0.10
PRR2CM (Pepacton)	12	0.00	0.0%	0	0.00	0.92	66.7%	3 (50.0 L)	0.06
RDRRCM (Rondout)	12	0.00	0.0%	0	0.00	2.29	66.7%	8 (35.9 L)	0.22
SRR2CM (Schoharie)	12	0.17	8.3%	2 (50.0 L)	0.04	8.93	75.0%	31 (38.9 L)	0.80
WDTO (Cannonsville)	12	0.17	8.3%	2 (50.0 L)	0.04	3.10	75.0%	8 (50.0 L)	0.16

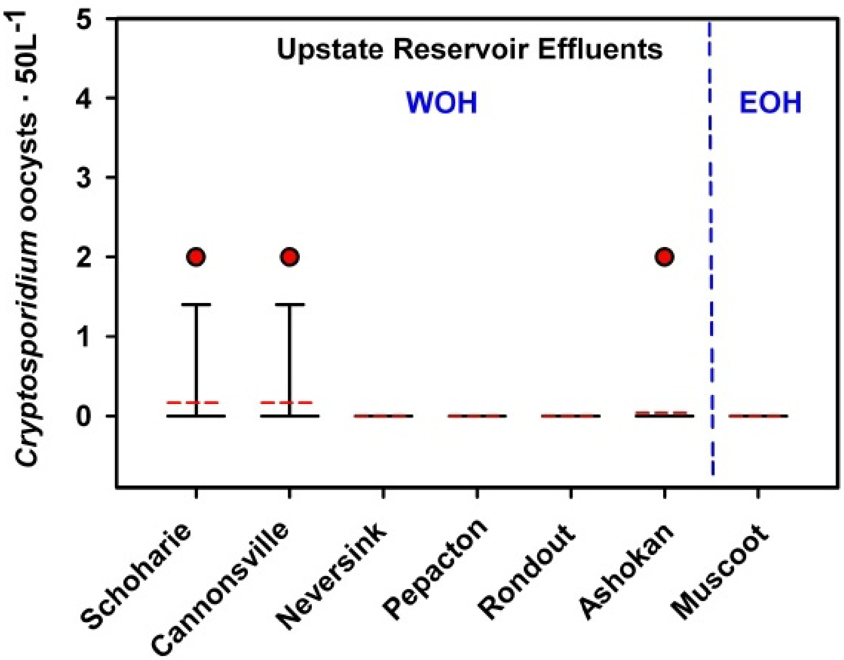

Figure 4.6 2010 summary of *Cryptosporidium* distribution among WOH and EOH basins (--- Mean, __ Median, ● outliers). All sites had 12 samples for the year, except water representative of the Ashokan Reservoir effluent (CATALUM), which had 52 samples.

Giardia was detected in 68 samples in 2010 (54.8%), which is a cyst detection rate approximately 10% less than last year. This drop in detection was largely due to 12 fewer detections at the CATALUM site, which represents the Ashokan effluent. Mean concentrations in 2010 (Table 4.3) were similar to those in 2009 with the exception of Muscoot. Muscoot had a *Giardia* result of 55 cysts $50L^{-1}$, which contributed greatly to increasing the annual mean from 2.45 cysts $50L^{-1}$ in 2009 to 6.50 in 2010 (Figure 4.7).

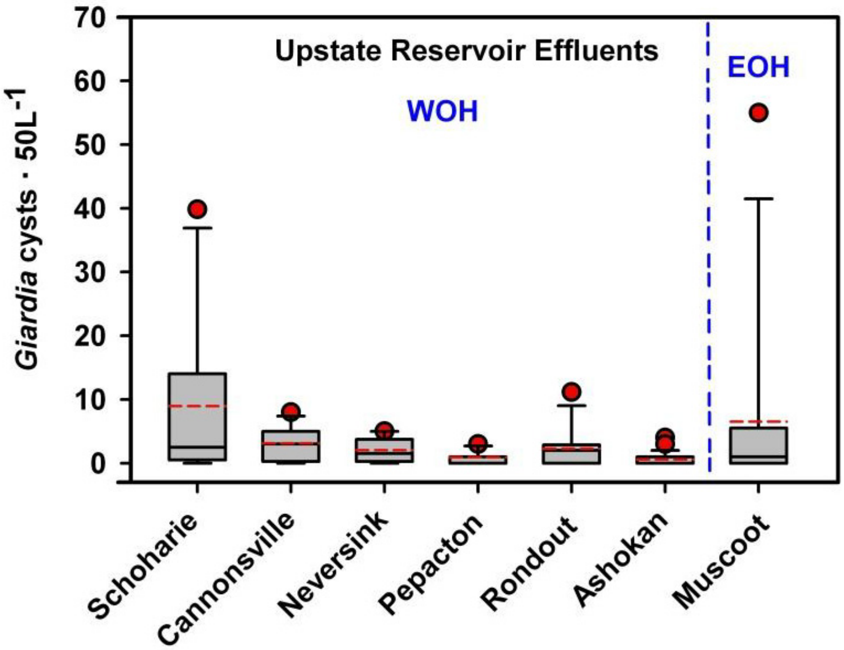

Figure 4.7 2010 summary of *Giardia* distribution among WOH and EOH basins (--- Mean, __ Median, ● outliers). All sites had 12 samples for the year, except water representative of the Ashokan Reservoir effluent (CATALUM), which had 52 samples.

4.4 Watershed Streams

Routine monitoring for *Giardia* and *Cryptosporidium* also includes monthly collection at stream sites around the NYC watershed. Eighteen stream sites were selected for monitoring in the 2009 Watershed Water Quality Monitoring Plan, including eight streams in the WOH district, eight perennial streams in the Kensico basin (EOH), and two sites in the Croton watershed (also required for CCD monitoring). During 2010, a total of 213 samples were collected, one of which was not analyzed because it did not meet temperature acceptance criteria, making the total number of analyzed samples 212.

The list of WOH sites has been adjusted as part of an effort to determine if point sources can be identified upstream of sites with the highest mean protozoan concentrations. For this reason, two of the sites sampled in 2009 (ABCG and PMSB) were not sampled in 2010, so that two new upstream sites could be sampled above the site found to have the highest concentrations (S7i) (Table 4.4). The upstream sites were changed twice during the year for a total of four new upstream sites (S7iA, B, C, and D). During 2010, DEP sampled two of the upstream sites monthly, concurrent with S7i.

Table 4.4: Watershed stream protozoan results summary for WOH sites in 2010. ns = not sampled (in order to sample upstream of S7i).

Site	n	*Cryptosporidium* Mean ($50L^{-1}$)	*Cryptosporidium* Max/Vol.	*Cryptosporidium* Max (L^{-1})	*Giardia* Mean ($50L^{-1}$)	*Giardia* Max/Vol.	*Giardia* Max (L^{-1})
ABCG	0	ns	ns	ns	ns	ns	ns
CDG1	12	0.60	2 (45.5 L)	0.04	39.69	141 (50.1 L)	2.81
PMSB	0	ns	ns	ns	ns	ns	ns
PROXG	12	0.33	2 (50 L)	0.04	68.99	54 (9.2 L)	5.87
S4	12	0.26	1 (15.8 L)	0.06	102.82	251 (15.8 L)	15.89
S5i	12	0.00	0	0.00	48.89	145 (27.3 L)	5.31
S7i	12	0.57	1 (21.9 L)	0.05	162.10	153 (21.9 L)	6.99
S7iA	5	0.00	0	0.00	8.04	22 (50.1 L)	0.44
S7iB	11	0.36	2 (50 L)	0.04	42.45	162 (50.1 L)	3.23
S7iC	4	0.00	0	0.00	1.00	2 (50 L)	0.04
S7iD	3	1.65	2 (35 L)	0.06	92.40	58 (23.9 L)	2.43
WDBN	12	0.25	1 (50 L)	0.02	25.99	67 (50 L)	1.34

Incidence of *Cryptosporidium* in the WOH watershed streams was low in 2010, with 20 out of 95 (21.1%) samples testing positive and a maximum single sample concentration of 1 oocyst 15.8 L^{-1} at S4 in December (Table 4.4). The highest mean *Cryptosporidium* concentration per site (1.65 oocysts $50.0L^{-1}$) was found at site S7iD (upstream of S7i). Note that there were only three samples taken at this site in 2010. *Giardia* was observed far more frequently at the WOH stream sites than *Cryptosporidium*, with 97.9% of samples (93 of 95) testing positive. *Giardia* was also more abundant in WOH stream samples, with 8 of the 10 sampled sites having annual mean concentrations of 25 cysts $50.0L^{-1}$ or higher (Table 4.4).

Monitoring of S7i sites progressed upstream systematically. Locations were selected in order to help separate the influences of a few tributaries at a time. *Giardia* results from sites S7iA and S7iC were consistently low compared to those at downstream sites. By the end of 2010, DEP was sampling concurrently at S7iB, S7iD, and S7i, frequently finding comparable *Giardia* levels between these sites, consistent with the goal of source tracking.

EOH sites exhibited consistently low *Cryptosporidium* concentrations, with the highest single sample concentration being 1 oocyst $13L^{-1}$ at E9, and all sites having very low mean concentrations, below 0.8 oocysts $50L^{-1}$ (Table 4.5). As was the case in WOH during 2010, *Giardia* concentrations were consistently much higher than those for *Cryptosporidium*. Two sites (E9 and HH7) had mean *Giardia* concentrations several times higher than most of the other EOH sites. Maximum concentrations at these two sites were greater than 4.0 cysts L^{-1}, heavily influencing the means at each site.

Table 4.5: Watershed stream protozoan results summary for EOH sites in 2010.

Site	n	*Cryptosporidium* Mean ($50L^{-1}$)	*Cryptosporidium* Max/Vol.	*Cryptosporidium* Max (L^{-1})	*Giardia* Mean ($50L^{-1}$)	*Giardia* Max/Vol.	*Giardia* Max (L^{-1})
BG9	12	0.22	1 (50.0 L)	0.02	12.75	40 (50.0 L)	0.80
E10	12	0.08	1 (50.0 L)	0.02	4.17	23 (50.0 L)	0.46
E11	12	0.00	0	0.00	6.31	34 (41.5 L)	0.82
E9	12	0.69	1 (13.0 L)	0.08	39.75	75 (15 L)	5.00
HH7	12	0.25	1 (50.0 L)	0.02	34.17	233 (50.0 L)	4.66
MB-1	12	0.22	2 (38.0 L)	0.05	4.05	24 (50.0 L)	0.48
N12	12	0.00	0	0.00	6.25	17 (50.0 L)	0.34
N5-1	12	0.42	2 (50.0 L)	0.04	3.73	10 (50.0 L)	0.20
WF	9*	0.78	2 (50.0 L)	0.04	2.56	8 (50.0 L)	0.16
WHIP	12	0.08	1 (50.0 L)	0.02	5.42	26 (50.0 L)	0.52

*Three of the 12 monthly samples scheduled to be collected at WF (July-September) were attempted, but there was either no flow or not enough flow to take a representative sample.

4.5 Wastewater Treatment Plants

DEP monitored wastewater treatment plant (WWTP) effluents for protozoa and viruses at eight WOH plants and three EOH plants during 2010. Sampling was conducted quarterly at all treatment plants except Brewster (BSTP), which was monitored monthly for protozoa and bi-monthly for viruses, as specified by the CCD. In November 2010, NYSDOH approved the discontinuation of all DEP virus sampling at WWTPs, again with the exception of Brewster, as that sampling is mandated by the CCD. A total of 54 protozoan samples and 38 virus samples were collected at WWTPs by DEP in 2010, with 12 samples positive for *Giardia* and no samples positive for *Cryptosporidium* or viruses (Table 4.6).

Table 4.6: Protozoan detections at WWTPs in 2010.

Date	Site	Plant	Sample Volume (L)	*Giardia* Result	*Cryptosporidium* Result
1/12/2010	BSTP	Brewster	50.0	1	0
3/2/2010	BSTP	Brewster	50.0	1	0
3/9/2010	PFTP	Fleischmanns	50.0	1	0
3/15/2010	STP	Stamford	50.0	4	0
3/22/2010	STP	Stamford	50.0	1	0
4/19/2010	HUNTER WTP	Hunter	50.0	2	0
9/14/2010	BSTP	Brewster	47.0	215	0

Table 4.6: (Continued) Protozoan detections at WWTPs in 2010.

Date	Site	Plant	Sample Volume (L)	*Giardia* Result	*Cryptosporidium* Result
9/20/2010	STP	Stamford	50.0	2	0
9/23/2010	BSTP	Brewster	50.0	2	0
10/19/2010	BSTP	Brewster	50.0	1	0
12/8/2010	HUNTER HIGH-LANDS BD	Hunter Highlands	50.0	11	0
12/20/2010	STP	Stamford	51.4	1	0

Two of the 12 WWTPs where *Giardia* was detected were sampled again, Stamford (STP) in March, and Brewster in September. A detection of 4 cysts at STP in March led to a follow-up sample a week later to see if the count had returned to normal. The plant flow at this time of year (spring) is normally elevated; however, due to increased snowpack and rainfall, flow this year was particularly high. Plant operators have since modified the plant process during high flow periods and believe this will alleviate some of the high flow issues.

The September detection at Brewster was unusually elevated and initiated an investigation into potential causes. Upon return to the plant for a follow-up sample, DEP was informed that the plant was having issues with the compressors and had to bypass microfiltration due to the loss of process air. One compressor was off-line awaiting a replacement manifold, while the second compressor experienced an emergency shutdown due to a cracked fitting. The absence of process air renders the microfiltration units useless. While the facility does utilize flow equalization, operators could not sustain detention of sewage long enough for necessary repairs to the compressors and had no choice but to bypass microfiltration. The facility repaired the air compressors, purchased a mobile compressor to avoid loss of pressure caused by a mechanical failure, and executed a service agreement with the compressor manufacturer to perform proper preventive and corrective maintenance on the units. A Notice of Violation was issued and the plant's operator was issued two corrective actions to improve the compressor on-site.

5. Modeling and Watershed Management

5.1 Modeling

5.1.1 Overview of DEP Modeling System

DEP uses models to examine how changes in land use, population density, ecosystem processes, climate, and watershed and reservoir management policies affect the NYC drinking water supply (Figure 5.1). Changing conditions in the watersheds present both ongoing and new challenges that DEP must plan for and respond to in its mission to ensure the continued reliability and high quality of the NYC drinking water supply. Changing patterns of land use and population in the watersheds influence nutrient loadings, which can increase eutrophication in the reservoirs. Changes in stream channel erosion related to climate and to urbanization may exacerbate turbidity in the water supply system. Climate change and changes in watershed ecosystem functions may impact both the future quantity and quality of water in the upstate reservoir system. Understanding the effects of changing conditions is critical for decision making, long-term planning, and management of the NYC watersheds and reservoir system.

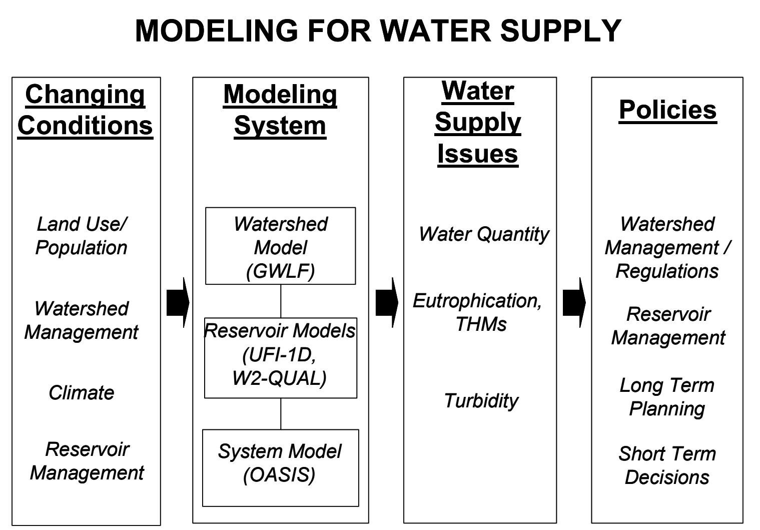

Figure 5.1 Use of models for the NYC water supply.

The DEP modeling system consists of a series of linked models that simulate the transport of water and dissolved and suspended materials within the watersheds and reservoirs that comprise the upstate water supply Catskill and Delaware Systems. Watershed models, including the Generalized Watershed Loading Function (GWLF) models, simulate generation and transport of water, sediment, and nutrients from the land surface to the reservoirs. Reservoir models (including the UFI-1D and the CE-QUAL-W2 models) simulate hydrothermal structure and hydrodynamics of the reservoirs and the nutrient and sediment distribution within the reservoir body and at aqueduct outlets. The water supply system model (OASIS) simulates the operation of the multiple reservoirs that comprise the water supply system, including the storage of water within the reservoirs and the transfer of water between them. The modeling system is used to explore how the water supply system and its components may behave in response to changes in land use, population, climate, ecosystem disturbances, watershed/reservoir management, and system operations.

Major water supply issues that the modeling system is used to address include turbidity in the Catskill System, eutrophication in the Delaware System, and water quantity in the entire system to meet NYC demand. Simulations are performed during and in the aftermath of storm events to provide guidance for operating the reservoir system in response to elevated turbidity levels, particularly in the Catskill System. The models have been used to examine alternative structural and operational changes in the Schoharie and Ashokan Reservoirs to mitigate the need to use alum to treat elevated turbidity. The effects of changing land use and watershed management on nutrient loading and eutrophication in Delaware System reservoirs (Cannonsville and Pepacton) have been analyzed using linked watershed and reservoir models. The effects of climate change on the water supply are currently under investigation using the modeling system.

5.1.2 Modeling Applications to Support Reservoir Operations Decisions

Storm-generated turbidity in the NYC water supply watersheds—particularly in the Catskill System (consisting of Schoharie and Ashokan Reservoirs and their respective watersheds)—is an important water quality issue that can at times constrain the operation of the NYC water supply. When turbidity events occur, Catskill System reservoirs, and the flow and turbidity levels in the Catskill Aqueduct, are carefully managed to ensure that Kensico Reservoir effluent turbidity levels remain below regulatory limits. In extreme cases, alum treatment may be applied to reduce turbidity in Kensico Reservoir. Such treatment is costly and has potential environmental impacts. Consequently, every effort is made to avoid alum treatment by careful operation of the reservoir system.

Figure 5.2 Turbidity in a reservoir.

An integral component in DEP's strategy of controlling turbidity in the Catskill System involves the development and use of an Operational Support Tool (OST). The OST combines reservoir water quality and water supply system models with near-real-time flow and water quality data and meteorological and streamflow forecasts. The modeling backbone of the OST includes an implementation of the CE-QUAL-W2 reservoir model, developed specifically to simulate turbidity in the Catskill System reservoirs. This reservoir model has been integrated with the OASIS model, a water system model used to simulate reservoir system volumes and flows. The combined modeling system allows for testing of water system operational strategies to control turbidity levels while continuing to reliably meet water demands. Although the full OST is not yet completed, the CE-QUAL-W2 model is already being used to help inform operating decisions during turbidity events.

When a significant turbidity event occurs, DEP uses the CE-QUAL-W2 reservoir model to help inform operational decisions. A "positional analysis" strategy is followed for these model runs. Under this strategy, the current initial conditions of the reservoir and watershed are used as the starting point for the model. For analysis of Ashokan Reservoir, the model is run for a forecast period (typically three months into the future), using as inputs the flows, derived turbidity loads, and meteorologic inputs associated with the same three-month period during each year of the historical record (1948-2004). For Kensico Reservoir, a similar positional analysis approach is used, except that input aqueduct flows and turbidity levels are fixed, to enhance understanding of the sensitivity of effluent turbidity to different aqueduct influent turbidity loads. This helps to determine the optimal ratios of Catskill and Delaware System inputs to the reservoir, given the turbidity levels in each system. Positional analysis results are typically a range of potential outcomes based on the potential variability in near-term future meteorology, flows, and turbidity.

During 2010, there were two separate periods of elevated turbidity in the Catskill System, one during the winter and one in the fall. During the winter of 2010, a large rain and snowmelt storm event during January caused high turbidity inputs to Ashokan Reservoir. Turbidity in the reservoir slowly decreased throughout January and February, but increased again due to a series of March snowmelt and rain events. Turbidity finally decreased in late April and early May. The fall event began with an extremely large precipitation event in October and was further influenced by another large event at the beginning of December. In response to both of these turbidity events, 18 sets of model analyses were performed in 2010. Operational decisions, partially informed by model results, helped to avoid alum use during these two events in 2010. However, alum was necessary during the winter of 2011 due to residual turbidity from the fall 2010 storm events and additional winter-spring storm events.

A typical example of an analysis of varying aqueduct flows into Kensico Reservoir is illustrated by the analyses carried out in the wake of the March storm/snowmelt event. Although turbidity levels in Ashokan Reservoir had not yet risen to levels of concern as a result of this event, a set of Kensico Reservoir simulations were performed as a planning measure, to ascertain which levels of possible future turbidity in the Catskill Aqueduct would require a flow reduction (via installation of stop shutters in the aqueduct).

Sensitivity simulations for Kensico Reservoir were done in the positional analysis framework using meteorological and aqueduct input water temperature data 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 covering March 15-June 15. Initial reservoir conditions were based on automated monitoring stations operating in Kensico Reservoir. 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 assumed that these inputs and outputs were constant for the three-month forecast period.

Figure 5.3 shows example results for the 15 NTU Catskill input scenarios. In this case, flow of 100 MGD from the Catskill Aqueduct caused Kensico effluent turbidity to remain at about 2 NTU, while increasing Catskill Aqueduct flow to 300 MGD predicted the Kensico effluent turbidity to rise to 2.5-4.0 NTU. These runs indicated that if turbidity in the East Basin of Ashokan Reservoir increased beyond 15 NTU, use of stop shutters to reduce Catskill Aqueduct flow to below 300 MGD would be necessary.

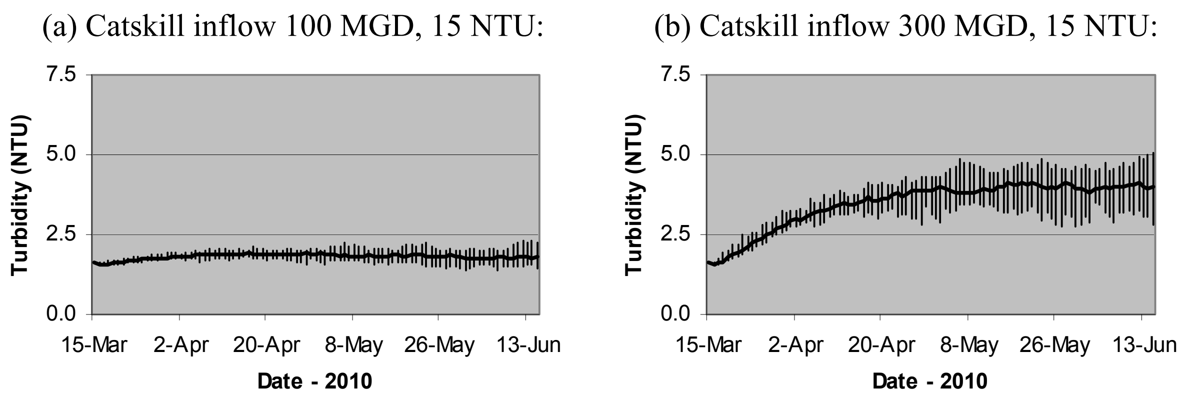

Figure 5.3 Results of CEQUAL-W2 simulations from March 17, 2010 for effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of (a) 100 MGD and (b) 300 MGD and influent Catskill turbidity of 15 NTU. The line on the graph shows the median of the 18 traces from the positional analysis; the vertical bars show the range of values for all traces.

5.1.3 Use of Modeling System to Evaluate Watershed Management Programs

The effects of non-point source management, point source upgrades, and land use change on eutrophication in Cannonsville and Pepacton Reservoirs were evaluated using DEP's Eutrophication Modeling System (Figure 5.4). Output from the GWLF watershed model provided loading estimates to evaluate watershed programs implemented as part of the Memorandum of Agreement (MOA) and FAD. Four watershed management programs were evaluated: the Watershed Agricultural Program, the Urban Stormwater Retrofit Program, the Septic Rehabilitation and Replacement Program, and the Wastewater Treatment Plant (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 the Cannonsville and Pepacton watersheds 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 represented conditions existing in the 1990s prior to implementation of FAD programs. Two FAD evaluation scenarios represented conditions of the early 2000s (*FADPERIOD1*) and late 2000s (*FADPERIOD2*), during which substantial implementation of FAD programs occurred. Nutrient reductions due to watershed management programs and their extent of implementation were applied to represent watershed management effects in each *FADPERIOD* scenario.

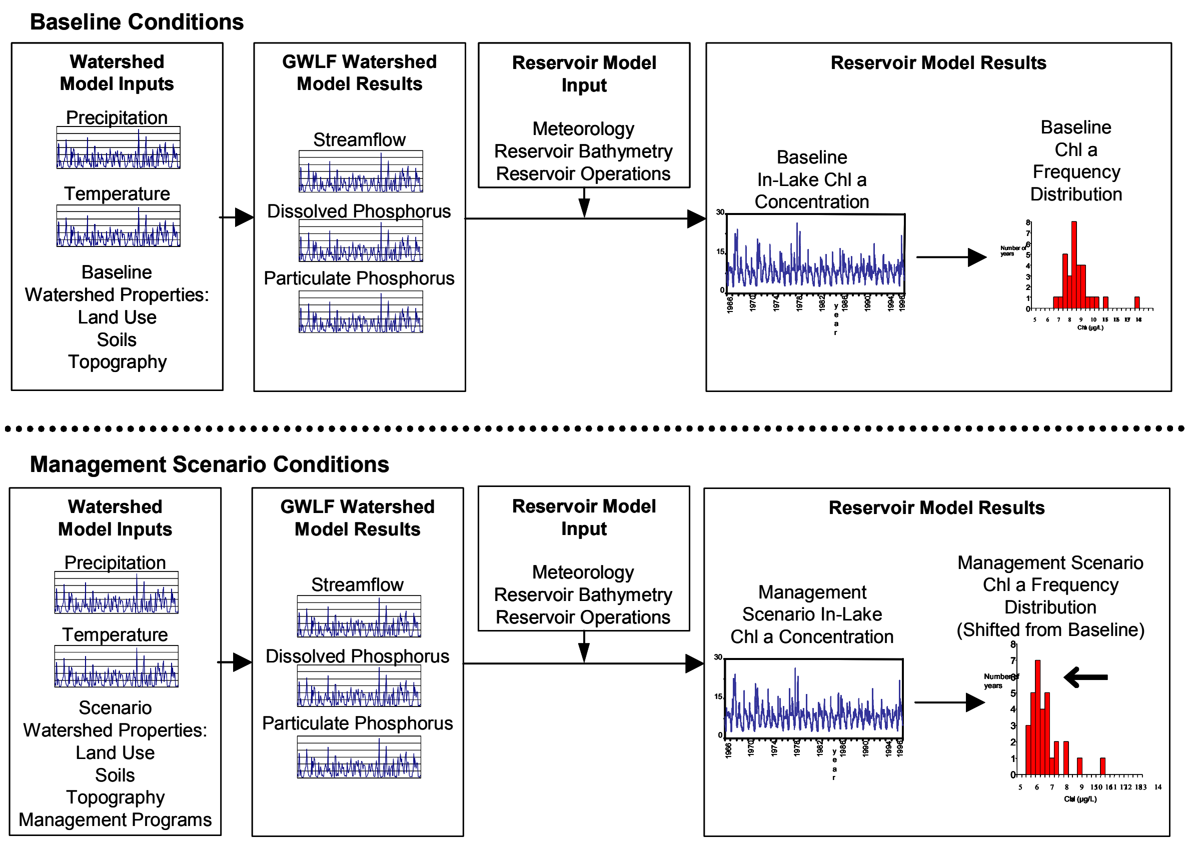

Figure 5.4 DEP's Eutrophication Modeling System.

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 an approximate 49% reduction in dissolved phosphorus (DP) loads from the Cannonsville watershed from the *BASELINE* to *FADPERIOD1* and an additional approximate 7% reduction from *FADPERIOD1* to *FADPERIOD2* (Figure 5.5a). For the Pepacton watershed, DP export was reduced by approximately 23% from *BASELINE* to *FADPERIOD1* and an additional approximate 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 substantial reduction in agricultural activity during that period. Continued but slower declines in DP loads from *FADPERIOD1* to *FADPERIOD2* occurred as FAD programs became more focused on maintenance and improvement than on new program development, and as the reduction in agricultural activity continued.

The relative effects of land use change versus watershed management on load reductions were examined in more detail using comparisons of *BASELINE* and *FADPERIOD2*, where effects of land use change (decline in agriculture) and watershed management were examined separately. Both produced substantial reductions in DP loading. Loading reductions due to land use change alone were approximately 18% for DP in Cannonsville (Figure 5.5b), and approximately 10% for DP in Pepacton. The combination of land use change and watershed management produced reductions of approximately 55% in Cannonsville (Figure 5.5b) and approximately 26% 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.

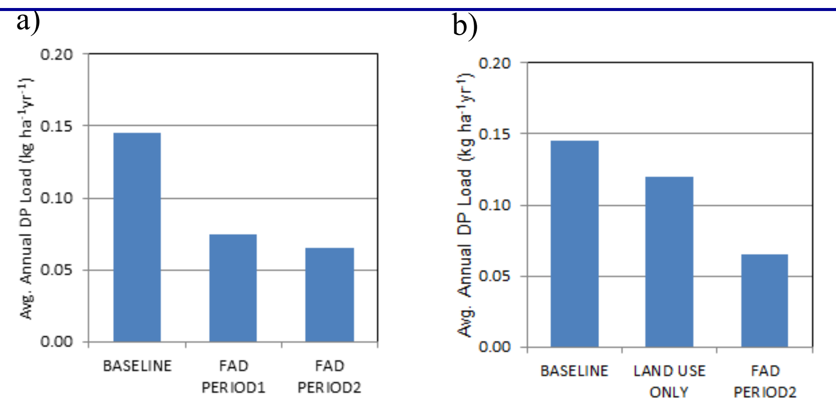

Figure 5.5 Comparison of DP loading for Cannonsville Reservoir under conditions for *BASELINE* period versus *FADPERIOD*s: (a) Comparison of *BASELINE* (1990s), *FADPERIOD1* (early 2000s), and *FADPERIOD2* (late 2000s); (b) Comparison of *BASELINE* (1990s), land use changes only through late 2000s, and *FADPERIOD2*, which includes both land use changes and watershed management through late 2000s.

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. For Cannonsville Reservoir, simulated loading reductions due to combined land use change and watershed management between *BASELINE* and *FADPERIOD1* resulted in an approximate 34% reduction in May-October epilimnetic chlorophyll concentrations, and an approximate 30% reduction in

May-October epilimnetic total phosphorus concentrations (Figure 5.6). For Pepacton Reservoir, the same reductions in concentration were approximately 15% and approximately 9% for chlorophyll and total phosphorus, 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 approximately 5% in May-October epilimnetic chlorophyll concentrations and an approximate 3% further reduction in May-October epilimnetic total phosphorus concentrations in Cannonsville Reservoir. For Pepacton Reservoir, the additional reductions in concentration simulated as occurring between *FADPERIOD1* and *FADPERIOD2* were approximately 3% and approximately 2% for chlorophyll and total phosphorus, respectively.

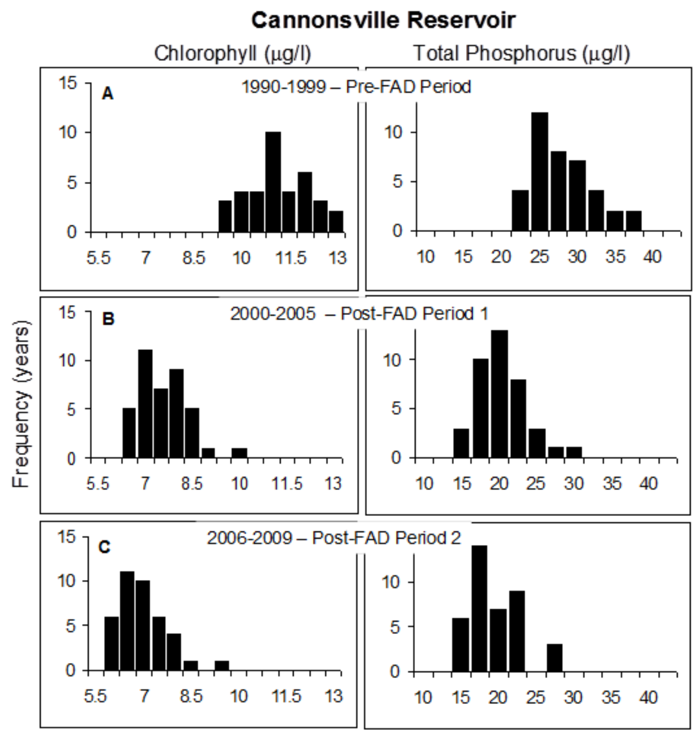

Figure 5.6 Frequency distributions of mean summer (May-October) epilimnetic chlorophyll and total phosphorus concentrations in Cannonsville Reservoir, showing progressive improvement in reservoir water quality as a result of FAD programs: A) *BASELINE* conditions when no FAD programs were in place, B) combined effects of land use change and FAD programs for simulations of *FADPERIOD1,* representing early 2000s, and C) combined effects of land use change and FAD programs for simulation of *FADPERIOD2*, representing late 2000s conditions.

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 approximately 9% for in-lake growing season chlorophyll *a* and approximately 8% for total phosphorus. Greater reductions were predicted when the FAD programs were considered in addition to land use change (approximately 39% for chlorophyll *a* and approximately 32% for total phosphorus). 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.

5.1.4 Use of Modeling to Evaluate the Impacts of Future Climate Change

DEP is using a suite of simulation models to investigate the effects of climate change on the New York City water supply (Figure 5.1). This work is part of the DEP Climate Change Integrated Modeling Project (CCIMP), that specifically focuses on three potential impacts:

- The effects of climate change on system-wide storage and operations.
- The effects of climate change on Catskill System reservoir turbidity levels and the processes that regulate erosion and transport of turbidity-causing suspended particles.
- The effects of climate change on Delaware System reservoir tropic status. This includes studies of the watershed processes that regulate nutrient loss and transport, reservoir thermal structure and mixing, and processes that regulate reservoir nutrient use and phytoplankton growth.

Preliminary Phase I investigations focused on generating future climate projections using four Global Climate Models (GCMs), looking 65 years and 100 years into the future under three greenhouse gas emission scenarios. For each combination of GCM, time period, and emission scenario, scenarios of the meteorological data needed to drive watershed and reservoir models were developed, and watershed and reservoir model simulations were run. The results of this work have led to a number of publications that have focused on the effects on reservoir system operations (Matonse et al. 2011), the importance of changes in snow-related processes regulating watershed hydrology (Zion et al. 2011, Pradhanang et al. 2011), and methods of evaluating and downscaling the climate scenarios (Anandhi et al. 2011a, 2011b). The most consistent finding of this preliminary work is a shift in winter streamflow timing, with more flow occurring during the mid-winter period and slightly reduced flow during the traditional early spring snowmelt period. This is mainly due to increased temperatures during the winter, which produces more rain and snowmelt in mid-winter. That, in turn, increases winter streamflow and leads to filling of the reservoirs earlier in the year. Increased snowmelt and rain during the winter also leads to reduced snowpack storage, which decreases the peak early spring runoff (Figure 5.7).

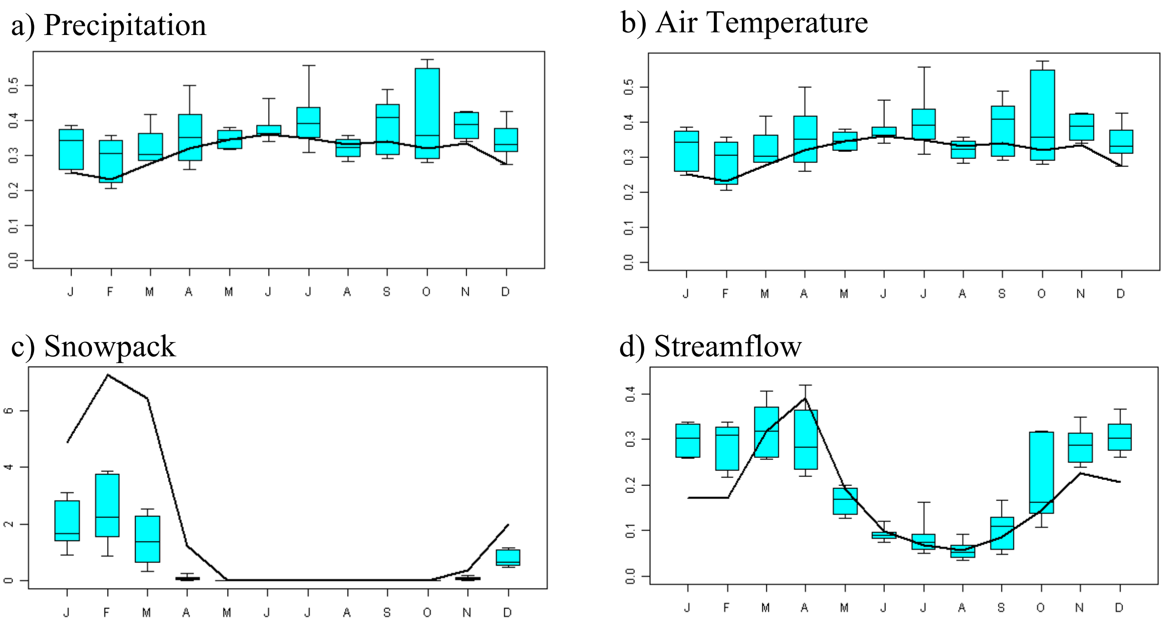

Figure 5.7 Phase I climate change results, showing current observed conditions (solid line) and range of climate change results for three GCMs for 2080-2100 time slice for (a) monthly precipitation (cm), (b) monthly average air temperature (deg C), (c) average monthly watershed snowpack snow water equivalent (cm), and (d) monthly streamflow expressed as a unit depth (cm/month). Results show shift of winter streamflow from early spring to mid-winter.

This work also served as the foundation for ongoing studies of watershed hydrology, biogeochemistry, and forest processes, as well as reservoir thermal structure, turbidity transport biogeochemistry, and phytoplankton growth. To accomplish these continuing studies, the full suite of models used by DEP (Figure 5.1) is being evaluated and applied. DEP has also obtained a much more extensive set of approximately 165 future climate model scenarios. Ongoing CCIMP work that occurred during 2010 included:

- Development of future meteorological data sets from approximately 20 GCM model scenarios, three emission scenarios, and two future time periods. These scenarios were developed using an event frequency distribution downscaling method developed by the DEP modeling group.
- Evaluation of GCM model scenarios by comparison with historical climate data from the WOH watershed.
- Development of a Soil and Water Assessment Tool (SWAT) model application for providing

simulations of the processes that regulate hydrology and stream water chemistry in the Cannonsville and Pepacton watersheds. The model also provides simulations of the impacts of future climate change on hydrologic response, nutrient biogeochemistry, and loadings.

- Development of a Regional Hydro-Ecologic Simulation System (RHESSys) model application of forest processes and their effects on hydrology and biogeochemistry in the Biscuit Brook sub-basin of the Neversink Reservoir watershed.
- Testing of the SWAT model for simulating total suspended solids and turbidity transport in the Esopus Creek watershed.
- Development of improved turbidity rating curves for predicting the turbidity loads entering Ashokan Reservoir from the Esopus Creek watershed.
- Calibration of the Cannonsville and Pepacton 1D reservoir eutrophication models using the full record of DEP monitoring data, and evaluation of these models in simulating the consequences of climate change on reservoir nutrient and phytoplankton concentrations.
- Calibration and testing of the hydrothermal part of the 1D reservoir model and simulating the effects of future climate change on reservoir thermal structure and hydrodynamics.
- Inclusion of the EOH and lower Delaware watersheds into OASIS model simulations that evaluate the effects of climate change on NYC water supply storage and operations.

5.2 Watershed Management Programs

There is a close relationship between human activity within a watershed and the quality of its water resources. With this in mind, the City, EPA, the New York State Department of Health, and watershed stakeholders have, over the last 18 years, developed watershed management programs as set forth in various agreements, including the FAD and MOA. These watershed management programs form a comprehensive set of activities to improve and protect the City's high quality water supply, while preserving and enhancing the economic vitality and social character of the communities within the watershed.

A brief summary of many of the watershed management programs is provided on the following pages. Figures 5.8 and 5.9 illustrate the locations of watershed management projects within the WOH and EOH watersheds, respectively. More detailed information on the management programs can be found in the FAD Assessment (DEP 2011a), the 2006 Long-Term Watershed Protection Program (DEP 2006b), and the 2007 Filtration Avoidance Determination (USEPA 2007).

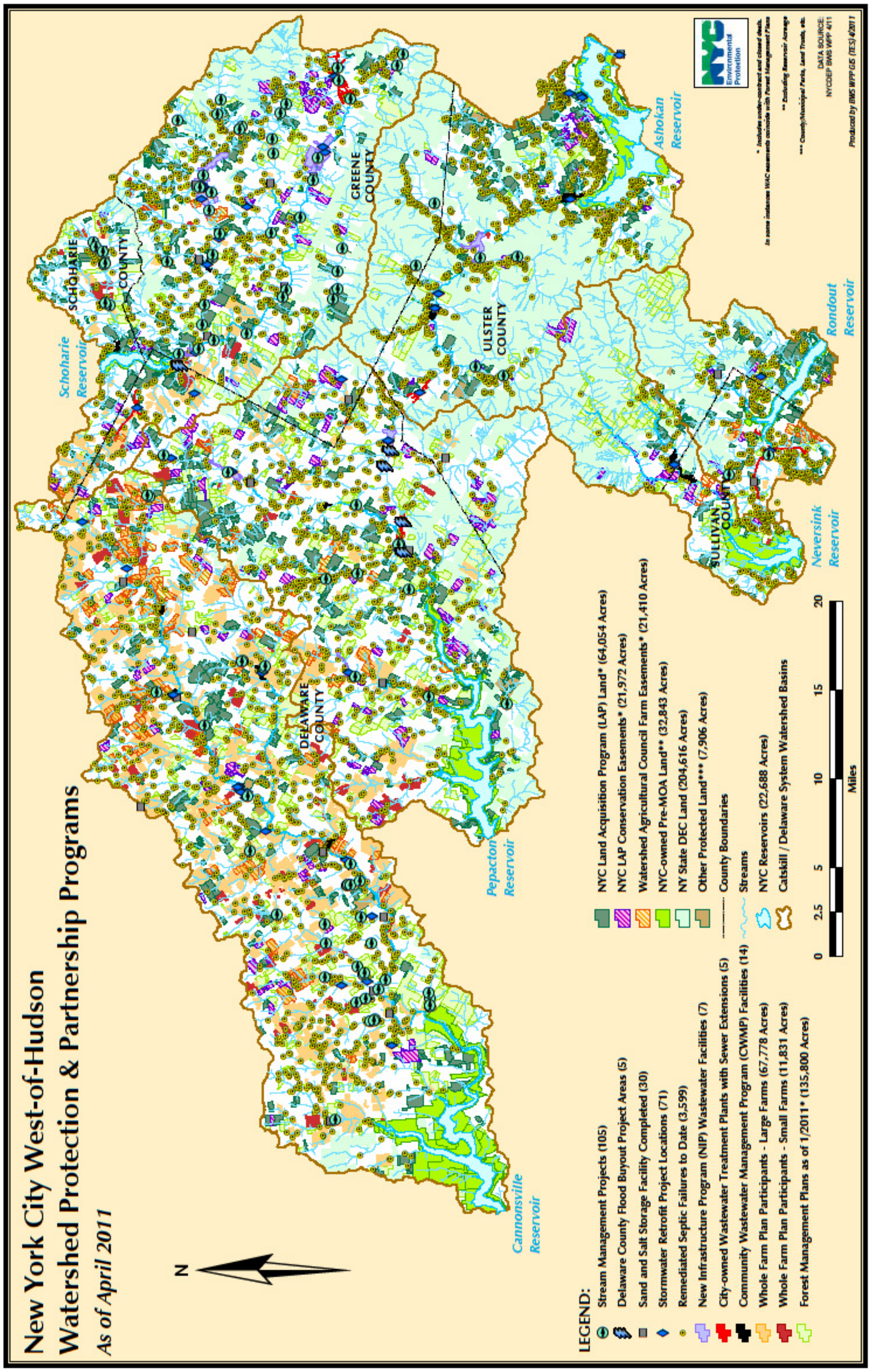

Figure 5.8 New York City West-of-Hudson watershed protection and partnership programs.

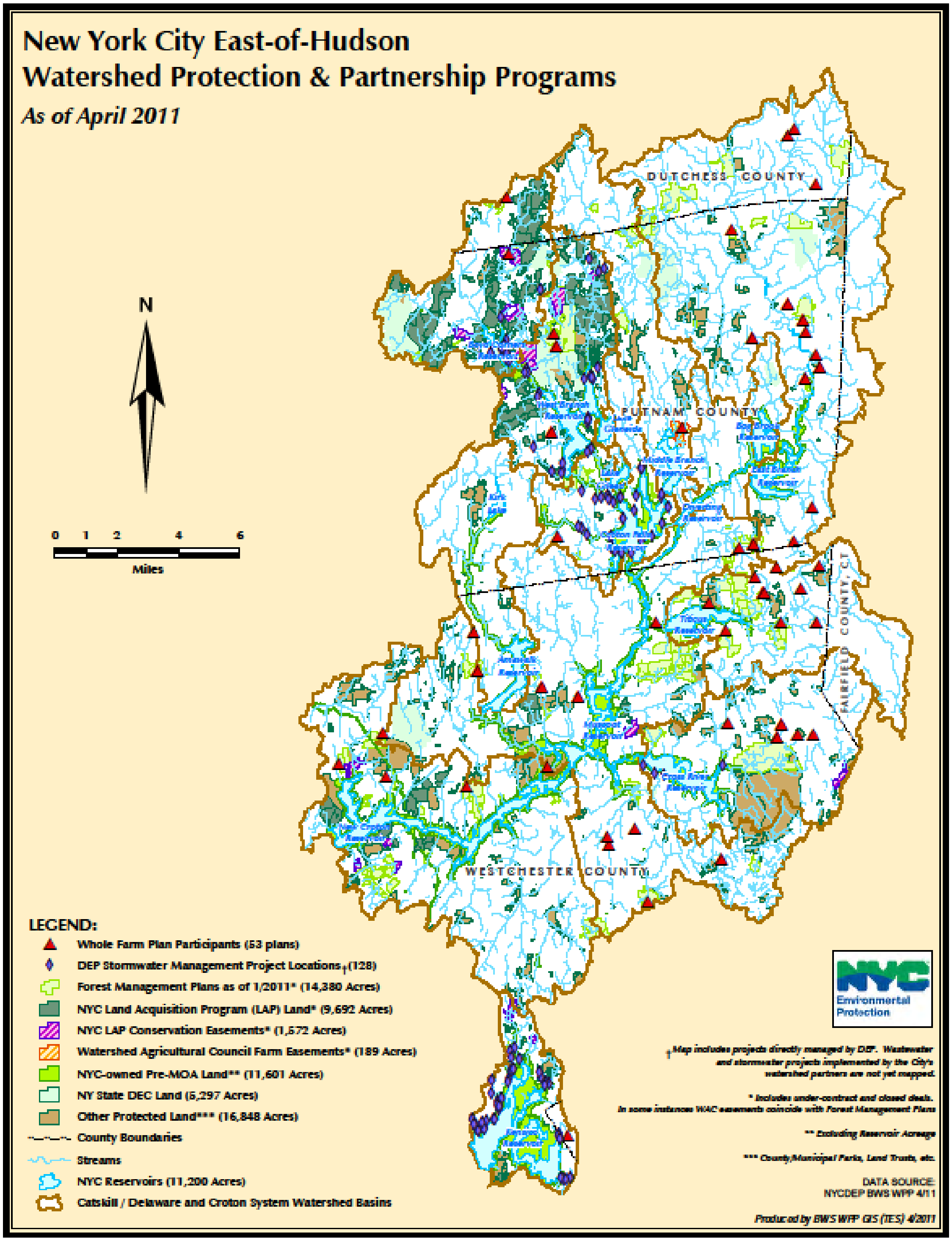

Figure 5.9 New York City East-of-Hudson watershed protection and partnership programs.

5.2.1 Land Acquisition

The Land Acquisition Program seeks to prevent future degradation of water quality by acquiring lands to ensure that undeveloped, environmentally-sensitive watershed lands remain protected and that the watershed continues to be a source of high quality drinking water to the City and upstate counties. Protection is assured either by direct fee, simple acquisition, or in the form of a conservation easement. Over the last 10 years, the proportion of City-owned or -controlled land within the Catskill/Delaware watershed (not including reservoir areas) has increased from 3.5% to 14.6%. Tax map data and other sources indicate that at least another 21% of the land area is owned or controlled by non-City public agencies and land trusts, bringing the total protected land to over 35% of the Catskill/Delaware watershed.

5.2.2 Land Management

Management of City-owned and -controlled lands has become more important, as a result of the great increase in the total area of these lands brought about by the success of the Land Acquisition Program. The Land Management Program has four major areas of concentration: property management, forest management, natural resources, and land uses on City lands. Land management activities in these four areas result in a variety of programs, including monitoring and inspection of City-owned lands and conservation easements, maintaining boundary lines, posting of lands, developing and implementing forest management plans, responding to the threats of invasive species, developing and implementing rules and policies for recreational opportunities on City-owned land, issuing permits for land use by other entities as necessary, allowing limited agricultural applications on some lands, and developing a pilot recreational boating program.

5.2.3 Watershed Agricultural Program

The Watershed Agricultural Program (WAP) is a voluntary partnership between DEP and the Watershed Agricultural Council (WAC). The WAC is focused on improving non-industrial family farms in the watershed. The overall objective of the WAP is to prevent agricultural pollution and improve water quality by reducing pollutants leaving farms through the implementation of best management practices (BMPs). The partnership works with watershed residents to identify and eliminate potential pollution sources through the development of Whole Farm Plans, implementation of BMPs, development of nutrient management plans, annual status reviews, the Conservation Reserve Enhancement Program (CREP), and farmer education. In September 2010, the WAP achieved a major FAD milestone by having 90% of all WOH large farms meeting the definition of having at least one "substantially implemented" Whole Farm Plan. During 2010, WAP staff completed Tier I questionnaires for 310 small farms (earning between $1,000 and $10,000 per year), of which 85 (27%) have Whole Farm Plans. In the EOH watershed, the WAP has approved 56 Whole Farm Plans through 2010.

5.2.4 Watershed Forestry Program

The Watershed Forestry Program is a partnership between DEP, the WAC, and the USDA Forest Service that promotes and supports well-managed working forests as a beneficial land use for watershed protection. Major program components include forest management planning and stewardship, BMP implementation, logger and forester training, model forest program, forestry education program, and wood products marketing and utilization. Through 2010, more than 914 landowners had completed forest management plans covering approximately 163,513 watershed acres in both the WOH and EOH watersheds.

5.2.5 Stream Management

The objective of the Stream Management Program is to protect and/or restore stream stability and ecological integrity by providing for the long-term stewardship of streams and floodplains. The program is involved in the development and implementation of stream management plans; education and outreach programs; implementation of stream projects that focus on flood hazard mitigation, aquatic habitat enhancement, and riparian restoration or protection; floodplain mapping; and riparian buffer protection.

5.2.6 Riparian Buffer Protection

The Riparian Buffer Protection Program was instituted as part of the 2007 FAD, committing the City to continue its riparian buffer protection efforts through existing programs (e.g., the Land Acquisition, Watershed Agricultural, Stream Management, and Watershed Forestry Programs), as well as by initiating the Catskill Streams Buffer Initiative (CSBI), a riparian-focused program available to landowners who may not qualify for other existing watershed programs. For example, the program develops Riparian Corridor Management Plans (RCMPs) that provide landowners with a detailed analysis of their property in relation to the broader watershed and to their streamside neighbors. The RCMP proposes a suite of recommendations based on existing stream management plans (where available), historical information, and landowner concerns. The CSBI also includes an education and outreach component that focuses on the importance of riparian buffers, with a long-term goal of promoting positive riparian stewardship.

5.2.7 Wetlands Protection

Wetlands are key features of the watershed, as they maintain or improve water quality in streams and reservoirs, moderate peak runoff, recharge groundwater, and maintain baseflow in watershed streams. In addition to these hydrologic and water quality functions, wetlands also provide important fish and wildlife habitat. DEP's Wetlands Protection Program includes mapping and participation in research programs such as the National Wetlands Inventory (NWI), Wetland Status and Trends, and reference wetland monitoring. All of these provide information on the status, trends, distribution, and functions of wetlands, and in turn support other watershed protection programs such as wetland permit review, land acquisition (including fee simple and conservation easements), and Watershed Agricultural, Forestry, and Stream Management Programs. These programs result in increased awareness, protection, and in some cases, restoration of wetlands and their important water quality functions.

5.2.8 Septic Programs

Failing septic systems can have a negative effect on water quality. The Septic System Rehabilitation and Replacement Program helps fund the remediation of failed or likely-to-fail septic systems for single- or two-family residences in the WOH watershed. Since the program's inception, the City has repaired, replaced, or managed a total of 3,562 failing or likely-to-fail septic systems. The Septic System Maintenance Program works to help home owners pay the costs of regular pump-outs and maintenance, thus reducing the occurrence of septic system failures. Since 2004, 575 home owners have been paid 50% of eligible costs for septic system maintenance. Both of these programs are administered through the Catskill Watershed Corporation.

5.2.9 New Infrastructure Program and Community Wastewater Management Program

The New Sewage Treatment Infrastructure Program funds the study, design, and construction of new wastewater projects, and projects have now been completed in six of seven communities. The Community Wastewater Management Program provides funding for the design and construction of community wastewater systems, including related sewer systems and/or the creation of septic maintenance districts in identified WOH communities.

5.2.10 Sewer Extension Program

The Sewer Extension Program funds extensions of sewers from existing WWTPs in the watershed to areas where on-site septic systems are either failing or are likely to fail. WWTPs in the watershed where sewer extensions were planned include Grahamsville, Margaretville, Pine Hill, Tannersville, and Grand Gorge. During the past five years, DEP achieved several significant accomplishments under the program with the completed construction of three extension projects and near completion of planning and design for two other projects.

5.2.11 WWTP Regulatory and SPDES Upgrade Program

Under this program, the City funds the eligible costs of designing, permitting, and constructing upgrades of all non-City-owned WWTPs in the watershed. For the purposes of the program, "upgrades" means equipment and methods of operations that are required solely by the New York City Watershed Rules and Regulations (WR&R) (2010). The effort is divided into two distinct programs: regulatory upgrades and SPDES upgrades. 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 technologies. The SPDES Upgrade Program is designed to assist each WWTP achieve and maintain compliance with its current SPDES permit through replacement of equipment which is unreliable or near the end of its useful life.

5.2.12 Stormwater Programs

The Stormwater Retrofit Program funds stormwater BMPs at locations where stormwater runoff problems occur within the WOH watershed. The Future Stormwater Controls Program pays for the costs of stormwater BMPs which are the result of requirements imposed by the WR&R over and above existing federal and state requirements. The Local Technical Assistance Program provides funding for eligible stormwater projects that support watershed protection and community planning.

5.2.13 Environmental Project Reviews

DEP reviews a wide variety of projects to assess their potential impacts on water quality and watershed natural resources. Under the New York State Environmental Quality Review Act (SEQRA), DEP is often an involved agency because of its regulatory authority over certain actions. By participating in the SEQRA process, DEP can ensure that water quality concerns are addressed early on in the project planning process. In 2010, DEP reviewed 84 SEQRA actions, including Notices of Intent to Act as Lead Agency; Determinations of Action Types; Environmental Assessment Forms; Scoping Documents; Draft, Final, and Supplemental Environmental Impact Statements; and Findings to Approve or Deny.

In addition to projects in the SEQRA process, DEP reviewed other projects upon request. Review of these projects helps ensure that they are designed and executed in a way that minimizes impacts on water quality. DEP provides its expertise in reviewing and identifying on-site impacts to wetlands, vegetation, fisheries, and wildlife, and also provides recommendations on how to avoid or mitigate proposed impacts. These reviews also provide guidance on interpreting regulations as they apply to wetlands and to threatened and endangered species. Approximately 35 of these projects were reviewed and commented on by DEP in 2010. Many of these projects were large, multi-year efforts with ongoing reviews, while others were smaller scale projects scattered throughout the NYC watershed.

DEP also coordinates review of federal, state, and local wetland permit applications in the watershed. In 2010, approximately 28 stream disturbance and wetland permit applications were reviewed and commented on to ensure compliance with the WR&R.

5.2.14 Waterfowl Management

Migratory populations of waterbirds utilize NYC reservoirs as temporary staging areas and wintering grounds, and in doing so can contribute to increases in fecal coliform loadings during the autumn and winter, primarily from direct fecal deposition in the reservoirs. These waterbirds generally roost nocturnally and occasionally forage and loaf diurnally on the reservoirs, although most feeding activity occurs away from the reservoirs. Fecal samples collected and analyzed for fecal coliform bacteria concentrations from both Canada geese (*Branta canadensis*) and Ring-billed gulls (*Larus delawarensis*) revealed that fecal coliform concentrations are relatively high per gram of feces (Alderisio and DeLuca 1999). Data from water samples collected near waterbird roosting locations demonstrated that fecal coliform levels were correlated with waterbird populations at several NYC reservoirs for several years (DEP 2002, 2003, 2004, 2005, 2006b, 2007, 2008, 2009c). Based on these data, DEP determined that waterbirds were the largest contributor to seasonal fecal coliform bacteria loads to Kensico and other terminal reservoirs (West Branch, Rondout, Ashokan), and that waterbirds can also lead to increased seasonal fecal coliform levels in other potential source reservoirs (Croton Falls and Cross River).

In response to these data, which clearly demonstrate the relationship between waterbird population density and reservoir fecal coliform levels, DEP developed and implemented a Waterfowl Management Program (WMP) to reduce or eliminate the waterbird populations inhabiting the reservoir system (DEP 2002). The WMP uses standard bird management techniques (approved by USDA Wildlife Services and DEC), and has implemented them at several NYC reservoirs. DEP has also acquired a depredation permit from the United States Fish and Wildlife Service and DEC to implement some of the avian management techniques. Bird dispersal measures include non-lethal harassment by pyrotechnics, motorboats, Husky Airboats, and propane cannons, as well as bird deterrence measures, such as waterbird reproductive management, shoreline fencing, bird netting, overhead deterrent wires, and meadow management. The combined effects of these measures has led to continued reductions in local breeding opportunities around water intake structures and reduced fecundity. Monitoring the effects of bird dispersal and deterrence programs has been achieved through continued routine population surveys on each reservoir.

The Surface Water Treatment Rule (40 CFR 141.71(a)(1)) states that no more than 10% of fecal coliform samples may be above 20 CFU over the course of the previous six months. Since waterbird management began, no such violation has occurred at Kensico Reservoir. This represents a significant reduction as compared to the period prior to the implementation of the WMP (Figure 5.10). DEP will continue implementation of the WMP indefinitely to help ensure the best possible water quality.

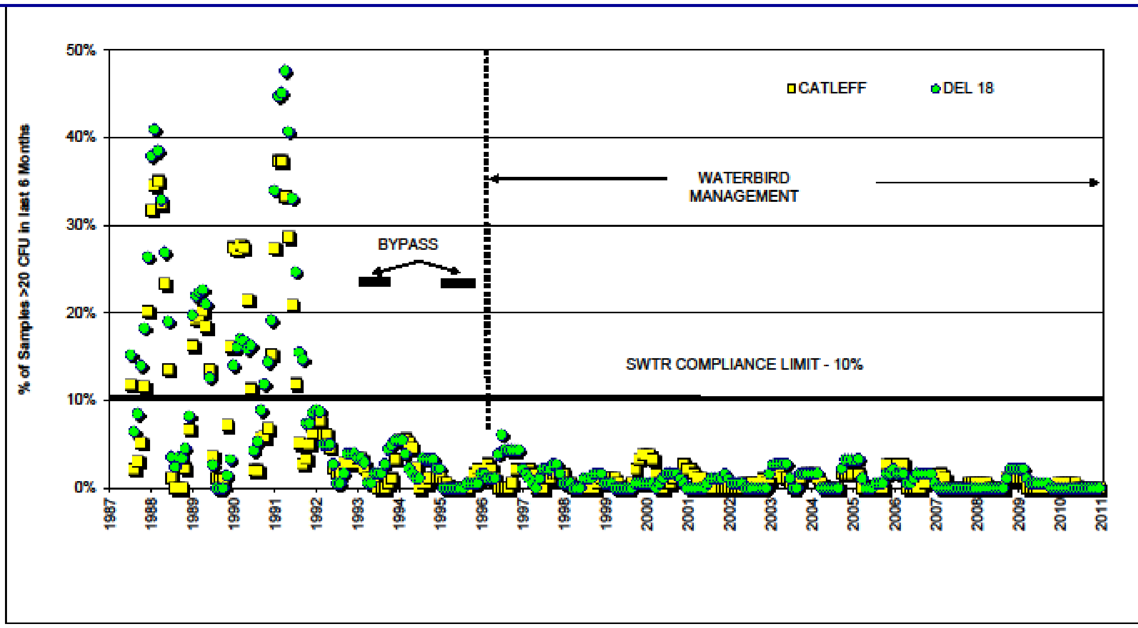

Figure 5.10 Percent of keypoint fecal coliform samples at Kensico Reservoir >20 CFU for previous six months period during 1987-2011.

5.2.15 Kensico Water Quality Control Program

Kensico Reservoir provides the last impoundment of Catskill/Delaware water prior to entering the City's distribution system, so protection of this reservoir's water quality is critical. As such, DEP has prioritized watershed protection in this basin to ensure the continued success of past protection efforts and promote the development of new source water protection initiatives. The protection effort includes construction, operation and maintenance of stormwater BMPs at critical reservoir tributaries; monitoring of installed BMPs; installation and maintenance of spill containment facilities to minimize any water quality impacts arising from a spill; maintenance of a turbidity curtain between the Catskill Upper Effluent Chamber (CATUEC) and Malcolm and Young Brooks; development and implementation of the Kensico Action Plan; planning and implementation of a sanitary sewer remote monitoring system that will warn of leaks from important sewer trunk lines; visual inspection of sewer trunk lines; septic repair program in the Kensico watershed; shoreline stabilization in the cove near the CATUEC to protect from localized turbidity events; monitoring of construction activities for NYS Route 120; and review of activities at Westchester County Airport that may affect water quality.

5.2.16 EOH Non-Point Source Pollution Control Program

The EOH Nonpoint Source Pollution Control Program is a comprehensive effort to address nonpoint pollutant sources in the four EOH watersheds that can contribute to the Catskill/Delaware water system (West Branch, Croton Falls, Cross River, Boyd Corners). The program supplements DEP's existing regulatory efforts and nonpoint source management initiatives. Data on these watersheds and their infrastructure are generated, and that information is used to evaluate, eliminate, and remediate existing nonpoint pollutant sources, maintain system infrastructure, and evaluate DEP's programs.

5.2.17 Zebra Mussel Monitoring Program

Zebra mussels were first introduced to North America in the mid-1980s, transported by ships from Europe in their freshwater ballast, which was discharged into the Great Lakes. Water bodies in New York State affected include Lakes Erie and Ontario, the Erie Canal, the Mohawk River, the St. Lawrence River, the Susquehanna River, and the Hudson River, as well as several lakes.

Zebra mussels reproduce quickly and can have the potential to obstruct and create taste and odor problems in drinking water. To ensure that zebra mussels do not pose a significant risk to New York City's water supply system, DEP has a program that includes the following:

- Monitoring for early identification of any zebra mussel problems to make it possible to gain control of the situation quickly. The reservoirs monitored include:

    1. *East of Hudson*: New Croton, West Branch, East Branch, Croton Falls, Bog Brook, Boyd Corners, Middle Branch, Titicus, Cross River, Amawalk, Muscoot, Diverting, and Kensico. These reservoirs are monitored on a monthly basis from May through October.

    2. *West of Hudson*: Ashokan, Schoharie, Rondout, Neversink, and Pepacton are monitored in July and September of each year. Cannonsville is sampled at the same frequency as the East of Hudson reservoirs.

Sampling includes pump/plankton net sampling to monitor for veligers, and substrate sampling and sampling using a "bridal veil" (a mesh-like material which acts as a potential settling substrate) to monitor for juveniles and adults.

- Steam cleaning boats and equipment is required for all boats allowed on the NYC reservoirs. All boats must be inspected and thoroughly steam-cleaned prior to being allowed on the reservoir in order to prevent infestations.

- Public Education - DEP provides educational pamphlets to fishermen on NYC's reservoirs and to bait and tackle shops in NYC's watersheds explaining how to prevent the introduction and spread of zebra mussels to bodies of water that do not have them. Fishermen can inadvertently introduce zebra mussels to a body of water through their bait buckets, which may have zebra mussels in them (depending on where the bait was obtained). In addition, signs are put up throughout the watershed providing information on how to prevent the spread of zebra mussels.

No zebra mussels were detected in the water supply system in 2010.

5.2.18 Results of the Second Year of Data for the Cannonsville Recreational Boating Pilot Study

Cannonsville Reservoir is routinely monitored as part of DEP's comprehensive water quality monitoring program. This includes monitoring for various constituents to assess the water quality of the reservoir, identify trends, protect public health, and support the delivery of the highest quality water possible to the City's nine million consumers. In 2009, the Cannonsville Recreational Boating Pilot Program was initiated as a three-year pilot project, allowing kayaks, canoes, sculls, and small sailboats onto the reservoir for the first time since its construction in 1965. DEP continued to investigate whether this new activity had any measurable impact on water quality in 2010. The routine water quality monitoring program, with the enhancement of an additional sampling station in the vicinity of the anticipated boating activity, was used in this assessment. The target analytes were turbidity and bacteria, as per the SWTR. Specifically, six water quality stations were sampled at multiple depths on a monthly basis (May-October) for turbidity, fecal coliform bacteria, total nitrogen, and, at selected sites, zebra mussels. These data were compared to data from the previous five years. No measurable changes in water quality were found in 2010 as a result of the implementation of the recreational boating program.

In an effort to better discern water quality effects of boating activity, additional samples were also collected in 2010 before and after the Fourth of July weekend near the Dry Brook Landing and Launch Area. A very slight increase in turbidity was observed on July 6, but this was well within the range of natural variation caused by such factors as wind, rain, and plankton, and could not be attributed to boating.

6. Further Research

The analytical, monitoring, and research activities of DEP are supported through a variety of contracts and through participation in research projects conducted by the Water Research Foundation. These contracts and projects are noted in the two sections below.

6.1 Contracts Managed by the Water Quality Directorate in 2010

In 2010, the Water Quality Directorate managed nine water quality-related contracts to enhance its ability to monitor and model the watershed. The contracts support surveillance, model development, and management goals. A brief description of each contract is provided below.

6.1.1 Virus Analysis Contract

The 2007 FAD and the Croton Consent Decree (CCD) each include a requirement to sample for protozoa (*Giardia* and *Cryptosporidium*) and human enteric viruses. Since the DEP Water Quality laboratory is approved to analyze water samples for protozoa but not yet viruses, the Virus Analysis Contract is needed to provide for the shipping and analysis of water samples for human enteric viruses to meet the regulatory requirements. The contract specifies that the laboratory must have the capacity to handle a maximum of 40 Information Collection Rule (ICR) samples per month, and up to 50 polymerase chain reaction (PCR) samples annually, though typically less than half of that limit is needed. DEP began virus monitoring in 1995, so the data record is approximately 16 years long for some keypoint locations.

6.1.2 Laboratory Analytic Support Contract

MWH Laboratories is utilized by DEP to conduct various analyses for which DEP's laboratories are not certified. The contract with MWH Laboratories is administered by DEP's Distribution Water Quality laboratory.

In 2010, contracted analyses included: Volatile organic carbon (VOC) and semi-volatile organic carbon (SVOC) analyses on selected aqueduct samples; total Kjeldahl nitrogen analyses on wastewater samples; pharmaceuticals and personal care products analyses on aqueduct samples; trace metals, cyanide, fluoride, and New York State Sanitary Code Part 5 organics analyses on DEP facility drinking water samples; and additional organics analyses (e.g., Diesel Range Organics) on special investigation samples.

6.1.3 Water Quality Operation and Maintenance and Assessment for the Hydrological Monitoring Network

During 2010, data analysis and report preparation were carried out by the USGS in fulfillment of a contract with DEP titled, "Water Quality Operation and Maintenance and Assessment for the Hydrological Monitoring Network." The purpose of this project was to evaluate the effects of land use and land cover on stream water quality and provide data to accurately assess potential sources of contamination in the Catskill and Delaware Systems. Stream water quality samples were collected and stream discharge measured at 13 sites in the Catskill and Delaware Systems from October 1, 1999 to September 30, 2009. Samples were collected at a fixed frequency and during selected storm events. The four main tasks associated with the program were (1) collection of stream water quality samples, (2) analysis of stream water quality samples, (3) electronic dissemination of the stream water quality data, and (4) evaluation of the effects of land use and land cover on stream water quality, identification of potential sources of contamination, and quantification of trends in water quality in the Catskill and Delaware Systems. The first three tasks were completed at the end of the 2009 Water Year (September 30, 2009). The interpretive report, which will evaluate effects of land use and land cover on stream water quality, identify potential sources of contamination, and quantify trends in water quality in the Catskill and Delaware Systems, will be delivered in 2011.

6.1.4 Turbidity and Suspended Sediment Monitoring in the Upper Esopus Creek Watershed, Ulster County, NY

This is a contract with the USGS to monitor turbidity and suspended sediment concentrations at five sites within the Upper Esopus Creek watershed, by upgrading existing USGS gauging stations to automatically measure in-stream turbidity. Automated sampling for total suspended solids during both base flow and selected storm events will also occur. The objectives of the project are to:

- Quantify the suspended sediment and turbidity concentrations and suspended sediment loads at each of five gauging stations in the Upper Esopus Creek for a period of three years
- Evaluate the relations between turbidity and suspended sediment concentration and construct sediment and turbidity rating curves for each site if possible
- Examine temporal and spatial trends in turbidity and suspended sediment in the Upper Esopus Creek watershed

The contract period runs from August 2010 to August 2013. Most of the automated equipment has been installed and monitoring is expected to begin in 2011.

6.1.5 Robotic Monitoring of Selected New York City Reservoirs and Major Tributaries

The purpose of this contract was to develop a network of automated monitoring systems that had the primary purpose of providing near-real-time information on Catskill System and Kensico Reservoir turbidity levels. This information was used to (1) inform reservoir managers of turbidity levels to help them make operational decisions, (2) provide data to initialize and verify reservoir modeling simulations, and (3) provide data in support of the DEP Operations Support Tool (OST). As part of this project, eight reservoir monitoring buoys were installed and three stream monitoring sites were upgraded or installed. The project has been run by the Upstate

Freshwater Institute (UFI), which has been responsible for developing, installing, and maintaining all the monitoring sites. The contract began in December 2008 and is scheduled to end in December 2011.

6.1.6 Integrated Program of Measurements, Process Studies, and Modeling for the Turbidity at Schoharie Reservoir and Esopus Creek

The purpose of this long-running contract has been to develop reservoir models which predict the transport of turbidity and resultant levels of turbidity in Schoharie, Ashokan, and Kensico Reservoirs. As part of the model development, extensive field work and process studies have been carried out to provide data to support model development, testing, calibration, and verification. The models developed as part of this contract are used routinely by the water quality modeling group to predict reservoir turbidity levels, and have also formed a key component of the OST. The contractor is the UFI. The contract began in 2003, and originally focused on Schoharie Reservoir, but it has been amended and extended on several occasions to include work on Ashokan and Kensico Reservoirs and to allow for a longer period of data collection. The contract is now expected to end in December 2011.

6.1.7 CUNY Postdoctoral Support Contract for Modeling

The purpose of the contract is to provide DEP water quality modeling staff with support from postdoctoral research associates and City University of New York (CUNY) faculty. Seven postdoctoral associates have been hired at CUNY, and are stationed in Kingston to work with the DEP modeling group. Three faculty advisors are also working with the postdocs and modeling group staff. The postdocs are helping the modeling group fulfill its FAD and climate-change-related research missions. Postdoctoral projects involve obtaining and downscaling future climate scenarios, reservoir system modeling, reservoir model development and application, watershed turbidity modeling, watershed nutrient modeling, and forest modeling. The project began in June 2009 and will end in June 2013.

6.1.8 Waterfowl Management Contract

The Waterfowl Management Program (WMP) (see Section 5.2.14) was developed in response to seasonal elevations of fecal coliform bacteria first identified at Kensico Reservoir in the late 1980s through the early 1990s. A contract was first let in 1995 to a private environmental consulting firm and has been re-bid every four years to help fulfill compliance with the federal Surface Water Treatment Rule for fecal coliform bacteria.

The current WMP contract requires staffing of up to 40 contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. A new contract was recently bid, and is intended to run from August 1, 2011 to July 31, 2014.

6.1.9 Zebra Mussel Monitoring Contract

DEP has been monitoring all 19 of New York City's reservoirs for the presence of zebra mussel larvae (veligers) and the settlement of mature zebra mussels since the early 1990s (see Section 5.2.17), via contract with a series of laboratories that have professional experience in identifying zebra mussels. All East of Hudson reservoirs and Cannonsville Reservoir are monitored on a monthly basis between May and October, while the remaining West of Hudson reservoirs are monitored in July and September of each year. The contract laboratory analyzes these samples and provides a monthly report to the project manager indicating whether or not zebra mussels have been detected.

6.2 Water Research Foundation Projects and DEP participation in 2010

The Water Research Foundation (WaterRF) is an internationally-renowned research organization that conducts research projects to benefit water supply utilities. In 2010 Commissioner Caswell F. Holloway served on the Board of Trustees for the Foundation. Board members are subscribers and leaders in the water supply community who represent water utilities around the world. The appointed trustees represent the interests of the Association of Metropolitan Water Agencies (AMWA), the National Association of Water Companies (NAWC), and the American Water Works Association (AWWA), others from the drinking water community, and one representative from the international water supply community. In this way, research projects remain focused on the primary issues of water utilities worldwide.

The WaterRF is a highly interactive organization that involves its subscribers, such as DEP, to the extent that subscribers choose to volunteer time and experience. Water supply leaders help to set the research agenda and oversee projects. There are many opportunities for participation in WaterRF activities and projects, and DEP staff members are currently involved as either Project Advisory Committee (PAC) members, liaisons when DEP has volunteered as a Participating Utility (PU), or Strategic Initiative Expert Panel members. DEP involvement in WaterRF projects on PACs or as a PU is summarized in Table 6.1. A full description of these and other WaterRF projects can be found at the WaterRF website, http://www.waterrf.org/ .

WQD personnel have also been involved in two WaterRF Strategic Initiative Expert Panels. The role of the Expert Panels is to assist in shaping the long-term research agenda by composing RFPs, setting priorities, and developing appropriate funding levels for projects projected for future years. S. Schindler is on the panel for Endocrine Disruptors and Pharmaceuticals and Personal Care Products (ED/PPCPs). Trace amounts of endocrine disrupting compounds (EDCs), pharmaceuticals, and personal care products (PPCPs) have been found in drinking water for more than 30 years. These compounds are receiving growing attention from the scientific community, regulatory agencies and the public at large. The Foundation created this EDC/PPCP Strategic Initiative to help establish drinking water treatment strategies for EDCs/PPCPs, and to develop appropriate risk communication strategies. L. Janus has participated on the panel for the Climate Change Strategic Initiative. The Climate Change Expert Panel developed a website named the

Climate Change Clearinghouse www.theclimatechangeclearinghouse.org (begun in 2008) to act as a central knowledge repository website to assist water utilities in assessing and managing the impacts of climate change on water resources and potential adaptation measures. It has also conducted workshops and developed the multi-year research agenda to investigate potential climate change impacts and adaptation for water utilities.

Table 6.1: WaterRF projects.

Project #	Title	Project Summary	Lead Bureau/ Staff	PAC	Participating Utility	Status
3132	Incorporating Climate Change Information In Water Utility Planning: A Collaborative, Decision Analytic Approach	Will identify vulnerabilities of drinking water utilities to changing climate conditions and the adaptations drinking water utilities will need to make to manage risk, given unavoidable uncertainties regarding the specific nature of future changes in local hydrologic conditions. Will also develop flexible and responsive short- and long-term management strategies to help utilities deal effectively with this new source of uncertainty when planning for and implementing changes in response to climate change. Research partner: National Center for Atmospheric Research (NCAR).	BWS/ Janus	Yes	No	Project completed in 2010.
4179	Selecting and Standardizing the Most Appropriate Tool for Regulatory *Cryptosporidium* Genotyping	The objectives of this research are (in part) to select and standardize a reference small subunit (SSU) rRNA-based nested polymerase chain reaction restriction fragment length polymorphism (PCR RFLP) sequencing/genotyping tool for *Cryptosporidium* from 1623 slides, to develop a secondary confirmatory gene target for human infectious oocysts, and to perform a round-robin and field testing of the tools of choice.	BWS/ K. Alderisio	Yes	Yes	RFP awarded. Project start date: August 1, 2009
4208	Identifying and Developing Climate Change Resources for Water Utilities: Content for Central Knowledge Repository Website	Will identify and develop content for a central knowledge repository website to assist water utilities in assessing and managing the impacts of climate change.	BWS/ Janus	Yes	No	Project completed in 2010.

Table 6.1: (Continued)WaterRF projects.

Project #	Title	Project Summary	Lead Bureau/ Staff	PAC	Participating Utility	Status
4262	Vulnerability Assessment And Risk Management Tools For Climate Change: Assessing Potential Impacts And Identifying Adaptation Options	Will identify the most likely vulnerabilities typically associated with climate change, provide utilities with a tool to assess their own utility-specific vulnerabilities, and produce a suite of risk management tools to assist utilities in identifying appropriate strategies and actions to respond to the vulnerabilities that are identified. Research partners: NYS Energy Research Development Authority (NYSERDA) and Water Services Association of Australia.	BWS/ Beckhardt	No	Yes	Awarded to Hazen & Sawyer, NCAR, Rand, Stockholm Inst. Team.
4263	Analysis Of Changes In Water Use Under Regional Climate Change Scenarios	Will study anticipated water demands and use patterns under a range of climate change scenarios, categorized by specific customer class and industry sector, so that water utilities may better plan for and respond to changing water use patterns as a result of climate change. Will provide recommendations for water utilities to plan for and respond to the anticipated water use patterns, and will identify key concerns and areas for additional analysis by region.	BEPA/ Cohn	No	Yes	Awarded to the consulting team of Hazen & Sawyer and Stratus Consulting Inc.
4264	Changing Mindsets To Promote Design Of "Sustainable Water Infrastructure" Under Climate Change	This project will define a new planning approach and will set out a comprehensive sustainable planning framework to include a broad suite of considerations. Examples of sustainable systems and design concepts will be considered, including low-impact development, decentralized systems, integrated water systems, alternate delivery modes, point of use/point of entry (POU/POE) treatment, and use of triple bottom line evaluation methods (embedded, operational, and supply chain) for carbon accounting.	BEPA/ Cohn	No	Yes	Awarded to Stratus Consulting Inc; NYC Office of Long Term Planning also a participating organization
4324	Water Quality Impacts Of Extreme Weather Events	The objective of this research is to identify and characterize water quality impacts of extreme weather-related events.	BWS/ Beckhardt	No	Yes	Awarded to Hazen & Sawyer team (November 22, 2010)
4348	Matrix Effects in the Bull Run Watershed on *Cryptosporidium* Recovery	The objective of this study is to determine what factor(s) in Portland Water Bureau's Bull Run source water result in the inability to recover *Cryptosporidium* oocysts at certain times of the year. Examining seeded recoveries with different water quality characteristics, as well as modifying laboratory methods, is involved.	BWS/ K. Alderisio	Yes	No	Tailored Collaboration awarded. Project start date: November 12, 2010

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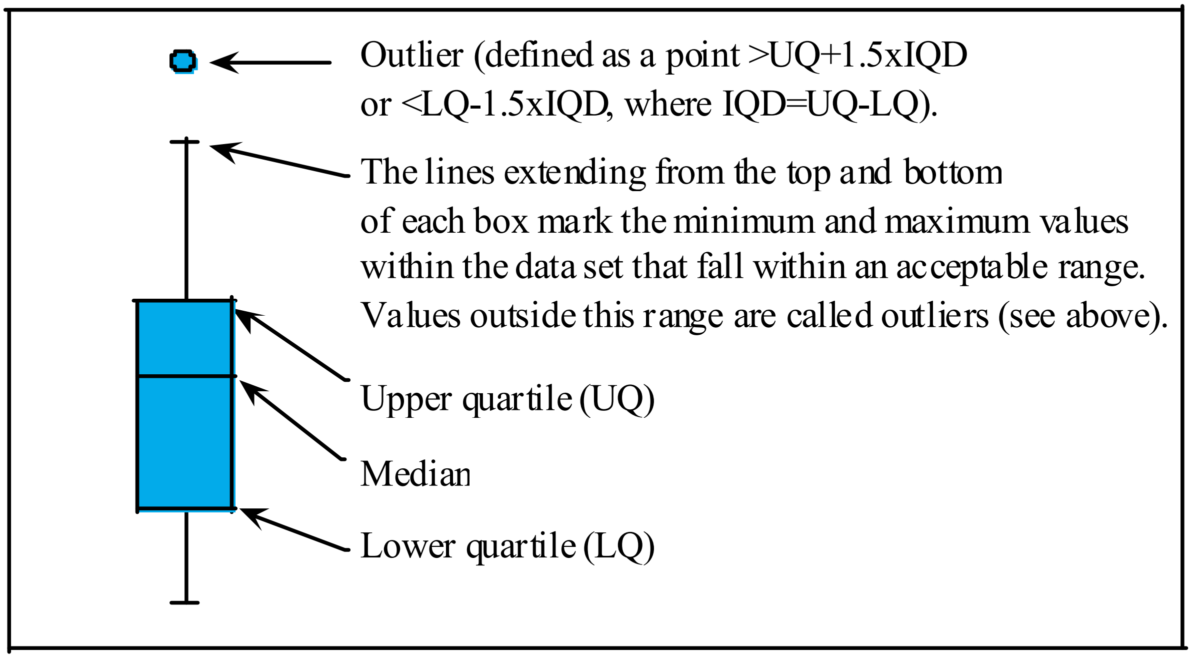
Appendix A. Key to Boxplots and Summary of Non-Detect Statistics Used in Data Analysis



Water quality data are often left-censored in that many analytical results occur below the instrument's detection limit. Substituting some value for the detection limit results, and then using parametric measures such as means and standard deviations, will often produce erroneous estimates. In this report we used the nonparametric Kaplan-Meier (K-M) Method, described in Helsel (2005), to estimate summary statistics for analytes where left-censoring occurred (e.g., fecal and total coliforms, ammonia, nitrate, suspended solids). If a particular site had no censored values for a constituent, the summary statistics reported are the traditional mean and percentiles, not K-M estimates.

Appendix B. Monthly Coliform-Restricted Calculations for Total Coliform Counts on Non-terminal Reservoirs

Appendix Table 1: Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU 100mL^{-1})	Percentage > Standard
Amawalk	A (2400, 5000)	Apr-10	5	TNTC	TNTC
Amawalk		May-10	5	<50	0
Amawalk		Jun-10	5	TNTC	≤20
Amawalk		Jul-10	5	63	0
Amawalk		Aug-10	5	TNTC	≤40
Amawalk		Sep-10	4	Insufficient Data	N/A
Amawalk		Oct-10	5	TNTC	≤20
Amawalk		Nov-10	5	<50	0
Bog Brook	AA (50, 240)	Apr-10	5	5	0
Bog Brook		May-10	5	10	0
Bog Brook		Jun-10	5	50	0
Bog Brook		Jul-10	5	<50	0
Bog Brook		Aug-10	5	520	80
Bog Brook		Sep-10	5	<50	0
Bog Brook		Oct-10	5	<50	0
Bog Brook		Nov-10	5	200	40
Boyd Corners	AA (50, 240)	Apr-10	6	38	0
Boyd Corners		May-10	7	<10	14
Boyd Corners		Jun-10	7	<10	0
Boyd Corners		Jul-10	5	36	0
Boyd Corners		Aug-10	6	<100	0
Boyd Corners		Sep-10	5	TNTC	≤20
Boyd Corners		Oct-10	6	250	50
Boyd Corners		Nov-10	0	Insufficient Data	N/A
Croton Falls	A/AA (50, 240)	Apr-10	6	<5	0
Croton Falls		May-10	6	14	0
Croton Falls		Jun-10	8	TNTC	≤38
Croton Falls		Jul-10	6	<395	50
Croton Falls		Aug-10	6	<315	50
Croton Falls		Sep-10	6	<150	0
Croton Falls		Oct-10	0	Insufficient Data	N/A
Croton Falls		Nov-10	6	<50	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU $100mL^{-1}$)	Percentage > Standard
Cross River	A/AA (50, 240)	Apr-10	6	44	0
Cross River		May-10	6	25	13
Cross River		Jun-10	6	29	0
Cross River		Jul-10	6	<20	0
Cross River		Aug-10	6	<20	0
Cross River		Sep-10	6	50	33
Cross River		Oct-10	6	200	50
Cross River		Nov-10	6	<10	0
Diverting	AA (50, 240)	Apr-10	0	Insufficient Data	N/A
Diverting		May-10	0	Insufficient Data	N/A
Diverting		Jun-10	5	115	0
Diverting		Jul-10	5	<500	40
Diverting		Aug-10	5	230	40
Diverting		Sep-10	0	Insufficient Data	N/A
Diverting		Oct-10	0	Insufficient Data	N/A
Diverting		Nov-10	5	55	0
East Branch	AA (50, 240)	Apr-10	4	Insufficient Data	N/A
East Branch		May-10	6	3600	100
East Branch		Jun-10	6	140	33
East Branch		Jul-10	5	<200	0
East Branch		Aug-10	5	1500	100
East Branch		Sep-10	5	TNTC	TNTC
East Branch		Oct-10	5	<200	40
East Branch		Nov-10	5	<100	0
Lake Gilead	A (2400, 5000)	Apr-10	5	15	0
Lake Gilead		May-10	5	9	0
Lake Gilead		Jun-10	5	<5	0
Lake Gilead		Jul-10	5	<5	0
Lake Gilead		Aug-10	5	<50	0
Lake Gilead		Sep-10	5	<50	0
Lake Gilead		Oct-10	5	<20	0
Lake Gilead		Nov-10	5	<10	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU $100mL^{-1}$)	Percentage > Standard
Lake Gleneida	AA (50, 240)	Apr-10	3	Insufficient Data	N/A
Lake Gleneida		May-10	5	<5	0
Lake Gleneida		Jun-10	5	9	0
Lake Gleneida		Jul-10	5	<5	0
Lake Gleneida		Aug-10	5	<50	0
Lake Gleneida		Sep-10	5	<50	0
Lake Gleneida		Oct-10	5	<50	0
Lake Gleneida		Nov-10	5	<20	0
Kirk Lake	B (2400, 5000)	Apr-10	5	78	0
Kirk Lake		May-10	5	45	0
Kirk Lake		Jun-10	5	<50	0
Kirk Lake		Jul-10	5	40	0
Kirk Lake		Aug-10	5	280	0
Kirk Lake		Sep-10	5	33	0
Kirk Lake		Oct-10	5	TNTC	TNTC
Muscoot	A (2400, 5000)	Apr-10	7	180	≤29
Muscoot		May-10	7	<100	0
Muscoot		Jun-10	7	1500	0
Muscoot		Jul-10	7	<100	0
Muscoot		Aug-10	7	<100	0
Muscoot		Sep-10	7	<500	14
Muscoot		Oct-10	6	<100	0
Muscoot		Nov-10	7	67	0
Middle Branch	A (2400, 5000)	Apr-10	5	80	0
Middle Branch		May-10	5	50	0
Middle Branch		Jun-10	5	17	0
Middle Branch		Jul-10	5	<100	0
Middle Branch		Aug-10	5	83	0
Middle Branch		Sep-10	5	<100	0
Middle Branch		Oct-10	5	83	0
Middle Branch		Nov-10	5	80	0
Titicus	AA (50, 240)	Apr-10	5	TNTC	TNTC

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU $100mL^{-1}$)	Percentage > Standard
Titicus		May-10	5	50	0
Titicus		Jun-10	5	18	0
Titicus		Jul-10	5	250	60
Titicus		Aug-10	5	80	≤20
Titicus		Sep-10	5	TNTC	≤20
Titicus		Oct-10	5	45	20
Titicus		Nov-10	5	80	0
Pepacton	A/AA (50/240)	Apr-10	16	2	≤31
Pepacton		May-10	15	4	≤20
Pepacton		Jun-10	15	20	≤47
Pepacton		Jul-10	15	<100	≤13
Pepacton		Aug-10	15	<50	≤13
Pepacton		Sep-10	14	<20	0
Pepacton		Oct-10	15	<50	0
Pepacton		Nov-10	15	<20	0
Neversink	AA (50/240)	Apr-10	13	2	0
Neversink		May-10	13	2	≤23
Neversink		Jun-10	13	<2	0
Neversink		Jul-10	12	TNTC	≤33
Neversink		Aug-10	11	<100	0
Neversink		Sep-10	10	<35	≤10
Neversink		Oct-10	13	<50	0
Neversink		Nov-10	12	18	0
Schoharie	AA (50/240)	Apr-10	12	150	25
Schoharie		May-10	11	240	45
Schoharie		Jun-10	11	TNTC	≥65
Schoharie		Jul-10	11	600	100
Schoharie		Aug-10	10	350	70
Schoharie		Sep-10	10	350	80
Schoharie		Oct-10	12	4000	100
Schoharie		Nov-10	12	850	100
Cannonsville	A/AA (50/240)	Apr-10	15	16	7

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs. 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU $100mL^{-1}$)	Percentage > Standard
Cannonsville		May-10	15	<20	≤7
Cannonsville		Jun-10	18	TNTC	≤72
Cannonsville		Jul-10	17	900	76
Cannonsville		Aug-10	17	TNTC	≤53
Cannonsville		Sep-10	15	200	≤27
Cannonsville		Oct-10	17	TNTC	≤35
Cannonsville		Nov-10	14	<50	7

Notes: The reservoir class is defined by 6 NYCRR Subpart C. For those reservoirs that have dual designations, the higher standard has been applied. The median could not be estimated for samples determined to be Too Numerous To Count (TNTC).

Appendix C. Phosphorus-Restricted Basin Assessment Methodology

A phosphorus-restricted basin is defined in the New York City Watershed Regulations, amended April 4, 2010, as "(i) the drainage basin of a source water reservoir in which the phosphorus load to the reservoir results in the phosphorus concentration in the reservoir exceeding 15 micrograms per liter, or (ii) the drainage basin of a reservoir other than a source water reservoir or of a controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus concentration in the reservoir or controlled lake exceeding 20 micrograms per liter in both instances as determined by the Department pursuant to its annual review conducted under §18-48 (e) of Subchapter D" (DEP 2010a). The phosphorus-restricted designation of a reservoir basin has two primary effects: (1) new or expanded wastewater treatment plants with surface discharges are prohibited in the reservoir basin, and (2) stormwater pollution prevention plans required by the Watershed Regulations must include an analysis of phosphorus runoff, before and after the land disturbance activity, and must be designed to treat the 2-year, 24-hour storm. The list of phosphorus-restricted basins is updated annually in the Watershed Water Quality Annual Report.

A summary of the methodology used in the phosphorus-restricted analysis will be given here; the complete description can be found in A Methodology for Determining Phosphorus Restricted Basins (DEP 1997). The data utilized in the analysis is from the routine limnological monitoring of the reservoirs during the growing season, which is defined as May 1 through October 31. Any recorded concentrations below the analytical limit of detection are analyzed using non-detect statistics described in Helsel (2005). The detection limit for DEP measurements of total phosphorus is assessed each year by the DEP laboratories, and typically ranges between 2-5 $\mu g\ L^{-1}$. The phosphorus concentration data for the reservoirs approaches a lognormal distribution; therefore, a geometric mean is used to characterize the annual phosphorus concentrations. Appendix Table 2 provides the annual geometric mean for the past six years.

The five most recent annual geometric means are averaged arithmetically, and this average constitutes one assessment. This "running average" method weights each year equally, thus reducing the effects of unusual hydrological events or phosphorus loading, while maintaining an accurate assessment of the current conditions in the reservoir. Should any reservoir have less than three surveys during a growing season, the annual average may or may not be representative of the reservoir, and the data for the under-sampled year is removed from the analysis. In addition, each five-year assessment must incorporate at least three years of data.

To provide some statistical assurance that the five-year arithmetic mean is representative of a basin's phosphorus status, given the interannual variability, the five-year mean plus the standard error of the five-year mean is compared to the NYS guidance value of 20 $\mu g\ L^{-1}$ (15 $\mu g\ L^{-1}$ for potential source waters). A basin is considered **unrestricted** if the five-year mean plus standard error is below the guidance value of 20 μg L^{-1} (15 μg L^{-1} for potential source waters). A basin is considered phosphorus-**restricted** if the five-year mean plus standard error is equal to or greater than 20 μg L^{-1} (15 μg L^{-1} for potential source waters), unless the Department, using its best professional judgment, determines that the phosphorus-restricted designation is due to an unusual and unpredictable event unlikely to occur in the future. A reservoir basin designation, as phosphorus-restricted or unrestricted, may change through time based on the outcome of this annual assessment. However, a basin must have two consecutive assessments (i.e., two years in a row) that result in the new designation in order to officially change the designation.

Appendix Table 2: Geometric mean total phosphorus data utilized in the phosphorus-restricted assessments. All reservoir samples taken during the growing season (May 1 through October 31) are used.

Reservoir Basin	2005 μg L^{-1}	2006 μg L^{-1}	2007 μg L^{-1}	2008 μg L^{-1}	2009 μg L^{-1}	2010 μg L^{-1}
Delaware						
Cannonsville	19.6	20.5	14.0	13.4	14.0	16.4
Pepacton	8.7	10.8	9.7	8.2	7.6	9.9
Neversink	7.3	7.3	4.7	4.7	5.9	6.5
Catskill						
Schoharie	20.6	17.4	9.7	9.5	11.2	13.4
Croton District						
Amawalk	24.0	24.5	20.2	17.9	19.4	20.5
Bog Brook	18.6	18.7	24.0	21.5	22.8	31.1
Boyd Corners	*	17.4	15.6	11.6	8.6	8.4
Diverting	*	*	*	22.8	*	29.1
East Branch	28.3	28.4	23.0	21.6	26.1	33.8
Middle Branch	31.5	24.2	25.0	27.9	22.4	25.5
Muscoot	26.8	27.9	25.7	27.6	24.9	28.7
Titicus	24.6	29.6	21.6	17.5	20.8	26.4
Lake Gleneida	*	24.2	*	*	22.7	25.9
Lake Gilead	*	30.5	33.6	*	36.0	30.1
Kirk Lake	*	29.7	28.6	*	31.4	27.6
Source Waters						
Ashokan-West	26.0	11.2	8.1	7.2	8.6	12.9
Ashokan-East	11.0	9.9	7.3	7.5	9.5	9.8
Cross River	18.7	18.6	17.8	13.8	13.8	15.4

Appendix Table 2: (Continued) Geometric mean total phosphorus data utilized in the phosphorus-restricted assessments. All reservoir samples taken during the growing season (May 1 through October 31) are used.

Reservoir Basin	2005 $\mu g\ L^{-1}$	2006 $\mu g\ L^{-1}$	2007 $\mu g\ L^{-1}$	2008 $\mu g\ L^{-1}$	2009 $\mu g\ L^{-1}$	2010 $\mu g\ L^{-1}$
Croton Falls	*	19.2	*	14.4	14.7	13.3
Kensico	9.7	7.6	7.0	6.4	5.8	6.6
New Croton	18.2	18.1	17.7	15.5	14.4	15.7
Rondout	7.8	8.6	7.1	6.1	8.1	8.0
West Branch	14.8	10.3	9.6	9.4	9.6	9.4

*Less than three successful surveys were performed during the growing season (May - October).

Appendix D. Comparison of Reservoir Water Quality Results to Benchmarks

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Kensico Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	24			≥10	12
Chloride (mg L^{-1})	12	24	0	0	8	10.0
Chlorophyll *a* (µg L^{-1})	12	56	0	0	7	4.8
Color (Pt-Co units)	15	311	41	13	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	200	0	0	3	1.7
Fecal coliform (CFU 100mL^{-1})	20	311	1	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	200	0	0	0.3	0.13
pH (units)	6.5-8.5	311	36	12	na	na
Sodium, undig., filt. (mg L^{-1})	16	24	24	100	3	6.0
Soluble reactive phosphorus (µg L^{-1})	15	200	0	0	na	na
Sulfate (mg L^{-1})	15	24	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	199	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	311	113	36	40	49
Total phosphorus (µg L^{-1})	15	200	2	1	na	na
Total phytoplankton (ASU)	2000	135	0	0	na	na
Primary genus (ASU)	1000	135	0	0	na	na
Secondary genus (ASU)	1000	134	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	79	0	0	5	<1
Turbidity (NTU)	5	350	9	3	na	na
Amawalk Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			≥40	78
Chloride (mg L^{-1})	40	11	11	100	30	100.0
Chlorophyll *a* (µg L^{-1})	15	16	4	25	10	11.4
Color (Pt-Co units)	15	39	37	95	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	39	0	0	3	3.7
Fecal coliform (CFU 100mL^{-1})	20	39	3	8	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	39	1	3	0.3	0.02
pH (units)	6.5-8.5	39	8	21	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	52.1
Soluble reactive phosphorus (µg L^{-1})	15	39	1	3	na	na
Sulfate (mg L^{-1})	25	11	0	0	15	10.6
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	39	4	10	na	na
Total dissolved solids (mg L^{-1})[3]	175	39	39	100	150	334
Total phosphorus (µg L^{-1})	15	39	31	79	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	3	19	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	1	11	5	3
Turbidity (NTU)	5	39	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Bog Brook Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			≥40	76
Chloride (mg L^{-1})	40	6	6	100	30	48.5
Chlorophyll *a* (µg L^{-1})	15	8	4	50	10	21.7
Color (Pt-Co units)	15	16	15	94	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	16	0	0	3	3.6
Fecal coliform (CFU $100mL^{-1}$)	20	40	4	10	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	16	0	0	0.3	0.01
pH (units)	6.5-8.5	35	9	26	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	26.2
Soluble reactive phosphorus (µg L^{-1})	15	16	1	6	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	9.5
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	16	2	13	na	na
Total dissolved solids (mg L^{-1})[3]	175	16	16	100	150	217
Total phosphorus (µg L^{-1})	15	16	14	88	na	na
Total phytoplankton (ASU)	2000	8	2	25	na	na
Primary genus (ASU)	1000	8	2	25	na	na
Secondary genus (ASU)	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	4
Turbidity (NTU)	5	16	4	25	na	na
Boyd Corners Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	5			≥40	32
Chloride (mg L^{-1})	40	5	1	20	30	38.7
Chlorophyll *a* (µg L^{-1})	15	8	0	0	10	4.2
Color (Pt-Co units)	15	16	13	81	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	16	0	0	3	2.9
Fecal coliform (CFU $100mL^{-1}$)	20	42	8	19	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	16	0	0	0.3	0.04
pH (units)	6.5-8.5	42	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	22.1
Soluble reactive phosphorus (µg L^{-1})	15	16	0	0	na	na
Sulfate (mg L^{-1})	25	5	0	0	15	7.5
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	16	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	16	0	0	150	140
Total phosphorus (µg L^{-1})	15	16	1	6	na	na
Total phytoplankton (ASU)	2000	7	0	0	na	na
Primary genus (ASU)	1000	7	0	0	na	na
Secondary genus (ASU)	1000	7	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	5	0	0	5	<1
Turbidity (NTU)	5	20	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Croton Falls Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18			≥40	52
Chloride (mg L^{-1})	40	18	18	100	30	81.5
Chlorophyll *a* (µg L^{-1})	15	12	1	8	10	7.1
Color (Pt-Co units)	15	42	33	79	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	36	0	0	3	2.8
Fecal coliform (CFU 100mL^{-1})	20	42	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	42	1	2	0.3	0.19
pH (units)	6.5-8.5	42	6	14	na	na
Sodium, undig., filt. (mg L^{-1})	20	18	18	100	15	46.5
Soluble reactive phosphorus (µg L^{-1})	15	42	0	0	na	na
Sulfate (mg L^{-1})	25	18	0	0	15	10.5
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	42	2	5	na	na
Total dissolved solids (mg L^{-1})[3]	175	42	40	95	150	268
Total phosphorus (µg L^{-1})	15	42	22	52	na	na
Total phytoplankton (ASU)	2000	14	0	0	na	na
Primary genus (ASU)	1000	14	1	7	na	na
Secondary genus (ASU)	1000	14	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	2
Turbidity (NTU)	5	42	2	5	na	na
Cross River Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			≥40	44
Chloride (mg L^{-1})	40	12	0	0	30	37.5
Chlorophyll *a* (µg L^{-1})	15	14	0	0	10	6.7
Color (Pt-Co units)	15	48	42	88	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	48	0	0	3	3.1
Fecal coliform (CFU 100mL^{-1})	20	48	2	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	42	0	0	0.3	0.04
pH (units)	6.5-8.5	48	6	13	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	19.3
Soluble reactive phosphorus (µg L^{-1})	15	48	0	0	na	na
Sulfate (mg L^{-1})	25	12	0	0	15	8.9
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	48	2	4	na	na
Total dissolved solids (mg L^{-1})[3]	175	48	1	2	150	152
Total phosphorus (µg L^{-1})	15	48	32	67	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	0	0	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2
Turbidity (NTU)	5	48	4	8	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Diverting Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	0			≥40	
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (µg L^{-1})	15	0			10	
Color (Pt-Co units)	15	1	0	0	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			3	
Fecal coliform (CFU 100mL^{-1})	20	20	1	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	0			na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	0			150	
Total phosphorus (µg L^{-1})	15	13	13	100	na	na
Total phytoplankton (ASU)	2000	0			na	na
Primary genus (ASU)	1000	0			na	na
Secondary genus (ASU)	1000	0			na	na
Total suspended solids (mg L^{-1})	8.0	0			5	
Turbidity (NTU)	5	0			na	na
East Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	5			≥40	85
Chloride (mg L^{-1})	40	5	5	100	30	48.7
Chlorophyll *a* (µg L^{-1})	15	7	5	71	10	61.6
Color (Pt-Co units)	15	18	18	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	18	0	0	3	4.3
Fecal coliform (CFU 100mL^{-1})	20	43	5	12	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	18	0	0	0.3	0.03
pH (units)	6.5-8.5	26	4	15	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	25.5
Soluble reactive phosphorus (µg L^{-1})	15	18	3	17	na	na
Sulfate (mg L^{-1})	25	5	0	0	15	12.8
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	18	7	39	na	na
Total dissolved solids (mg L^{-1})[3]	175	18	17	94	150	210
Total phosphorus (µg L^{-1})	15	24	22	92	na	na
Total phytoplankton (ASU)	2000	7	3	43	na	na
Primary genus (ASU)	1000	7	3	43	na	na
Secondary genus (ASU)	1000	7	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	5	0	0	5	6
Turbidity (NTU)	5	18	5	28	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Lake Gilead						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			≥40	44
Chloride (mg L^{-1})	40	9	0	0	30	37.5
Chlorophyll *a* (µg L^{-1})	15	3	0	0	10	6.9
Color (Pt-Co units)	15	9	4	44	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	3	3.0
Fecal coliform (CFU 100mL^{-1})	20	40	1	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	<0.02
pH (units)	6.5-8.5	15	1	7	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	20.0
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7.3
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	0	0	150	153
Total phosphorus (µg L^{-1})	15	9	7	78	na	na
Total phytoplankton (ASU)	2000	3	0	0	na	na
Primary genus (ASU)	1000	3	0	0	na	na
Secondary genus (ASU)	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	<1
Turbidity (NTU)	5	9	0	0	na	na
Lake Gleneida						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			≥40	71
Chloride (mg L^{-1})	40	9	9	100	30	88.1
Chlorophyll *a* (µg L^{-1})	15	3	0	0	10	5.1
Color (Pt-Co units)	15	9	4	44	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	3	2.7
Fecal coliform (CFU 100mL^{-1})	20	38	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	<0.02
pH (units)	6.5-8.5	15	1	7	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	46.9
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7.5
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	9	100	150	295
Total phosphorus (µg L^{-1})	15	9	7	78	na	na
Total phytoplankton (ASU)	2000	3	0	0	na	na
Primary genus (ASU)	1000	2	0	0	na	na
Secondary genus (ASU)	1000	2	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1
Turbidity (NTU)	5	9	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Kirk Lake						
Alkalinity (mg $CaCO_3$ L^{-1})	na	3			≥40	54
Chloride (mg L^{-1})	40	3	3	100	30	67.8
Chlorophyll *a* (µg L^{-1})	15	2	1	50	10	26.5
Color (Pt-Co units)	15	3	3	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	3	0	0	3	4.3
Fecal coliform (CFU 100mL^{-1})	20	35	7	20	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	3	0	0	0.3	<0.02
pH (units)	6.5-8.5	10	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	3	3	100	15	34.6
Soluble reactive phosphorus (µg L^{-1})	15	3	0	0	na	na
Sulfate (mg L^{-1})	25	3	0	0	15	9.0
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	3	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	235
Total phosphorus (µg L^{-1})	15	6	6	100	na	na
Total phytoplankton (ASU)	2000	2	1	50	na	na
Primary genus (ASU)	1000	2	2	100	na	na
Secondary genus (ASU)	1000	2	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	3	0	0	5	4
Turbidity (NTU)	5	3	2	67	na	na
Muscoot Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			≥40	77
Chloride (mg L^{-1})	40	6	6	100	30	74.4
Chlorophyll *a* (µg L^{-1})	15	32	14	44	10	19.5
Color (Pt-Co units)	15	55	55	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	55	0	0	3	3.6
Fecal coliform (CFU 100mL^{-1})	20	52	2	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	55	6	11	0.3	0.20
pH (units)	6.5-8.5	55	6	11	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	39.4
Soluble reactive phosphorus (µg L^{-1})	15	55	2	4	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	10.5
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	55	5	9	na	na
Total dissolved solids (mg L^{-1})[3]	175	55	55	100	150	265
Total phosphorus (µg L^{-1})	15	55	55	100	na	na
Total phytoplankton (ASU)	2000	32	10	31	na	na
Primary genus (ASU)	1000	32	8	25	na	na
Secondary genus (ASU)	1000	32	2	6	na	na
Total suspended solids (mg L^{-1})	8.0	2	0	0	5	3
Turbidity (NTU)	5	55	10	18	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Middle Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	7			≥40	57
Chloride (mg L^{-1})	40	7	7	100	30	97.8
Chlorophyll *a* (µg L^{-1})	15	16	9	56	10	17.0
Color (Pt-Co units)	15	39	39	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	39	0	0	3	3.1
Fecal coliform (CFU 100mL^{-1})	20	40	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	39	0	0	0.3	0.02
pH (units)	6.5-8.5	40	8	20	na	na
Sodium, undig., filt. (mg L^{-1})	20	7	7	100	15	55.7
Soluble reactive phosphorus (µg L^{-1})	15	39	3	8	na	na
Sulfate (mg L^{-1})	25	7	0	0	15	10.8
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	39	5	13	na	na
Total dissolved solids (mg L^{-1})[3]	175	39	39	100	150	308
Total phosphorus (µg L^{-1})	15	39	35	90	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	1	6	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	5	0	0	5	2
Turbidity (NTU)	5	39	4	10	na	na
New Croton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	28			≥40	63
Chloride (mg L^{-1})	40	29	29	100	30	62.2
Chlorophyll *a* (µg L^{-1})	15	56	5	9	10	11.3
Color (Pt-Co units)	15	246	237	96	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	163	0	0	3	3.0
Fecal coliform (CFU 100mL^{-1})	20	241	13	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	166	18	11	0.3	0.15
pH (units)	6.5-8.5	233	28	12	na	na
Sodium, undig., filt. (mg L^{-1})	20	28	28	100	15	33.6
Soluble reactive phosphorus (µg L^{-1})	15	166	3	2	na	na
Sulfate (mg L^{-1})	25	29	0	0	15	10.3
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	166	6	4	na	na
Total dissolved solids (mg L^{-1})[3]	175	246	246	100	150	235
Total phosphorus (µg L^{-1})	15	166	86	52	na	na
Total phytoplankton (ASU)	2000	62	4	6	na	na
Primary genus (ASU)	1000	62	3	5	na	na
Secondary genus (ASU)	1000	62	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	56	0	0	5	2
Turbidity (NTU)	5	246	4	2	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Titicus Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			≥40	68
Chloride (mg L^{-1})	40	9	4	44	30	40.1
Chlorophyll *a* (µg L^{-1})	15	16	3	19	10	11.9
Color (Pt-Co units)	15	35	31	89	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	35	0	0	3	3.2
Fecal coliform (CFU 100mL^{-1})	20	40	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	35	0	0	0.3	0.02
pH (units)	6.5-8.5	40	9	23	na	na
Sodium, undig., filt. (mg L^{-1})	20	10	10	100	15	20.2
Soluble reactive phosphorus (µg L^{-1})	15	35	4	11	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	9.1
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	35	5	14	na	na
Total dissolved solids (mg L^{-1})[3]	175	35	33	94	150	187
Total phosphorus (µg L^{-1})	15	35	33	94	na	na
Total phytoplankton (ASU)	2000	16	1	6	na	na
Primary genus (ASU)	1000	16	2	13	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	2
Turbidity (NTU)	5	35	2	6	na	na
West Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	10			≥10	15
Chloride (mg L^{-1})	12	12	4	33	8	14.8
Chlorophyll *a* (µg L^{-1})	12	32	1	3	7	5.6
Color (Pt-Co units)	15	102	45	44	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	58	0	0	3	1.9
Fecal coliform (CFU 100mL^{-1})	20	102	8	8	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	53	0	0	0.3	0.13
pH (units)	6.5-8.5	94	2	2	na	na
Sodium, undig., filt. (mg L^{-1})	16	10	10	100	3	9.2
Soluble reactive phosphorus (µg L^{-1})	15	58	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	6.1
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	58	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	102	56	55	40	56
Total phosphorus (µg L^{-1})	15	58	10	17	na	na
Total phytoplankton (ASU)	2000	49	1	2	na	na
Primary genus (ASU)	1000	49	2	4	na	na
Secondary genus (ASU)	1000	49	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	7	0	0	5	1
Turbidity (NTU)	5	111	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Ashokan-East Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			≥10	11
Chloride (mg L^{-1})	12	9	0	0	8	6.2
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	3.8
Color (Pt-Co units)	15	87	18	21	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	64	1	2	3	1.6
Fecal coliform (CFU 100mL^{-1})	20	87	3	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	0	0	0.3	0.04
pH (units)	6.5-8.5	84	22	26	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	3.9
Soluble reactive phosphorus (µg L^{-1})	15	64	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.10	64	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	64	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	87	0	0	40	35
Total phosphorus (µg L^{-1})	15	64	8	13	na	na
Total phytoplankton (ASU)	2000	40	0	0	na	na
Primary genus (ASU)	1000	40	0	0	na	na
Secondary genus (ASU)	1000	40	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	56	2	4	5	2
Turbidity (NTU)	5	88	21	24	na	na
Ashokan-West Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			≥10	10
Chloride (mg L^{-1})	12	12	0	0	8	4.7
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	3.4
Color (Pt-Co units)	15	98	35	36	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	78	0	0	3	1.7
Fecal coliform (CFU 100mL^{-1})	20	153	10	7	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	78	0	0	0.3	0.18
pH (units)	6.5-8.5	156	44	28	na	na
Sodium, undig., filt. (mg L^{-1})	16	8	5	63	3	3.3
Soluble reactive phosphorus (µg L^{-1})	15	78	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.9
Total ammonia-N (mg L^{-1})	0.10	78	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	78	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	154	0	0	40	33
Total phosphorus (µg L^{-1})	15	78	33	42	na	na
Total phytoplankton (ASU)	2000	40	0	0	na	na
Primary genus (ASU)	1000	40	0	0	na	na
Secondary genus (ASU)	1000	40	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	77	31	40	5	5
Turbidity (NTU)	5	157	117	75	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Pepacton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	21			≥10	12
Chloride (mg L^{-1})	12	21	0	0	8	6.6
Chlorophyll *a* (µg L^{-1})	12	39	5	13	7	5.4
Color (Pt-Co units)	15	120	42	35	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	120	0	0	3	1.6
Fecal coliform (CFU $100mL^{-1}$)	20	120	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	120	0	0	0.3	0.16
pH (units)	6.5-8.5	105	36	34	na	na
Sodium, undig., filt. (mg L^{-1})	16	21	21	100	3	4.2
Soluble reactive phosphorus (µg L^{-1})	15	120	0	0	na	na
Sulfate (mg L^{-1})	15	21	0	0	10	4.6
Total ammonia-N (mg L^{-1})	0.10	120	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	120	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	120	2	2	40	40
Total phosphorus (µg L^{-1})	15	120	21	18	na	na
Total phytoplankton (ASU)	2000	57	1	2	na	na
Primary genus (ASU)	1000	57	1	2	na	na
Secondary genus (ASU)	1000	57	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	57	0	0	5	1
Turbidity (NTU)	5	120	7	6	na	na
Neversink Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	10			≥10	3
Chloride (mg L^{-1})	12	10	0	0	8	2.9
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	2.4
Color (Pt-Co units)	15	96	15	16	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	73	0	0	3	1.9
Fecal coliform (CFU $100mL^{-1}$)	20	97	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	73	0	0	0.3	0.14
pH (units)	6.5-8.5	96	75	78	na	na
Sodium, undig., filt. (mg L^{-1})	16	10	0	0	3	1.9
Soluble reactive phosphorus (µg L^{-1})	15	73	0	0	na	na
Sulfate (mg L^{-1})	15	10	0	0	10	3.6
Total ammonia-N (mg L^{-1})	0.10	73	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	73	1	1	na	na
Total dissolved solids (mg L^{-1})[3]	50	96	0	0	40	18
Total phosphorus (µg L^{-1})	15	73	1	1	na	na
Total phytoplankton (ASU)	2000	48	0	0	na	na
Primary genus (ASU)	1000	48	0	0	na	na
Secondary genus (ASU)	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	23	0	0	5	1
Turbidity (NTU)	5	96	0	0	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Rondout Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			≥10	10
Chloride (mg L^{-1})	12	12	0	0	8	6.7
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	3.9
Color (Pt-Co units)	15	160	45	28	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.7
Fecal coliform (CFU 100mL^{-1})	20	160	5	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	56	0	0	0.3	0.17
pH (units)	6.5-8.5	150	43	29	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	5.0
Soluble reactive phosphorus (µg L^{-1})	15	56	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	4.5
Total ammonia-N (mg L^{-1})	0.10	56	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	56	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	160	0	0	40	37
Total phosphorus (µg L^{-1})	15	80	1	1	na	na
Total phytoplankton (ASU)	2000	49	0	0	na	na
Primary genus (ASU)	1000	49	0	0	na	na
Secondary genus (ASU)	1000	49	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	32	0	0	5	<1
Turbidity (NTU)	5	160	2	1	na	na
Schoharie Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			≥10	13
Chloride (mg L^{-1})	12	9	0	0	8	5.9
Chlorophyll *a* (µg L^{-1})	12	32	0	0	7	3.4
Color (Pt-Co units)	15	73	46	63	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	89	0	0	3	2.2
Fecal coliform (CFU 100mL^{-1})	20	89	10	11	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	68	0	0	0.3	0.13
pH (units)	6.5-8.5	89	8	9	na	na
Sodium, undig., filt. (mg L^{-1})	16	8	8	100	3	4.4
Soluble reactive phosphorus (µg L^{-1})	15	68	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	4.1
Total ammonia-N (mg L^{-1})	0.10	65	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	65	1	2	na	na
Total dissolved solids (mg L^{-1})[3]	50	89	19	21	40	43
Total phosphorus (µg L^{-1})	15	89	38	43	na	na
Total phytoplankton (ASU)	2000	48	0	0	na	na
Primary genus (ASU)	1000	48	0	0	na	na
Secondary genus (ASU)	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	89	20	22	5	4
Turbidity (NTU)	5	89	55	62	na	na

Appendix Table 3: (Continued) Comparison of reservoir water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2010 Mean[1]
Cannonsville Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18			≥10	17
Chloride (mg L^{-1})	12	18	3	17	8	11.1
Chlorophyll *a* (µg L^{-1})	12	40	8	20	7	7.6
Color (Pt-Co units)	15	128	57	45	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	113	0	0	3	1.9
Fecal coliform (CFU 100mL^{-1})	20	128	7	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	113	18	16	0.3	0.32
pH (units)	6.5-8.5	96	18	19	na	na
Sodium, undig., filt. (mg L^{-1})	16	18	18	100	3	7.1
Soluble reactive phosphorus (µg L^{-1})	15	113	3	3	na	na
Sulfate (mg L^{-1})	15	18	0	0	10	5.7
Total ammonia-N (mg L^{-1})	0.10	113	4	4	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	113	6	5	na	na
Total dissolved solids (mg L^{-1})[3]	50	128	121	95	40	57
Total phosphorus (µg L^{-1})	15	128	80	63	na	na
Total phytoplankton (ASU)	2000	56	0	0	na	na
Primary genus (ASU)	1000	56	2	4	na	na
Secondary genus (ASU)	1000	56	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	48	1	2	5	3
Turbidity (NTU)	5	128	28	22	na	na

[1]Means estimated using either the Kaplan-Meier or robust ROS method as described in Helsel (2005). In cases where the number of nondetects was greater than 80% of total N, the detection limit (identified as <) is reported in place of the mean.

[2]Dissolved organic carbon replaced total organic carbon in 2000. In New York City Reservoirs, the dissolved portion comprises the majority of the total organic carbon.

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

na = not applicable.

Appendix E. Comparison of Stream Water Quality Results to Benchmarks

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
E10I (Bushkill inflow to Ashokan)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	11	10	91	na	na
Chloride (mg L^{-1})	50	12	0	0	10	2.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.11
Sulfate (mg L^{-1})	15	4	0	0	10	4.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	22
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.6
E16I (Esopus Creek at Coldbrook)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	10	3	30	na	na
Chloride (mg L^{-1})	50	11	0	0	10	6.2
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	1.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.17
Sulfate (mg L^{-1})	15	4	0	0	10	4.4
Total ammonia-N (mg L^{-1})	0.20	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	3	27	40	40
Dissolved sodium (mg L^{-1})	10	2	0	0	5	3.5
E5 (Esopus Creek at Allaben)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	7	58	na	na
Chloride (mg L^{-1})	50	12	0	0	10	5.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.16
Sulfate (mg L^{-1})	15	4	0	0	10	4.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	4	33	40	36
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.6

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
S5I (Schoharie Creek at Prattsville)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	9	1	11	na	na
Chloride (mg L^{-1})	50	9	0	0	10	9.5
Dissolved organic carbon (mg L^{-1})	25	9	0	0	9	1.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	9	0	0	0.40	0.11
Sulfate (mg L^{-1})	15	3	0	0	10	5.0
Total ammonia-N (mg L^{-1})	0.20	9	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	9	5	56	40	55
Dissolved sodium (mg L^{-1})	10	3	1	33	5	7.5
S6I (Bear Creek at Hardenburgh Falls)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	na
Chloride (mg L^{-1})	50	12	1	8	10	19.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.6
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.46
Sulfate (mg L^{-1})	15	4	0	0	10	6.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	92
Dissolved sodium (mg L^{-1})	10	4	1	25	5	10.0
S7I (Manor Kill)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	na
Chloride (mg L^{-1})	50	12	0	0	10	7.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.10
Sulfate (mg L^{-1})	15	4	0	0	10	5.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	7	58	40	59
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.4

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
SRR2CM (Schoharie Reservoir Diversion)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	1	8	na	na
Chloride (mg L^{-1})	50	10	0	0	10	9.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.20
Sulfate (mg L^{-1})	15	4	0	0	10	4.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	248	139	56	40	52
Dissolved sodium (mg L^{-1})	10	3	0	0	5	6.6
C-7 (Trout Creek above Cannonsville Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	na
Chloride (mg L^{-1})	50	12	0	0	10	15.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.27
Sulfate (mg L^{-1})	15	4	0	0	10	6.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	10	83	40	66
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.3
C-8 (Loomis Brook above Cannonsville Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	na
Chloride (mg L^{-1})	50	12	1	8	10	15.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.24
Sulfate (mg L^{-1})	15	4	0	0	10	6.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	9	75	40	66
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.5

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
WDBN (West Branch Delaware River at Beerston Bridge)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	1	8	na	na
Chloride (mg L^{-1})	50	12	0	0	10	13.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.50
Sulfate (mg L^{-1})	15	4	0	0	10	6.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	8	67	40	69
Dissolved sodium (mg L^{-1})	10	4	1	25	5	6.8
NCG (Neversink Reservoir near Claryville)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	12	100	na	na
Chloride (mg L^{-1})	50	12	0	0	10	3.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.16
Sulfate (mg L^{-1})	15	4	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	21
Dissolved sodium (mg L^{-1})	10	4	1	25	5	7.9
NK4 (Aden Brook above Neversink Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	11	92	na	na
Chloride (mg L^{-1})	50	12	0	0	10	5.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.15
Sulfate (mg L^{-1})	15	4	0	0	10	4.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	29
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.2

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
NK6 (Kramer Brook above Neversink Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	8	67	na	na
Chloride (mg L^{-1})	50	12	1	8	10	34.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.49
Sulfate (mg L^{-1})	15	4	0	0	10	6.4
Total ammonia-N (mg L^{-1})	0.20	12	1	8	0.05	0.13
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	99
Dissolved sodium (mg L^{-1})	10	4	3	75	5	13.0
P-13 (Tremper Kill above Pepacton Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	na
Chloride (mg L^{-1})	50	12	0	0	10	13.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.28
Sulfate (mg L^{-1})	15	4	0	0	10	5.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	8	67	40	62
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.8
P-21 (Platte Kill at Dunraven)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	na
Chloride (mg L^{-1})	50	12	0	0	10	10.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.21
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	7	58	40	57
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.2

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
P-60 (Mill Brook near Dunraven)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	6	50	na	na
Chloride (mg L^{-1})	50	12	0	0	10	1.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.25
Sulfate (mg L^{-1})	15	4	0	0	10	4.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	28
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.1
P-7 (Terry Clove above Pepacton Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	1	8	na	na
Chloride (mg L^{-1})	50	12	0	0	10	1.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.34
Sulfate (mg L^{-1})	15	4	0	0	10	5.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	34
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.3
P-8 (Fall Clove above Pepacton Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	1	8	na	na
Chloride (mg L^{-1})	50	12	0	0	10	2.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.33
Sulfate (mg L^{-1})	15	4	0	0	10	5.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	36
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.1

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
PMSB (East Branch Delaware River near Margaretville)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	0	0	na	na
Chloride (mg L^{-1})	50	12	0	0	10	11.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.30
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	8	67	40	58
Dissolved sodium (mg L^{-1})	10	3	0	0	5	6.2
RD1 (Sugarloaf Brook near Lowes Corners)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	11	11	100	na	na
Chloride (mg L^{-1})	50	12	0	0	10	6.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.11
Sulfate (mg L^{-1})	15	4	0	0	10	5.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	31
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.4
RD4 (Sawkill Brook near Yagerville)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	11	92	na	na
Chloride (mg L^{-1})	50	12	0	0	10	6.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.07
Sulfate (mg L^{-1})	15	4	0	0	10	5.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	1	8	40	33
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.8

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
RDOA (Rondout Creek near Lowes Corners)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	12	100	na	na
Chloride (mg L^{-1})	50	12	0	0	10	4.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.10
Sulfate (mg L^{-1})	15	4	0	0	10	4.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	23
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.5
RGB (Chestnut Creek below Grahamsville WWTP)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥10.0	12	9	75	na	na
Chloride (mg L^{-1})	50	12	0	0	10	15.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.26
Sulfate (mg L^{-1})	15	4	0	0	10	6.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	8	67	40	56
Dissolved sodium (mg L^{-1})	10	4	1	25	5	9.7
AMAWALKR (Amawalk Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	1	17	35	98.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.20
Sulfate (mg L^{-1})	25	4	0	0	15	10.5
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	0.04
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	334
Dissolved sodium (mg L^{-1})	20	4	4	100	15	52.6

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	57.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.20
Sulfate (mg L^{-1})	25	4	0	0	15	12.1
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	11	92	150	238
Dissolved sodium (mg L^{-1})	20	4	3	75	15	25.4
BOYDR (Boyd Corners Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	1	8	na	na
Chloride (mg L^{-1})	100	6	0	0	35	37.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.11
Sulfate (mg L^{-1})	25	4	0	0	15	10.6
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	140
Dissolved sodium (mg L^{-1})	20	4	4	100	15	26.1
CROFALLSR (Croton Falls Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	68.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.6
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.21
Sulfate (mg L^{-1})	25	4	0	0	15	9.7
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	225
Dissolved sodium (mg L^{-1})	20	4	4	100	15	35.7

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
CROSS2 (Cross River near Cross River Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	45.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.19
Sulfate (mg L^{-1})	25	4	0	0	15	11.8
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	8	67	150	184
Dissolved sodium (mg L^{-1})	20	4	2	50	15	23.1
CROSSRVR (Cross River Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	37.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.15
Sulfate (mg L^{-1})	25	4	0	0	15	8.5
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	156
Dissolved sodium (mg L^{-1})	20	4	1	25	15	19.6
DIVERT2R (Diverting Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	62.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.28
Sulfate (mg L^{-1})	25	4	0	0	15	13.7
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	245
Dissolved sodium (mg L^{-1})	20	4	4	100	15	32.9

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
EASTBR (East Branch Croton River above East Branch River)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	46.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.14
Sulfate (mg L^{-1})	25	4	0	0	15	12.5
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	13	12	92	150	244
Dissolved sodium (mg L^{-1})	20	4	4	100	15	28.6
GYPSYTRL1 (Gypsy Trail Brook)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	11	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	44.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.09
Sulfate (mg L^{-1})	25	4	1	25	15	31.2
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	5	42	150	190
Dissolved sodium (mg L^{-1})	20	4	2	50	15	35.9
HORSEPD12 (Horse Pound Brook)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	50.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.39
Sulfate (mg L^{-1})	25	4	1	25	15	14.8
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	13	5	38	150	189
Dissolved sodium (mg L^{-1})	20	4	4	100	15	27.3

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
KISCO3 (Kisco River above New Croton Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	1	17	35	113.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.66
Sulfate (mg L^{-1})	25	4	1	25	15	25.0
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	362
Dissolved sodium (mg L^{-1})	20	4	4	100	15	70.9
LONGPD1 (Long Pond outflow above West Branch Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	2	33	35	86.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.20
Sulfate (mg L^{-1})	25	4	0	0	15	13.5
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	13	12	92	150	288
Dissolved sodium (mg L^{-1})	20	4	4	100	15	65.7
MIKE2 (Michael Brook)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	5	83	35	186.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	6	50	0.35	2.60
Sulfate (mg L^{-1})	25	4	1	25	15	25.1
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	13	13	100	150	476
Dissolved sodium (mg L^{-1})	20	4	3	75	15	104.0

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
MUSCOOT10 (Muscoot River above Amawalk Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	3	50	35	138.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	5.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	1	8	0.35	0.80
Sulfate (mg L^{-1})	25	4	1	25	15	16.7
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	0.04
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	423
Dissolved sodium (mg L^{-1})	20	4	4	100	15	86.2
TITICUSR (Titicus Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	43.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.19
Sulfate (mg L^{-1})	25	4	0	0	15	9.6
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	11	92	150	193
Dissolved sodium (mg L^{-1})	20	4	4	100	15	21.4
WESTBR7 (West Branch Croton River above Boyd Corners Reservoir)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	0	0	na	na
Chloride (mg L^{-1})	100	6	0	0	35	34.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.07
Sulfate (mg L^{-1})	25	4	0	0	15	10.2
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	3	25	150	141
Dissolved sodium (mg L^{-1})	20	4	4	100	15	33.4

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks.

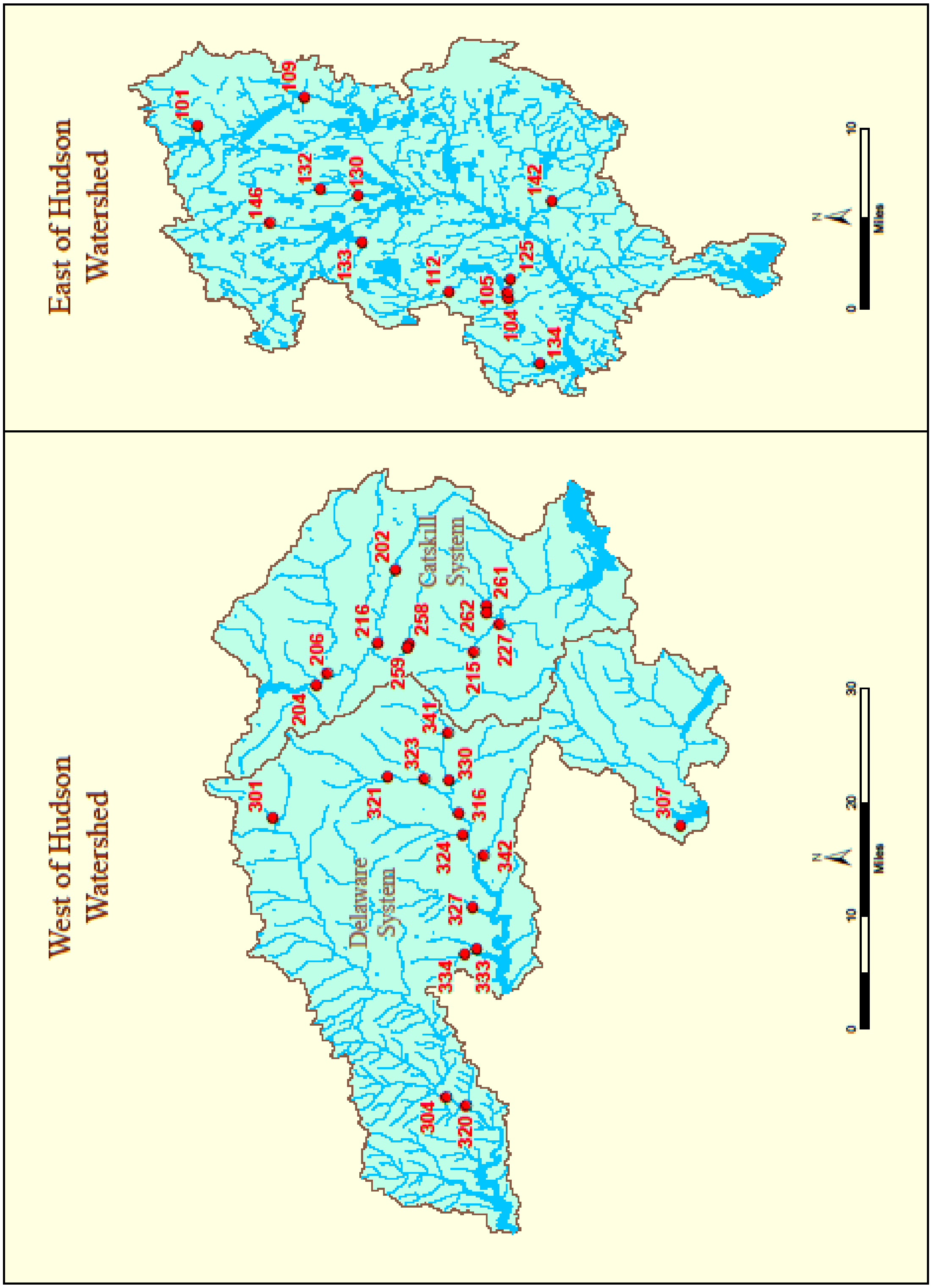
Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2010 mean[1]
WESTBRR (West Branch Reservoir Release)						
Alkalinity (mg $CaCO_3$ L^{-1})	≥40.0	12	1	8	na	na
Chloride (mg L^{-1})	100	6	0	0	35	16.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.16
Sulfate (mg L^{-1})	25	4	0	0	15	5.6
Total ammonia-N (mg L^{-1})	0.20	3	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	63
Dissolved sodium (mg L^{-1})	20	4	0	0	15	11.4

[1]Mean estimated using the Kaplan-Meier method as described in Helsel (2005). In cases where the number of nondetects was greater than 50% of total N, the detection limit (identified as <) is reported in place of the mean.

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

na = not applicable.

Appendix F. Biomonitoring Sampling Sites



Appendix Figure 1. Biomonitoring sampling sites.