New York City Department of Environmental Protection

NYC Environmental Protection

2011 Watershed Water Quality Annual Report

Revised August 2013

Carter H. Strickland Jr., Commissioner,
Paul V. Rush, P.E., Deputy Commissioner

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Acknowledgements

This report provides a summary of the scientific work conducted in 2011 to manage the water quality of the NYC water supply and to provide information for regulatory agencies and the general public. Commissioner of the Department of Environmental Protection, Mr. Carter H. Strickland, Jr., and Deputy Commissioner of the Bureau of Water Supply, Mr. Paul Rush, P.E., provided guidance throughout 2011, with emphasis on operational excellence and compliance. Director of the Water Quality Directorate (WQD), Mr. Steven Schindler, continued to provide oversight and direction for the many activities of the Directorate. Chief of Watershed Water Quality Operations, Ms. Lori Emery, provided oversight of the watershed field and lab operations, quality assurance, and environmental health and safety. Watershed Water Quality Operations staff were responsible for providing the water quality monitoring and the database used to produce this report.

Chief of Watershed Water Quality Science and Research (WWQSR), Dr. Lorraine Janus, provided oversight, planning, and content for the production of this report, including lead responsibility for Chapters 1 and 6. Mr Andrew Bader and Mr. Charles Cutietta-Olson provided the description of operations in Chapter 1. Mr. James Mayfield, Section Chief of Program Evaluation and Planning was responsible as lead author for Chapter 2 on Water Quantity. Mr. Alec Fu, Strategic Services, was most helpful in providing rainfall and operations data for Chapter 2. The lead authors of Chapter 3 were Mr. Gerry Marzec and Mr. Rich VanDreason. Mr. Martin Rosenfeld was the program manager and author of the biomonitoring research described in Chapter 3. Mr. Chris Nadareski was program manager and author of the sections on the Waterfowl Management Program in Chapter 3 and 6. Ms. Kerri Alderisio, Section Chief of Pathogen Planning and Assessment, was responsible for the direction of programs and was lead author for Chapter 4 on Pathogens, aided by Mr. Christian Pace. Dr. Don Pierson, Section Chief of Watershed Modeling, Dr. Elliot Schneiderman, and Mr. Mark Zion were the primary authors of Chapter 5 on Modeling, which describes ongoing model development and applications. Ms. Sharon Neuman, program manager for the zebra mussel monitoring contract, provided the information on that and other contracts listed in Chapter 6.

Ms. Pat Girard, Supervisor of Reporting and Publications, was responsible for desktop publishing of the report, aided by Mr. Martin Rosenfeld, who applied his editing and proofreading skills to finalize the document in a polished form. Other support was provided by Mr. David Quentin, Mr. Ray Homolac, Mr. Donald Kent, Mr. David Lounsbury, Ms.Kelly Seelbach, Dr. Adao Matonse, Dr. Anandhi Aavudai, Dr. Rajith Mukundan, and Dr. Soni Pradhanang.

The production of this report required the scientific expertise and cooperation of many staff members in WQD. All deserve special recognition and thanks for their willing participation in the many facets of the Directorate's work. This report would not exist without the extensive field work, laboratory analysis, scientific interpretation, and administrative work needed to keep the watershed programs of the Directorate operating. Therefore, thanks are due to all field and laboratory staff who collected and analyzed the thousands of samples required for the watershed monitoring programs; the administrative, computing, health and safety, and quality assurance staff who support them; and the scientific staff responsible for planning, interpreting, and documenting the results of our collective work. Although we could not name everyone, thanks go to all those who contributed to this report.

Executive Summary

Hydrology of the Water Supply

The NYC Water Supply System is dependent on precipitation and subsequent runoff to supply the reservoirs in each of the three watersheds, Catskill, Delaware, and Croton. Overall, the total precipitation in the watershed for 2011 was 1,600 mm (63.0 inches), which was 449 mm (17.7 inches) above normal. It was a very wet spring with a large rainfall/snowmelt event in early March. Two tropical storms (Irene and Lee) struck the watershed with great impact in August and September, respectively, as is seen throughout this report. Overall, it was the wettest year on record in New York since 1895. With the record precipitation, the 2011 annual runoff was also well above the normal historical values, with Tropical Storm Irene leading to many new maximum discharge values. The United States Geological Survey reported that the 2011 water year (Oct. 1, 2010-Sept. 30, 2011) had the highest overall average runoff for New York State over the last 111 years. While systemwide usable storage levels in the reservoir system began the year slightly below average, the events in early March increased capacity well above normal, where it stayed for the remainder of the year, peaking with the tropical storms in late summer.

Water Quality Highlights

In 2011, watershed water quality was assessed using data collected at keypoint, reservoir, and stream sites. Despite flooding associated with spring snowmelt and then with Tropical Storms Irene and Lee in late summer, keypoint data demonstrated that NYC source waters remained compliant with Surface Water Treatment Rule (USEPA 1989) limits for fecal coliform and turbidity.

Most of the Catskill/Delaware System reservoirs were impacted by the flooding events. As a result, turbidity, total phosphorus, and fecal and total coliforms were all elevated compared to historical levels. Flooding impacts were less discernible in Cannonsville and in the Croton System, where reservoirs were generally within historical limits. For source waters, coliform-restricted calculations indicated that Ashokan and West Branch were "restricted" with respect to fecal coliforms. For non-terminal reservoirs, total coliforms exceeded the assessment standards for at least one month in 11 of 17 reservoirs. The phosphorus-restricted calculations indicated that eight basins associated with the Catskill/Delaware System (including West Branch and Kensico) and one basin in the Croton System (Boyd Corners) were non-restricted in 2011. Restricted basins included the West Basin of Ashokan and 12 of 13 Croton System reservoirs. Trophic status results based on chlorophyll *a* revealed large decreases in most Catskill/Delaware reservoirs and mostly increases in the Croton reservoirs. Decreases were associated with reduced clarity from turbidity-producing flood events, and in some cases from decreases in dissolved nutrients. Increases in trophic status were associated with warm water temperatures and increases in total phosphorus.

Stream sample data were evaluated for turbidity, total phosphorus, and fecal coliform. Turbidity medians for the major inflowing streams of the Delaware and Croton basins were near normal in 2011. Catskill inflows, however, were greatly impacted by Tropical Storms Irene and

Lee, with turbidity levels at or above their highest point since 2001. Similar patterns were observed for total phosphorus, with the exception that the Neversink inflow was also elevated in 2011. Fecal coliform results were mixed in 2011. Increases were apparent at the Cannonsville, Amawalk, Boyd Corners, and Croton inflows, while decreased counts occurred at Schoharie, East Branch, and Cross River. All other inflows were within historical limits. In a comparison to stream benchmarks, excursions were observed at varying frequencies for alkalinity, sodium, chloride, total dissolved solids, sulfate, and nitrate. Stream biomonitoring results showed that 14 of 23 sites monitored in the Catskill and Delaware Systems were non-impaired, while only 2 of 13 Croton sites attained non-impaired status. At most sites, the impact from Tropical Storms Irene and Lee was evidenced by markedly lower taxa counts than those observed in previous years, although in most cases those low counts did not translate into lower assessments.

A three-year study to determine the impact of recreational boating on Cannonsville Reservoir ended in October 2011. Long-term negative effects were not observed on any of the monitored analytes.

Pathogen Monitoring and Research

DEP collected 642 samples for protozoan analysis and 277 samples for human enteric virus (HEV) monitoring in 2011. Most samples were collected at keypoint locations and watershed streams, with additional samples collected at upstate reservoir releases, wastewater treatment plants (WWTPs), and at Hillview Reservoir. *Giardia* cysts continued to be detected at a higher frequency and concentration than *Cryptosporidium* in the watershed, and the highest concentrations continued to occur in the colder months of the year. From January 1, 2010 through December 31, 2011, DEP source water continued to be well below the LT2 threshold for additional treatment at unfiltered water supplies (0.010 oocysts L^{-1}), with means of 0.0010 oocysts L^{-1} and 0.0004 oocysts L^{-1} at the Catskill and Delaware effluent sites, respectively, and 0.0012 at the New Croton Reservoir effluent. Overall, protozoan concentrations were lower leaving the upstate reservoirs and Kensico Reservoir, compared to the levels at the stream sites that feed those reservoirs, suggesting a reduction as water passes through the system. However, the Catskill Aqueduct leaving Kensico Reservoir did have more detections of *Giardia* than those at either aqueduct influent site. While there were a few detections of *Giardia* cysts at WWTPs, and one HEV detection, there were no *Cryptosporidium* oocysts detected at plants in 2011. As per the Hillview Administrative Order, DEP resumed weekly protozoan monitoring at the Hillview Reservoir outflow (Site 3) in August 2011. Twenty-two samples were collected, with four detections of *Giardia* and no detections of *Cryptosporidium*.

Watershed and Water Quality Modeling

DEP uses models to examine how changes in land use, population density, ecosystem processes and climate, as well as both watershed and reservoir management policies, affect the NYC Water Supply. The DEP modeling system consists of a series of linked watershed, reservoir, and water system models that simulate the sources and transport of water and dissolved and suspended materials within the watersheds and reservoirs of the water supply system. Modeling is used to support operational decisions, evaluate watershed management programs, and to further understand potential impacts of climate change on the water supply system.

Reservoir and water system models are used for operational decision support during periods of elevated turbidity in the Catskill System, to inform aqueduct flow decisions, and to ensure that water quality standards are met while minimizing the use of alum. During 2011, there were three periods of elevated turbidity in the Catskill System. In response to these turbidity events, 17 sets of model analyses were performed to minimize alum use and help ensure high water quality at the effluent points of Kensico Reservoir.

The effects of nonpoint 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 and reported in the 2011 Watershed Protection Program Summary and Assessment. The analysis showed that significant declines in phosphorus loadings and chlorophyll levels, particularly in Cannonsville Reservoir from the 1990s thru the 2000s, were attributable to a combination of point source reductions by wastewater treatment plant upgrades, nonpoint source reductions by application of best management practices (BMPs) (particularly agricultural BMPs), and naturally-occurring reductions in agricultural land use. Work continues on upgrading modeling capabilities for continued watershed-scale analysis of the effects of agricultural BMPs, improved analysis of turbidity in the Catskill System watersheds, and development of a forest ecosystem watershed modeling application.

DEP is also using its suite of simulation models to investigate the effects of climate change on the NYC Water Supply as part of the Climate Change Integrated Modeling Project (CCIMP). The report on Phase I of the project was completed. The major finding of this preliminary work was a shift in winter streamflow timing, with more flow occurring during the midwinter period and slightly reduced flow during the traditional early spring snowmelt period. Phase II of the project, now under way, first focused on improved downscaling methods to produce climate change predictions that are used as input to DEP's watershed, reservoir, and system models. During 2011 DEP began to evaluate the differences between this and previously used downscaling methods. The latest climate scenarios, using the new downscaling method, were applied using the GWLF hydrologic model to develop simulated flows which were, in turn, used to drive the OASIS system model. This work was carried out as part of Water Research Foundation project 4262, "Vulnerability Assessment and Risk Management Tools for Climate Change." A second set of CCIMP Phase II simulations involved simulating the impacts of climate change on the trophic status of Cannonsville Reservoir, with results suggesting a modest increase in future reservoir chlorophyll levels and an earlier timing of the spring phytoplankton peak. DEP's efforts to evaluate the potential impacts of climate change on the water supply are being documented in a case study being conducted by the Water Utility Climate Alliance (WUCA) project, of which DEP was a participating utility during 2011.

Scientific Contracts and Collaboration

Contracts with external partners and participation in projects with other organizations, such as the Water Research Foundation, greatly extend scientific manpower and broaden thinking about water quality issues. DEP gains insight and assistance in problem solving by participating in scientific collaborations. In 2011, DEP managed eight water quality-related contracts (listed below) to extend its capabilities:

- Virus analysis
- Laboratory analytical support
- Water quality operation and maintenance and assessment for the hydrological monitoring network
- Turbidity and suspended sediment monitoring in the upper Esopus Creek watershed, Ulster County, NY
- Robotic monitoring of selected New York City reservoirs and major tributaries
- CUNY postdoctoral support, resulting in six publications
- Waterfowl Management Program
- Zebra mussel monitoring

In addition to this, DEP staff participated in eight Water Research Foundation projects:

- WRF # 4179: Selecting and Standardizing the Most Appropriate Tool for Regulatory *Cryptosporidium* Genotyping.
- WRF # 4239: Climate Change Impacts on the Regulatory Landscape
- WRF # 4262: Vulnerability Assessment and Risk Management Tools for Climate Change: Assessing Potential Impacts and Identifying Adaptation Options
- WRF # 4263: Analysis of Changes in Water Use under Regional Climate Change Scenarios
- WRF # 4264 Changing Mindsets to Promote Design of "Sustainable Water Infrastructure" under Climate Change
- WRF # 4324 Water Quality Impacts of Extreme Weather Events
- WRF # 4348 Matrix Effects on Cryptosporidium Recovery in the Bull Run Watershed
- WRF # 4382: Impacts of Algal Blooms on the Ecology of Algae

Participating in these activities is an important way for DEP scientists to stay informed of the latest science for the benefit and protection of the water supply.

Errata Sheet issued November 1, 2012

1) In Table 3.3, replace “Restricted” with “Indeterminate” for West Branch Reservoir. The fecal coliform source was not definitively anthropogenic.

2) In section 3.6 add the following bullet:

•In August and September 2011, Ashokan Reservoir was impacted by severe flooding, as a result of Tropical Storms Irene and Lee, respectively. These storms brought in large amounts of suspended material that resulted in higher total phosphorus concentrations than normal. Prior assessments were also impacted by the snowmelt and runoff in April of 2005. Since these events are unpredictable and did not result in eutrophication of the reservoir, the Department is utilizing its best professional judgment and is not designating the Ashokan Reservoir West Basin as phosphorus restricted at this time.

3) In section 3.6, replace the second to last bullet with:

•Source water reservoirs were held to the new limit of 15 $\mu g\ L^{-1}$, which placed three reservoirs into the phosphorus-restricted category: Cross River, Croton Falls, and New Croton Reservoirs.

4) In section 3.7 add this sentence to the last bullet:

•Ashokan West Basin was exempt from restricted status as noted above.

5) In Table 3.6, change “Restricted” to “Non-restricted” for Cannonsville (transcription error) and Ashokan-West (for reason described in #2 above).

6) In Appendix C, change the second to last sentence in the first paragraph (the stormwater plans were not included in the revised regulations promulgated in 2010):

“The phosphorus-restricted designation prohibits new or expanded wastewater treatment plants with surface discharges in the reservoir basin.”

7) In Appendix Table 2, change the geometric mean in 2011 for Ashokan West Basin Reservoir to 30.7 $\mu g\ L^{-1}$, and Ashokan East Basin Reservoir to 13.5 $\mu g\ L^{-1}$ (transcription error).

Errata Sheet issued August 21, 2013

Figures 2.7, 2.8, and 2.9 in Section 2.4 should be replaced with the figures below in order to conform to the DEC Stormwater Management Design Manual.

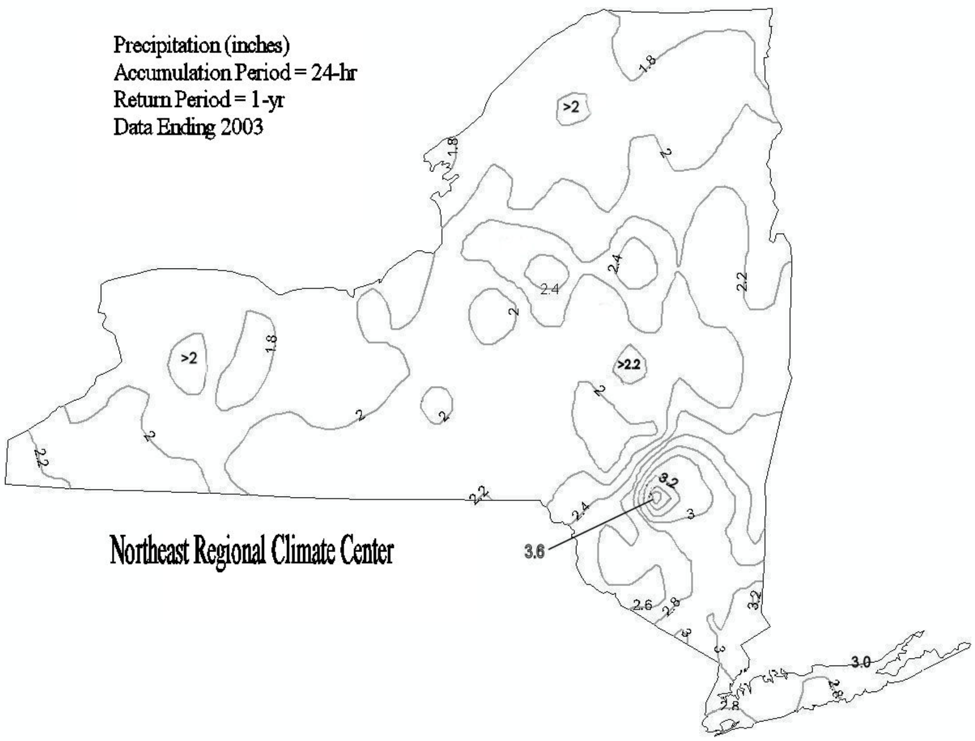

Figure 2.7. The 1-year, 24-hour storm for New York State from the 2010 Stormwater Management Design Manual (NYSDEC 2010).

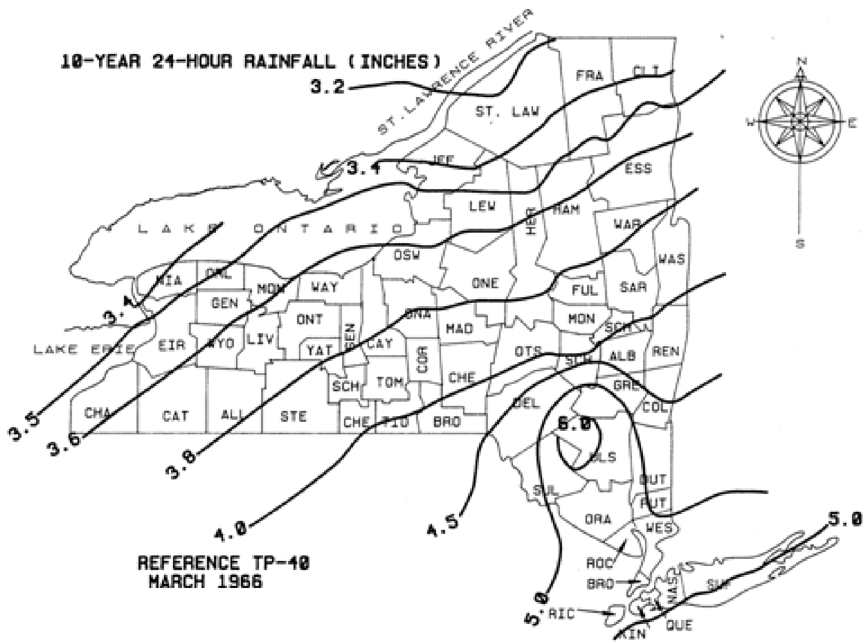

Figure 2.8 The 10-year, 24-hour storm for New York State from the 2010 Stormwater Management Design Manual (NYSDEC 2010).

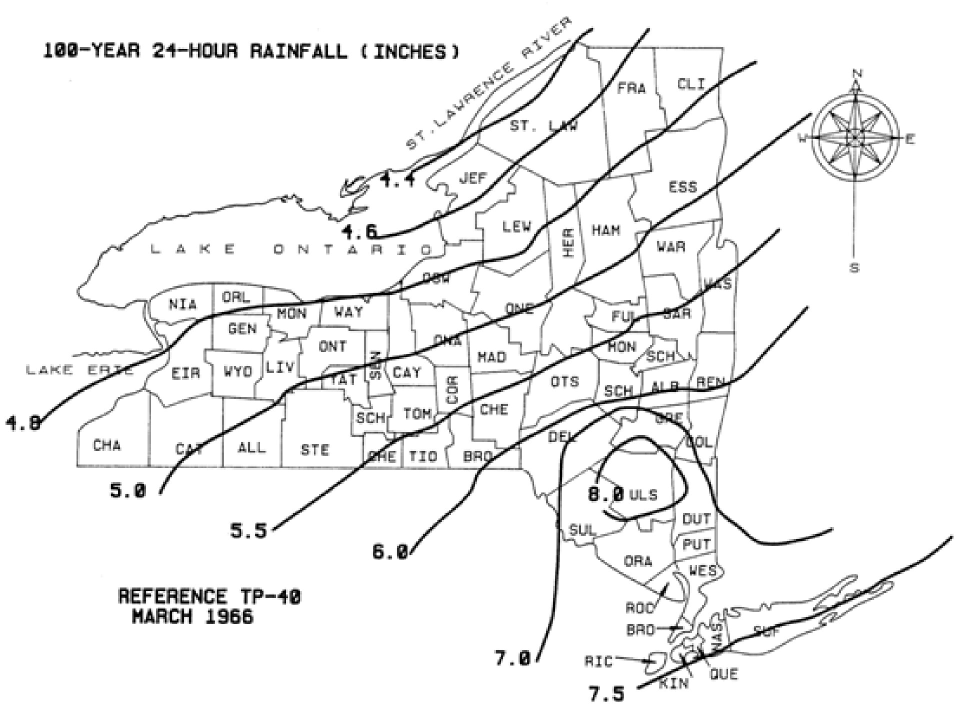

Figure 2.9 The 100-year, 24-hour storm for New York State from the 2010 Stormwater Management Design Manual (NYSDEC 2010).

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 2011, 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/.

Figure 1.1 The New York City Water Supply System.

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 8 million people in New York City and 1 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 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 2011 by the four upstate laboratories, and the number of sites that were sampled, is provided in Table 1.1. The sampling effort for the distribution system is also listed for completeness; however, those monitoring results are presented elsewhere, as noted earlier.

Table 1.1: Water quality sampling summary for 2011.

System/Laboratory	Number of samples	Number of analyses	Number of sites
Catskill/Kingston	4,015	73,045	117
Delaware/Grahamsville	4,042	56,979	132
EOH/Kensico	12,915	116,459	170
EOH/Brewster	1,200	10,547	64
Watershed	22,172	257,030	483
Distribution	33,000	357,000	1,000
Total	55,172	614,030	1,483

1.2 Operations in 2011 to Control Fecal Coliforms and Turbidity

Watershed Water Quality Operations conduct extensive water quality monitoring at multiple sampling sites from aqueducts, reservoirs, and streams within the Croton, Catskill, and Delaware Systems to support System Operations. In 2011, nearly 260,000 physical, chemical, and microbiological analyses were performed on approximately 22,000 samples that were collected from hundreds of watershed sampling locations. The Water Quality Directorate also continued to operate and maintain continuous monitoring instrumentation at critical locations to provide real-time water quality data to support operational decision making. Water Quality managers review data from the aqueduct and limnology programs on a continuous basis, and work cooperatively with the Bureau of Water Supply's Operations Directorate to determine the best operational strategy for delivering the highest quality water to City consumers.

The year 2011 was an historic one for DEP in terms of water quality management. In response to unprecedented storm events, including Tropical Storms Irene and Lee, DEP implemented enhanced water quality monitoring and numerous operational and treatment techniques to effectively manage the City's water supply, specifically, to reduce higher than normal fecal coliform counts and turbidity levels caused by these storms. Examples of specific operational and treatment strategies employed for this purpose in 2011 include: alum treatments, selective diversion, releases from reservoirs to streams, and selective withdrawal, as described below.

Treatment Operations

There were three separate alum treatment events and one disinfection event in 2011.

Turbidity in the Catskill System resulting from two large runoff events in October and December 2010 ultimately required alum treatment of the Catskill System again early in 2011. Alum treatment occurred for 11 days from January 31 to February 11. Alum treatment was initiated again on March 2 and continued until May 20 to further restore water quality in Kensico Reservoir. On August 28, the entire water supply system was impacted by flooding from Tropical Storm Irene, inundating Ashokan Reservoir with highly turbid water. To prevent this turbid water from impacting Kensico Reservoir, alum treatment of the Catskill supply began on August 29. On September 7, 10 days after the flooding from Tropical Storm Irene, the watershed was impacted by a second flooding event caused by Tropical Storm Lee. Alum treatment resulting from the tropical storms continued into 2012.

Kensico Reservoir also experienced unusually high fecal coliform counts following these two tropical storms. To reduce fecal coliform loads entering Kensico Reservoir, for the protection of public health and to ensure compliance with the Surface Water Treatment Rule (USEPA 1989), DEP initiated chlorine treatment of the Delaware Aqueduct at Shaft 10 on September 9. This chlorine treatment event lasted until October 18.

Each of these four treatment events, including their associated enhanced monitoring, is documented in after action reports. These reports are submitted as part of Filtration Avoidance Determination Section 5.1 (USEPA 2007).

Selective Diversion

In addition to the treatment operations described above, both aqueducts, as well as several West of Hudson (WOH) reservoirs, were subjected to selective diversion as a result of Tropical Storms Irene and Lee. The Catskill Aqueduct leaving Kensico Reservoir was shut down on the evening of August 28 until the morning of August 29 when turbidity from the Kensico watershed impacted the Catskill effluent leaving Kensico. In addition, the Catskill Aqueduct leaving Kensico was shut down on September 9 and 12 to minimize the delivery of Kensico Reservoir water containing elevated fecal coliform counts.

From September 3 to September 5, the Delaware Aqueduct was placed on bypass mode at Shaft 18 because Kensico Reservoir was continuing to experience elevated fecal coliform counts as a result of Tropical Storm Irene.

Selective diversion was also routinely implemented at the WOH reservoirs to ensure the delivery of the best quality water to Kensico. Neversink Reservoir was taken off-line on August 25 to prevent anticipated elevated turbidity from Tropical Storms Irene and Lee from entering Rondout Reservoir. After turbidity levels had declined and the reservoir had been monitored for other contaminants, the diversion was brought back on-line on October 27.

At Ashokan Reservoir, the dividing weir separates the West and East Basins. Since water quality was satisfactory in the West Basin, the dividing weir had been open prior to Tropical Storm Irene, allowing water to move from West to East. However, immediately following the storm, the weir was closed to prevent turbid water from moving from the West Basin to the East Basin. This strategy temporarily delayed the need for alum treatment by capturing turbid water in the West Basin.

Release Operations

DEP also utilized the Ashokan Release Channel for turbidity and flood control in 2011. As the elevation of the West Basin is drawn down by releasing water, the capacity to absorb additional storm event water volume increases; the drawdown also provides enhanced protection from uncontrolled spillage of turbid waters over the top of the dividing weir into the East basin. During the tropical storms, the West Basin was able to hold large volumes of flood water due to prior releases, thus mitigating downstream flooding and reducing the amount of turbid water in the water supply.

Selective Withdrawal

Drawing water from different elevations within reservoirs was also used in 2011 to control turbidity. For example, in Pepacton Reservoir turbidity levels were lower in the bottom depths of the reservoir immediately following the tropical storms, so by moving the elevation of withdrawal to the bottom intake window, DEP ensured the delivery of the best quality water from Pepacton to Rondout. By November, the surface waters in Pepacton had the best quality water, so DEP moved the elevation of the intake window to the upper level to ensure ongoing delivery of the best quality water.

2. Water Quantity

2.1 The Source of New York City's Drinking Water

Figure 2.1 Spruceton Falls on the West Kill, which delivers water to Schoharie Creek, the main input to Schoharie Reservoir in the Catskill System.

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 (Figure 2.1). The water is then moved via a series of aqueducts to terminal reservoirs before it 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.

2.2 2011 Watershed Precipitation

The average precipitation for each watershed was determined from daily readings collected from a network of precipitation gauges located in or near each watershed. The total monthly precipitation is the sum of the daily average precipitation values calculated for each reservoir watershed. The 2011 monthly precipitation total for each watershed is plotted along with the historical monthly average in Figure 2.2.

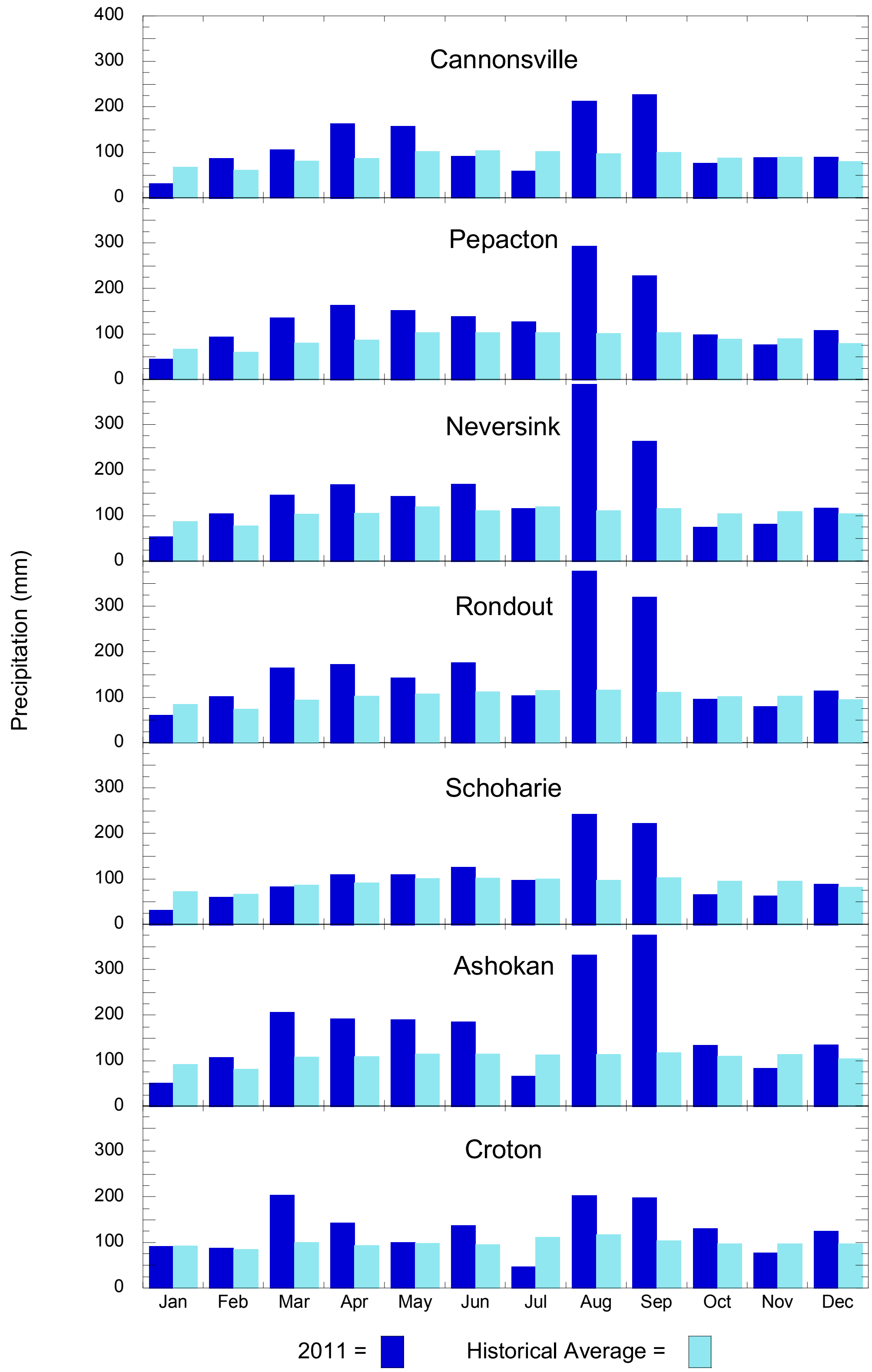

Figure 2.2 Monthly rainfall totals for NYC watersheds, 2011 and historical values.

The total monthly precipitation figures show that in general precipitation was below normal for January in all watersheds except Croton, which was near normal, whereas February's precipitation was slightly above normal in all watersheds except Schoharie and Croton, which were about normal. March and April had above average precipitation except for the Schoharie watershed, which was again about average. May and June also had above average precipitation, except for the Croton watershed in May, which was about normal, and the Cannonsville watershed in June, which was slightly less than normal. July had mixed results, ranging from below average in Cannonsville, Rondout, and Ashokan, to near normal in Neversink and Schoharie, and somewhat above average in Pepacton. August and September had very high precipitation totals in all watersheds. These results will be discussed in more detail below. The remainder of the year had mixed results, but without extremes. Overall, the total precipitation in the watershed for 2011 was 1,600 mm (63.0 inches), which was 449 mm (17.7 inches) above normal.

The National Climatic Data Center's (NCDC) 2011 Annual Climate Summary (http://www.ncdc.noaa.gov/sotc/national/2011/13) reported that the 2011 spring period (March-May) was the wettest on record (1895-2011) for New York, and that the summer period (June-August) was the eighth wettest. Spring and summer were also warmer than normal, and the fall (September-November) was much warmer than normal. (It was the fourth warmest fall period on record.) Overall for New York, it was the wettest year on record and the eighth warmest since 1895.

As mentioned above, precipitation totals for August and September 2011 were very high throughout the watersheds. This was due to two very significant events, Tropical Storms Irene and Lee. These storms greatly impacted the NYC Watershed, as will be seen throughout this report.

Figure 2.3 Tropical Storm Irene at Margaretville.

Hurricane Irene weakened to a tropical storm as its center of circulation moved over New York City on August 28, 2011, but still brought torrential rains to the area and caused record flooding and catastrophic damage throughout the Catskill/Delaware watershed (Figure 2.3). National Weather Service reports indicated that the storm produced over 11 inches of rain at Slide Mountain in Ulster County, and 13.3 inches in East Jewett in the Schoharie watershed. Radar based NEXRAD precipitation predictions by the National Oceanic and Atmospheric Administration (NOAA) indicated that areas of the Schoharie watershed near Windham might have received up to 16.5 inches of rainfall from this event. NCDC has confirmed the 24-hour rainfall total of 11.6 inches at Tannersville during Tropical

Storm Irene as the new New York State 24-hour record rainfall (http://www.ncdc.noaa.gov/extremes/scec/getextreme.php?forwhat=st&elem=ALL&state=NY). As mentioned, there were reports of higher amounts, but those were not verifiable according to the criteria established by NCDC. Many locations in the Catskill Mountains received up to 10 inches of rain in a 12-hour period, causing record runoff and flash flooding. As discussed in the next section, many United States Geological Survey (USGS) stream gauges in the Catskill/Delaware watersheds recorded new maximum discharges during this historic event. The flooding caused catastrophic damage to watershed communities, washing out many roads and bridges, damaging many homes, and causing widespread power outages. Damage was so severe throughout watershed counties that the Federal Emergency Management Agency declared a major disaster on August 31, 2011 (FEMA-DR-4020) and began providing assistance to flood victims and communities.

On September 7, 2011, only 10 days after the catastrophic flooding from Tropical Storm Irene, the watershed received a second flooding event caused by Tropical Storm Lee. This storm produced rainfall totals of 4 to 9 inches in the region. Runoff from Lee again caused many watershed streams to exceed flood stage. Tropical Storm Lee was not as large an event as Tropical Storm Irene, but the ground was still saturated and the Catskill/Delaware reservoirs had not recovered from the impacts of the prior storm, so they were unable to attenuate runoff from this second significant rain event. The runoff from Tropical Storm Lee exacerbated the already poor water quality conditions in both Ashokan and Rondout Reservoirs.

Figure 2.4 portrays total rainfall from August 26 to September 9, 2011, as estimated by the National Weather Service's River Forecast Centers using a combination of radar, rain gauges and satellite rainfall estimates. Some areas of the watershed are shown receiving 16 to over 24 inches of rain during this time. The flooding runoff from these two events degraded the water quality in all Catskill and Delaware System reservoirs. The rainfall and runoff from these storms also impacted the EOH reservoir watersheds, including West Branch and Kensico Reservoirs.

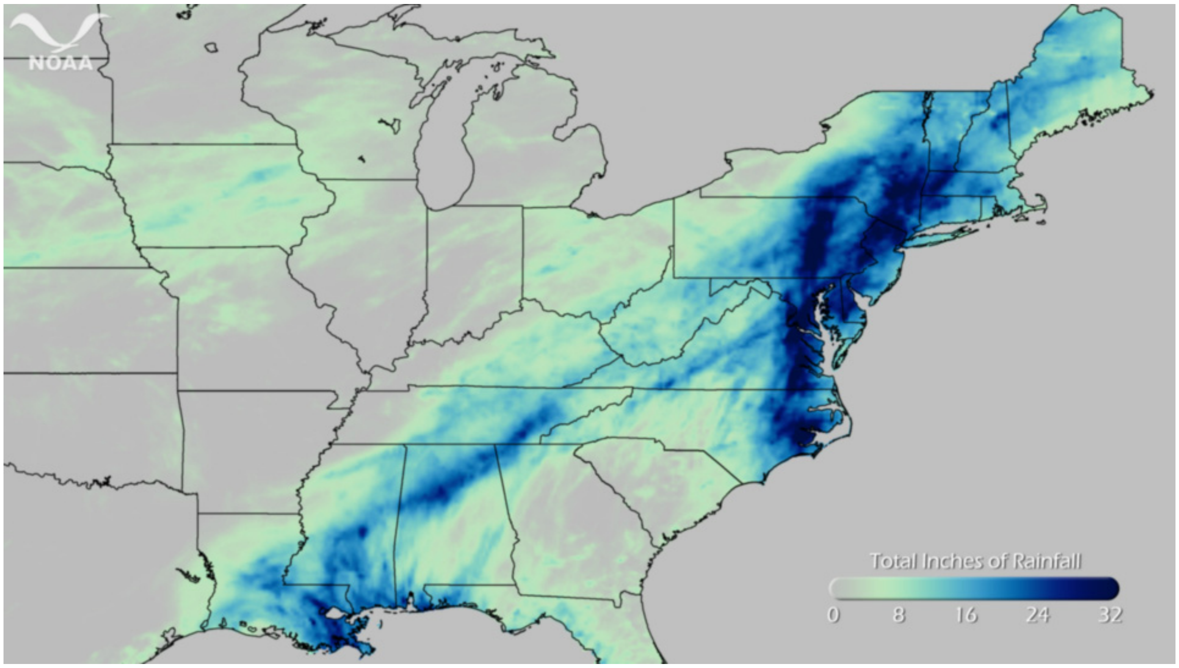

Figure 2.4 Total rainfall from August 26-September 9, 2001, as estimated by the National Weather Service's River Forecast Centers using a combination of radar, rain gauges, and satellite rainfall data. Figure is from the NOAA Environmental Visualization Lab (http://www.nnvl.noaa.gov/MediaDetail.php?MediaID=835&MediaTypeID=1).

2.3 2011 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 (rain, snow, 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 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.

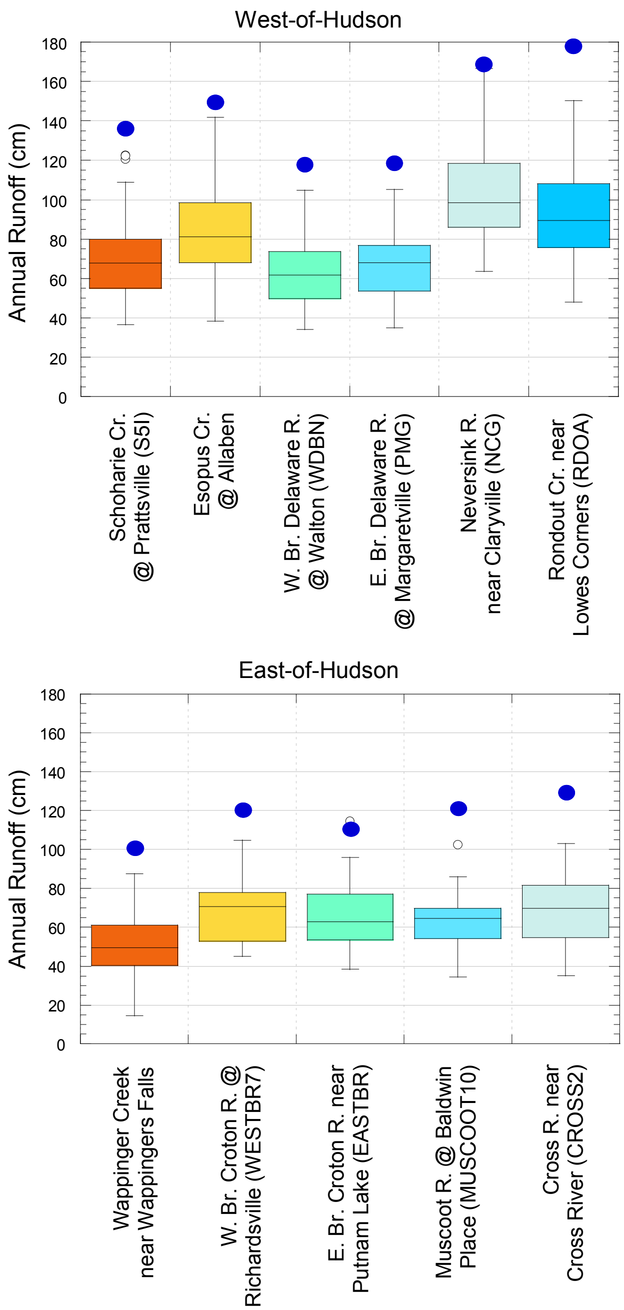

Figure 2.5 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds, with the values for 2011 displayed as a dot.

Selected USGS stations were used to characterize annual runoff in the different NYC watersheds (Figure 3.9). As discussed in the previous section, 2011 was the wettest year on record for New York, and the annual runoff reflects this. The annual runoff value for all but one of the WOH sites was the maximum value recorded over the sites' periods of record. The exception was the East Branch of the Delaware River, whose runoff value in 2011 was second to the value recorded in 1996. In the EOH watersheds, the 2011 annual runoff was also the maximum recorded value at all but one site, the exception being the East Branch of the Croton River, whose value, like the East Branch Delaware's, was second to the annual runoff in 1996 (Figure 2.5). The EOH stations have a 16-year period of record, except for the Wappinger Creek site (83-year period of record). The period of record for the WOH stations, by contrast, ranges from 48 years at the Esopus Creek Allaben station to 105 years at the Schoharie Creek Prattsville gauge. The 2011 water year (Oct. 1, 2010-Sept. 30, 2011) had the highest overall average runoff computed for New York State by the USGS over the last 111 years (http://waterwatch.usgs.gov/index.php?r=ny&id=statesum).

Tropical Storm Irene led to many new maximum daily discharge records. Figure 2.6 shows the 2011 mean daily, minimum, and maximum discharge along with the median daily discharge for the same USGS stations that were used to characterize annual runoff. Six of these stations were WOH reservoir inflows, and of these, five established new mean daily maximum discharges on August 28, the date of the storm. (Only the West Branch of the Delaware River at Walton did not.) In all, 23 of 40 WOH USGS stations established new mean maximum discharges on that date, as did the Titicus River in the EOH System. In addition to the record maxima, precipitation from the tropical storms produced the highest observed average mean daily discharge for August and September over the period of record for the USGS stations displayed in Figure 2.6. (For the West Branch of the Delaware River and Wappinger Creek, the record discharge occurred only in the month of September.) The USGS is preparing a report on the flooding in New York State as a result of Tropical Storms Irene and Lee.

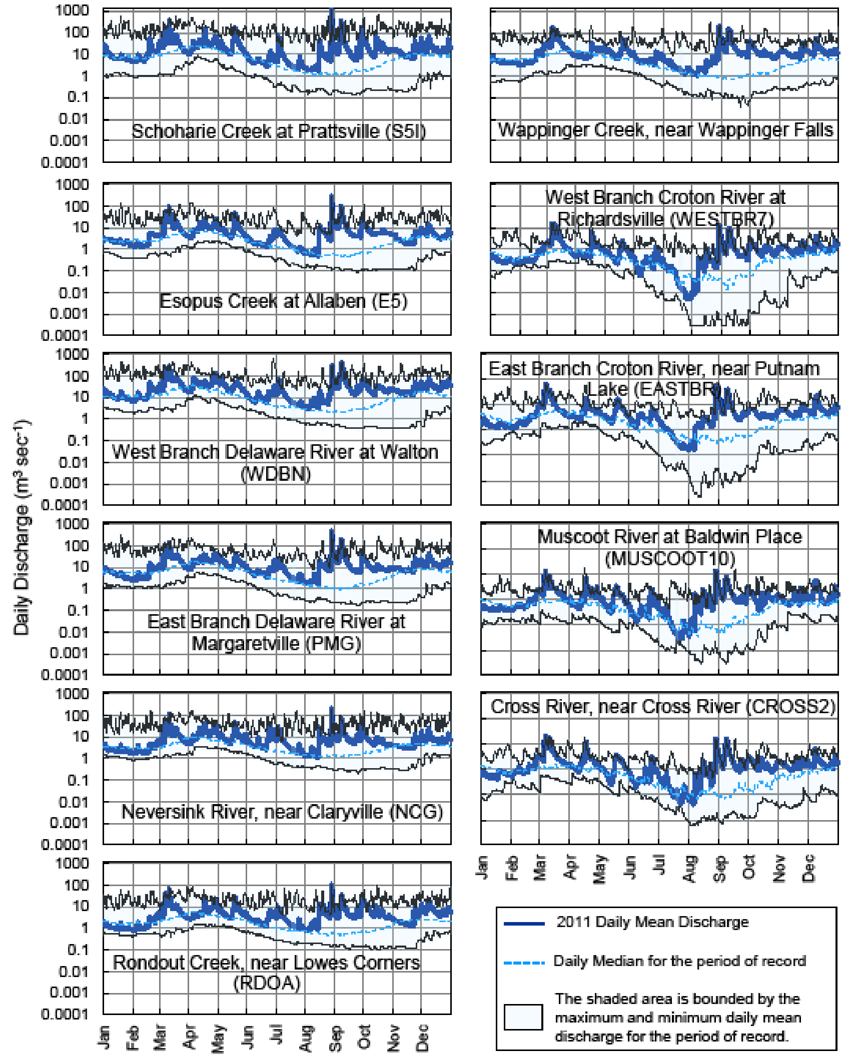

Figure 2.6 Daily mean discharge for 2011 at selected USGS stations. The daily median along with the minimum and maximum daily mean for the period of record for each station is also displayed.

Other high discharge values in 2011 were unconnected to the tropical storms. As previously noted, 2011 had the wettest spring on record, resulting in record runoff. This is reflected in the average mean daily flows for March for the EOH USGS and Rondout Creek stations displayed in Figure 2.6, which were the highest observed for the period of record. March rainfall/snowmelt also led to new daily maximum values for the Titicus River and the East Branch of the Croton River.

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 (WR&R) (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 (SWPPPs) are submitted, as well as applications for Individual Residential Stormwater Permits and Stream Crossing, Piping and Diversion Permits. Residential-, commercial-, institutional-, and transportation-related activities are among the land uses requiring DEP review under this section.

The SWPPPs 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 to size stormwater management practices and gauge a variety of runoff conditions and predict downstream impacts. These records 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 (see Figures 2.7 through 2.10). 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 2.7 through 2.10 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 SWPPP in accordance with the WR&R, 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/swdm2011chptr4.pdf.

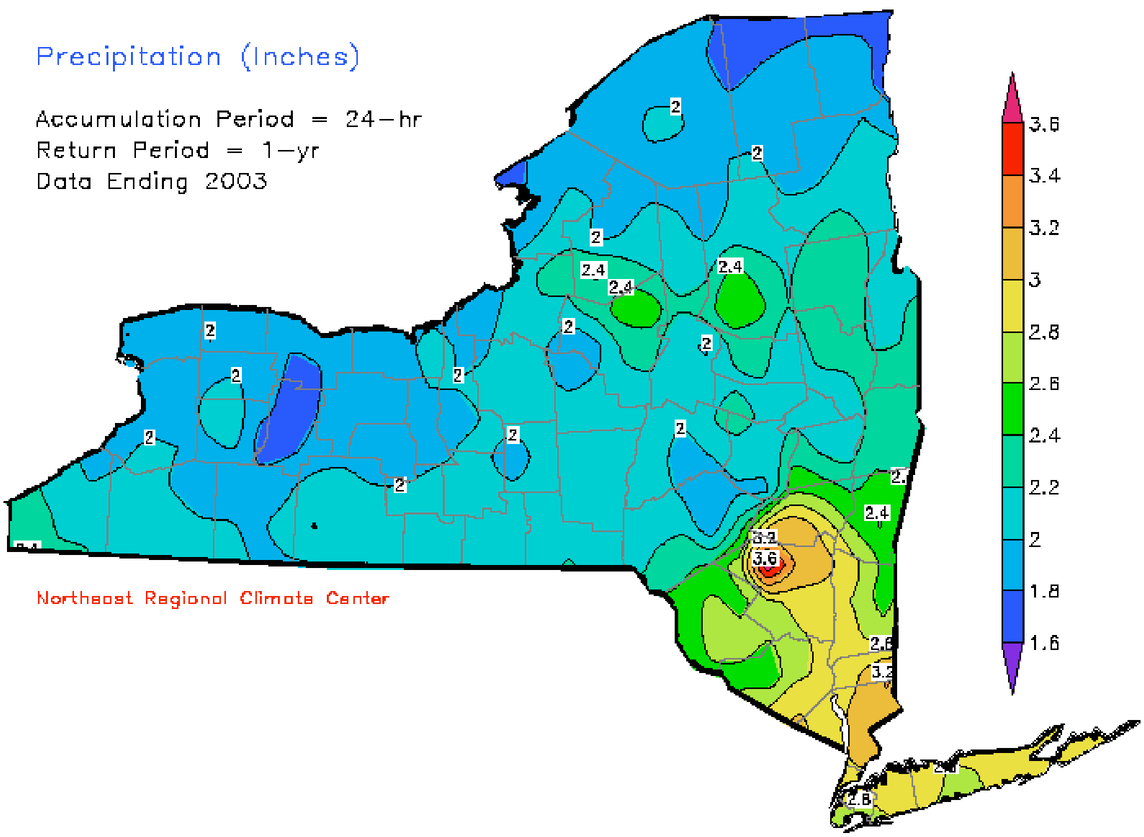

Figure 2.7 The 1-year, 24-hour storm for New York State as determined by the Northeast Regional Climate Center (http://www.nrcc.cornell.edu/pptext/isomaps.html).

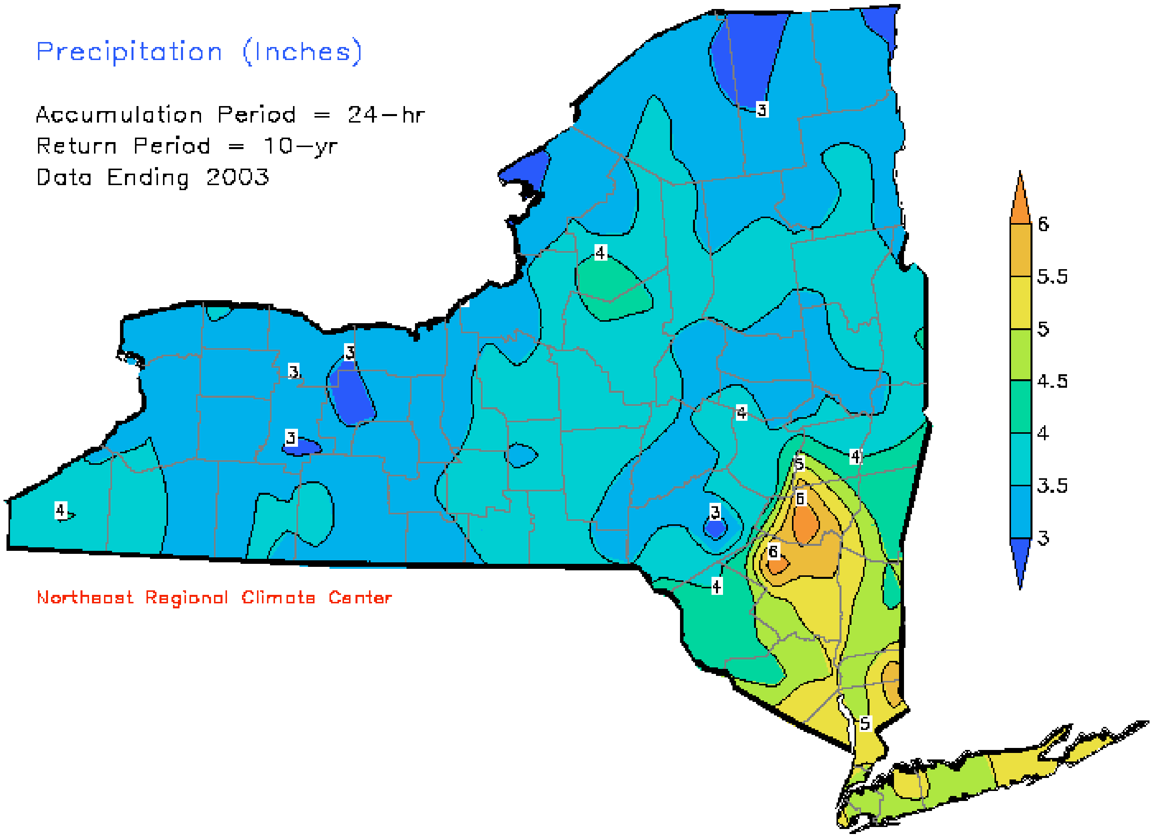

Figure 2.8 The 10-year, 24-hour storm for New York State as determined by the Northeast Regional Climate Center (http://www.nrcc.cornell.edu/pptext/isomaps.html).

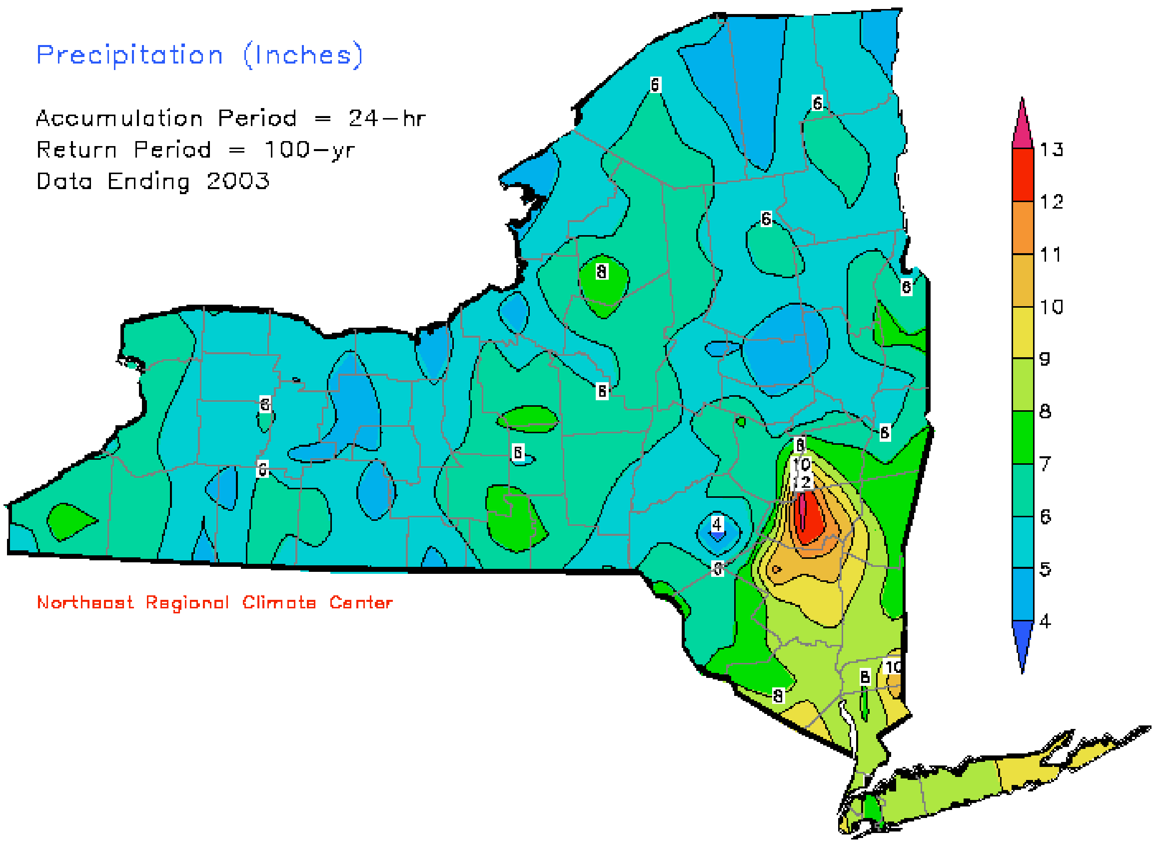

Figure 2.9 The 100-year, 24-hour storm for New York State as determined by the Northeast Regional Climate Center (http://www.nrcc.cornell.edu/pptext/isomaps.html).

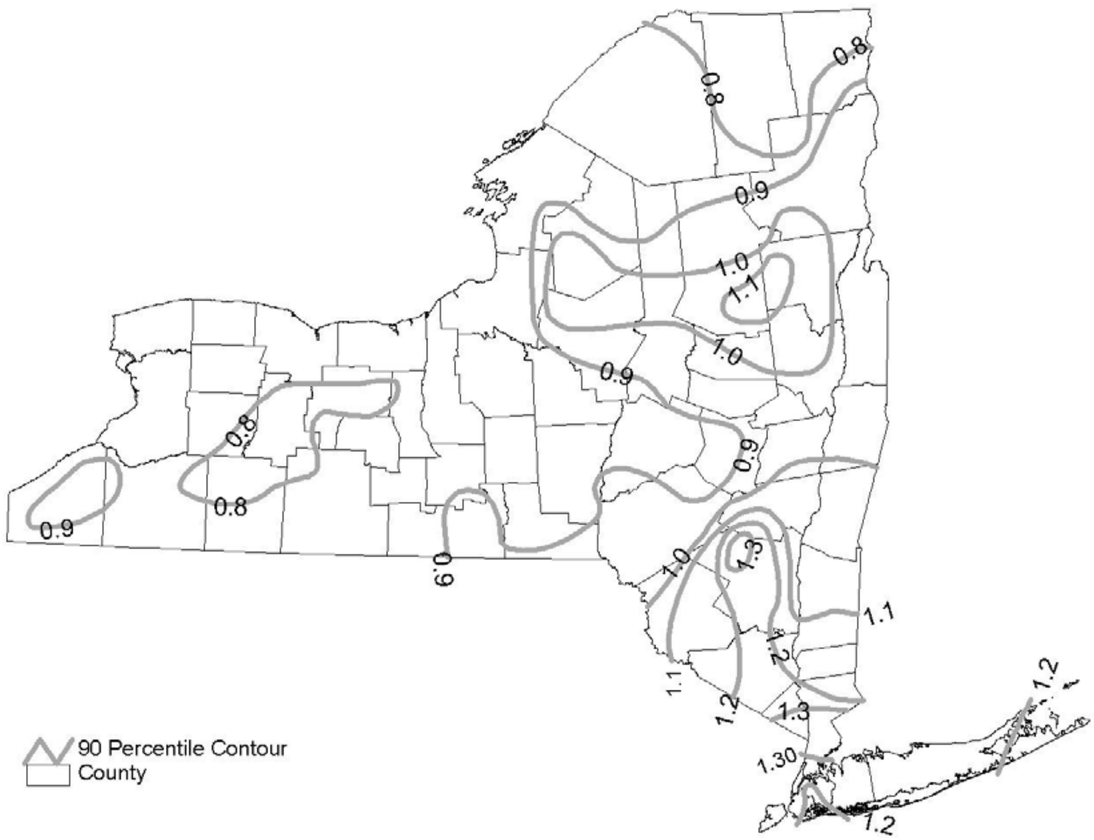

Figure 2.10 Ninety percent rainfall in New York State (New York State Stormwater Management Design Manual) (http://www.dec.ny.gov/docs/water_pdf/swdmchapter4.pdf)).

2.5 Reservoir Usable Storage Conditions in 2011

Ongoing daily monitoring of reservoir storage allows DEP to compare the present system-wide storage against what is considered “normal” for any given day of the year.“Normal” system-wide usable storage levels were determined by calculating the average daily storage from 1991-2010. In 2011 the actual system-wide storage capacity began the year slightly above normal (Figure 2.11), but declined to less than 80% capacity by mid-February due to below average precipitation (see Section 2.2). Two large rain events (>2.5 inches) in early March caused a sharp increase in capacity, and above average rainfall from April to June kept capacity levels near 100%. Capacity declined in July, as is typical, but remained above 90% at the end of July. Frequent rain events occurred in August culminating in very heavy rain from Tropical Storm Irene on August 27-28. As a result, capacity spiked above 100%, more than 20% higher than normal. Approximately eight days after Irene, rains associated with Tropical Storm Lee began to impact the watershed, and capacity spiked again on September 8. Large storms also occurred in late September and early December, maintaining capacity at 14 to 25% above normal for the remainder of the year.

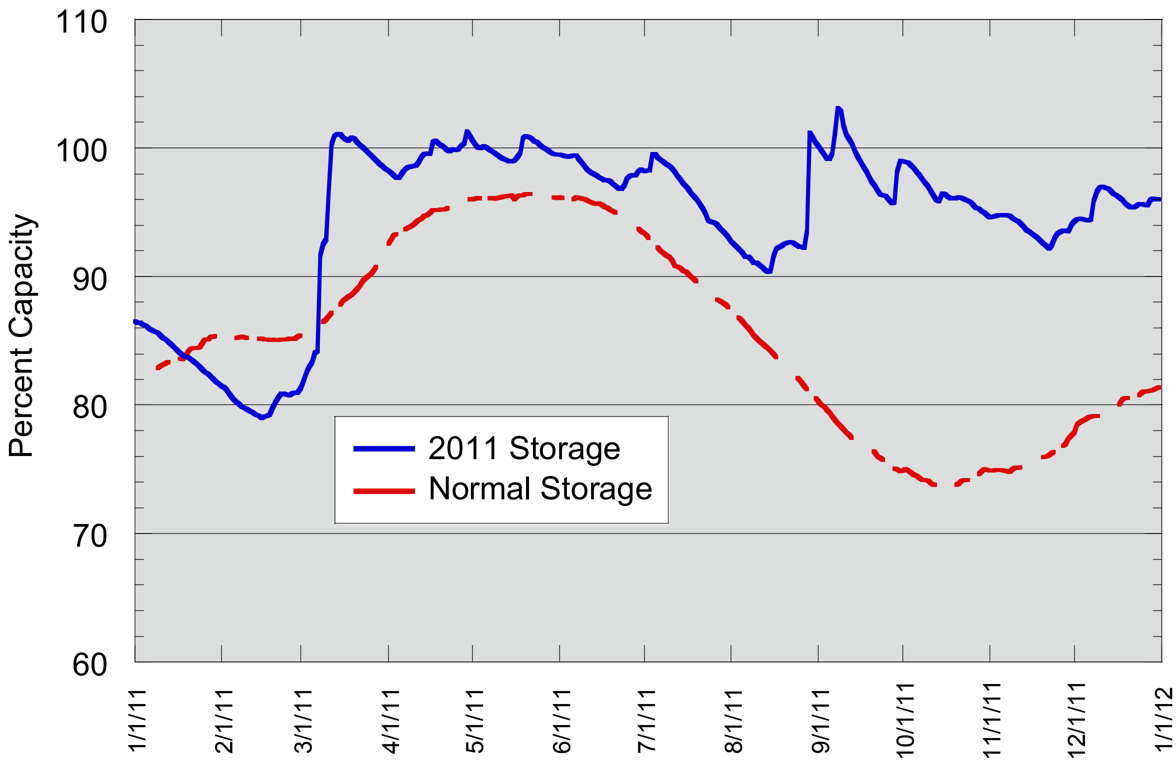

Figure 2.11 2011 system-wide usable storage compared to historical storage. Storage of greater than 100% is possible when the reservoirs are spilling or when the water surface elevation is greater than the spillway elevation.

3. Water Quality

3.1 Keypoint Compliance with the Surface Water Treatment Rule

The Surface Water Treatment Rule (SWTR) (USEPA 1989) 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 2011. The turbidity graphs include horizontal lines marking the SWTR limit.

Table 3.1: Fecal coliform at the keypoints compared to the SWTR limit for 2011 (percent daily samples > 20 fecal coliforms 100mL^{-1} in the previous six months).

Month	Croton %	Catskill %	Delaware %
Jan	0.00	0.00	0.00
Feb	0.00	0.00	0.00
Mar	0.00	0.00	0.00
Apr	0.00	0.00	0.00
May	0.00	1.10	2.20
Jun	0.00	1.11	2.21
Jul	0.00	1.10	2.21
Aug	0.00	3.26	4.35
Sep	0.00	6.63	8.74
Oct	0.00	6.59	8.70
Nov	0.00	5.52	6.56
Dec	0.00	5.49	6.52

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 more than 20 fecal coliforms 100mL^{-1}. The 2011 calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were below this limit. The percent that exceeded the standard increased in the latter half of the year due to the two tropical storms in late summer. Median fecal coliform counts (coliforms 100mL^{-1}) in raw water samples taken at these sites were < 1, 1, and 1 fecal coliform 100mL^{-1}, while maxima were 68, 760, and 150 fecal coliforms 100mL^{-1}, respectively.

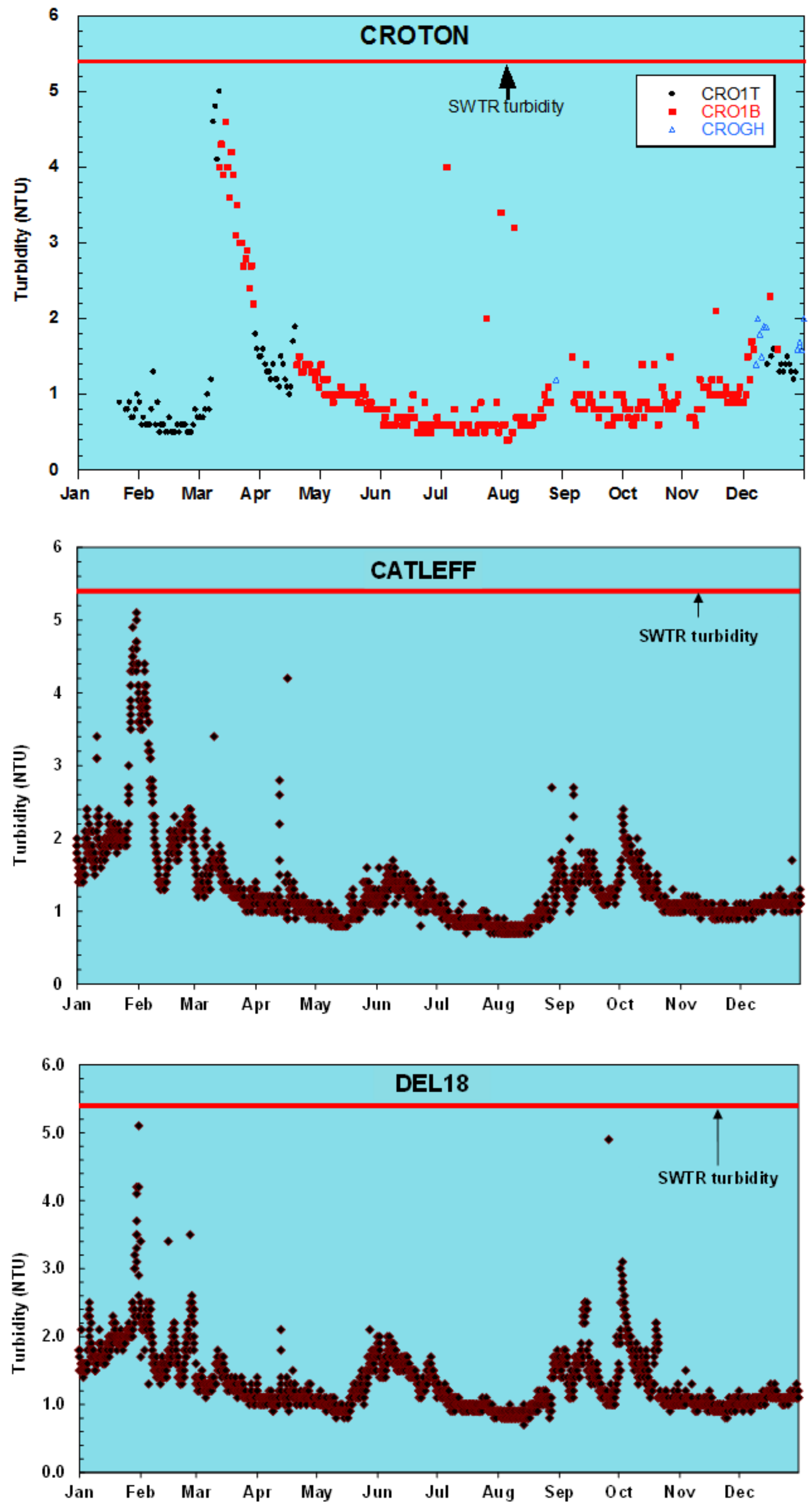

Figure 3.1 Turbidity at keypoints in 2011 compared to the SWTR limit. CROTON panel provides data from all potential keypoint samples.

The SWTR limit for turbidity is 5 NTU, which includes levels up to 5.4, since values can be rounded to the nearest whole number. Catskill/Delaware effluents are measured at 4-hour intervals. When New Croton is not on-line, a daily sample may be collected from a representative location such as CROGH, CRO1T, or CRO1B. These different samples are noted in Figure 3.1. As indicated in this figure, all three effluent waters were below the limit in 2011. Snowmelt in late winter and tropical storms in late summer caused increased turbidity that led to management strategies to minimize turbidity impact. For CROGH, CATLEFF, and DEL18, all median turbidity values were the same, at 1.0 NTU, while maximum values were 5.0, 5.0, and 5.1 NTU, respectively. These findings highlight the continued success of the management of the New York City Watershed, as well as effective operational strategies to maintain compliance with drinking water standards.

3.2 Reservoir Turbidity Patterns in 2011

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

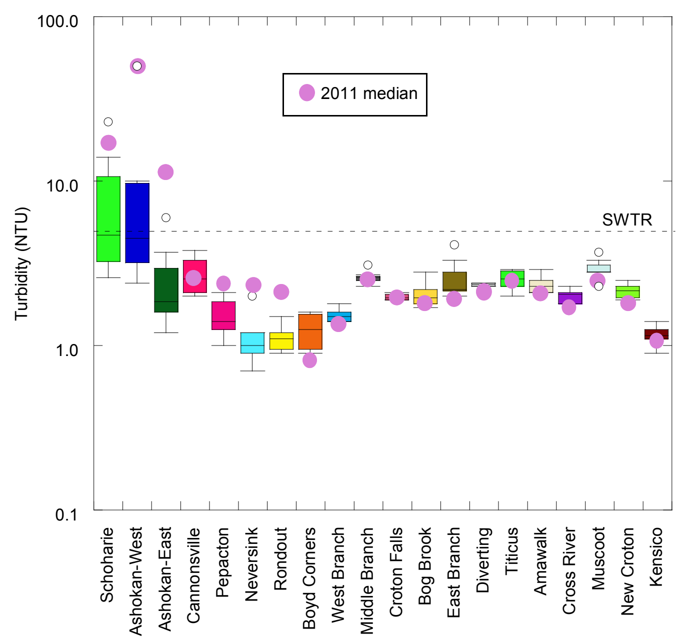

Figure 3.2 Annual median turbidity in NYC water supply reservoirs (2011 vs. 2003-2010). The dashed line at 5 NTU refers to the SWTR criterion that considers two consecutive days > 5NTU as a violation in source water reservoirs. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

Turbidity in the Catskill System reservoirs was much higher than normal in 2011 (Figure 3.2). An explanation of the boxplots used in this and other figures in this chapter is provided in Appendix A. Although winter runoff events produced high springtime values, the primary cause of the elevated turbidity was the flooding events associated with Tropical Storm Irene in late August and Tropical Storm Lee in early September. Turbidity levels peaked in September but remained much above normal levels for the remainder of the year. In response to the storms, diversions from Schoharie to Ashokan were greatly reduced in 2011. With limited Schoharie input, it may be concluded that the elevated turbidity observed in the East and West Ashokan Basins originated from the local

Ashokan watershed. The lower turbidity observed in the East Basin was, in part, due to the diversion of water out of the West Basin to the lower Esopus via the release channel.

In the Delaware System, winter runoff and the August-September flooding events caused turbidity to be much higher than normal in Neversink, Pepacton, and Rondout Reservoirs. Cannonsville Reservoir was not greatly impacted by any of these runoff events; its annual median turbidity remained similar to historical levels.

Turbidity at Kensico, the terminal reservoir for the Catskill/Delaware Systems was down slightly for the year, largely due to more reliance on the Delaware and Croton (i.e., West Branch and Boyd Corners) Systems during periods when the Catskill System was impacted by turbidity. Alum treatment, initiated in the Catskill Aqueduct on August 29, also helped to keep Kensico turbidity levels within the low levels observed historically.

The impact of the summer storms on the turbidity levels of most Croton reservoirs is not known. To facilitate increased storm-related sampling at West Branch and Kensico, a number of analyses, including turbidity, were canceled in September and October at most Croton reservoirs. Monthly turbidity results were only available in 2011 from one Croton System reservoir, West Branch. Turbidity levels at that reservoir were lower than normal, indicating that impacts from the tropical storms were limited in at least one Croton System watershed. Without considering storm-influenced data in September and October, it appears that turbidity levels in the Croton System were relatively low in 2011 (Figure 3.2). Turbidity results for the Croton System controlled lakes Gilead, Gleneida, and Kirk were within historical levels (Table 3.2). At these locations, turbidity samples were only collected in May and August, and, as was the case for the Croton reservoirs, the storm effects of Irene and Lee were not captured.

Table 3.2: Turbidity summary statistics for NYC controlled lakes (in NTU).

Lake	Median turbidity (2003-10)	Median turbidity (2011)
Gilead	1.9	1.7
Gleneida	2.2	1.7
Kirk	4.5	5.1

3.3 Coliform-Restricted Basin Assessments in 2011

Coliform bacteria are used widely as indicators of potential pathogen contamination. To protect its water supply, the New York City Watershed Rules and Regulations (WR&R) (2010) restrict potential sources of coliforms in threatened water bodies. 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: Sections 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 "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 2011, assessments were made for all five terminal basins. 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 $\geq$ 20 fecal coliforms $100mL^{-1}$, 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. West Branch and Ashokan Reservoirs had relatively high fecal coliforms for the second half of 2011 (Table 3.3). Since specific microbial tests for identification of anthropogenic sources were not performed on these samples, the results for West Branch and Ashokan East Basin are only presented as an initial assessment for 2011. The high values were coincident with record storms.

Table 3.3: Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2011.

Reservoir basin	Effluent keypoint	2011 Assessment
Kensico	CATLEFF and DEL18	Non-restricted
New Croton	CROGH	Non-restricted[1]
Ashokan	EARCM	Restricted[2] (17% $\geq$20 fecal coliforms $100mL^{-1}$)
Rondout	RDRRCM	Non-restricted
West Branch	CWB1.5	Restricted[2] (14% $\geq$20 fecal coliforms $100mL^{-1}$)

[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 more than 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 3.4 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 3.4: Coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2011). 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 values in order to exceed the standard. TNTC = coliform plates too numerous to count.

Reservoir	Class[1]	Standard monthly median/>20% (total coliforms $100mL^{-1}$)	Number of months that exceeded the standard/ months of data	Months not evaluated due to TNTC data[2]
CA	A	2400/5000	0/8	
CBB	AA	50/240	0/8	
CBC	AA	50/240	1/5	
CCF	A/AA	50/240	2/8	
CCR	A/AA	50/240	3/8	
CD	AA	50/240	5/8	
CEB	AA	50/240	7/8	
CGD	A	2400/5000	0/8	
CGL	AA	50/240	0/8	
CKL	B	2400/5000	0/7	
CM	A	2400/5000	1/8	
CMB	A	2400/5000	0/8	
CT	AA	50/240	4/8	
EDP	A/AA	50/240	1/9	
NN	A	50/240	1/9	1/9
SS	A	50/240	9/9	
WDC	A/AA	50/240	4/9	1/9

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

[2] Determination of the monthly median or individual sample exceedance of the standard was not possible for TNTC samples.

Six reservoirs never exceeded the Part 703 standard for total coliform in 2011: Amawalk, Bog Brook, Lake Gilead, Lake Gleneida, Kirk Lake, and Middle Branch. Schoharie Reservoir exceeded the standard for all nine months it was sampled. The remaining reservoirs exceeded the standard for one to seven months during the sampling season. Appendix B shows that many of the reservoirs, particularly those located West of Hudson (WOH), were affected by the impacts of Tropical Storms Irene and Lee in late summer.

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 3.4 represent only an initial assessment of total coliforms for the non-terminal basins in 2011.

3.4 Reservoir Total and Fecal Coliform Patterns in 2011

Total coliform and fecal coliform bacteria are monitored at all reservoirs because they are important as indicators of potential pathogen contamination. Total coliforms include both fecal coliforms and other coliforms that typically originate in water, soil, and sediments. Fecal coliform bacteria are a subset of the total coliform genera and their source is the gut of warm-blooded animals.

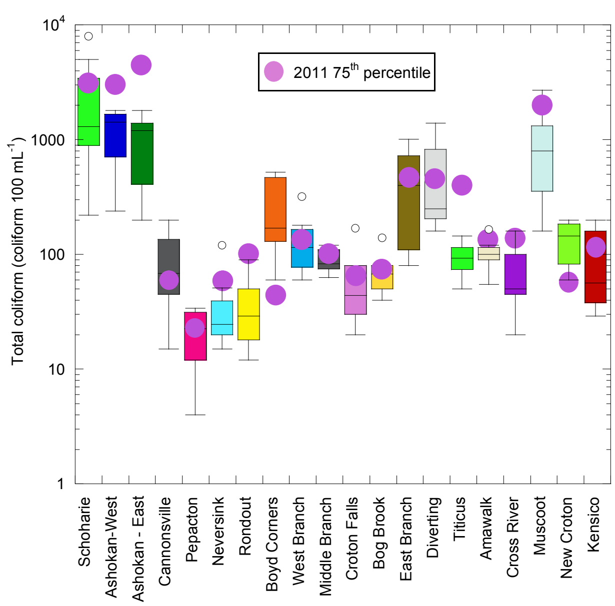

Figure 3.3 Annual 75th percentile total coliforms in NYC water supply reservoirs (2011 vs. 2003-2010). In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

Reservoir total coliform results are presented in Figure 3.3 and reservoir fecal coliform results in Figure 3.4. Coliform results for the controlled lakes of the Croton System are summarized in Table 3.5. Note that data used to construct the box-plots are annual 75th percentiles rather than medians. Generally, more than 50% of coliform data is below the detection limit. Using the 75th percentile, it is easier to discern differences among reservoirs. Dots in the graphs (75th percentiles) should be compared to the top of the box.

Historically, the highest total coliform counts occur in the Catskill System reservoirs (Figure 3.3) and counts continued to be high in 2011. 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. Once in the reservoirs, bacterial productivity of some coliform species usually increases around July, peaks in September, and remains elevated into the fall. In 2011, total coliforms were also unusually high in the spring due to the numerous runoff events that occurred in early March, late April, and mid-May. The highest counts of the year were associated with the late summer tropical storms. Median counts at Schoharie were 24,000 total coliforms 100mL^{-1} on September 12 and 9,450 total coliforms 100mL^{-1} at Ashokan West on September 14. Unusually high counts were also observed at Ashokan in mid-July, particularly in the East Basin.

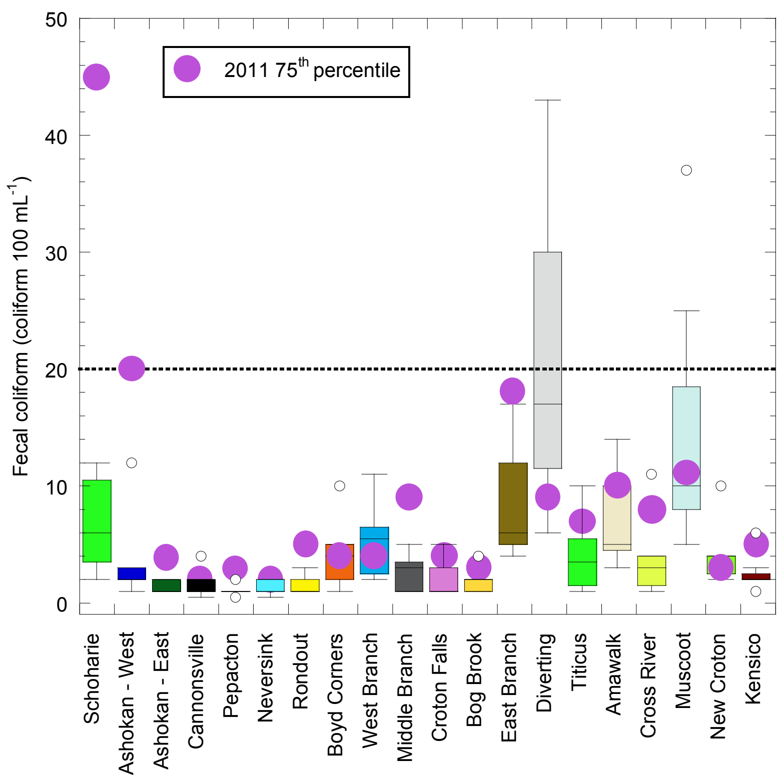

Figure 3.4 Annual 75th percentile of fecal coliforms in NYC water supply reservoirs (2011 vs. 2003-2010). The dashed line represents the SWTR standard for source waters as a reference. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

Table 3.5: A comparison of the 75th percentile levels of historical (2003-2010) and current (2011) total and fecal coliform concentrations (100mL^{-1}) in NYC's three controlled lakes.

Lake	Historical total coliforms	2011 total coliforms	2011 no. of samples	Historical fecal coliforms	2011 fecal coliforms	2011 no. of samples
Gilead	40	53	40	4	4	40
Gleneida	25	28	38	1	1	38
Kirk	180	330	35	5	6	33

In the Delaware System, elevated total coliform counts were apparent at Neversink, Rondout, and West Branch. High counts in September could be attributed to the tropical storms. Elevated counts also occurred in May and June at West Branch, July and August at Neversink, and August and October at Rondout. All sampling events occurred within close proximity to periods of elevated rainfall. Counts at Pepacton and Cannonsville were very close to their historical levels, indicating that rain events, including the tropical storms, had less impact in these basins.

Counts in Kensico Reservoir were above normal in 2011 but generally within historical levels. High counts were observed in April and May, coinciding with spring runoff events that impacted the Catskill System. Peaks in late August and September were related to the late summer tropical storms.

The Croton System reservoirs were generally within historical levels. Boyd Corners appears low but was not sampled after August 17 and does not reflect the impacts from the tropical storms. Total coliform counts at Amawalk and Titicus were high much of the year coinciding with rain events, including the late summer tropical storms. Titicus, in particular, was impacted by a large rain event on October 29 (1.7 inches), achieving a median coliform count of 1,200 total coliforms $100mL^{-1}$ on November 2.   Muscoot and Kirk Lake (Table 3.5) were also elevated but their highest values often did not coincide with rain events. Muscoot and Kirk are much shallower than the other Croton System reservoirs and are susceptible to wind derived resuspension 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. Coliform counts in New Croton Reservoir were well below normal in 2011. Elevated counts occurred only in early August and September.

In 2011, fecal coliform counts in all Catskill System reservoirs were much higher than historical levels. Counts were less elevated in the Delaware System, with highest counts observed at Rondout, the terminal reservoir of the system. In both systems the highest counts were observed in late August and September, following Tropical Storms Irene and Lee. Note that diversions from Neversink, Cannonsville, and Pepacton were suspended prior to the storms, so the high counts observed in Rondout were derived solely from Rondout's local watershed. Additional operational changes were made in response to the storms; the diversions from Ashokan and Rondout to Kensico were reduced and replaced with water from West Branch Reservoir. Alum was applied to the Catskill supply and chlorination initiated in the Delaware Aqueduct at Shaft 10. Despite these measures, fecal coliform counts in Kensico became elevated, presumably due to local sources in the Kensico watershed.

Fecal counts were also elevated in many Croton System reservoirs in 2011, but with the exception of Gilead, Gleneida, and Kirk Lakes and Middle Branch and New Croton Reservoirs, tropical storm impacts on fecal coliform levels in most of the Croton System were not discernible. Instead snowmelt and rain events in the spring and fall were associated with high fecal counts in the majority of the Croton System reservoirs.

3.5 Fecal Coliform Control through Waterfowl Management

In response to data clearly demonstrating 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). In 2011, additional wildlife management methods were introduced that included lethal removal of resident Ruddy Ducks (*Oxyura jamaicensis*) through a United States Department of Agriculture contract and mammal trapping in locations where fecal concentrations have been identified. The combined efforts of these measures have led to continued reductions in local breeding opportunities around water intake structures and reduced fecundity. Monitoring the effects of wildlife dispersal, deterrence, and depredation programs has been achieved through continued routine population surveys on each reservoir.

The Surface Water Treatment Rule (USEPA 1989) states that no more than 10% of fecal coliform samples may contain more than 20 coliforms $100mL^{-1}$ during the previous six-month period. Since waterbird management began, no such violation has occurred at Kensico Reservoir. (Figure 3.5). This represents a significant reduction as compared to the period prior to the implementation of the WMP. It should be noted that the increase in fecal coliform counts exhibited in 2011 was related to the unprecedented rainfall received during Tropical Storms Irene and Lee. DEP will continue implementation of the WMP indefinitely to help ensure the best possible water quality.

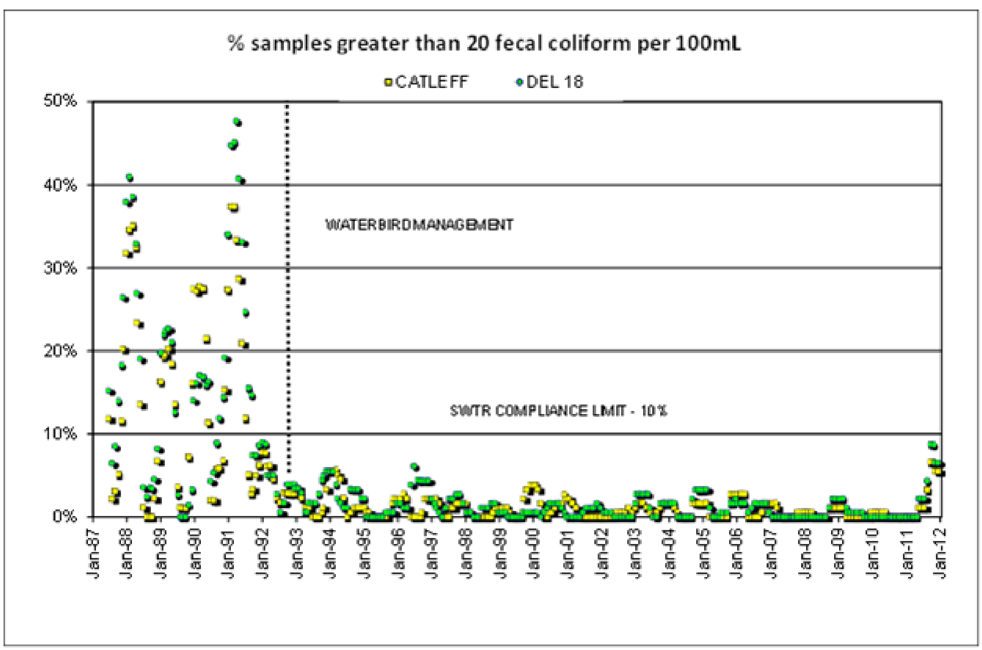

Figure 3.5 Percent of keypoint fecal coliform samples at Kensico Reservoir >20 fecal coliforms 100 mL^{-1} for the previous six-month period, 1987-2012. The dotted vertical line represents the date bird harassment activities began (August 1, 1992).

3.6 Phosphorus-Restricted Basin Assessments in 2011

Phosphorus-restricted basin status is presented in Table 3.6 and was derived from two consecutive assessments (2006-2010 and 2007-2011) using the methodology stated in Appendix C. Appendix Table 2 lists the annual growing season geometric mean phosphorus concentration for NYC reservoirs. Reservoir basins whose geometric mean phosphorus concentrations exceed the benchmarks in the WR&R (DEP 2010a) for both assessments are classified as restricted. Figure 3.6 graphically depicts the phosphorus restriction status of the NYC reservoirs and the 2011 geometric mean phosphorus concentrations.

Table 3.6: Phosphorus-restricted status of reservoir basins for 2011.

Reservoir Basin	06-10 Assessment (mean + S.E.) ($\mu g\ L^{-1}$)	07-11 Assessment (mean + S.E.) ($\mu g\ L^{-1}$)	Phosphorus Restricted Status
Delaware District			
Cannonsville	17.0	15.1	Non-restricted
Pepacton	9.8	10.0	Non-restricted
Neversink	6.3	7.4	Non-restricted
Catskill District			
Schoharie	13.7	18.0	Non-restricted
Croton District			
Amawalk	21.6	19.8	Restricted
Bog Brook	25.7	26.3	Restricted
Boyd Corners	14.1	12.0	Non-restricted
Diverting	Insufficient data	30.2	Restricted
East Branch	28.7	29.8	Restricted
Middle Branch	25.9	27.4	Restricted
Muscoot	27.7	27.9	Restricted
Titicus	25.3	24.4	Restricted
Lake Gleneida	25.2	29.5	Restricted
Lake Gilead	33.9	33.8	Restricted
Kirk Lake	30.1	31.4	Restricted
Source Waters (Terminal Basins)			
Ashokan-East	9.4	10.6	Non-restricted
Ashokan-West	10.7	17.9	Non-restricted
Cross River	16.9	16.9	Restricted

Table 3.6: (Continued)Phosphorus-restricted status of reservoir basins for 2011.

Reservoir Basin	06-10 Assessment (mean + S.E.) (µg L^{-1})	07-11 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus Restricted Status
Croton Falls	16.7	16.0	Restricted
Kensico	7.0	7.0	Non-restricted
New Croton	17.0	17.0	Restricted
Rondout	8.0	8.1	Non-restricted
West Branch	9.8	10.1	Non-restricted

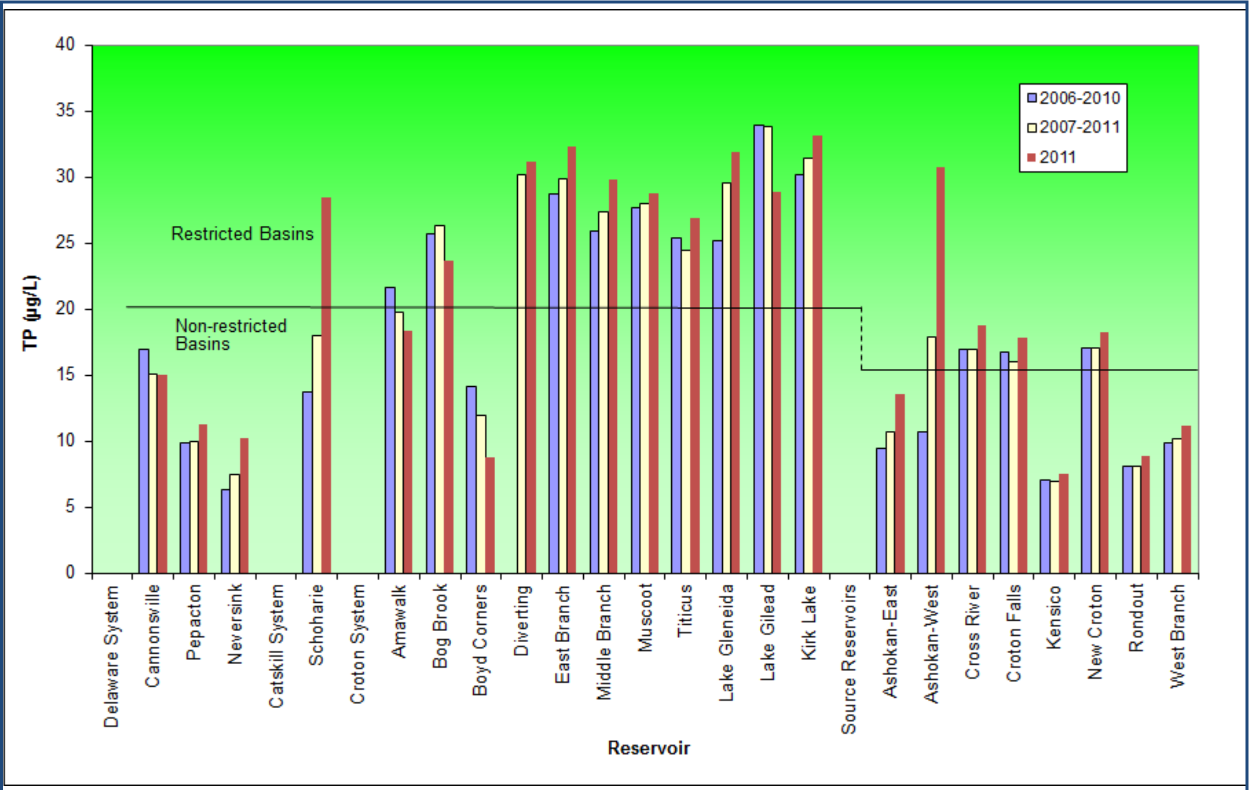

Figure 3.6 Phosphorus-restricted basin assessments, with the current year (2011) geometric mean phosphorus concentration displayed for comparison. The horizontal solid lines at 20µg L^{-1} and 15µg L^{-1} represent the NYC Watershed Rules and Regulations standard for non-source waters and source waters, respectively.

Some notes and highlights regarding phosphorus-restricted basin status in 2011:

- In August and September 2011, Ashokan Reservoir was impacted by severe flooding, as a result of Tropical Storms Irene and Lee, respectively. These storms brought in large amounts of suspended material that resulted in higher total phosphorus concentrations than normal. Prior assessments were also impacted by the snowmelt and runoff in April of 2005.Since these events are unpredictable and did not result in eutrophication of the reservoir, the Department is utilizing its best professional judgment and is not designating the Ashokan Reservoir West Basin as phosphorus restricted at this time.

- The Delaware System reservoirs remained non-restricted with respect to total phosphorus (TP). Figure 3.7 shows that the 2011 geometric mean was higher than in the two previous assessment periods for Pepacton and Neversink. Further examination of the data showed that TP increased dramatically after the two tropical storms in the late summer. Cannonsville Reservoir did not exhibit the same magnitude of increased TP.
- The Catskill System's Schoharie Reservoir was highly impacted by the tropical storms, to the extent that the TP concentrations were among the highest in the WOH System for 2011. The reservoir remained non-restricted based upon the two assessment periods.
- The Croton System reservoirs remained phosphorus-restricted, with the exception of Boyd Corners, which remained non-restricted. The geometric mean TP for Boyd Corners was low compared to other Croton System reservoirs, since only May through August samples were used in the calculation. Due to drawdown after the tropical storms, the reservoir was inaccessible after August.
- The geometric means of the TP concentrations in the Croton System reservoirs for 2011 were generally similar to previous years (Appendix C). Most of the Croton reservoirs were not impacted as heavily as the WOH reservoirs by the tropical storms in 2011.
- Three terminal reservoirs remained restricted: Cross River, Croton Falls, and New Croton.
- Kensico, Ashokan East Basin, Rondout, and West Branch Reservoirs were non-restricted, although the 2011 geometric mean TP was higher than in previous years. The Ashokan Reservoir West Basin was exempt from restricted status as noted above.

3.7 Reservoir Total Phosphorus Patterns in 2011

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

TP in the Catskill and most Delaware System reservoirs was much higher than normal in 2011. Winter runoff and especially runoff associated with the late summer tropical storms produced 10-year TP highs in Pepacton, Neversink, Rondout, Schoharie, and Ashokan's East and West Basins (Figure 3.7). East Basin levels were mitigated somewhat due to the diversion of water out of the West Basin to the lower Esopus via the release channel. In contrast, Cannonsville TP levels were lower than normal, due primarily to low spring concentrations and minimal impacts from Tropical Storms Irene and Lee.

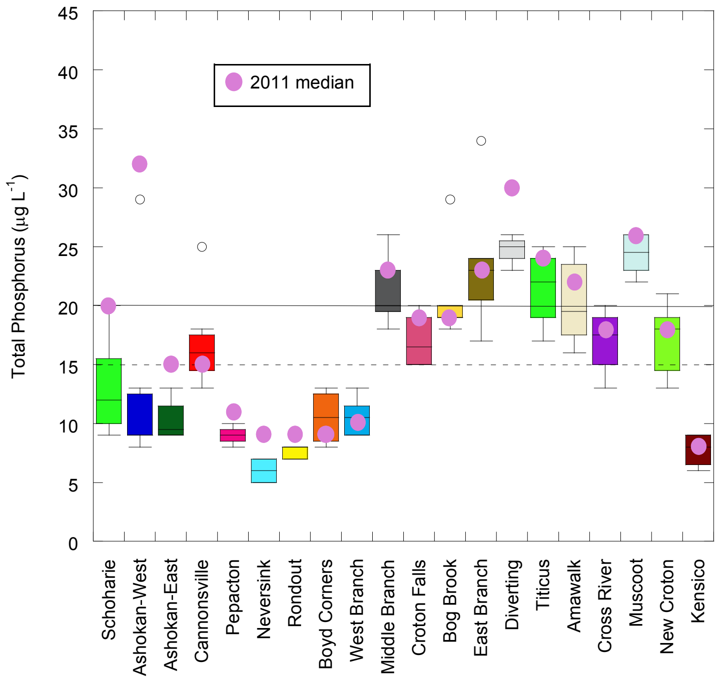

Figure 3.7 Annual median total phosphorus in NYC water supply reservoirs (2011 vs. 2003-2010). The horizontal dashed line at 15 µg L^{-1} refers to the NYC Total Maximum Daily Loads guidance value for source waters. Although Kensico and New Croton are usually operated as source waters, these reservoirs can be bypassed so that any or all of the following can also be operated as source waters: Rondout, Ashokan East, Ashokan West and West Branch. The horizontal solid line at 20µg L^{-1} refers to the NYSDEC's ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs). In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

TP concentrations in West Branch were very close to their historical median concentration and slightly higher than concentrations in West Branch's primary input, Rondout Reservoir. Concentrations in Boyd Corners, West Branch's other main input, were also slightly lower than in West Branch. However, Boyd Corners was not sampled after August, so its 2011 annual median does not reflect the impacts from the tropical storms.

TP concentrations in Kensico Reservoir, which receives water from Rondout, West Branch, and Ashokan, were similar to the historical median TP concentration. Note that higher TP concentrations from Ashokan were greatly mitigated by reducing the flow and treating with alum prior to entry into Kensico.

Compared to the Catskill/Delaware System, the Croton watershed has a greater abundance of TP 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 3.7) and controlled lakes (Table 3.7) are normally much higher than in the reservoirs of the Catskill/Delaware System. In 2011, most Croton reservoirs and controlled lakes were within historical levels, ranging from 10 to 30 µg L^{-1}. Diverting appears exceptionally high at 30 µg L^{-1}, but historical data may not accurately represent previous conditions, since sampling at Diverting was infrequent in the 2003-2010 period as a result of dam repairs.

Table 3.7: TP summary statistics for NYC controlled lakes (µg L^{-1}).

Lake	Median TP (2003-10)	Median TP (2011)
Gilead	20	19
Gleneida	18	20
Kirk	27	30

Efforts to reduce TP loads in the Croton watershed are ongoing. Many WWTPs have been upgraded; others are at some intermittent stage of upgrade. Septic repair and pump out programs continue in Putnam and Westchester Counties, as does the implementation of farm (usually equestrian-based) best management practices. 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 2011 TP concentrations were generally within historical ranges.

3.8 Terminal Reservoir Comparisons to Benchmarks in 2011

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 2011 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 3.8. These benchmarks, in turn, are based on applicable federal, state, and DEP standards or guidelines, also listed in Table 3.8. Note that the standards in this table are not necessarily applicable to all individual samples and medians described herein (e.g., SWTR limits for turbidity and fecal coliforms apply only to the point of entry to the system). It should also be noted that different values apply to Croton reservoirs than to WOH reservoirs. Placing the data in the context of these benchmarks assists in understanding the robustness of the water system and water quality issues.

Table 3.8: Reservoir and controlled lake benchmarks as listed in the WR&R (2010).

Analyte	Croton System		Catskill/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 (coliforms 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) New York State Department of Health (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 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. For all reservoirs, monthly (April-November) sample results from multiple sites and depths were used in the comparison.

Highlights of the benchmark comparisons are as follows. Summer algal blooms caused only 7% 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 low alkalinity, however, readings dropped below the benchmark of 6.5 for 50% of the Ashokan East Basin samples and 40% of the Rondout samples. The pH values in Kensico were outside the benchmark range for 38% of the samples.

All chloride samples in New Croton exceeded the benchmarks of the 40 mg L^{-1} single sample standard and the annual mean standard of 30 mg L^{-1}. Kensico and West Branch exceeded both the annual mean benchmark for chloride and the single sample standard for the WOH reservoirs (46% and 58% of samples, respectively). Rondout and Ashokan East Basin were below the limits for these standards. All chloride samples were lower than the health standard of 250 mg L^{-1}.

Turbidity levels in West Branch Reservoir exceeded the single sample maximum of 5 NTU in 3% of the samples. Rondout, New Croton, and Kensico turbidity exceeded 5 NTU for 13%, 4%, and 1% of the samples, respectively. Ashokan samples exceeded this criterion for 63% of the samples in the East Basin and 86% in the West Basin. The two tropical storm events caused turbidity events, primarily in the WOH basins. Management of diversions and the use of alum treatment helped to minimize the impact on Kensico Reservoir.

TP values exceeded the single sample maximum of 15 µg L^{-1} in only 8% of the samples in Rondout and never exceeded the standard in Kensico. In the other terminal reservoirs, the percent of samples exceeding this benchmark ranged from 29 in West Branch to 75 in New Croton. Nitrate samples were below the single sample maximum and the annual mean benchmarks for most reservoirs except New Croton and West Branch. In New Croton, 19% of the samples were above the benchmark and exceeded the annual mean, while West Branch exceeded the single sample maximum in only 2% of the samples. Ammonia was very low and did not exceed the benchmarks in the Ashokan basins or in Rondout. No ammonia samples were analyzed for Kensico, West Branch, and New Croton Reservoirs.

Phytoplankton counts in Kensico and Rondout Reservoirs were below the 2,000 ASU benchmark. In the remaining terminal reservoirs, between 0% and 13% of samples exceeded this benchmark or the single genus benchmark of 1,000 ASU. New Croton exceeded the single sample maximum and the annual mean benchmark for chlorophyll *a*, while West Branch and Kensico exceeded the single sample standard by only 10% and 2%, respectively. Kensico and Rondout never exceeded the criteria for chlorophyll *a*.

Color readings in New Croton were above the secondary (aesthetic) color benchmark of 15 units in 100% of the samples collected. West Branch Reservoir followed, with 80% of the samples exceeding the benchmark. Exceedances at the other terminal reservoirs ranged from 21% of the samples at Ashokan East Basin to 43% at Rondout.

Fecal coliform counts were the lowest in Kensico, where only 5% of the samples exceeded the single sample maximum of 20 coliforms $100mL^{-1}$. In the remaining terminal basins, the percent of samples exceeding this criterion ranged from 2 in New Croton to 14 in Rondout.

3.9 Reservoir Trophic Status in 2011

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

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

where CHLA is the concentration of chlorophyll *a*

The Carlson Trophic State Index 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. Water supply reservoirs are managed to achieve a low trophic state, because such reservoirs 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 (2003-2010) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.8. The 2011 annual median TSI appears in the figure as a circle containing an "x". This analysis generally shows a split between WOH reservoirs, which usually fall into the mesotrophic category, and East of Hudson (EOH) reservoirs, which are typically classified as eutrophic. The exceptions to these generalities are Cannonsville, which has a history of being eutrophic (although it has been mesotrophic for the last four years); West Branch, which is mesotrophic due to incoming water from Rondout Reservoir; and Kensico, which is mesotrophic due to inputs from Rondout (usually via West Branch) and from the East Basin of Ashokan.

In 2011, TSI was much lower than normal in the Catskill and most Delaware System reservoirs. In the Catskill System, elevated turbidity from snowmelt and numerous storms in the spring and summer reduced clarity during the growing season and greatly limited algal productivity. Turbidity levels in the Delaware System were elevated enough to inhibit algal growth only in September and October (post-Irene and Lee). Since TP levels were relatively high, the low TSI values from May to August at Pepacton, Neversink, and Rondout may be linked to very low nitrogen concentrations observed throughout the year in these reservoirs. The tropical storms did not greatly impact Cannonsville Reservoir, where turbidity and TP levels, along with TSI, were generally within historical levels. TSI in West Branch Reservoir was slightly elevated. Algal productivity in West Branch was probably stimulated by unusually warm water temperatures in June, July, and August and by increased TP from tropical storm runoff.

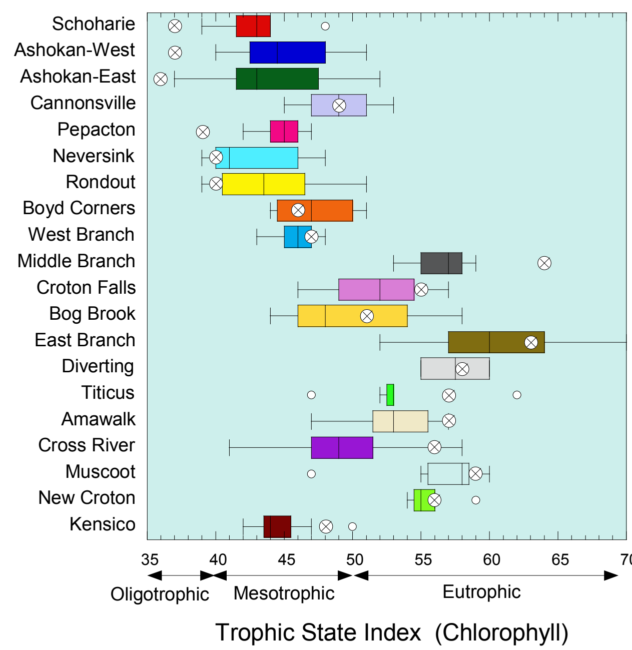

Figure 3.8 Annual median Trophic State Index in NYC water supply reservoirs (2011 vs. 2003-2010). In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per month from May through October. TSI is based on chlorophyll *a* concentration.

Kensico Reservoir, the terminal reservoir for the Catskill/Delaware System, is primarily a blend of Ashokan East Basin and Rondout (usually via West Branch) water, with small contributions from local watershed streams. In 2011, Kensico's median TSI was 4 units higher than its historical median (9% increase). As in West Branch, algal productivity may have been stimulated by unusually warm water temperatures in June, July, and August and by increased TP resulting from tropical storm runoff in September.

TSI was almost universally elevated in the Croton System in 2011. However, for the most part, the elevated TSI depicted in Figure 3.7 is not a result of impacts from Irene and Lee. This is because very few of the Croton reservoirs were sampled for chlorophyll *a* after the storms (Croton Falls, Cross River, Diverting, and Middle Branch only), and of those that were, only Cross River displayed lingering effects from the tropical storms (higher phosphorus and TSI). Algal blooms (some severe), which sporadically occurred from May to August in the Croton System, are the best explanation for the elevated TSI in 2011. Nutrient increases associated with rain events explain some of the blooms but in the majority of cases nutrient concentrations were normal and rain was not a factor.

TSI summary statistics for the controlled lakes are presented in Table 3.9. TSI was similar to past levels, but note that chlorophyll *a* was only sampled on May 11 and August 30. The August survey occurred several days after Tropical Storm Irene, which may explain the high TP and TSI observed on this date at all three controlled lakes.

Table 3.9: Trophic State Index (TSI) summary statistics for NYC controlled lakes.

Lake	Median TSI (2003-10)	Median TSI (2011)
Gilead	46	47
Gleneida	42	43
Kirk	56	56

3.10 Water Quality in the Major Inflow Streams in 2011

The stream sites discussed in this section are listed in Table 3.10 and shown pictorially in Figure 3.9. These stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/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 3.10: 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
CROSS2	Cross River, above Cross River Reservoir
KISCO3	Kisco River, input to New Croton Reservoir
HUNTER1	Hunter Brook, input to New Croton Reservoir

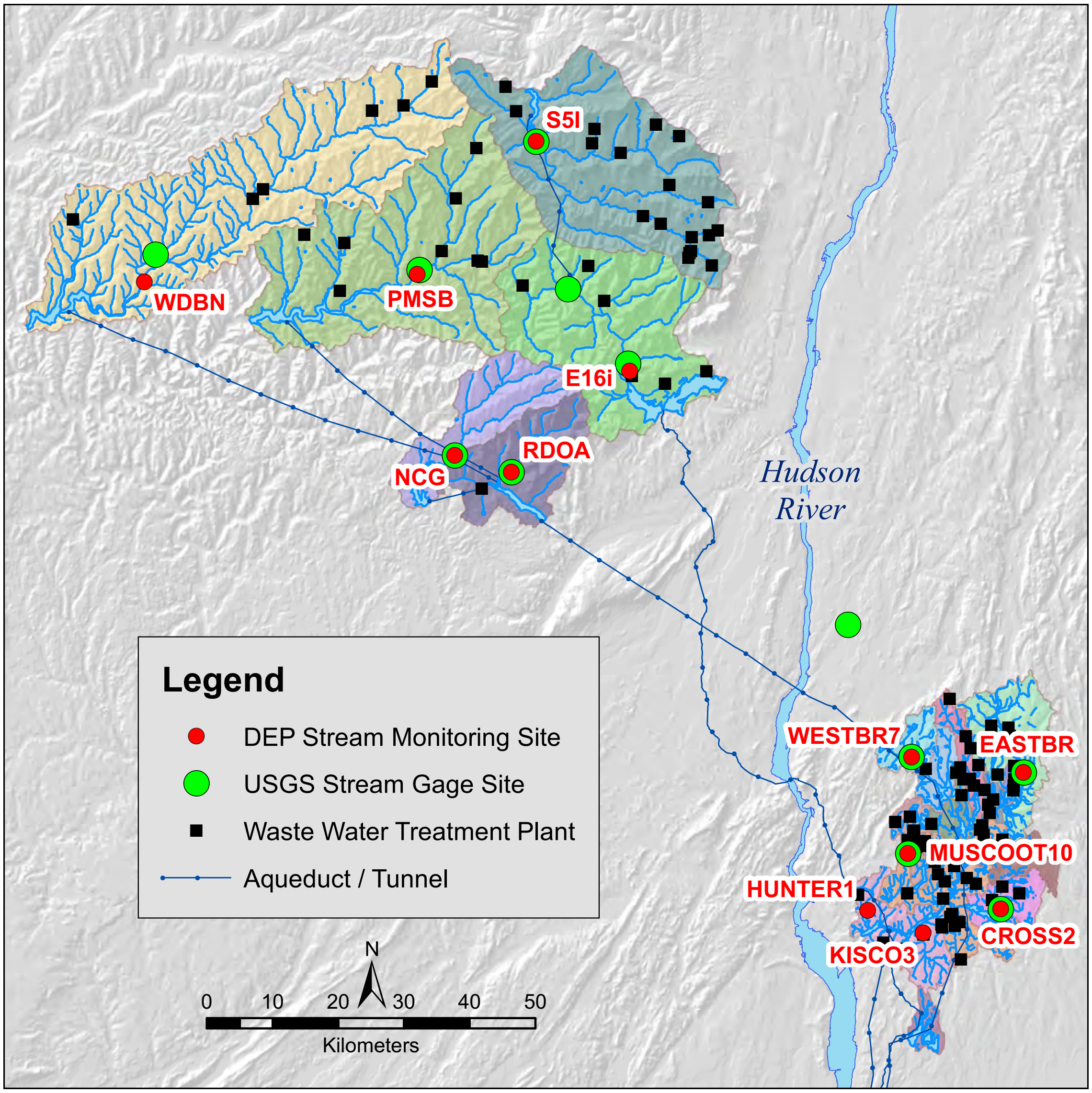

Figure 3.9 Locations of major inflow stream water quality sampling sites and USGS gauge stations used to calculate runoff values (see Section 2.3).

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 and fecal coliform bacteria to maintain compliance with the SWTR, and TP to control nutrients and eutrophication.

The results presented in Figure 3.10 are based on grab samples generally collected once a month in 2011 (twice a month for coliforms for the EOH sites). The figures compare the 2011 median values against historical median annual values for the previous 10 years (2001-2010).

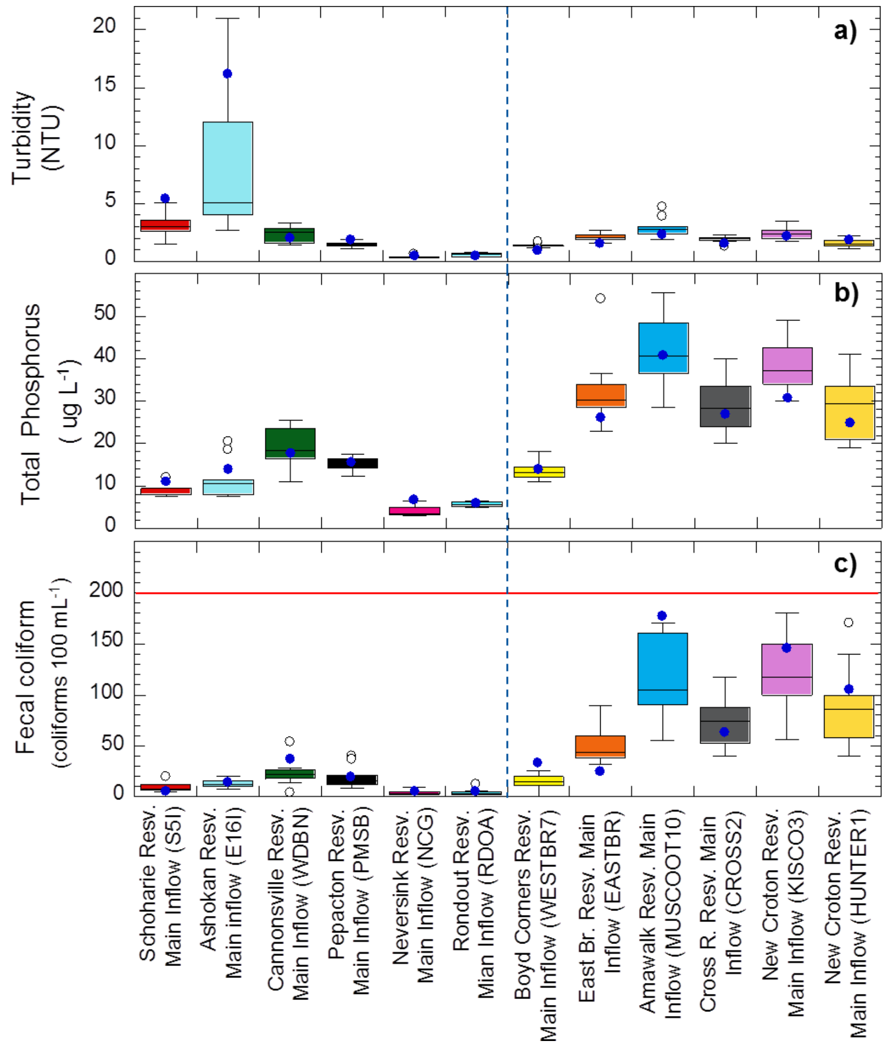

Figure 3.10 Boxplot of annual medians (2001-2010) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2011 displayed as a dot. The dotted line separates WOH streams (left) from EOH streams (right). The solid red line indicates the fecal coliform benchmark of 200 coliforms $100mL^{-1}$.

Turbidity

The turbidity levels for 2011 were generally near "normal" values, except for the Catskill inflows (Schoharie (S5I) and Ashokan (E16I)), which were elevated for the year (the highest annual median in the last 10 years for Schoharie and the second highest for Ashokan). The elevated turbidities were due to the storm and snowmelt in early March and the effects of Tropical Storms Irene and Lee in August and September, respectively, which resulted in somewhat elevated turbidities in the Catskill streams for the remainder of the year. The annual median turbidities for the EOH inflows (except for Hunter Brook) were all somewhat below their typical historical values.

Total Phosphorus

In the Catskill/Delaware Systems, the 2011 median TP concentrations were near or above typical historical values. Ashokan, Schoharie, and Neversink streams were somewhat above the historical TP medians. As with turbidity, the March storm elevated TP concentrations at Schoharie and Ashokan. The tropical storms resulted in elevated TP levels at those two inflow sites and at Neversink as well. In contrast, the 2011 TP medians in the Croton System were all generally less than historical values, except for the Boyd Corners inflow and the Muscoot River above Amawalk Reservoir, which were both slightly above the historical median when compared to the last 10 years of annual medians.

Fecal Coliform Bacteria

The 2011 median fecal coliform bacteria levels in the Catskill/Delaware streams were generally near typical historical levels, except for Schoharie Creek, which was below its historical median, and Cannonsville, which was above. For the Croton Reservoir inflows, the annual fecal coliform levels were somewhat elevated, with the Boyd Corners inflow and the Muscoot River above Amawalk Reservoir having the highest annual median fecal coliform level in the last 10 years. East Branch had the lowest annual median fecal coliform level it has had in the last 10 years, and Cross River was somewhat below its typical annual median. A fecal coliform benchmark of 200 coliforms $100mL^{-1}$ is shown as a solid line in Figure 3.10. This benchmark relates to the NYSDEC water standard for fecal coliforms (expressed as a monthly geometric mean of five samples, the standard being <200 coliforms $100mL^{-1}$) (6 NYCRR §703.4b). The 2011 median values for all streams shown here lie below this value.

3.11 Stream Comparisons to Benchmarks in 2011

Select water quality benchmarks have been established for reservoirs and reservoir stems (any watercourse segment which is tributary to a reservoir and lies within 500 feet or less of the reservoir) in the WR&R (2010). In this section, the application of these benchmarks was extended to 41 streams and reservoir releases in order to evaluate stream status in 2011 (DEP 2009). The benchmarks are provided in Table 3.11.

Table 3.11: Stream water quality benchmarks as listed in the WR&R (2010).

	Croton System		Catskill/Delaware Systems	
	Annual mean	Single sample maximum	Annual mean	Single sample maximum
Alkalinity (mg $CaCO_3$ L^{-1})	N/A	≥40.00	N/A	≥10.00
Ammonia-N (mg L^{-1})	0.1	0.2	0.05	0.25
Dissolved chloride (mg L^{-1})	35	100	10	50
Nitrite+nitrate (mg L^{-1})	0.35	1.5	0.4	1.5
Organic Nitrogen[1]	0.5	1.5	0.5	1.5
Dissolved sodium (mg L^{-1})	15	20	5	10
Sulfate (mgL^{-1})	15	25	10	15
Total dissolved 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.

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

[3] Dissolved organic carbon was used in this analysis since total organic carbon is 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. Note that the Catskill/Delaware System criteria are applied to the release from West Branch Reservoir (WESTBRR) since it is usually predominately Delaware System water via Rondout Reservoir.

Alkalinity is a measure of water's ability to neutralize acids. A stable pH in the 6.5 to 8.5 range is a necessary condition for a healthy ecosystem. It is also important to monitor alkalinity levels, to facilitate water treatment processes such as chemical coagulation, water softening, and corrosion control.

In the NYC water supply the lowest alkalinity levels typically occur in the winter and spring when acidic snowmelt reaches the streams. Streams in the Schoharie, Cannonsville, and Pepacton basins generally met the 10 mg L^{-1} criterion. Excursions slightly below 10 mg L^{-1} occasionally occurred during the winter. 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. A benchmark of 40 mg L^{-1} is used for the Croton System streams, which reflects the much higher natural buffering capacity of this region. However, less buffering capacity does occur in the Boyd Corners and West Branch Reservoir basins on account of the low alkalinity of their input streams. Alkalinity results from these inputs (GYPSYTRL1, HORSEPD12, LONGPD1, WESTBR7 and BOYDSR) were often below 40 mg L^{-1}, and lows from these streams ranged from 13.5 to 32.4 mg L^{-1}.

Regarding chlorides, none of the Catskill or Delaware streams (including WESTBRR) exceeded the single sample chloride benchmark of 50 mg L^{-1} in 2011. However, the annual mean benchmark of 10 mg L^{-1} was exceeded in 5 of the 25 streams monitored in these two systems. The highest annual mean, 29.3 mg L^{-1}, occurred at Kramer Brook above Neversink Reservoir. In contrast, the two other monitored streams in the Neversink watershed, Aden Brook (NK4) and the Neversink River (NCG), averaged between 2.7 and 3.4 mg L^{-1}. The Kramer Brook watershed is very small (<1 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 (14.2 mg L^{-1}), a tributary to Schoharie Reservoir; Trout Creek (14.0 mg L^{-1}) and Loomis Brook (13.8 mg L^{-1}), both tributaries to Cannonsville Reservoir; and Chestnut Creek (12.0 mg L^{-1}), a tributary to Rondout Reservoir. The outflow from West Branch Reservoir (WESTBRR) barely exceeded the benchmark, averaging 10.5 mg L^{-1}. 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 16 monitored Croton streams exceeded the annual mean benchmark of 35 mg L^{-1}, collectively averaging 62.6 mg L^{-1} in 2011. By comparison, chloride was much lower in the Catskill/Delaware Systems, averaging 7.1 and 8.3 mg L^{-1}, respectively. 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 wastewater treatment effluent.

Total dissolved solids (TDS) is a measure of the combined content of all inorganic and organic substances in the filtrate of a sample. Although TDS is not analyzed directly by DEP, it is commonly estimated in the water supply industry using specific conductivity measurements. Conversion factors for TDS relate to the water type (International Organization for Standardization 1985, Singh 1975). For NYC waters, specific conductivity was used to estimate TDS by multiplying specific conductivity by 0.65 (van der Leeden 1990). In 2011, 13 of 25 Catskill/Delaware streams had at least one exceedance of the single sample maximum of 50 mg L^{-1}. Fourteen Catskill/Delaware streams also exceeded the annual mean benchmark of 40 mg L^{-1}. Most elevated TDS was associated with periods of low flow and occasionally with high chloride. Only streams with very low chloride concentrations (<6.5 mg L^{-1}) could consistently meet the TDS benchmarks. In the Croton System only BOYDR (Boyd Corners release), WESTBR7 (above Boyd Corners Reservoir) and CROSSRVR (Cross River Reservoir release) met the annual benchmark of 150 mg L^{-1} and the single sample maximum criterion of 175 mg L^{-1}. As with the Catskill/Delaware streams, these Croton streams and reservoir releases had relatively low chloride concentrations. TDS excursions in the Croton System are most likely associated with one or more of the following sources: elevated salt concentrations from road salt, water softening brine waste, septic system leachate, and 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 one Croton stream, Michael Brook, located upstream of Croton Falls Reservoir. The benchmark was exceeded in 9 of 12 monthly samples and was especially high in January (4.9 mg L^{-1}), February (3.6 mg L^{-1}), September (3.7 mg L^{-1}), and October (3.9 mg L^{-1}). Four Croton streams exceeded the annual average benchmark of 0.35 mg L^{-1}: the Kisco River, 0.61 mg L^{-1} at KISCO3; the Muscoot River, 0.50 mg L^{-1} at MUSCOOT10; Michael Brook, 2.5 mg L^{-1} at MIKE2; and the Diverting Reservoir release (DIVERT2R), 0.35 mg L^{-1}. No streams from the Catskill/Delaware System exceeded the single sample nitrate benchmark of 1.5 mg L^{-1}. However, the average annual benchmark of 0.40 mg L^{-1} was exceeded at Kramer Brook (0.43 mg L^{-1}), a tributary to Neversink Reservoir. The source of the nitrogen is unclear. Relatively few homes are located upstream and treatment plants and farms are not present in the watershed.

None of the Catskill/Delaware System streams exceeded the mean annual ammonia benchmark of 0.05 mg L^{-1} or the single sample maximum of 0.20 mg L^{-1} in 2011. Almost all samples were at or near the analytical detection limit of 0.02 mg L^{-1}. Croton System streams were not sampled for ammonia in 2011.

Neither the single sample maximum (15 mg L^{-1}) nor the annual mean (10.0 mg L^{-1}) benchmarks for sulfate were surpassed in the Catskill/Delaware streams in 2011. While all Croton stream results in 2011 were below the Croton System single sample maximum (25 mg L^{-1}), the Croton annual mean sulfate benchmark of 15 mg L^{-1} was surpassed in two streams, with averages of 18.1 mg L^{-1} at the Diverting Reservoir release and 15.5 mg L^{-1} at Michael Brook. WWTPs are located upstream of these sampling locations and are the probable source of the excess sulfate.

Dissolved organic carbon (DOC) was used in this analysis instead of total organic carbon since the latter is not 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 2011. The highest DOC in the Catskill/Delaware System, 5.6 mg L^{-1}, occurred at Kramer Brook, and the annual mean Catskill/Delaware DOC ranged from 0.8 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 have higher DOC concentrations than those in Catskill/Delaware; this is reflected in the 2011 annual means, which ranged from 3.0 to 5.7 mg L^{-1}. The highest single sample DOC in the Croton Systems was 8.1 mg L^{-1}, which occurred in a tributary to Boyd Corners Reservoir at WESTBR7.

3.12 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 2009.) In 2011, DEP sampled 36 sites in 28 streams throughout the City's water supply watershed, 13 in the Croton System, 7 in Catskill, and 16 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 3.11 and 3.12).

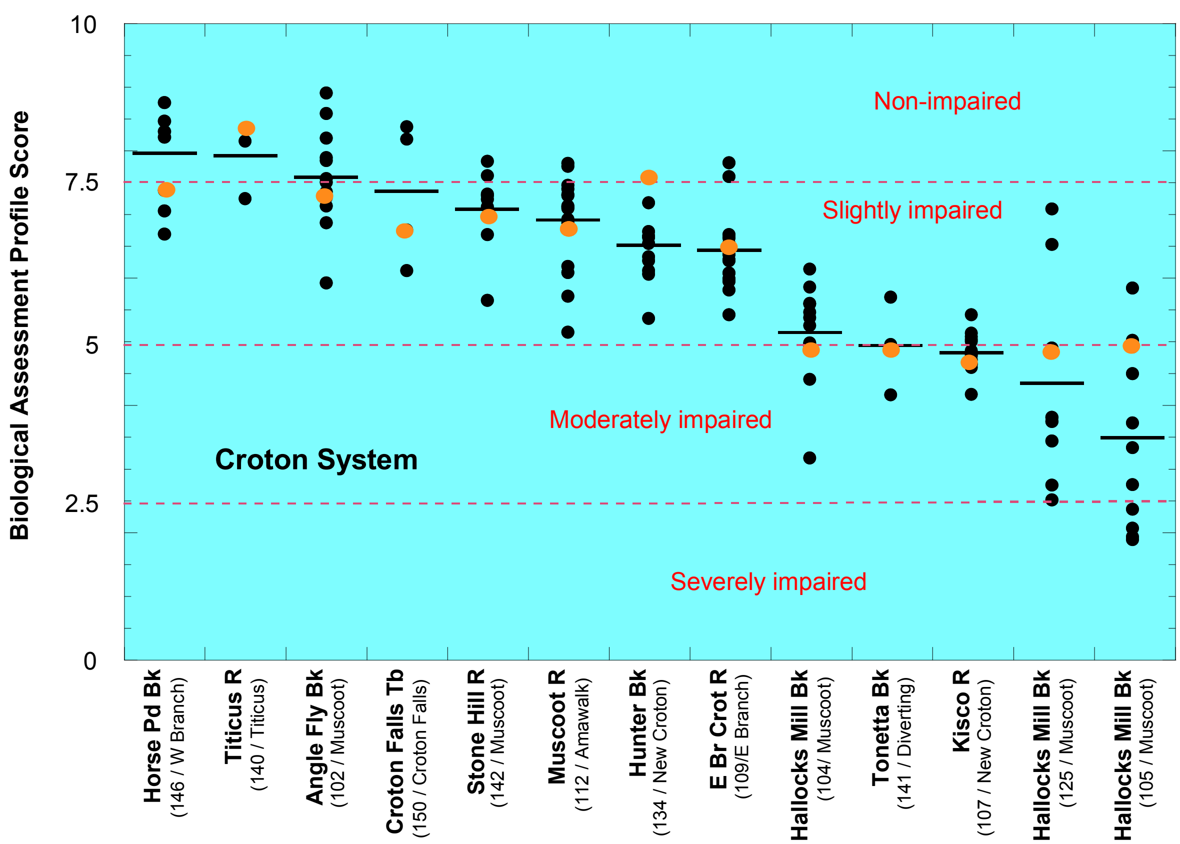

Figure 3.11 Biological Assessment Profile scores for East of Hudson biomonitoring sites sampled in 2011, arranged by mean score (——) from highest to lowest. ● = 2011 score; ● = pre-2011 score. The site's number and watershed are indicated in parentheses following the site name.

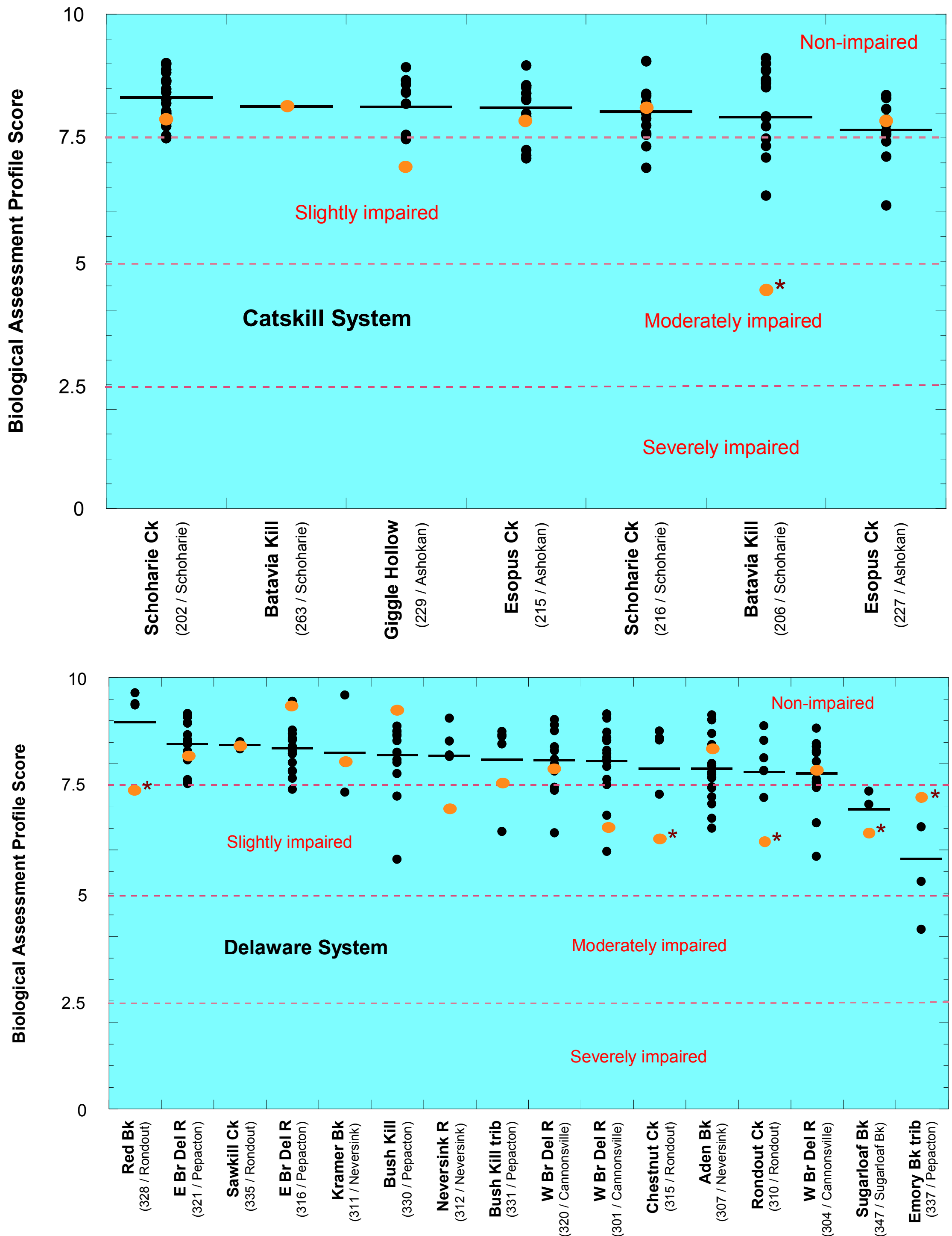

Figure 3.12 Biological Assessment Profile scores for West of Hudson biomonitoring sites sampled in 2011, arranged by mean score (——) from highest to lowest. ● (orange) = 2011 score; ● (black) = pre-2011 score. The site's number and watershed are indicated in parentheses following the site name. Scores marked with an asterisk are considered unreliable because of low subsample counts. See text for explanation.

Only 2 of the 13 East of Hudson sites were rated as non-impaired; of the rest, 7 were assessed as slightly impaired and 4 as moderately impaired. The two non-impaired sites were at the Titicus River (Site 140), which received its highest Biological Assessment Profile (BAP) score ever (8.35), and Hunter Brook (Site 134), the first time that site has ever been assessed as non-impaired (7.59).

Of the slightly impaired sites, four were very close to their long-term means, while three (Horse Pound Brook (Site 146), Croton Falls tributary (Site 150), and Hallocks Mill Brook below the Yorktown Heights wastewater treatment plant (Site 105)) demonstrated greater divergence. Horse Pound Brook's score of 7.39 was just slightly below the non-impaired/slightly impaired threshold of 7.5, and while this was considerably less than the long-term mean (7.96), it should be remembered that scores at this site have historically demonstrated considerable variability (Figure 3.11). At the unnamed tributary to Croton Falls Reservoir, an unusually large number of blackflies depressed the Percent Model Affinity and Total Taxa metrics, resulting in the low BAP score. It is not clear if this score actually represents a decline in water quality, however, as the subsample included 12 EPT—a high figure for East of Hudson—as well as 6 individuals belonging to the stonefly genus *Sweltsa* and 3 belonging to *Rhyacophila*, both very sensitive genera. The Hallocks Mill score was substantially *above* its mean (5.03 vs. 3.49) and reflects the improved community present at this site since the 2008 WWTP upgrade. (For details on the upgrade and sampling results from 2008 to 2010, see DEP 2009, 2010, and 2011.) In 2011, for the first time ever, a stonefly, *Paragnetina media*, was recorded at the site. Stoneflies are among the most sensitive macroinvertebrates recorded in streams, and have been seen on only two prior occasions in Hallocks Mill, both times at Site 104, the site above the plant. Two mayflies, one particularly sensitive (*Isonychia*), were also observed at Site 105, but were not found in the subsample.

An unexpected discovery at one of the slightly impaired sites—Anglefly Brook—was the reappearance of the stonefly *Eccoptura xanthenes*. This species, uncommon in New York State streams, was last collected at Anglefly in 1994, before construction of an upstream golf course. The previous three years had seen steadily declining scores, so the presence of *Eccoptura* in this year's subsample, together with the sharply higher score (7.36 vs. 2009's 5.93) are encouraging developments.

The four moderately impaired sites all had scores close to the moderately impaired/slightly impaired threshold of 5 (104—4.98, 107—4.72, 125—4.91, 141—4.96) and were all close to their long-term means.

Two of the moderately impaired sites were at Hallocks Mill Brook, one of them upstream of the treatment plant (Site 104), the other (Site 125) below, near the confluence with the Muscoot River. What is notable about the 2011 BAP scores at all three Hallocks Mill sites is that they are virtually identical (104—4.98, 105—5.03, 125—4.91), a reversal from prior years when the two sites below the plant consistently assessed as moderately to severely impaired, compared to the slightly impaired rating usually achieved by the upstream site. The 2011 results suggest that, three years after completion of the plant upgrade, the distinction between the macroinvertebrate communities upstream and downstream of the plant resulting from the plant's discharge has been eliminated. All sites are now dominated by hydropsychid caddisflies, riffle beetles, and midges, in addition to harboring small numbers of mayflies and the occasional stonefly. Formerly, downstream sites consisted almost entirely of midges and worms. While the improvement to the downstream sites has not been as dramatic as the initial results suggested, their scores, roughly at the slightly-to-moderately impaired threshold, represent considerable improvement nonetheless. And while all three sites do remain significantly impaired, those impairments no longer appear to be a function of the treatment plant's discharges, but more likely derive from other sources of disturbance in the Hallocks Mill Brook watershed, among them the high level of impervious surface (almost 10%).

In the Catskill System, five of the seven sites were non-impaired, one was slightly impaired (Site 229, Giggle Hollow), and one was moderately impaired (Site 206, Batavia Kill) (Figure 3.12). The Giggle Hollow assessment may not be an accurate reflection of the site's water quality, however, given that the community was dominated (62.7% of the total) by four highly sensitive taxa—*Sweltsa* sp., *Malirekus iroquois*, *Pteronarcys* sp., and *Parapsyche apicalis*. Dominance by a few sensitive taxa is a situation frequently encountered in headwater streams. The Batavia Kill site clearly reflects the impacts of Tropical Storm Irene (see below).

In the Delaware System, 9 of 16 sites were non-impaired, the rest, slightly impaired (Figure 3.12). Almost all of the slightly impaired results, however, must be considered unreliable, because of the low subsample counts (see below).

Given the severity of Tropical Storms Irene and Lee and their wide-ranging impacts throughout the watershed, the effects of the storms on West of Hudson benthic communities was remarkably light. At most sites, the impact was evidenced by markedly lower taxa counts than those observed in previous years. Other metrics were relatively unaffected, with EPT counts and HBI values actually better than normal (Figure 3.13). In most cases, the low taxa counts did not translate into lower assessments; in fact, of the 22 sites with a prior sampling record, only 5 received assessments lower than their previous ones. Four sites received improved assessments and the rest remained unchanged.

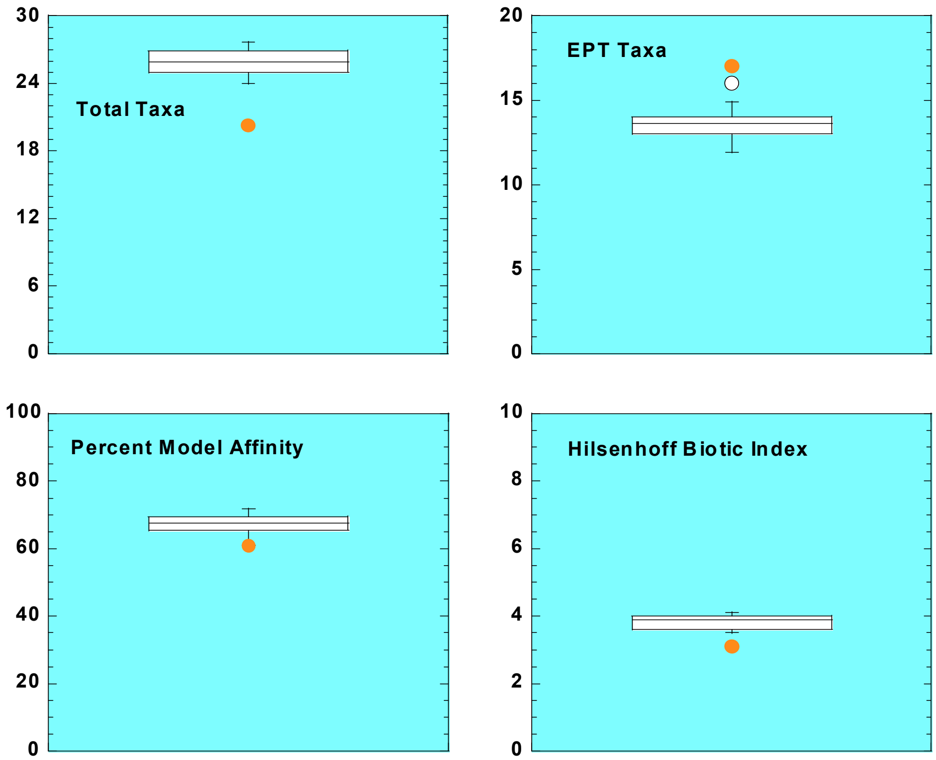

Figure 3.13 Boxplots of West of Hudson biomonitoring metric scores, 1994-2010, with the value for 2011 displayed as a dot. Note that low HBI scores indicate lack of sewage effects.

Figure 3.14 Batavia Kill at Site 206 approximately one week after being struck by Tropical Storm Lee and two weeks after Tropical Storm Irene. Arrow indicates location of sampling site.

While taxa numbers dropped everywhere, and did so with little obvious impact, a small number of sites were severely scoured by the high flows caused by the storms. As a result, subsample counts were far below the 100-count subsample mandated by the NYS Stream Biomonitoring Unit's protocols, rendering those sites' final assessments unreliable indicators of water quality. Thus, the subsample at Site 206 on the Batavia Kill had only 7 organisms, which undoubtedly contributed greatly to the 4.44 score, far less than the long-term mean of 8.13. The stream channel at this location was severely disrupted (Figure 3.14), as it was along the entire length of the Batavia Kill. (Interestingly, however, about two miles upstream, the macroinvertebrate community at Site 263 produced a remarkably high score of 8.13.) The other sites with very low abundance were all in the Delaware System: Site 315 on Chestnut Creek (12 organisms in the subsample), Site 310 on Rondout Creek (23 organisms), Site 328 on Red Brook (30 organisms), Site 347 on Sugarloaf Brook (52 organisms), and Site 337, an unnamed tributary to Emory Brook (71 organisms). All were rated slightly impaired, but as with the Schoharie Creek site, these results must be discounted based on the low subsample numbers. Sampling in future years will monitor the rate and degree of recovery of the macroinvertebrate communities at these sites.

3.13 Results of the Cannonsville Recreational Boating Pilot Study

The Cannonsville Recreational Boating Pilot (CRBP) program was initiated in 2009 to improve recreational opportunities and the economic viability of the watershed as per the New York City Watershed Memorandum of Agreement (MOA) (1997). During the program's three-year (2009-2011) trial period, canoes, kayaks, sculls, and small sailboats were allowed to utilize designated areas of Cannonsville Reservoir.

To determine if this change in boating policy would lead to a noticeable deterioration of water quality, six reservoir sites were monitored monthly from May to October in 2009, 2010, and 2011 and the resulting data were compared to water quality data from these same sites for the five-year period (2004-2008) prior to the program. The target analytes were turbidity, coliform bacteria (as per the SWTR), total nitrogen, and zebra mussels. Results from these comparisons indicated no differences between the "existing condition" time period (2004-08) and any of the CRBP years (2009, 2010, and 2011).

In 2011, an additional study was performed, evaluating the Apex Bridge Landing and Launch Area before and after the July 4 weekend. Results indicated that the site closest to the launch area had somewhat higher turbidity, fecal coliform, color, and phosphorus compared to an upstream control site, although it is uncertain how many boats were in the area during the study period. It is possible that these increases occurred through disturbance of bottom sediments during the launching of a boat. Other downstream sites during the study were not affected, and were similar to the upstream control site, suggesting that the increases were localized and short-lived.

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 642 samples for protozoan analysis during 2011, and 277 samples for HEV analysis. Source water samples (Kensico and New Croton keypoints) comprised the greatest portion of the 2011 protozoan sampling effort, accounting for 43.0% of the samples, followed by stream samples, which were 34.4% of the sample load. Sampling at the upstate reservoir effluents, wastewater treatment plants (WWTPs), the Hillview downtake, and a single limnological sample made up the remaining 22.6% (Figure 4.1).

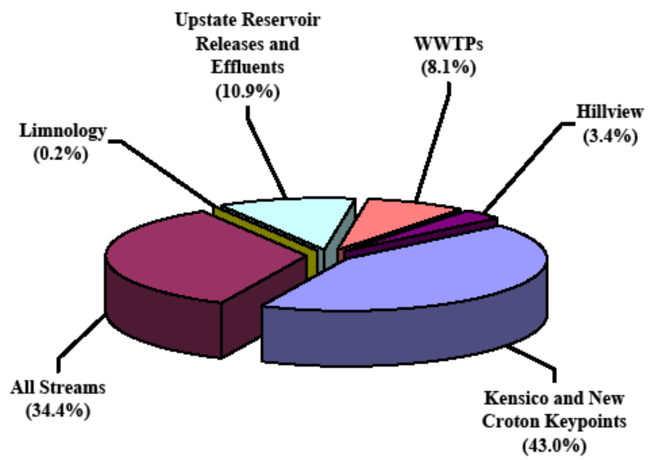

Figure 4.1 DEP protozoan sample type distribution for 2011. Data include both routine and enhanced monitoring samples.

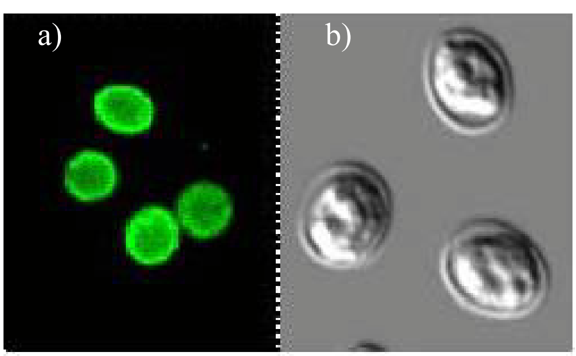

Figure 4.2 *Cryptosporidium* spp. oocysts with (a) immunofluorescent antibody stain, and (b) under differential interference contrast microscopy.

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 HEVs. All 52 weekly protozoan samples were collected and analyzed this year, with the exception of one weekly HEV sample (CATALUM), which was not collected when the Catskill influent to Kensico Reservoir was not flowing (September 6). An additional HEV sample was taken at CATALUM in January as part of a filter study, so the total number of HEV samples for this site remains at 52. The effluent results are posted 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 semiannually and annually in the FAD reports (DEP 2006c).

4.2 Source Water Results

Catskill Aqueduct

Cryptosporidium oocysts were not detected in any samples taken at CATALUM (Catskill influent to Kensico Reservoir) in 2011 (Table 4.1). *Cryptosporidium* results at CATLEFF (Catskill effluent of Kensico Reservoir) were also low, with 2 detections out of 60 samples (3.3%) and a mean of 0.03 oocysts $50L^{-1}$ for the year.

Table 4.1: Summary of *Giardia*, *Cryptosporidium*, and HEV compliance monitoring data at the five DEP keypoints for 2011.

	Keypoint location	Number of positive samples	Mean**	Maximum
Cryptosporidium oocysts $50L^{-1}$	CATALUM (n = 52)	0	0.00	0
	CATLEFF (n = 60)	2	0.03	1
	DEL17 (n = 53)	1	0.02	1
	DEL18* (n = 59)	1	0.02	1
	CROGH* (n = 52)	1	0.02	1
Giardia cysts $50L^{-1}$	CATALUM (n =5 2)	16	0.54	4
	CATLEFF (n = 60)	47	1.70	6
	DEL17 (n = 53)	41	2.06	8
	DEL18* (n = 59)	46	1.69	5
	CROGH* (n = 52)	39	2.50	12
Human Enteric Virus $100L^{-1}$	CATALUM (n = 52)	14	0.57	4.87
	CATLEFF (n = 52)	9	0.76	9.16
	DEL17 (n = 52)	7	0.38	4.46
	DEL18* (n = 52)	10	0.64	8.32
	CROGH* (n = 52)	9	1.13	18.32

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

** Samples not exactly equal to 50L are calculated to per L concentrations and then re-calculated to 50L for determination of means. Zero values are substituted for non-detect values when calculating means.

The mean *Giardia* cyst concentration at CATALUM was 0.54 cysts $50L^{-1}$, with 16 detections out of the 52 weekly samples (30.8%) (Table 4.1). CATLEFF results were higher than those at CATALUM, with a mean of 1.70 cysts $50L^{-1}$ and 47 detections (78.3%). These higher values at the Catskill effluent could be the influence of the *Giardia* entering at the Delaware Aqueduct influent, and/or 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 elevated in 2011, with a mean concentration of 0.57 MPN $100L^{-1}$ and 14 detections (26.9%) (Table 4.1), compared to a 2010 mean of 0.19 MPN $100L^{-1}$ and only 4 detections (7.7%). Detections were less frequent at CATLEFF than at CATALUM (9 detections out of 60 samples (17.3%)); however, the mean HEV concentration at CATLEFF was slightly higher (0.76 MPN $100L^{-1}$). CATLEFF HEV results also displayed an increase from the 2010 mean concentration of 0.04 MPN $100L^{-1}$ and 1 detection.

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 53 (1.9%) (Table 4.1). As in past years, *Cryptosporidium* mean concentration and detections at DEL18 (Delaware effluent of Kensico Reservoir) were quite similar to those at the influent (0.02 oocysts $50L^{-1}$ and 1 detection in 59 samples (1.7%)).

Giardia cyst mean concentration at DEL17 was 2.06 cysts $50L^{-1}$, with 41 positive samples out of the 53 collected (77.4%) (Table 4.1). The mean *Giardia* concentration at DEL18 was slightly lower (1.69 cysts $50L^{-1}$) than at DEL17, but DEL18's detection frequency was similar, with 46 positives out of 59 samples (77.9%).

HEV concentration and detection frequency at DEL17 were 0.38 MPN $100L^{-1}$ and 7 positive samples out of 52 (13.5%), respectively (Table 4.1). HEV results for DEL18 were higher than those for DEL17 during 2011, with a mean concentration of 0.64 MPN $100L^{-1}$ and 10 positive samples out of 53 (18.9%).

New Croton Aqueduct

Protozoan sample data at CROGH (New Croton Reservoir effluent) for 2011 showed a mean *Cryptosporidium* concentration of 0.02 oocysts $50L^{-1}$ and 1 positive sample out of 52 (1.9%) (Table 4.1). CROGH had a mean *Giardia* concentration of 2.50 cysts $50L^{-1}$ and 39 positive samples (75.0%). Results for HEV sampling at CROGH were higher than the previous year (2010 mean concentration of 0.08 and 2 detects out of 52 samples (3.9%) vs. a mean of 1.13 MPN $100L^{-1}$ and 9 out of 52 positive samples (17.3%) for 2011).

As in previous years, a seasonal variation could be detected for *Giardia* at all influent and effluent sites in 2011, 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 are too few oocysts detected in the source water to be statistically confident in this hypothesis. In general, *Giardia* occurrences are much more frequent and at higher concentrations than *Cryptosporidium* at the source water sites, which is common for the NYC Watershed.

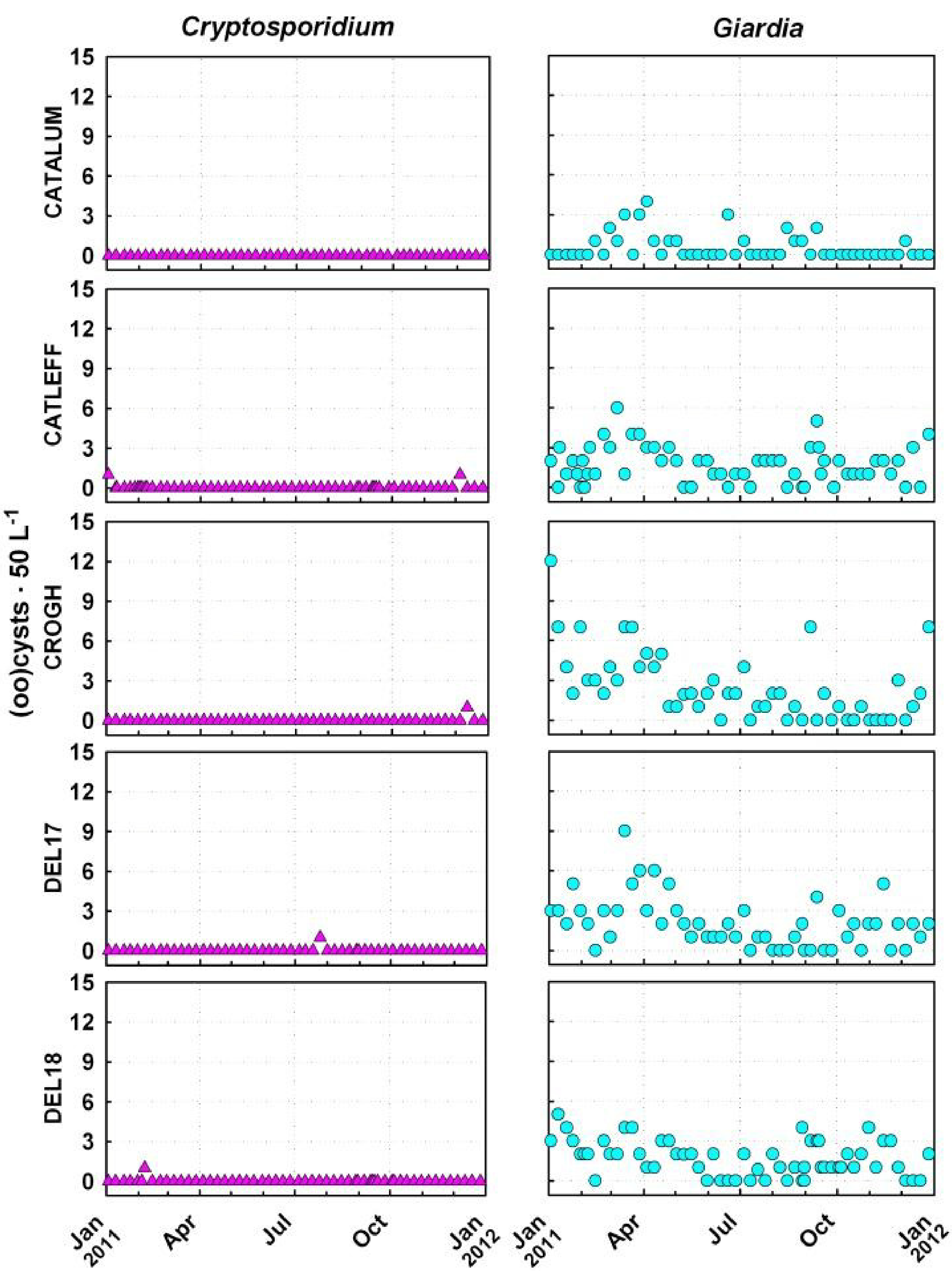

Figure 4.3 Routine weekly source water keypoint monitoring results for 2011.

4.2.1 2011 Source Water Compared to Historical Data

Water quality can vary at the source water sites depending on several factors in their respective watersheds, such as stormwater runoff, environmental impacts from land use, effects of other ecological processes, and operational changes. 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 to detect seasonal patterns and long-term changes in protozoan concentrations.

Pathogen sample data collected in 2011 indicate that concentrations of *Cryptosporidium* for most of the source water sites were comparable to data collected from 2001 to 2010. *Cryptosporidium* detections, however, were notably less frequent at source water sites in 2011, with just a few detects (5) during the year, all at concentrations of 1 oocyst $50L^{-1}$. *Giardia* concentrations at CROGH and DEL17 were slightly elevated compared to the past few years (Figure 4.4). This may be due to the occurrence of larger and more frequent precipitation events in 2011.

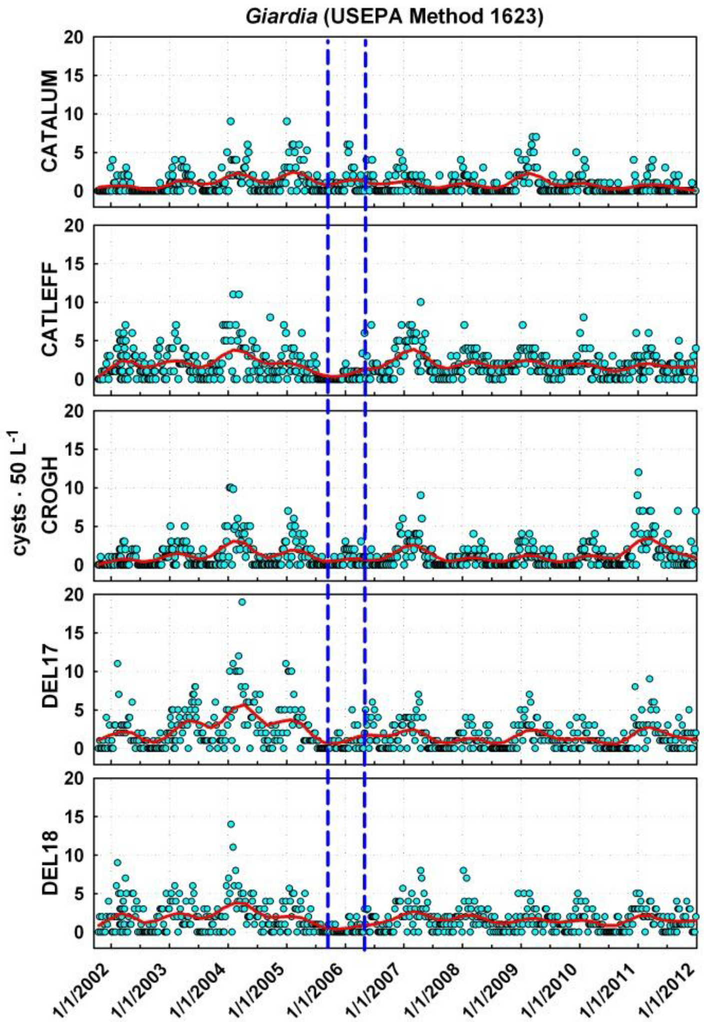

Figure 4.4 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2011. The area between the blue dotted lines indicates the period during which DEP temporarily switched to a different EPA-approved stain.

4.2.2 2011 Source Water Compared to Regulatory Levels

The Long Term 2 Enhanced Surface Water Treatment rule (LT2) (USEPA 2006) required that utilities conduct monthly source water monitoring for *Cryptosporidium* and report data from a two-year period, though a more frequent sampling schedule was permitted. 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 calculated based on the mean monthly results over the course of two years, and taking a mean of those monthly means. Figure 4.4 presents results of these calculations for the most recent two-year period (January 1, 2010-December 31, 2011) compared to the previous eight two-year periods (i.e., 2002-2010). Data from all routine and non-routine samples were used to perform the calculations. Table 4.2 displays the number and types of these samples.

Table 4.2: Number and type of samples used to calculate the LT2 bin classification set from January 1, 2010 to December 31, 2011.

Aqueduct	Number of routine samples, 2010-2011	Number of non-routine samples, 2010-2011	Total n
Croton	104	0	104
Catskill	104	8	112
Delaware	104	7	111

The mean level of *Cryptosporidium* oocysts at each of the three source waters remained below the LT2 threshold level of 0.01 oocysts L^{-1}, achieving the 99% (2-log) reduction for years 2010-2011, as it has in all previous years. Unfiltered systems that meet this requirement do not require further treatment. The averages, as shown in Figure 4.5, are as follows: 0.0012 oocysts L^{-1} at the Croton effluent, 0.0010 oocysts L^{-1} at the Catskill effluent, and 0.0004 oocysts L^{-1} at the Delaware effluent.

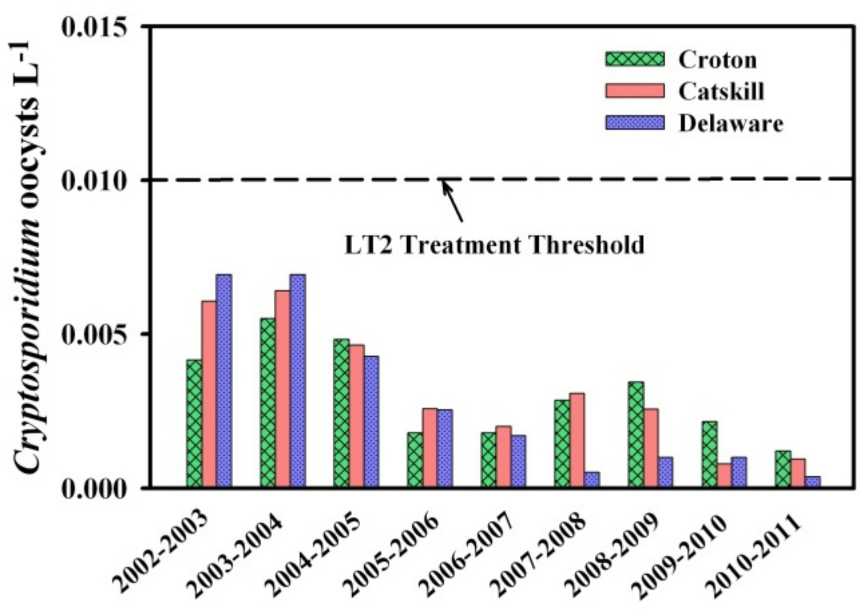

Figure 4.5 LT2 calculated means for *Cryptosporidium* since initiation of Method 1623 at DEP's three source waters (Croton, Catskill, Delaware Aqueducts), 2002-2011.

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. In the past, the effluents of the six West of Hudson (WOH) reservoirs were sampled monthly, with the Ashokan effluent being sampled weekly at the aluminum sulfate plant (CATALUM) on the Catskill Aqueduct. In 2011, DEP's monitoring plan for the upstate reservoir effluents (not including CATALUM) was modified to require monthly protozoa monitoring only when the effluent water was being sent to Kensico Reservoir. Monthly sampling also occurred in 2011 at Muscoot Reservoir (the major input to New Croton Reservoir), as specified by the CCD. Additionally, one sample was collected at Croton Falls Reservoir Release (CROFALLSR) as part of an anticipated startup to supplement water in the Delaware Aqueduct, and a non-routine sample was taken at the Ashokan Reservoir effluent (EARCM) in the aftermath of Tropical Storm Irene, when the reservoir was offline.

Of 122 protozoa samples taken from the effluents of upstate reservoirs in 2011, 7 were positive for *Cryptosporidium* (Table 4.3), representing 5.7% of samples, compared to 2.4% of samples in 2010. The seven detections for the year occurred at three different sites: three at Muscoot, three at Schoharie, and one at Ashokan (Figure 4.6). C*ryptosporidium* was not detected in the one sample collected at Croton Falls. C*ryptosporidium* concentrations remained low at upstate effluent sites, with a highest mean of 0.31 oocysts $50L^{-1}$ and a maximum of 2 oocysts $50L^{-1}$.

Table 4.3: Summary of upstate reservoir effluent protozoan results for 2011.

		Cryptosporidium				*Giardia*			
Site	n	Mean ($50\ L^{-1}$)	% Detects	Maximum	Maximum (L^{-1})	Mean ($50\ L^{-1}$)	% Detects	Maximum	Maximum (L^{-1})
CATALUM (1 @ EARCM) (Ashokan)	53	0.04	1.9%	2 (50.0 L)	0.04	0.55	32.1%	4 (50.0 L)	0.08
CROFALLSR	1	0.00	0.0%	0	0.00	1.00	100%	1 (50.0 L)	0.02
MUSCOOTR	12	0.31	25.0%	1 (28.7 L)	0.03	11.32	83.3%	43 (28.7 L)	1.50
NRR2CM (Neversink)	9	0.00	0.0%	0	0.00	5.09	77.8%	4 (9.0 L)	0.44
PRR2CM (Pepacton)	12	0.00	0.0%	0	0.00	0.99	50.0%	3 (50.0 L)	0.06
RDRRCM (Rondout)	12	0.00	0.0%	0	0.00	1.42	58.3%	2 (31.2 L)	0.06
SRR2CM (Schoharie)	11	0.27	27.3%	1 (30.4 L)	0.03	11.54	90.9%	37 (50.0 L)	0.74

Table 4.3: (Continued) Summary of upstate reservoir effluent protozoan results for 2011.

		Cryptosporidium				*Giardia*			
Site	n	Mean (50 L^{-1})	% Detects	Maximum	Maximum (L^{-1})	Mean (50 L^{-1})	% Detects	Maximum	Maximum (L^{-1})
WDTO (Cannonsville)	12	0.00	0.0%	0	0.00	2.34	66.7%	9 (32.0 L)	0.28

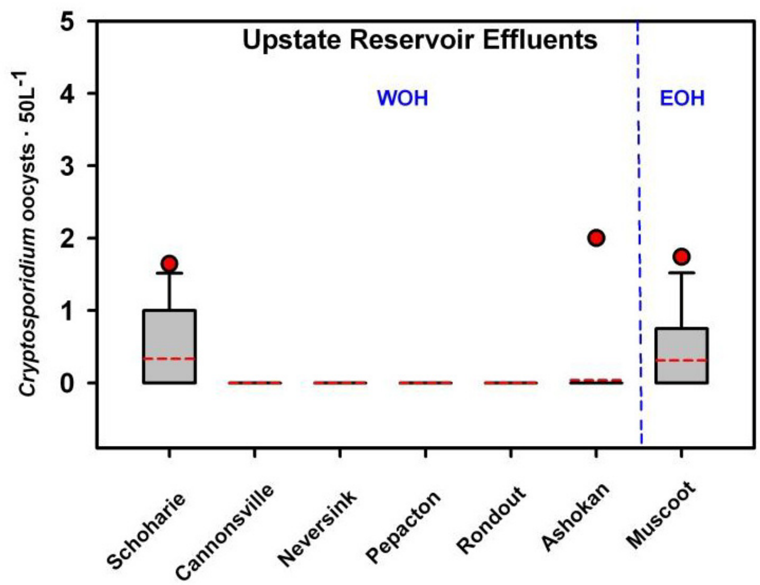

Figure 4.6 2011 summary of *Cryptosporidium* distribution among WOH and EOH basins (--- mean, — median, ● outliers). Refer to Table 4.3 for sample sizes.

Giardia was detected in 66 samples in 2011 (54.1%), which is 0.7% less than detections in 2010. Mean concentrations in 2011 (Table 4.3) were similar to those in 2010 at CATALUM, PRR2CM, RDRRCM, SRR2CM, and WDTO. Muscoot and Neversink mean *Giardia* concentrations were elevated in 2011 (74% and 250% change, respectively), each heavily influenced by a single high result. Muscoot had a *Giardia* result in March of 43 cysts 28.7L^{-1}, which contributed greatly to increasing the annual mean per 50 liters from 6.50 in 2010 to 11.32 in 2011 (Figure 4.7). Similarly, a sample taken in July from the Neversink effluent had 4 cysts 9L^{-1}, increasing the annual mean per 50 liters from 2.04 in 2010 to 5.09 in 2011. The only sample taken at Croton Falls in 2011 had one *Giardia* cyst 50L^{-1}.

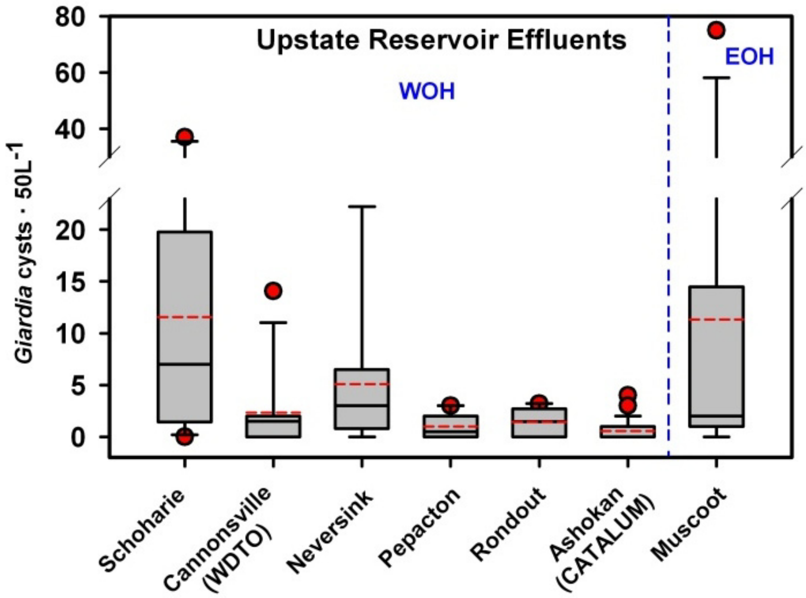

Figure 4.7 2011 summary of *Giardia* distribution among WOH and EOH basins (--- mean, — median, ● outliers). Refer to Table 4.3 for sample sizes.

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 (WWQMP) (DEP 2009), including 8 streams in the WOH System and 10 in the East of Hudson (EOH) System (of which 8 are perennials in the Kensico basin and 2 are located in the Croton watershed, as required for CCD monitoring). During 2011, 221 samples were collected, which includes 5 additional samples taken in the WOH System and one additional sample in the EOH System.

West of Hudson Streams

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. Thus, two of the sites listed for monitoring in the 2009 WWQMP (ABCG and PMSB) were not sampled in 2011, so that new upstream sites could be sampled above the site found to have had the highest *Giardia* concentrations in 2009 (S7i). During 2011, DEP sampled two upstream sites monthly, concurrently with S7i. Because the upstream sites were changed twice during the year, a total of four different upstream sites (S7iB, S7iD, S7iE, and S7iD1) were sampled in 2011. Five additional samples were taken at S7i on May 24 as part of a study designed to look at the variability in

Giardia cyst concentration. Moreover, one additional sample was taken at Malcolm Brook after Tropical Storm Irene, and one scheduled sample was missed at site S7iD in January when the section of the Manorkill where the site is located was frozen over.

Incidence of *Cryptosporidium* in the WOH watershed streams was low in 2011, with 28 out of 100 samples (28.0%) testing positive and a maximum single sample concentration of 5 oocysts $25.1L^{-1}$ at PROXG (East Branch Delaware River at Roxbury) in September (Table 4.4). As a result, the highest mean *Cryptosporidium* concentration per site (1.52 oocysts $50.0L^{-1}$) was found at PROXG. C*ryptosporidium* was detected at this site in 8 out of 12 samples (66.6%). G*iardia* was observed far more frequently at the WOH stream sites compared to *Cryptosporidium*, with 98.0% of samples (98 of 100) testing positive. G*iardia* also occurred in higher concentrations in WOH stream samples, with 7 of the 10 sampled sites having annual mean concentrations of 25 cysts $50.0L^{-1}$ or higher (Table 4.4).

Table 4.4: Summary of watershed stream protozoa results for WOH sites in 2011. ns = not sampled to allow new sites to be sampled upstream of S7i. See text for explanation.

		Cryptosporidium			*Giardia*		
Site	n	Mean ($50\ L^{-1}$)	Maximum	Maximum (L^{-1})	Mean ($50\ L^{-1}$)	Maximum	Maximum (L^{-1})
ABCG	0	ns	ns	ns	ns	ns	ns
CDG1	12	0.92	6 (50.0 L)	0.12	45.07	243 (50.0 L)	4.86
PMSB	0	ns	ns	ns	ns	ns	ns
PROXG	12	1.52	5 (25.1 L)	0.20	88.16	156 (41.4 L)	3.77
S4	12	0.17	1 (50.0 L)	0.02	56.09	136 (50.0 L)	2.72
S5i	12	0.08	1 (50.1 L)	0.02	34.36	79 (50.0 L)	1.58
S7i	17	0.29	2 (50.0 L)	0.04	26.24	84 (50.0 L)	1.68
S7iB	12	0.42	3 (49.9 L)	0.06	21.75	54 (50.0 L)	1.08
S7iD	4	0.00	0	0.00	20.75	60 (50.0 L)	1.20
S7iD1	2	1.50	3 (50.1 L)	0.06	31.46	43 (50.1 L)	0.86
S7iE	5	0.20	1 (50.0 L)	0.02	3.20	8 (50.0 L)	0.16
WDBN	12	0.17	1 (50.0 L)	0.02	29.69	226 (50.0 L)	4.52

Monitoring of S7i sites has progressed upstream for the last few years as DEP selects sites every few months which systematically segregate the influence of a few tributaries . *Giardia* results from sites S7iB and S7iD were consistent with those at the downstream S7i site, so a new site further upstream (S7iE) was selected to replace S7iD while keeping S7iB as a downstream reference (Figure 4.8). Monitoring results indicated low *Giardia* concentrations at the S7iE site, inconsistent with higher results at downstream sites sampled on the same day. After five months of sampling at S7iE, a new site (S7iD1) was selected downstream of S7iE and upstream of S7iD to try to narrow down the potential source between the two. Results from November and December 2011 show comparable *Giardia* levels at S7i, S7iB, and S7iD1, consistent with the goal of source tracking.

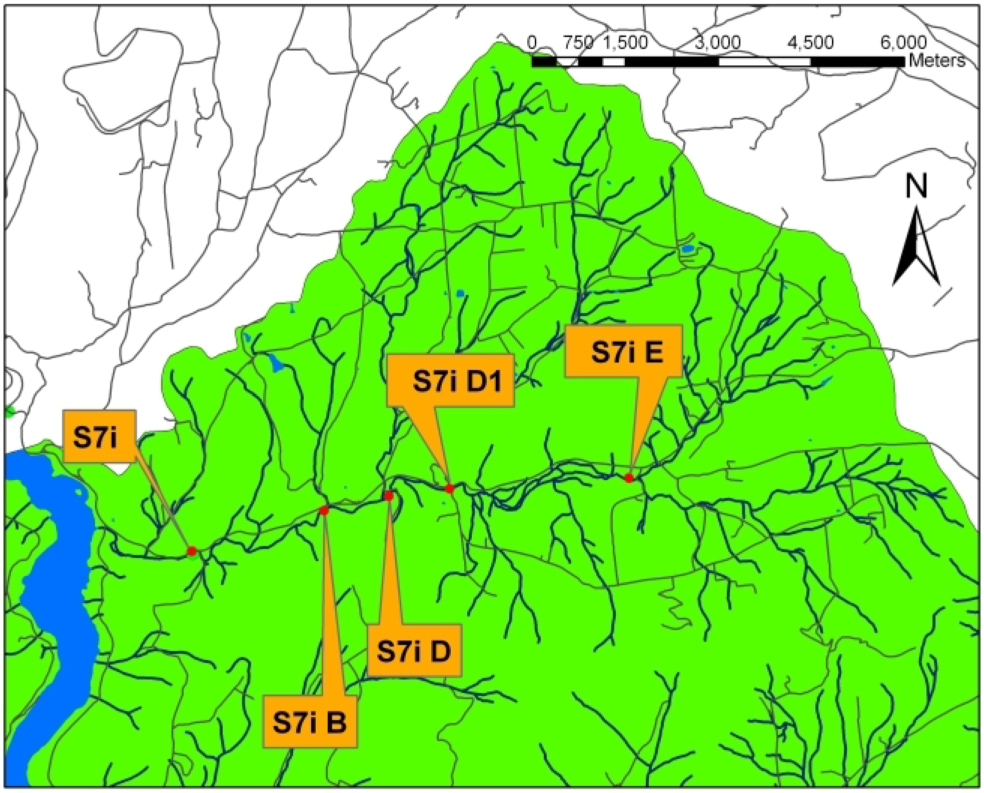

Figure 4.8 Map of the Manorkill sub-basin in the Schoharie watershed, portraying pathogen monitoring sites sampled in 2011.

In addition to routine monitoring, supplemental samples were collected at S7i in 2011 to get a preliminary idea of the intrasite and temporal variability of protozoan concentrations during baseflow. Samples were collected in duplicate approximately two hours apart from each other, at three different times throughout the day, for a total of six 50-L samples. Duplicate sample data were in accord with the initial sample data for both protozoans on all three occasions, with a maximum difference of 5 cysts for *Giardia* and 2 oocysts for *Cryptosporidium*. Temporal differences ranged from a low of 7 *Giardia* at the end of the day compared to a high of 20 cysts collected in the middle of the day. This preliminary temporal difference provides valuable information to consider when comparing data from sites that are collected along the stream at different times of the day. *Cryptosporidium* results were low for all samples, ranging from 0 to 2 oocysts.

In summary, the main source of *Giardia* along this reach of S7i has been narrowed down to somewhere between S7iE and S7iD1. An alternate site, S7iD2, has been selected and will be sampled in 2012. Additionally, preliminary intrasite and temporal sampling indicate reasonable differences between samples and their duplicates, and show a range of variability of *Giardia* of between 7 and 20 cysts $50L^{-1}$ throughout the course of seven hours. This information will be considered in the future when comparing data from samples at different sites collected throughout the course of a day.

East of Hudson Streams

Results at EOH stream sites showed consistently low *Cryptosporidium* concentrations with the highest single sample concentration being 4 oocysts $41.7L^{-1}$ at E9, and all sites having low mean concentrations (below 0.9 oocysts $50L^{-1}$) (Table 4.5). EOH streams also had a very low detection rate of 12.4% (15 out of 121 samples).

Table 4.5: Summary of watershed stream protozoan results for EOH sites in 2011.

		Cryptosporidium			*Giardia*		
Site	n	Mean (50 L^{-1})	Maximum	Maximum (L^{-1})	Mean (50 L^{-1})	Maximum	Maximum (L^{-1})
BG9	12	0.08	1 (50.0 L)	0.02	11.19	36 (50.0 L)	0.72
E10	12	0.00	0	0.00	3.76	9 (50.0 L)	0.18
E11	12	0.08	1 (50.0 L)	0.02	25.98	54 (27.0 L)	2.00
E9	12	0.85	4 (41.7 L)	0.10	49.01	143 (49.9 L)	2.85
HH7	12	0.00	0	0.00	109.65	537 (41.6 L)	12.91
MB-1	13	0.00	0	0.00	9.47	17 (19.5 L)	0.87
N12	12	0.08	1 (52.0 L)	0.02	10.99	59 (47.6 L)	1.24
N5-1	12	0.17	1 (50.0 L)	0.02	18.78	38 (24.0 L)	1.58
WF	12	0.35	1 (23.0 L)	0.04	9.78	12 (14.9 L)	0.81
WHIP	12	0.42	2 (50.0 L)	0.04	10.58	27 (50.0 L)	0.54

As with the WOH results, *Giardia* concentrations in EOH stream samples were consistently much higher—with means 25 to 325 times more—than concentrations of *Cryptosporidium*. As was the case in 2010, HH7 and E9 had mean *Giardia* concentrations several times higher than at most other EOH sites. Maximum *Giardia* concentrations for both of these sites were over 100 cysts $50L^{-1}$, with each site having five samples over 45 cysts $50L^{-1}$.

4.5 Wastewater Treatment Plants

DEP monitored WWTP effluents for protozoa at eight WOH plants and three EOH plants during 2011. Sampling was conducted quarterly at all treatment plants except at Brewster (BSTP), which was monitored monthly for protozoa and bimonthly for human enteric viruses (HEV), as specified by the CCD. A total of 52 protozoa samples and 6 virus samples were collected, of which 5 were positive for *Giardia,* 1 was positive for HEV, and no samples were positive for *Cryptosporidium* (Table 4.6).

Table 4.6: Protozoan and HEV results at WWTPs in 2011. ns = not sampled, nd = non-detect.

Date	Site	Plant	Sample Volume (L)	*Cryptosporidium*	*Giardia*	HEV
2/22/2011	Windham WTP	Windham	50.0	0	3	ns
4/12/2011	BSTP	Brewster	50.0	0	1	ns
5/17/2011	BSTP	Brewster	50.0	0	1	nd
9/15/2011	PANDE	Andes	50.0	0	2	ns
11/15/2011	BSTP	Brewster	50.0	0	0	1.03
12/21/2011	HUNTER HIGHLANDS BD	Hunter Highlands	50.0	0	1	ns

Of the eight WOH plants, three had *Giardia* detections (Windham, Andes, and Hunter Highlands), each plant with one positive sample. The highest concentration was 3 cysts $50L^{-1}$ at Windham in February. Windham WWTP operators reported no violations that might have led to the February detection; however, it should be noted that the sample was taken on the Tuesday after President's Day, a three-day holiday weekend, and that the WWTP receives flow from the local ski center and lodgings. The inspector's reports indicate there were high flows from the Windham Ski Center and a total of 0.6 inches of precipitation that weekend. While the turbidity values were higher than normal, they were well within allowable limits.

On September 15, approximately one week after Tropical Storm Lee, *Giardia* cysts were detected at Andes (2 cysts $50L^{-1}$). The storm and subsequent plant operations may provide a possible explanation for these detections. In order to prevent an overflow at the plant after the storm, some treatment steps (sequential batch reactors, sand, microfiltration) were bypassed on September 7. Plant operators resumed treatment steps on September 8, with sand and microfiltration coming back on-line September 9 at 8:00 am. After the plant resumed normal operations on September 9, the post-aeration tank, ultraviolet lights and trough, and the effluent meter pit were cleaned. All of this activity, in addition to continued drainage from the storms, may have provided a source for the 2 *Giardia* cysts found in the sample collected on September 15.

The third WOH *Giardia* detection was at the Hunter Highlands WWTP. The sample for the last quarter at this location had to be rescheduled three times due to low flow. Eventually, a sample was collected on December 21, which was positive for *Giardia* (1 cyst $50\ L^{-1}$). However, it was later discovered that the plant was performing a recirculation procedure at the time of collection, and that the sample was not representative of the final effluent. DEP will be coordinating with operators to avoid sampling under these conditions in the future.

In the EOH System, two samples were found positive for *Giardia*, both at the Brewster WWTP and both at very low concentrations (1 cyst 50 L^{-1}). In addition, for the first time since September 2006, there was a positive HEV detection at the Brewster WWTP, occurring on November 15 (1.03 MPN 100 L^{-1}). Plant operators did not indicate any abnormal circumstances or special conditions which might explain the virus detection.

4.6 Hillview Monitoring

After an assessment of data collected from 2006 to 2008, and as part of the Hillview Administrative Order, a routine sampling program for *Giardia* and *Cryptosporidium* was developed for the Catskill outflow from Hillview Reservoir at Site 3. Weekly monitoring began in August 2011, with 22 samples being collected from the site by the end of the year. Four of the samples (18.2%) were positive for *Giardia* (Table 4.7), and in all of them concentrations were low, with only one sample greater than 1 cyst 50L^{-1} (range = 0-2). C*ryptosporidium* was not detected in any of the 2011 Site 3 samples.

Table 4.7: Summary of Hillview Site 3 monitoring results for 2011.

	Cryptosporidium	*Giardia*
n	22	22
Detects	0	4
% Detects	0.0	18.2
Mean (50L^{-1})	0.00	0.23
Maximum (50L^{-1})	0.00	2.00

5. Modeling for Watershed Management

5.1 Overview of DEP Modelling System

DEP uses models to examine how changes in land use, population density, ecosystem processes, and climate, as well as both watershed and reservoir management policies, affect the NYC Water Supply. 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 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).

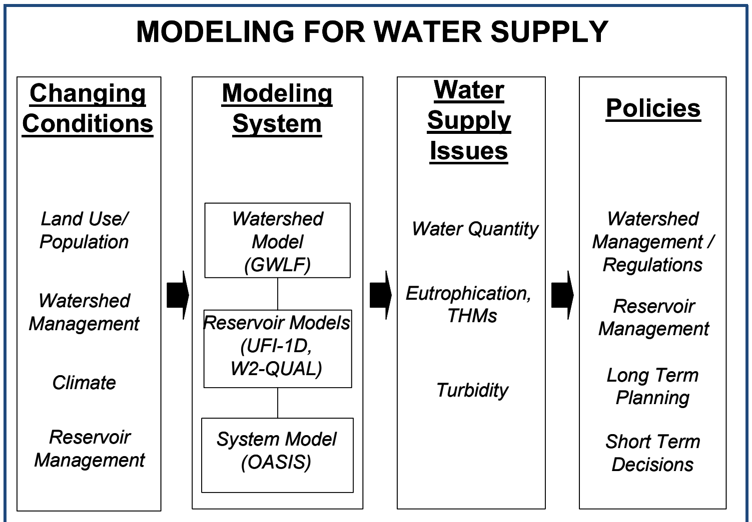

Figure 5.1 Use of models to manage the NYC Water Supply.

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 Catskill/Delaware System. 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. Model improvements are under way to enhance DEP's ability to evaluate agricultural best management practices (BMPs), stream channel stability and turbidity transport in the Catskill System, and forest management. The effects of climate change on the water supply are currently under investigation using the modeling system.

5.2 Modeling Applications to Support Reservoir Operations Decisions

Storm-generated turbidity in the NYC Watershed—particularly in the Catskill System, consisting of the Schoharie and Ashokan Reservoirs and their respective watersheds—is an important water quality issue that constrains the operation of the NYC Water Supply. When turbidity events occur, water system reservoirs are carefully managed to control turbidity at keypoints where regulatory limits must be maintained. In extreme cases, alum treatment may be applied to reduce turbidity in Kensico Reservoir. Such treatment is costly and has environmental implications, and every effort is made to avoid alum treatment by careful operation of the reservoir system.

An integral component 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 system models, near-real-time data describing flows and water quality, and meteorological and streamflow forecasts, to test operational strategies that control turbidity levels and at the same time ensure that water demands continue to be reliably met. The OST couples implementation of the CE-QUAL-W2 reservoir model, developed specifically to simulate turbidity in the Catskill System reservoirs, to the OASIS model, a water system model used to simulate reservoir system volumes and flows. The combined modeling system simulates the relationship and feedback between reservoir turbidity levels and reservoir operations. The OST can be used to evaluate water system operational strategies in order to gain understanding of the effects of these decisions on future water system quantity and quality. 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. A number of improvements to the modeling system continue to be developed, including: updating of the underlying reservoir models to use the latest versions of the W2 software, improvements to the reservoir model setup to decrease run time, continuing efforts to improve turbidity-flow relationships for forecasting turbidity loads to the reservoirs and evaluation of results of model applications.

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. Multiple future forecasts are made, using the flows, derived turbidity loads, and meteorological inputs for the same three-month period in each year from 1948 to 2004. For Kensico, a similar positional analysis approach is used, except that aqueduct input flows and turbidities are fixed at differing levels to evaluate the sensitivity of effluent turbidity to variations in input conditions. Such simulations help determine the optimal ratios of Catskill System and Delaware System inputs to the reservoir, given the turbidity levels in each system, while accounting for the variability associated with year-to-year changes in weather. The results of the positional analysis are typically presented as a range of potential outcomes based on the potential variability in near-term future meteorology, flows, and turbidity.

During 2011, there were three periods of elevated turbidity in the Catskill System. Alum treatment was needed during portions of all three events, and model runs were used to minimize both the duration of alum treatment and the amount of alum used when treatment was necessary. In response to these turbidity events, 17 sets of model analyses were performed.

The first period was during January 2011. At that time turbidity in Ashokan Reservoir was already elevated due to a combination of storm events that had occurred between October and December 2010. During the fall of 2010, model simulations were helpful in successfully mitigating the effects of these events without the use of alum (DEP 2010). Continuing model runs were used to develop operational strategies that were successful in avoiding alum use through much of January, while maintaining acceptable Kensico effluent turbidity, despite a prolonged period of relatively high Catskill turbidity. However, by the end of January, water quality conditions in Kensico Reservoir had declined. A plume of turbid Catskill water that traveled directly under the ice had reached the effluents, necessitating alum treatment of water entering Kensico from the Catskill influent. In February, alum treatment ended early in the month, and more modeling simulations were required to optimize aqueduct flows in the absence of alum treatment.

The second modeling period occurred in May 2011. DEP began using alum on the Catskill influent to Kensico Reservoir again in March, due to late winter/early spring snowmelt events that increased turbidity in Ashokan Reservoir. The modeling simulations in May were used to help determine the best time to end alum treatment and the appropriate flow rates after alum treatment was concluded.

The final set of 2011 modeling simulations was performed during the fall. Due to the effects of Tropical Storms Irene and Lee on both Ashokan and Rondout Reservoirs, alum treatment was initiated on the Catskill influent to Kensico Reservoir immediately following the storms. These events resulted in unusually challenging conditions. The record flows associated with Irene resulted in extremely high Ashokan Reservoir turbidity as well as unusually elevated turbidity from the Delaware influent. Kensico Reservoir water quality modeling was performed during September and October to inform decisions regarding aqueduct flow rates into Kensico Reservoir to maintain acceptable effluent turbidity levels. In addition, simulations of Ashokan and Schoharie Reservoirs were completed to estimate the potential length of time during which alum use might continue to be necessary.

A typical example of an analysis for Kensico Reservoir is described here. From March through early May, alum was used to reduce turbidity entering Kensico Reservoir from the Catskill Aqueduct. By mid-May, turbidity in the Ashokan Reservoir effluent had declined, and a decision to stop alum treatment was being contemplated. Modeling simulations were run to examine the effects of ceasing alum treatment, and to provide guidance for setting Catskill Aqueduct flows into Kensico Reservoir in the absence of alum addition.

Sensitivity simulations for Kensico Reservoir were performed in the positional analysis framework, using meteorological forcings and aqueduct input water temperatures for the years 1987 to 2004 (18 traces) to represent historical variability in the model forcings. The simulations were run for a 30-day forecast period from May 18 to June 17. Initial reservoir conditions were based on a combination of data from limnological surveys and from automated monitoring buoys operating in Kensico Reservoir. For all runs the input turbidity from the Delaware Aqueduct was set to 1.2 NTU based on conditions at the time. To test various inflow and turbidity combinations from the Catskill Aqueduct to Kensico Reservoir, flows were set to 300 and 400 MGD and input turbidities were set to 6, 8, 10, and 12 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow to the reservoir equaled 1,100 MGD. Each of the simulations assumed that these inputs and outputs were constant for the 30-day forecast period.

In Figure 5.2, results of a subset of the simulations covering the 300 and 400 MGD flow rates and 8 and 12 NTU influent turbidities are shown. A sustained Catskill Aqueduct turbidity of 8 NTU, at a flow of 300 MGD, produced Kensico effluent turbidity levels of 1.8 to 2.5 NTU by the end of the period (Figure 5.2a), while increasing the flow to 400 MGD produced simulated Kensico effluent turbidity in the range of 2.2 to 3.2 NTU (Figure 5.2b). Simulations using inputs of 12 NTU water from the Catskill Aqueduct generally suggested that Kensico effluent turbidity would be greater than 3 NTU at either flow rate (Figure 5.2c, d). These results indicated that without alum treatment, 8 NTU at 300 MGD from Ashokan Reservoir could be used for input to Kensico Reservoir without compromising safe water quality standards.

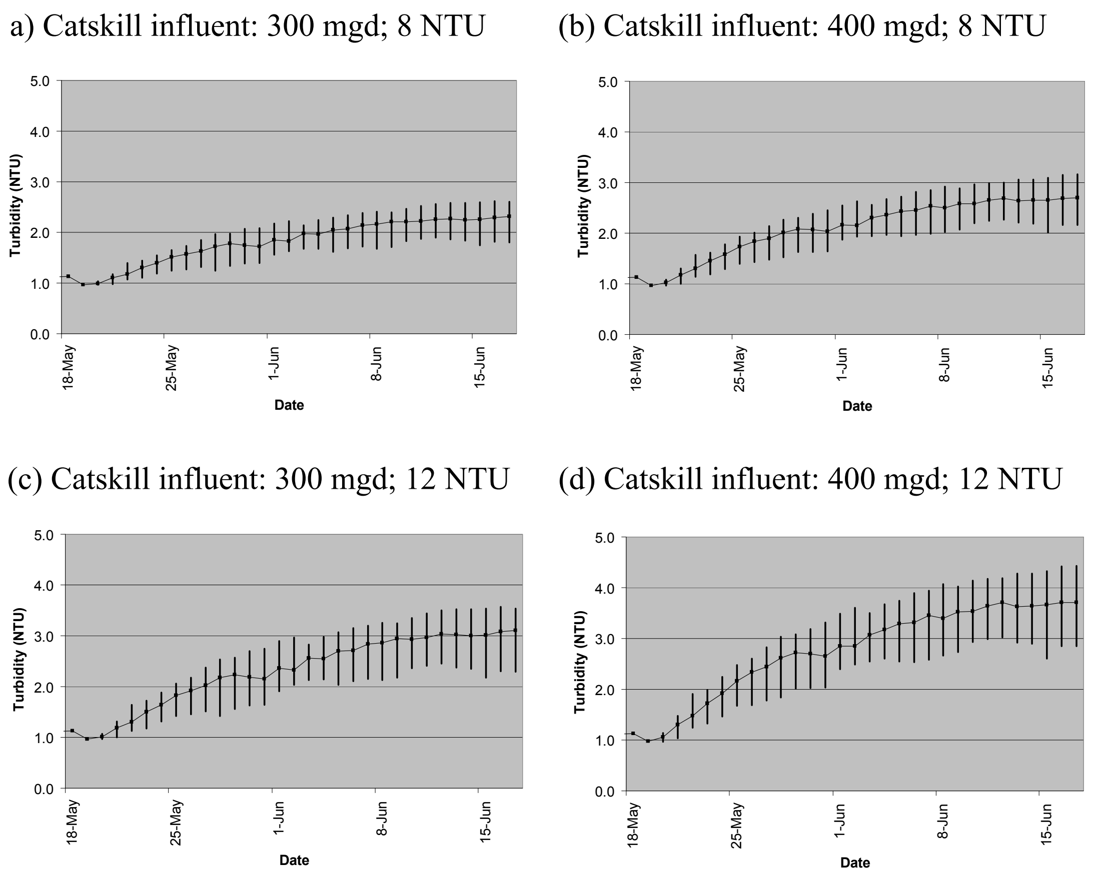

Figure 5.2 Selected results of Kensico Reservoir turbidity simulations for May 18, 2012. Simulated Catskill Aqueduct effluent turbidity with constant input from Catskill Aqueduct of (a) 8 NTU at 300 MGD and (b) 8 NTU at 400 MGD, and (c) 12 NTU at 300 MGD and (d) 12 NTU at 400 MGD. The line on the graph shows the median of the 18 traces from the positional analysis; the vertical bars show the range of values for all traces.

5.3 Use of Modeling System to Evaluate Watershed Management Programs

DEP utilizes simulation models to understand and quantify the effects of land use and watershed management on the quality and reliability of the NYC Water Supply. The models encapsulate the key processes and interactions that control generation and transport of water, sediment, and nutrients from the land surface, through the watersheds, and within the reservoirs. This allows the estimation of watershed loads and reservoir water quality under varying land use and watershed management scenarios. Information provided by model applications on nutrient and sediment sources and flow pathways can help focus watershed management and planning on the critical land uses and transport pathways that influence loads to reservoirs. Coupling simulated watershed loading estimates to reservoir water quality models allows the timing and the source of watershed loads to be examined in relation to simulated changes in reservoir water quality.

Previous applications of the modeling system have focused on evaluating the effects of nonpoint source watershed management programs, point source upgrades, and land use change on eutrophication in Cannonsville and Pepacton Reservoirs (DEP 2011). Nonpoint source programs evaluated by simulating their effects on nutrient loading in the GWLF model included the watershed agricultural program, riparian buffer protection program, stormwater upgrade program, and the septic upgrade program. Reductions in point source sewage treatment releases as a result of wastewater treatment plant (WWTP) upgrades were also included in the model simulations. As reported in the 2011 Watershed Protection Program Summary and Assessment (DEP 2011), comparison of modeling scenarios for a baseline period (1990s prior to implementation of Filtration Avoidance Determination watershed management programs) and two post-implementation periods (early 2000s and late 2000s) showed significant declines in phosphorus loadings and chlorophyll levels in Delaware System reservoirs. The decline was particularly noticeable in Cannonsville Reservoir from the 1990s through the two post-implementation periods, and could be attributed to a combination of point source reductions through WWTP upgrades, nonpoint source reductions by application of BMPs (particularly agricultural BMPs), and naturally-occurring reductions in agricultural land use.

Work is under way to integrate the United States Department of Agriculture Soil and Water Assessment Tool (SWAT) (Gassman et al. 2007) into the DEP suite of simulation models. SWAT was developed for agricultural watersheds and simulates farm management practices in more detail than the GWLF watershed model currently in use in DEP's modeling system. Applications of the SWAT model should provide enhanced estimation of the effectiveness of agricultural BMPs to control nutrient loadings in the NYC Watershed.

Turbidity control is of great importance, particularly in the Catskill System watershed. Work is under way to enhance the DEP modeling system for evaluating sources and transport of sediment and turbidity in the Catskill System watershed and the potential role of watershed management in turbidity control. DEP is collaborating with National Sedimentation Laboratory (NSL) and Cornell University scientists to develop a CONCEPTS model application in the Esopus Creek watershed. The CONCEPTS model (Langendoen et al. 2009) simulates stream channel processes that are believed to be the main sources of turbidity in the Catskill System watershed. DEP scientists participated in a CONCEPTS model workshop given by Dr. Eddy Langendoen of NSL (the developer of the model). A grant proposal has been submitted jointly by NSL, Cornell, and DEP scientists to provide data and further support this effort.

The DEP modeling program is developing an application of the RHESSys forest ecosystem model (Tague and Band 2004). Forests cover the majority of the 1,600-square-mile drainage area of the West of Hudson System. As the predominant land cover type in the NYC Watershed, forests play an important role in determining the water, nutrient, and sediment inputs to the reservoir system by regulating evapotranspiration, storing nutrients, stabilizing soils, and attenuating surface runoff. New York City has active programs to manage forests on City-owned lands and to guide forest management on privately-owned lands in the watershed. These programs have a primary goal of maintaining high water quality in the reservoir system, and are developing initiatives to promote long-term forest health as well as respond to forest disturbances. RHESSys is a spatially-distributed forest ecosystem model useful for assessing forest management strategies. DEP scientists are collaborating with Dr. Lawrence Band of the University of North Carolina (the primary author of the model) to develop a NYC Watershed model application, and hope to participate in a proposed project to evaluate forest ecosystems in the eastern United States using the RHESSys model.

5.4 DEP Modeling Efforts 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 NYC Water Supply (Figure 5.3). This work is occurring as part of the DEP Climate Change Integrated Modeling Project (CCIMP) that specifically focuses on three potential impacts:

- The effects of climate change on systemwide 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 trophic status. This includes studies of the watershed processes that regulate nutrient loss and transport, reservoir thermal structure and mixing, and reservoir nutrient use and phytoplankton growth.

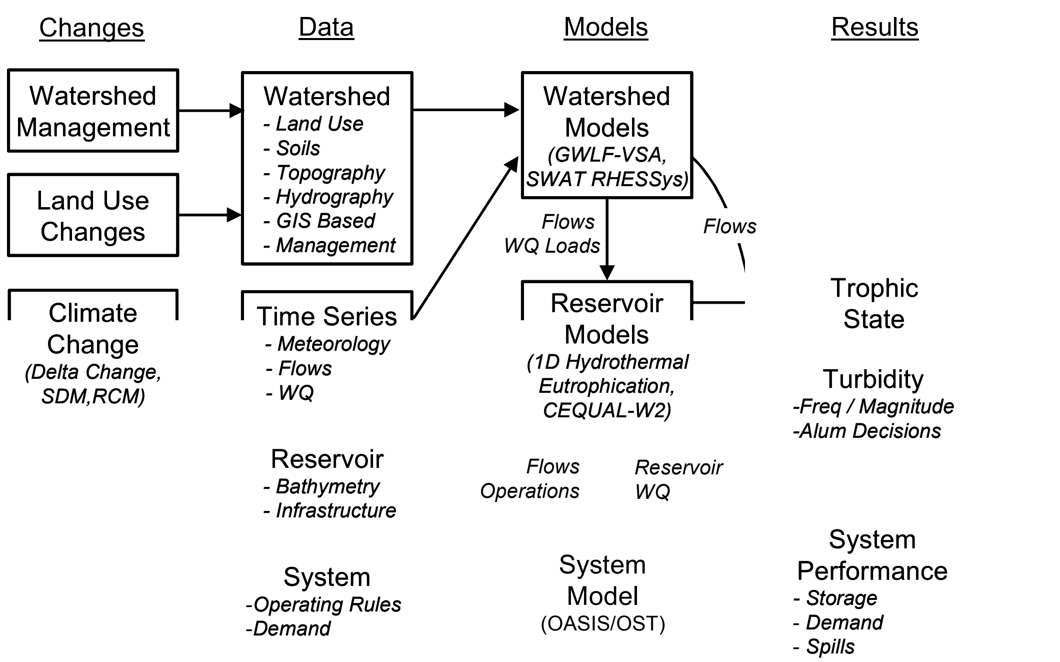

Figure 5.3 Schematic diagram depicting DEP modeling system and its use. During 2011 all models shown in the figure were used for climate change-related simulations.

Preliminary Phase I investigations focused on estimating future climate projections using four climate models, looking 65 years and 100 years into the future under three greenhouse gas emission scenarios. For each combination of Global Climate Model (GCM), time period, and emission scenario, future scenarios of the meteorological data needed to drive watershed and reservoir models were developed, and watershed and reservoir model simulations run. The most consistent finding of this preliminary work was 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. To date, 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, 2012), 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). During 2011, a report detailing the results of the first phase of the CCIMP was completed (DEP 2012), fulfilling the requirements outlined in the NYC DEP climate change action plan (DEP 2006).

In 2011, following completion of the first phase of the CCIMP, work began on the second phase of the climate change evaluation. While the general goals of the evaluation remained the same, a number of improvements were made to both the models used in the evaluation and the future climate scenarios used to drive the modeling system (Figure 5.3). An important improvement to the work defining Phase II of the CCIMP was the use of a much more extensive set of future climate scenarios. DEP downloaded all GCM scenarios that contained the data needed by its models from the Intergovernmental Panel on Climate Change Coupled Model Intercomparison Project phase three archive (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php/), and used these to develop future meteorological scenarios. From the 20 GCM model scenarios, 3 emission scenarios, and 2 future time periods, scenarios were developed using two different change factor downscaling methods. The first developed monthly change factors by comparing baseline and future GCM scenarios and applying these change factors to local records of meteorology to produce the future climate scenarios. The second downscaling method was developed by DEP itself (Anandhi et al. 2011a). This method is similar in concept to the single monthly change factor method described above, but makes use of the monthly frequency distribution of the meteorological data to develop multiple monthly change factors. In this method, the magnitude of the change factor can vary with the magnitude of the meteorological variable, so that, for example, large precipitation events can be increased by a greater magnitude than small events. During 2011, DEP began to evaluate the differences between the two downscaling methods based on the statistical characteristics of the derived climate scenarios and the output of watershed models.

Two sets of model simulations were developed during 2011 based on the Phase II downscaled data. The first was a set of GWLF hydrologic model simulations, which were used to drive the OASIS system model as part of Water Research Foundation project 4262, "Vulnerability Assessment and Risk Management Tools for Climate Change". This project is being carried out as a collaboration between DEP, the Stockholm Environment Institute, the Rand Corporation, Hazen and Sawyer, Hydrologics, and the National Center for Atmospheric Research. For this work, DEP initially produced 145 future streamflow scenarios for all NYC Water Supply watersheds by driving the GWLF model with climate scenarios based on 29 GCMs, 3 emission scenarios, and 2 future time periods. From this large set of future scenarios, a subset of 32 scenarios was chosen that represented middle ground and extreme conditions that would be expected to stress the system with respect to water quality (turbidity) and quantity (system storage, drought status).

These future streamflow scenarios were then used to drive the OASIS simulations that evaluated the effects of future changes in water supply demand, flow-related variations in reservoir turbidity, and different operating strategies, on key performance metrics such as water supply usable storage, reservoir turbidity levels, alum use, and system drought status (Figure 5.4). Statistical analyses to formally evaluate adaptation strategies utilized the Robust Decision Making decision analysis framework of Groves and Lempert (2007).

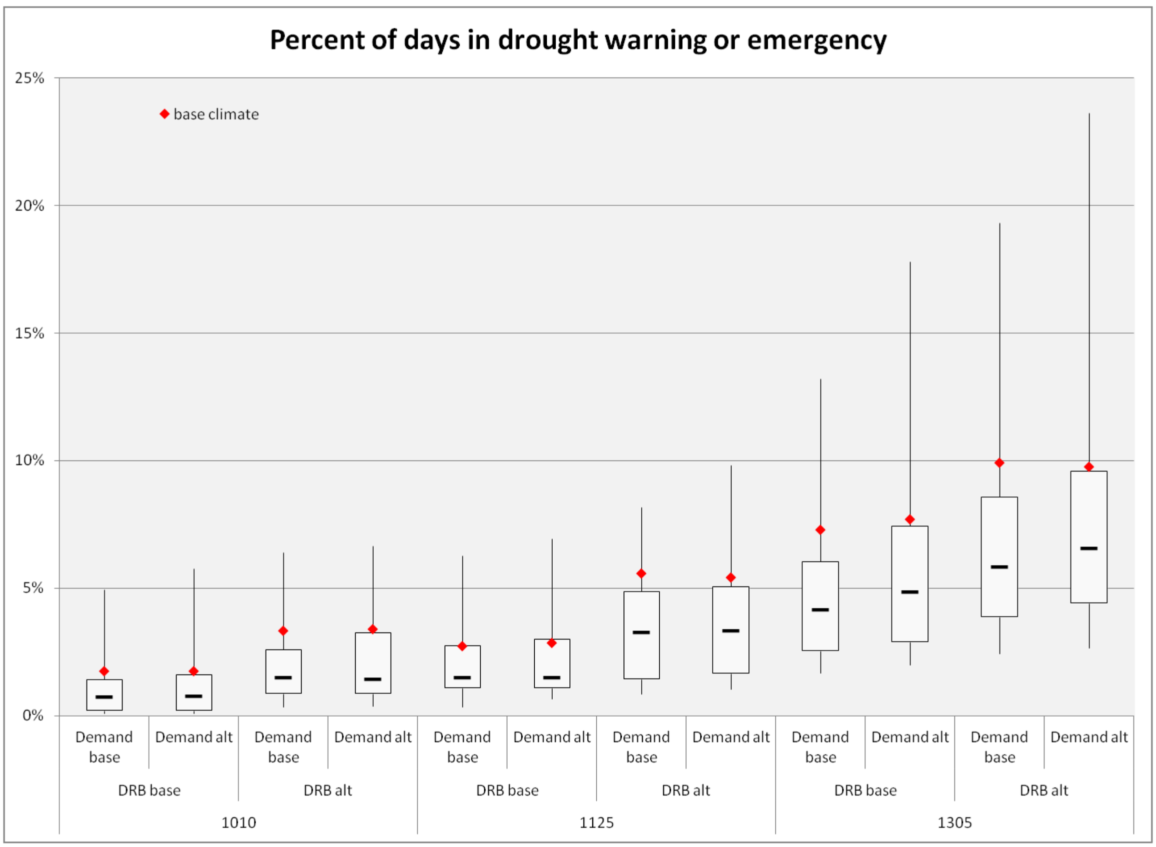

Figure 5.4 Percentage of simulation days with water storage levels that would trigger drought warning or emergency conditions. Boxplots show the variability in the 32 future scenarios. Red symbol displays the result when the OASIS model is driven with present day climate conditions. The different climate scenarios are run under three different demand levels (1010, 1125, and 1305 MGD) and two alternative operating strategies (DRBbase and DRBalt).

A second set of CCIMP Phase II simulations involved simulating the impacts of climate change on the trophic status of Cannonsville Reservoir. These simulations made use of a set of future climate scenarios that contained data for the meteorological variables needed to drive both the GWLF model and DEP's reservoir eutrophication models. For these simulations, 36 future scenarios were evaluated that were derived from 6 GCM models, 3 future emission scenarios, and 2 future time periods. The results suggested a modest increase in future reservoir chlorophyll levels (Figure 5.5) and also predicted that the spring phytoplankton peak would on average occur 10 to 13 days earlier under future conditions, largely as a result of an earlier onset of thermal stratification in the reservoir.

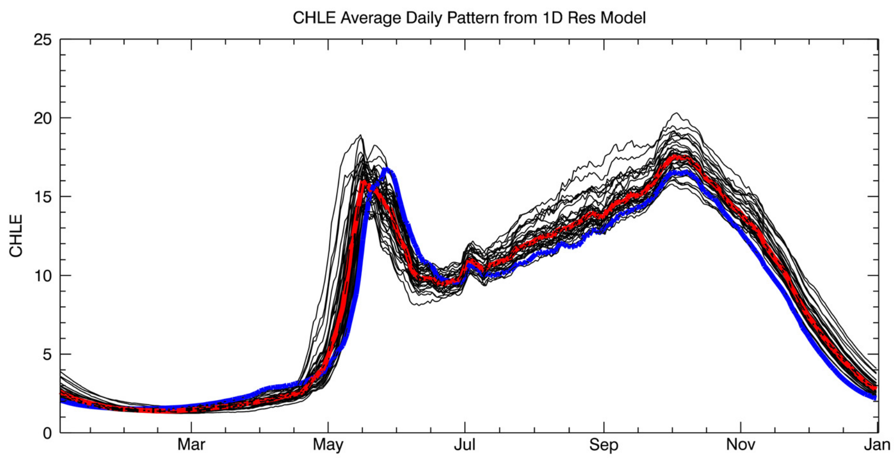

Figure 5.5 Simulated variations in epilimnetic chlorophyll (CHLE) ($\mu g\ l^{-1}$) in Cannonsville Reservoir. Lines are an average annual pattern produced from multi-year simulations. Blue line is the average pattern associated with present day conditions. Black lines are traces associated with different future climate scenarios. Red line is the median of the future scenarios.

DEP's efforts to evaluate the potential impacts of climate change on the water supply are being documented in a case study being conducted by the Water Utility Climate Alliance (WUCA) (http://www.wucaonline.org/html/) Piloting Utility Modeling Applications (PUMA) project, of which DEP was a participating utility during 2011. The goal of the study is to describe the strategies used to obtain climate data and develop climate modeling tools, as well as demonstrate how utilities incorporate future climate scenarios into existing modeling strategies to provide data valuable for water supply decision making. The CCIMP provides a useful case study, not only because of DEP's use of university postdoctoral support to accomplish much of the evaluation and modeling work in-house, but also because the NYC Water Supply is on the East Coast of North America, which is expected to experience climate change impacts different from those affecting western water utilities, namely, impacts associated with increased runoff and reduced water quality. DEP's progress will be followed through interviews with the consultant charged with preparing a WUCA policy document on the PUMA project.

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 described in the two sections below.

6.1 Contracts Managed by the Water Quality Directorate in 2011

In 2011, the Water Quality Directorate managed eight water quality-related contracts to enhance its ability to monitor and model the watershed. The contracts supported surveillance, model development, and management goals. A brief description of each contract is provided below.

6.1.1 Virus Analysis

The 2007 Filtration Avoidance Determination (FAD) and the Croton Consent Decree each include a requirement to sample for protozoa (*Giardia* and *Cryptosporidium*) and human enteric viruses. The Virus Analysis Contract was needed to provide for the shipping and analysis of water samples for human enteric viruses to meet the regulatory requirements, because DEP did not have the ability to perform these analyses in-house in 2011. The contract specifies that the laboratory must have the capacity to handle a maximum of 40 Information Collection Rule method samples per month, and up to 50 polymerase chain reaction samples annually, though typically less than half that amount is needed. DEP began virus monitoring in 1995, so the data record is approximately 17 years long for some keypoint locations. During 2011, the DEP Pathogen Laboratory continued training to analyze samples for viruses, and officially began analyzing samples without the need of a contract laboratory as of June 1, 2012.

6.1.2 Laboratory Analytic Support

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 2011, contracted analyses included: volatile organic carbon (VOC) and semivolatile 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 of DEP facility drinking water samples; and additional organics analyses (e.g., Diesel Range Organics) on special investigation (SI) samples.

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

DEP contracted with the United States Geological Survey (USGS) for a project titled, "Water Quality Operation and Maintenance and Assessment for the Hydrological Monitoring Network." The objectives of this project were 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/Delaware System. Stream water quality samples were collected and stream discharge measured at 13 sites in the Catskill/Delaware System 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/Delaware System. The first three tasks were completed at the end of the 2009 Water Year (September 30, 2009). In 2011, the USGS completed the final task of the contract with a project report, titled "The Water Quality of Selected Streams in the Catskill/Delaware Water Supply Watershed." This interpretive report evaluated the effects of land use stream water quality and trends in water quality, quantified sediment and turbidity concentrations and loads, and evaluated the relationship between suspended sediment concentration and turbidity, as well as their temporal and spatial trends.

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 of total suspended solids during both base flow and selected storm events will be performed. 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 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 to determine major source areas.

The contract period runs from August 2010 to August 2013. All of the automated equipment has been installed, and monitoring is under way. All sites were damaged during the extreme flows associated with Tropical Storm Irene, but in most cases this damage was repaired within several weeks. Data collected are being made available to the water quality modeling group and analysis of these data is now under way. This dataset will also be used in watershed and channel erosion studies planned for coming years. The Stony Clove tributary of upper Esopus Creek is one of the sites being monitored, and in this sub-basin a stream management project is being installed. Automated stream turbidity monitoring will aid in the quantification and validation of the project's effects.

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:

- Inform reservoir managers of turbidity levels to help them make operational decisions
- Provide data to initialize and verify reservoir modeling simulations
- Provide inputs to 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 was originally scheduled to end in December 2011. During Tropical Storm Irene, the robotic monitoring buoys continued to function on Ashokan and Kensico Reservoirs, providing important information to support reservoir operations (Figure 6.1).

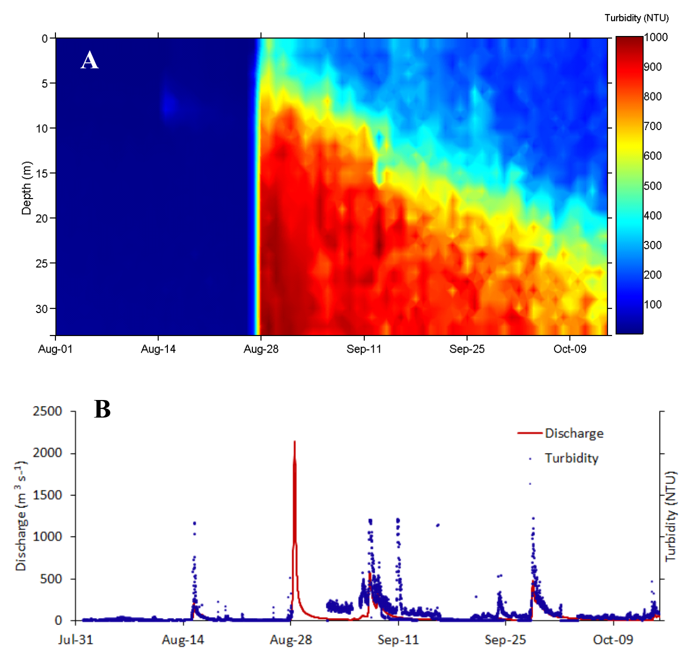

Figure 6.1 A) Isopleths of turbidity in the West Basin of Ashokan Reservoir. The effects of Tropical Storm Irene (August 28) led to some of the highest recorded turbidity levels in the reservoir. The isopleths were created by interpolating between 6-hour turbidity profiles collected by an automated monitoring buoy near the center of the West Basin (site 1.4). B) Stream discharge collected by the USGS gauge at Coldbrook, and turbidity measured by a nearby DEP monitoring hut. During Tropical Storm Irene (August 28) the turbidity monitoring system was damaged and data were lost.

Following the damage to stream monitoring stations caused by Tropical Storm Irene, the contract was extended for an additional year to provide support both for operating the monitoring network and to address modeling issues that became evident following the impacts of Irene. The change order tasks included:

- Repair of stream monitoring stations that were damaged during the storm
- Providing logistical and technical support to DEP as DEP takes over responsibility for the operation and maintenance of the robotic monitoring network

- Developing a reservoir turbidity transport model for Rondout Reservoir based on the same CE-Qual-W2 model framework that was previously used to develop models for Schoharie, Ashokan, and Kensico Reservoirs. This model will allow DEP to better predict Rondout turbidity levels in response to future extreme events.
- Improving the turbidity transport algorithms to better account for transport of highly turbid inputs with a density that can override thermal density stratification

6.1.6 CUNY Postdoctoral Support

The purpose of this 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, but are stationed to work with the DEP modeling group in Kingston. Three faculty advisors are also working with the postdoctoral associates and modeling group staff. The postdoctoral associates are helping the modeling group fulfill FAD- and climate change-related research objectives. Postdoctoral projects involve modeling focused on different parts of the hydrologic cycle and their water quality impacts, including: 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 was originally scheduled to end in June 2013. As a result of some initial delays, the modeling group is developing a time extension for the contract. During 2011, work supported by the CUNY contract led to six publications, which are listed below.

Anandhi, A., A. Frei, D. C. Pierson, E. M. Schneiderman, M. S. Zion, D. Lounsbury, and A. H. Matonse. 2011. Examination of change factor methodologies for climate change impact assessment. Water Resour. Res. 47:W03501.

Anandhi, A., A. Frei, S. M. Pradhanang, M. S. Zion, D. C. Pierson, and E. M. Schneiderman. 2011. AR4 climate model performance in simulating snow water equivalent over Catskill Mountain watersheds, New York, USA. Hydrol. Process. 25:3302-3311.

Matonse, A. H., D. C. Pierson, A. Frei, M. S. Zion, E. M. Schneiderman, A. Anandhi, R. Mukundan, and S. M. Pradhanang. 2011. Effects of changes in snow pattern and the timing of runoff on NYC water supply system. Hydrol. Process. 25:3278-3288.

Pierson, D. C., G. A. Weyhenmeyer, B. B. L. Arvola, T. K. T. Blenckner, D. M. Livingstone, H. Markensten, G. Marzec, K. Petterson, and K. Weathers. 2011. An automated method to monitor lake ice phenology. Limnol. Oceanogr-Meth. 9:74-83.

Pradhanang, S. M., A. Anandhi, R. Mukundan, M. S. Zion, D. C. Pierson, E. M. Schneiderman, A. Matonse, and A. Frei. 2011. Application of SWAT model to assess snowpack development and streamflow in the Cannonsville watershed, New York, USA. Hydrol. Process. 25:3268-3277.

Zion, M. S., S. M. Pradhanang, D. C. Pierson, A. Anandhi, D. G. Lounsbury, A. H. Matonse, and E. M. Schneiderman. 2011. Investigation and modeling of winter streamflow timing and magnitude under changing climate conditions for the Catskill Mountain region, New York, USA. Hydrol. Process. 25:3289-3301.

6.1.7 Waterfowl Management

The Waterfowl Management Program (WMP) was developed in response to seasonal elevations of fecal coliform bacteria first identified at Kensico Reservoir from the late 1980s to the early 1990s. In 1993, DEP demonstrated a direct relationship between the waterfowl populations present and the concentrations of fecal coliforms in reservoirs, and this highly effective management program was developed based on this scientific finding. A contract was first let in 1995 to a private environmental consulting firm and has been re-bid every four years to help fulfill compliance with the federal Surface Water Treatment Rule for fecal coliform bacteria (USEPA 1989). The current WMP contract requires staffing of up to 25 contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. A new contract was let on September 18, 2011 and is intended to run through September 17, 2014.

6.1.8 Zebra Mussel Monitoring

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, 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. To date, no infestations have been detected.

6.2 Water Research Foundation Projects in which DEP Participated in 2011

The Water Research Foundation (WaterRF) is an internationally renowned research organization that conducts research projects to benefit water supply utilities. The Board of Trustees for the Foundation consists of subscribers and leaders in the water supply community who represent water utilities around the world, as well as the interests of the Association of Metropolitan Water Agencies, the National Association of Water Companies, the American Water Works Association, 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 whose subscribers, like DEP, can become involved by volunteering their time and experience. Several DEP staff members are currently involved as Project Advisory Committee members. A full description of WaterRF projects, and their status, can be found at the WaterRF website, http://www.waterrf.org/. The projects that DEP participated in during 2011 are listed below.

WRF # 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 Method 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. (K. Alderisio)

WRF # 4239: Climate Change Impacts on the Regulatory Landscape

This project examines the major federal legislation and regulations governing water utilities for the purpose of identifying situations in which they reduce a utility's ability to adapt to climate change and reduce greenhouse gas emissions cost effectively. By reviewing climate change legislation and regulations at the state, regional, and federal levels, the project identifies opportunities for policy changes that may allow utilities to balance reducing their carbon footprint with meeting drinking water standards and regulations, water supply demands, and other social and financial goals. To better understand the need for regulatory change, these findings are accompanied by case studies of a diverse number of drinking water utilities, and by a white paper to assist water utilities formulate an action plan to achieve the regulatory flexibility through public policy change. (L.Janus)

WRF # 4262: Vulnerability Assessment and Risk Management Tools for Climate Change: Assessing Potential Impacts and Identifying Adaptation Options

This project will identify the vulnerabilities most 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 and Water Services Association of Australia. (L. Beckhardt)

WRF # 4263: Analysis of Changes in Water Use under Regional Climate Change Scenarios

This project 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. The project 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. (L. Beckhardt)

WRF # 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. (L. Beckhardt)

WRF # 4303: Analysis of Reservoir Operations under Climate Change

The objective of this research is to identify how reservoir operations can be adjusted to adapt to hydrologic changes associated with climate change and the uncertainties associated with climate variability. Water supply planning and management predominantly rely on the assumption that future climate largely mimics past experience. Such an approach might constrain the ability of water supply managers to adapt to these hydrologic changes. Dynamic management of reservoirs may help utilities respond to or mitigate the impacts of climate change or climate variability. Dynamic management of reservoirs includes adjusting operating criteria based on current or forecasted climate conditions, water demands, water quality, energy efficiency, and other factors, thus allowing water utilities to meet water supply needs through management of the system rather than through capital improvements.

Expected impacts of climate change on water resources include higher temperature; changes in the intensity, severity, and timing of major storms; increased precipitation and evaporation; and changes in patterns of rainfall, snowfall, snowmelt, and drought. All these changes directly impact water supply planning and management in one way or another. It would be helpful for water agencies to comprehensively understand what parameters influence and/or control reservoir operations, what attributes of a water system (e.g., supply, water quality, flood management, environmental releases) are affected by reservoir management, and which stakeholders can be affected by and/or have influence over reservoir operations. (L. Beckhardt)

WRF # 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. (L. Beckhardt)

WRF # 4348: Matrix Effects on Cryptosporidium Recovery in the Bull Run Watershed

The objective of this study is to determine what factor(s) in the Portland (Ore.) 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. (K. Alderisio)

WRF # 4382: Impacts of Algal Blooms on the Ecology of Algae

The goal of this project is to describe how climate change will affect the frequency, severity, and types of algal blooms that occur in sources of drinking water. The ecology of blooms will be affected by climate change (such as warmer surface water temperatures, changes in stratification, and shorter periods of ice cover). The increase in the likelihood of impacts, such as toxin production, taste and odor problems, and other situations that require advanced treatment, will be quantified to the extent possible. Potential watershed management and operational or infrastructure adaptation measures to minimize costs to consumers will be outlined.

The causes of algal blooms that lead to taste and odor problems for water supplies are not well known and can occur unpredictably. Toxic algal blooms can threaten public health through the production of neuro- and hepato-toxins. Algal blooms can result in increased costs for monitoring, surface water treatment, and post-disinfection treatment for disinfection byproducts (which are carcinogens). Public health advisories are not well-developed, detection methods and guidelines for response options are not consolidated, and communications to the public are not well-defined. The project should address these issues. (L. Janus)

To summarize Chapter 6, contracts with external partners and participation in projects with other organizations, such as the WaterRF, greatly extend scientific manpower and broaden thinking about water quality issues. DEP gains insight and assistance in problem solving by participating in scientific contracts and collaborations. The activities described above are important ways in which DEP scientists retain access to current methodologies and remain informed of current science for the benefit and protection of the water supply.

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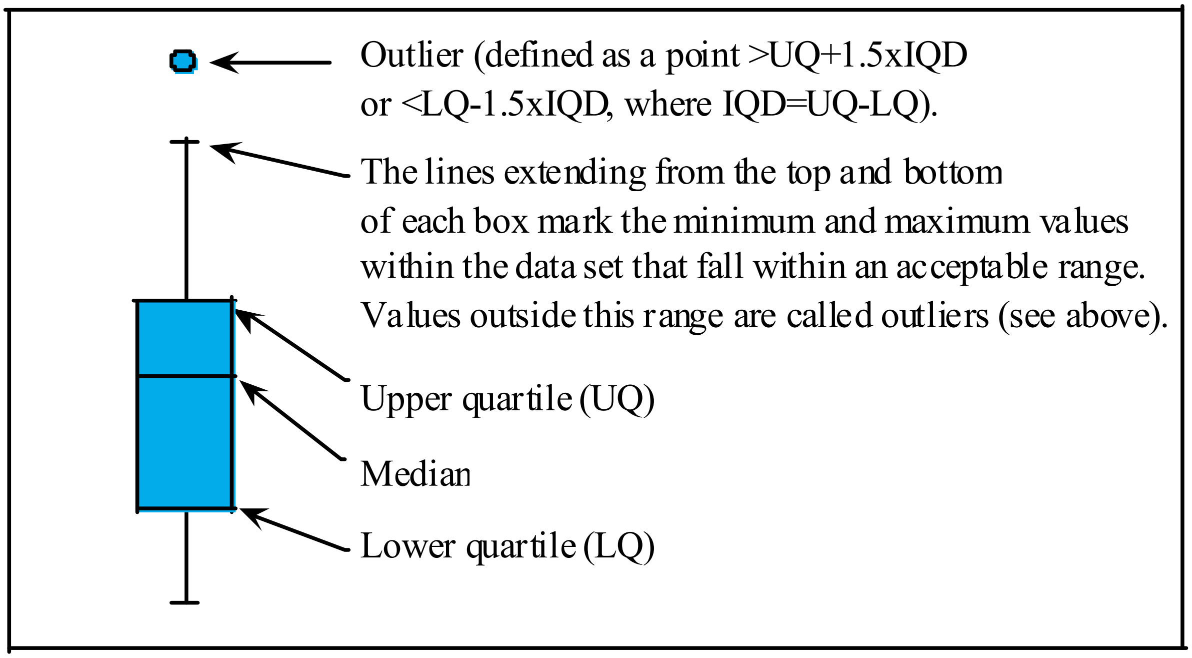
Appendix A. Key to Boxplots and Summary of Non-Detect Statistics Used in Data Analysis



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. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (Median, value not >20% of samples)	Collection date	n	Median total coliforms (coliforms $100mL^{-1}$)	Percentage greater than standard
Amawalk	A (2400, 5000)	Apr-11	5	<50	0
Amawalk		May-11	5	160	0
Amawalk		Jun-11	5	<200	0
Amawalk		Jul-11	5	<50	0
Amawalk		Aug-11	5	94	0
Amawalk		Sep-11	5	140	0
Amawalk		Oct-11	5	<200	0
Amawalk		Nov-11	5	33	0
Bog Brook	AA (50, 240)	Apr-11	5	<10	0
Bog Brook		May-11	5	50	0
Bog Brook		Jun-11	5	62	0
Bog Brook		Jul-11	5	92	0
Bog Brook		Aug-11	5	76	0
Bog Brook		Sep-11	5	<200	0
Bog Brook		Oct-11	5	43	0
Bog Brook		Nov-11	5	50	0
Boyd Corners	AA (50, 240)	Apr-11	7	27	0
Boyd Corners		May-11	6	38.5	0
Boyd Corners		Jun-11	6	11.5	0
Boyd Corners		Jul-11	6	17	0
Boyd Corners		Aug-11	7	67	29
Boyd Corners		Sep-11	0	Insufficient data	N/A
Boyd Corners		Oct-11	0	Insufficient data	N/A
Boyd Corners		Nov-11	0	Insufficient data	N/A
Croton Falls	A/AA (50, 240)	Apr-11	6	5	0
Croton Falls		May-11	8	41	0
Croton Falls		Jun-11	8	13	0
Croton Falls		Jul-11	8	9	0
Croton Falls		Aug-11	8	88	25
Croton Falls		Sep-11	8	71.5	38
Croton Falls		Oct-11	8	76	13

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. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (Median, value not >20% of samples)	Collection date	n	Median total coliforms (coliforms $100mL^{-1}$)	Percentage greater than standard
Croton Falls		Nov-11	8	55	0
Cross River	A/AA (50, 240)	Apr-11	6	117	33
Cross River		May-11	6	18	0
Cross River		Jun-11	5	180	40
Cross River		Jul-11	6	<200	0
Cross River		Aug-11	6	91	33
Cross River		Sep-11	6	116	17
Cross River		Oct-11	6	42	0
Cross River		Nov-11	5	58	20
Diverting	AA (50, 240)	Apr-11	5	45	0
Diverting		May-11	5	330	80
Diverting		Jun-11	5	256	40
Diverting		Jul-11	5	320	60
Diverting		Aug-11	5	120	40
Diverting		Sep-11	5	200	40
Diverting		Oct-11	5	50	0
Diverting		Nov-11	5	58	0
East Branch	AA (50, 240)	Apr-11	6	<200	33
East Branch		May-11	6	265	50
East Branch		Jun-11	6	290	67
East Branch		Jul-11	6	7,000	100
East Branch		Aug-11	6	223	50
East Branch		Sep-11	6	200	33
East Branch		Oct-11	6	85.5	0
East Branch		Nov-11	6	450	67
Lake Gilead	A (2400, 5000)	Apr-11	5	<5	0
Lake Gilead		May-11	5	5	0
Lake Gilead		Jun-11	5	40	0
Lake Gilead		Jul-11	5	22	0
Lake Gilead		Aug-11	5	420	0
Lake Gilead		Sep-11	5	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. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (Median, value not >20% of samples)	Collection date	n	Median total coliforms (coliforms $100mL^{-1}$)	Percentage greater than standard
Lake Gilead		Oct-11	5	19	0
Lake Gilead		Nov-11	5	16	0
Lake Gleneida	AA (50, 240)	Apr-11	5	5	20
Lake Gleneida		May-11	5	2	0
Lake Gleneida		Jun-11	5	8	0
Lake Gleneida		Jul-11	5	<20	0
Lake Gleneida		Aug-11	5	150	0
Lake Gleneida		Sep-11	5	21	0
Lake Gleneida		Oct-11	5	<200	0
Lake Gleneida		Nov-11	5	<5	0
Kirk Lake	B (2400, 5000)	Apr-11	5	41	0
Kirk Lake		May-11	5	13	0
Kirk Lake		Jun-11	5	100	0
Kirk Lake		Jul-11	5	530	0
Kirk Lake		Aug-11	5	1,600	40
Kirk Lake		Sep-11	5	130	0
Kirk Lake		Oct-11	5	45	0
Muscoot	A (2400, 5000)	Apr-11	7	102	0
Muscoot		May-11	7	39	0
Muscoot		Jun-11	7	17,000	100
Muscoot		Jul-11	6	1,300	0
Muscoot		Aug-11	5	388	20
Muscoot		Sep-11	7	544	0
Muscoot		Oct-11	6	140	0
Muscoot		Nov-11	7	80	0
Middle Branch	A (2400, 5000)	Apr-11	5	<20	0
Middle Branch		May-11	5	80	0
Middle Branch		Jun-11	5	25	0
Middle Branch		Jul-11	5	<10	0
Middle Branch		Aug-11	5	2,100	0
Middle Branch		Sep-11	5	83	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. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (Median, value not >20% of samples)	Collection date	n	Median total coliforms (coliforms $100mL^{-1}$)	Percentage greater than standard
Middle Branch		Oct-11	5	14	0
Middle Branch		Nov-11	5	50	0
Titicus	AA (50, 240)	Apr-11	5	67	20
Titicus		May-11	5	<100	0
Titicus		Jun-11	5	<100	20
Titicus		Jul-11	5	<100	0
Titicus		Aug-11	5	120	40
Titicus		Sep-11	5	320	80
Titicus		Oct-11	5	400	80
Titicus		Nov-11	5	1,300	100
Pepacton	A/AA (50, 240)	Apr-11	16	2	0
Pepacton		May-11	16	<10	0
Pepacton		Jun-11	16	10	6
Pepacton		Jul-11	15	50	0
Pepacton		Aug-11	31	50	32
Pepacton		Sep-11	16	100	38
Pepacton		Oct-11	16	21	6
Pepacton		Nov-11	16	25	0
Pepacton		Dec-11	10	18	0
Neversink	AA (50, 240)	Apr-11	13	4	0
Neversink		May-11	13	8	8
Neversink		Jun-11	13	12	0
Neversink		Jul-11	13	TNTC[2]	0
Neversink		Aug-11	13	100	31
Neversink		Sep-11	13	100	0
Neversink		Oct-11	13	<50	8
Neversink		Nov-11	12	10	0
Neversink		Dec-11	10	32	0
Schoharie	AA (50, 240)	Apr-11	11	380	64
Schoharie		May-11	11	1,100	100
Schoharie		Jun-11	11	950	100

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. TNTC = coliform plates too numerous to count.

Reservoir	Class[1] and standard (Median, value not >20% of samples)	Collection date	n	Median total coliforms (coliforms $100mL^{-1}$)	Percentage greater than standard
Schoharie		Jul-11	11	700	91
Schoharie		Aug-11	11	1700	100
Schoharie		Sep-11	11	24,000	100
Schoharie		Oct-11	12	4,000	100
Schoharie		Nov-11	11	400	82
Schoharie		Dec-11	6	425	100
Cannonsville	A/AA (50, 240)	Apr-11	15	60	7
Cannonsville		May-11	15	15	0
Cannonsville		Jun-11	17	<50	0
Cannonsville		Jul-11	17	TNTC[2]	29
Cannonsville		Aug-11	17	100	29
Cannonsville		Sep-11	24	100	21
Cannonsville		Oct-11	18	38	0
Cannonsville		Nov-11	15	3	0
Cannonsville		Dec-11	9	>=275	50

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

[2]The median could not be estimated for TNTC samples.

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 2010). The phosphorus restricted designation of a reservoir basin prohibits new or expanded wastewater treatment plants with surface discharges in the reservoir basin. The list of phosphorus restricted basins is updated annually in the Watershed Water Quality Annual Report.

A summary of the methodology used in the phosphorus restricted analysis will be given here; the complete description can be found in A Methodology for Determining Phosphorus Restricted Basins (DEP 1997). The data utilized in the analysis 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 $\mu g\ L^{-1}$ (15 $\mu g\ L^{-1}$ 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	2006 µg L^{-1}	2007 µg L^{-1}	2008 µg L^{-1}	2009 µg L^{-1}	2010 µg L^{-1}	2011 µg L^{-1}
	20.5	14.0	13.4	14.0	16.4	15.0
	10.8	9.7	8.2	7.6	9.9	11.3
	7.3	4.7	4.7	5.9	6.5	10.2
	17.4	9.7	9.5	11.2	13.4	28.4
	24.5	20.2	17.9	19.4	20.5	18.3
	18.7	24.0	21.5	22.8	31.1	23.6
	17.4	15.6	11.6	8.6	8.4	8.7
	*	*	22.8	*	29.1	31.1
	28.4	23.0	21.6	26.1	33.8	32.3
	24.2	25.0	27.9	22.4	25.5	29.8
	27.9	25.7	27.6	24.9	28.7	28.8
	29.6	21.6	17.5	20.8	26.4	26.9
	24.2	*	*	22.7	25.9	31.9
	30.5	33.6	*	36.0	30.1	28.9
	29.7	28.6	*	31.4	27.6	33.1
	11.2	8.1	7.2	8.6	12.9	30.7
	9.9	7.3	7.5	9.5	9.8	13.5
	18.6	17.8	13.8	13.8	15.4	18.7
	19.2	*	14.4	14.7	13.3	17.8

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	2006 $\mu g\ L^{-1}$	2007 $\mu g\ L^{-1}$	2008 $\mu g\ L^{-1}$	2009 $\mu g\ L^{-1}$	2010 $\mu g\ L^{-1}$	2011 $\mu g\ L^{-1}$
	7.6	7.0	6.4	5.8	6.6	7.5
	18.1	17.7	15.5	14.4	15.7	18.2
	8.6	7.1	6.1	8.1	8.0	8.9
	10.3	9.6	9.4	9.6	9.4	11.1

* indicates less than three successful surveys during the growing season (May - October).

Appendix D. Comparison of Reservoir Water Quality Results to Benchmarks

Appendix Table 2: Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Kensico Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	24			>10	11
Chloride (mg L^{-1})	12	24	11	46	8	10.7
Chlorophyll *a* (µg L^{-1})	12	63	1	2	7	5.7
Color (Pt-Co units)	15	200	57	29	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	198	0	0	3	1.9
Fecal coliform (FC 100mL^{-1})	20	197	10	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	200	0	0	0.3	0.14
pH (units)	6.5-8.5	200	38	19	na	na
Sodium, undig., filt. (mg L^{-1})	16	18	18	100	3	6.5
Soluble reactive phosphorus (µg L^{-1})	15	200	0	0	na	na
Sulfate (mg L^{-1})	15	24	0	0	10	5.9
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	200	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	200	110	55	40	50
Total phosphorus (µg L^{-1})	15	199	0	0	na	na
Total phytoplankton (ASU)	2,000	96	0	0	na	na
Primary genus (ASU)	1,000	96	0	0	na	na
Secondary genus (ASU)	1,000	96	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	92	0	0	5	1.2
Turbidity (NTU)	5	213	3	1	na	na
Amawalk Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	69
Chloride (mg L^{-1})	40	9	9	100	30	95.4
Chlorophyll *a* (µg L^{-1})	15	12	6	50	10	14.8
Color (Pt-Co units)	15	30	28	93	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	30	0	0	6	3.9
Fecal coliform (FC 100mL^{-1})	20	38	6	16	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	30	1	3	0.3	0.18
pH (units)	6.5-8.5	40	5	13	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	50.4
Soluble reactive phosphorus (µg L^{-1})	15	30	1	3	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	10.4
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	30	5	17	na	na
Total dissolved solids (mg L^{-1})[3]	175	30	30	100	150	319
Total phosphorus (µg L^{-1})	15	40	30	75	na	na
Total phytoplankton (ASU)	2,000	12	1	8	na	na
Primary genus (ASU)	1,000	12	2	17	na	na
Secondary genus (ASU)	1,000	12	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.5

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Turbidity (NTU)	5	30	1	3	na	na
Bog Brook Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	71
Chloride (mg L^{-1})	40	9	9	100	30	47.8
Chlorophyll *a* (µg L^{-1})	15	6	2	33	10	10.8
Color (Pt-Co units)	15	17	16	94	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	17	0	0	6	3.8
Fecal coliform (FC $100mL^{-1}$)	20	46	1	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	17	0	0	0.3	0.07
pH (units)	6.5-8.5	46	4	9	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	24.4
Soluble reactive phosphorus (µg L^{-1})	15	17	2	12	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	10
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	17	2	12	na	na
Total dissolved solids (mg L^{-1})[3]	175	17	17	100	150	214
Total phosphorus (µg L^{-1})	15	23	17	74	na	na
Total phytoplankton (ASU)	2,000	6	0	0	na	na
Primary genus (ASU)	1,000	6	0	0	na	na
Secondary genus (ASU)	1,000	6	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.1
Turbidity (NTU)	5	17	2	12	na	na
Boyd Corners Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	5			>40	30
Chloride (mg L^{-1})	40	5	5	100	30	40.5
Chlorophyll *a* (µg L^{-1})	15	5	0	0	10	4.6
Color (Pt-Co units)	15	12	12	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	12	0	0	6	3.4
Fecal coliform (FC $100mL^{-1}$)	20	32	3	9	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	12	0	0	0.3	0.07
pH (units)	6.5-8.5	32	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	2	2	100	15	22.4
Soluble reactive phosphorus (µg L^{-1})	15	12	0	0	na	na
Sulfate (mg L^{-1})	25	5	0	0	15	7.2
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	12	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	12	0	0	150	141
Total phosphorus (µg L^{-1})	15	12	0	0	na	na
Total phytoplankton (ASU)	2,000	5	0	0	na	na
Primary genus (ASU)	1,000	5	0	0	na	na
Secondary genus (ASU)	1,000	5	0	0	na	na

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Total suspended solids (mg L^{-1})	8.0	5	0	0	5	1.4
Turbidity (NTU)	5	12	0	0	na	na
Croton Falls Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18			>40	56
Chloride (mg L^{-1})	40	18	18	100	30	62.4
Chlorophyll *a* (µg L^{-1})	15	16	5	31	10	21
Color (Pt-Co units)	15	48	47	98	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	48	0	0	6	3.4
Fecal coliform (FC 100mL^{-1})	20	48	3	6	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	48	0	0	0.3	0.23
pH (units)	6.5-8.5	48	5	10	na	na
Sodium, undig., filt. (mg L^{-1})	20	12	12	100	15	34.1
Soluble reactive phosphorus (µg L^{-1})	15	48	0	0	na	na
Sulfate (mg L^{-1})	25	18	0	0	15	10.3
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	46	96	150	248
Total phosphorus (µg L^{-1})	15	48	33	69	na	na
Total phytoplankton (ASU)	2,000	16	2	13	na	na
Primary genus (ASU)	1,000	16	3	19	na	na
Secondary genus (ASU)	1,000	16	1	6	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.8
Turbidity (NTU)	5	48	1	2	na	na
Cross River Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	41
Chloride (mg L^{-1})	40	9	0	0	30	32.5
Chlorophyll *a* (µg L^{-1})	15	14	6	43	10	15.4
Color (Pt-Co units)	15	40	40	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	40	0	0	6	3.3
Fecal coliform (FC 100mL^{-1})	20	45	3	7	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	40	0	0	0.3	0.13
pH (units)	6.5-8.5	46	5	11	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	16.4
Soluble reactive phosphorus (µg L^{-1})	15	40	0	0	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	8.6
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	40	1	3	na	na
Total dissolved solids (mg L^{-1})[3]	175	40	0	0	150	140
Total phosphorus (µg L^{-1})	15	46	35	76	na	na
Total phytoplankton (ASU)	2,000	14	2	14	na	na

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Primary genus (ASU)	1,000	14	4	29	na	na
Secondary genus (ASU)	1,000	14	1	7	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.2
Turbidity (NTU)	5	40	3	8	na	na
Diverting Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	8			>40	78
Chloride (mg L^{-1})	40	6	6	100	30	51.8
Chlorophyll *a* (µg L^{-1})	15	14	5	36	10	16.9
Color (Pt-Co units)	15	28	28	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	28	0	0	6	4.1
Fecal coliform (FC $100mL^{-1}$)	20	40	4	10	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	28	0	0	0.3	0.14
pH (units)	6.5-8.5	40	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	4	4	100	15	26.5
Soluble reactive phosphorus (µg L^{-1})	15	28	0	0	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	9.3
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	28	2	7	na	na
Total dissolved solids (mg L^{-1})[3]	175	28	28	100	150	218
Total phosphorus (µg L^{-1})	15	33	33	100	na	na
Total phytoplankton (ASU)	2,000	14	1	7	na	na
Primary genus (ASU)	1,000	14	2	14	na	na
Secondary genus (ASU)	1,000	14	1	7	na	na
Total suspended solids (mg L^{-1})	8.0	8	0	0	5	3.5
Turbidity (NTU)	5	28	1	4	na	na
East Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	79
Chloride (mg L^{-1})	40	9	6	67	30	39.5
Chlorophyll *a* (µg L^{-1})	15	6	3	50	10	23
Color (Pt-Co units)	15	18	18	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	18	0	0	6	4.3
Fecal coliform (FC $100mL^{-1}$)	20	48	12	25	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	18	0	0	0.3	0.06
pH (units)	6.5-8.5	49	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	20.4
Soluble reactive phosphorus (µg L^{-1})	15	18	2	11	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	9
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	18	3	17	na	na
Total dissolved solids (mg L^{-1})[3]	175	18	18	100	150	199

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Total phosphorus ($\mu g\ L^{-1}$)	15	24	24	100	na	na
Total phytoplankton (ASU)	2,000	6	1	17	na	na
Primary genus (ASU)	1,000	6	2	33	na	na
Secondary genus (ASU)	1,000	6	1	17	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	9	0	0	5	1.8
Turbidity (NTU)	5	18	2	11	na	na
Lake Gilead						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	6			>40	41
Chloride ($mg\ L^{-1}$)	40	6	5	83	30	40.9
Chlorophyll *a* ($\mu g\ L^{-1}$)	15	2	0	0	10	5.4
Color (Pt-Co units)	15	6	3	50	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	7.0	6	0	0	6	3
Fecal coliform (FC $100mL^{-1}$)	20	15	3	20	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	6	0	0	0.3	0.06
pH (units)	6.5-8.5	15	0	0	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	20	3	3	100	15	22
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	6	1	17	na	na
Sulfate ($mg\ L^{-1}$)	25	6	0	0	15	8.3
Total ammonia-N ($mg\ L^{-1}$)	0.10	0			0.05	
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	6	1	17	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	175	6	1	17	150	160
Total phosphorus ($\mu g\ L^{-1}$)	15	9	9	100	na	na
Total phytoplankton (ASU)	2,000	2	0	0	na	na
Primary genus (ASU)	1,000	2	0	0	na	na
Secondary genus (ASU)	1,000	2	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	6	0	0	5	1.7
Turbidity (NTU)	5	6	0	0	na	na
Lake Gleneida						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	6			>40	67
Chloride ($mg\ L^{-1}$)	40	6	6	100	30	92.1
Chlorophyll *a* ($\mu g\ L^{-1}$)	15	2	0	0	10	3.9
Color (Pt-Co units)	15	6	0	0	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	7.0	6	0	0	6	2.7
Fecal coliform (FC $100mL^{-1}$)	20	15	0	0	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	6	0	0	0.3	
pH (units)	6.5-8.5	15	3	20	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	20	3	3	100	15	49.9
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	6	1	17	na	na
Sulfate ($mg\ L^{-1}$)	25	6	0	0	15	7.4
Total ammonia-N ($mg\ L^{-1}$)	0.10	0			0.05	
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	6	1	17	na	na

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Total dissolved solids ($mg\ L^{-1}$)[3]	175	6	6	100	150	297
Total phosphorus ($\mu g\ L^{-1}$)	15	9	6	67	na	na
Total phytoplankton (ASU)	2,000	2	0	0	na	na
Primary genus (ASU)	1,000	2	0	0	na	na
Secondary genus (ASU)	1,000	2	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	6	0	0	5	1.4
Turbidity (NTU)	5	6	0	0	na	na
Kirk Lake						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	2			>40	46
Chloride ($mg\ L^{-1}$)	40	2	2	100	30	59.1
Chlorophyll *a* ($\mu g\ L^{-1}$)	15	2	1	50	10	15.1
Color (Pt-Co units)	15	2	1	50	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	7.0	2	0	0	6	4.6
Fecal coliform ($FC\ 100mL^{-1}$)	20	15	3	20	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	2	0	0	0.3	0.07
pH (units)	6.5-8.5	15	0	0	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	20	1	1	100	15	34.1
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	2	0	0	na	na
Sulfate ($mg\ L^{-1}$)	25	2	0	0	15	9.1
Total ammonia-N ($mg\ L^{-1}$)	0.10	0			0.05	
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	2	0	0	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	175	2	2	100	150	202
Total phosphorus ($\mu g\ L^{-1}$)	15	3	3	100	na	na
Total phytoplankton (ASU)	2,000	2	1	50	na	na
Primary genus (ASU)	1,000	2	1	50	na	na
Secondary genus (ASU)	1,000	2	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	2	0	0	5	5.1
Turbidity (NTU)	5	2	1	50	na	na
Muscoot Reservoir						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	6			>40	70
Chloride ($mg\ L^{-1}$)	40	6	6	100	30	68
Chlorophyll *a* ($\mu g\ L^{-1}$)	15	24	13	54	10	17.8
Color (Pt-Co units)	15	39	39	100	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	7.0	39	0	0	6	3.5
Fecal coliform ($FC\ 100mL^{-1}$)	20	49	9	18	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	39	5	13	0.3	0.31
pH (units)	6.5-8.5	52	1	2	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	20	4	4	100	15	34.2
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	39	1	3	na	na
Sulfate ($mg\ L^{-1}$)	25	6	0	0	15	9.5
Total ammonia-N ($mg\ L^{-1}$)	0.10	0			0.05	

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	39	2	5	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	175	39	39	100	150	251
Total phosphorus ($\mu g\ L^{-1}$)	15	52	51	98	na	na
Total phytoplankton (ASU)	2,000	24	7	29	na	na
Primary genus (ASU)	1,000	24	5	21	na	na
Secondary genus (ASU)	1,000	24	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	6	0	0	5	3
Turbidity (NTU)	5	39	3	8	na	na
Middle Branch Reservoir						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	6			>40	57
Chloride ($mg\ L^{-1}$)	40	6	6	100	30	81.1
Chlorophyll *a* ($\mu g\ L^{-1}$)	15	12	7	58	10	22.6
Color (Pt-Co units)	15	30	30	100	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	7.0	30	0	0	6	3.6
Fecal coliform (FC $100mL^{-1}$)	20	40	4	10	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	30	2	7	0.3	0.2
pH (units)	6.5-8.5	40	1	3	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	20	6	6	100	15	46.8
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	30	0	0	na	na
Sulfate ($mg\ L^{-1}$)	25	6	0	0	15	10.4
Total ammonia-N ($mg\ L^{-1}$)	0.10	0			0.05	
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	30	2	7	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	175	30	30	100	150	279
Total phosphorus ($\mu g\ L^{-1}$)	15	40	39	98	na	na
Total phytoplankton (ASU)	2,000	12	1	8	na	na
Primary genus (ASU)	1,000	12	0	0	na	na
Secondary genus (ASU)	1,000	12	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	6	0	0	5	1.8
Turbidity (NTU)	5	30	2	7	na	na
New Croton Reservoir						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	30			>40	57
Chloride ($mg\ L^{-1}$)	40	30	30	100	30	61.3
Chlorophyll *a* ($\mu g\ L^{-1}$)	15	42	16	38	10	14.4
Color (Pt-Co units)	15	126	126	100	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	7.0	126	0	0	6	3.2
Fecal coliform (FC $100mL^{-1}$)	20	166	4	2	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	126	24	19	0.3	0.31
pH (units)	6.5-8.5	166	7	4	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	20	20	20	100	15	31.8
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	126	1	1	na	na
Sulfate ($mg\ L^{-1}$)	25	30	0	0	15	10.7

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	126	2	2	na	na
Total dissolved solids (mg L^{-1})[3]	175	126	126	100	150	228
Total phosphorus (µg L^{-1})	15	166	124	75	na	na
Total phytoplankton (ASU)	2,000	47	6	13	na	na
Primary genus (ASU)	1,000	47	3	6	na	na
Secondary genus (ASU)	1,000	47	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	40	0	0	5	1.9
Turbidity (NTU)	5	126	5	4	na	na
Titicus Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	62
Chloride (mg L^{-1})	40	8	0	0	30	36.2
Chlorophyll *a* (µg L^{-1})	15	12	6	50	10	17.5
Color (Pt-Co units)	15	26	26	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	26	0	0	6	3.6
Fecal coliform (FC $100mL^{-1}$)	20	40	4	10	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	26	0	0	0.3	0.11
pH (units)	6.5-8.5	40	4	10	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	17.8
Soluble reactive phosphorus (µg L^{-1})	15	26	1	4	na	na
Sulfate (mg L^{-1})	25	8	0	0	15	8.8
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	26	5	19	na	na
Total dissolved solids (mg L^{-1})[3]	175	26	17	65	150	180
Total phosphorus (µg L^{-1})	15	34	32	94	na	na
Total phytoplankton (ASU)	2,000	12	3	25	na	na
Primary genus (ASU)	1,000	12	2	17	na	na
Secondary genus (ASU)	1,000	12	2	17	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	3.1
Turbidity (NTU)	5	26	4	15	na	na
West Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	17
Chloride (mg L^{-1})	12	12	7	58	8	18.4
Chlorophyll *a* (µg L^{-1})	12	31	3	10	7	7
Color (Pt-Co units)	15	59	47	80	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	59	0	0	3	2.4
Fecal coliform (FC $100mL^{-1}$)	20	59	8	14	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	59	1	2	0.3	0.12
pH (units)	6.5-8.5	51	3	6	na	na
Sodium, undig., filt. (mg L^{-1})	16	8	8	100	3	9.7
Soluble reactive phosphorus (µg L^{-1})	15	59	0	0	na	na

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Sulfate (mg L^{-1})	15	12	0	0	10	5.9
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	59	1	2	na	na
Total dissolved solids (mg L^{-1})[3]	50	59	40	68	40	69
Total phosphorus (µg L^{-1})	15	59	17	29	na	na
Total phytoplankton (ASU)	2,000	38	0	0	na	na
Primary genus (ASU)	1,000	38	1	3	na	na
Secondary genus (ASU)	1,000	38	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	1.1
Turbidity (NTU)	5	59	2	3	na	na
Ashokan East Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	10
Chloride (mg L^{-1})	12	9	0	0	8	5.3
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	1.9
Color (Pt-Co units)	15	39	8	21	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	64	0	0	3	1.6
Fecal coliform (FC 100mL^{-1})	20	64	5	8	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	0	0	0.3	0.12
pH (units)	6.5-8.5	64	32	50	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	7	78	3	3.4
Soluble reactive phosphorus (µg L^{-1})	15	64	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.10	64	0	0	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	64	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	64	0	0	40	32
Total phosphorus (µg L^{-1})	15	64	32	50	na	na
Total phytoplankton (ASU)	2,000	40	0	0	na	na
Primary genus (ASU)	1,000	40	0	0	na	na
Secondary genus (ASU)	1,000	40	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	64	26	41	5	11.2
Turbidity (NTU)	5	64	40	63	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	4.4
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	1.3
Color (Pt-Co units)	15	29	11	38	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	78	0	0	3	1.7
Fecal coliform (FC 100mL^{-1})	20	78	20	26	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	78	0	0	0.3	0.15
pH (units)	6.5-8.5	78	61	78	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	8	67	3	2.9

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	78	2	3	na	na
Sulfate ($mg\ L^{-1}$)	15	12	0	0	10	3.5
Total ammonia-N ($mg\ L^{-1}$)	0.10	78	0	0	0.05	0.02
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	78	4	5	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	50	78	0	0	40	30
Total phosphorus ($\mu g\ L^{-1}$)	15	78	57	73	na	na
Total phytoplankton (ASU)	2,000	40	0	0	na	na
Primary genus (ASU)	1,000	35	0	0	na	na
Secondary genus (ASU)	1,000	35	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	78	56	72	5	66.7
Turbidity (NTU)	5	78	67	86	na	na
Pepacton Reservoir						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	21			>10	12
Chloride ($mg\ L^{-1}$)	12	21	0	0	8	6.3
Chlorophyll *a* ($\mu g\ L^{-1}$)	12	40	0	0	7	2.9
Color (Pt-Co units)	15	126	36	29	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	4.0	126	0	0	3	1.6
Fecal coliform ($FC\ 100mL^{-1}$)	20	126	8	6	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	125	1	1	0.3	0.17
pH (units)	6.5-8.5	127	42	33	na	na
Sodium, undig., filt. ($mg\ L^{-1}$)	16	20	19	95	3	3.8
Soluble reactive phosphorus ($\mu g\ L^{-1}$)	15	125	0	0	na	na
Sulfate ($mg\ L^{-1}$)	15	21	0	0	10	4.3
Total ammonia-N ($mg\ L^{-1}$)	0.10	126	0	0	0.05	0.02
Total dissolved phosphorus ($\mu g\ L^{-1}$)	15	126	3	2	na	na
Total dissolved solids ($mg\ L^{-1}$)[3]	50	126	2	2	40	38
Total phosphorus ($\mu g\ L^{-1}$)	15	126	38	30	na	na
Total phytoplankton (ASU)	2,000	62	0	0	na	na
Primary genus (ASU)	1,000	62	0	0	na	na
Secondary genus (ASU)	1,000	62	0	0	na	na
Total suspended solids ($mg\ L^{-1}$)	8.0	62	2	3	5	2.4
Turbidity (NTU)	5	126	33	26	na	na
Neversink Reservoir						
Alkalinity ($mg\ CaCO_3\ L^{-1}$)	na	12			>10	3
Chloride ($mg\ L^{-1}$)	12	12	0	0	8	3
Chlorophyll *a* ($\mu g\ L^{-1}$)	12	24	0	0	7	2.9
Color (Pt-Co units)	15	103	72	70	na	na
Dissolved organic carbon ($mg\ L^{-1}$)[2]	4.0	79	1	1	3	2.3
Fecal coliform ($FC\ 100mL^{-1}$)	20	103	8	8	na	na
Nitrate+nitrite-N ($mg\ L^{-1}$)	0.5	79	0	0	0.3	0.15
pH (units)	6.5-8.5	90	78	87	na	na

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Sodium, undig., filt. (mg L^{-1})	16	12	0	0	3	1.7
Soluble reactive phosphorus (µg L^{-1})	15	79	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.3
Total ammonia-N (mg L^{-1})	0.10	79	0	0	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	79	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	103	0	0	40	17
Total phosphorus (µg L^{-1})	15	79	16	20	na	na
Total phytoplankton (ASU)	2,000	48	0	0	na	na
Primary genus (ASU)	1,000	48	0	0	na	na
Secondary genus (ASU)	1,000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	24	4	17	5	4.1
Turbidity (NTU)	5	103	41	40	na	na
Rondout Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	8
Chloride (mg L^{-1})	12	12	0	0	8	6.2
Chlorophyll *a* (µg L^{-1})	12	25	0	0	7	2.5
Color (Pt-Co units)	15	80	34	43	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.8
Fecal coliform (FC 100mL^{-1})	20	80	7	9	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	57	0	0	0.3	0.17
pH (units)	6.5-8.5	80	32	40	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	4.2
Soluble reactive phosphorus (µg L^{-1})	15	56	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	4.3
Total ammonia-N (mg L^{-1})	0.10	56	0	0	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	56	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	80	0	0	40	32
Total phosphorus (µg L^{-1})	15	80	6	8	na	na
Total phytoplankton (ASU)	2,000	48	0	0	na	na
Primary genus (ASU)	1,000	48	0	0	na	na
Secondary genus (ASU)	1,000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	32	1	3	5	1.7
Turbidity (NTU)	5	80	10	13	na	na
Schoharie Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	16
Chloride (mg L^{-1})	12	9	0	0	8	6.3
Chlorophyll *a* (µg L^{-1})	12	32	0	0	7	1.6
Color (Pt-Co units)	15	45	36	80	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	89	9	10	3	2.6
Fecal coliform (FC 100mL^{-1})	20	88	35	40	na	na

Appendix Table 2: (Continued) Comparison of reservoir water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual Mean Standard	2011 Mean [1]
Nitrate+nitrite-N (mg L^{-1})	0.5	66	0	0	0.3	0.12
pH (units)	6.5-8.5	89	31	35	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	4.4
Soluble reactive phosphorus (µg L^{-1})	15	66	2	3	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	3.7
Total ammonia-N (mg L^{-1})	0.10	66	1	2	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	66	11	17	na	na
Total dissolved solids (mg L^{-1})[3]	50	89	10	11	40	42
Total phosphorus (µg L^{-1})	15	89	62	70	na	na
Total phytoplankton (ASU)	2,000	48	0	0	na	na
Primary genus (ASU)	1,000	46	0	0	na	na
Secondary genus (ASU)	1,000	46	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	89	48	54	5	41.3
Turbidity (NTU)	5	89	75	84	na	na
Cannonsville Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18			>10	16
Chloride (mg L^{-1})	12	18	1	6	8	9.9
Chlorophyll *a* (µg L^{-1})	12	40	7	18	7	7.3
Color (Pt-Co units)	15	129	66	51	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	117	0	0	3	1.9
Fecal coliform (FC 100mL^{-1})	20	129	13	10	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	117	1	1	0.3	0.27
pH (units)	6.5-8.5	130	37	28	na	na
Sodium, undig., filt. (mg L^{-1})	16	18	18	100	3	6.4
Soluble reactive phosphorus (µg L^{-1})	15	117	3	3	na	na
Sulfate (mg L^{-1})	15	18	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.10	117	2	2	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	117	9	8	na	na
Total dissolved solids (mg L^{-1})[3]	50	129	73	57	40	52
Total phosphorus (µg L^{-1})	15	129	76	59	na	na
Total phytoplankton (ASU)	2,000	56	3	5	na	na
Primary genus (ASU)	1,000	56	7	13	na	na
Secondary genus (ASU)	1,000	56	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	48	0	0	5	1.8
Turbidity (NTU)	5	129	20	16	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 in van der Leeden et al. (1990).

Appendix E. Comparison of Stream Water Quality Results to Benchmarks

Appendix Table 3: Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
E10I (Bushkill inflow to Ashokan)						
Alkalinity (mg L^{-1})	≥10.0	11	11	100	na	7.1
Chloride (mg L^{-1})	50	11	0	0	10	1.7
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	0.8
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.08
Sulfate (mg L^{-1})	15	3	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.20	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	0	0	40	21
Dissolved sodium (mg L^{-1})	10	3	0	0	5	1.4
E16I (Esopus Creek at Coldbrook)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	12.4
Chloride (mg L^{-1})	50	12	0	0	10	6.1
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	0.15
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	1	8	40	38
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.6
E5 (Esopus Creek at Allaben)						
Alkalinity (mg L^{-1})	≥10.0	11	7	64	na	9.7
Chloride (mg L^{-1})	50	11	0	0	10	4.1
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	1.1
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.13
Sulfate (mg L^{-1})	15	3	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.20	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	0	0	40	29
Dissolved sodium (mg L^{-1})	10	3	0	0	5	3.2
S5I (Schoharie Creek at Prattsville)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	19.9
Chloride (mg L^{-1})	50	12	0	0	10	9.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.19

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
Sulfate (mg L^{-1})	15	4	0	0	10	4.7
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	6	50	40	55
Dissolved sodium (mg L^{-1})	10	4	0	0	5	7.5
S6I (Bear Creek at Hardenburgh Falls)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	25.8
Chloride (mg L^{-1})	50	12	0	0	10	14.2
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	0.33
Sulfate (mg L^{-1})	15	4	0	0	10	6.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	75
Dissolved sodium (mg L^{-1})	10	4	2	50	5	11.6
S7I (Manor Kill)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	25.1
Chloride (mg L^{-1})	50	12	0	0	10	7.1
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	0.10
Sulfate (mg L^{-1})	15	4	0	0	10	5.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	7	58	40	56
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.6
SRR2CM (Schoharie Reservoir Diversion)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	16.0
Chloride (mg L^{-1})	50	10	0	0	10	6.4
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	2.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.17
Sulfate (mg L^{-1})	15	4	0	0	10	3.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	13	2	15	40	45
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.7

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
C-7 (Trout Creek above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	14.5
Chloride (mg L^{-1})	50	12	0	0	10	14.0
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	6.2
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	58
Dissolved sodium (mg L^{-1})	10	4	1	25	5	9.9
C-8 (Loomis Brook above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	13.8
Chloride (mg L^{-1})	50	12	0	0	10	13.8
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	0.22
Sulfate (mg L^{-1})	15	4	0	0	10	6.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	7	58	40	57
Dissolved sodium (mg L^{-1})	10	4	2	50	5	11.1
NCG (Neversink Reservoir near Claryville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	3.3
Chloride (mg L^{-1})	50	12	0	0	10	2.7
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	0.20
Sulfate (mg L^{-1})	15	4	0	0	10	3.8
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	18
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.7
NK4 (Aden Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	5.2
Chloride (mg L^{-1})	50	12	0	0	10	3.4
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	0.13

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
Sulfate (mg L^{-1})	15	4	0	0	10	4.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	22
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.1
NK6 (Kramer Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	8	67	na	8.5
Chloride (mg L^{-1})	50	12	0	0	10	29.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.43
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	12	100	40	85
Dissolved sodium (mg L^{-1})	10	4	4	100	5	18.0
P-13 (Tremper Kill above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	17.3
Chloride (mg L^{-1})	50	12	0	0	10	9.4
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	0.29
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	7	58	40	52
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.3
P-21 (Platte Kill at Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	18.0
Chloride (mg L^{-1})	50	12	0	0	10	7.7
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	0.23
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	5	42	40	48
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.6

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
P-60 (Mill Brook near Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	5	42	na	11.1
Chloride (mg L^{-1})	50	12	0	0	10	1.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	0.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.26
Sulfate (mg L^{-1})	15	4	0	0	10	4.5
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	26
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.1
P-7 (Terry Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	3	25	na	13.7
Chloride (mg L^{-1})	50	12	0	0	10	0.9
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	0.31
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	1.1
P-8 (Fall Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	3	25	na	13.3
Chloride (mg L^{-1})	50	12	0	0	10	2.0
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	0.33
Sulfate (mg L^{-1})	15	4	0	0	10	5.0
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	32
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.8
PMSB (East Branch Delaware River near Margaretville)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	18.2
Chloride (mg L^{-1})	50	12	0	0	10	9.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.25

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
Sulfate (mg L^{-1})	15	4	0	0	10	4.7
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	6	50	40	52
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.2
RD1 (Sugarloaf Brook near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	4.3
Chloride (mg L^{-1})	50	12	0	0	10	5.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.1
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.10
Sulfate (mg L^{-1})	15	4	0	0	10	4.8
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	25
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.4
RD4 (Sawkill Brook near Yagerville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	4.2
Chloride (mg L^{-1})	50	12	0	0	10	5.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.8
Nitrate+nitrite-N (mg L^{-1})	1.5	12	1	8	0.40	0.75
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	0	0	40	26
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.5
RDOA (Rondout Creek near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	3.7
Chloride (mg L^{-1})	50	12	0	0	10	3.0
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	0.12
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	0	0	40	19
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.2

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
RGA (Chestnut Creek above Grahamsville STP)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	7.0
Chloride (mg L^{-1})	50	12	0	0	10	11.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.20
Sulfate (mg L^{-1})	15	4	0	0	10	5.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	3	25	40	44
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.5
RGB (Chestnut Creek below Grahamsville STP)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	7.0
Chloride (mg L^{-1})	50	12	0	0	10	12.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.22
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	1	8	40	44
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.5
WDBN (West Branch Delaware River at Beerston Bridge)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	15.7
Chloride (mg L^{-1})	50	12	0	0	10	8.8
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	0.36
Sulfate (mg L^{-1})	15	4	0	0	10	6.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	5	42	40	50
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.4
AMAWALKR (Amawalk Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	10	0	0	na	70.5
Chloride (mg L^{-1})	100	4	1	25	35	94.4
Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	3.8
Nitrate+nitrite-N (mg L^{-1})	1.5	10	0	0	0.35	0.25

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
Sulfate (mg L^{-1})	25	4	0	0	15	11.0
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	10	10	100	150	319
Dissolved sodium (mg L^{-1})	20	3	3	100	15	48.6
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)						
Alkalinity (mg L^{-1})	≥40.0	10	0	0	na	74.4
Chloride (mg L^{-1})	100	4	0	0	35	50.5
Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	4.0
Nitrate+nitrite-N (mg L^{-1})	1.5	10	0	0	0.35	0.15
Sulfate (mg L^{-1})	25	4	0	0	15	11.0
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	10	9	90	150	220
Dissolved sodium (mg L^{-1})	20	3	3	100	15	26.4
BOYDR (Boyd Corners Release)						
Alkalinity (mg L^{-1})	≥40.0	11	11	100	na	30.8
Chloride (mg L^{-1})	100	4	0	0	35	37.0
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	3.8
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.35	0.11
Sulfate (mg L^{-1})	25	4	0	0	15	8.0
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	11	0	0	150	132
Dissolved sodium (mg L^{-1})	20	3	2	67	15	21.1
CROFALLSR (Croton Falls Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	51.3
Chloride (mg L^{-1})	100	4	0	0	35	68.4
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	0.30
Sulfate (mg L^{-1})	25	4	0	0	15	10.8
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	228
Dissolved sodium (mg L^{-1})	20	3	3	100	15	38.2

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
CROSS2 (Cross River near Cross River Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	49.9
Chloride (mg L^{-1})	100	4	0	0	35	37.9
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	0.19
Sulfate (mg L^{-1})	25	4	0	0	15	9.1
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	12	2	17	150	160
Dissolved sodium (mg L^{-1})	20	3	1	33	15	20.0
CROSSRVR (Cross River Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	40.8
Chloride (mg L^{-1})	100	4	0	0	35	33.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.10
Sulfate (mg L^{-1})	25	4	0	0	15	9.0
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	141
Dissolved sodium (mg L^{-1})	20	3	0	0	15	17.1
DIVERT2R (Diverting Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	4	0	0	na	67.0
Chloride (mg L^{-1})	100	1	0	0	35	99.9
Dissolved organic carbon (mg L^{-1})	25	4	0	0	9	3.6
Nitrate+nitrite-N (mg L^{-1})	1.5	4	0	0	0.35	0.35
Sulfate (mg L^{-1})	25	1	0	0	15	18.1
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	4	2	50	150	239
Dissolved sodium (mg L^{-1})	20	1	1	100	15	51.4
EASTBR (East Branch Croton River above East Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	10	1	10	na	86.2
Chloride (mg L^{-1})	100	4	0	0	35	42.4
Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	4.1
Nitrate+nitrite-N (mg L^{-1})	1.5	10	0	0	0.35	0.12

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
Sulfate (mg L^{-1})	25	4	0	0	15	9.9
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	10	8	80	150	210
Dissolved sodium (mg L^{-1})	20	3	1	33	15	22.1
GYPSYTRL1 (Gypsy Trail Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	11	92	na	26.5
Chloride (mg L^{-1})	100	4	0	0	35	36.9
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	0.06
Sulfate (mg L^{-1})	25	4	0	0	15	6.9
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	12	2	17	150	119
Dissolved sodium (mg L^{-1})	20	3	2	67	15	22.7
HORSEPD12 (Horse Pound Brook)						
Alkalinity (mg L^{-1})	≥40.0	11	7	64	na	36.2
Chloride (mg L^{-1})	100	4	0	0	35	44.6
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	3.2
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.35	0.33
Sulfate (mg L^{-1})	25	4	0	0	15	9.0
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	11	4	36	150	159
Dissolved sodium (mg L^{-1})	20	3	2	67	15	24.3
KISCO3 (Kisco River above New Croton Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	10	0	0	na	70.1
Chloride (mg L^{-1})	100	4	1	25	35	83.2
Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	3.5
Nitrate+nitrite-N (mg L^{-1})	1.5	10	0	0	0.35	0.61
Sulfate (mg L^{-1})	25	4	0	0	15	14.4
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	10	10	100	150	297
Dissolved sodium (mg L^{-1})	20	3	3	100	15	47.9

Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
LONGPD1 (Long Pond outflow above West Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	3	25	na	50.6
Chloride (mg L^{-1})	100	4	0	0	35	61.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.20
Sulfate (mg L^{-1})	25	4	0	0	15	8.7
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	12	11	92	150	235
Dissolved sodium (mg L^{-1})	20	3	3	100	15	38.3
MIKE2 (Michael Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	84.9
Chloride (mg L^{-1})	100	4	3	75	35	161.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	9	75	0.35	2.47
Sulfate (mg L^{-1})	25	4	0	0	15	15.5
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	467
Dissolved sodium (mg L^{-1})	20	3	3	100	15	95.8
MUSCOOT10 (Muscoot River above Amawalk Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	11	0	0	na	72.2
Chloride (mg L^{-1})	100	4	1	25	35	107.3
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	4.7
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.35	0.50
Sulfate (mg L^{-1})	25	4	0	0	15	9.6
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	11	11	100	150	381
Dissolved sodium (mg L^{-1})	20	3	3	100	15	64.3
TITICUSR (Titicus Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	10	0	0	na	60.4
Chloride (mg L^{-1})	100	4	0	0	35	38.6
Dissolved organic carbon (mg L^{-1})	25	10	0	0	9	3.5
Nitrate+nitrite-N (mg L^{-1})	1.5	10	0	0	0.35	0.19

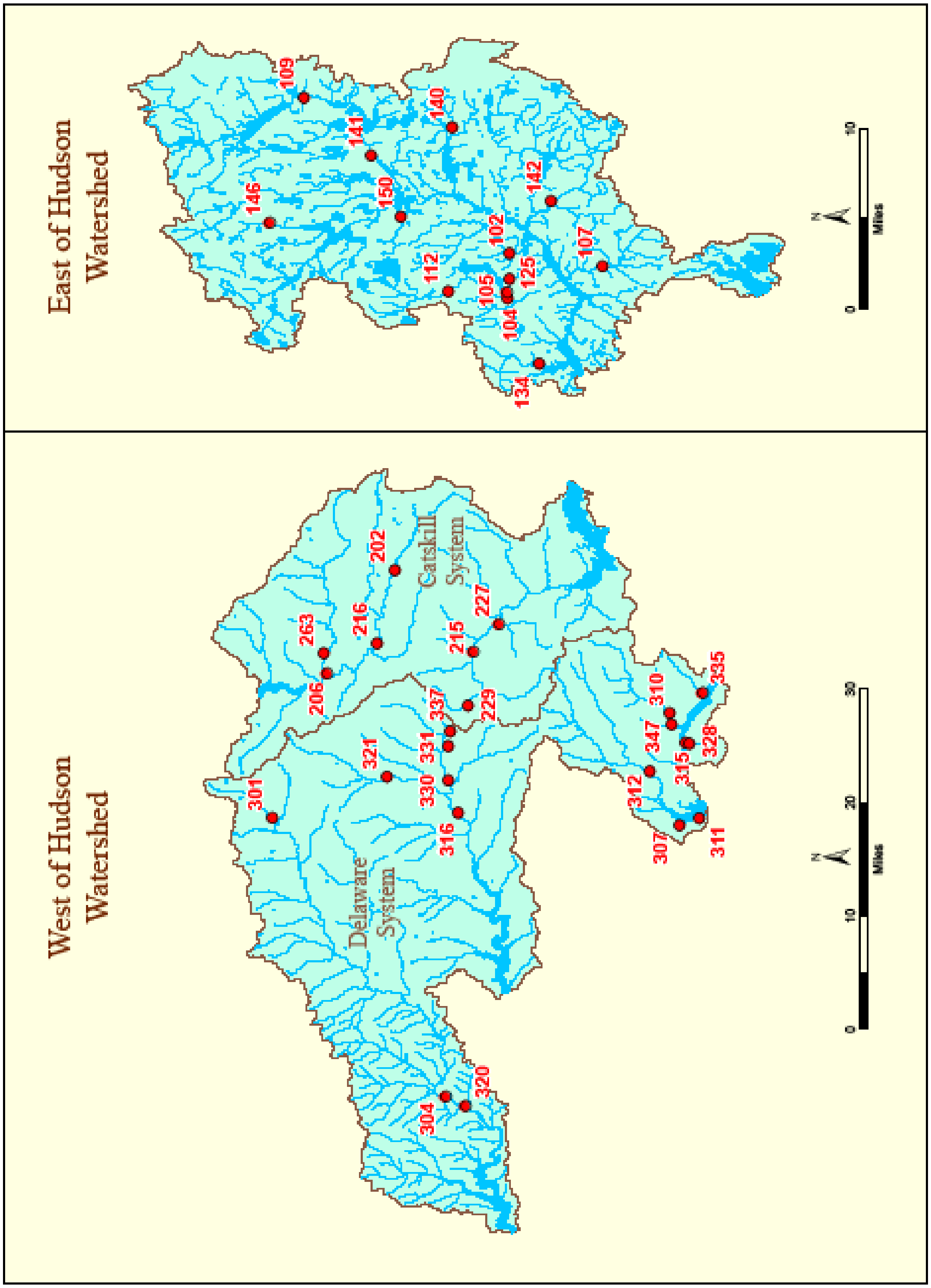
Appendix Table 3: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2011 mean[1]
Sulfate (mg L^{-1})	25	4	0	0	15	9.7
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	10	5	50	150	176
Dissolved sodium (mg L^{-1})	20	3	1	33	15	18.8
WESTBR7 (West Branch Croton River above Boyd Corners Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	11	92	na	29.8
Chloride (mg L^{-1})	100	4	0	0	35	33.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	5.7
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.04
Sulfate (mg L^{-1})	25	4	0	0	15	7.6
Total ammonia-N (mg L^{-1})	0.20	0			0.10	
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	120
Dissolved sodium (mg L^{-1})	20	3	2	67	15	19.6
WESTBRR (West Branch Reservoir Release)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	12.7
Chloride (mg L^{-1})	50	4	0	0	10	10.5
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	0.15
Sulfate (mg L^{-1})	15	4	0	0	10	5.8
Total ammonia-N (mg L^{-1})	0.20	0			0.05	
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	56
Dissolved sodium (mg L^{-1})	10	3	0	0	5	6.2

[1] Means estimated using 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 in van der Leeden et al. (1990).

Appendix F. Biomonitoring Sampling Sites



Appendix Figure 1. Biomonitoring sampling sites.