New York City Environmental Protection

2012 Watershed Water Quality Annual Report

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NYC Environmental Protection

Cover photo by Aron Thomas, NYCDEP

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Acknowledgements

This report provides a summary of the scientific work conducted in 2012 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 2012, 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.

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Executive Summary

Water Quality Operations

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. There were two changes in sampling that should be noted for 2012: (1) the DEL18 sample site was relocated from a pump located within the forebay at Shaft 18 at Kensico Reservoir to a new sample pump installed in the downtake at Shaft 18, and (2) the Catskill-Delaware Water Ultraviolet Disinfection Facility Plant (CDUV) was activated on September 14, 2012. This led to the shutdown of the section of the Catskill Aqueduct from Kensico to Eastview because it is not pressurized and thus not able to deliver water to the plant. With this development, CATLEFF was discontinued as a keypoint site.

When Hurricane Sandy arrived in the New York City area, DEP was able to monitor near-real-time turbidity using continuous monitoring at site DEL18DT and a robotic monitoring buoy in front of the Delaware effluent chamber Shaft 18. As turbidity began to rise rapidly, the decision was made to place the Delaware Aqueduct on float mode. Hurricane Sandy highlighted the potential for high wind coming from the north and northeast to impact turbidity in water near Delaware Shaft 18. As a result, float operations were implemented again during wind and rain events on November 7-8 and December 26-27.

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 2012 was 981 mm (38.6 inches), which was 170 mm (6.7 inches) below normal. With precipitation in the watershed for the year being somewhat below the normal historical values, the annual runoff was also generally somewhat below normal, except for the Rondout and Neversink watersheds, which had near normal runoff for the year. The United States Geological Survey reported that New York State had near normal annual runoff for the 2012 water year (October 1, 2011-September 30, 2012), but was much below normal for the spring season, and below normal for summer. While systemwide usable storage levels in the reservoir system began the year well above average, capacity generally declined through April, but recovered to near normal after a large rain event in later April and more rain in May. Capacity declined through the summer until another large rain event in September brought capacity to above normal, where it stayed for the remainder of the year. Surprisingly little precipitation accompanied Hurricane Sandy; in our area there were primarily high wind impacts.

Water Quality Highlights

In 2012, watershed water quality was assessed using data collected at keypoint, reservoir, and stream sites. Precipitation for the year was below normal, although there were storms in September that impacted the Neversink and Schoharie watersheds. The most significant weather event for New York in 2012 was Hurricane Sandy, which had devastating effects on the region, with high winds having the most impact on the watershed area. In particular, the high winds led to a period of elevated turbidity in Kensico Reservoir. This caused a compliance sample to briefly exceed the Surface Water Treatment Rule (SWTR) limit for turbidity of 5 NTU, resulting in a Tier 2 treatment technique notification. Keypoint data demonstrated that the City's source waters remained compliant with SWTR limits for fecal coliform and turbidity during the rest of the year.

The effects of localized storms and residual effects of Tropical Storms Irene and Lee varied in the Catskill/Delaware System reservoirs. Turbidity was elevated in Schoharie, Ashokan, and Neversink Reservoirs. Rondout, Pepacton, and Cannonsville had low to normal turbidity levels in 2012. Total phosphorus (TP) concentrations followed a similar pattern except in Ashokan, where TP levels were within the historical range. Fecal and total coliform counts were most notably elevated in Schoharie and Neversink. Kensico Reservoir was at the low end of the historical range for turbidity, coliform, and TP. In the Croton System, reservoirs were generally within historical ranges for these analytes. For source waters, coliform-restricted calculations indicated that none of the reservoirs were "restricted" with respect to fecal coliforms. For non-terminal reservoirs, total coliforms exceeded the assessment standards for at least one month in 6 of 17 reservoirs. The phosphorus-restricted calculations indicated that nine 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 2012. Restricted basins included 12 of 13 Croton System reservoirs. Trophic status indices (TSI) based on chlorophyll *a* remained relatively low for Catskill/Delaware reservoirs compared to their historical ranges. Turbidity was responsible for the decrease in TSI in Ashokan and Schoharie, while low rainfall and ongoing loading reductions of TP resulted in lower TSI for Cannonsville and Pepacton. Kensico, Rondout, and Neversink were within their historical ranges. West Branch had an increase in TSI due to operational use of more Croton water. Many of the Croton System reservoirs were at or below their long-term median TSI levels.

Stream sample data were evaluated for turbidity, TP, and fecal coliform. Turbidity medians for the major inflowing streams of the Catskill/Delaware and Croton Systems were near normal in 2012, with the exception of the Schoharie input. The elevated turbidities were due to the continued impact of Tropical Storms Irene and Lee from 2011. TP concentrations were higher for the Schoharie and Rondout streams compared to the 10-year median. All other TP medians in streams were generally within their historical ranges. Fecal coliform results for 2012 showed that the Catskill/Delaware and Croton streams were generally near or slightly below typical historical ranges. In a comparison to stream benchmarks, excursions were observed at varying frequencies for alkalinity, sodium, chloride, total dissolved solids, sulfate, ammonia, and nitrate. Because stream biomonitoring assessments were calculated using a new NYSDEC metric, comparison to previous years' assessments requires further analysis. In the Catskill and Delaware Systems, 14 of 32 sites monitored in 2012 were non-impaired, while none of the 9 Croton sites attained non-impaired status. Taxa counts at sites that were impacted in 2011 by Tropical Storms Irene and Lee increased in 2012, demonstrating some recovery at these sites, but spikes in caddisfly numbers suggested some lingering effects from these storms.

Pathogen Monitoring and Research

DEP collected 587 samples for protozoan analysis and 238 samples for human enteric virus (HEV) monitoring in 2012. Most samples were collected at keypoint locations and watershed streams, with additional samples collected at upstate reservoir effluents, Hillview Reservoir, and wastewater treatment plants (WWTPs). *Giardia* cysts continued to be detected at higher frequencies and concentrations in the watershed as compared to *Cryptosporidium* oocysts. For the two- year period from January 1, 2011 to December 31, 2012, DEP source water continued to be well below the LT2 threshold for additional treatment at an unfiltered water supply (0.010 oocysts L^{-1}), with means of 0.0006 oocysts L^{-1} and 0.0002 oocysts L^{-1} at the Catskill and Delaware effluent sites, respectively, and 0.0010 at the New Croton Reservoir effluent. Overall, protozoan concentrations leaving the upstate reservoirs and Kensico Reservoir were lower than levels at the stream sites that feed these reservoirs, suggesting a reduction as water passes through the system. For the first time since monitoring began, no *Cryptosporidium* oocysts were detected leaving Kensico Reservoir at the Delaware effluent. The Catskill Aqueduct leaving Kensico Reservoir, however, did have more detections of *Giardia* than those at the Catskill Aqueduct influent site. This higher rate of detection is likely a result of the combination of input from the Delaware influent and additional *Giardia* contributions from the local Kensico watershed. While there were a few detections of *Giardia* cysts at WWTPs East of Hudson, there were no HEV or *Cryptosporidium* oocysts detected at any plants in 2012. This was the first year since protozoan monitoring began that there were no *Giardia* detections at West of Hudson monitoring plants. As per the Hillview Administrative Order, DEP continued weekly protozoan monitoring at the Hillview Reservoir outflow (Site 3) through 2012, with 53 weekly samples and one additional sample collected after Hurricane Sandy. Of the 54 samples taken, there were 17 detections of *Giardia* but no detections of *Cryptosporidium*.

Modeling

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

For operational decision support, reservoir and water system models are used during periods of elevated turbidity in the Catskill System to inform aqueduct flow decisions to ensure that water quality standards are met while minimizing the use of alum. During 2012, there were two periods of elevated turbidity in the Catskill System. In response to these turbidity events, model analyses were used to evaluate reservoir operating policies that could minimize alum use and help ensure high effluent water quality.

DEP continued in 2012 to enhance its watershed turbidity modeling capability, through development of a GIS-based screening tool to predict areas of potential stream channel erosion based on estimations of stream power, and development of an improved turbidity prediction method that in addition to stream discharge also accounts for stream turbidity levels using time series autocorrelation. Development and testing of these tools represents an advance in DEP's ability to model watershed turbidity.

DEP is using its suite of simulation models to investigate the effects of climate change on the New York City Water Supply as part of the Climate Change Integrated Modeling Project (CCIMP). A major finding of Phase I of the project is 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 is now under way. During 2012, DEP conducted modeling analyses of the effects of climate change on eutrophication in Cannonsville Reservoir and turbidity in the Ashokan West Basin. For Ashokan Reservoir, there is a shift in timing of turbidity loading into the reservoir, which generally follows the shift in streamflow with increased turbidity loading in winter. The loading of total dissolved phosphorus, which is a critical nutrient for algal growth, is also affected by the seasonal shift in flow, with greater loads to Cannonsville Reservoir in late fall and winter compared with current climate conditions. DEP continued to participate in the Water Utility Climate Alliance (WUCA) project, and in two Water Research Foundation Projects related to climate change: Vulnerability Assessment and Risk Management Tools for Climate Change (Project 4262), and Analysis of Reservoir Operations under Climate Change (Project 4306).

Further Research

The analytical, monitoring, and research capabilities of DEP are supplemented through a variety of contracts and participation in research projects conducted by the Water Research Foundation.

The contracts include:

Virus Analysis: DEP officially began analyzing its own virus samples without the need of a contract laboratory as of June 1, 2012. DEP began overall virus monitoring in 1995; therefore, the data record is now approximately 17 years long for some keypoint locations.

Laboratory Analytical Support: In 2012, Eurofins Eaton Analytical contracted analyses included: volatile organic carbon (VOC) and semivolatile organic carbon (SVOC) analyses on selected aqueduct samples; total Kjeldahl nitrogen analyses on wastewater 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.

Water Quality Operation and Maintenance and Assessment for the Hydrological Monitoring Network: USGS measures stage, discharge, and water quality at some or all of approximately 55 stream gauges throughout the watershed of New York City.

Turbidity and Suspended Sediment Monitoring in the Upper Esopus Creek Watershed, Ulster County, NY: This contract with the USGS involves retrofitting the five existing USGS stream flow gauges in the Esopus Creek watershed to automatically monitor turbidity at high (15 minute) frequency to evaluate temporal and spatial variations in turbidity sources and transport within the Esopus Creek watershed.

CUNY Postdoctoral Support: This four-year contract provides CUNY with the funding needed to hire seven postdoctoral research associates working with the Water Quality Modeling Group on a day-to-day basis. To date, 17 peer reviewed publications in the following areas of research have resulted from this contract:

- Climate data analysis
- Reservoir system modeling
- Reservoir turbidity modeling
- Reservoir eutrophication modeling
- Watershed nutrient modeling
- Watershed sediment erosion and transport modeling
- Forest ecosystem modeling

Robotic Monitoring of Selected New York City Reservoirs and Major Tributaries: This contract provides a network of automated monitoring systems that provide near-real-time information on Catskill System and Kensico Reservoir turbidity levels. Eight reservoir monitoring buoys were installed and three stream monitoring sites were upgraded or installed by the Upstate Freshwater Institute (UFI). Since 2011, DEP has fully taken over operation of the robotic monitoring system. Data collected by the system is automatically uploaded to the DEP Laboratory Information Management System (LIMS) and is used by Operations, Modeling, and the Operational Support Tool (OST).

Waterfowl Management: The Waterfowl Management Program 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 on the reservoirs and the reservoirs’ concentrations of fecal coliforms. This highly effective management program was developed based on this finding.

Zebra Mussel Monitoring: DEP has been monitoring all 19 of New York City's reservoirs for the presence of zebra mussel larvae (veligers) and mature zebra mussels since the early 1990s. To date, this invasive mussel has not established itself in the New York City system.

Water Research Foundation Projects in 2012:

The Water Research Foundation (WaterRF) is an internationally-renowned research organization that conducts research projects to benefit water supply utilities worldwide. Several DEP staff members are currently involved as Project Advisory Committee (PAC) members in the projects listed below. A full description of WaterRF projects, and their status, can be found at the WaterRF website http://www.waterrf.org/.

- WRF # 4179: Selecting and Standardizing the Most Appropriate Tool for Regulatory *Cryptosporidium* Genotyping
- WRF # 4222: Reservoir Operations and Maintenance Strategies
- WRF # 4261: The EDC Network for Water Utilities
- 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 # 4306: Analysis of Reservoir Operations under Climate Change
- WRF # 4324:Water Quality Impacts of Extreme Weather Events
- WRF # 4348: Matrix Effects in the Bull Run Watershed on *Cryptosporidium* Recovery
- WRF # 4382: Impacts of Climate Change on the Ecology of Algal Blooms
- WRF # 4422: On-Line NOM Characterization: Advanced Techniques for Controlling DBPs and for Monitoring Changes in NOM Under Future Climate Change Scenarios

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 2012, 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 2012 Drinking Water Supply and Quality Report (http://www.nyc.gov/html/dep/pdf/wsstate12.pdf), which is distributed to consumers annually to provide information about the quality of the City's tap water. More detailed reports on some of the topics described herein can be found in other DEP publications, accessible through the DEP website at http://www.nyc.gov/dep/.

The New York City Water Supply System (Figure 1.1) supplies drinking water to almost half the population of the State of New York, which includes over 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 historically supplied 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.

Figure 1.1 The New York City Water Supply System.

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 2012 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 in the Drinking Water Supply and Quality Report, as noted earlier.

Table 1.1: Water quality sampling summary for 2012.

System/Laboratory	Number of samples	Number of analyses	Number of sites
Catskill/Kingston	3,561	60,331	133
Delaware/Grahamsville	4,276	50,164	136
EOH/Kensico	10,536	108,379	157
EOH/Brewster	1,037	8,348	60
Watershed	19,410	227,222	486
Distribution	30,236	355,647	1,000
Total	**49,646**	**582,869**	**1,486**

There were two changes in sampling that should be noted for 2012. The changes occurred at the Kensico effluent keypoints, which represent water leaving the reservoir and entering the Catskill (site code CATLEFF) and Delaware (site code DEL18) Aqueducts at points just prior to disinfection, and are the sites which must meet SWTR “raw water” requirements. As of August 20, 2012, the DEL18 sample was relocated from a pump located within the forebay at Shaft 18 at Kensico to a new sample pump installed in the downtake at Shaft 18. The new site, named DEL18DT, replaced the previous site, DEL18, as the DEL18 effluent keypoint sample. Also, the Catskill-Delaware Water Ultraviolet Disinfection Facility Plant (CDUV) was activated on September 14, 2012. This led to the shutdown of the section of the Catskill Aqueduct from Kensico to Eastview because it is not pressurized and thus not able to deliver water to the plant. With this development CATLEFF was discontinued as a keypoint site.

1.2 Operations in 2012 to Control Fecal Coliforms and Turbidity

In January 2012, the Bureau of Water Supply was treating the Catskill System input to Kensico Reservoir with alum to manage turbidity that remained in the system from Tropical Storms Lee and Irene. Alum treatment was discontinued on May 15, 2012, and there were no further alum treatments in 2012.

In the Catskill System, the elevation at which water was withdrawn from Ashokan Reservoir was adjusted throughout the year, as necessary, to draw the best quality water from the basin and to meet operational needs. In the first six months of the year, the best water quality was available in the surface waters of the reservoir’s East Basin. In July, water was of sufficient quality in the West Basin to allow diversion from that basin as well. A blend of East/West and upper and lower elevations from each basin was utilized into September. By October, diversion of water into the Catskill Aqueduct had returned to the east side at a middle draw elevation.

DEP also used the Ashokan Reservoir Release works (which discharges water to lower Esopus Creek) to control reservoir turbidity and storage levels. Release waters are generally taken from the bottom of the West basin, but elevation can be changed when quality and volume conditions allow. The release of waters from the reservoir to the creek occurred throughout 2012.

Selective withdrawal is also used in the Delaware System. Diversion elevation changes were made at the intake chambers of Rondout, Pepacton, and Cannonsville Reservoirs to deliver the best quality water. In July 2012, for example, the elevation of withdrawal at these three reservoirs was changed from a surface withdrawal elevation to a middle level withdrawal to divert less turbid waters. Additional modifications were made later in the year at the Rondout and Pepacton intake chambers, as needed.

When Hurricane Sandy arrived in the New York City area, DEP was able to monitor near-real-time turbidity using continuous monitoring at site DEL18DT and a robotic monitoring buoy in front of the Delaware effluent chamber Shaft 18. As turbidity began to rise rapidly on October 30 at the Delaware Shaft 18 source water monitoring station, the decision was made to place the Delaware Aqueduct on float mode. Float operation allows DEP to deliver better quality water from Rondout Reservoir and/or West Branch Reservoir to Hillview, with Kensico Reservoir water added only if needed to meet demand. Hurricane Sandy highlighted the potential for high winds coming from the north and northeast to impact turbidity in water near Delaware Shaft 18 more so than when the Catskill Aqueduct leaving Kensico was operational. As a result, float operations were implemented as a precautionary measure again during wind and rain events that occurred on November 7 to 8 and December 26 to 27.

Fecal coliform concentrations remained low throughout 2012, and there were no operational responses related to fecal coliforms.

1.3 Recreation in the Watershed

Although the majority of land in the watershed is privately owned by local residents, New York City is also a watershed landowner, with responsibilities for managing nearly 34,000 acres of reservoirs and approximately 150,000 acres of water supply lands.Over the past few years, DEP has focused on opening more City-owned lands and waters for outdoor recreational uses. The reservoirs themselves have been a haven for fishermen for many years, and at one point comprised the majority of City-owned acreage open for public recreation. Recently, DEP purchased land in the watershed beyond the immediate area of the reservoirs as part of its program to protect the water supply for more than nine million New Yorkers. These recently-acquired watershed lands have been recog-

Figure 1.2 For more information on recreational opportunities, please visit http://www.nyc.gov/html/dep/pdf/recreation/2013_spring_newsletter.pdf.

nized as a regional resource that can not only help protect the water supply, but also provide outdoor recreational opportunities—including fishing, boating, hiking, hunting, and trapping—to watershed residents and visitors. These lands, in combination with the reservoirs, now total more than 100,000 acres open to the public for recreation.

In 2012, DEP expanded a three-year pilot program for recreational boating on Cannonsville Reservoir to Neversink, Pepacton, and Schoharie Reservoirs. Since May 25, 2012, recreational boats, including, kayaks, canoes, rowboats, sculls, and sailboats, have been allowed on all four reservoirs, opening an additional 12,544 acres to boating. Now, boaters will no longer have to be fishing to enjoy the pristine environments of these reservoirs. The goal of the program is to increase regional recreational opportunities for watershed residents and visitors, and to promote environmentally sound economic development.

Figure 1.3 Recreational boaters compete in a 2012 race event held at Pepacton Reservoir in Delaware County. Photo by Vladimir Bukalo

2. Water Quantity

2.1 The Source of New York City's Drinking Water

New York City's water is supplied by a system consisting of 19 reservoirs and 3 controlled lakes with a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The system's watershed drains approximately 5,100 square kilometers (1,972 square miles) (Figure 1.1). The system is dependent on precipitation (rainfall and snowmelt) and subsequent runoff to supply the reservoirs in each of three watershed systems, Catskill, Delaware, and Croton. The first two are located West of Hudson (WOH), while the Croton System is located East of Hudson (EOH). As the water drains from the watershed, it is carried via streams and rivers to the reservoirs. The water is then moved via a series of aqueducts to terminal reservoirs before 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.

Figure 2.1 Schoharie Creek, upstream of the Village of Hunter. Schoharie Creek is the main input to Schoharie Reservoir in the Catskill System.

2.2 2012 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 2012 monthly precipitation total for each watershed is plotted along with the historical monthly average in Figure 2.2.

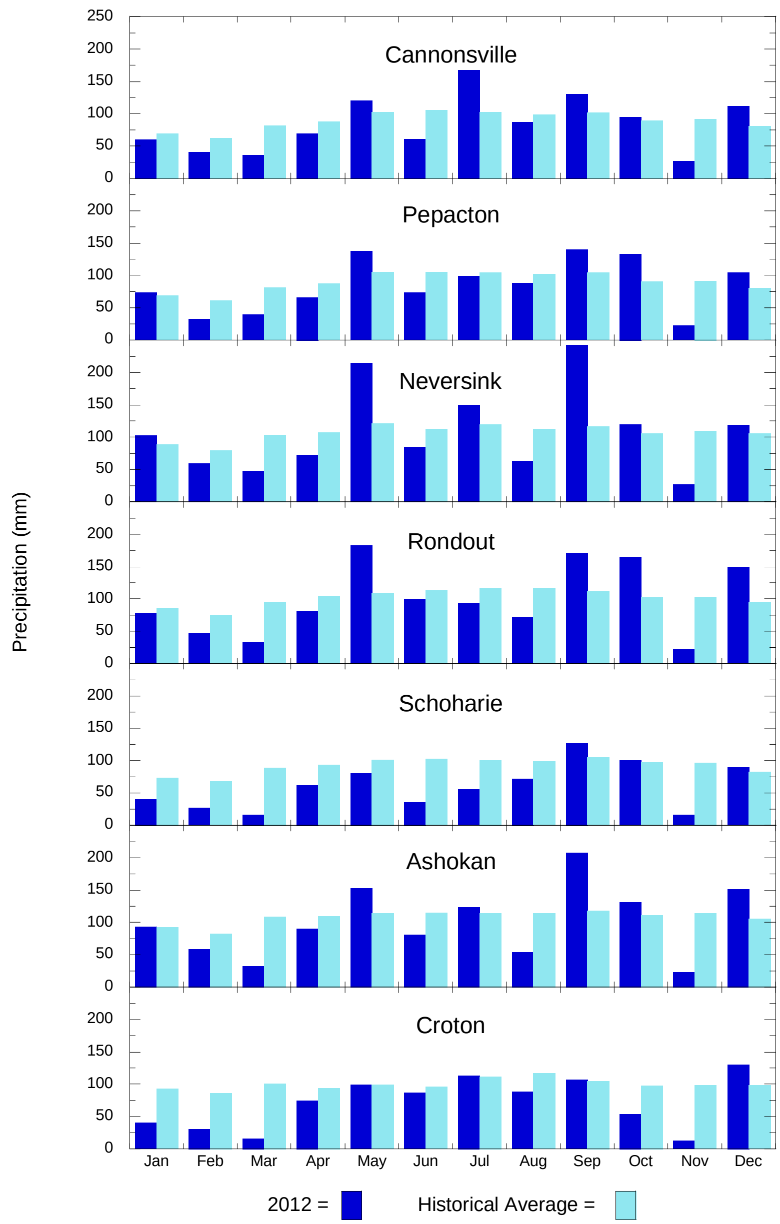


Figure 2.2 Monthly precipitation totals for New York City watersheds, 2012 and historical values.

The total monthly precipitation figures show that in general precipitation was about normal for January in all watersheds except Croton and Schoharie, which were below normal. February through April had below average precipitation for all watersheds, although a large event in late April brought two to three inches or more of rain to the watershed. May had above average precipitation, except for the Croton watershed, which was about normal, and the Schoharie watershed, which was slightly less than normal. June had below average precipitation, while July had mixed results, ranging from below average in Schoharie and Rondout to near normal in Pepacton and Croton to somewhat above average in Cannonsville, Neversink, and Ashokan. Precipitation in August was below average in all watersheds, and September was above average, except for Croton, which was near normal. It should be noted that a large wind and rain event impacted the watershed on September 18. DEP reported a rainfall total of 4.57 inches for Neversink, but other observers in the area reported totals exceeding 7 inches. The impact of this storm on water quality will be discussed in this report (see Chapter 3). October was variable, with the WOH watershed somewhat above average, while Croton was below average. In November, all watersheds were well below normal and in December they were all above average. Overall, the total precipitation in the watershed for 2012 was 981 mm (38.6 inches), which was 170 mm (6.7 inches) below normal.

The National Climatic Data Center's (NCDC) 2012 Annual Climate Summary (http://www.ncdc.noaa.gov/sotc/national/2012/13) reported that the annual precipitation total for 2012 in New York was near normal. Winter (December 2011-February 2012), spring (March-May), and fall (September-November) were all near normal with respect to precipitation, while summer (June-August) was below normal (the 33rd driest in the last 118 years). Also, 2012 was the warmest year on record (1895-2012) for New York.

The most significant weather event for New York in 2012 was Hurricane Sandy, which had devastating effects on the region. The storm made landfall as a post-tropical cyclone around 7:30 pm on October 29 near Brigantine, NJ. At that time, it had an estimated wind speed near 80 mph, and tropical storm force winds extended approximately 1,000 miles outward from the storm center (National Weather Service 2013). It was the high winds that had the most impacts on the watershed area. For example, the storm caused nearly 2,000 trees to be toppled around the Cross River, Croton Falls, East Branch, Kensico, Muscoot, New Croton, Rondout, Titicus and West Branch Reservoirs. The wind also led to a brief period of elevated turbidity in Kensico Reservoir, with a compliance grab sample exceeding the 5 NTU limit, which resulted in a Tier 2 treatment technique violation of the Surface Water Treatment Rule (SWTR). Additional details may be found in Section 3.1 of this report and in the after action report that was prepared following this event (DEP 2012a).

2.3 2012 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.

Selected USGS stations were used to characterize annual runoff in the different NYC watersheds (Figure 3.9). The annual runoff in 2012 was somewhat below normal for four of the WOH basins (Schoharie, Esopus Creek, West Branch and East Branch of the Delaware River) at about the 25th percentile, while Neversink and Rondout were about normal for the year (Figure 2.3). In the EOH watersheds, the 2012 annual runoff was generally below normal (Figure 2.3). The EOH stations have a 17-year period of record, except for the Wappinger Creek site (84-year period of record). (Wappinger Creek is not located in the EOH System, but is included here because it is located in nearby Dutchess County, and its longer period of record is more comparable to those found in the WOH System.) The period of record for the WOH stations ranges from 49 years at the Esopus Creek Allaben station to 106 years at the Schoharie Creek Prattsville gauge. New York State had near normal runoff for the 2012 water year (October 1, 2011-September 30, 2012) compared to the last 83 years (1930-2012), as determined by the USGS (http://waterwatch.usgs.gov/2012summary/). However, the USGS did report runoff for the state to be much below normal for the spring season (April-June) and below normal for the summer season (July-September).

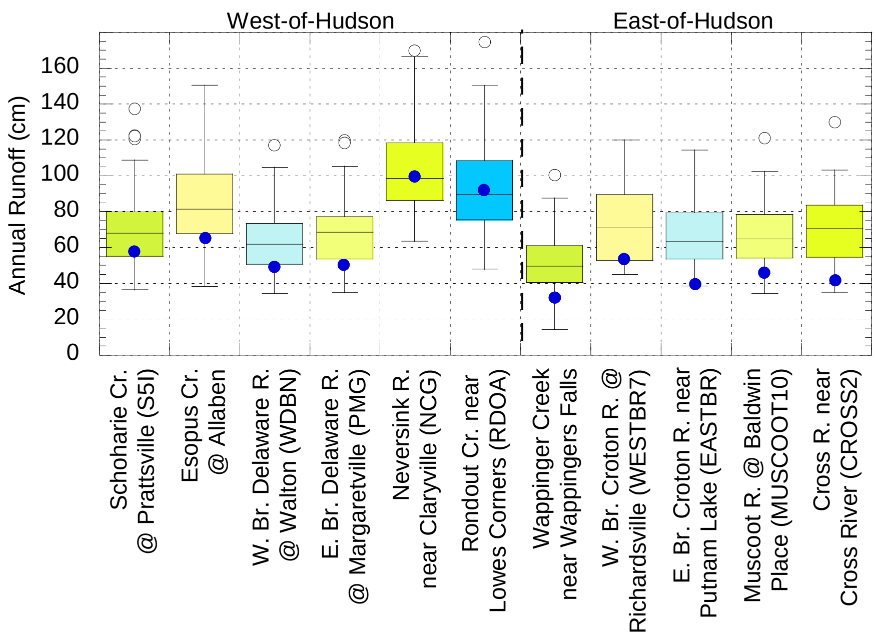


Figure 2.3 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds, with the values for 2012 displayed as a dot.

Figure 2.4 shows the 2012 mean daily discharge, along with the minimum, maximum, and median daily discharge for the period of record, for the same USGS stations that were used to characterize annual runoff. For the WOH stations, discharge was near normal to start the year but fell below normal in April until rains late in the month caused a spike in flows. May and June had near normal daily flows, which fell below normal in late June and July, except for Rondout and Neversink, which remained near normal. Storms in September brought flows above normal until early November, when they fell somewhat below normal until a storm in December caused a spike in flows. For EOH stations, discharge was near or slightly below normal to start the year. Flows were well below normal from March until late April, when they rose back to near or slightly below normal. They generally remained below normal until mid-July, when they again rose to near normal before falling to below normal in late August. Flows rose in September and remained near normal until falling below normal again in November. The below-normal flows persisted until the same late December storm that caused a rise at WOH stations caused EOH flows to reach normal levels at the end of the month.

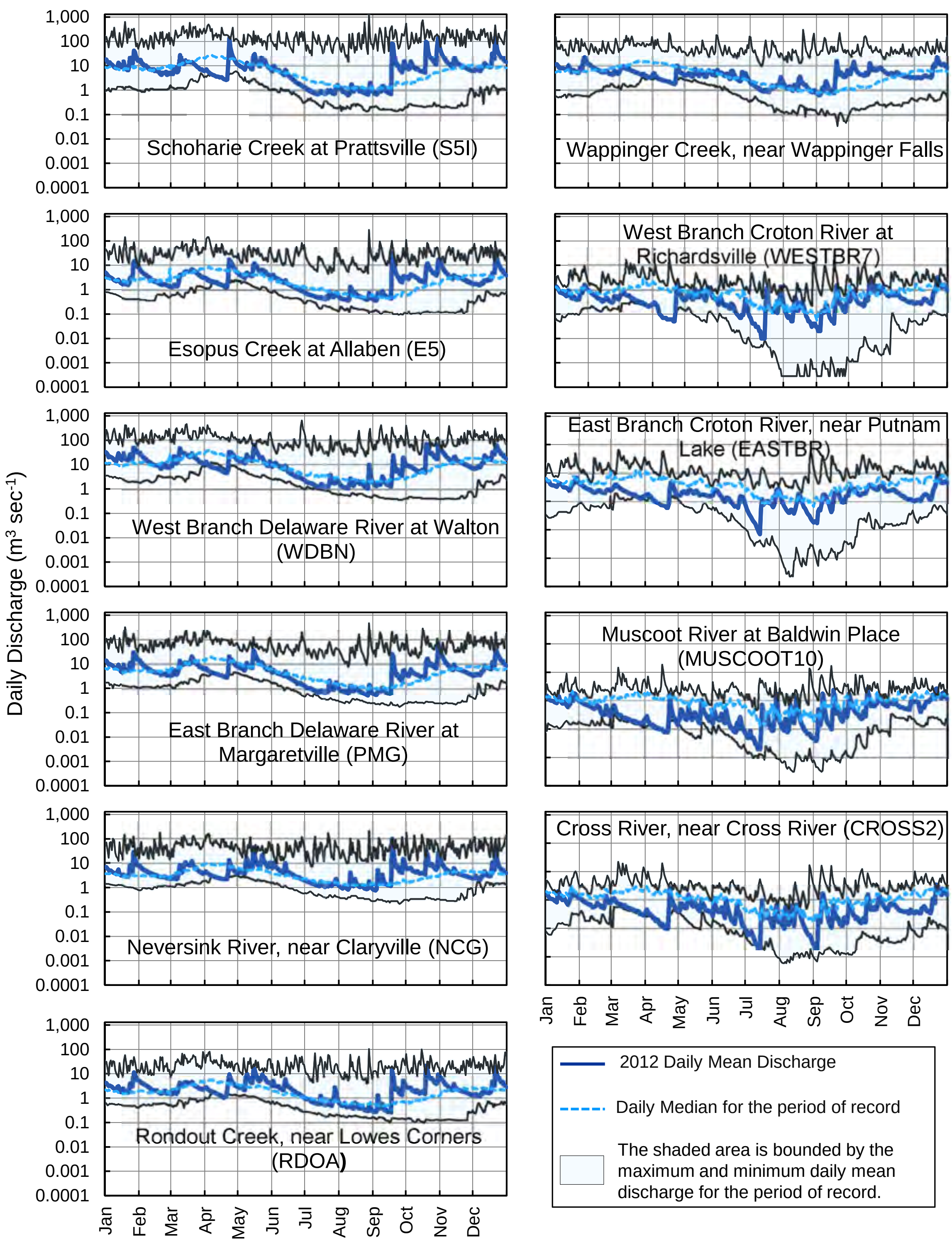


Figure 2.4 Daily mean discharge for 2012 at selected USGS stations.

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) (DEP 2010a). Section 18-39 established DEP's authority to regulate the management and treatment of stormwater runoff, created 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.

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 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 2.5 through 2.8). The 1-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 100% chance of occurring in any given year, while the 10-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 10% chance of occurring in any given year. The 100-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 1% chance of occurring in any given year. Figures 2.5 through 2.8 are isohyetal maps that present estimates of these precipitation return periods for New York State. 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 August 2010) or online at http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf.

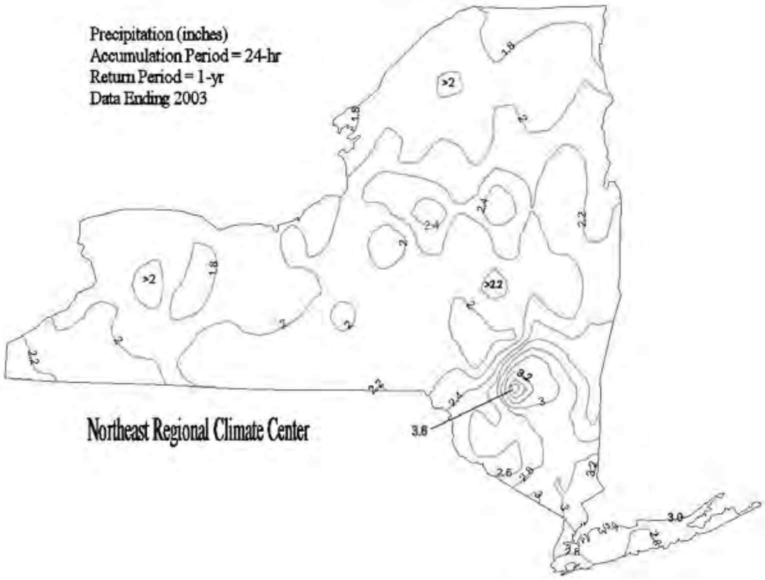


Figure 2.5 The 1-year, 24-hour storm for New York State from the 2010 Stormwater Management Design Manual (NYSDEC 2010) (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

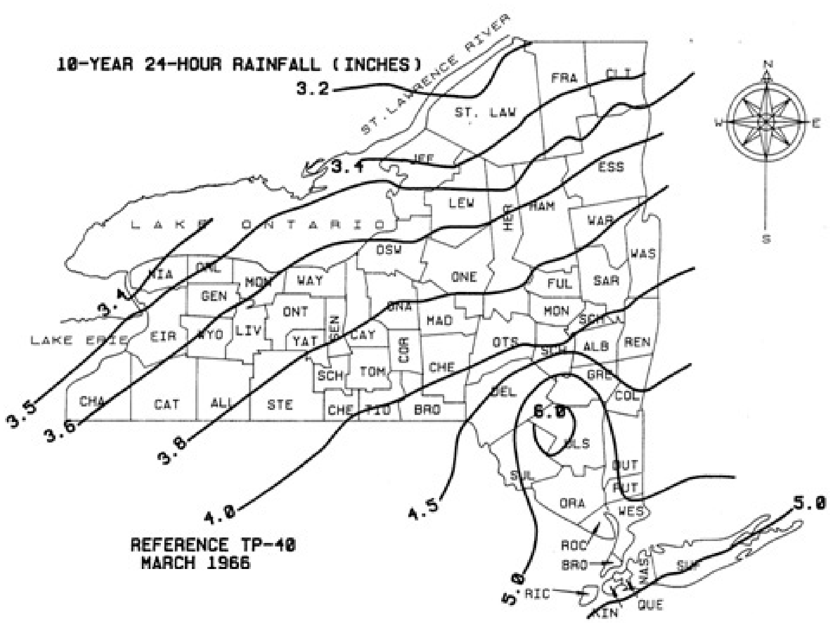


Figure 2.6 The 10-year, 24-hour storm for New York State from the 2010 Stormwater Management Design Manual (NYSDEC 2010) (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

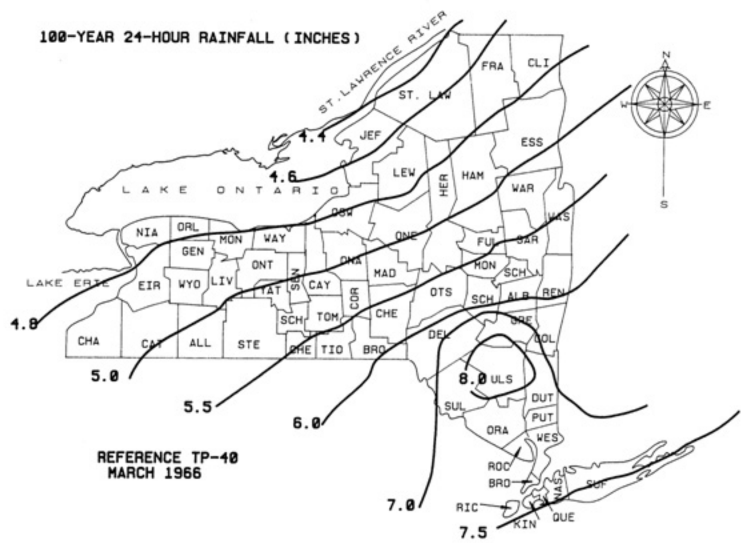


Figure 2.7 The 100-year, 24-hour storm for New York State from the 2010 Stormwater Management Design Manual (NYSDEC 2010) (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

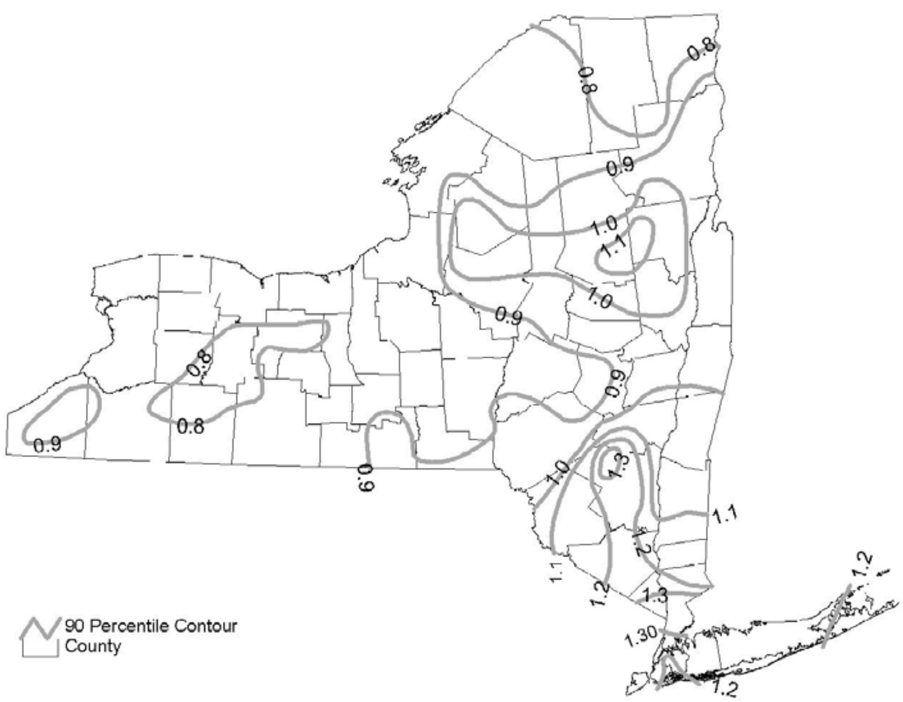


Figure 2.8 Ninety percent rainfall in New York State from the 2010 Stormwater Management Design Manual (NYSDEC 2010) (http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf).

2.5 Reservoir Usable Storage Capacity in 2012

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 to 2011. At the start of 2012 the actual systemwide storage capacity was well above normal due to inputs from several large rain events (including Tropical Storms Irene and Lee) that occurred from late August to December in the previous year (Figure 2.9). However, winter was very mild in 2012 and storage capacity generally declined until late April, leaving the total capacity of the system about 5% below normal. Capacity quickly recovered to nearly 100% due to a large rain event in late April and abundant rainfall throughout May. The normal decline during the summer months was somewhat steeper in 2012, driven by a very dry August and first half of September. Capacity recovered to above normal after a large rain event from September 17 to 18 caused localized flooding, which was especially severe in the Neversink basin. Additional rain events later in September and above average rainfall in October and December kept system capacity higher than normal for the remainder of the year.

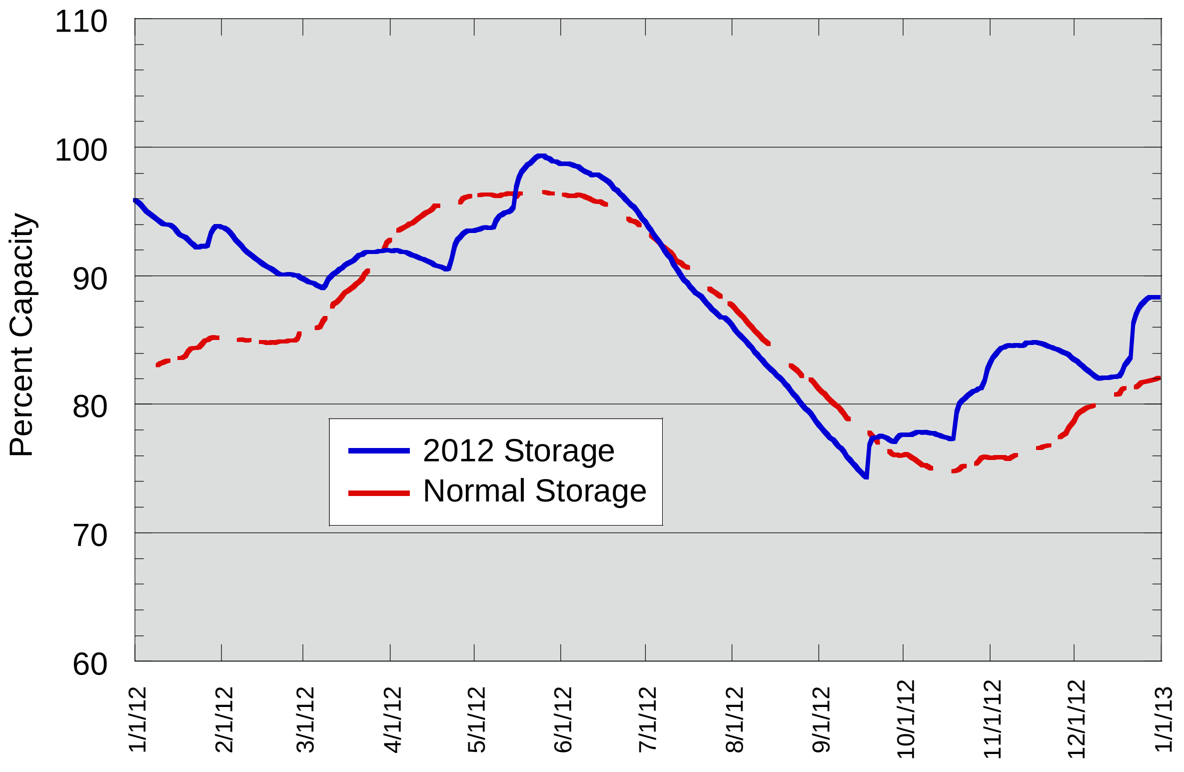


Figure 2.9 2012 systemwide usable storage compared to historical storage. Storage greater than 100% is possible when the reservoirs are spilling or when the water surface elevation is greater than the spillway elevation.

3. Water Quality

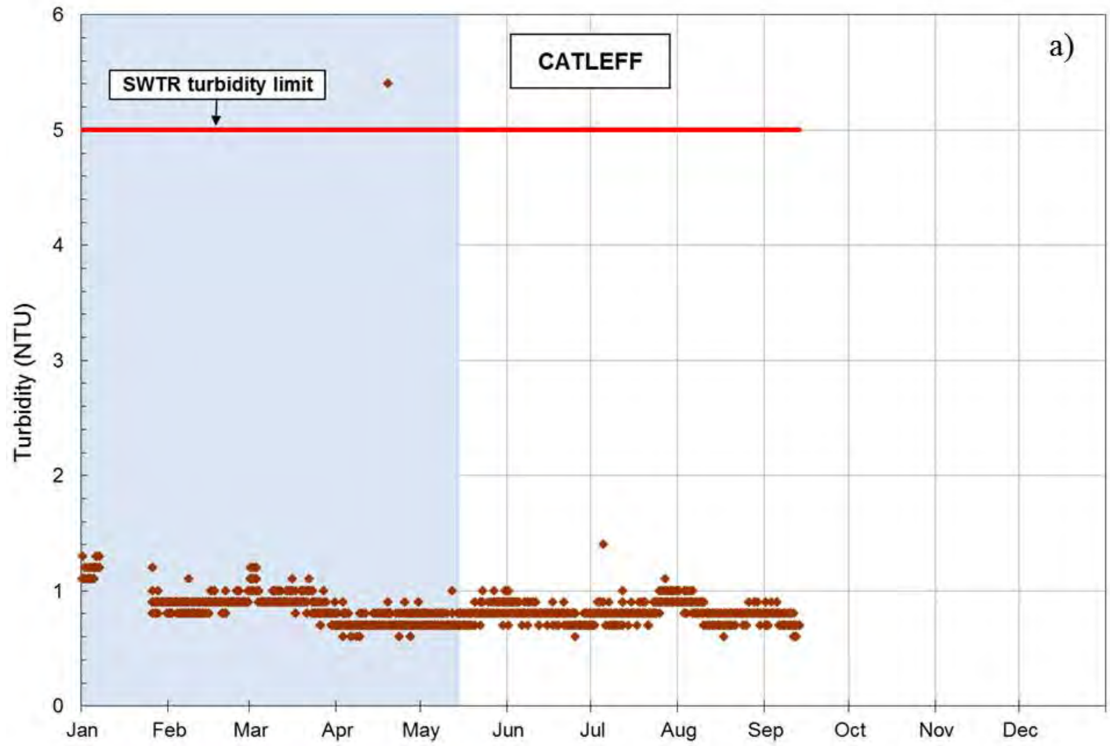
3.1 Keypoint Compliance with the Surface Water Treatment Rule

The Surface Water Treatment Rule (SWTR) (USEPA 1989) requires that water at a point just prior to disinfection not exceed specific 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). In 2012, water from Croton was not used in the distribution system and was therefore not subject to these requirements. Also, as discussed in Chapter 1, there were changes to the keypoint sampling in 2012. Prior to August 2012, the sample for Shaft 18 was collected by a pump in the forebay (site code: DEL18), but late in the month the sampling site was moved to the downtake shaft to provide a representative sample during all operational conditions and renamed DEL18DT. Also, the activation on September 14, 2012 of the Catskill-Delaware Water Ultraviolet Disinfection Facility Plant (CDUV) led to a shutdown of the 2.5-mile section of the Catskill Aqueduct from Kensico Reservoir to Eastview. The shutdown was required because this section of the aqueduct is not pressurized and cannot overcome the 40 feet of gravitational pressure needed to convey water from Kensico to the CDUV plant. As a result, the CATLEFF effluent keypoint was discontinued, leaving DEL18DT as the only Kensico effluent keypoint**.** Table 3.1 shows that the 2012 fecal coliform counts at the CATLEFF and DEL18/18DT compliance sampling locations met the SWTR standard that no more than 10% of daily samples in a six-month period contain more than 20 fecal coliforms $100mL^{-1}$. The 2012 calculated percentages for effluent waters at CATLEFF and DEL18/DEL18DT were below this limit. Median fecal coliform counts in raw water samples taken at these sites were <1 and 1 fecal coliform $100mL^{-1}$, while maxima were 6 and 15 fecal coliforms $100mL^{-1}$, respectively.

Table 3.1: Fecal coliform at the keypoints compared to the SWTR limit for 2012 (percent daily samples > 20 fecal coliforms $100mL^{-1}$ in the previous six months).

Month	Catskill (CATLEFF)%	Delaware (DEL18/18DT)%
Jan	6.10	6.52
Feb	3.70	4.40
Mar	0.00	0.00
Apr	0.00	0.00
May	0.00	0.00
Jun	0.00	0.00
Jul	0.00	0.00
Aug	0.00	0.00
Sep	0.00	0.00
Oct	-	0.00
Nov	-	0.00
Dec	-	0.00

The SWTR limit for turbidity is 5 NTU, which includes levels up to 5.4, since values are rounded to the nearest whole number. Catskill/Delaware effluents are measured at 4-hour intervals. Figure 3.1 depicts the 2012 turbidity data from the CATLEFF and DEL18/DEL18DT sites, and includes horizontal reference lines marking the SWTR limit. Median turbidity at the DEL18/DEL18DT sites from January 1-December 31, 2012 was 1.0 NTU, while at CATLEFF it was 0.80 NTU from January 1 until that keypoint was shut down on September 14, 2012. Maximum values at the two locations were 6.0 and 5.4 NTU, respectively. The 6.0 NTU reading was due to the impact of Hurricane Sandy. On October 29, 2012, as Hurricane Sandy neared the New Jersey shore, gale force winds and the resulting wave action in Kensico caused shoreline erosion and a rapid increase in turbidity levels at Shaft 18. Operational changes to control the event were ultimately successful and turbidity levels rapidly declined after having remained above 5 NTU for about 105 minutes. During this period of elevated turbidity, the 8:00 pm raw water turbidity compliance grab sample measured 6.0 NTU. This resulted in a treatment technique violation of the SWTR that required Tier 2 notification as outlined in the New York State Sanitary Code 10 NYCRR Section 5-1.78(d). Additional details may be found in the 2012 Kensico Water Quality Annual Report (DEP 2013a) and in the after action report (DEP 2012a). Other than this exceptional event, compliance was maintained, highlighting the continued success of the management of the New York City Watershed, as well as effective operational strategies to meet drinking water standards.



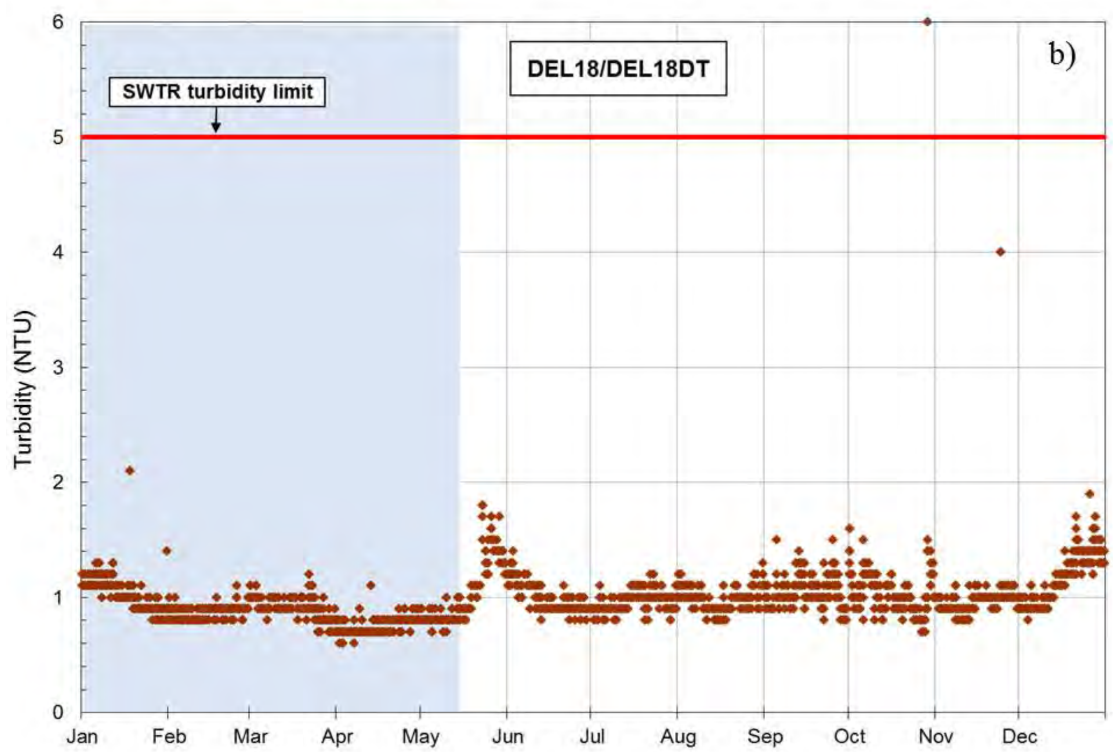


Figure 3.1 Turbidity at keypoints in 2012 compared to the SWTR limit.

3.2 Reservoir Turbidity Patterns in 2012

Turbidity in reservoirs consists of both inorganic (e.g., clay, silt) and organic (e.g., plankton) particulates suspended in the water column. 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).

Turbidity in the Catskill System reservoirs was much higher than normal in 2012 (Figure 3.2). (An explanation of the boxplots used in this and other figures in this chapter is provided in Appendix A.) Schoharie was very high all year primarily due to the effects of Tropical Storms Irene and Lee in the summer of 2011. Turbidity levels peaked again in late September 2012 due to an additional large rain event on September 18, and 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 2012. 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. Early spring turbidity was low to normal in the Ashokan basins, reflecting a small snowpack and subsequent snowmelt. However, numerous >1-inch rain events in the spring and summer kept turbidity slightly above normal levels through the summer. The September 18 rain event caused both basins to peak in late September. An additional large rain event in October kept turbidity levels high for the remainder of the year. 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.

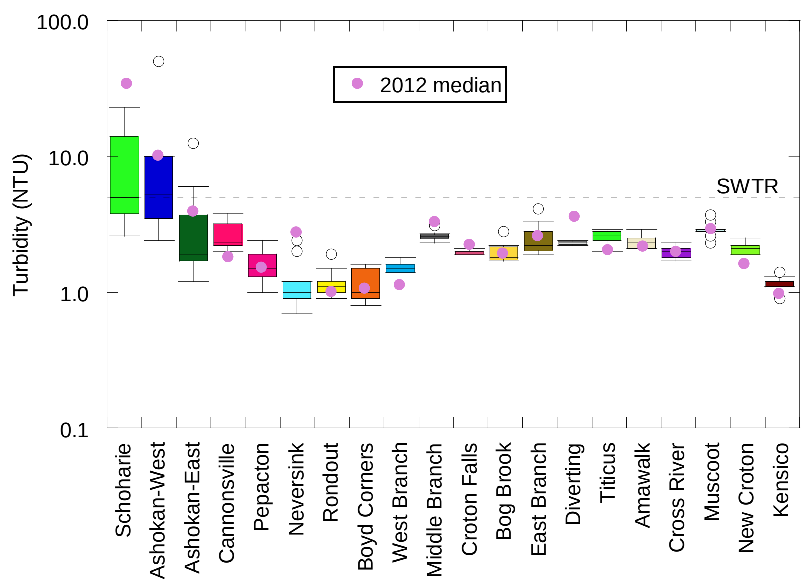


Figure 3.2 Annual median turbidity in New York City water supply reservoirs (2012 vs. 2003-2011). The dashed line at 5 NTU refers to the SWTR criterion that considers 2 consecutive days > 5NTU as a violation in source water reservoirs. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

In the Delaware System, 2012 turbidity levels were normal at Rondout and Pepacton and very low at Cannonsville. Relatively few large rain events occurred in these watersheds and impacts from the September 18 rain event were not severe. In contrast, large rain events were common in the Neversink watershed, with many occurring just prior to sampling. Six >1-inch storms occurred from May-July (four in May alone), coinciding with elevated turbidity levels in these months. In early September two more rain events (>1 inch), followed by a flooding event (5.3 inches of rain) on September 17-18, caused turbidity to peak in September and remain higher than normal for the remainder of the year. In response to the elevated turbidity, diversions from Neversink were greatly reduced for much of the year. West Branch Reservoir, which receives inputs from both the Delaware and Croton Systems, had lower than normal turbidity for the year. In 2012, West Branch was almost exclusively operated in "float" status, resulting in a higher percentage of Croton water relative to Delaware water in the reservoir. Low turbidity inputs from Rondout and Boyd Corners Reservoirs and from local West Branch streams explains the lower than normal turbidity observed in West Branch Reservoir in 2012.

Turbidity at Kensico, the terminal reservoir for the Catskill and Delaware Systems, was down slightly for the year, largely due to more reliance on the Delaware System (although less so on Neversink) during periods when the Catskill System was impacted by turbidity. Alum treatment, applied to Catskill Aqueduct water from August 29, 2011 to May 15, 2012, also helped keep Kensico turbidity at its historical low level.

Turbidity in the Croton System was generally normal to below normal in 2012 (Figure 3.2, Table 3.2). Rainfall was well below average and large rain events were infrequent. Middle Branch and Diverting had elevated turbidity levels, probably the result of sampling soon after some small rain events and, in some months, because of particulate contributions from algal blooms. The slightly elevated turbidity at Kirk Lake was likely related to the anoxic condition of the water in August.

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

Lake	Median Turbidity (2003-11)	Median Turbidity (2012)
Gilead	1.4	1.4
Gleneida	1.6	1.4
Kirk	3.8	4.3

3.3 Coliform-Restricted Basin Assessments in 2012

Coliform bacteria are used widely as indicators of potential pathogen contamination. To protect the City's water supply, the New York City Watershed Rules and Regulations (WR&R) (DEP 2010a) restrict potential sources of coliforms in the watershed area of 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 2012, 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 ≥ 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. All the terminal basins had fecal coliform counts that were well below the 10% threshold and were non-restricted for both six-month assessment periods in 2012. Table 3.3 displays these results, as well as the changes in sampling sites used for the analysis in 2012.

Table 3.3: Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2012.

Reservoir basin	Effluent keypoint	2012 assessment
Kensico	CATLEFF and DEL18DT[1]	Non-restricted
New Croton	CROGH	Non-restricted[2]
Ashokan	EARCM	Non-restricted
Rondout	RDRRCM	Non-restricted
West Branch	CWB1.5	Non-restricted

[1] DEL18 was changed to DEL18DT (downtake) starting on August 20, 2012. CATLEFF was discontinued after September 13, 2012, when all flow was routed through DEL18DT to the UV plant.

[2] Data from sites CRO1B and CRO1T were also used for analysis.

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 in 2012. 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]
Amawalk	A	2400/5000	0/8	
Bog Brook	AA	50/240	0/8	1/8
Boyd Corners	AA	50/240	2/7	
Croton Falls	A/AA	50/240	0/8	2/8
Cross River	A/AA	50/240	0/9	
Diverting	AA	50/240	4/7	1/7
East Branch	AA	50/240	1/8	1/8
Lake Gilead	A	2400/5000	0/8	
Lake Gleneida	AA	50/240	1/8	
Kirk Lake	B	2400/5000	0/7	
Muscoot	A	2400/5000	0/8	
Middle Branch	A	2400/5000	0/8	
Titicus	AA	50/240	0/8	1/8
Pepacton	A/AA	50/240	0/10	1/10
Neversink	AA	50/240	1/10	1/10
Schoharie	AA	50/240	6/9	
Cannonsville	A/AA	50/240	0/10	2/10

[1] The reservoir class for each waterbody is set forth in 6 NYCRR Chapter X, Subchapter B. 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.

Eleven reservoirs never exceeded the Part 703 standard for total coliform in 2012: Amawalk, Bog Brook, Croton Falls, Cross River, Lake Gilead, Kirk Lake, Middle Branch, Muscoot, Titicus, Pepacton, and Cannonsville. The remaining reservoirs exceeded the standard for one to six months during the sampling season. From Appendix B it can be seen that Neversink and Schoharie Reservoirs were particularly affected by the impacts of a regionally heavy storm in September.

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 2012. There was no other data indicating an anthropogenic source.

3.4 Reservoir Total and Fecal Coliform Patterns in 2012

Total coliform and fecal coliform bacteria are regulated at raw water intakes by the SWTR at levels of 100 coliforms100mL^{-1} and 20 coliforms 100mL^{-1}, respectively. Both are important as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific, in that their source is the gut of warm-blooded animals; total coliforms include both fecal coliforms and other coliforms that typically originate in water, soil, and sediments.

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 boxplots are annual 75th percentiles rather than medians. Using the 75th percentile makes it easier to discern differences among reservoirs, since more than 50% of coliform data is generally below the detection limit.

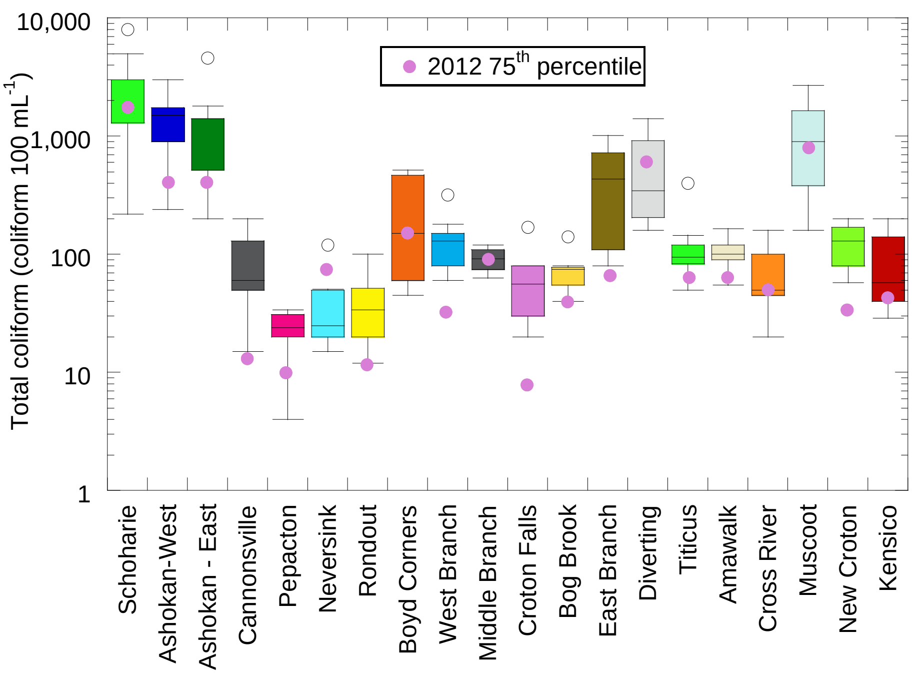


Figure 3.3 Annual 75th percentile total coliforms in New York City water supply reservoirs (2012 vs. 2003-2011). In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

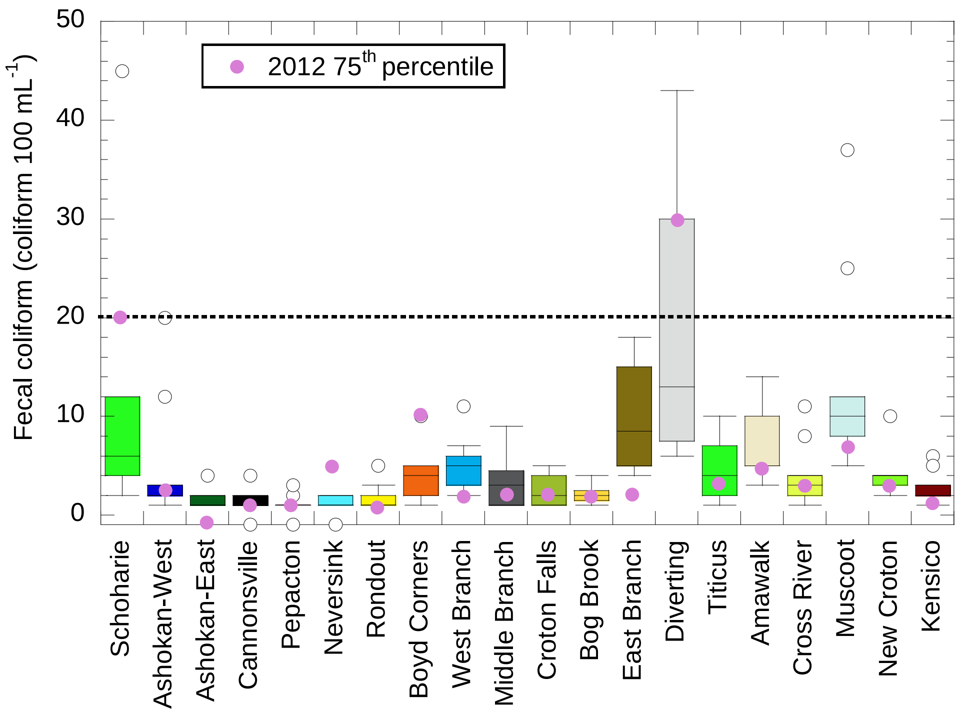


Figure 3.4 Annual 75th percentile of fecal coliforms in New York City water supply reservoirs (2012 vs. 2003-2011). The dashed line represents the SWTR standard for source waters as a reference. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November. Note: 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 (2003-2011) and current (2012) total and fecal coliform concentrations ($100mL^{-1}$).

Lake	Historical total coliforms	Current total coliforms	Historical fecal coliforms	Current fecal coliforms
Gilead	51	16	4	1
Gleneida	28	20	1	0
Kirk	190	180	6	2

Historically, the highest total coliform counts occur in the Catskill System reservoirs (Figure 3.3). 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.

Counts in Schoharie peaked in late September following the large rain event on the 18th of that month. For reasons that are not clear, total coliforms in the Ashokan basins were much lower than historical levels, particularly in the summer.

In the Delaware System, total coliform counts were well below historical levels in Cannonsville, Pepacton, Rondout and West Branch. Rainfall was below average in these watersheds and large storms were relatively infrequent. In contrast, large rain events were common in the Neversink watershed, with many occurring just prior to sampling. Six >1-inch storms occurred from May-July (4 in May alone) coinciding with elevated total coliform levels in these months. In early September, two more rain events (>1 inch), followed by a flooding event (5.3 inches of rain) on September 17-18, caused total coliforms to peak in September and remain higher than normal for the remainder of the year. Counts in Kensico Reservoir were low in 2012 but generally within the historical range.

Low total coliform counts were apparent in most Croton System reservoirs, coinciding with the low rainfall experienced by the region in 2012. The exceptions occurred at Muscoot and Diverting Reservoirs (Figure 3.3) and Kirk Lake (Table 3.5), where elevated total coliforms are historically observed due to these reservoirs' shallow depth. Shallow reservoirs 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.

Fecal coliform patterns were very similar to those observed for total coliforms. Counts in most reservoirs were low (or low to normal), coinciding with the generally low rainfall. Elevated counts were only observed at Schoharie, Neversink, Boyd Corners, and Diverting. High spring and late summer counts at Schoharie were associated with rain events in April and the large September 18 rain event. The Neversink basin experienced numerous rain events in 2012, all associated with elevated fecal coliform counts. Counts peaked after widespread flooding from the September 18 storm. High counts at Boyd Corners were associated with May and July rain events, while April, June, and August rain events correlated with high counts at Diverting.

3.5 Fecal Coliform Control through Waterfowl Management

Migratory populations of waterbirds utilize New York City reservoirs as temporary staging areas and wintering grounds, and in doing so contribute to increases in fecal coliform loadings during the autumn and winter, primarily from direct fecal deposition in the reservoirs. These waterbirds generally roost nocturnally and occasionally forage and loaf diurnally on the reservoirs, although most foraging activity occurs away from the reservoirs. Fecal samples collected and analyzed for fecal coliform bacteria concentrations from both Canada Geese (*Branta canadensis*) and Ring-billed Gulls (*Larus delawarensis*) revealed that fecal coliform concentrations are relatively high per gram of feces (Alderisio and DeLuca 1999). Data from water samples collected near waterbird roosting and loafing locations for several years demonstrated that fecal coliform levels were correlated with waterbird populations at several NYC reservoirs (DEP 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009a, 2010b). Based on these data, DEP determined that waterbirds were the most important contributor to seasonal fecal coliform bacteria loads to Kensico Reservoir and other terminal reservoirs (West Branch, Rondout, Ashokan), and that waterbirds can also lead to increased seasonal fecal coliform levels in other reservoirs from which water can be pumped into the Delaware Aqueduct (Croton Falls and Cross River).

In response to these data, which clearly demonstrate the relationship between waterbird population density and reservoir fecal coliform levels, DEP developed and implemented a Waterfowl Management Program (WMP) to reduce or eliminate waterbird populations inhabiting the reservoir system (DEP 2002). At several of the City's reservoirs, the WMP has implemented standard bird management techniques that are approved by the United States Department of Agriculture's Wildlife Services (part of USDA's Animal and Plant Health Inspection Service), the United States Fish and Wildlife Service (USFWS), and the New York State Department of Environmental Conservation (NYSDEC). DEP has also acquired a depredation permit from the USFWS and NYSDEC to implement additional avian management techniques. Bird dispersal measures include non-lethal harassment by pyrotechnics, motorboats, airboats, and propane cannons, as well as bird deterrence measures, such as waterbird reproductive management, shoreline fencing, bird netting, overhead bird deterrent wires, and meadow management. Wildlife management methods that continued to be employed at Hillview Reservoir in 2012 included lethal removal of resident Ruddy Ducks (*Oxyura jamaicensis*) and other migratory ducks through a USDA contract. In addition, mammals were trapped and removed in locations where fecal concentrations have been identified. A federal wildlife depredation permit was also used to eliminate nesting Mallards where necessary. These efforts 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 SWTR (40 CFR 141.71(a)(1)) states that no more than 10% of source water fecal coliform samples may exceed 20 fecal coliforms100mL^{-1} over the previous six-month period. Since waterbird management began, no such violation has occurred at Kensico Reservoir. This is a vast improvement compared to the period prior to the implementation of the WMP (Figure 3.5). DEP will continue implementation of the WMP to help ensure delivery of high quality water to New York City consumers.

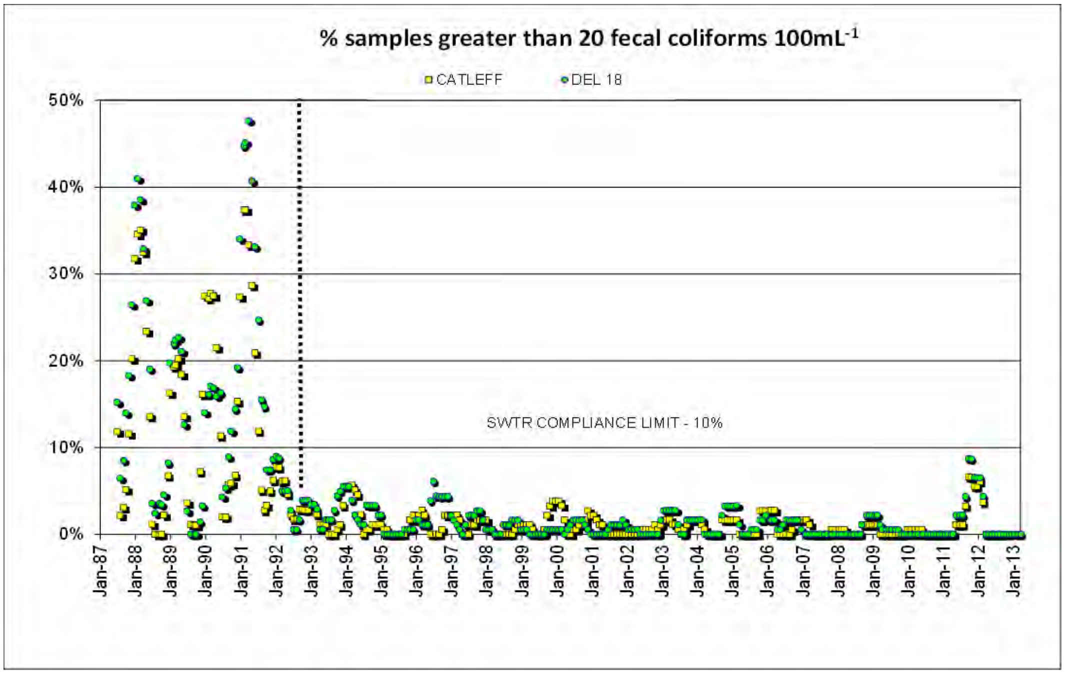


Figure 3.5 Percent of keypoint fecal coliform samples at Kensico Reservoir >20 FC/100 mL for the previous six month period during 1987-2013. The dotted vertical line represents the date bird harassment activities began (August 1, 1992).

3.6 Phosphorus-Restricted Basin Assessments in 2012

Phosphorus-restricted basin status is presented in Table 3.6 and was derived from two consecutive assessments (2007-2011 and 2008-2012) using the methodology stated in Appendix C. Appendix Table 2 lists the annual growing season geometric mean phosphorus concentration for New York City 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 City's reservoirs and their 2012 geometric mean phosphorus concentrations.

Table 3.6: Phosphorus-restricted reservoir basins for 2012.

Reservoir basin	07-11 Assessment (mean + S.E.) ($\mu g\ L^{-1}$)	08-12 Assessment (mean + S.E.) ($\mu g\ L^{-1}$)	Phosphorus restricted status
Delaware System			
Cannonsville Reservoir	15.5	15.3	Non-restricted
Pepacton Reservoir	10.2	10.0	Non-restricted
Neversink Reservoir	7.4	8.5	Non-restricted

Table 3.6: (Continued) Phosphorus-restricted reservoir basins for 2012.

Reservoir basin	07-11 Assessment (mean + S.E.) (µg L^{-1})	08-12 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus restricted status
Catskill System			
Schoharie Reservoir	18.4	20.3	Non-restricted
Croton System			
Amawalk Reservoir	19.8	20.5	Restricted
Bog Brook Reservoir	26.3	27.2	Restricted
Boyd Corners Reservoir	12.0	10.1	Non-restricted
Diverting Reservoir	30.2	29.2	Restricted
East Branch Reservoir	29.8	30.7	Restricted
Middle Branch Reservoir	27.4	31.2	Restricted
Muscoot Reservoir	27.9	29.4	Restricted
Titicus Reservoir	24.4	25.0	Restricted
Lake Gleneida	29.5	28.4	Restricted
Lake Gilead	33.8	32.0	Restricted
Kirk Lake	31.4	33.2	Restricted
Source Waters			
Ashokan-East Reservoir	10.7	10.8	Non-restricted
Ashokan-West Reservoir	18.0	18.3	Non-restricted
Cross River Reservoir	16.9	16.7	Restricted
Croton Falls Reservoir	17.4	17.7	Restricted
Kensico Reservoir	7.0	6.8	Non-restricted
New Croton Reservoir	17.0	17.3	Restricted
Rondout Reservoir	8.1	8.1	Non-restricted
West Branch Reservoir	10.1	10.7	Non-restricted

Some notes and highlights regarding phosphorus-restricted basin status in 2012:

- 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, DEP 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 3.6 shows that the 2012 geometric mean was higher than in the two previous assessment periods for Neversink. Further examination of the data showed that TP increased after a locally heavy storm in the late summer. Cannonsville and Pepacton Reservoirs had geometric means in 2012 that were lower than in the two previous evaluation periods.
- The Catskill System's Schoharie Reservoir had a geometric mean in 2012 that was similar to the two previous assessment periods. Both of the five-year assessments (2007-2011 and 2008-2012) reflect the inclusion of the impacts of tropical storms in 2011. A storm in September 2012 caused elevated TP in the reservoir that continued into October. 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. Middle Branch had a 2012 geometric mean TP that was higher than in the two assessment periods. Review of the data showed that there were six hypolimnetic samples collected during hypoxic conditions that had high TP values compared to previous years. Lake Gilead's low geometric mean in 2012 was due to a non-representative bottom sample during late stratification in October.
- Source water reservoirs were subject to the 15 µg L^{-1} limit, which placed three reservoirs into the phosphorus-restricted category: Cross River, Croton Falls, and New Croton.
- Kensico, Ashokan East Basin, Rondout, and West Branch Reservoirs were non-restricted. The geometric means for 2012 decreased substantially as compared to the two five-year assessment periods for the Ashokan West Basin, which was exempt from restricted status as noted above.

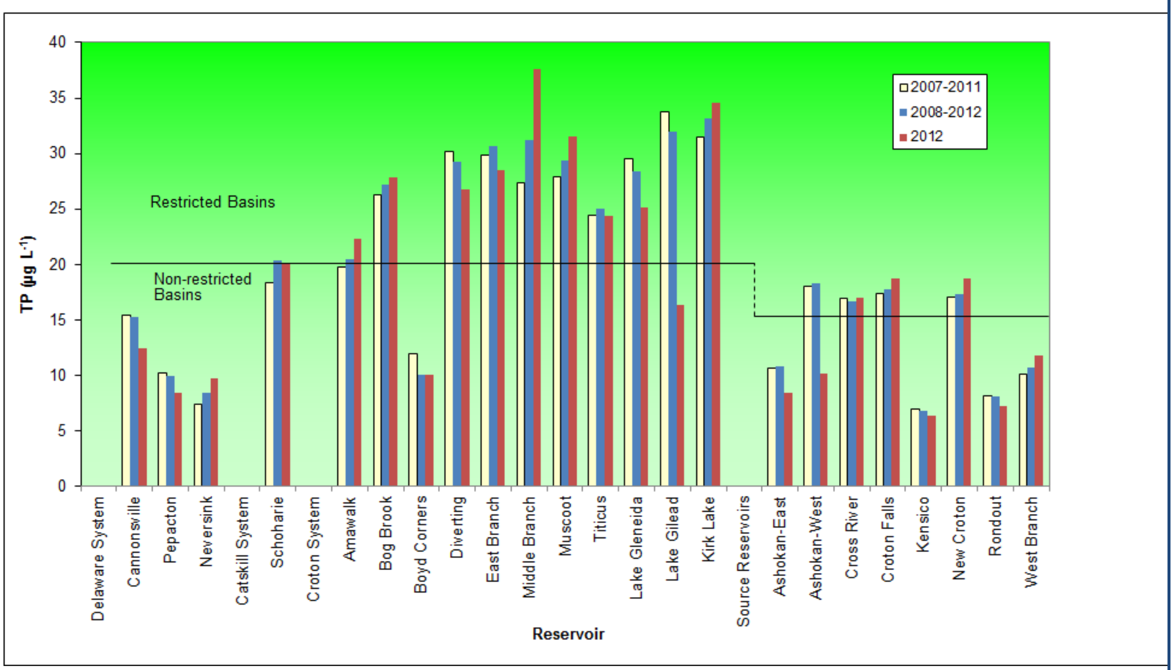


Figure 3.6 Phosphorus-restricted basin assessments, with the current year (2012) geometric mean phosphorus concentration displayed for comparison. The horizontal solid lines at 20µg L^{-1} and 15µg L^{-1} represent the NYC Watershed Rules and Regulations standard for non-source waters and source waters, respectively.

3.7 Reservoir Total Phosphorus Patterns in 2012

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.

While TP concentrations in most Catskill and Delaware reservoirs were normal to low in 2012, notable exceptions were evident in both systems (Figure 3.7). In the Catskill System, Schoharie TP was at its highest since 2003. The long lasting effects of the major storms Irene and Lee in 2011, coupled with a smaller rain event in late April, resulted in high TP levels during spring 2012. Summer TP levels were normal, but peaked in September following a large rain event (2.4 inches) on September 18. TP remained higher than normal at the reservoir for the remainder of the year. In contrast, both Ashokan basins were within their historical TP range. The effects of Irene and Lee were not apparent, as normal spring TP levels were observed in both basins. In fact, TPs were normal all year except for a brief early October peak in Ashokan West following the large rain event on September 18.

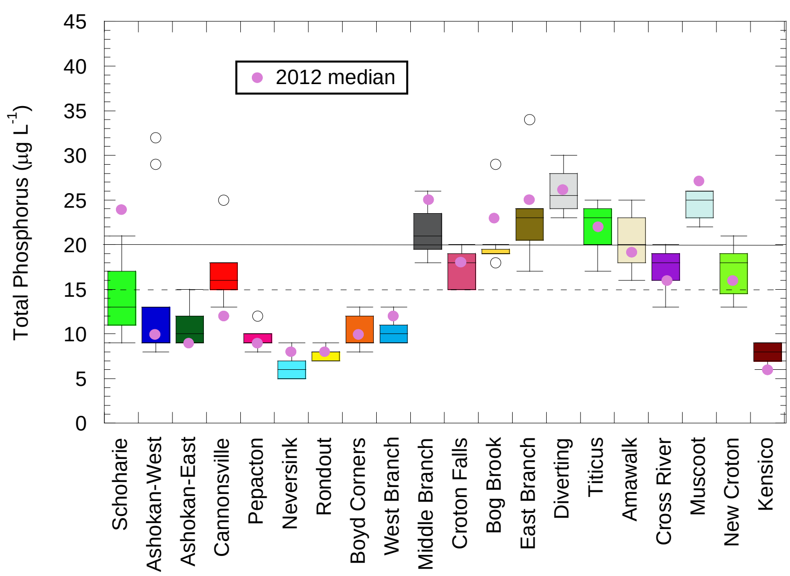


Figure 3.7 Annual median total phosphorus in New York City water supply reservoirs (2012 vs. 2003-2011). The horizontal dashed line at 15 µg L^{-1} refers to the NYC Total Maximum Daily Loads guidance value for source waters. The horizontal solid line at 20 µg L^{-1} refers to the NYSDEC's ambient water 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. 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 be operated as source waters: Rondout, Ashokan East, Ashokan West and West Branch.

In the Delaware System, TP levels were normal in Pepacton and Rondout, and at their lowest levels since 2003 in Cannonsville. Large rain events (>1 inch) were infrequent in 2012, especially at Cannonsville. In contrast, large rain events were common in the Neversink watershed, often occurring just prior to sampling. Six >1-inch storms occurred from May-July (four in May alone), coinciding with elevated TP levels in these months. In early September two more rain events (>1 inch), followed by a flooding event (5.3 inches of rain) on September 17-18, caused TP to peak in September and remain higher than normal for the remainder of the year.

TP concentrations at West Branch were higher than normal in 2012. In two West Branch inputs, Rondout and Boyd Corners, TP was relatively low, suggesting that the higher TP observed at West Branch was due to increased loading from local West Branch streams in 2012.

TP concentrations in Kensico Reservoir, which receives water from Rondout, West Branch, and Ashokan, were lower than normal in 2012. Kensico and Rondout median TP concentrations were similar, reflecting the predominance of Rondout water (versus West Branch and Ashokan) diverted to Kensico in 2012. Alum treatment of Ashokan water entering Kensico (until May 15) also contributed to the low TP concentrations observed in 2012.

Compared to the Catskill and Delaware Systems, the Croton watershed has a greater abundance of phosphorus sources: there are 60 waste water treatment plants (WWTPs), numerous septic systems, and extensive paved surfaces scattered throughout the watershed. Because of this more extensive development, as well as 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 and Delaware Systems. In 2012, most Croton reservoirs and controlled lakes were within their historical range, with median TP values of 10 to 32 µg L^{-1}. Higher than normal concentrations were observed at Middle Branch, Bog Brook, East Branch, Muscoot, and Kirk Lake. Anoxic conditions in August coincided with elevated TP at Kirk Lake, while sampling soon after rain events is the best explanation for elevated TP at Middle Branch. Both rain events and summer anoxia contributed to elevated TP in Bog Brook, East Branch, and Muscoot.

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

Lake	Median TP (2003-11)	Median TP (2012)
Gilead	20	17
Gleneida	18	16
Kirk	28	32

3.8 Terminal Reservoir Comparisons to Benchmarks in 2012

The New York City 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 2012 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 West of Hudson (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 (DEP 2010a).

Analyte	Basis[1]	Croton System		Catskill/Delaware System	
		Annual mean	Single sample maximum	Annual mean	Single sample maximum
Alkalinity (mg L^{-1})	(a)	≥40.00		≥40.00	
Ammonia-N (mg L^{-1})	(a)	0.05	0.10	0.05	0.10
Dissolved chloride (mg L^{-1})	(a)	30.00	40.00	8.00	12.00
Chlorophyll *a* (mg L^{-1})	(a)	0.010	0.015	0.007	0.012
Color (Pt-Co units)	(b)		15		15
Dominant genus (SAU)	(c)		1000		1000
Fecal coliform (coliforms 100 mL^{-1})	(d)		20		20
Nitrite+nitrate (mg L^{-1})	(a)	0.30	0.50	0.30	0.50
pH (units)	(b)		6.5-8.5		6.5-8.5
Phytoplankton (SAU)	(c)		2000		2000
Dissolved sodium (mg L^{-1})	(a)	15.00	20.00	3.00	16.00
Soluble reactive phosphorus (µg L^{-1})	(c)		15		15
Sulfate (mg L^{-1})	(a)	15.00	25.00	10.00	15.00
Total dissolved solids (mg L^{-1})[2]	(a)	150.00	175.00	40.00	50.00
Total organic carbon (mg L^{-1})[3]	(a)	6.00	7.00	3.00	4.00
Total dissolved phosphorus (µg L^{-1})	(c)		15		15
Total phosphorus (µg L^{-1})	(c)		15		15
Total suspended solids (mg L^{-1})	(a)	5.00	8.00	5.00	8.00
Turbidity (NTU)	(d)		5		5

[1] (a) WR&R (Appendix 18-B) – based on 1990 water quality results, (b) NYSDOH Drinking Water Secondary Standard, (c) DEP Internal standard/goal, (d) NYSDOH Drinking Water Primary Standard.

[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 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 15% 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 29% of the Ashokan East Basin samples, 12% of the Ashokan West Basin samples, and 16% of the Rondout samples. The pH values in Kensico and West Branch were outside the benchmark range for 16% and 8% of the samples, respectively.

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}. West Branch exceeded both the annual mean benchmark for chloride and the single sample standard for the WOH reservoirs (in 92% of samples). Kensico, Rondout, and both Ashokan basins were below the limits for these standards. All chloride samples were lower than the health standard of 250 mg L^{-1}.

Turbidity levels in Kensico, Rondout, and West Branch Reservoirs did not exceed the single sample maximum of 5 NTU in the fixed-frequency reservoir samples. New Croton turbidity exceeded 5 NTU for 9% of the reservoir samples. Ashokan samples exceeded this criterion for 42% of the samples in the East Basin and 77% in the West Basin. Although this represents a decrease from the 2011 sample data, there were several storms throughout the year that caused turbidity to exceed 5 NTU.

TP values never exceeded the single sample maximum of 15 µg L^{-1} in Rondout, and only 1% of samples exceeded the limit in Kensico. In the other terminal reservoirs, the percent of samples exceeding this benchmark ranged from 13% in Ashokan East Basin to 59% in New Croton. Nitrate samples only exceeded the single sample maximum in New Croton, where 11% of the samples were above the benchmark. None of the reservoirs exceeded the annual mean for nitrate. Ammonia levels were very low and did not exceed the benchmarks in the Ashokan basins, Rondout, or in West Branch. Kensico exceeded the single sample maximum in 1% of the samples. New Croton Reservoir exceeded the maximum in 17% of the samples and also exceeded the ammonia annual mean standard.

Phytoplankton counts in both Ashokan basins and Rondout Reservoir were below the 2,000 ASU benchmark. In the remaining terminal reservoirs, between 1% and 13% of samples exceeded this benchmark or the single genus benchmark of 1,000 ASU. New Croton and West Branch chlorophyll *a* levels exceeded the single sample maximum in 23% and 13% of the samples, respectively, as well as the annual mean benchmark. Kensico, Ashokan (both basins), 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 94% of the samples collected. West Branch Reservoir followed, with 74% of the samples exceeding the benchmark. Exceedances at the other terminal reservoirs ranged from 3% at Ashokan East Basin to 18% of the samples at Kensico.

Fecal coliform counts did not exceed the single sample maximum of 20 coliforms $100mL^{-1}$ in Rondout and Ashokan East Basin. In the remaining terminal basins, the percent of samples exceeding this criterion ranged from 1 in Kensico and New Croton to 7 in West Branch.

3.9 Reservoir Trophic Status in 2012

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. DEP water supply managers prefer reservoirs of a lower 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 (2003-2011) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.8. The 2012 annual median TSI appears in the figure as a circle containing an “x”. Results for the East of Hudson (EOH) controlled lakes are provided in Table 3.9. This analysis indicates that WOH reservoirs (including Kensico and West Branch) and three EOH reservoirs (Boyd Corners, Gilead and Gleneida) usually fall into the mesotrophic category. The remaining EOH reservoirs tend to fall into the meso-eutrophic to eutrophic range.

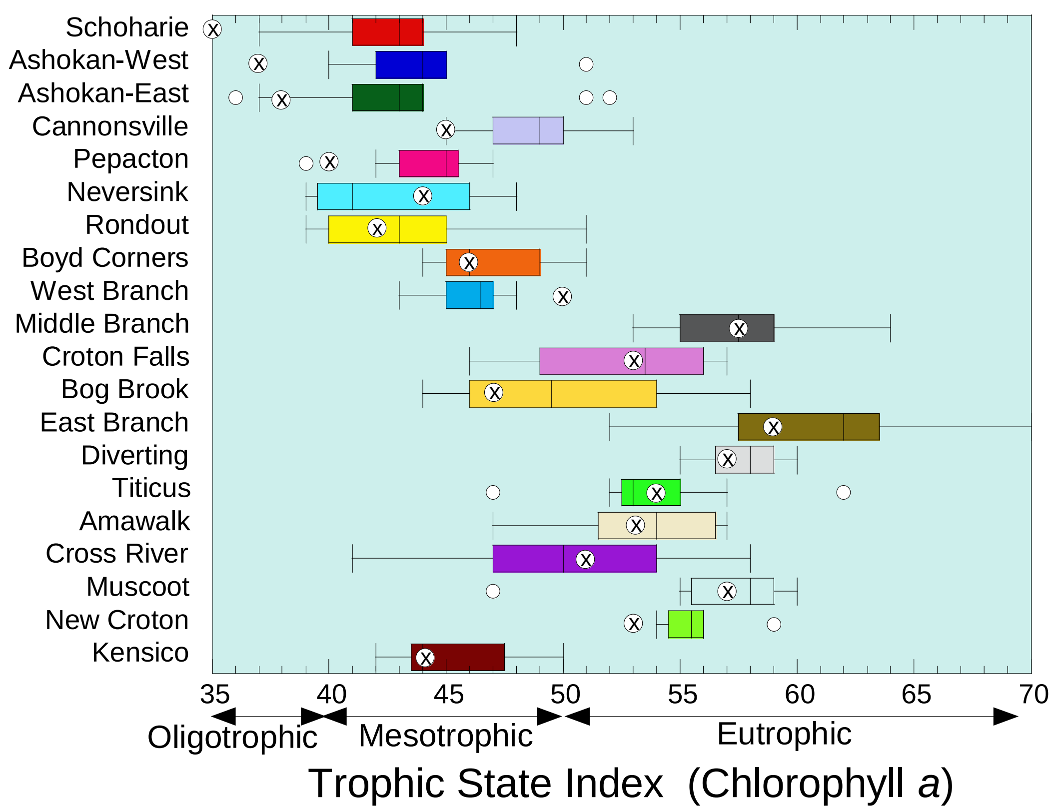


Figure 3.8 Annual median Trophic State Index in New York City water supply reservoirs (2012 vs. 2003-2011). In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per month from May through October. TSI is based on chlorophyll *a* concentration.

Table 3.9: Trophic State Index (TSI) summary statistics for New York City controlled lakes.

Lake	Median TSI (2003-11)	Median TSI (2012)
Gilead	47	48
Gleneida	43	48
Kirk	56	55

In 2012, TSI was much lower than normal in the Catskill and most Delaware System reservoirs. In Schoharie, high turbidity from the 2011 floods and a large September 2012 rain event reduced clarity during the growing season and greatly limited algal productivity. Higher turbidities and low nutrient concentrations explain the low productivity of the Ashokan basins in 2012. Low rainfall in conjunction with ongoing efforts to reduce phosphorus loading in the Cannonsville and Pepacton basins resulted in relatively low 2012 TSI determinations. Rondout and Neversink were within their historical ranges. Neversink started the growing season with higher TP concentrations due to loadings associated with significant rain events in May-July. However, productivity decreased after the September 18 flooding event, as the associated turbidity increase in the water column greatly diminished algal growth.

West Branch Reservoir was borderline eutrophic in 2012. West Branch is usually mesotrophic because, in most years, the bulk of its water is from mesotrophic Rondout Reservoir. In 2012, Rondout input was reduced, and West Branch was comprised of more warm, higher nutrient water from local streams, resulting in higher than normal productivity.

Kensico Reservoir, the terminal reservoir for the Catskill/Delaware System, is primarily a blend of Ashokan-East and Rondout water (and varying amounts from West Branch), with small contributions from local watershed streams. In 2012, Kensico's TSI fell between the TSIs of its major inputs and was well within its historical range.

TSI was within historic ranges for most reservoirs and controlled lakes of the Croton System in 2012. Many reservoirs were slightly below their historical medians and New Croton was at its lowest TSI since 2003. The low amount of rainfall in the region probably helped to keep nutrient loadings relatively low in 2012.

3.10 Water Quality in the Major Inflow Streams in 2012

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 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

Table 3.10: (Continued) Site codes and site descriptions for the major inflow streams.

Site code	Site description
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

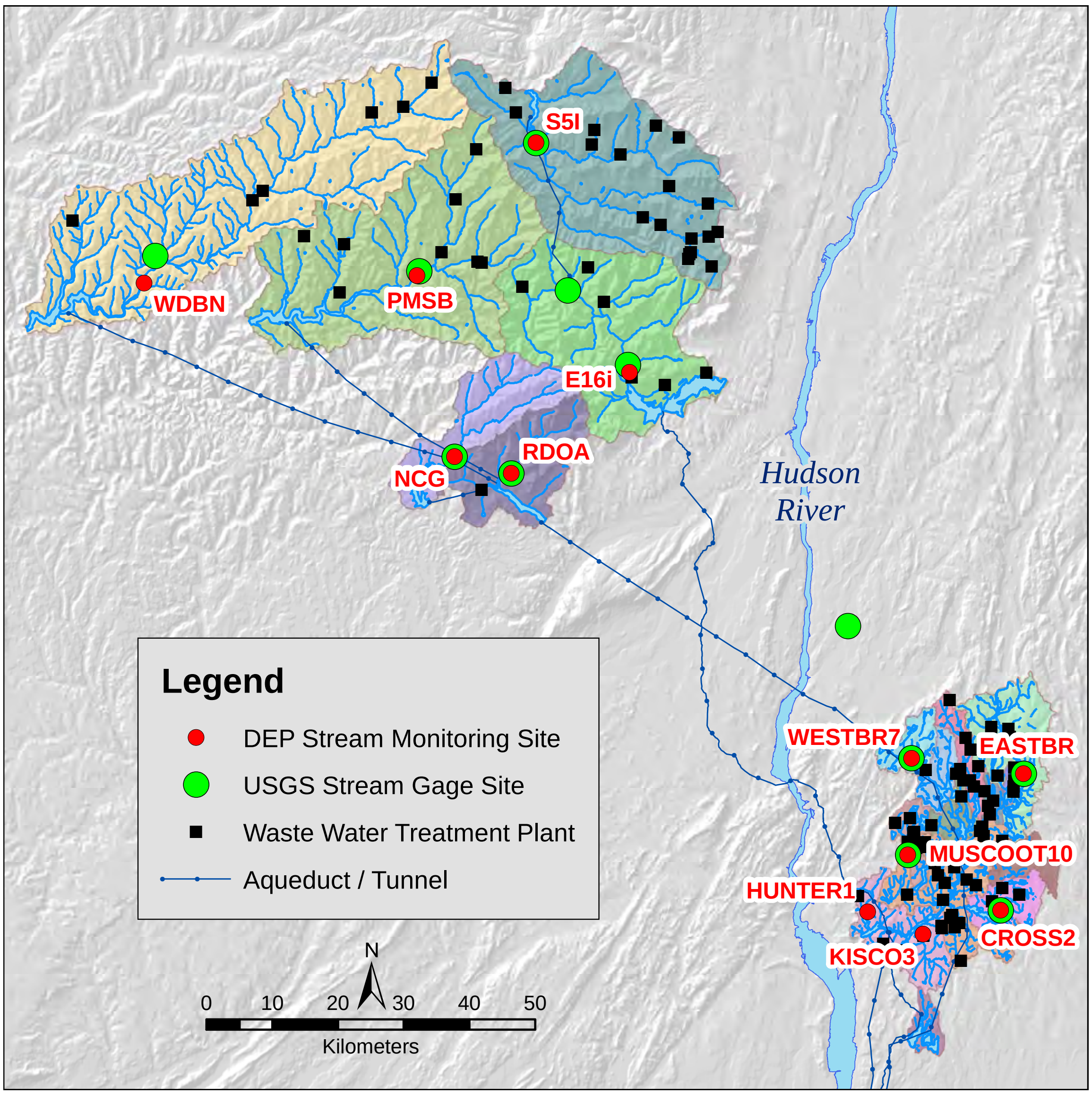


Figure 3.9 Locations of major inflow stream water quality sampling sites and USGS gauge stations used to calculate runoff values (see Section 2.3).

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 2012, but twice a month for coliforms at the EOH sites until August 2012 (when a modification to the Croton Consent Order went into effect), and weekly for turbidity data at the Esopus Creek at Boiceville bridge (E16I). The figures compare the 2012 median values against historical median annual values for the previous 10 years (2002-2011).

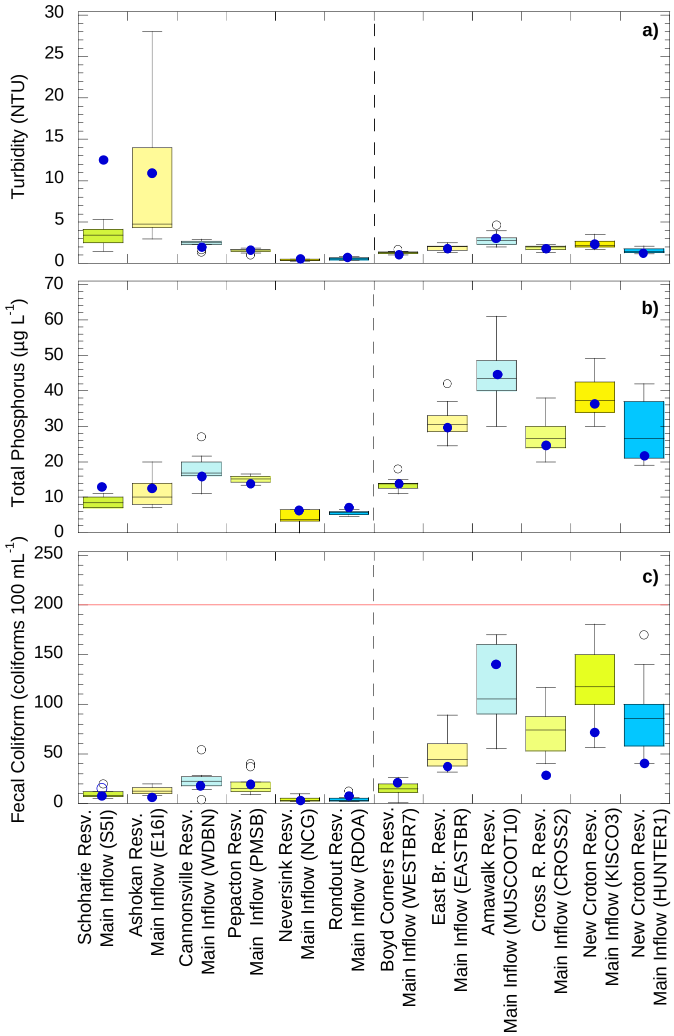


Figure 3.10 Boxplot of annual medians (2002-2011) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2012 displayed as a dot. The dotted line separates WOH streams (left) from EOH streams (right). The solid red line indicates the fecal coliform benchmark of 200 coliforms $100mL^{-1}$.

Turbidity

The turbidity levels for 2012 were generally near “normal” values, except for the Schoharie Creek inflow (S5I), which was elevated for the year (the highest annual median in the last 10 years for Schoharie Creek). The elevated turbidities were due to the continued impact of Tropical Storms Irene and Lee in August and September 2011, respectively. The annual median turbidities for the EOH inflows were all near their typical historical values.

Total Phosphorus

In the Catskill/Delaware Systems, the 2012 median TP concentrations showed varied results. As with turbidity, Schoharie Creek was above normal, with the highest TP annual median over the last 10 years. Ashokan, Cannonsville, Pepacton, and Neversink streams were within the normal ranges of their historical TP median, while Rondout Creek was slightly above, with the highest annual TP median for the last 10 years. The 2012 TP medians in the Croton System were all generally within their normal historical ranges.

Fecal Coliform Bacteria

The 2012 median fecal coliform bacteria levels in Catskill/Delaware streams were generally near or slightly below typical historical levels. For the Croton Reservoir inflows, the annual fecal coliform levels were near normal for Boyd Corners, East Branch, and the Muscoot River above Amawalk Reservoir, while Cross River and the two inflows to Croton, Kisco, and Hunter were somewhat below their typical annual medians. 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 2012 median values for all streams shown here lie below this value.

3.11 Stream Comparisons to Benchmarks in 2012

Selected 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 (DEP 2010a). In this section, the application of these benchmarks was extended to 41 streams and reservoir releases in order to evaluate stream status in 2012 (DEP 2009b). The benchmarks are provided in Table 3.11.

Table 3.11: Stream water quality benchmarks as listed in the WR&R (DEP 2010a). The basis for all analytes is the WR&R (Appendix 18-B) based on 1990 water quality results.

	Croton System		Catskill/Delaware Systems	
Analyte	Annual mean	Single sample maximum	Annual mean	Single sample maximum
Alkalinity (mg $CaCO_3$ L^{-1})	N/A	$\geq$40.00	N/A	$\geq$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 (mg L^{-1})	15	25	10	15
Total dissolved solids (mg L^{-1})[2]	150	175	40	50
Total organic carbon (mg L^{-1})[3]	9	25	9	25
Total suspended solids (mg 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 usually consists predominately of 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. Alkalinity levels are also important to monitor 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 of the Schoharie, Cannonsville, and Pepacton basins generally met the 10 mg L^{-1} criterion. Excursions slightly below 10 mg L^{-1} occasionally occurred at Mill Brook (P-60) in the Pepacton basin during the winter and spring. In contrast, excursions below 10 mg L^{-1} were common in the streams of the Ashokan, Rondout, and Neversink basins. Such low buffering capacity is typical of the surficial materials in this region of the Catskills. 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. Alkalinity results from stream sites in these basins (GYPSYTRL1, HORSEPD12, WESTBR7, BOYDR) were often below 40 mg L^{-1}, and lows from these streams ranged from 23.7 to 33.9 mg L^{-1}.

None of the Catskill or Delaware streams (including WESTBRR) exceeded the single sample chloride benchmark of 50 mg L^{-1} in 2012. However, the annual mean benchmark of 10 mg L^{-1} was exceeded in 8 of the 24 streams monitored in these two systems. The highest annual mean, 26.3 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 3.6 and 2.8 mg L^{-1}, respectively. 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 (19.9 mg L^{-1}), a tributary to Schoharie Reservoir; at Trout Creek (14.2 mg L^{-1}), Loomis Brook (13.2 mg L^{-1}), and the West Branch of the Delaware River (12.9 mg L^{-1}), all tributaries to Cannonsville Reservoir; and at Chestnut Creek (11.7 mg L^{-1}), a tributary to Rondout Reservoir. The outflow from West Branch Reservoir (WESTBRR) increased from 10.5 mg L^{-1} in 2011 to 14.1 mg L^{-1} in 2012. The increase reflects greater inputs of local, higher chloride Croton water to West Branch Reservoir in 2012.

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, and on Michael Brook (MIKE2) above Croton Falls Reservoir. No other Croton stream exceeded 100 mg L^{-1} in 2012. However, 8 of the 16 monitored Croton streams did exceed the annual mean benchmark of 35 mg L^{-1}. Means exceeding the benchmark ranged from 36.4 to150 mg L^{-1}. The mean 2012 chloride value for all 16 Croton streams was 50.7 mg L^{-1}. By comparison, chloride was much lower in the Catskill and Delaware Systems, averaging 8.7 mg L^{-1} and 8.6 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 New York City waters, specific conductivity was used to estimate TDS by multiplying specific conductivity by 0.65 (van der Leeden 1990). In 2012, 15 of 24 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 summer flow. Occasional winter excursions were correlated to high chloride concentrations. Only streams with very low chloride concentrations

(<6.8 mg L^{-1}) could consistently meet the TDS benchmarks. In the Croton System only BOYDR (Boyd Corners release), WESTBR7 (above Boyd Corners Reservoir) and GYPSYTR1 (above West Branch Reservoir) met both the annual benchmark of 150 mg L^{-1} and the single sample maximum criterion of 175 mg L^{-1}. However, CROSS2, CROSSRVR (above and below Cross River Reservoir) and HORSEPD12 (above West Branch Reservoir) did meet the annual mean benchmark and only exceeded the single sample maximum in one month. 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 March (7.1 mg L^{-1}), May (4.9 mg L^{-1}), June (5.7 mg L^{-1}), and July (11.0 mg L^{-1}). Three Croton streams exceeded the annual average benchmark of 0.35 mg L^{-1}: the Kisco River, 0.56 mg L^{-1} at KISCO3; the Muscoot River, 0.82 mg L^{-1} at MUSCOOT10; and Michael Brook, 4.1 mg L^{-1} at MIKE2. 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 in Bear Creek at S6I, and in the West Branch of the Delaware River at WDBN. Several streams in the Pepacton watershed (Terry Clove, Fall Clove, East Branch Delaware River) were just under the annual benchmark. The source of the nitrogen is unclear in some streams, but treatment plant input is a likely contributor to Michael Brook and the Kisco, Muscoot, and West Branch Delaware Rivers.

None of the Catskill/Delaware System streams exceeded the ammonia single sample maximum of 0.20 mg L^{-1} in 2012. With the exception of Kramer Brook, almost all samples were at or near the analytical detection limit of 0.02 mg L^{-1}. Ammonia results were elevated enough at Kramer Brook for it to reach the mean annual ammonia benchmark of 0.05 mg L^{-1}. Several Croton System streams exceeded the ammonia single sample maximum. The reservoir releases from Amawalk, Cross River, and Titicus all exceeded 0.2 mg L^{-1} during the summer. Elevated ammonia is produced during anoxia caused by the breakdown of summer algal blooms that commonly occur in these relatively productive reservoirs. The mean annual benchmark was not reached in the Croton System in 2012.

Neither the single sample maximum (15 mg L^{-1}) nor the annual mean (10 mg L^{-1}) benchmarks for sulfate were surpassed in the Catskill/Delaware streams in 2012. All Croton stream results in 2012 were below the Croton System single sample maximum (25 mg L^{-1}) as well. However, the Croton annual mean sulfate benchmark of 15 mg L^{-1} was surpassed in two streams, with averages of 15.4 mg L^{-1} at the Kisco River (KISCO3) and 20.1 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 mg L^{-1}) were not surpassed by any stream in 2012. The highest single sample DOC in the Catskill/Delaware System, 5.2 mg L^{-1}, occurred at Kramer Brook, and the annual mean Catskill/Delaware DOC ranged from 0.8 to 2.8 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 the Catskill/Delaware System; this is reflected in the 2012 annual means, which ranged from 3.0 to 5.2 mg L^{-1}. The highest single sample DOC was 8.4 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. Assessments are made following protocols developed by the New York State Stream Biomonitoring Unit (SBU). (For details, see NYSDEC 2009.) In brief, four metrics, each a different measure of biological integrity, are calculated and averaged to produce a Biological Assessment Profile (BAP) score ranging from 0-10; these scores correspond to four levels of impairment (non-impaired, 7.5-10; slightly impaired, 5-7.5; moderately impaired, 2.5-5; severely impaired, 0-2.5). In 2012, the SBU introduced a new metric to the calculation, the NBI-P, an indicator of nutrient enrichment in streams. The resulting BAP scores are different from what they would have been had the NBI-P been excluded, and in a few cases the changed scores altered the impairment assessment. Since, as of this writing, all prior years' results have not been recalculated using the revised method, comparisons to specific scores and means from previous years will not be made in this year's report. (General, systemwide, comparisons, however, can be made since BAP scores calculated with and without the NBI-P metric do not vary substantially, and changes in assessment, while possible, are uncommon.) Instead, attention will focus on changes or trends in taxonomic composition and in selected metrics used in the BAP computation.

In 2012, DEP sampled 41 sites in 30 streams throughout the New York City watershed, 9 in the Croton System, 21 in Catskill, and 11 in Delaware. (For site locations, see Appendix F.) Scores in Croton were generally lower than in Catskill and Delaware, which is consistent with previous years' results (see, e.g., DEP 2013b, 2013c, 2013d).

Eight of the nine Croton sites sampled in 2012 assessed as slightly impaired; the remainder, Site 112 on the Muscoot River, assessed as moderately impaired (Figure 3.11). The high percentage of impaired sites is typical of the Croton System (e.g., 2008—84.6%, 2009—78.6%, 2010—100%, 2011—84.6%). On a positive note, the sensitive stonefly *Eccoptura xanthenes*, which was seen last year at Anglefly Brook (Site 102) for the first time since 1994, was recorded at the site again in 2012.

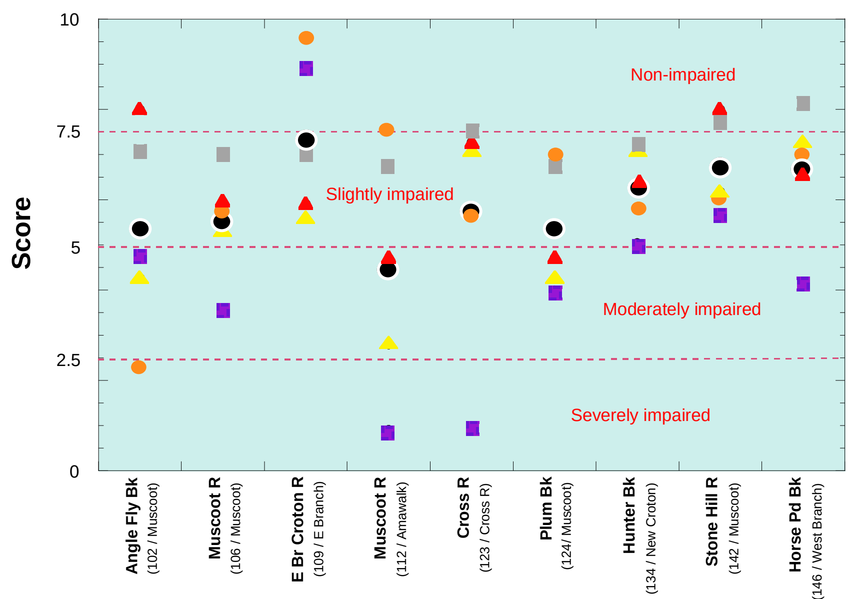


Figure 3.11 Biological Assessment Profile (BAP) and metric scores for East of Hudson biomonitoring sites sampled in 2012. Metric scores are raw values converted to a common scale and reflect the various categories of impairment. BAP scores are an average of the five metric scores. ● = BAP score, ▲ = total taxa, ▲ = EPT, ● = PMA, ■ = HBI, ■ = NBI-P. The site's number and watershed are indicated in parentheses following the site name.

In the Catskill and Delaware Systems, the sites that had extremely low sample numbers in 2011 (a function of the high level of scour associated with Tropical Storms Irene and Lee) all had sufficient organisms present in the sample in 2012 to generate the 100-count subsample required by the SBU protocols. Thus, at Site 206 (Batavia Kill), where the entire sample in 2011 consisted of only 7 organisms, the subsample count in 2012 was 103. Corresponding numbers at the other affected sites were: Site 315 (Chestnut Creek)—12 (2011), 115 (2012); Site 310 (Rondout Creek)—23 (2011), 104 (2012); Site 328 (Red Brook)—30 (2011), 110 (2012); Site 347 (Sugarloaf Brook)—52 (2011), 107 (2012).

Even though subsample numbers returned to normal, an unusually high percentage of sites in both these systems was rated as impaired in 2012. In the Catskill System, 13 sites (61.9%) were rated slightly impaired, while only 8 assessed as non-impaired (Figure 3.12). In the Delaware System, the percentage was lower, but still almost half (5 of 11, (45.5%)) were designated as slightly impaired (Figure 3.13). Of the 18 impaired sites, one, Site 206, was clearly still recovering from the severe scour caused by the 2011 storms. All metrics at this site were well below the historical average: 10 EPT (the total mayfly, stonefly, caddisfly taxa) versus an average of 13.89, 23 total taxa versus an average of 26.72, 41.76 Percent Model Affinity (PMA) versus an average of 69.57, and 5.70 Hilsenhoff Biotic Index (HBI) versus an average of 4.59. (Higher HBI values indicate increasing levels of organic pollution.) The new NBI-P metric was high as well (6.30), placing the stream's trophic state in the eutrophic range.

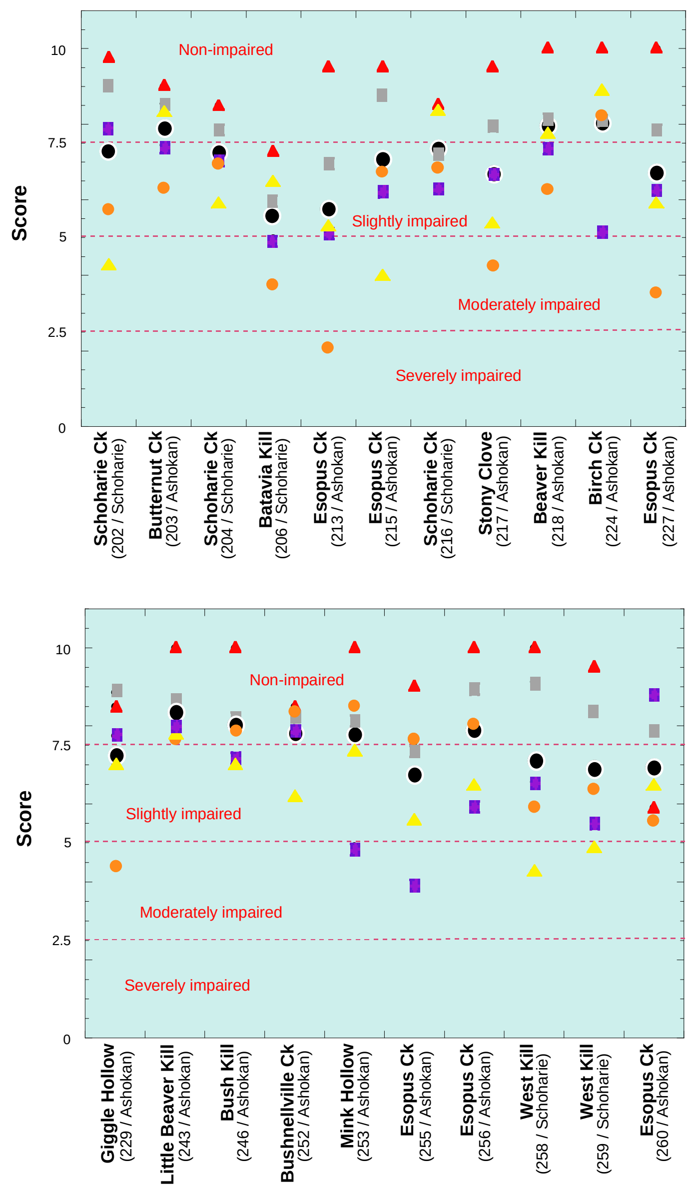


Figure 3.12 Biological Assessment Profile (BAP) and metric scores for Catskill biomonitoring sites sampled in 2012. Metric scores are raw values converted to a common scale and reflect the various categories of impairment. BAP scores are an average of the five metric scores. ● = BAP score, ▲ = total taxa, ▲ = EPT, ● = PMA, ■ = HBI, ■ = NBI-P. The site's number and watershed are indicated in parentheses following the site name.

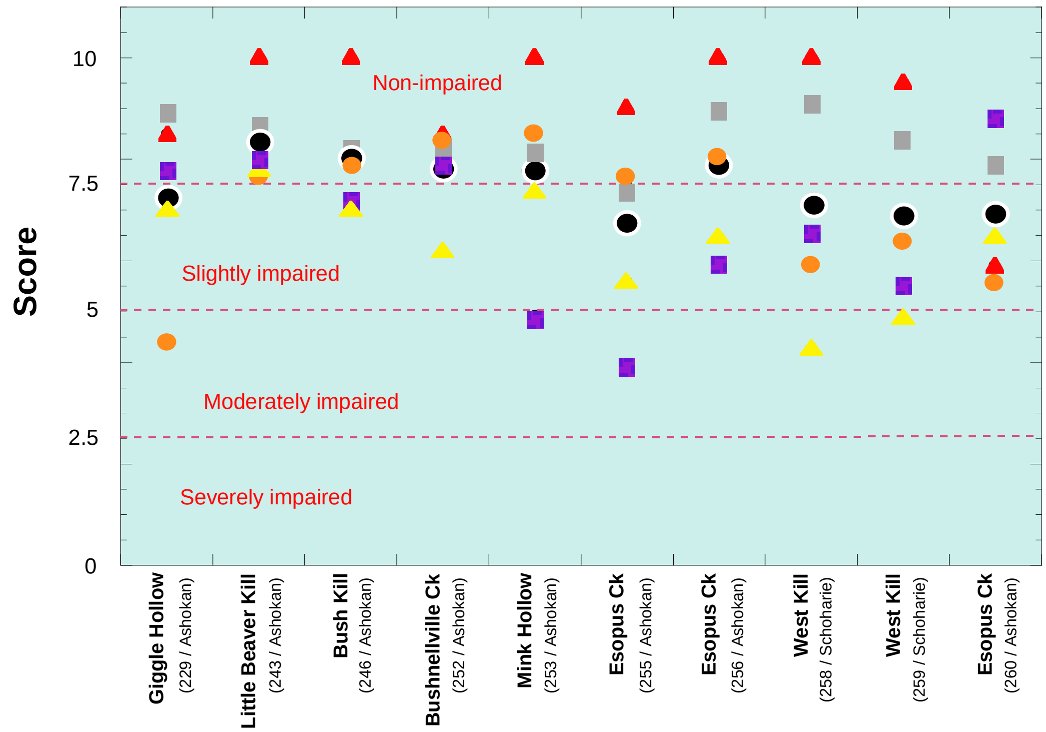


Figure 3.13 Biological Assessment Profile (BAP) and metric scores for Delaware biomonitoring sites sampled in 2012. Metric scores are raw values converted to a common scale and reflect the various categories of impairment. BAP scores are an average of the five metric scores. ● = BAP score, ▲ = total taxa, ▲ = EPT, ● = PMA, ■ = HBI, ■ = NBI-P. The site's number and watershed are indicated in parentheses following the site name.

For the other sites, however, the source of impairment was not so clear-cut. One possible cause is suggested by the NBI-P metric, which was high at most impaired sites. (As with HBI, higher NBI-P values, which range from 0-10, indicate greater levels of enrichment.) This was particularly true at Site 206 (see above); Site 255 (Esopus Creek at Mount Tremper), where the NBI-P was 6.43; Site 301 (West Branch Delaware River at Hobart), where it was 6.47; and Site 304 (West Branch Delaware River near Walton), where it was 7.21. The high score at Site 304 was directly attributable to the large numbers of the beetle *Psephenus herricki* present in the sample (40 individuals, representing 39.2% of the total). *P. herricki* feeds on algae, whose growth presumably would be enhanced under elevated phosphorus conditions. A similar spike (27 individuals) occurred in 2007, raising the possibility that periodic inputs of phosphorus may occur at this location. It should be remembered, though, that a high NBI-P does not necessarily mean that a stream is phosphorus enriched, as indicated by the high values at a number of non-impaired sites in 2012.

Another metric whose depressed scores in 2012 contributed greatly to the many impaired results was Percent Model Affinity. Low PMA values, often accompanied by low total taxa counts, were widespread, occurring at 17of the 18 impaired sites and at some non-impaired sites as well. PMA is a measure of what is considered the typical composition of a macroinvertebrate community in New York State streams, so low scores indicate a departure from this model, and often the dominance of one group over other groups. At Site 304, as discussed previously, the dominant group was psephenid beetles, but in almost all other cases, the dominant group was the family Hydropsychidae, the net-spinning caddisflies, specifically the genera *Hydropsyche* and *Cheumatopsyche*. At 13 of the 18 impaired sites West of Hudson (72.2%), hydropsychids constituted at least 30% of the community; in Catskill alone, the figure was 11 of 13 (84.6%). At many of these sites, the percentage was far higher than 30% (Figure 3.14). Hydropsychid dominance was also observed at several non-impaired sites (Site 218 (Beaver Kill), Site 246 (Bush Kill), Site 316 (East Branch Delaware River), Site 347 (Sugarloaf Brook)).

Figure 3.14 Impaired sites West of Hudson where members of the family Hydropsychidae comprised more than 30% of the macroinvertebrate community in 2012.

It is not clear what factor or factors were responsible for the high proportion of hydropsychids at West of Hudson sites in 2012, but one possible explanation lies in the significant damage done to these streams by the exceedingly high flows of Tropical Storms Irene and Lee in 2011. Hydropsychids construct retreats of organic matter which they fasten with silk to the undersides of rocks. These retreats may provide a degree of protection from scour not available to other organisms, especially those that graze the rocks' upper surfaces. Hydropsychids that escape dislodgment may also face more favorable conditions in the aftermath of a storm because of the additional area made available for colonization following the removal of more vulnerable taxa.

Spikes in hydropsychid numbers have occurred before, which, given the number of high flow events in recent years, is consistent with the view that these increases may be storm-related. Since 2005, the West of Hudson watershed has experienced a series of very wet years, with flooding occurring in almost every year. At the same time, large increases in hydropsychids (measured as the percent of all organisms collected at routine sites in a given year) have become more frequent and grown in size (Figure 3.15). Additional research needs to be done to determine if these cyclical increases in hydropsychid abundance are in fact linked to storm events. Such a linkage, if found, would imply that the SBU metrics have not been entirely successful in capturing the impacts of large storms on the benthic community, since sites that experience these periodic peaks in hydropsychid abundance sometimes, as was the case in 2012, assess as non-impaired.

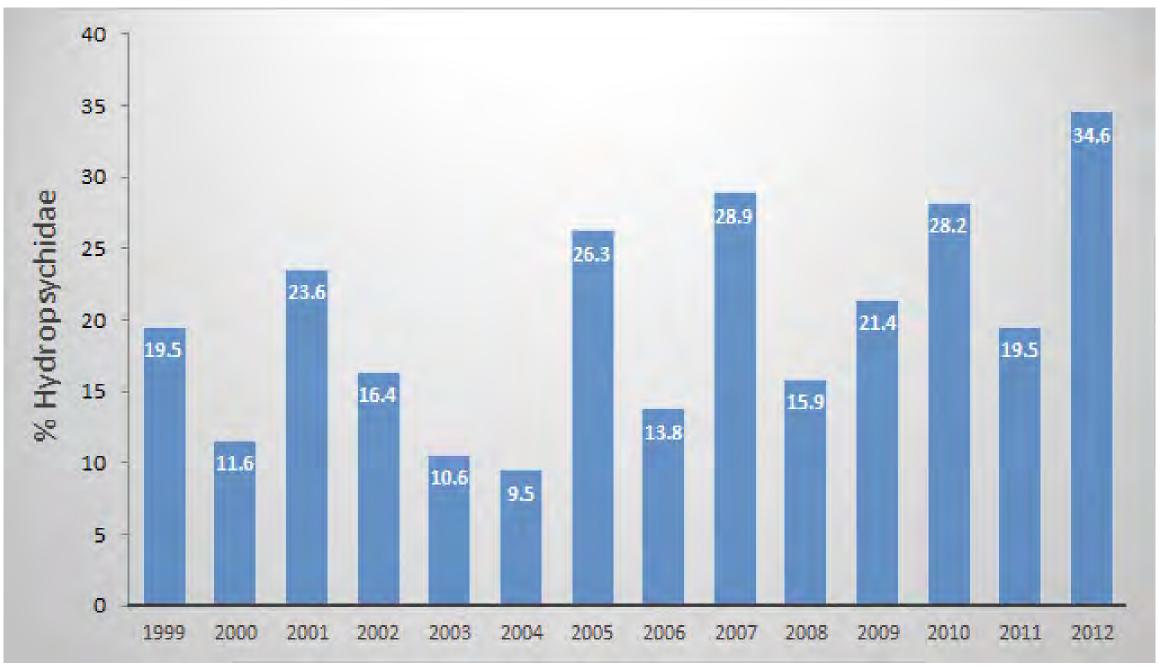


Figure 3.15 Percent of macroinvertebrates collected at routine West of Hudson biomonitoring sites consisting of members of the family Hydropsychidae, 1999-2012. Pre-1999 data are not shown because the number of routine sites varied prior to that year.

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 587 samples for protozoan analysis during 2012, and 238 samples for HEV analysis. Source water samples (Kensico and New Croton keypoints) comprised the greatest portion of the 2012 protozoan sampling effort, accounting for 39.2% of the samples, followed by stream samples, which were 31.2% of the sample load. Sampling at the Hillview Reservoir Catskill downtake, upstate reservoir effluents, and wastewater treatment plants (WWTPs) made up the remaining 29.7% (Figure 4.1).

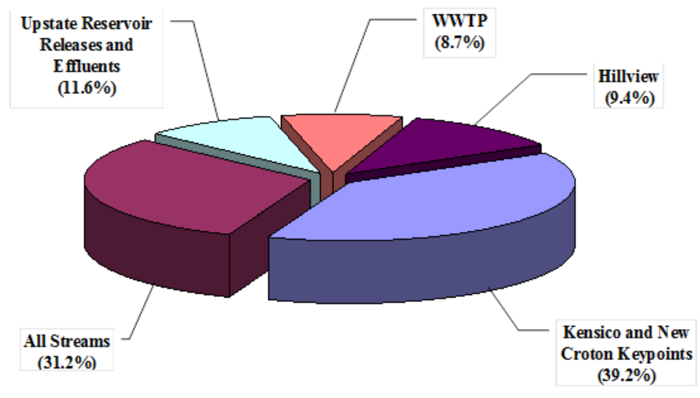


Figure 4.1 DEP protozoan sample type distribution for 2012. Data include both routine and enhanced monitoring samples.

In 2012, as in most years, there were adaptations made to the monitoring plan in response to regulatory changes, water quality events, and operational needs. During routine reservoir operations, the two influents and the two effluents of Kensico Reservoir and the one New Croton Reservoir effluent are considered the five keypoint source water sampling sites requiring weekly pathogen sampling. In 2012, the Kensico Catskill Aqueduct effluent was shut down briefly in January and then on a more long-term basis beginning in September, due to the startup of the UV plant and lack of pressurization in the segment of the aqueduct from Kensico to Eastview. The last protozoan sample was collected at CATLEFF on September 10, 2012, for a total of 34 samples from that site during the year. Another difference this year was a sampling reduction under the Croton Consent Decree (CCD). DEP received notice from the NYSDOH in July 2012 that DEP's requested reductions in CCD sampling had been approved. For protozoan and HEV monitoring, this meant a reduction in sampling frequency from weekly to monthly at the New Croton Reservoir effluent, and cessation of sampling at the Croton stream sites, beginning in August 2012. Additional samples this year included four non-routine protozoan samples, three of which were taken to assess water quality impacts of Hurricane Sandy (one from the Delaware effluent of Kensico and one each from the two Hillview downtakes), and one re-sample at an upstate keypoint (Rondout), necessitated by the low filtered volume of a prior sample. Another change for 2012 was that, beginning June 1, 2012, DEP began processing its own virus samples in-house rather than at a contract laboratory. Lastly, the routine DEL18 sample location was changed to a new location, DEL18DT, and the first routine samples were collected there on August 20, 2012. 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 pathogen surveillance reports (e.g., DEP 2012b).

4.2 Source Water Results

Catskill Aqueduct

In 2012, for the second year in a row, *Cryptosporidium* oocysts were not detected in any samples taken at CATALUM (Catskill influent to Kensico Reservoir) (Table 4.1). C*ryptosporidium* results at CATLEFF (Catskill effluent of Kensico Reservoir) were also low, with 1 detection out of 34 samples (2.9%) 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 2012.

	Keypoint location	Number of positive samples	Mean**	Maximum
Cryptosporidium oocysts $50L^{-1}$	CATALUM (n = 53)	0	0.00	0
	CATLEFF (n = 34)	1	0.03	1
	DEL17 (n = 53)	1	0.02	1
	DEL18/DEL18DT* (n = 54)	0	0.00	0
	CROGH* (n = 36)	1	0.03	1
Giardia cysts $50L^{-1}$	CATALUM (n = 53)	8	0.17	2
	CATLEFF (n = 34)	18	0.91	4
	DEL17 (n = 53)	32	1.08	5
	DEL18/DEL18DT* (n = 54)	25	0.87	4
	CROGH* (n = 36)	14	0.72	5
Human Enteric Virus $100L^{-1}$	CATALUM (n = 53)	10	0.76	23.00
	CATLEFF (n = 34)	3	0.27	6.93
	DEL17 (n = 53)	10	0.53	11.12

Table 4.1: (Continued) Summary of *Giardia*, *Cryptosporidium*, and HEV compliance monitoring data at the five DEP keypoints for 2012.

	Keypoint location	Number of positive samples	Mean**	Maximum
	DEL18/DEL18DT* (n = 53)	9	0.86	14.36
Human Enteric Virus	CROGH* (n = 36)	12	2.00	>23.03

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

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

Giardia results at CATALUM included 8 detections out of 53 samples (15.1%) and a mean concentration of 0.17 cysts $50L^{-1}$ (Table 4.1). CATLEFF *Giardia* results were higher, with 18 detections out of 34 samples (52.9%) and a mean of 0.91 cysts $50L^{-1}$. These higher results likely reflect the influence of *Giardia* entering at the Delaware Aqueduct influent and *Giardia* contributions from the local watershed. Based on previous research in the Kensico basin, the most likely source of these cysts is wildlife feces.

HEV detections at CATALUM decreased from 14 detections (26.9%) in 2011 to 10 detections (18.9%) in 2012. Mean and maximum concentration of HEVs at CATALUM were higher in 2012 (0.72 and 23.00 MPN $100L^{-1}$, respectively) than in 2011, when the mean was 0.57 and the maximum 4.87 MPN $100L^{-1}$. Detections were less frequent at CATLEFF (3 detections out of 34 samples (8.8%)) than at CATALUM in 2012, and lower than at CATLEFF in 2011 (9 detections out of 52 samples (17.3%)). The 2012 mean HEV concentration at CATLEFF (0.27 MPN $100L^{-1}$) was lower than at CATALUM, and lower than the 2011 CATLEFF mean (0.76 MPN $100L^{-1}$).

Delaware Aqueduct

DEL17 (Delaware influent to Kensico Reservoir) *Cryptosporidium* results were very low, with only 1 positive sample out of 53 (1.9%) and a mean concentration of 0.02 oocysts $50L^{-1}$ (Table 4.1), similar to the 2011 results. DEL18/DEL18DT (Delaware effluent of Kensico Reservoir) results reached a milestone: in 2012, for the first time, *Cryptosporidium* was not detected in any samples during a calendar year. DEL18 results for the previous two years (2010-2011) were also low, with only 1 detection in each of those years.

Giardia detection at DEL17 was 32 out of the 53 samples collected (60.4%), with a mean concentration of 1.08 cysts $50L^{-1}$ (Table 4.1). The G*iardia* detection at DEL18/ DEL18DT was slightly lower, with 25 out of 54 samples (46.3%) and a mean concentration of 0.87 cysts $50L^{-1}$. One non-routine protozoan sample was collected at DEL18DT following Hurricane Sandy on October 31, and was negative for *Giardia*.

HEV mean and maximum concentration and detection frequency at DEL17 were 0.53 MPN $100L^{-1}$, 11.12 MPN $100L^{-1}$, and 10 positive samples out of 53 (18.9%), respectively (Table 4.1). 2012 HEV mean and maximum concentrations for DEL18DT were slightly higher, with a mean concentration of 0.86 MPN $100L^{-1}$ and a maximum of 14.36 MPN $100L^{-1}$; however, this difference is within the variability of the method. DEL17 had one more HEV detection in 2012 compared to DEL18DT, where 9 out of 53 samples were positive (17.0%).

New Croton Aqueduct

Protozoan sampling at the New Croton Reservoir effluent (CROGH or most representative site) for 2012 resulted in 1 positive for *Cryptosporidium* out of 36 samples collected (2.8%) and a mean *Cryptosporidium* concentration of 0.03 oocysts $50L^{-1}$ (Table 4.1). For *Giardia*, New Croton had 14 positive samples (38.9%) and a mean concentration of 0.72 cysts $50L^{-1}$. HEV detection frequency and mean concentration at New Croton were higher than in 2011, with 12 out of 36 samples positive (33.3%) and a mean of 2.00 MPN $100L^{-1}$. (2011 had 9 detects out of 52 samples and a mean concentration of 1.13 MPN $100L^{-1}$.)

Despite *Giardia*'s low detection frequency at CATALUM, the fact that it was detected in higher concentrations and occurred more frequently in winter and spring than in summer and fall suggests that seasonal variation may have been present at all influent and effluent sites in 2012 (Figure 4.2). While there may also be some seasonality associated with *Cryptosporidium* occurrence, there are too few oocysts detected in source water to provide statistical confidence in this hypothesis. In general, *Giardia* occurrences were much more frequent and at higher concentrations than *Cryptosporidium* at the source water sites, which is common for the NYC Watershed.

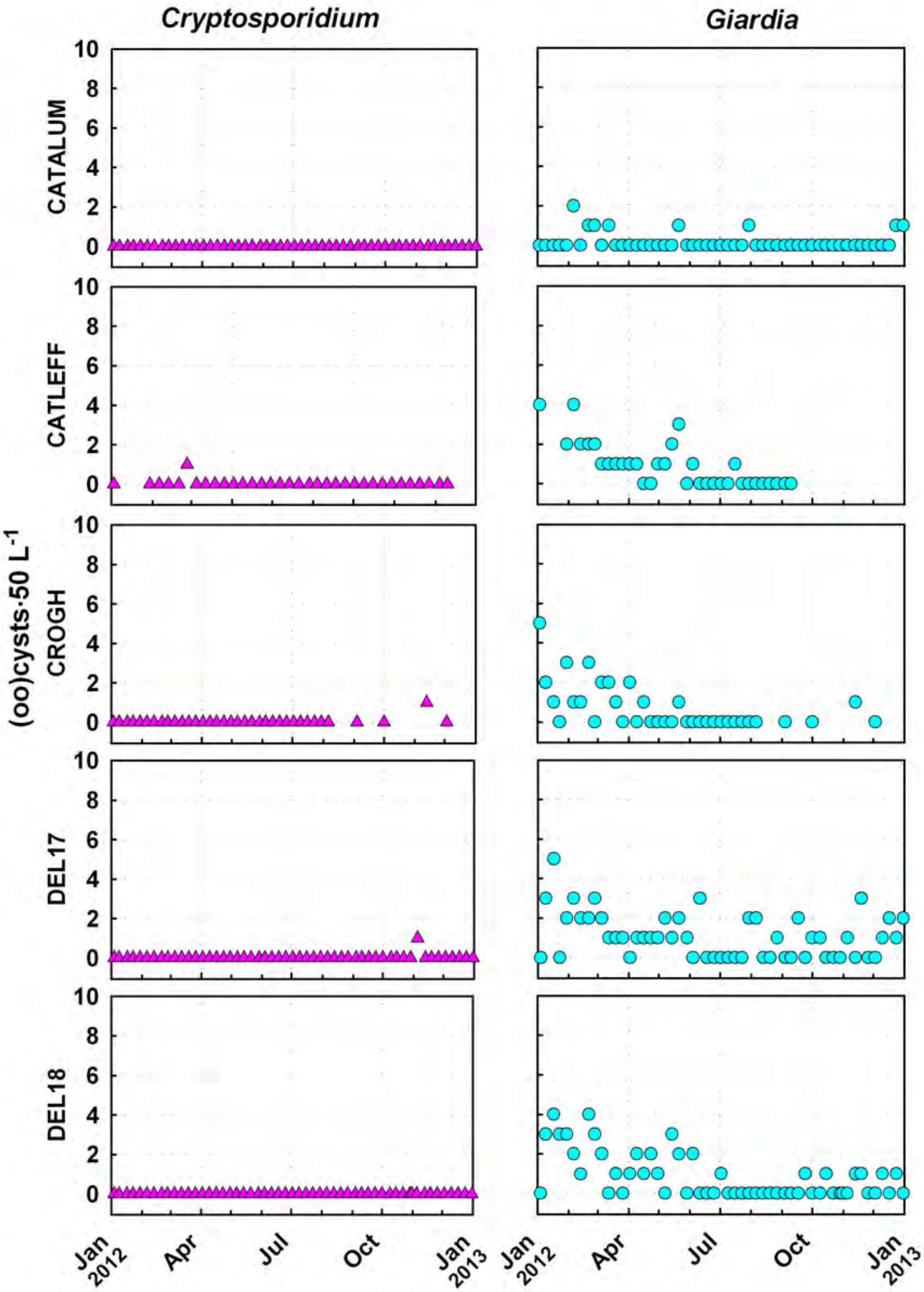


Figure 4.2 Routine weekly source water keypoint monitoring results for 2012.

4.2.1 2012 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, impacts from land use, effects of other ecological processes, and operational changes. Beginning in October 2001 and continuing until August 2012, each source water site was sampled weekly, using USEPA Method 1623HV. This has given DEP a large dataset with several years of samples for the detection of seasonal patterns and long-term changes in protozoan concentrations. However, the August 2012 modifications to the New Croton Reservoir effluent monitoring schedule (weekly to monthly) and the September 2012 shutdown of the Catskill Aqueduct effluent from Kensico to Eastview make a simple comparison of 2012 summary statistics with previous annual results inappropriate at the CROGH and CATLEFF sites. At New Croton, where monitoring will continue monthly, some increase in variability is expected, as the number of samples taken annually has decreased by 75 percent. Despite these difficulties, some basic observations can be highlighted from the protozoan data.

In 2012, *Cryptosporidium* detections were less frequent at keypoint sites than in previous years, with just three detects of single oocysts during the year. Overall oocyst detection and concentration have been declining at the Kensico and New Croton keypoints during the last few years (Tables 4.2 and 4.3). The low number of *Cryptosporidium* detections in these years has made it impossible to detect seasonal variation at any of the keypoint sites.

Table 4.2: Annual detection and mean oocyst concentration of *Cryptosporidium* at influent keypoints to Kensico Reservoir.

	CATALUM			DEL17		
	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)
2001*	5	41.7	0.42	1	8.3	0.08
2002	6	11.5	0.17	8	15.4	0.15
2003	8	15.4	0.25	15	25.0	0.28
2004	10	19.2	0.29	11	19.6	0.20
2005	1	1.7	0.02	6	10.2	0.10
2006	3	5.8	0.06	3	6.0	0.06
2007	1	1.9	0.02	4	7.7	0.08
2008	7	13.5	0.13	6	11.5	0.15
2009	7	13.5	0.15	4	7.7	0.08
2010	1	1.9	0.04	1	1.9	0.02
2011	0	0.0	0.00	1	1.9	0.02
2012	0	0.0	0.00	1	1.9	0.02

* Monitoring from October 15 to December 31, 2001 only.

Table 4.3: Annual detection and mean oocyst concentration of *Cryptosporidium* at Kensico and New Croton Reservoir effluent keypoints.

	CATLEFF			DEL18			CROGH		
	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)
2001*	3	25.0	0.25	3	25.0	0.25	4	33.3	0.33
2002	21	29.2	0.35	18	25.0	0.31	13	20.0	0.28
2003	20	28.6	0.34	21	29.6	0.45	7	11.9	0.17
2004	20	27.0	0.38	25	34.7	0.36	28	40.0	0.51
2005	16	16.3	0.21	15	15.5	0.23	3	5.5	0.05
2006	8	12.5	0.13	7	10.8	0.12	7	13.5	0.13
2007	4	7.1	0.07	2	4.0	0.04	3	5.7	0.06
2008	10	19.2	0.23	1	1.9	0.02	8	14.3	0.21
2009	1	1.9	0.02	4	7.7	0.08	4	7.7	0.12
2010	3	5.8	0.06	1	1.9	0.02	5	9.6	0.10
2011	2	3.3	0.03	1	1.7	0.02	1	1.9	0.02
2012	1	2.9	0.03	0	0.0	0.00	1	2.8	0.03

* Monitoring from October 15 to December 31, 2001 only.

Concentrations of *Giardia* were low at all keypoint sites in 2012, with the results at CATLEFF, CROGH, and DEL17 generally comparable to those from 2001 to 2011. Catskill and Croton effluent mean *Giardia* concentrations were 46% and 71% (respectively), lower than their 2011 means but comparable to means found in some prior years. However, any potential differences or similarities to prior annual statistics can be misleading, as the sample size at these locations was smaller this year than in previous years. Delaware influent mean *Giardia* concentration in 2012 (1.08 cysts $50L^{-1}$) was almost half the 2011 mean (2.06 cysts $50L^{-1}$), but similar to means found in some prior years. The Catskill influent and Delaware effluent to Kensico had the lowest mean *Giardia* concentrations since analysis by Method 1623HV began in 2001 (0.17 and 0.87 cysts $50L^{-1}$, respectively). As in past years, the five keypoint sites showed seasonal variation in *Giardia* results, demonstrating higher values during colder months (Figure 4.3).

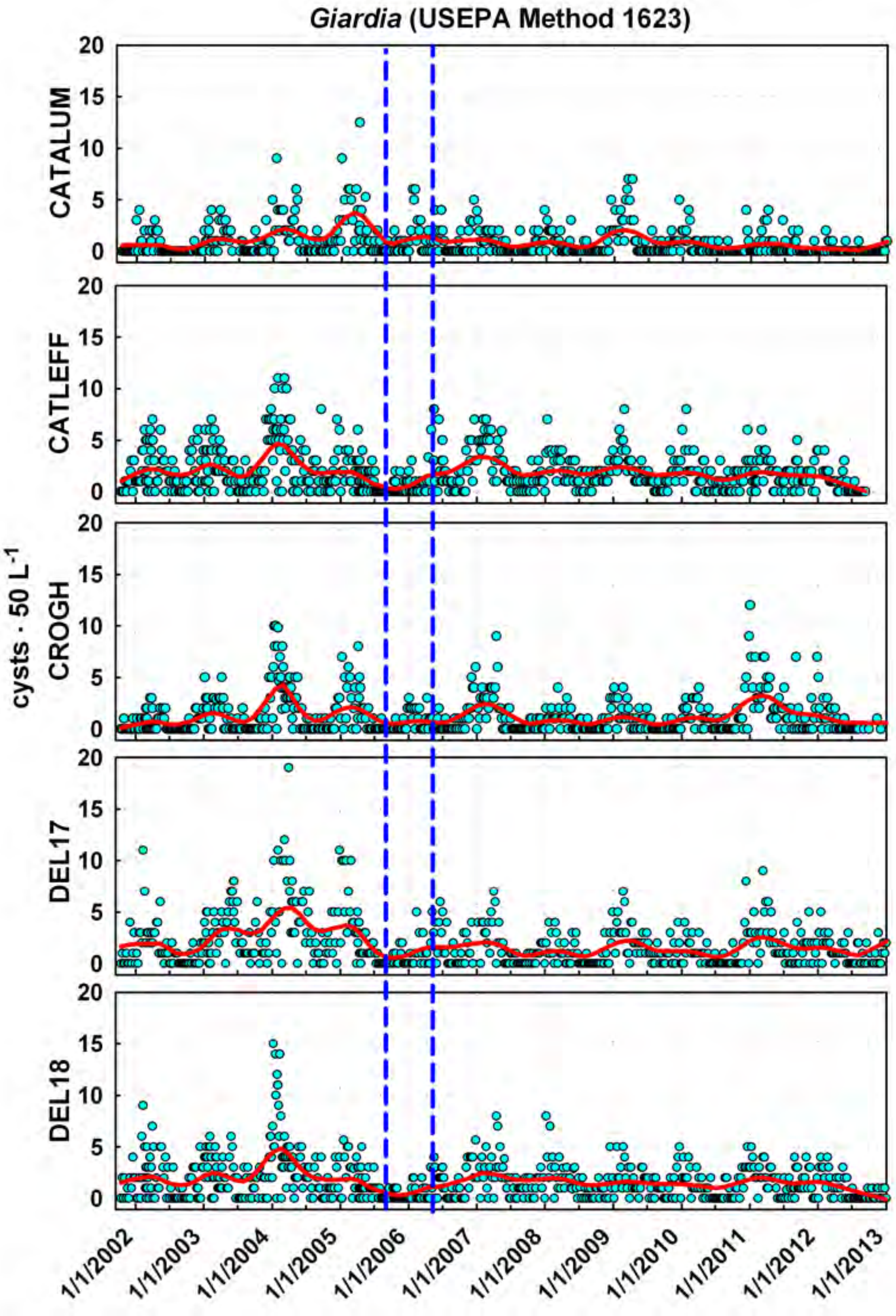


Figure 4.3 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2012. The area between the blue dotted lines indicates the period during which DEP temporarily switched to a different EPA-approved stain.

4.2.2 2012 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. For perspective, results have been calculated here using data from the most recent two-year period (January 1, 2011-December 31, 2012), using all routine and non-routine samples (Table 4.4).

Table 4.4: Number and type of samples used to calculate the LT2 bin classification set from January 1, 2011 to December 31, 2012.

Aqueduct	Number of routine samples, 2011-2012	Number of non-routine samples, 2011-2012	Total n
Croton	88	0	88
Catskill	86	8	94
Delaware	105	8	113

The mean level of *Cryptosporidium* oocysts, as measured at the keypoints for 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 2011 to 2012, as it has in all previous years. Unfiltered systems that meet this requirement do not require further treatment. Figure 4.4 presents results of the LT2 calculations for the most recent two-year period (January 1, 2011-December 31, 2012) compared to the previous nine two-year periods (i.e., 2002-2011). All New York City source water was at or below 10% of the threshold value: 0.0010 oocysts L^{-1} at the Croton effluent, 0.0006 oocysts L^{-1} at the Catskill effluent, and 0.0002 oocysts L^{-1} at the Delaware effluent.

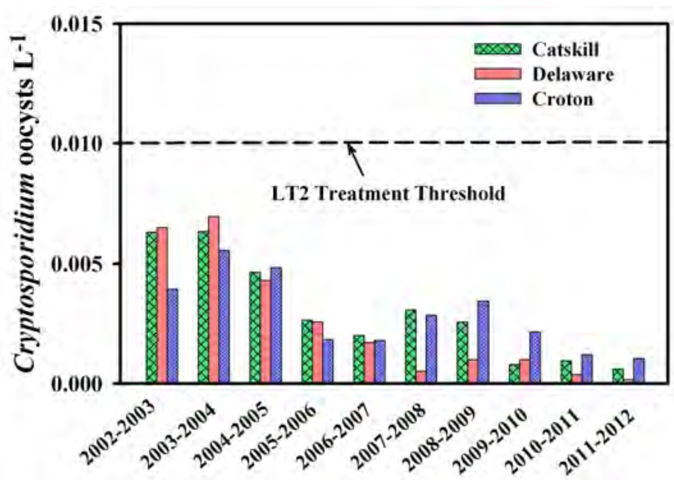


Figure 4.4 LT2 calculated means for *Cryptosporidium* since initiation of Method 1623 at DEP's three source waters (Croton, Catskill, and Delaware Aqueducts), 2002-2012.

4.3 Upstate Reservoir Effluents

DEP samples the effluents of upstate reservoirs monthly (except for CATALUM, which is sampled weekly) to determine potential sources of protozoa and to help ensure the quality of water entering downstream reservoirs. In 2011, DEP's monitoring plan for the upstate reservoirs was modified to require monthly effluent sampling only when effluent water is being sent to Kensico Reservoir. For this reason, not all WOH reservoirs were sampled in every month of 2012. Among East of Hudson (EOH) reservoirs, Muscoot Reservoir (the major input to New Croton Reservoir) was sampled monthly, as specified by the CCD, until July 2012, when NYSDOH agreed to a reduction in sampling frequency, including the complete cessation of sampling at Muscoot. Six protozoan samples were collected at the Cross River Reservoir effluent throughout January, April, and June 2012, as part of anticipated startups to supplement water in the Delaware Aqueduct. Additionally, one HEV sample was collected and analyzed in 2012 from each of the following effluents: Muscoot, Croton Falls, and Cross River. All results were negative.

Of 121 protozoan samples collected from the effluents of upstate reservoirs in 2012, only two (1.7%) were positive for *Cryptosporidium* (Table 4.5), compared to seven (5.7%) in 2011. *Cryptosporidium* concentrations were low in the two positive samples, with a maximum concentration of 1 oocyst $41.8L^{-1}$ at Neversink's effluent.

Table 4.5: Summary of upstate reservoir effluent protozoan results for 2012.

		Cryptosporidium				*Giardia*			
Site	n	Mean ($50L^{-1}$)	% Detects	Maximum (Liters sampled)	Maximum (L^{-1})	Mean ($50L^{-1}$)	% Detects	Maximum (liters sampled)	Maximum (L^{-1})
Ashokan (CATALUM)	53	0.00	0.0%	0	0.00	0.17	15.1%	2 (50.0 L)	0.04
Cross River	6	0.00	0.0%	0	0.00	1.33	50.0%	4 (50.0 L)	0.08
Muscoot	7	0.14	14.3%	1 (50.0 L)	0.02	2.00	57.1%	8 (50.0 L)	0.16
Neversink	8	0.15	12.5%	1 (41.8 L)	0.02	1.46	62.5%	4 (44.9 L)	0.09
Pepacton	12	0.00	0.0%	0	0.00	0.92	58.3%	4 (50.0 L)	0.08
Rondout	13	0.00	0.0%	0	0.00	1.79	46.2%	7 (43.4 L)	0.16
Schoharie	11	0.00	0.0%	0	0.00	4.53	81.8%	14 (50.1 L)	0.28
Cannonsville	11	0.00	0.0%	0	0.00	3.97	72.7%	19 (50.8 L)	0.37

Giardia was detected in 50 upstate reservoir effluent samples in 2012 (41.3%), compared to a 54% detection rate in 2011. Mean concentrations in 2012 (Table 4.5) were lower than those in 2011, with the exception of Rondout and Cannonsville. Rondout's 2012 mean (1.79 cysts $50L^{-1}$) was slightly higher than 2011's (1.42 cysts $50L^{-1}$); however, early in the year this site had some issues with sample pressure and achieving full sample volumes. (Four of ten samples were under 10L volume.) In October, the monthly sample was retaken, employing a slight modification in field collection (while still adhering to Method 1623HV protocols) to obtain the full 50L volume.

Cannonsville Reservoir's 2012 mean concentration was higher than 2011's (2.19 cysts $50L^{-1}$), but was heavily influenced by a high sample in August (19 cysts $50.8L^{-1}$) (Figure 4.5). This sample, which exceeded the 95th percentile(16.2 cysts $50L^{-1}$) for historical data from this site, was likely influenced by the approximately 1.8 inches of rain (as recorded at Binghamton Airport's weather station) that had fallen in the preceding 36 hours. All 2012 *Giardia* means for upstate reservoir effluents were lower than means calculated using data combined from prior years of sampling.

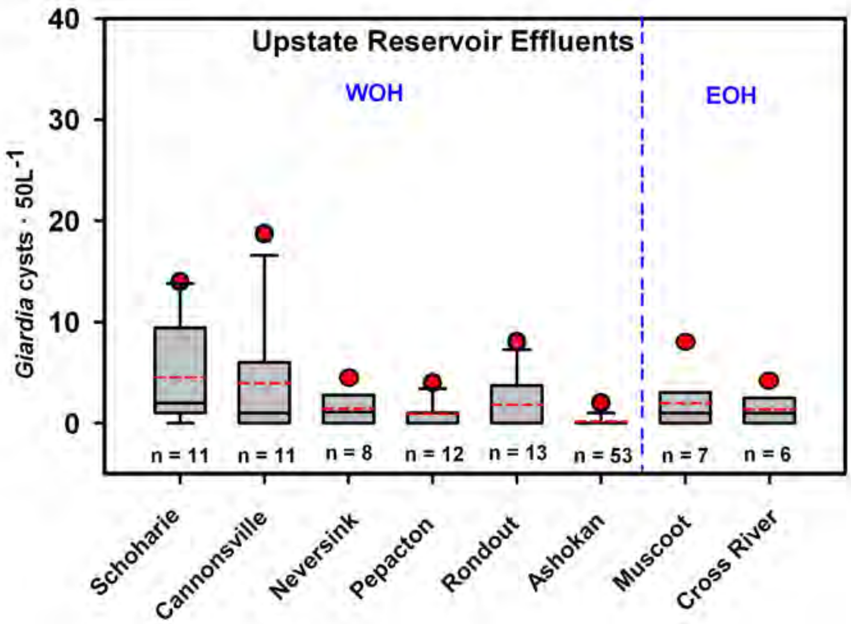


Figure 4.5 2012 summary of *Giardia* distribution among WOH and EOH basins (--- Mean, __ Median, ● outliers).

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), including 8 stream sites in the WOH System and 10 in the EOH System (of which 8 are perennial streams in the Kensico basin and two are streams in the Croton Watershed, as required for CCD monitoring). During 2012, 183 samples were collected, 73 in the WOH System and 110 in the EOH System.

West of Hudson Streams

The list of WOH sites was adjusted in 2010 as part of an effort to determine if point sources could be identified upstream of sites with the highest mean protozoan concentrations. For this reason, two of the sites listed for monitoring in the 2009 WWQMP (ABCG and PMSB) were not sampled in 2012, so that new upstream sites on the Manor Kill could be sampled above the site found to have had the highest *Giardia* concentrations in 2009 (S7i). DEP performed monthly sampling at two such sites in 2012, concurrently with S7i. These upstream sites were changed twice during the year, for a total of four different upstream sites (S7iB, S7iD1, S7iD2, S7iD3) in 2012. Samples at these sites were collected on April 3 in place of the March sampling, and routine sampling was done later in the month (April 25) to represent April. March sampling at PROXG (East Branch Delaware River at Roxbury) was missed. Monitoring was reduced at four other sites (CDG1, S4, S5i, WDBN) from monthly to bimonthly. An additional sample was taken at two of these sites, S4 and S5i, in June 2012, due to a scheduling issue, for a total of seven samples at each site (Table 4.6). Sampling at PROXG continued monthly, as this site appears to be next in line for upstream investigation for potential sources.

Table 4.6: Watershed stream protozoan results summary for WOH sites in 2012. ns = not sampled to allow new sites to be sampled upstream of S7i. See text for explanation.

		Cryptosporidium			*Giardia*		
Site	n	Mean ($50L^{-1}$)	Maximum (Liters sampled)	Maximum (L^{-1})	Mean ($50L^{-1}$)	Maximum (Liters sampled)	Maximum (L^{-1})
ABCG	0	ns	ns	ns	ns	ns	ns
CDG1	6	0.00	0	0	40.94	92 (50.0 L)	1.84
PMSB	0	ns	ns	ns	ns	ns	ns
PROXG	11	0.36	1 (50.0 L)	0.02	38.42	66 (50.0 L)	1.32
S4	7	0.54	1 (20.4 L)	0.05	65.58	202 (50.0 L)	4.04
S5i	7	0.76	1 (12.5 L)	0.08	48.60	69 (38.8 L)	1.78
S7i	12	0.17	1 (50.0 L)	0.02	51.33	164 (50.0 L)	3.28
S7iB	12	0.17	1 (50.0 L)	0.02	20.32	84 (50.1 L)	1.68
S7iD1	5	0.40	2 (50.0 L)	0.04	35.76	110 (50.1 L)	2.20
S7iD2	5	0.20	1 (50.0 L)	0.02	66.11	82 (29.2 L)	2.81
S7iD3	2	0.00	0	0	2.00	3 (50.0 L)	0.06
WDBN	6	0.17	1 (50.0 L)	0.02	17.66	27 (50.0 L)	0.54

The incidence of *Cryptosporidium* in the WOH streams was low in 2012, with 15 out of 73 (20.5%) samples testing positive and a maximum single sample concentration of 1 oocyst $12.5L^{-1}$ at S5i in September (Table 4.6). G*iardia* was observed far more frequently, with 100.0% of samples testing positive. G*iardia* was also more abundant, with 7 of the 10 sites having annual mean concentrations of 35 cysts $50.0L^{-1}$ or higher (Table 4.4).

Monitoring of S7i sites, which began in 2010, has continued to progress upstream, with a new site selected every few months to systematically segregate potential source tributaries. In 2011, site S7iD1 was established downstream of S7iE, a site approximately five miles above S7i where monitoring in 2011 indicated low *Giardia* concentrations. High concentrations at S7iD1 in

2011 and 2012, similar to those at S7i, indicated that the *Giardia* source lay further upstream, but below S7iE. Accordingly, another site, S7iD2, was established a short distance above S7iD1 to try to isolate the source. When high *Giardia* concentrations were encountered at this site too, sampling was moved upstream to site S7iD3, about 500 m below S7iE. Results from November and December showed lower *Giardia* levels at this site than at S7i and S7iB (the downstream reference), indicating a possible source downstream, between S7iD2 and S7iD3. This assessment, however, is considered preliminary, since only two rounds of sampling have thus far been completed.

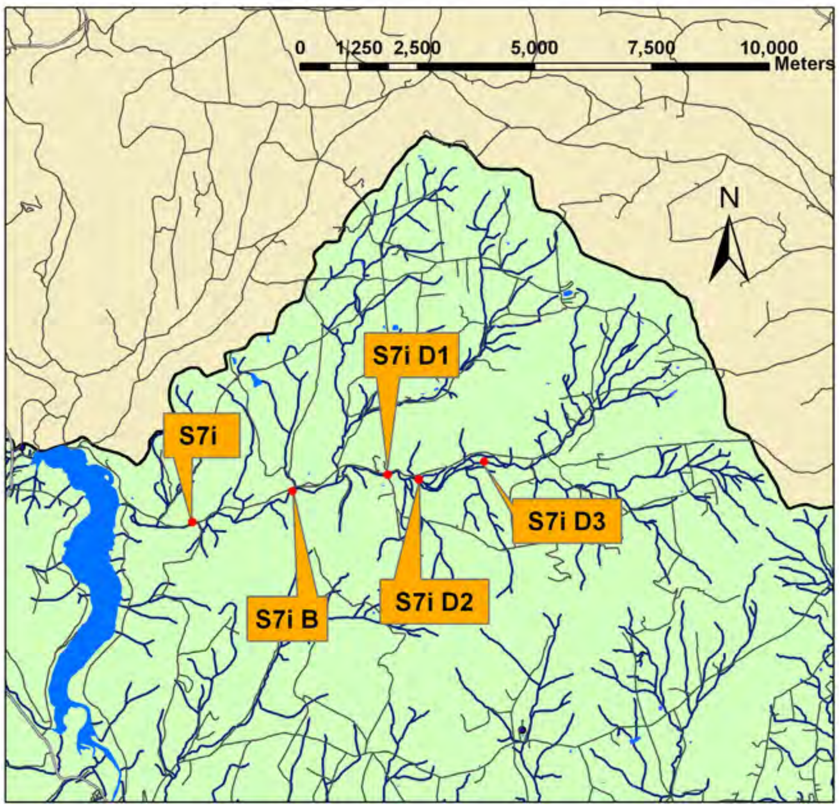


Figure 4.6 The Manor Kill sub-basin in the Schoharie watershed, depicting pathogen monitoring sites sampled in 2012.

East of Hudson Streams

Protozoan sampling of EOH streams in 2012 consisted of monthly sampling at eight perennial streams around Kensico Reservoir and two streams in the Croton watershed. Kensico perennial streams were sampled monthly. Monthly sampling at the two Croton sites (HH7 and WF) continued through July, after which sampling was discontinued pursuant to an agreement with NYSDOH. As a result, only seven samples were collected at each site in 2012.

Results at EOH stream sites showed a low detection rate (9.0%) for *Cryptosporidium* (10 out of 110 samples) and very low concentrations when oocysts were detected. The highest single sample concentration was 2 oocysts $50L^{-1}$ at N12 (Table 4.7). EOH streams had low mean concentrations, with all sites averaging below 0.30 oocysts $50L^{-1}$.

Table 4.7: Watershed stream protozoan results summary for EOH sites in 2012.

		Cryptosporidium			*Giardia*		
Site	n	Mean ($50L^{-1}$)	Maximum (Liters sampled)	Maximum (L^{-1})	Mean ($50L^{-1}$)	Maximum (Liters sampled)	Maximum (L^{-1})
BG9	12	0.08	1 (50.0 L)	0.02	2.95	8 (34.7 L)	0.23
E10	12	0.00	0	0.00	2.50	14 (50.0 L)	0.28
E11	12	0.10	1 (40.0 L)	0.03	21.21	67 (50.0 L)	1.34
E9	12	0.00	0	0.00	54.73	240 (34.8 L)	6.90
HH7	7	0.14	1 (50.0 L)	0.02	26.86	47 (50.0 L)	0.94
MB-1	12	0.08	1 (50.0 L)	0.02	1.79	4 (34.5 L)	0.12
N12	12	0.25	2 (50.0 L)	0.04	4.83	14 (50.0 L)	0.28
N5-1	12	0.08	1 (50.0 L)	0.02	4.09	13 (31.8 L)	0.41
WF	7	0.29	1 (50.0 L)	0.02	11.86	35 (50.0 L)	0.70
WHIP	12	0.08	1 (50.0 L)	0.02	8.00	18 (50.0 L)	0.36

As with the WOH results, detection of *Giardia* in EOH streams occurred much more frequently than did *Cryptosporidium*, with 86 of 110 (78.2%) samples positive for *Giardia*. As in 2010 and 2011, E9 and HH7 had the two highest mean *Giardia* concentrations (54.73 and 26.86 cysts $50L^{-1}$, respectively), with seven of the other eight sites reporting annual means below 10 cysts $50L^{-1}$. The two highest *Giardia* concentrations were found at E9 and E11 (6.90 and 1.34 cysts L^{-1}, respectively) on November 5, which was approximately one week after Hurricane Sandy affected the Kensico Reservoir area. Due to the elapsed time, however, the relationship between the storm and the high *Giardia* counts is uncertain. The storm was not significant as a precipitation event (0.43 inches of precipitation recorded at the Westchester County Airport gauge on October 29, 2012), but severe winds with gusts measured at up to 72 miles per hour increased turbidity and caused widespread damage to the forest landscape surrounding Kensico Reservoir.

4.5 Wastewater Treatment Plants

DEP monitored WWTP effluents for protozoa at eight WOH plants and three EOH plants during 2012. Sampling was conducted quarterly at all treatment plants except Brewster (BSTP), which was monitored monthly for protozoa and bimonthly for HEV, as specified by the CCD. Protozoan and HEV monitoring at BSTP were both discontinued in August, based on a change in the requirements of the CCD that took effect at that time.

Fifty-one protozoan samples and four virus samples were collected at WWTPs in 2012. No detections were recorded at WOH plants, the first year this has ever happened. In the EOH System, two samples were positive for *Giardia*, both at BSTP, and both at very low concentrations (1 cyst $50L^{-1}$) (Table 4.8). No EOH samples were positive for *Cryptosporidium* or HEV.

Table 4.8: Protozoan and HEV detections at WWTPs in 2012. ns = not sampled, nd = non-detect.

Date	Site	Plant	Sample volume	*Crypto* Result	*Giardia* Result	HEV Result
3/13/2012	BSTP	Brewster	50.0	0	1	nd
4/10/2012	BSTP	Brewster	50.0	0	1	ns

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. In 2012, 54 samples were collected from Site 3, including a non-routine sample taken shortly after Hurricane Sandy (on October 30) to ensure water quality. On the same day, an additional protozoan sample was taken at Hillview Downtake 2 (Site 58), also to provide information on any microbial impact from the hurricane. The sample taken at Site 58 was negative for both *Cryptosporidium* and *Giardia*.

All results from Hillview Site 3 in 2012 were negative for *Cryptosporidium* (Table 4.9). Seventeen of the 54 samples (31.5%) were positive for *Giardia*, and concentrations ranged from 0 to 3 cysts $50L^{-1}$.

Table 4.9: Hillview Site 3 monitoring results summary for 2012.

	Cryptosporidium	*Giardia*
n	54	54
Detects	0	17
% Detects	0.0	31.5
Mean ($50L^{-1}$)	0.00	0.44
Maximum ($50L^{-1}$)	0.00	3.00

5. Modeling for Watershed Management

5.1 Overview of DEP Modeling System

DEP uses models to examine how changes in land use, population density, ecosystem processes, and climate, as well as watershed and reservoir management policies, affect the New York City drinking water supply (Figure 5.1). Changing conditions in the watersheds present both ongoing and new challenges that DEP must plan for and respond to in its mission to ensure the continued reliability and high quality of the City's drinking water supply. Changing patterns of land use and population in the watersheds influence nutrient loadings, which can increase eutrophication in the reservoirs. Changes in stream channel erosion related to climate and 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 City's watersheds and reservoir system.

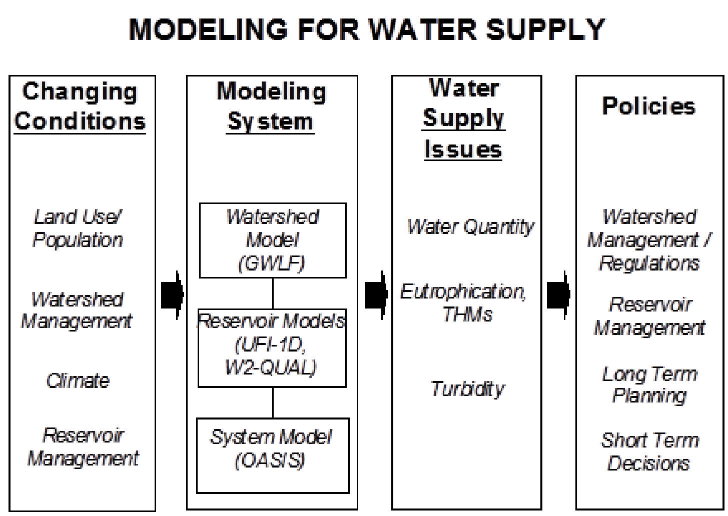


Figure 5.1 Use of models for the NYC Water Supply.

The DEP modeling system consists of a series of linked models that simulate the transport of water and dissolved and suspended materials within the watersheds and reservoirs that comprise the upstate Catskill/Delaware System. Watershed models are used to simulate the amount and seasonal variability of water, sediment, and nutrients transported from the land surface to the reservoirs. The Generalized Watershed Loading Function (GWLF) model is widely applied across the entire West of Hudson watershed region. The modeling group has also developed a Soil Water Assessment Tool (SWAT) model application in the Cannonsville and Ashokan watersheds. 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 New York City 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 operational changes in the Schoharie and Ashokan Reservoirs to mitigate the impacts of elevated turbidity and limit the use of alum treatment. The effects of changing land use and watershed management on nutrient loading and eutrophication in Delaware System reservoirs (Cannonsville and Pepacton) have been analyzed using linked watershed and reservoir models. The effects of climate change on the water supply are currently under investigation using the modeling system.

5.2 Modeling Applications to Support Reservoir Operations Decisions

Storm-generated turbidity in the NYC Watershed—particularly in the Catskill System, consisting of 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 effective operational strategies to both control turbidity levels and continue to reliably meet water demands. The modeling backbone of the OST includes a version of the CE-QUAL-W2 reservoir model developed specifically to simulate turbidity in the Catskill System reservoirs, coupled 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 still under development, the OASIS and CE-QUAL-W2 models are already being used to help inform operating decisions during turbidity events.

When a significant turbidity event occurs, DEP uses the CE-QUAL-W2 reservoir model to help inform operational decisions. A “positional analysis” strategy is followed for these model runs. Under this strategy, the current initial conditions of the reservoir and watershed are used as the starting point for the model. For analysis of Ashokan Reservoir, the model is run for a forecast period (typically three months) into the future, using as inputs the flows, derived turbidity loads, and meteorological inputs that are based on the historical record for the same three-month period during the years 1948-2004. 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. This helps determine the optimal ratios of Catskill System and Delaware System inputs to the reservoir, given the turbidity levels in each system. The results of the positional analysis are typically a range of potential outcomes based on the potential variability in near-term future meteorology, flows, and turbidity.

During 2012, there were two periods of elevated turbidity in the Catskill System during which modeling analyses helped to inform operational decisions. The first period was at the beginning of the calendar year, when the lingering effects of Tropical Storms Irene and Tropical Storm Lee were still impacting the system. These two extreme events occurred during August and September 2011, and as a consequence, alum treatment of Catskill System water was required until late May 2012. In the period up until the end of alum treatment, seven sets of simulations were used to evaluate the turbidity levels in Ashokan and Kensico Reservoirs. Simulations focusing on the conditions in Ashokan Reservoir evaluated potential future increases in turbidity that might be expected, especially those that might occur during spring snowmelt-supplemented streamflow. Some of these simulations also evaluated the impacts of using the Ashokan Release Channel on the transfer of turbidity from the West to the East Basin of Ashokan Reservoir and on the turbidity of the water withdrawn from the East Basin. Kensico Reservoir simulations were used to help better define the optimal Catskill Aqueduct flow rates, while maintaining Kensico effluent turbidity levels at safe and acceptable levels. These simulations, therefore, helped better define the timing of stop shutter use needed to reduce Catskill Aqueduct flow, flow rates that could minimize the volume of water treated with alum, and the length of time over which alum treatment was required. The simulations were run in response to declining Ashokan turbidity, the eventual increase in flows to Kensico once conditions allowed the removal of stop shutters, and the cessation of alum treatment.

The second period of elevated turbidity occurred during September, when a large and intense rain event led to a large turbidity input to Ashokan Reservoir and an unusually large increase in turbidity in Neversink Reservoir. This storm prevented the water from Neversink Reservoir from being used, while in Ashokan Reservoir turbidity inputs were initially confined to the West Basin and had only a small impact on the turbidity in the water transferred to Kensico Reservoir. Simulations done in response to this storm focused on forecasting the effects of the loss of Neversink water on water storage in the remainder of the system, and on the timing of future transfers of turbidity to the East Basin of Ashokan, as the West Basin eventually filled. The potential effect of Ashokan Release Channel use on the transfer of turbidity between the West and East Basins of the reservoir was also evaluated. As a progression of storm events eventually led to the transfer of turbidity to the East Basin, simulations focused on Kensico Reservoir, and were used to help define acceptable Catskill Aqueduct flow rates in response to first increasing and later decreasing levels of turbidity input to the Catskill Aqueduct. Unlike the extreme levels of turbidity associated with the tropical storms in 2011, the fall event in 2012 could be managed by changes in reservoir operations, and alum treatment was not needed.

A typical example of an analysis for Kensico Reservoir involved conditions occurring in early November 2012. The turbidity in Ashokan East Basin near the gatehouse was above 15 NTU, and turbidity in the West Basin of Ashokan was elevated to even higher levels, so that continued movement of water from the West to the East Basin would further increase turbidity in the East Basin. At the time, stop shutters were in place to limit turbid Catskill Aqueduct flow into Kensico Reservoir. Kensico Reservoir turbidity was generally quite low throughout the reservoir, except for a slightly higher turbidity of about 2 to3 NTU near the Catskill influent. Modeling simulations were run to provide guidance for the levels of turbidity that could be tolerated as inputs to Kensico Reservoir from the Catskill Aqueduct, given the current turbidity and possible future turbidity increases as the flow over the dividing weir continued to affect East Basin turbidity.

Sensitivity simulations for Kensico Reservoir were performed using the positional analysis framework, with meteorological forcings and aqueduct input water temperatures for the years 1987-2004 (18 traces) representing historical variability in the model forcings. The simulations were run for a 30-day forecast period from November 1 to 30. Initial reservoir conditions were based on a combination of data from limnological surveys conducted at the end of October. For all runs the input turbidity from the Delaware Aqueduct was set to 1.5 NTU based on conditions at the time. To test various inflow and turbidity combinations input from the Catskill Aqueduct to Kensico Reservoir, flows were set to 50, 150, and 250 MGD and input turbidities were set to 15, 20, and 25 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow to the reservoir equaled 1100 MGD. Each of the simulations assumed that these inputs and outputs were constant for the 30-day forecast period.

Figure 5.2 shows the results of a subset of the simulations covering the 50 and 150 MGD flow rates and the 15 and 25 NTU influent turbidities. A sustained Catskill Aqueduct turbidity of 15 NTU, at a flow of 50 MGD, produced Kensico effluent turbidity levels of 1.5 to 1.6 NTU (Figure 5.2a), while sustained input of 25 NTU water at the same flow rate resulted in only slightly higher effluent turbidity of 1.7 to 1.9 NTU (Figure 5.2b). At the 150 MGD flow, sustained 15 NTU Catskill influent into Kensico resulted in effluent turbidity ranging from 2.0 to 2.4, NTU while sustained 25 NTU influent resulted in an effluent turbidity range of 2.7 to 3.4 NTU (Figure 5.2c,d). These results indicated that the continued use of stop shutters without alum treatment would be sufficient to maintain water quality even if the turbidity in the Ashokan withdrawal were to increase to 25 NTU, provided that appropriate aqueduct flow rates were used.

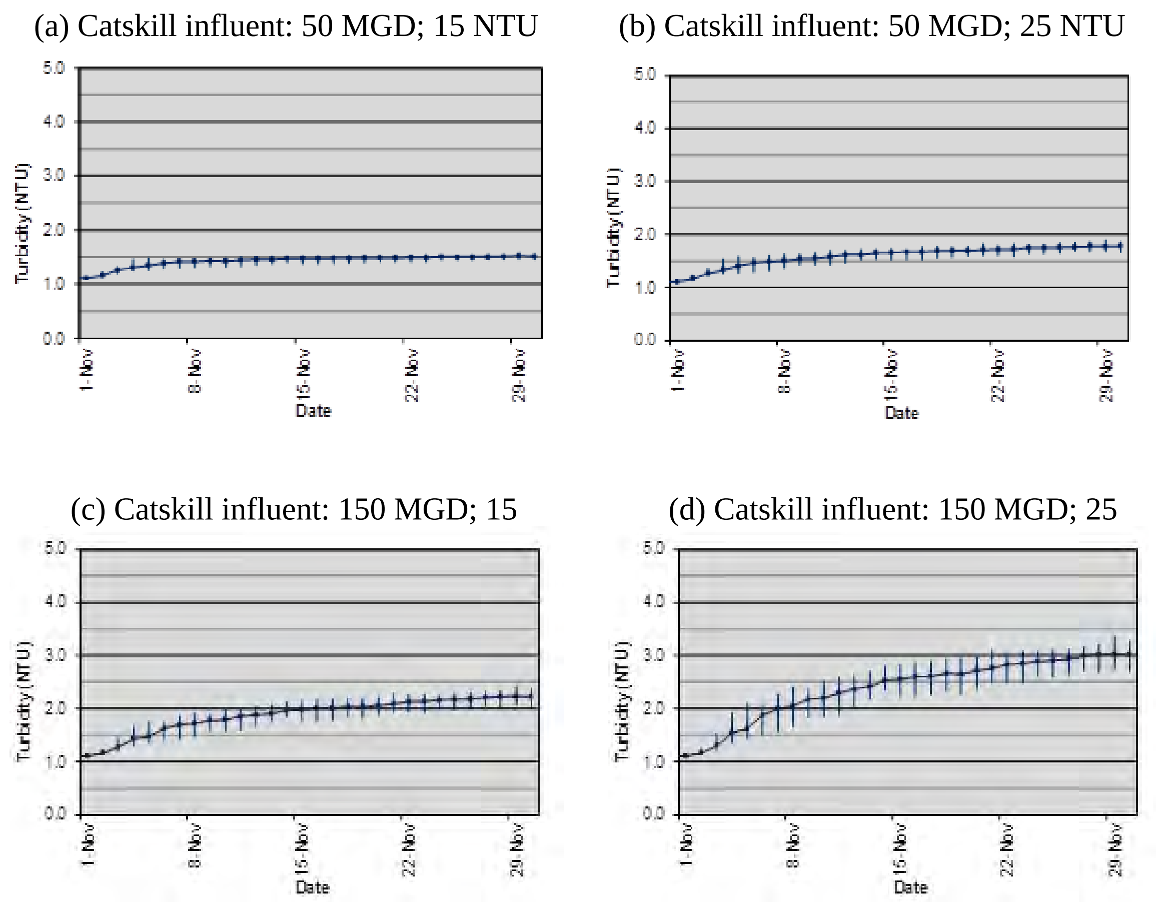


Figure 5.2 Selected results of Kensico Reservoir turbidity simulations of November 2, 2012. Simulated Kensico Reservoir effluent turbidity with constant input from Catskill Aqueduct of (a) 15 NTU at 50 MGD, (b) 25 NTU at 50 MGD, (c) 15 NTU at 150 MGD, and (d) 25 NTU at 150 MGD. The line on the graph shows the median of the 18 traces from the position analysis; the vertical bars show the range of values for all traces.

5.3 Modeling Watershed Turbidity

Catskill System reservoir turbidity events are generated by storm-related watershed turbidity inputs. The ability to simulate watershed sources of streamflow turbidity for historical, near-real-time, and future forecasts is critical for guiding reservoir operations and for evaluating the effects of watershed management and climate change on water supply system water quality. Two research streams are under way to enhance DEP's watershed turbidity modeling capability: (1) development of a screening tool to predict areas of potential stream channel erosion based on stream power analysis; and (2) development of an improved turbidity prediction method that accounts for the turbidity levels at the time of prediction using time series autocorrelation. Development and testing of these tools in 2012 represents an advance in DEP's ability to model watershed turbidity.

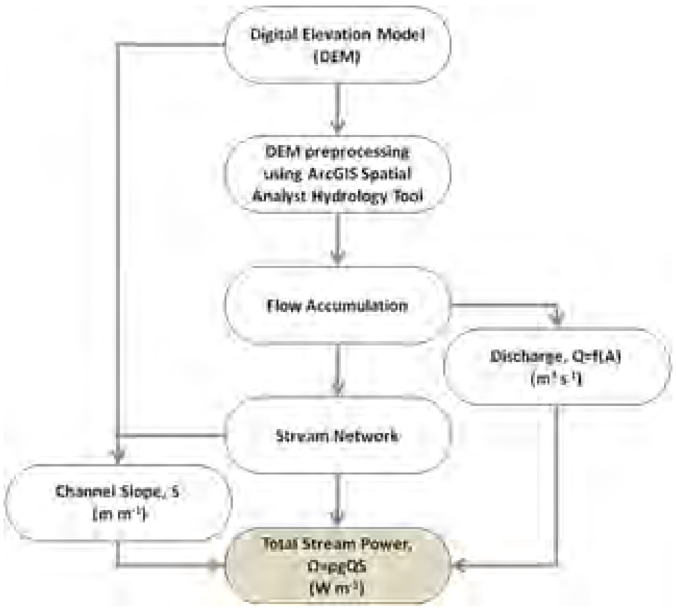


Figure 5.3 Flow chart of GIS processes involved in estimating stream power.

The planning level tool for identifying stream channel erosion sites applies a stream power-based approach for ranking the relative susceptibility of channel reaches to degradation caused by fluvial erosion at the watershed scale. This approach was evaluated by comparing the relative potential for bank erosion of different stream reaches, calculated according to the stream power model, with those given by two commonly used rapid stream channel assessment methods—the bank erosion hazard index (BEHI) and the rapid geomorphic assessment (RGA) index. Stream power was calculated for each stream reach in test watersheds at bankfull discharge. To estimate fine scale variations in stream power which could be used for inter-reach analyses, a geographic information system (GIS) tool for mapping the longitudinal distribution of stream power along a stream network was developed and tested using differing resolution digital elevation model (DEM) data in the Stony Clove sub-basin of the Esopus Creek watershed. In this approach, streamflow is routed from one upstream cell (pixel) to one downstream cell, creating a channel network that is one cell wide. The "horizontal slice slope" approach was used for slope calculation, and slope was calculated in the direction of the stream channel to estimate channel slope for use in the total stream power equation. A moving window of 100-m radius in either direction of the cell of interest that is part of a channel was used for estimating and mapping channel slope along the stream network. Stream discharge estimates were based on the bankfull discharge calculated using the regional curve equation for the Catskill region that relates drainage area to bankfull discharge. Figure 5.3 describes the steps involved in calculating stream power for each cell in the network.

The analyses demonstrate that changes in stream power can be used to identify potential sites of channel instability (Figure 5.4). Variations in stream power were comparable with the results of field observations of stream channel stability. The BEHI and RGA data used in this study were from sites where bank erosion was apparent, hence the scores may be considered an index of relative susceptibility to bank erosion. These geomorphic assessment indexes are qualitative metrics of channel stability, considering both erosional as well as depositional processes. This includes consideration of dominant erosional processes such as mass wasting and fluvial erosion; specific stream power, on the other hand, represents relative changes in transport capacity among stream reaches. One could therefore argue that higher transport capacities are a major factor causing higher rates of stream channel erosion in these watersheds. While land use analysis can provide information on landscape sediment sources, stream power analysis provides an effective method to compare streams in terms of bank erosion potential.

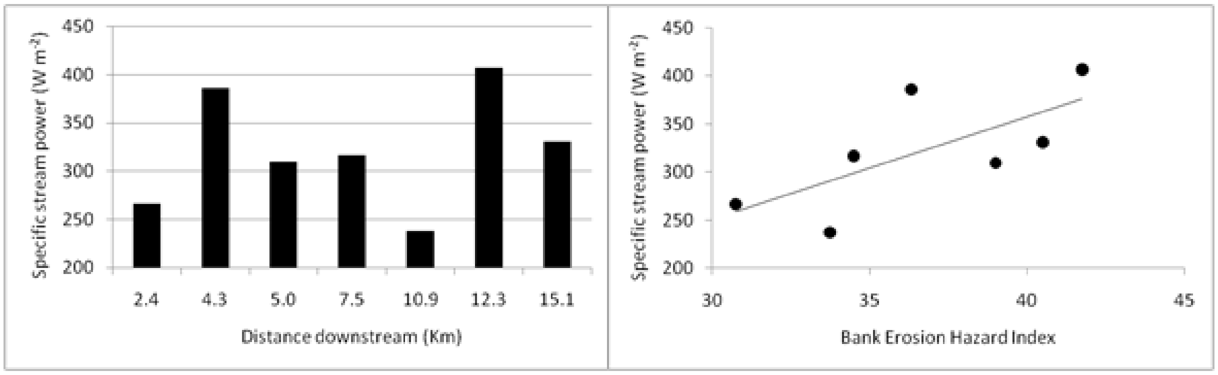


Figure 5.4 Reach scale variation in specific stream power and relationship to BEHI in the Stony Clove.

The results suggest that although channel vegetation and nature of bank and bed material can influence the resistance of these channels to erosion, the major factor controlling channel erosion in these Esopus Creek stream channels is the stream power generated within a stream reach. Details of this study are in Section 4.2 of the 2012 Multi-Tiered Water Quality Modeling Program Annual Status Report (DEP 2012c).

A time series model for in-stream turbidity prediction was developed based on observed serial correlation of turbidity at the daily time step. This is explained in a plot of the sample autocorrelation function (ACF) of log-transformed turbidity in Esopus Creek at Allaben (Figure 5.5). The plot shows the autocorrelation of the turbidity observations at different time steps. Statistically significant values show up above the upper blue dotted line in Figure 5.5, and these show strong serial correlation ($r > 0.6$) at lags of 4 to 5 days.

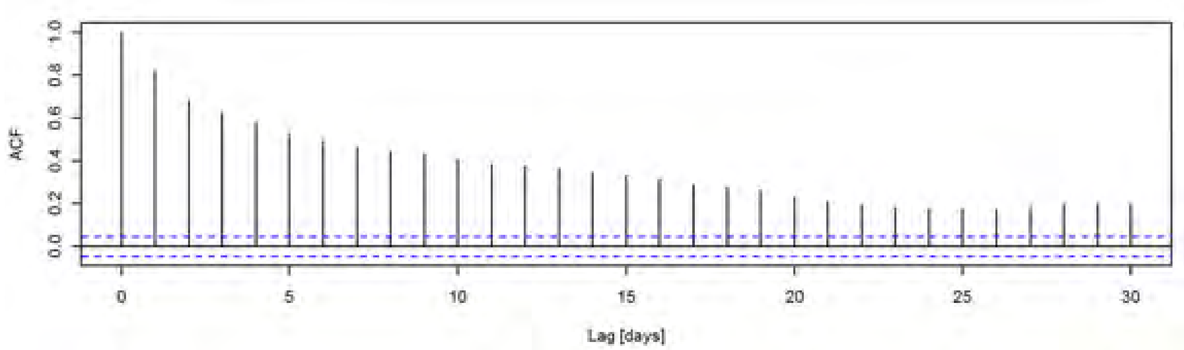


Figure 5.5 ACF of log-transformed turbidity at Allaben.

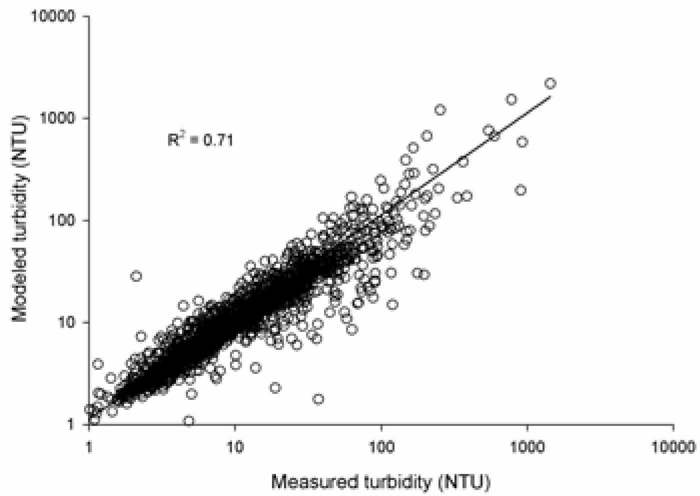


Figure 5.6 Scatter plot of measured and modeled turbidity pairs relative to the 1:1 line.

The time series model was used to estimate missing turbidity data from a continuous time series of average daily stream turbidity collected between June 13, 2003 and August 31, 2011 in Esopus Creek at Coldbrook. As an input to this analysis, a daily time series of measured instantaneous turbidity at the outlet of the Schoharie Tunnel was used to account for the effects of point source inputs to Esopus Creek. Residual analysis from the ordinary least squares regression model using three predictor variables (streamflow at the watershed outlet, Schoharie Tunnel turbidity, and an index of the hysteresis in the relationship between streamflow turbidity) showed a lag of four days in the autocorrelation function. This information was used in selecting an autoregressive model capable of predicting log-transformed daily turbidity. Figure 5.6 shows a very close fit when applying the final autoregressive turbidity loading model to Esopus Creek at Coldbrook. As a consequence, the model allowed DEP to accurately fill in missing data gaps in the analyzed time series. Other potential applications of the autoregressive model include short-term water quality forecasting for operational decision support, and determining optimal sampling (baseflow) frequency for water quality parameters. Details of this study can be found in Section 4.4 of the 2012 Multi-Tiered Water Quality Modeling Program Annual Status Report (DEP 2012c).

5.4 DEP Modeling Efforts to Evaluate the Impacts of Future Climate Change

DEP has been using its suite of simulation models to investigate the effects of climate change on the New York City Water Supply. This work is part of the DEP Climate Change Integrated Modeling Project (CCIMP), which focuses on the potential impacts of climate change on: (1) systemwide storage and operations; (2) Catskill System reservoir turbidity levels, including the processes that regulate erosion and transport of turbidity-causing suspended particles; and (3) Delaware System reservoir trophic status, including studies of the watershed processes that regulate nutrient loss and transport, reservoir thermal structure and mixing, and processes that regulate reservoir nutrient use and phytoplankton growth.

During 2012, DEP conducted modeling analyses of the effects of climate change on eutrophication in Cannonsville Reservoir and turbidity in the Ashokan West Basin. The investigation was facilitated by applying the suite of DEP watershed, reservoir, and water system models in an integrated fashion (Figure 5.7). Predicted climate change was represented by future time series of meteorology which were developed using a change factor methodology (Anandhi et al. 2011a). This method produces a number of future climate scenarios which serve as inputs to watershed and reservoir model simulations. These representations of future climate were then used as input to the DEP watershed model, GWLF-VSA (Schniederman et al. 2002, 2007), to simulate flows and nutrient loads. These were then used to specify future stream inflows and constituent loads within the reservoir models. The modeled flows were also used in the water system model, OASIS, to predict reservoir operations withdrawal and storage. For eutrophication in Cannonsville Reservoir, a one-dimensional hydrothermal reservoir model (Owens 1998) was used, along with two different phytoplankton models developed and adapted for Cannonsville Reservoir: UFI3.5 (Doerr et al. 1998) and the PROTBAS model (Markensten and Pierson 2007). For turbidity, the two-dimensional CE-QUAL-W2 model (Gelda et al. 2009, Cole and Buchak 1995, Cole and Wells 2002), adapted for turbidity transport, was applied using simulated future flows and turbidity loads.

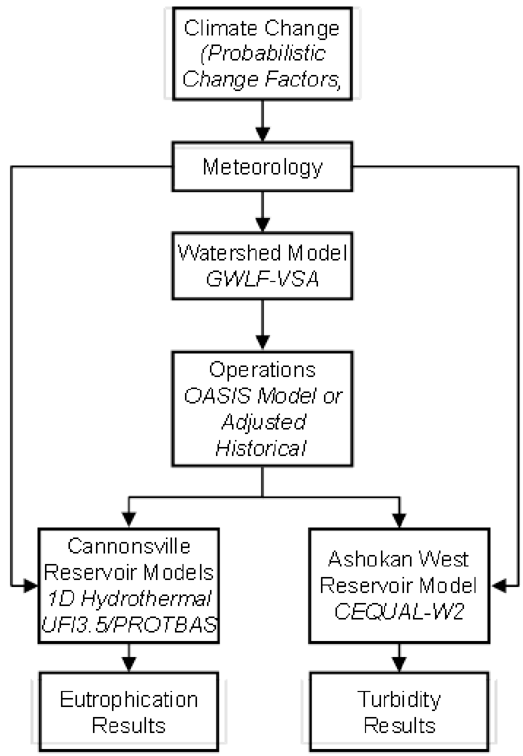


Figure 5.7 DEP modeling system and its use. During 2012, the models shown in this figure were used for climate change-related simulations to analyze turbidity in Ashokan Reservoir and eutrophication in Cannonsville Reservoir.

The most consistent finding of Phase I of the CCIMP was a projected shift in winter streamflow timing, with more flow occurring during the midwinter period and slightly reduced flow during the traditional early spring snowmelt period (Figure 5.8). This shift was largely due to higher predicted temperatures in the winter, resulting in more precipitation falling as rain instead of snow, and greater snowmelt during the winter months, producing a smaller snowpack.

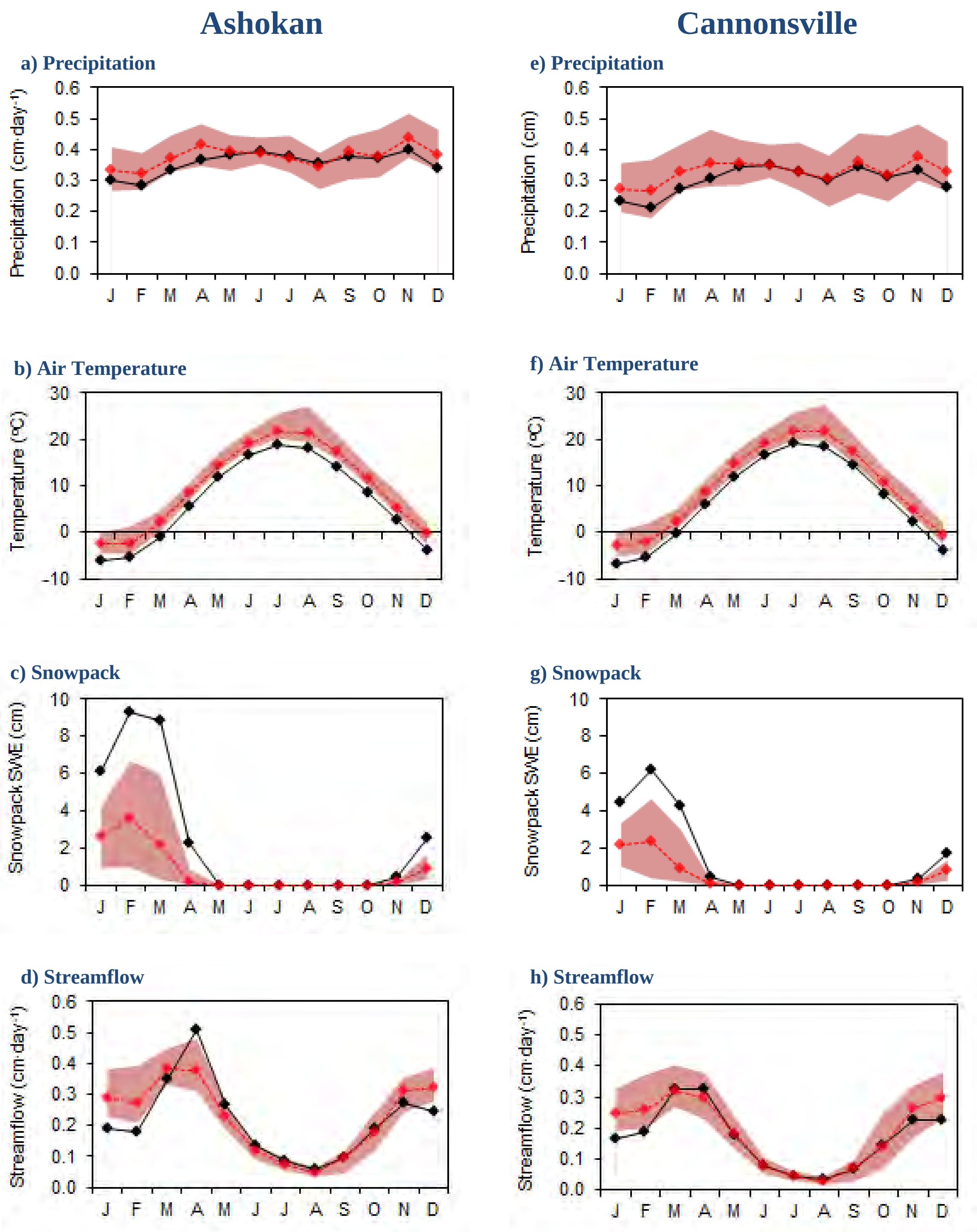


Figure 5.8 Monthly average simulation results calculated using data from current and future climate scenarios of precipitation, air temperature, snowpack, and streamflow for the Ashokan (a-d) and Cannonsville (e-h) watersheds. Black line shows the current conditions, the red area shows the range of future climate scenario results, and the red line shows the median of all future climate scenarios.

The increase in winter streamflow and slight decrease in early spring flows has implications for both reservoir turbidity and eutrophication. For Ashokan Reservoir, there was a predicted shift in the timing of turbidity loading into the reservoir (Figure 5.9), which generally follows the flow pattern shown in Figure 5.8. Note, however, that although the timing of the turbidity load changed, the total annual load (shown as the December value in Figure 5.9(b)) was about the same under future climate and current conditions. As a consequence of these projected shifts in the seasonality of reservoir inputs, changes in the seasonal pattern of reservoir volume, water temperature, and turbidity (Figure 5.10) are predicted. The increased flow during the late fall and winter causes the reservoir to fill earlier in the year. The increased air temperature throughout the year results in the reservoir temperature increasing, especially from the spring through the fall, and also means that thermal stratification begins earlier in the spring and ends later in the fall. Finally, reservoir turbidity is simulated to increase during the winter months, due to the increased turbidity load that accompanies the seasonal shift in streamflow. During the summer months, the simulations indicate that turbidity will be largely unchanged.

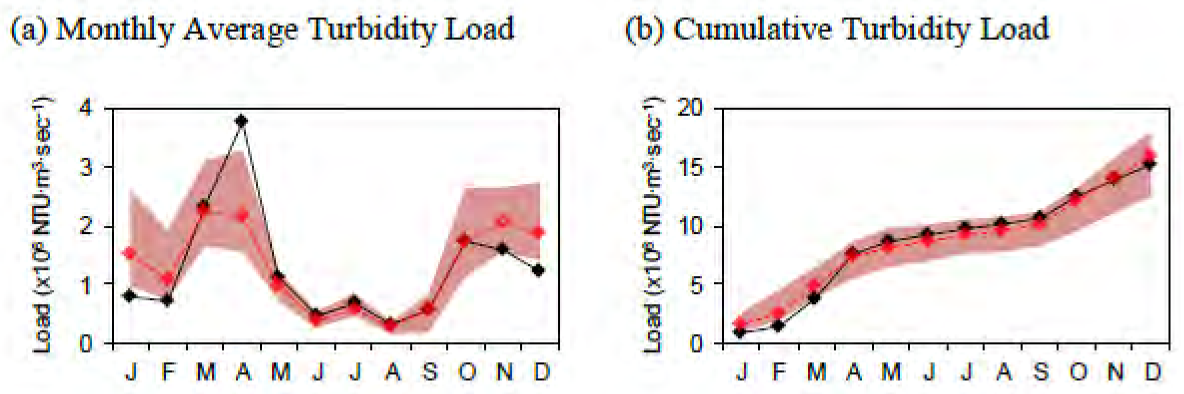


Figure 5.9 Monthly average simulated turbidity load (a) and cumulative turbidity load (b) entering Ashokan Reservoir under current conditions and simulated future climate scenarios. Black line shows the current conditions, the red area shows the range of climate change scenario results, and the red line shows the median of the future scenario results.

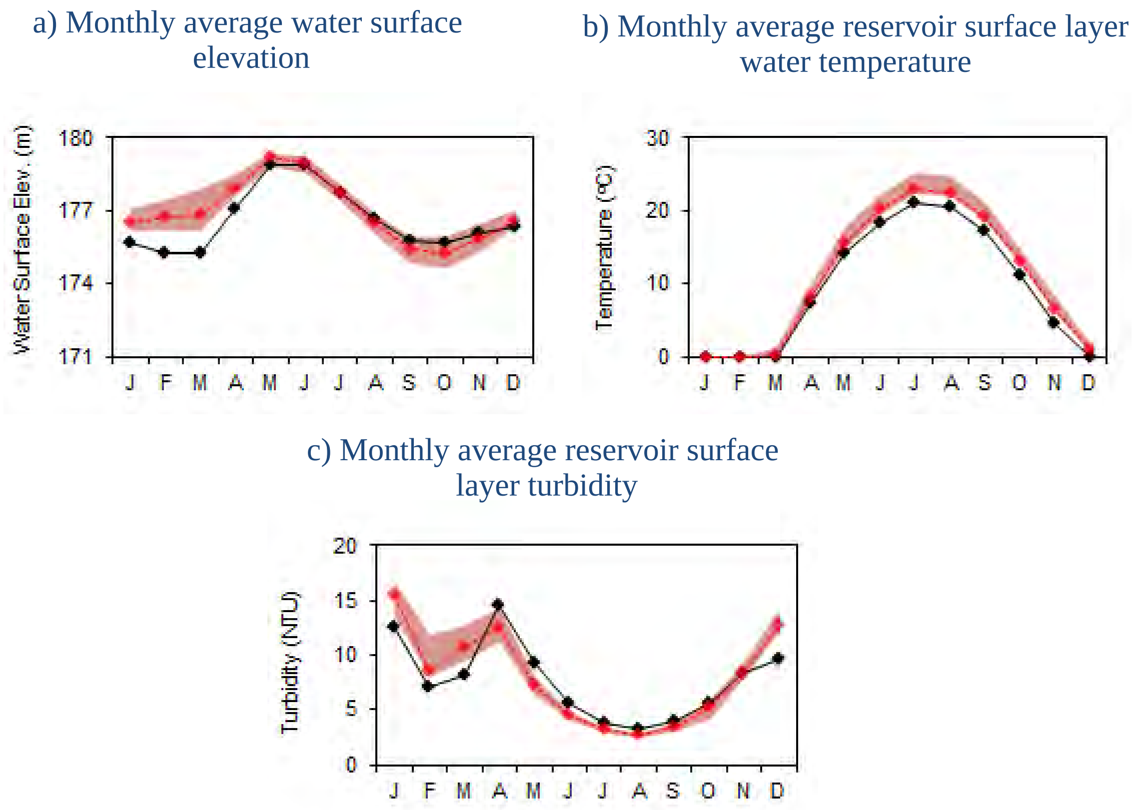


Figure 5.10 Monthly average simulated (a) water surface elevation (a representation of reservoir storage volume), (b) surface water temperature and (c) surface layer turbidity for Ashokan Reservoir under current conditions and climate change scenarios. Black line shows the current conditions, the red area shows the range of climate change scenario results, and the red line shows the median of the climate change scenarios.

For algal growth in Cannonsville, the critical nutrient is total dissolved phosphorus (TDP). The loading of TDP under potential future climate was also affected by the seasonal shift in flow, with greater loads in late fall and winter compared with current climate conditions (Figure 5.11).

Figure 5.12 shows the simulated seasonal pattern of mixed layer chlorophyll *a* concentrations under current and future conditions. It was expected that shifting a greater proportion of the TDP load to the early winter would decrease the availability of this nutrient in the reservoir during the later spring period and, in turn, decrease the intensity of the spring bloom. However, the simulated magnitude of the bloom did not change significantly under climate change conditions. This could be indicative of limitations in the simulation of phytoplankton and nutrient processes under winter conditions. The results also show a notable shift in the timing of the spring algal bloom, with the simulated peak chlorophyll *a* occurring about two weeks earlier in the spring (Figure 5.12). This shift is related to the earlier onset of thermal stratification caused by the increase in air temperature that occurs under climate change.

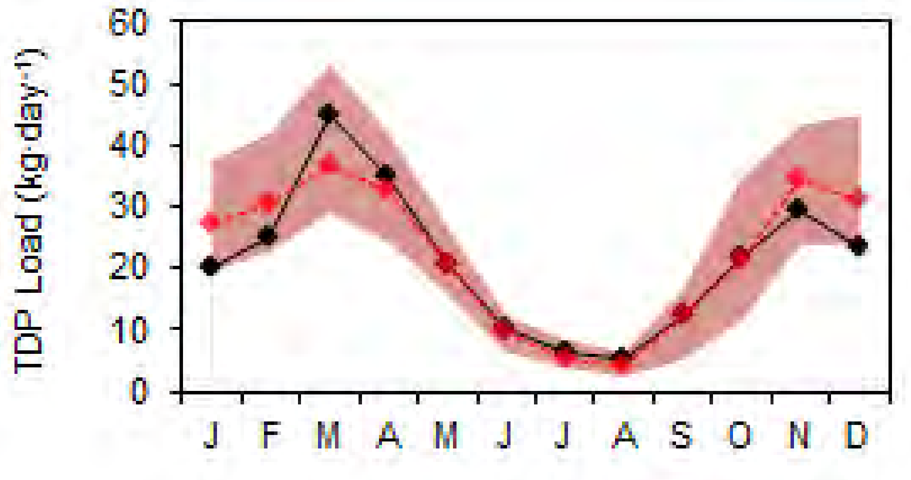


Figure 5.11 Monthly average simulated TDP load to Cannonsville Reservoir under current conditions and climate change scenarios. Black line shows the current conditions, the red area shows the range of climate change scenario results, and the red line shows the median of the climate change scenarios.

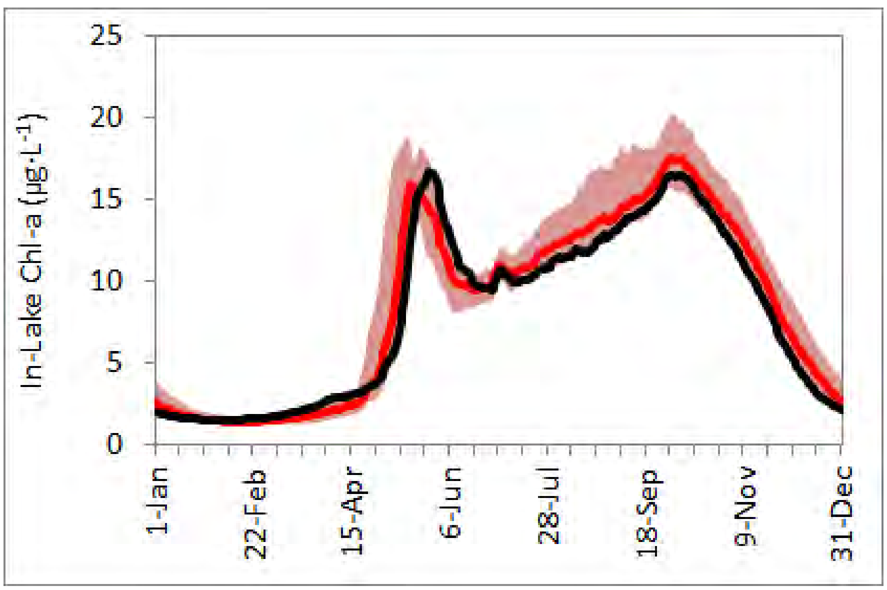


Figure 5.12 Daily average simulated chlorophyll *a* concentrations in Cannonsville Reservoir under current conditions and future climate conditions. Black line shows the current conditions, the red area shows the range of climate change scenario results, and the red line shows the median of the climate change scenarios.

During 2012, DEP continued to be a participating utility in the Water Utility Climate Alliance (WUCA) (http://www.wucaonline.org) and the associated Piloting Utility Modeling Applications (PUMA) project. The CCIMP is one of several case studies being highlighted as part of a case study designed to document strategies used by water utilities to obtain climate data and develop climate modeling tools, and to illustrate how utilities incorporate future climate scenarios into existing modeling strategies to provide data valuable for water supply decision making. The CCIMP demonstrates an approach used by a water utility to evaluate the potential impacts of climate change on a water supply. It also provides a window on climate change impacts in the northeastern United States, where water quality-related impacts are expected to predominate, as opposed to the water quantity concerns that prevail in the western United States. Information for these case studies is being collected through a series of interviews and surveys developed for WUCA by Stratus Consulting. DEP was one of the first utilities to participate in the survey and during 2013 expects to be re-surveyed based on more recent results of the project.

6. Further Research

DEP's analytical, monitoring, and research activities 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 2012

In 2012, 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) (USEPA 2007) and the Croton Consent Decree each includes 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 these regulatory requirements, because DEP did not have the ability to perform these analyses in-house in the first half of 2012. The contract specified 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 has been needed. During the first half of the year, the DEP Pathogen Laboratory continued training to analyze samples for viruses, and officially began analyzing its own virus samples without the need of a contract laboratory as of June 1, 2012. DEP began overall virus monitoring in 1995; therefore, the data record is now approximately 17 years long for some keypoint locations.

6.1.2 Laboratory Analytical Support

Outside contract laboratories are used by DEP's Watershed Water Quality Laboratories for various analyses that are not currently conducted in-house. Eurofins/Eaton Analytical Laboratories in Monrovia, CA (formerly MWH) provided the majority of this work. The contract with Eurofins/Eaton Analytical Laboratories is administered by DEP's Distribution Water Quality Laboratory.

In 2012, samples sent to Eurofins for analysis included:

- Pepacton Reservoir diesel fuel leak samples. Collection for this special investigation spill event commenced on April 30, 2012 and continued throughout 2012. Over the course of the event, elevation tap reservoir samples were collected to determine the composition of the spilled substance and its potential impacts on the water supply. Various tests were performed and monitored, including those for PCBs, VOCs, SVOCs, and DRO.
- Wastewater Treatment Plant (WWTP) effluent samples. City and non-City-operated WWTP samples were sent out for TKN, MBAS, and TDS analysis. This occurred twice each month, with the exception of TKN samples from the Brewster Sewage Treatment Plant, which are sent monthly.

- Drinking water samples. Various regulated and non-regulated drinking water sites at City-owned upstate facilities were analyzed for DRO, VOA, SVOCs, sodium, HAA5, TTHM, total fluoride, and free cyanide.
- Aqueduct keypoint samples. Selected keypoint samples underwent routine annual analysis for volatile (EPA 524.2) and semivolatile (EPA 525.2) organic compounds.

Other laboratories used for contracted analyses in 2012 were:

- H2M Laboratories (formerly known as ECOTEST Laboratories). Pepacton spill event samples collected at the keypoint or elevation tap were sent to this lab for DRO, VOC, and SVOC analysis on a weekly basis from May to September. In September, analyses were reduced to DRO only, due to the lack of positive detections. In December, the sampling frequency was reduced from weekly to every other week on the keypoint or tap collections for DRO, due to lack of detections.
- Source Molecular Laboratories. Samples from storm events occurring at Kensico Reservoir in April and September were sent to this lab for microbial source tracking analysis. The results are discussed in Chapter 4.

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 for the Hydrological Monitoring Network." Under this agreement, USGS measures stage and discharge at some or all of approximately 55 stream gauges throughout the watershed of the City's Croton, Catskill, and Delaware Systems. The operation and maintenance of the gauges involves: (1) retrieving the stage, water temperature, and/or turbidity data; measuring stream flow; and/or collecting sediment samples at specified gauges; (2) ensuring the integrity of these data; (3) maintaining the automatic equipment used to collect these data; (4) preparing selected data for real-time distribution over the Internet; (5) analyzing stage, water temperature, turbidity, and stream flow data; and (6) preparing an annual summary report. The above mentioned data provide information to DEP necessary to support the development of multi-tiered water quality models, a requirement of the 2007 FAD. These data also provide DEP with information it needs to support its protection and remediation programs, including Land Acquisition, the Watershed Agricultural Program, the Watershed Forestry Program, the Stream Management Program, the Wetlands Protection Program, and Catskill Turbidity Control, all of which are mandated by the 2007 FAD.

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

This contract with the USGS involves retrofitting the five existing USGS stream flow gauges in the Esopus Creek watershed to automatically monitor turbidity at high (15-min) frequency. These five stations will provide a record of flow and turbidity that will allow the Water Quality Modeling Group to evaluate temporal and spatial variations in turbidity sources and transport within the Esopus Creek watershed; develop improved turbidity versus discharge rating relationships; and collect high quality data that can be used to develop and test watershed sediment erosion and transport models. Approximately two years of data have been collected so far, and these data are presently being analyzed and used for model testing. This project is scheduled to end in 2013. Channel best management practices (BMPs) were implemented in tributaries of Esopus Creek during 2012 and several are planned for 2013. These are intended to reduce suspended sediment entrainment, with consequent reductions in turbidity. Turbidity monitoring at these tributaries will allow quantification of BMP effects. These high frequency monitoring data can also help integrate point measurements of suspended sediment and turbidity into the temporal and spatial sampling of stream habitats, macroinvertebrates, periphyton, and fish populations throughout the watershed.

6.1.5 CUNY Postdoctoral Support

This contract provides the City University of New York (CUNY) with the funding needed to hire seven postdoctoral research associates (postdocs) who are jointly advised by CUNY faculty, external faculty advisors, and DEP scientists. The postdocs are stationed in Kingston, New York, working with the Water Quality Modeling Group on a day-to-day basis. The positions are for an initial two-year period, with the possibility of an additional two-year extension. The project was originally scheduled to end in 2013, but has been extended to ensure that all of the hired postdocs have a chance to use their full four-year term of employment.

Postdocs funded by this contract have supported the modeling group's work in:

- Climate data analysis
- Reservoir system modeling
- Reservoir turbidity modeling
- Reservoir eutrophication modeling
- Watershed nutrient modeling
- Watershed sediment erosion and transport modeling
- Forest ecosystem modeling

The contract has been very successful, leading to the development and testing of improved modeling tools, new and improved datasets (including future climate scenarios used by the Climate Change Integrated Modeling Project (CCIMP)), and modeling-based evaluations of climate change impacts. To date, 17 peer reviewed publications have resulted from this project (Anandhi et al. 2011a, Anandhi et al. 2011b, Matonse et al. 2011, Pradhanang et al. 2011, Zion et al. 2011, Huang and D. Pierson 2012, Klug et al. 2012, Matonse et al. 2012, Mukundan et al., 2012, Pradhanang et al. 2012, Samal et al. 2012, Mukundan et al. 2013a, Mukundan et al. 2013b, Pierson et al. 2013, Pradhanang et al. 2013, Samal et al. 2013, Schneiderman et al. 2013). The sections of this report describing modeling-based evaluation, model development, and data analysis (Chapter 5) have also benefited from the work of the postdoctoral scientists.

6.1.6 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. Until 2011, the system was run by the Upstate Freshwater Institute (UFI) which was responsible for developing, installing, and maintaining all the monitoring sites. During 2011, the operation and maintenance of the robotic monitoring system was transferred from UFI to DEP, and DEP has now fully assumed operation of the robotic monitoring system. Data collected by the system is automatically uploaded to the DEP Laboratory Information Management System (LIMS), and also to the OST (Figure 6.1).

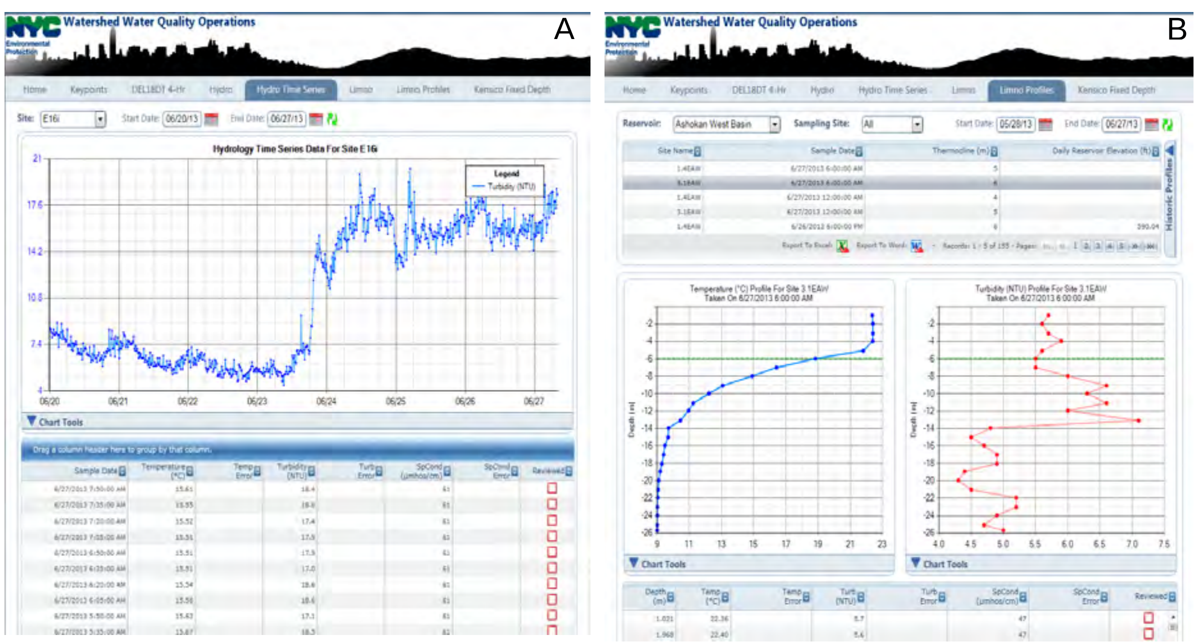


Figure 6.1 Examples of robotic monitoring data displayed by the DEP LIMS system. A) Time series of stream water turbidity measured at 15-minute intervals in Esopus Creek near its confluence with Ashokan Reservoir. B) Reservoir temperature and turbidity profiles measured at 6-hour intervals in the West Basin of Ashokan Reservoir.

The contract began in December 2008 and was originally scheduled to end in December 2011. However, following the damage to the monitoring system caused by Tropical Storm Irene, it was extended for an additional year to provide support for the operation of the monitoring network and to address modeling issues that became evident following the impacts of Irene. The change order tasks required UFI to:

- Repair stream monitoring stations that were damaged during the hurricane.
- Provide logistical and technical support to DEP as it takes over responsibility for the operation and maintenance of the robotic monitoring network.
- Develop 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.
- Improve the turbidity transport algorithms to better account for transport of highly turbid inputs with a density that can override thermal density stratification.

All of these tasks have now been completed. Work on the Rondout turbidity model (Task 3) and improved turbidity transport algorithms (Task 4) have been reviewed by the Water Quality Modeling Group, and the new or improved modeling products are being incorporated into the OST.

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 on the reservoirs and the reservoirs' concentrations of fecal coliforms; the WMP was developed based on this finding. A contract was first let in 1995 to a private environmental consulting firm and has been re-bid every three to four years to facilitate compliance with the federal Surface Water Treatment Rule for fecal coliform bacteria (USEPA 1989). The current contract requires staffing of up to 25 contractor personnel annually to perform waterfowl management activities at several upstate reservoirs. The contract is with Henningson Durham & Richardson and runs 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, through contracts with a series of laboratories that have professional experience identifying zebra mussels. All East of Hudson reservoirs are monitored on a monthly basis between May and October, while the West of Hudson reservoirs are monitored in July and September of each year. The contract laboratory analyzes the samples and provides a monthly report to the project manager indicating whether or not zebra mussels have been found. To date, no infestations have been detected.

6.2 Water Research Foundation Projects in which DEP Participated in 2012

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 (AMWA), the National Association of Water Companies (NAWC), the American Water Works Association (AWWA), others from the drinking water community, and one representative from the international water supply community. In this way, research projects remain focused on the primary issues of water utilities worldwide.

The WaterRF is a highly interactive organization whose subscribers, like DEP, can become involved by volunteering their time and experience. Several DEP staff members are currently involved as Project Advisory Committee (PAC) 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 2012 are described 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, develop a secondary confirmatory gene target for human infectious oocysts, and perform a round-robin and field testing of the tools of choice. (K. Alderisio)

WRF # 4222: Reservoir Operations and Maintenance Strategies

This project will identify, compile, and describe (1) leading practices for lake and reservoir oxygenation/circulation techniques, (2) the use of rapid, or near-real-time, sensors and traditional water quality monitoring tools, and (3) the range of water quality models that are being used to guide operational decisions. Three state-of-the-industry reports will be published. Research partner: United Kingdom Water Industry Research. (G. Marzec)

WRF # 4261: The EDC Network for Water Utilities

This project produced the EDC Network for Water Utilities, an on-line network to promote collaboration among water utilities and improve utility responses to challenges posed by endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs). The EDC Network provides a secure website resource for utilities to share best practices, documents, other tools, and materials related to EDCs and PPCPs. The EDC Network is open only to utility professionals, regardless of whether they are WaterRF subscribers. Please feel free to forward and invite your utility peers to participate. Visit The EDC Network for Water Utilities and register: your request will be reviewed and login credentials sent within 24 hours. (Dave Lipsky)

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

This project will identify the most likely vulnerabilities typically associated with climate change, provide utilities with a tool to assess their own utility-specific vulnerabilities, and produce a suite of risk management tools to assist utilities in identifying appropriate strategies and actions to respond to the vulnerabilities that are identified. Research partners: NYS Energy Research and Development Authority (NYSERDA) 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. (A. Cohn)

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. (A. Cohn)

WRF # 4306: 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 what 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 the water quality parameters that result in the inability to recover *Cryptosporidium* oocysts at certain times of the year from the Portland (Ore.) Water Bureau's Bull Run source water. Examining seeded recoveries with different water quality characteristics, as well as modifying laboratory methods, has been part of the investigation approach. While much information has been gained, and some correlations exist, no "smoking gun" has been identified as the single source of the low recovery. (K. Alderisio)

WRF # 4382: Impacts of Climate Change on the Ecology of Algal Blooms

The goal of this research is to determine how cyanobacterial risk may change with climate change. Different lakes may have different sensitivity to cyanobacteria and climate change, which may be a function of latitude, nutrient loading, and lake size. Further objectives are to determine the factors leading to cyanobacterial blooms, determine if these factors are common across all lake types and latitude, and predict how cyanobacteria risk may change using predictive coupled climate-hydrodynamic-biogeochemical models. This program of work will deliver five products for use by the water industry to predict and respond to the impacts of climate change on cyanobacteria:

1. A literature review of the key drivers of cyanobacterial blooms and how these are likely to vary with anticipated climate change scenarios
2. An analysis of water bodies from North America, New Zealand, Europe, and Australia that span a range of latitudes, represent a range of lake sizes, and have different nutrient status.
3. A generalized model of lake/reservoir sensitivity to cyanobacteria and climate change
4. Quantification of the possible risk, in terms of cyanobacterial biomass, that could be expected with climate and nutrient loading scenarios, documented in a table that uses correlations between biomass and the major threats from cyanobacteria: toxins, taste and odors, and organic carbon
5. Fact sheets that build on existing fact sheets, alert level frameworks, and monitoring plans; a user friendly, web-based tool linked to a smart phone application (L. Janus)

WRF # 4422: On-Line NOM Characterization: Advanced Techniques for Controlling DBPs and for Monitoring Changes in NOM under Future Climate Change Scenarios

The objective of the project is to develop an effective on-line monitoring strategy and response system to detect changes in the character and amount of NOM (natural organic matter) and its associated DBP (disinfection by-products) precursor concentration that occurs (1) during current operating conditions, (2) during extreme weather events, and (3) under future climate change scenarios. The focus is on evaluating the ability of advanced on-line instrumentation utilizing UV absorbance spectral derivative measurements to detect changes in the concentration and characteristics of NOM associated with increased DBP formation potential. (Steven Schindler/ Bill Becker; Co-PIs)

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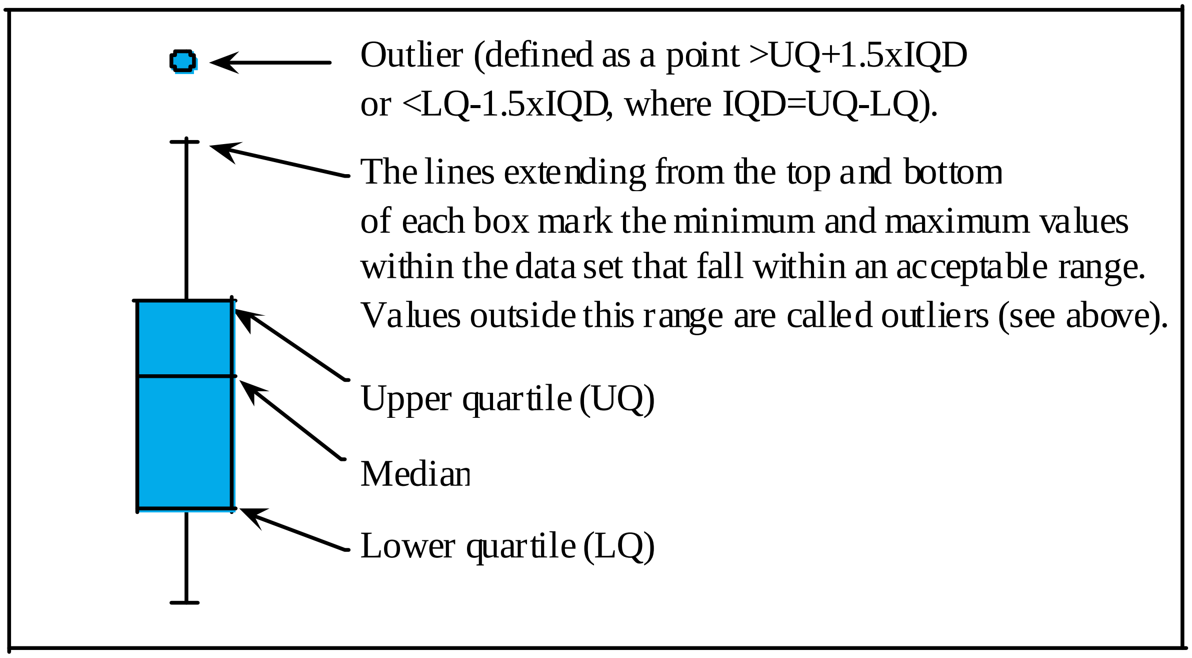
Appendix A. Key to Boxplots and Summary of Non-Detect Statistics Used in Data Analysis



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-12	5	14	0
Amawalk		May-12	5	14	0
Amawalk		Jun-12	5	18	0
Amawalk		Jul-12	5	<100	0
Amawalk		Aug-12	5	100	0
Amawalk		Sep-12	5	<1000	0
Amawalk		Oct-12	5	33	0
Amawalk		Nov-12	5	<50	0
Bog Brook	AA (50, 240)	Apr-12	6	8	0
Bog Brook		May-12	6	9	0
Bog Brook		Jun-12	6	TNTC	0
Bog Brook		Jul-12	5	80	20
Bog Brook		Aug-12	5	<200	0
Bog Brook		Sep-12	5	83	0
Bog Brook		Oct-12	5	40	0
Bog Brook		Nov-12	5	<100	0
Boyd Corners	AA (50, 240)	Apr-12	0		
Boyd Corners		May-12	6	160	33
Boyd Corners		Jun-12	6	91	0
Boyd Corners		Jul-12	5	<100	20
Boyd Corners		Aug-12	6	33	17
Boyd Corners		Sep-12	6	<100	0
Boyd Corners		Oct-12	7	100	29
Boyd Corners		Nov-12	5	<20	0
Croton Falls	A/AA (50, 240)	Apr-12	8	8	0
Croton Falls		May-12	8	12	0
Croton Falls		Jun-12	8	8	0
Croton Falls		Jul-12	8	TNTC	0
Croton Falls		Aug-12	8	TNTC	0
Croton Falls		Sep-12	6	<200	0
Croton Falls		Oct-12	8	<100	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-12	6	<50	0
Cross River	A/AA (50, 240)	Jan-12	6	12	0
Cross River		Apr-12	12	25	0
Cross River		May-12	6	16	0
Cross River		Jun-12	24	14	0
Cross River		Jul-12	6	77	17
Cross River		Aug-12	6	9	0
Cross River		Sep-12	6	50	0
Cross River		Oct-12	6	<20	0
Cross River		Nov-12	6	7	0
Diverting	AA (50, 240)	Apr-12	5	TNTC	0
Diverting		May-12	5	720	100
Diverting		Jun-12	5	750	100
Diverting		Jul-12	4	<5 samples/month	50
Diverting		Aug-12	5	920	100
Diverting		Sep-12	5	170	40
Diverting		Oct-12	5	<100	0
Diverting		Nov-12	5	67	20
East Branch	AA (50, 240)	Apr-12	6	<20	0
East Branch		May-12	6	58	0
East Branch		Jun-12	6	37.5	0
East Branch		Jul-12	6	TNTC	0
East Branch		Aug-12	6	<500	50
East Branch		Sep-12	5	140	20
East Branch		Oct-12	5	<100	0
East Branch		Nov-12	6	<100	0
Lake Gilead	A (2400, 5000)	Apr-12	5	4	0
Lake Gilead		May-12	5	<5	0
Lake Gilead		Jun-12	5	18	0
Lake Gilead		Jul-12	5	10	0
Lake Gilead		Aug-12	5	<200	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		Sep-12	5	<100	0
Lake Gilead		Oct-12	5	<50	0
Lake Gilead		Nov-12	5	<2	0
Lake Gleneida	AA (50, 240)	Apr-12	5	<5	0
Lake Gleneida		May-12	5	10	40
Lake Gleneida		Jun-12	5	9	0
Lake Gleneida		Jul-12	5	29	40
Lake Gleneida		Aug-12	5	<500	60
Lake Gleneida		Sep-12	5	10	0
Lake Gleneida		Oct-12	5	9	0
Lake Gleneida		Nov-12	5	<5	0
Kirk Lake	B (2400, 5000)	Apr-12	0		
Kirk Lake		May-12	5	<5	0
Kirk Lake		Jun-12	5	9	0
Kirk Lake		Jul-12	5	39	0
Kirk Lake		Aug-12	5	180	0
Kirk Lake		Sep-12	5	500	20
Kirk Lake		Oct-12	5	80	0
Kirk Lake		Nov-12	5	<20	0
Muscoot	A (2400, 5000)	Apr-12	6	21	0
Muscoot		May-12	7	33	0
Muscoot		Jun-12	7	2200	0
Muscoot		Jul-12	7	1050	0
Muscoot		Aug-12	7	270	29
Muscoot		Sep-12	7	80	0
Muscoot		Oct-12	6	80	0
Muscoot		Nov-12	6	40	0
Middle Branch	A (2400, 5000)	Apr-12	5	130	0
Middle Branch		May-12	5	25	0
Middle Branch		Jun-12	5	<20	0
Middle Branch		Jul-12	5	<20	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		Aug-12	5	19	0
Middle Branch		Sep-12	5	<200	0
Middle Branch		Oct-12	5	<200	0
Middle Branch		Nov-12	5	67	0
Titicus	AA (50, 240)	Apr-12	5	<10	0
Titicus		May-12	5	<10	0
Titicus		Jun-12	5	<10	0
Titicus		Jul-12	5	55	0
Titicus		Aug-12	5	18	20
Titicus		Sep-12	5	<100	20
Titicus		Oct-12	5	TNTC	0
Titicus		Nov-12	5	<100	0

[1] The reservoir class for each waterbody is set forth in 6 NYCRR Chapter X, Subchapter B. 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 2010a). The phosphorus-restricted designation 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 to 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 $\mu g\ L^{-1}$ (15 $\mu g\ L^{-1}$ 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	2007 $\mu g\ L^{-1}$	2008 $\mu g\ L^{-1}$	2009 $\mu g\ L^{-1}$	2010 $\mu g\ L^{-1}$	2011 $\mu g\ L^{-1}$	2012 $\mu g\ L^{-1}$
Delaware System						
Cannonsville Reservoir	14.0	13.5	14.0	16.4	16.3	12.4
Pepacton Reservoir	9.7	8.2	7.6	9.9	11.9	8.4
Neversink Reservoir	4.7	4.7	5.9	6.5	10.2	9.7
Catskill System						
Schoharie Reservoir	9.7	9.5	11.2	13.4	29.4	20.0
Croton System						
Amawalk Reservoir	20.2	17.9	19.4	20.5	18.3	22.3
Bog Brook Reservoir	24.0	21.5	22.8	31.1	23.6	27.9
Boyd Corners Reservoir	15.6	11.6	8.6	8.4	8.7	10.1
Diverting Reservoir	*	22.7	*	29.1	31.1	26.8
East Branch Reservoir	23.0	21.6	26.1	33.8	32.3	28.5
Middle Branch Reservoir	25.0	27.9	22.4	25.5	29.8	37.6
Muscoot Reservoir	25.7	27.6	24.9	28.7	28.8	31.5
Titicus Reservoir	21.6	17.5	20.8	26.4	26.9	24.4
Lake Gleneida	*	*	22.7	25.9	31.9	25.1
Lake Gilead	33.6	*	36.0	30.1	28.9	16.4
Kirk Lake	28.6	*	31.4	27.6	33.1	34.6
Source Waters						
Ashokan-West Reservoir	8.1	7.2	8.6	12.9	31.0	10.2
Ashokan-East Reservoir	7.5	7.6	9.5	9.8	13.5	8.4
Cross River Reservoir	17.8	13.8	13.8	15.4	18.7	17.0
Croton Falls Reservoir	*	14.4	14.7	13.3	20.6	18.7
Kensico Reservoir	7.0	6.4	5.8	6.6	7.5	6.4

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

Reservoir basin	2007 µg L^{-1}	2008 µg L^{-1}	2009 µg L^{-1}	2010 µg L^{-1}	2011 µg L^{-1}	2012 µg L^{-1}
New Croton Reservoir	17.7	15.5	14.4	15.7	18.2	18.7
Rondout Reservoir	7.1	6.1	8.1	8.0	8.9	7.2
West Branch Reservoir	9.6	9.2	9.6	9.4	11.1	11.8

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

Appendix D. Comparison of Reservoir Water Quality Results to Benchmarks

Appendix Table 3: Comparison of reservoir water quality results to benchmarks. 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	12
Chloride (mg L^{-1})	12	24	0	0	8	6.4
Chlorophyll a (µg L^{-1})	12	64	0	0	7	4
Color (Pt-Co units)	15	194	35	18	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	200	0	0	3	1.5
Fecal coliforms (FC $100mL^{-1}$)	20	200	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	200	0	0	0.3	0.17
pH (units)	6.5-8.5	188	30	16	na	na
Sodium, undig., filt. (mg L^{-1})	16	16	16	100	3	4.5
Soluble reactive phosphorus (µg L^{-1})	15	200	0	0	na	na
Sulfate (mg L^{-1})	15	24	0	0	10	4.8
Total ammonia-N (mg L^{-1})	0.10	200	2	1	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	200	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	201	2	1	40	41
Total phosphorus (µg L^{-1})	15	200	1	1	na	na
Total phytoplankton (ASU)	2000	96	0	0	na	na
Primary genus (ASU)	1000	96	1	1	na	na
Secondary genus (ASU)	1000	96	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	84	0	0	5	1.1
Turbidity (NTU)	5	202	0	0	na	na
Amawalk Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	82
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	1	6	10	9.5
Color (Pt-Co units)	15	40	40	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (FC $100mL^{-1}$)	20	40	4	10	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	9	23	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	40	40	100	150	294
Total phosphorus (µg L^{-1})	15	40	28	70	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	0	0	na	na

Appendix Table 3: (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]
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.2
Turbidity (NTU)	5	40	2	5	na	na
Bog Brook Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	8			>40	77
Chloride (mg L^{-1})	40	8	8	100	30	43.2
Chlorophyll a (µg L^{-1})	15	7	1	14	10	6.8
Color (Pt-Co units)	15	20	18	90	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	19	0	0	6	3.6
Fecal coliforms (FC 100mL^{-1})	20	43	1	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	19	0	0	0.3	0.13
pH (units)	6.5-8.5	37	4	11	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	23.8
Soluble reactive phosphorus (µg L^{-1})	15	19	1	5	na	na
Sulfate (mg L^{-1})	25	8	0	0	15	7.1
Total ammonia-N (mg L^{-1})	0.10	19	7	37	0.05	0.19
Total dissolved phosphorus (µg L^{-1})	15	19	5	26	na	na
Total dissolved solids (mg L^{-1})[3]	175	20	19	95	150	197
Total phosphorus (µg L^{-1})	15	22	15	68	na	na
Total phytoplankton (ASU)	2000	7	0	0	na	na
Primary genus (ASU)	1000	7	0	0	na	na
Secondary genus (ASU)	1000	7	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	8	0	0	5	2
Turbidity (NTU)	5	23	3	13	na	na
Boyd Corners Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	40
Chloride (mg L^{-1})	40	6	0	0	30	25.5
Chlorophyll a (µg L^{-1})	15	7	0	0	10	4.5
Color (Pt-Co units)	15	15	15	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	15	0	0	6	3.9
Fecal coliforms (FC 100mL^{-1})	20	41	6	15	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	15	0	0	0.3	0.03
pH (units)	6.5-8.5	41	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	17.8
Soluble reactive phosphorus (µg L^{-1})	15	15	0	0	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	6.7
Total ammonia-N (mg L^{-1})	0.10	15	1	7	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	15	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	15	0	0	150	118

Appendix Table 3: (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 (µg L^{-1})	15	15	1	7	na	na
Total phytoplankton (ASU)	2000	7	0	0	na	na
Primary genus (ASU)	1000	7	0	0	na	na
Secondary genus (ASU)	1000	7	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	1.2
Turbidity (NTU)	5	15	0	0	na	na
Croton Falls Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18			>40	73
Chloride (mg L^{-1})	40	18	18	100	30	57.3
Chlorophyll a (µg L^{-1})	15	21	8	38	10	13
Color (Pt-Co units)	15	60	58	97	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	60	0	0	6	3.2
Fecal coliforms (FC $100mL^{-1}$)	20	60	1	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	60	7	12	0.3	0.23
pH (units)	6.5-8.5	60	16	27	na	na
Sodium, undig., filt. (mg L^{-1})	20	18	18	100	15	32.7
Soluble reactive phosphorus (µg L^{-1})	15	60	0	0	na	na
Sulfate (mg L^{-1})	25	18	0	0	15	10
Total ammonia-N (mg L^{-1})	0.10	60	10	17	0.05	0.05
Total dissolved phosphorus (µg L^{-1})	15	60	2	3	na	na
Total dissolved solids (mg L^{-1})[3]	175	60	60	100	150	252
Total phosphorus (µg L^{-1})	15	60	45	75	na	na
Total phytoplankton (ASU)	2000	22	1	5	na	na
Primary genus (ASU)	1000	22	2	9	na	na
Secondary genus (ASU)	1000	22	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.9
Turbidity (NTU)	5	60	10	17	na	na
Cross River Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	49
Chloride (mg L^{-1})	40	9	0	0	30	29.5
Chlorophyll a (µg L^{-1})	15	15	2	13	10	9.6
Color (Pt-Co units)	15	48	48	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	48	0	0	6	3.3
Fecal coliforms (FC $100mL^{-1}$)	20	48	2	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	48	0	0	0.3	0.07
pH (units)	6.5-8.5	48	9	19	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	15.7
Soluble reactive phosphorus (µg L^{-1})	15	48	1	2	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	8.2

Appendix Table 3: (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	48	10	21	0.05	0.11
Total dissolved phosphorus (µg L^{-1})	15	48	4	8	na	na
Total dissolved solids (mg L^{-1})[3]	175	48	0	0	150	140
Total phosphorus (µg L^{-1})	15	48	34	71	na	na
Total phytoplankton (ASU)	2000	16	1	6	na	na
Primary genus (ASU)	1000	16	3	19	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	1.9
Turbidity (NTU)	5	48	4	8	na	na
Diverting Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	93
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	7	44	10	16.2
Color (Pt-Co units)	15	31	31	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	1	0	0	6	4.7
Fecal coliforms (FC 100mL^{-1})	20	39	13	33	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	35	4	11	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	31	31	100	150	235
Total phosphorus (µg L^{-1})	15	31	31	100	na	na
Total phytoplankton (ASU)	2000	16	0	0	na	na
Primary genus (ASU)	1000	16	0	0	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	3.8
Turbidity (NTU)	5	31	4	13	na	na
East Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	93
Chloride (mg L^{-1})	40	9	5	56	30	39.7
Chlorophyll a (µg L^{-1})	15	7	4	57	10	17.9
Color (Pt-Co units)	15	21	21	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	21	0	0	6	3.8
Fecal coliforms (FC 100mL^{-1})	20	46	1	2	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	21	0	0	0.3	0.05
pH (units)	6.5-8.5	40	3	8	na	na

Appendix Table 3: (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})	20	6	6	100	15	22.9
Soluble reactive phosphorus (µg L^{-1})	15	21	3	14	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	8.8
Total ammonia-N (mg L^{-1})	0.10	21	5	24	0.05	0.08
Total dissolved phosphorus (µg L^{-1})	15	21	4	19	na	na
Total dissolved solids (mg L^{-1})[3]	175	21	21	100	150	213
Total phosphorus (µg L^{-1})	15	24	19	79	na	na
Total phytoplankton (ASU)	2000	7	1	14	na	na
Primary genus (ASU)	1000	7	1	14	na	na
Secondary genus (ASU)	1000	7	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.6
Turbidity (NTU)	5	24	4	17	na	na
Lake Gilead						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	42
Chloride (mg L^{-1})	40	9	9	100	30	41
Chlorophyll a (µg L^{-1})	15	3	0	0	10	6
Color (Pt-Co units)	15	9	2	22	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	2.9
Fecal coliforms (FC 100mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	0.09
pH (units)	6.5-8.5	10	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	21.8
Soluble reactive phosphorus (µg L^{-1})	15	9	1	11	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7.3
Total ammonia-N (mg L^{-1})	0.10	9	1	11	0.05	0.09
Total dissolved phosphorus (µg L^{-1})	15	9	1	11	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	0	0	150	158
Total phosphorus (µg L^{-1})	15	9	6	67	na	na
Total phytoplankton (ASU)	2000	3	0	0	na	na
Primary genus (ASU)	1000	3	0	0	na	na
Secondary genus (ASU)	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.3
Turbidity (NTU)	5	9	0	0	na	na
Lake Gleneida						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	69
Chloride (mg L^{-1})	40	9	9	100	30	94.3
Chlorophyll a (µg L^{-1})	15	3	0	0	10	5
Color (Pt-Co units)	15	9	2	22	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	2.8

Appendix Table 3: (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]
Fecal coliforms (FC 100mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	
pH (units)	6.5-8.5	10	2	20	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	50.3
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	6.4
Total ammonia-N (mg L^{-1})	0.10	9	2	22	0.05	0.18
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	9	100	150	305
Total phosphorus (µg L^{-1})	15	9	6	67	na	na
Total phytoplankton (ASU)	2000	3	0	0	na	na
Primary genus (ASU)	1000	3	0	0	na	na
Secondary genus (ASU)	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.6
Turbidity (NTU)	5	9	0	0	na	na
Kirk Lake						
Alkalinity (mg $CaCO_3$ L^{-1})	na	4			>40	58
Chloride (mg L^{-1})	40	4	4	100	30	49.2
Chlorophyll a (µg L^{-1})	15	3	1	33	10	12.8
Color (Pt-Co units)	15	4	4	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	4	0	0	6	4.7
Fecal coliforms (FC 100mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	4	0	0	0.3	0.05
pH (units)	6.5-8.5	10	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	20	4	4	100	15	26.6
Soluble reactive phosphorus (µg L^{-1})	15	4	0	0	na	na
Sulfate (mg L^{-1})	25	4	0	0	15	9
Total ammonia-N (mg L^{-1})	0.10	4	1	25	0.05	0.07
Total dissolved phosphorus (µg L^{-1})	15	4	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	4	2	50	150	182
Total phosphorus (µg L^{-1})	15	4	4	100	na	na
Total phytoplankton (ASU)	2000	3	0	0	na	na
Primary genus (ASU)	1000	3	1	33	na	na
Secondary genus (ASU)	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	4	1	25	5	4.6
Turbidity (NTU)	5	4	2	50	na	na
Muscoot Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	81
Chloride (mg L^{-1})	40	6	6	100	30	54.1

Appendix Table 3: (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]
Chlorophyll a (µg L^{-1})	15	32	13	41	10	25.9
Color (Pt-Co units)	15	53	53	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	53	0	0	6	3.8
Fecal coliforms (FC 100mL^{-1})	20	53	6	11	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	53	5	9	0.3	0.2
pH (units)	6.5-8.5	46	4	9	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	30.7
Soluble reactive phosphorus (µg L^{-1})	15	53	1	2	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	8.6
Total ammonia-N (mg L^{-1})	0.10	53	10	19	0.05	0.1
Total dissolved phosphorus (µg L^{-1})	15	53	4	8	na	na
Total dissolved solids (mg L^{-1})[3]	175	53	53	100	150	233
Total phosphorus (µg L^{-1})	15	53	51	96	na	na
Total phytoplankton (ASU)	2000	32	9	28	na	na
Primary genus (ASU)	1000	32	9	28	na	na
Secondary genus (ASU)	1000	31	2	6	na	na
Total suspended solids (mg L^{-1})	8.0	6	1	17	5	4.1
Turbidity (NTU)	5	53	10	19	na	na
Middle Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	70
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	9	56	10	14.9
Color (Pt-Co units)	15	40	40	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (FC 100mL^{-1})	20	40	1	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	35	7	20	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	40	40	100	150	255
Total phosphorus (µg L^{-1})	15	40	36	90	na	na
Total phytoplankton (ASU)	2000	16	1	6	na	na
Primary genus (ASU)	1000	16	1	6	na	na
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.3
Turbidity (NTU)	5	40	4	10	na	na

Appendix Table 3: (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]
New Croton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	30			>40	71
Chloride (mg L^{-1})	40	29	29	100	30	53.9
Chlorophyll a (µg L^{-1})	15	56	13	23	10	13.7
Color (Pt-Co units)	15	168	158	94	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	167	0	0	6	3.2
Fecal coliforms (FC 100mL^{-1})	20	168	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	167	19	11	0.3	0.23
pH (units)	6.5-8.5	147	22	15	na	na
Sodium, undig., filt. (mg L^{-1})	20	27	27	100	15	29.9
Soluble reactive phosphorus (µg L^{-1})	15	167	5	3	na	na
Sulfate (mg L^{-1})	25	29	0	0	15	10.2
Total ammonia-N (mg L^{-1})	0.10	167	29	17	0.05	0.08
Total dissolved phosphorus (µg L^{-1})	15	167	13	8	na	na
Total dissolved solids (mg L^{-1})[3]	175	168	168	100	150	224
Total phosphorus (µg L^{-1})	15	168	99	59	na	na
Total phytoplankton (ASU)	2000	64	6	9	na	na
Primary genus (ASU)	1000	64	8	13	na	na
Secondary genus (ASU)	1000	64	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	53	0	0	5	1.6
Turbidity (NTU)	5	168	15	9	na	na
Titicus Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	75
Chloride (mg L^{-1})	40	0			30	
Chlorophyll a (µg L^{-1})	15	16	3	19	10	11.3
Color (Pt-Co units)	15	32	32	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (FC 100mL^{-1})	20	39	2	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	39	10	26	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	32	14	44	150	174
Total phosphorus (µg L^{-1})	15	32	26	81	na	na
Total phytoplankton (ASU)	2000	16	2	13	na	na
Primary genus (ASU)	1000	16	2	13	na	na

Appendix Table 3: (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]
Secondary genus (ASU)	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.5
Turbidity (NTU)	5	32	5	16	na	na
West Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	25
Chloride (mg L^{-1})	12	12	11	92	8	16.4
Chlorophyll a (µg L^{-1})	12	32	4	13	7	7.4
Color (Pt-Co units)	15	61	45	74	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	61	0	0	3	2.3
Fecal coliforms (FC $100mL^{-1}$)	20	61	4	7	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	61	0	0	0.3	0.05
pH (units)	6.5-8.5	53	4	8	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	10.7
Soluble reactive phosphorus (µg L^{-1})	15	61	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	5.6
Total ammonia-N (mg L^{-1})	0.10	61	0	0	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	61	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	61	59	97	40	74
Total phosphorus (µg L^{-1})	15	61	17	28	na	na
Total phytoplankton (ASU)	2000	39	2	5	na	na
Primary genus (ASU)	1000	39	4	10	na	na
Secondary genus (ASU)	1000	39	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	1.9
Turbidity (NTU)	5	61	0	0	na	na
Ashokan East Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	12
Chloride (mg L^{-1})	12	9	0	0	8	4.3
Chlorophyll a (µg L^{-1})	12	24	0	0	7	2.4
Color (Pt-Co units)	15	63	2	3	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	64	0	0	3	1.5
Fecal coliforms (FC $100mL^{-1}$)	20	64	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	0	0	0.3	0.12
pH (units)	6.5-8.5	56	16	29	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	7	78	3	3.2
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	65	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	64	0	0	40	33

Appendix Table 3: (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 (µg L^{-1})	15	64	8	13	na	na
Total phytoplankton (ASU)	2000	40	0	0	na	na
Primary genus (ASU)	1000	40	0	0	na	na
Secondary genus (ASU)	1000	40	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	64	7	11	5	3.5
Turbidity (NTU)	5	64	27	42	na	na
Ashokan West Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	14
Chloride (mg L^{-1})	12	12	0	0	8	4.6
Chlorophyll a (µg L^{-1})	12	24	0	0	7	1.7
Color (Pt-Co units)	15	69	9	13	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	77	0	0	3	1.4
Fecal coliforms (FC 100mL^{-1})	20	77	8	10	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	77	0	0	0.3	0.24
pH (units)	6.5-8.5	77	9	12	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	3.3
Soluble reactive phosphorus (µg L^{-1})	15	77	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.10	77	0	0	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	77	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	77	2	3	40	38
Total phosphorus (µg L^{-1})	15	77	17	22	na	na
Total phytoplankton (ASU)	2000	40	0	0	na	na
Primary genus (ASU)	1000	39	0	0	na	na
Secondary genus (ASU)	1000	39	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	77	22	29	5	7.7
Turbidity (NTU)	5	77	59	77	na	na
Pepacton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	21			>10	14
Chloride (mg L^{-1})	12	21	0	0	8	5.6
Chlorophyll a (µg L^{-1})	12	40	1	3	7	3.5
Color (Pt-Co units)	15	120	11	9	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	120	0	0	3	1.6
Fecal coliforms (FC 100mL^{-1})	20	120	5	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	120	0	0	0.3	0.16
pH (units)	6.5-8.5	120	33	28	na	na
Sodium, undig., filt. (mg L^{-1})	16	21	21	100	3	3.8
Soluble reactive phosphorus (µg L^{-1})	15	120	0	0	na	na
Sulfate (mg L^{-1})	15	14	0	0	10	4.3

Appendix Table 3: (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	120	2	2	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	120	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	120	1	1	40	40
Total phosphorus (µg L^{-1})	15	120	16	13	na	na
Total phytoplankton (ASU)	2000	59	0	0	na	na
Primary genus (ASU)	1000	59	1	2	na	na
Secondary genus (ASU)	1000	59	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	59	0	0	5	1.5
Turbidity (NTU)	5	120	11	9	na	na
Neversink Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	11			>10	3
Chloride (mg L^{-1})	12	11	0	0	8	2.7
Chlorophyll a (µg L^{-1})	12	24	0	0	7	2.7
Color (Pt-Co units)	15	95	39	41	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	71	1	1	3	2.1
Fecal coliforms (FC 100mL^{-1})	20	95	7	7	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	71	0	0	0.3	0.22
pH (units)	6.5-8.5	95	70	74	na	na
Sodium, undig., filt. (mg L^{-1})	16	11	0	0	3	1.7
Soluble reactive phosphorus (µg L^{-1})	15	71	0	0	na	na
Sulfate (mg L^{-1})	15	11	0	0	10	3.3
Total ammonia-N (mg L^{-1})	0.10	71	1	1	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	71	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	95	0	0	40	18
Total phosphorus (µg L^{-1})	15	71	12	17	na	na
Total phytoplankton (ASU)	2000	48	0	0	na	na
Primary genus (ASU)	1000	48	0	0	na	na
Secondary genus (ASU)	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	24	2	8	5	2.9
Turbidity (NTU)	5	95	34	36	na	na
Rondout Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	11
Chloride (mg L^{-1})	12	12	0	0	8	5.9
Chlorophyll a (µg L^{-1})	12	24	0	0	7	2.9
Color (Pt-Co units)	15	80	4	5	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.6
Fecal coliforms (FC 100mL^{-1})	20	79	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	56	0	0	0.3	0.2
pH (units)	6.5-8.5	80	13	16	na	na

Appendix Table 3: (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	12	100	3	4
Soluble reactive phosphorus (µg L^{-1})	15	56	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	4.4
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	36
Total phosphorus (µg L^{-1})	15	80	0	0	na	na
Total phytoplankton (ASU)	2000	48	0	0	na	na
Primary genus (ASU)	1000	48	0	0	na	na
Secondary genus (ASU)	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	32	0	0	5	1.2
Turbidity (NTU)	5	80	0	0	na	na
Schoharie Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	21
Chloride (mg L^{-1})	12	9	0	0	8	7.1
Chlorophyll a (µg L^{-1})	12	31	0	0	7	1.7
Color (Pt-Co units)	15	43	24	56	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	87	2	2	3	2.2
Fecal coliforms (FC $100mL^{-1}$)	20	87	28	32	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	64	3	5	0.3	0.25
pH (units)	6.5-8.5	88	0	0	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	5
Soluble reactive phosphorus (µg L^{-1})	15	64	1	2	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	4.2
Total ammonia-N (mg L^{-1})	0.10	64	0	0	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	64	1	2	na	na
Total dissolved solids (mg L^{-1})[3]	50	87	64	74	40	54
Total phosphorus (µg L^{-1})	15	87	68	78	na	na
Total phytoplankton (ASU)	2000	47	0	0	na	na
Primary genus (ASU)	1000	46	0	0	na	na
Secondary genus (ASU)	1000	46	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	87	48	55	5	21.5
Turbidity (NTU)	5	87	79	91	na	na
Cannonsville Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	17			>10	18
Chloride (mg L^{-1})	12	17	0	0	8	9.9
Chlorophyll a (µg L^{-1})	12	35	2	6	7	5.1
Color (Pt-Co units)	15	110	22	20	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	110	0	0	3	1.6

Appendix Table 3: (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]
Fecal coliforms (FC $100mL^{-1}$)	20	110	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	110	8	7	0.3	0.28
pH (units)	6.5-8.5	104	24	23	na	na
Sodium, undig., filt. (mg L^{-1})	16	17	17	100	3	7
Soluble reactive phosphorus (µg L^{-1})	15	110	0	0	na	na
Sulfate (mg L^{-1})	15	17	0	0	10	5.5
Total ammonia-N (mg L^{-1})	0.10	110	3	3	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	111	1	1	na	na
Total dissolved solids (mg L^{-1})[3]	50	110	95	86	40	57
Total phosphorus (µg L^{-1})	15	110	34	31	na	na
Total phytoplankton (ASU)	2000	56	2	4	na	na
Primary genus (ASU)	1000	56	8	14	na	na
Secondary genus (ASU)	1000	56	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	48	1	2	5	1.8
Turbidity (NTU)	5	110	12	11	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 non-detects 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 4: Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
E10I (Bushkill inflow to Ashokan)						
Alkalinity (mg L^{-1})	≥10.0	12	9	75	na	8.9
Chloride (mg L^{-1})	50	12	0	0	10	1.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	0.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.16
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	12	0	0	40	24
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.3
E16I (Esopus Creek at Coldbrook)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	17.3
Chloride (mg L^{-1})	50	12	0	0	10	6.8
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	4.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	5	42	40	47
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.9
E5 (Esopus Creek at Allaben)						
Alkalinity (mg L^{-1})	≥10.0	12	6	50	na	12.4
Chloride (mg L^{-1})	50	12	0	0	10	5.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.20
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	4	33	40	35
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.8

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
S5I (Schoharie Creek at Prattsville)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	25.8
Chloride (mg L^{-1})	50	12	0	0	10	10.7
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.26
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	12	100	40	67
Dissolved sodium (mg L^{-1})	10	4	0	0	5	7.1
S6I (Bear Creek at Hardenburgh Falls)						
Alkalinity (mg L^{-1})	≥10.0	11	0	0	na	32.8
Chloride (mg L^{-1})	50	11	0	0	10	19.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.45
Sulfate (mg L^{-1})	15	4	0	0	10	8.0
Total ammonia-N (mg L^{-1})	0.20	11	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	11	11	100	40	102
Dissolved sodium (mg L^{-1})	10	4	1	25	5	10.5
S7I (Manor Kill)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	32.4
Chloride (mg L^{-1})	50	12	0	0	10	7.5
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.12
Sulfate (mg L^{-1})	15	4	0	0	10	5.7
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	11	10	91	40	66
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.2

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
SRR2CM (Schoharie Reservoir Diversion)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	21.5
Chloride (mg L^{-1})	50	13	0	0	10	9.2
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	13	0	0	0.40	0.28
Sulfate (mg L^{-1})	15	5	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	13	9	69	40	58
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.3
C-7 (Trout Creek above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	16.4
Chloride (mg L^{-1})	50	12	0	0	10	14.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.29
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	11	92	40	62
Dissolved sodium (mg L^{-1})	10	4	0	0	5	7.5
C-8 (Loomis Brook above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	16.0
Chloride (mg L^{-1})	50	12	0	0	10	13.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.25
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	8	67	40	59
Dissolved sodium (mg L^{-1})	10	4	1	25	5	7.1

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
NCG (Neversink Reservoir near Claryville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	3.9
Chloride (mg L^{-1})	50	12	0	0	10	2.8
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.30
Sulfate (mg L^{-1})	15	4	0	0	10	3.5
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	19
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.8
NK4 (Aden Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	6.1
Chloride (mg L^{-1})	50	12	0	0	10	3.6
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.18
Sulfate (mg L^{-1})	15	4	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	24
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.0
NK6 (Kramer Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	7	58	na	10.7
Chloride (mg L^{-1})	50	12	0	0	10	26.3
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	2.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.26
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.05
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	81
Dissolved sodium (mg L^{-1})	10	4	4	100	5	14.9

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
P-13 (Tremper Kill above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	18.7
Chloride (mg L^{-1})	50	12	0	0	10	9.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.30
Sulfate (mg L^{-1})	15	4	0	0	10	5.3
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	55
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.0
P-21 (Platte Kill at Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	19.6
Chloride (mg L^{-1})	50	12	0	0	10	7.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.28
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	5	42	40	50
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.0
P-60 (Mill Brook near Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	5	42	na	12.1
Chloride (mg L^{-1})	50	12	0	0	10	1.6
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	0.33
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	28
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.2

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
P-7 (Terry Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	15.5
Chloride (mg L^{-1})	50	12	0	0	10	1.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.36
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	0	0	40	33
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.4
P-8 (Fall Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	14.7
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	0.38
Sulfate (mg L^{-1})	15	4	0	0	10	5.4
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	34
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.9
PMSB (East Branch Delaware River near Margaretville)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	20.8
Chloride (mg L^{-1})	50	12	0	0	10	9.9
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	0.37
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	7	58	40	57
Dissolved sodium (mg L^{-1})	10	4	1	25	5	7.3

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
RD1 (Sugarloaf Brook near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	5.3
Chloride (mg L^{-1})	50	12	0	0	10	5.1
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.18
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	27
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.1
RD4 (Sawkill Brook near Yagerville)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	5.4
Chloride (mg L^{-1})	50	12	0	0	10	5.3
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.07
Sulfate (mg L^{-1})	15	4	0	0	10	4.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	28
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.7
RDOA (Rondout Creek near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	12	12	100	na	4.3
Chloride (mg L^{-1})	50	12	0	0	10	3.0
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	0.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.25
Sulfate (mg L^{-1})	15	4	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.03
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	21
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.9

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
RGB (Chestnut Creek below Grahamsville STP)						
Alkalinity (mg L^{-1})	≥10.0	12	9	75	na	8.5
Chloride (mg L^{-1})	50	12	0	0	10	11.7
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	2.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.34
Sulfate (mg L^{-1})	15	4	0	0	10	5.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	4	33	40	47
Dissolved sodium (mg L^{-1})	10	4	1	25	5	7.7
WDBN (West Branch Delaware River at Beerston Bridge)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	20.8
Chloride (mg L^{-1})	50	12	0	0	10	12.9
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	0.56
Sulfate (mg L^{-1})	15	4	0	0	10	6.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.02
Total dissolved solids (mg L^{-1})[2]	50	12	9	75	40	67
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.0
AMAWALKR (Amawalk Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	78.9
Chloride (mg L^{-1})	100	12	0	0	35	81.4
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	0.18
Sulfate (mg L^{-1})	25	5	0	0	15	9.5
Total ammonia-N (mg L^{-1})	0.20	12	1	8	0.10	0.06
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	289
Dissolved sodium (mg L^{-1})	20	4	4	100	15	44.5

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	89.3
Chloride (mg L^{-1})	100	12	0	0	35	42.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.12
Sulfate (mg L^{-1})	25	5	0	0	15	9.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.06
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	219
Dissolved sodium (mg L^{-1})	20	3	3	100	15	24.2
BOYDR (Boyd Corners Release)						
Alkalinity (mg L^{-1})	≥40.0	12	4	33	na	39.9
Chloride (mg L^{-1})	100	12	0	0	35	25.8
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	3.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.11
Sulfate (mg L^{-1})	25	4	0	0	15	7.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.05
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	120
Dissolved sodium (mg L^{-1})	20	4	0	0	15	17.2
CROFALLSR (Croton Falls Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	64.5
Chloride (mg L^{-1})	100	12	0	0	35	51.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.1
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.14
Sulfate (mg L^{-1})	25	5	0	0	15	9.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	210
Dissolved sodium (mg L^{-1})	20	3	3	100	15	30.1

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
CROSS2 (Cross River near Cross River Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	58.8
Chloride (mg L^{-1})	100	12	0	0	35	32.3
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.8
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.13
Sulfate (mg L^{-1})	25	5	0	0	15	8.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.01
Total dissolved solids (mg L^{-1})[2]	175	11	1	9	150	159
Dissolved sodium (mg L^{-1})	20	4	0	0	15	17.1
CROSSRVR (Cross River Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	48.0
Chloride (mg L^{-1})	100	12	0	0	35	28.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.10
Sulfate (mg L^{-1})	25	5	0	0	15	8.0
Total ammonia-N (mg L^{-1})	0.20	12	1	8	0.10	0.09
Total dissolved solids (mg L^{-1})[2]	175	12	1	8	150	142
Dissolved sodium (mg L^{-1})	20	4	0	0	15	15.7
DIVERTR (Diverting Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	88.4
Chloride (mg L^{-1})	100	12	0	0	35	47.8
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	0.17
Sulfate (mg L^{-1})	25	5	0	0	15	10.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.05
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	230
Dissolved sodium (mg L^{-1})	20	3	3	100	15	28.4

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
EASTBR (East Branch Croton River above East Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	104.0
Chloride (mg L^{-1})	100	12	0	0	35	36.4
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	0.08
Sulfate (mg L^{-1})	25	5	0	0	15	10.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.03
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	223
Dissolved sodium (mg L^{-1})	20	3	3	100	15	23.4
GYPSYTRL1 (Gypsy Trail Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	10	83	na	33.4
Chloride (mg L^{-1})	100	12	0	0	35	22.1
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	4.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.07
Sulfate (mg L^{-1})	25	4	0	0	15	5.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	102
Dissolved sodium (mg L^{-1})	20	4	0	0	15	14.4
HORSEPD12 (Horse Pound Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	4	33	na	45.9
Chloride (mg L^{-1})	100	12	0	0	35	32.2
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	3.0
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.32
Sulfate (mg L^{-1})	25	4	0	0	15	8.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	1	8	150	145
Dissolved sodium (mg L^{-1})	20	4	2	50	15	20.0

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
KISCO3 (Kisco River above New Croton Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	82.1
Chloride (mg L^{-1})	100	12	0	0	35	67.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.56
Sulfate (mg L^{-1})	25	5	0	0	15	15.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	11	92	150	274
Dissolved sodium (mg L^{-1})	20	4	4	100	15	36.0
LONGPD1 (Long Pond outflow above West Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	57.5
Chloride (mg L^{-1})	100	12	0	0	35	51.1
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	3.9
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.19
Sulfate (mg L^{-1})	25	4	0	0	15	8.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	200
Dissolved sodium (mg L^{-1})	20	4	4	100	15	29.0
MIKE2 (Michael Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	96.2
Chloride (mg L^{-1})	100	12	11	92	35	149.8
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	3.7
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	10	83	0.35	4.10
Sulfate (mg L^{-1})	25	4	0	0	15	20.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	495
Dissolved sodium (mg L^{-1})	20	4	4	100	15	83.8

Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
MUSCOOT10 (Muscoot River above Amawalk Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	95.1
Chloride (mg L^{-1})	100	12	5	42	35	102.8
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	4.5
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.82
Sulfate (mg L^{-1})	25	4	0	0	15	11.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.05
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	366
Dissolved sodium (mg L^{-1})	20	4	4	100	15	52.9
TITICUSR (Titicus Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	79.9
Chloride (mg L^{-1})	100	12	0	0	35	34.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.4
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.18
Sulfate (mg L^{-1})	25	5	0	0	15	9.3
Total ammonia-N (mg L^{-1})	0.20	12	2	17	0.10	0.08
Total dissolved solids (mg L^{-1})[2]	175	12	8	67	150	188
Dissolved sodium (mg L^{-1})	20	3	1	33	15	18.6
WESTBR7 (West Branch Croton River above Boyd Corners Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	9	75	na	37.3
Chloride (mg L^{-1})	100	12	0	0	35	21.9
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	5.2
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.05
Sulfate (mg L^{-1})	25	4	0	0	15	5.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	106
Dissolved sodium (mg L^{-1})	20	4	0	0	15	15.7

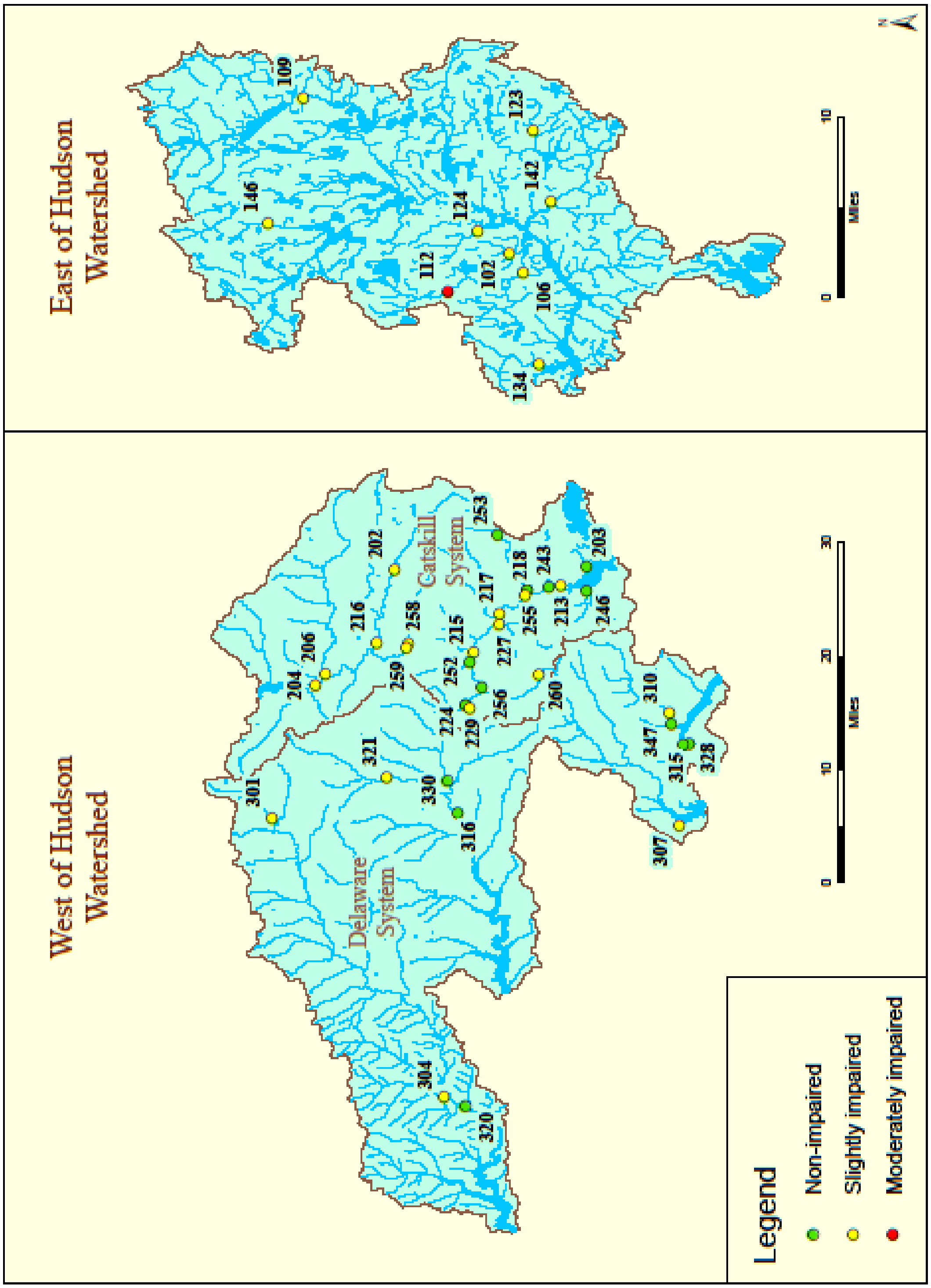
Appendix Table 4: (Continued) Comparison of stream water quality results to benchmarks. na = not applicable.

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2012 Mean[1]
WESTBRR (West Branch Reservoir Release)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	24.1
Chloride (mg L^{-1})	50	11	0	0	10	14.1
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	2.3
Nitrate+Nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.09
Sulfate (mg L^{-1})	15	3	0	0	10	5.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.05	0.09
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	72
Dissolved sodium (mg L^{-1})	10	4	2	50	5	9.3

[1] Means estimated using Kaplan-Meier method as described in Helsel (2005). In cases where the number of non-detects 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.