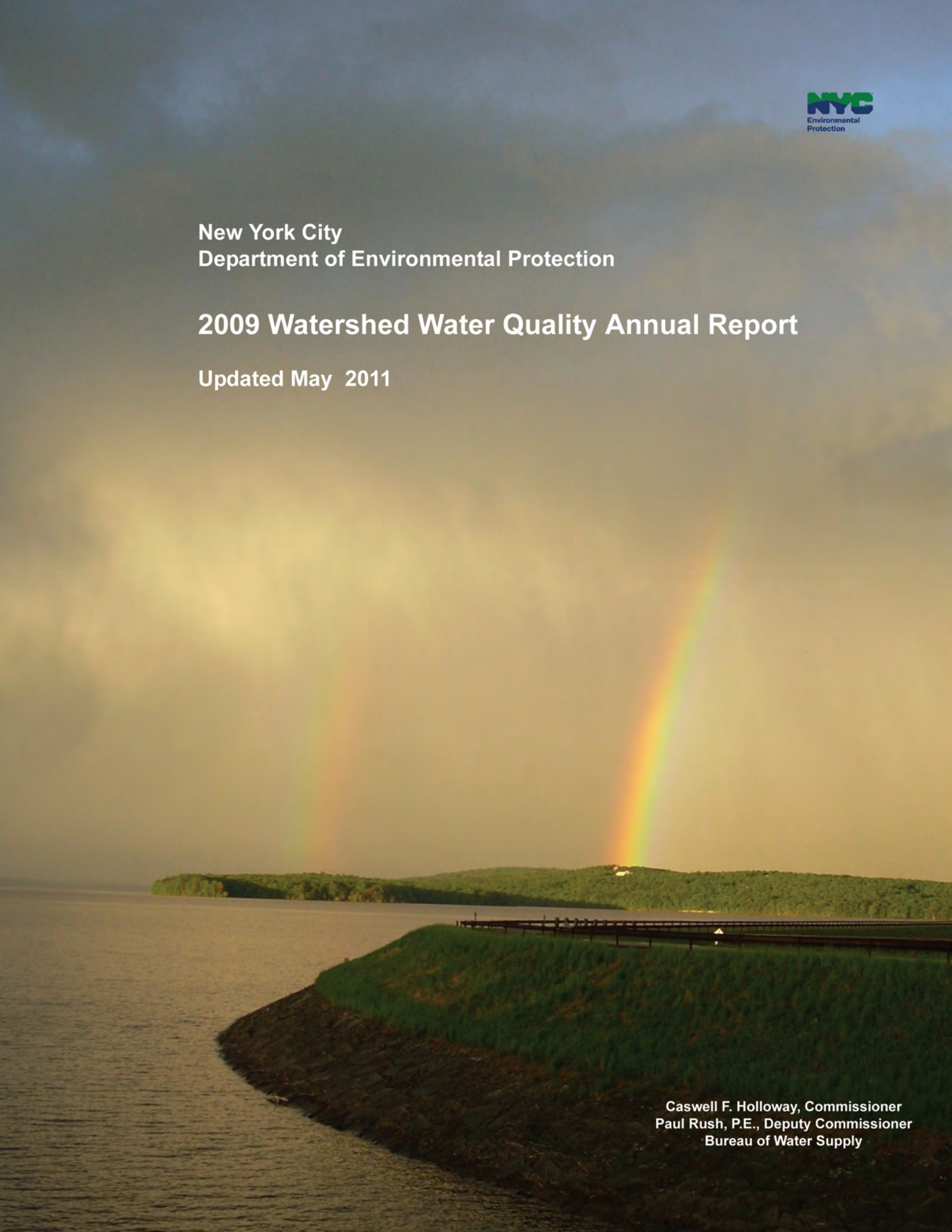

New York City
Department of Environmental Protection

2009 Watershed Water Quality Annual Report

Updated May 2011

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Bureau of Water Supply

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Acknowledgements

This report is intended to provide an accurate description of the scientific work conducted in 2009 to manage water quality for NYC, and at the same time to be engaging for a wide audience, from regulatory agencies to the general public. The Deputy Commissioner of the Bureau of Water Supply, Mr. Paul Rush, provided guidance for the Bureau throughout 2009 with emphasis on accountability and compliance. Mr. Steven Schindler, Director of the Water Quality Directorate (WQD), continued to provide general direction. Dr. Lorraine Janus, Chief of Watershed Water Quality Science and Research, provided the oversight for planning the content, data analysis, and production of this report. Ms. Lori Emery, Chief of Watershed Water Quality Operations, provided oversight of the sections devoted to watershed field and lab, quality assurance, environmental health and safety, and database management.

Leading authorship roles were taken by the members of the Watershed Water Quality Science and Research Division. Dr. Lorraine Janus was responsible for overall organization of the report and Chapter 1. Mr. James Mayfield was responsible as lead author for Chapter 2 on hydrology. He was also responsible for oversight of Chapter 3 and Chapter 5. The lead authors of Chapter 3 were Mr. Gerry Marzec and Mr. Rich VanDreason. Ms. Kerri Alderisio, Section Chief of Pathogen Planning and Assessment, was responsible for the direction of programs and as lead author for the pathogen research in Chapter 4, aided by Mr. Christian Pace. Mr. Steve DiLonardo took responsibility as lead author for the diverse aspects of watershed management in Chapter 5. Dr. Don Pierson, Dr. Elliot Schneiderman, and Mr. Mark Zion were authors of sections describing model development and applications in Chapter 6. Mr. Martin Rosenfeld was the primary author of future research described in Chapter 7. Ms. Pat Girard, Supervisor of Reporting and Publications, was responsible for desktop publishing of the report, aided by Mr. Martin Rosenfeld, who applied his editing and proofreading skills to finalize the document in a polished form. Other contributors included: Tracy Lawrence, Andrew Bader, Christopher Nadareski, David Quentin, Ray Homolac, Sharon Neuman, Donald Kent, David Lounsbury, Kelly Seelbach, Yucel Tokuz, Adao Matonse, Anandhi Aavudai, Rajith Mukundan, Soni Pradhanang, Matthew Giannetta, Barbara Dibeler, Michael J. Meyer, Brenda Drake, Robert Ravallo, Kimberlee Kane, Deborah Layton, James Broderick, Jeffrey Hurley, Aspa Capetanakis, Michael L. Usai.

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Special thanks to Aron Thomas of DEP for the cover photo taken at the dividing weir of the Ashokan Reservoir looking over the East Basin.

Errata Sheet Issued May 4, 2011

This errata sheet provides updated maps required for the 2009 Watershed Water Quality Annual Report, which was submitted as a Filtration Avoidance Determination deliverable to USEPA and NYSDOH on July 31, 2010. Where construction activities require DEP review and approval of a Stormwater Pollution Prevention Plan in accordance with the New York City Watershed Regulations, these maps are used in the design of stormwater management practices and are available in Chapter 4 of the New York State Stormwater Management Design Manual (issued Aug. 2010) or online at http://www.dec.ny.gov/docs/water_pdf/swdm2010chptr4.pdf .

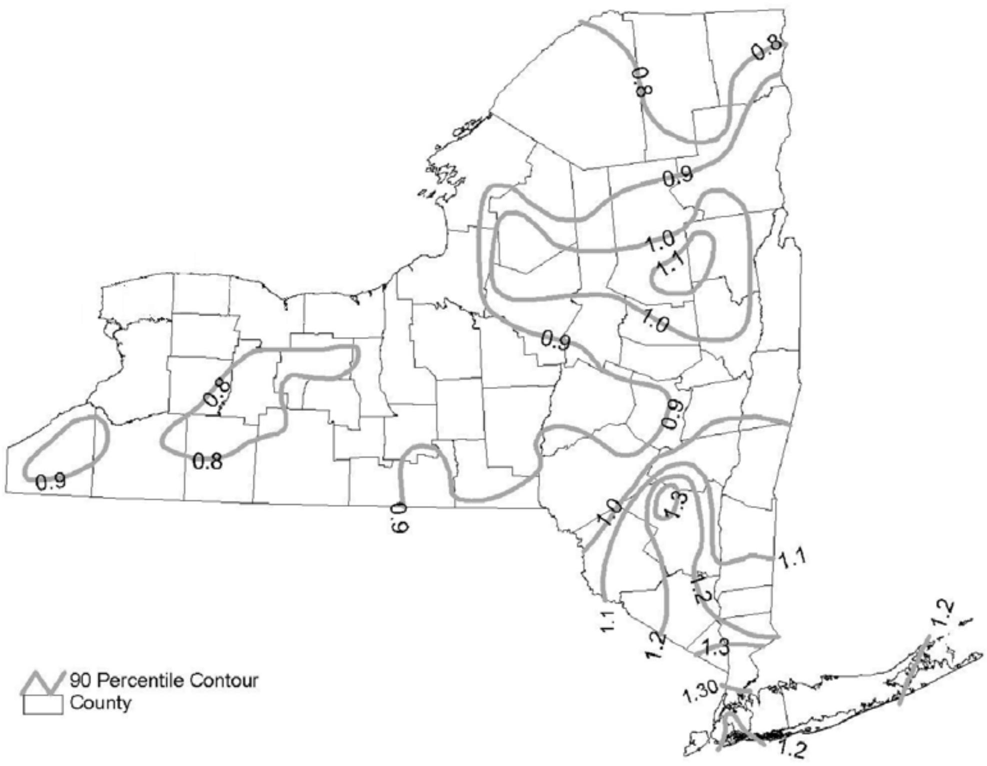

Figure 4.1 90% Rainfall in New York State (NYSDEC, 2000)

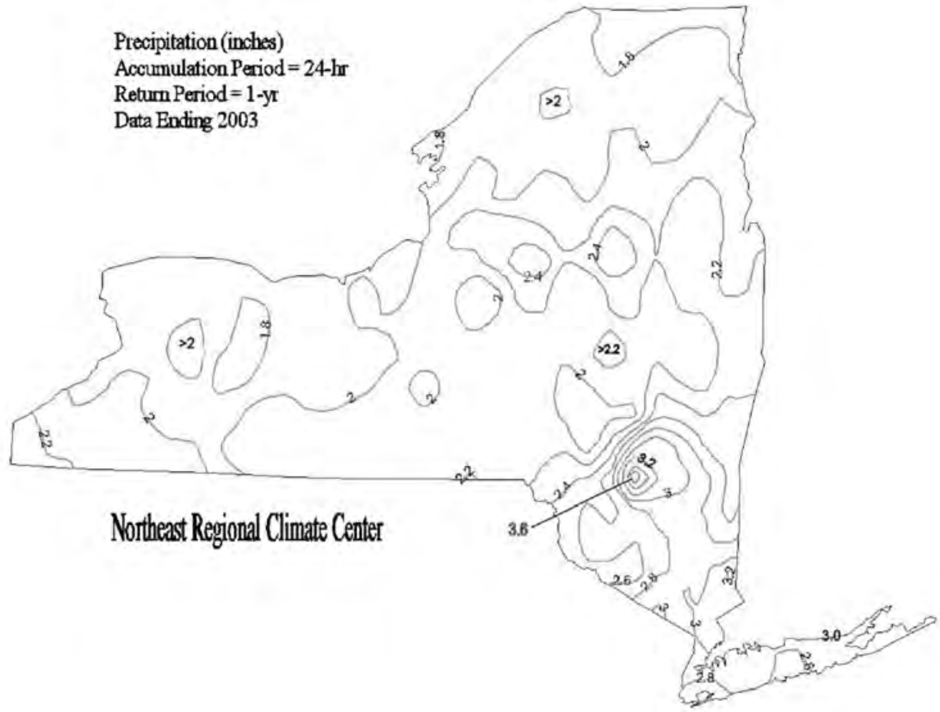

Figure 4.2 One-Year Design Storm

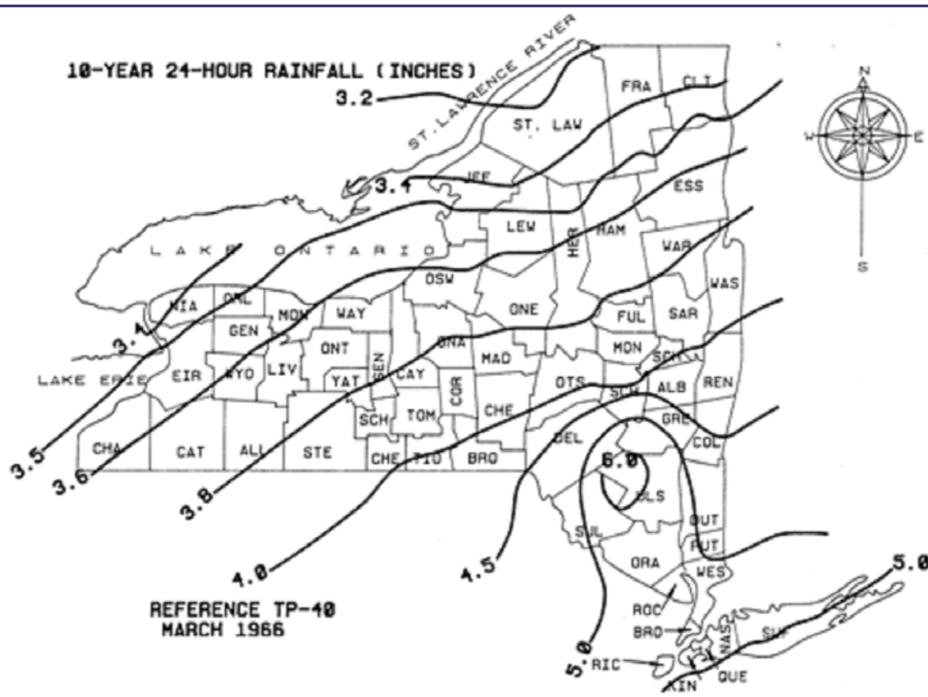

Figure 4.3 10-Year Design Storm

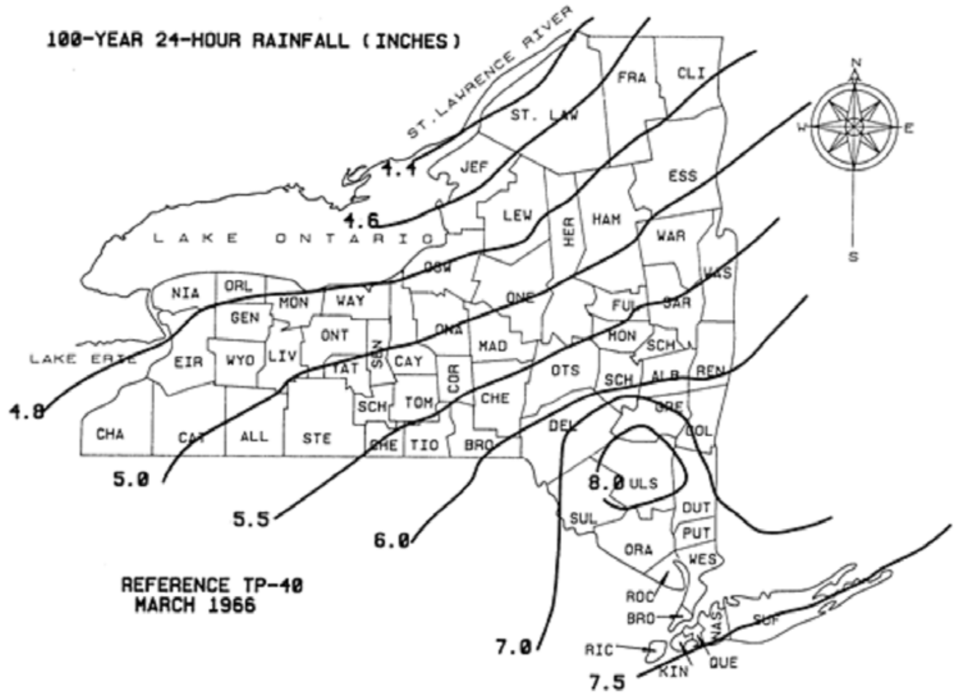

Figure 4.4 100-Year Design Storm

1. Introduction

1.1 What is the purpose and scope of this report?

Figure 1.1 The DEP website at http://www.nyc.gov/dep/

This report provides summary information about the watersheds, streams, and reservoirs that are the sources of the 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 2009, and compliance with regulatory standards or guidelines during this period. It also provides information on the water quality status of the City's drinking water sources upstream of the distribution system, and how watershed management protects those sources. The report also describes the efforts of the New York City Department of Environmental Protection (DEP) to evaluate the effectiveness of watershed protection and remediation programs, and to develop and use predictive models for management of the water supply. It is complementary to another report titled "New York City 2009 Drinking Water Supply and Quality Report," a report that is distributed to consumers annually to provide information about the quality of the City's tap water. More detailed reports on some of the topics described herein can be found in other DEP publications accessible through the DEP website at http://www.nyc.gov/dep/ (Figure 1.1).

1.2 What constitutes the New York City water supply system?

The New York City water supply system (Figure 1.2) supplies drinking water to almost half the population of the State of New York, which includes over eight million people in New York City and one million people in upstate counties, plus millions of commuters and tourists. New York City's Catskill/Delaware System is one of the largest unfiltered surface water supplies in the world. (The Croton System, which can supply on average 10% of the City's demand, is expected to be filtered by 2012.) The water is supplied from a network of 19 reservoirs and three 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 1.2 The New York City Water Supply System watersheds.

1.3 What are the objectives of water quality monitoring and how are the sampling programs organized?

Monitoring Program Objectives and Design

In order to ensure high quality drinking water, DEP conducts extensive water quality monitoring that encompasses all areas of the watershed, including sites at water supply intakes and aqueducts (keypoints), streams, and reservoirs. The watershed monitoring program meets the sampling needs for regulatory compliance requirements and also forms the basis for the DEP's ongoing assessment of watershed conditions, changes in water quality, and ultimately for developing any modifications to the policies, strategies, and management of the watershed protection programs. The watershed monitoring plan is documented in detail in the Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a), which establishes an objective-based water quality monitoring network. This plan provides for the development of scientifically defensible information regarding the understanding, protection, and management of the New York City water supply. The objectives of this monitoring plan have been defined by the requirements of those who ultimately require the information, including DEP program administrators, regulators, and other external agencies. As such, monitoring requirements were derived from legally binding mandates, stakeholder agreements, operations, and watershed management information needs. The plan covers four major areas that require ongoing attention: Compliance, Filtration Avoidance Determination (FAD) Program Evaluation, Modeling Support, and Surveillance Monitoring, with many specific objectives within these major areas. These objectives are described below.

Monitoring design must consider several elements, including choice of sites, analytes, analytical methodology and detection limits, and sampling frequency. Statistical features of the water quality database were used to guide the sampling design. For example, analyses of past data revealed that some sites were not significantly different from others, indicating that they could be adequately represented by similar sites. Sampling frequencies were based approximately on the rates of processes governing variability in water quality data. This statistical screening of differences between sites and collection times was used to streamline the monitoring site plans and to determine appropriate collection frequencies.

Compliance Sampling

The objectives of this sampling are focused on meeting the regulatory compliance monitoring requirements for the New York City watershed. This includes the requirements of the Surface Water Treatment Rule (SWTR) and its subsequent extensions, as well as the New York City Watershed Rules and Regulations (WR&R) (DEP 2002a), the Croton Consent Decree (CCD), Administrative Orders (AO), and State Pollution Discharge Elimination System (SPDES) permits. The sampling sites, analytes, and frequencies are defined in each objective according to each specific rule or regulation and are driven by the need of the water supply as a public utility to comply with all regulations. These include regulations issued by the United States Environmental Protection Agency (USEPA), New York State Department of Health (NYSDOH), and DEP's Watershed Rules and Regulations (DEP 2010a).

Filtration Avoidance and Watershed Protection Program Evaluation

New York City's water supply is one of the few large water supplies in the country that qualifies for Filtration Avoidance, based on both objective water quality criteria and subjective watershed protection requirements. USEPA has specified many requirements in the 2007 FAD that must be met to protect public health. These objectives form the basis for the City's ongoing assessment of watershed conditions, changes in water quality, and ultimately any modifications to the strategies, management, and policies of the long-term watershed protection program (DEP 2006a). As watershed protection programs develop and analytical techniques for key parameters change, it is necessary to reassess the monitoring program to ensure that it continues to support DEP's watershed management programs. The periodic reassessment of the City's monitoring program is achieved by critical review and revision of the monitoring plan approximately every five years. The City also conducts a periodic assessment of the effectiveness of the watershed protection program. DEP's water quality monitoring data are essential to evaluate watershed programs. Program effects on water quality are reported in the Watershed Protection Summary and Assessment reports, also produced approximately every five years.

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

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

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

Water Quality Modeling

Modeling data are used to meet the long-term goals for water supply policy and protection and to provide guidance for short-term operational strategies when unusual water quality events occur. The modeling goals of FAD projects include: implementation of watershed and reservoir model improvements based on ongoing data analyses and research results; ongoing testing of DEP's watershed and reservoir models; updating of data necessary for models, including land use, watershed program implementation data, and time series of meteorological, stream flow and water chemistry data; development of data analysis tools supporting modeling projects; and applications of DEP models to support watershed management, reservoir operations, climate change analysis and long-term planning, as identified in DEP's Climate Change Task Force Action Plan (DEP 2008a).

There are several types of data needed to generate models: stream, reservoir and aqueduct, and meteorological. Stream monitoring includes flow monitoring and targeted water quality sampling to support watershed and reservoir model development, testing, and applications. Reservoir monitoring provides flow and reservoir operations data to support reservoir water balance calculations. The water balance and reservoir water quality data are necessary model inputs, and are required to continue to test, apply, and further develop DEP's one- and two-dimensional modeling tools. The meteorological data collection effort provides critical input necessary to meet both watershed and reservoir modeling goals.

Water Supply Surveillance

The surveillance monitoring plan contains several objectives that provide information to guide the operation of the water supply system, other objectives to help track the status and trends of constituents and biota in the system, and specific objectives that include aqueduct monitoring for management and operational decisions. The aqueduct network of sampling points consists of key locations along the aqueducts, developed to track the overall quality of water as it flows through the system. Data from these key aqueduct locations are supplemented by reservoir water quality data. Another surveillance objective relates to developing a baseline understanding of potential contaminants that include trace metals, volatile organic compounds, and pesticides, while another summarizes how DEP monitors for the presence of zebra mussels in the system, a surveillance activity meant to trigger actions to protect the infrastructure from becoming clogged by these mussels. The remaining objectives pertain to recent water quality status and long-term trends for reservoirs, streams, and benthic macroinvertebrates in the Croton System. It is important to track the water quality of the reservoirs to be aware of developing problems and to pursue appropriate actions. Together, these objectives allow DEP to maintain an awareness of water quality for the purpose of managing the supply to provide the highest quality drinking water possible.

1.4 What types of monitoring networks are used to provide coverage of such a large watershed?

DEP's watershed monitoring networks cover the entire watershed and include meteorological stations, snow surveys, stream sites, reservoir sites, aqueducts, and wastewater treatment plants. Each network provides data that are used to characterize "state variables" (quantities), as well as their transformation rates, which are important components of the water supply's hydrology and water quality. Hydrological flow is the essential underlying element of water quality phenomena and water quality models are based on the hydrodynamics of the system. The interplay of water flow rates and physical, chemical, and biological rates determine water quality outcomes. These outcomes can only be estimated through water quality modeling. Therefore, it is essential to know the basic hydrology of the watershed in order to anticipate water quality changes for proactive management of the water supply.

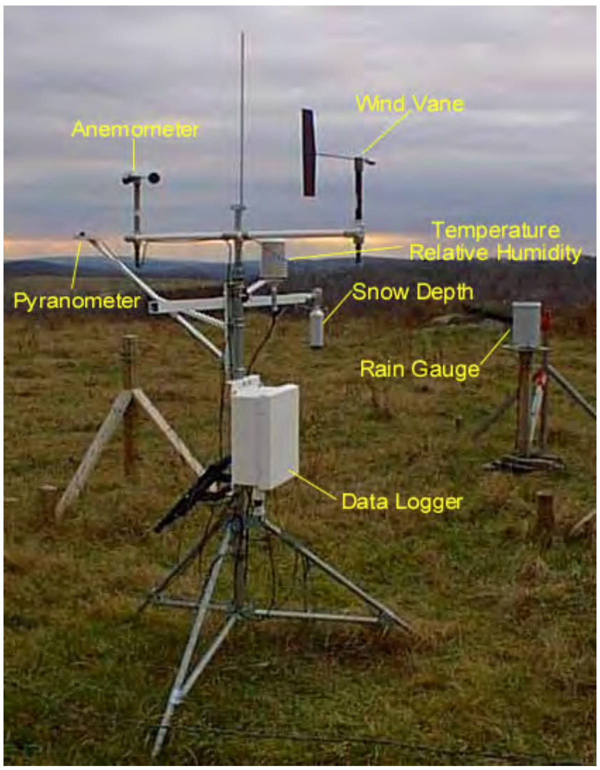

Figure 1.3 One of DEP's meteorological stations.

During the winter, snow surveys are periodically conducted to estimate how much water is stored on the watershed as snow and ice. These estimates are important in anticipating spring runoff and the impacts of rain-on-snow events, which may result in unusually large influxes of water to the reservoirs. Snow survey results also are used to help determine reservoir release rates in accordance with the Flexible Flow Management Plan for DEP's Delaware System reservoirs. Snow is an important part of the hydrological cycle and has an impact on stream and reservoir water temperatures throughout the spring.

Meteorological stations are located throughout the watershed (Figure 1.3). There are 20 sites west of the Hudson River and five sites east of the Hudson. This network was designed to provide the best data characterization of the conditions throughout the watershed in order to allow extrapolation and estimation of total precipitation entering the system. Orographic effects (such as greater precipitation at higher elevation on the windward side of mountains) were considered during site selection, so different site elevations were selected to represent the full range of conditions, i.e., from the mountain peaks in the Catskills to the lower elevations of the Croton System. Sites were also located on the reservoirs in order to characterize the temperature, wind, and solar radiation (including photosynthetically active radiation) needed for model input.

Stream sampling sites have been selected to meet several objectives, including: assessing the status and trends of stream water quality, monitoring and pinpointing various potential sources of pollution, evaluating the effectiveness of watershed programs, and providing calibration and verification data for water quality models. They also allow quantification of pollutants entering the system so that appropriate measures can be taken to minimize impairment of the drinking water. A typical stream site being sampled is shown in Figure 1.4. Water quality of the streams and tributaries provides essential input for reservoir models that guide the management of the NYC reservoirs. A companion network to DEP's water quality stream sites is the network of US Geological Survey (USGS) stream gages. Most of the gage sites are operated and maintained by the USGS on behalf of DEP and provide important flow data. These data are available on the internet and are used widely by a variety of stakeholders. They are used by DEP to track the current condition of the system's stream flows and guide operational decisions, including meeting mandated flow targets, as well as during droughts and floods. Stream flow data are particularly important to modeling, as they can provide key inputs to reservoir models that are used to evaluate the consequences of different operating strategies. They also provide data to calibrate and verify watershed models, which can estimate loads of water and nutrients to the reservoirs.

Figure 1.4 Stream sampling in progress.

Limnological surveys (Figure 1.5) play an important role in achieving many objectives. They provide information on the current status of basic physical, chemical, and biological conditions that determine water quality in the system, allow tracking of trends, provide data for models, and guide current operational decisions. Reservoir sampling sites have been selected to provide coverage of water quality and physical conditions throughout each reservoir, and are typically sampled at multiple depths.

Figure 1.5 Limnological survey in progress.

Figure 1.6 Continuously recording equipment used to monitor water quality in the aqueducts.

Aqueduct "keypoint" monitoring is conducted as a means of keeping a "finger on the pulse" of the water supply with respect to the major water flowing through the system and into distribution. Monitoring at these sites is conducted through the use of continuous monitoring equipment (Figure 1.6), and taking daily or weekly grab samples. These sites have some of the highest frequencies of sampling, the purpose of which is to maintain a high degree of reliability in the quality of water entering the distribution system. In addition to sites used for operational decisions, aqueduct monitoring includes compliance sites for the Surface Water Treatment Rule (SWTR) and are of utmost importance for operation of the system to maintain the status of Filtration Avoidance.

Finally, DEP monitors wastewater treatment plants (WWTPs) located throughout the watershed. Although treatment plants are potential sites of impairment, this risk has been enormously reduced in recent years because all treatment plants in the watershed have been equipped with microfiltration (or the equivalent) and tertiary treatment (nutrient removal). (For details on the WWTP upgrade program, see Chapter 5.) Plant upgrades have nearly eliminated the impacts that these plants formerly had in terms of nutrient and microbiological inputs. In the WWQMP (i.e., the monitoring plan), WWTP monitoring relies primarily on compliance monitoring to ensure that SPDES requirements are met. Although DEP only owns six of the treatment plants and conducts monitoring according to their SPDES permits, additional monitoring of all plants throughout the watershed (approximately 100) is conducted to ensure that no problems arise.

1.5 How do the different monitoring efforts complement each other?

The WWQMP describes a system of data collection networks that complement each other to provide multidimensional information and multiple lines of evidence to support operational and policy decisions. Water quality management requires a network design that can characterize water quality variation at different spatial and temporal scales. Efficient monitoring efforts reflect this and vary according to the variable being tracked. For example, some variables require a combination of long-term fixed-frequency surveys, supplemented by intensive short-term strategies. The design of water quality monitoring networks can be significantly enhanced by the coordination and integration of such monitoring strategies. The integration of water quality monitoring networks is essential for deriving the best value from the water quality data collected. The use of data gathered by the water quality monitoring network is routinely used to support water supply operations. The importance of the monitoring networks and full value of the data is realized when scientists provide analysis and interpretation for scientific reports and publications.

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

1.6 How many water samples did DEP collect in 2009 to monitor the water quality of reservoirs, streams, and aqueducts throughout the upstate watershed?

A summary table of the number of samples and analyses that were processed in 2009 by the five upstate laboratories, and the number of sites that were sampled, is provided below (Table 1.1). The sampling effort of the distribution system is also listed. The number of sample sites in the watershed is roughly half the number in the distribution system. The reason for this is that sites in the watershed are often located in remote areas that are difficult to reach. Many require long drives, trekking, and boat launching, so fewer sites can be reached on a routine basis in the watershed than in the City.

Table 1.1: Water quality monitoring summary for 2009.

District/Laboratory	Number of Samples	Number of Analyses	Number of Sites
Catskill/Kingston	2,923	60,282	117
Delaware/Grahamsville	2,821	38,896	122
EOH/Kensico	8,624	117,442	176
EOH/Brewster	1,513	12,110	60
Watershed/Pathogen	included in Kingston tally	3,674	included in Kingston tally
Watershed	15,881	228,730	475
Distribution	27,270	330,162	1,000
Total	43,151	558,892	1,475

1.7 How has water quality information been used to guide Health and Safety procedures?

Historical water quality data can sometimes be used to support the development of working policies. The predictable nature of seasonal temperature changes makes this possible. For example, long-term records of surface water temperature data (Figure 1.7) were used to develop guidance for proper cold water personal floatation devices (PFDs) for DEP staff from November through April (which is considered the routine field season for reservoir surveys).

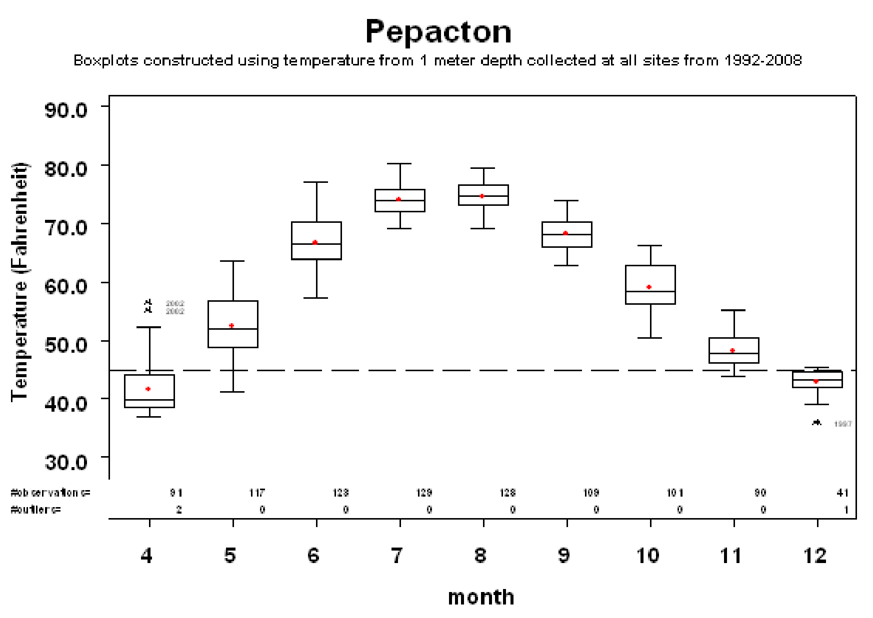

Figure 1.7 Long-term record of surface temperatures in Pepacton Reservoir, showing range and means for each month.

Equipped with information on water temperature, field staff can prepare for surveys by using the table below to select the PFD required for cold weather boat operations.

Table 1.2: Personal flotation devices recommended for various water temperatures.

	MINIMUM PFD SELECTION GUIDANCE TABLE		
WATER TEMPERATURE		80°F+(26.7°C)	*Water temps can be directly measured or predicted based on other data. From November through April, water temps must be measured or assumed to be at or less than 45°F.*
		70°F (21.1°C)	Water temperature greater than 46°F (7.8°C)... • Type V Inflatable PFD ("suspenders"), **or** • Type III (any style[1]) PFD
	Very Chilly	65°F (18.3°C)	
	Extremely Chilly	60°F (15.5°C)	
		50°F (10.0°C)	
	May Cause Shock	45°F (7.2°C)	Water temperature 32°F to 45°F (0.0°C to 7.2°C)... • Type V Anti-exposure Suit For Airboats Only: a Type V Immersion Suit[2] is recommended when the water AND air temperatures are either at or below 35°F (1.7°C)
		32°F (0.0°C)	

[1] Type III Float Coat-style PFD is recommended for conditions in the Extremely Chilly range.

[2] Immersion Suits can be carried aboard, ready for use. They must be periodically inspected and maintained.

Field staff also use other watershed data for health and safety. DEP has developed a new layer in the Watershed Lands Information System (WaLIS) that gives field staff access to information they need to know to maintain safe working conditions in the field, including (1) whether permission has been granted for sample site access to private property, (2) sample site maintenance status (e.g., plowing and mowing), and (3) specific hazards at sample collection points. DEP strives to keep staff members safe under all work conditions.

1.8 What enhancements were made to DEP's monitoring capabilities in 2009?

DEP moved toward implementing a Laboratory Information Management System (LIMS) in 2009. The system will be phased in beginning in 2010. Laboratory, field, and compliance staff developed user requirements, and began setting up client projects and test methods, in 2009. In addition to being able to take over all of the functionality of the current database system, the LIMS will provide many new benefits. For the first time, quality control data will be centrally stored and incorporated directly into online approval of data. Immediate benefits will be seen in improved sample planning, labeling, and tracking.   Data will be captured electronically, either by handheld field device or in laboratory apparatus, allowing for faster data submission, with fewer transcription errors. All these improvements will support earlier availability of data for analysis and reporting.

Figure 1.8 Water quality monitoring buoy, part of a robotic network in Kensico Reservoir.

In 2009, the Upstate Freshwater Institute under contract to DEP began acquisition and deployment of the Robotic Water Quality Monitoring Network (Figure 1.8). The network of water quality monitoring stations generating continuous real-time data accessible via internet browser will eventually feed data to DEP's Operations Support Tool. Robotic water quality monitoring buoys were deployed at three sites on Ashokan Reservoir, one site on Rondout Reservoir, one site on Schoharie Reservoir, and three sites on Kensico Reservoir. Monitoring stations were also placed at stream sites on Esopus Creek and Rondout Creek, with a site on Schoharie Creek to be implemented in 2010.

Two new 22-foot boats (a Grady White Fisherman and a Boston Whaler Guardian) were acquired at the end of 2009. These boats replaced aging, worn out, 19-foot vessels. The new, larger boats allow monitoring personnel to bring additional sampling equipment (e.g., pumps and coolers) on board to facilitate sampling activities. The new vessels will allow DEP monitoring teams to conduct limnological surveys of the Catskill and Delaware System reservoirs in a more efficient manner.

Figure 1.9 A new 22-foot Grady White motorboat.

Other improvements to the monitoring systems included hazardous material remediation in buildings and installation of new monitoring instrumentation. A continuous turbidimeter was installed in the renovated room at West Branch Reservoir station CWB 1.5. Progress was also made on the new monitoring rooms at DEL9, DEL10, DEL17, DEL18, and DEL19, which are shaft building sites located on the Delaware Aqueduct.

The Robotic Water Quality Monitoring Network, the LIMS, the boat acquisitions, and the installation of new monitoring instrumentation substantially improve the timeliness and accuracy of the water quality database.

2. Water Quantity

2.1 What is NYC's source of drinking water?

New York City's water is supplied by a system consisting of 19 reservoirs and three controlled lakes with a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The total watershed area for the system drains approximately 5,100 square kilometers (1,972 square miles) (Figure 2.1). The system is dependent on precipitation (rainfall and snowmelt) and subsequent runoff to supply the reservoirs in each of three watershed systems, Catskill, Delaware, and Croton. The first two are located West of Hudson (WOH), while the Croton System is located East of Hudson (EOH). As the water drains from the watershed, it is carried via streams and rivers to the reservoirs. The water is then moved via a series of aqueducts to terminal reservoirs before the water is piped to the distribution system. In addition to supplying the reservoirs with water, precipitation and surface water runoff also directly affect the nature of the reservoirs. The hydrologic inputs to and outputs from the reservoirs control the nutrient and turbidity loads and hydraulic residence time, which in turn directly influence the reservoirs' water quality and productivity.

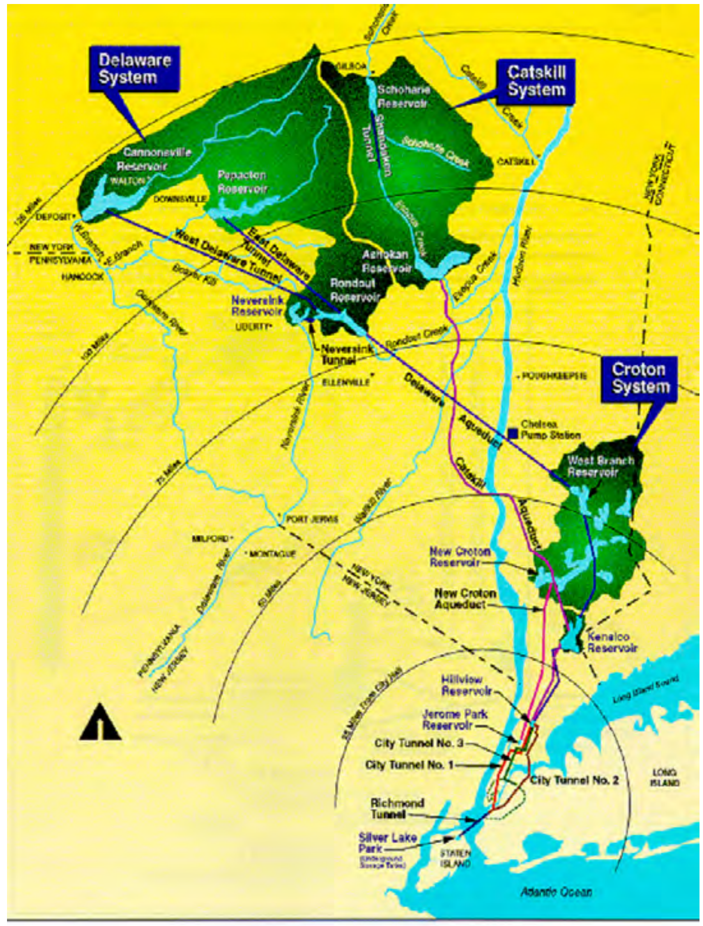

Figure 2.1 New York City water supply watershed.

2.2 How much precipitation fell in the watershed in 2009?

The average precipitation for each watershed was determined from a network of precipitation gages located in or near the watershed that collect readings daily. The total monthly precipitation is the sum of the daily average precipitation values calculated for each reservoir watershed. The 2009 monthly precipitation total for each watershed is plotted along with the historical monthly average in Figure 2.2.

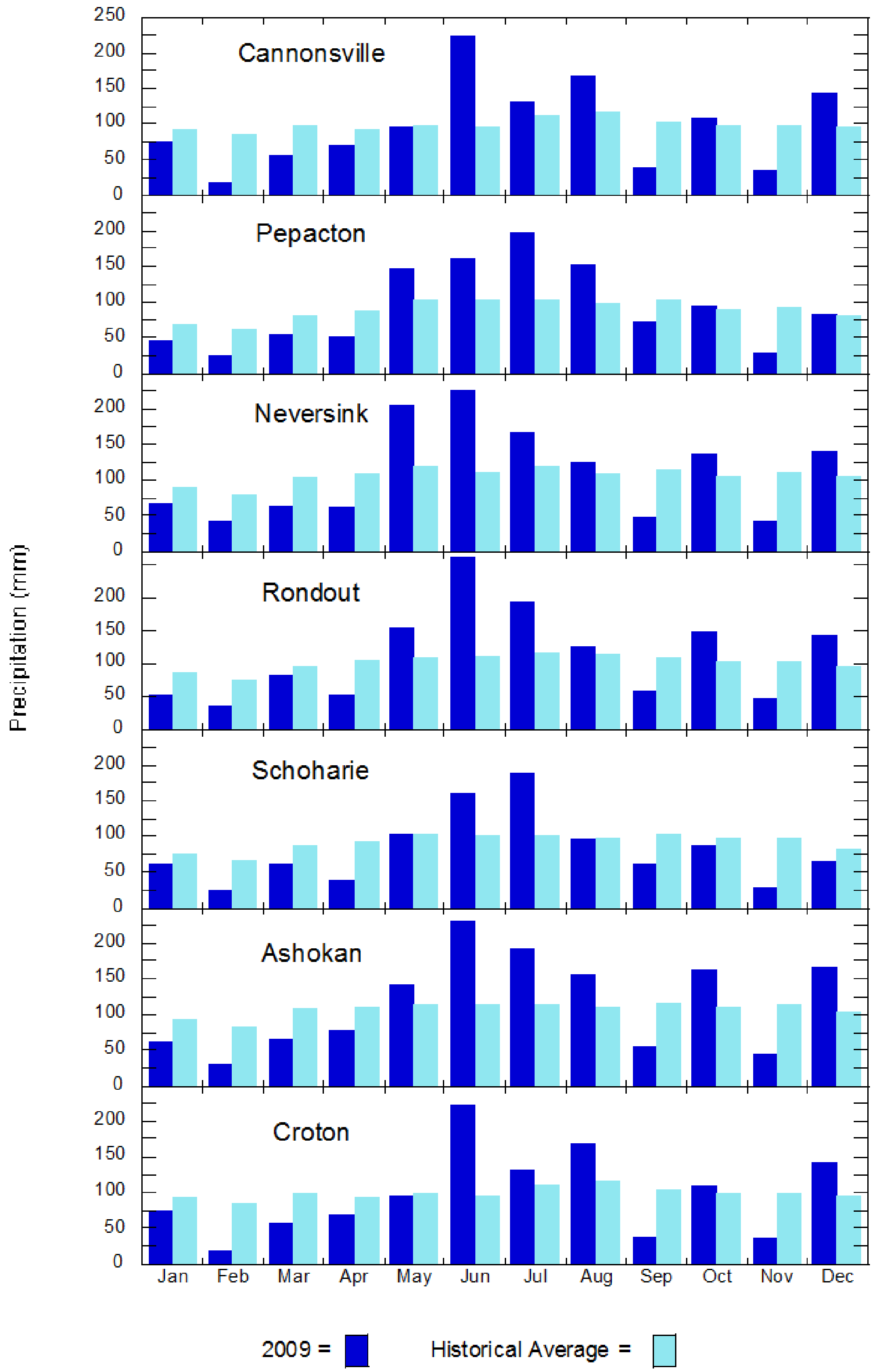

Figure 2.2 Monthly rainfall totals for NYC watersheds, 2009 and historical values.

The total monthly precipitation figures show that in general precipitation was below normal for January through April. May was about normal, except for the Ashokan, Rondout, and Neversink watersheds, which were somewhat above average. Precipitation was above normal in the summer period (June-August). In fact, the National Climatic Data Center's (NCDC) 2009 Annual Climate Review U.S. Summary (http://www.ncdc.noaa.gov/sotc/?report=national&year=2009&month=ann) reports that the June-August precipitation in New York State resulted in the sixth wettest summer on record (1895-2009). In September, precipitation was below normal, while October was near normal to slightly above normal. Precipitation in all watersheds was below normal in November and above normal in December for most watersheds. Overall, the total precipitation in the watershed for 2009 was 1,139 mm (44.8 inches), which was 7 mm (0.3 inches) below normal.

2.3 What improvements were made to DEP's meteorological data network in 2009, and how were the data used?

Weather is one of the major factors affecting both water quality and quantity. As such, weather data is one of the critical components of an integrated data collection system. Timely and accurate weather forecasts are essential, especially with regard to rainfall. The worst episodes of stream bank erosion and associated nutrient, sediment, and pollutant transport occur during high streamflow events caused by heavy rain. Monitoring these events is critical to responding, making operational decisions, understanding, and ultimately reducing, the amounts of sediment, turbidity, nutrients, and other pollutants entering the reservoirs.

Recognizing that, in addition to the precipitation data that have been historically collected, meteorological data are valuable in meeting DEP's mission of providing high quality drinking water, DEP maintained and upgraded the network of 25 Remote Automated Weather Stations (RAWS) covering both the EOH and WOH watersheds. Each station measures air temperature, relative humidity, rainfall, snow depth, solar radiation, wind speed, and wind direction. A reading is taken every minute, and values are summarized hourly (summed or averaged). In addition to being used by DEP, these data are shared with the National Weather Service (NWS) to help it make more accurate and timely severe weather warnings for watershed communities. The data are also important as input for DEP's water quality models (Chapter 6).

In 2009, DEP continued to upgrade its rain gages and telemetry system. The RAWS network originally used tipping bucket rain gages, which only measure liquid precipitation. These are being replaced with a weighing bucket gage (the Ott Pluvio) which can also measure frozen precipitation such as snow and freezing rain. The Pluvios are also more accurate than tipping buckets, and they are equipped with wind shields to help reduce catch error. Installation of the Pluvios began in 2007 and will be completed between 2010 and 2012. The telemetry upgrade was mostly completed in 2008, with the final installation of high-speed networking capability at one remote base station site occurring in 2009. This upgrade utilizes multiple base stations located at DEP facilities (wastewater treatment plants, valve chambers, etc.) spread throughout both the East and West of Hudson watersheds. All of the stations are now telemetered. Each RAWS transmits data to the nearest base station, where it is put onto the DEP computer network and routed to the master dataset at Grahamsville, as well as to a separate backup location. This upgrade has improved the reliability of data reception, increased data security, and brought EOH stations into the near-real-time data program.

DEP continued to develop the automated snow water monitoring system it started building in 2007. DEP purchased five more "SnoScale" devices in 2009. Four of these were installed in the Platte Kill sub-basin of the Pepacton watershed to help develop the optimum strategy for the concentration and placement of units to accurately estimate snow water equivalents (SWE). The site selection was done in conjunction with a research project being conducted by the NWS in relation to flood modeling. The fifth unit was installed in the West Delhi region of the Cannonsville watershed, where data were used in conjunction with another research project conducted by the NWS. Finally, a SnoScale unit on loan for research purposes was installed at a site in the Neversink watershed to conduct a side by side comparison with a U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) unit already in place there. Modifications were made to the CRREL unit at the time of the installation to remove the influence of frost on the measurements. This location has now become an SWE research site with the installation of multiple instruments measuring snowfall and snow water content.

2.4 How much runoff occurred in 2009?

Runoff is defined as the part of the rainfall and snowmelt that flows from the ground surface of a basin to a stream channel. Runoff includes "overland flow" and quick "lateral flow", the latter referring to water that moves relatively fast through macropores to a stream channel. The runoff from the watershed can be affected by meteorological factors such as type of precipitation (e.g., 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 from continuing downstream. 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. The total annual runoff is the depth to which the drainage area would be covered if all the runoff for the year were uniformly distributed over the basin. This statistic allows comparisons to be made of the hydrologic conditions in watersheds of varying sizes.

Selected USGS stations (Figure 3.4) were used to characterize annual runoff in the different NYC watersheds (Figure 2.3). The annual runoff in 2009 from the WOH watersheds was generally in the normal range, i.e. between the 25^{th} and 75^{th} percentile, with five stations above the median historical value for 2009. Two of these—the Neversink River and Rondout Creek—were above the 75th percentile. In the EOH watersheds, the 2009 annual runoff was also generally near the watersheds' historical medians (50th percentile), except for Cross River, which was nearer the 25th percentile. The EOH stations have a 14-year period of record, except for the Wappinger Creek site (81-year period of record). On the other hand, the period of record for the WOH stations ranges from 46 years at the Esopus Creek at Allaben station to 103 years at the Schoharie Creek at Prattsville gage.

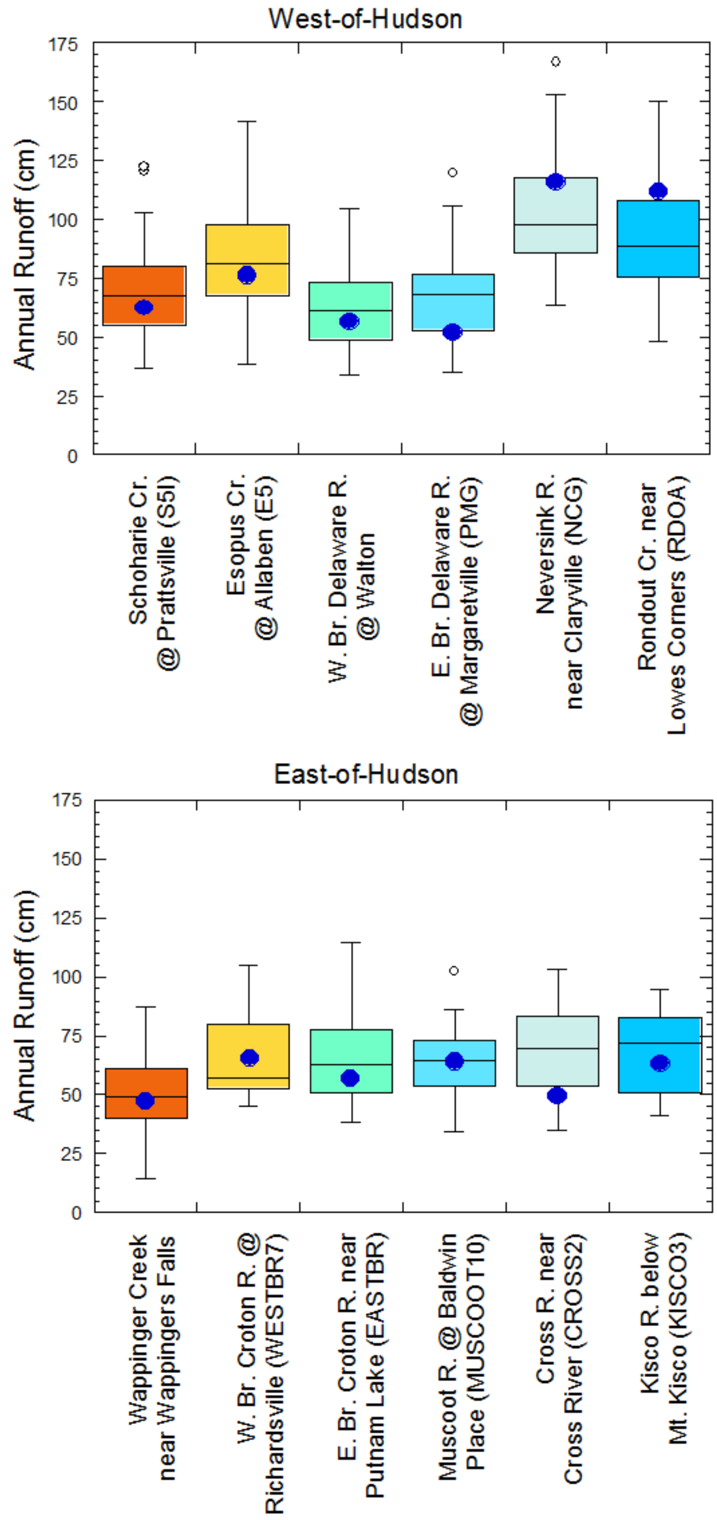

Figure 2.3 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds, with the values for 2009 displayed as a dot.

2.5 What was the storage history of the reservoir system in 2009?

DEP has established typical or "normal" system-wide usable storage levels for each calendar day. These levels are based on historical storage values, which are a function of system demand, conservation releases, and reservoir inflows. Ongoing daily monitoring of these factors allows DEP to compare the present system-wide storage against what is considered typical for any given day of the year. In 2009 the actual system-wide storage began the year above the normal storage values (Figure 2.4), but fell to near normal levels in February due to below normal precipitation (see section 2.2). The storage values remained near normal or somewhat below normal through spring as precipitation values remained below normal. In order to meet system demand and required releases during the summer drawdown period, DEP aims to have the system-wide usable storage at 100% (547.531 billion gallons (BG)) on June 1 of each year. In 2009 on June 1 the system-wide usable storage was at 98.6% of capacity, or 539.63 BG. However, with a rather wet summer, the storage values were above normal from mid-June through the remainder of the year. Daily storage levels can be found on the DEP web site at www.nyc.gov/html/dep.

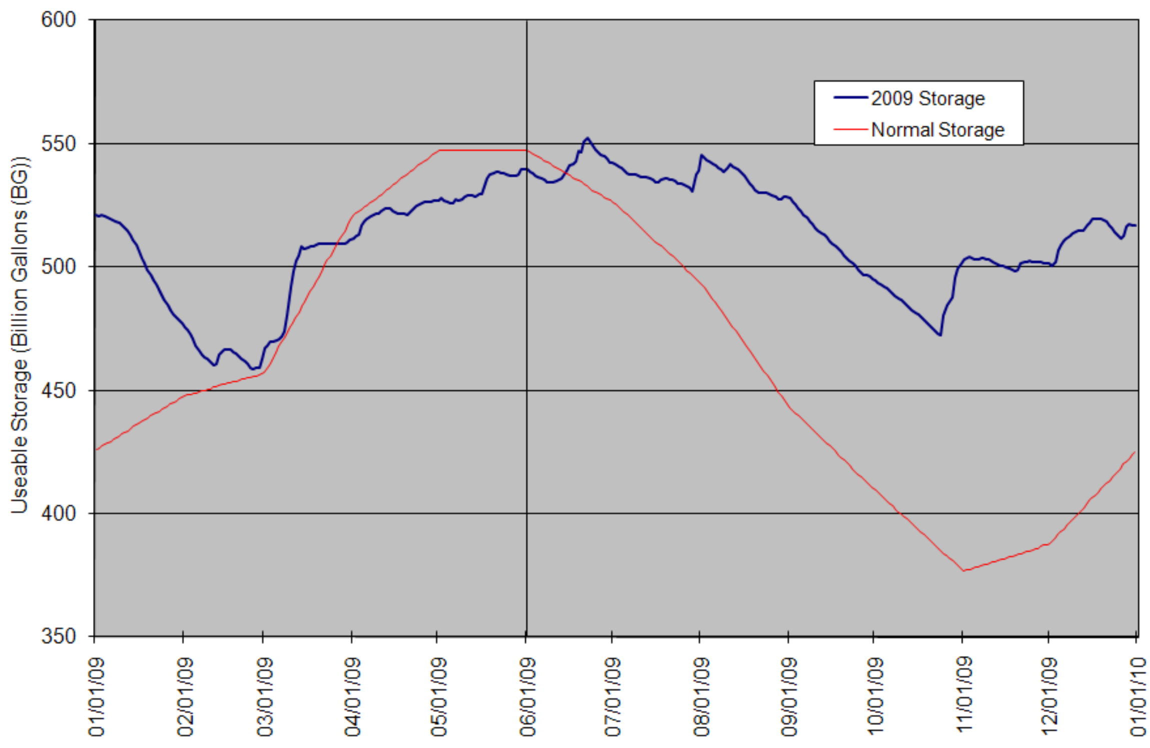

Figure 2.4 Actual system-wide usable storage compared to normal system-wide usable storage.

2.6 What rainfall data are necessary 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 2010 NYC Watershed Rules and Regulations (DEP 2010a). Section 18-39 established DEP's authority to regulate the management and treatment of stormwater runoff; established standards for the delineation and protection of watercourses; and codified prohibitions regarding the construction of impervious surfaces. This is the section under which Stormwater Pollution Prevention Plans (SPPP) are submitted, as well as applications for Individual Residential Stormwater Permits (IRSP) and Stream Crossing, Piping and Diversion Permits (CPDP). Residential-, commercial-, institutional-, and transportation-related activities are among the land uses requiring DEP review under this section.

The SPPPs require specific hydrologic modeling and analyses of site runoff conditions prior to and after proposed construction and development activities. Stormwater computer models rely on the most current rainfall data for a number of storm events, namely the 1-year, 10-year, and 100-year/24-hour events, and the 90% rainfall event, in order to size stormwater management practices and to gauge a variety of runoff conditions and predict downstream impacts. The 1-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 100% chance of occurring in any given year, while the 10-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 10% chance of occurring in any given year. The 100-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 1% chance of occurring in any given year. Isohyetal maps that present the most current estimates of these precipitation return periods for New York are produced by the Northeast Regional Climate Data Center and are available online at: http://www.nrcc.cornell.edu/pptext/isomaps.html.(Figures 2.5, 2.6 and 2.7 reproduce these maps for the 1-year, 10-year, and 100-year/24-hour events, respectively.) The 90% rainfall map (Figure 2.8) is also available in chapter 4 of the New York State Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/swdmchapter4.pdf).

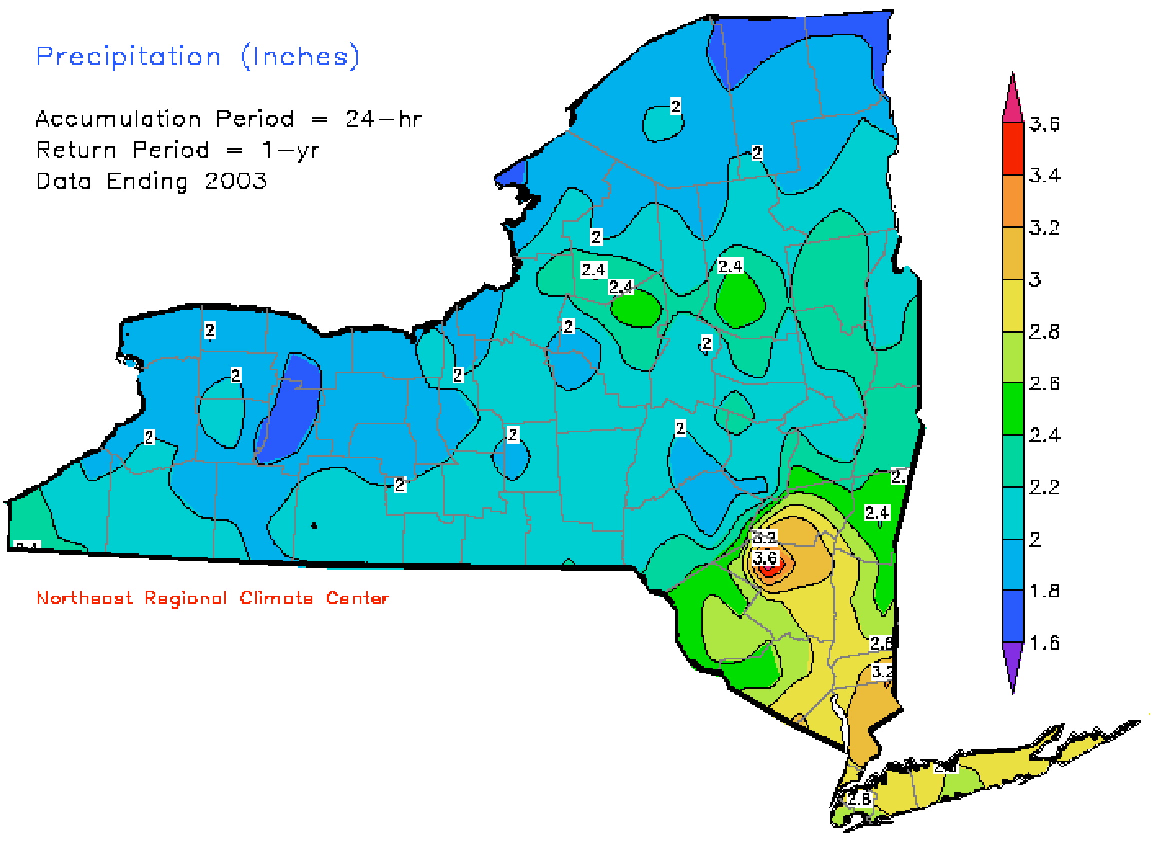

Figure 2.5 The 1-year, 24-hour storm for New York State as determined by the Northeast Regional Climate Center (http://www.nrcc.cornell.edu/pptext/isomaps.html).

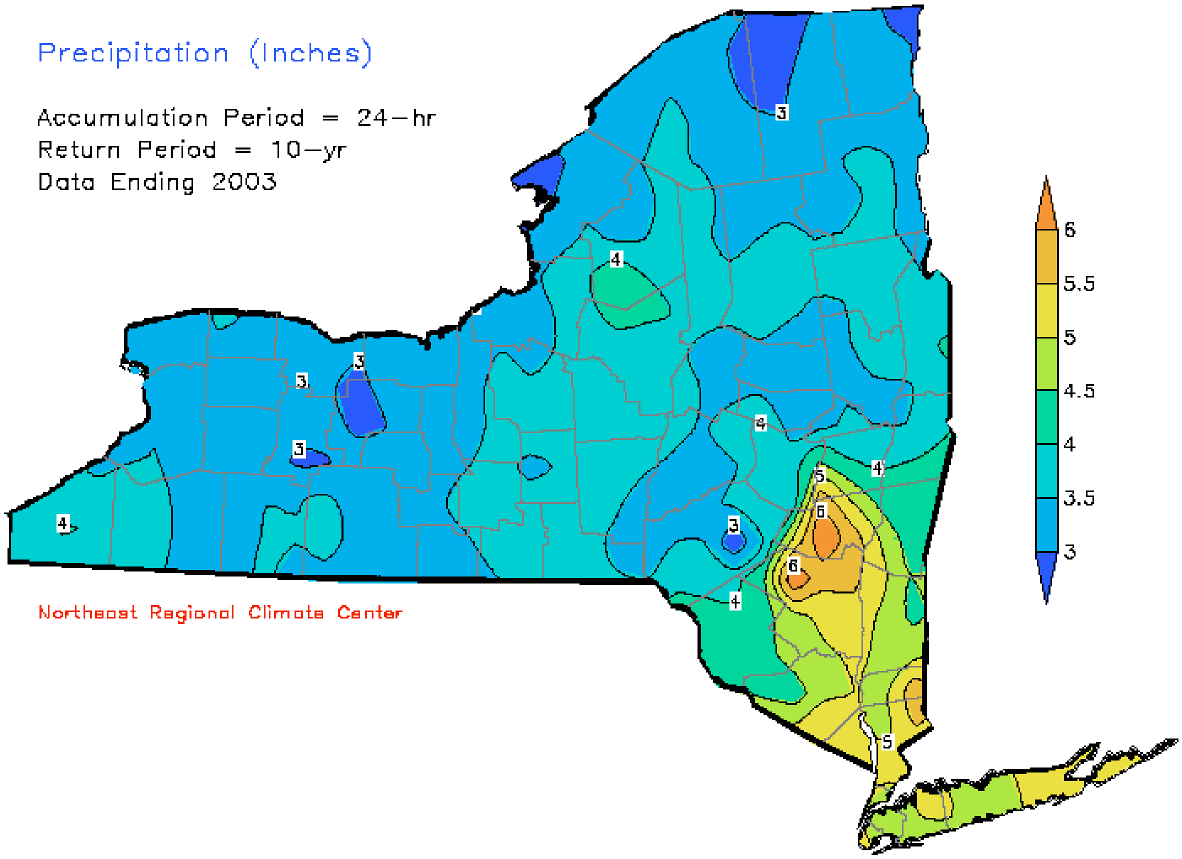

Figure 2.6 The 10-year, 24-hour storm for New York State as determined by the Northeast Regional Climate Center (http://www.nrcc.cornell.edu/pptext/isomaps.html).

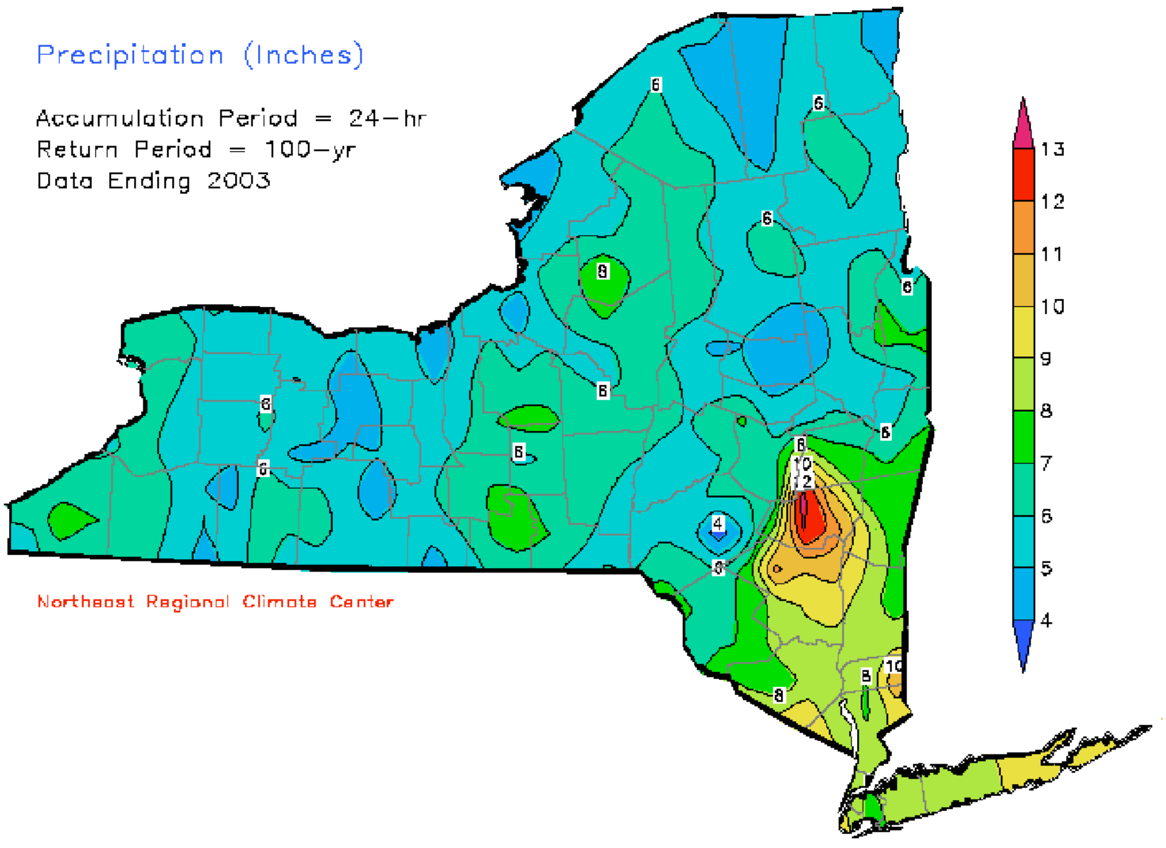

Figure 2.7 The 100-year, 24-hour storm for New York State as determined by the Northeast Regional Climate Center (http://www.nrcc.cornell.edu/pptext/isomaps.html).

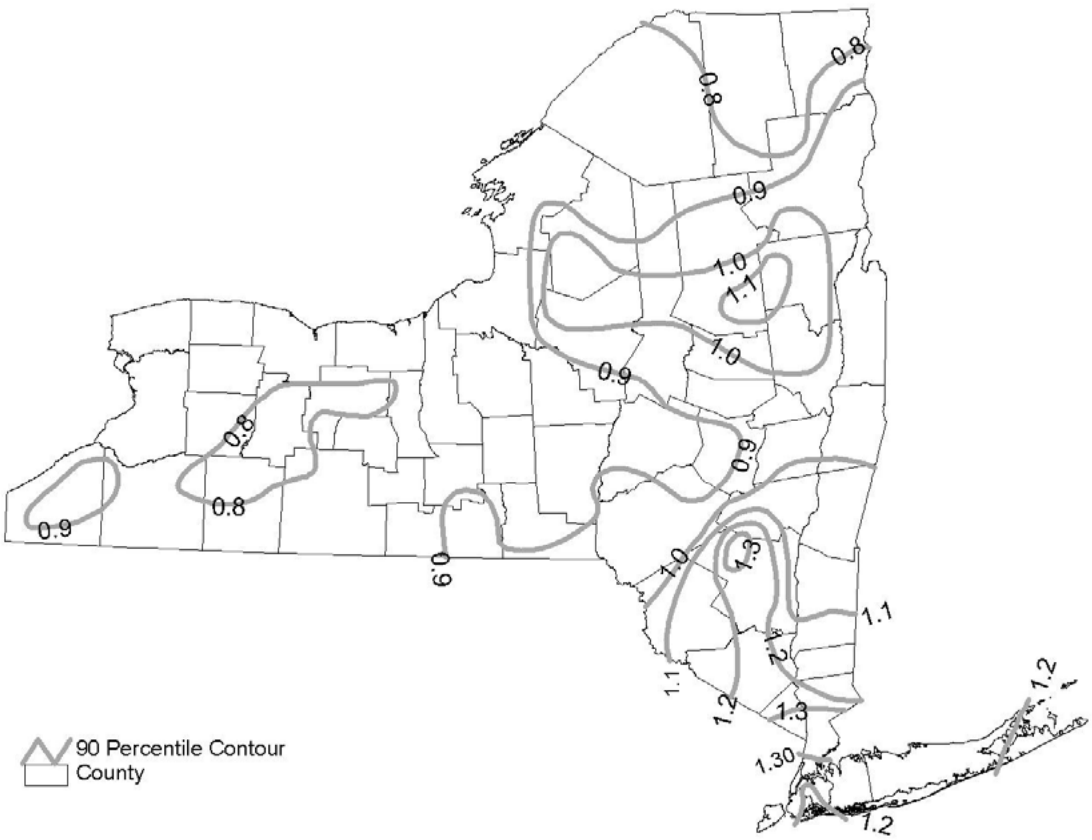

Figure 2.8 Ninety percent rainfall in New York State (New York State Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/swdmchapter4.pdf)).

2.7 How is the flow of water to the City maintained when an aqueduct must be shut down for maintenance or repair?

The New York City Water Supply System is an interconnected system of cascading reservoirs and connecting aqueducts. This system design provides DEP the flexibility to route and deliver water from several different sources. In December 2009, scheduled system maintenance required that the Delaware Aqueduct be temporarily shut down. While the Delaware System was offline, DEP needed to rely more heavily on the Catskill and Croton Systems to meet the City's water demand. One option was to provide more water from the Croton System via operation of the Croton Falls [Hydraulic] Pump Station. This station, located at Croton Falls Reservoir, enables DEP to pump water from that reservoir into the Delaware Aqueduct (downstream of the shutdown) where it flows into Kensico Reservoir. Terms of operation of the Croton Falls Pump Station are explicitly described in the 2007 FAD. DEP must justify the need for operation and receive approval from NYSDOH prior to operation. In 2009, DEP received approval and operated the Croton Falls Pump Station to help supplement the supply while Delaware System maintenance was being performed.

In response to this change in the system configuration, DEP modified its water quality monitoring program to closely track the quality of Croton Falls water and the effects of using that water, if any, on Kensico Reservoir. One element of this enhanced monitoring program included collecting daily samples of the water entering the Croton Falls Pump Station and flowing through the Delaware Aqueduct into Kensico Reservoir. Croton Falls Reservoir was closely monitored with weekly reservoir surveys. In addition to water quality monitoring, DEP increased surveillance of other potential contaminant sources by conducting weekly reservoir waterfowl surveys and increasing inspections of wastewater treatment plants. The operation of the Croton Falls Pump Station successfully augmented the supply. The quality of Kensico Reservoir remained high throughout the entire operation and appeared unaffected throughout this period.

3. Water Quality

3.1 How did DEP ensure the delivery of the highest quality water from upstate reservoirs in 2009?

DEP continued to perform extensive water quality monitoring at multiple sampling sites from aqueducts, reservoir intakes, and tunnel outlets within the Catskill, Delaware, and Croton Systems. In 2009, 228,730 physical, chemical, and microbiological analyses were performed on 15,881 samples that were collected from 475 different locations. DEP's Early Warning Remote Monitoring Group also continued to operate and maintain continuous monitoring instrumentation at critical locations to provide real-time water quality data to support operational decision making.

Scientists in the Watershed Water Quality Operations Division work cooperatively with the Bureau's Operations Directorate to determine the best operational strategy for delivering the highest quality water to NYC consumers. DEP continued to implement numerous operational and treatment techniques to effectively manage the Catskill, Delaware, and Croton Systems. Operational and treatment strategies employed in 2009 included:

Selective Diversion

DEP optimized the quality of water being sent into distribution by maximizing the flow from reservoirs with the best water quality and minimizing the flow from reservoirs with inferior water quality.

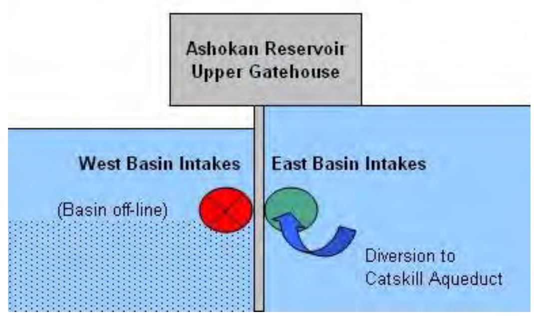

Figure 3.1 Selective diversion of water into the Catskill Aqueduct from the East Basin of Ashokan Reservoir.

On October 8, 2009, DEP began implementation of a partial by-pass of Kensico Reservoir on the Delaware Aqueduct in response to a number of metallic taste complaints submitted by City residents (see Section 3.3). By October 9, 2009, the Delaware by-pass tunnel at Shaft 17 was in 'float" mode, with Shaft 9 at West Branch Reservoir also in "float" mode. Because of this operational configuration, about 90% of the water being delivered to Hillview Reservoir via the Delaware System came directly from Rondout Reservoir. This operation circumvented Delaware water around Kensico and West Branch Reservoirs, which improved the quality of the water being delivered to the City and resulted in a reduction in the number of consumer calls.

On several occasions throughout the year (July, September, November) DEP diverted acceptable quality water from the West Basin of Ashokan Reservoir to keep Kensico Reservoir full and to create a void in the West Basin to protect water quality. When turbidity levels in the Ashokan West Basin began to increase due to rain events, DEP responded by isolating the West

Basin and diverting water from the East Basin where turbidity levels were lower (Figure 3.1). These basin operations allowed DEP to continue to deliver a sufficient quantity of good quality water to Kensico Reservoir and to absorb the impacts of storms in the isolated West Basin.

Selective Withdrawal

DEP continued to monitor water quality at different intake elevations within the reservoirs and used the data obtained to determine the optimal level of withdrawal. In the Ashokan West Basin in July, for example, the elevation of withdrawal was moved from 514 feet above sea level to 540 feet above sea level to avoid higher turbidity levels in the bottom waters. For the same reasons the elevation of withdrawal on the Ashokan East Basin was moved from 528.5 to 560 feet above sea level in October.

Other Strategies

DEP continued to look for strategies to improve water that is diverted to Kensico Reservoir, as well as prepare upstate reservoirs for potential flooding during spring snowmelt. In February 2009, the Ashokan waste channel was operated to remove water from the Catskill System. Water from the Ashokan West Basin was wasted to the Beaver Kill (and ultimately the lower Esopus Creek), to create a void in the West Basin to allow capture of spring runoff.

3.2 How did the 2009 water quality of NYC's source waters compare with SWTR standards for fecal coliforms and turbidity?

The Surface Water Treatment Rule (SWTR) (40 CFR141.71(a)(1)) requires that water at a point just prior to disinfection not exceed the thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the water supply systems at "keypoints" (entry points from the reservoirs to the aqueducts) just prior to disinfection (the Croton System at CROGH, the Catskill System at CATLEFF, and the Delaware System at DEL18). Figures 3.2 and 3.3 depict fecal coliform and turbidity data, respectively, for 1992-2009. Each graph includes a horizontal line marking the SWTR limit.

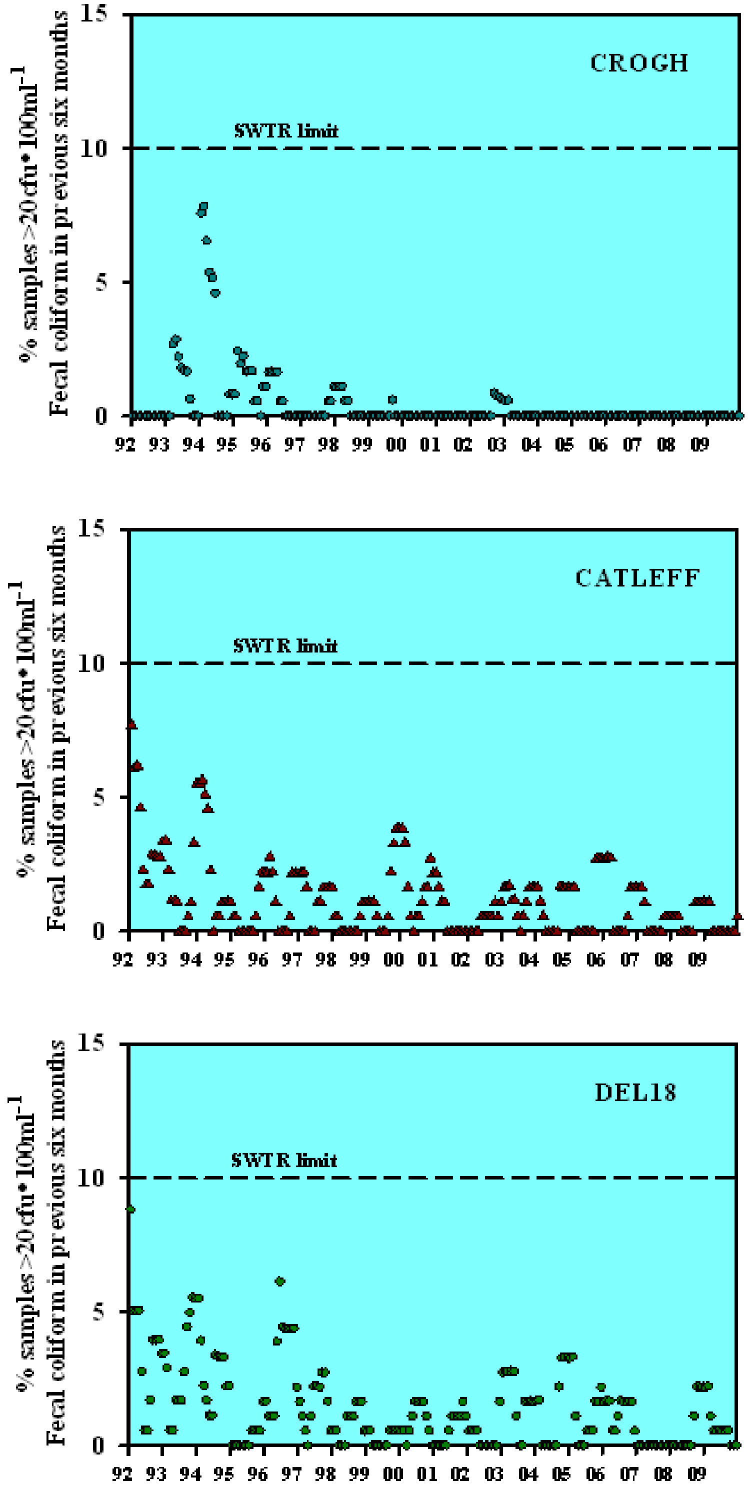

Figure 3.2 Fecal coliform (percent of daily samples > 20 CFU 100ml^{-1} in the previous six months) at keypoints compared to Surface Water Treatment Rule limit, 1992–2009.

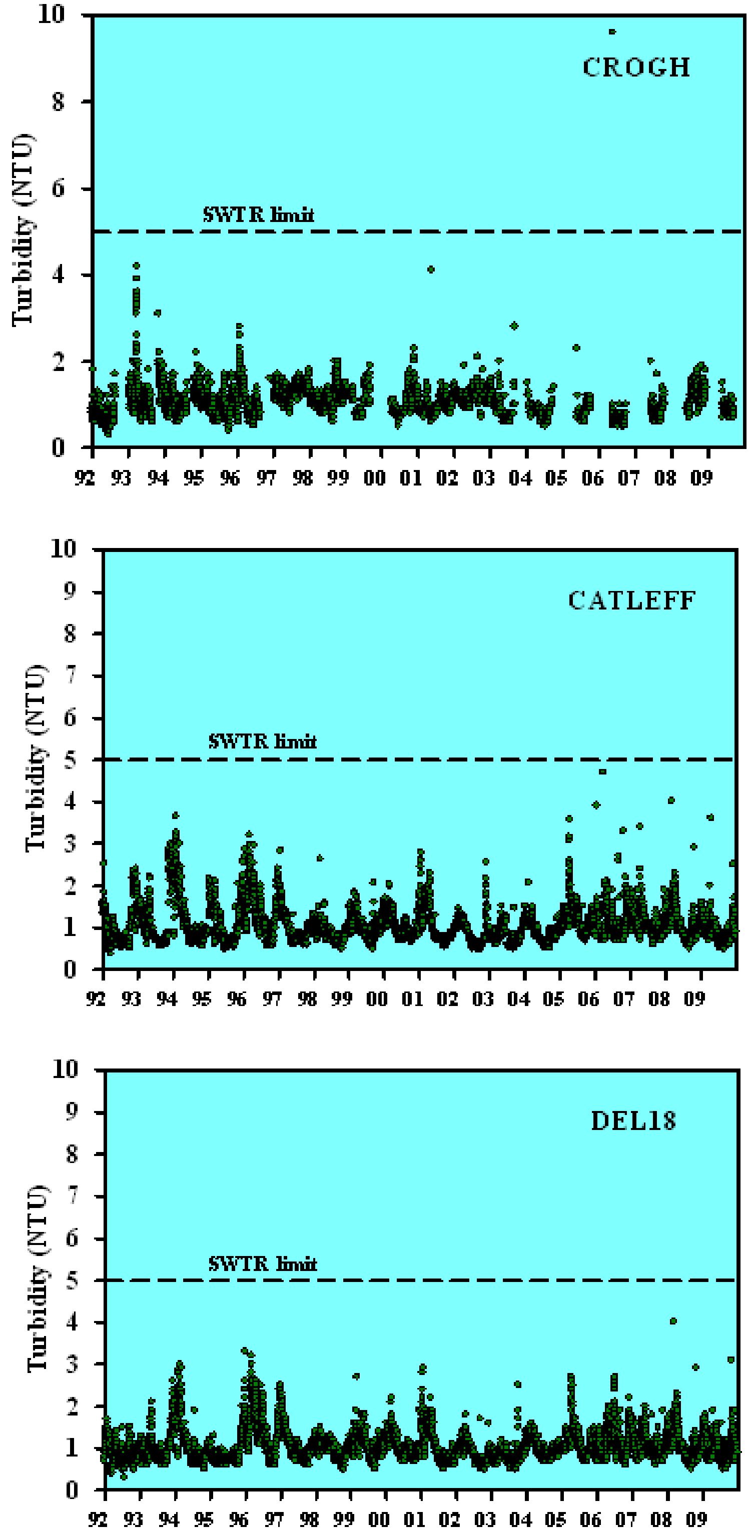

Figure 3.3 Turbidity at keypoints compared to Surface Water Treatment Rule limit, 1992–2009.

As indicated in Figure 3.2, the fecal coliform counts at all three keypoints consistently met the SWTR standard that no more than 10% of daily samples may contain > 20 CFU $100mL^{-1}$. The 2009 calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 were far below this limit. Median fecal coliform counts (CFU $100mL^{-1}$) in raw water samples taken at these sites were all the same, at 1 CFU $100mL^{-1}$, while maxima were 6, 24, and 30 CFU $100mL^{-1}$, respectively.

The SWTR limit for turbidity is 5 NTU. As indicated in Figure 3.3, all three effluent waters, measured at 4-hour intervals, were consistently well below this limit in 2009. For CROGH, CATLEFF, and DEL18, all median turbidity values were the same, at 0.9 NTU, while maximum values were 1.5, 1.9, and 1.9 NTU, respectively. (Note: The plot shows one high value at CROGH in 2006 that was caused by an operational adjustment, as discussed in the Watershed Water Quality Annual Report for 2006 (DEP 2007a).)

In comparison to 2008, there was a slight improvement in the fecal coliform maxima, and an improvement in both median and maximum turbidity values. These findings highlight the continued success of the management of the NYC watershed as well as effective operational strategies in maintaining high quality drinking water.

3.3 Why did some water consumers experience a “metallic taste” of their drinking water in October 2009 and how did DEP control it?

On October 4, 2009, routine surveillance of the New York City 311 System indicated an unusual increase in the number of complaints of metallic tasting water from City consumers. The 311 System is an online Web site and phone number for government information and non-emergency services. DEP immediately began an investigation to identify the source of this taste problem. Initial actions, such as reviewing all current water quality data and collecting additional samples from areas reporting complaints, focused on confirming that the water was safe to drink and that only the taste of the water was impaired. The review of water quality data indicated that all parameters were within normal ranges and confirmed that the water was safe to drink. By October 7, 2009, the daily number of metallic taste complaints had risen to 26, representing a small portion of the over 8 million NYC residents, but enough to be unusual, warranting further investigation.

Since 311 calls were received from all five boroughs, and since such system-wide taste problems are typically related to the quality of source waters, DEP began to focus its investigation on algal counts within Kensico Reservoir. The alga *Chrysosphaerella*, known to impart a “metallic” or “musty” taste following disinfection, was identified as being present in Kensico Reservoir. The BWS immediately implemented system operational changes to control the problem. On October 8, 2009, the Delaware Aqueduct at Kensico was placed into a “by-pass” mode, which excludes Kensico Reservoir water from the Delaware Aqueduct and distribution system. The flow of Catskill Aqueduct water leaving Kensico Reservoir was reduced. Following the implementation of these actions, consumer taste complaints immediately began to decline. To keep apprised of the status of this taste problem, DEP implemented an enhanced water quality monitoring program on Kensico Reservoir and tracked and reported the number of 311 System complaints received daily.

To keep NYC water consumers informed on this drinking water taste issue, DEP provided informational updates through both the 311 System and the DEP internet web site. By the beginning of November, counts of *Chrysosphaerella* in Kensico Reservoir began to naturally decline. After being in by-pass mode for 33 days, the Delaware Aqueduct was slowly phased back to “reservoir” mode in a series of steps beginning on November 10, 2009. No increase in the number of taste complaints from City consumers was observed during this blending operation, and on November 29, 2009, the Delaware System resumed normal operations with Kensico Reservoir fully online.

Although drinking water taste and odor issues related to algal blooms are frequently observed by many water utilities throughout the country, such taste issues are rare to the NYC water supply. This incident was the first record of the alga *Chrysosphaerella* causing a taste problem in the water supply. Because of its comprehensive 311 System, DEP was able to detect this taste issue immediately and, through operational flexibility, was able to manage the problem successfully. As a result, this algal event caused little to no impact to drinking water consumers.

3.4 What was the water quality in the major inflow streams of NYC’s reservoirs in 2009?

The stream sites discussed in this section are listed in Table 3.1 and shown pictorially in Figure 3.4. The stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/Delaware reservoirs and into five of the Croton reservoirs. This means they are the main stream sites immediately upstream from the reservoirs and therefore represent the bulk of the water entering the reservoirs from their respective watersheds (except for New Croton, where the major inflow is from the Muscoot Reservoir release). Kisco River and Hunter Brook are tributaries to New Croton Reservoir and represent water quality conditions in the New Croton watershed.

Table 3.1: Site codes and site descriptions of the stream sample locations discussed in Section 3.4.

Site Code	Site Description
S5I	Schoharie Creek at Prattsville, above Schoharie Reservoir
E16I	Esopus Creek at Boiceville bridge, above Ashokan Reservoir
WDBN	West Branch Delaware River at Beerston, above Cannonsville Reservoir
PMSB	East Branch Delaware River below Margaretville WWTP, above Pepacton Reservoir
NCG	Neversink River near Claryville, above Neversink Reservoir
RDOA	Rondout Creek at Lowes Corners, above Rondout Reservoir
WESTBR7	West Branch Croton River, above Boyd Corners Reservoir
EASTBR	East Branch Croton River, above East Branch Reservoir
MUSCOOT10	Muscoot River, above Amawalk Reservoir
CROSS2	Cross River, above Cross River Reservoir
KISCO3	Kisco River, input to New Croton Reservoir
HUNTER1	Hunter Brook, input to New Croton Reservoir

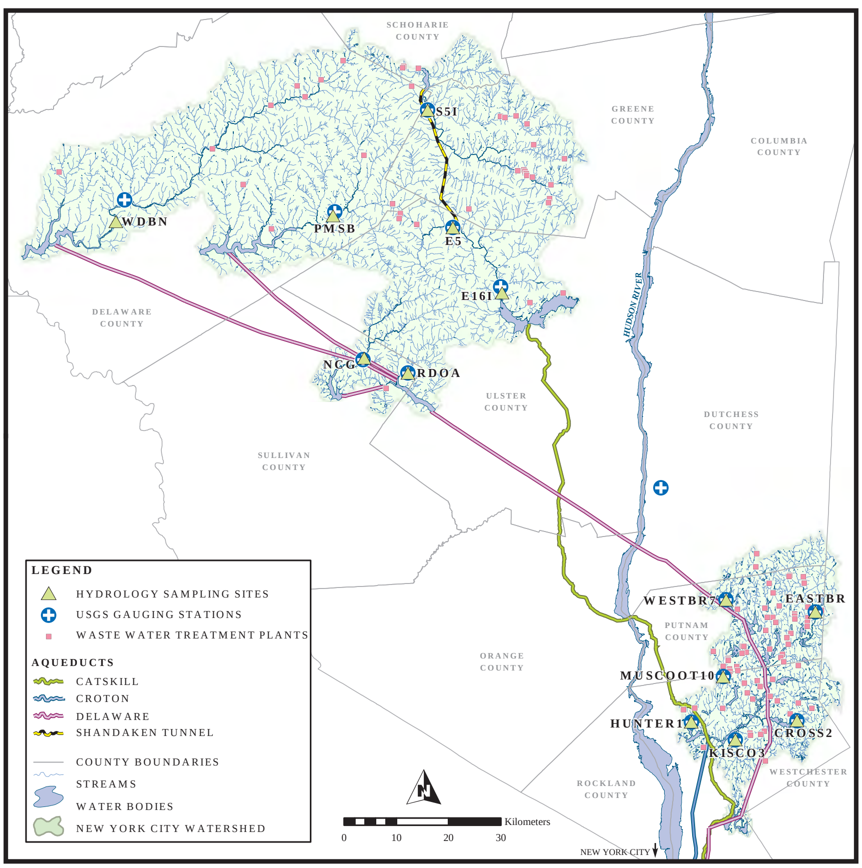

Figure 3.4 Locations of stream sampling sites discussed in Section 3.4 and USGS stations used to calculate the runoff values (see Section 2.4).

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

The results presented in Figure 3.5 are based on grab samples generally collected once a month in 2009 (twice a month for coliforms for the East of Hudson (EOH) sites). The figures compare the 2009 median values against historical median annual values for the previous 10 years (1999-2008).

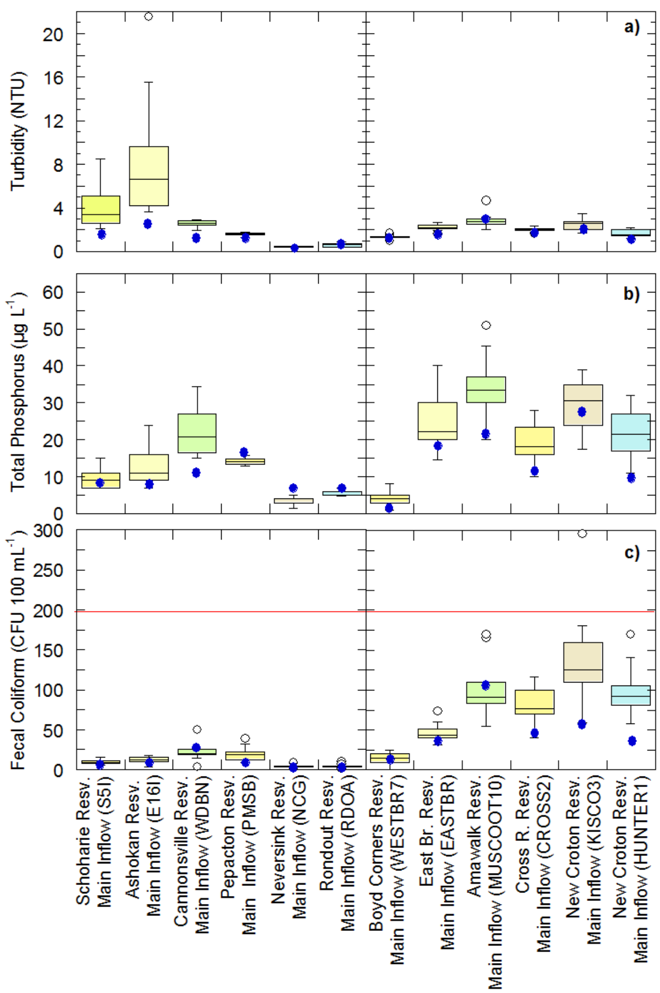

Figure 3.5 Boxplot of annual medians (1999–2008) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2009 displayed as a dot.

Turbidity

The turbidity levels for 2009 were generally below or near "normal" values (Figure 3.5a). The below normal results are due in part to the below average precipitation during the first part of the year (see section 2.2).

Total Phosphorus

In the Catskill and Delaware Systems, the 2009 median total phosphorus (TP) concentrations (Figure 3.5b) were below or near typical historical values for Ashokan, Schoharie, and Cannonsville and above the historical TP medians for Pepacton, Neversink, and Rondout. The 2009 TP medians in the Croton System were all less than historical values.

Fecal Coliform Bacteria

The 2009 median fecal coliform bacteria levels (Figure 3.5c) in the Catskill, Delaware, and Croton Systems were generally near typical historical levels except for Cross River, Kisco River, and Hunter Brook, which were all below their historical median for 2009. A fecal coliform benchmark of 200 CFU $100mL^{-1}$ is shown as a solid line in Figure 3.5c. This benchmark relates to the New York State Department of Environmental Conservation water standard (expressed as a monthly geometric mean of five samples, the standard being <200 CFU $100mL^{-1}$) for fecal coliform (6 NYCRR §703.4b). The 2009 median values for all streams shown here lie below this value.

3.5 What factors contributed to the turbidity patterns observed in the reservoirs in 2009?

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

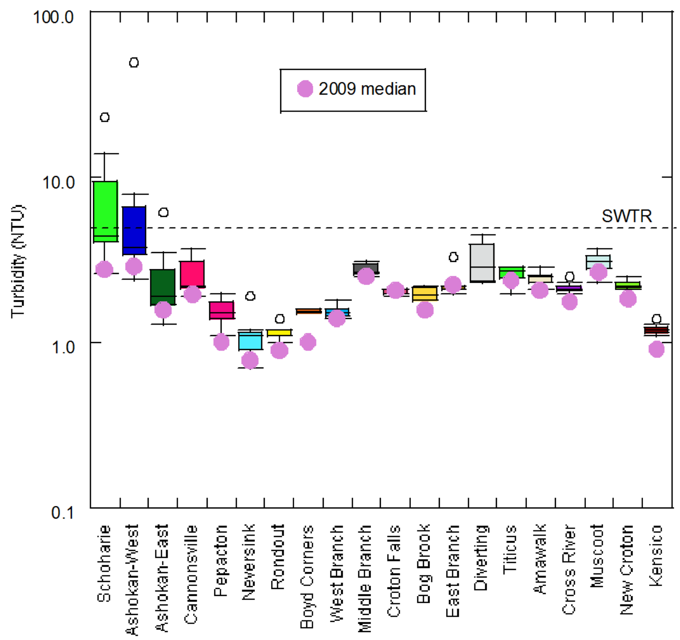

Figure 3.6 Annual median turbidity in NYC water supply reservoirs (2009 vs. 2002–2008). The dashed line at 5 NTU represents the SWTR criterion that considers 2 consecutive days > 5 NTU a violation in source water reservoirs.

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Medians were not calculated in 2009 for Diverting Reservoir due to insufficient data.

With the exception of West Branch Reservoir, turbidity in the Catskill and Delaware Systems (including Kensico) was generally much lower than normal in 2009 (Figure 3.6). Decreases ranged from 11% at Ashokan East and Cannonsville to about 35% at Pepacton and Schoharie. Turbidity in Kensico Reservoir was at its lowest since 2002, reflecting the low 2009 turbidities of its primary inputs—Rondout, West Branch, and Ashokan Reservoirs. West Branch Reservoir waters consist of a mix of waters from Rondout and Boyd Corners Reservoirs. This reservoir had turbidity values that were slightly higher than its historical median.

Low turbidities were also observed in most of the Croton System reservoirs in 2009. The largest decrease (35%) occurred at Boyd Corners, while 9 of the remaining 12 Croton reservoirs decreased by 5 to 16% compared to historical medians. Small turbidity increases of 6% did occur at East Branch and Lake Gleneida. A significant increase of 100% was apparent at Lake Gilead, where the turbidity doubled from 1.3 to 2.6 NTU. Because Gilead is only sampled three times per year, a plankton bloom in May and rain events in October were enough to cause the median turbidity to be “high” for the year.

The lower turbidities observed in most reservoirs of the Croton and Cat/Del Systems are attributable to a limited snowmelt and to the relative absence of large rain events in the spring and fall. Although precipitation was high in June, July, and August, erosion events are often limited in the summer by the rapidly growing plant canopy, which intercepts a large portion of the rain, and by evapotranspiration, limiting the amount of runoff generated by the storms.

3.6 How were the total phosphorus concentrations in the reservoirs affected by precipitation and runoff in 2009?

Precipitation and the resulting runoff are important mechanisms by which phosphorus is transported from watersheds into streams and reservoirs. Primary sources of phosphorus include: human and animal waste, fertilizer run-off, and internal recycling from reservoir sediments.

In 2009, median total phosphorus (TP) results in all Catskill System reservoirs were low, near their historical 25th percentile concentrations (Figure 3.7). Monthly TP concentrations at Schoharie and Ashokan West were especially low in April and May, presumably due to a limited snowmelt and below average rainfall in April. In contrast, TP was relatively high in the Ashokan East Basin during April and May. The low annual TP median in the East Basin was driven primarily by low values in July, August, and September.

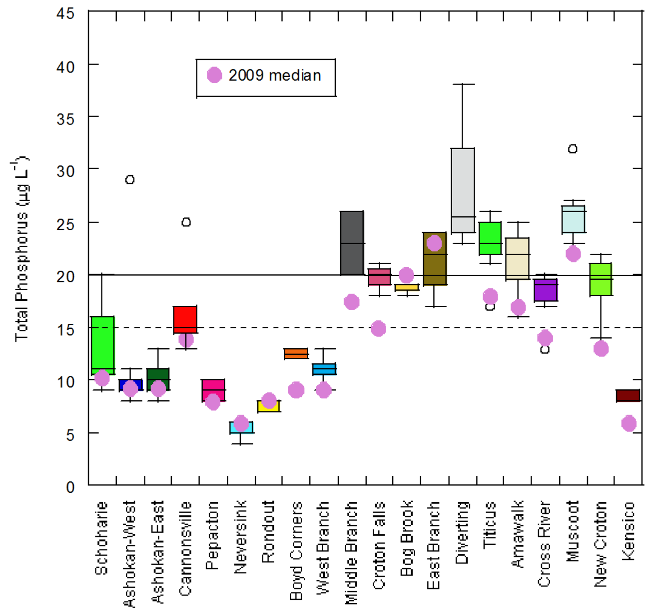

Figure 3.7 Annual median total phosphorus in NYC water supply reservoirs (2009 vs. 2002-2008). The horizontal dashed line at 15 µg L^{-1} refers to the NYC TMDL guidance value for source waters. The horizontal solid line at 20µg L^{-1} refers to the NYSDEC ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs).

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. However, the median was not calculated in 2009 for Diverting Reservoir due to insufficient data.

In the Delaware System, TP results were mixed (Figure 3.7.). Annual median TP was about 8% lower than historical concentrations at Pepacton and Cannonsville Reservoirs. Despite high rainfall from May to August, TP concentrations were generally low to normal during this period, perhaps due in part to the ongoing protection efforts in these watersheds. The limited snowmelt and low rainfall in early spring and fall are additional factors that contributed to the low TP concentrations in Cannonsville. Compared to historical data, TP concentrations were unchanged at Rondout and slightly higher at Neversink in 2009. The boxplots in Figure 3.7 may be somewhat misleading, however, since the historical data are lower than the 2009 data in large part because a lower detection limit was used in the past.

West Branch Reservoir consists of a blend of Rondout water from the Delaware System and of Boyd Corners water from the Croton System. TP concentrations in these inputs were both below the median and resulted in a TP median below the historical value in West Branch in 2009.

Kensico Reservoir, which receives water from Rondout, West Branch, and Ashokan, had a low TP median in 2009, largely due to the low TP concentrations of its inputs.

As shown in Figure 3.7 and Table 3.2, TP concentrations in the Croton System reservoirs and controlled lakes are normally much higher than in the reservoirs of the Catskill and Delaware Systems. The Croton watershed has a greater abundance of phosphorus sources: there are 60 wastewater treatment plants, numerous septic systems, and extensive paved surfaces scattered throughout the watershed.

Table 3.2: Total phosphorus summary statistics for NYC controlled lakes (µg mL^{-1}).

Lake	Median Total Phosphorus (2002-08)	Median Total Phosphorus (2009)
Gilead	20	24
Gleneida	18	16
Kirk	29	30

Although eutrophication is prevalent in the Croton System, TP concentrations in 2009 appeared to be very low relative to past concentrations for most reservoirs and lakes. Several factors may have been responsible. A limited snowmelt kept April TP levels low while high rainfall in June, July, and August kept the reservoirs mostly full in the summer. Typically in the summer, the reservoirs become drawn down and resuspension of exposed sediments can be an important source of TP. Also, there have been a number of watershed management efforts undertaken in the Croton system to improve water quality (see Section 5.5), and these may also be playing a role in the lower TP concentrations.

Total phosphorus did not decrease in all Croton water bodies in 2009. A small increase of 1 µg L^{-1} was observed at Bog Brook and East Branch Reservoirs. These results may be biased, however, since Bog Brook and East Branch were not sampled in April and May when TP concentrations were very low in all of the other Croton reservoirs. The largest 2009 TP increase occurred at Lake Gilead (Table 3.2). This increase, though, was a function of the high TP results in May (which followed 2.6 inches of rain during the week prior to sampling). Because Gilead was sampled only three times in 2009, the May results were enough to produce the elevated median concentrations reported in Table 3.2. Note also that because Diverting had low elevations during the year and was sampled on only a few occasions in 2009, a representative median could not be calculated; therefore, only the distribution of past annual medians is provided in Figure 3.7.

3.7 Which basins were phosphorus-restricted in 2009?

Phosphorus-restricted basin status is presented in Table 3.3 and was derived from two consecutive assessments (2004-2008 and 2005-2009) using the methodology stated in Appendix C. Appendix Table C.1 in Appendix C lists the annual growing season geometric mean phosphorus concentration for NYC reservoirs. Reservoir basins whose geometric mean phosphorus concentrations exceed the NYS guidance value for both assessments are classified as restricted. Figure 3.8 graphically depicts the phosphorus restriction status of the NYC reservoirs and the 2009 geometric mean phosphorus concentration. As of April 4, 2010, the New York City Watershed Rules and Regulations were amended to lower, from 20 to 15 $\mu g\ L^{-1}$, the acceptable geometric mean for total phosphorus for reservoirs that serve, or potentially serve, as source waters (DEP 2010a). These reservoirs are Ashokan-East Basin, Ashokan-West Basin, Cross River, Croton Falls, Kensico, New Croton, Rondout, and West Branch Reservoirs. The assessments for these reservoirs were calculated using the new, lower TP limit.

Some notes and highlights regarding phosphorus-restricted basin status in 2009 are listed below:

- The Delaware System reservoirs remained non-restricted with respect to TP. Figure 3.8 shows that the 2009 geometric mean was lower than the mean for the two five-year assessment periods for these non-terminal reservoirs.
- The Croton System reservoirs remained phosphorus-restricted, with the exception of Boyd Corners, which remained non-restricted.
- The geometric means of the TP concentrations for 2009 were generally lower than in previous years (Appendix C), the exceptions being Bog Brook, Lake Gilead, and Kirk Lake.
- Due to a limited number of surveys, Lake Gleneida and Diverting Reservoir had insufficient data to evaluate either the 2004–2008 or 2005–2009 assessments.
- Source waters were held to the new limit of 15 $\mu g\ L^{-1}$, which placed four reservoirs into the phosphorus-restricted category: Ashokan-West Basin, Cross River, Croton Falls, and New Croton Reservoirs.
- Kensico, Ashokan-East Basin, Rondout, and West Branch Reservoirs were well below this new, lower threshold.

Table 3.3: Phosphorus-restricted reservoir basin status for 2009.

Reservoir Basin	04 - 08 Assessment (mean + S.E.) (µg L^{-1})	05-09 Assessment (mean + S.E.) (µg L^{-1})	Phosphorus-Restricted Status
Delaware System			
Cannonsville	18.0	17.8	Non-Restricted
Pepacton	9.8	9.6	Non-Restricted
Neversink	6.4	6.7	Non-Restricted
Catskill System			
Schoharie	16.3	15.9	Non-Restricted
Croton System			
Amawalk	24.2	22.5	Restricted
Bog Brook	23.5	22.2	Restricted
Boyd Corners	15.8	15.3	Non-Restricted
Diverting	Insufficient data	Insufficient data	Restricted
East Branch	33.1	26.9	Restricted
Middle Branch	28.8	27.8	Restricted
Muscoot	27.2	27.2	Restricted
Titicus	25.8	24.9	Restricted
Lake Gleneida	Insufficient data	Insufficient data	Restricted
Lake Gilead	32.2	35.0	Restricted
Kirk Lake	Insufficient data	Insufficient data	Restricted
Source Waters			
Ashokan-East	9.9	9.8	Non-Restricted
Ashokan-West	15.8	15.7	Restricted
Cross River	18.9	17.7	Restricted
Croton Falls	18.7	17.7	Restricted
Kensico	8.5	9.0	Non-Restricted
New Croton	19.5	17.6	Restricted
Rondout	8.1	8.0	Non-Restricted
West Branch	12.1	11.8	Non-Restricted

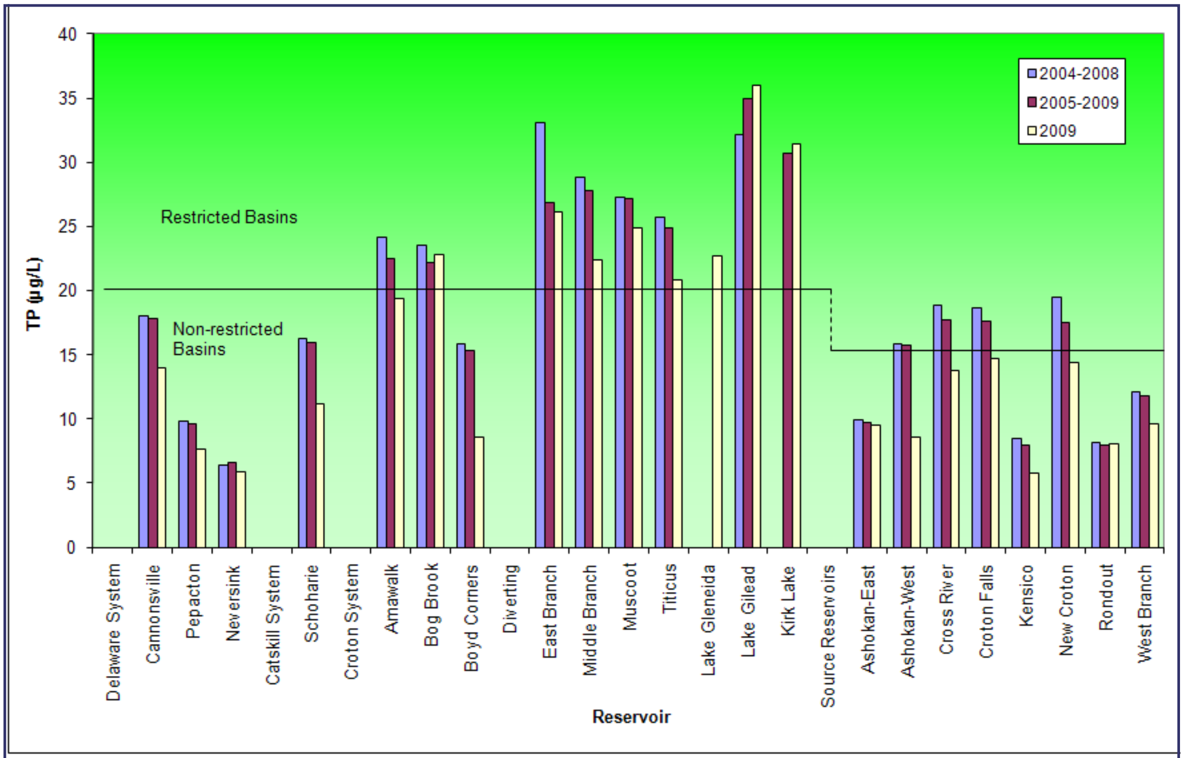

Figure 3.8 Phosphorus-restricted basin assessments, with the current year (2009) geometric mean phosphorus concentration displayed for comparison. The horizontal solid lines at 20 µg L^{-1} and 15 µg L^{-1} represent the NYC Watershed Rules and Regulations standard for non-source waters and source waters, respectively.

3.8 What was the trophic status of each of the City's 19 reservoirs and why is this important?

The trophic state index (TSI) is commonly used to describe the productivity of lakes and reservoirs. Three trophic state categories—oligotrophic, mesotrophic, and eutrophic—are used to separate and describe water quality conditions. Oligotrophic waters are low in nutrients, low in algal growth, and tend to have high water clarity. Eutrophic waters, on the other hand, are high in nutrients, high in algal growth, and low in water clarity. Mesotrophic waters are intermediate. The indices developed by Carlson (1977, 1979) use commonly measured variables (chlorophyll *a*, total phosphorus, 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* in µg L^{-1}.

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 typically reduce the need for chemical treatments and produce better water quality at the tap; eutrophic waters, by contrast, may be aesthetically unpleasant from a taste and odor perspective.

Historical (2002-2008) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.9. The 2009 annual median TSI appears in the figure as a circle containing an “x”. This analysis generally shows a split between West of Hudson reservoirs, which usually fall into the mesotrophic category, and East of Hudson reservoirs, which are typically classified as eutrophic. The exceptions to these generalities are Cannonsville, which is usually considered eutrophic; West Branch, which is considered mesotrophic due to incoming water from Rondout Reservoir; and Kensico, which is considered mesotrophic due to inputs from Rondout (usually via West Branch) and from the East Basin of Ashokan.

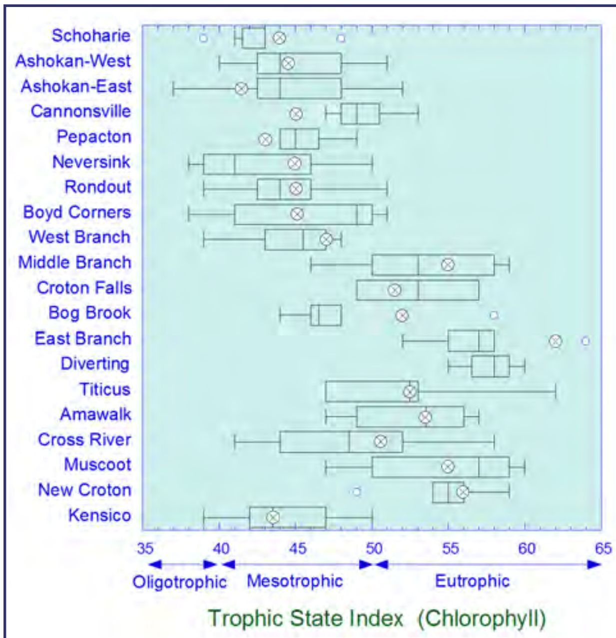

Figure 3.9 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2009 vs. 2002-2008).

Note: In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies (1 or 2x per month) from May through October. TSI is based on chlorophyll *a* concentration.

TSI was slightly elevated at Schoharie and Ashokan-West in 2009. Water clarity was deeper than usual for much of the growing season, and phytoplankton responded accordingly. Despite better clarity and normal nutrient and temperature levels, TSI was lower than historical levels in Ashokan-East.

In the Delaware System, TSI levels were their lowest since 2002 at Cannonsville and Pepacton Reservoirs. Phosphorus reductions from ongoing watershed protection efforts are the likely cause. Neversink is normally a low TSI reservoir. However, TSI increased about 11% in 2009. Rain events just prior to sampling surveys in May, June, and July increased nutrient levels in the reservoir, which probably stimulated algal growth. A slight increase was also apparent at Rondout, the terminal reservoir of the Delaware System. The increase was likely due to storm-related nutrient increases in August and September.

TSI at West Branch increased slightly in 2009. This reservoir consists of a blend of Rondout and Boyd Corners Reservoirs, but its TSI was two units higher than either, indicating some local production may have occurred. Kensico Reservoir, the terminal reservoir for the Catskill/ Delaware System, is primarily a blend of Ashokan-East and Rondout (usually via West Branch) waters, with small contributions from local streams. In 2009, Kensico's TSI was lower than its inputs', suggesting that in-reservoir processes such as sedimentation, predation, and die off produced a net loss of algal cells in the reservoir this year. Note that this analysis only considers data collected from May to October, so the *Chrysosphaerella* growth which occurred in October is only partially reflected in the boxplot. Water quality conditions prior to the bloom indicate that the photic zone was unusually deep and that nutrient concentrations were very low during the summer. These conditions are favorable to *Chrysosphaerella* because unlike many phytoplankton (1) it is motile, so it can avoid excess solar radiation and predation, and (2) it can feed on bacteria when dissolved nutrients are not available (Patterson et al. 2004).

TSI patterns were not consistent for the Croton System reservoirs in 2009 (Figure 3.9). Bog Brook and East Branch Reservoirs, and Lakes Gilead and Kirk showed the biggest increases. Cross River, Middle Branch, and New Croton were up slightly for the year, while Titicus and Amawalk remained unchanged from historical levels. Storm-related, short-term nutrient inputs are the likely explanation for the observed increases. Several decreases in TSI were also apparent in 2009. The largest decrease occurred at Boyd Corners, with lesser declines observed at Muscoot, Croton Falls, and Lake Gleneida. Low phosphorus concentrations were associated with these declines. Even with the decrease, Muscoot's TSI was still higher than would have been predicted from its inputs (Amawalk, Diverting, Titicus, and Cross River). Normally the receiving water in a cascading system will show less productivity than its inputs due to predation, die off, and settling. The morphometry of Muscoot may be partly responsible. Most of the reservoir is shallow, so the water is warm and the likelihood of nutrient re-suspension from the sediments by passing storms is increased. In addition, the dendritic morphometry of Muscoot's shoreline creates many backwater areas with abundant macrophyte growth, which greatly restricts flow. All of these factors tend to promote algal growth. Note that TSI results are not available for Diverting Reservoir due to insufficient sampling of the reservoir in 2009.

3.9 What were the total and fecal coliform levels in NYC's reservoirs?

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

Total and fecal coliform results are presented in Figure 3.10, Figure 3.11, and Table 3.4. Note that data used to construct the boxplots are annual 75th percentiles rather than medians. Generally, more than 50% of coliform data is below the detection limit. Using annual medians, the resulting boxplot is compressed at the bottom of the y-axis. By using the 75th percentile, the data are "spread out", making it easier to discern differences among reservoirs.

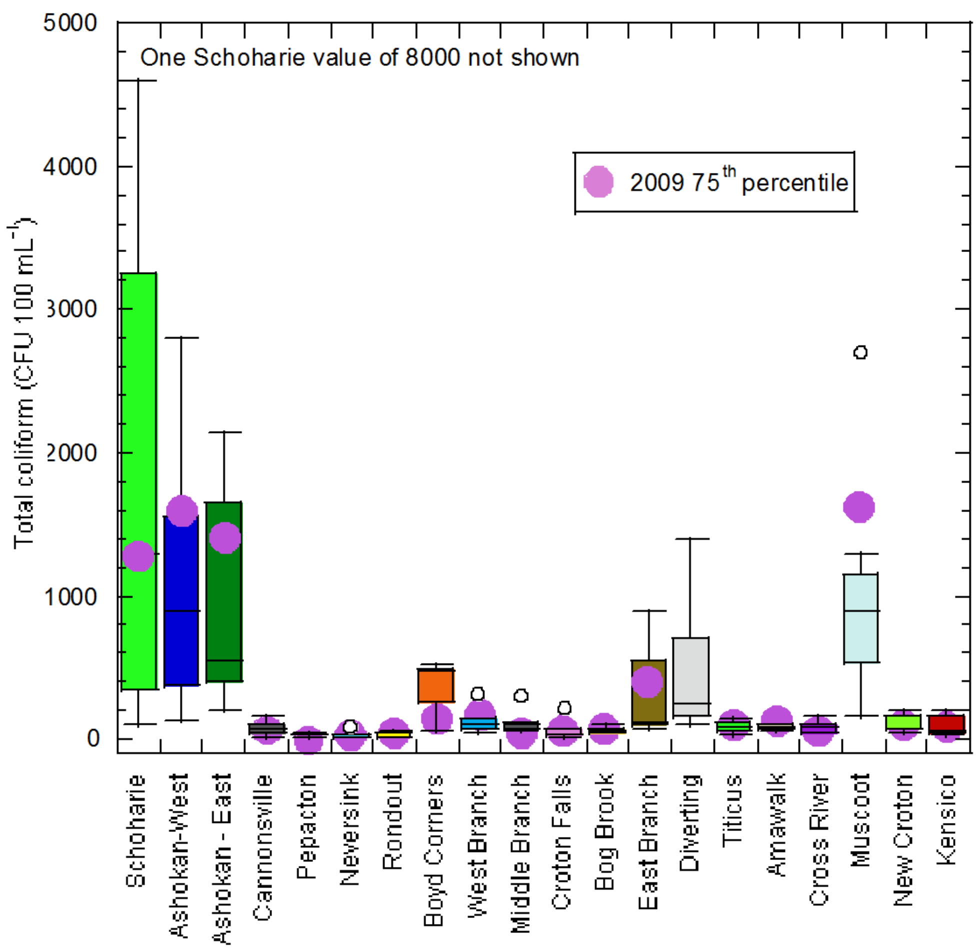

Figure 3.10 Annual 75th percentile total coliform in NYC water supply reservoirs (2009 vs. 2002-2008).

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. In 2009, Diverting Reservoir was not calculated due to insufficient data.

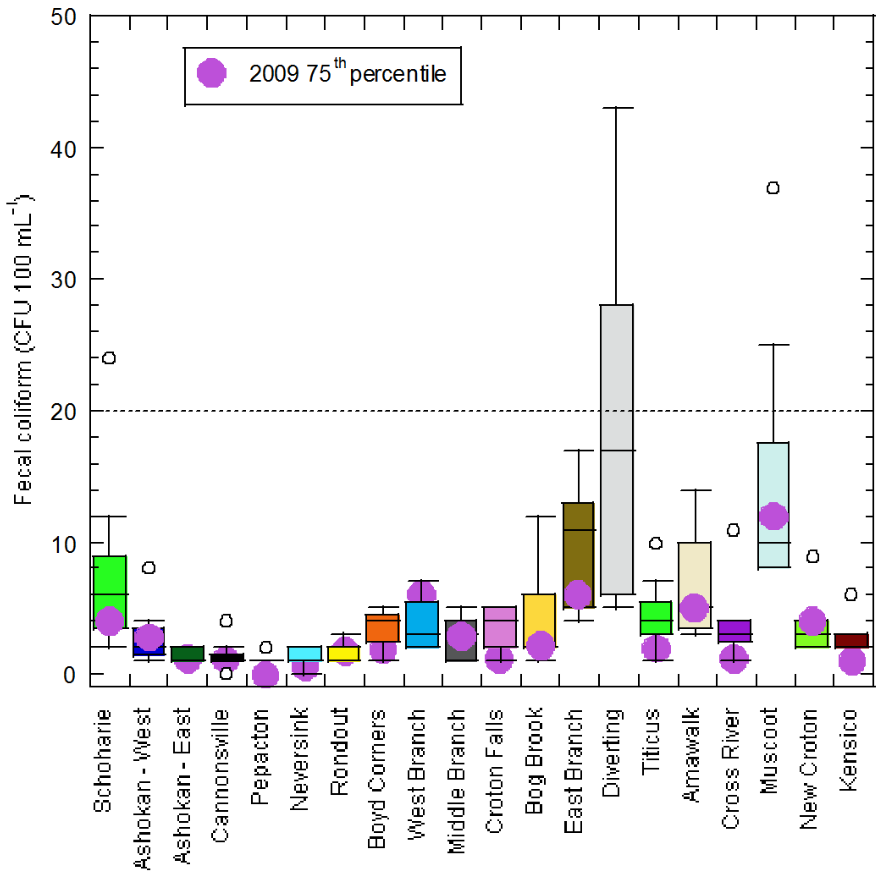

Figure 3.11 Annual 75th percentile of fecal coliform in NYC water supply reservoirs (2009 vs. 2002-2008). The dashed line represents the SDWA standard for source waters as a reference.

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. In 2009, Diverting Reservoir was not calculated due to insufficient data.

Table 3.4: Coliform summary statistics for NYC controlled lakes (CFU 100 mL^{-1}).

Lake	Historical total coliform (75th percentile 2002-08)	Current total coliform (75th percentile 2009)	Historical fecal coliform (75th percentile 2002-08)	Current fecal coliform (75th percentile 2009)
Gilead	42	25	4	4
Gleneida	44	12	1	1
Kirk	150	180	4	2

Historically, the highest total coliform counts occur in the Catskill System reservoirs (Figure 3.10) and counts continued to be high in 2009. Bacterial productivity usually begins to increase around July and peaks in September, with coliform levels remaining elevated into the fall period. Extensive periods of elevated coliform counts have occurred in all three Catskill basins since 2005 and have coincided with above average runoff in these years. Research has shown that total coliforms commonly adhere to soil particles and are probably transported to the reservoirs in runoff events. The Catskill System is underlain with glacial lacustrine clays that are easily mobilized during large storm events.

In contrast, total coliform counts in the Delaware, and most Croton, reservoirs are typically much lower than those of the Catskills. Because coliforms commonly adhere to soil particles, and soils are less susceptible to erosion in the Delaware and Croton watersheds, an equal volume of runoff tends to produce much lower total coliform counts. Despite less erodible soils, Muscoot and Diverting Reservoirs and Kirk Lake have had historically high total coliform levels. Muscoot and Kirk are much shallower than the other Croton System reservoirs and are susceptible to wind derived re-suspension events which distribute bacteria and detritus into the water column. The shallow depths are also conducive to warm temperatures which allow many types of coliforms to survive. Although not as shallow, Diverting is deeper, but has a small volume, and rapid flow through this reservoir may influence total coliform levels.

In 2009, several Croton reservoirs showed large increases in total coliforms compared to their historical levels, even though the broad Y-axis scale of Figure 3.10 makes this difficult to discern. The increases occurred at East Branch (233%), Croton Falls (212%), Muscoot (206%), and Amawalk (74%). At these reservoirs, the highest coliform counts were associated with rainfall events in June, July, August, and October. Decreases were also apparent, most notably at Boyd Corners and Cross River, down 64% and 78%, respectively. Reasons for these declines are not clear but coliform “blooms” can be extremely short-lived, so it is possible to miss peaks with fixed-frequency sampling. The remaining Croton reservoirs were very close to their long-term annual 75th percentile values.

Most Delaware reservoirs were within their historical levels. West Branch, a blend of Delaware’s Rondout and Croton’s Boyd Corners, was up 57%, reflecting a higher percentage of Boyd Corners water utilized in 2009. Although Boyd Corners median coliform counts decreased for the year, they remained higher than those in Rondout. An increased volume of water withdrawn from Boyd Corners could account for the increase in West Branch.

Reservoir fecal coliform data are summarized in Figure 3.11. The controlled lakes of the Croton System are summarized in Table 3.4. With the exception of West Branch, 2009 fecal counts in the Catskill and Delaware Systems were slightly below or very close to their historical levels. The source of the fecal coliform in West Branch appears to be localized, since counts in that reservoir were higher than in those of its primary inputs, Rondout and Boyd Corners. Fecal coliform counts were very low at Kensico, the terminal reservoir for the Cat/Del System, presumably due to the ongoing success of the waterfowl abatement program.

Fecal coliform counts were generally low in the Croton System in 2009. Notable increases were only apparent at Muscoot and New Croton, and were associated with storms in June, July, and October. Not enough data were collected in 2009 to estimate an accurate 75th percentile for Diverting Reservoir.

3.10 Which basins were coliform-restricted in 2009?

Coliform bacteria are used by water suppliers as indicators of pathogen contamination. To protect its water supply, the New York City Watershed Rules and Regulations restrict potential sources of coliforms in threatened water bodies (DEP 2010a). 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) and 18-48(d)(1), and Sections 18-48(c)(1) and 18-48(d)(2). Section 18-48(a)(1) applies to all reservoirs and Lakes Gilead and Gleneida ("non-terminal basins") and specifies that coliform-restricted assessments of these basins be based on compliance with NYS ambient water quality standard limits on total coliform bacteria (6 NYCRR Parts 701 and 703). 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 is based on compliance with federally-imposed limits on fecal coliforms collected from waters within 500 feet of the reservoir's aqueduct effluent chamber.

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 on each basin. Both the median value and >20% of the total coliform counts for a given month need to exceed the values ascribed to the reservoir class to exceed the standard. Table 3.5 provides a summary of the coliform-restricted calculation results for the non-terminal reservoirs. A detailed listing of these calculations is provided in Appendix D.

Table 3.5: Coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2009). 6 NYCRR Part 703 requires a minimum of five samples per month. **Both** the median value and >20% of the total coliform counts for a given month need to exceed the stated values to exceed the standard.

Reservoir	Class	Standard monthly median/>20% (CFU $100mL^{-1}$)	Number of months that exceeded the standard/ Number of months of data
Amawalk	A	2400/5000	0/8
Bog Brook	AA	50/240	0/6
Boyd Corners	AA	50/240	3/7
Croton Falls	A/AA	50/240	3/7
Cross River	A/AA	50/240	0/8
Diverting	AA	50/240	2/2
East Branch	AA	50/240	2/6
Lake Gilead	A	2400/5000	0/8
Lake Gleneida	AA	50/240	0/6
Kirk Lake	B	2400/5000	0/6
Muscoot	A	2400/5000	1/8
Middle Branch	A	2400/5000	0/8
Titicus	AA	50/240	0/6
Pepacton	A/AA	50/240	0/8
Neversink	A	50/240	0/4
Schoharie	A	50/240	7/8
Cannonsville	A/AA	50/240	3/8

Note: The reservoir class is defined in 6 NYCRR Subpart C. For those reservoirs that have dual designations, the higher standard was applied.

Ten reservoirs never exceeded the Part 703 standard for total coliform in 2010: Amawalk, Bog Brook, Cross River, Lake Gilead, Lake Gleneida, Kirk Lake, Middle Branch, Titicus, Pepacton, and Neversink. Schoharie Reservoir, however, exceeded the standard for seven out of eight months. The remaining reservoirs exceeded the standard for one to three months during the sampling season.

Total coliforms originate from a variety of natural and anthropogenic (man-made) sources. However, Section 18-48(d)(2), 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 3.5 are only presented as an initial assessment of total coliform for the non-terminal basins in 2009.

Terminal Basin Assessments

In 2009, assessments were made for all five terminal basins, and none received a restricted assessment (Table 3.6). 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. The threshold for fecal coliform is 20 CFU $100mL^{-1}$. If 10% or more of the effluent samples measured have values ≥ 20 CFU $100mL^{-1}$, and the source of the coliforms is determined to be anthropogenic, the associated basin is deemed a coliform-restricted basin. If fewer than 10% of the effluent keypoint samples measure ≥ 20 CFU $100mL^{-1}$, the associated basin is deemed non-restricted.

Table 3.6: Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2009.

Reservoir Basin	Effluent Keypoint	2009 Assessment
Kensico	CATLEFF and DEL18	Non-restricted
New Croton	CROGH	Non-restricted*
Ashokan	EARCM	Non-restricted
Rondout	RDRRCM	Non-restricted
West Branch	CWB1.5	Non-restricted

*Data from sites CROGH and CRO1T were used for analysis.

3.11 How did reservoir water conductivity in 2009 compare to previous years?

Conductivity is the measurement of the ability of water to conduct electrical currents. It varies as a function of the amount and type of ions that the water contains. The ions which typically contribute to reservoir conductivity are: calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+1}), potassium (K^{+1}), bicarbonate (HCO_3^{-1}), sulfate (SO_4^{-2}) and chloride (Cl^{-1}). Dissolved forms of iron, manganese, and sulfide may also make significant contributions to the water's conductivity given the right conditions (e.g., anoxia). Background conductivity of water bodies is a function of the watershed's bedrock, surficial deposits, and topography. For example, watersheds underlain with highly soluble limestone deposits will produce waters of high conductivity compared with watersheds comprised of relatively insoluble granite. If the topography of a watershed is steep, deposits tend to be thin and water is able to pass through quickly, thus reducing the ability of the water to dissolve substances. The result is water of low conductivity. Such is the case with NYC's water supply reservoirs.

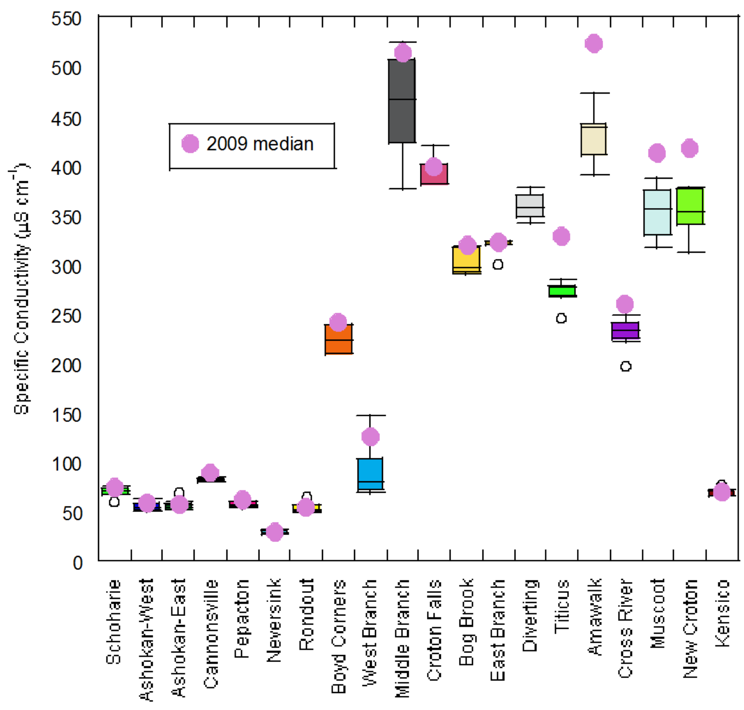

Figure 3.12 Annual median specific conductivity in NYC water supply reservoirs (2009 vs. 2002-2008). Specific conductivity is conductivity at 25°C.

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. However, the median was not calculated in 2009 for Diverting Reservoir due to insufficient data.

Catskill and Delaware System reservoirs have displayed uniformly low median conductivities in the past as well as in 2009 (Figure 3.12). These reservoirs are situated in mountainous terrain underlain by relatively insoluble deposits, which produce relatively low conductivities in the 25 to 100 µS cm^{-1} range. Because West Branch and Kensico generally receive most of their water from the Catskill and Delaware reservoirs, the conductivities of West Branch and Kensico are also low, usually in the 50 to 100 µS cm^{-1} range. Reservoirs of the Croton System have higher baseline conductivities than those of the Catskill and Delaware Systems. In part, this is due to the flatter terrain of the Croton watershed as well as to the occurrence of soluble alkaline deposits (e.g., marble and/or limestone) within the watershed. Another factor is the degree of urbanization pressure in the Croton System. The higher percentage of paved surfaces in more urbanized areas facilitates transport of runoff to waterways and also yields higher salt concentrations due to roadway de-icing operations.

Conductivity in all Catskill and Delaware System reservoirs (including Kensico and West Branch) was higher in 2009 compared to historical median levels. Neversink, Rondout, Ashokan East, and Kensico increased slightly from 3 to 7%. Ten to 14% increases were observed at Ashokan West, Pepacton, Cannonsville, and Schoharie. The largest increase (56%) occurred at West Branch Reservoir. West Branch is a blend of Rondout and the more conductive Boyd Corners Reservoir. In 2009, the Delaware Aqueduct was occasionally shut down and West Branch was often in “float” mode. This led to a greater contribution from Boyd Corners, causing an increase in conductivity. Similar situations occurred in 2002 and 2003 which explains the large variation in conductivity depicted in the West Branch boxplot in Figure 3.12.

Conductivity median values in the Croton System were higher for all reservoirs in 2009 (Figure 3.12). Bog Brook, East Branch, Middle Branch, Boyd Corners, and Croton Falls were close to their historical highs while Amawalk, Titicus, Cross River, Muscoot, New Croton, and Lakes Gilead, Gleneida, and Kirk exceeded their previous highs by an average of 15%. Sufficient data were not available to report on Diverting Reservoir. Although fewer chloride samples than conductivity samples were collected in 2009 on the Croton reservoirs, the increase in conductivity corresponds to an observed increase in chloride. Previous studies have shown that major sources of chloride include salt for de-icing roads, salt from water softener discharge, and even deposition from coastal storms. Additional investigations of weather patterns, de-icing operations, and other factors are necessary before these Croton System conductivity trends can be explained.

3.12 How did water quality status in terminal reservoirs compare with regulatory benchmarks in 2009?

The NYC reservoirs and water supply system are subject to the federal SWTR standards, NYS ambient water quality standards, and DEP's own guidelines. In this section, the 2009 sampling data, encompassing a variety of physical, biological, and chemical analytes for the terminal reservoirs (reservoirs that serve, or potentially serve, as source waters—Kensico, New Croton, Ashokan East and West basins, Rondout, and West Branch), are evaluated by comparing the results to the water quality benchmarks, which are based on the applicable standards or guidelines listed in Table 3.7. Note that the standards in this table are not necessarily applicable to the individual samples and medians described herein (e.g., SWTR limits for turbidity and fecal coliform apply only to the point of entry to the system). It should also be noted that different values apply to Croton reservoirs versus West of Hudson reservoirs. Placing the data in the context of these benchmarks assists in understanding the robustness of the water system and water quality issues.

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Table 3.7: Reservoir and controlled lake benchmarks as listed in the Watershed Water Quality Monitoring Plan.

Analyte	Croton System		Catskill/Delaware System		
	Annual mean	Single sample maximum	Annual mean	Single sample maximum	Basis
Alkalinity (mg L^{-1})	≥40.00		≥10.00		(a)
Total ammonia-N (mg L^{-1})	0.05	0.10	0.05	0.10	(a)
Chloride (mg L^{-1})	30.00	40.00	8.00	12.00	(a)
Chlorophyll *a* (µg L^{-1})	0.010	0.015	0.007	0.012	(a)
Color (Pt-Co units)		15		15	(b)
Primary genus (ASU)		1000		1000	(c)
Fecal coliform (CFU 100 mL^{-1})		20		20	(d)
Nitrate+nitrite-N (mg L^{-1})	0.30	0.50	0.30	0.50	(a)
pH (units)		6.5-8.5		6.5-8.5	(b)
Total phytoplankton (ASU)		2000		2000	(c)
Sodium, undig., filter (mg L^{-1})	15.00	20.00	3.00	16.00	(a)
Soluble reactive phosphorus (µg L^{-1})		15		15	(c)
Sulfate (mg L^{-1})	15.00	25.00	10.00	15.00	(a)
Total dissolved solids (mg L^{-1})	150.00	175.00	40.00	50.00	(a)
Total organic carbon (mg L^{-1})	6.00	7.00	3.00	4.00	(a)
Total dissolved phosphorus (µg L^{-1})		15		15	(c)
Total phosphorus (µg L^{-1})		15		15	(c)
Total suspended solids (mg L^{-1})	5.00	8.00	5.00	8.00	(a)
Turbidity (NTU)		5		5	(d)

(a) NYC Rules and Regulations (p. 123) – based on 1990 water quality results.
(b) NYSDOH Drinking Water Secondary Standard.
(c) DEP internal standard/goal.
(d) NYSDOH Drinking Water Primary Standard.
Note also that additional benchmarks may be developed.

Table 3.8 shows, for each reservoir, the 2009 annual mean for several analytes, the number of samples collected, and the number of those samples that exceeded the single sample maximum in each reservoir. The benchmarks for these analytes are also provided. Appendix A gives additional statistical information for the six reservoirs investigated here and for other reservoirs in the system. The analytes are discussed as groups of related variables.

Table 3.8: Terminal reservoir benchmark comparisons; 2009 annual mean, number of samples collected, and number of samples that exceeded the single sample maximum in each reservoir.

Analyte	Benchmark[3]		Kensico			Ashokan East		
	Single sample maximum	Annual mean benchmark	Number samples	Number exceeded	Annual mean	Number samples	Number exceeded	Annual mean
Alkalinity (mg/L)		≥10	30		11	9		11
Chloride (mg/L)	12	8	24	0	9.1	15	0	7.0
Chlorophyll *a* (µg/L)	12	7	50	0	4.2	24	0	4.1
Color (Pt-Co units)	15		399	7		85	12	
Dissolved organic carbon (mg/L)[1]	4.0	3	193	0	1.7	63	0	1.7
Fecal coliform (CFU/100mL)	20		353	0		86	0	
Nitrate+nitrite-N mg/L)	0.50	0.30	193	0	0.13	63	0	0.06
pH (units)	6.5-8.5		394	64		86	19	
Sodium, undig., filt. (mg/L)	16	3	24	3	7.7	9	0	4.7
Soluble reactive phosphorus (µg/L)	15		193	0		63	0	
Sulfate (mg/L)	15	10	24	1	9.3	15	0	4.6
Total ammonia-N (mg/L)	0.10	0.05	193	0	<0.02	63	3	0.03
Total dissolved phosphorus (µg/L)	15		192	0		63	1	
Total dissolved solids (mg/L)[2]	50	40	-	-	-	-	-	-
Total phosphorus (µg/L)	15		193	0		63	3	
Total phytoplankton (ASU)	2000		206	0		42	0	
Primary genus (ASU)	1000		206	0		42	0	
Secondary genus (ASU)	1000		205	0		42	0	
Total suspended solids (mg/L)	8.0	5	78	0	1.1	63	0	1.7
Turbidity (NTU)	5		399	0		86	3	

Table 3.8: (Continued) Terminal reservoir benchmark comparisons; 2009 annual mean and number of samples that exceeded the single sample maximum in each reservoir.

Analyte	**Benchmar[3]**		**Ashokan West**			**Rondout**		
	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Annual Mean	Number samples	Number exceeded	Annual Mean
Alkalinity (mg/L)		≥10	12		11	12		8.7
Chloride (mg/L)	12	8	20	0	7.3	20	0	6.6
Chlorophyll *a* (µg/L)	12	7	24	1	3.8	24	0	4.3
Color (Pt-Co units)	15		155	40		110	8	
Dissolved organic carbon (mg/L)[1]	4.0	3	77	0	1.7	56	0	1.8
Fecal coliform (CFU/100mL)	20		155	12		110	2	
Nitrate+nitrite-N (mg/L)	0.50	0.30	77	0	0.14	56	0	0.17
pH (units)	6.5-8.5		154	27		109	25	
Sodium, undig., filt. (mg/L)	16	3	12	0	4.5	12	0	4.2
Soluble reactive phosphorus (µg/L)	15		77	0		56	0	
Sulfate (mg/L)	15	10	20	0	4.5	20	0	4.9
Total ammonia-N (mg/L)	0.10	0.05	77	0	0.02	56	0	0.02
Total dissolved phosphorus (µg/L)	15		77	0		56	0	
Total dissolved solids (mg/L)[2]	50	40	-	-	-	-	-	-
Total phosphorus (µg/L)	15		77	4		80	0	
Total phytoplankton (ASU)	2000		45	0		54	0	
Primary genus (ASU)	1000		45	0		54	0	
Secondary genus (ASU)	1000		45	0		54	0	
Total suspended solids (mg/L)	8.0	5	77	3	2.8	28	0	1.1
Turbidity (NTU)	5		155	21		110	0	

Table 3.8: (Continued) Terminal reservoir benchmark comparisons; 2009 annual mean and number of samples that exceeded the single sample maximum in each reservoir.

Analyte	Benchmark[3]		West Branch			New Croton		
	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Annual Mean	Number samples	Number exceeded	Annual Mean
Alkalinity (mg/L)		≥10 (≥40)	15		23	20		68
Chloride (mg/L)	12 (40)	8 (30)	15	15	23	20	20	72
Chlorophyll *a* (µg/L)	12 (15)	7 (10)	31	2	6.5	42	12	13
Color (Pt-Co units)	15		155	101		245	231	
Dissolved organic carbon (mg/L)[1]	4.0 (7.0)	3.0 (6.0)	72	1	2.4	145	0	3.1
Fecal coliform (CFU/100mL)	20		137	8		241	6	
Nitrate+nitrite-N (mg/L)	0.50	0.30	72	0	0.07	145	12	0.26
pH (units)	6.5-8.5		141	3		236	12	
Sodium, undig., filt. (mg/L)	16 (20)	3 (15)	15	4	13	20	20	37
Soluble reactive phosphorus (µg/L)	15		72	0		145	1	
Sulfate (mg/L)	15 (25)	10 (15)	15	0	6.5	20	0	12
Total ammonia-N (mg/L)	0.10	0.05	72	1	0.03	145	17	0.05
Total dissolved phosphorus (µg/L)	15		72	0		145	6	
Total dissolved solids (mg/L)[2]	50 (270)	40 (230)	-	-	-	-	-	-
Total phosphorus (µg/L)	15		72	12		145	60	
Total phytoplankton (ASU)	2000		68	1		49	11	
Primary genus (ASU)	1000		68	1		49	9	
Secondary genus (ASU)	1000		68	0		49	2	
Total suspended solids (mg/L)	8.0	5	9	0	1.8	46	0	1.6
Turbidity (NTU)	5		155	1		245	7	

[1]Dissolved organic carbon was used in this analysis since TOC is no longer analyzed. In NYC reservoirs the dissolved organic carbon comprises the majority of the total organic carbon.

[2]Total dissolved solids were not analyzed.

[3]Croton values are in parentheses.

Highlights of the benchmark comparisons are as follows. New Croton pH can temporarily rise above the water quality benchmark of 8.5, especially in the upper waters during summer algal blooms. The pH readings in WOH reservoirs were generally circumneutral. As a result of low alkalinity, however, readings can drop below the benchmark of 6.5, which they occasionally did in 2009. Alkalinity provides a buffer for acidic precipitation. Another factor contributing to lower pH values at depths below the thermocline is the acidifying effect of respiration. The pH values in Kensico are strongly influenced by the WOH reservoirs.

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}. Only Kensico and West Branch exceeded the benchmark for chloride for the WOH reservoirs. Since these two impoundments are located East of Hudson, they are influenced by local sources of chloride, which tend to have higher concentrations of the ion than the WOH water that primarily supplies these reservoirs. However, all chloride samples were much lower than the health standard of 250 mg L^{-1}. All terminal reservoirs exceeded the annual mean benchmark for sodium, and all New Croton samples also exceeded the single sample maximum of 20 mg L^{-1}.

Turbidity levels in Kensico and Rondout Reservoirs never exceeded the single sample maximum of 5 NTU. New Croton turbidity exceeded 5 NTU in seven samples. Four of these samples were collected at 3 m depth during phytoplankton blooms in August 2009. The other three occurred when hypoxia caused hypolimnetic waters to release metals from the sediments. This was the same reason West Branch and Ashokan East Basin had samples above the turbidity benchmark. Turbidity readings in Ashokan West Basin surpassed the benchmark during rain events in May, June, August, October, and November. These were not major storms compared to events in previous years that substantially raised the turbidity.

Total phosphorus values were lower than the single sample maximum of 15 $\mu g\ L^{-1}$ for all samples in Kensico and Rondout in 2009. High values in the Ashokan West Basin were mostly associated with a runoff event in November. The East Basin of Ashokan was above the guidance value in three bottom samples as a result of anoxic sediments during late summer. West Branch Reservoir was above the benchmark for TP in12 samples, primarily in the Site 4 basin. This basin is isolated by a causeway and comprised of water from the local watershed, whereas the main basin is strongly influenced by Rondout water. New Croton Reservoir had 41% of the samples above the benchmark for TP. Hypoxic conditions caused a large number of these occurrences, while algal blooms coincided with elevated TP levels in surface samples. Nitrate was uniformly low in all WOH reservoirs. New Croton had 12 samples above the 0.5 mg L^{-1} single sample maximum. Ammonia was very low for WOH terminal reservoirs, with only three samples above the benchmark, all in Ashokan East Basin. These were related to anoxic conditions in the early fall. Low dissolved oxygen levels were also responsible for the 17 samples above the benchmark in New Croton.

The Croton System typically has greater nutrient inputs than the WOH reservoirs, which results in higher phytoplankton counts and chlorophyll *a* levels. In 2009, phytoplankton counts in the WOH terminal reservoirs were above the 2000 ASU benchmark in only one sample, in the Site 4 basin of West Branch Reservoir. New Croton Reservoir had a diatom bloom in May and a bloom of cyanobacteria in August that caused 11 samples to exceed the benchmark. Chlorophyll *a* for New Croton exceeded the single sample maximum in 12 samples, while the annual average was just above the benchmark of 10 $\mu g\ L^{-1}$.

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 65% of the samples exceeding this benchmark. Both reservoirs are within the Croton watershed, which has higher background levels of colored substances, such as humic acids. The highest color readings were observed in bottom samples during summer, when iron and manganese were released from sediments and further discolored the water. WOH reservoirs have less humic input from their watersheds, and as a result, a smaller percentage of samples exceeded the color benchmark. One exception was Ashokan West, where 26% of the samples exceeded the color benchmark. Reasons for the elevated color levels varied, including runoff events with corresponding readings of elevated turbidity, increases of turbidity levels in bottom samples, which can interfere with color measurements, and surface readings potentially elevated by algal activity.

Fecal coliform counts in Kensico and Ashokan East Basin did not exceed the single sample maximum of 20 CFU 100 mL^{-1}. Ashokan West exceeded the benchmark in 8% of the samples, primarily caused by rain events in May, June, and July. Rondout Reservoir samples exceeded the threshold in only 2% of the samples. Summer rainstorms and a storm in November contributed to the 6% of samples that exceeded the maximum in West Branch Reservoir. In New Croton Reservoir, only 2% of the samples exceeded the standard. In contrast to some of the WOH reservoirs, summer rain events were not responsible for New Croton's elevated fecal coliform counts. An event in October accounted for the majority of the samples above the benchmark.

3.13 Has DEP monitoring of watershed streams revealed any changes to the macroinvertebrate community?

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994, using protocols developed by the DEC's Stream Biomonitoring Unit (SBU) (DEC 2009). Streams are sampled in areas of riffle habitat, using the traveling kick method; collected organisms are preserved in the field and later identified, following which a series of metrics is generated from the tallies of macroinvertebrates found to be present. The metric scores are converted to a common scale and averaged, to produce a single biological assessment profile (BAP) score of 0-10 for each site, corresponding to non (7.5-10), slightly (5-7.5), moderately (2.5-5), or severely (0-2.5) impaired. A change (or lack of change) to the macroinvertebrate community, as reflected in the BAP score, can provide important information to DEP managers. This is because sites are often selected to evaluate impacts from land use changes or BMPs, or to assess conditions in major reservoir tributaries.

Through the close of the 2009 sampling season, DEP had established 165 sampling sites in streams throughout the water supply watershed, with the greatest number in the Catskill System, followed by Croton and Delaware. Many of these sites have been sampled for only a few years, because sampling began at later dates at some sites than at others, and because only routine sites are sampled annually. To investigate changes to the macroinvertebrate community, only sites with a 5-year-or-better record that were sampled in 2009 were examined, to reduce the chances that short-term variation, or aberrant samples, might unduly influence the analysis. (For sites with a five-year-or-better record not sampled in 2009, see DEP 2008.) Twenty-seven sites met the 5-year criterion, 12 in the Croton System, 7 in Catskill, and 8 in Delaware (Figure 3.13). Of these, all but six are routine sites (generally, major tributaries to receiving reservoirs).

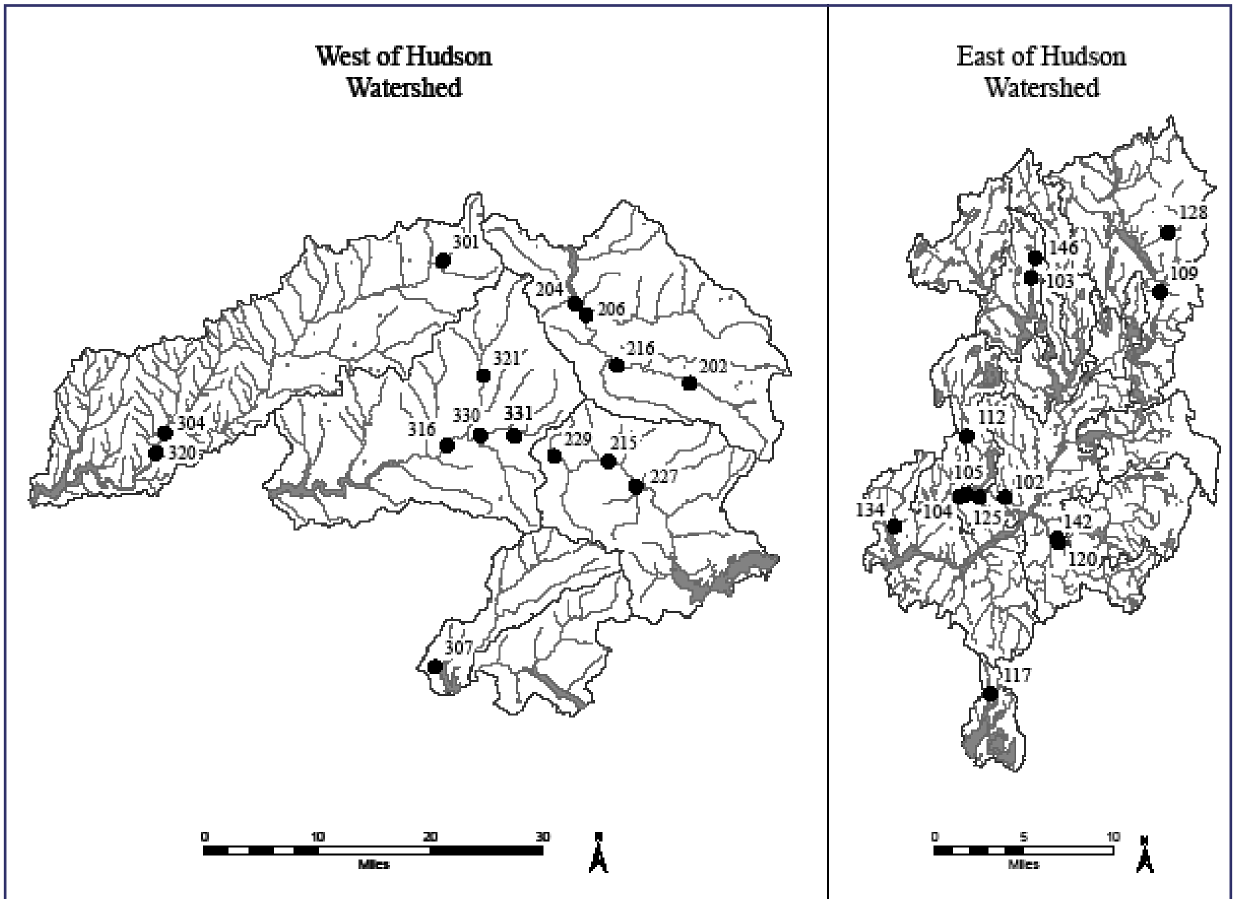

Figure 3.13 Stream biomonitoring sites with a 5-year-or-better record.

The data are plotted in Figures 3.14 and 3.15 for the East of Hudson and West of Hudson watersheds, respectively. The Kendall tau coefficient of rank correlation was used to test for trends in BAP scores over time. Of the 26 sites examined, 24 displayed no significant trend (i.e., $p>0.05$), suggesting that habitat and water quality conditions in these indicator streams remained relatively stable during the period of record. The two sites where a trend was detected, both in the East of Hudson watershed, are marked with red arrows in Figure 3.14, an upward pointing arrow indicating a positive trend, and a downward pointing one the reverse.

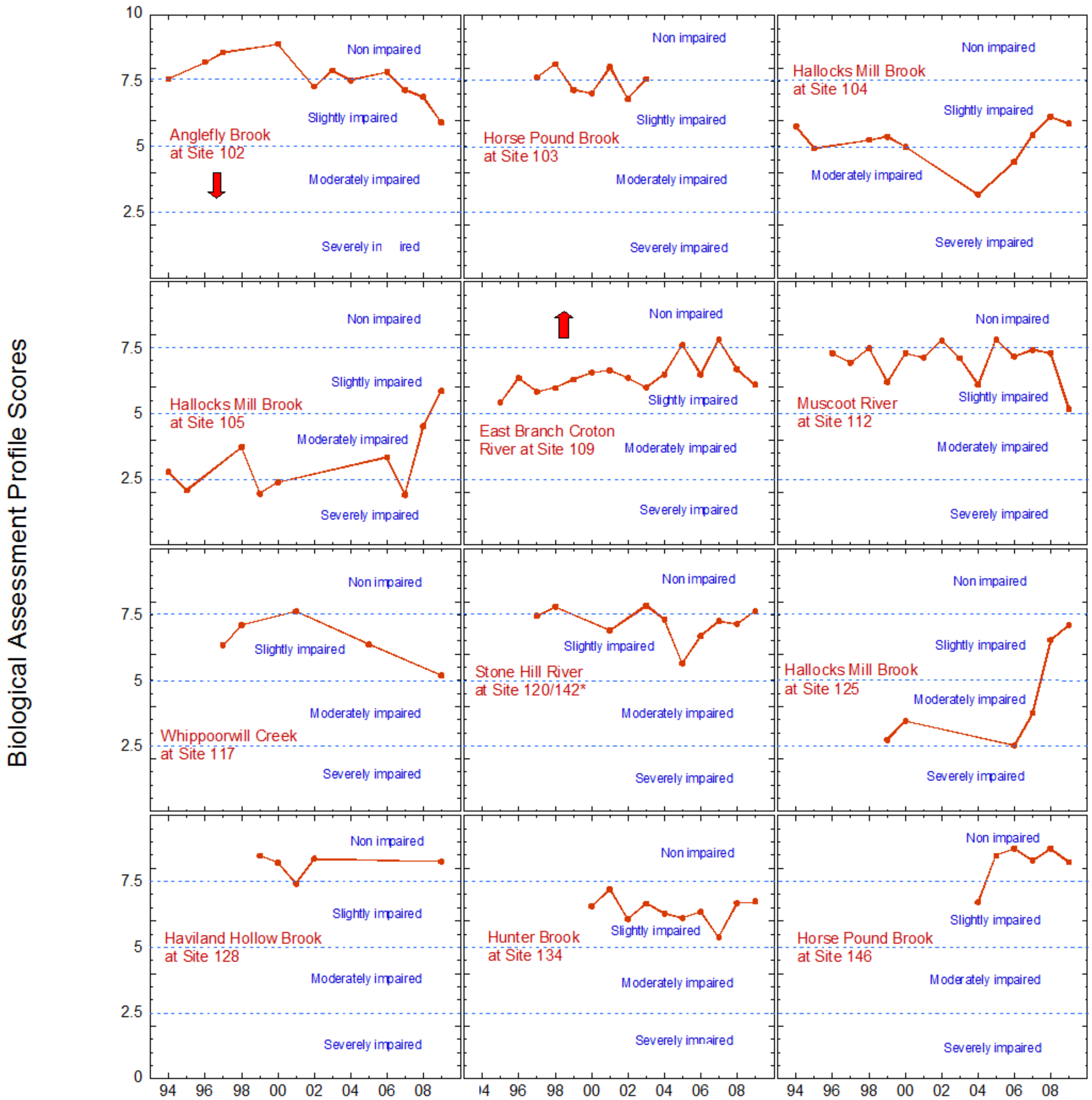

Figure 3.14 Biological Assessment Profile scores based on stream biomonitoring data for East of Hudson streams with a 5-year-or-better record.

*The Stone Hill River site was moved from Site 120 to Site 142 in 2003. Data for the combined sites are plotted as a single graph.

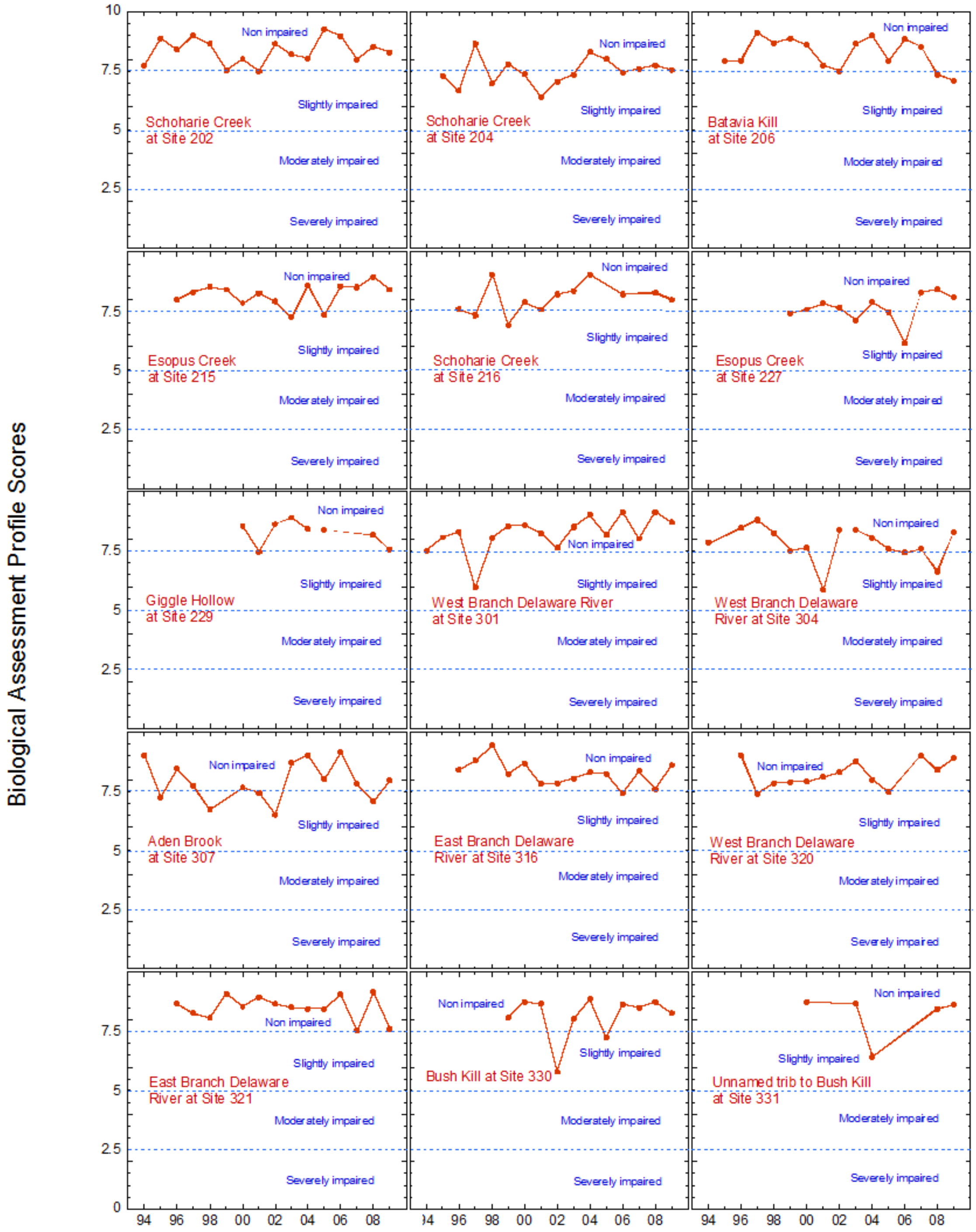

Figure 3.15 Biological Assessment Profile scores based on stream biomonitoring data for West of Hudson streams with a 5-year-or-better record.

The downward trend was observed at Anglefly Brook (Site 102), a stream which, though assessed as non-impaired in every year but one from 1994-2006, has rated as slightly impaired in every year since then. The three consecutive years of slightly impaired assessments (2007-2009) have been accompanied by successive drops in score, reaching a new low in 2009 of 5.9, just above the slightly impaired/moderately impaired threshold. These declines are largely attributable to declining percent model affinity (PMA) scores, which have been falling since 2003; only since 2007, however, has the drop been sharp enough to produce slightly impaired assessments (Figure 3.16). The falling PMA scores reflect large increases in the number of caddisflies (mostly members of the tolerant family Hydropsychidae) and lower numbers of mayflies. The reason for the falling scores is not known, as there has been no recent development activity in the stream's watershed, nor any indication that habitat conditions in the stream have degraded (e.g., failing streambanks, removal of canopy). DEP will continue to monitor the stream to try to identify the disturbance responsible for this downward trend.

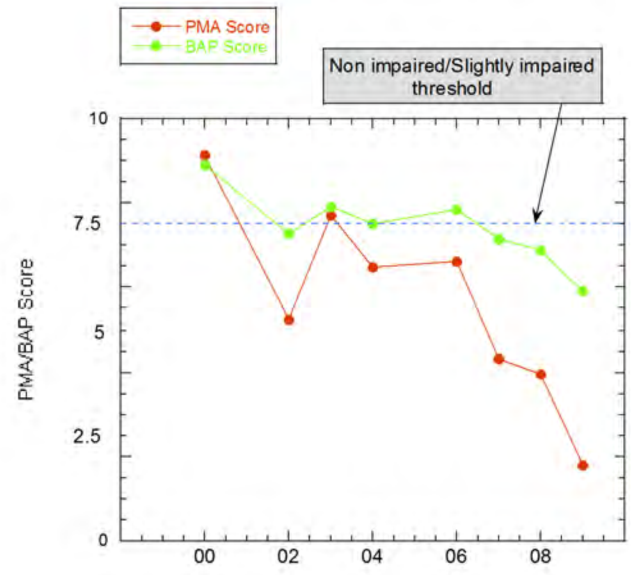

Figure 3.16 Percent Model Affinity (PMA) versus Biological Assessment Profile (BAP) scores for Anglefly Brook, 2000-2009. Percent Model Affinity is a measure of the macroinvertebrate community's similarity to a model non-impacted community as defined by the NYS Stream Biomonitoring Unit.

The upward trend at Site 109 on the East Branch Croton River in the Town of Southeast does not reflect an overall improvement in assessment, which remains slightly impaired. Rather, it appears to be largely a function of the non-impaired scores in 2005 and 2007, which in turn resulted from the dominance of mayflies in those years. This contrasts with the usual outcome at this site, namely, low mayfly numbers and the predominance of other groups, usually hydropsychid caddisflies. Which of these patterns—high mayflies versus dominance by other groups—will continue in future years is unknown, as are the reasons for the fluctuations in mayfly abundance. Following the non-impaired score in 2007, mayfly numbers dropped in 2008 and beetle numbers rose, resulting in a return to a slightly impaired assessment in that year. In 2009, while mayfly numbers returned to 2007 levels, heavy rain and correspondingly high flows at the time of sampling resulted in much higher than usual amphipod numbers. This depressed the PMA metric and quite possibly the total taxa richness metric as well, resulting in a score of 6.1 and another slightly impaired assessment. Additional sampling will be required to determine if, under normal flow conditions, mayfly numbers rise and assessments return to the non-impaired range.

Several other sites, although not yet showing any detectable trend, bear watching. Scores at Giggle Hollow (Site 229), a tributary to Birch Creek in the watershed of the planned Belleayre Resort, have declined continuously since 2003. The stream is still rated as non-impaired, but only barely. Site 117 on Whippoorwill Creek in the Kensico Reservoir watershed, which assessed as non-impaired in 2001, has recorded successive declines on the two sampling dates since then (2005 and 2009). The most recent score, 5.2, is only marginally above the slightly impaired/moderately impaired threshold. Eroding streambanks introduce significant quantities of suspended solids into this stream, a problem scheduled to be addressed in the near future by installation of stream stabilization structures. On the positive side, scores from the last three years at Site 227, on Esopus Creek below the Shandaken Tunnel Portal, are the highest recorded since sampling began there in 1999. In addition, the benthic communities at the two sites on Hallocks Mill Brook below the Yorktown Heights WWTP have clearly improved since the plant's upgrade (DEP 2008b, Section 3.14). The failure of the Kendall rank correlation test to detect a significant trend is almost certainly a function of insufficient *n* (i.e., low sample numbers). These sites will be revisited in 2010.

3.14 What can sampling a stream's macroinvertebrate community tell us about the effectiveness of wastewater treatment plant upgrades?

Stream water quality plays a large role in the composition of benthic macroinvertebrate communities, since unpolluted streams generally harbor more sensitive organisms and a more diverse assemblage than streams whose water quality is poor. Because upgrades to wastewater treatment plants often result in improved water quality to the receiving stream, the effectiveness of these enhancements can often be measured by sampling the stream's macroinvertebrate community and noting any changes that might indicate improved community composition. Chief among these changes is an increase in the biological assessment profile (BAP) score, derived from applying protocols used by the NYS Stream Biomonitoring Unit (DEC 2009). Other critical measures include an increase in the number of sensitive organisms, like mayflies, caddisflies, and stoneflies, as well as the number of total taxa.

In 2008, DEP gathered data providing strong evidence that improvements at the Yorktown Heights wastewater treatment plant in Westchester County, NY, resulted in an improved biotic community in the receiving stream, Hallocks Mill Brook. (For details, see DEP 2008b). Prior to the upgrade, Hallocks Mill Brook was the most seriously impacted stream in the entire New York City water supply watershed, with scores well below the average for other streams both East and West of Hudson. The poor state of the macroinvertebrate community was largely due to the high levels of ammonia in the plant's discharges. Following reductions in the ammonia levels, the site located farthest downstream of the plant (Site 125) was rated as slightly impaired (the second highest category) for the first time ever. Almost one-third of the sample was composed of mayflies, a sensitive group of organisms never before recorded at the site. At the site just downstream of the plant's discharge (Site 105), no sensitive organisms were observed, but the score climbed to 4.38, a record high, though still in the moderately impaired range.

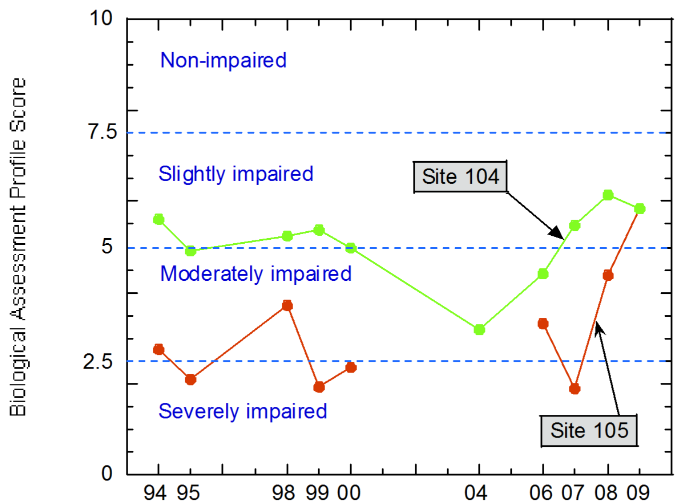

Figure 3.17 Comparison of Biological Assessment Profile scores for Hallocks Mill Brook above the Yorktown Heights WWTP outfall (Site 104) and below the outfall (Site 105), 1994-2009. Site 105 was not sampled in 2004.

The data from 2009 indicate that conditions at these sites have continued to improve. With ammonia levels in the stream falling to below the detection limit (0.020 mg L^{-1}) for the first time, Site 125's BAP score rose to a new high of 7.12, higher than the long-term average for all other East of Hudson streams (6.50), and close to a rating of non-impaired (Figure 3.14). Moreover, the nine taxa of mayflies and caddisflies present in the sample was the greatest number of these taxa ever recorded in Hallocks Mill above or below the wastewater treatment plant. For its part, Site 105 achieved slightly impaired status for the first time (Figure 3.14), indicating that in the year since the previous sampling date, more sensitive organisms had made their way upstream from Site 125 and/or downstream from the site above the plant's outfall (Site 104) in response to improved water quality conditions. Site 105's BAP score (5.85) was virtually the same as Site 104's (5.86) (Figure 3.17), providing further evidence that the plant's effluent is no longer a source of impairment to the stream. The improvement in Site 105's score was largely attributable to the presence of 6 mayflies in the sample, five of which were members of the particularly sensitive taxa Heptageniidae and *Isonychia*. For comparison, only one mayfly had ever been collected from the site before, and it belonged to one of the more tolerant mayfly genera.

The dramatic improvement in the benthic community observed in the last two years at the two sites downstream of the plant's outfall provides convincing evidence that plant upgrades have significantly improved water quality in Hallocks Mill Brook. DEP will return to these sites in 2010 to see if assessments at these sites continue to improve, and if Site 104 (representative of conditions in Hallocks Mill Brook above the discharge) and the Muscoot River continue to contribute sensitive taxa to the sites below the discharge.

3.15 What are disinfection by-products, and did organic concentrations in source waters allow DEP to meet compliance standards in the distribution system in 2009?

Disinfection by-products (DBPs) form when naturally occurring acids from decomposing vegetative matter (such as tree leaves, algae, and macrophytes) react with chlorine from chlorination of drinking water. DEP adds the chlorine to kill bacteria and viruses that can cause disease. The quantity of DBPs in drinking water varies from day to day depending on the temperature, the quantity of organic material in the water, the quantity of chlorine added, and a variety of other factors.

DEP monitors two important groups of DBPs: trihalomethanes (TTHM) and haloacetic acids (HAA). The TTHMs include chloroform, bromoform, bromodichloromethane, and chlorodibromomethane. Chloroform is the main constituent of this group. The HAAs include mono-, di-, and trichloroacetic acids, and mono- and dibromoacetic acids. USEPA has set limits on these groups of DBPs under the Stage 1 Disinfectant/Disinfection By-Products Rule. The Maximum Contaminant Level (MCL) for TTHM is 80 $\mu g\ L^{-1}$ and the MCL for the five haloacetic acids covered by the rule (HAA5) is 60 $\mu g\ L^{-1}$. According to the Stage 1 Rule, monitoring is required to be conducted quarterly from designated sites in the distribution system, which represent the service areas, and not necessarily the source water, for each system. The MCL is calculated as a running annual average based on quarterly samplings over a 12-month period. The 2009 annual running quarterly averages are presented in Table 3.9 and show system compliance for TTHM and HAA5 in both the Catskill/Delaware and Croton Distribution Areas of New York City.

Table 3.9: Stage 1 distribution system annual running quarterly average DBP concentrations ($\mu g\ L^{-1}$) for 2009.

	Catskill/Delaware		Croton	
2009 Quarter	TTHM	HAA5	TTHM	HAA5
1st	38	40	49	46
2nd	36	38	45	42
3rd	38	40	48	44
4th	43	43	49	44
MCL	80	60	80	60

3.16 How does DEP protect the water quality of the Catskill Aqueduct at Kensico Reservoir from stormwater impacts?

Figure 3.18 Turbidity curtain in Kensico Reservoir at the Catskill Upper Effluent Chamber (UEC) diverts stormwater away from the intake.

DEP has a two turbidity curtains installed in Kensico Reservoir near the vicinity of the Catskill Effluent (the Aqueduct intake). These curtains divert water from Malcolm Brook away from the intake and out into the main body of the reservoir. This allows turbidity from stormwater to settle to the reservoir bottom before the water enters the intake. Approximately every two weeks, DEP inspects the curtains to ensure they are in good operating condition. The inspection record is presented below. There was only one instance—in September—when inspections showed that the boom had come loose from the shoreline and therefore needed repair. The damage was reported and inspection one week later documented that the repair had been made.

Table 3.10: Turbidity curtain inspection dates and observations in 2009.

Date	Observation
1/9/2009	The main boom and the deflecting boom are intact and anchored.
1/21/2009	Boom appears in good condition from shore, frozen in.
2/5/2009	Boom appears in good condition from shore, frozen in.
2/18/2009	Boom appears in good condition from shore, frozen in.
3/4/2009	Boom appears intact from shore, partially frozen in.
3/19/2009	Boom appears intact from shore—no ice.
4/1/2009	Boom appears in good condition from shore.
4/15/2009	Boom appears in good condition from shore.
4/29/2009	Boom appears in good condition from shore.
5/13/2009	Boom appears in good condition as is the shore boom south of the UEC.
5/27/2009	Boom appears in good condition as is the shore boom south of the UEC.
6/11/2009	Boom appears in good condition from shore.
6/24/2009	All booms appear to be in good condition.
7/9/2009	All booms appear to be in good condition.
7/27/2009	All booms appear to be in good condition.
8/5/2009	All booms appear to be in good condition. Contractor working in cove.
8/19/2009	All booms appear to be in good condition. Contractor working in cove.
9/3/2009	All booms appear to be in good condition. Contractor working in cove.
9/10/2009	UEC shoreline boom came apart; compromised. MH called in BRK survey.
9/17/2009	All booms appear to be in good condition.

Table 3.10: (Continued) Turbidity curtain inspection dates and observations in 2009.

Date	Observation
10/1/2009	All booms appear to be in good condition.
10/15/2009	All booms appear to be in good condition.
10/28/2009	All booms appear to be in good condition.
11/12/2009	All booms appear to be in good condition.
11/25/2009	All booms appear to be in good condition.
12/10/2009	All booms appear to be in good condition.
12/23/2009	All booms appear to be in good condition.

3.17 Did the first year of data for the Cannonsville Recreational Boating Pilot study show any significant water quality impacts?

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

3.18 What was the status of compliance with applicable benchmarks for NYC's streams in 2009?

Select water quality benchmarks have been established in the City's Watershed Rules and Regulations (DEP 2010a). In this section stream status is evaluated by comparing 2009 results from 39 streams to the benchmarks listed in Table 3.11.

Table 3.11: Stream water quality benchmarks as listed in the Watershed Rules and Regulations.

	Croton System		Catskill/Delaware System (including Kensico)	
	Annual Mean	Single Sample Maximum	Annual Mean	Single Sample Maximum
Alkalinity (mg $CaCO_3$/L)	N/A	$\geq$40.00	N/A	$\geq$10.00
Ammonia-N (mg L^{-1})	0.1	0.2	0.05	0.25
Chloride (mg L^{-1})	35	100	10	50
Nitrite+nitrate–N (mg L^{-1})	0.35	1.5	0.4	1.5
Organic nitrogen (mg L^{-1})[1]	0.5	1.5	0.5	1.5
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 are currently not analyzed.

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

Results from this analysis are provided in Appendix E along with site descriptions, which appear next to the site codes. In general, the WOH streams showed few instances where these analytes exceeded the benchmarks. The EOH streams had more samples that exceeded the benchmarks for some analytes. The highlights from Appendix E follow.

Results for alkalinity indicate that 17 streams located in the Catskill and Delaware Systems are generally below the benchmark alkalinity of 10 mg L^{-1} for a single sample. Such low buffering capacity is typical of the bedrock in some areas of the Catskills. Alkalinity is also important for effective use of alum during turbidity events. The Croton System streams have much higher natural buffering capacity and no samples were below the benchmark of 40 mg L^{-1} in 2009.

The single sample chloride benchmark of 100 mg L^{-1} was routinely exceeded on the Muscoot River above (MUSCOOT10) and below (AMAWALKR) Amawalk Reservoir, on Michael Brook (MIKE2) above Croton Falls Reservoir, and on the Kisco River (KISCO3), a tributary of the New Croton Reservoir. The annual mean chloride at these sites ranged from 97 to 168 mg L^{-1}, greatly exceeding the annual mean benchmark of 35 mg L^{-1}. In all, 14 of the 16 monitored Croton streams exceeded this annual mean benchmark. The two sites that did not go above the benchmarks were Gypsy Trail Brook and West Branch Release. Potential sources of chloride at the other sites include road salt, septic system leachate, water softening brine waste, and wastewater treatment effluent. While no Catskill or Delaware stream exceeded the single sample benchmark in 2009, the annual mean benchmark of 10 mg L^{-1} was exceeded in 7 of the 22 streams monitored in these two systems. The highest annual mean, 31 mg L^{-1}, occurred at Kramer Brook above Neversink Reservoir. This watershed is very small (<1 sq. mile) with pockets of development that may contribute to the relatively high chloride levels. Other high annual means occurred at Bear Kill Creek (17.3 mg L^{-1}), a tributary to Schoharie Reservoir, and at Chestnut Creek (14.4 mg L^{-1}), a tributary to Rondout Reservoir. Both sites are located downstream of WWTPs.

As expected, all streams associated with elevated chlorides also exceeded benchmarks for sodium. Sodium and chloride commonly occur together as salt, a popular road de-icer and water softener component.

When present in excess, nitrogen, especially in the bioavailable forms of nitrate and ammonia, is one of the important nutrients which can contribute to excessive algal growth in the reservoirs. The single sample nitrate benchmark of 1.5 mg L^{-1} was exceeded in only one stream, Michael Brook, located upstream of Croton Falls Reservoir. The benchmark was exceeded in 6 of 12 monthly samples and was especially high in January (2.8 mg L^{-1}), February (2.5 mg L^{-1}), and August (3.3 mg L^{-1}). Three Croton streams exceeded the annual benchmark of 0.35 mg L^{-1} for 2009: the Kisco River, 0.566 mg L^{-1} at KISCO3; the Muscoot River, 0.63 mg L^{-1} at MUSCOOT10; and Michael Brook, 1.579 mg L^{-1} at MIKE2. Two streams in the Delaware System exceeded the annual benchmark of 0.40 mg L^{-1}. The 2009 averages at Kramer Brook and the West Branch of the Delaware River at Beerston were 0.481 and 0.410 mg L^{-1}, respectively. Most of these sites are downstream of WWTPs, the probable source of the elevated nitrate, sulfate, and chlorides. At Kramer Brook failing septics are the likely source.

These data indicate that the issues EOH include WWTP effluents and the use of road salt, whereas WOH, localized impacts of wastewater may be present.

3.19 What were the water quality trends in NYC's reservoirs as of 2009?

This section examines recent temporal trends from 2002-2010 for Kensico and New Croton, the terminal reservoirs for the Catskill/Delaware and Croton Systems, respectively. To increase confidence in the results, two independent techniques were used to detect trends for most analytes. First, locally-weighted scatterplot smoothing (LOWESS) curves were fit to the data to describe both the long-term and intermediate data patterns (Cleveland 1979). Second, the occurrence of long-term monotonic trends was tested using the nonparametric Seasonal Kendall Test (Hirsch et al. 1982). The magnitude of detected trends was determined using the Seasonal Kendall Slope Estimator (Hirsch et al. 1982). Different techniques were required for fecal coliform data, where results were often below the detection limit and where detection limits varied over the period of record. In these cases DEP used methods recommended by Helsel (2005) to determine the statistical significance of the trend and to fit the data with the Akritas-Theil-Sen line, a non-parametric regression based on Kendal's Tau. See Appendix F for a more detailed description of the methods used.

The *p*-values for all trend tests are symbolized as follows:

p- value	Significance	Symbol
$p \geq 0.20$	None	NS
$p < 0.20$	Moderate	*
$p < 0.10$	High	**
$p < 0.05$	Very High	***

Kensico Reservoir

Water quality temporal plots from 2002-2009 are presented in Figures 3.19 and 3.20. Results of the Seasonal Kendall trend analysis are provided in Table 3.12, along with monthly precipitation trend results for all major basins which supply Kensico Reservoir. Water quality analytes listed in the table pertain only to Kensico Reservoir.

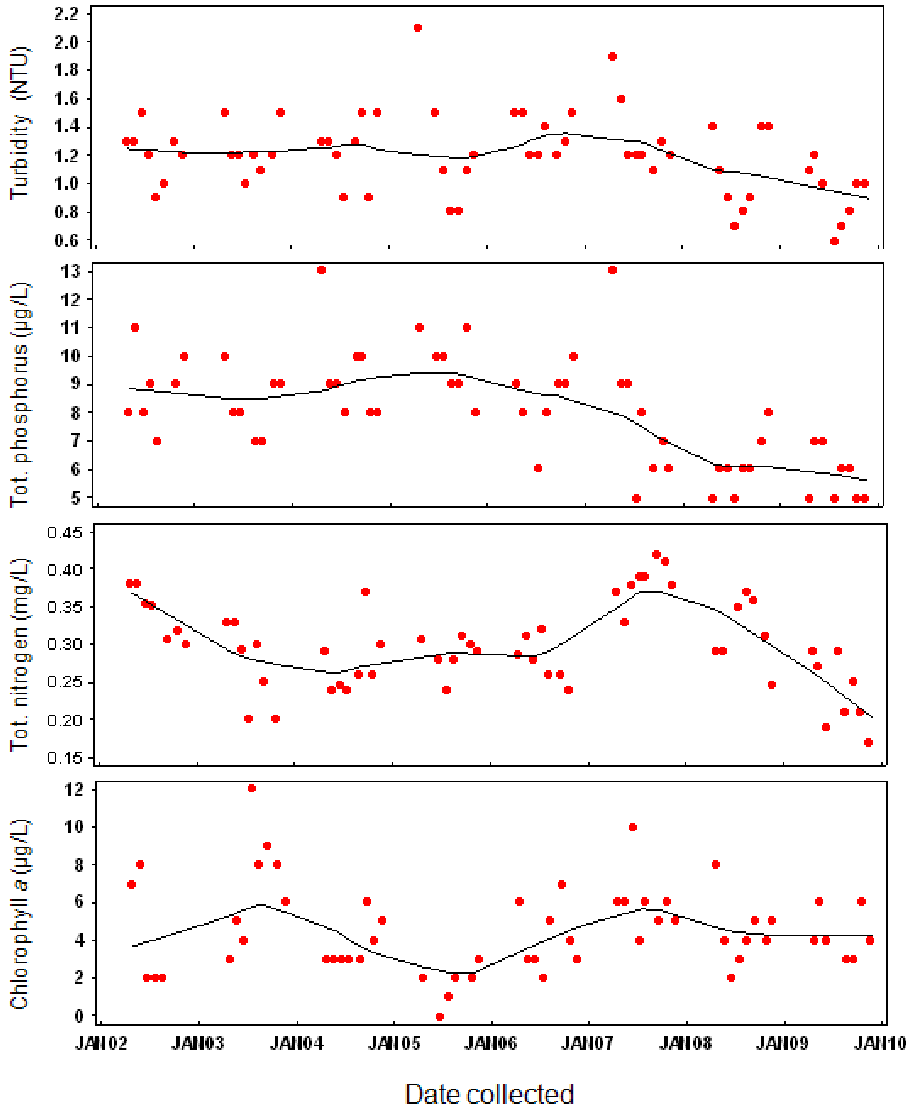

Figure 3.19 Kensico Reservoir temporal plots of selected water quality analytes. Red dots are monthly medians. The black line is a LOWESS curve with a 30% smooth factor. Chlorophyll medians were calculated from samples collected at all sites at a depth of 3 meters and represent surface water conditions. Turbidity, total phosphorus, and total nitrogen medians were calculated from all sites and depths and represent whole reservoir conditions.

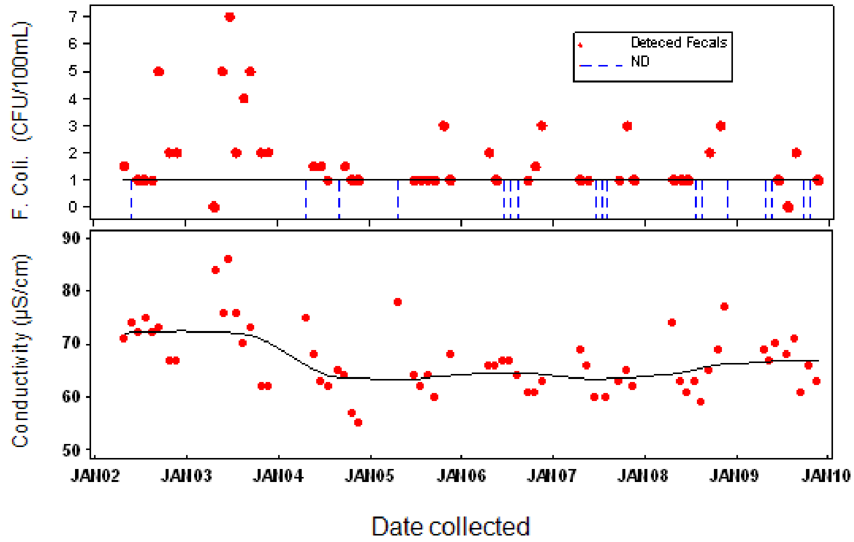

Figure 3.20 Kensico Reservoir temporal plots of selected water quality analytes. Red dots are monthly medians. The black line on the fecal coliform plot is the Akritas-Theil-Sen line, while the dashed blue lines indicate non-detects. On the conductivity plot the black line is a LOWESS curve with a 30% smooth factor. Fecal coliform and conductivity medians were calculated using samples collected from all sites and depths and represent whole reservoir conditions.

Table 3.12: Kensico Reservoir trend results.

Analyte	Months sampled yr^{-1}	n	Tau	*p*-value	Change yr^{-1}	%Change [1] (2002-09)
Precipitation $_{Cannonsville}$ (in.)	12	96	-0.12	*	-0.09	-2
Precipitation $_{Pepacton}$ (in.)	12	96	-0.15	**	-0.11	-3
Precipitation $_{Neversink}$ (in.)	12	96	-0.09	NS	-0.07	-2
Precipitation $_{Rondout}$ (in.)	12	96	-0.04	NS	-0.06	-2
Precipitation $_{Schoharie}$ (in.)	12	96	-0.14	*	-0.17	-5
Precipitation $_{Ashokan}$ (in.)	12	96	-0.09	NS	-0.10	-2
Precipitation $_{Kensico}$ (in.)	12	96	-0.06	NS	-0.08	-2
Turbidity (NTU)	8	63	-0.22	***	-0.03	-2
Total Phosphorus (µg L^{-1})	8	60	-0.44	***	-0.50	-6
Total Nitrogen (mg L^{-1})	8	59	-0.16	*	-0.01	-2
Chlorophyll *a* (µg L^{-1})	8	58	-0.15	NS	0.00	0
Fecal coliform (CFU 100 mL^{-1})	8	63	-0.28	***	0.00	na
Conductivity (µS cm^{-1})	8	63	-0.23	***	-1.00	1

[1] %Change $_{(2002-09)}$ = (Change yr^{-1} ÷ median $_{(2002-09)}$) x 100.

Decreasing trends in amount of monthly precipitation from 2002-2009 were detected in Cannonsville, Pepacton, and Schoharie, the largest headwater basins of the Catskill/Delaware System (plots not shown). Decreases ranged from 2 to 5 %. All other basins, including Kensico's local watershed, showed no long-term change over the 2002-2009 period.

Long-term turbidity levels decreased 2 % in Kensico Reservoir. The decrease was largely driven by a 23% drop from 2007-2009, a period characterized by mild winter snowmelts and relatively few high intensity rainfall events.

Decreases were also apparent for total phosphorus and total nitrogen. Similar to the trend in turbidity, total phosphorus experienced a 5 % decrease since 2002, with a 33 % drop since 2005. In addition to a general lack of large storm events in the latter half of the period of record, ongoing watershed protection efforts to reduce phosphorus loads could also be a factor (DEP 2006a). Although a slight overall decrease (2 %) was also indicated for total nitrogen, intermediate nitrogen and phosphorus patterns were occasionally quite different. This was particularly true from 2006 to 2007, when total nitrogen increased sharply while total phosphorus decreased, continuing its pattern of declining concentrations that started in 2005. The nitrogen increase may be linked to recent insect infestations. Beginning in 2002, the Catskill Mountains experienced outbreaks (some severe) of both forest tent caterpillars and gypsy moths (DEC 2005). Several pathways linking the infestation to the observed increase are possible. Forest defoliation, for example, which occurred in some areas, can lead to decreased uptake of nitrogen by the forest. Fortunately, the outbreak seems to have subsided, as indicated by the sharp decrease in nitrogen since 2007.

Long-term trends were not detected for chlorophyll, a measurement of total algal productivity. Chlorophyll concentrations were generally low and relatively stable, with a majority of data in the 2 to 6 $\mu g\ L^{-1}$ range. The taste and odor event in October-November 2009 did not coincide with a notable increase in chlorophyll. This is not unexpected, since *Chrysosphaerella*, the organism believed responsible for the event, can cause taste problems even in relatively small numbers.

An overall decreasing trend was observed for fecal coliforms. Since 2004 most of the monthly median counts have been 1 or less than the detection limit, with the highest counts ranging to 3 CFU 100 mL^{-1} in most years. The low counts can mostly be attributed to the waterfowl management program in place at Kensico since 1993. The higher counts observed in 2003 occurred because the annual waterfowl management contract was delayed that year until October.

An overall decrease of 1% was indicated for specific conductivity, which was driven largely by higher values in 2002 and 2003. The high values were caused by a drought from 2001-2002. In drought conditions, increases in reservoir specific conductivity naturally occur due to a greater relative contribution from more concentrated groundwater versus more dilute rainwater. The LOWESS curve indicates a small, gradual increase in conductivity from 2003 to 2009, perhaps as a result of road salt usage in the Catskill/Delaware watersheds.

New Croton Reservoir

Water quality temporal plots from 2002-2009 are presented in Figures 3.21 and 3.22. Results of the Seasonal Kendall trend analysis are provided in Table 3.13, along with the monthly precipitation trend results for the Croton watershed.

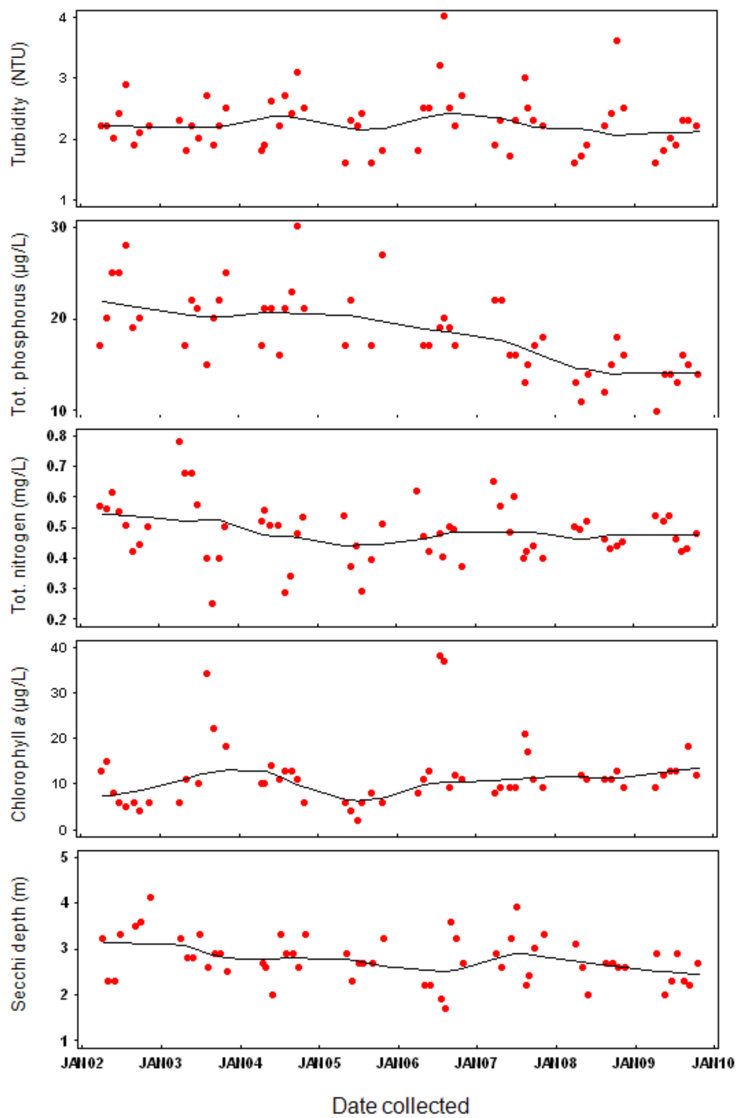

Figure 3.21 New Croton Reservoir temporal plots of selected water quality analytes. Red dots are monthly medians. The black line is a LOWESS curve with a 30% smooth factor. Chlorophyll and Secchi depth medians are representative of surface water conditions. Turbidity, total phosphorus, and total nitrogen medians were calculated from all sites and depths and represent whole reservoir conditions.

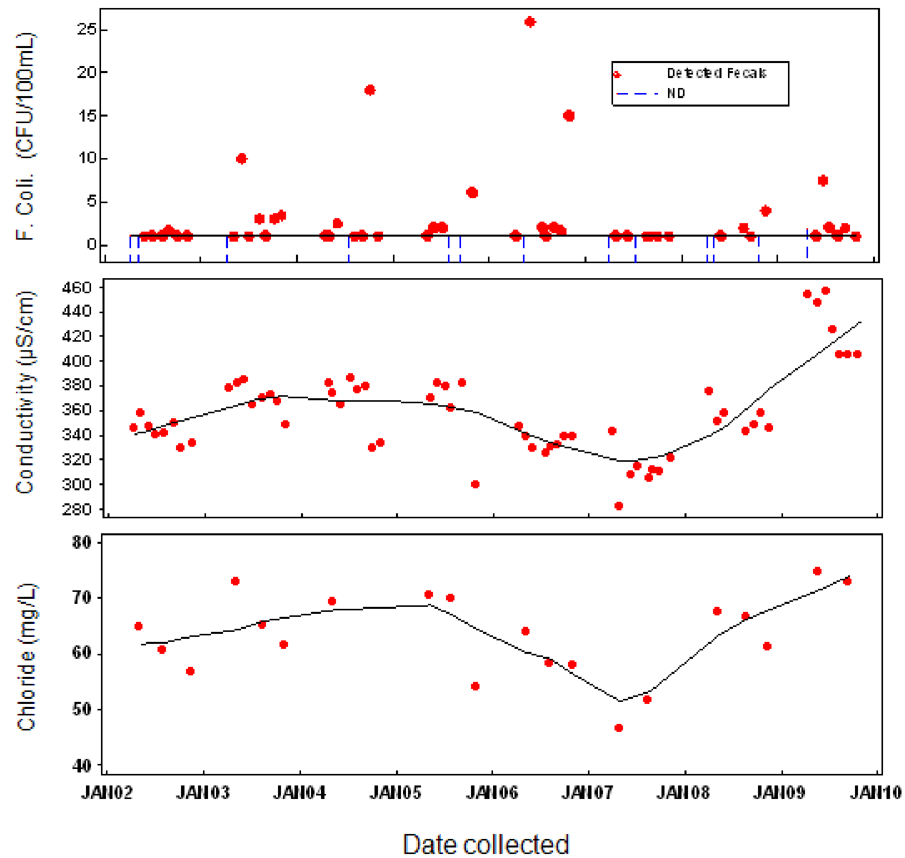

Figure 3.22 New Croton Reservoir temporal plots of selected water quality analytes. Red dots are monthly medians. The black line on the fecal coliform plot is the Akritas-Theil-Sen line, while the dashed blue lines indicate non-detects. On the conductivity and chloride plots the black line is a LOWESS curve with a 30% smooth factor. Fecal coliform and conductivity medians were calculated using samples collected at all sites and depths and represent whole reservoir conditions. Chloride medians were calculated from all depths collected at Site 1.

Table 3.13: New Croton Reservoir trend results.

Analyte	Months sampled yr^{-1}	n	Tau	*p*-value	Change yr^{-1}	%Change [1] (2002-09)
Precipitation (in.)	12	96	-0.01	NS	-0.03	-1
Turbidity (NTU)	8	60	-0.07	NS	0.00	0
Total phosphorus (μgL^{-1})	8	54	-0.58	***	-1.25	-7
Total nitrogen (mg L^{-1})	8	59	-0.04	NS	0.00	0
Chlorophyll *a* ($\mu g\ L^{-1}$)	8	56	0.19	**	0.50	+5
Secchi depth (m)	8	58	-0.28	***	-0.06	+2
F. coliform (CFU 100 mL^{-1})	8	63	0.03	NS	0.00	na
Conductivity ($\mu S\ cm^{-1}$)	8	60	0.04	NS	1.83	+1

[1]%Change $_{(2002\text{-}09)}$ = (Change yr^{-1} ÷ median $_{(2002\text{-}09)}$) x 100.

Monthly median precipitation amounts were stable in the Croton watershed, generally ranging from 2 to 6 inches per month during the 2002-2009 period. Because supplies from the Catskill/Delaware System were sufficient, very little New Croton water was delivered to New York City during this time period. Except for 2002, the reservoir was near capacity and excess was allowed to spill to the Hudson River.

Turbidity was also stable during the period of record; no overall trends were detected. The highest median turbidity of 4.0 NTU occurred in August 2006 and was associated with a large cyanobacteria bloom.

Nutrient levels were much higher than those of Kensico Reservoir during the 2002-2009 period. However, trend results indicate a long, continuous decline of 1.25 $\mu gL^{-1}\ yr^{-1}$ for total phosphorus, yielding an overall drop of 7 % for the period. Upgrades to 40 WWTPs (Section 5.5) and a lack of high intensity storms, coupled with mild snowmelts in the latter part of the data record, are the primary reasons for the trend. Long-term trends were not detected for total nitrogen. Seasonal trends, however, are readily apparent, with the highest concentrations occurring with spring snowmelt. During the growing season, concentrations declined as a result of uptake by terrestrial plants and in-reservoir algae.

Algal productivity, as measured by surface water chlorophyll *a*, increased by approximately 5 % during the 2002-2009 period. Secchi depth, a surrogate for water clarity, declined 2 %, most likely because of the increase in algal production. Reasons for the productivity increase, especially in light of the significant decrease in phosphorus, are not clear. However, many studies have found that reductions in productivity may lag many years behind reductions in nutrients due to factors such as climate change (Tadonléké et al. 2009), internal loading from anoxic sediments, and reservoir residence time (Meals et al. 2010).

Long-term trends were not detected for fecal coliforms. The majority of monthly values were below 3 CFU $100mL^{-1}$, with occasional high counts generally associated with high flow events.

Long-term conductivity trends were also not detected. Decreases in 2006 and 2007 were apparently enough to offset the approximately 30 % increase observed from 2008 to 2009. The close correlation between conductivity and chloride (Figure 3.22) is strong evidence that salt is responsible for the elevated conductivity in the reservoir. Primary sources for the salt include road de-icers and effluent from home water softeners.

4. Pathogens

4.1 How many samples did DEP collect for *Cryptosporidium*, *Giardia*, and human enteric viruses in 2009, and what were their occurrences and concentrations in the source waters?

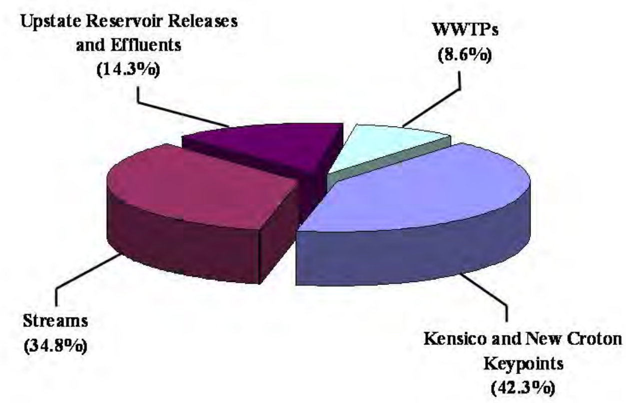

Figure 4.1 DEP protozoan sample type distribution for 2009 (includes routine and enhanced monitoring samples).

DEP conducts monitoring for protozoan pathogens and human enteric viruses (HEV) throughout the 1,972-square-mile NYC watershed. DEP staff collected and analyzed a total of 615 samples for protozoan analysis during 2009, compared to 781 collected in 2008, and 316 samples for HEV analysis. Five of the HEV samples collected were rejected, based on an elevated sample temperature. Five replacement samples were collected. Source water samples (Kensico and New Croton keypoints) comprised the greatest portion of the 2009 sampling effort, accounting for 42.3% of the samples, followed by stream samples, which were 34.8% of all samples. Upstate reservoir effluents and wastewater treatment plants made up the remaining 22.9% of samples (Figure 4.1).

Under routine reservoir operation, the two influents and the two effluents of Kensico Reservoir and the one effluent of New Croton Reservoir are considered the source water sampling sites for the NYC water supply. DEP's Watershed Water Quality Monitoring Plan outlines weekly sampling at these five sites for *Cryptosporidium*, *Giardia*, and HEVs. The effluent results are posted weekly on DEP's website (DEP), monthly in the Croton Consent Decree and EPA reports, and annually in the Kensico Water Quality Annual Report (see, e.g., DEP 2009b).

A discussion of protozoan occurrences in the Catskill influent and effluent at Kensico Reservoir (Catskill Aqueduct), the Delaware influent and effluent at Kensico Reservoir (Delaware Aqueduct), and the New Croton Reservoir effluent (New Croton Aqueduct) is presented below.

Catskill Aqueduct

The *Cryptosporidium* oocyst concentration and detection frequency at CATALUM (Catskill influent to Kensico Reservoir) were low, with a mean of 0.15 oocysts $50L^{-1}$ and 7 positive detections out of 52 samples (13.5%) (Table 4.1). The *Cryptosporidium* results at CATLEFF (Catskill effluent of Kensico Reservoir) were even lower, with a mean of 0.02 oocysts $50L^{-1}$ and 1 positive detection out of 52 samples (1.9%).

The *Giardia* cyst concentration at CATALUM had a mean of 1.50 cysts $50L^{-1}$, with 30 positive detections out of the 52 samples (57.7%) (Table 4.1), which was higher than last year. Mean *Giardia* concentrations at CATLEFF were higher than those at CATALUM, with a mean of 2.02 cysts $50L^{-1}$ and 44 positive detections (84.6%).

Concentration and detection frequency of HEVs at CATALUM were low in 2009, with a mean concentration of 0.25 MPN $100L^{-1}$ and 6 positive detections out of 52 samples (11.5%) (Table 4.1). Similar to previous years, HEV results were lower at CATLEFF than at CATALUM during 2009, at 0.12 MPN $100L^{-1}$ and 4 positive detections (7.7%).

Table 4.1: Summary of *Giardia*, *Cryptosporidium*, and HEV compliance monitoring data at the five DEP keypoints for 2009.

	Keypoint Location	# of samples	# of positive samples	Mean***	Max
Cryptosporidium oocysts 50 L^{-1}	Catskill Influent	52	7	0.15	2
	Catskill Effluent	52	1	0.02	1
	Delaware Influent*	52	4	0.08	1
	Delaware Effluent	52	4	0.08	1
	New Croton Effluent**	52	4	0.12	3
Giardia cysts 50 L^{-1}	Catskill Influent	52	30	1.50	7
	Catskill Effluent	52	44	2.02	8
	Delaware Influent *	52	41	1.81	7
	Delaware Effluent	52	38	1.54	5
	New Croton Effluent **	52	22	0.73	4
Human Enteric Virus 100 L^{-1}	Catskill Influent	52	6	0.25	5.75
	Catskill Effluent	52	4	0.12	3.25
	Delaware Influent*	52	4	0.08	1.03
	Delaware Effluent	52	4	0.08	1.03
	New Croton Effluent **	52	5	0.12	2.11

*Includes alternate sites sampled to best represent DEL17 during “off-line” status.

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

***Samples greater or less than 50L are brought down to per L concentrations and then brought back up to 50L for calculation of means. Zero values are substituted for non-detect values when calculating means.

Delaware Aqueduct

The *Cryptosporidium* oocyst concentration and detection frequency at DEL17 (Delaware influent to Kensico Reservoir) were low, with a mean of 0.08 oocysts $50L^{-1}$ and 4 positive detections out of 52 samples (7.7%) (Table 4.1). *Cryptosporidium* values at DEL18 (Delaware effluent of Kensico Reservoir) were the same as the influent, with a mean of 0.08 oocysts $50L^{-1}$ and 4 positive detections out of 52 samples (7.7%).

The *Giardia* cyst concentration at DEL17 had a mean of 1.81 cysts $50L^{-1}$, with 41 positive detections out of the 52 samples (78.9%) (Table 4.1). Mean *Giardia* concentration and detection frequency at DEL18 were slightly lower than those at DEL17, with DEL18's mean concentration at 1.54 cysts $50L^{-1}$ and 38 positive detections out of 52 samples (73.1%).

HEV concentration and detection frequency at DEL17 and DEL18 were both 0.08 MPN $100L^{-1}$ and 4 positive detections out of 52 samples (7.7%) (Table 4.1). However, detections of HEVs at DEL18 were clustered into the earlier part of the year, whereas DEL17 detections were more dispersed throughout the year.

New Croton Aqueduct

At CROGH (New Croton Reservoir effluent) in 2009, the mean *Cryptosporidium* concentration and detection frequency were 0.12 oocysts $50L^{-1}$ and 4 positive detections out of 52 samples (7.7%) (Table 4.1). CROGH had a mean *Giardia* concentration of 0.73 cysts $50L^{-1}$ and 22 positive detections (42.3%).

Concentration and detection frequency for HEV at CROGH were low, with a mean of 0.12 MPN $100L^{-1}$ and 5 positive detections out of 52 samples (9.6%).

In general, *Giardia* occurrences were much more frequent and at higher concentrations than *Cryptosporidium* at the source water sites, which is typical for the NYC watershed.

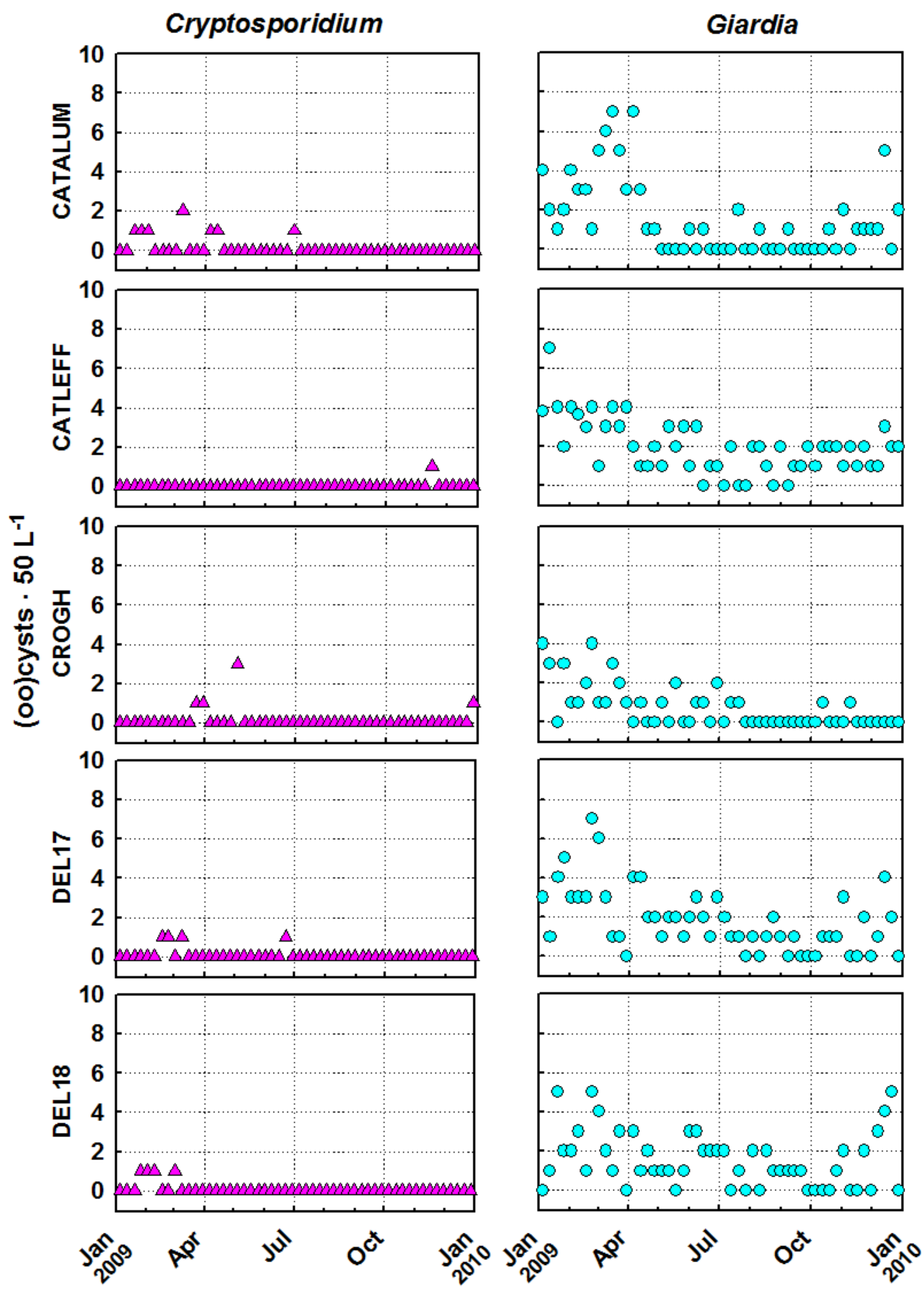

Figure 4.2 Routine weekly source water keypoint monitoring results for 2009.

4.2 How did protozoan concentrations compare with past regulatory levels?

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA 2006) requires that utilities conduct monthly source water monitoring for *Cryptosporidium* over a two-year period, though a more frequent sampling schedule may be used. The LT2 requires all unfiltered public water supplies to "provide at least 2-log (i.e., 99 percent) inactivation of *Cryptosporidium*." If the average source water level exceeds 0.01 oocysts per liter 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 by taking a mean of the mean monthly results over the course of two years. For perspective, results have been calculated here using data from the most recent two-year period (January 1, 2008 to December 31, 2009), including all routine and non-routine samples (Table 4.2).

Table 4.2: Number and type of samples used to calculate the LT2 bin classification set under the LT2 from January 1, 2008 to December 31, 2009.

Aqueduct	# of routine samples	# of non-routine samples	Total n
Croton	104	4	108
Catskill	104	0	104
Delaware	104	0	104

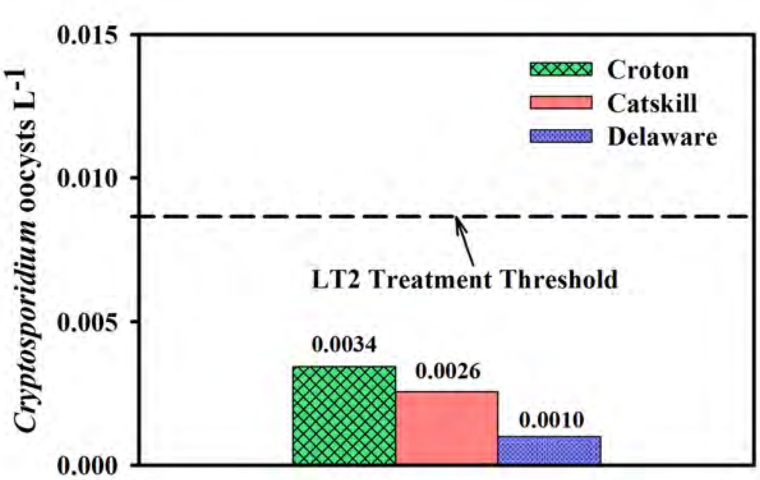

Figure 4.3 The 2008-2009 LT2 calculated means for *Cryptosporidium* at DEP's three source waters: Croton, Catskill, and Delaware.

The mean level of *Cryptosporidium* oocysts at each of the three source waters was below the LT2 threshold level of 0.01 oocysts per liter, achieving the 99% (2-log) reduction. Unfiltered systems that meet this requirement do not require further treatment. The averages, as shown in Figure 4.3, are as follows: 0.0034 oocysts L^{-1} at the Croton effluent, 0.0026 oocysts L^{-1} at the Catskill effluent, and 0.0010 oocysts L^{-1} at the Delaware effluent.

Since 2002, the three source water locations for the NYC water supply have yielded two year running LT2 means well below the level requiring additional treatment (Figure 4.4). Compared to the previous LT2 period

(2007-2008), the Croton and Delaware means were slightly higher for the 2008-2009 period, while the Catskill System showed a slight decrease from the previous LT2 mean. These slight increases and decreases are likely due to natural variability of oocyst load and weather patterns within the watershed in the studied timeframe.

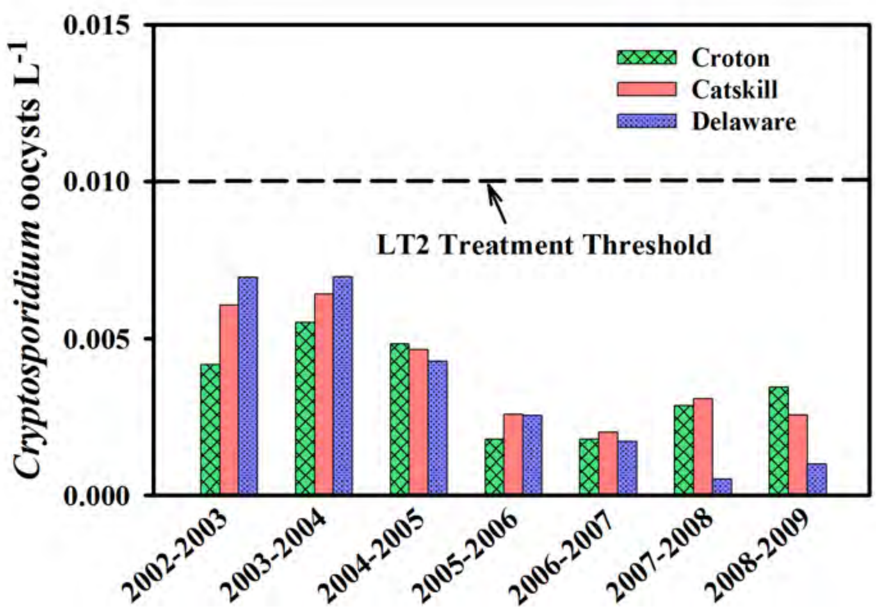

Figure 4.4 LT2 calculated means for *Cryptosporidium* since the start of Method 1623 at DEP's three source waters (2002-2009): Croton, Catskill, and Delaware.

4.3 How do 2009 source water concentrations compare to historical data?

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

Pathogen sample data collected in 2009 indicate that concentrations of *Giardia* and *Cryptosporidium* remained relatively low for most of the source water sites compared to data collected from 2001 to 2008 (Figure 4.5). While there were some slightly higher *Giardia* values in the spring of 2009 at the Catskill influent (CATALUM), all data fell within the ranges previously recorded. When compared to 2008 only, mean values for all sites for 2009 were all within the same order of magnitude, with three exceptions (Table 4.3). For *Cryptosporidium* in 2009, the Delaware influent and the Catskill effluent means were much lower compared to 2008. For *Giardia*, the 2009 mean value was higher at the Catskill influent than it was in 2008.

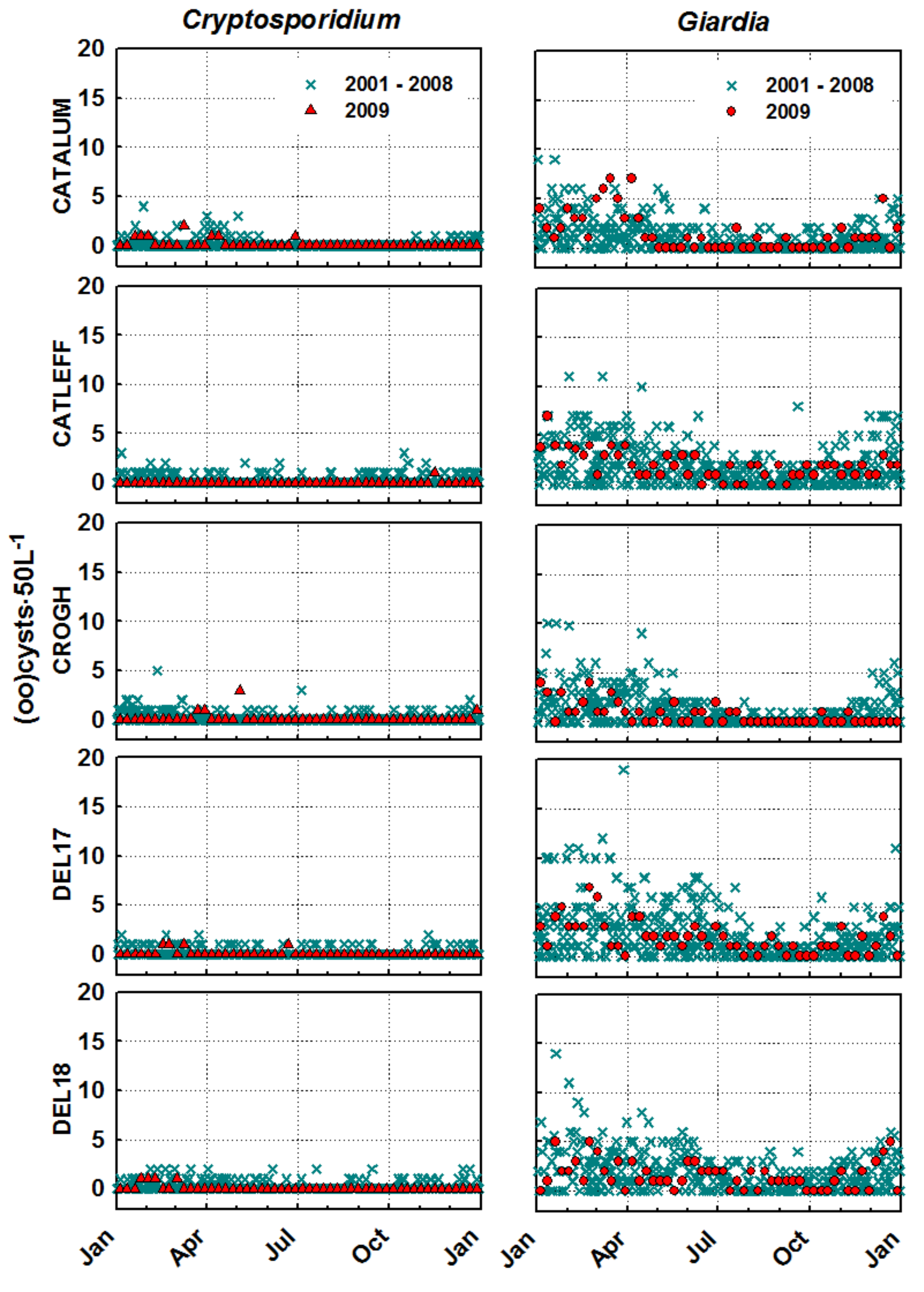

Figure 4.5 Source water keypoint weekly sampling results from October 2001-December 2009. For *Cryptosporidium* red triangles represent 2009 and the blue "X" represents 2001-2008 data. For *Giardia*, the red circles represent the 2009 data, whereas the blue "X" represents the 2001-2008 data.

Table 4.3: Mean concentrations for *Cryptosporidiu*m and *Giardia* at the source water keypoints at Kensico and New Croton Reservoirs in 2009.

Site	n		*Cryptosporidium* 50L^{-1}		*Giardia* 50L^{-1}	
	2008	2009	2008	2009	2008	2009
Catskill Influent	52	52	0.135	0.154	0.712	1.499
Catskill Effluent	52	52	0.229	0.019	2.006	2.019
Delaware Influent	52	52	0.153	0.077	1.017	1.807
Delaware Effluent	52	52	0.019	0.077	1.686	1.539
New Croton	56	52	0.214	0.115	0.731	0.731

A seasonal pattern is evident for *Giardia* at all source water sites in 2009; however, this seasonal pattern is much less clear, or absent, for *Cryptosporidium* due to a heavy predominance of non-detects and detects at low concentrations. To more clearly illustrate the presence or absence of this seasonal pattern at the different source water sites, a locally weighted scatterplot smooth (LOWESS) curve was fitted through the data points (Figures 4.6a, b). LOWESS curves for *Giardia* sampling show increasing concentrations of cysts generally in the fall and winter months and decreasing concentrations in the spring and summer months. There is some disturbance to this seasonal pattern caused by a change of methods in 2005-2006, where a different EPA-approved stain was used for laboratory analysis. A less pronounced seasonal trend can be discerned for *Cryptosporidium* at source water sites, but not for all sample years at each source water site. While this seasonality can be visually detected in the LOWESS curve for *Cryptosporidium,* it is not a statistically significant pattern, due to the abundance of non-detects (zeroes) in the dataset.

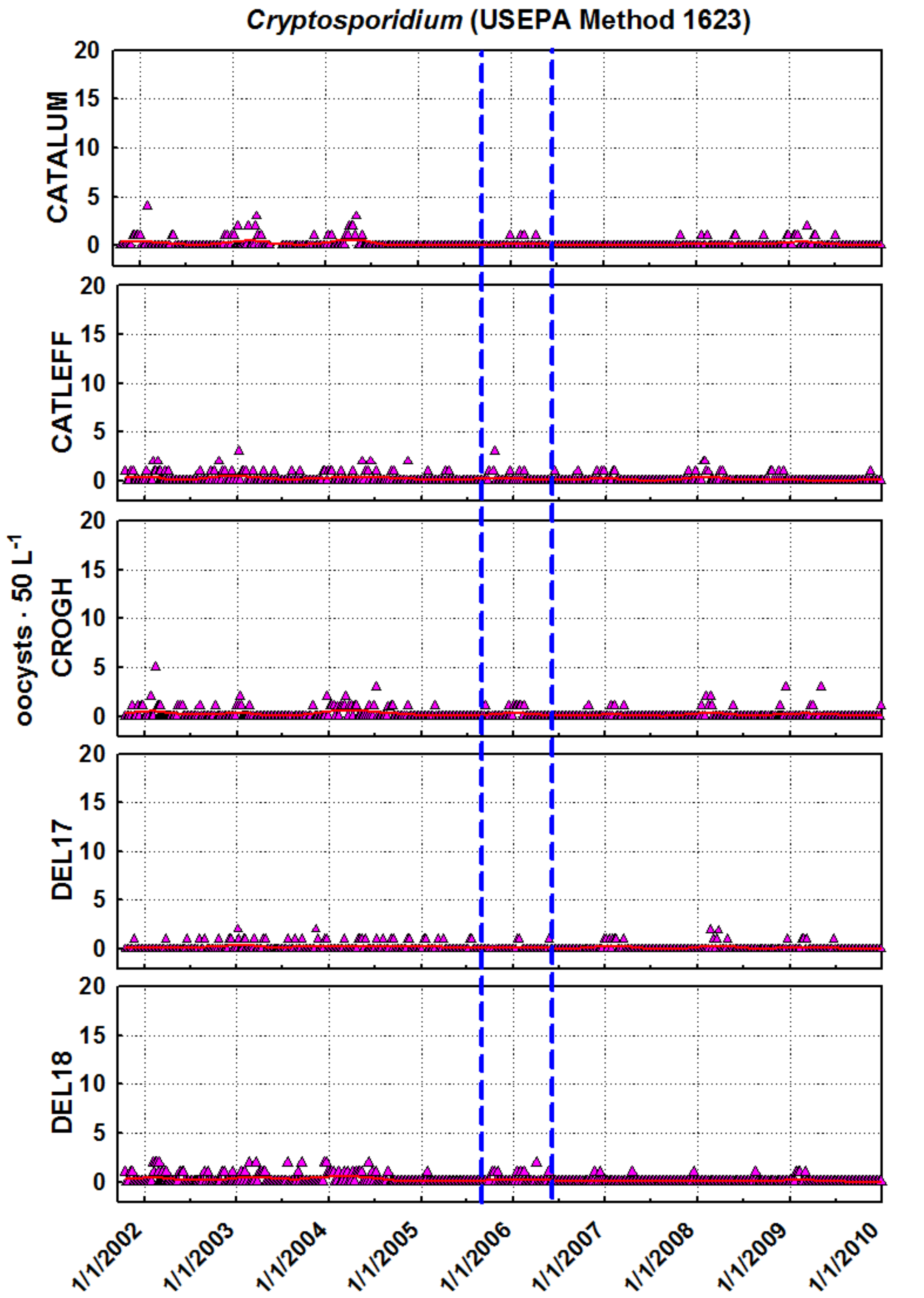

Figure 4.6a Weekly routine source water keypoint results for *Cryptosporidium* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2009. The area between the blue dotted lines indicates the period during which the DEP laboratory temporarily switched to a different EPA-approved stain.

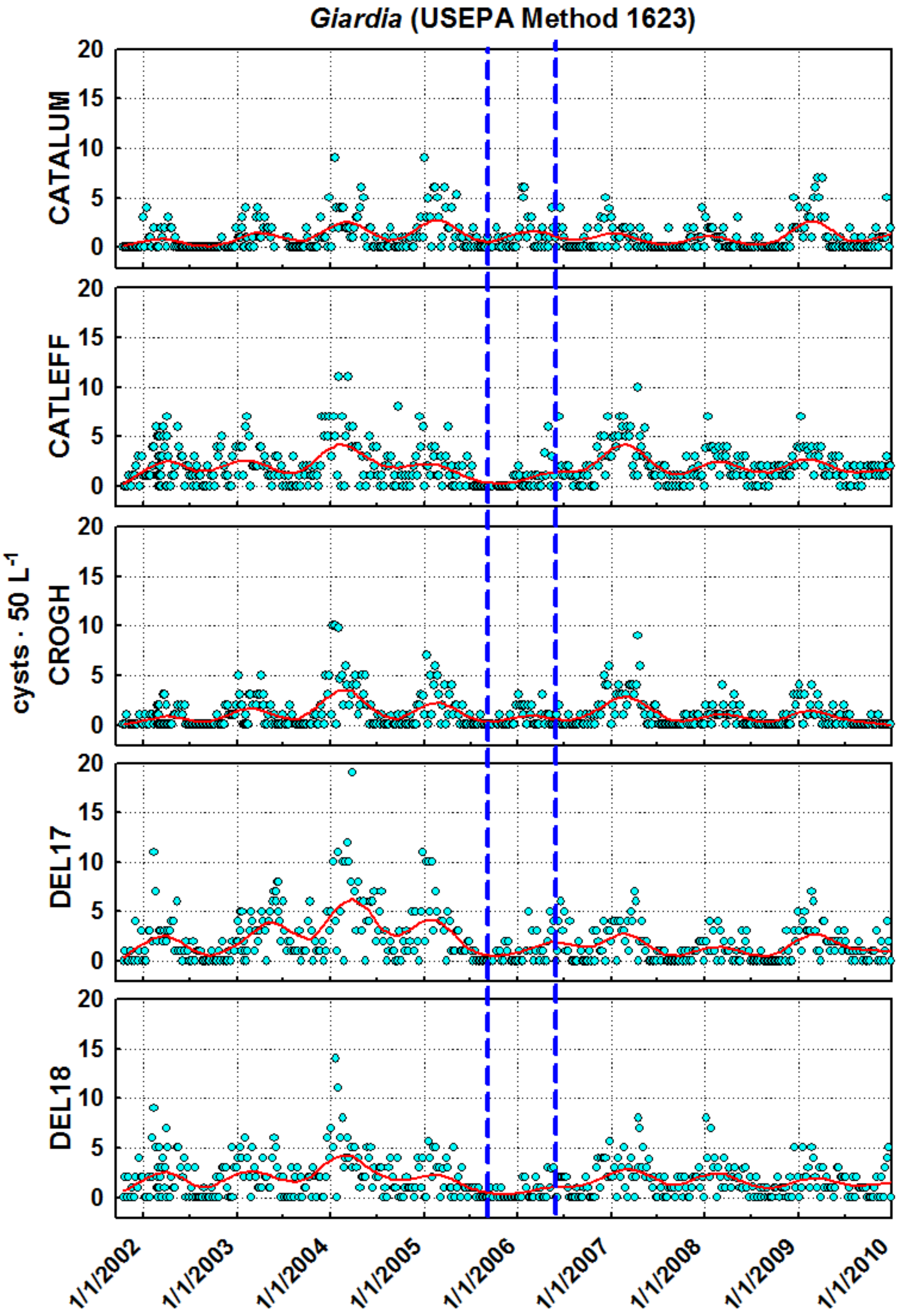

Figure 4.6b Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2009. The area between the blue dotted lines indicates the period during which the DEP laboratory temporarily switched to a different EPA-approved stain. Note the absence of a seasonal peak during that period.

4.4 What concentrations of *Cryptosporidium* and *Giardia* were found at the various NYC watersheds in 2009?

As part of the objectives outlined in the new Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a), DEP has monitored the major tributaries and reservoir releases of some of the reservoirs to assess and compare the relative pathogen concentrations in each of their watersheds.

The monthly fixed-frequency monitoring results indicate very low concentrations of *Cryptosporidium* in the West of Hudson (WOH) watershed in 2009 (Figure 4.7). Results for all sites were similar to 2008 data. While having a relatively low mean concentration of 1.08 oocysts $50L^{-1}$, Site PROXG, in the Pepacton watershed, had the highest mean *Cryptosporidium* concentration compared to the other WOH sites. PROXG is among those that have been identified for further monitoring in the WWQMP.

WOH *Giardia* concentrations were consistently high at PROXG, S5i, S7i, CDG1, and WDBN (85.1, 62.0, 61.6, 55.7, and 44.7 mean cysts $50L^{-1}$, respectively) in 2009. These sites are located in the Pepacton, Schoharie, and Cannonsville Reservoir watersheds and the results are similar to the 2008 findings. These sites had been identified as locations for future monitoring in the WWQMP and will continue to be sampled. The *Giardia* concentrations at the remaining sites ranged from very low to moderate and are similar to the 2008 results (Figure 4.8).

Eleven of the 12 scheduled samples were collected and analyzed from Sites S5i and ABCG. Results from one sample at each of these two sites could not be recorded due to ice cover at one site, and a sample from the other site freezing during transport to the laboratory in January. Since the original sample collection was attempted at the end of the month, no re-sampling was able to be performed before the routine February sample was collected.

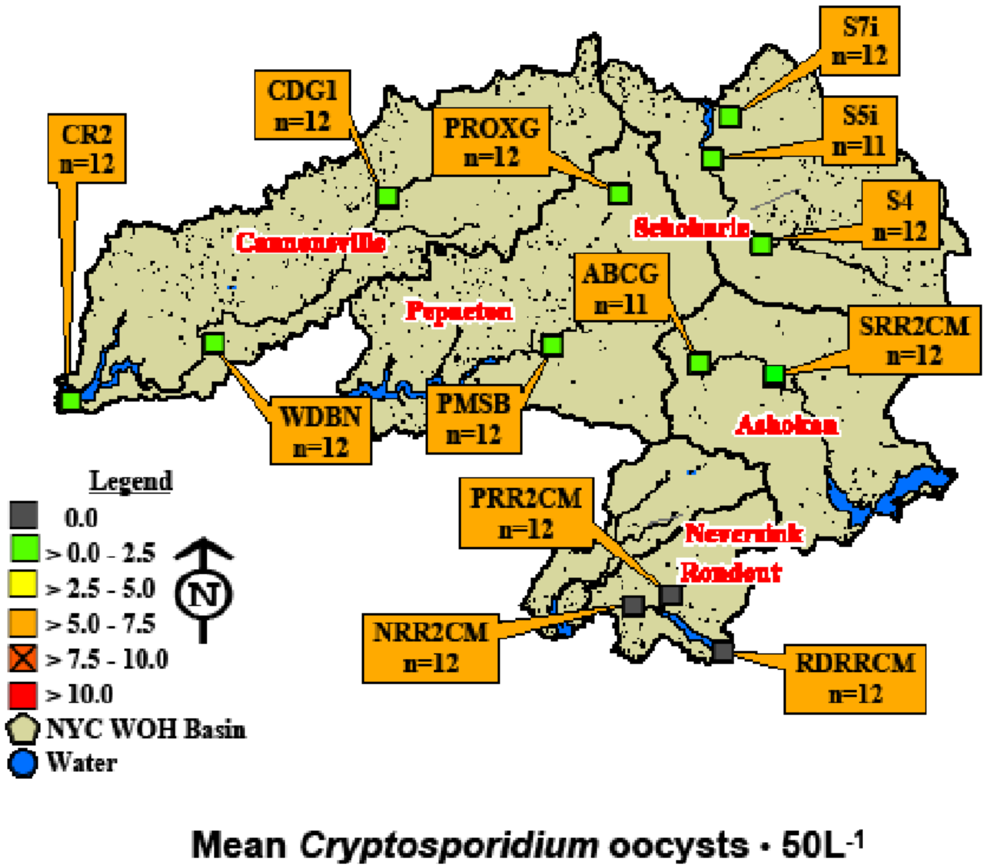

Figure 4.7 Fixed-frequency *Cryptosporidium* monitoring results in the WOH watershed in 2009. (n = 154)

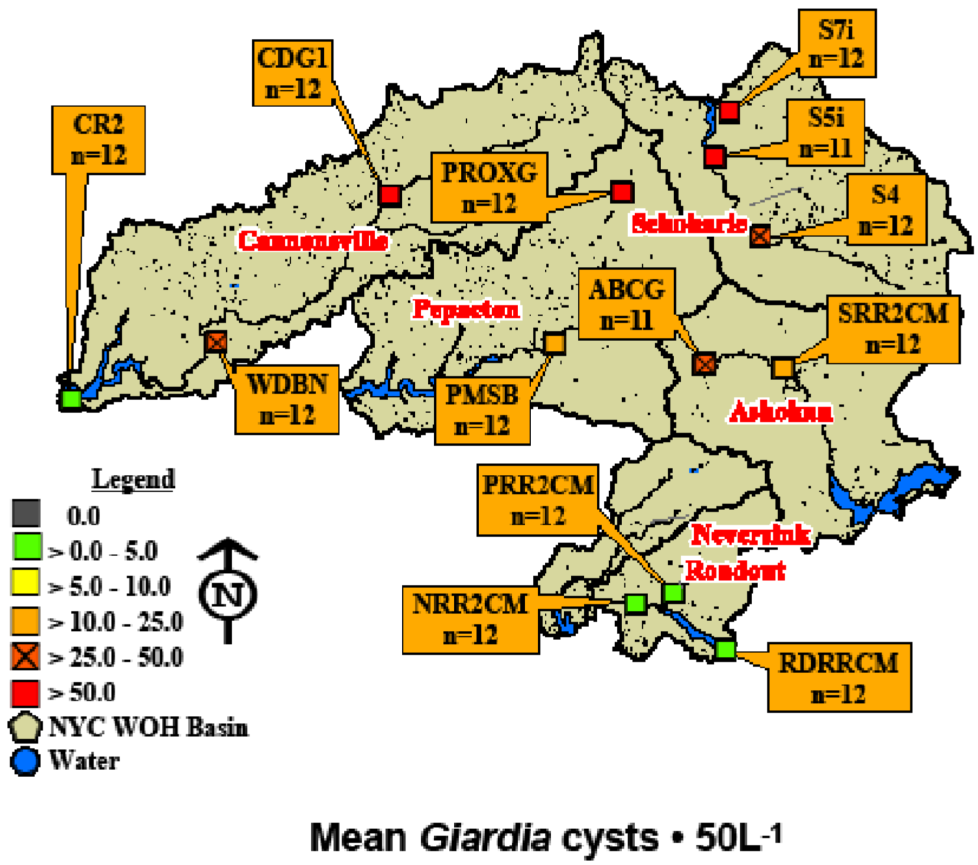

Figure 4.8 Fixed-frequency *Giardia* monitoring results in the WOH watershed in 2009. (n = 154)

The sample sites in the Croton watershed were sampled monthly. Mean *Cryptosporidium* concentrations were found to be very low, except for sites WF and HH7 (Willow Farm and Haviland Hollow Brook), located in the East Branch watershed (Figure 4.9). These sites had the highest mean *Cryptosporidium* concentrations in the NYC watershed for 2009 (1.3 and 1.2 oocysts $50L^{-1}$, respectively). However, it should be noted that the two highest concentrations found at each of these sites in 2009 occurred in samples with very low volumes of water analyzed. Due to turbidity and high filter pressure, only 5.5L could be analyzed (of the original 13L filtered) for the HH7 sample, with a result of 1 oocyst, and only 11L could be filtered for the sample taken at WF, with a result of 2 oocysts. Both of these samples were taken during a rain event on June 9, 2009.

Mean *Giardia* concentrations were very low to low, except for site HH7, which had a mean *Giardia* concentration of 54.8 cysts $50L^{-1}$ (Figure 4.10). The single sample with low analyzed volume (5.5L) at HH7 had the highest recorded *Giardia* concentration (7.6 cysts L^{-1}) for EOH and throughout the watershed on a per liter basis in 2009.

The release from Muscoot Reservoir was sampled monthly during 2009. Results indicate that the concentration of *Cryptosporidium* remained quite low (mean <0.1 oocysts $50L^{-1}$), with only one positive sample. *Giardia* was low to moderate at this site, with a mean concentration of 2.5 cysts $50L^{-1}$ and a maximum of 10 cysts, found in the December 2009 sample. Boyd Corners, Croton Falls, Cross River, and Titicus Reservoirs each had one fixed-frequency routine sample pulled in January 2009 before the WWQMP took effect, and these sites were removed from the list of sites sampled monthly.

Enhanced sampling occurred at Croton Falls Reservoir (CROFALLSR) in 2009 as part of DEP's startup of Croton Falls Reservoir and its use to supplement the Delaware Aqueduct supply to Kensico Reservoir. All of these samples were negative for *Cryptosporidium*, while *Giardia* was found to be present at low levels (mean = 0.5 cysts $50L^{-1}$, n = 12).

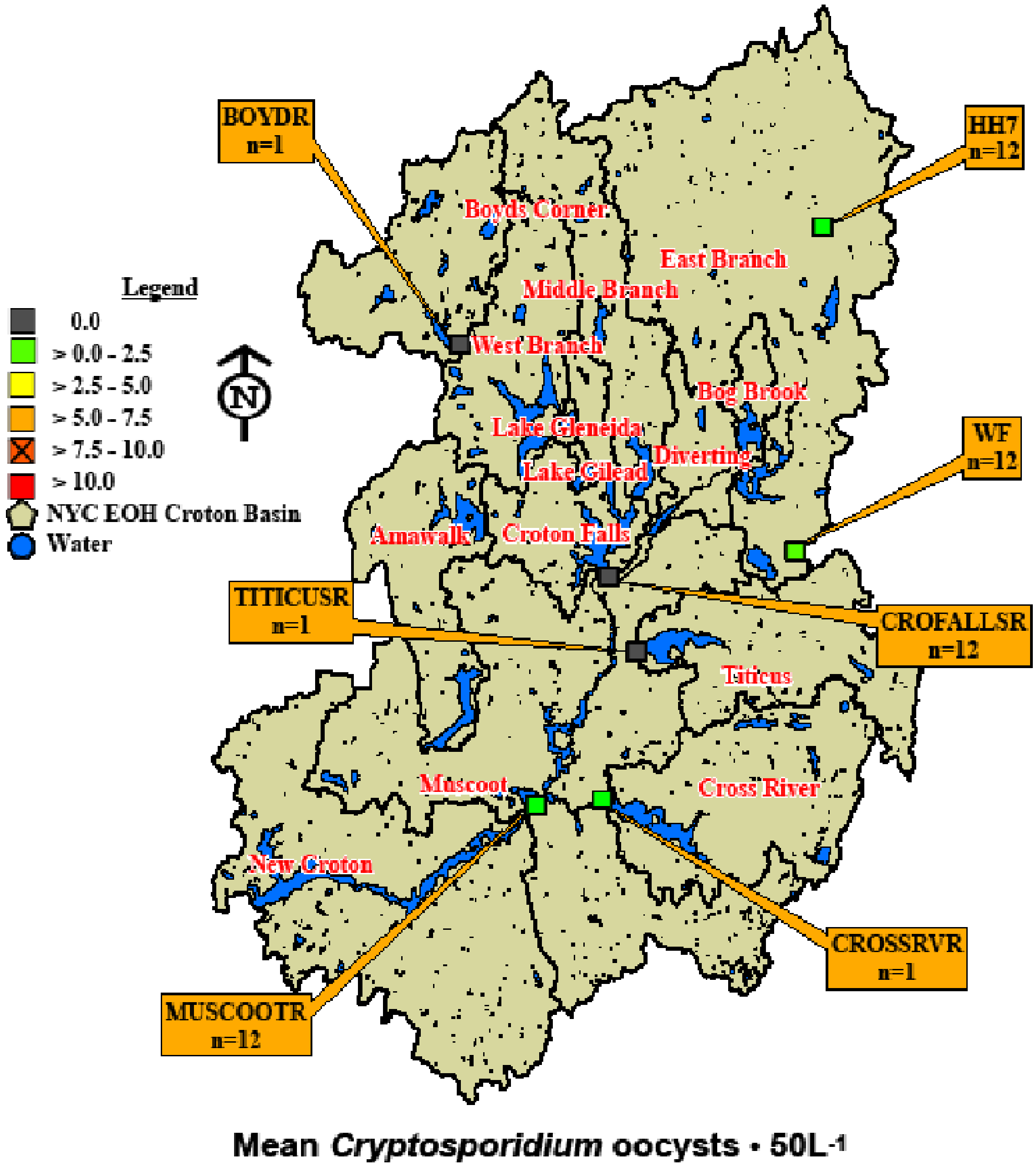

Figure 4.9 Fixed-frequency *Cryptosporidium* monitoring results in the Croton watershed in 2009. (n = 51)

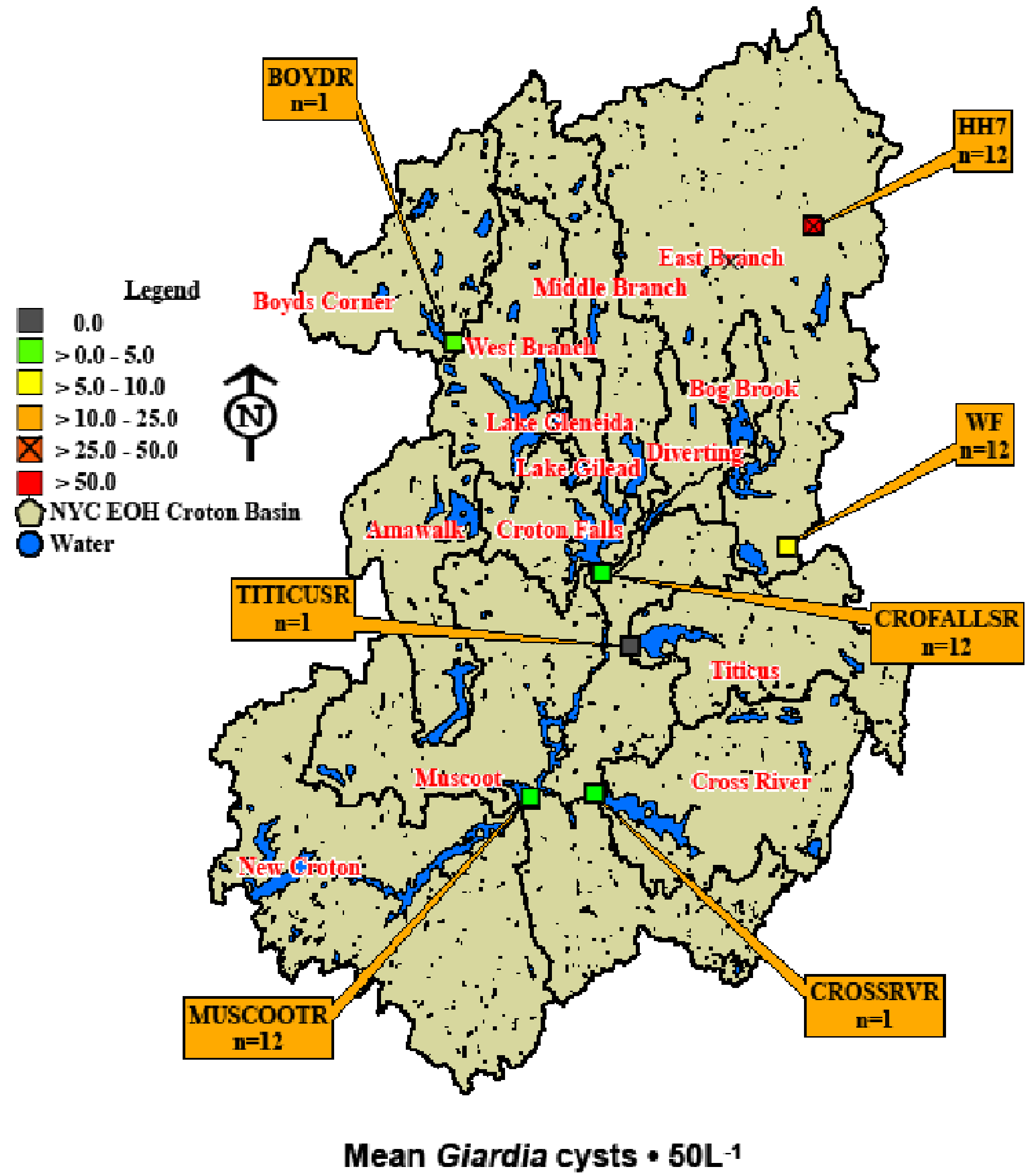

Figure 4.10 Fixed-frequency *Giardia* monitoring results in the Croton watershed in 2009. (n = 51)

The Kensico watershed stream sites were sampled monthly in 2009, which is an increase in sampling frequency from 2008, when these sites were for the most part sampled bi-monthly. The WWQMP requires monthly sampling, to distinguish seasonality from other causes of variation, such as storms. Mean *Cryptosporidium* concentrations were found to be very low at all sites, with the highest mean concentration found at site E9 (0.7 oocysts $50L^{-1}$). This was similar to the result obtained in 2008, when E9 also had the highest mean *Cryptosporidium* concentration (Figure 4.11). *Cryptosporidium* was found sporadically in samples at the Kensico perennial streams, generally at low levels, with results ranging from 0-3 oocysts per sample, detection rates ranging from 0% (E11) to 50% (WHIP), and mean concentrations ranging from 0.0 to 0.7 oocysts $50L^{-1}$. These results were generally similar to, or lower than, those seen in 2008.

Mean *Giardia* concentrations were very low to moderate, with site BG9 having the highest mean *Giardia* concentration in 2009 (19.1 cysts $50L^{-1}$) (Figure 4.10). Site BG9 also had the highest *Giardia* concentration for a single sample in the Kensico watershed (94 cysts $50L^{-1}$). *Giardia* was found frequently in samples at the Kensico perennial streams, with results ranging from 0-94 cysts per sample and detection rates ranging from 50% (N12) to 92% (BG9 and E9), and mean concentrations ranging from 1.2 to 19.1 oocysts $50L^{-1}$. These results are quite similar to those found in 2008, with the exception of E11, whose 2009 mean (6.1 cysts $50L^{-1}$) was markedly lower than the 2008 mean (112.2 cysts $50L^{-1}$).

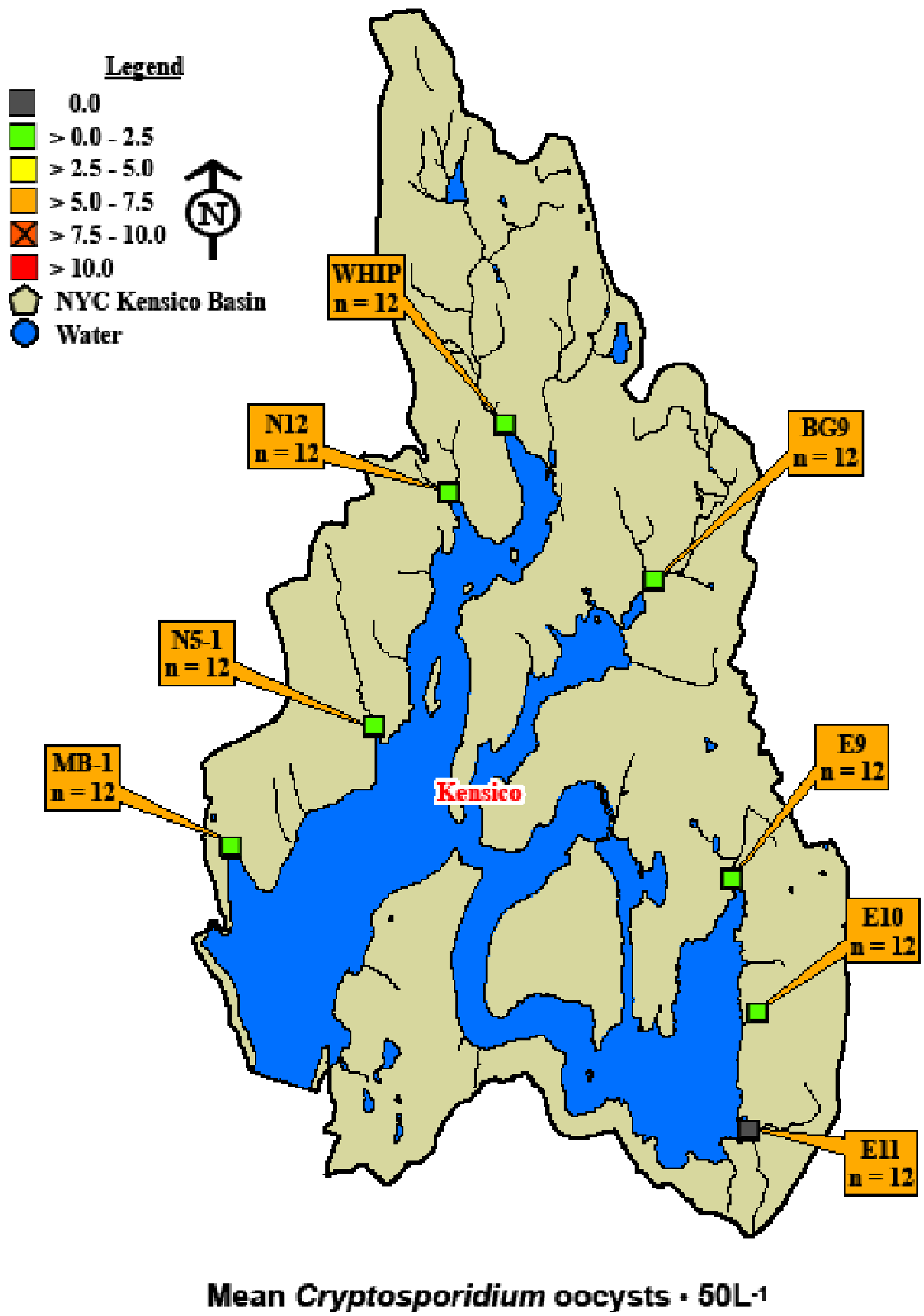

Figure 4.11 Fixed-frequency *Cryptosporidium* monitoring results in the Kensico watershed in 2009. (n = 96)

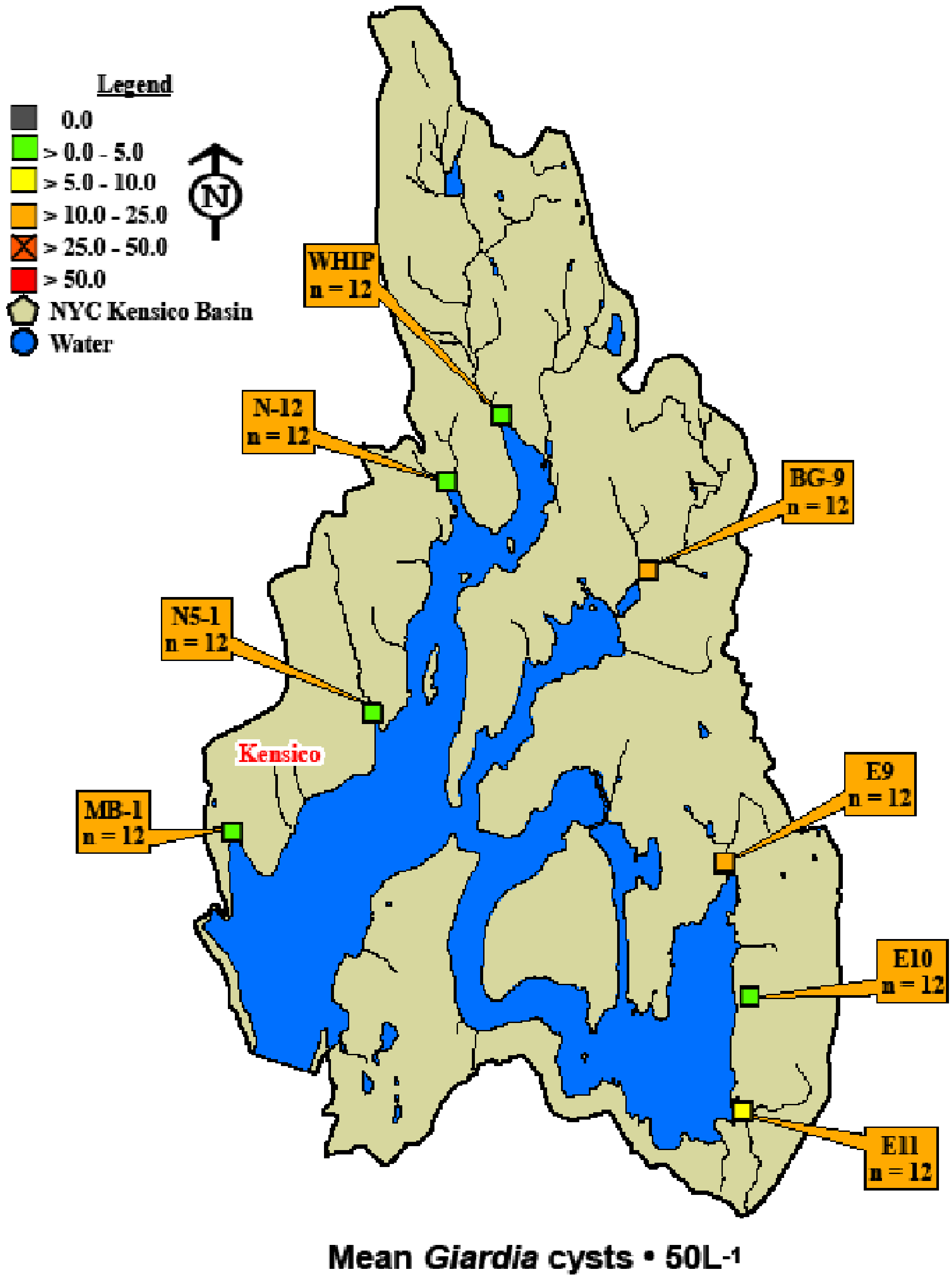

Figure 4.12 Fixed-frequency *Giardia* monitoring results in the Kensico watershed in 2009. (n = 96)

4.5 What levels of protozoa and human enteric viruses were found in wastewater treatment plant effluents in 2009?

DEP began monitoring for protozoa and HEV at 10 WOH wastewater treatment plants (WWTPs) in July 2002 as part of the integrated monitoring plan (IMP). Since then, sampling at each plant's final effluent has been conducted a minimum of four times annually. The new WWQMP maintained three of the previous 10 plants for monitoring, and added seven plants that had not been monitored under the IMP (Figure 4.13). The final new list includes eight WOH plants (Andes, Fleischmanns, Prattsville, Windham, and Hunter, along with the three previously sampled sites—Stamford, Grahamsville, and Hunter Highlands) and two EOH plants (Carmel and Mahopac) (Figure 4.14). In addition, the EOH Brewster Sewage Treatment Plant (BSTP) was sampled monthly for *Cryptosporidium* and *Giardia* and bimonthly for HEV to satisfy the requirements of the Croton Consent Decree (CCD).

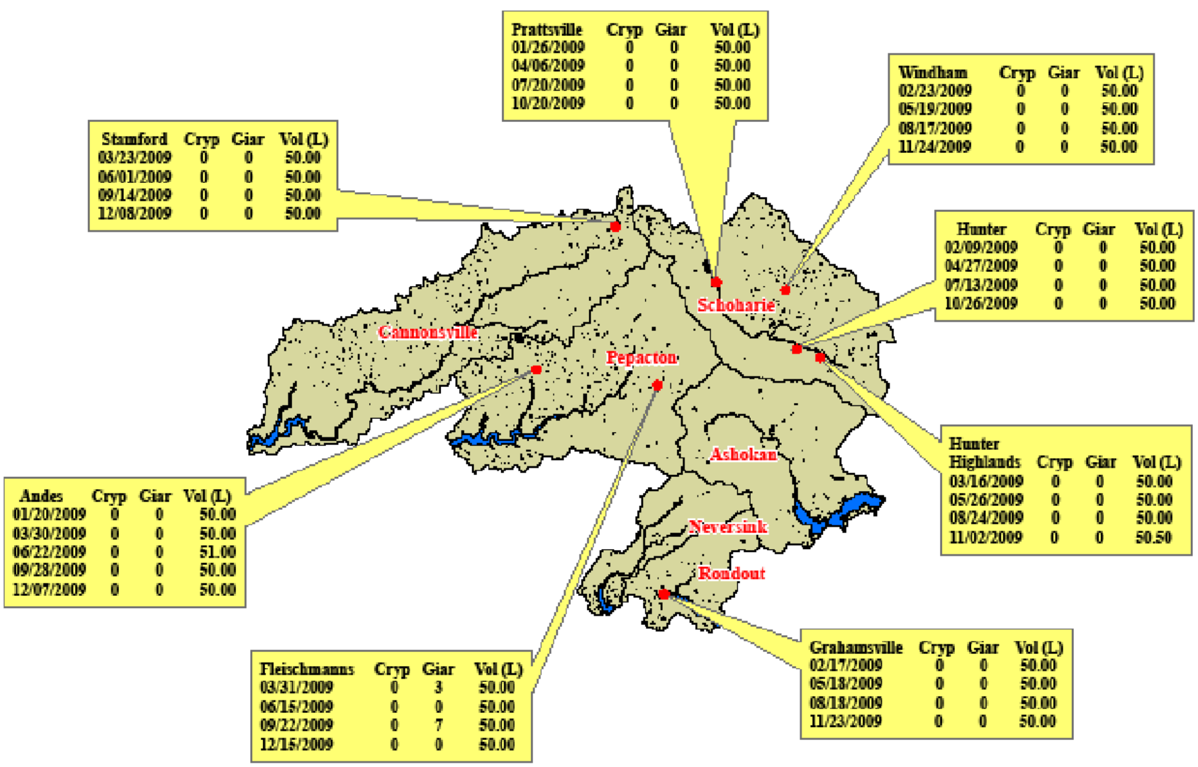

Figure 4.13 2009 *Cryptosporidium* and *Giardia* sample results for Catskill and Delaware System WWTPs.

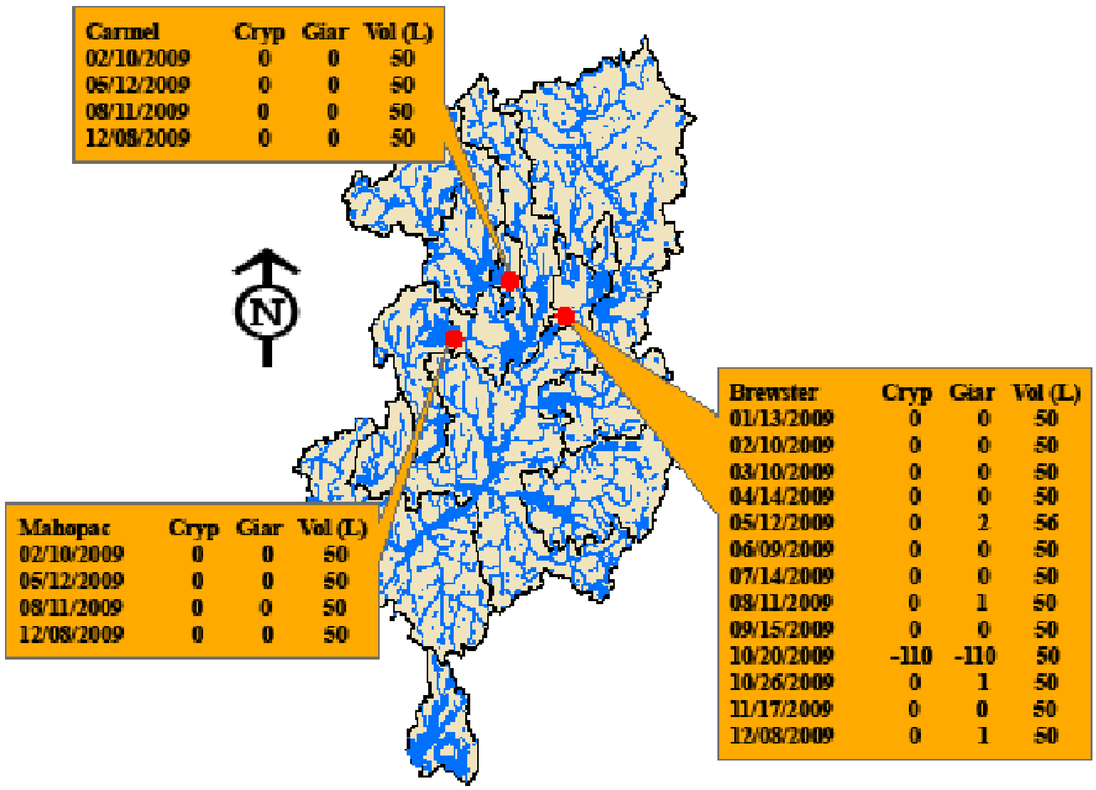

Figure 4.14 2009 *Cryptosporidium* and *Giardia* sample results for Croton System WWTPs.

West of Hudson

A total of 33 *Cryptosporidium* and *Giardia* samples were taken at the eight WOH WWTP sites. Of the 33 samples taken, none were positive for *Cryptosporidium* and 2 (6.1%) were positive for *Giardia*. During the first quarter of the year the protozoan and virus samples were not collected on the same day at the Andes site, due to a delay caused by a necessary pH adjustment for the virus sample. When the field crew returned for the virus sample, an extra protozoan sample was collected as well; therefore, there is one extra sample for Andes for 2009.

As has been noted in the past, there is evidence that positive results, at some sites, may be attributable to wildlife contamination in the uncovered chlorine tanks or grates near WWTP effluents. Therefore, sampling will continue to be conducted prior to the point of potential wildlife exposure at the Grahamsville WWTP and the Hudson Highland WWTP, which have the greatest potential for wildlife contamination.

A total of 32 HEV samples were taken at the eight WOH WWTPs, which is the minimum number of samples required to be taken at each site by the WWQMP. One WWTP sample was positive for HEV in 2009. This sample was taken at the effluent of the Grahamsville plant's microfiltration system, but prior to chlorination and the uncovered contact tank. As previously indicated, this alternate site was used because of the potential that wildlife feces might contaminate samples collected after the open chlorine contact tank.

East of Hudson

In addition to the WOH WWTP sites, DEP monitored three WWTP sites East of Hudson. The BSTP was sampled monthly for *Cryptosporidium* and *Giardia* and bimonthly for HEVs as part of the requirements of the CCD. Beginning in 2009, DEP began monitoring two plants not previously sampled for protozoans or HEVs—Carmel and Mahopac. In total, 20 protozoan and 14 HEV samples were taken from the three EOH sites. Four samples were positive for *Giardia*, all from the Brewster site (Figure 4.14). No WWTP samples in the Croton System were positive for *Cryptosporidium* or HEVs in 2009.

4.6 What concentrations of *Cryptosporidium* and *Giardia* were found at the effluents in various NYC reservoirs in 2009?

DEP's pathogen monitoring program samples upstate reservoirs and streams in the NYC watershed to help identify the sources of potential protozoan contamination and assist with estimation of the variability of concentrations between watersheds. Sampling at the upstate reservoir outlets also helps to evaluate the effect of each reservoir and its role in the reduction of pathogen concentrations as water flows to terminal reservoirs.

In 2009, *Cryptosporidium* levels remained very low in the WOH watersheds, with all WOH reservoir outlets reporting mean concentrations below 0.2 oocysts 50 L^{-1} (Figure 4.15a). EOH reservoir *Cryptosporidium* levels remained low, with Muscoot and Croton Falls mean concentrations below 0.1 oocysts 50 L^{-1}. Four of the five EOH reservoirs previously sampled in 2008 (Boyd Corners, Croton Falls, Cross River, and Titicus) were sampled only in January 2009, after which routine sampling of these sites was discontinued when the new WWQMP went into effect. However, beginning in the fall of 2009, 11 additional samples were taken at the release of Croton Falls Reservoir, when water was being pumped from this reservoir into the Delaware Aqueduct to supplement the system during a shutdown of the Rondout-West Branch Tunnel. These 11 samples were needed for operational purposes, and should not be considered representative of the entire year's pathogen variability at the Croton Falls release.

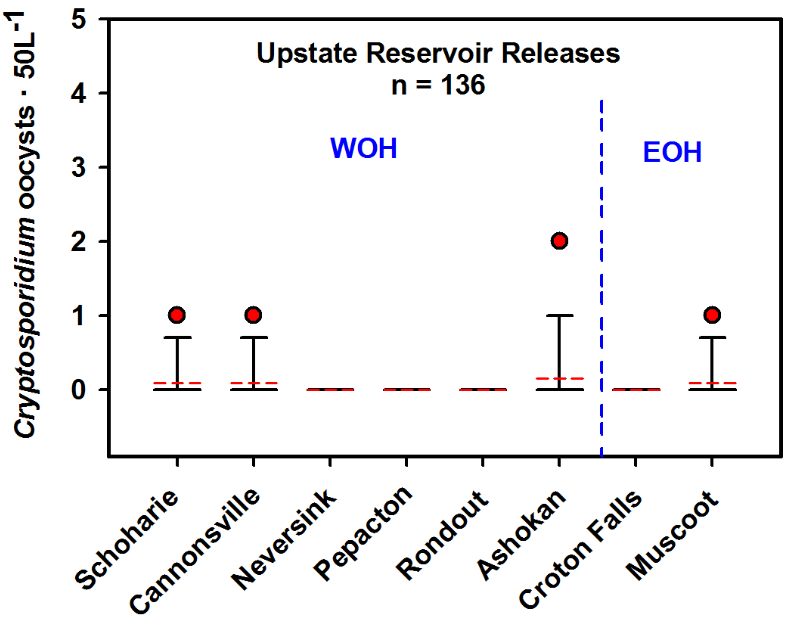

Figure 4.15a 2009 summary of *Cryptosporidium* distribution among WOH and EOH basins (--- mean, ___ median, ● outliers). All sites had 12 samples for the year, except water representative of the Ashokan Reservoir effluent (collected at CATALUM), which had 52 samples.

WOH mean *Giardia* concentrations increased for three out of the five reservoir releases (Neversink, Rondout, and Cannonsville) when compared to 2008 means. These sites averaged below 1.3 cysts 50 L^{-1} in 2008, but from 2.5 to 4.5 cysts 50 L^{-1} in 2009 (Figure 4.15b). Although Schoharie Reservoir's mean concentration (13.0 cysts 50 L^{-1}) was higher than the concentrations observed at these releases, it was similar to its 2008 mean of 15.1 cysts 50 L^{-1}. Pepacton Reservoir's mean *Giardia* concentrations in 2009 (0.7 cysts 50 L^{-1}) also remained quite similar to the reservoir's 2008 level (0.8 cysts 50 L^{-1}).

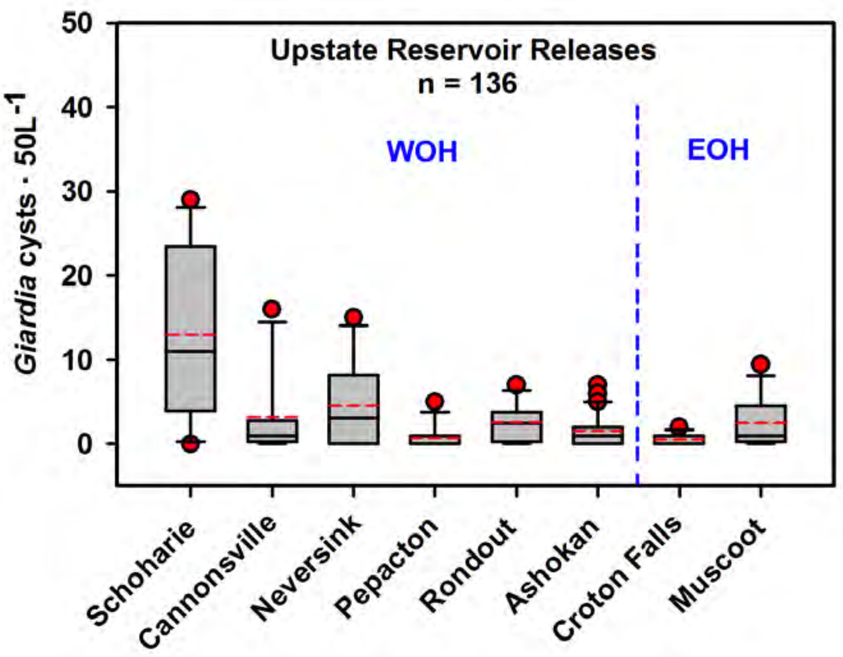

Figure 4.15b 2009 summary of *Giardia* distribution among WOH and EOH basins (--- mean, ___ median, ● outliers). All sites had 12 samples for the year, except water representative of the Ashokan Reservoir effluent (collected at CATALUM), which had 52 samples.

Mean *Cryptosporidium* values were very low for both sides of the Hudson River in 2009 (Figure 4.15c). Mean *Giardia* concentrations at reservoir effluents East of Hudson were lower than the WOH mean and remained below 2.5 cysts 50 L^{-1}. WOH sites had many more outlier results than EOH during 2009. As stated above, Muscoot Release was the only EOH reservoir sampled routinely (monthly) throughout 2009, with Croton Falls having additional samples taken as a result of the activation of the Croton Falls Pump Station late in the year.

Sampling was conducted at the other three EOH reservoirs (Boyd Corners, Cross River, and Titicus) in January 2009 only, for a total of one sample from each of the three sites. These three samples were not included in the site-by-site comparison of mean concentrations, since the sample size was distinctly different from past years. However, these three results are included in Figure 4.15c, and results ranged from 0 to 1 (oo)cyst 50 L^{-1} for the single sampling event at each of these locations.

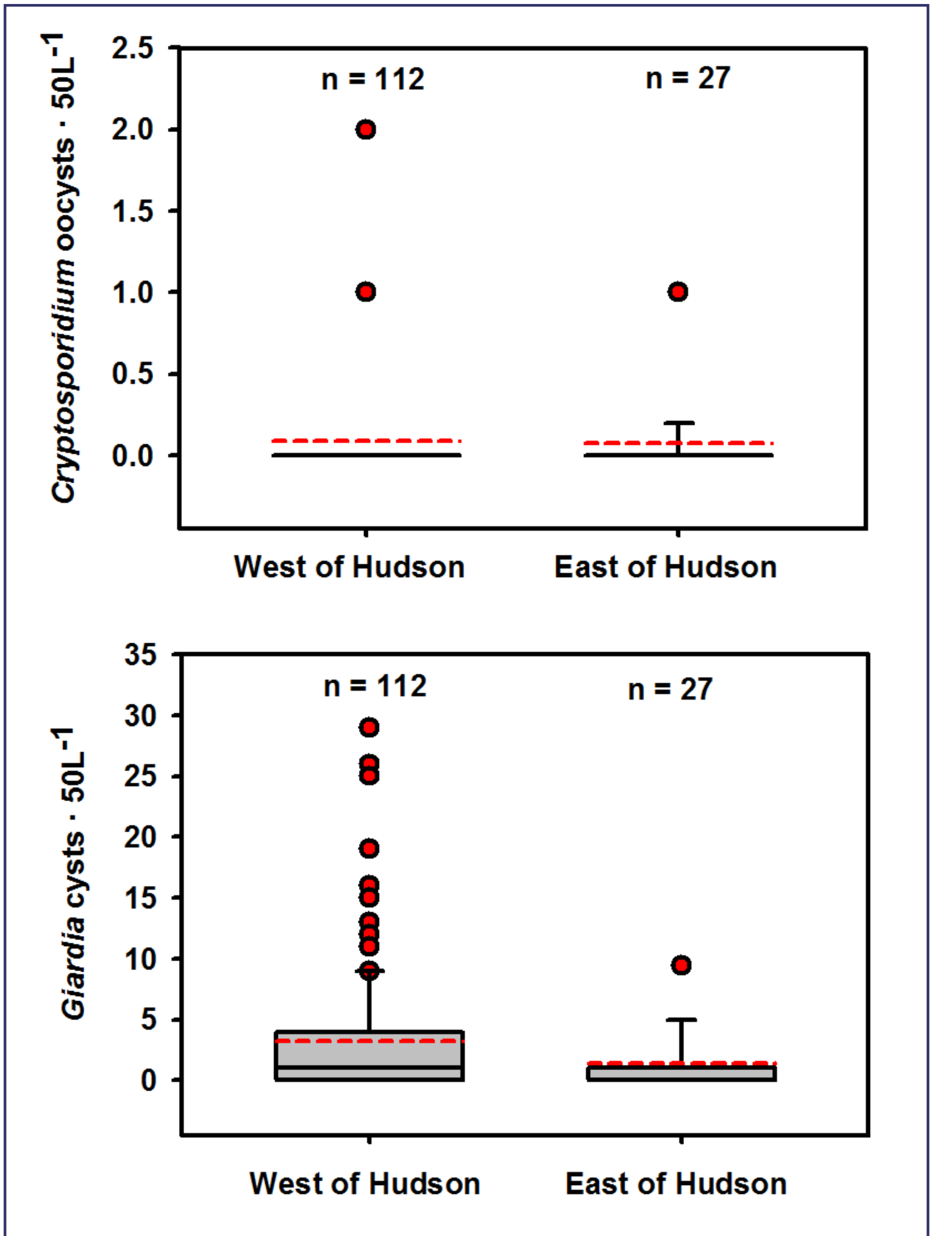

Figure 4.15c 2009 Comparison of WOH and EOH *Cryptosporidium* and *Giardia* concentrations $50L^{-1}$.

5. Watershed Management

5.1 What watershed management programs are required for filtration avoidance and how do they protect the water supply?

Several of DEP's watershed management programs are described in the 2007 Filtration Avoidance Determination (FAD) (USEPA 2007) and summarized below.

Waterfowl Management

The Waterfowl Management Program includes three activities: avian population monitoring, avian harassment activities (motorboats, air boats, propane cannons, bird distress tapes, pyrotechnics), and avian deterrence (depredation of nests and eggs, shoreline fencing, bird netting, overhead deterrent wires, meadow management). Monitoring the results is achieved through continued routine population surveys and by expanding research that identifies sources of bacteria. The objective of the program is to minimize the fecal coliform loading to the reservoirs that results from birds roosting on the reservoir overnight during the migratory season.

Land Acquisition

The Land Acquisition Program seeks to prevent future degradation of water quality by acquiring sensitive lands to ensure that undeveloped, environmentally-sensitive watershed lands remain protected and that the watershed continues to be a source of high quality drinking water to the City and upstate counties. The land is either purchased or easements are put in place.

Land Management

The objective of Land Management is preservation of current environmental quality. The scope of the Land Management Program includes property management, natural resources management, implementing/administering the recreational use programs, monitoring water supply lands, monitoring and enforcing conservation easements, maintaining a watershed land information system (GIS), and developing a forest management plan. DEP has also increased the amount of land open for recreational use, e.g., fishing, hiking, hunting, trapping, cross-country skiing.

Watershed Agricultural Program

The voluntary partnership between DEP and the Watershed Agricultural Council (WAC) continued in 2009. The WAC is focused on improving non-industrial family farms in the watershed. The overall objective of the Watershed Agricultural Program is to prevent agricultural pollution and improve water quality by reducing pollutants leaving farms through the implementation of best management practices (BMPs). The partnership works with watershed residents to identify and eliminate potential pollution sources.

Watershed Forestry Program

As required by the 2007 FAD, a project for developing a forest management plan for City watershed lands was started in 2009. In that year, DEP entered into a partnership agreement with the US Forest Service to conduct a forest inventory of all DEP lands and to develop the plan. The project will continue through 2011, with a plan required to be submitted to EPA in November 2011. The objective is to keep the forest healthy and growing, rather than in a state of decline, in order to maintain the functions of soil stabilization and nutrient uptake.

Stream Management

The objective of the Stream Management Program is to protect and restore stream stability through the development and implementation of stream management plans and demonstration projects, and the enhancement of long-term stream stewardship through increased community participation resulting from partnerships, education, and training. Stabilizing stream reaches provides multiple environmental benefits, including overall water quality improvement and turbidity reduction through decreased streambank erosion.

Riparian Buffer Protection

The Riparian Buffer Protection Program is part of the 2007 FAD, committing the City to continue its riparian buffer protection efforts through existing programs (e.g., Land Acquisition, Watershed Agricultural, Stream Management, and Forestry Programs) as well as by initiating selected program enhancements. The enhancements focus on improving riparian buffer protections along privately-owned stream reaches. For example, within the context of the Stream Management Program, DEP is strengthening its landowner agreements by acquiring enhanced management agreements for the protection of riparian buffers for all current and future stream restoration projects. In addition, riparian landowners have access to technical assistance targeted to their needs. Specifically, enhanced education and training focus on proper streamside management, including development and design assistance with plans for riparian plantings.

Wetlands Protection

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

East of Hudson Non-Point Source Pollution Control Program

DEP has developed a comprehensive nonpoint source program for the West Branch, Boyd Corners, Croton Falls, and Cross River Reservoir basins located east of the Hudson River. Program elements in these basins include an agricultural program, a forestry program, new septic and stormwater initiatives, and cooperative planning efforts by the City as well as Westchester and Putnam Counties. These efforts provide for integrated watershed management to protect and improve water quality in the West Branch, Boyd Corners, Croton Falls, and Cross River Reservoir basins. In addition, DEP addresses many concerns in the East of Hudson watersheds through the effective implementation of the Watershed Rules and Regulations (DEP 2010a), continued and increased involvement in project reviews, and a grant program to assist stormwater districts or municipalities reduce stormwater pollutant loading to the Croton Falls and Cross River basins.

Kensico Water Quality Control

Because Kensico Reservoir is the last impoundment of Catskill/Delaware water prior to entering the City's distribution system, protection of this reservoir is critical to maintaining filtration avoidance for the City. Since the early 1990s, DEP has prioritized watershed protection in the Kensico watershed. FADs (USEPA 1997, 2002) built a foundation of expanded watershed protection and pollution prevention initiatives for the Kensico watershed. Under the 2007 FAD, DEP is instituting new watershed protection and remediation programs designed to ensure the continued success of past efforts while providing for new source water protection initiatives that are specifically targeted toward stormwater and wastewater pollution sources. An example of one of the programs is the construction of stormwater management and erosion abatement facilities to reduce loads of coliform bacteria and suspended solids washed into the reservoir by storms.

Catskill Turbidity Control

The Catskill Turbidity Control Program includes analysis and implementation of engineering, structural, and operational alternatives to address elevated turbidity in the Catskill watershed. Detailed water quality modeling is used to guide operations to minimize turbidity.

Environmental Infrastructure Programs

WWTP Upgrade Program

As part of the Memorandum of Agreement, the City agreed to fund the upgrade of all existing non-City-owned wastewater treatment plants (WWTPs) in the watershed. Upgrades to City-owned WWTPs, which account for more than a third of WWTP flow in the Catskill/Delaware watershed, were completed in 1999. This includes the Brewster WWTP, which was transferred to the Village of Brewster in 2007 after its upgrade was completed. The upgrades of non-City-owned WWTPs, of which the vast majority are complete, provide highly advanced treatment of WWTP effluent.

Septic Programs

Failing septic systems can have a negative effect on water quality. The various septic programs fund the remediation of failed or likely-to-fail septic systems for residents and small businesses, as well as helping homeowners get their septic systems pumped on a regular basis (every three to five years). Since the program's inception, the City has repaired, replaced, or managed a total of 3,227 failing or likely-to-fail septic systems. In 2007, the program was expanded to include commercial septic systems operated by small businesses and $2 million in funding for repair or replacement of existing cluster systems or creating new cluster systems.

New Infrastructure Program and Community Wastewater Management Program

The New Sewage Treatment Infrastructure and Community Wastewater Management Programs fund the construction of new community wastewater treatment facilities. Communities that have participated in these programs include: Andes, Roxbury, Hunter, Windham, Fleischmanns, Phoenicia, Prattsville, Bovina, DeLancey, Bloomville, Hamden, Boiceville, and Ashland. An example of a facility built under this program is the recently constructed WWTP in the hamlet of Boiceville in the Town of Shandaken. The state-of-the-art wastewater treatment process consists of an extended aeration, activated sludge wastewater treatment plant comprised of a sequencing batch reactor (SBR) process, followed by sand filtration, microfiltration, ultraviolet disinfection, and sludge dewatering systems, all enclosed within a single building.

Sewer Extension Program

The Sewer Extension Program funds extensions of sewers from existing City-owned WWTPs in the watershed to areas where onsite septic systems are either failing or are likely to fail. In 2009 construction was completed on the extensions for the newly-expanded Grahamsville sewer system as part of a sewer extension project that will help protect the Delaware watershed. Connections to the system will begin in 2010, with approximately 100 more connections to be made to the system by the end of summer 2010; this will result in an additional 40,000 gallons of sewage being processed daily at the Grahamsville plant. By hooking into the Grahamsville sewer system, residents will be able to discontinue the use of stand-alone septic systems that under certain circumstances can threaten water quality; hence, these connections will contribute to the protection of New York City's watershed.

5.2 How can watershed management improve water quality?

Watersheds are the most effective management unit for the protection of water resources water from rain and melting snow or ice drains downhill into a body of water, such as a river, lake, reservoir, estuary, wetland, sea, or ocean. Therefore, land use within a watershed (e.g., wastewater treatment plants, farms) can greatly affect water quality.

The close relationship between land use in a drainage basin and the quality of its water resources forms the underlying premise for all watershed management programs. In 1997, the Governor and numerous state, local, and federal officials, as well as representatives from environmental organizations, signed the historic NYC Watershed Memorandum of Agreement (MOA). This Agreement represented a comprehensive effort to protect and preserve the high-quality water supply produced by the watershed of the City of New York while preserving and enhancing the economic vitality and social character of the communities within the watershed. To help achieve that goal, DEP has designed a comprehensive watershed monitoring plan and a series of protection programs that focus on monitoring various regulated and supporting parameters (e.g., turbidity, fecal coliform), as well as implementing watershed protection and remediation initiatives. Watershed protection programs, such as the Land Acquisition Program, protect against potential future degradation of water quality from land use changes. Remedial programs, such as the WWTP Upgrade Program and the Streambank Stabilization Program, are targeted towards existing sources of impairment.

A brief summary of the watershed protection programs is provided below. More detailed information on the management programs and water quality analysis can be found in the 2009 Watershed Water Quality Monitoring Plan (DEP 2009a) and the 2006 Long-Term Watershed Protection Program (DEP 2006a).

5.3 What are DEP's watershed management efforts in the Catskill/Delaware System?

Watershed Agricultural Program

Since 1992, the Watershed Agricultural Program has developed pollution prevention plans (also known as Whole Farm Plans) on more than 416 small and large farms in the Catskill, Delaware, and Croton watersheds. To date, more than 95.1% of the 306 large farms in the Catskill/ Delaware watersheds have Whole Farm Plans. Of these, 94.7% of the active farms have commenced implementation and 85.9% have reached the substantially implemented milestone at least once. The Conservation Reserve Enhancement Program (CREP) has protected more than 191 stream miles with riparian forest buffers. WAC has also secured over 18,000 acres of farms under conservation easement using City funds (included in Figure 5.1).

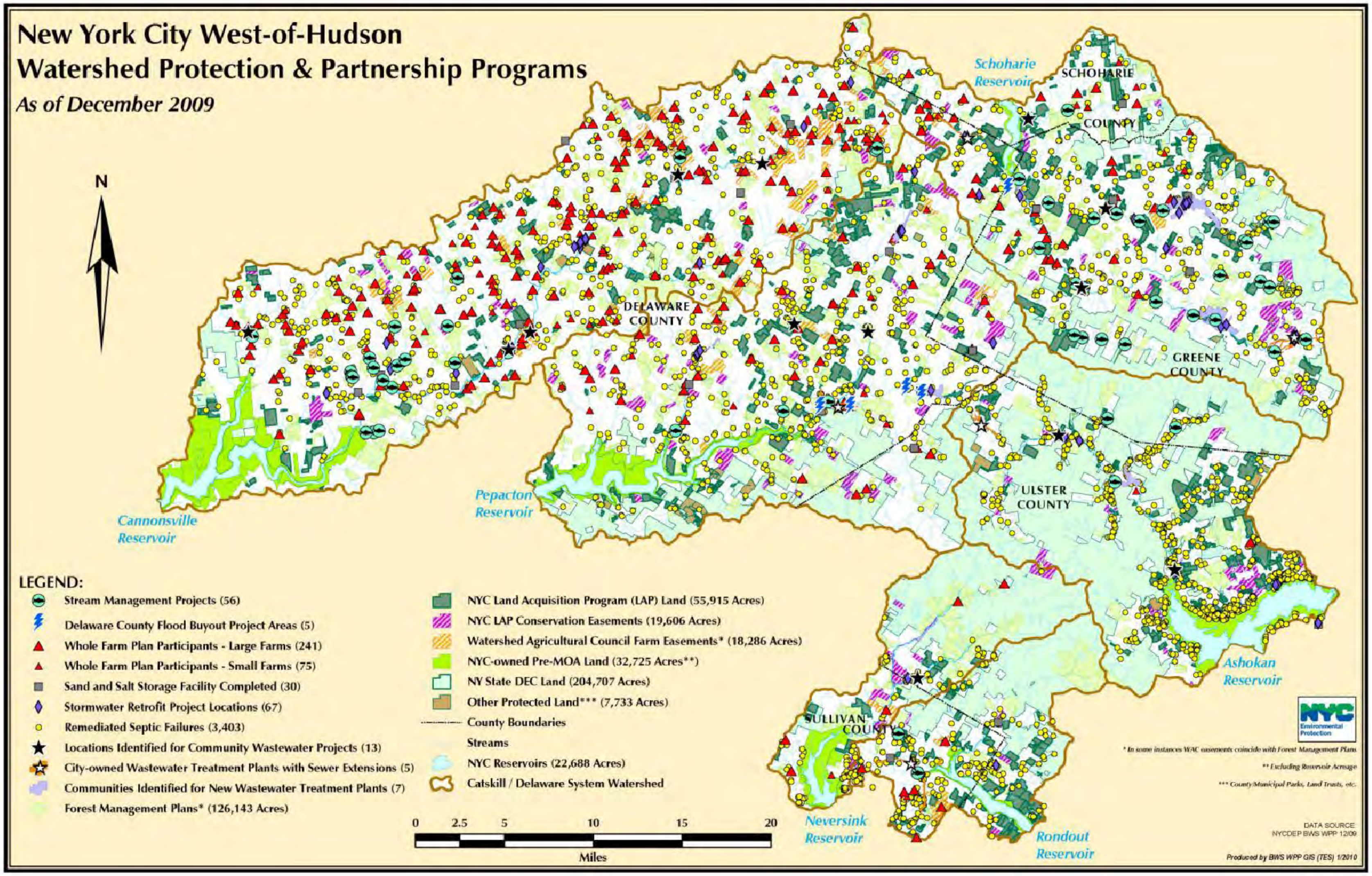

Figure 5.1 New York City West of Hudson watershed protection and partnership programs as of December 2009.

Land Acquisition

Between 1997 and the end of 2009, the City secured more than 102,000 acres in the Catskill/Delaware System (including fee simple and conservation easements acquired or under contract by DEP, and farm easements secured by WAC). This brings to over 137,000 acres the total land area (excluding reservoirs) in the Cat/Del System that have been brought under city ownership for purposes of protecting drinking water. This is more than triple the land area held before the program began and roughly 13% of the total watershed (up from 3.5% in 1997).

WWTP Upgrades

The five City-owned WWTPs in the Catskill/Delaware System were upgraded in the late 1990s. Of the total flow from all non-City-owned Catskill/Delaware plants, 99% emanates from plants that have been upgraded.

New Infrastructure Program (NIP)

The New Sewage Treatment Infrastructure Program provides funding for the study, design, and construction of new sewage facilities in some of the oldest and most populated communities in the Catskill/Delaware watershed. The seven villages and hamlets identified for inclusion in the program are generally located along streams and have small-size lots—many on steep slopes—making it problematic to remediate individual septic systems to current standards. New WWTPs have been constructed in five communities (Andes, Fleischmanns, Hunter, Prattsville, and Windham) and a collection system and force main has been built that connects the Hamlet of Roxbury to the City-owned Grand Gorge WWTP. In Roxbury, construction of a sewer collection system for the Hubbell Corners supplemental service area commenced in 2009 and is expected to be completed in the second half of 2010. In 2009, the Town of Shandaken expressed interest in obtaining assistance from the Catskill Watershed Corporation (CWC) to advance a wastewater project for the Hamlet of Phoenicia. A contract between the Town and the CWC is expected to be executed in 2010.

Partnership Programs

Partnering with DEP, the CWC administers a number of watershed protection and partnership programs, including the Septic Program, the Community Wastewater Management Program, and the Stormwater Retrofit Program (Figure 5.1). The Septic Program funded the remediation of 363 septic systems in 2009. Through the Community Wastewater Management Program, one community has established a septic maintenance district (DeLancey), while three communities (Bovina, Bloomville, and Hamden) have completed community septic system projects, two of which—in Bloomville and Hamden—were completed in 2009. Also in 2009, work began on a Sequencing Batch Reactor (SBR) WWTP for the Hamlet of Boiceville, and DEP approved design plans for a recirculating sand filter WWTP for the Hamlet of Ashland, with construction to commence in 2010. Sixty-six stormwater retrofit projects have been funded through 2009 by the CWC, resulting in the construction and implementation of stormwater BMPs throughout the West of Hudson watershed. Thirty new municipal sand and salt storage facilities have been constructed to house road deicing materials.

5.4 How has DEP tracked water quality improvements in the Catskill/Delaware System?

Water quality has been and continues to be excellent in the Catskill/Delaware System. From 1993-2009, many improvements in water quality have been observed. The most dramatic change has been the reduction in phosphorus in the Catskill/Delaware watershed due to WWTP upgrades. As an example, Figure 5.2 shows phosphorus loads and flows from WWTPs in the Cannonsville watershed. The reduction in total phosphorus loads between 1994 and 1999 can be attributed to the intervention and assistance of DEP at the Village of Walton's WWTP and at Walton's largest commercial contributor, Kraft. The substantial additional reductions in phosphorus loads realized after 1999 can be attributed to final upgrades of five plants and the diversion of another. As a result, Cannonsville Reservoir was taken off the phosphorus-restricted basin list in 2002.

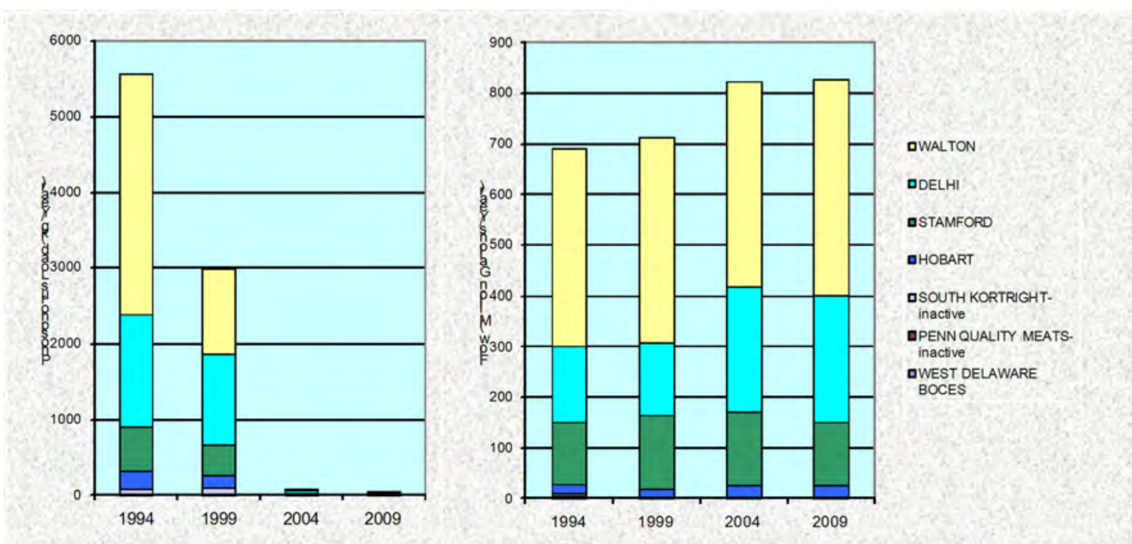

Figure 5.2 WWTP total phosphorus loads and flow in the Cannonsville watershed, 1999-2009.

Many other water quality improvements are monitored by DEP. A good summary is the New York City 2009 Drinking Water Supply and Quality Report (DEP 2010), available on DEP's web site at http://www.nyc.gov/html/dep/html/home/home.shtml, along with many other sources of information about DEP programs to improve water quality.

5.5 What are the watershed management efforts in the Croton System?

The watershed management programs are implemented somewhat differently in the Croton System than in the Catskill/Delaware System. The Croton System does not operate under a filtration waiver; however, watershed protection is still very important for water quality. Instead of explicitly funding certain management programs, DEP provided funds to Putnam and Westchester Counties to develop a watershed plan and to support water quality investment projects in the Croton watershed. In addition to funding watershed management activities undertaken by the counties and municipalities, DEP has implemented an East of Hudson Nonpoint Source Pollution Control Program to address specific watershed concerns (e.g., stormwater retrofits). Other DEP management programs (e.g., the WWTP Upgrade Program, the Watershed Agricultural Program) operate similarly in all systems.

Water Quality Investment Program

DEP provided funds to Putnam and Westchester Counties to develop a watershed plan to protect water quality and guide the decision making process for Water Quality Investment Program (WQIP) funds. Many municipalities have begun implementing actions proposed in the watershed plans, including zoning modifications, regulatory updates, stormwater retrofits, and wastewater control programs. The counties have continued the distribution of the WQIP funds, which were provided by the City for use on watershed improvement projects. A few notable projects for 2009 are described below.

- *Putnam County Septic Repair Program (SRP)*. Putnam County continued to fund and implement the Septic Repair Program in high priority areas, has repaired over 120 systems to date, and has rehabilitated systems in close proximity to water bodies.
- *Westchester County Local Grant Program*. Twelve Westchester County municipalities continued the use of grant funding for projects, including sanitary sewer extensions, stormwater improvements, and enhanced storage of highway de-icing materials.
- *Westchester County Septic Program*. Westchester County continues to track septic repairs and pump-outs as well as train and license septic contractors.
- *Putnam and Westchester: Peach Lake Sewer Project.* The counties have jointly allocated funds toward a project that will provide for the wastewater collection and treatment of sewage around Peach Lake. Construction on the Peach Lake WWTP began in 2009.

EOH Nonpoint Source Program

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

- Stormwater remediation projects were identified and continue to be implemented. Thirty small remediation projects were completed over the past four years in accordance with FAD obligations. The designs and permitting necessary for the larger remediation projects are currently under way.

- Development of a Stormwater Prioritization Assessment was completed, including the establishment of criteria to be used to locate potential future stormwater retrofits in the EOH FAD basins.
- A grant program was developed to help EOH municipalities address stormwater issues through the construction of stormwater retrofits. The program is available to EOH municipalities who have committed to work together as a regional stormwater entity. After design, permitting, and surveying were completed, a significant portion of construction work was accomplished on roadway and drainage improvement projects that will reduce erosion potential and turbidity from unpaved roads. The retrofit project will improve the functionality of existing stormwater conveyance system along the roadways.

WWTP Upgrade Program

The Croton watershed has a large number of WWTPs, with the bulk of them serving schools, developments, and commercial properties. Of the 70 non-City-owned WWTPs located East of Hudson (EOH), 60 are in the Croton System (totaling 4.99 million gallons per day) and 10 are in the West Branch, Croton Falls, and Cross River watersheds (totaling 1.36 million gallons per day). Sixty-two of them (88.6%) have flows less than 100,000 gallons per day; 40 of them (87% of the permitted flow) completed their upgrades as of December 2009 and are either ready to start up or have already done so. An additional 27 WWTPs either have commenced construction of the upgrades or are in the design phase. Upgrade plans for three remaining EOH WWTPs (1% of the permitted flow) are on hold pending decisions on diversion, either to existing plants or out of the Croton watershed.

Thirty-four of the 70 non-City-owned WWTPs are located within the 60-day travel time area. Sixteen of these (49% of the permitted flow) have completed their upgrades. The flow from the 16 WWTPs equates to 86% of the permitted flow within the 60-day travel time.

East of Hudson Watershed Agricultural Program

The farms East of Hudson tend to be smaller and more focused on equestrian-related activities than WOH farms, and the EOH Watershed Agricultural Program has been specifically tailored to address these issues. At the end of 2009, 50 farms in the Croton System had approved Whole Farm Plans. Forty-one of these farms have commenced implementation of BMPs, and a total of 374 BMPs have been installed.

5.6 How does DEP avoid water quality impacts which can occur from the presence of waterbirds (Canada geese, gulls, cormorants, and other waterfowl)?

Following preliminary waterbird population monitoring, DEP's scientific staff identified birds as a significant source of fecal coliform at several NYC reservoirs (e.g., Kensico Reservoir, Figure 5.3).

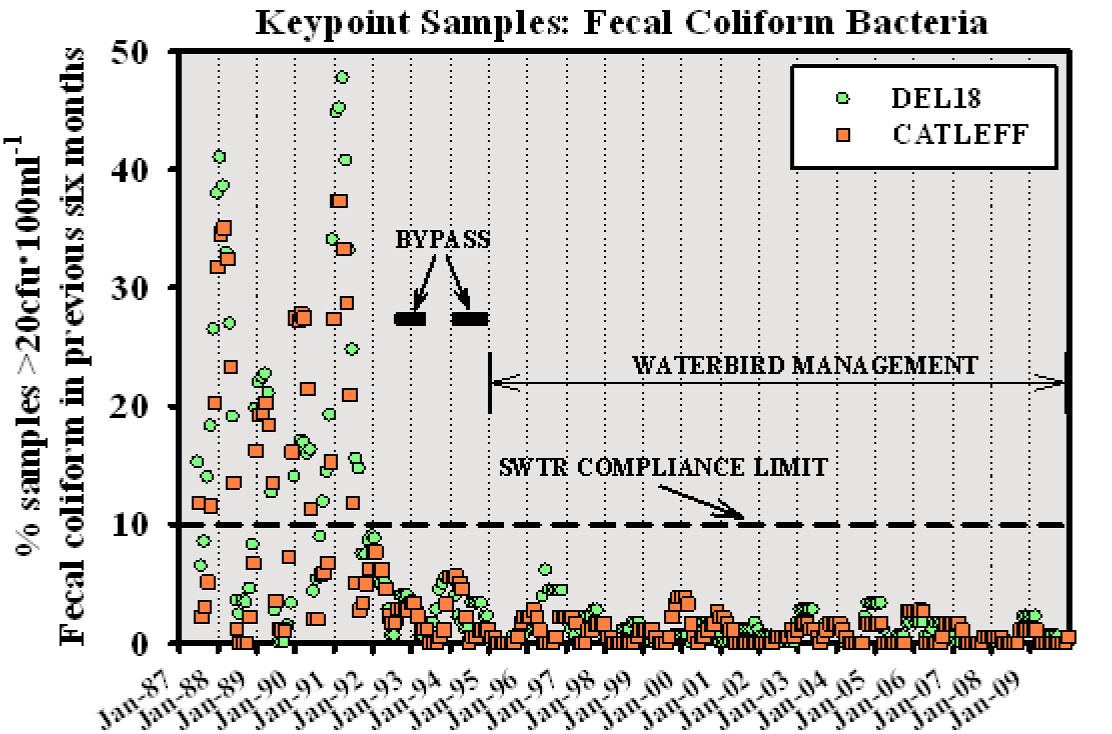

Figure 5.3 Keypoint fecal coliforms at Kensico Reservoir effluents before and after initiation of waterbird management.

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

In response, DEP developed and implemented a Waterfowl Management Program (WMP) using standard bird management techniques (approved by the United States Department of Agriculture, Wildlife Services (USDA) and the New York State Department of Environmental Conservation (DEC)) to reduce or eliminate the waterbird populations inhabiting the reservoir system (DEP 2002). The WMP is implemented at several NYC reservoirs. DEP has also acquired depredation permits from the United States Fish and Wildlife Service and DEC to implement some management techniques.

Bird dispersal measures, including non-lethal harassment by pyrotechnics, motorboats, Husky Airboats, propane cannons, and bird distress tapes, as well as bird deterrence measures, such as waterbird reproductive management, shoreline fencing, bird netting, overhead deterrent wires, and meadow management, continued to reduce local breeding opportunities around water intake structures and eliminate fecundity. Monitoring the effects of bird dispersal and deterrence programs was achieved through continued routine population surveys on each reservoir.

The Surface Water Treatment Rule (40 CFR141.71(a)(1)) states that less than 10% of fecal coliform samples must be below 20 CFU over the course of the previous six months. Since waterbird management began, no such violation has occurred at Kensico Reservoir. This represents a significant reduction as compared to the period prior to the implementation of the WMP (Figure 5.4).

The survey results demonstrated that high levels of fecal coliform bacteria in terminal reservoirs were largely related to avian fecal matter, and have made it possible to evaluate the effectiveness of the dispersal measures employed to reduce those loads. DEP will continue implementation of the WMP indefinitely to help ensure the best possible water quality.

5.7 Why is DEP's Forest Science Program developing forest growth models?

The Forest Science Program has begun using data collected from the establishment and initial measurements of a system of long-term forest monitoring plots across the entire watershed to develop forest growth models to streamline measurements for forest management and facilitate the forecasting of forest growth, mortality, and regeneration. Like other models, forest growth models are a mathematical representation of observed relationships between factors known to affect tree growth and forest or stand condition. Data collected from the monitoring plots are used to develop forest growth models. Information obtained from these models will help predict forest conditions and prioritize forest management.

By comparing these initial models for the watershed with other models for estimating tree heights and volumes developed for the Northeast, DEP can determine whether existing models appear to be suitable for application to its watershed. Figure 5.4 depicts a typical model output of harvestable oak, displaying the time at which it is appropriate to harvest the lumber. Harvesting lumber is a management technique to keep forests in a healthy state of growth.

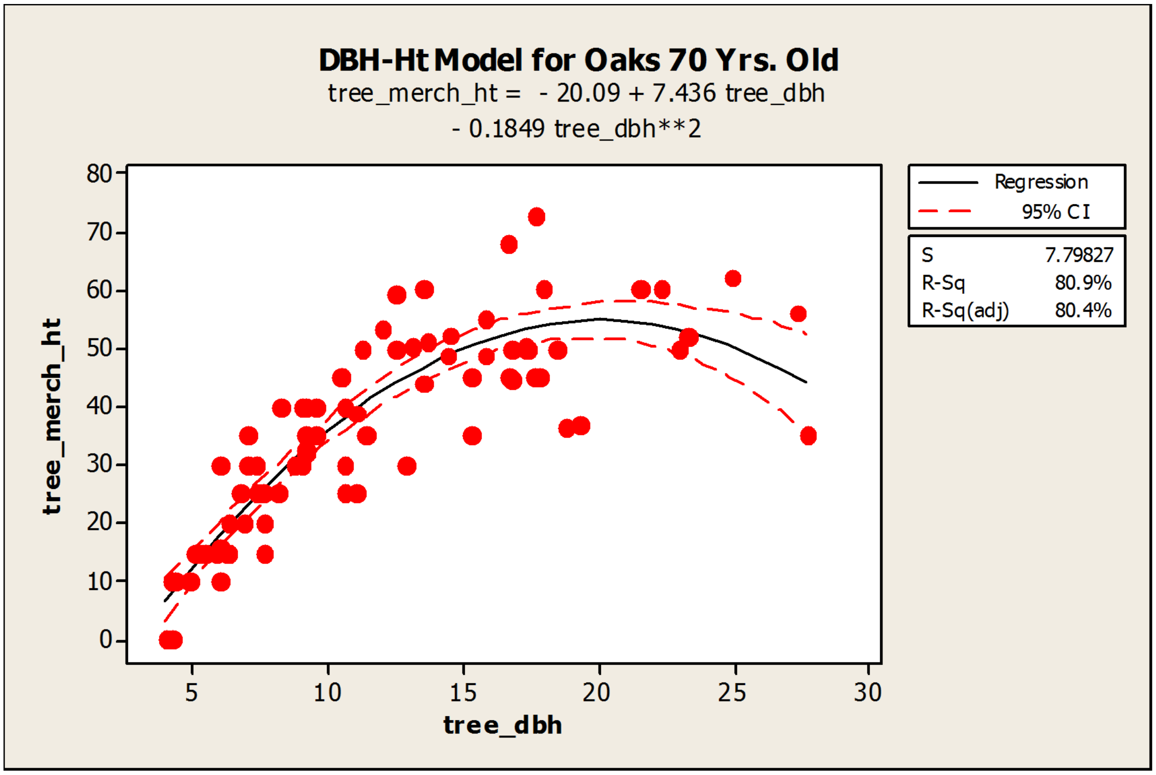

Figure 5.4 Relationship of merchantable height of oak trees in feet to diameter breast height in inches.

5.8 How does DEP address threats to the water supply posed by invasive species?

Damage caused by invasive species can lead to profound and irreversible changes to water supply infrastructure and to the fundamental ecosystem services that sustain water quality and quantity. Some invasive species impacts are direct and obvious, as when zebra mussels foul water supply infrastructure and interfere with water treatment and delivery (see Section 5.11), or when a forest pest causes widespread mortality to an important tree species. Other invasive impacts are indirect and subtle, as when pests or invasive plants alter native forest species composition, resulting in far-reaching changes to fundamental ecosystem processes such as sedimentation and erosion, tree seedling growth, nutrient cycling, nitrogen leaching, hydrologic cycles, and fire frequency. Many of these impacts are presently occurring in the NYC watershed forests (Figure 5.5).

Figure 5.5 Examples of invasive species in the NYC watershed:
a) Giant hogweed (*Heracleum mantegassianum*) and
b) Pale swallow-wort (*Cynanchum rossicum*).

To address the problems posed by invasive species, DEP formed a Bureau-wide Invasive Species Working Group (ISWG) at the end of 2008. The goal of the ISWG is to minimize the risk of invasive-caused damage to the NYC water supply by adopting a proactive, agency-wide comprehensive plan to identify, prioritize, and address invasive species threats, and to eradicate or control established invasive species. DEP is also part of the Catskill Regional Invasive Species Partnership (CRISP), whose goal is to promote the "prevention, early detection and rapid response, and in limited areas/cases, broader control of invasive species to protect natural resources." In turn, CRISP is one of eight Partnerships for Regional Invasive Species Management (PRISMs) in New York State.

In 2009, invasive species-related activities by DEP and regional partners included the following:

- Control of Giant hogweed discovered in 2006 in the Croton Falls watershed.
- Asian Longhorned Beetle surveys conducted in campgrounds. Campgrounds are at risk for Asian Long-horned Beetle and other forest pests and pathogens because infested firewood may be brought in from affected areas.
- Management of a pale swallow-wort (*Vincetoxicum rossicum*) occurrence as part of a DEC grant-funded project, in partnership with the Eastern New York chapter of The Nature Conservancy.
- Adoption of a boot cleaning protocol to prevent the spread of Didymo (*Didymosphenia geminata*) by field scientists.

5.9 What does DEP do to protect the water supply from Zebra mussels?

Source: Wisconsin Dept. of Natural Resources

Figure 5.6 Zebra mussels clogging a pipe. http://dnr.wi.gov/org/water/success/2008/ballast.htm.

Zebra mussels were first introduced to North America in the mid-1980s, and first identified on this continent in 1988. It is believed that they were transported by ships from Europe in their freshwater ballast, which was discharged into freshwater ports of the Great Lakes. Since their arrival in the United States, zebra mussels have been reproducing rapidly and migrating to other bodies of water at a much faster rate than any of our nation's scientists had predicted. They have been found as far west as California, as far south as Louisiana, as far east as New York State, and north well into Canada. They have been found in all of the Great Lakes and many major rivers in the Midwest and the South. In New York State, in addition to Lakes Erie and Ontario, zebra mussels have migrated throughout the Erie Canal, and are found in the Mohawk River, the St. Lawrence River, the Susquehanna River, and the Hudson River, as well as several lakes.

DEP is concerned about infestation of New York City's reservoirs by this mollusk, because it can reproduce quickly and is capable of clogging pipes (Figure 5.6). This would seriously impair DEP's operations, preventing an adequate flow of water from the reservoirs to the City and those upstate communities dependent on the New York City water supply. In addition, zebra mussels create taste and odor problems in the water. To protect the system from zebra mussels, DEP does the following:

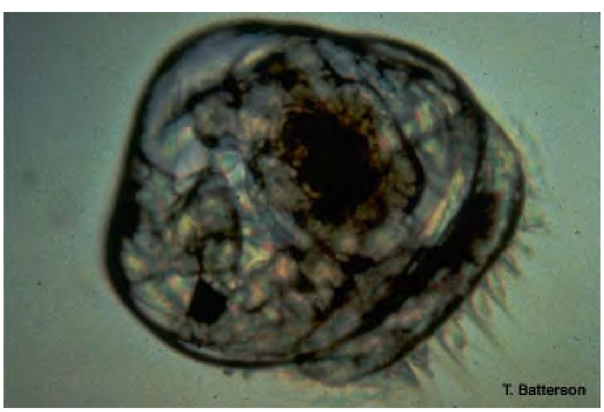

Figure 5.7 Zebra mussel veliger.

•*Monitoring*. As suppliers of water to over nine million people, DEP has the responsibility to monitor New York City's water supply for zebra mussels, since early identification of a zebra mussel problem will make it possible to gain control of the situation quickly, preserve the excellent water quality of the system, and save money in the long run. DEP has been monitoring NYC's reservoirs for zebra mussels since the early 1990s, under a contract with a series of laboratories that have professional experience in identifying zebra mussels. The objective of the contract is to monitor all 19 of New York City's reservoirs for the presence of zebra mussel larvae (known as veligers, Figure 5.7) and settlement on a monthly basis in April, May, June, October, and November, and on a twice-monthly basis during the warm months of July, August, and September.

Sampling includes pump/plankton net sampling to monitor for veligers, and substrate sampling and sampling using a “bridal veil” (a potential mesh-like settling substrate) to monitor for juveniles and adults. The contract laboratory analyzes these samples and provides a monthly report to the project manager as to whether or not zebra mussels have been detected.

Figure 5.8 Steam cleaning a boat to prevent transport of zebra mussels.

- *Steam cleaning boats and equipment*. DEP requires that all boats allowed on the NYC reservoirs for any reason be inspected and thoroughly steam cleaned prior to being allowed on the reservoir (Figure 5.8).

Any organisms or grasses found anywhere on the boat are removed prior to the boat being steam cleaned. The steam cleaning kills all zebra mussels, juveniles, and veligers that may be found anywhere on the boat, thus preventing their introduction into the NYC reservoir system. The steam cleaning requirement applies to all boats that will be used on the reservoirs, whether they are rowboats used by the general public, or motorboats used by DEP. Additionally, all contractor boats, barges, dredges, equipment (e.g., anchors, chains, lines), and trailer parts must be thoroughly steam cleaned inside and out. All water must be drained from boats, barges, their components (including outdrive units, all bilge water (if applicable), and raw engine cooling systems), and equipment at an offsite location, away from any NYC reservoirs or streams that flow into NYC reservoirs or lakes, prior to DEP inspection.

- *Public Education*. DEP provides educational pamphlets to fishermen on NYC’s reservoirs and to bait and tackle shops in NYC’s watersheds explaining how to prevent the introduction and spread of zebra mussels to bodies of water that do not have them. Fishermen can inadvertently introduce zebra mussels to a body of water through their bait buckets, which may have zebra mussels in them (depending on where the bait was obtained), or by failing to clean equipment that has been used in bodies of water infested with zebra mussels before using it in bodies of water that are not. In addition, signs are put up throughout the watershed providing information as to how to prevent the spread of zebra mussels.

5.10 How do environmental project reviews help protect water quality, and how many were conducted in 2009?

DEP reviews a wide variety of projects to assess their potential impacts on water quality and watershed natural resources. Under the New York State Environmental Quality Review Act (SEQRA), DEP is often an involved agency because of its regulatory authority over certain actions. By participating in the SEQRA process, DEP can ensure that water quality concerns are addressed early on in the project planning process. In 2009, DEP staff reviewed a total of 121 SEQRA actions, including Notices of Intent to Act as Lead Agency; Determinations of Action Types; Environmental Assessment Forms; Scoping Documents; Draft, Final, and Supplemental Environmental Impact Statements; and Findings to Approve or Deny.

In addition to projects in the SEQRA process, DEP reviewed other projects upon request. Review of these projects helps ensure that they are designed and executed in a way that minimizes impacts to water quality. DEP provides its expertise in reviewing and identifying on-site impacts to wetlands, vegetation, fisheries, and wildlife, and also provides recommendations on avoiding or mitigating proposed impacts. These reviews also provide guidance on interpreting regulations as they apply to wetlands and to threatened and endangered species. Approximately 99 of these projects were reviewed and commented on by DEP in 2009. Many of these projects were large, multi-year efforts with ongoing reviews, while others were smaller scale projects scattered throughout the NYC Watershed.

DEP also coordinates review of federal, state, and local wetland permit applications in the watershed. In 2009, approximately 28 wetland permit applications were reviewed and commented on to ensure compliance with watershed rules and regulations.

5.11 What was the status of WWTP TP loads in the watershed in 2009?

The sum of the annual total phosphorus (TP) loads from all surface-discharging WWTPs from 1999-2009 are depicted, by system, in Figure 5.9. The far right bar displays the calculated wasteload allocation (WLA) for all these WWTPs, which is the TP load allowed by the State Pollutant Discharge Elimination System (SPDES) permits—in other words, the maximum permitted effluent flow multiplied by the maximum permitted TP concentration. Overall, the TP loads from WWTPs since 2003 have remained far below the WLA. The fact that loads in the Delaware and Catskill Systems remain so far below their respective WLAs reflects the efficacy of the WWTP upgrade program, which is largely complete, in watersheds both west and east of the Hudson River.

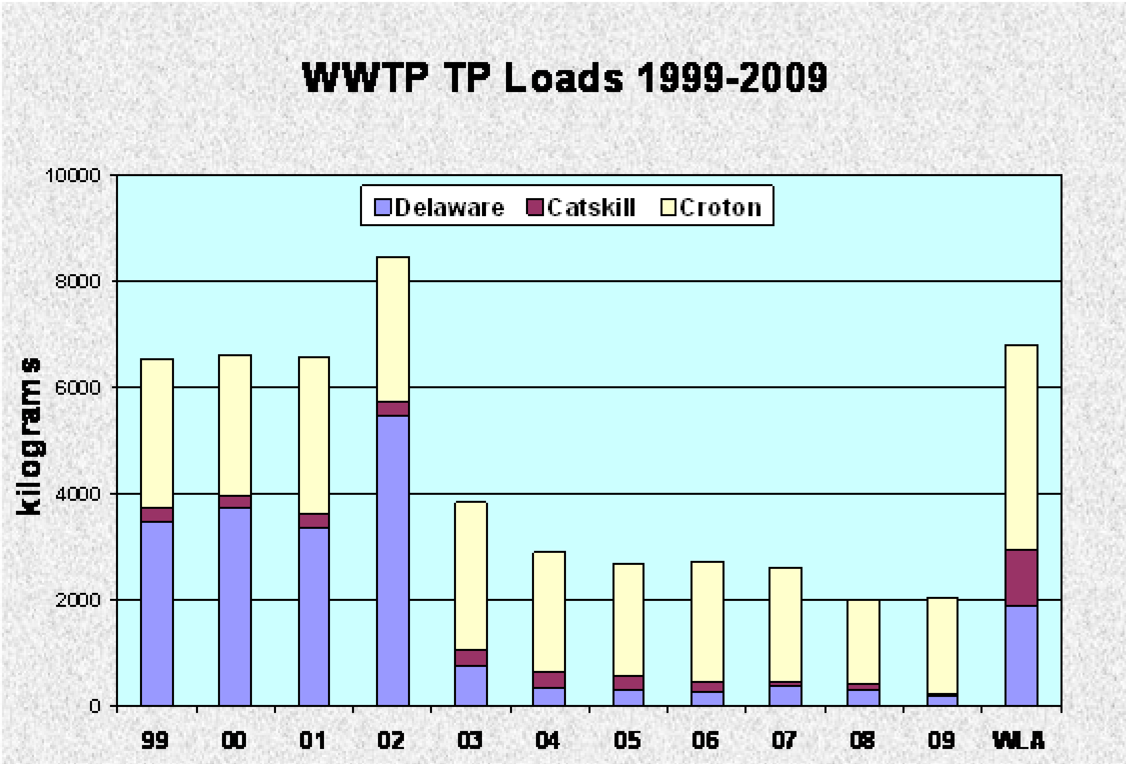

Figure 5.9 Wastewater Treatment Plant TP loads, 1999-2008. The wasteload allocation for the entire watershed is shown in the right-hand bar for comparison.

5.12 What "Special Investigations" were conducted in 2009?

The term "Special Investigation" (SI) refers to limited non-routine collection of environmental data, including photographs and/or analysis of samples, in response to a specific concern or event. Reports are prepared to document each incident and DEP's response and remedial actions as appropriate. In 2009, 5 SIs were conducted, all of which were as a result of events that occurred in the East of Hudson Watershed. The investigations included one fish kill, two diesel fuel spills, one fecal coliform investigation, and one aqueduct leakage investigation. None of the investigations identified a pollution or contamination problem that was an immediate or long-term threat to consumers of the water supply. Below is a list of investigations which occurred in 2009, classified by reservoir watershed, which occurred in 2009, with the date and summary of each investigation.

Muscoot Reservoir (SI09CM01)

On February 26, 2009, a diesel fuel spill (estimated at 900 gallons) occurred in the Muscoot Reservoir drainage basin in Bedford Hills, NY. Northeast Environmental (a contractor) and DEP Haz Mat responded to the spill by establishing oil absorbing booms along Beaver Dam Brook (a.k.a. Stone Hill River), and a branch of the Muscoot Reservoir. Samples were taken by DEP the afternoon of the spill and the next day for volatile compounds. Results indicated the presence of select fuel-related compounds for samples taken on February 26, but none of these compounds were found in samples taken the next day, February 27. The quick response by the contractor and DEP HazMat was important in isolating the spread of fuel oil to Muscoot Reservoir's main basin. No follow-up investigation or further sampling was necessary.

Muscoot Reservoir (SI09CM02)

On May 14, 2009, DEP collected water samples from a drainage ditch adjacent to Interstate 684 in the Town of Purdys, NY, within the Muscoot Reservoir watershed. The goal of the sampling was to determine whether coliform bacteria were present down-gradient of a suspected failed septic system. Sampling results did not detect elevated coliform numbers, so no further samples were obtained.

Kensico Reservoir (SI09BRK01)

On On June 30, 2009 a tractor trailer travelling southbound on Interstate 684 jackknifed, causing it to spill approximately 55 gallons of diesel fuel oil near Kensico Reservoir. Responders included the Armonk Fire Department, Westchester County, Department of Health, DEP Police, DEP Haz Mat and Tri-State Environmental (the clean-up consultant). DEP determined the spill was sufficiently contained, so reservoir water samples were not necessary. Tri-State Environmental removed the contaminated soil and replaced it with fresh topsoil. No further action was necessary.

Muscoot River (SIFKIR09)

On July 11, 2009, a caller reported a dead fish at the Amawalk Outlet (Muscoot River) to the Eastview Precinct. Additional dead fish were reported on July 14. DEP Police, Water Quality Operations and Watershed Protection (Fisheries) staff responded. Field necropsies were conducted on three brown trout and tissue samples were submitted to a fish health diagnostics lab (Micro Technologies, Inc., Richmond, ME). Whole fish were also submitted for bacterial and viral culturing. Although organ tissues from all three fish retained copper-indicating stain, no definitive determinations as to the cause of the fish kill were made. The investigation was considered closed.

Catskill Aqueduct at the Eastview Construction Site (SI09CATEV)

Water infiltrating the excavation site of the Catskill Aqueduct connection to the Cat/Del UV plant was sampled to determine if the source of the infiltrate was a leak from the Catskill Aqueduct. Laboratory results indicated that the infiltrate was not water from the Aqueduct. No further action was taken.

6. Model Development and Application

6.1 Why are models important and how are they used by DEP?

DEP uses models to examine the effects of changing land use, population, ecosystems, climate, and both watershed and reservoir management on the NYC drinking water supply (Figure 6.1). Changing conditions in the watersheds present both ongoing and new challenges that DEP must plan for and respond to in its mission to ensure the continued reliability and high quality of the NYC drinking water supply. Changes in land use, population, and watershed management influence nutrient loadings, which can affect levels of eutrophication in reservoirs. Changes in stream channel erosion related to climate and to urbanization may exacerbate turbidity in the water supply system. Climate change and changes in watershed ecosystem functions may impact both the future quantity and quality of water in the upstate reservoir system. Understanding the effects of changing conditions is critical for decision making, long-term planning, and management of the NYC watersheds and reservoir system.

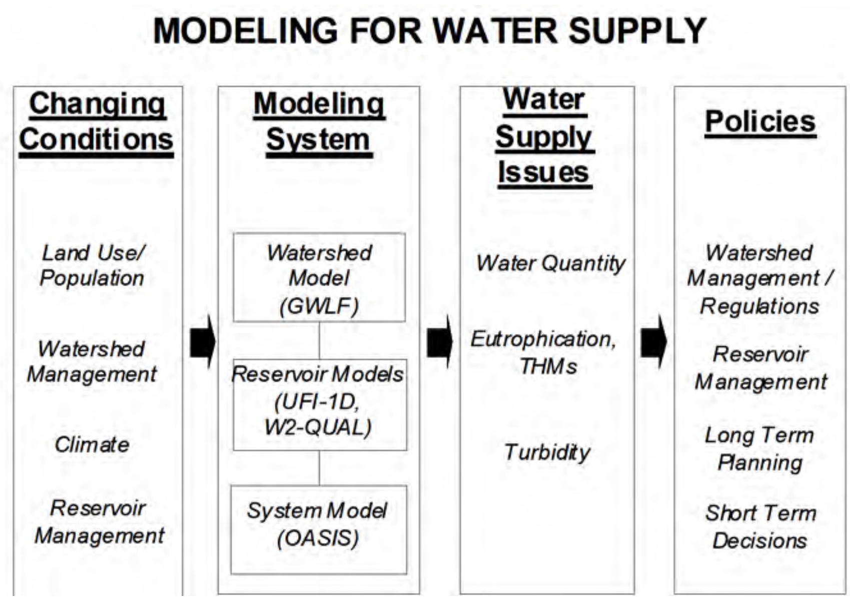

Figure 6.1 Use of models for the NYC Water Supply.

The DEP modeling system consists of a series of linked models that simulate the transport of water and contaminants within the watersheds and reservoirs that affect the Catskill and Delaware upstate water supply systems. Watershed models, including the Generalized Watershed Loading Function (GWLF) models that DEP has adapted, simulate generation and transport of water, sediment, and nutrients from the watersheds to the reservoirs. Reservoir models (including the UFI-1D and the CE-QUAL-W2 models) simulate hydrothermal structure, hydrodynamics, and nutrient and sediment distribution within the reservoir body and outlets. The water supply system model (OASIS) simulates the operation of the multiple reservoirs that comprise the water supply system. The entire modeling system is used to explore alternative future scenarios and examine how the water supply system and its components may behave in response to changes in land use, population, climate, ecosystem disturbances, watershed and 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 to meet NYC demand. Simulations are performed during, and in the aftermath of, storm events to provide guidance for operating the Catskill/Delaware System tunnels in response to elevated turbidity levels, particularly in the Catskill System. The models have been used to identify major sources of turbidity, and to examine alternative structural and operational changes in Schoharie and Ashokan Reservoirs to mitigate the need to use alum to treat elevated turbidity. The effects of changing land use and watershed management on nutrient loading and eutrophication in Delaware System reservoirs (Cannonsville and Pepacton) have been analyzed using linked watershed and reservoir models. The effects of climate change on the water supply are currently under investigation using the modeling system.

6.2 What can models tell us about the effects of 2009's weather on nutrient loads and flow pathways to reservoirs?

Watershed modeling provides insight into the flow paths of water and nutrients through the watershed. Total streamflow is comprised of direct runoff and baseflow. Direct runoff is water that moves rapidly on or near the land surface during and after storm events, as opposed to much slower-moving baseflow that sustains streamflow between storm events. Direct runoff has a high potential for transporting phosphorus (P) as it interacts with P sources on the land surface. Frequent and intense storm events may produce above-average nutrient loads to reservoirs due to increased direct runoff. Long-term watershed model simulations that include the current year can be used to place annual results for 2009 in context with the historical climatology.

Figure 6.2 depicts the annual streamflow, direct runoff, and non-point source (NPS) dissolved nutrient loads simulated by the GWLF-VSA watershed model (Schneiderman et al. 2002, 2007) for 2009 in comparison to annual statistics associated with long-term simulations (1966-2009) for each variable. These model runs only account for year-to-year climatic variability and do not account for changes in land use or management practices, as these are assumed to be static over the simulation period. The boxplots show that in 2009 streamflow and direct runoff were generally at or above the median annual values. The modeled 2009 NPS dissolved nutrient loads (total dissolved nitrogen and total dissolved phosphorus) were consistent with the statistics for flow. Annual 2009 nutrient loads were near or above median values calculated from long-term simulations for each of the WOH reservoir basins.

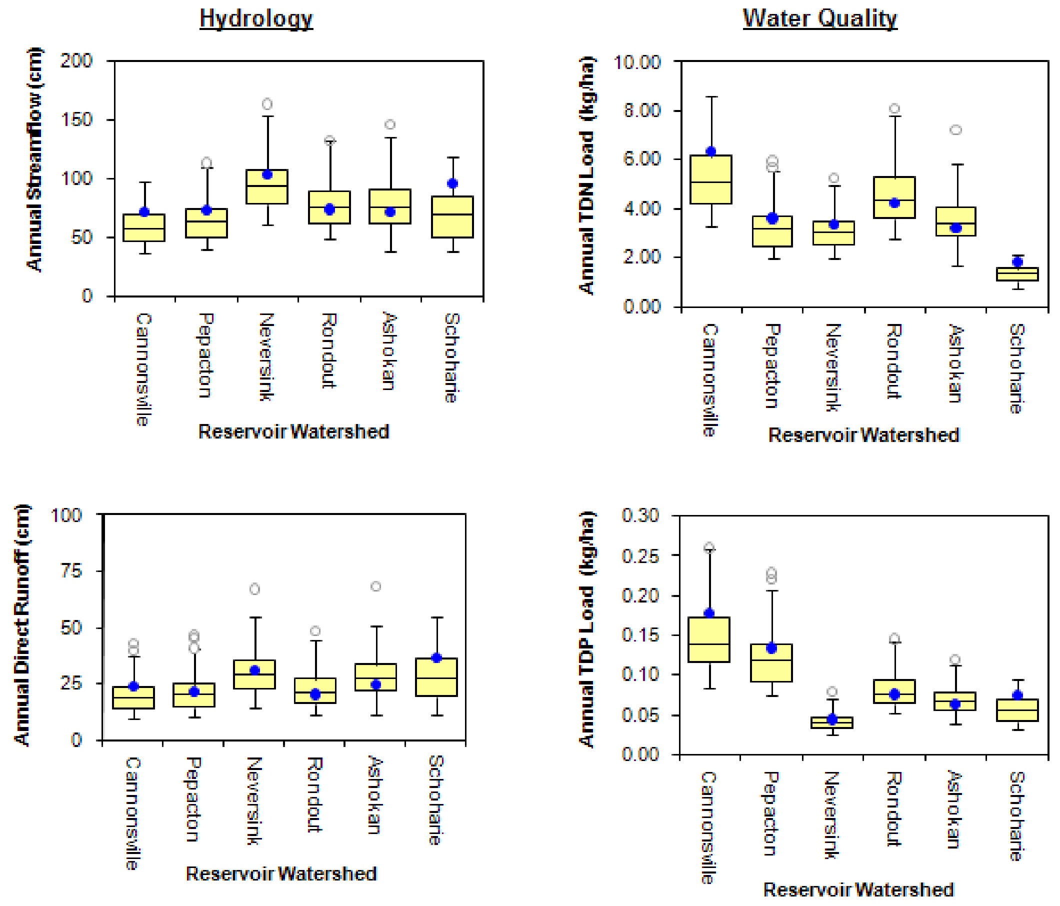

Figure 6.2 Annual streamflow, direct runoff, and non-point source total dissolved phosphorus (TDP) and nitrogen (TDN) loads simulated by the GWLF-VSA model for 2009 in relation to long-term simulated annual statistics based on long term historical meteorologic input (1966-2009). Boxplots show long-term statistics. Blue dots show 2009 results.

6.3 How is DEP using its modeling capabilities to investigate the effects of climate change on water quality?

DEP is using a suite of simulation models to investigate the effects of climate change on water quality in the West of Hudson portion of the water supply. Preliminary investigations focus on estimating future climate projections, looking 65 years and 100 years forward using DEP's modeling system (see Section 6.1). Projections of future air temperature and precipitation were developed from three Global Climate Models (GCMs), one developed by the Goddard Institute for Space Studies (GISS), another by the Canadian Center for Climate Modeling and Analysis (CGCM3), and a third by the Max Planck Institute for Meteorology (ECHAM); three greenhouse gas emission scenarios (A1B, A2, and B1) were also used. For each combination of GCM and emission scenario, monthly delta change coefficients were derived by comparing GCM output for control (1980-2000) vs. future prediction periods (2045-2065 and 2080-2100).

In the initial work on simulating reservoir water quality, the GWLF watershed model simulated the effects of future changes in meteorology on streamflow and nutrient inputs to the Cannonsville Reservoir, and the PROTECH reservoir water quality model simulated the effects of changing reservoir inputs on nutrient loads, chlorophyll *a* concentration and phytoplankton functional group biomass.

One of the clearest projected effects of climate change is a pronounced shift in the timing of stream discharge and nutrient export (Figure 6.3). As a result of increasing levels of fall and winter precipitation and air temperature, less winter precipitation falls as snow, and the snow that does fall melts earlier. Increased winter rain and snowmelt and a reduced snow pack lead to greater stream discharge during winter and a reduction in the snowmelt-influenced discharge peak that presently occurs during spring. Along with these changes in stream discharge come similar shifts in the timing of nutrient loading, so that a greater proportion of the annual nutrient load enters the reservoir during future winters (Figure 6.4). When examining annual changes (Figure 6.5), it is striking that moderate increases in streamflow and phosphorus loading lead to relatively small increases in reservoir chlorophyll *a*. Median future stream discharge is projected to increase by 13% and 16% for the two future time periods (2046-2065 and 2081-2100) and phosphorus loading is similarly projected to increase by 15% and 17%. For the same future time periods, reservoir chlorophyll *a* concentrations show relatively small increases of 4% and 9%. While work is still under way, preliminary results suggest that shifting nutrient export from spring to winter reduces the response of reservoir phytoplankton to an increased nutrient load associated with future climate scenarios. There are at least three reasons for this moderating effect.

- The nutrients are delivered to the reservoir at a time when other environmental conditions do not favor phytoplankton growth. Water temperatures are cold. Levels of light are low due to seasonal variations in incoming light, deep isothermal mixing, and ice and snow covering the reservoir.
- Water entering the reservoir during winter is more likely to be lost as spill in the future (see Section 6.4). Nutrient exported with this spill can not support phytoplankton growth later in the year.
- Discharges during the contemporary spring discharge peak are higher than those projected to occur during future winters. During high spring discharge, greater proportions of stream flow will occur as surface runoff, which may contain higher phosphorus concentrations.

Work will continue in 2010 to investigate these processes in more detail. Seasonal changes in nutrient loading will be examined using a greater number of climate change scenarios that are downscaled using a method that will better account for variations in storm frequency and intensity (see section 6.6).

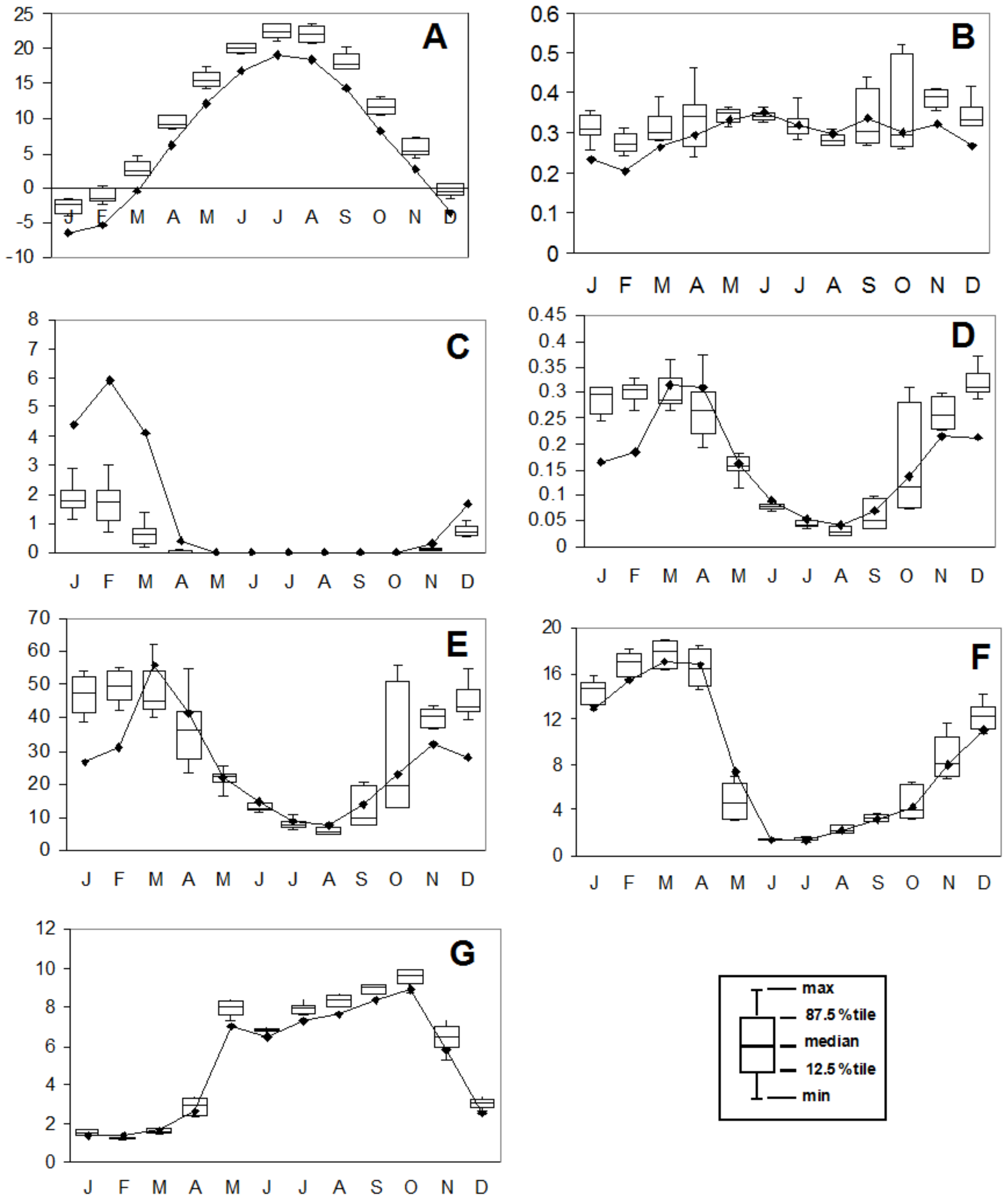

Figure 6.3 Average conditions for present day (solid line) and a range of future conditions (bar) for Cannonsville Reservoir and watershed. A) Mean daily air temperature (°C), B) Mean daily precipitation (cm), C) Mean snow pack water equivalent (cm), D) Mean daily stream discharge (cm), E) Mean reservoir dissolved phosphorus export (kg km^{-2} mo^{-1}), F) Mean reservoir dissolved phosphorus concentration (mg m^{-3}), G) Mean reservoir chlorophyll *a* concentrations (mg m^{-3}).

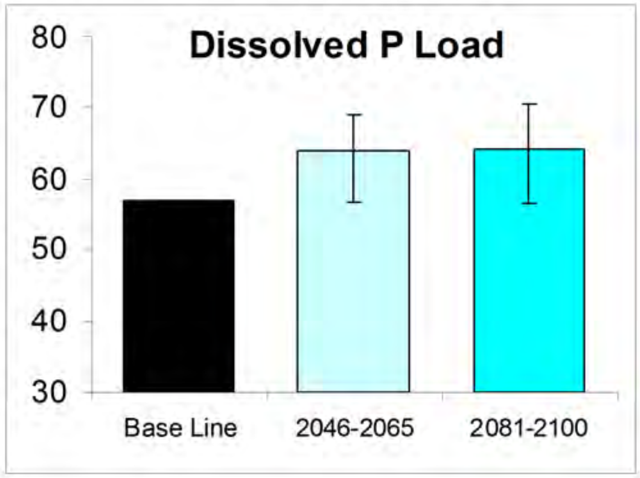

Figure 6.4 Percent of the annual dissolved phosphorus load that occurs during winter (Dec.-Mar.). For the future time periods, the solid bar shows the median and vertical lines show the range of nine simulations.

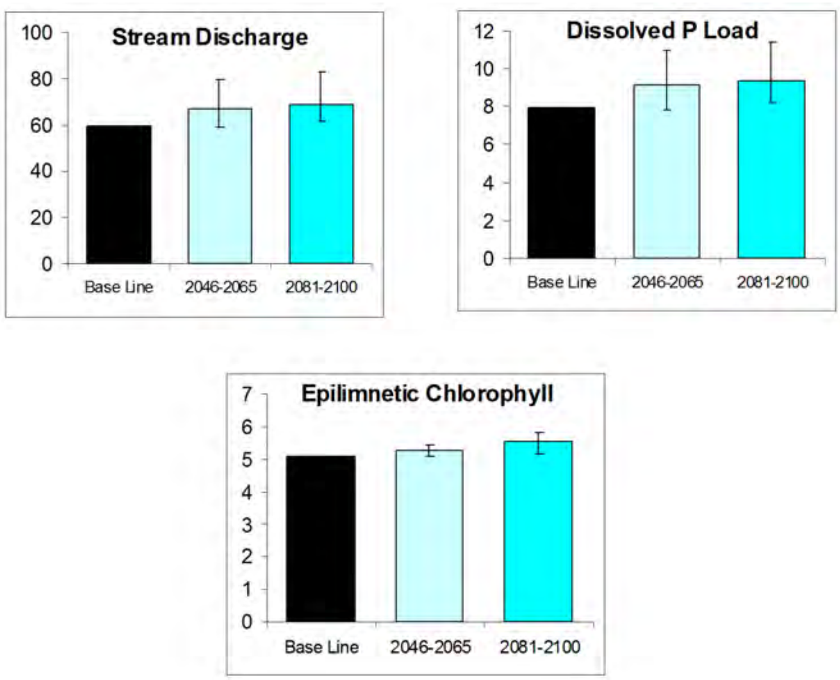

Figure 6.5 Total annual streamflow, and dissolved phosphorus loading compared with the mean annual reservoir chlorophyll *a* concentration. For the future time periods, the solid bar shows the median and vertical lines show the range of nine simulations.

6.4 How is DEP using its modeling capabilities to investigate the effects of climate change on indicators of water quantity?

The potential impact of climate change on water quantity in the WOH reservoir system was investigated by running the OASIS reservoir system model (Figure 6.1). OASIS model simulations for baseline and future climate change scenarios were driven by input streamflows simulated by the GWLF watershed model. Simulations assumed that future demands and reservoir operation rules would remain similar to present day conditions. The status of the reservoir system, the system's management, and its response to climate change are evaluated by comparing selected system indicators such as storage volume, spill, and release for baseline and future climate scenarios. System indicators also give DEP information on long-term system performance, such as reservoir resilience (a measure of probability that the reservoir system will recover from a drought) and vulnerability (an indicator of the average duration of drought events).

Preliminary results suggest that future climate change will impact regional hydrology, and ultimately affect water system indicators. The combined effect of projected increases in winter air temperatures, increased winter rain, and earlier snowmelt result in a subsequent increase in runoff during winter. This shift in the timing of runoff, combined with increased evapotranspiration (ET), leads to reservoir storage levels, water release, and spill being increased during the winter months, while remaining similar or slightly reduced during summer (Figure 6.6). These patterns are consistent with a reduction in the number of days the system is likely to be under watch, warning, and emergency drought conditions (Figure 6.7).

As for reservoir system performance, simulations based on future climate change scenarios suggest that under future conditions the NYC reservoir system will continue to have a high resilience, and a relatively low vulnerability.

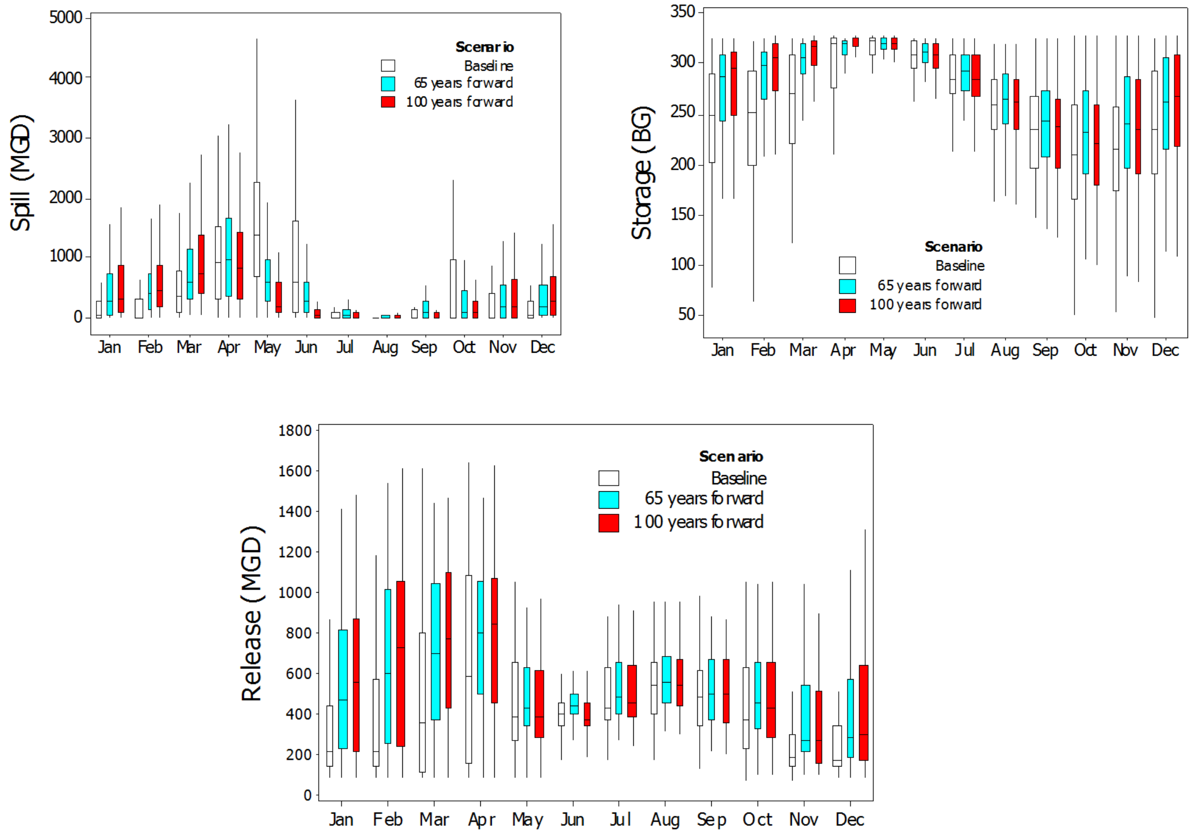

Figure 6.6 Monthly WOH storage, controlled release, and uncontrolled spill to downstream rivers for baseline and 65 and 100 years forward. Middle lines represent the median, boxes the 25th and 75th interquartile range.

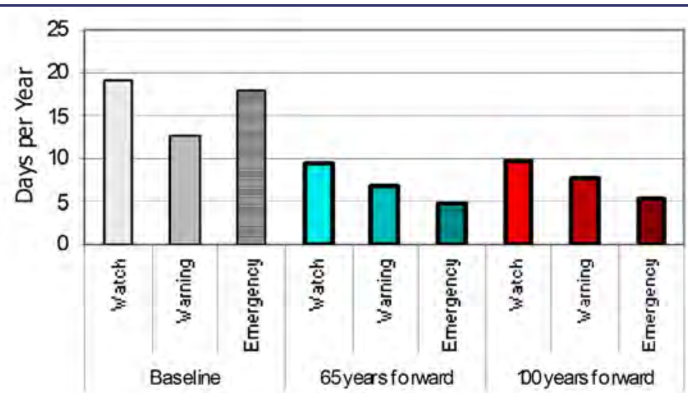

Figure 6.7 Average yearly number of days the WOH reservoir system is under watch, warning, and emergency drought conditions for the baseline and future climate scenarios.

6.5 How are models being used to support reservoir operations decisions?

Operation of the NYC reservoir system is a dynamic process of adapting to changing conditions to balance sometimes competing goals. These goals include meeting water demand, maintaining high quality water in the system, meeting regulatory requirements, and accommodating environmental concerns. The complexity of the NYC water supply gives the system operators a degree of flexibility in the timing of storage and movement of water from different parts of the system. This flexibility has been instrumental in DEP's ability to provide high quality drinking water to NYC, and is expected to play an important role in adapting to future uncertainty related to climate and land use change.

An important use of models is for the management of turbidity. Storm-generated turbidity in the NYC water supply watersheds—particularly in the Catskill System (comprised of Schoharie and Ashokan Reservoirs and their respective watersheds)—is a water quality issue that impacts the operation of the NYC water supply. When turbidity events occur, Catskill 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 may have environmental implications, so every effort is made to avoid alum treatment by careful operation of the reservoir system.

When a significant turbidity event occurs, DEP uses reservoir models applied in a probabilistic framework to project turbidity in the Catskill System under varying operational and meteorological scenarios. The models currently used for these applications are incorporated into the LinkRes System developed for DEP by the Upstate Freshwater Institute. LinkRes simulates the behavior of the Catskill reservoir system by linking CE-QUAL-W2 models for Schoharie, Ashokan East, Ashokan West, and Kensico Reservoirs. These two-dimensional hydrothermal and turbidity transport models have been calibrated and tested for each respective reservoir, and are linked so that the cascading effects of varying turbidity inputs and reservoir operations are simulated throughout the system.

DEP is also in the process of developing the Operational Support Tool (OST), a database and modeling system that will be used to refine operating decisions to minimize turbidity and otherwise improve the management of the water supply system. The OST will combine reservoir water quality and water system models, near real-time data of flows and water quality, and meteorological and streamflow forecasts, to predict reservoir operational strategies to both control turbidity levels and continue to reliably meet water demands. The modeling backbone of the OST includes an implementation of the CE-QUAL-W2 reservoir model developed specifically to simulate turbidity in the Catskill System reservoirs. This reservoir model has been integrated with the OASIS model, a water system model used to simulate reservoir system volumes and flows. The combined modeling system allows decisions on the use and transfer of water within the reservoir system to be based both on volume and turbidity levels in the individual reservoirs. The OST facilitates the testing of water system operational strategies in order to gain understanding of the effects of these decisions on future water system quantity and quality. After consideration of multiple alternatives, the OST modeling system was chosen as the most effective measure for reducing potential turbidity issues within the water supply.

6.6 How does DEP develop future climate change scenarios?

The future climate is unknown and uncertain, but to evaluate impacts of climate change it is necessary to develop plausible future climate scenarios. A variety of methods are available to estimate climate scenarios of meteorological variables at future times and at spatial scales appropriate for local climate change impact assessment. One commonly used method is Change Factor Methodology (CFM), sometimes referred to as "delta change methodology". This methodology takes the difference in GCM output for present and future conditions, and adds the difference to local meteorological records to simulate possible future changes in local weather. Although more sophisticated methods exist, CFM is still widely used in climate impact analysis studies.

There are a number of different variations of CFM. During 2009, DEP systematically examined the consequences of using different forms of CFM. As a result of this study, DEP concluded that monthly change factors calculated additively over 25 frequency bins provided an optimal downscaling method for the NYC watershed region. This method should allow CFM to more adequately represent future changes in event frequency.

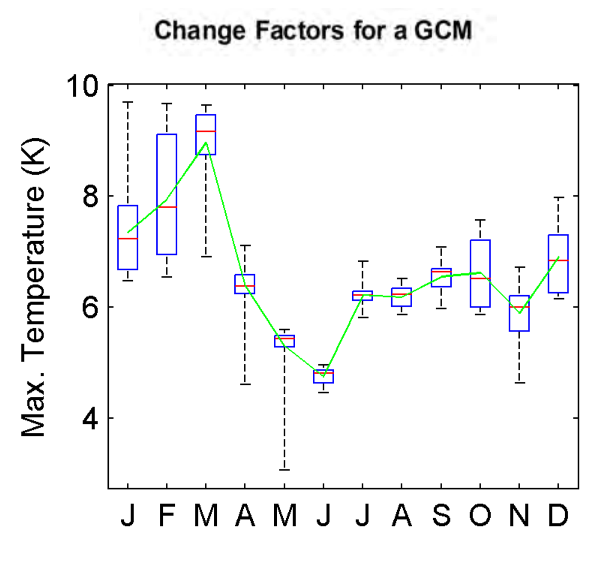

Figure 6.8 Variation in monthly change factors used to adjust local records of maximum air temperature to produce a future climate scenario.

For each GCM, change factors are calculated by pooling for each month all the daily data from a baseline scenario (1981-2000) and comparing these data to two time periods of future GCM data (2046-2065, 2081-2100). For example, for January, data are pooled from 20 Januarys in the GCM baseline data set and 20 Januarys in one of the GCM future scenarios. Using the pooled data in the baseline and future data sets DEP estimates the empirical cumulative distribution functions (CDFs) for future and baseline GCM data (*GCMf* and *GCMb*). Both frequency distributions are divided into 25 equal bins, and 25 additive change factors are calculated as the difference between the corresponding bins in the future and baseline scenarios. A typical set of change factors for air temperature is shown in Figure 6.8. The variability in the monthly change factors is illustrated by the boxplots, in which the middle line shows the median value, top and bottom of the box show the upper and lower quartiles (75th and 25th percentile values, respectively), and whiskers show the minimum and maximum change factor values for the month. A similar analysis is carried out for the remaining months of the year.

To produce a future climate scenario these change factors are then added to records from local meteorological stations, again based on the frequency distributions of pooled monthly observed data, as illustrated in Figure 6.9. For example, based on the data in Figure 6.8, maximum January air temperature data will be increased by anywhere form 6.5 °C to 9.5 °C, depending on the value of the observed January temperature.

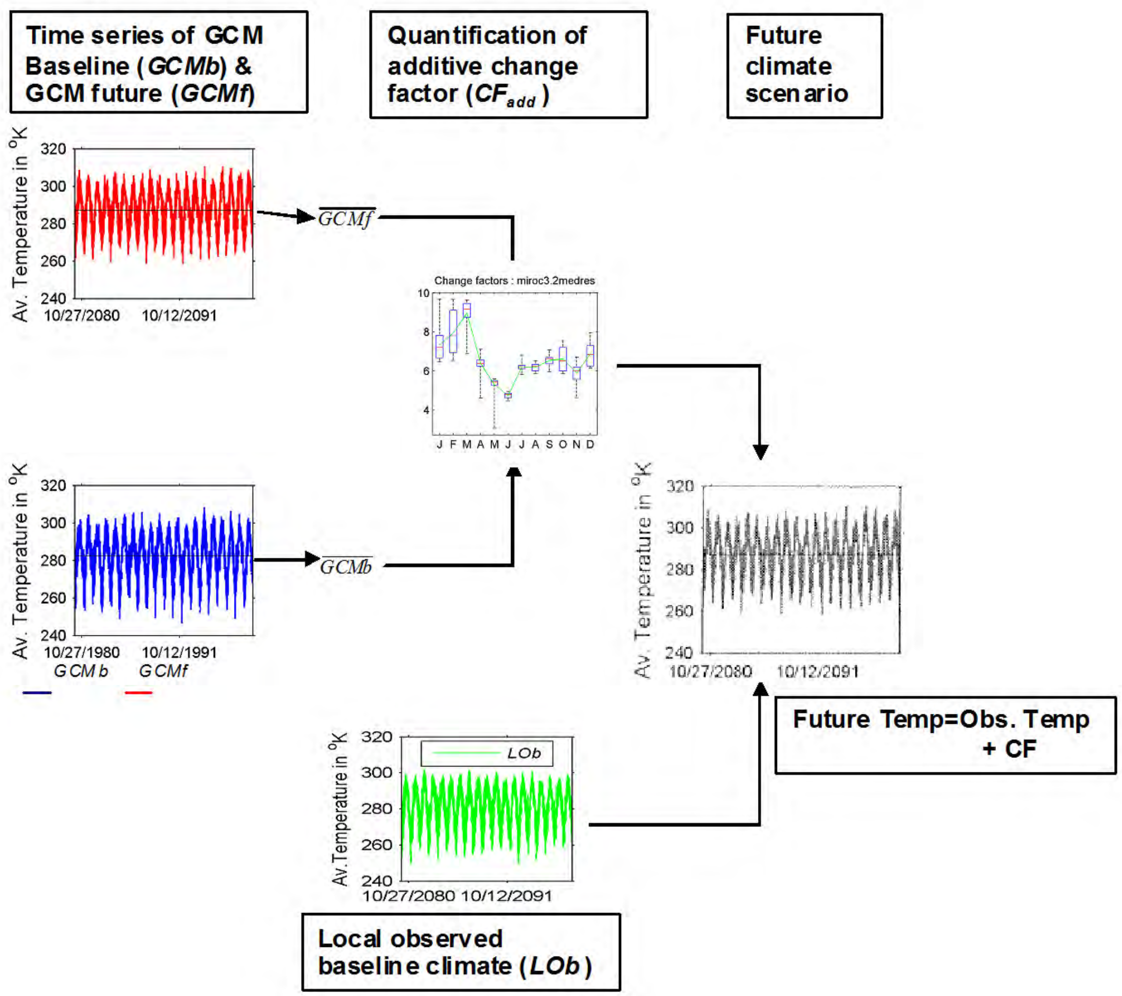

Figure 6.9 Methodology to estimate future climate scenarios using change factors.

6.7 How is DEP improving its watershed modeling capability?

Watershed models are used to determine the rate of pollutant loading in the NYC reservoirs and to evaluate the impact of climate, land use, and management practices on these loads. A new watershed model being used by DEP is the physically based Soil and Water Assessment Tool (SWAT) model (Neitsch et al. 2005), developed and supported by the USDA-Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas (http://swatmodel.tamu.edu/). The SWAT model uses a semi-distributed approach in watershed modeling by dividing the watershed into relatively small sub-basins and using the concept of Hydrologic Response Units (HRUs) that are unique combinations of soils, land use, and topography (White et al. 2009) (Figure 6.10). Routing of flow, sediment, and nutrients from the sub-basins to the channel network and to the watershed outlet can be simulated in SWAT.

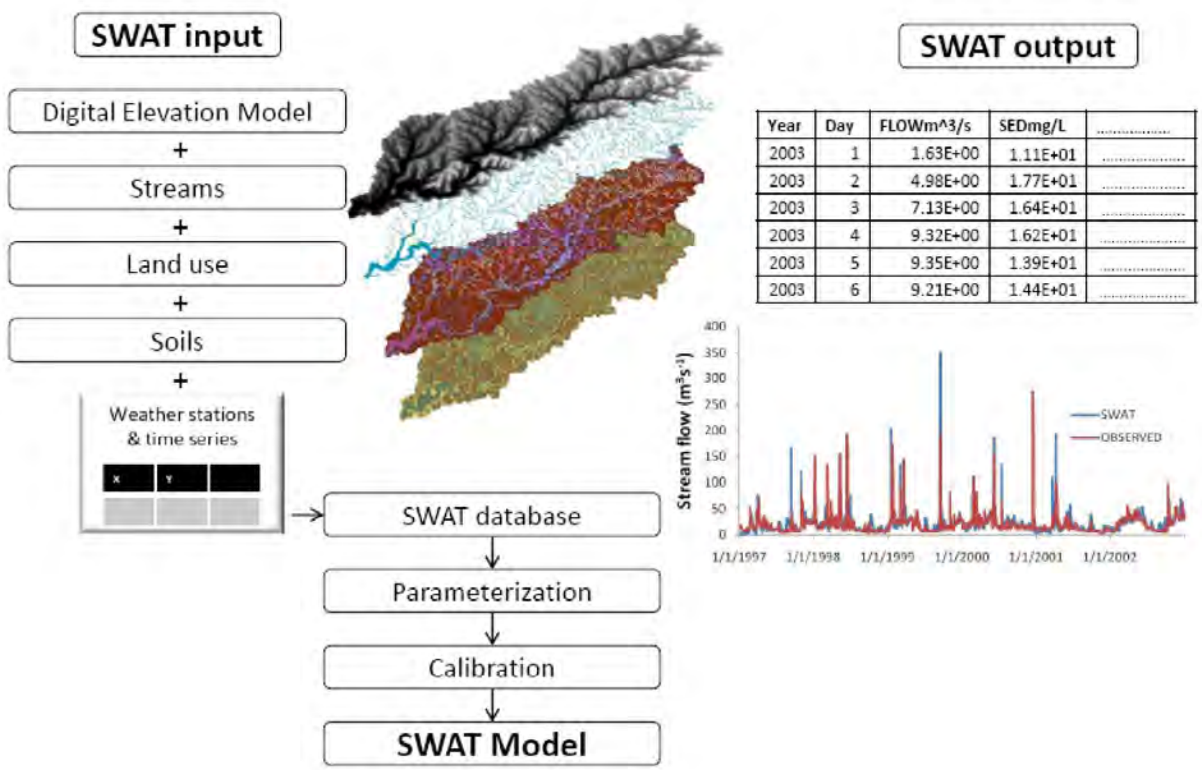

Figure 6.10 SWAT model framework.

The model has the capability to determine the spatial sources of nutrients or the site-specific processes that could support the ongoing watershed management efforts related to the Filtration Avoidance Determination (FAD) program. These include management programs to reduce nutrients and sediment loads from agricultural runoff and stream restoration projects to reduce stream channel erosion. Another major advantage of using the SWAT model is its ability to simulate biogeochemical processes. Processes such as mineralization of organic matter and plant uptake of nutrients become important when simulating the impact of climate change on water quality using projected future weather parameters, as many of these processes are dependent on weather. Such capabilities of the SWAT model are being utilized in the work that is under way to simulate nutrient loading in the Cannonsville and Pepacton Reservoir watersheds.

The SWAT model has a sediment routing component with the capability to discriminate the sediment coming from the landscape versus sediment entrained by fluvial erosion within the channel. The relative contribution of sediment from each stream reach within a stream network and the landscape contribution from each sub-basin within a watershed can be quantified. The newest version of the model has several improvements in the stream channel erosion component, including separate sub-routines based on channel characteristics such as stream bank and bed material. Work is under way using SWAT to simulate sediment loading to Ashokan Reservoir with a focus on identifying watershed sediment sources.

7. Further Research

7.1 What is the Watershed/Reservoir Atlas and what information will it contain?

In 2009, work continued on development of a NYC Watershed/Reservoir Atlas that presents information about the reservoirs and drainage basins of the NYC water supply system in map and tabular formats. The current draft of the Atlas includes some information for each of the reservoir drainage basins while focusing on the six reservoirs (and their basins) that comprise the West of Hudson region (Ashokan, Cannonsville, Neversink, Pepacton, Rondout, Schoharie) and two reservoirs in the East of Hudson region (Kensico, West Branch).

For each of the eight reservoirs, three maps are provided. The first displays the reservoir and shows the extent of its drainage basin, utilizing basemap and hillshaded Digital Elevation Model (DEM) data layers to identify population centers, water features, roads, and place names overlaid on a topographic (three-dimensional) representation of the terrain. The second map presents a 2001 classification (Level 1) of land cover/land use in each reservoir's drainage basin. The final map portrays the morphology of each reservoir via a graduated shading of equal intervals of reservoir depth, overlaid with bathymetric contours. (Bathymetric surveys of the eight reservoirs were performed in the 1990s, utilizing Global Positioning System (GPS) and Sonar technologies.)

The Atlas also includes tables of land cover/land use statistics for each of the eight basins, grouped by water supply system (Catskill, Delaware, Catskill/Delaware, Croton) and watershed region (East of Hudson, West of Hudson). There are also graphs indicating reservoir surface area and available water storage for increments of water surface elevation. This information was obtained from tables used by the Operations Directorate for system management or calculated from bathymetric data using the Geographic Information System (GIS).

As the development effort continues, overview maps and land cover/land use maps of the remaining East of Hudson reservoirs will be added to the Atlas, as will a table of key reservoir parameters. There will be a brief, written description of each system and the reservoirs that comprise it. Bathymetric information for the remaining East of Hudson reservoirs will be incorporated when they are surveyed and new data products become available.

7.2 What modeling efforts are under way to help manage the water supply?

During the coming year, DEP will undertake two major modeling projects, one involving the evaluation of FAD programs and the other evaluating the effects of climate change on the City's water supply.

A modeling-based evaluation of the FAD programs will be undertaken as part of the upcoming FAD assessment process due in 2011. DEP will be evaluating the impact of watershed management on nutrient loading and the trophic status of Cannonsville and Pepacton Reservoirs. To accomplish this it will be necessary to evaluate changes in FAD-related watershed management programs and watershed land use since the last FAD evaluation. These changes will then be used to parameterize DEP's models so they represent current watershed conditions. As in previous model-based evaluations, simulations of present conditions will be compared to simulations of pre-FAD conditions. Watershed loads will be input to reservoir models to allow changes in reservoir phytoplankton to be simulated.

DEP is also continuing the evaluation of the effects of climate change on the NYC water supply. During 2009, the first phase of the Climate Change Integrated Modeling Project (CCIMP) was completed. The work involved a preliminary examination of the effects of climate change on levels of turbidity in Schoharie Reservoir, eutrophication in Cannonsville Reservoir, and water availability and reservoir operation in the West of Hudson portion of the water supply. As of 2010, the second phase of the CCIMP is under way and will continue for a number of years. During this phase a more extensive set of climate scenarios will be used, as well as more sophisticated methods to downscale these scenarios to local conditions. The impact of climate change on turbidity and eutrophication will be investigated at all relevant reservoirs in the water supply. The effects of climate change on water supply operation and performance will be investigated further, using improved climate downscaling and by accounting more explicitly for potential feedbacks from the East of Hudson and Lower Delaware Systems on the West of Hudson portions of the water supply.

As it continues its work on these projects, DEP continues to test and evaluate watershed and reservoir models and modeling algorithms that more realistically simulate hydrology, watershed biogeochemistry, forest ecosystem processes, and erosion and sediment transport, as these are important components that regulate the quantity and quality of water entering the water supply and, therefore, have important implications for overall water supply management.

7.3 How does DEP remain involved in "cutting-edge research"?

DEP remains involved in the most current and important research through its involvement with the Water Research Foundation (WRF; see www.WaterResearchFoundation.org). This organization, founded in 1966, is an international, 501c(3) nonprofit organization, with 950 subscriber members that provide water for 80% of the U.S. population. WRF sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to the public. DEP is involved in several ways—in 2009, the DEP Commissioner was chosen to serve on the Board of Trustees, and DEP's Water Quality Directorate serves on two Expert Panels of Strategic Initiatives (Endocrine Disruptor Compounds/Pharmaceuticals and Personal Care Products (EDC/PPCP) and Climate Change (CC)), as well as on several Project and Technical Advisory Committees. Descriptions of the Strategic Initiatives (condensed from the WRF website) and Research Project list are provided below.

The Endocrine Disruptor Compounds/Pharmaceuticals and Personal Care Products (EDC/PPCP) Strategic Initiative

EDCs and PPCPs are classes of emerging contaminants that occur ubiquitously in municipal wastewater effluents and subsequently occur in source waters for drinking water treatment plants. While EDCs and PPCPs have been known to occur in source waters for more than 30 years, it is only in the past decade that information linking these chemicals to impacts on aquatic species has brought the issue to the forefront. These compounds are receiving growing attention from the scientific community, regulatory agencies, and the public at large because a number of them have been reported to interfere with human and animal hormone systems, and thus have the potential to produce adverse developmental and reproductive outcomes at sub-nanogram levels of exposure.

The following three objectives have been established for the EDC/PPCP Strategic Initiative.

Objective 1: [Develop] Integrative Frameworks to Assess and Communicate Risk
Objective 2: Analytical Methods to Support EDC/PPCP Research Objectives
Objective 3: Assess Watershed and Treatment Impact on EDC/PPCP Exposure at the Tap
More information about this initiative can be found at: http://www.waterresearchfoundation.org/thefoundation/ourPrograms/ResearchProgramSIEDCPPCP.aspx.

The Climate Change Strategic Initiative

Climate change is expected to present profound challenges to the water industry in the future. In many cases, these challenges are already present. To plan effectively, it is important to understand the relationship between climate change and water quality and quantity issues, as well as the impacts of climate change at different points in the hydrologic cycle. It is also important to understand how utilities can effectively engage customers, regulators, and other stakeholders in these planning efforts to help ensure support for the water supply changes that climate change will necessitate.

The following four objectives have been established for the Climate Change Strategic Initiative (CCSI).

Objective 1: Enhance and improve water industry awareness of climate change issues and impacts
Objective 2: Provide water utilities with a set of tools to identify and assess their vulnerabilities, and develop effective adaptation strategies
Objective 3: Provide water utilities with a set of tools to assess and minimize their carbon footprint
Objective 4: Communicate information to internal/external stakeholders

More information about this initiative can be found at: http://www.waterresearchfoundation.org/thefoundation/ourPrograms/ResearchProgramSIClimateChange.aspx.

DEP also serves on several **Project and Technical Advisory Committees** for the WRF. The role of the advisory committees is to select winning research proposals, guide research as it progresses, and provide technical review of all project reports. Through this process, DEP gains insight into the problems and solutions provided by the international scientific community. DEP is also involved as a "**Participating Utility**", which allows researchers to communicate with DEP staff for the development of case studies. Projects (and WRF project numbers) in which DEP is involved include:

Project Advisory Committees:

- Incorporating climate change information in water utility planning: A collaborative, decision analytic approach (# 3132)
- Identifying and Developing Climate Change Resources for Water Utilities: Content for Central Knowledge Repository Website (# 4208)
- Climate Change Impacts on the Regulatory Landscape: Evaluation of Opportunities for Regulatory Change (# 4239)
- Analysis Of Reservoir Operations Under Climate Change (# 4306)

Technical Advisory Committee:

- Selecting and Standardizing the Most Appropriate Tool for Regulatory *Cryptosporidium* Genotyping (# 4179)

Participating Utility:

- Reservoir Operations and Maintenance Strategies (# 4222)
- Water Quality Impacts Of Extreme Weather Events (# 4324)
- Vulnerability Assessment And Risk Management Tools For Climate Change: Assessing Potential Impacts And Identifying Adaptation Options (# 4262)
- Changing Mindsets To Promote Design Of "Sustainable Water Infrastructure" Under Climate Change (# 4264)
- Analysis Of Changes In Water Use Under Regional Climate Change Scenarios (# 4263)

7.4 What work is supported through contracts?

DEP accomplishes several goals through the contracts listed in Table 7.1. The primary types of contracts are: (1) Operation and Maintenance, (2) Monitoring, and (3) Research and Development. The Operations and Maintenance contracts are typically renewed each year because they are devoted to supporting the ongoing activities of the laboratory and field operations. The Monitoring contracts are devoted to handling some of the laboratory analyses that must be done to keep up-to-date on the status of the water supply. Research and Development contracts typically answer questions that allow DEP to implement effective watershed management and plan for the future.

Table 7.1: DEP contracts related to water quality monitoring and research.

Contract Description	Contract Term
Operation and Maintenance	
Operation and Maintenance of DEP's Hydrological Monitoring Network (Stream Flow)	10/1/09–9/30/12
Operation and Maintenance of DEP's Hydrological Monitoring Network (Water Quality)	10/1/06–9/30/10
Waterfowl Management at Kensico Reservoir	8/1/07–7/31/10
SAS Software Contract	7/1/09-6/30/10
Monitoring	
Monitoring of NYC Reservoirs for Viruses	7/29/08–7/28/11
Monitoring of NYC Reservoirs for Zebra Mussels	8/1/08–6/30/10
Organic Analysis Laboratory Contract	7/1/08–6/30/11
Analysis of Stormwater at Beerston, Cannonsville Watershed	11/1/09–0/31/10
Research and Development	
Development of Turbidity Models for Schoharie Reservoir and Esopus Creek	8/26/03–12/31/10
Croton System Model Development and Protech	11/15/05–6/30/10
Robotic Water Quality Monitoring Network	1/1/09-12/31/11

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Appendix A. Reservoir-wide status summary statistics for comparison to benchmarks

Appendix Table A.1. Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Kensico Reservoir						
Alkalinity (mg/L)		≥10	30			11
Chloride (mg/L)	12	8	24	0	0	9.1
Chlorophyll *a* (µg/L)	12	7	50	0	0	4.2
Color (Pt-Co units)	15		399	7	2	
Dissolved organic carbon (mg/L)*	4.0	3	193	0	0	1.7
Fecal coliform (CFU/100mL)	20		353	0	0	
Nitrate+nitrite-N (mg/L)	0.5	0.3	193	0	0	0.13
pH (units)	6.5-8.5		394	64	16	
Sodium, undig., filt. (mg/L)	16	3	24	3	13	7.7
Soluble reactive phosphorus (µg/L)	15		193	0	0	
Sulfate (mg/L)	15	10	24	1	4	9.3
Total ammonia-N (mg/L)	0.10	0.05	193	0	0	<0.02
Total dissolved phosphorus (µg/L)	15		192	0	0	
Total dissolved solids (mg/L)*	50	40	399	43	11	46
Total phosphorus (µg/L)	15		193	0	0	
Total phytoplankton (ASU)	2000		206	0	0	
Primary genus (ASU)	1000		206	0	0	
Secondary genus (ASU)	1000		205	0	0	
Total suspended solids (mg/L)	8.0	5	78	0	0	1.1
Turbidity (NTU)	5		399	0	0	
Amawalk Reservoir						
Alkalinity (mg/L)		≥40	9			78
Chloride (mg/L)	40	30	9	9	100	99
Chlorophyll *a* (µg/L)	15	10	14	4	29	11
Color (Pt-Co units)	15		40	37	93	
Dissolved organic carbon (mg/L)*	7.0	3	40	1	3	4.0
Fecal coliform (CFU/100mL)	20		37	5	14	
Nitrate+nitrite-N (mg/L)	0.5	0.3	40	2	5	0.13
pH (units)	6.5-8.5		40	7	18	
Sodium, undig., filt. (mg/L)	20	15	9	9	100	52
Soluble reactive phosphorus (µg/L)	15		40	2	5	
Sulfate (mg/L)	25	15	9	0	0	11
Total ammonia-N (mg/L)	0.10	0.05	40	5	13	0.07
Total dissolved phosphorus (µg/L)	15		39	3	8	
Total dissolved solids (mg/L)*	175	150	40	39	98	318
Total phosphorus (µg/L)	15		40	25	63	
Total phytoplankton (ASU)	2000		16	0	0	
Primary genus (ASU)	1000		16	2	13	
Secondary genus (ASU)	1000		16	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	2.7
Turbidity (NTU)	5		40	0	0	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Bog Brook Reservoir						
Alkalinity (mg/L)		≥40	6			79
Chloride (mg/L)	40	30	6	6	100	44
Chlorophyll *a* (µg/L)	15	10	6	0	0	10
Color (Pt-Co units)	15		16	15	94	
Dissolved organic carbon (mg/L)*	7.0	3	16	0	0	4.2
Fecal coliform (CFU/100mL)	20		33	0	0	
Nitrate+nitrite-N (mg/L)	0.5	0.3	16	0	0	0.02
pH (units)	6.5-8.5		33	4	12	
Sodium, undig., filt. (mg/L)	20	15	6	6	100	24
Soluble reactive phosphorus (µg/L)	15		16	2	13	
Sulfate (mg/L)	25	15	6	0	0	8.1
Total ammonia-N (mg/L)	0.10	0.05	16	2	13	0.11
Total dissolved phosphorus (µg/L)	15		16	3	19	
Total dissolved solids (mg/L)*	175	150	16	16	100	207
Total phosphorus (µg/L)	15		15	13	87	
Total phytoplankton (ASU)	2000		6	1	17	
Primary genus (ASU)	1000		6	1	17	
Secondary genus (ASU)	1000		6	0	0	
Total suspended solids (mg/L)	8.0	5	6	0	0	1.6
Turbidity (NTU)	5		16	2	13	
Boyd Corners Reservoir						
Alkalinity (mg/L)		≥40	5			34
Chloride (mg/L)	40	30	5	3	60	40
Chlorophyll *a* (µg/L)	15	10	6	0	0	4.5
Color (Pt-Co units)	15		19	19	100	
Dissolved organic carbon (mg/L)*	7.0	3	19	0	0	3.3
Fecal coliform (CFU/100mL)	20		47	3	6	
Nitrate+nitrite-N (mg/L)	0.5	0.3	19	0	0	0.07
pH (units)	6.5-8.5		47	0	0	
Sodium, undig., filt. (mg/L)	20	15	5	4	80	21
Soluble reactive phosphorus (µg/L)	15		19	0	0	
Sulfate (mg/L)	25	15	5	0	0	7.7
Total ammonia-N (mg/L)	0.10	0.05	19	0	0	<0.02
Total dissolved phosphorus (µg/L)	15		19	0	0	
Total dissolved solids (mg/L)*	175	150	19	0	0	148
Total phosphorus (µg/L)	15		19	1	5	
Total phytoplankton (ASU)	2000		7	0	0	
Primary genus (ASU)	1000		7	0	0	
Secondary genus (ASU)	1000		7	0	0	
Total suspended solids (mg/L)	8.0	5	4	0	0	1.2
Turbidity (NTU)	5		19	0	0	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Croton Falls Reservoir						
Alkalinity (mg/L)		≥40	18			58
Chloride (mg/L)	40	30	18	18	100	80
Chlorophyll *a* (µg/L)	15	10	15	6	40	14
Color (Pt-Co units)	15		54	49	91	
Dissolved organic carbon (mg/L)*	7.0	3	42	0	0	3.1
Fecal coliform (CFU/100mL)	20		54	0	0	
Nitrate+nitrite-N (mg/L)	0.5	0.3	42	0	0	0.14
pH (units)	6.5-8.5		48	4	8	
Sodium, undig., filt. (mg/L)	20	15	18	18	100	44
Soluble reactive phosphorus (µg/L)	15		42	0	0	
Sulfate (mg/L)	25	15	18	0	0	11
Total ammonia-N (mg/L)	0.10	0.05	42	8	19	0.07
Total dissolved phosphorus (µg/L)	15		42	2	5	
Total dissolved solids (mg/L)*	175	150	54	53	98	258
Total phosphorus (µg/L)	15		42	24	57	
Total phytoplankton (ASU)	2000		26	8	31	
Primary genus (ASU)	1000		26	9	35	
Secondary genus (ASU)	1000		26	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	1.7
Turbidity (NTU)	5		54	10	19	
Cross River Reservoir						
Alkalinity (mg/L)		≥40	9			46
Chloride (mg/L)	40	30	9	0	0	38
Chlorophyll *a* (µg/L)	15	10	16	1	6	10
Color (Pt-Co units)	15		48	45	94	
Dissolved organic carbon (mg/L)*	7.0	3	48	0	0	3.3
Fecal coliform (CFU/100mL)	20		48	0	0	
Nitrate+nitrite-N (mg/L)	0.5	0.3	48	0	0	0.09
pH (units)	6.5-8.5		48	8	17	
Sodium, undig., filt. (mg/L)	20	15	9	3	33	20
Soluble reactive phosphorus (µg/L)	15		48	0	0	
Sulfate (mg/L)	25	15	9	0	0	9.8
Total ammonia-N (mg/L)	0.10	0.05	48	8	17	0.05
Total dissolved phosphorus (µg/L)	15		48	3	6	
Total dissolved solids (mg/L)*	175	150	48	0	0	162
Total phosphorus (µg/L)	15		48	18	38	
Total phytoplankton (ASU)	2000		16	2	13	
Primary genus (ASU)	1000		16	0	0	
Secondary genus (ASU)	1000		16	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	2.4
Turbidity (NTU)	5		48	5	10	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Diverting Reservoir						
Alkalinity (mg/L)		≥40	5			92
Chloride (mg/L)	40	30	5	5	100	46
Chlorophyll *a* (µg/L)	15	10	4	1	25	12
Color (Pt-Co units)	15		8	8	100	
Dissolved organic carbon (mg/L)*	7.0	3	8	0	0	4.8
Fecal coliform (CFU/100mL)	20		10	4	40	
Nitrate+nitrite-N (mg/L)	0.5	0.3	8	0	0	0.11
pH (units)	6.5-8.5		10	0	0	
Sodium, undig., filt. (mg/L)	20	15	5	5	100	26
Soluble reactive phosphorus (µg/L)	15		8	1	13	
Sulfate (mg/L)	25	15	5	0	0	7.5
Total ammonia-N (mg/L)	0.10	0.05	8	1	13	0.05
Total dissolved phosphorus (µg/L)	15		8	2	25	
Total dissolved solids (mg/L)*	175	150	8	8	100	229
Total phosphorus (µg/L)	15		8	8	100	
Total phytoplankton (ASU)	2000		4	0	0	
Primary genus (ASU)	1000		4	0	0	
Secondary genus (ASU)	1000		4	0	0	
Total suspended solids (mg/L)	8.0	5	4	0	0	1.6
Turbidity (NTU)	5		8	0	0	
East Branch Reservoir						
Alkalinity (mg/L)		≥40	6			89
Chloride (mg/L)	40	30	0	0		
Chlorophyll *a* (µg/L)	15	10	6	4	67	20
Color (Pt-Co units)	15		18	18	100	
Dissolved organic carbon (mg/L)*	7.0	3	18	0	0	4.7
Fecal coliform (CFU/100mL)	20		35	3	9	
Nitrate+nitrite-N (mg/L)	0.5	0.3	18	0	0	0.04
pH (units)	6.5-8.5		35	2	6	
Sodium, undig., filt. (mg/L)	20	15	6	6	100	21
Soluble reactive phosphorus (µg/L)	15		18	1	6	
Sulfate (mg/L)	25	15	0	0		
Total ammonia-N (mg/L)	0.10	0.05	18	2	11	0.04
Total dissolved phosphorus (µg/L)	15		18	3	17	
Total dissolved solids (mg/L)*	175	150	18	18	100	207
Total phosphorus (µg/L)	15		18	16	89	
Total phytoplankton (ASU)	2000		6	3	50	
Primary genus (ASU)	1000		6	5	83	
Secondary genus (ASU)	1000		6	1	17	
Total suspended solids (mg/L)	8.0	5	6	0	0	2.9
Turbidity (NTU)	5		18	1	6	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Lake Gilead						
Alkalinity (mg/L)		≥40	9			43
Chloride (mg/L)	40	30	6	0	0	35
Chlorophyll *a* (µg/L)	15	10	3	0	0	5.4
Color (Pt-Co units)	15		9	5	56	
Dissolved organic carbon (mg/L)*	7.0	3	9	0	0	3.2
Fecal coliform (CFU/100mL)	20		39	2	5	
Nitrate+nitrite-N (mg/L)	0.5	0.3	9	0	0	0.03
pH (units)	6.5-8.5		25	3	12	
Sodium, undig., filt. (mg/L)	20	15	6	0	0	18
Soluble reactive phosphorus (µg/L)	15		9	1	11	
Sulfate (mg/L)	25	15	6	0	0	7.9
Total ammonia-N (mg/L)	0.10	0.05	9	3	33	0.17
Total dissolved phosphorus (µg/L)	15		9	2	22	
Total dissolved solids (mg/L)*	175	150	9	0	0	147
Total phosphorus (µg/L)	15		9	7	78	
Total phytoplankton (ASU)	2000		3	1	33	
Primary genus (ASU)	1000		3	1	33	
Secondary genus (ASU)	1000		3	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	2.2
Turbidity (NTU)	5		9	0	0	
Lake Gleneida						
Alkalinity (mg/L)		≥40	12			67
Chloride (mg/L)	40	30	9	9	100	84
Chlorophyll *a* (µg/L)	15	10	3	0	0	2.2
Color (Pt-Co units)	15		9	2	22	
Dissolved organic carbon (mg/L)*	7.0	3	9	0	0	2.8
Fecal coliform (CFU/100mL)	20		38	0	0	
Nitrate+nitrite-N (mg/L)	0.5	0.3	8	0	0	<0.02
pH (units)	6.5-8.5		25	4	16	
Sodium, undig., filt. (mg/L)	20	15	9	9	100	44
Soluble reactive phosphorus (µg/L)	15		8	1	13	
Sulfate (mg/L)	25	15	9	0	0	8.5
Total ammonia-N (mg/L)	0.10	0.05	9	2	22	0.08
Total dissolved phosphorus (µg/L)	15		9	2	22	
Total dissolved solids (mg/L)*	175	150	9	9	100	279
Total phosphorus (µg/L)	15		9	6	67	
Total phytoplankton (ASU)	2000		3	0	0	
Primary genus (ASU)	1000		3	0	0	
Secondary genus (ASU)	1000		3	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	1.4
Turbidity (NTU)	5		9	0	0	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Kirk Lake						
Alkalinity (mg/L)		≥40	8			62
Chloride (mg/L)	40	30	6	6	100	67
Chlorophyll *a* (µg/L)	15	10	3	2	67	19
Color (Pt-Co units)	15		6	6	100	
Dissolved organic carbon (mg/L)*	7.0	3	6	0	0	4.5
Fecal coliform (CFU/100mL)	20		35	0	0	
Nitrate+nitrite-N (mg/L)	0.5	0.3	6	0	0	<0.02
pH (units)	6.5-8.5		20	4	20	
Sodium, undig., filt. (mg/L)	20	15	6	6	100	32
Soluble reactive phosphorus (µg/L)	15		6	0	0	
Sulfate (mg/L)	25	15	6	0	0	9.5
Total ammonia-N (mg/L)	0.10	0.05	6	2	33	0.06
Total dissolved phosphorus (µg/L)	15		6	0	0	
Total dissolved solids (mg/L)*	175	150	6	6	100	235
Total phosphorus (µg/L)	15		6	6	100	
Total phytoplankton (ASU)	2000		3	3	100	
Primary genus (ASU)	1000		3	3	100	
Secondary genus (ASU)	1000		3	0	0	
Total suspended solids (mg/L)	8.0	5	5	0	0	5.0
Turbidity (NTU)	5		6	0	0	
Muscoot Reservoir						
Alkalinity (mg/L)		≥40	6			79
Chloride (mg/L)	40	30	5	5	100	73
Chlorophyll *a* (µg/L)	15	10	32	11	34	13
Color (Pt-Co units)	15		54	54	100	
Dissolved organic carbon (mg/L)*	7.0	3	54	1	2	3.8
Fecal coliform (CFU/100mL)	20		48	10	21	
Nitrate+nitrite-N (mg/L)	0.5	0.3	54	4	7	0.24
pH (units)	6.5-8.5		47	3	6	
Sodium, undig., filt. (mg/L)	20	15	6	6	100	38
Soluble reactive phosphorus (µg/L)	15		54	2	4	
Sulfate (mg/L)	25	15	5	0	0	11
Total ammonia-N (mg/L)	0.10	0.05	54	10	19	0.11
Total dissolved phosphorus (µg/L)	15		54	3	6	
Total dissolved solids (mg/L)*	175	150	54	54	100	270
Total phosphorus (µg/L)	15		54	48	89	
Total phytoplankton (ASU)	2000		32	1	3	
Primary genus (ASU)	1000		32	4	13	
Secondary genus (ASU)	1000		32	0	0	
Total suspended solids (mg/L)	8.0	5	6	0	0	2.5
Turbidity (NTU)	5		54	1	2	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Middle Branch Reservoir						
Alkalinity (mg/L)		≥40	9			65
Chloride (mg/L)	40	30	9	9	100	103
Chlorophyll *a* (µg/L)	15	10	12	5	42	15
Color (Pt-Co units)	15		40	39	98	
Dissolved organic carbon (mg/L)*	7.0	3	40	0	0	3.4
Fecal coliform (CFU/100mL)	20		40	1	3	
Nitrate+nitrite-N (mg/L)	0.5	0.3	40	0	0	0.10
pH (units)	6.5-8.5		40	3	8	
Sodium, undig., filt. (mg/L)	20	15	9	9	100	58
Soluble reactive phosphorus (µg/L)	15		40	2	5	
Sulfate (mg/L)	25	15	9	0	0	11
Total ammonia-N (mg/L)	0.10	0.05	40	9	23	0.11
Total dissolved phosphorus (µg/L)	15		40	3	8	
Total dissolved solids (mg/L)*	175	150	40	40	100	324
Total phosphorus (µg/L)	15		40	33	83	
Total phytoplankton (ASU)	2000		16	2	13	
Primary genus (ASU)	1000		16	1	6	
Secondary genus (ASU)	1000		16	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	1.9
Turbidity (NTU)	5		40	3	8	
New Croton Reservoir						
Alkalinity (mg/L)		≥40	20			68
Chloride (mg/L)	40	30	20	20	100	72
Chlorophyll *a* (µg/L)	15	10	42	12	29	13
Color (Pt-Co units)	15		245	231	94	
Dissolved organic carbon (mg/L)*	7.0	3	145	0	0	3.1
Fecal coliform (CFU/100mL)	20		241	6	2	
Nitrate+nitrite-N (mg/L)	0.5	0.3	145	12	8	0.26
pH (units)	6.5-8.5		236	12	5	
Sodium, undig., filt. (mg/L)	20	15	20	20	100	37
Soluble reactive phosphorus (µg/L)	15		145	1	1	
Sulfate (mg/L)	25	15	20	0	0	12
Total ammonia-N (mg/L)	0.10	0.05	145	17	12	0.05
Total dissolved phosphorus (µg/L)	15		145	6	4	
Total dissolved solids (mg/L)*	175	150	245	245	100	260
Total phosphorus (µg/L)	15		145	60	41	
Total phytoplankton (ASU)	2000		49	11	22	
Primary genus (ASU)	1000		49	9	18	
Secondary genus (ASU)	1000		49	2	4	
Total suspended solids (mg/L)	8.0	5	46	0	0	1.6
Turbidity (NTU)	5		245	7	3	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Titicus Reservoir						
Alkalinity (mg/L)		≥40	9			72
Chloride (mg/L)	40	30	11	11	100	42
Chlorophyll *a* (µg/L)	15	10	16	1	6	10
Color (Pt-Co units)	15		37	37	100	
Dissolved organic carbon (mg/L)*	7.0	3	37	0	0	3.5
Fecal coliform (CFU/100mL)	20		38	3	8	
Nitrate+nitrite-N (mg/L)	0.5	0.3	37	0	0	0.08
pH (units)	6.5-8.5		38	4	11	
Sodium, undig., filt. (mg/L)	20	15	9	7	78	21
Soluble reactive phosphorus (µg/L)	15		37	2	5	
Sulfate (mg/L)	25	15	11	0	0	10
Total ammonia-N (mg/L)	0.10	0.05	37	5	14	0.06
Total dissolved phosphorus (µg/L)	15		37	3	8	
Total dissolved solids (mg/L)*	175	150	37	37	100	201
Total phosphorus (µg/L)	15		37	26	70	
Total phytoplankton (ASU)	2000		16	0	0	
Primary genus (ASU)	1000		16	2	13	
Secondary genus (ASU)	1000		16	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	2.3
Turbidity (NTU)	5		37	4	11	
West Branch Reservoir						
Alkalinity (mg/L)		≥40	15			23
Chloride (mg/L)	12	8	15	15	100	23
Chlorophyll *a* (µg/L)	12	7	31	2	6	6.5
Color (Pt-Co units)	15		155	101	65	
Dissolved organic carbon (mg/L)*	4.0	3	72	1	1	2.4
Fecal coliform (CFU/100mL)	20		137	8	6	
Nitrate+nitrite-N (mg/L)	0.5	0.3	72	0	0	0.07
pH (units)	6.5-8.5		141	3	2	
Sodium, undig., filt. (mg/L)	16	3	15	4	27	13
Soluble reactive phosphorus (µg/L)	15		72	0	0	
Sulfate (mg/L)	15	10	15	0	0	6.5
Total ammonia-N (mg/L)	0.10	0.05	72	1	1	0.03
Total dissolved phosphorus (µg/L)	15		72	0	0	
Total dissolved solids (mg/L)*	50	40	155	151	97	81
Total phosphorus (µg/L)	15		72	12	17	
Total phytoplankton (ASU)	2000		68	1	1	
Primary genus (ASU)	1000		68	1	1	
Secondary genus (ASU)	1000		68	0	0	
Total suspended solids (mg/L)	8.0	5	9	0	0	1.8
Turbidity (NTU)	5		155	1	1	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Ashokan East Basin Reservoir						
Alkalinity (mg/L)		≥40	9			11
Chloride (mg/L)	12	8	15	0	0	7.0
Chlorophyll *a* (µg/L)	12	7	24	0	0	4.1
Color (Pt-Co units)	15		85	12	14	
Dissolved organic carbon (mg/L)*	4.0	3	63	0	0	1.7
Fecal coliform (CFU/100mL)	20		86	0	0	
Nitrate+nitrite-N (mg/L)	0.5	0.3	63	0	0	0.06
pH (units)	6.5-8.5		86	19	22	
Sodium, undig., filt. (mg/L)	16	3	9	0	0	4.7
Soluble reactive phosphorus (µg/L)	15		63	0	0	
Sulfate (mg/L)	15	10	15	0	0	4.6
Total ammonia-N (mg/L)	0.10	0.05	63	3	5	0.03
Total dissolved phosphorus (µg/L)	15		63	1	2	
Total dissolved solids (mg/L)*	50	40	86	0	0	40
Total phosphorus (µg/L)	15		63	3	5	
Total phytoplankton (ASU)	2000		42	0	0	
Primary genus (ASU)	1000		42	0	0	
Secondary genus (ASU)	1000		42	0	0	
Total suspended solids (mg/L)	8.0	5	63	0	0	1.7
Turbidity (NTU)	5		86	3	3	
Ashokan West Basin Reservoir						
Alkalinity (mg/L)		≥40	12			11
Chloride (mg/L)	12	8	20	0	0	7.3
Chlorophyll *a* (µg/L)	12	7	24	1	4	3.8
Color (Pt-Co units)	15		155	40	26	
Dissolved organic carbon (mg/L)*	4.0	3	77	0	0	1.7
Fecal coliform (CFU/100mL)	20		155	12	8	
Nitrate+nitrite-N (mg/L)	0.5	0.3	77	0	0	0.14
pH (units)	6.5-8.5		154	27	18	
Sodium, undig., filt. (mg/L)	16	3	12	0	0	4.5
Soluble reactive phosphorus (µg/L)	15		77	0	0	
Sulfate (mg/L)	15	10	20	0	0	4.5
Total ammonia-N (mg/L)	0.10	0.05	77	0	0	0.02
Total dissolved phosphorus (µg/L)	15		77	0	0	
Total dissolved solids (mg/L)*	50	40	155	0	0	39
Total phosphorus (µg/L)	15		77	4	5	
Total phytoplankton (ASU)	2000		45	0	0	
Primary genus (ASU)	1000		45	0	0	
Secondary genus (ASU)	1000		45	0	0	
Total suspended solids (mg/L)	8.0	5	77	3	4	2.8
Turbidity (NTU)	5		155	21	14	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Pepacton						
Alkalinity (mg/L)		≥40	21			13
Chloride (mg/L)	12	8	28	0	0	7.2
Chlorophyll *a* (µg/L)	12	7	21	1	5	6.0
Color (Pt-Co units)	15		85	2	2	
Dissolved organic carbon (mg/L)*	4.0	3	84	0	0	1.6
Fecal coliform (CFU/100mL)	20		85	3	4	
Nitrate+nitrite-N (mg/L)	0.5	0.3	91	0	0	0.20
pH (units)	6.5-8.5		67	18	27	
Sodium, undig., filt. (mg/L)	16	3	21	0	0	4.4
Soluble reactive phosphorus (µg/L)	15		91	0	0	
Sulfate (mg/L)	15	10	28	0	0	5.0
Total ammonia-N (mg/L)	0.10	0.05	85	0	0	<0.02
Total dissolved phosphorus (µg/L)	15		85	0	0	
Total dissolved solids (mg/L)*	50	40	85	0	0	42
Total phosphorus (µg/L)	15		85	9	11	
Total phytoplankton (ASU)	2000		48	0	0	
Primary genus (ASU)	1000		48	0	0	
Secondary genus (ASU)	1000		48	0	0	
Total suspended solids (mg/L)	8.0	5	64	0	0	1.1
Turbidity (NTU)	5		85	2	2	
Neversink Reservoir						
Alkalinity (mg/L)		≥40	12			2.8
Chloride (mg/L)	12	8	16	0	0	3.5
Chlorophyll *a* (µg/L)	12	7	14	0	0	3.5
Color (Pt-Co units)	15		56	6	11	
Dissolved organic carbon (mg/L)*	4.0	3	47	0	0	1.9
Fecal coliform (CFU/100mL)	20		56	1	2	
Nitrate+nitrite-N (mg/L)	0.5	0.3	50	0	0	0.11
pH (units)	6.5-8.5		36	29	81	
Sodium, undig., filt. (mg/L)	16	3	12	0	0	2.1
Soluble reactive phosphorus (µg/L)	15		50	0	0	
Sulfate (mg/L)	15	10	16	0	0	4.0
Total ammonia-N (mg/L)	0.10	0.05	47	0	0	0.02
Total dissolved phosphorus (µg/L)	15		47	0	0	
Total dissolved solids (mg/L)*	50	40	56	0	0	19
Total phosphorus (µg/L)	15		47	0	0	
Total phytoplankton (ASU)	2000		34	0	0	
Primary genus (ASU)	1000		34	0	0	
Secondary genus (ASU)	1000		34	0	0	
Total suspended solids (mg/L)	8.0	5	24	0	0	1.0
Turbidity (NTU)	5		56	0	0	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

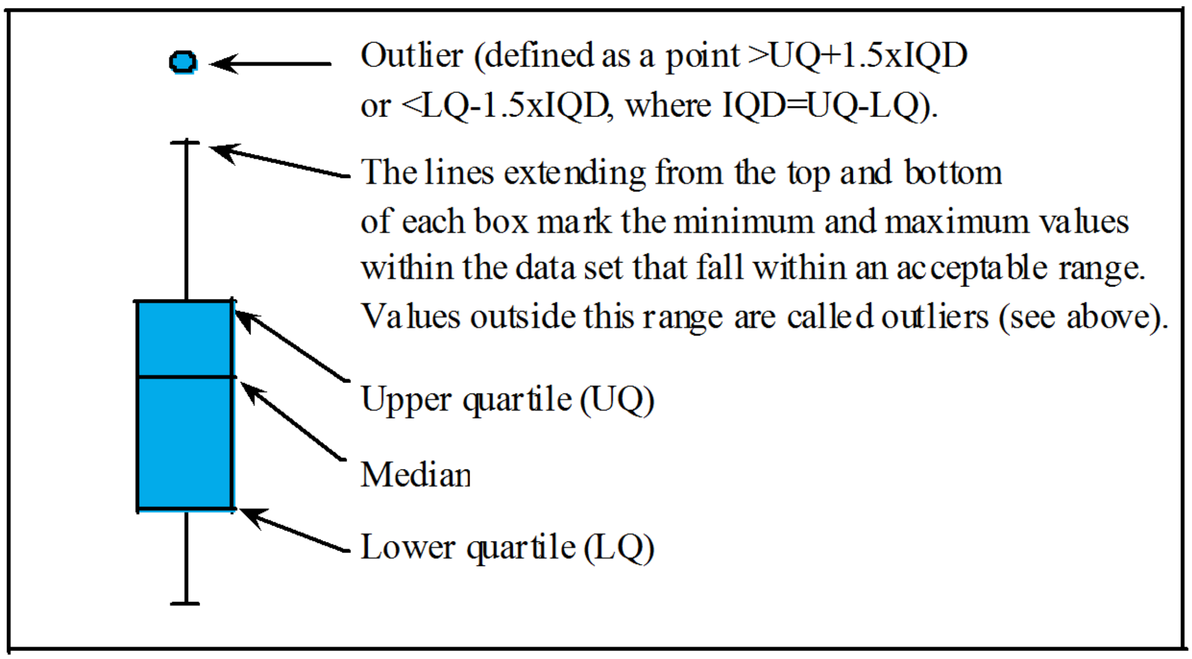
Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Rondout Reservoir						
Alkalinity (mg/L)		≥40	12			8.7
Chloride (mg/L)	12	8	20	0	0	6.6
Chlorophyll *a* (µg/L)	12	7	24	0	0	4.3
Color (Pt-Co units)	15		110	8	7	
Dissolved organic carbon (mg/L)*	4.0	3	56	0	0	1.8
Fecal coliform (CFU/100mL)	20		110	2	2	
Nitrate+nitrite-N (mg/L)	0.5	0.3	56	0	0	0.17
pH (units)	6.5-8.5		109	25	23	
Sodium, undig., filt. (mg/L)	16	3	12	0	0	4.2
Soluble reactive phosphorus (µg/L)	15		56	0	0	
Sulfate (mg/L)	15	10	20	0	0	4.9
Total ammonia-N (mg/L)	0.10	0.05	56	0	0	0.02
Total dissolved phosphorus (µg/L)	15		56	0	0	
Total dissolved solids (mg/L)*	50	40	110	0	0	36
Total phosphorus (µg/L)	15		80	0	0	
Total phytoplankton (ASU)	2000		54	0	0	
Primary genus (ASU)	1000		54	0	0	
Secondary genus (ASU)	1000		54	0	0	
Total suspended solids (mg/L)	8.0	5	28	0	0	1.1
Turbidity (NTU)	5		110	0	0	
Schoharie Reservoir						
Alkalinity (mg/L)		≥40	9			14
Chloride (mg/L)	12	8	12	0	0	10
Chlorophyll *a* (µg/L)	12	7	31	0	0	3.6
Color (Pt-Co units)	15		89	44	49	
Dissolved organic carbon (mg/L)*	4.0	3	89	0	0	2.2
Fecal coliform (CFU/100mL)	20		88	8	9	
Nitrate+nitrite-N (mg/L)	0.5	0.3	89	0	0	0.15
pH (units)	6.5-8.5		89	7	8	
Sodium, undig., filt. (mg/L)	16	3	9	0	0	6.2
Soluble reactive phosphorus (µg/L)	15		89	0	0	
Sulfate (mg/L)	15	10	12	0	0	4.7
Total ammonia-N (mg/L)	0.10	0.05	68	0	0	0.02
Total dissolved phosphorus (µg/L)	15		74	0	0	
Total dissolved solids (mg/L)*	50	40	89	67	75	51
Total phosphorus (µg/L)	15		89	13	15	
Total phytoplankton (ASU)	2000		48	0	0	
Primary genus (ASU)	1000		48	0	0	
Secondary genus (ASU)	1000		48	0	0	
Total suspended solids (mg/L)	8.0	5	89	5	6	2.9
Turbidity (NTU)	5		89	15	17	

Appendix Table A.1. (Continued) Reservoir-wide status summary statistics for comparison to benchmarks.

Analyte	Single sample Maximum	Annual Mean Standard	Number samples	Number exceeded	Percent exceeded	Annual Mean
Cannonsville Reservoir						
Alkalinity (mg/L)		≥40	18			17
Chloride (mg/L)	12	8	24	13	54	11
Chlorophyll *a* (µg/L)	12	7	40	3	8	6.2
Color (Pt-Co units)	15		138	76	55	
Dissolved organic carbon (mg/L)*	4.0	3	120	0	0	1.9
Fecal coliform (CFU/100mL)	20		136	7	5	
Nitrate+nitrite-N (mg/L)	0.5	0.3	120	19	16	0.31
pH (units)	6.5-8.5		119	17	14	
Sodium, undig., filt. (mg/L)	16	3	17	0	0	7.3
Soluble reactive phosphorus (µg/L)	15		120	0	0	
Sulfate (mg/L)	15	10	24	0	0	5.8
Total ammonia-N (mg/L)	0.10	0.05	120	0	0	0.02
Total dissolved phosphorus (µg/L)	15		120	3	3	
Total dissolved solids (mg/L)*	50	40	138	138	100	60
Total phosphorus (µg/L)	15		138	76	55	
Total phytoplankton (ASU)	2000		56	3	5	
Primary genus (ASU)	1000		56	3	5	
Secondary genus (ASU)	1000		56	1	2	
Total suspended solids (mg/L)	8.0	5	48	1	2	1.9
Turbidity (NTU)	5		138	14	10	

*Dissolved organic carbon was used in this analysis since TOC is no longer analyzed. In NYC reservoirs the dissolved organic carbon comprises the majority of the total organic carbon. Total dissolved solids were not analyzed directly and were estimated from the specific conductivity according to the USGS in van der Leeden et al. (1990).

Appendix B. Key to boxplots and summary of non-detect statistics used in data analysis



Water quality data is often left-censored in that many analytical results occur below the instruments 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 (i.e. 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 C. Phosphorus-restricted basin assessment methodology

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

A summary of the methodology used in the phosphorus-restricted analysis will be given here; the complete description can be found in A Methodology for Determining Phosphorus Restricted Basins (DEP 1997). The data utilized in the analysis are 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 set equal to half the detection limit. The detection limit for DEP measurements of total phosphorus is assessed each year by the DEP laboratories, and typically ranges between 2-5 $\mu g\ L^{-1}$. The phosphorus concentration data for the reservoirs approaches a lognormal distribution; therefore, a geometric mean is used to characterize the annual phosphorus concentrations. Appendix Table C1 provides the annual geometric mean for the past six years.

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

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

Appendix Table C.1 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	**2004 μg L^{-1}**	**2005 μg L^{-1}**	**2006 μg L^{-1}**	**2007 μg L^{-1}**	**2008 μg L-1**	**2009 μg L^{-1}**
Delaware						
Cannonsville	15.1	19.6	20.5	14.0	13.4	14.0
Pepacton	9.2	8.7	10.8	9.7	8.2	7.6
Neversink	5.0	7.3	7.3	4.7	4.7	5.9
Catskill						
Schoharie	13.3	20.6	17.4	9.7	9.5	11.2
Croton						
Amawalk	26.5	24.0	24.5	20.2	17.9	19.4
Bog Brook	26.8	18.6	18.7	24.0	21.5	22.8
Boyd Corners	13.8	*	17.4	15.6	11.6	8.6
Diverting	28.3	*	*	*	22.8	*
East Branch	44.2	28.3	28.4	23.0	21.6	26.1
Middle	*	31.5	24.2	25.0	27.9	22.4
Muscoot	26.0	26.8	27.9	25.7	27.6	24.9
Titicus	25.4	24.6	29.6	21.6	17.5	20.8
Lake Gleneida	*	*	24.2	*	*	22.7
Lake Gilead	21.8	*	30.5	33.6	*	36.0
Kirk Lake	*	*	29.7	28.6	*	31.4
Source						
Ashokan-West	9.3	26.0	11.2	8.1	7.2	8.6
Ashokan-East	10	11.0	9.9	7.3	7.5	9.5
Cross River	20.2	18.7	18.6	17.8	13.8	13.8

Appendix Table C.1 (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	2004 $\mu g\ L^{-1}$	2005 $\mu g\ L^{-1}$	2006 $\mu g\ L^{-1}$	2007 $\mu g\ L^{-1}$	2008 µg L-1	2009 $\mu g\ L^{-1}$
Croton Falls	18.1	*	19.2	*	14.4	14.7
Kensico	8.8	9.7	7.6	7.0	6.4	5.8
New Croton	22.4	18.2	18.1	17.7	15.5	14.4
Rondout	8.6	7.8	8.6	7.1	6.1	8.1
West Branch	11.5	14.8	10.3	9.6	9.4	9.6

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

Appendix D. Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2009)

Appendix Table D.1: Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2009). 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU 100 mL^{-1})	Percentage >Standard
Amawalk	A 2400, 5000	Apr-09	5	30	0
Amawalk		May-09	5	170	0
Amawalk		Jun-09	5	160	0
Amawalk		Jul-09	5	45	0
Amawalk		Aug-09	5	440	0
Amawalk		Sep-09	5	<100	0
Amawalk		Oct-09	5	40	0
Amawalk		Nov-09	5	14	0
Bog Brook	AA 50, 240	Apr-09	0	Insufficient Data	N/A
Bog Brook		May-09	0	Insufficient Data	N/A
Bog Brook		Jun-09	6	100	0
Bog Brook		Jul-09	5	<50	0
Bog Brook		Aug-09	6	<50	0
Bog Brook		Sep-09	5	<200	20
Bog Brook		Oct-09	5	40	0
Bog Brook		Nov-09	6	100	17
Boyd Corners	AA 50, 240	Apr-09	7	5	0
Boyd Corners		May-09	7	20	0
Boyd Corners		Jun-09	7	9	0
Boyd Corners		Jul-09	7	1200	100
Boyd Corners		Aug-09	7	170	29
Boyd Corners		Sep-09	6	<500	33
Boyd Corners		Oct-09	6	<100	0
Boyd Corners		Nov-09	0	Insufficient Data	N/A
Croton Falls	A/AA 50, 240	Apr-09	0	Insufficient Data	N/A
Croton Falls		May-09	6	23	0
Croton Falls		Jun-09	6	5	0
Croton Falls		Jul-09	6	9	17
Croton Falls		Aug-09	6	190	33
Croton Falls		Sep-09	6	1100	67
Croton Falls		Oct-09	39	200	44
Croton Falls		Nov-09	30	50	0
Croton Falls		Dec-09	57	50	4

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2009). 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU 100 mL^{-1})	Percentage >Standard
Cross River	A/AA 50, 240	Apr-09	6	5	0
Cross River		May-09	6	8	0
Cross River		Jun-09	6	<20	0
Cross River		Jul-09	6	14	0
Cross River		Aug-09	6	43	0
Cross River		Sep-09	6	<50	0
Cross River		Oct-09	6	<50	0
Cross River		Nov-09	6	25	0
Diverting	AA 50, 240	Apr-09	0	Insufficient Data	N/A
Diverting		May-09	0	Insufficient Data	N/A
Diverting		Jun-09	0	Insufficient Data	N/A
Diverting		Jul-09	0	Insufficient Data	N/A
Diverting		Aug-09	5	620	100
Diverting		Sep-09	5	240	40
Diverting		Oct-09	0	Insufficient Data	N/A
Diverting		Nov-09	0	Insufficient Data	N/A
East Branch	AA 50, 240	Apr-09	0	Insufficient Data	N/A
East Branch		May-09	0	Insufficient Data	N/A
East Branch		Jun-09	6	425	100
East Branch		Jul-09	6	91	0
East Branch		Aug-09	6	570	66
East Branch		Sep-09	6	200	17
East Branch		Oct-09	5	120	0
East Branch		Nov-09	6	40	17
Lake Gilead	A 2400, 5000	Apr-09	5	<5	0
Lake Gilead		May-09	5	12	0
Lake Gilead		Jun-09	5	12	0
Lake Gilead		Jul-09	5	<5	0
Lake Gilead		Aug-09	5	400	0
Lake Gilead		Sep-09	5	25	0
Lake Gilead		Oct-09	5	17	0
Lake Gilead		Nov-09	5	<10	0
Lake Gleneida	AA 50, 240	Apr-09	5	<5	0

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2009). 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU 100 mL^{-1})	Percentage >Standard
Lake Gleneida		May-09	5	<5	0
Lake Gleneida		Jun-09	5	8	0
Lake Gleneida		Jul-09	5	<50	0
Lake Gleneida		Aug-09	5	TNTC+	TNTC+
Lake Gleneida		Sep-09	5	<100	20
Lake Gleneida		Oct-09	3	Insufficient Data	N/A
Lake Gleneida		Nov-09	5	<10	20
Kirk Lake	B 2400, 5000	Apr-09	5	<5	0
Kirk Lake		May-09	5	8	0
Kirk Lake		Jun-09	5	TNTC+	TNTC+
Kirk Lake		Jul-09	5	91	0
Kirk Lake		Aug-09	5	240	0
Kirk Lake		Sep-09	5	120	0
Kirk Lake		Oct-09	5	86	0
Muscoot	A 2400, 5000	Apr-09	7	<20	0
Muscoot		May-09	6	365	0
Muscoot		Jun-09	7	1400	0
Muscoot		Jul-09	7	1100	0
Muscoot		Aug-09	7	5000	43
Muscoot		Sep-09	7	430	0
Muscoot		Oct-09	7	860	14
Muscoot		Nov-09	6	140	0
Middle Branch	A 2400, 5000	Apr-09	5	30	0
Middle Branch		May-09	5	<50	0
Middle Branch		Jun-09	5	55	0
Middle Branch		Jul-09	5	<20	0
Middle Branch		Aug-09	5	<200	0
Middle Branch		Sep-09	5	<130	0
Middle Branch		Oct-09	5	160	0
Middle Branch		Nov-09	5	80	0
Titicus	AA 50, 240	Apr-09	4	Insufficient Data	N/A
Titicus		May-09	5	120	0
Titicus		Jun-09	4	Insufficient Data	N/A

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2009). 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU 100 mL^{-1})	Percentage >Standard
Titicus		Jul-09	5	29	0
Titicus		Aug-09	5	TNTC+	TNTC+
Titicus		Sep-09	5	<100	0
Titicus		Oct-09	5	<100	0
Titicus		Nov-09	5	10	0
Pepacton	A/AA 50/240	Apr-09	16	1	0
Pepacton		May-09	8	1	0
Pepacton		Jun-09	8	<10	0
Pepacton		Jul-09	8	4	0
Pepacton		Aug-09	8	4	0
Pepacton		Sep-09	8	TNTC	TNTC
Pepacton		Oct-09	13	<10	0
Pepacton		Nov-09	16	<30	0
Neversink	AA 50/240	Apr-09	13	0.4	0
Neversink		May-09	7	8	0
Neversink		Jun-09	3	Insufficient Data	N/A
Neversink		Jul-09	3	Insufficient Data	N/A
Neversink		Aug-09	3	Insufficient Data	N/A
Neversink		Sep-09	3	Insufficient Data	N/A
Neversink		Oct-09	11	<20	0
Neversink		Nov-09	13	20	0
Schoharie	AA 50/240	Apr-09	11	28	9
Schoharie		May-09	11	250	55
Schoharie		Jun-09	11	400	64
Schoharie		Jul-09	11	830	100
Schoharie		Aug-09	11	6800	100
Schoharie		Sep-09	11	3400	100
Schoharie		Oct-09	11	200	45
Schoharie		Nov-09	12	285	58
Cannonsville	A/AA 50/240	Apr-09	15	1	0
Cannonsville		May-09	18	4	0
Cannonsville		Jun-09	18	460	44
Cannonsville		Jul-09	18	135	22

Appendix Table D.1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs (2009). 6 NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class & Standard (Median, Value not >20% of samples)	Collection Date	N	Median Total Coliform (CFU 100 mL^{-1})	Percentage >Standard
Cannonsville		Aug-09	18	130	33
Cannonsville		Sep-09	18	<20	0
Cannonsville		Oct-09	17	10	0
Cannonsville		Nov-09	15	30	0

Note: The reservoir class is defined by 6 NYCRR Subpart C. For those reservoirs that have dual designations, the higher standard was applied. The median could not be estimated for samples determined to be Too Numerous To Count (TNTC). A TNTC with a + designation indicates the presence of coliform.

Appendix E. A comparison of stream water quality results to regulatory benchmarks

Appendix Table E.1: A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark Single sample maximum	Benchmark Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
E10I; Bushkill, inflow to Ashokan						
Alkalinity (mg/L)	≥10.0	na	12	12	100	
Chloride (mg/L)	50	10	12	0	0	2.0
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	0.9
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.100[a]
Sulfate (mg/L)	15	10	6	0	0	4.4
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	<0.020[a]
Total dissolved solids (mg/L)[b.]	50	40	10	0	0	22
Dissolved sodium (mg/L)	10	5	4	0	0	1.6
E16I; Esopus Brook at Coldbrook						
Alkalinity (mg/L)	≥10.0	na	12	3	25	
Chloride (mg/L)	50	10	12	0	0	7.8
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	1.6
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.155[a]
Sulfate (mg/L)	15	10	6	0	0	4.7
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	<0.020[a]
Total dissolved solids (mg/L)[b.]	50	40	10	2	20	**43**
Dissolved sodium (mg/L)	10	5	4	0	0	**5.2**
E5; Esopus Creek at Allaben						
Alkalinity (mg/L)	≥10.0	na	12	8	67	
Chloride (mg/L)	50	10	12	0	0	4.7
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	1.1
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.165[a]
Sulfate (mg/L)	15	10	6	0	0	4.5
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	0.020[a]
Total dissolved solids (mg/L)[b.]	50	40	10	0	0	33
Dissolved sodium (mg/L)	10	5	3	0	0	3.4
S5I; Schoharie Creek at Prattsville						
Alkalinity (mg/L)	≥10.0	na	10	1	10	
Chloride (mg/L)	50	10	10	0	0	**10.5**
Dissolved Organic Carbon (mg/L)	25	9	10	0	0	2.1
Nitrate+Nitrite-N (mg/L)	1.5	0.40	10	0	0	0.139[a]
Sulfate (mg/L)	15	10	4	0	0	4.6
Total Ammonia-N (mg/L)	0.20	0.05	10	0	0	<0.020[a]

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark: Single sample maximum	Benchmark: Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Total dissolved solids (mg/L)[b]	50	40	10	7	70	**55**
Dissolved sodium (mg/L)	10	5	3	0	0	**6.4**
S6I; Bear Creek at Hardenburgh Falls						
Alkalinity (mg/L)	≥10.0	na	11	0	0	na
Chloride (mg/L)	50	10	11	0	0	**17.3**
Dissolved Organic Carbon (mg/L)	25	9	11	0	0	2.8
Nitrate+Nitrite-N (mg/L)	1.5	0.40	11	0	0	0.235[a]
Sulfate (mg/L)	15	10	5	0	0	6.3
Total Ammonia-N (mg/L)	0.20	0.05	11	0	0	0.020[a]
Total dissolved solids (mg/L)[b]	50	40	10	10	100	**86**
Dissolved sodium (mg/L)	10	5	3	1	33	**9.6**
S7I; Manor Kill						
Alkalinity (mg/L)	≥10.0	na	12	1	8	
Chloride (mg/L)	50	10	12	0	0	8.4
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	1.8
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.097[a]
Sulfate (mg/L)	15	10	6	0	0	5.6
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	0.020[a]
Total dissolved solids (mg/L)[b]	50	40	10	8	80	**58**
Dissolved sodium (mg/L)	10	5	4	0	0	4.9
SRR2CM; Schoharie Reservoir Diversion						
Alkalinity (mg/L)	≥10.0	na	12	1	8	
Chloride (mg/L)	50	10	12	0	0	9.4
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	2.3
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.187[a]
Sulfate (mg/L)	15	10	6	0	0	4.8
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	0.022[a]
Total dissolved solids (mg/L)[b]	50	40	219	122	56	**50**
Dissolved sodium (mg/L)	10	5	3	0	0	**6.0**
C-7; Trout Creek above Cannonsville						
Alkalinity (mg/L)	≥10.0	na	8	0	0	
Chloride (mg/L)	50	10	8	0	0	**13.3**
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.3
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.327[a]
Sulfate (mg/L)	15	10	4	0	0	6.0

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark: Single sample maximum	Benchmark: Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	8	100	**63**
Dissolved sodium (mg/L)	10	5	3	1	33	**8.7**
C-8; Loomis Brook above Cannonsville Reservoir						
Alkalinity (mg/L)	≥10.0	na	8	0	0	
Chloride (mg/L)	50	10	8	0	0	**13.4**
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.2
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.300[a]
Sulfate (mg/L)	15	10	4	0	0	5.8
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	7	88	**63**
Dissolved sodium (mg/L)	10	5	3	1	33	**9.5**
NCG; Neversink Reservoir near Claryville						
Alkalinity (mg/L)	≥10.0	na	12	12	100	
Chloride (mg/L)	50	10	10	0	0	2.9
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	1.6
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.134[a]
Sulfate (mg/L)	15	10	5	0	0	4.2
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	<0.020[a]
Total dissolved solids (mg/L)[b]	50	40	12	0	0	19
Dissolved sodium (mg/L)	10	5	4	0	0	1.8
NK6; Kramer Brook above Neversink Reservoir						
Alkalinity (mg/L)	≥10.0	na	8	6	75	
Chloride (mg/L)	50	10	8	0	0	**31.2**
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	2.6
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	**0.481[a]**
Sulfate (mg/L)	15	10	4	0	0	6.3
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	0.036[a]
Total dissolved solids (mg/L)[b]	50	40	8	8	100	**93**
Dissolved sodium (mg/L)	10	5	3	3	100	**17.9**
P-13; Tremper Kill above Pepacton Reservoir						
Alkalinity (mg/L)	≥10.0	na	8	1	13	
Chloride (mg/L)	50	10	8	0	0	9.0
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.4

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark: Single sample maximum	Benchmark: Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.333[a]
Sulfate (mg/L)	15	10	4	0	0	5.7
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	4	50	**50**
Dissolved sodium (mg/L)	10	5	3	0	0	**5.4**
P-21; Platte Kill at Dunraven						
Alkalinity (mg/L)	≥10.0	na	8	0	0	
Chloride (mg/L)	50	10	8	0	0	7.8
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.4
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.259[a]
Sulfate (mg/L)	15	10	4	0	0	5.3
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	<0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	2	25	**48**
Dissolved sodium (mg/L)	10	5	3	0	0	4.8
P-60; Mill Brook near Dunraven						
Alkalinity (mg/L)	≥10.0	na	8	6	75	
Chloride (mg/L)	50	10	8	0	0	1.6
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.0
Nitrate+Nitrite-N (mg/L)	1.5	0.40	7	0	0	0.381[a]
Sulfate (mg/L)	15	10	5	0	0	4.0
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	0.02[a]
Total dissolved solids (mg/L)[b]	50	40	8	0	0	28
Dissolved sodium (mg/L)	10	5	3	0	0	1.1
P-7; Terry Clove above Pepacton Reservoir						
Alkalinity (mg/L)	≥10.0	na	8	2	25	
Chloride (mg/L)	50	10	8	0	0	0.9
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.4
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.298[a]
Sulfate (mg/L)	15	10	4	0	0	5.6
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	<0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	0	0	29
Dissolved sodium (mg/L)	10	5	3	0	0	1.2
P-8; Fall Clove above Pepacton Reservoir						
Alkalinity (mg/L)	≥10.0	na	8	2	25	na

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark: Single sample maximum	Benchmark: Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Chloride (mg/L)	50	10	8	0	0	2.5
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.3
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.354[a]
Sulfate (mg/L)	15	10	4	0	0	5.7
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	0	0	32
Dissolved sodium (mg/L)	10	5	3	0	0	2.0
PMSB; East Branch Delaware River near Margaretville						
Alkalinity (mg/L)	≥10.0	na	12	0	0	
Chloride (mg/L)	50	10	12	0	0	8.8
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	1.4
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.236[a]
Sulfate (mg/L)	15	10	5	0	0	5.1
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	0.020[a]
Total dissolved solids (mg/L)[b]	50	40	12	7	58	**52**
Dissolved sodium (mg/L)	10	5	4	0	0	**5.5**
RD1; Sugarloaf Brook near Lowes Corners						
Alkalinity (mg/L)	≥10.0	na	8	8	100	
Chloride (mg/L)	50	10	8	0	0	6.1
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	1.4
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.092[a]
Sulfate (mg/L)	15	10	4	0	0	5.3
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	<0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	0	0	29
Dissolved sodium (mg/L)	10	5	3	0	0	3.2
RD4; Sawkill Brook near Yagerville						
Alkalinity (mg/L)	≥10.0	na	8	8	100	
Chloride (mg/L)	50	10	8	0	0	7.3
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	2.0
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.061[a]
Sulfate (mg/L)	15	10	4	0	0	5.8
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	<0.020[a]
Total dissolved solids (mg/L)[b]	50	40	8	0	0	31
Dissolved sodium (mg/L)	10	5	3	0	0	3.8

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark Single sample maximum	Benchmark Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
RDOA; Rondout Creek near Lowes Corners						
Alkalinity (mg/L)	≥10.0	na	12	12	100	
Chloride (mg/L)	50	10	12	0	0	3.6
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	1.4
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	0.117[a]
Sulfate (mg/L)	15	10	5	0	0	4.7
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	<0.020[a]
Total dissolved solids (mg/L)[b]	50	40	12	0	0	22
Dissolved sodium (mg/L)	10	5	4	0	0	2.3
RGB; Chestnut Creek below Grahamsville STP						
Alkalinity (mg/L)	≥10.0	na	8	7	88	
Chloride (mg/L)	50	10	8	0	0	**14.4**
Dissolved Organic Carbon (mg/L)	25	9	8	0	0	2.7
Nitrate+Nitrite-N (mg/L)	1.5	0.40	8	0	0	0.242[a]
Sulfate (mg/L)	15	10	4	0	0	6.0
Total Ammonia-N (mg/L)	0.20	0.05	8	0	0	0.03[a]
Total dissolved solids (mg/L)[b]	50	40	8	6	75	**52**
Dissolved sodium (mg/L)	10	5	3	1	33	**9.0**
WDBN; West Branch Delaware River at Beerston Bridge						
Alkalinity (mg/L)	≥10.0		12	2	17	
Chloride (mg/L)	50	10	12	0	0	**10.6**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	1.4
Nitrate+Nitrite-N (mg/L)	1.5	0.40	12	0	0	**0.410**[a]
Sulfate (mg/L)	15	10	6	0	0	6.2
Total Ammonia-N (mg/L)	0.20	0.05	12	0	0	0.020
Total dissolved solids (mg/L)[b]	50	40	12	7	58	**53**
Dissolved sodium (mg/L)	10	5	4	1	25	**5.8**
AMAWALKR; Amawalk Reservoir Release						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	3	25	**97.0**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.6
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.206[a]
Sulfate (mg/L)	25	15	4	0	0	11.4

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark: Single sample maximum	Benchmark: Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.038[a]
Total dissolved solids (mg/L)[b]	175	150	12	12	100	**326**
Dissolved sodium (mg/L)	20	15	4	4	100	**50.7**
BOGEASTBRR; Combined release for Bog Brook and East Branch Reservoirs						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	**51.8**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.9
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.146[a]
Sulfate (mg/L)	25	15	4	0	0	9.8
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.024[a]
Total dissolved solids (mg/L)[b]	175	150	12	12	100	**234**
Dissolved sodium (mg/L)	20	15	4	4	100	**26.3**
BOYDR; Boyd Corners Reservoir Release						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	**37.7**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.6
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.091[a]
Sulfate (mg/L)	25	15	4	0	0	8.3
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.036[a]
Total dissolved solids (mg/L)[b]	175	150	12	0	0	140
Dissolved sodium (mg/L)	20	15	4	4	100	**22.6**
CROFALLSR; Croton Falls Reservoir Release						
Alkalinity (mg/L)	≥40	na	12	0	0	na
Chloride (mg/L)	100	35	12	0	0	**62.7**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	2.7
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.157[a]
Sulfate (mg/L)	25	15	4	0	0	10.9
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.025[a]
Total dissolved solids (mg/L)[b]	175	150	12	11	92	**214**
Dissolved sodium (mg/L)	20	15	4	4	100	**34.8**
CROSS2; Cross River near Cross River						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	**44.7**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.6

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark Single sample maximum	 Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.182[a]
Sulfate (mg/L)	25	15	4	0	0	9.6
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.007[a]
Total dissolved solids (mg/L)[b]	175	150	12	8	67	**187**
Dissolved sodium (mg/L)	20	15	3	3	100	**21.0**
CROSSRVR; Cross River Reservoir Release						
Alkalinity (mg/L)	≥40	na	12	0	0	na
Chloride (mg/L)	100	35	12	0	0	**37.9**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.2
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.095[a]
Sulfate (mg/L)	25	15	4	0	0	>10.075
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.064[a]
Total dissolved solids (mg/L)[b]	175	150	12	0	0	**160**
Dissolved sodium (mg/L)	20	15	3	1	33	**19.8**
DIVERTR; Diverting Reservoir Release						
Alkalinity (mg/L)	≥40	na	7	0	0	
Chloride (mg/L)	100	35	7	0	0	**69.6**
Dissolved Organic Carbon (mg/L)	25	9	7	0	0	3.4
Nitrate+Nitrite-N (mg/L)	1.5	0.35	7	0	0	0.276[a]
Sulfate (mg/L)	25	15	2	0	0	12.2
Total Ammonia-N (mg/L)	0.20	0.10	7	1	14	0.056[a]
Total dissolved solids (mg/L)[b]	175	150	7	7	100	**272**
Dissolved sodium (mg/L)	20	15	3	3	100	**32.9**
EASTBR; East Branch Croton River above East Branch Reservoir						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	**43.5**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.9
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.089[a]
Sulfate (mg/L)	25	15	4	0	0	9.8
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	<0.010[a]
Total dissolved solids (mg/L)[b]	175	150	12	12	100	**229**
Dissolved sodium (mg/L)	20	15	4	4	100	**24.0**
GYPSYTRL1; Gypsy Trail Brook						
Alkalinity (mg/L)	≥40	na	12	0	0	

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark: Single sample maximum	Benchmark: Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Chloride (mg/L)	100	35	12	0	0	31.9
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.7
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.046[a]
Sulfate (mg/L)	25	15	4	0	0	6.7
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.022[a]
Total dissolved solids (mg/L)[b]	175	150	12	0	0	117
Dissolved sodium (mg/L)	20	15	4	1	25	17.4
HORSEPD12; Horse Pound Brook						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	**52.2**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.0
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.293[a]
Sulfate (mg/L)	25	15	4	0	0	9.4
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.042[a]
Total dissolved solids (mg/L)[b]	175	150	12	8	67	**178**
Dissolved sodium (mg/L)	20	15	4	4	100	**25.4**
KISCO3; Kisco River above New Croton Reservoir						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	3	25	**116.9**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.1
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	**0.566[a]**
Sulfate (mg/L)	25	15	4	0	0	**15.4**
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.023[a]
Total dissolved solids (mg/L)[b]	175	150	12	12	100	**381**
Dissolved sodium (mg/L)	20	15	4	3	75	**53.2**
MIKE2; Michael Brook						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	11	92	**168.1**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.6
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	6	50	**1.579[a]**
Sulfate (mg/L)	25	15	4	1	25	**20.4**
Total Ammonia-N (mg/L)	0.20	0.10	12	1	8	0.092[a]
Total dissolved solids (mg/L)[b]	175	150	12	12	100	**522**
Dissolved sodium (mg/L)	20	15	4	4	100	**79.1**

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

Analyte	Benchmark: Single sample maximum	Benchmark: Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
MUSCOOT10; Muscoot River above Amawalk Reservoir						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	11	92	**124.9**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	4.3
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	**0.630[a]**
Sulfate (mg/L)	25	15	4	0	0	12.1
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.025[a]
Total dissolved solids (mg/L)[b]	175	150	12	12	100	**399**
Dissolved sodium (mg/L)	20	15	4	4	100	**61.3**
TITICUSR; Titicus Reservoir Release						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	**42.9**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	3.2
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.183[a]
Sulfate (mg/L)	25	15	4	0	0	10.3
Total Ammonia-N (mg/L)	0.20	0.10	12	1	8	0.079[a]
Total dissolved solids (mg/L)[b]	175	150	12	12	100	**202**
Dissolved sodium (mg/L)	20	15	4	4	100	**22.0**
WESTBR7; West Branch Croton River above Boyd Corners Reservoir						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	**35.0**
Dissolved Organic Carbon (mg/L)	25	9	12	0	0	5.1
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.052[a]
Sulfate (mg/L)	25	15	4	0	0	6.6
Total Ammonia-N (mg/L)	0.20	0.10	12	0	0	0.048[a]
Total dissolved solids (mg/L)[b]	175	150	12	0	0	132
Dissolved sodium (mg/L)	20	15	3	3	100	**22.2**
WESTBRR; West Branch Reservoir Release						
Alkalinity (mg/L)	≥40	na	12	0	0	
Chloride (mg/L)	100	35	12	0	0	16.6
Dissolved Organic Carbon (mg/L)	25	9	10	0	0	2.2
Nitrate+Nitrite-N (mg/L)	1.5	0.35	12	0	0	0.143[a]
Sulfate (mg/L)	25	15	4	0	0	6.1

Appendix Table E.1: (Continued) A comparison of stream water quality results to benchmarks. Results in bold indicate an exceedance of the annual mean standard.

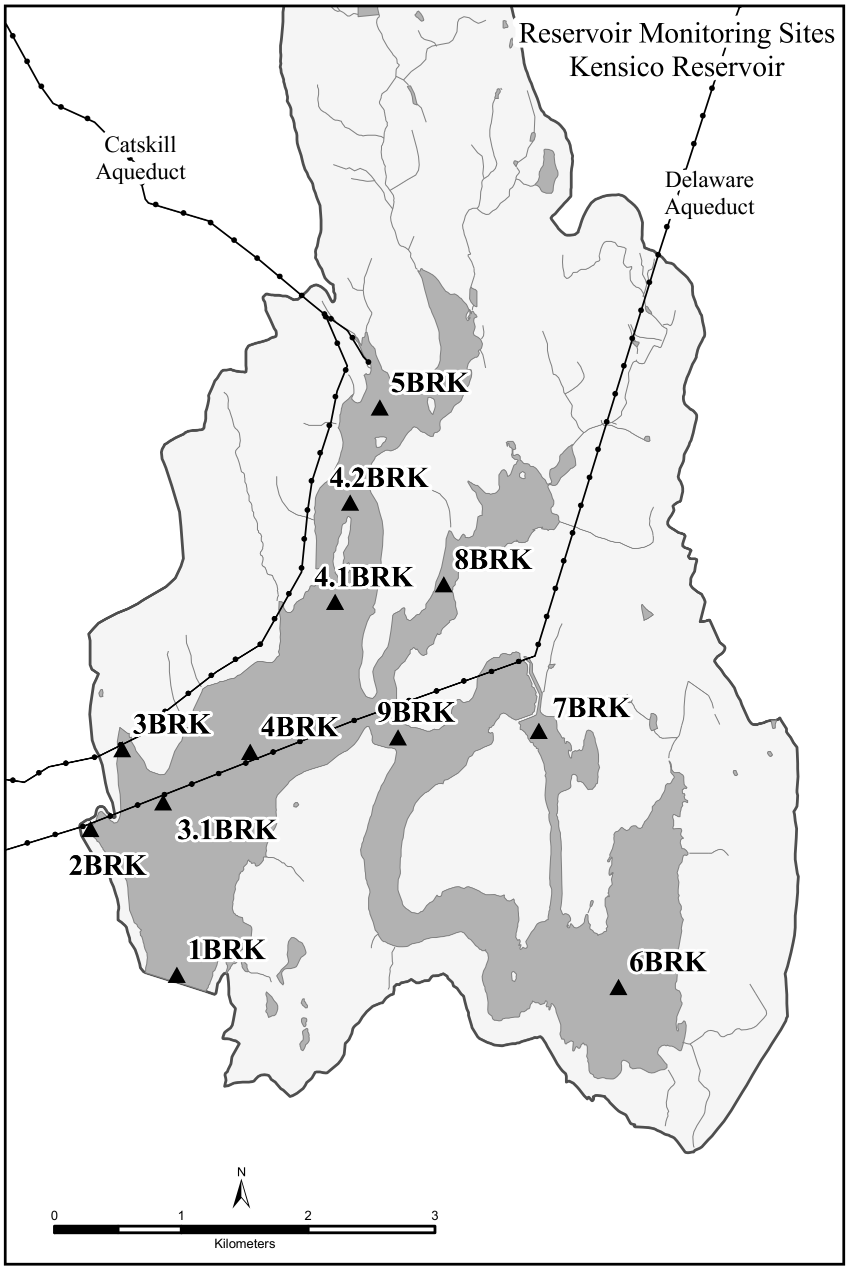
Analyte	Benchmark Single sample maximum	Benchmark Annual mean standard	Number samples	Number exceeded	Percent exceeded	Annual mean[a]
Total Ammonia-N (mg/L)	0.20	0.10	11	0	0	0.028[a]
Total dissolved solids (mg/L)[b]	175	150	12	0	0	73
Dissolved sodium (mg/L)	20	15	3	0	0	9.6

[a]Mean estimated using Kaplan-Meier method as described in Helsel (2005).
[b]Total dissolved solids estimated from specific conductivity according to the USGS in van der Leeden et al. (1990).
na = not applicable.

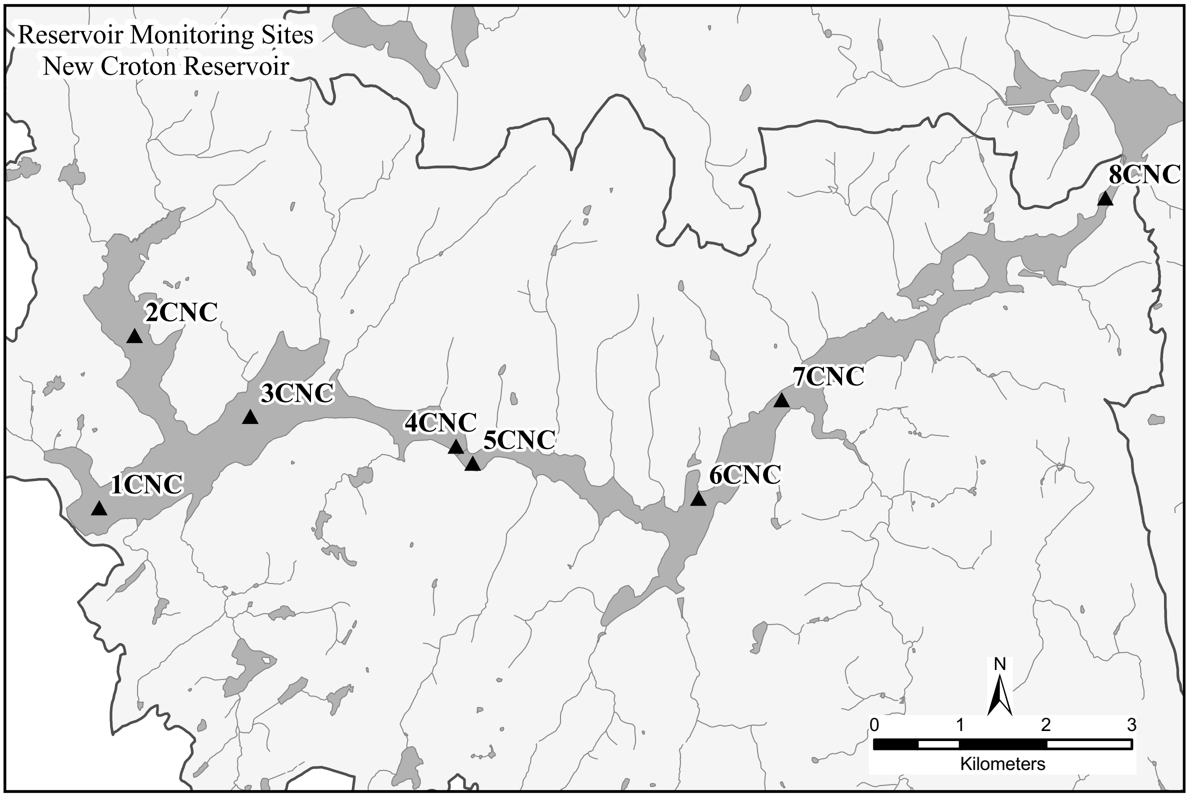
Appendix F. Reservoir trend analysis

Sites

Sites used for water quality trends are shown pictorially in Figures 1 and 2. The reservoirs evaluated are Kensico, the terminal reservoir for the Catskill/Delaware System, and New Croton, the terminal reservoir for the Croton System.



Appendix Figure F.1 Sites included in the trends analysis for Kensico Reservoir.



Appendix Figure F.2 Sites included in the trends analysis for New Croton Reservoir.

Data collection

The reservoir water quality data were obtained from DEP's water quality monitoring program, as described in the WWQMP (DEP 2009a). Samples used in the analysis were collected from April to November, from 2002 to 2009. Each reservoir was sampled at multiple depths at the dam, mid-reservoir, near major stream influent areas, and at other important sites, e.g., near aqueducts. Most analytes considered in this report , such as turbidity, fecal coliform, total phosphorus, total nitrogen, and specific conductivity, were sampled at all depths. For chlorophyll trends, only surface samples, collected at the 3 meter depth, were used. Secchi depth was determined from the surface water at each site. Chloride was only sampled at the dam sites three times per year, usually in May, August, and November. All analytical and sampling methods are NELAP-approved and were consistent throughout the period of record.

Dataset Construction

Prior to trend analysis, the data were plotted over time and examined for outliers. Suspect data were flagged and the original records reviewed to determine if a transcription error had occurred. All discovered transcription errors were corrected. Remaining outliers were removed only if they were far outside the normal range of historical data.

To create a balanced, unbiased dataset all special surveys were eliminated and the data were restricted to those which were routinely collected in “full” surveys each month. A survey was considered “full” if results were available from at least 75 % of the required samples. The traditional median value from each full monthly survey was used in both the trend analysis and the temporal plots of the data. For analytes where data censoring occurred (e.g., fecal coliform) the medians were estimated using the nonparametric Kaplan-Meier (K-M) Method, described in Helsel (2005).

Trend Methods

Several independent techniques were used to detect trends. Locally-weighted scatterplot smoothing (LOWESS) curves were fit to the data to describe both the long-term and intermediate data patterns (Cleveland 1979). The nonparametric LOWESS technique was chosen because, unlike parametric methods such as linear regression, it provides a robust description of the data without presupposing any relationship between the analytes and time, and because the distribution of the data does not need to be of a particular type (e.g., normal). The LOWESS technique is also preferable to parametric methods because it performs iterative re-weighting, which lessens the influence of outliers and highly skewed data.

LOWESS curves were constructed using the PROC LOESS procedure in SAS 9.1 (SAS 2002-3). In PROC LOESS, weighted least squares are used to fit linear or quadratic functions to the center of a group of data points. The closer a data point is to the center, the more influence or weight it has on the fit. The size of the data group is determined by the smooth factor chosen by the user. In this analysis a smooth factor of 0.3 was used, which means that 30 % of the data were used to perform the weighted least squares calculation for each data point. Through experimentation it was found that a smooth factor of 0.3 provided a good description of the overall long-term trend and important intermediate trends as well.

Increasing the number of iterations or re-weightings that PROC LOESS performs on the data can further reduce the influence of outliers. With each iteration, data points are weighted less the further they are removed from the data group. Selecting one iteration corresponds to no re-weighting. Given the prevalence of extreme values commonly observed in coliform data, DEP found that selecting one iteration produced a fit that was excessively driven by outliers. Three iterations, corresponding to two re-weightings, have been recommended in other studies (Cleveland 1979) and yielded a good fit with DEP’s coliform data. For the other analytes presented (e.g., turbidity, total phosphorus), the number of iterations chosen had little discernible effect on the LOWESS fit. For ease of presentation, in this report LOWESS curves for all analytes were determined using three iterations.

For non-censored data, the occurrence of long-term monotonic trends was tested for statistical significance using the nonparametric Seasonal Kendall Test (Hirsch et al. 1982). The magnitude of detected trends was determined using the Seasonal Kendall Slope Estimator (Hirsch et al. 1982).

The test was performed using a compiled Fortran program provided in Reckhow et al. (1993). The Seasonal Kendall test poses the null hypothesis that there is no trend; the alternative hypothesis being that there is in fact an upward or downward trend (a two-sided test). The *p*-values for all trend tests are symbolized as follows:

p- value	Significance	Symbol
$p \geq 0.20$	None	NS
$p < 0.20$	Moderate	*
p □ 0.10	High	**
$p < 0.05$	Very High	***

The lower the p value, the more likely the observed trend is not attributable to chance. Note that the term "NS" does not mean that there is no trend. It means that the null hypothesis of "no trend" cannot be rejected (at the p = 0.2 level of significance—80% confidence level), and any observed trend could be attributed to chance.

A strong advantage of the nonparametric test is that there are no assumptions made, apart from monotonicity, about the functional form of any trend that may be present; the test merely addresses whether the within-season, between-year differences tend to be monotonic. Outliers also have a lesser effect on nonparametric tests because non-parametric tests consider the ranks of the data rather than actual values. The effects of serial correlation are always ignored; this is justified because the scale of interest is confined to the period of record (Loftis et al. 1991, McBride 2005).

The Seasonal Kendall Slope Estimator technique is used to estimate trend magnitude (i.e., amount of change per year). In this technique slope estimates are first computed for all possible data pairs of like months. The median of these slopes is then determined. This median is the Seasonal Kendall Slope estimator. It should also be pointed out that it is possible to obtain a "statistically significant" trend with the Seasonal Kendall Test, yet obtain a zero Seasonal Kendall Slope Estimator. This is an odd feature of the procedures and occurs when there are many tied values in the dataset, e.g., many "non-detects". There is a dislocation between the trend test and the slope estimate, that is, the two procedures are carried out independently of each other. The trend slope is computed from the median of all slopes between data pairs of the same month and, in this instance, can be zero.

Different techniques were required for censored fecal coliform data, where results were often below the detection limit and where detection limits varied over the period of record. In these cases, Minitab® macros produced by Dennis Helsel were used to determine the statistical significance of the trend and fit the data with the Akritas-Theil-Sen line, a nonparametric regression based on Kendal's Tau. The slope of the Akritas-Theil-Sen line represents the change per year as reported in the text. These techniques are recommended and fully described in Helsel (2005). The macros (CKend.mac and ATS.mac) used in this analysis are available from the author's website, **www.practicalstats.com/nada.**